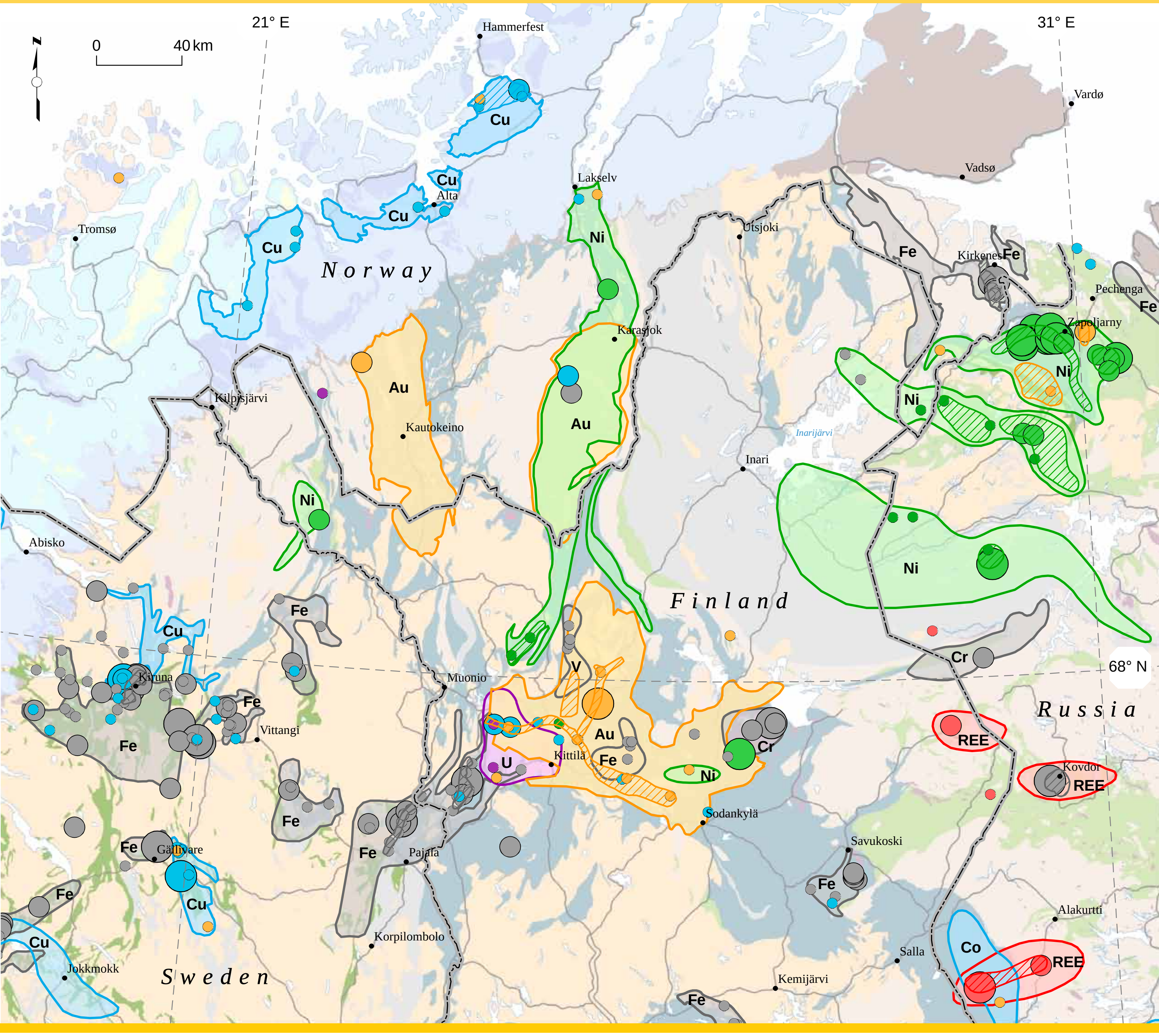
GEOLOGICAL SURVEY OF FINLAND

Special Paper 53

2012



Mineral deposits and metallogeny of Fennoscandia

Edited by Pasi Eilu

GTK

Geological Survey of Finland, Special Paper 53

Mineral deposits and metallogeny of Fennoscandia

Edited by
Pasi Eilu

Geological Survey of Finland
Espoo 2012

Unless otherwise indicated, the figures have been prepared by the authors of the article.

Front cover: Metallogenic areas of the northern part of the Fennoscandian shield.

ISBN 978-952-217-174-0 (paperback)
ISBN 978-952-217-175-7 (PDF)
ISSN 0782-8535

Layout: Elvi Turtiainen Oy
Printing house: Tammerprint Oy

Eilu, P. (ed.) 2012. Mineral deposits and metallogeny of Fennoscandia. *Geological Survey of Finland, Special Paper 53*, 401 pages, 248 figures, 105 tables.

This book aims to give the first comprehensive explanation of the metallogenic areas of Fennoscandia, which have recently been described in the Metallogenic Map of the Fennoscandian Shield. The Fennoscandian metallogenic map shows the extent of presently known metallogenic areas. They are defined by the presence of metal mines, deposits, favourable bedrock geology, and by indications from geophysical and geochemical surveys. The following metals are included: Ag, Au, Be, Co, Cr, Cu, Fe, Li, Mn, Mo, Nb, Ni, Pb, Pd, Pt, Rh, REE, Sc, Sn, Ta, Ti, U, V, W, Y, Zn and Zr. The potential for exploration and mining is expressed by two types of areas: 'Areas of good exploration potential' include most of the known occurrences, past and present mines, and bedrock assumed to contain more deposits. Areas with the 'highest potential for new discoveries' are specifically indicated within these domains

There are 168 major metallogenic areas within Fennoscandia. Of these areas, 47 are entirely or mostly in Finland, 40 in Norway, 40 in Russia, and 41 in Sweden. These include 24 areas that cross international borders. In terms of metal groups, there are 48 areas showing potential predominantly for ferrous metals (Fe, Mn, Ti, V, Cr), 36 for copper, zinc and/or lead, 31 for precious metals (Ag, Au, Pd, Pt), 30 for nickel or cobalt, and 11 for metals mostly used in modern, advanced technologies ('high-tech metals' Li, Nb, REE, Ta, Zr).

More than 30 major genetic types of metal deposits are known from Fennoscandia. According to past production and present resources, the most significant types and areas include: apatite-iron ore (Kiruna), BIF (Kostomuksha), carbonatite and peralkaline intrusion-associated rare metals (Kola Province), black shale-hosted U (alum shales in Sweden), mafic intrusion-hosted Ti-Fe±V (Tellnes), mafic to ultramafic-hosted Cr (Kemi), magmatic Ni-Cu-PGE (Pechenga, Portimo), orogenic gold (Kittilä), porphyry Cu-Au (Aitik), VMS (Bergslagen, Skellefte, Vihanti-Pyhäsalmi, Caledonides), and the somewhat enigmatic cases of Outokumpu Cu-Co and Talvivaara Ni-Zn.

Most of the known metal endowment of Fennoscandia was formed in just a few distinct events, the most important of which was the Svecofennian orogeny at ca. 1.9–1.8 Ga, accounting for an overwhelming majority of deposits and genetic types. Other significant metallogenic episodes were 1) ca. 2.8 Ga deposition of BIFs; 2) 2.45–1.92 Ga rifting, which produced mafic to ultramafic hosted Cr, PGE and Ni; 3) 2.1(?)–1.95 Ma black shale and ophiolite-related processes producing the proto-ores of the Talvivaara and Outokumpu types; 4) mafic intrusion-hosted ilmenite in the Sveconorwegian Orogen at 930–920 Ma; 5) Palaeozoic (Caledonian) rifting to collision-related sandstone-hosted Pb-Zn, black shale-hosted U, VMS and magmatic Ni-Cu deposits; and 6) 380–360 Ma carbonatite and peralkaline-related deposits (Kola and Northern Karelia).

The metallogenic areas are described by known metal deposits and areas of potential for future discoveries in the Fennoscandian Shield. Thus, this publication can be used in selecting strategic areas for mineral exploration as well as for research in economic geology. Importantly, this book will also serve as a tool for land-use planning and political decision-making, as it gives indications of the areas that have the greatest potential for future metal mines in northern Europe, fulfilling the requirements set by the raw materials policy of the European Union, and for similar objectives set by the countries in the region. The work was carried out in a joint project of the national geological surveys of Finland, Norway, Russia (VSEGEI and SC Mineral) and Sweden.

Keywords (GeoRef Thesaurus, AGI): metallogeny, metallogenic provinces, mineral resources, metal ores, mining industry, Fennoscandian Shield, Paleozoic, Precambrian, Fennoscandia, Finland, Sweden, Norway, Russian Federation

Pasi Eilu
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

E-mail: pasi.eilu@gtk.fi

CONTENTS

INTRODUCTION

Pasi Eilu (GTK)

The European Union (EU) produces roughly 3 % of the metals consumed annually in the world, while it uses 20–30 % of the metals produced (Brown et al. 2009a, 2009b). For the whole of Europe, both figures are higher, but the ratio between production and consumption largely remains the same: our economies and standard of living are heavily dependent on raw materials produced elsewhere. For industrial minerals, the ratio between production and consumption is better. In 2006, the EU was the world's largest producer of feldspar (60 %), perlite (54 %), kaolin (31 %), gypsum (23 %) and salt (22 %). In addition, Norway is the worlds largest producer of olivine (45 %) and third largest of nepheline syenite (15 %) (Brown et al. 2009b). Still, the EU is a net importer of industrial minerals (Thiess 2010). Projected trends seem to show no change from an increasing demand for metals (Eilu 2011), but at the same time, exploration for, and the development of new mineral resources all over the world are facing increasing competition from other land uses (e.g., Briskey et al. 2007, Commission of the European Communities 2008). In addition, the global minerals market is not completely open, but faces significant hurdles due to national protectionism in the form of regulated and even prohibited export of certain metals, such as platinum, palladium, rare earth elements (REE) and tungsten, from countries producing a globally significant share of these metals.

Recycling of raw materials can be an effective way to respond to increasing demand, and most probably will be so in the near future (Brown et al. 2009a, Buchert et al. 2009, Johnson Matthey 2009). However, recent investigations indicate the difficulty of satisfying growing needs for raw materials solely by increasing recycling. For example, the extent of recycling of precious metals, such as the platinum group metals, is already so high that enhanced recycling cannot be the primary solution for increasing consumption (Buchert et al. 2009). Also, recovering metals, or any other raw material, can be very difficult, perhaps the most extremely multifaceted challenge being the recycling of uranium used in nuclear power plants.

In this context, certain parts of Europe are of great importance as both present and future major producers of essential raw materials needed by our society in manufacturing and other industries. Fennoscandia (the Precambrian shield and the Caledonides; Fig. 1) is one of these regions: it has a geology similar to other mineral-rich shield areas of the world, such as Australia, South Africa and Canada, has a long tradition in mining and related industries, also currently has a large number of active mines, it is the sole or dominant producer of many metals in Europe, will strengthen that position in the near future and the region still has a great potential for new significant mineral discoveries (Weihed et al. 2005, Brown et al. 2009a, Eilu et al. 2009, Fennoscandian Ore Deposit Database 2011, Eilu 2011). This is also indicated by the fact that almost half of present exploration expenditure for metals in Europe is used in Finland and Sweden (SGU 2009).

Since 2003, the geological surveys of Finland, Norway, Russia and Sweden, and the State Company Mineral (St Petersburg, Russia) have had a joint project working on the metallogeny of Fennoscandia. Our project has often been called the 'FODD Project', according its first major product, the Fennoscandian Ore Deposit Database. Also in the present report, the name 'FODD Project' is used in the meaning of the Fennoscandian joint project on the mineral deposit database, maps and metallogeny. A major background document for the FODD effort was created by the work by the above-mentioned organisations during 1995–2002 in producing the geological, magnetic and gravity maps of Fennoscandia (Koistinen et al. 2001, Korhonen et al. 2002a, 2002b). The FODD project has now produced and published a database on metallic mineral deposits, a deposit map and a metallogenic map (Eilu et al. 2008, 2009). The deposit database was first published on the Internet in 2007 (accessible at http://en.gtk.fi/ExplorationFinland/fodd), and is updated annually by the FODD Project.

All products of the FODD Project are based on data gathered by its member organisations, NGU, SGU, GTK, SC Mineral, and VSEGEI. The main data sources are the national geology, mineral deposit, mineral indication and metallogeny databases, published deposit and metallogeny research, mining registers, and variably public exploration report archives. Significant information has also been gathered from mining and exploration company reports and, in some cases, by interviewing exploration geologists with experience on certain deposits, mining camps, and other areas which have been the focus of mineral exploration in Fennoscandia.

The Fennoscandian deposit database and the deposit map are almost self-explanatory products. Hence, only an explanation of the general principles of the deposit database has been considered necessary (Eilu et al. 2007). On the other

Figure 1. Geological map of Fennoscandia, based on Koistinen et al. (2001) and the most significant metal mines of the region. The largest active mines are named. Black squares indicate major cities.

hand, a metallogenic map is always an interpretation based on the current knowledge of the local geology, the extent of exploration and mining in the region, and the state of understanding of processes producing mineral deposits. Therefore, a metallogenic map almost invariably needs an explanatory text, and the present report aims to meet that need.

Principles of the Metallogenic Map of the Fennoscandian Shield

Definitions

A metallogenic map presents domains of mineral occurrences of certain types. Commonly, such areas are called metallogenic zones, belts, provinces or fields (e.g., Lafitte 1984, Juve & Størseth 2000, Zappettini 2005, Saltikoff et al. 2006). However, a zone or belt often implies an elongated or even linear shape, even if there was no such intention. To avoid any idea that metallogenic domains necessarily are elongated, or of any certain shape, we have used the term 'metallogenic area'. Obviously, many metallogenic areas in Fennoscandia are elongated, but clearly not all (Fig. 2).

The Fennoscandian metallogenic map (Eilu et al. 2009) depicts the extent of presently known metallogenic areas. They are defined by the presence of metal mines, deposits and other indications of certain types of metallic mineralisation, by the local and regional bedrock geology, and by indications from geophysical and geochemical surveys. The following metals are included: Ag, Au, Be, Co, Cr, Cu, Fe, Li, Mn, Mo, Nb, Ni, Pb, Pd, Pt, Rh, REE, Sc, Sn, Ta, Ti, U, V, W, Y, Zn, and Zr. Industrial minerals and gems are excluded, as these commodities would need a significantly different approach compared to the metals listed above, and because it is typically difficult to obtain comprehensive data on them. Also excluded are elements not forming any known or even suspected significant deposits within Fennoscandia. However in 2011, we started to work on industrial minerals and on a number of elements not listed above. The latter work will eventually result in an updated, extended deposit database, production of commodity-specific reports and, possibly, an updated metallogenic map for Fennoscandia.

Metallogenic area

The present metallogenic map indicates two categories of metallogenic domains: 'Areas of good exploration potential' and 'Areas of high potential of discoveries'. These are the main metallogenic areas and subareas, respectively. The main metallogenic areas are domains with an indicated potential for one or a few genetic types of metal deposits. There may be active or closed mines, a number of unexploited deposits and/or other strong indications that a certain type of ore probably exists in the area. Within a main metallogenic area, there may be subareas where we think that the probability of further discoveries of economic deposits is especially high; these are marked on the map as high-potential areas.

For brevity and to make the map easier to read, the metallogenic areas are given identity codes (Fig. 2, Table 1). The code of a main area comprises a letter and a three-digit number. The letter indicates the country where the metallogenic area, or most of the area is found, as follows: F = Finland, N = Norway, R = Russia, S = Sweden. The numbers start from 001 in each country and run in a roughly geographical order within the country. On the map the most important metal is shown for a metallogenic area. For example, the marking 'Ni R002' on the map tells that this is a metallogenic area where nickel is the most important metal, it is in Russia, and has the code R002 which indicates the Pechenga metallogenic area. The ID code for a high-potential subarea is the code of the main area plus a fourth number. Hence, 'R002.1' indicates the North Pechenga subarea. Due to their small size, the subareas are not shown in Figure 2.

Mineral potential beyond metallogenic areas

The possibilities to find metal deposits are not restricted to the metallogenic areas drawn on the map. This is indicated for Fennoscandia by the presence of deposits outside the metallogenic areas. These even include deposits mined, such as the Korsnäs Pb-REE and Mätäsvaara Mo mines in Finland, which have not been included in any metallogenic area. Such cases are typically either single deposits with no similar occurrences in the vicinity or where there are only a few similar occurrences in a very restricted area. An example of the latter is the ferrous-metal deposits of the Akanvaara intrusion in NE Finland: they may be of significant size, but are all in a very small area and there are no similar ferrous metal-potential intrusions in the vicinity.

It is important to keep in mind that the metallogenic map of Fennoscandia is drawn based on present knowledge of indications of metal deposits in the region. There may very well be significant deposits beyond the metallogenic areas defined by us. For example, there may be a group of Korsnäs-type REE±Pb deposits of significant size in a geographically extensive domain in western Finland – perhaps these just do not crop out or define easily detectable geophysical or geochemical footprints. Many parts of Fennoscandia are still under-explored for all mineral commodities or are explored only for some, such as gold, iron and the base metals. It is also important to note that the present map depicts metal deposit domains; industrial mineral deposit domains would probably cover large parts of Fennoscandia beyond the metallogenic areas of the present map.

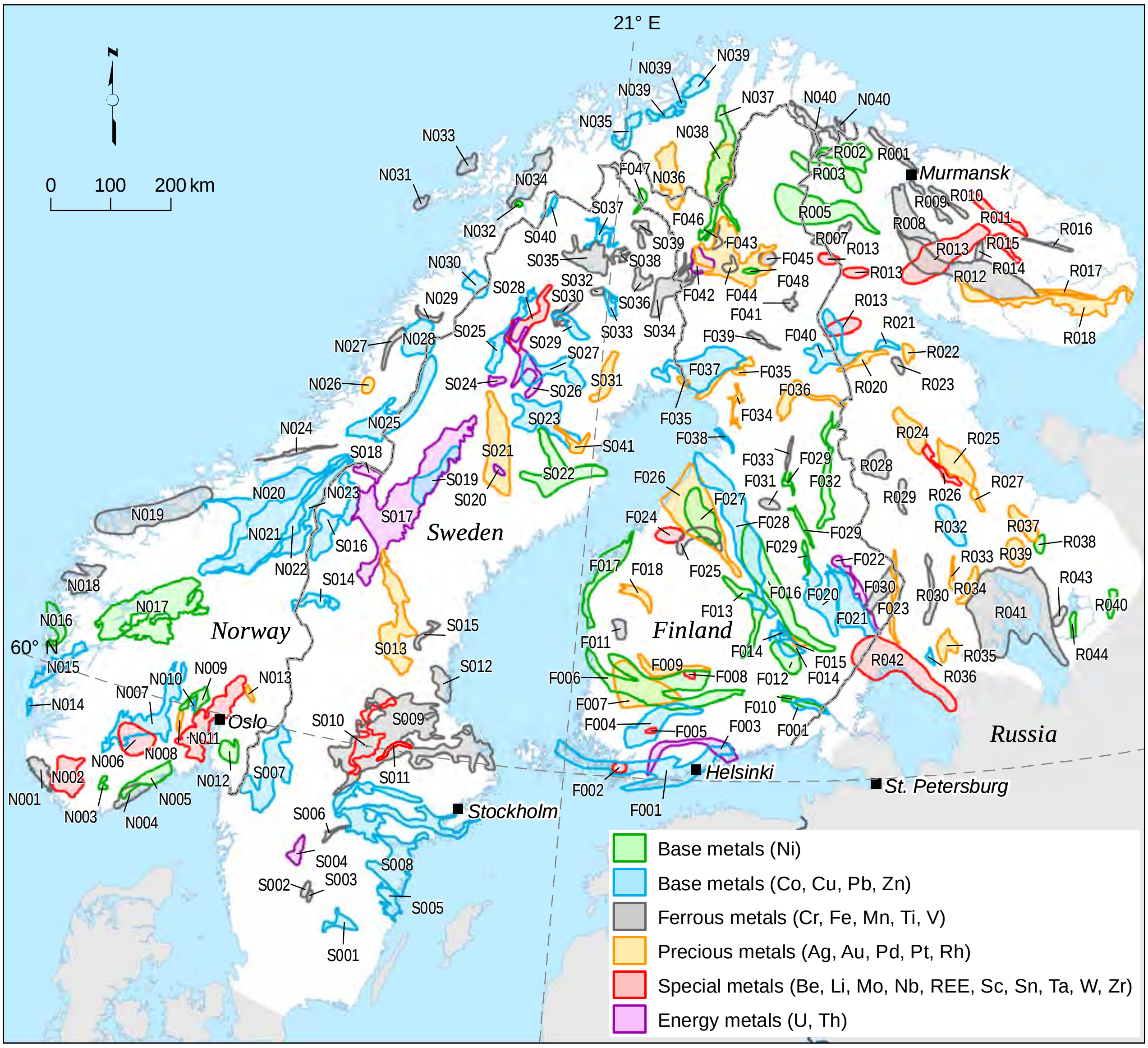


Figure 2. Metallogenic areas in Fennoscandia, simplified from Eilu et al. (2009). The names of the metallogenic areas are listed in Table 1.

Table 1. List of the metallogenic areas in Fennoscandia, as shown in Figure 2 and in the printed metallogenic map (Eilu et al. 2009).

Finland		**Norway**	
F001	Orijärvi Zn, Cu, Ag, Pb	N001	Rogaland Ti, Fe, V
F002	Kemiö Ta, Be	N002	Agder Mo
F003	Palmottu U	N003	Evje Ni, Cu
F004	Häme Zn, Au,Ag	N004	Arendal Fe
F005	Somero Li	N005	Bamble Ni, Cu, Fe, Ti
F006	Vammala Ni, Co, Cu	N006	Bandak-Nisser Mo
F007	Pirkkala Au	N007	Telemark Cu, Au, Ag
F008	Eräjärvi Ta, Li, Be	N008	Kongsberg Ag
F009	Tampere Au, Cu	N009	Ringerike Ni, Cu
F010	Telkkälä Ni, Co	N010	Modum Co, As, Au, Ag
F011	Peräkorpi Ti	N011	Oslo Mo
F012	Puumala Ni, Co	N012	Indre Østfold Ni, Cu
F013	Ilmolahti Ni, Co, Cu	N013	Eidsvoll Au
F014	Virtasalmi Cu	N014	Karmøy Cu, Zn
F015	Rantasalmi Au	N015	Hardanger Cu, Zn
F016	Kotalahti Ni, Co	N016	Bergen-Hosanger Ni, Cu, Fe, Ti
F017	Oravainen Ni, Co	N017	Jotunheimen Ni, Cu, PGE
F018	Seinäjoki Au, Sb	N018	Sunnfjord Ti, Fe
F020	Outokumpu Co, Cu	N019	Møre Fe, Ti
F021	Hammaslahti Cu, Zn	N020	Støren-Løkken Cu, Zn
F022	Koli U	N021	Kvikne-Singsås Cu, Zn, Ni
F023	Ilomantsi Au	N022	Folldal-Meråker Cu, Zn
F024	Emmes Li	N023	Røros-Tydal Zn, Cu, Pb
F025	Koivusaarenneva Ti, V	N024	Fosdalen Fe, Cu
F026	Laivakangas Au, Cu	N025	Grong-Stekenjokk Cu, Zn, Au
F027	Hitura Ni, Co	N026	Bindal Au
F028	Vihanti-Pyhäsalmi Zn, Cu	N027	Vefsn Fe
F029	Talvivaara Ni, Co, Zn	N028	Rana-Hemnes Zn, Pb, Cu
F030	Huhus Fe	N029	Rana Fe
F031	Otanmäki V, Fe, Ti	N030	Sulitjelma Cu, Zn
F032	Kuhmo Ni, Ag, Au	N031	Lofoten Fe, Ti
F033	Pääkkö Fe	N032	Råna Ni, Cu
F034	Oijärvi Au, Ag	N033	Selvåg Fe, Ti
F035	Portimo PGE, Cr, Ni	N034	Troms Fe
F036	Koillismaa PGE, V, Ni, Fe, Cu	N035	Vaddas-Birtavarre Cu, Zn
F037	Peräpohja Cu, Co, Fe	N036	Kautokeino Au, Cu
F038	Haukipudas Zn, Cu	N037	Karasjok-Lakselv Ni, Cu, PGE
F039	Misi Fe, V	N038	Karasjok Au, Cu
F040	Kuusamo-Kuolajärvi Co, Au	N039	Alta-Repparfjord Cu, Au
F041	Jauratsi Fe	N040	Sør-Varanger Fe
F042	Kesänkitunturi U		
F043	Kittilä Au, Cu		
F044	Porkonen-Pahtavaara Fe, Mn		
F045	Koitelainen Cr, V, PGE		
F046	Pyhäjärvi V, Fe, Ti		
F047	Ruossakero Ni, Co		
F048	Sattasvaara Ni		

Table 1. Continued.

Russia		**Sweden**	
R001	Uraguba-Murmansk Fe	S001	Vetlanda Cu, Ni, Au
R002	Pechenga Ni, Cu, PGE, Co, Au	S002	Taberg Fe, Ti, V
R003	Allarechka Ni, Cu	S003	Spexeryd Mn
R005	Lotta Ni, Cu	S004	Billingen U, V, Mo
R007	Korvatundra Cr	S005	Gladhammar-Västervik Cu, Co, U, REE, Fe
R008	Zaimandrovskaya Fe, Ti	S006	Bölet Mn
R009	Sholtanyavr Fe	S007	Dalsland-Värmland Cu, Ag, U, Au, Fe, Mn
R010	Pinkelyavr Fe	S008	Southern Bergslagen Zn, Pb, Fe, Co, Ni
R011	Porosozero-Voron’ya Li, Nb, Ta	S009	Northern Bergslagen Fe, Cu, Zn, Pb, Ag
R012	Imandra-Varzuga Cr, PGE, Ni, Cu	S010	Western Bergslagen W, Mo
R013	Kovdor-Lovozero REE, Nb, Ta, Zr, Ti, Fe	S011	Riddarhyttan REE, Fe
R014	Tsaginskaya V, Fe, Ti	S012	Hamrånge Fe, Cu, W
R015	West-Keyvy Zr, Nb	S013	Överturingen-Los Au, Zn, U
R016	Kuroptevskaya V, Fe, Ti	S014	Vassbo Pb, Zn
R017	Purnachskaya Au	S015	Dellen-Ljusdal V
R018	South Varzuga Au	S016	Sylarna Cu, Zn, Pb, Ag
R020	Olanga PGE	S017	Caledonian Black Shale U, V, Mo
R021	Kukas Cu	S018	Hotagen U
R022	Vinchozero Au	S019	Dorotea Pb, Zn, Ag
R023	Eletozaro Ti, Fe, V, Nb	S020	Björkråmyran U
R024	Shombozero Au	S021	Gold Line Au
R025	Lehta Au, Cu	S022	Lappvattnet Ni, Cu
R026	Päävaara-Lobash Mo, Au	S023	Skellefte District Zn, Cu, Pb, Ag, Au
R027	Parandovo-Nadvoiza Au, Mo, Cu	S024	Duobblon U
R028	Kostomuksha Fe, Au	S025	Laisvall Pb, Zn, Ag
R029	Bolshozero Fe, Au	S026	Arjeplog-Arvidsjaur U
R030	Gimoly Fe, U	S027	Radnejaur-Moskosel Cu, Au, Zn, pb, Ag
R032	Elmozero-Segozero Pb, Cu	S028	Rappen-Ultevis Mo, Cu, Au
R033	Jangozero Au, Cu	S029	Vaikijaur Cu, Mo, Au
R034	Pedrolapi-Elmus Au, Cu, Zn	S030	Kallak Fe, Mn, Cu, Au
R035	Hautovaara-Shotozero Au, Pb, Zn, Ta, Nb, Ni	S031	Boden Au, Ag, Cu
R036	Tulomozero Zn, Pb, Fe	S032	Gällivare-Malmberget Fe
R037	Pulozero Au	S033	Aitik-Nautanen Cu, Au
R038	Kamennozero Ni, Zn, Cu	S034	Pajala-Kolari Fe, Cu, Au
R039	South Vygozero Au, Ni, Cr	S035	Kiruna Fe, Cu, Au
R040	Voloshovo Ni, Au, Cu	S036	Tärendö Fe, Zn, Cu
R041	Onega V, Ti, U, PGE, Cu, Au	S037	Viscaria-Sautusvaara Cu, Fe, Au, Zn, Ag, Co
R042	Northern Ladoga Sn, Zn, Pb, U, Au, W, Fe, V	S038	Vittangi Fe, Cu, Au, Co, Mo
R043	Burakovka Cr, PGE, Ni	S039	Lannavaara Fe, Cu
R044	Matkalahta Ni	S040	Sjangeli Cu, Ag, Au, U
		S041	Skellefte District Gold Au

ACKNOWLEDGEMENTS

We are grateful to a large number of colleagues in our organisations, at university geology departments, and in mining and exploration companies active in Fennoscandia, who made this contribution possible by providing information, images and photograps. It is practically impossible to list all of them here. However, the Editor wants especially to thank Ms Mirjam Ajlani, at GTK, who drafted all the index maps and a large number of maps on the Finnish metallogenic areas.

REFERENCES

Briskey, J. A., Schulz, K. J., Mosesso, J. P., Horwitz, L. R. & Cunningham C. G. 2007. Environmental planning issues and a conceptual global assessment of undiscovered nonfuel mineral resources. In: Briskey, J. A. & Schulz, K. J. (eds) Proceedings for a Workshop on Deposit Modeling, Mineral Resources Assessment, and Their Role in Sustainable Development, 31st International Geological Congress, Rio de Janeiro, Brazil, August 18–19, 2000. U.S. Geological Survey, Circular 1294, 19−28.

Brown, T. J., Hetherington, L. E., Idoine, N. E., Hobbs, S. F. & Bide, T. 2009a. European mineral statistics. Nottingham: British Geological Survey. 334 p.

Brown, T. J., Hetherington, L. E., Hannis, S. D., Bide, Benham, A. J., Idoine, N. E. & Lusty, P. A. J. 2009b. World mineral statistics. Nottingham: British Geological Survey. 109 p.

Buchert, M., Schüler, D. & Beher, D. 2009. Critical metals for future sustainable technologies and their recycling potential. Freiburg: Öko-Institut e.V. Paris: United Nations Environment Programme. 82 p.

Commission of the European Communities 2008. The raw material initiative – meeting our critical needs for growth and jobs in Europe. Communication from the Commission to the European Parliament and the Council. SEC(2008) 2741. Brussels, 4.11.2008. 13 p.

Eilu, P. 2011. Metallic mineral resources of Fennoscandia. Geological Survey of Finland, Special Paper 49, 13−21.

Eilu, P., Hallberg, A., Bergman, T., Feoktistov, V., Korsakova, M., Krasotkin, S., Lampio, E., Litvinenko, V., Nurmi, P. A., Often, M., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. 2007. Fennoscandian Ore Deposit Database – explanatory remarks to the database. Geological Survey of Finland, Report of Investigation 168. 17 p.

Eilu, P., Hallberg, A., Bergman, T., Feoktistov, V., Korsakova. M., Krasotkin, S., Kuosmanen, E., Lampio, E., Litvinenko, V., Nurmi, P., Often, M., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. 2008. Metallic Mineral Deposit Map of the Fennoscandian Shield, 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, St. Petersburg: The Federal Agency of Use of Mineral Resources of the Ministry of Natural Resources of the Russian Federation. The latest update available at: http://en.gtk.fi/ExplorationFinland/fodd.

Eilu, P., Bergman, T., Bjerkgård, T., Feoktistov, V., Hallberg, A., Ihlen, P. M., Korneliussen, A., Korsakova, M., Krasotkin, S., Muradymov, G., Nurmi, P. A., Often, M., Perdahl, J.-A., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. (comps.) 2009. Metallogenic Map of the Fennoscandian Shield, 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, St. Petersburg: The Federal Agency of Use of Mineral Resources of the Ministry of Natural Resources and Ecology of the Russian Federation.

Fennoscandian Ore Deposit Database 2011. Geological Survey of Finland (GTK), Geological Survey of Norway (NGU), Geological Survey of Russia (VSEGEI), Geological Survey of Sweden (SGU), SC Mineral. Online database, available at: http://en.gtk.fi/ExplorationFinland/fodd.

Johnson Matthey 2009. Platinum and palladium supply and demand 1999–2008. Available at: www.platinum.matthey.com.

Juve, G. & Størseth, L. G. 2000. Mineral Atlas of the World. Explanation to the Map Sheet no 9. Europe and neighbouring countries. Trondheim: NGU, Paris: CGMW–CCGM. 231 p.

Koistinen, T., Stephens, M. B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comp.) 2001. Geological map of the Fennoscandian Shield, scale 1:2 000 000. Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia, Espoo: Geological Survey of Finland.

Korhonen, J. V., Aaro, S., All, T., Nevanlinna, H., Skilbrei, J. L., Säävuori, H., Vaher, R., Zhdanova, L. & Koistinen, T. 2002a. Magnetic anomaly map of the Fennoscandian Shield: DGRF-65 anomaly of total field. Anomaly continued upwards to 500 m above ground, scale 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia.

Korhonen, J. V., Aaro, S., All. T., Elo, H., Haller, L. Å., Kääriäinen, J., Kulinich, A., Skilbrei, J. L., Solheim, D., Säävuori, H., Vaher, R., Zhdanova, L. & Koistinen, T. 2002b. Bouguer anomaly map of the Fennoscandian Shield: ISGN 71 gravity system, GRS80 normal gravity formula. Bouguer density 2670 kg/m^3, terrain correction applied. Anomaly continued upwards to 500 m above ground, scale 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia.

Lafitte, P. 1984. Foreword. In: Commission of the Geological Map of the World. Explanatory memoir of the metallogenic map of Europe and neighbouring countries. UNEXCO, IUGS, Earth Sciences 17: XIII–XVI.

Saltikoff, B., Puustinen, K. & Tontti, M. 2006. Metallogenic zones and metallic mineral deposits in Finland: explanation to the Metallogenic map of Finland. Geological Survey of Finland, Special Paper 35. 66 p.

SGU 2009. Metals and minerals. Sweden's contribution to raw material supply in Europe. Uppsala: SGU. 44 p.

Thiess, G. 2010. Minerals policy in Europe: Some recent developments. Resources Policy 35, 190–198.

Weihed, P., Arndt, N., Billström, C., Duchesne, J. C., Eilu, P., Martinsson, O., Papunen, H. & Lahtinen R. 2005. Precambrian geodynamics and ore formation: the Fennoscandian Shield. Ore Geology Reviews 27, 273–322.

Zappettini, E. (ed.) 2005. Mapa metalogénico de América del Sur = Mapa metalogénico da América do Sul = Metallogenic map of South America. Buenos Aires: Instituto de geologia y resursos minerales. 275 p. + 4 maps.

MAIN GEOLOGICAL FEATURES OF FENNOSCANDIA

Lahtinen, R. 2012. Main geological features of Fennoscandia. *Geological Survey of Finland, Special Paper 53*, 13–18, 1 figure.

The Fennoscandian Shield shares a similar geology and metallogeny with the ancient shields in Canada, Australia, Brazil and South Africa. The shield is situated in the north-westernmost part of the East European Craton and is the largest exposed area of Precambrian rocks in Europe. The shield constitutes large parts of Fennoscandia in Finland, NW Russia, Norway and Sweden. The Precambrian rocks can be followed below the Phanerozoic cover sequences of the East European platform towards the south and southeast, forming as a whole the Fennoscandian crustal segment. The Norrbotten province, with its Archaean and Proterozoic cover rocks, most probably also continues to the NW, below the Caledonian orogenic belt, and crops out again in the Lower Allochthon.

Keywords (GeoRef Thesaurus, AGI): bedrock, tectonics, orogenic belts, Fennoscandian Shield, Phanerozoic, Proterozoic, Archean, Fennoscandia

Raimo Lahtinen
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

E-mail: raimo.lahtinen@gtk.fi

ARCHAEAN

The Archaean crust, either exposed or concealed under Palaeoproterozoic cover rocks and granitoids, occurs in the east and north of Fennoscandia. Four major Archaean provinces have been outlined (Fig. 1; modified after Hölttä et al. 2008). The western and eastern parts of the Karelian Province comprise Mesoarchaean 2.8–3.0 Ga lithologies, but rocks older than 3.0 Ga (Fig. 1) have locally been found. The central part of the Karelian province is mainly Neoarchaean, having plutonic and volcanic rocks of 2.75–2.70 Ga in age. This age difference is also seen in the nature of volcanic rocks, where the older rocks formed in within-plate, probably oceanic, environments, whereas younger volcano-sedimentary belts show arc-type characteristics (Sorjonen-Ward & Luukkonen 2005, Hölttä et al. 2008). Sanukitoid-type plutonic rocks of the Archaean domain have ages grouping at 2740 and 2718 Ma (Heilimo et al. 2011).

The Belomorian province (Fig. 1) is dominated by 2.9–2.7 G granitoids and includes volcanic rocks formed at 2.88–2.82 Ga, 2.8–2.78 Ga and 2.75–2.66 Ga. The Neoarchaean ophiolite-like rocks and 2.7 Ga eclogites in the Belomorian province are possible examples of Phanerozoic-style subduction and collision (Hölttä et al. 2008). The Kola province (combined Kola and Murmansk provinces of Hölttä et al. 2008) is a mosaic of Mesoarchaean and Neoarchaean units, together with some Palaeoproterozoic components. The Archaean growth (accretion) of this province occurred from 2.9 Ga to 2.7 Ga and was followed by a collision with the Karelian craton at 2.72 Ga along the Belomorian province. The Archaean part of the Norrbotten province is dominantly concealed under cover rocks, and very limited data are available (Bergman et al. 2001, Mellqvist et al. 1999).

PALAEOPROTEROZOIC COVER ROCKS OF THE ARCHAEAN CONTINENTS

Rifting of the Archaean continent or continents contained in the Fennoscandian shield began in north-eastern Fennoscandia and became widespread after the emplacement of 2.50–2.44 Ga, plume-related, layered gabbro-norite intrusions and dyke swarms (Iljina & Hanski 2005). Erosion and deep weathering after 2.44 Ga was followed by the Huronian glaciation, and later deep chemical weathering again covered large areas in the Karelian province at ca. 2.35 Ga (Laajoki 2005, Melezhik 2006). Rifting events at 2.4–2.1 Ga are associated with mostly tholeiitic mafic dykes and sills, sporadic volcanism and typically fluvial to shallow-water sedimentary rocks (Laajoki 2005, Vuollo & Huhma 2005). Local shallow-marine environments were marked by deposition of carbonates at 2.2–2.1 Ga, showing a large positive $\delta^{13}C$ isotope anomaly during the Lomagundi–Jatuli Event (Karhu 2005, Melezhik et al. 2007). Along the present western edge of the Karelian province, 2.05 Ga bimodal felsic-mafic volcanic rocks of alkaline affinity are intercalated with deep-water turbiditic sediments.

No clear examples of subduction-related magmatism between 2.70 and 2.05 Ga have been found in Fennoscandia. The 2.02 Ga felsic volcanic rocks in Finnish Lapland (Kittilä in Fig. 1) occur in association with oceanic island arc-type rocks and are the oldest candidates for Palaeoproterozoic subduction-related rocks (Hanski & Huhma 2005). Associated continental within-plate volcanic rocks are possibly related to the continuing craton break-up. Bimodal alkaline-tholeiitic magmatism in central Lapland (Hanski et al. 2005) and rift-related magmatism in Kola (Pechenga) show that rift magmatism continued further until 1.98 Ga. Jormua–Outokumpu ophiolites (Fig. 1), tectonically intercalated with deep-water turbidites, are a unique example of Archaean subcontinental lithospheric mantle with a thin veneer of oceanic crust formed at 1.95 Ga along the western edge of the present Karelian province (Peltonen 2005).

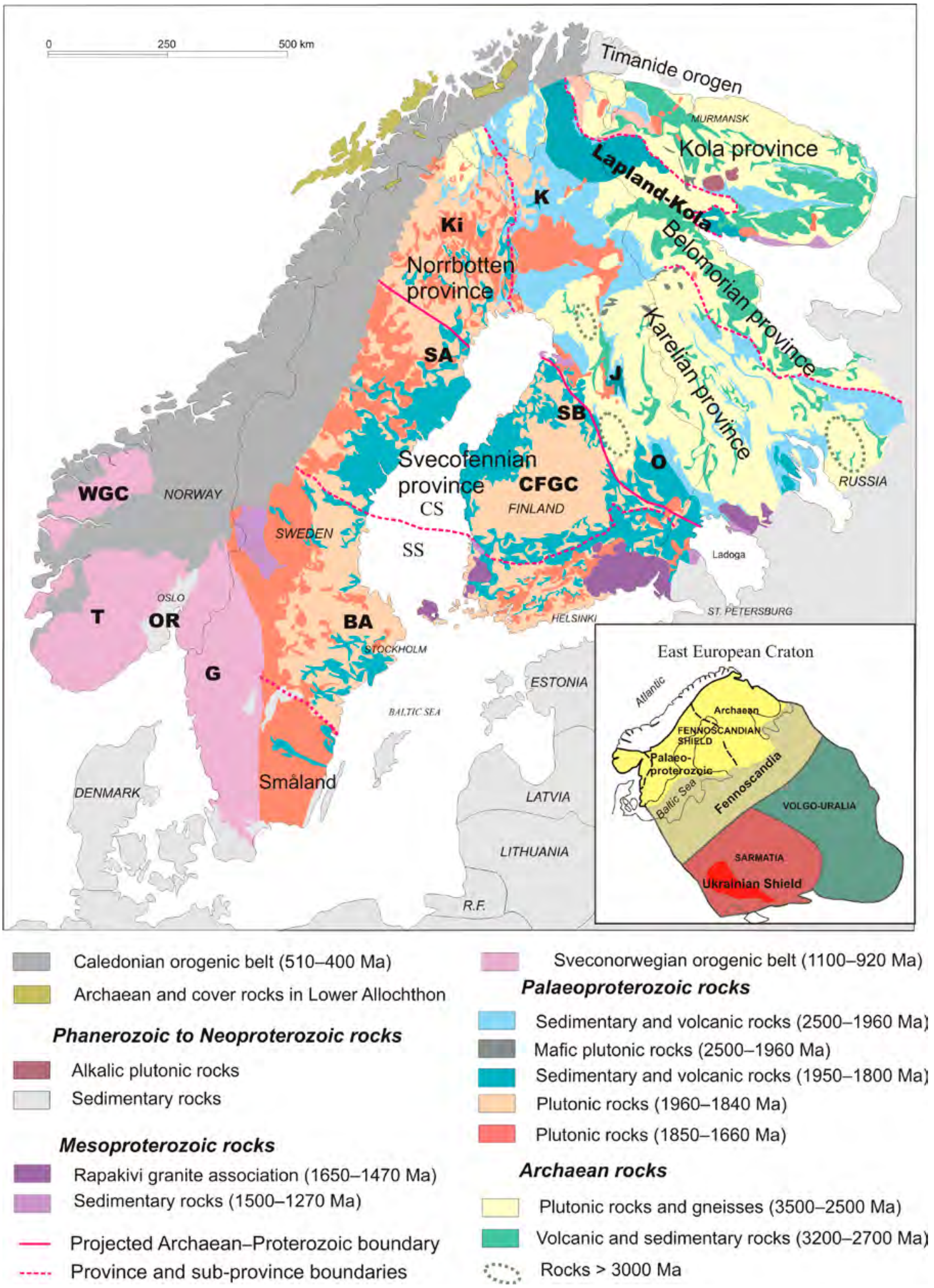


Figure 1. Fennoscandia and its location within the East European Craton. Simplified geological map based on Koistinen et al. (2001) and insert map based on Gorbatschev and Bogdanova (1993). Subareas: CS – Central Svecofennia; SS – Southern Svecofennia. Areas and localities: BA – Bergslagen area; G – Gothian terranes; J – Jormua; K – Kittilä; Ki – Kiruna; O – Outokumpu; OR – Oslo rift; SA – Skellefte Area; SB – Savo Belt; T – Telemarkian terranes; WGC – Western Gneiss Complex.

PALAEOPROTEROZOIC OROGENIC ROCKS

The main Palaeoproterozoic orogenic evolution of Fennoscandia can be divided into the Lapland–Kola orogen (1.94–1.86 Ga; Daly et al. 2006) and the composite Svecofennian orogen (1.92–1.79 Ga; Lahtinen et al. 2005, 2008). The latter is divided into the Lapland–Savo, Fennian, Svecobaltic and Nordic orogens. Whereas the Lapland–Kola orogen shows only limited formation of new crust, the composite Svecofennian orogen produced a large volume of Palaeoproterozoic crust in the Svecofennian province.

The Palaeoproterozoic rocks in the Lapland-Kola orogen (Fig. 1) include small amounts of juvenile, 1.96–1.91 Ga, island arc-type rocks and large volumes of felsic granulites (Daly et al. 2006, Huhma et al. 2011). The oldest rocks in the central Svecofennian province are the 1.95 Ga supracrustal rocks and granitoids south of the Skellefte area (Wasström 2005) and the 1.93–1.92 Ga island-arc rocks in the Savo belt (Fig.1). Arc-type volcanic rocks are slightly older (ca. 5–10 Ma) than granitoids, but the igneous rocks are predominantly 1.89–1.87 Ga in age in the Central Finland granitoid complex (CFGC) and surrounding belts (Kähkönen 2005), and in the Skellefte and Kiruna areas (Allen et al. 1996, Bergman et al. 2001). Sedimentary rocks are typically metapsammites with local intercalations of black schists and tholeiitic lavas. Abundant, ca. 1.80 Ga, plutonic rocks occur in the western part of the central Svecofennia and in northern Fennoscandia.

The southern Svecofennia in the Bergslagen area (Stephens et al. 2009) and its extension to southern Finland (Väisänen & Mänttäri 2002) comprise arc-type volcanism at 1.90–1.88 Ga with partly coeval plutonism at 1.89–1.87 Ga. Sedimentary sequences also include metacarbonate rocks, whereas graphite-bearing rocks are rare. Two metamorphic peaks, at 1.88–1.87 and 1.83–1.80 Ga, have been detected in the southern Svecofennia. A major unconformity between them is indicated by the occurrence of lateritic palaeosols (Lahtinen & Nironen 2010) and ≤ 1.87 Ga quartzites and meta-arkoses (e.g., Bergman et al. 2008). Younger syn- to post-tectonic granites (1.85–1.79 Ga) are common in southern Svecofennia.

The Småland area of the Svecofennian province includes subduction-related juvenile volcanic and plutonic rocks formed between 1.83 and 1.82 Ga. They were metamorphosed and deformed before the extrusion and intrusion of the surrounding WNW-trending, 1.81–1.77 Ga, volcanic and plutonic rocks (Mansfeld et al. 2005). The 1.81–1.77 Ga plutonic rocks can be followed northwards under the Caledonian orogenic belt to the Lower Allochthon (Fig. 1), and they form the core of the Nordic orogen proposed by Lahtinen et al. (2005).

MESO- AND NEOPROTEROZOIC

Rocks of the Gothian (1.64–1.52 Ga) and Telemarkian events (1.52–1.48 Ga), their areas indicated by G and T in Figure 1, respectively, are present in the Sveconorwegian orogenic belt in the SW part of Fennoscandia. These rocks, Palaeoproterozoic basement windows in western Norway (WGC in Fig. 1) and some of the 1.81–1.77 Ga rocks were heavily reworked during repeated orogenies in the Meso- and Neoproterozoic (Bingen et al. 2008). Rocks of the rapakivi granite association (1.65–1.47 Ga) are locally voluminous and especially characteristic for the southern Svecofennia (Rämö & Haapala 2005). The 1.34–1.14 Ga period includes some bimodal magmatism associated with sedimentation. The Sveconorwegian orogeny (1.14–0.97 Ga) involved accretion of terranes followed by post-collisional magmatism between 0.96 and 0.90 Ga (Bingen et al. 2008). A NW-trending Neoproterozoic belt (part of the Timanide orogen) occurs in the northeastern edge of the Fennoscandian Shield (Fig. 1).

The Caledonian orogenic belt (Fig. 1) consists of four levels of thrust sheets where the Lower and Middle Allochthons are generally considered to represent E-vergent thrusts of pre-collisional continental margin rocks (Gee et al. 2008). Archaean and Palaeoproterozoic parts of the Lower Allochthon are probably autochthonous and a direct continuation of the Norrbotten province rocks. Meso- and Neoproterozoic rocks are common in the Lower and Middle Allochthons. Some of the passive margin-related Neoproterozoic marine sandstones and bituminous Alum Shales in the Lower Allochthon can also be autochthonous. Most of these rocks are related to the opening of the Iapetus Ocean (Gee et al. 2008).

PHANEROZOIC

The opening of the Iapetus Ocean started ca. 600 Ma ago, and the final continent-continent collision occurred during the Scandian orogeny (430–390 Ma), followed by an orogenic collapse. The Upper Allochthon in the Caledonian orogenic belt (Fig. 1) is characterised by Phanerozoic rocks (500–430 Ma) derived from the Iapetus Ocean, including ophiolites and island-arc complexes. The Uppermost Allochthon has affinities to the Laurentian margin and can be regarded as an exotic terrane (Gee et al. 2008). Significant amounts of Devonian alkaline rocks occur in the Kola province, and voluminous Late Carboniferous to Early Triassic rift magmatism is seen in the Oslo Rift (Fig. 1).

REFERENCES

Allen, R. L., Weihed, P. & Svenson, S.-Å. 1996. Setting of Zn-Cu-Au-Ag massive sulphide deposits in the evolution and facies architecture of a 1.9 Ga marine volcanic arc, Skellefte district, Sweden. Economic Geology 91, 1022–1053.

Bergman, S., Kübler, L. & Martinsson, O. 2001. Description of regional geological and geophysical maps of northern Norrbotten County (east of the Caledonian orogen). Sveriges geologiska undersökning, Ba 56, 1–110.

Bergman, S., Högdahl, K., Nironen, M., Ogenhall, E., Sjöström, H., Lundqvist, L. & Lahtinen, R. 2008. Timing of Palaeoproterozoic intra-orogenic sedimentation in the central Fennoscandian Shield; evidence from detrital zircon in metasandstones. Precambrian Research 161, 231–249.

Bingen, B., Andersson, J., Söderlund, U. & Möller, C. 2008. The Mesoproterozoic in the Nordic countries. Episodes 31, 29–34.

Daly, J. S., Balagansky, V. V., Timmerman, M. J. & Whitehouse, M. J. 2006. The Lapland-Kola orogen: Palaeoproterozoic collision and accretion of the northern Fennoscandian lithosphere. In: Gee, D. G. & Stephenson, R. A. (eds) European Lithosphere Dynamics. Geological Society, London, Memoirs 32, 561–578.

Gee, D. G., Fossen, H., Henriksen, N. & Higgins, A. K 2008. From the Early Paleozoic platforms of Baltica and Laurentia to the Caledonide Orogen of Scandinavia and Greenland. Episodes 31, 44–51.

Gorbatschev, R. & Bogdanova, S. 1993. Frontiers in the Baltic Shield. Precambrian Research 64, 3–21.

Hanski, E. & Huhma, H. 2005. Central Lapland greenstone belt. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 139–194.

Hanski, E., Huhma, H. & Perttunen, V. 2005. SIMS U-Pb, Sm-Nd isotope and geochemical study of an arkosite-amphibolite suite, Peräpohja Schist Belt: evidence for ca. 1. 98 Ga A-type felsic magmatism in northern Finland. Geological Society of Finland, Bulletin 77, 5–29.

Heilimo, E., Halla, J. & Huhma, H. 2011. Single-grain zircon U-Pb age constraints of the western and eastern sanukitoid zones in the Finnish part of the Karelian Province. Lithos 121, 87–99.

Hölttä, P., Balagansky, V., Garde, A., Mertanen, S., Peltonen, P., Slabunov, A., Sorjonen-Ward, P. & Whitehouse, M. 2008. Archean of Greenland and Fennoscandia. Episodes 31, 13–19.

Huhma, H., O'Brien, H., Lahaye, Y. & Mänttäri, I. 2011. Isotope geology and Fennoscandian lithosphere evolution. In: Nenonen, K. & Nurmi, P. A. (eds) Geoscience for society: 125th anniversary volume. Geological Survey of Finland, Special Paper 49, 35–48.

Iljina, M. & Hanski, E. 2005. Layered mafic intrusions of the Tornio-Näränkävaara belt. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian. Shield Developments in Precambrian Geology 14. Amsterdam: Elsevier, 101–138.

Kähkönen, Y. 2005. Svecofennian supracrustal rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 343–406.

Karhu, J. 2005. Paleoproterozoic carbon isotope excursion. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 669–680.

Koistinen, T., Stephens, M. B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comp.) 2001. Geological map of the Fennoscandian Shield, scale 1:2 000 000. Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia, Espoo: Geological Survey of Finland.

Laajoki, K. 2005. Karelian supracrustal rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 279–342.

Lahtinen, R. & Nironen, M. 2010. Paleoproterozoic lateritic paleosol-ultra-mature/mature quartzite-meta-arkose successions in southern Fennoscandia-intra-orogenic stage during the Svecofennian orogeny. Precambrian Research 183, 770–790.

Lahtinen, R., Korja, A. & Nironen, M. 2005. Palaeoproterozoic tectonic evolution of the Fennoscandian Shield. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 418–532.

Lahtinen, R., Garde, A. A. & Melezhik, V. A. 2008. Paleoproterozoic evolution of Fennoscandia and Greenland. Episodes 31, 20–28.

Mansfeld, J., Beunk, F. F. & Barling, J. 2005. 1.83–1.82 Ga formation of a juvenile volcanic arc – implications from U-Pb and Sm-Nd analyses of the Oskarshamn–Jönköping Belt, southeastern Sweden. GFF 127, 149–157.

Melezhik, V. A. 2006. Multiple causes of Earth's earliest global glaciation. Terra Nova 18, 130–137.

Melezhik, V. A., Huhma, H., Condon, D. J., Fallick, A. E. & Whitehouse, M. J. 2007. Temporal constraints in the Paleoproterozoic Lomagundi–Jatuli carbon isotopic event. Geology 35, 655–658.

Mellqvist, C., Öhlander, B., Skiöld, T. & Wikström, A. 1999. The Archaean–Proterozoic Palaeoboundary in the Luleå area, northern Sweden: field and isotope geochemical evidence for a sharp terrane boundary. Precambrian Research 96, 225–243.

Peltonen, P. 2005. Ophiolites. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 237–278.

Rämö, O. T. & Haapala, I. 2005. Rapakivi granites. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 533–562.

Sorjonen-Ward, P. & Luukkonen, E. J. 2005. Archean rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 19–99.

Stephens, M. B., Ripa, M., Lundström, I., Persson, L., Bergman, T., Ahl, M., Wahlgren, C.-H., Persson, P.-O. & Wickström, L. 2009. Synthesis of the bedrock geology in the Bergslagen region, Fennoscandian Shield, south-central Sweden. Sveriges geologiska undersökning, Ba 58, 1–260.

Väisänen, M. & Mänttäri, I. 2002. 1.90–1.88 Ga arc and back-arc basin in the Orijärvi area, SW Finland. Geological Society Finland, Bulletin 74, 185–214.

Vuollo, J. & Huhma, H. 2005. Paleoproterozoic mafic dikes in NE Finland. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 195–236.

Wasström, A. 2005. Petrology of a 1.95 Ga granite-granodiorite-tonalite-trondhjemite complex and associated extrusive rocks in the Knaften area, northern Sweden. GFF 127, 67–82.

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 19–32, 2012

MINING HISTORY OF FENNOSCANDIA

Eilu, P., Boyd, R., Hallberg, A., Korsakova, M., Krasotkin, S., Nurmi, P. A., Ripa, M., Stromov, V. & Tontti, M. 2012. Mining history of Fennoscandia. *Geological Survey of Finland, Special Paper 53*, 19–32, 3 figures and 4 tables.

The earliest indications of mining in Fennoscandia are from Sweden and Norway where exploitation of bog and bedrock iron deposits started more than 2000 years ago. Signs of prehistoric mining have been detected also from Finland. Sweden and Norway also record the first underground mining in the region, at about 11th and 12th centuries. Mining grew extensively in the 16th and 17th centuries in Sweden and Norway, both in the number of operations and in metals mined. In addition to iron, copper and silver, later also nickel, zinc and cobalt become significant products. Underground mining probably started in the 17th century in Finland and in the 18th century in NW Russia. Mining in modern industrial scales started in the region about 100 years ago with the extension of old mines and opening of new mines. This also resulted in globally substantial development in mining and ore processing technology in the whole region. A large number of mines were closed during the 20th century. On the other hand, there has been a huge increase in the size of individual operations in Fennoscandia since the end of the Second World War. Presently, mining is in increase with extension and reopening of old mines and with opening of new, dominantly very large mines. The present metals production is dominated by iron, titanium, copper, nickel and zinc, but also production of gold, cobalt, vanadium, uranium, lithium, and the REE are projected to significantly increase in the near future.

Keywords (GeoRef Thesaurus, AGI): mining industry, mineral resources, metal ores, mines, mining, production, history, review, Fennoscandia, Norway, Sweden, Finland, Russian Federation

Pasi Eilu, Pekka A. Nurmi, Mikko Tontti
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

Rognvald Boyd
Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway

Anders Hallberg, Magnus Ripa
Geological Survey of Sweden, P.O. Box 670, 75128 Uppsala, Sweden

Margarita Korsakova, Stanislav Krasotkin
State Company Mineral, Detskaya str., 26 liter A office 4H, 199106 St. Petersburg, Russia

Victor Stromov†
VSEGEI, Sredny Prospekt 74, 199108 St. Petersburg, Russia
† Deceased

E-mail: pasi.eilu@gtk.fi

INTRODUCTION

Fennoscandia has a long history of mining and exploration. For example, archaeological evidences shows that sponge iron was produced in Sweden in Bloomery furnaces using magnetite ore during the second century AD (Kresten 1993). Archaeological evidence shows that early copper produc-

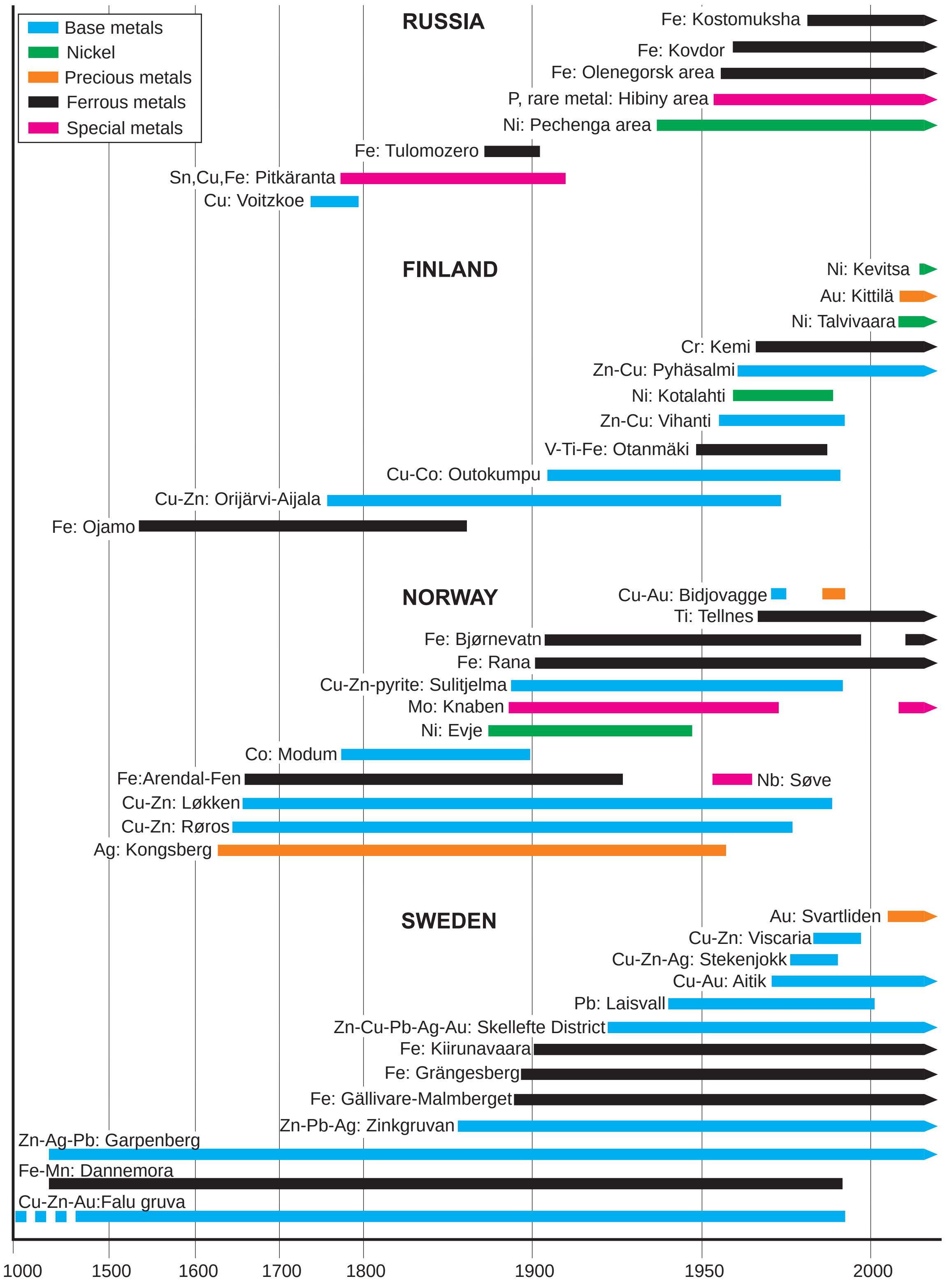


Figure 1. Milestones of the mining history of Fennoscandia: life of the most significant mines and mining camps. Lines ending as arrows indicate presently active mines. Note the non-linear time scale.

tion at the Falu mine took place during the 8th century (Eriksson & Qvarfort 1996). Statistics on copper production at Falun are available from the mid-16th century and until the closure of the mine in 1992. A similar historical background can be shown for the other countries of Fennoscandia.

Metal mining and production has constantly been significant across the region. Hence, the history of mining in Fennoscandia is briefly reviewed in this report. Below, the major developments, 'milestones', mines and mining camps important in their time are presented for each country, as individual subsections, by local experts. Furthermore, some of the immediate effects of these mines on the metals industry are discussed. The main mines and mining camps important in their time in Fennoscandia are listed in Figure 1 and their locations indicated in Figure 2.

Figure 2. Location of the most significant mines and mining camps of their time in Fennoscandia. Geological map based on Koistinen et al. (2001).

NORWAY

Pre-1500

Bog iron ores were exploited in Norway as long ago as 400 BC, and according to C^{14} dating, 28 deposits had been exploited in the Trøndelag counties (in central Norway) alone prior to 200 AD (Stenvik 2005). The oldest record of underground mining is from the late 12th century: it relates to the Akersberg silver deposit in Oslo (Berg 2000) and indicates that operations had by then been closed due to flooding. These deposits were again mined in the period 1520–1537. Small-scale copper mining in the Kongsberg district commenced before 1490. Other types of mineral resource have a much more continuous record of use – especially soapstone for household articles and building, and various types of rock used as millstone.

16th – 17th Centuries

Copper ores were discovered at Ytterøy in Trondheimsfjord at least as early as 1516 (Falck-Muus 1924), but sources disagree as to whether these were exploited at that time. King Frederik I issued a permit to the Bishop of Hamar in 1524 for mining of the Guldnes copper and silver deposits at Seljord in Telemark: these deposits were mined until 1537. Frederik's eldest son, the new king, Christian III, was responsible in 1538–1539 for the introduction of mining laws modelled on those of Saxony and including elements that are still found in the current mining law – a system of claims administered by mining inspectors. Christian III also encouraged prospecting, but with little success. His grandson, Christian IV, who reigned from 1588 to 1648, had greater fortune – in his case also with the aid of miners from Saxony. The first of the silver mines at **Kongsberg** was opened in 1623 (Fig. 1); the king himself visited the mine and founded the city in the following year (Berg 2000). Mining and smelting activities continued, with shorter periods of closure, until 1958. At the most, in 1770, 4200 people were employed in the mines.

Long-term copper mining developed in the following thirty years, first at Kvikne (1630) and then at **Røros** (1644) and **Løkken** (1654), all in deposits in the central Norwegian Caledonides (Table 1). Mining at Røros and Løkken continued until 1977 and 1987, respectively. Numerous iron mines were also opened in the 16th century, primarily in southernmost Norway, but few of these survived to recent times.

18th – 19th Centuries

The Kongsberg Mining Academy ("Bergseminaret") was established in 1757 as the first centre of higher education in Norway, to provide professional training for mining engineers: it was closed in 1814, its role to be taken over by the newly-established University of Oslo.

The established copper mines were joined by another long-term operation at **Folldal** in 1748 and new, though more short-lived, iron mines opened on the southern coast of Norway. New types of metallic ore and minerals were also exploited in addition to the established copper, silver and iron.

Cobalt was discovered at **Modum** in 1772, leading to the establishment of Blaafarveværket as a royal company for the production of the dye "cobalt blue". Mining continued after 1820 in private ownership, but closed in 1898 after periods in British and German ownership, mainly due to competition from alternative types of dye. At its peak, in the 1820s and 1830s, the company was Norway's largest industrial corporation and produced 80 % of the world's cobalt blue.

Nickel was discovered in **Espedalen** in 1837 and mining operations commenced there in 1846 and at **Ertelien** in 1849, the nickel being used in alloys with copper and zinc (Nordsteien 2000). There followed a period of almost 100 years of semi-continuous nickel mining in Norway, including a period in the early 1870s during which Norway was the world's major supplier (a position supplanted by New Caledonia after the discovery of nickel laterite ores).

Mining of pyrite for sulphuric acid production began in the mid-19th century, for example at Vigsnes and Stord and later, in 1888 at **Sulitjelma** (also a major copper producer) and at other new deposits, as well as production from the established copper mines at Røros, Løkken and Folldal. Molybdenum deposits were also discovered in the late 1800s, including the Knaben deposits, which were mined from 1885 (until 1973).

Several new, large deposits of iron ore had been discovered before the end of the 19th century. The Dunderland (**Rana**) deposits were discovered in the 18th C and those at **Bjørnevatn** in Sydvaranger in 1865.

Foreign investment was important in prospecting and mine development in the late 1800s and early 1900s, especially in northernmost Norway. The most long-lived evidence of this is the town of Longyearbyen on Svalbard, named after the founder of the Arctic Coal Company. Established in 1906, this company was the forerunner of Store Norske Spitsbergen Kullkompani, which still operates two coal mines on Svalbard (Vik 2000).

20th Century

Mining commenced at three major iron ore deposits within the first decade of the new century – at Sydvaranger (1906), **Fosdalen** (1906) and Rødsand (1910). Operations also began at Dunderland, but were sporadic until 1937. The first steps that ultimately led to Norway's major role as a producer of titanium pigments were also taken in the early 1900s, with the establishment of a company to exploit a patent for the manufacture of titanium pigment from titanium dioxide. Titania A/S opened mining operations on the Storgangen deposit in Rogaland in 1916. Titania was taken over by an American company, National Lead (NL), in 1927, and is now part of the NL subsidiary, Kronos. In 1957, the **Tellnes** deposit, one of the first in Norway to be discovered with the aid of airborne geophysical methods, was opened. Tellnes is one of the largest ilmenite deposits in the world, currently providing about 6 % of world production of Ti minerals. Other new ore types to be exploited included Zn-Pb-Cu ores such as that at **Mofjell**, just south of Mo i Rana, which was opened in 1928 and was mined until 1987.

The occupation of Norway during World War II had an important impact on mining in the country due to the strategic importance of certain types of ore that were not readily obtainable in Germany. Deposits of several types were intensively exploited and at least two, the nickel deposits at Hosanger and Flåt, were mined out. Considerable emphasis was placed on exploration for new deposits, but no significant new metal mines were opened.

Table 1. Selected mines in Norway (Fig. 2). The most important mines of their time are also shown in Figure 1.

Mine	Main commodities	Production Period (s)	Ore mined (Mt)	Produced metals (kt)
Kongsberg	Ag	1623–1958	7	1.35 Ag
Røros[1,2]	Cu, Zn	1644–1977	6.5	175 Cu; 275 Zn
Løkken[2]	Cu, Zn	1654–1987	24	552 Cu; 432 Zn
Fen	Fe	1657–1927	1	500 Fe
Folldal[1,2]	Cu, Zn, pyrite	1748–1970	4.45	60.9 Cu; 115.2 Zn
Modum	Co	1773–1898	1	20 Co
Evje	Ni, Cu	1872–1946	2.7	20.2 Ni; 13 Cu
Knaben	Mo	1885–1973	8	160 Mo
Sulitjelma[1,2]	Cu, Zn, pyrite	1887–1991	25	469 Cu; 214 Zn
Rana	Fe	1902–	100	25000 Fe
Fosdalen	Fe	1906–1997	35	11600 Fe
Bjørnevatn	Fe	1908–	140	43400 Fe
Mofjell	Zn, Pb, (Cu)	1928–1987	4.35	157 Zn; 31 Pb; 13.5 Cu
Skorovas	Cu, Zn	1952–1984	5.6	64 Cu; 152 Zn
Søve	Nb	1953–1965	1.15	4.1 Nb_2O_5
Bleikvassli	Pb, Zn	1957–1997	4.9	200 Zn; 100 Pb 7.5 Cu
Tverrfjell	Cu, Zn, pyrite	1968–1993	15	150 Cu; 180 Zn; 30 Pb
Tellnes	Ilmenite	1965–	112	21250 TiO_2
Bidjovagge	Cu, Au	1971–1991	2.38	30 Cu; 0.006 Au
Joma	Cu, Zn	1972–1998	11.453	171 Cu; 166 Zn
Bruvann	Ni, Cu	1989–2002	8.5	32.5 Ni; 9.1 Cu; 1.5 Co

[1] Combined figures for several mines in a district.

[2] In historical times, zinc was not exploited, and the Zn figures represent estimates based on average ore grades and not actually produced.

The period of reconstruction and industrial development following WW II saw the opening of numerous new sulphide mines, partly based on known deposits but also on deposits found using new geophysical exploration methods and intensive exploration. These included **Bleikvassli** (Zn-Pb-Cu), **Skorovas** (Zn-Cu-pyrite), **Tverrfjell** (Cu-Zn-pyrite), **Joma** (Cu-Zn), **Bidjovagge** (Cu-Au), Ulveryggen (Cu), **Bruvann** (Ni-Cu) and new deposits in the Røros province (Cu-Zn). More exotic ores were exploited at **Søve**, in the **Fen** carbonatite, where niobium was mined from 1953–1965, and iron had previously been produced (1657–1929). Outokumpu, the Finnish mining giant, developed an important role in mining in Norway in the period from 1983–2003 with ownership or part-ownership in operations at Løkken, Tverrfjell, Joma, Bruvann and Bidjovagge.

Exhaustion of a number of deposits, erratic metal prices and competition from large, easily-mined deposits in other parts of the world led to the closure of most of the remaining sulphide deposits in the last quarter of the 20th century: the only sulphide mine to survive past 2000, Bruvann, closed in 2003, as Outokumpu withdrew from mining operations in general. Norway had, by then, become an important producer of many industrial minerals. Now, early in the 21st century, demand for metals in Asia, higher metal prices and the paucity of resources in much of Europe are driving a new search for mineable ores in Norway and its Nordic neighbours.

SWEDEN

Pre-1600

According to a legend, the **Falu** deposit in the Bergslagen area of south-central Sweden was discovered by a white goat named Kåre who, one day, came back to his owner with horns and hair dyed red from weathered sulphides. ^{14}C dating of charcoal-bearing Cu-rich sediments from a lake in the vicinity of the current mine site indicated that mining (by men or goats) commenced sometime during early Viking times, ca. 700 AD (Eriksson & Qvarfort 1996). The deposit was worked continuously until the closure of the mine in 1992 (Figs. 1 and 2). The first written document mentioning the mine is from 1288 and deals with shares in the mining activity, thus making the Falu mine one of the oldest, if not the oldest, extant companies in the world (Rydberg 1979). The current incarnation of the company is Swedish-Finnish forestry company Stora Enso. The Falu mine site (Fig. 3) was registered as a World Heritage site in 2001.

Archaeological evidence shows that hard-rock iron ore mining began in Sweden even earlier, during Roman Iron age (0-400AD). Bloomery furnaces, dated to around 100 AD, with fragments of magnetite ore have been excavated north of Uppsala and it is suggested that the iron ore came from the nearby Stenby-Lenaberg deposit (FODD ID: S1450) some 8 kilometres up the Fyris river (Kresten 1993). Archaeological excavations and ^{14}C dating of the Lapphyttan blast furnace in the

Figure 3. Panoramic view of the open pit at the Falu mine. Photo: Torbjörn Bergman, SGU.

Norberg area indicates that iron was produced with more modern techniques during the 12th century (Almevik et al. 1992). The first written documents on Fe ore mining come from the mid-14th century (Rydberg 1981).

17th – 19th Centuries

During the end of the 16th century and the beginning of the 17th century the demand for iron and steel increased and paved the way for technological improvements in the mines, blast furnaces and smelters. From being small-scale operations operated by local farmers, the mines became larger industrial units. The industrial revolution, which took place during the late 19th century, brought steam engines, efficient pumps, railways, explosives, methods to process P rich (apatite-bearing) Fe ore and the use of coal instead of charcoal in the blast furnaces completely changing the industrial landscape of Sweden. The innovations, in particular the development of a Swedish railway network, made it possible to start large-scale mining of ores from outside of the Bergslagen district.

20th Century

The Fe ores in Norrbotten County, northernmost Sweden, were already known in the 17th century but it was not until a railway was built that they became economic. In 1888, the railway between **Malmberget** at Gällivare and Luleå by the Baltic Sea coast was completed and production rose from 60 to 600 000 tons of ore annually. In 1902 a railway to Narvik on the Atlantic coast was completed and in 1903 the production from the ores in Malmberget and **Kiruna** made up more than 50 % of all iron ore produced in Sweden. The mines in the north have held a leading position ever since, and today all iron ore produced in Sweden comes from these two mines.

The improved infrastructure in northern Sweden also opened the region for exploration for other commodities. In 1930 boulders from what was to become the large **Aitik** Cu-deposit were found (Malmqvist & Parasnis 1972). Several years of exploration work by Boliden AB eventually led to the opening of the mine in 1968. Initial production was 2 Mt per year and several phases of expansion, the latest approved in 2010, will lead to an annual production of 36 Mt per year by 2015. In 1973, a Cu-mineralised area was found 4 km west of the Kiruna Fe ore deposit (Godin 1976). The initial exploration method was the recognition of the "copper plant", *Viscaria Alpina*, and the mine, which was named after the flower, was in production from 1982 to 1997. Today there are advanced plans to re-open the **Viscaria** mine.

During the first decades of the 20th century, several small holding companies called "emissionsbolag" were created by Swedish banks. One of these was Centralgruppens Emissionsbolag with the mission to acquire stakes in new mining companies and to develop mines, thus it was a kind of early junior exploration company. In 1924, at a time when the company was nearly bankrupt, the **Boliden** Au-Cu-As deposit was found, and was put into production two years later. During the following years several new massive sulphide deposits was found west of Boliden. Today these deposits and their host rocks form the **Skellefte District**, one of the most important ore-districts in Sweden. Discoveries are still being made in the district. For example, the **Björkdal** Au deposit was found by geochemical methods (till sampling) in 1985 by Terra Mining AB and went into production in 1988. It is still in production but with a new owner. The **Åkerberg** Au deposit was found in 1988 by Boliden Mineral AB and was in production from 1989 to 2001. One of the most Cu- and Zn-rich deposits ever found in the district, the **Storliden** deposit, was discovered in 1997 by North Atlantic Natural Resources (NAN) and was in production 2002 to 2008.

The **Caledonian mountains** are another important mineralised region whose metal potential has been known for a long time. Although the lack of infrastructure and, more recently, environmental protection policies has limited exploitation, several mining attempts have nevertheless been made over the centuries. The best known and most "mythical" mine is the Nasafjäll Ag deposit close to the Norwegian border (Bromé 1923, Du Rietz 1949). The deposit was mined for a few years in the mid 17th century but was never profitable. The Fröå Cu deposit was found in the mid 18th century and was intermittently mined during several periods, the latest being from 1910 to 1919. Ore production reached a peak in 1917-1918 but less than 100 000 tons of ore was produced during the mine's lifetime (Helfrich 1967).

More significant deposits in the Caledonides were found and put into production during the

1940s. Galena-bearing sandstone boulders found in 1938 led to the discovery of the **Laisvall** Pb-Zn deposit. Exploitation started in 1943, mainly as a measure to secure domestic supplies of Pb during World War II, but turned out to be economic in peace time as well, and mining lasted until 2001 (Rickard et al. 1979). Exploration for sandstone-hosted Pb-Zn led to several discoveries of similar mineralisation along the Caledonian front, and the Vassbo and Guttusjö deposits 500 km to the south-southwest of Laisvall have also been in production. Exploration by the Geological Survey in the 1970s also led to the discovery of several massive sulphide deposits in the Caledonides (Zachrisson 1969) however the only deposit that has been in production is **Stekenjokk** which was mined for Cu between 1976 and 1988.

The most recent mining district to be recognised in Sweden is the so-called **Gold Line** in Västerbotten County. The Gold Line refers to a southeast-trending Au anomaly detected by the State Mining Property Commission (NSG) during a till geochemistry survey in the late 1980s. The anomaly attracted exploration to this new district, and the first deposit to be found and later put into production by Dragon Mining Ltd. was the **Svartliden** Au deposit. Several other Au deposits are waiting to be opened.

Parallel to, and in interaction with the expansion of the exploration and mining industry there was a tremendous development of the Swedish engineering industry which supplied materials to these enterprises for more than a century. In 1893, ASEA built Sweden's first three-phase power transmission system for the **Grängesberg** Fe mine. About a hundred years later, in 1987, ASEA merged with the Swiss company BrownBoveri to form ABB, a global leader in power and automation technologies. Atlas Copco was established in 1873 with the objective to manufacture and sell equipment for railway construction and operation. At the turn of the century, compressed air machinery and later pneumatic rock-drill equipment became important. Today Atlas Copco tools are found in mines around the world. Sandvik was founded in 1862 and from the very start, the company delivered rock-drilling equipment to the exploration and mining industries. Through mergers and acquisitions the Swedish and Finnish engineering industries have amalgamated to form multinational companies that today are market leaders as suppliers to the world's exploration and mining industries.

Table 2. Selected mines in Sweden (Fig. 2). The most important mines of their time are also shown in Figure 1.

Mine	Main metals	Production Period (s)	Ore mined (Mt)	Produced metals (kt)	Remaining resource (Mt)
Falu mine	Cu, Zn, Au	<800–1992	11.4*	3432 Cu; 456 Zn; 0.034 Au	-
Dannemora distrcit	Fe, Mn	<1200–1992	27.6*	10719 Fe; 536 Mn	59.4
Garpenberg district	Zn, Ag, Pb	<1200–	35.1*	1757 Zn; 4.9 Ag; 808 Pb	54.3
Zinkgruvan	Zn, Pb	1857–	32.4	2847 Zn; 1294 Pb	30.5
Malmberget	Fe	1888–	509.8	260425 Fe	423
Grängesberg	Fe	1892–1989	132.6	79946 Fe	120
Kirunavaara	Fe	1903–	940.3	505155 Fe	1003
Skellefte district (>30 deposits)	Cu, Zn, Au	1924–	105.6	992 Cu; 4856 Zn; 0.25 Au	108
Boliden (Skellefte district)	Au, Cu	1926–1967	8.3	0.13 Au; 119 Cu	-
Laisvall	Pb	1943–2001	64.5	2450 Pb	-
Aitik	Cu, Au	1968–	502.2	1055 Cu; 0.085 Au	2248
Stekenjokk	Cu, Zn, Ag	1976–1988	7.0	94 Cu; 225 Zn; 0.38 Ag	10.1
Viscaria	Cu, Zn	1982–1997	12.5	179 Cu; 88 Zn	57.2
Svartliden	Au	2005–	1.6	0.006 Au	2.7

* Documented production from 1860 to the closure of the mines. Estimated total productionfor the Falu mine probably > 25 Mt, for the other deposits pre-1860 production unknown.

FINLAND

16th – 19th Centuries

The **Ojamo** iron ore mine, which started production in 1530, can be regarded as the first metal mine in Finland (Fig. 1, Table 3). Following this, over 350 metal mines has been in operation before the Second World War. The scale of production in these mines was modest, although mining played an important role in the slowly developing society. Before the 1920s, the mines mainly produced iron ore for iron works in southern Finland. Sulphide ore production was mostly from one mine, **Orijärvi** (Cu-Zn) in SW Finland. During the first 400 years (1530–1945), ore production totalled 10.5 Mt, of which sulphide mines comprised 9.7 Mt (most of which was produced during the 1920s to 1930s) and iron mines 0.8 Mt (Puustinen 2003).

20th Century

In Finland, the modern mining industry started to form along with the **Outokumpu** mine. The deposit was discovered in 1910 (Kuisma 1985) and gradually developed into the first major sulphide ore mine in the country. Small-scale production started in 1910, production gradually increased in the 1930s, and total ore output was almost 6 Mt between 1930 and 1945. During its lifetime, from 1910–1989, about 28 Mt of ore was mined and 1 Mt copper produced (Puustinen 2003). The **Petsamo** (Pechenga) nickel deposit was found in 1921, in the then northeasternmost corner of Finland (Autere & Liede 1989). The development of a mine at Petsamo was complicated, but eventually, during 1936–1944, about 0.5 Mt of ore was mined, first as a Finnish-Canadian cooperation, and during WWII by Germany. The war between Finland and the Soviet Union ended in September 1944, and the Petsamo region was subsequently ceded to the Soviet Union.

Soon after the war, in the late 1940s, the **Aijala** (Cu) and **Otanmäki** (Fe-Ti-V) mines were opened (Table 3). Otanmäki gradually developed into a globally significant vanadium mine responsible for about 10 % of the world's vanadium production during the 1960s and 1970s (Illi et al. 1985). Seven metal mines were opened in the 1950s, including **Vihanti** (Zn) and **Kotalahti** (Ni) mines. The most active mine development period thus far in Finnish mining history was from 1960–1980, when more than twenty metal mines started production. The most important were the still operating Kemi Cr and Pyhäsalmi Zn-Cu mines. As a consequence, total metal ore output peaked in 1979 at slightly over 10 Mt. A few small mines were opened in the 1980s, but at the same time a number of major mines were closed, and total production gradually declined to about 3 Mt in the early 2000s (Puustinen 2003).

Before the opening of the Talvivaara mine in 2008, the most important sulphide mine in Finland was **Pyhäsalmi**. The deposit was discovered in 1958 when a local farmer dug a well through the overburden till into a subcrop of the massive ore (Helovuori 1979). By the end of 2010, over 40 Mt of ore had been mined and the remaining ore has secured a further 10 years of production.

The **Kemi** chromite deposit was found 1959 by a local layman (Alapieti et al. 2005). Open-pit chromite mining began in 1966 and ferrochrome production in 1967 at nearby Tornio, at the far northern end of the Gulf of Bothnia. Stainless steel production at Tornio commenced in 1976. In 2006, the underground mine became the sole source of ore. Its design capacity is 2.7 Mt/y of ore. The known ore reserves will enable mining to continue for several decades, and a recent seismic reflection survey suggested further large resources at depth (Outokumpu 2010).

Currently, we are living in a new era in Finnish mining history. Two major mines, **Kittilä** (Suurikuusikko) gold and **Talvivaara** nickel, were opened in 2008, and the development of the **Kevitsa** Ni-Cu-PGE deposit has started. These three mines will multiply Finnish metal ore output to over 20 Mt/y. In addition to these major deposits, a number of smaller projects have recently started; for example, the **Jokisivu** mine produced its first gold in 2008, and production at the **Pampalo** gold mine started in early 2011. The **Laiva** (Laivakangas) gold mine in western Finland started production in mid-2011, and the mine is expected to yield 118 000 ounces or around 3700 kg of gold per year (Nordic Mines 2010). At the **Kylylahti** Outokumpu-type Cu-Co-Ni-Zn deposit, mine construction has commenced with first production envisaged during 2012 (Universal Resources 2010).

The Talvivaara Ni-Zn-Cu-Co deposit was discovered in 1977 (Loukola-Ruskeeniemi & Heino 1996). The resource was found to be large but of relatively low grade, and it was concluded at the time that exploitation was not economically viable using conventional metal extraction techniques. Bio-heap leaching was later found to be a suitable method to operate this sulphide deposit. The mine successfully produced the first metals in October 2008, and Talvivaara has been in full production since 2010. With a planned annual production of approximately 50 000 tonnes of nickel, Talvivaara has the potential to provide 2.3 % of the world's annual production of primary nickel. In October 2010, the company announced an upgrade of the mineral resources to 1550 Mt (Talvivaara Mining 2010). The mine is anticipated to produce metals for a minimum of 60 years.

Geological Survey of Finland discovered gold in the Suurikuusikko area of the Central Lapland greenstone belt in 1986 (Patison et al. 2007). A preliminary estimate of inferred resources in 2000 amounted to 8.3 Mt, with an average grade of 6.1 grams of gold per tonne. In 2011, proven and probable gold reserves amount to 4.0 million ounces (26 million tonnes at 4.8 g/t). Construction of the mine began in June 2006, and mine was named after the local municipality of **Kittilä**. The first gold was poured on 14 January 2009. The processing plant achieved commercial production in May 2009. Life-of-mine annual gold production was then expected to average 150 000 ounces from 2009 for at least 15 years (Agnico-Eagle 2009).

The **Kevitsa** Ni-Cu-PGE deposit was found 1987 (Mutanen 1997). The property has estimated global resources of 208 million tonnes of ore at grades listed in Table 3, at 0.1 % Ni cut-off. Process facilities are under construction for a starting production of 5 Mt/y ore, with built-in expansion capabilities. The average annual production is planned at 10 000 tonnes of nickel and 20 000 tonnes of copper. Commercial production is expected to start in mid-2012. The estimated mine life is over 20 years (First Quantum Minerals 2009).

Table 3. Significant deposits in Finnish mining history (Fig. 2). Ore and metal production by the end of 2010. Data sources are given in text and in Fennoscandian Ore Deposit Database (2011). The most important mines of their time are also indicated in Figure 1.

Mine	Discovery year	Discovery by	Production Period	Ore mined (Mt)	Produced metals (kt)
Ojamo	<1530	Not known	1542–1863	0.0118	5.3 Fe
Orijärvi	1757	Layman	1758–1954	0.925	12 Cu; 12 Zn; 9.5 Pb
Outokumpu	1910	GTK	1910–1989	28.5	957 Cu; 54 Co; 227 Zn; 34 Ni; 23 Au
Petsamo	1921	GTK	1936–1944	0.462*	16.7 Ni; 8.9 Cu*
Aijala	1945	Suomen Malmi	1948–1960	0.839	13 Cu; 5.5 Zn
Otanmäki	1938	GTK	1949–1985	25.4	8616 Fe; 1 923 Ti; 66 V
Vihanti	1946	GTK	1954–1992	27.9	1445 Zn; 129 Cu; 98 Pb
Kotalahti	1954	Outokumpu	1959–1987	12.36	82 Ni; 32 Cu; 3.7 Co
Pyhäsalmi	1958	Layman	1962–	44.9	988 Zn; 359 Cu; 0.013 Au; 0.63 Ag
Kemi	1959	Layman	1966–	35.8	6 802 Cr
Talvivaara	1977	GTK	2008–	27	11 Ni; 29 Zn; 0.1 Co
Kittilä	1986	GTK	2008–	2.2	0.006 Au
Kevitsa	1987	GTK	2012 –	-	-

* Production when the area was part of Finland

RUSSIAN PART OF THE FENNOSCANDIAN SHIELD

18th – 19th Centuries

The mining history of Karelia began from the first half of the 18th century for the purpose of establishing a resource base for the Olonets mining factories. During the 18th and 19th centuries, up to 200 mine workings were in operation. The main products of that time were gold and copper at **Voitzkoe**, copper at **Voronov Bor**, copper, tin and iron at **Pitkäranta**, and iron at **Tulomozero** and **Velimäki** (Fig. 1, Table 4).

20th Century

In the 1940s, all the territory of Karelia was covered by an aeromagnetic survey at the scale 1:200 000. This resulted in the detection of a number of magnetic anomalies of high intensity. After the verification of these anomalies by drilling, three banded iron formation deposits were discovered: **Kostomuksha**, Gimoly-I and Mezhozerskoye. At Kostomuksha, detailed exploration was followed by resource estimation in the 1970s. Slightly later, similar work was performed on the **Korpanga** and Juzhno-Korpanga deposits located a few kilometres to the north of Kostomuksha, and on several other, smaller occurrences close to Kostomuksha. As a result, a reliable raw material base for the Kostomukshaore dressing complex (Karelsky Okatysh) was created. Commercial production of the Kostomuksha deposit began in 1982 and continues at the present time. The marketable products of the company Karelsky Okatysh are non-fluxed iron ore pellets with an iron content of 65.5 %. Their main consumers are the Severstal metallurgical complex and the countries of Western Europe (2.7 Mt/a), including Finland (Rautaruukki Co – 0.9 Mt/a). The known remaining resources of iron ore at Kostomuksha cover 42 years of production at the present rate. The small **Maiskoe** gold deposit, 200 km north of the Kostomuksha region, was exploited in 1995–1997 by Vuosna Ltd.

Exploitation of bedrock resources of the Kola Peninsula only started in the 20th century. During 1932–1933, all the iron deposits of the Olenegorsk Group were discovered. In 1965–1967, the Olenegorskoye, Komsomolskoye and Kurkenpahk deposits were explored, and in 1971–1975, the Kirovogorskoye, Professor Bauman and Yuzhno-Kokhozerskoye deposits were discovered. Five deposits, **Olenegorskoe**, **Kirovogorskoe**, **Professor Bauman**, **XV Oktjabrskoy Revolutsii** and **Komsomolskoe** (Table 4), are presently mined by the Olcon company, while others in the area are in reserve. The ore production supplies the Severstal steel company.

The **Kovdor** iron deposit was discovered in 1933. It has been exploited by the Kovdorsky ore-dressing complex since 1961. In 1963–1971, the complex features of the baddeleyite-apatite-magnetite ores were determined. At present, a magnetite concentrate with 64.0–64.2 % Fe is being produced from the ore; the main user is the Severstal company. Apatite and baddeleyite are sold on the foreign markets. At full exploitation capacity, the explored reserves at Kovdor will last for 34–35 years.

In the 1920s, the first deposits of the Pechenga nickel region were discovered by the Geological Survey of Finland. In 1937–1940, the Canadian company INCO performed detailed exploration of the **Kaula** deposit with estimation of reserves (6 Mt of ore at 3.68 % Ni and 1.82 % Cu). The mine, the metallurgical plant and the settlement of Petsamonickel were constructed. During the Second World War, the deposits of Kaula and Kammikivi were exploited by Germany, and 460 000 t of ore were mined (16 000 t Ni and 8000 t Cu produced). In 1945, after the annexation of the Pechenga region to the USSR, the mining of ore was recommenced. During intense exploration in 1946–1960, the **Zdanovskoe**, **Semiletka**, Sputnik, **Zapolyarnoe**, and many other deposits were discovered in the area. At present, the company Kolskaya GMK is conducting underground mining at **Kotselvaara**, Semiletka, Sputnik and Zapolyarnoe. In addition, open pit and underground mining are taking place at Severny and Severny-Gluboky mines of the Zdanovskoe deposit. The mined ore (Table 4) is processed at dressing plants in the towns of Nickel and Zapolyarny. The derived nickel sulphide matte (‘fineshtain’) is sent to the company Severonickel for further processing.

In 1931, the Monchegorsk group of copper-nickel deposits was discovered. On the basis of this discovery, the Severonickel mining and smelting complex and the city of Monchegorsk were constructed. Mining of these deposits lasted until 1968. In 1957–1961, the deposits of the Allarechka copper-nickel ore region were discovered. Mining of the **Allarechka** and **Vostok** deposits took

Table 4. The data from all metal mines in the Russian part of the Fennoscandian shield (Fig. 2). The most important mines of their time are also indicated in Figure 1.

Name	**Main commodities**	**Production Period (s)**	**Produced metals (kt)**	**Metal contents**	**Mined ore (Mt)**	**Remaining resource (Mt)**
Voitzkoe	Cu	1737–1794	0.7 Cu, 0.0001 Au	1.3 % Cu 1.9 g/t Au	0.088	0.047
Pitkäranta	Cu, Sn, Fe	1772–1920	7.6 Cu, 0.5 Sn, 102 Fe	1.5 % Cu 0.1 % Sn 40 % Fe	1.1128	38.93
Voronov Bor	Cu	1887–1914	0.1 Cu	1.3 % Cu	0.008	0.769
Tulomozero	Fe	1872–1902	Not reported	35.2 % Fe	Not reported	3.27
Velimäki	Fe	1889–1909	58 Fe	15.46 % Fe	0.4	130
Kostomuksha	Fe	1982–	127 792 Fe	30.55 % Fe	396.87	2454.5
Korpanga	Fe	2006–	Not reported	29.5 % Fe	Not reported	693.122
Maiskoe	Au	1995–1997	0.00005 Au	7.6 g/t Au	0.006	0.033
Olenegorskoe	Fe	1954–	22 967 Fe	30.6% Fe	75.057	412.92
Kirovogorskoe	Fe	1978–	1939 Fe	30.3 % Fe	6.4	259.92
Komsomolskoe	Fe	1989–	1635 Fe	29.2 % Fe	5.6	160.52
XV Oktjabrskoy Revolutzii	Fe	1986–	2228 Fe	29.7 % Fe	7.5	56.94
Professor Bauman	Fe	1986–	13 718 Fe	30.6 % Fe	44.83	16.17
Kovdor	Fe, Zr	1961–	187 495 Fe	24.4 % Fe 0.16 % ZrO_2	768.42	486.9
Nittis-Kunuzhja-Travjanaja	Ni, Co, Cu	1935–1975	56.8 Cu, 100 Ni	2.5 % Cu 5.1 % Ni	1.96	3.098
Zapoljarnoe	Ni	1973–	214 Ni, 113 Cu	2.19 % Ni 1.16 % Cu	9.77	10.958
Kaula	Ni, Co, Cu	1937–1944 1949–1999	Not reported	2.6 % Ni 1.4 % Cu	Not reported	14.6
Kootselvaara-Kammikivi	Ni, Cu	1952–	323 Ni, 172 Cu	1.2 % Ni 0.6 % Cu	26.92	7.45
Semiletka	Ni, Co	1968–2006	63 Ni, 30 Cu	0.73 % Ni 0.35 % Cu	8.63	7.52
Zhdanovskoe	Ni, Cu	1959–	419 Ni, 184 Cu	0.57 % Ni 0.25 % Cu	73.51	619.24
Allarechka	Ni, Cu	1962–1972	Not reported	3.59 % Ni 1.77 % Cu	Not reported	2.23
Vostok	Ni	1969–2000	Not reported	2.1 % Ni 0.95 % Cu	Not reported	2.34
Karnasurt	REE, Nb, Ta	1951–	Not reported	1.33 % REE 0.2 % Nb_2O_5 0.02 % Ta_2O_5	Not reported	23.759
Umbozero	REE, Nb, Ta	1984–	Not reported	0.95 % REE 0.2 % Nb_2O_5 0.01 % Ta_2O_5	Not reported	180.469
Juksorskoe	REE, Sr	1957–	Not reported	0.38 % REE 1.38 % SrO	Not reported	542.2
Rasvuchorr	REE, Sr	1963–	Not reported	0.34 % REE 1.14 % SrO	Not reported	35.4
Koashvinskoe	REE, Sr	1978–	Not reported	0.4 % REE 1.58 % SrO	Not reported	856.6

place in 1962–1972 and 1969–1974, respectively.

In 1921–1927, mining of the apatite-nepheline deposits of the **Khibiny** massive started. At present, such deposits are considered to be major world reserves of strontium and rare metals (87 % and 70 % of the entire Russian reserves, respectively). The average grade of strontium in these deposits varies from 1.13 % up to 1.58 %. The Khibiny deposits are mined by the company OOO Apatit. Presently, strontium production from the apatite-nepheline concentrate is taking place at a rather limited volume, and rare metals are not produced at all. The Lovozero mines of loparitic ores were opened in the 1920s and 1930s. Such ores are the source of tantalum, niobium and rare metals. At the moment, two mines are in production: **Karnasurt** (started from 1951) and **Umbozero** (started from 1984). They are mined by ZAO Lovozero ore-dressing and processing company. Their reserves are estimated to last 40–50 years.

REFERENCES

Agnico-Eagle 2009. Annual Report 2008. Available at: www.agnico-eagle.com.

Alapieti, T. T. & Huhtelin, T. A. 2005. The Kemi Intrusion and associated chromite deposit. Geological Survey of Finland, Guide 51a, 13–32.

Almevik, G., Eriksson, P. & Pawlak, E. 1992. Nya Lapphyttan: en rekonstruerad medeltid. Göteborgs universitet, Institutionen för kulturvård, 1101–3303; 1992:22. 73 p. (in Swedish)

Autere, E. & Liede, J. 1989. Petsamon nikkeli: taistelu strategisesta metallista. Helsinki: Vuorimiesyhdistys r.y. 305 p. (In Finnish)

Berg, B. I. 2000. Klassisk fase. Norske bergverk før industrialiseringen. In: Carstens, H. (ed.) … bygger i berge. Tapir, 82–87. (in Norwegian)

Bromé, J. 1923. Nasafjäll: ett norrländskt silververks historia. Stockholm: Nordiska bokhandeln. 352 p. (in Swedish)

Du Rietz, T., 1949. The Nasafjäll region in the centre of the Scandinavian Caledonides. Geologiska Föreningen i Stockholm Förhandlingar (GFF) 71, 243–252

Eriksson, J. A. & Qvarfort, U. 1996. Age determination of the Falu coppermine by ^{14}C-datings and palynology. GFF 118, 43–47.

Falck-Muus, R. 1924. Bergverksdriften. Den historiske og tekniske utvikling i Norge samt dens betydning for landet. Den Norske Ingeniørforening. Oslo: Festskrift. (in Norwegian)

Fennoscandian Ore Deposit Database 2011. Geological Survey of Finland (GTK), Geological Survey of Norway (NGU), Geological Survey of Russia (VSEGEI), Geological Survey of Sweden (SGU), SC Mineral. Online database, available at: http://en.gtk.fi/ExplorationFinland/fodd.

First Quantum Minerals 2009. Press release 30 November 2009. Available at: www.first-quantum.com

Godin, L. 1976. Viscaria – en ny kopparmineralisering i Kirunagrönstenen. Abstracts, XII Nordiska Geologvintermötet, Göteborg 7–10 januari 1976, Geologiska Institutionen, Chalmers Tekniska Högskola/Göteborgs Universitet, 17–17. (in Swedish)

Helfrich, H. 1967. Ein Beitrag zur Geologie des Åresgebietes. Sveriges geologiska undersökning serie C 612.

Helovuori, O. 1979. Geology of the Pyhäsalmi ore deposit, Finland. Economic Geology 74, 1084–1101

Illi, J., Lindholm, O., Levanto, U.-M., Nikula, J., Pöyliö, E. & Vuoristo, E. 1985. Otanmäen kaivos. Summary: Otanmäki mine. Vuoriteollisuus 43, 98–107.

Koistinen, T., Stephens, M.B., Bogatchev, V., Nordgulen, O., Wennerstrom, M. & Korhonen, J. (comp.) 2001. Geological map of the Fennoscandian Shield, 1:2,000,000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia.

Kresten, P. 1993. Undersökning av malmer och slagger. Ett tvärsnitt genom Gamla Uppsala sn. Arkeologiska undersökningar inför gång- och cykelvägen mellan Gamla Uppsala och Storvreta. In: Karlenby, L., Kresten, P. & Sigvallius, B. (eds) RAÅ Rapport UV 1993:3. Stockholm. (in Swedish)

Kuisma, M. 1985. Kuparikaivoksesta suuryhtiöksi: Outokumpu 1910–1985. Outokumpu Oy. 463 p. (in Finnish).

Loukola-Ruskeeniemi, K. & Heino, T. 1996. Geochemistry and genesis of the black shale-hosted Ni-Cu-Zn deposit at Talvivaara, Finland. Economic Geology 91, 80–110.

Malmqvist, D. & Parasnis, D. S. 1972. Aitik: geophysical documentation of a third-generation copper deposit in north Sweden. Geoexploration 10, 149–200.

Mutanen, T. 1997. Geology and ore petrology of the Akanvaara and Koitelainen mafic layered intrusions and the Keivitsa-Satovaara layered complex, northern Finland. Geological Survey of Finland, Bulletin 395. 233 p.

Nordic Mines 2010. Press release, 10 March 2010.

Nordsteien, O. 2000. Nikkelgruvene I Norge. In: Carstens, H. (ed.) … bygger i berge. Trondheim: Tapir, 136–137. (In Norwegian)

Outokumpu 2010. Press release, 19 January 2010. Available at: http://hugin.info/3010/R/1374631/337048.pdf

Patison, N. L., Salamis, G. & Kortelainen, V. J. 2007. The Suurikuusikko gold deposit: project development summary of northern Europe's largest gold resource. Geological Survey of Finland, Special Paper 44, 125–136.

Puustinen, K. 2003. Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530–2001, historiallinen katsaus erityisesti tuotantolukujen valossa. Geological Survey of Finland, unpublished report M10.1/2003/3. 578 p. (in Finnish)

Rickard, D. T., Willden, M. Y., Marinder, N. E. & Donnelly, T. H. 1979. Studies on the genesis of the Laisvall sandstone lead-zinc deposit, Sweden. Economic Geology 74, 1255–1285.

Rydberg, S. 1979. Stora Kopparberg – 1000 years of an industrial activity. Gullers International AB. 95 p.

Rydberg, S. 1981. Dannemora genom 500 år. Dannemora 1981. 22 p. (in Swedish)

Stenvik, L. F. 2005. Jernalderen. In: Alsaker, S. K., Sognnes, K., Stenvik, L. F., Røskaft, M. & Skevik, O. (eds) Landskapet blir Landsdel, fram til 1350. Trøndelags historie I, 107–180. (in Norwegian)

Talvivaara Mining 2010. Stock exchange release, 27 October 2010. Available at: www.talvivaara.com

Universal Resources 2010. Stock exchange release, 2 August 2010. Available at: www.altonamining.com

Vik, J. 2000. Bergverksdrift på Svalbard. In: Carstens, H. (ed.)… bygger i berge. Tapir, 222–223. (in Norwegian)

Zachrisson, E. 1969. Caledonian geology of Northern Jämtland – Southern Västerbotten. Sveriges geologiska undersökning serie C 644. 33 p.

METALLOGENIC AREAS OF FENNOSCANDIA

The metallogenic areas of Fennoscandia are described below by country in geographic order from west to east, starting from Norway and ending with Russia, and within each country in order of the ID codes of the areas. A metallogenic area description contains the general metallogenic features of the area and how the local metallogeny relates to the geological features of the area. It reports what types of metal deposits, other ore indications and geology define the area, and commonly includes brief descriptions of typical deposits and the high-potential subareas. For the economically most important metallogenic areas, there is more information than for the so far less significant areas. An area description may contain geological maps and figures, and a table listing the mines and main deposits of the area. References to the main sources of information are given in the bibliography at the end of each country section. In a number of the maps presented below, white irregularly shaped areas indicate areas covered by lakes and the sea.

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 35–138, 2012

METALLOGENIC AREAS IN NORWAY

Sandstad, J. S., Bjerkgård, T., Boyd, R., Ihlen, P., Korneliussen A., Nilsson, L. P., Often, M., Eilu, P. & Hallberg, A. 2012. Metallogenic areas in Norway. *Geological Survey of Finland, Special Paper 53*, 35–138, 82 figures and 15 tables.

There are 40 major metallogenic areas within the Norwegian part of the Fennoscandian shield. Of these, 12 areas show potential dominantly for copper, zinc and lead, 11 for ferrous metals (Fe, Ti, V), 9 for nickel and cobalt, 5 for precious metals (Ag, Au), and 3 for molybdenum. A large number of major genetic types of metal deposits are known from Norway. By past production and present resources, the most significant deposits and areas include: mafic intrusion-hosted Ti-Fe±V (Tellnes), VMS (Løkken, Folldal, Røros, Grong, Mofjell, Sulitjelma), sedimentary Fe (Rana, Sør-Varanger), sediment-hosted Cu (Repparfjord, Nussir), ortho-magmatic Ni±Cu (Råna) and porphyry Mo (Nordli). Most of the known metallic mineral deposits in Norway were formed during the Caledonian rifting to subduction and collision, during 600–390 Ma (VMS in several districts, sedimentary Fe, orthomagmatic Ni-Cu, metamorphic Ti). Other major metallogenic events include Neoarchaean, 2900–2800 Ma (BIF), Paleoproterozoic 2400–1800 Ma (sediment-hosted Cu, orogenic Au, Cu), Sveconorwegian, 1200–900 Ma (mafic-intrusion hosted Ti-Fe) and the Oslo Rift, 300–240 Ma (porhyry Mo).

Keywords (GeoRef Thesaurus, AGI): metallogenic provinces, mineral resources, metal ores, mines, production, Phanerozoic, Precambrian, Norway

Terje Bjerkgård, Rognvald Boyd, Peter Ihlen, Are Korneliussen, Lars Petter Nilsson, Morten Often*, Jan Sverre Sandstad
Geological Survey of Norway, P.O. Box 6315 Sluppen, N-7491 Trondheim, Norway

* *Present address for Morten Often:*
Store Norske Spitsbergen Grubekompani AS, P.O. Box 613, N-9171 Longyearbyen, Norway

Pasi Eilu
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

Anders Hallberg
Geological Survey of Sweden, P.O. Box 670, 75128 Uppsala, Sweden

E-mail: jan.sandstad@ngu.no

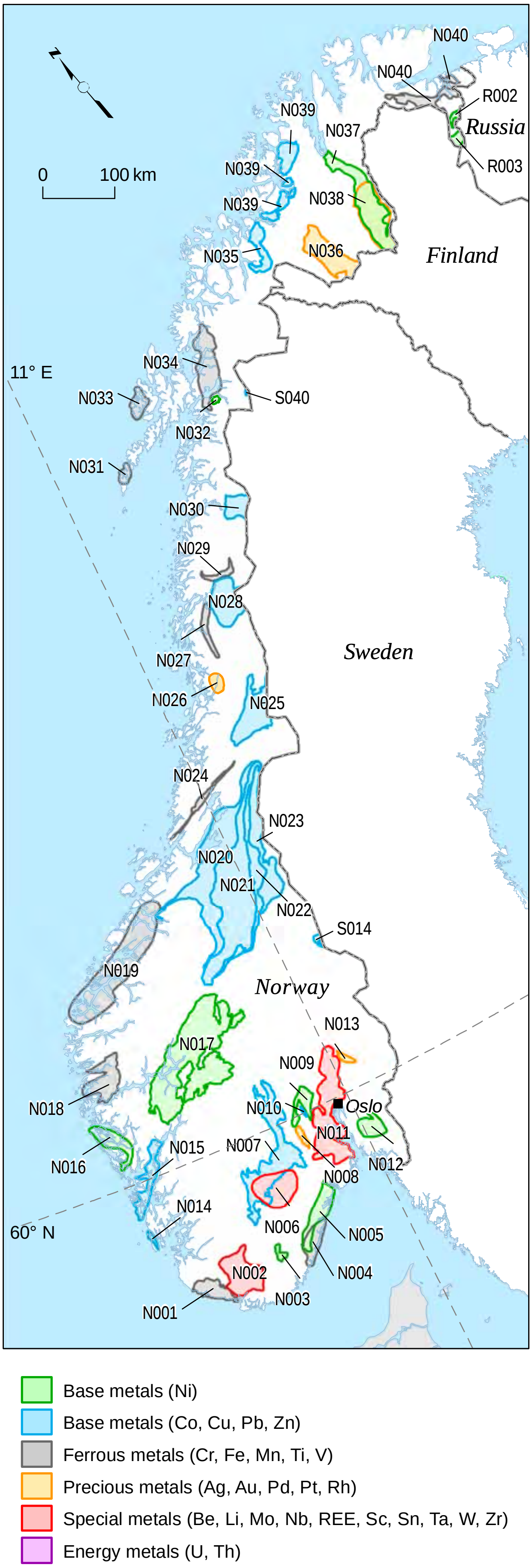


Figure 1. Index map of metallogenic areas in Norway. The names of the metallogenic areas are listed in Table 1.

Table 1. List of the metallogenic areas in Norway.

Code	Area name, main metals
N001	Rogaland Ti, Fe, V
N002	Agder Mo
N003	Evje Ni, Cu
N004	Arendal Fe
N005	Bamble Ni, Cu, Fe, Ti
N006	Bandak-Nisser Mo
N007	Telemark Cu, Au, Ag
N008	Kongsberg Ag
N009	Ringerike Ni, Cu
N010	Modum Co, As, Au, Ag
N011	Oslo Mo
N012	Indre Østfold Ni, Cu
N013	Eidsvoll Au
N014	Karmøy Cu, Zn
N015	Hardanger Cu, Zn
N016	Bergen-Hosanger Ni, Cu, Fe, Ti
N017	Jotunheimen Ni, Cu, PGE
N018	Sunnfjord Ti, Fe
N019	Møre Fe, Ti
N020	Støren-Løkken Cu, Zn
N021	Kvikne-Singsås Cu, Zn, Ni
N022	Folldal-Meråker Cu, Zn
N023	Røros-Tydal Zn, Cu, Pb
N024	Fosdalen Fe, Cu
N025	Grong-Stekenjokk Cu, Zn, Au
N026	Bindal Au
N027	Vefsn Fe
N028	Rana-Hemnes Zn, Pb, Cu
N029	Rana Fe
N030	Sulitjelma Cu, Zn
N031	Lofoten Fe, Ti
N032	Råna Ni, Cu
N033	Selvåg Fe, Ti
N034	Troms Fe
N035	Vaddas-Birtavarre Cu, Zn
N036	Kautokeino Au, Cu
N037	Karasjok-Lakselv Ni, Cu, PGE
N038	Karasjok Au, Cu
N039	Alta-Repparfjord Cu, Au
N040	Sør-Varanger Fe

The metallogenic areas id-coded to neighbouring countries are listed and described in the respective country sections of this book.

N001 ROGALAND Fe-Ti-V

Are Korneliussen (NGU)

The Rogaland Anorthosite Province (Fig. 2), with large massif-type anorthosites and associated noritic, mangeritic and charnockitic intrusions, was emplaced in a migmatised Mesoproterozoic terrain at intermediate crustal levels in a post-collisional regime (Duchesne et al. 1985, Duchesne 1999, Bingen et al. 2008b). The major plutonism, including the emplacement of the anorthosites, took place between 932 and 920 Ma (Schärer et al. 1996). Ti-Fe deposits, mainly ilmenite-magnetite rich cumulate and ilmenite-magnetite rich dykes, are widespread in the province (Duchesne 2001).

The area has a long history of ilmenite mining, going back to 1785 when ilmenite was mined for iron ore, as reviewed by Krause et al. 1985. Based on the large ilmenite resources in the region, an industrial process for the production of white TiO_2 pigment (the sulphate process) was developed in 1916 by P. Farup and G. Jebsen (Jonsson 1992). As a consequence of this development, the company Titania started to mine the **Storgangen** deposit (Figs. 2 and 3) in 1917; this operation continued until 1965, when mining began at the nearby Tellnes deposit (also called Tellenes) (Fig. 2). The **Tellnes** deposit is an ilmenite-rich noritic dyke within anorthosite, as described in detail by, for example, Krause et al. (1985) and Charlier et al. (2007). It contains 575 Mt proven and possible ore averaging 18 % TiO_2, based on information provided by Titania AS.

The **Blåfjell** ilmenite ores (Fig. 2) are related to noritic pegmatitic dykes within the surrounding anorthosite; several of these dykes have been mined on a small scale in the past. The layered Storgangen intrusion (Fig. 3), with Fe-Ti rich noritic cumulates, was emplaced as a sill in the anorthosite (Schiellerup et al. 2003). The remaining ore resource is 60 Mt ore with 17–18 % TiO_2

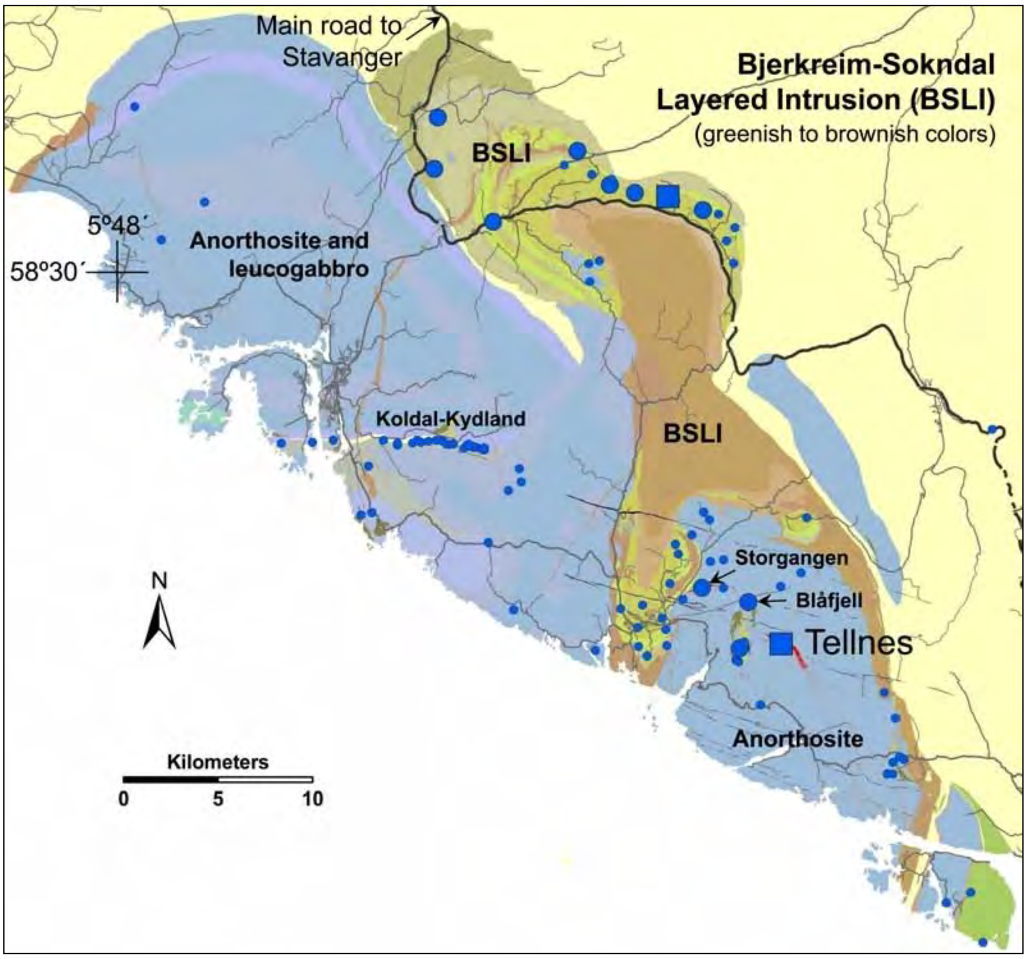


Figure 2. Geological map of the Rogaland Anorthosite Province based on Marker et al. (2003) showing the Tellnes, Blåfjell and Storgangen deposits as well as registered Fe-Ti occurrences. Undifferentiated Mesoproterozoic gneisses are shown in yellow.

(Krause et al. 1985).

The **Koldal–Kydland** deposits (Fig. 2) are layers of hemo-ilmenite up to 1–2 m thick, accumulated from a fractionally crystallizing melt that intruded as a concordant sill in the contact zone between two anorthosite massifs (Duchesne 2001). The Bjerkreim–Sokndal intrusive complex (Fig. 2) is a part of the Rogaland anorthosite province, with anorthosites, leuconorites, troctolites, norites, gabbro-norites, jotunites and mangerites derived through crystallisation from a jotunitic parental magma (Wilson et al. 1996). It contains Fe-Ti-rich noritic and gabbronoritic cumulates that have been mined on a small scale at several locations in its southern extension.

The Tellnes ilmenite deposit, more correctly called Tellenes, is located in the central part of the Åna–Sira anorthosite, one of several anorthosite intrusions in the Rogaland Anorthosite Province. It forms the core of the **Tellnes–Sokndal** subarea (N001.1), and is regarded as a world-class titanium mineral deposit, with an annual production

Figure 3. Storgangen layered ilmenite ore. Photo: A. Korneliussen, NGU.

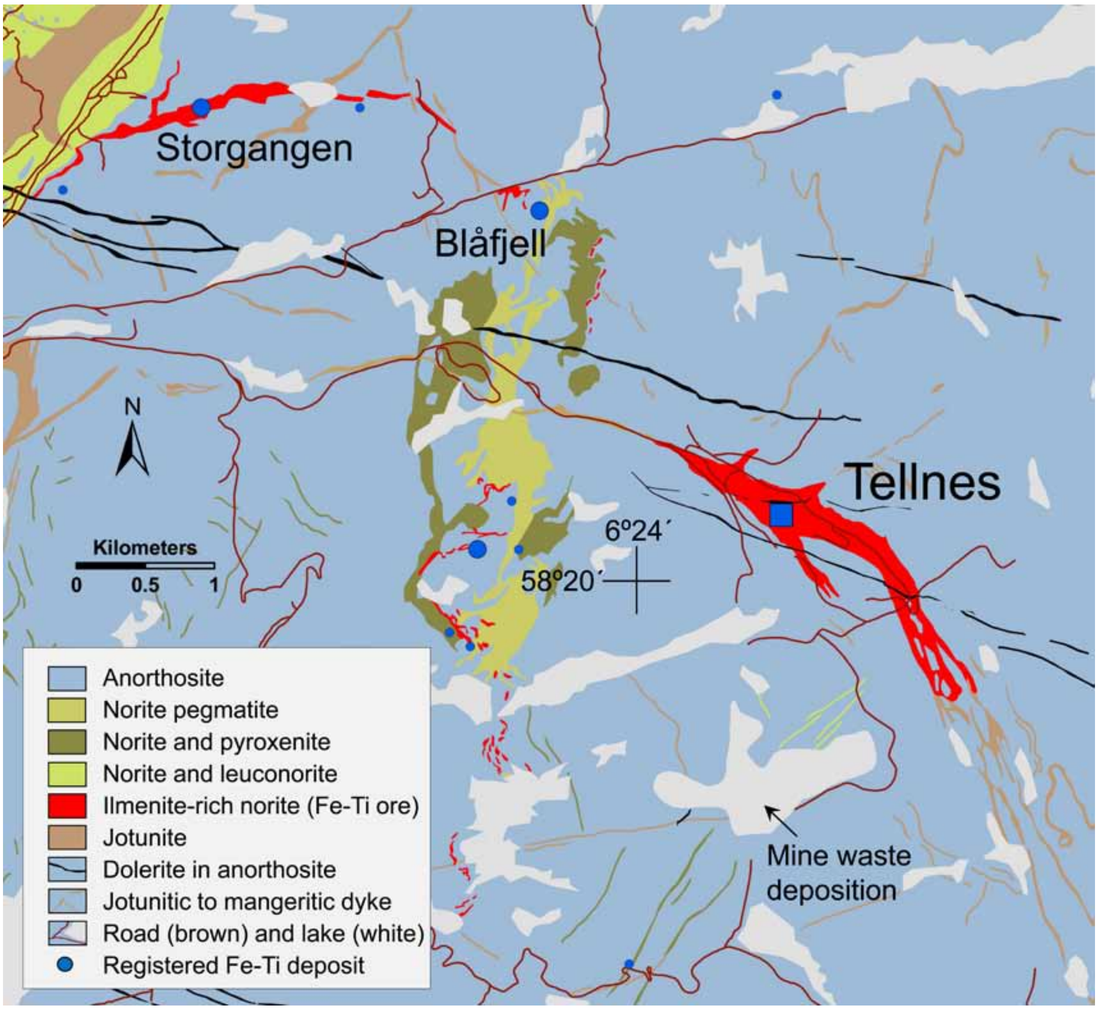


Figure 4. The Tellnes ilmenite deposit and its geological surroundings, based on Marker et al. (2003), which for these parts is mainly after Krause et al. (1985).

of 0.8–0.9 Mt of ilmenite concentrate equivalent to 6–7 wt.% of the total production of titanium minerals in the world by TiO_2 content. So far, more than 110 Mt (2008) have been mined, while proven reserves are 200 Mt containing 18 % TiO_2 and additional possible reserves are 375 Mt. The ilmenite is used for the production of titanium pigment by the sulphate process and for the production of Fe-Ti slag and pig iron.

The Tellnes Ti-rich noritic ore body (Figs. 4–6) is almost 3 km long, more than 400 m wide and plunges eastwards at depth. The intrusion is apparently fairly homogeneous in its main characteristics, but is highly complex and variable in its oxide mineral-chemical details (Kullerud 2003, Charlier et al. 2007). The average modal composition of the Tellnes ore body is 53 vol.% plagioclase ($An_{45–42}$), 29 vol.% hemo-ilmenite and 10 vol.% orthopyroxene, together with some biotite and accessory amounts of olivine, magnetite, Ca-rich pyroxene, apatite and sulphides (Gierth & Krause 1973, Krause et al. 1985, Duchesne 1999).

The intrusion crops out as a 2700 x 400 m wide sickle-shaped body with a synclinal cross section (Fig. 5). This morphology is interpreted as resulting from gravity-induced subsidence of a subhorizontal sill (Charlier et al. 2006). The parental magma had the composition of a Fe-Ti-P-rich ferrodiorite (jotunite), as indicated by the presence of fine-grained rocks at the margins of the intrusion and the pressure of emplacement, constrained by phase relations, is around 5 kbar (Charlier et al. 2006). The Tellnes deposit yields a

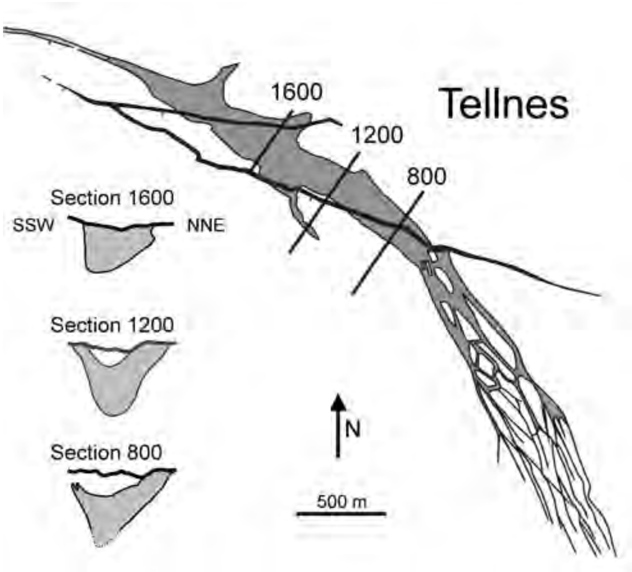


Figure 5. Tellnes ilmenite deposit with three cross sections after Charlier et al. (2007).

Figure 6. Eastward view of the Tellnes open pit. Photo: A. Korneliussen, NGU.

zircon U-Pb age of 920 ± 3 Ma, 10 Ma younger than the average zircon age of 931 ± 2 Ma for three of the large hosting anorthosite plutons (Schärer et al. 1996). It is cross-cut by two doleritic dykes.

Tellnes ilmenite is characteristically a hemo-ilmenite with numerous hematite (Fe_2O_3) exsolutions in ilmenite (Fig. 7), as described in detail by Gierth & Krause (1973), Krause et al. (1985) and McEnroe et al. (1996, 2000). One effect of the significant hematite component is a decrease in the TiO_2 content relative to stoichiometric ilmenite (52.8 % TiO_2). Another TiO_2-reducing factor is due to an MgO-solid solution with FeO in the ilmenite crystal lattice, commonly at 3–4 % MgO. Due to these mineral effects, combined with silicate impurities in the company's ilmenite concentrate, the standard Tellnes ilmenite concentrate contains 44–45 % TiO_2. The positive effect of the hematite lamellae is that Tellnes ilmenite dissolves more easily in acids than homogeneous ilmenite, and is therefore highly suitable to sulphate-process titanium pigment production (Chernet 1999, 2003).

As summarised by Schiellerup et al. (2003), the Bjerkreim–Sokndal Layered Intrusion (BSLI) consists of a layered cumulate sequence, ranging in composition from anorthosite and troctolite to norite, gabbronorite, jotunite and mangerite (Fig. 8). This is essentially the **Bjerkreim** metallogenic subarea (N001.2). The intrusion comprises a layered series of norites, more than 7000 m thick, suggested to be derived by fractional crystallisation of jotunitic parental magmas (Duchesne 1987, Duchesne & Hertogen 1988, Robins et al. 1997). It is capped by mangeritic, quartz-mangeritic and charnockitic rocks. The layered series is divided into 6 megacyclic units (MCUs) with a characteristic cumulate sequence. Distinct enrichment of ilmenite, vanadium-bearing magnetite and apatite occur at certain positions in the layered sequence (Meyer et al. 2002, Schiellerup et al. 2001). The most significant enrichment zones with approximately 30 wt.% of the three valuable minerals are illustrated in Figures 9 and 10.

The layered series in the northern part of the Bjerkreim–Sokndal intrusion, the Bjerkreim Lobe, comprises six megacyclic units (MCUs) subdivided into a sequence of zones (a–f) defined by the presence or absence of certain index minerals; for further details of the layered series, see Meyer et al. (2002) and references therein. Three sequences, MCU IBe, MCU IIIe and MCU IVe, in which the three high value minerals, apatite, ilmenite and vanadiferous magnetite, coexist, are

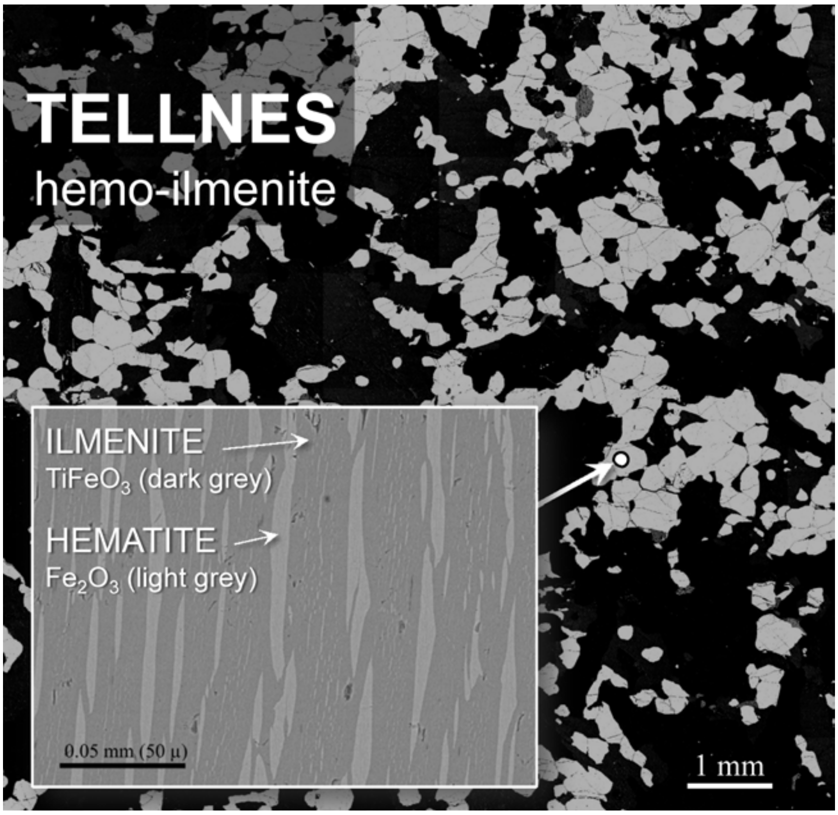


Figure 7. SEM images of Tellnes ilmenite ore. The inserted image shows the hemo-ilmenite character of the ilmenite, with numerous exsolution lamellae of hematite within ilmenite.

shown as expanded red intervals in Figure 10 and labelled Zone A, B and C, respectively. The mineral resource potential associated with these zones is very large, more than 500 Mt to 100-m depth (Table 2) based on surface mapping and sampling, but not documented by drilling.

Ilmenite from within the layered norites of the Bjerkreim–Sokndal layered intrusion is usually homogeneous without hematite exsolution lamellae, such as the ilmenite in Figure 11, which is from Zone C, and it is distinctly different from Tellnes ilmenite (hemo-ilmenite). Another difference is that Bjerkreim–Sokndal ilmenite tends to have a fairly low magnesium content (1–2.5 % MgO) compared with Tellnes ilmenite (3–4 % MgO).

The Bjerkreim–Sokndal magnetite (Fig. 11) is a titanomagnetite with lamellae of ilmenite and numerous tiny exsolutions of spinel following crystallographic directions in the host magnetite. The vanadium content in magnetite is considerable, from 0.5 % to more than 1 % V_2O_3. Over large volumes of ore in the Bjerkreim Lobe, the vanadium content in magnetite is in the range 0.8–1.0 % V_2O_3.

In general, the southern lobe (Sokndal area) is regarded as having higher titanium contents in cumulates than the northern lobe (Bjerkreim Lobe). A number of registered ilmenite occurrences in the Sokndal area (not shown here) are disseminated to semi-massive ilmenite-rich cumulate layers in norite, whereas the majority of Fe-Ti deposits within anorthosite and leuconorite are ilmenite-rich cumulate layers and massive bands (Duchesne & Korneliussen 2003).

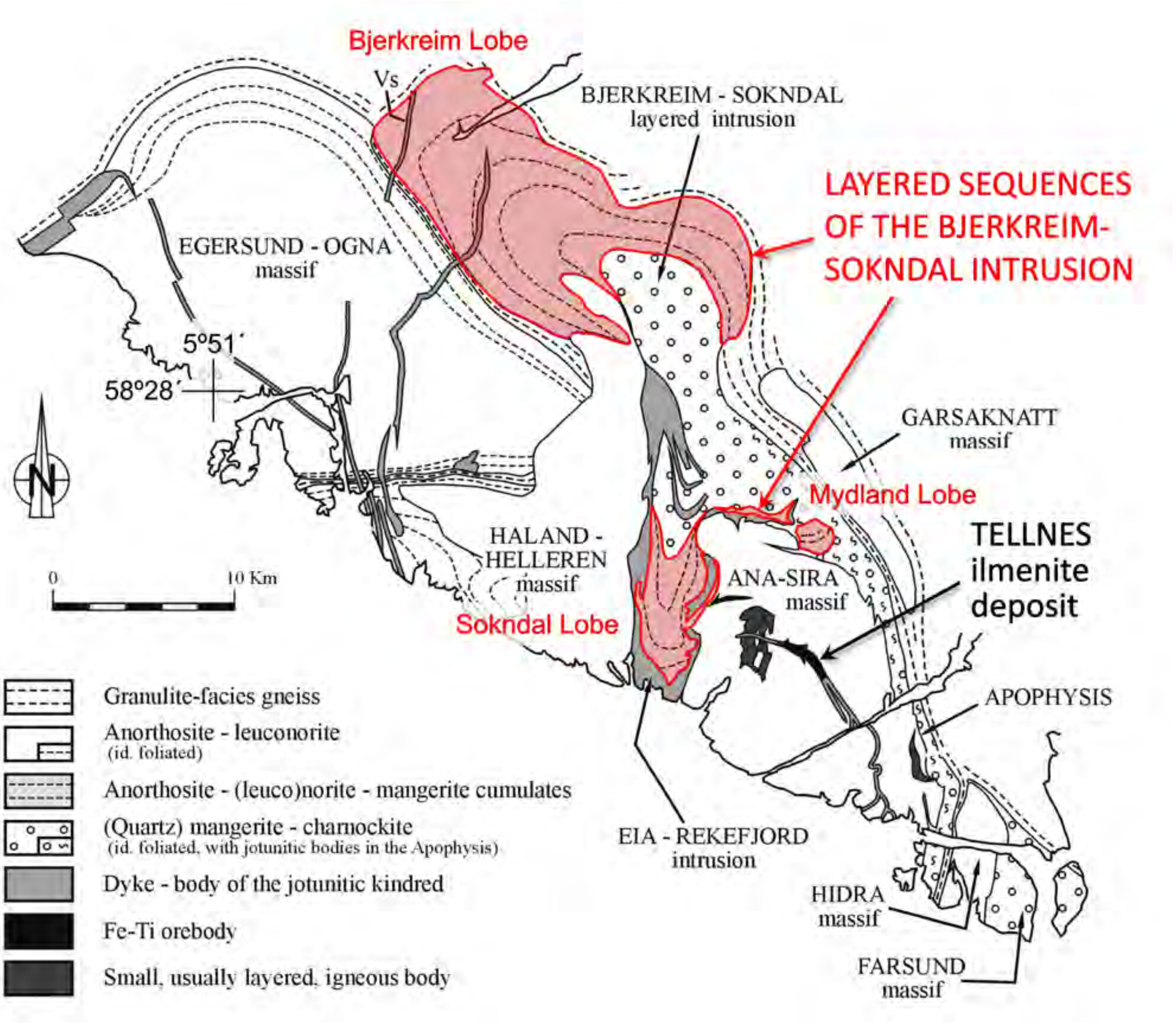


Figure 8. Simplified geological map of the Rogaland Anorthosite Province after Charlier et al. (2007); the layered sequences of the Bjerkreim–Sokndal intrusion are enhanced.

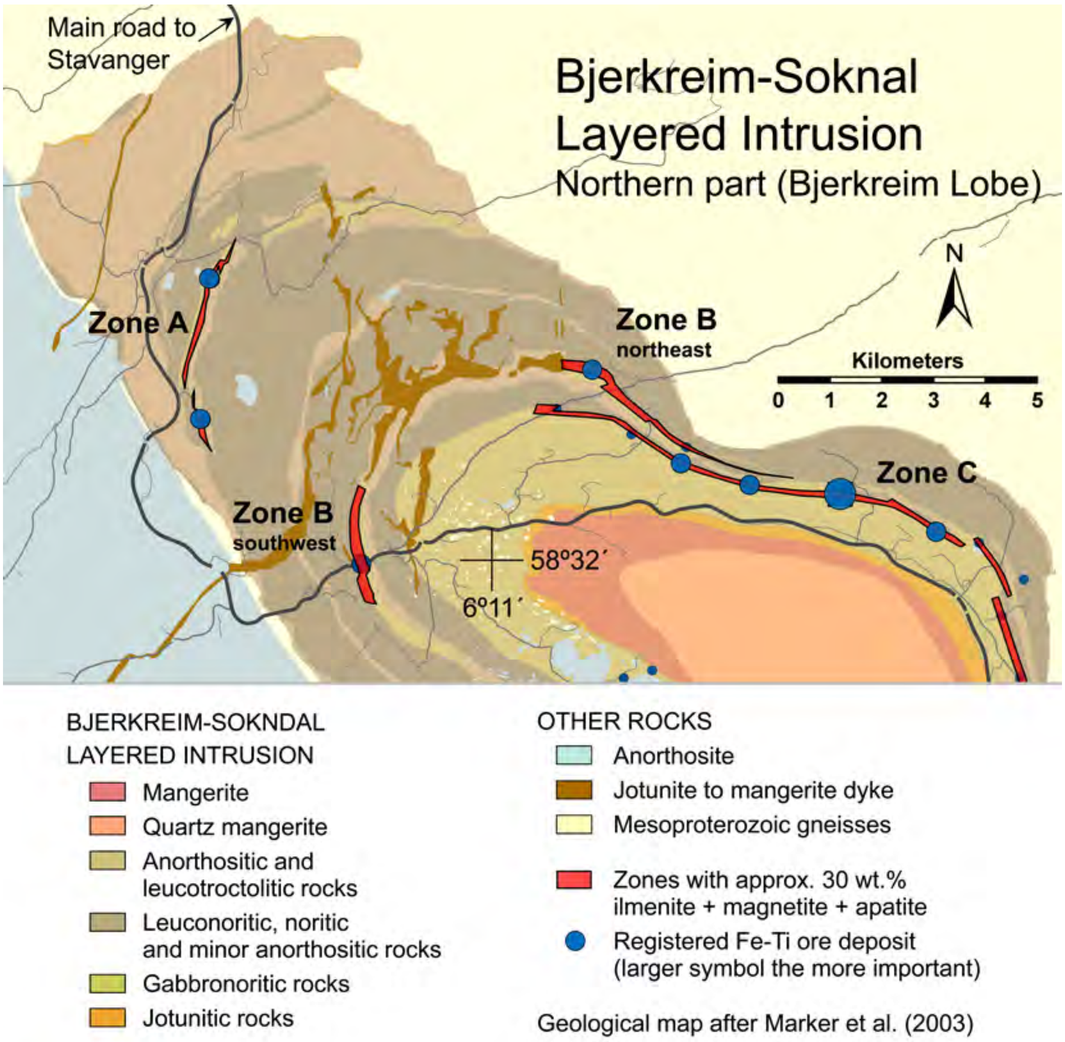


Figure 9. Northern part (Bjerkreim Lobe) of the Bjerkreim–Sokndal layered intrusion, with ore-grade enrichment zones containing approximately 30 wt.% ilmenite + magnetite + apatite.

Table 2. Indicated ore resources with 30 wt.% combined ilmenite, vanadium-bearing magnetite and apatite in the northern parts of the Bjerkreim–Sokndal intrusion (the Bjerkreim Lobe), based on Meyer et al. (2002) and Schiellerup et al. (2001).

				Dimensions (distances in metre)				**Mineral composition**	
Deposit	Zone	Unit	Length	Width	Area	Depth	Mt	V_2O_3 Mt	MgO Ilm
Åsen	A	MCU IB	2000	50	100 000	100	29	2.0 %	0.9 %
Helleland	B SW	MCU III	2000	130	260 000	100	75	2.1 %	1.0 %
Terland	B NE	MCU III	4000	120	480 000	100	139	2.5 %	0.9 %
Lauvneset	C		12000	90	1 080 000	100	313	1.5 %	0.8 %
				Sum:	1 920 000	m²	557	million metric tons	

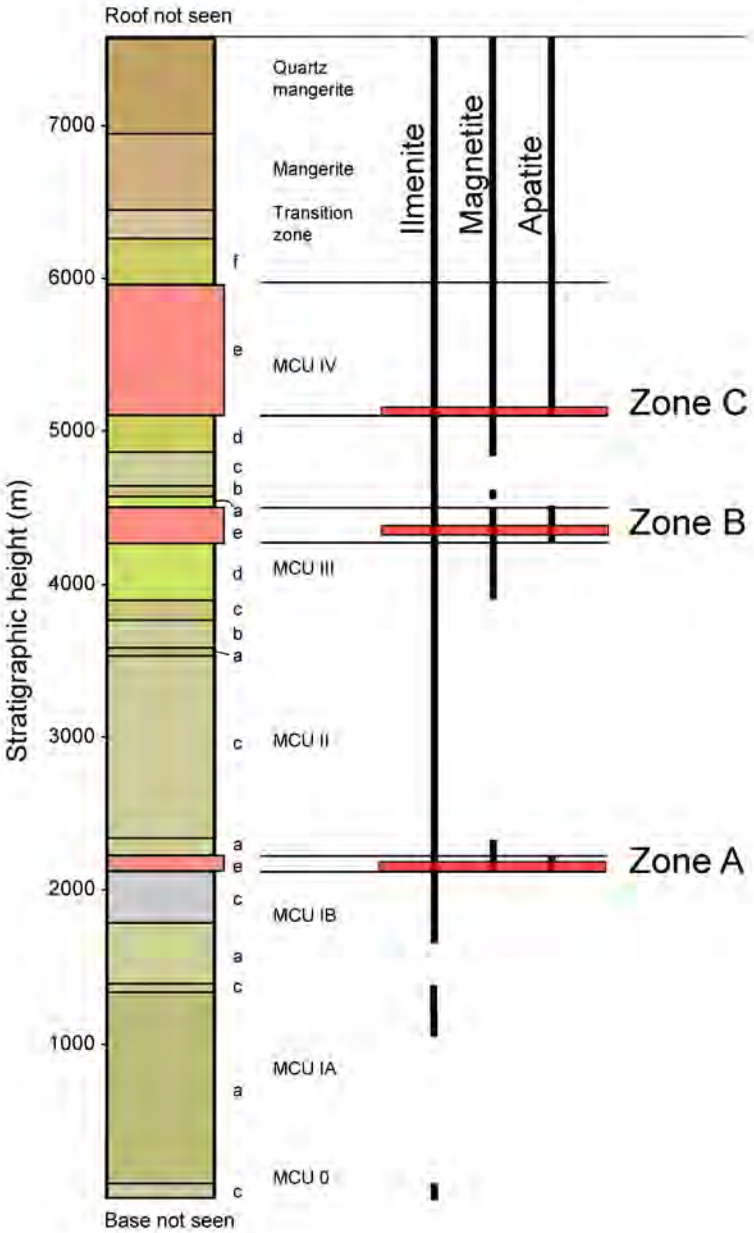


Figure 10. Cumulate stratigraphy of the Bjerkreim Lobe based on Figure 9 in Meyer et al. (2002).

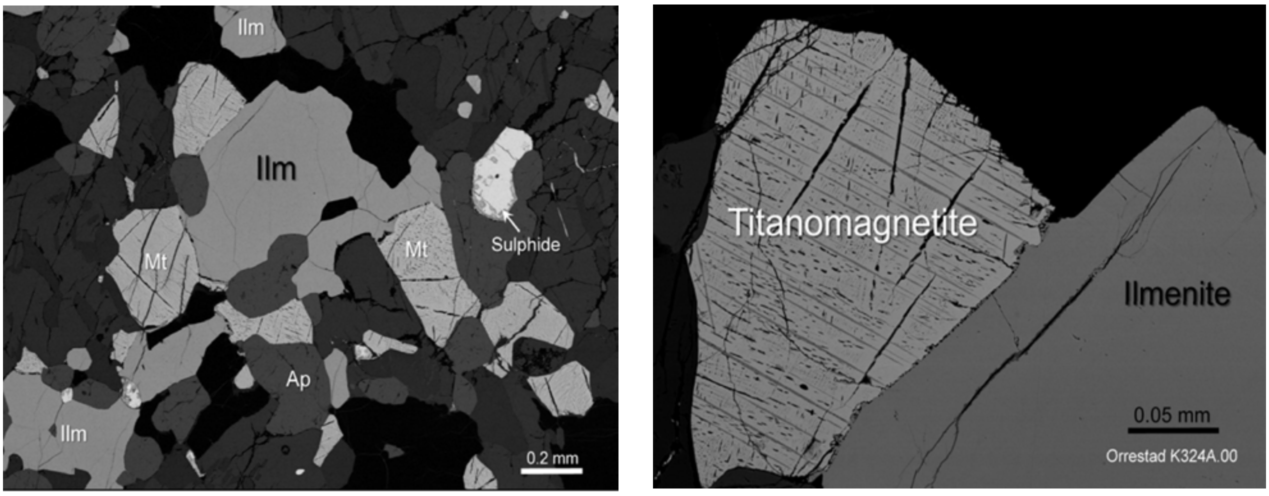


Figure 11. Two representative SEM bse images of ilmenite-magnetite-apatite mineralisation, zone C (Fig. 10) in the Bjerkreim Lobe.

N002 Agder Mo

Jan Sverre Sandstad (NGU)

Several molybdenum (Mo) deposits occur in the Agder metallogenic area, which has also been named the Kvinesdal–Sirdal province. The most significant of these is the Knaben deposit, which was mined from 1885 to 1973 and is the only Mo deposit included in FODD from this area. Eight million tonnes of ore, comprising 0.2 % Mo, were produced from open pits and underground workings. When it closed, it was the last producing molybdenite mine in Europe. Small-scale production started again in late 2007. In the Agder metallogenic area, tungsten (W) occasionally occurs in these deposits, although it is the major metal only in the Ørsdal deposit. The area N002 can be divided into several districts: Knaben (subarea N002.1), Gursli, Flottorp, Sira, Sirdal, Netland, Kvinesdal and Ørsdal (W) (Fig. 12).

The molybdenite deposits are hosted by Sveconorwegian gneiss complexes of Meso- to Neoproterozoic age within the Rogaland–Vest Agder Sector as part of the Telemarkia terrane (Bingen et al. 2008b). The form and size of the molybdenite deposits vary; both irregular veins, disseminations and stratiform or stratabound bodies are present. They occur in granitic gneisses, amphibolites and paragneisses. The genesis of these occurrences is not clear. They have not been studied in detail in recent years, and various genetic types most probably exist. Metamorphogenic, intra-/exomagmatic veins and sedimentary-exhalative formation, as well as porphyry-style models have been proposed. Several of the molybdenite occurrences have been dated by the Re-Os method as part of research on the geochronological evolution of the Sveconorwegian geology of South Norway. The results suggest that most of these are deformed, are parallel to the regional foliation, and formed during the post-peak stage of the Sveconorwegian regional metamorphism (Bingen et al. 2006, Bingen & Stein 2003, 2007).

In the **Gursli** district, there are several molybdenite occurrences in a NNW trending gneiss complex containing granitic gneiss, banded gneiss, mafic granulite boudins and locally, garnet-bearing paragneiss. In 1915–1919, around 27 000 t of ore with an average grade of 0.166 % MoS$_2$ was produced from the largest Gursli mine. The molybdenite occurrences are associated with coarse-grained, commonly zoned, quartz and quartz-feldspar veins up to 1 m thick and parallel to the regional foliation (Bugge 1963). Molybdenite occurs in veins, along joints and disseminated in the surrounding gneisses. Minor chalcopyrite and pyrite are found in the veins. Dissemination of

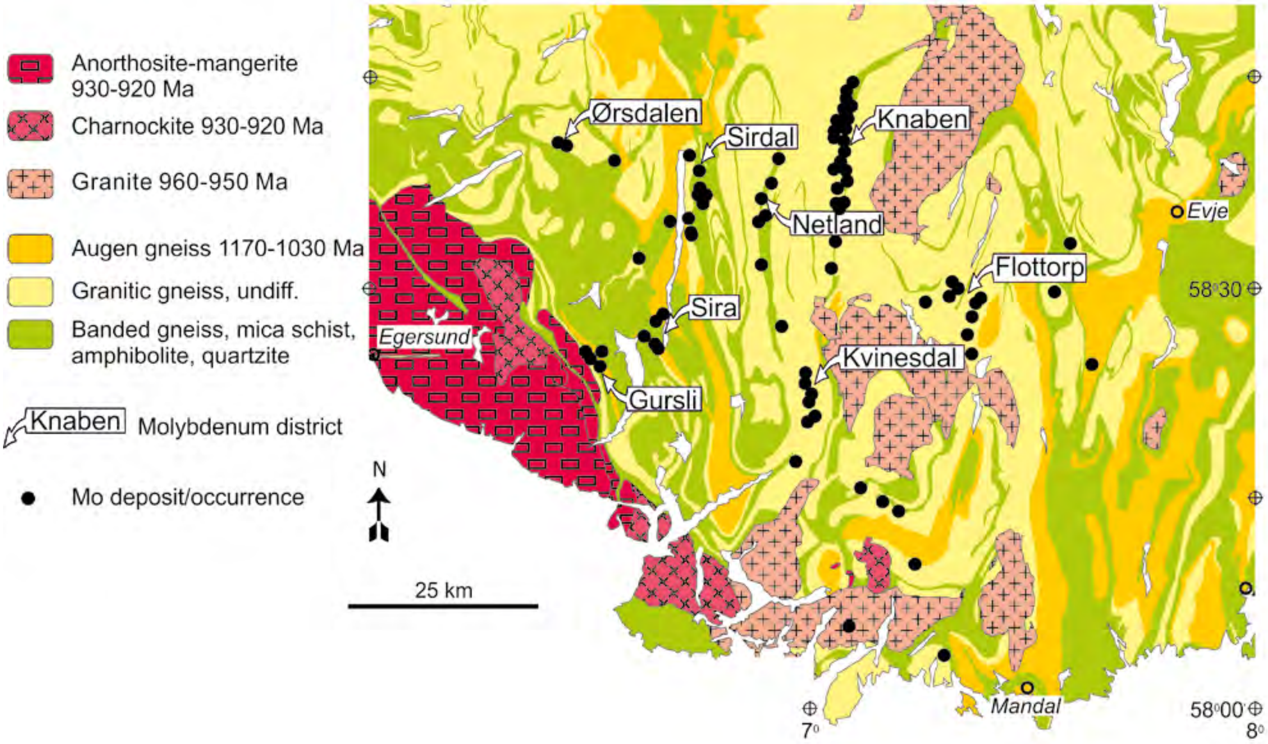


Figure 12. Geological map of the Agder area modified from Bingen et al. (2006). The most important Mo districts with deposits and occurrences are also shown.

molybdenite is also present in amphibolitic bands. The Re-Os dating yielded an age of 939 ± 3 Ma for molybdenite disseminated in leucocratic gneiss, and 917 ± 3 and 918 ± 3 Ma for molybdenite along vein contacts (Bingen et al. 2006).

The molybdenite occurrences in the **Flottorp** district are associated with narrow (approximately 100 m wide) units of banded gneisses within NNE-trending granitic gneisses over a length of 10 km (Bugge 1963). At the most significant mine, Øvre Flottorp, 37 t of molybdenite was produced: here, the ore bodies occur in an equigranular to porphyritic granitic gneiss with conformable layers of banded gneiss containing dark layers of biotite-rich gneiss (Bingen et al. 2006). Locally, molybdenite occurs as dissemination and stringers within about 1-m-thick biotite-rich layers, commonly in association with thin pegmatite and aplite dykes and quartz veins (Bugge 1963). The Re-Os dating of molybdenite yielded model ages of 956 ± 3 and 947 ± 3 Ma. Further south, in the Vårdal occurrences, molybdenite is mainly hosted by quartz-dominated rock and granitic gneiss: Re-Os dates yielded here model ages of 982 ± 3 and 974 ± 3 Ma (Bingen et al. 2006).

In the **Sira** district, five molybdenite occurrences are hosted in NW-trending banded and augen gneisses. Molybdenite is hosted by amphibolites and quartzofeldspathic layers, as well as by zoned pegmatitic dykes (Bingen et al. 2006). Molybdenite defines two distinct age clusters at 950 and 932 Ma. Further north, the **Sirdal** district has several deposits on the east side of the lake. The north-trending **Netland** district is west of the Knaben district, and south of these districts there are minor occurrences in the **Kvinesdal** area, over a distance of 12 km along strike.

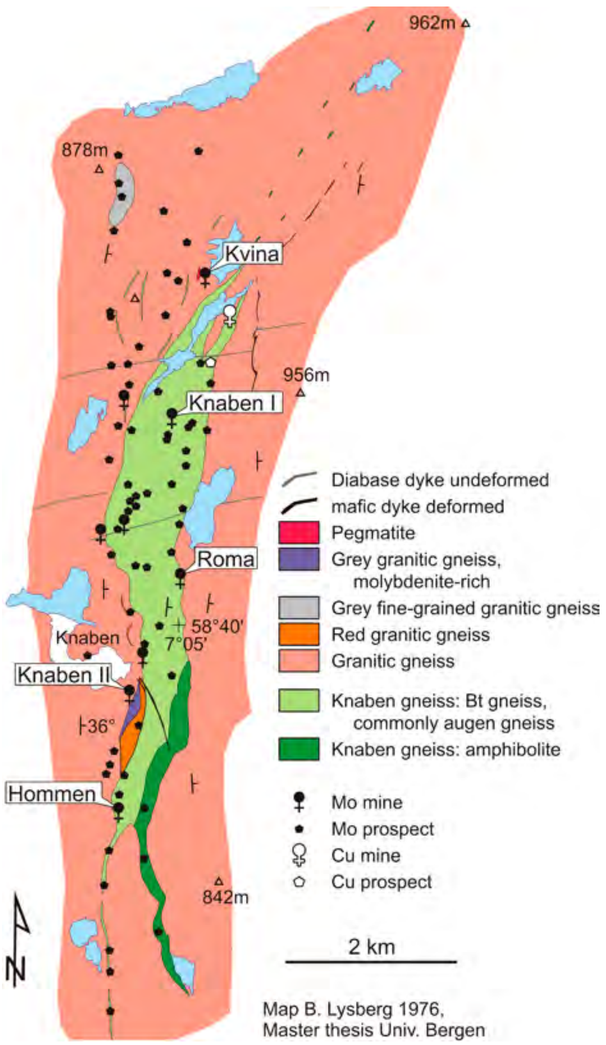
W-Mo occurrences in the **Ørsdal** district occur in orthopyroxene-bearing leucocratic veins parallel to the regional foliation in a granulite-facies gneiss complex made up of about 50–200-m-thick units of mainly biotite gneiss, amphibole-biotite gneiss and amphibolites (Bingen & Stein 2003). The district consists of a number of thin mineralized zones enriched in W and Mo, distributed along two roughly 50-m-thick, conformable layers of biotite gneiss containing amphibolite lenses. Molybdenite, scheelite and wolframite in variable relative proportions are closely associated with thin (<1 m) leucocratic veins, elongated parallel to the gneiss foliation. The veins are interpreted as migmatic leucosomes formed by fluid-absent incongruent melting of the biotite-rich host rock, at above 800 °C, producing a granulite-facies orthopyroxene-garnet residual assemblage (Bingen & Stein 2003). Molybdenite is interpreted as a product of the melting reaction, crystallised from trace amounts of Mo released from biotite in the host rock during partial melting. Four Re-Os analyses of molybdenite from three samples representing two mines yielded an isochron age of 973.4 Ma.

The **Knaben** metallogenic subarea (N002.1) comprises more than 30 molybdenite deposits and occurrences over a distance of more than 15 km from north to south. Three mines have been in operation, Knaben I, Knaben II and Kvina, with a total production about 8.6 Mt. Mining at Knaben I started in 1885, although the first regular combined mining and milling operations commenced in 1912 (Bugge 1963). This production ceased in 1917, and minor production was carried out in the period 1934–1939. The major mine, Knaben II, was operated nearly continuously from 1918–1973 and produced 8 Mt of ore with 0.2 % Mo. Small-scale production was carried out in the Kvina mine in the periods 1913–1919, 1925 and 1952–1955. Knaben II was reopened in 2007 and small-scale mining with an annual production of 50 000 t of ore yielding 100 t molybdenite is planned (Bingen & Stein 2007).

Molybdenite occurs both in and along quartz veins and as dissemination in various gneisses, with minor amounts of chalcopyrite and pyrite. The most important mineralisation commonly occurs concordantly in association with sulphide-bearing gneisses (‘Fahlband’), augen gneiss and grey gneisses, along a 6 km strike and 1 km width (Fig. 13; Bugge 1963, Lysberg 1976). In the Knaben II deposit, two major types of molybdenite mineralisation have been distinguished. In the upper part of the deposit, molybdenite mainly occurs as dissemination and along joints or veinlets in grey granitic gneisses (Fig. 14) that are assumed to represent altered red granitic gneiss with higher contents of quartz and mica (Bugge 1963, Lysberg 1976). The lens-shaped, molybdenite-bearing grey gneiss has a length of around 500 m N-S, is 50 m thick and dips at 30° to the east. It thins towards depth and to the south. In the southern part of the deposit, molybdenite is mainly located along 1–20-cm-thick quartz veins, within the grey granitic gneiss. Carbonate is common in the core of the veins (Lysberg 1976). The gneiss is also transsected by dykes of fine-grained, grey, granitic gneiss and aplite that also carries molybdenite mineralisation. Hence, the host rock locally has a brecciated appearance (Bugge 1963).

In the Knaben I deposit, the molybdenite occurs in up to 2-m-thick quartz veins and lenses in red granitic gneiss concordant to a 10-m-thick fluorspar-bearing biotite gneiss. The red granitic gneiss is altered to grey gneiss around the mineralised veins. Most of the molybdenite mineralisation in the Kvina deposit occurs in a zoned pegmatite in red granitic gneiss. Molybdenite is concentrated in the outer zone of the pegmatite, which mainly comprises smoky quartz (Lysberg 1976).

The Re-Os dating of molybdenite from various occurrences in the Knaben district gives three model ages in the ranges of 956 ± 3 Ma, 996 ± 4 Ma and 1021 ± 2 Ma, with the oldest age correlating with zircon U-Pb ages of the granitic gneiss (Bingen & Stein 2007). Thus, the genesis of the molybdenite occurrences is partly associated with granitic magmatism, and probably later remobilised during the Sveconorwegian deformation. A porphyry model is possible for these deposits.



Map B. Lysberg 1976,
Master thesis Univ. Bergen

Figure 13. Geology of the Knaben district (Lysberg 1976).

Figure 14. Molybdenite veinlet in grey gneiss (Photo from www.knaben.no). Field of view 0.5 m.

N003 EVJE Ni-Cu

Rognvald Boyd (NGU)

The **Flåt** nickel-copper deposit is associated with the plagioclase-rich Flåt diorite, a variant of the larger Mykleås diorite (Pedersen & Konnerup-Madsen 2000) 3 km east of Evje in Setesdal, approximately 60 km N of Kristiansand in southern Norway. The diorite is located on the western margin of a larger, early Sveconorwegian complex, the Iveland-Gautestad metagabbroic complex. The latter, which is pre-Sveconorwegian, has been dated (U-Pb on zircon) at 1279 ± 3 Ma and the Mykleås diorite at 1034 ± 2 Ma (Pedersen et al. 2009), that is, late Sveconorwegian.

The Flåt ore was discovered prior to 1840 and was mined from 1844 as a copper deposit, and from 1872 as a copper-nickel deposit. In the mid-1870s, the deposit contributed to Norway's position as the world's major nickel producer, a status that was lost after the discovery of lateritic nickel ore in New Caledonia in the 1880s. The Flåt deposit was part of the reason for the establishment of the nickel refinery at Kristiansand in 1910. The mine was worked intensively during WW II and was closed in 1946. Total production is estimated to have been 3.2 Mt, containing 20 200 t Ni, 14 500 t Cu and 2400 t Co. (www.smartminerals.com/norvegia/trip/Evje_Iveland.htm). By the time the mine closed, it had produced 75 % of Norway's total production of nickel and it was, for some time, the largest nickel mine in Europe.

Bjørlykke (1947) described the ore body in detail. It forms a pencil-shaped body plunging, at the surface, 45° southwards within fine-grained diorite, the plunge becoming shallower with depth. The ore is underlain by an irregular body of gneiss. Typical ore contains 12–13 % sulphides, 75 % silicates, 8 % magnetite and 4 % apatite. The major sulphides are pyrite, pyrrhotite, pentlandite and chalcopyrite. The ore includes Cu-rich and Ni-rich varieties (Barnes et al. 1988): the former is enriched in gold relative to the latter (the geometric mean of Au in the sulphide phase in five samples is 441 ppb, as opposed to 18 ppb in six samples of Ni-rich ore). Platinum metal contents are low. The mine is now open as a tourist attraction.

In addition to the Flåt mine, over twenty nickel occurrences are known in the area, several in the Flåt-Mykleås diorite but over fifteen in the older Iveland-Gautestad metagabbro (www.blv.ca/s/Evje.asp). The area is also famous for its pegmatites, which have been exploited for quartz, potassium feldspar and, on a small scale, thortveitite ($(\mathrm{Sc,Y})_2\mathrm{Si}_2\mathrm{O}_7$), but which are also rich in a wide range of special-metal minerals.

N004 ARENDAL Fe

Peter Ihlen (NGU)

The country rocks in the Arendal Fe area (N004) are part of the Bamble Terrane (Fig. 15), which represents a Sveconorwegian tectonic wedge developed in the collision zone between the Idefjorden Terrane in the east (at the margin of the Fennoscandian craton) and the Telemarkia Terrane in the west (Fig. 15; Bingen et al. 2008b). This wedge comprises strongly deformed volcano-sedimentary arc sequences truncated by 1.6–1.5 Ga granitic intrusions (Andersen et al. 2004). The arc sequences locally carry volcanic exhalative base metal deposits, whereas a few SEDEX type deposits occur hosted by quartzite units comprising prominent members of younger cover sequences. The Mesoproterozoic arc and its cover are intruded by abundant gabbroic to noritic stocks, dykes and sills, which carry associated small orthomagmatic deposits of Fe-Ti(-V) oxides and Ni-Cu sulphides. The rocks became strongly reworked during the Sveconorwegian orogeny when they were affected by two tectonothermal events, including high-grade metamorphism at 1.14–1.125 Ga with the development of granulite facies rocks along the coast followed by amphibolite facies metamorphism at 1.11–1.08 Ga. The latter episode occurred in conjunction with northwestward thrusting of the Bamble Terrane onto the Telemarkia Terrane at 1.09–1.08 Ga (Fig. 15; Bingen et al. 2008b), when emplacement of multistage granitic pegmatites was initiated.

The production of hand-cobbed massive magnetite ores from the mines at Arendal started in the late 16th century when the first small ironworks were erected in the area. The mining activity peaked in the middle of the 18th century when the mines delivered lump magnetite ores with 45–65 % Fe to other ironworks in Europe, as well as 22 blast furnaces situated close to the coast in southern Norway. From about 1850 the production declined, and during 1860–1870 most of the ironworks and mines were closed down. However, **Klodeborg**, **Bråstad** and **Langøy** mines (Fig. 15) were later reopened to produce high-grade lump ore and magnetite concentrates. The mining activity in the province ceased in 1975 when the Bråstad mine was closed. The total amount of crude ore mined over the 400 years of activity is estimated at 3 Mt on the basis of production numbers given by Vogt (1910). The ores are with a few exceptions very low in phosphorus and contain only accessory amounts of Fe and Cu sulphides.

The individual iron deposits in area N004 are generally small, with ore reserves of up to 1–3 Mt. They can be subdivided into epigenetic and syngenetic types. The former comprise magnetite veins and breccias, as well as more important deposits of magnetite skarn. All of the deposits have been affected by ductile deformation and both pre- and post-date the emplacement of granitic pegmatites.

The vein deposits, which post-date the pegmatites, comprise parallel veins and vein networks intersecting dykes and small bodies of leucocratic granites, pegmatitic granites and aplites cutting Mesoproterozoic gneissic biotite-hornblende granites and adjacent micaceous paragneisses. All of the granitic rocks, and especially those along the ore zone, are commonly affected by pervasive to fracture-bound albitisation. The pervasive alteration generates medium-grained albitites char-

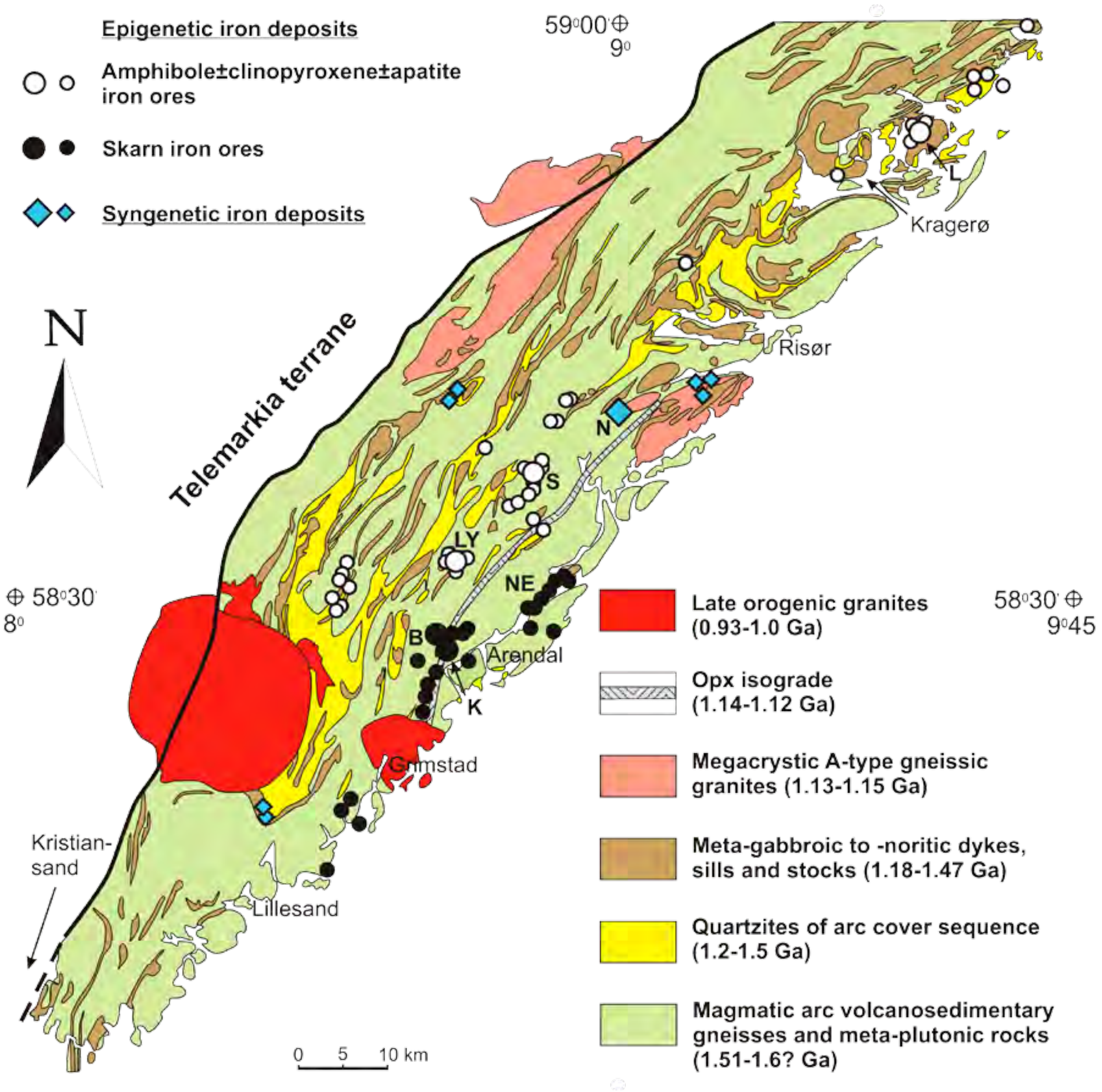


Figure 15. Geology of the Bamble Terrane showing the distribution of different types of iron deposits. Compilation based on Padget & Brekke (1996), Andersen et al. (2004) and Bingen et al. (2008b). Mines: B = Bråstad, K = Klodeborg, L = Langøy, LY = Lyngrot, N = Nævestadheia, NE = Neskilen and S = Solberg

acterised by widely distributed stringers, veinlets and disseminated aggregates of magnetite and/or hornblende.

The Solberg type of deposits are the dominant vein type occurrences in the central part of the Bamble Terrane (Fig. 15). It comprises up to 5-m-wide and 10–50-m-long ruler-shaped ore zones plunging steeply towards the south parallel to the stretching lineation in the country rocks. The vein system in the Solberg mine has been mined to a depth of 150 m. The ore bodies are generally comprised of a series of parallel veins of semi-massive to massive magnetite ore, 0.2–0.5 m wide, being separated by and grading along strike into albitised gneissic leuco-granites carrying stringers, aggregates and banded disseminations of magnetite. Some of the ore zones represent transposed networks of thin magnetite veins. Magnetite is typically intergrown with subordinate hornblende, which becomes very abundant in deposits where the vein system intersects or is developed in bodies of pegmatitic granite as in the Solberg mine. The pegmatites contain veins and irregular segregations of semi-massive magnetite-hornblende ore. The intervening low-grade pegmatite is irregularly flooded by magnetite and/or hornblende along crystal boundaries, fractures and cleavage planes in areas with coarsely crystalline feldspar. Dense dissemination of cm-sized magnetite aggregates occur in quartz-rich pockets in the pegmatite. The Solberg type vein deposits were also mined in the Lyngrot area to the south, where the apatite-rich Lyngrot type occurs.

The Lyngrot type of deposits only occurs in the Lyngrot area. It shares most of the geological, mineralogical and morphological features typical for the Solberg type. However, the magnetite veins in the Lyngrot area are generally richer in hornblende and, in three deposits, contain abundant apatite and clinopyroxene. In these deposits, which were mined to a maximum depth of 150 m, the gneissic leuco-granites and pegmatites are replaced by up to 10-m-wide and 50-m-long bodies of coarse-grained apatite-hornblende-augite rock containing irregular segregations and veins of semi-massive magnetite ore as well as a variable density of magnetite dissemination. These bodies are surrounded by up to 10-m-wide low-grade zones of albitised leuco-granites with a variable enrichment of magnetite as veins, stringers, veinlets and dissemination.

The skarn deposits are numerous but generally small in size. The ore reserves of the individual mines rarely exceed 1 Mt. They occur distributed as linear trains over a distance of about 50 km from south of Grimstad to the Neskilen mines north of Arendal (Fig. 15). The 100–200 m wide ore sequences residing in a complex of fine-grained, partly migmatitic, biotite gneisses comprise intercalated units of banded amphibolite, marble, calc-silicate gneiss and fine-grained granitic gneiss (Kjerulf & Dahll 1861). The marbles form trains 5–20 m (max. 50 m) thick and lenses several hundred metres long, which occur along one or two tectonostratigraphic levels in the sequence. However, most of the marbles have been partly or totally replaced by hydrous and anhydrous skarn minerals and fine- to medium-grained semi-massive to massive magnetite ores with interstitial calcite and/or skarn minerals. The skarns are composed of variable proportions of calcic garnet (andradite-grossularite), clinopyroxene (diopside-augite), epidote, amphibole and serpentine (Vogt 1910). The presence of Mg-rich clinopyroxene amphibole and serpentine in the skarns suggests that, besides calcite, the marbles also locally contained abundant dolomite.

The massive magnetite ores form trains of steeply-dipping ruler-shaped ore bodies usually 1–5 m wide and 25–75 m long. The largest dimension is down the steep S to SW plunge of the ore bodies, which at Klodeborg, Bråstad and Neskilen mines have been exploited to a depth of 200–250 m. The magnetite ores can, on the basis of dominant gangue minerals, be separated into several types including garnet, pyroxene, epidote, amphibole, serpentine and calcite ores, as well as a number of intermediate subtypes.

The parageneses of the skarns and magnetite ores do not reflect the metamorphic grade of the wallrocks, especially in the granulite facies areas where the presence of hydrous skarn minerals such as epidote suggests that the hydrothermal activity post-dates the high-grade metamorphism. However, the iron ores are cross-cut by pegmatite dykes, indicating that the skarn deposits predate the magnetite veins in the Solberg and Lyngrot areas. The ore-forming fluids were possibly derived from intrusions of hornblende granites occurring in a number of the individual skarn iron ore fields. These granites are similar to those occurring in the two latter areas. Semi-massive iron ores in clinopyroxene and amphibole skarns of a similar relative age to those in the Arendal area also are found at Langøya, near Kragerø (Fig. 15). However, these skarns are developed as fracture-bound to pervasive alteration post-dating brecciated scapolite-hornblende rocks and pre-dating albitites derived from metasomatically altered metagabbros.

The syngenetic iron deposits have in the past been of minor economic importance. They generally comprise narrow stratabound, possibly stratiform, magnetite ores in amphibolites. The best examples are found in the Nævestadheia area, where magnetite ores occur in folded units of amphibolite that can be followed along strike for more than 1 km. The ore-bearing amphibolites occur in a complex of banded biotite and hornblende gneisses containing subordinate cm- and dm-wide bands of amphibolite. These gneisses possibly represent felsic to intermediate metavolcanic rocks of island-arc affinity. The ores are confined to two parallel amphibolite units with thicknesses in the range 0.5–1 m and 2–4 m, respectively. The narrow amphibolite zone is nearly fully occupied by dense dissemination of magnetite grading into 0.5 m thick bands of semi-massive ore when the amphibolites becomes wider. The thickest amphibolite contains several 0.1–1-m-thick semi-massive bands of magnetite. A banded structure can, in well-exposed areas, be recognised in the thicker ore zones where it comprises alternating 2–10-mm-thick bands of magnetite ore and amphibolite. The ore zones frequently carry weak dissemination of Fe sulphides and minor chalcopyrite.

N005 BAMBLE Ni-Cu, Fe-Ti

Are Korneliussen, Terje Bjerkgård & Morten Often (NGU)

The Bamble Ni-Cu and Fe-Ti province (Fig. 16) is a part of the Bamble sector, which is one of several sectors of the Precambrian crust in SW Scandinavia with late Palaeoproterozoic to Mesoproterozoic rocks affected by the Sveconorwegian orogeny (Bingen et al. 2008a and references therein). It is characterised by amphibolite- to granulite-facies gneisses with a strong SW-oriented structural pattern (Padget & Brekke 1996). The oldest rocks are a variety of 1570–1460 Ma gneisses (Andersen et al. 2002, de Haas et al. 2002, Andersen et al. 2004). Sveconorwegian mafic magmatic activity at 1200–1180 Ma (Andersen et al. 2002, 2004) was followed by high-grade metamorphism at 1140–1125 Ma, and overprinted by amphibolite facies metamorphism at 1110–1080 (Cosca et al. 1998, Bingen et al. 2008b). Many lithologies in the Bamble sector have been affected by localised, but

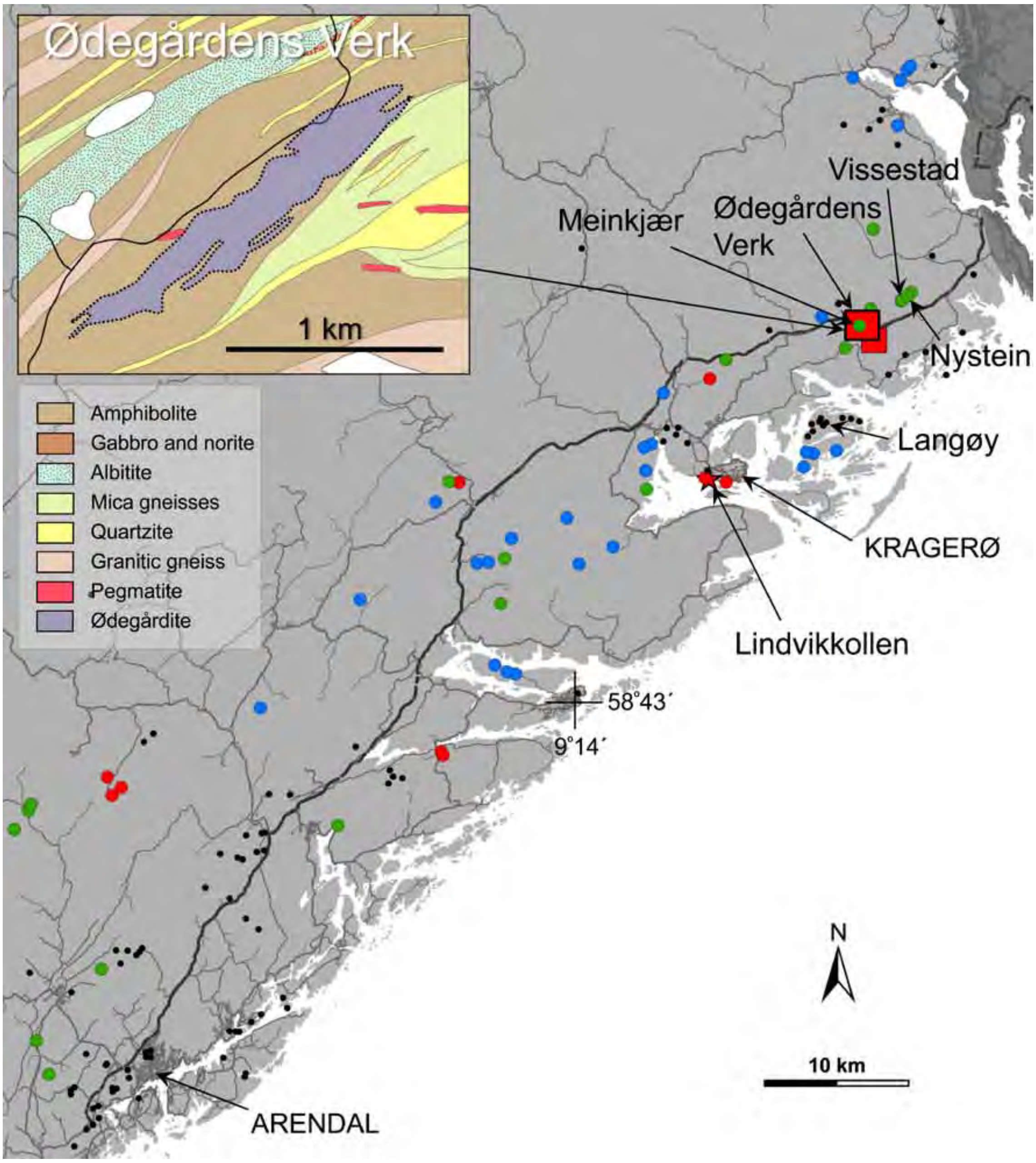


Figure 16. Distribution of Ti (rutile; red symbols), Fe-Ti (ilmenite-magnetite; blue symbols), Fe deposits (black symbols) and Ni deposits (green symbols) in the Bamble metallogenic area. Inserted is a map of the Ødegården area based on a combined interpretation of rock exposures and ground magnetic data (Lauritsen 1992).

penetrative, scapolitisation and albitisation (e.g., Brøgger 1935, Green 1956, Bodart 1968, Engvik et al. 2010).

The metallogenic area N005 is characterised by a large number of mineral deposits of various types including magmatic Ni-Cu, magmatic ilmenite-magnetite and metasomatic rutile deposits, and a variety of iron deposits (Fig. 16) that are regarded as predominantly hydrothermal.

A total of 20 *Ni-Cu occurrences* are registered in the Bamble area. They are hosted by small mafic to ultramafic bodies, mostly metanorites (Brickwood 1986). A number of mines were in operation from 1859 to 1885, and 1916–1920. The main deposit was Meinkjær, which together with Nystein and Vissestad produced the bulk of the Bamble Ni ore, a total of about 55 000 tons. The ore produced during the first production period is reported to have contained 1.1 % Ni and 0.5 % Cu.

Norsk Hydro explored the region in the period 1968–1973. Sulfidmalm AS, in association with Falconbridge, and later Blackstone Ventures, performed extensive exploration from 2004 to 2009. Airborne geophysics was carried out over a large area. Grab samples gave interesting results (e.g., 2.88 % Ni, 0.86 % Cu, 0.12 % Co, 0.06 ppm Pt, 0.20 ppm Pd at Meinkjær and 1.95 % Ni, 0.43 % Cu, 0.17 % Co at Nystein; Blackstone Ventures Inc. 2010a), but extensive core drilling on Meinkjær as well as other prospects did not return results encouraging enough to continue activities.

More than half of the Ni-Cu ore (34 000 t of enriched ore) was produced from the **Meinkjær** deposit. The mine consists of a number of open pits, shafts and underground workings, situated around a central gabbroic to noritic intrusive body. The gabbro is about 100 x 55 m in horizontal cross section and mineralisation is mainly found along the contacts between the intrusive and the surrounding granitic to micaceous gneisses. Most of the ore occurs along the eastern footwall of the intrusive, and was mined for 35–40 m along strike and to a depth of 75–80 m along the dip. The ore is up to 6 m thick and mainly consists of impregnations of pyrrhotite, chalcopyrite, pentlandite and pyrite (Brickwood 1986).

In total, 20 700 t of concentrate was originally produced from two mines in the **Nystein** deposit, which was the main producer in the last mining period (1916–1920). The ore occurs along the southern contact of a gabbroic to metanoritic intrusive body within amphibolitic gneiss. The intrusive body has a length of >1 km. The mineralisation resembles that at Meinkjær. The **Vissestad** mine produced about 3000 t of concentrate (Fig. 17). The ore mainly occurs along the southern contact of a small norite body. The workings are 53 m deep, 15–20 m long and 2–4 m wide.

Figure 17. Grab sample of massive ore containing 5.05% Cu, 0.15% Ni and 0.15% Co from the Vissestad waste dump. Diameter of the coin is 18.5 mm. Photo from http://www.blv.ca/s/Bamble.asp.

During the Falconbridge–Blackstone exploration campaign, the **Seljeåsen** occurrence in the southwestern part of the area was extensively drilled. Geophysical indications and the existence of a significantly larger mafic–ultramafic intrusion than at the other known Bamble deposits indicated a potential that was, however, not confirmed by the drilling.

Magmatic ilmenite-magnetite (Aggerholm 1979) occurs as dissemination, bands and lenses in metagabbro and amphibolite related to early Sveconorwegian magmatism, presumably of 1200–1180 Ma in age, in the area N005. Rutile occurs within scapolitised metagabbro, albitite, albitic pegmatite and associated hornblendite, which are presumably associated with the 1110–1080 Ma amphibolite-facies metamorphic period.

At **Ødegården Verk**, ilmenite and magnetite-bearing metagabbro or amphibolite has been variably altered to a rutile-bearing scapolite-hornblende rock called ødegårdite by Brøgger (1935); this alteration is distinct along a subvertical 1.5-km-long zone, as indicated in the inserted geologic map in Figure 15. Within this zone, there are numerous dykes or veins of an apatite-bearing phlogopite-enstatite rock up to 1 m wide that was mined for apatite from 1874 to 1945. The apatite mines reached a depth of approximately 150 m.

The rutile ore-forming process is associated with scapolitisation. Fluids appear to have migrated through the metagabbroic rock in amphibolite-facies conditions, transforming the ilmenite-magnetite-bearing metagabbro to a rutile-bearing

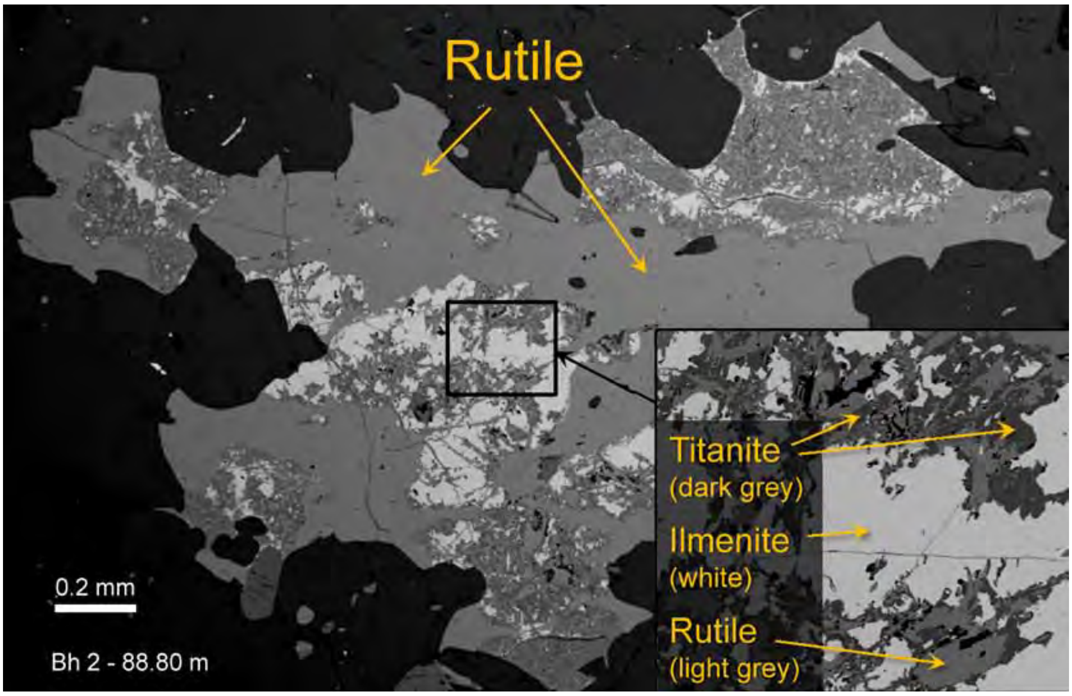


Figure 18. SEM-BSE images showing intermediate-stage transformation of ilmenite via titanite to rutile.

scapolite-hornblende rock (ødegårdite). In this process, magnetite disappears, presumably because iron is carried away with the fluids as FeCl, as suggested by Brøgger (1935). The ilmenite breaks down, first to symplectitic intergrowths of titanite and rutile, and then, with more intense alteration, to homogeneous rutile. The SEM image in Figure 18 is from a transitional sample in which magnetite has disappeared, but with ilmenite incompletely transformed to titanite and rutile. At complete metasomatic transformation to ødegårdite, almost all oxide present is rutile. Figure 19 shows titanite rimming rutile; this titanite is a late-stage retrograde product: rutile shows a weak alteration towards second-generation titanite.

The Ødegården deposit consists of a mixture of metagabbro or amphibolite and ødegårdite with 2–4 wt.% rutile (Korneliussen & Furuhaug 1993), showing various transitional stages depending on the extent of the metasomatic transformation. Consequently, the surface extension of the Ødegården "ore zone" shown in Figure 16 is not all ødegårdite, but includes mixtures with partly scapolitised metagabbro containing significant components of transitional ilmenite-rutile mineralisation.

Rutile from the Bamble area is distinctly enriched in trace elements such as U (50–100 ppm; Korneliussen et al. 2000a). The potential mineral resource at Ødegården is probably more than 50 Mt ødegårdite with 2–4 wt.% rutile: further documentation would require drilling.

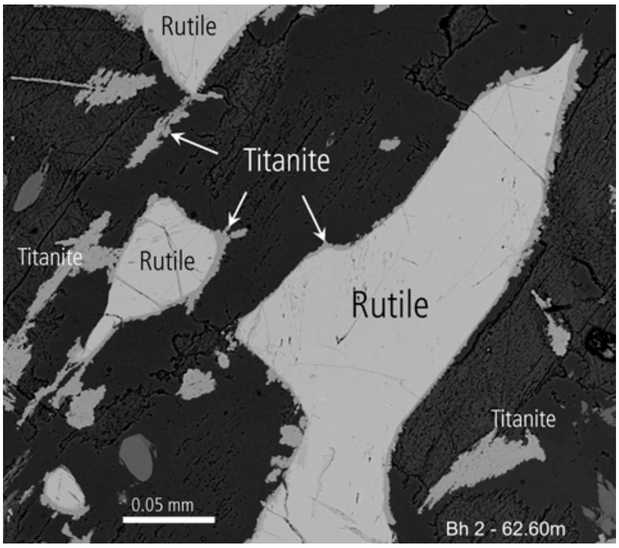


Figure 19. SEM-BSE image showing titanite rimming rutile.

N006 BANDAK–NISSER Mo

Jan Sverre Sandstad (NGU)

Several molybdenite deposits and occurrences are located in granites and granitic gneisses in the Telemark Sector of the Telemark Terrane. None of these is included in FODD due to their minor size or lack of data. Copper is the predominant metal in the region (see Section N007), but some of the copper occurrences also contain significant amounts of molybdenite. The Telemark Sector within the metallogenic area N006 mainly consists of pre-Sveconorwegian deformed magmatic suites at 1280–1130 Ma (e.g., the Vråvatn complex, crystallised 1201 ± 9 Ma to 1219 ± 8 Ma, Andersen et al. 2007), metavolcanic rocks of 1170–1140 Ma, <1120 Ma metasediments and several syn- (1050–1000 Ma) to post-collisional (970–930 Ma) Sveconorwegian plutonic suites (e.g., Vrådal granite, intrusive age of 966 ± 4 Ma, Andersen et al. 2007, Bingen et al. 2008b).

Several magmatic and hydrothermal molybdenite deposits and occurrences have been found in area N006. A multi-stage genetic model is assumed, as they seem to be related both to the pre- and syn- to post-collisional magmatic activities. Molybdenite-bearing quartz veins within metavolcanic rocks have also been exploited. Molybdenite also occurs disseminated in some of the granites, for example, the Vrådal granite (Sylvester 1964), although this type of mineralisation has not yet been exploited.

The **Bandaksli** deposit consists of several minor workings along a steep hill on the southern side of the lake Bandak. Small-scale production has been carried out in several periods, mainly during the two world wars: total production has been <100 t of ore with 20–40 % MoS_2 (Bugge 1963). Molybdenite mineralisation occurs along the northern border of an undeformed granite, within and along several sub-parallel pegmatitic quartz veins which are 0.2–1.0 m thick. Molybdenite is commonly enriched together with K feldspar and mica along the rim of the veins (Fig. 20), but also constitutes aggregates in the quartz core and along the contact to the granite. Minor enrichments of bismuth have been encountered. Fluorspar commonly occurs in the pegmatites and fluorspar-quartz veins have also been exploited in the area. Xenoliths of metasandstone are found in the granite. This deposit is located just north of the Kløvereidnuten Cu deposit.

The **Dalen** deposits are located north of the western end of Lake Bandak. Small-scale production, totalling around 100 t of MoS_2, was carried out from several workings in the period 1915–19 (Bugge 1963). Molybdenite occurs as stringers, veinlets and aggregates in several sub-parallel, milky quartz veins that are 5–70 cm thick and hosted by supracrustal rocks of the Morgedal Formation. The deposition of the Morgedal Formation took place between 1155 ± 3 and 1150 ± 4 Ma (Laajoki et al. 2002). The nearly flat-lying, undeformed quartz veins in the major Dalen deposit crosscut the foliation of the metasandstone. The quartz veins are located in metabasalt in the Askom mines and they locally comprise some chalcopyrite, bornite and tourmaline (Fig. 20). Re-Os dating of the molybdenite yields an age

Figure 20. Left: Molybdenite along the contact between pegmatitic quartz vein and granite in the Bandaksli deposit. Right: Molybdenite and bornite in a 15-cm-wide quartz vein in greenstone at the Askom mine (diameter of the coin is 22 mm). Photos: J. S. Sandstad, NGU.

of 1019 ± 3 Ma, interpreted as the age of formation of the quartz veins in the Hammaren deposit (Bingen et al. 2006). This age corresponds to the age of the syn-collisional granites, although none of these is exposed in the area nearby.

In the **Kleppe–Storemyr** area east of Fyresvatn, molybdenite occurs in networks of pegmatite dykes and quartz veins in granitic gneiss with xenoliths and bands of amphibolite. Most of the Mo mineralisation is in thin quartz veins cross-cutting up to 20 m wide pegmatites (Bugge 1963). The formation of these occurrences could be related to the Tørdal granite. Molybdenite also occurs over a wide area at **Mørkvasshei**, as dissemination in granitic gneiss and in up to 1-m-thick pegmatitic veins that are parallel to the foliation in the gneiss (Bugge 1963). Further northwest, there are several minor occurrences associated with the post-collisional Vrådal granite, for example at Tarjeisberget.

Molybdenite mineralisation in the **Husstøyl** occurrence mostly comprises thin quartz veins along the northern part of weakly foliated Vrådal granite, whereas the richest Mo mineralisation observed is hosted by a biotite-rich rock. There are several other occurrences where molybdenite occurs in quartz veins. Molybdenite-bearing quartz veins are also located in porphyritic, felsic metavolcanic rocks, for example the **Lindtjern** occurrence north of the central part of Lake Bandak. Molybdenite is also found in several of the Cu±Au±Ag deposits in the Telemark metallogenic area, for example at Moberg and Mosnap (see Section N007).

N007 TELEMARK Cu-Au-Ag

Jan Sverre Sandstad (NGU)

Historically, the Telemark Cu-Au-Ag province has been of great importance for metal mining in Norway. It was in this area that ‘modern’ metal mining commenced in the early 16th century. Copper is the major metal, although gold and silver also locally occur in substantial amounts. In addition, enrichments of molybdenum, zinc, lead, bismuth and arsenic are common. A great variety of copper deposits are present, both syngenetic VMS and sediment-hosted Cu, as well as hydrothermal vein deposits related to magmatic and/or metamorphic processes. They are mainly located in metavolcanic and metasedimentary rocks in the Telemark Sector of the Telemark Terrane.

The metallogenic area N007, at the central part of the Telemark Sector, is dominated by low-grade supracrustal rocks, and four main stratiform sequences separated by unconformities are defined (Bingen et al. 2008b and references therein). The lowest sequence consists of bimodal volcanic rocks (Rjukan Group, 1510–1500 Ma). It is overlain by a quartzite-dominated sequence (Vindeggen Group), followed unconformably by bimodal volcanic rocks interlayered with metasediments (1170–1140 Ma, named Høydalsmo and Oftefjell Groups in different parts of the area). Immature clastic metasediments comprise the uppermost sequence (<1120 Ma, Heddal Group). The major plutonic activity comprises pre-Sveconorwegian deformed magmatic suites at 1280–1130 Ma and several syn- (1050–1000 Ma) to post-collisional (970–930 Ma) Sveconorwegian plutonic suites (Andersen et al. 2007, Bingen et al. 2008b). Most of the copper deposits are located within the upper bimodal volcanic sequence interlayered with metasedimentary units.

Although the copper deposits have been of great historical importance, only one of these, Åmdal, is included into the Fennoscandian Ore Deposit Database (FODD), but the numerous deposits and occurrences substantiate this Cu province. The most widespread copper mineralisation is in quartz veins, partly in pegmatitic veins, for example, Åmdal, Mosnap, Moberg, Kløvereidnuten and Tjørnstaul (in Bandak–Fyresdal area), Goli, Glittenberg and Simonesvihus (in Heddal area) and Åmli (in Morgedal area). Some of these are spatially closely associated with granitic activity. Stratabound Cu deposits occur in metasandstone (Dalane) and amphibolite (Hovin), as well as minor stratiform occurrences in metavolcanic rocks (e.g., Listauli, Skolteberg).

The **Åmdal** mine has been the largest producer, with a total production of 60 000 t of cobbed (hand-picked) copper ore giving around 8400 t of Cu. The mine operated periodically from 1691 to 1945 (Fig. 21), and also treated copper ore from similar deposits nearby, for example, Mosnap 7 km further SSW. The copper ore at Åmdal was exploited from four parallel quartz veins in metasandstone/quartz schist over a length of 1650 m and more than 300 m down dip, just north

Figure 21. Upper photo: the dumps of the closed Åmdal mine. The ore zone continues up the hill to the left. Lower photo: chalcopyrite aggregates in a quartz vein in quartz schist at Åmdal mine. Photos: J. S. Sandstad and T. Bjerkgård, NGU.

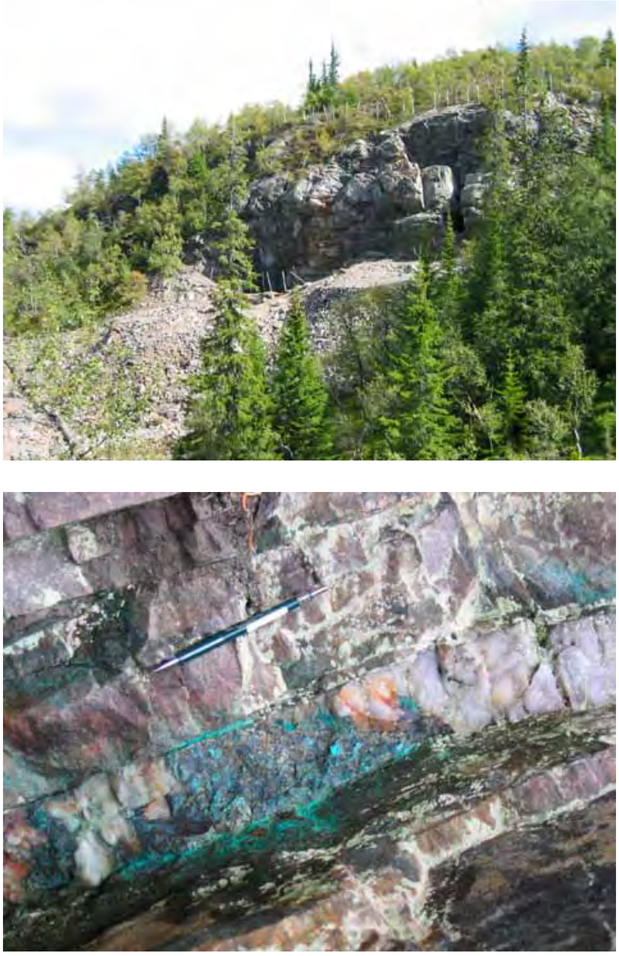


Figure 22. Upper photo: the dumps and entrances of the abandoned Mosnap mine. Lower photo: bornite aggregates in a quartz vein in metasandstone at Tjørnstaul deposit. Photos: J. S. Sandstad, NGU.

of, and parallel to a pre-Sveconorwegian granitic gneiss. The quartz veins are 0.1–1m thick, and form zones up to 1.5 m wide consisting of several veins and veinlets. Their orientation is relatively constant at 220°/54°. They commonly occur along the contact between quartz schist and thin (<2 m) layers or sills of mafic metavolcanic rocks. Chalcopyrite forms stringers and aggregates in the quartz veins. Minor amounts of bornite and molybdenite also occur in the veins.

The **Mosnap** deposit was operated periodically during 1691–1888 (Fig. 22). Chalcopyrite and bornite occur as stringers and aggregates in quartz lenses and veins, which are partly pegmatitic, in metasandstone and pegmatite. Molybdenite is commonly observed in the quartz veins, and the occurrence is also enriched in Ag and Bi. The ore zone is 1–2 m thick and comprises several quartz veins that both crosscut and are parallel to the foliation of the metasandstone. Minor dissemination of native copper also occurs in the metasandstone and in granite, features only observed in underground workings. The copper mineralisation at **Moberg** (Moisesberg) is hosted by up to 2-m-thick quartz veins, along the contact between fine-grained metabasalt in the NW and coarse-grained granite in the SE. It was first operated in the period 1541–1549, and is among the oldest metal mines in Norway (Berg 2006). In the **Kløvereidnuten** deposit, chalcopyrite and minor molybdenite, with some enrichment of Au and Ag, occur in quartz veins and pegmatite dykes in granite and metasandstone.

The ore minerals in the **Dalane** Cu-Ag deposit are native copper and silver. They occur as stringers and veinlets in a feldspar-carbonate-bearing quartzite close to the contact with a tectonostratigraphically overlying metabasalt. The deposit is located along the southeastern flank of an open antiform plunging to the SW (Dons 1963). The first exploitation of silver is thought to have been around 1660, but regular production was carried out in the periods 1883–1900 and 1907–1917. Mining has been conducted over about 1 km along the strike of the quartzite.

Gullnes (Straumsheia) copper and silver deposit is probably the oldest mine in the area: It was in operation before 1524 and periodically during 1538–1890. An epithermal origin for the deposit in a brecciated volcano-sedimentary sequence has been suggested.

The **Hovin** (Vasstveit) Cu deposit is located at the northeastern side of Lake Tinnsjø. The deposit is characterised by bornite, chalcocite and chalcopyrite dissemination and stringers in a fine-grained amphibolite enclosed in quartz-muscovite schist. The richest Cu ore is in a feldspar-altered part of the amphibolite along its western contact with the schist. Enrichment of Cu minerals is also present along thin carbonate veins. The amphibolite probably represents a metadolerite that is about 20 m thick, at least 2 km long N-S, and is intruded into a metasandstone. Small-scale production was carried out in the late 18th and early 20th centuries at Hovin.

The variation in deposit types in the metallogenic area N007 is illustrated in an area north of Lake Bandak (Dons 1963). Mafic metavolcanic rocks intercalated with minor felsic metavolcanic and metasedimentary rocks, the Transtaulhøgdi supracrustals (Laajoki et al. 2002), dominate the local bedrock. In these supracrustals, there are various minor mineral occurrences in addition to the widespread Cu sulphides in quartz veins. The **Listauli** As-Cu deposit was operated periodically in the years 1895–1919. Arsenopyrite occurs as dissemination and in veinlets and bands in strongly folded quartzite and metavolcanic rock. Representative samples of the ore contain 8–13 % As and around 2 % Cu. In addition, this mineralisation is enriched in Sb, Bi and Au. Further east, the **Myran** massive magnetite-bornite-chalcopyrite occurrence is located along the contact between felsic and mafic metavolcanic rocks. The **Skolteberg** lead-zinc-copper deposit, locally enriched in Au and Ag, occurs in amphibolitic rocks. Substantial enrichment of Ag is also present in the **Kroksmyr** Cu occurrence, which is hosted by strongly carbonatised and sheared amphibolite or metabasalt.

Other deposits in area N007 have no significant copper mineralisation, but are metallogenically interesting. These include the **Bleka** Au deposit, which is included in FODD, and other minor gold occurrences in the same area, in which gold occurs in quartz-ankerite veins in shear fractures of gabbroic sills in quartzitic rocks (Petersen & Jensen 1995). They contain visible gold and abundant tourmaline and bismuthinite (Ihlen 1999). The enrichment of bismuth in the province is further substantiated by the minor Bi deposits **Saude** and **Gjuv**, which are hosted by granitic pegmatite dykes in amphibolite and quartz-carbonate-tourmaline veins in quartzite, respectively.

N008 KONGSBERG Ag

Terje Bjerkgård (NGU)

The Permian Ag-Co-As veins in the Kongsberg metallogenic area (N008) are hosted by the Kongsberg gneiss complex, which represents island arc volcanosedimentary sequences and plutonic rocks (1.57–1.50 Ga, Andersen et al. 2004) affected by Sveconorwegian deformation and amphibolites facies metamorphism at 1.11–1.08 Ga (Bingen et al. 2008b).

The **Kongsberg** silver mines were in operation from 1623 to 1958. During the 335 years of mining, about 1350 t of Ag metal was produced from about 130 larger and smaller mines (Ihlen & Vokes 1978). The annual production was between 2 and 10 tons (Ihlen & Nordrum 1986). Most silver was produced from mines along the Overberget fahlband zone, of which the Kongens Mine alone produced 601 t. The Kongens mine was the largest and deepest of the silver mines, reaching a depth of more than 1000 m.

The mines were worked on silver-bearing calcite veins, and the ore shoots were mainly controlled by the intersection of the veins with sulphide-bearing units within Mesoproterozoic gneisses (Fig. 23). These so-called fahlbands (Bugge 1917) are generally rusty, very schistose mica-rich schists and gneisses, which are concordant with the country rocks. The rust is due to the weathering of sulphides, mainly pyrite and pyrrhotite, but also of subordinate to accessory chalcopyrite, sphalerite, galena, arsenopyrite and cobalt-bearing minerals. The most important of these units are the Overberget and Underberget fahlbands, located to the

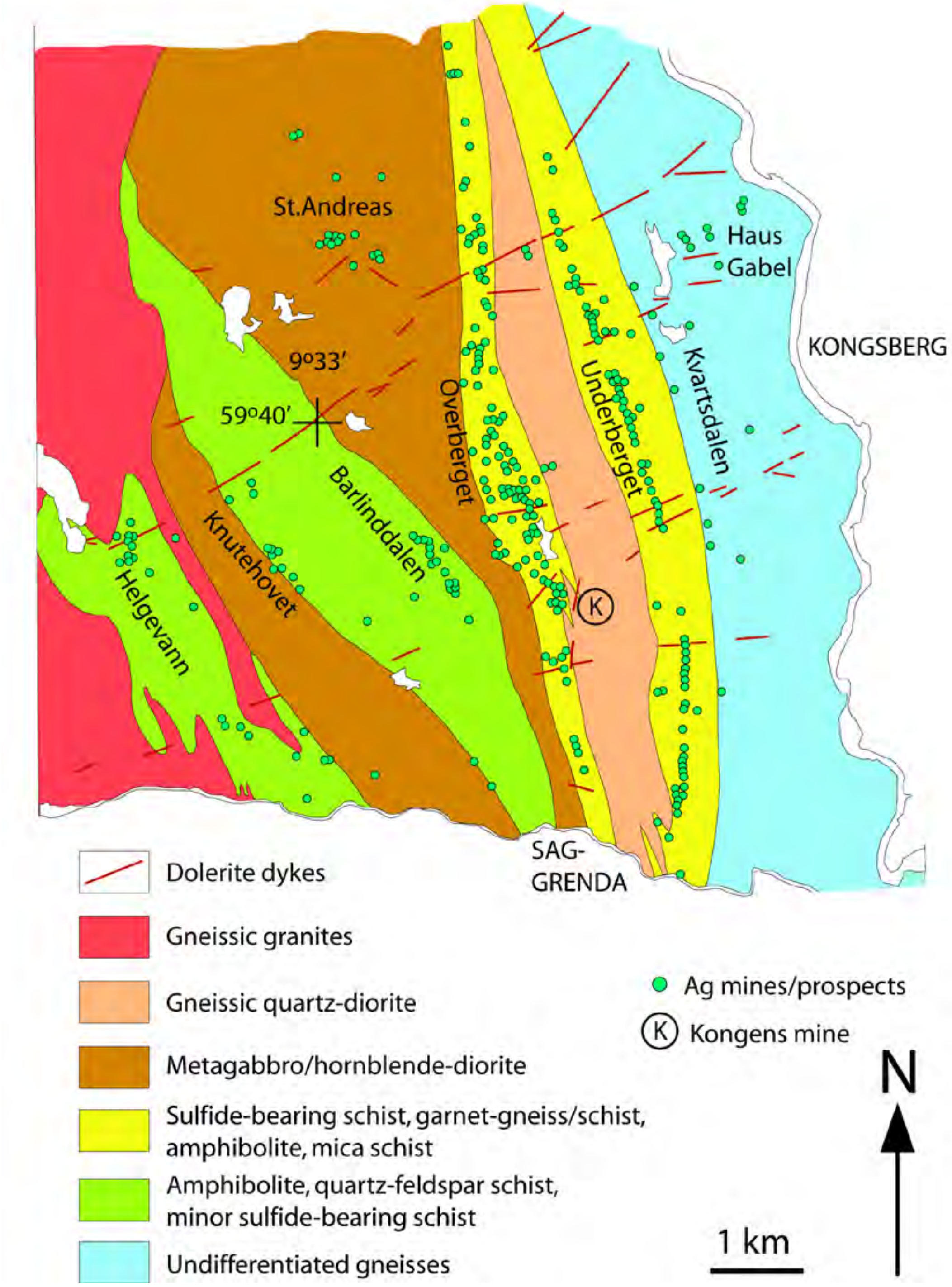


Figure 23. Geology of the main silver-mining area at Kongsberg. Modified from Ihlen & Nordrum (1986).

west of Kongsberg and striking north–south. The great majority of the richest silver mines are related to these two zones. The Overberget fahlband is 180–900 m wide and has a length of more than 10 km along strike (Ihlen & Vokes 1978).

The silver-bearing calcite veins usually strike about east–west and normally dip steeply towards the south (Fig. 24). The veins are very narrow, on average only 5–10 cm wide, seldom up to 50 cm in width. The length of individual veins rarely exceeds 100 m along strike and dip. They commonly appear in sets or form breccia. Some earlier-formed quartz-breccia veins within the fahlbands have been permeated by the same solutions that gave rise to the later silver-bearing veins. These modified veins (called 'main veins' by Bugge 1917) are typically rich in silver, occurring in vugs as so-called wire silver or silver crystals.

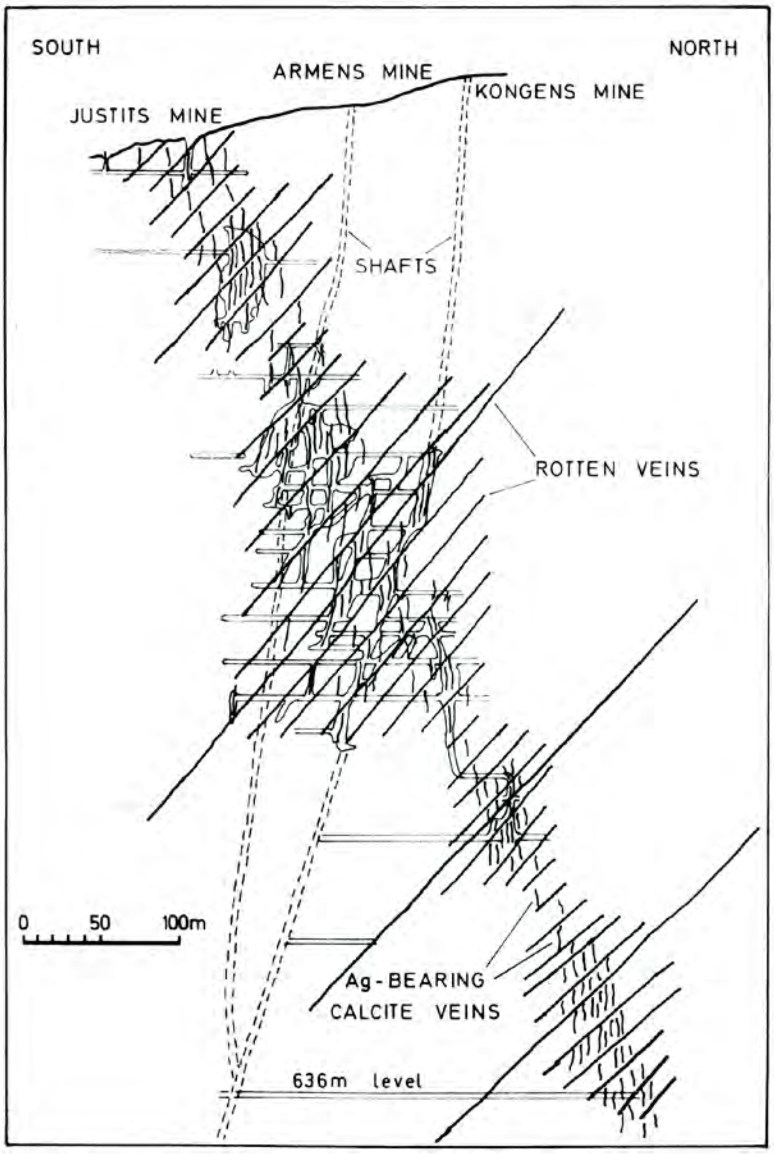


Figure 24. Schematic vertical N-S section through the major Justits, Armen and Kongens Mine in the Overberget fahlband zone, showing veins and fissures. The profile is drawn in the plane of a major strike vein (see text for further explanation). From Ihlen & Vokes (1978).

Other rich shoots were encountered where earlier generations of calcite veins along the strike of the fahlbands ('strike veins' of Bugge 1917) were crosscut by later east-west striking calcite veins. Neumann (1944) pointed out that the regular enrichment of silver close to the strike veins was because of tectonic control. Another vein type is the 'rotten veins' (*Råtaganger*, Bugge 1917), which are fissures formed by cataclasis, crosscutting the fahlbands, and filled with clay (Fig. 24). These fissures are important as concentrations of silver-bearing veins. Neumann (1944) considered these 'rotten veins' to represent sites of a localised high stress field.

In addition to calcite, the silver-bearing veins consist of quartz, fluorite, barite, zeolites, adularia, axinite and coalblende (Neumann 1944). The major ore minerals are (in decreasing abundance): pyrite, sphalerite, pyrrhotite, native silver, chalcopyrite, galena, argentite, Ni-Co arsenides and silver sulphosalts (Ihlen & Vokes 1978). According to Ihlen & Vokes (1978), the minerals in the veins can be assigned to three parageneses:

1: An early quartz-coalblende-fluorite-axinite-pyrite stage.
2: An intermediate calcite-barite-fluorite-sulphide-silver-Ni-Co-arsenide stage
3: A late calcite-zeolite stage, in places with rare ruby silver.

According to Neumann (1944), the main mass of silver extracted was 'matrix silver', occurring interstitially between the other minerals, whereas the wire silver and crystalline silver were more rare. Very little is known with respect to the sources and the chemistry regarding the deposition of silver. What is clear is that the calcite veins are Permian in age and younger than the quartz-breccia veins, which are very common in the eastern Kongsberg district (Ihlen & Vokes 1978, Ihlen et al. 1984, Ihlen 1986a). Fluid inclusion studies indicate that the silver was deposited at 250–280 °C at shallow depths (Johansen & Segalstad 1985). The fluid inclusions show salinities up to 21 % (NaCl eq.) and contain hydrocarbon phases (op. cit., Segalstad 1985) Reactions between the silver-bearing solutions and sulphides (mainly pyrrhotite) in the fahlbands have been proposed as the main mechanism for the silver and sulphide deposition in the veins (Segalstad 1985). The abundance of coalblende points to an origin of the carbon from the black shales or alum shales of the Oslo Rift. It is possible that silver has the same origin, but it could also come from the Precambrian sequences, extracted during the Permian magmatic-hydrothermal events.

N009 RINGERIKE Ni-Cu

Morten Often (NGU)

The Ringerike metallogenic area (N009) comprises the Ertelien deposit, the major producer in the area, another 11 small mines, and numerous other nickel showings (a total of 23 registered in the National database). Ertelien operated as a nickel mine between 1849 and 1920, with periodic interruptions, by the company Ringerikes Nikkelverk. The first known mining started at Ertelien in 1688, for copper, and continued until 1716. From 1789, colour pigments were produced, later also cobalt. The nickel content of the ore was discovered in 1837 (Boyd & Nixon 1985).

The Ringerike metallogenic area broadly covers the northernmost part of the Mesoproterozoic Kongsberg belt, comprising amphibolites, hornblende gneiss and gabbro in a zone of complexly folded and sheared metasediments and granitic gneisses formed between 1700 and 1500 Ma and subsequently metamorphosed and deformed during the Gothian orogeny (1600–1450 Ma) (Andersen et al. 2004). Mafic intrusions, locally called hyperites, were emplaced between 1450 Ma and 1100 Ma. These intrusions are dominantly composed of coarse-grained, plagioclase-rich mesocumulates and orthocumulates. Mafic intrusions range from subordinate ultramafics (including pyroxenite, picrite and peridotite) through troctolite to olivine-free gabbro, norite, and olivine-ferrogabbro. Nickel sulphides are associated with a number of these mafic intrusions. A second stage of metamorphism occurred in the area during the Sveconorwegian, between 1200 and 1180 Ma. This was essentially a thermal metamorphism with limited structural deformation (Bingen et al. 2008b).

The **Ertelien** deposit is at the margins of a minor (600 x 450 m) norite intrusion. Mineralisation consists of massive and brecciated ore in a narrow zone, located at the contact between norite and gabbro. The ore mineral assemblage comprises pentlandite, pyrrhotite and chalcopyrite. Both Ni-rich and Cu-rich ores are present. Barnes et al. (1988) suggest, on the basis of metal ratios, that the Ertelien ore formed from a primitive magma from which sulphides had already been removed at an early stage of the complex, leaving a magma still rich in Ni and Cu but depleted in precious metals.

Historic production at Ertelien is variously estimated at 280 000 t with 1 % Ni, 0.8 % Cu (National ore deposit database NGU) and 400 000 t with 1.04 % Ni, 0.69 % Cu and 0.17 % Co (Reddick Consulting Inc. 2009). The companies Sulfidmalm A/S and Norsk Hydro carried out exploration in the area from 1963 until 1979. Recent exploration commenced in 2004 with Falconbridge/Sulfidmalm, presently Blackstone Ventures/Sulfidmalm. In total, 70 diamond holes were drilled on the Ertelien Project between 2006 and 2008 (Fig. 25). Total cumulative metres were 17,417 for an average drill hole depth of 249 metres. These cores are stored in the NGU national core archive at Løkken. They provide the basis for the NI 43-101 compliant inferred resource (Reddick Consulting Inc. 2009) for Ertelien at 2.698 Mt at 0.83 % Ni, 0.69 % Cu, and 0.06 % Co. The current resource occurs immediately below the old workings. The second significant producer in area N009 was the **Langedals** mine, albeit much smaller than Ertelien. Production estimates vary considerably. The nickel ore occurs in a lenticular, deformed gabbro.

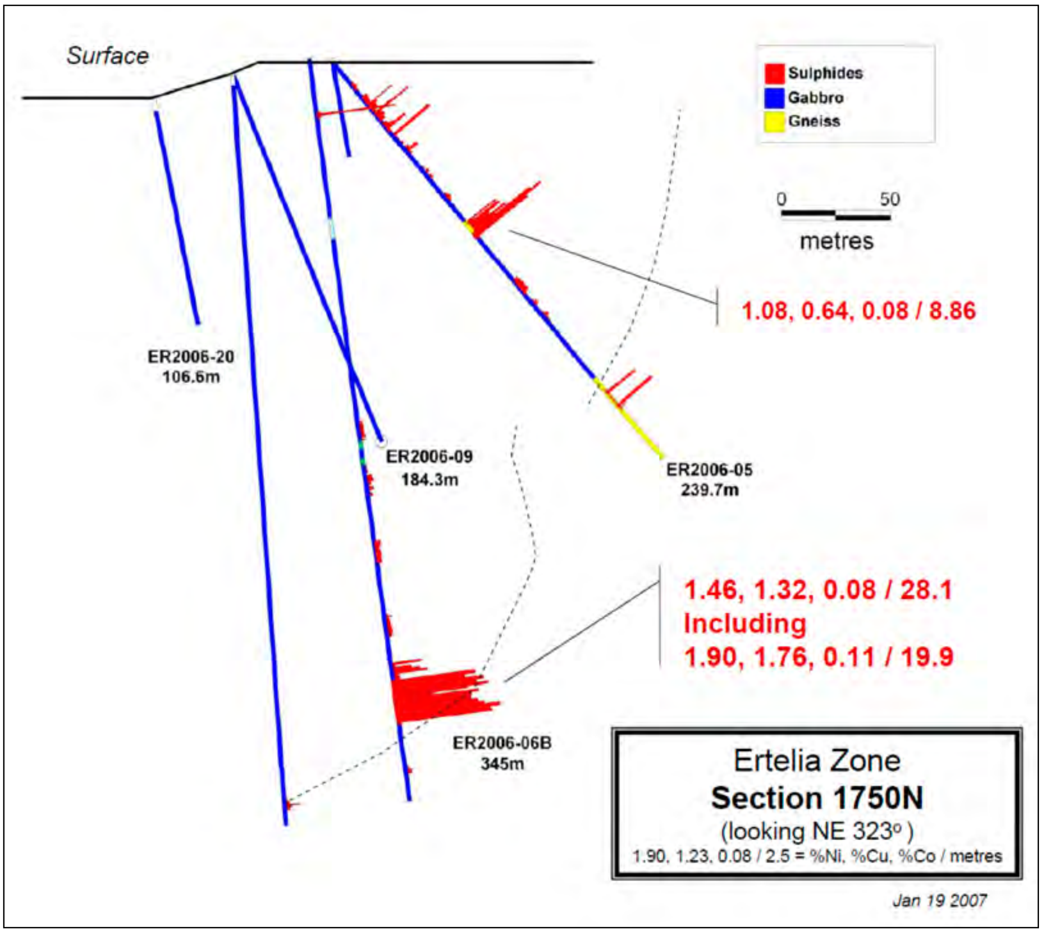


Figure 25. Ertelien deposit, drill section 1750N. From Blackstone Ventures Inc. (2010b).

N010 MODUM Co-As-Au-Ag

Terje Bjerkgård (NGU)

The cobalt occurrences at Modum are related to sulphide-rich schist zones, so-called fahlbands (Gammon 1966). The most extensive sulphide-rich zone has a length of 12 km along strike, and is up to 100–200 m wide. The main cobalt occurrences are associated with this zone. With reference to Gammon (1966), pyrrhotite is the most common iron sulphide in the southern part of the fahlband, whereas pyrite is more common in the north. Chalcopyrite is also quite common in parts of the zone. The rock type hosting the sulphides may be characterised as a quartz-plagioclase-tourmaline-phlogopite-sulphide gneiss or schist. Graphite is locally common and its content may attain more than 5 % of the rock.

The cobalt mineralisation probably is part of the fahlbands. It is, to a large degree, characterised by impregnation of cobaltite (CoAsS), glaucodote ((Co,Fe)AsS), safflorite ((Co,Fe)As$_2$) and skutterudite (CoAs$_3$), which partly occur enriched in quartz-rich zones and lenses (Jøsang 1966). The cobalt-rich lenses are structurally controlled, following fold axes and lineations in the area.

The cobalt ores at **Skuterud** (Fig. 26) were discovered in 1772 by Ole Withloch, a prospector from the Kongsberg silver mines. Test mining commenced the year after, and regular production started in 1776. There was quite limited open pit mining in the first 50 years, but the operation became more extensive from 1827, when underground mining began. In the 1840s, the artificial blue colour ultramarine was introduced, leading to a fall in demand for the blue colour from cobalt. However, as ultramarine decomposed under high temperatures, there remained a need for cobalt blue, and when rich cobalt ore was found in the 1870s, mining at Skuterud flourished again. In addition, a new transport adit was built. In the

Figure 26. Old mine workings at Skuterud Co mine, looking southwards. Photo: J. S. Sandstad, NGU.

1890s, ore reserves rapidly decreased, leading to the final shutdown of mining operation in 1898. The ore at Skuterud contained only 0.1–0.3 % Co and was upgraded to 3 % Co by simple hand separation (Horneman 1936). Because the mines at Modum were closed as early as in 1898, very little is known about how much ore was extracted from the mines, the cobalt grades of the ore or the distribution of ore minerals. On the basis of old mining reports, the total production is estimated to 1 Mt with 0.2 % Co. In addition to cobalt, the ores contain significant grades of copper (up to 1–2 %) and locally of gold (several ppm).

The genesis of the cobalt deposits is not known, but several theories have been advanced. Bugge (1978a) suggested a syngenetic sedimentary-exhalative to volcanogenic-exhalative formation. A number of other workers, including Gammon (1966), have suggested that the cobalt minerals were products from fluids released from the many gabbro bodies in the area. A third theory is that the ore minerals were produced by metasomatic processes, for example, related to regional albitisation (Munz et al. 1995).

N011 OSLO Mo

Peter Ihlen (NGU)

The Permo-Carboniferous Oslo Rift (N011) is an important metallogenic area where most of the felsic rocks of the igneous complex contain molybdenite as an accessory constituent or forming major deposits (Fig. 27). The palaeorift comprise two half grabens completely enclosed by Meso- to Neoproterozoic gneisses, which inside the grabens are covered by caledonidised Cambro-Silurian metasedimentary sequences. Both of these older units are enriched in molybdenum containing abundant Meso- to Neoproterozoic Mo deposits, especially west of the rift (Bugge 1963) and Upper Cambrian bituminous shales with up to 425 ppm Mo (Gautneb & Sæther 2009). Rifting commenced subsequent to peneplanisation of the Cambro-Silurian rocks in the Devonian and Carboniferous and coeval with deposition of fossiliferous Early Permian sediments. The igneous rocks within the grabens were emplaced at 300–240 Ma. Their emplacement occurred in three major stages, including an early stage of fissure eruptions of tholeiite, alkali basalt, trachyandesite and trachyte, an intermediate stage of bimodal central volcanoes with associated caldera formation, and a late batholith stage with emplacement of sub- to peralkaline monzonites, syenites and granites (Sundvoll et al. 1990). The vast majority of Mo deposits are both temporally and spatially related to highly differentiated extrusive and intrusive granitic rocks that evolved during the caldera formation and subsequent batholith emplacement. These are described below, mainly based on Schønwandt and Petersen (1983) and Ihlen (1986b and references therein).

Caldera stage epithermal Mo deposits occur inside remnants of caldera complexes (cauldrons) characterised by large-scale fluid circulation with associated pervasive to fracture-bound sericitisation, silicification and locally albitisation. The alteration is frequently accompanied by high amounts of pyrite, and in a number of cases molybdenite. The epithermal deposits of molybdenite, which mainly were formed during caldera resurgence, include major deposits in the Glitrevann and Ramnes cauldrons as well as subordinate deposits in rafts of altered caldera rocks in the Nannestad-Hurdal batholith. In the Glitrevann cauldron, molybdenite occurs as stratabound stockwork in densely welded ignimbrites, as fine dissemination in a rhyolitic vent breccia complex, as diffuse dissemination in ash flow tuffs and in quartz veins and pegmatite segregations in the central resurgent granite stock. The deposits in the Ramnes cauldron comprise diffuse dissemination and fracture filling of molybdenite in commonly pervasively sericite-altered rhyolite domes.

Batholith-stage Mo deposits comprise orthomagmatic deposits, intra-plutonic vein deposits, exocontact deposits and stockwork type deposits. True orthomagmatic mineralisation with molybdenite as a rock-forming mineral is rare and occurs locally in riebeckite and fayalite granites in the Feiring area. The transition from magmatic to late magmatic hydrothermal precipitation of molybdenite is indicated by the widespread occurrence of miarolitic cavities and small pegmatite dykes with scattered specks of molybdenite in most of the intrusions, even in the silica-undersaturated types. Intra-plutonic vein deposits are especially developed in the subalkaline Drammen granite batholith. The major occurrences comprise quartz-molybdenite veins intersecting unaltered wall rocks of quartz-feldspar porphyries and coarse-grained biotite granites. The veins, which occasionally carry minor K feldspar and beryl, succeed widespread biotite-topaz, topaz-sericite and sericite alteration developed in an intrusion of medium- to fine-grained leu-

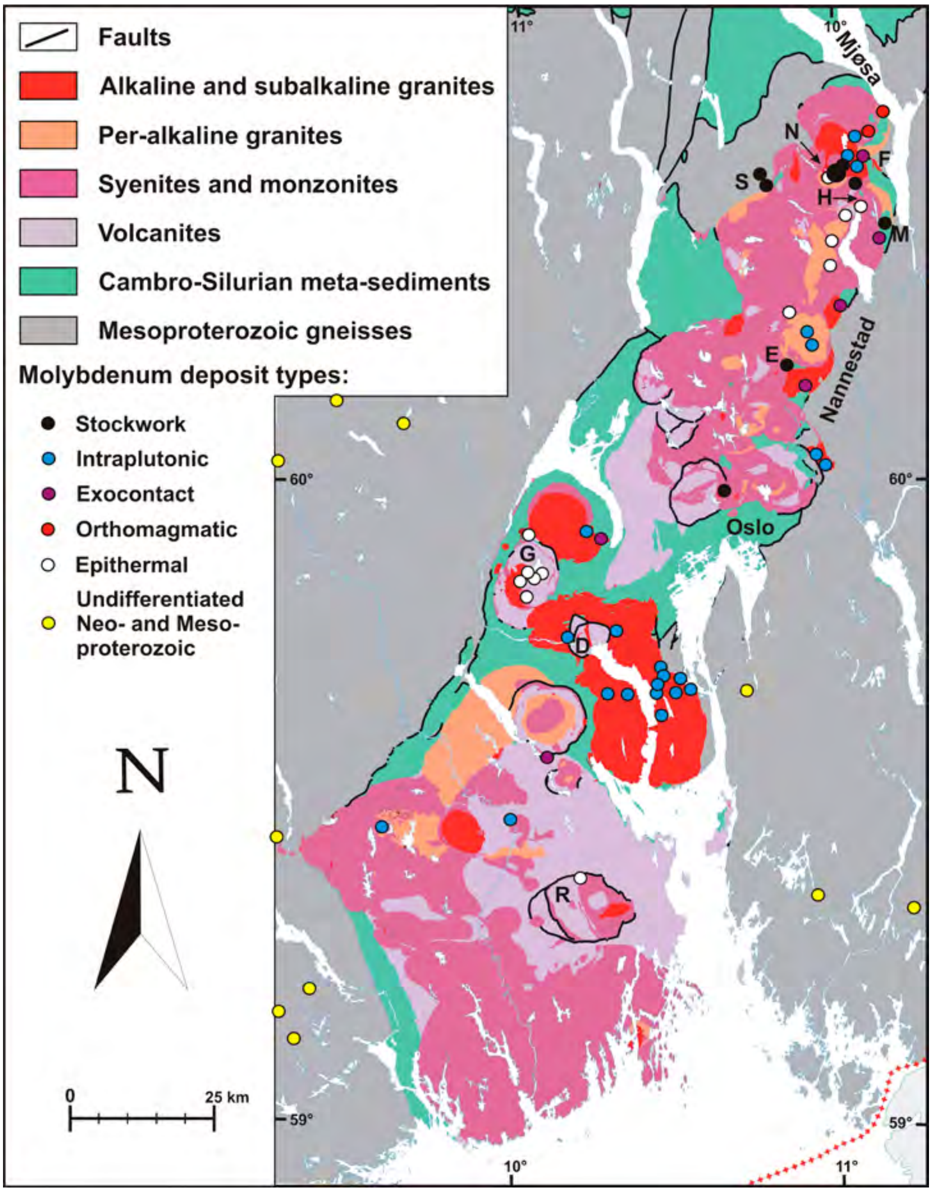


Figure 27. Simplified geological map of the Oslo Rift based on Lutro & Nordgulen (2008) showing the different types of Mo deposits in the metallogenic area. Abbreviations of locality names given in the text are: D = Drammen, E = Elsjø, F = Feiring, G = Glitrevann, H = Hurdal, M = Mistberget, N = Nordli, R = Ramnes and S = Skrukkelia.

cogranites in the central part of the batholith. The alteration zones, occurring like mineralised quartz veins along series of parallel fractures, contain abundant pyrite, but only minor amounts of molybdenite, wolframite and bismuthinite. Small, but numerous exocontact deposits of Fe, Cu, Zn, Pb and Bi are characteristic members of the Permian metallogeny and a number of them contain accessory molybdenite. However, deposits containing molybdenite as the dominant ore mineral are rare and are mainly found in garnet skarns in the exocontact of alkaline and per-alkaline granites of the Nannestad-Hurdal batholith. This batholith also carries the most important of the molybdenum occurrences in the Oslo Rift, the stockwork type deposits with associated breccia-pipe mineralisation. Weak development of molybdenite-bearing stockworks and associated fracture-bound alteration covering areas of 0.5–2 km^2 occurs associated with alkali feldspar granites both in their endocontact, as in the Elsjø area, and in their exocontact, where mineralisation is hosted both by Mesoproterozoic gneisses of the Skrukkelia area and by Cambro-Silurian metasedimentary rocks of the Mistberget area (Fig. 27). The two latter areas also carry matrix mineralisation in quartz-cemented collapse breccias and intrusive breccias, respectively.

The **Nordli** deposit in Hurdal is a well-developed stockwork mineralisation that was discovered by Norsk Hydro in 1978 and became the site of extensive exploration until 1983. The ore reserves of this Climax-type or porphyry-style occurrence was calculated on the basis of 24 drill holes (10,200 m) to contain about 200 Mt with 0.14 % MoS_2 with a 0.05 % cut-off grade. Intex Resources resumed exploration of the deposit in 2006–2008 with additional core drilling. The deposit is formed in a subvolcanic environment in the root zone of a deeply eroded and nested system of calderas in the northern part of the Nannestad-Hurdal batholith. The molybdenite stockworks are, as described by Pedersen (1986), related to the emplacement and crystallisation of the composite Nordli alkali-granite stock, which post-dates the major caldera-forming processes and which represent the final derivates of a large alkali granite pluton in the area (Fig. 28).

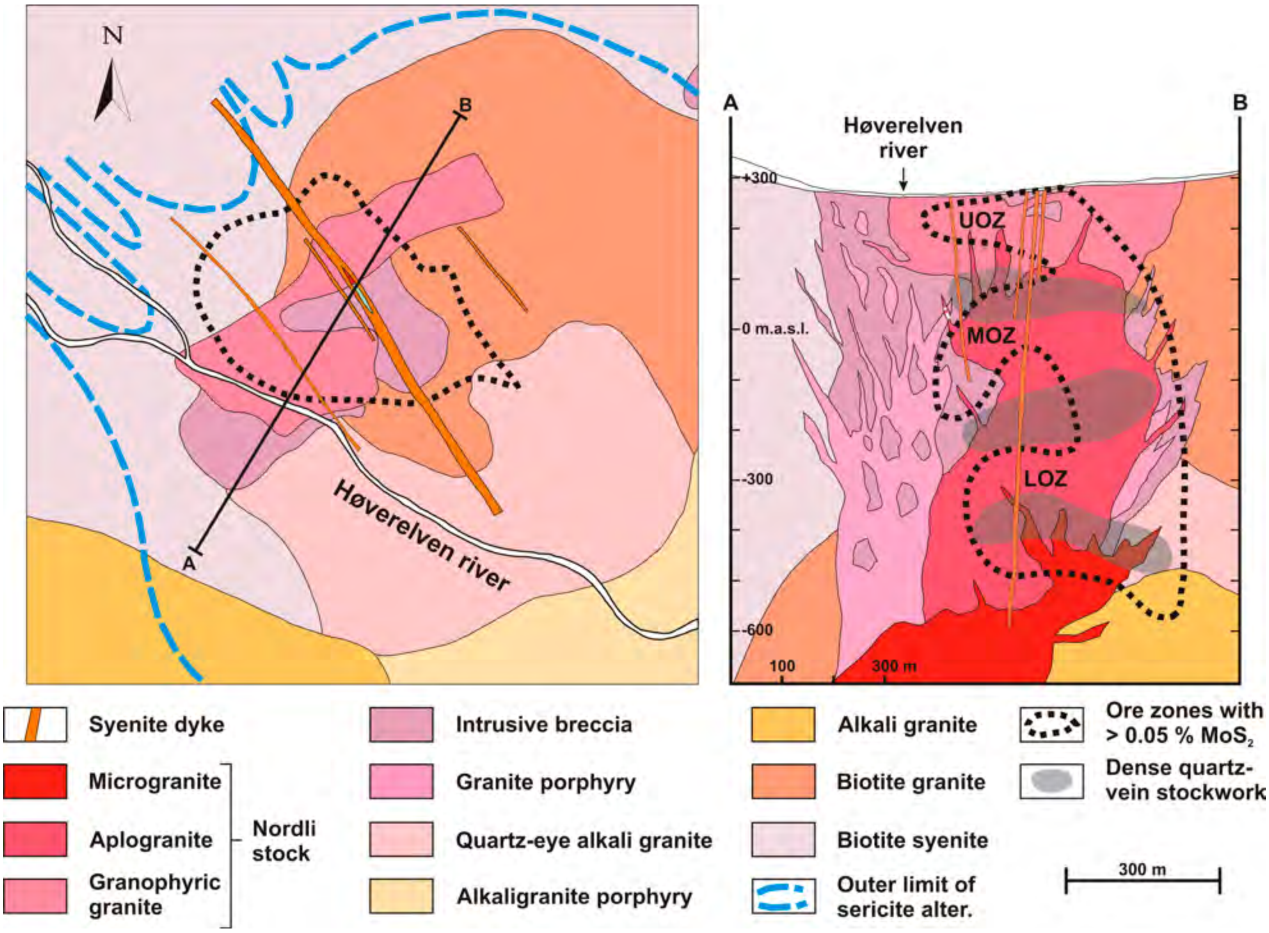


Figure 28. Geology of the Nordli deposit at surface (left) and in cross section (right) based on figures in Pedersen (1986). Abbreviations: UOZ = Upper Ore Zone, MOZ = Middle Ore Zone and LOZ = Lower Ore Zone.

Core drilling and assays have demonstrated that the deposits comprise three interconnected ore zones containing more than 0.05 % MoS_2. The ore zones are discs 150–250 m thick and 200–300 m across. They are situated above each other over a vertical distance of about 900 m and were formed by the expulsion of molybdenum-bearing magmatic fluids generating hydraulic fractures in the apical parts of the host intrusions, which include early granophyric granite (top), intermediate aplogranite and late micrograntie constituting the lower part of the Nordli stock. The ore bodies are connected along their northeastern periphery by a steeply dipping ore zone, which is probably caused by escape of the ore-forming solutions along the NW–SE-trending Høverelven fracture zone (Fig. 28). The ore zones comprise high-density zones of quartz veins and fracture coatings containing variable amounts of molybdenite and pyrite. In addition, the veinlets in the upper low-grade ore zone contain magnetite and hematite, the middle ore zone sericite, biotite and K feldspar, and the lower ore zone calcite, magnetite and K feldspar. All the ore zones occur shortly above areas with the high density of quartz veins and are surrounded and overlain by a telescoped system of different types of pervasive to fracture-bound K silicate and sericite alteration, containing variable amounts of magnetite, pyrite and hematite. These alteration types developed during both the prograde stage of ore formation and subsequent retrograde stage, when the magmatic hydrothermal system collapsed and caused an influx of meteoric water and the formation of widespread phyllic alteration.

N012 INDRE ØSTFOLD Ni-Cu

Morten Often & Lars Petter Nilsson (NGU)

The Indre Østfold Ni-Cu metallogenic area (N012) in the Precambrian of SE Norway comprises 22 registered occurrences of nickel-copper sulphide mineralisation within a roughly circular area 30 km across. The occurrences are not included into the FODD, as most of them are very small. They are all situated in the Stora Le–Marstrand Formation of the Iddefjorden terrane, which is part of the Sveconorwegian orogen of SW Scandinavia (Bingen et al. 2001a, 2005). The Stora Le–Marstrand Formation is dominated by migmatised supracrustals intruded by several generations of Pre-Sveconorwegian intrusives (e.g., Lundquist 1979, Åhäll & Daly 1985). The NW part of Iddefjorden terrane is cut by the Phanerozoic Oslo Rift, leaving a small, isolated segment of the terrane in the northwest, named the Begna sector. The Begna sector hosts several mafic bodies (metagabbro + diorite + dolerite) similar (coeval and cogenetic?) to the ones in Østfold, and the largest of them, the Follum diorite has yielded a U-Pb zircon age of 1555 +3/-2 Ma (Nordgulen 1999, Bingen et al. 2001a, 2005). Most of the Ni-Cu occurrences are hosted by minor mafic bodies and with slightly varying composition (diorite, gabbro, norite, quartz norite, dolerite, etc.). The intrusions are mostly strongly deformed and metamorphosed to relatively fine-grained, foliated amphibolites.

The **Romsås** nickel deposit, although itself not impressive in size, is by far the largest of the nickel sulphide occurrences in Indre Østfold. It is within a minor quartz noritic body of assumed Mesoproterozoic age surrounded by migmatitic gneisses of presumed sedimentary origin on the regional map of Berthelsen et al. (1996) and interpreted as Mesoproterozoic greywacke-dominated metasediments (Bingen et al. 2005). Neither the Romsås body, nor any of the other nickel sulphide mineralised mafic bodies in Østfold, has been dated to the knowledge of the present author. Therefore, both in space and time, the 1555 +3/-2 Ma Follum dioritic intrusion in the Begna sector in the NW is one of closest comparable to the mafic intrusions in Indre Østfold. The Romsås deposit is famous for its orbicular norite, mostly developed along the western margin of the intrusion, but also in the inner parts of the body. The orbicular norite is partly cut by the sulphide ore zones and partly cuts them (Støren 1909). No modern studies have been undertaken on the Romsås body with its sulphide mineralisation, but a wealth of classic works, mainly descriptive, both on this and other nickel-rich intrusions in Norway, exist from Professor Vogt and other pioneering Norwegian geologists. The most recent description of Romsås is in the review article by Boyd & Nixon (1985). Pyrrhotite, pentlandite and chalcopyrite constitute the main ore minerals in the Romsås ore, whereas pyrite is a rare, secondary mineral (Meinich 1879).

The company *Roms Nikkelverk* commenced mining on the Romsås deposit in 1866 and maintained continuous activity until 1876 (Fig. 29). During the first seven years, only test mining was carried out. In 1873, full-scale mining started, and in that year the company also built its own smelter (Meinich 1879). In 1875, 122 men were employed at the company (Helland 1900). When nickel prices dropped in 1876, the Romsås deposit closed down and never came into production again. Total ore production from Romsås was 13,205 tons with a nickel content of about 125–130 t. Total production from all the mines of the company during the period 1866–1876 was, according to official statistics, 16 465 t with a Ni content of about 150 t. The average ore grade at Romsås was 1.07 % Ni (+ Co) and 0.4 % Cu (Vogt 1902, Meinich & Vogt 1903).

Figure 29. The Romsås Ni mine, entrance at level 3, main production level. The spectacular orbicular norite is seen on the sides. Photo: L. P. Nilsson, NGU.

N013 EIDSVOLL Au

Peter Ihlen (NGU)

Visible gold was originally discovered in an abandoned copper mine in 1757 in the Eidsvoll region (Keilhau 1836). In the following years, more than 20 small mines were in production, and the largest of them, **Brustad**, was closed in 1907. Since then, several companies have conducted gold exploration campaigns in the area, the last one ending in 2008. The total gold production in the Eidsvoll mining field is unknown, but the Brustad mine yielded about 50 000 tonnes of crude ore with 2-15 g/t Au (Sundblad et al. 1995).

The vein deposits in the Eidsvoll metallogenic area (N013) and adjacent areas to the east are part of the Mjøsa-Vänern belt (Ihlen 1986c), comprising more than hundred small base and precious-metal vein deposits occurring distributed along the Mylonite Zone (MZ) and its hanging-wall rocks in Norway and Sweden (Sundblad et al. 1995). They are confined to structures formed in conjunction with the development of the MZ, which is a prominent N-trending transpressional shear zone of Sveconorwegian age (Viola & Henderson 2010, and references therein). In the Norwegian part of the belt, the deposits comprise three major types. The Eidsvoll type at the southwestern margin of the MZ is characterised by auriferous pyrite-chalcopyrite-bearing quartz veins containing 1–10 g/t Au (max. 137 g/t), whereas the Odal type deposits, found throughout the MZ, comprise small Cu sulphide mineralisation in narrow ductile shear zones, 0.1–0.5 m wide and with 0.5–1 g/t Au (max. 3 g/t). The Grinder type occurring at the northeastern margin of the MZ comprises up to 100-m-wide zones of pyrite-sericite phyllonites with 0.2–0.5 g/t Au (max 2 g/t).

The quartz veins in the Eidsvoll area are confined to steeply-dipping normal faults, which developed in conjunction with extensional tectonics and block-faulting subsequent to the ductile shearing along the MZ (Fig. 30). Isotope dating suggests that the hydrothermal activity responsible for the sericite alteration in conjunction with the pyrite deposition occurred in the period 0.9–0.7 Ga (Ihlen et al. 1978, Stein et al. 2008). The veins intersect a sheared complex of late Palaeoproterozoic gneissic granites-granodiorites and early Mesoproterozoic metagabbros/amphibolites (hyperites) which truncate sequences of late Palaeoproterozoic metavolcanic rocks. The gold-rich ores occur in the central part of the province and are mainly hosted by the granitic orthogneisses (Fig. 30).

The veins are 0.5–20 m wide and up to 1 km long and were formed during repeated episodes of fault movements, fluid influx and mineral deposition. They are mainly composed of coarsely crystalline milky quartz, and are invariably enveloped by sericite alteration. However, most of them are barren in gold and sulphides. Native gold is invariably confined to 10–100-m-long segments of the veins where the early barren quartz and associated sericite alteration are superimposed by irregularly distributed mineralisation of Fe and Cu sulphides. Visible gold is rarely encountered in the veins and thus the native gold predominantly occurs as microscopic grains (10–80 µm) intergrown with sulphides and locally quartz immediately surrounding the sulphides. The sulphides mainly comprise pyrite, chalcopyrite and galena, which occur intergrown with subordinate to accessory amounts of hematite, magnetite, carrolite, covellite, sphalerite, pyrrhotite, bornite, idaite, aikinite, hessite, and molybdenite (Telstø 2005).

The best-developed multistage veins are found in the Brustad deposit (Fig. 31), which has been studied in detail by Telstø (2005). The results of

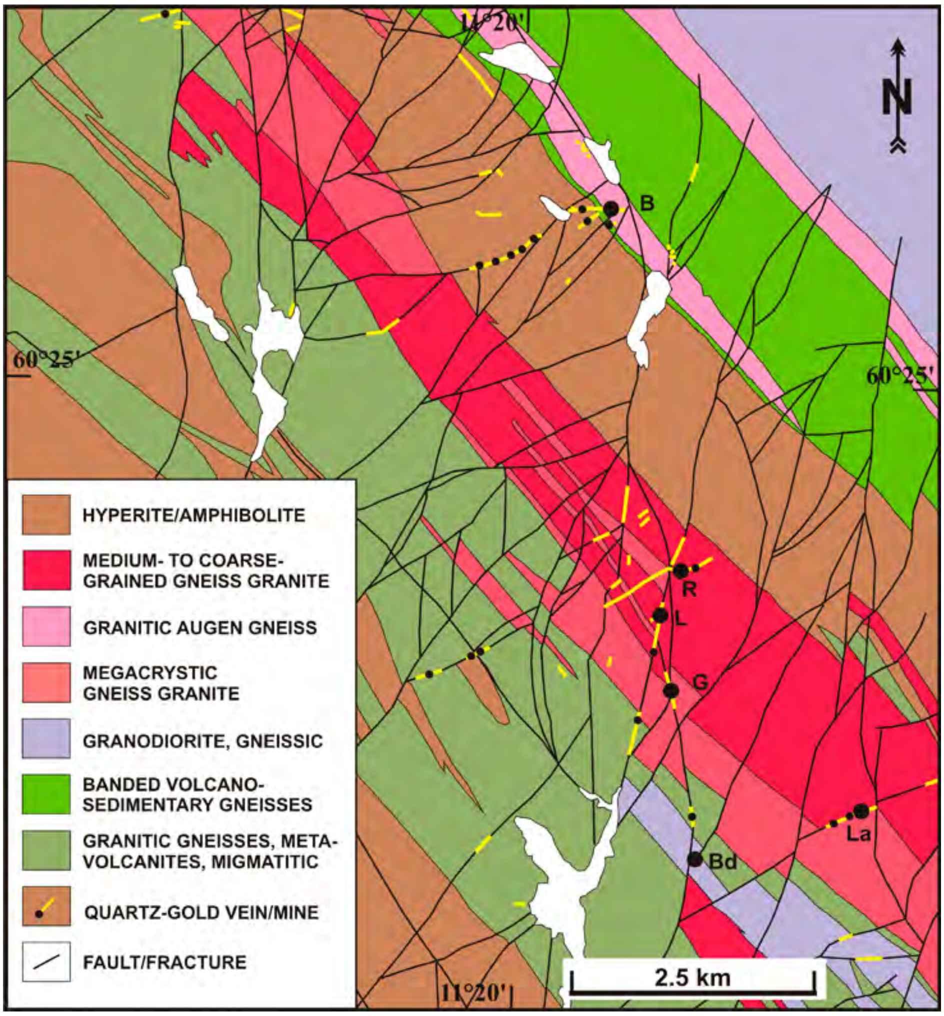


Figure 30. Simplified geological map of the central part of the Eidsvoll metallogenic area showing the distribution of normal faults with associated auriferous quartz veins. The most gold-rich ores were found in B = Brustad, Bd = Botshaugdalen, G = Guldkis, L = Lesja, La = Larsputten and R = Røysivangen mines. Redrawn from Telstø (2005).

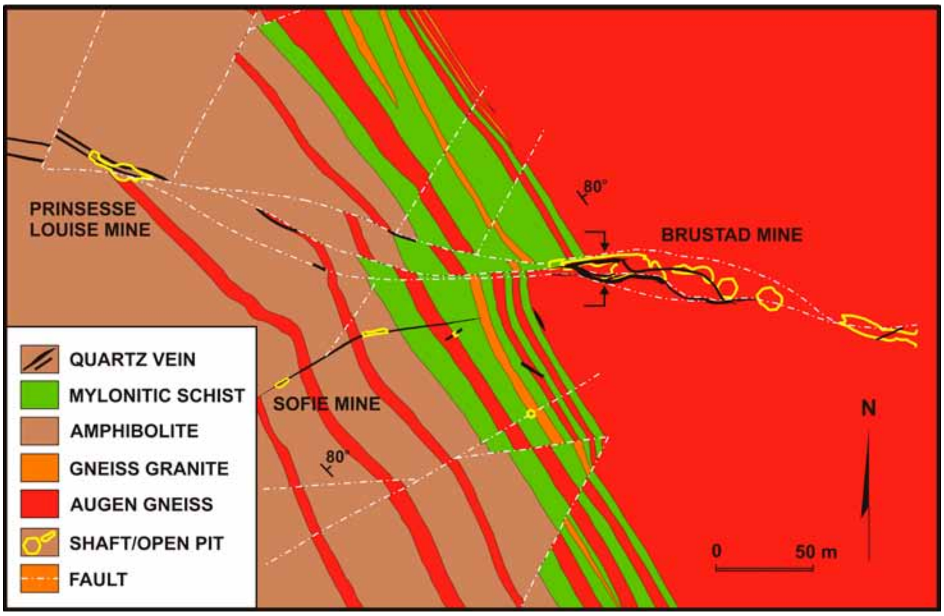


Figure 31. Geological map of the quartz vein system in the Brustad mining area. Arrows in the Brustad mine indicate the location of the cross section shown in Figure 32.

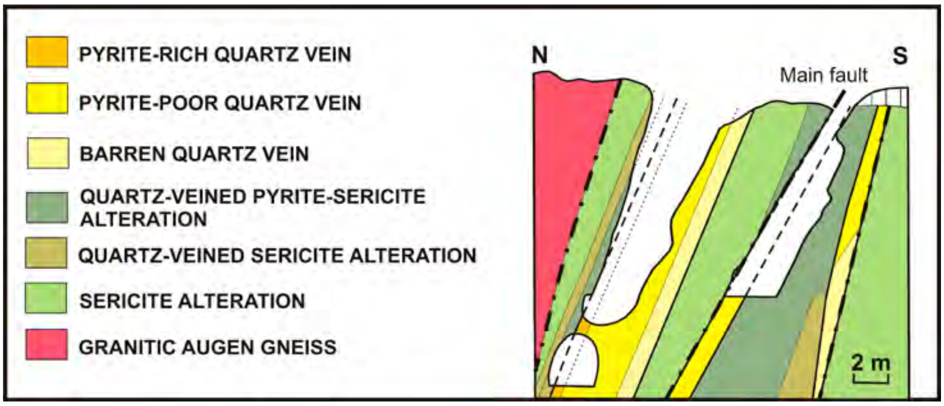


Figure 32. Cross section of the ore-bearing quartz veins in the Brustad mine. See Figure 31 for location.

his study are presented below. The ores in the Brustad and Prinsesse Louise mines are confined to an undulating system of 0.1–3-m-wide, WNW-trending and steeply-dipping veins quartz veins, which have become dismembered by post-ore normal faults (Figs. 31 and 32). The veins were mainly formed during an early barren quartz stage when weak sericitic alteration with minor pyrite developed in the immediately adjacent wall rocks. The subsequent mineralising stages started with an early pyrite stage characterised by increased sericite-pyrite alteration and silicification of the wall rocks together with the formation of locally semimassive pyrite related to a high density of quartz-pyrite filled fractures (Fig. 32).

During the intermediate gold stage, the early pyrite became cataclastically deformed and variably cemented and replaced by chalcopyrite and co-precipitated native gold, galena and quartz along microfractures. The gold stage was followed by a Fe-oxide stage, when thin quartz veins with abundant hematite, pyrite, chalcopyrite, and magnetite were deposited and terminated the main ore-forming event. The youngest event recognized in most of the veins in Eidsvoll area, including Brustad, is deposition of fracture-bound amorphous carbon together with minor pyrite along vein-parallel post-ore faults generating black fault gouges enveloped by black quartz veins, gneisses and sericite alteration. Fluid inclusion and stable isotope studies performed by Telstø (2005) demonstrate that the sulphide ores were deposited from moderately saline aqueous solutions (5–12 mole % CO_2) at about 380 ± 30 °C, at a palaeodepth of about 12 km. The precipitation is suggested to have occurred in response to the mixing of deeply-sourced metamorphic waters and evolved meteoric waters.

N014 KARMØY Cu-Zn

Jan Sverre Sandstad (NGU)

The Karmøy area (N014) comprises an ophiolite complex in the southwesternmost part of the Norwegian Caledonides. It constitutes part of an immature arc–supra-subduction zone (SSZ) ophiolite sequence of Laurentian affinity that includes the Karmøy–Bømlo–Hardanger area (Grenne et al. 1999). The ophiolite is assumed to have formed at a spreading axis in a marginal basin positioned above a subduction zone, as the result of back-arc spreading or arc rifting, and is thus a SSZ ophiolite (Pedersen & Furnes 1991). The sequence upwards from ultramafic and mafic intrusive, sheeted dykes, pillow lava, pyroclastic rock, volcanoclastic rock, pillow lava and sedimentary units is well exposed. The dyke density increases upwards until a true sheeted-dyke complex (1.5 km thick) is encountered. The dykes fed a thick (>1 km) sequence of non-vesicular and variolitic pillow lavas and pillow breccias. These tholeiitic basalts, both dykes and extrusives, comprise the Visnes Group. The oldest axial part of the ophiolite is dated to 493 +7/-3 Ma from a plagiogranite, whereas arc-related trondhjemite crosscutting the ophiolite crystallized at 485 ± 2 Ma (Dunning & Pedersen 1988). Several Cu-Zn deposits, mostly of VMS category, and a few vein deposits, are mainly confined to the lower pillow lavas and the sheeted-dyke complex (Visnes Group). A few minor Fe occurrences are present within the upper lava and overlying sediments of the Torvastad Group. A minor Ni-Cu deposit, **Feøy**, is located in the sheeted-dyke complex on the island of Feøy, just north of Karmøy.

The most significant VMS deposits are **Vigsnes** and **Rødkleiv** (Table 3), which are located only 650 m apart on the western side of the island of Karmøy. The Vigsnes deposit was discovered in 1865 and a Belgian company already commenced production in the following year. In 1880, when French interests took over, it was the largest mining company in Norway, with 3 000 persons directly or indirectly occupied, but mining ceased in 1894 due to the declining Cu content of the ore. Small-scale production took place in 1970–71. Small-scale test mining was carried out on the Rødkleiv deposit before regular production started in 1910. The mine closed in 1971. A frequently-mentioned curiosity is that the copper in the Statue of Liberty in New York Harbour was delivered from the Vigsnes mine (Geis 1965).

The ore bodies at both Vigsnes and Rødkleiv are in a 50–60 m wide zone dominated by chlorite-rich greenschist that represents sheared dykes and lava of the Visnes Group. The shearing is assumed to post-date the formation of the massive sulphide bodies (Scott 1992). The strike of the sequence is NW–SE with a steep dip towards the NE and across the island. The stratigraphy of the hosting sequence from footwall to hanging wall is: greenstone, chlorite schist, ore, chlorite schist, greenstone with minor intercalations of felsic metavolcanic rocks and magnetite, and chert (Geis 1957). At the Vigsnes mine, six cigar- or plate-shaped ore bodies were exploited to a depth of 732 m. The two largest of these were 400–450 m long, up to 175 m wide and with thicknesses of the order of 5–30 m. At Rødkleiv, two ore bodies were mined, the West and East ore bodies, separated by a fault. The western ore body was ruler-shaped and exploited from the surface to a depth of 400 m, whereas the eastern ore body was more irregular and was discovered at a depth of 210 m. The possible easterly extension of the eastern ore body was exploited from the minor Hinderaker mine.

The massive sulphide ores are banded and pyrite-rich. In the Vigsnes deposit, chalcopyrite and sphalerite are enriched in the upper parts of the

Table 3. Deposits and occurrences in the Karmøy metallogenic area included in the FODD database.

Deposit	Ore tonnage (Mt)	Cu %	Zn %	Ni %	S %	When mined	Genetic type	Reference
Vigsnes	1.44*	1.66	1.4		35	1865–1894, 1971–1972	VMS	Geis (1957)
Rødkleiv**	2.646*	0.78	1.71			1910–1920, 1924–1971	VMS	Gvein (1977)
Feøy	0.037*	2.6		2.1		1896–1922	Magmatic Ni-Cu-PGE	Boyd & Nixon (1985)

* Mined ore
** Variable ore grade recorded, average grade in the years 1961–69 listed.

sulphide bodies, and chalcopyrite is also enriched in the thinner part of these. Minor stringers or veinlets and dissemination of chalcopyrite also occur in the hanging wall. The Rødkleiv ore is dominated by pyrite with thin bands of sphalerite with more irregular enrichments of chalcopyrite, especially on the hanging-wall side.

Several minor massive sulphide deposits exist to the SE, along strike from Vigsnes and Rødkleiv, for example, Hinderaker, Sletthei, Knoff/Huelva and Jordan. The Sørstokke deposit is located at the SE side of Karmøy (total production of 7300 t with 0.5–0.6 % Cu) (Geis 1957). Both massive and disseminated pyrite-chalcopyrite occurrences are in doleritic greenstone in the lower part of the ophiolite complex. Stratigraphically above the Visnes Group, there are several minor occurrences consisting of thin bands of massive pyrite and/or magnetite (BIF) located in metalliferous sediments. Along the western side of Karmøy, there is a NNW-trending shear zone in the sheeted dyke complex. The central shear zone is up to 50 m wide, and several minor showings occur over a length of more than 1.5 km. Relatively rich chalcopyrite and pyrite occurs in the quartz veins (up to 0.5 m thick) and schistose greenstones, but no precious-metal enrichment is recorded. The Feøy Ni-Cu occurrence is in the dyke complex and gabbro and is located just outside the Karmøy metallogenic area.

N015 HARDANGER Cu-Zn

Jan Sverre Sandstad (NGU)

The Hardanger Cu-Zn area (N015) is located along the northern side of the Hardangerfjord, extending from the islands of Bømlo and Stord in the SW towards the inner part of the fjord for 100 kilometres to the northeast. The palaeotectonic setting of the area is complex and not very well constrained. On Bømlo and Stord, there are both immature arc-SSZ ophiolite complexes (Lykling ophiolite complex) and younger, overlying mature-arc volcanic-sedimentary sequences and their plutonic counterparts of Ordovician age (Pedersen & Dunning 1997, Grenne et al. 1999). Early Silurian sedimentary sequences (Langvåg/Mundheim Group) were deposited after rifting of the mature arc. The eastern part of the area is dominated by felsic volcaniclastic rocks and pelagic sediments. More than 150 mineral deposits and occurrences are known from this area, and a new exploration campaign has recently been commenced. Two of these, Stordø and Nygruva, are included as small deposits in the FODD.

The best-known ore occurrences, on the island of Bømlo in the southwest, are mesothermal gold-bearing quartz veins in shear zones in the Lykling ophiolite complex, frequently following the contacts of dolerite dykes (Wulff & Stendahl 1995, Ihlen 1999). The veins and their chloritised and carbonatised wallrocks are characterised by the presence of coarse-grained native gold, giving spectacular hand specimens that are extracted today. Analyses of bulk samples are normally in the range of 2–5 g/t Au. A few minor Cu-Zn and Fe-sulphide ('vasskis') occurrences are related to metabasalts and felsic metavolcanic rocks overlying the ophiolite complex (Wulff 1996).

Stordø (Litlabø) is the major VMS deposit in this metallogenic area (Table 4). It is located on the island of Stord, and the mine was operated from 1865 to 1968, to a depth of nearly 600 m. The total production was 9 Mt of fine-grained pyrite ore with a very low content of base metals, on average 40 % S and 0.26 % Zn in the "export" ore (Foslie 1926): recent analyses show up to only 0.11 % Cu. The deposit consists of several layers or lenses, 5–50 m thick, over a total stratigraphic thickness of 140 m. The strike of the ore lenses is NNE with a steep dip (70–80°) towards the SSE. There is massive pyrite and magnetite- and/or chert-banded ore. The major ore mineral is pyrite and there are lesser amounts of pyrrhotite. The stratabound ore bodies are in the sediments of the upper part of the Silurian Langevåg Group (Mundheim Group), which consists of turbidites (green phyllite and sandstone), chert and shallow marine metabasalts of tholeiitic to alkaline character. The lower part of the group is composed of subaerial calc-alkaline volcanic rocks overlain by submarine volcaniclastic breccias, tuffs and chert. Several minor Fe-sulphide deposits are found in these sequences on Stord. In the **Guldberg** deposit, which is located in the south of the island, the massive, phyllite-hosted, sulphide ore contains some copper (1–5 % Cu) and minor zinc (Wulff 1996). Similar small Cu-bearing massive sulphide deposits have been discovered on the islands further NE, for example, at Tveit, where bornite is the main Cu-sulphide mineral (Wulff 1996).

Several small (<1 Mt) stratiform and stratabound VMS deposits occur further northeast in area N015, on the islands of Tysnesøy, Fusa and Varaldsøy in the inner part of the Hardanger district (Fig. 33a). They occur as extensive, banded units up to a few metres thick, commonly in close association with felsic metavolcanic rocks (Foslie 1926, 1955). Modern investigations are lacking, but the ores are known to be pyrite-dominated with varying but generally rather low Cu and Zn contents (Grenne et al. 1999). The largest of these deposits are **Gravdal**, **Valaheien** and **Nygruva** (Table 4) on Varaldsøy, with a total production of at least 0.5 Mt. These deposits are located at the same stratigraphic level in the Varaldsøy Group, along the contact between metabasalt or tuff and minor bodies of feldspar porphyric rhyodacite. The average ore grades in Nygruva and Gravdal are 0.7 % Cu and 3.4 % Zn, and 1.35 % Cu and 0.7 % Zn, respectively. Some of these deposits are enriched in Au, for example, **Storhidleren**, where massive lenses of pyrite occur in fine-grained quartzite or chert enclosed within schist. Two samples of massive pyrite ore returned 6 and 10 g/t Au, and also showed enrichment in Ag and As (Wulff 1996). Along strike, pyritic deposits commonly pass into magnetite ores; interbanded sulphide-oxide units comprise common transitional types, for example, at **Gjersvik** on Tysnesøy and at **Jernsmauget/Dyråsen** in Ølve (Fig. 33b). Very extensive zones of pyrite and chalcopyrite dissemination are reported, but their metallogenic significance is not known (Grenne et al. 1999). The relatively large **Rauneli** occurrence at Ølve consists of chert-banded magnetite-haematite ore and resembles a banded iron formation. Rauneli is poorly known but, according to Foslie (1955), its dimensions are significant.

Figure 33. Typical ore samples from the Hardanger district. a) Pyrite-zinc ore from Haukanes deposit. b) Banded magnetite-pyrite ore from Dyråsen. Photos: P. Wulff; the labels are 5 cm long.

Table 4. Deposits and occurrences in the Hardanger metallogenic area (N015) included in the FODD database.

Deposit	Ore tonnage (Mt)	Cu %	Zn %	S %	When mined	Genetic type	Reference
Stordø	9.0*		0.28	35	1865–1968	VMS	Foslie (1926)
Nygruva	0.17* 0.03**	0.7	3.4		1865–1919	VMS	Gvein (1977)

* Mined ore
** Reserves

N016 BERGEN-HOSANGER Ni-Cu, Fe-Ti

Ron Boyd & Are Korneliussen (NGU)

The Bergen-Hosanger area (N016; Fig. 34) contains a tectonostratigraphic unit comprising Precambrian anorthositic, jotunitic and mangeritic rocks with a variety of Ni-Cu and ilmenite-magnetite deposits. Parts of the region experienced Caledonian high-pressure metamorphism and eclogitisation.

Ni-Cu occurrences are hosted by the lower parts of a pervasively deformed body of norite, the Hosanger intrusion, belonging to the Lindås Nappe (Ragnhildstveit & Helliksen, 1997). The nappe belongs to a unit previously called the Anorthosite Complex. Kvale (1960) proposed that these rocks were originally part of the intrusive complex that dominates the Jotun Nappe. Bingen et al. (2001b) confirmed the possibility of this correlation, and presented U-Pb zircon ages from two magmatic events: a charnockitic at 1237 +43/-35 Ma and a jotunitic–mangeritic at 951 ± 2 Ma. The latter is thought to be followed by a medium-pressure granulite-facies metamorphism at 929 ± 1 Ma (and a much later Caledonian overprint). Assuming a dry environment, it is possible that the Hosanger norite is a late minor intrusion linked to the 951 Ma magmatism. The surface extent of the main body is 2.5 km N–S and 1 km E–W, and

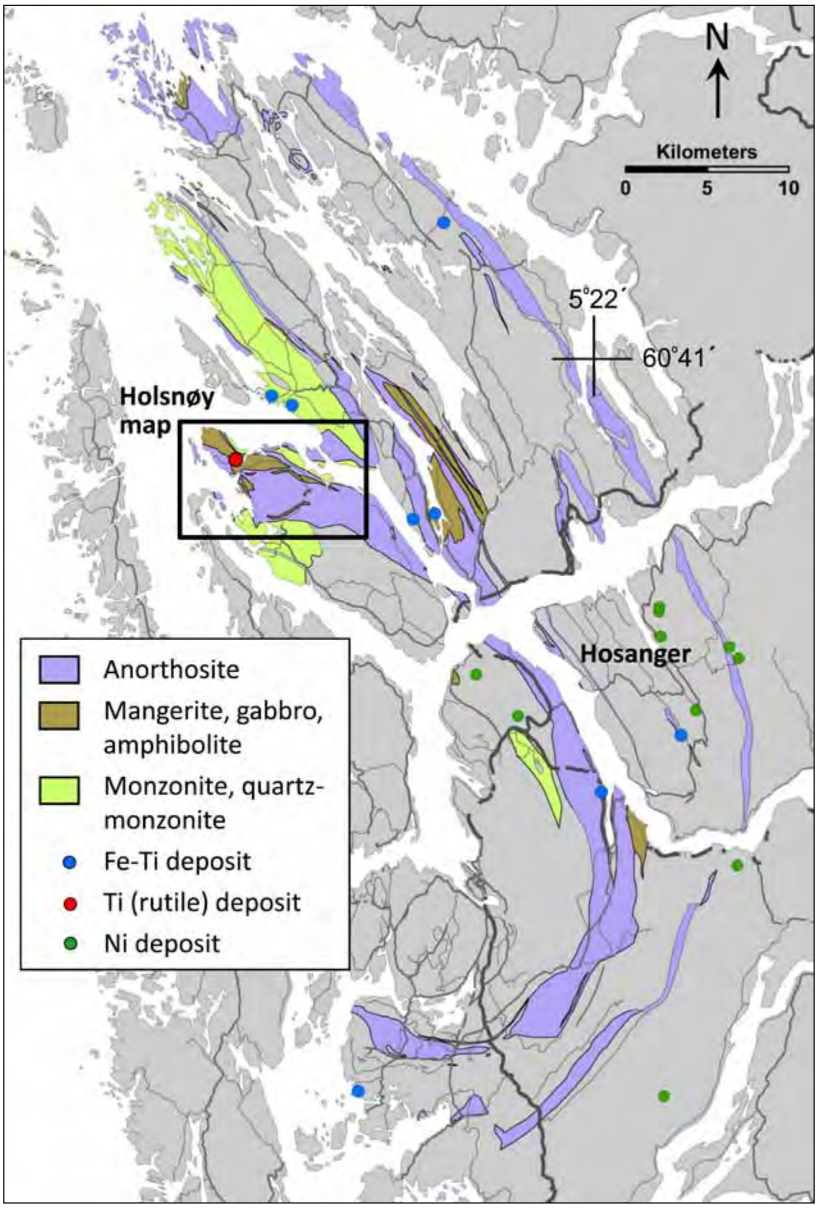


Figure 34. Registered Fe-Ti deposits and Ni-Cu in the Bergen region plotted on a simplified geologic map based on Ragnhildstveit & Helliksen (1997). Grey lines indicate roads.

there also are several satellite bodies with surface exposures up to 1 km x 300 m. The peripheral and lower parts of the intrusion are enriched in mafic minerals. The body contains numerous xenoliths of country rocks, which include granulite-facies quartz-feldspar gneiss and more mafic gneiss.

Bjørlykke (1949) described the historical development of mining in the Hosanger intrusion, from the discovery of the first of several ore bodies in 1875 until the closure of mining operations in 1945 due to the exhaustion of richer ore. Early operations, until 1898, focused on massive ore containing 2–4 % Ni in the southern part of the intrusion. Bjørlykke described these bodies as "offset" ore, as they occur as veins in the wall-rock. The **Litland** ore was discovered in 1899, but was first mined in 1915, and the **Lien** ore, further north, was discovered in 1915 but was not mined until 1938. Production figures (Bjørlykke 1949) show Ni grades varying from 0.67 to 1.215 % and Cu from 0.285 to 0.44 % from these deposits. Nickel content in sulphide concentrates varied at 5.8–6.16 %. Blackstone Ventures, which currently (2010) holds the claims to the deposit, states that past production totalled 460 000 t grading 1.05 % Ni, 0.35 % Cu and 0.05 % Co (Blackstone Ventures Inc. 2009a).

Foslie & Johnson Høst (1932) analysed Pt, Pd, Au and Ag in a rich sample from the Litland mine (2.35 % Ni) and one from Lien (1.51 % Ni). Both samples yielded 142 ppb Pd and much lower values for Pt and Au. Newer data (Barnes et al. 1988; Boyd et al. 1988) confirmed the low values for platinum metals and gold in the Ni-Cu ore (105 ppb Pd and 71 ppb Pt in 100 % sulphide), whereas three samples of Cu-rich mineralisation yielded an arithmetic mean of 120 ppb Au.

Geophysical surveys, including that by Eidsvig (1971), have largely excluded the possibility of concealed massive sulphide ore, but have been open to the possibility that the numerous diffuse anomalies detected may be due to disseminated sulphide. Jensen (1972) and Mathiesen (1978) concluded that the intrusion did not contain near-surface disseminated mineralisation of interest. However, data from 10 samples presented by Mathiesen (1978) suggested that the concentration of metals in the sulphide phase was significantly higher in disseminated mineralisation than in massive ore, and that certain samples of disseminated mineralisation from Nonås had particularly high grades of Cu in total sulphides.

The Geological Survey of Norway carried out a limited reconnaissance and analytical programme in the area in 2007. The results did not reveal anomalous enrichment of metal content in disseminated sulphides and confirmed the previous data on platinum metal contents. Small amounts of sulphide dissemination are almost ubiquitous in the intrusion (and in certain parts of the granulite-grade country rocks). Much of the area of the intrusion is either cultivated or used for vacation homes, hence restricting possible mining.

The local *Fe-Ti deposits* are related to eclogites. Eclogitisation along fractures and shear zones that formed conduits for circulating fluids, triggering the eclogitisation reactions, has been studied in detail from the western parts of Holsnøy (Fig. 35) by Austrheim & Griffin (1985), Austrheim (1987), Boundy et al. (1992), Jolivet et al.

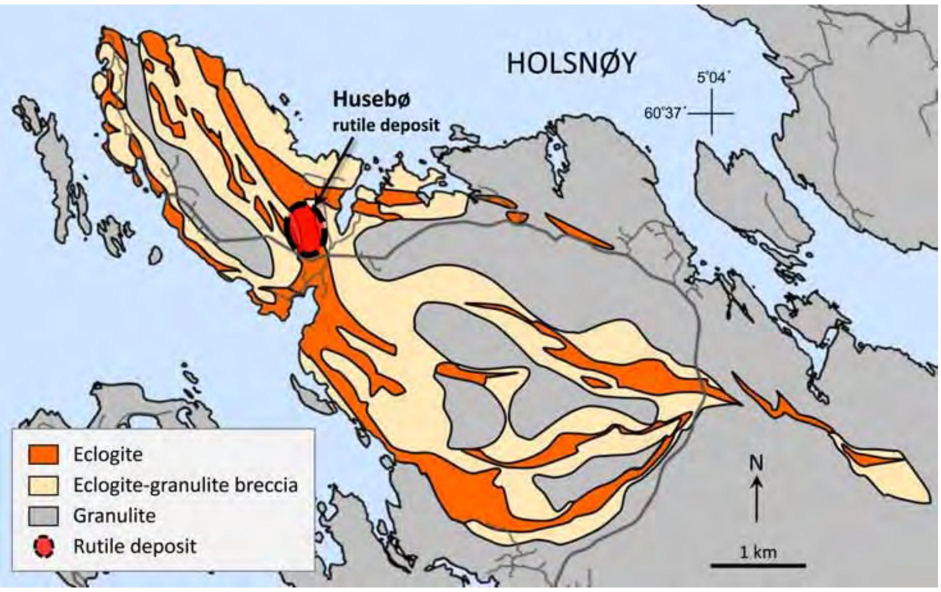


Figure 35. Map of western Holsnøy showing the distribution of eclogite facies shear zones, based on Jolivet et al. (2005). Grey lines indicate roads.

(2005). With eclogitisation, granulite-facies anorthosite and jotunitic rocks were recrystallised to consist predominantly of omphacite and garnet, and lesser amounts of quartz, amphibole, rutile, kyanite, phengite and zoisite. During the eclogitisation process, Fe-Ti oxides break down, iron goes into garnet and titanium forms rutile, as described for the Sunnfjord eclogites (Korneliussen et al. 2000a).

In general, the anorthosites and jotunitic rocks that are eclogitised are low in titanium, most commonly at less than 2 % TiO_2. Because the rutile content in eclogite reflects the TiO_2 content in the protolith, the corresponding eclogite has a low grade of rutile. However, the anorthosite and the jotunite are locally enriched in titanium; in such cases, the corresponding eclogite contains up to 5–7 wt.% rutile. Retrograde alteration tends to alter rutile to ilmenite, and in most cases in the region, the retrograde effects are significant. Consequently, the ore-quality Ti-rich eclogite such as the Husebø deposit (Korneliussen et al. 1990, 1991) has a significantly reduced grade due to retrograde alteration (amphibolitisation) of rutile to ilmenite and titanite. The **Husebø** deposit is the only rutile-bearing eclogite of significance identified in the area. It consists of variably eclogitised jotunite affected by retrograde alteration, with 4–5 % TiO_2 outcropping over about 100 000 m^2. About 60 % of the titanium, equivalent to 2.1 wt.% TiO_2, occurs as rutile (Korneliussen et al. 1991).

N017 JOTUNHEIMEN Ni-Cu-PGE

Morten Often & Lars Petter Nilsson (NGU)

The outline of the Jotunheimen metallogenic area follows the extent of the polymetamorphosed and polydeformed Jotun Nappe Complex (Meso-Neoproterozoic), consisting of several large, in places km-thick, thrust sheets stacked on top of each other during Caledonian deformation. The metallogenic area stretches from the Jotunheimen National Park ("home of giants"), constituting the highest mountain peaks in northern Europe, to the steep shores of Norway's largest fjord, the Sognefjord. The spectacular landscape has promoted the establishment of several national parks covering parts of the metallogenic area. In a Ni-Cu-PGE perspective, attention has focused on the northeastern part of the area, where the Upper Jotun Nappe is dominated by granulite facies rocks of charnockitic to jotunitic and gabbroic composition (Lutro & Tveten 1996). Shear zones, commonly with pervasive retrogradation, of various but unknown ages are common.

There are 23 nickel deposits registered in the national database within the Jotun Nappe Complex, only four of which are included in the FODD. They are concentrated in Espedalen subarea (N017.1) in the far NE part of the area N017, including the recently discovered **Stormyra** and **Dalen** deposits. To the west, near Bergen, the Hosanger deposits occur within the geologically correlated Lindås Nappe (N016). In the central part of the area, near Årdal, small copper occurrences in shear zones, carrying some Au and Pd, were mined in the early 18th century.

Magnetite-rich pyroxenites occur as small lenses in the metagabbros. Samples from Gråsubreen (Fig. 36) on the eastern slope of Glittertind show

Figure 36. Gråsubreen locality at Glittertind. Layered mafic granulite, jotunite, cut by retrograde shear zones. Photo: M. Often, NGU.

PGE enrichment up to 1 ppm. The grade is low, and low Ni/Pd and Cu/Ir ratios suggest that sulphides have not been segregated from the magma; hence, precious metals have not been scavenged. Any later sulphide segregation could thus be rich in precious metals (Barnes et al. 1988), contributing to the exploration potential of the Jotun Complex.

The **Espedalen** Ni-Cu subarea (N017.1), an outlier of the Jotun Nappe Complex, is situated between Gudbrandsdalen and Valdres, about 180 km NW of Oslo. The outlier consists of Proterozoic crustal rocks, mainly a high-grade anorthosite-gabbro-troctolite suite. Magmatic Ni-Cu sulphides have been mined in several periods in the region. Copper smelting is documented at Svatsum in 1665–1666, with a description of ongoing mining of unknown duration. The first analysis and description of a new Ni mineral, later named pentlandite, was reported from Espedalen by Scheerer (1845). The findings resulted in two mining periods of nickeliferous pyrrhotite (1846–1857 and 1874–1878) from Storgruva, Veslegruva and a number of smaller workings, making Espedalen one of the major mining districts at that time (up to 500 workers). An estimated total of about 50 000 tons of ore at 1.0 % Ni, 0.4 % Cu (Boyd & Nixon 1985) was produced. Modern exploration in the region started in the late 1960s. Sulfidmalm and Norsk Hydro carried out extensive exploration until 1980. The latest period of exploration started in 2003, and has so far resulted in the discovery of two new deposits, Stormyra and Dalen (Fig. 37). A recent evaluation (Reddick Consulting Inc. 2009) reports NI 43-101 classified resources presented in Table 5.

Table 5. NI 43-101 compliant resource for Stormyra and Dalen (Reddick Consulting Inc., 2009).

Deposit	Category	Tonnes	Ni %	Cu %	Co %
Stormyra	Inferred	1 013 000	1.09	0.48	0.04
Dalen	Indicated	4 625 000	0.29	0.12	0.02
Dalen	Inferred	5 438 000	0.25	0.11	0.02

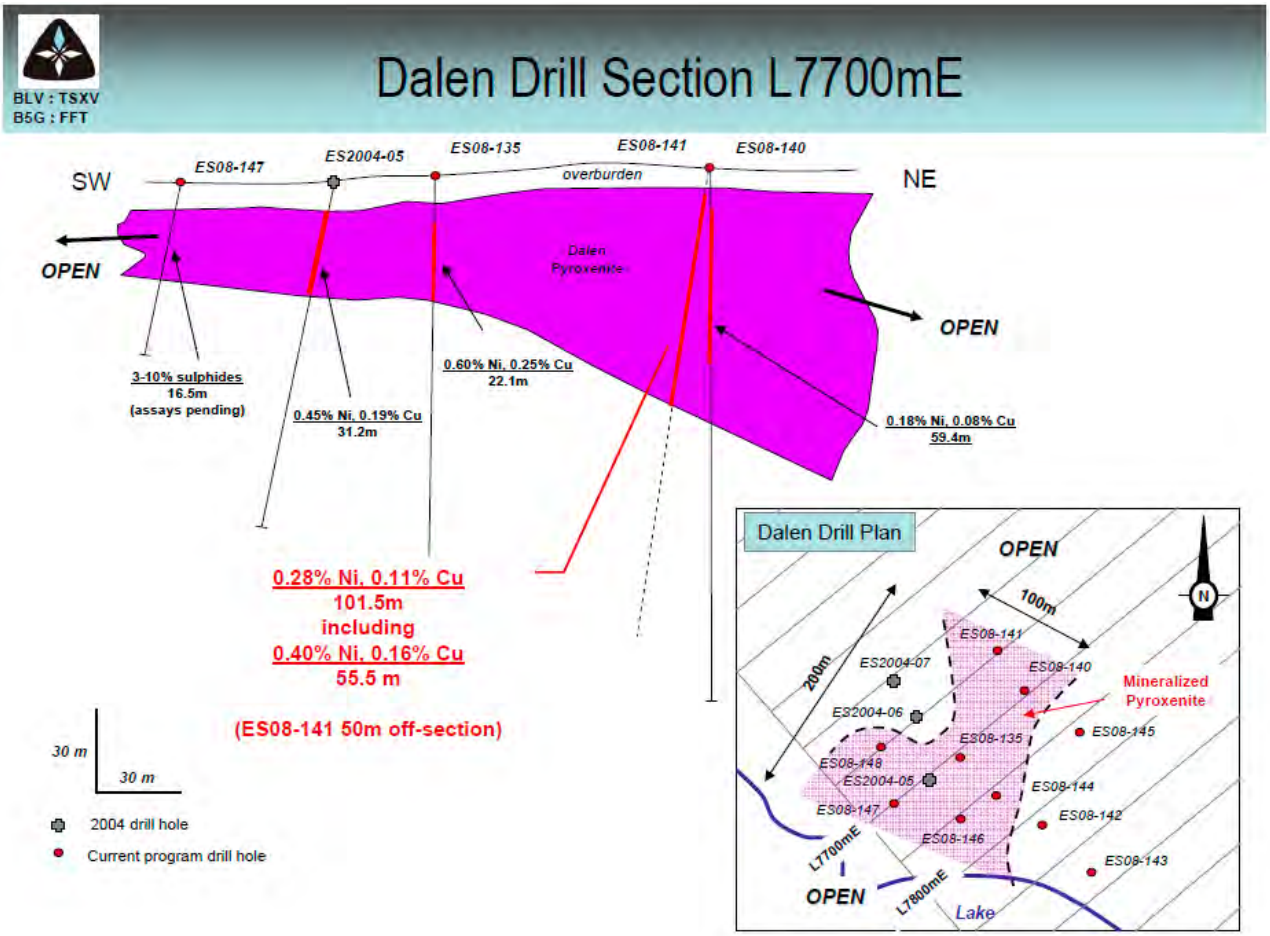


Figure 37. Dalen section, from Blackstone Ventures Inc (www.blv.ca, accessed in 2009).

N018 SUNNFJORD Ti

Are Korneliussen (NGU)

The Sunnfjord metallogenic area is a part of the Western Gneiss Region, predominantly composed of Palaeoproterozoic mafic and felsic igneous rocks that were strongly affected by the Caledonian orogeny. As described by Korneliussen et al. (2000b), two types of Ti deposit occur in this region: magmatic ilmenite-magnetite deposits associated with Palaeoproterozoic mafic intrusions, and rutile-bearing Caledonian eclogitic rocks (Fig. 38). The rutile-bearing eclogites are ca. 1500 Ma basic rocks that were transformed into eclogite during Scandian high-pressure metamorphism at approximately 400 Ma. During this process, ilmenite in the protolith broke down, with the Fe entering into garnet and Ti into rutile. Hence, large volumes of ilmenite-bearing mafic rock were transformed into rutile-bearing eclogitic rocks with no change in the TiO_2 content, but of more economic interest since the rutile is a more valuable mineral than ilmenite. From a mineral-resource perspective, the ilmenite deposits in the region are of only minor economic interest, whereas the rutile-bearing eclogites represent a major mineral resource, particularly the Engebøfjellet deposit described below.

The geology of the area south of Vilnesfjorden, including the deposits Saurdal, Ramsgrønova and Orkheia, is complex with a series of Palaeoproterozoic felsic and mafic rocks that have experienced considerable Caledonian deformation and metamorphism (e.g., Cuthbert 1985, Ragnhildsveit & Nilsen 1998, Engvik et al. 2000). Rocks typical for the region are granitoid gneiss, amphibolite, metagabbro, ultramafic rock (metaharzburgite), pyroxenite and eclogite. The Proterozoic mafic intrusions are commonly enriched in iron-titanium oxides as low-grade dissemination and as thin cumulate layers of semi-massive to massive magnetite-ilmenite. Most of the registered occurrences (Fig. 38) are of the

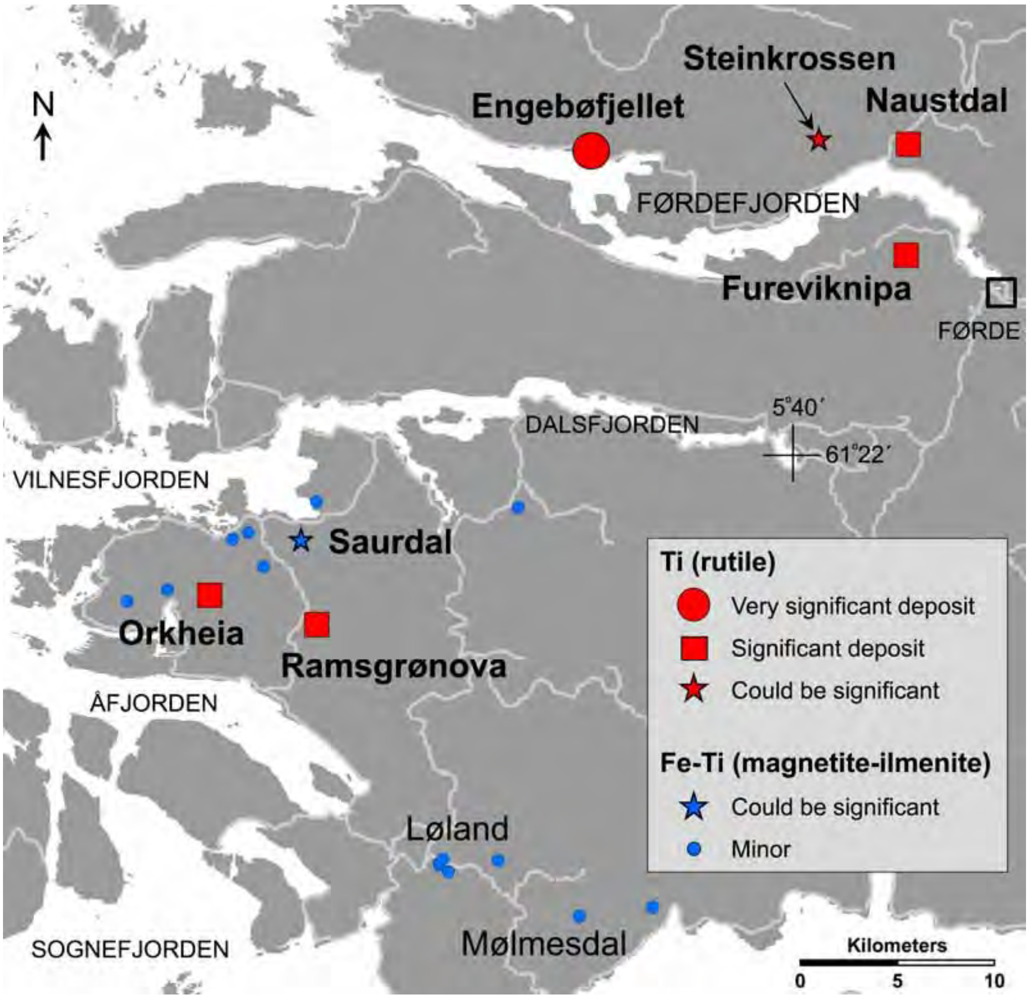


Figure 38. Registered titanium and iron-titanium deposits in the Sunnfjord region. Pale grey lines indicate roads.

massive to semimassive type, whereas in the Løland–Mølmesdal area large but low-grade Fe-Ti oxide dissemination is characteristic.

Mafic rocks between Vilnesfjorden and Åfjorden have been variably eclogitised (Engvik et al. 2000). At **Orkheia** and **Ramsgrønova**, the eclogitisation has been complete with rutile as the titanium mineral. At **Saurdal**, up to 0.5 m thick layers of massive Fe-Ti ore occur at the base of a partly eclogitised inverted metagabbro. Eclogitic parts of the host rock are rutile-bearing, but due to amphibolite- to greenschist-facies retrogression, rutile is frequently altered to ilmenite and, less commonly, to titanite. The Orkheia eclogite is a W-trending body (Korneliussen & Furuhaug 2000); it resembles a thick eclogite sheet occupying the upper part of Orkheia, approximately 400 m above sea level. The TiO_2 content varies from less than 1 to 5–6 wt.%, with more than 90 % of the titanium in rutile. A rough estimate of the possible resource gives 80 million tons; of this amount, approximately 1/3, i.e. 25–30 million tons, contains at least 3 % rutile.

The **Engebøfjellet** deposit (Korneliussen et al. 2000b) is a NE-trending mountain ridge located on the northern side of Førdefjord between Engebø and Vevring (Fig. 39). It is cut by a road tunnel. It is a Proterozoic gabbroic intrusion (1500 Ma, T. Krogh unpublished data) that experienced crystal fractionation processes leading to the enrichment of Fe and Ti, and was transformed into eclogite during Scandian high-pressure metamorphism at approx. 400 Ma. In this process, ilmenite in the protolith was replaced by rutile, and the Ti-rich parts of the body are now rutile ore. Although rutile is the primary value mineral, garnet (Fig. 40) represents a significant potential for additional value creation. The rocks enclosing the Engebøfjellet eclogite body are Palaeoproterozoic granitoid and mafic gneisses that were extensively deformed by the Caledonian orogeny. Approximately 300 Mt of eclogite averaging 3–4 % rutile and 25–30 % garnet was identified by DuPont by core drilling during 1995–1997 (Korneliussen et al. 2000b). The deposit is presently (2012) under investigation by the company Nordic Mining.

Eclogites are common in the area between Engebøfjellet and Naustdal, and a number of gravimetric anomalies (Elvebakk et al. 1999, Dalsegg et al. 1999) indicate large volumes of heavy rocks at depth (i.e., probably eclogite). At Steinkrossen, a distinct gravimetric anomaly is associated with outcropping rutile-rich eclogite (about 680 m.a.s.l.), indicating a large eclogitic rutile resource potential at depth. The **Naustdal** rutile deposit is a 2.5 km long eclogite hill extending eastwards from the river Nausta. The deposit was first mentioned by Eskola (1921), later described by Binns (1967) and Krogh (1980). The deposit is, in terms of size, mineralogy and rutile grade, roughly similar to Engebøfjellet.

The two areas with a very large mineral potential are, firstly, the Engebøfjellet–Steinkrossen–Naustdal area on the northern side of Førdefjord, and secondly, the poorly investigated Orkheia–Ramsgrønova–Saurdal area south of

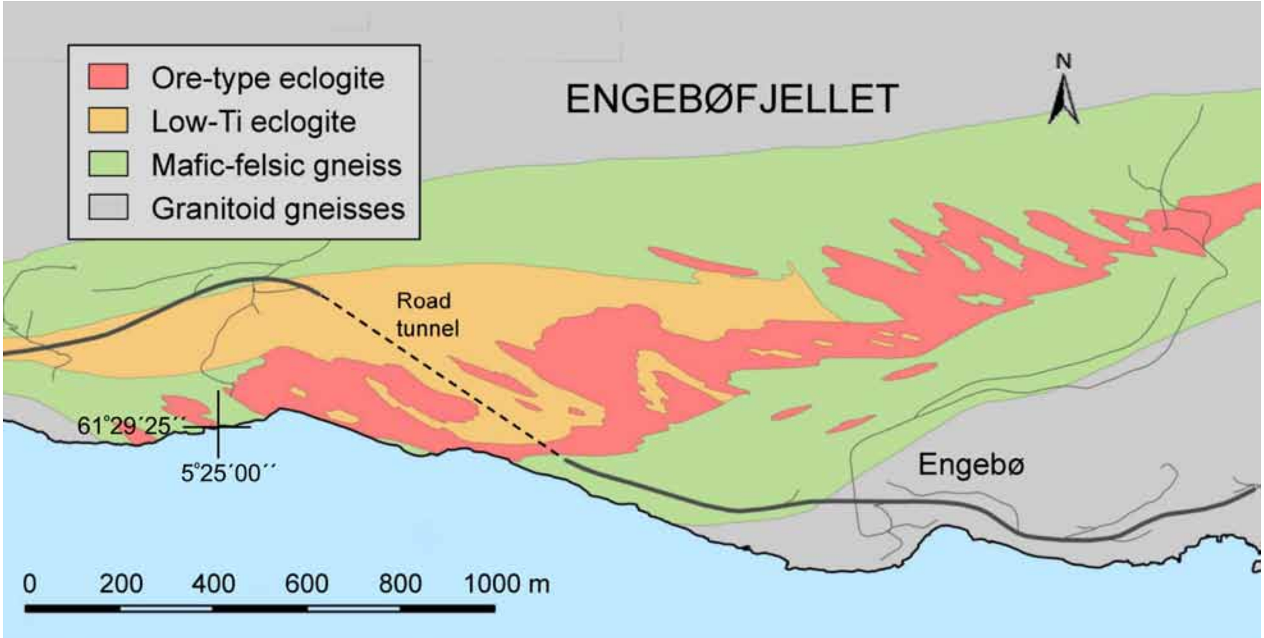


Figure 39. Geological map of the Engebøfjellet deposit, based on Korneliussen et al. (1998).

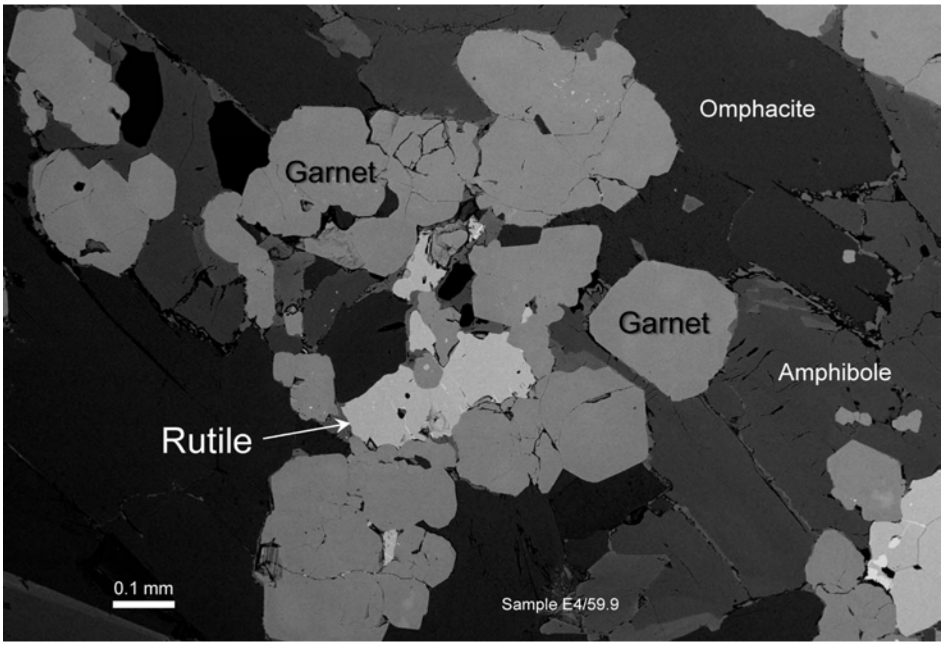


Figure 40. SEM-BSE image of rutile and garnet in eclogite, Engebøfjellet.

Vilnesfjorden. Of the known deposits, only Engebøfjellet has a drilled resource (about 300 Mt); the total resource potential of rutile-bearing eclogite on the northern side of Førdefjord might be several times this amount. Although no resource has been indicated by core drilling, outcropping rutile-bearing eclogites indicate a considerable resource potential.

N019 MØRE Fe-Ti

Are Korneliussen (NGU)

The Møre Fe-Ti metallogenic area is, like the Sunnfjord area (N018), a part of the Western Gneiss Region of southern Norway, with a large variety of Proterozoic rocks affected by the Caledonian orogeny. Magnetite-ilmenite ores (Geis 1971) are present in certain suites of metagabbro and amphibolite. Rutile-bearing eclogites are also common in parts of this area, but are not considered to be of economic interest due to their low rutile content.

The **Raudsand** deposit (Sanetra 1985, Fig. 41) was a major source of Fe-Ti-V ore in Norway for 80 years, until mining ceased in 1981. It is located on the western side of Sunndalsfjord, and is associated with Fe-Ti oxide-rich amphibolites surrounded by Palaeoproterozoic orthogneisses. The ore comprises disseminated to semimassive Fe-Ti oxides, and has been subdivided into a variety of ore bodies within three main amphibolite units. The ore bodies are ribbon-shaped, commonly *en echelon*, and appear to be restricted to the marginal parts of the amphibolites. Individual ore bodies contain massive and banded ores, and their lateral extension is from 50 m to 700 m, with thicknesses ranging from 5 m to 80 m. The main oxide minerals are titanomagnetite and hemo-ilmenite. Common accessory sulphide minerals are pyrite, pyrrhotite, chalcopyrite and pentlandite. The average ore composition is 27 vol.% titanomagnetite, 10.5 vol.% hemo-ilmenite and ilmeno-hematite, and 1 vol.% sulphides. During the 80 years of mining, 15 Mt ore was extracted. The ore mined contained 25–30 % magnetite, 3.5–4 % ilmenite and 0.15–0.20 % V. The magnetite concentrate contained 64 % Fe, 2 % TiO_2 and 0.5 % V, and was the raw material for production of pig iron and ferrovanadium. Proven and probable reserves are 11 Mt, whereas possible ore resources in the Rødsand area are 120 Mt altogether.

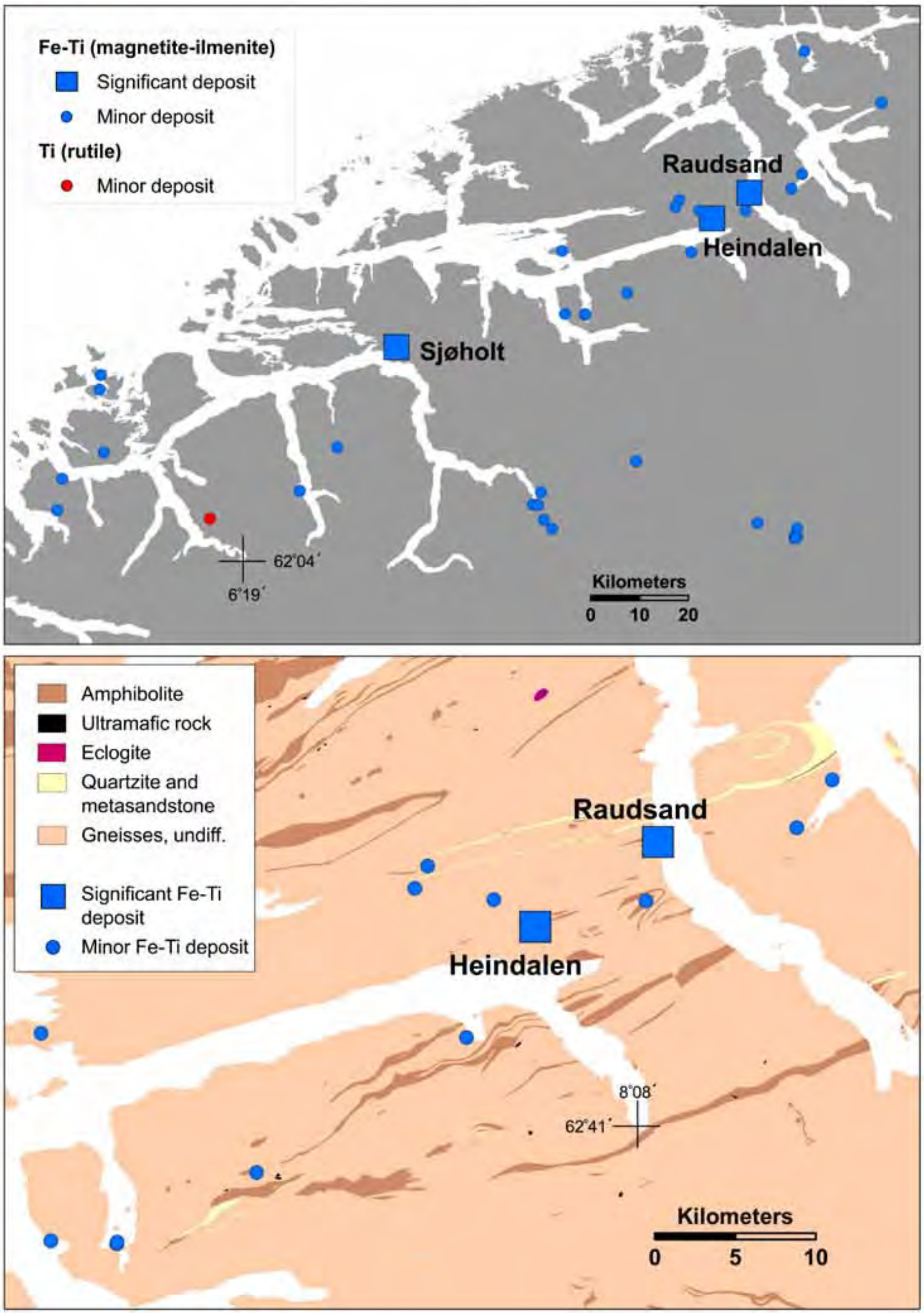


Figure 41. Registered Fe-Ti deposits and occurrences in the Møre region (upper map) and within the Rødsand area (lower map).

N020 STØREN–LØKKEN Cu-Zn

Terje Bjerkgård (NGU)

The Støren Group is to the west of the Gula Group in the Trondheim Nappe Complex, and is separated from the latter by a thrust contact. It is a several-km-thick sequence of mainly metabasalts (greenstones) of submarine origin (Grenne et al. 1999). Interlayered with the volcanic rocks there are ribbon cherts, black shales and tuffitic to cherty metasediments. Geochemical data from the metabasalts shows mainly MORB, but also WPB affinities (Gale & Roberts 1974, Grenne & Lagerblad 1985). In the northern part of the Trondheim Region, rhyolitic volcanic rocks are locally abundant, including a subvolcanic felsic intrusion dated to 495 ± 3 Ma (Roberts & Tucker, 1998).

The ophiolite sequence at Løkken, west of the Støren Group, has been established as a fragment of a supra-subduction-zone (SSZ) ophiolite (Grenne 1989a). It is a 1–2-km-thick volcanic sequence composed of a sheeted dyke complex overlain by three volcanic members (op. cit.). The volcanics comprise N-MORB to IAT basalts with lesser hyaloclastites, jasper beds, rhyolitic effusives and iron formations including sulphide, oxide and silicate layers (known as vasskis) (Grenne 1989a). Both the Støren and Løkken units contain one very large VMS deposit, Tverrfjellet and Løkken, respectively.

The **Tverrfjellet** mine was in operation from 1968 until 1993 and produced about 15 Mt of ore averaging at 1.0 % Cu, 1.2 % Zn, 0.2 % Pb and 36 % S (Table 6). In addition, the deposit contained approximately 4 % magnetite, 10 g/t Ag and 0.1 g/t Au. The potential resources when the mine was closed were estimated to be about 4 Mt of ore, but of poorer grade than the average production. The annual production of raw ore was approximately 650 000 t. From the copper concentrate, about 50 kg gold and 5 000 kg silver was extracted annually.

The deposit comprised three subvertical lenticular ore bodies, plunging to the east to a depth of approximately 650 m below the surface. The length of the ore field is approximately 1 200 m at the surface, narrowing down to 600–700 m at 500 m depth. The thickness of an ore body was, on average, 15 m, locally up to 60 m. The deposit is hosted by a sequence of greenstone, mica schist, quartzite and conglomerate, which probably form an equivalent to the Støren Group sequence. The deposit lies on the edge of an inverted part of the Trondheim Nappe Complex and is, consequently, structurally complex with tight folding and repetition of lithologies. These structures are responsible for the lenticular shape and the three almost separate ore bodies.

The main ore minerals at Tverrfjellet are pyrite, chalcopyrite, sphalerite and magnetite. Pyrrhotite and galena are accessory minerals. The most important gangue minerals are quartz, actinolite, and chlorite. The distribution of the various ore minerals follows fairly consistent patterns. Copper is concentrated in the lower folds and the southwestern flanks of the ore body, and is accompanied by the highest contents of magnetite. On the other hand, the zones of the ore body that are poorest in copper are richest in zinc, and have the highest sulphur contents.

Further north, about 20 km to the east of Levanger, is the minor **Åkervoll** deposit. It is associated with a tuffaceous unit within a thick volcanic sequence belonging to the Støren Group. The volcanics comprise tholeiitic, partly pillowed metabasalt and metarhyolite to rhyodacite. Co-magmatic felsic and mafic intrusives are present in the lower part of the sequence. The ore is mainly massive pyrite and sphalerite with some bands enriched in galena. Chalcopyrite-pyrrhotite vein networks are also present, especially in the western part of the deposit. The Åkervoll deposit is small, but very rich: <100 000 t with 1.5 % Cu, 20 % Zn, 1.75 % Pb and 100 g/t Ag. Another similar small deposit is **Ytterøya**, which mainly produced pyrite (500 000 t between 1861 and 1912, Foslie 1926). The metal grades were 1.9 % Cu, 2.4 % Zn and 0.3 % Pb. In addition, grab samples show significant grades of Ag (average of 62 g/t, 22 samples). There are other, even smaller, deposits that are not included in FODD, such as Mokk and Malså, in the same area.

The **Løkken** Cu-Zn deposit in the Løkken ophiolite was the largest ophiolite-hosted VMS deposit (i.e., Cyprus type) in the world (Grenne 1986, Grenne et al. 1999). It contained a premining 30 Mt at 2.3 % Cu, 1.8 % Zn, 0.02 % Pb, 16 g/t Ag and 0.2 g/t Au. About 24 Mt of the ore was mined over a period of 333 years (1654–1987), while 6–7 Mt is still left in pillars and walls in the mine (Table 6). The massive sulphide ore predominantly consists of pyrite with subordinate chalcopyrite and sphalerite, whereas galena, magnetite, hematite and bornite are minor components locally, and fahlore is the most important accessory phase (Grenne 1989b). Quartz is the main non-sulphide, constituting 12–14 % of the ore. Due to deformation, the ore body is disrupted into one major and several smaller bodies (Fig. 42). The total length of the ore body is about 4 km, the average width 150–200 m and the thickness about 50 m. This morphology can be ascribed to primary features such as subparallel faults at the seafloor, and an extensive, fissure-related hydrothermal vent system (Grenne & Vokes 1990). Associated

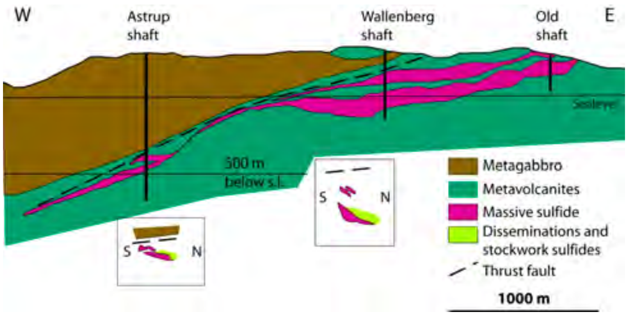


Figure 42. Longitudinal and cross sections of the Løkken massive sulphide deposit (modified from Grenne et al. 1980).

Table 6. Deposits and occurrences in the Støren-Løkken metallogenic area included in the FODD database.

Deposit	**Ore tonnage (Mt)**		**Cu**	**Zn**	**Pb**	**S**	**When**	**Genetic**	**Reference**
	Total	**Mined**	**%**	**%**	**%**	**%**	**mined**	**type**	
Tverrfjellet	19	15	1.0	1.2	0.2	36	1968–1993	VMS	Krupp & Krupp (1985)
Løkken	30	24	2.3	1.8	0.02		1654–1987	VMS	Grenne et al. (1999)
Åkervoll	<0.1	0.025	2.6		2.1		1893–1908	VMS	Nat. Ore database
Ytterøya		0.5	1.9	2.4	0.3	40	1861–1912	VMS	Foslie (1926)

with the massive ore body is an extensive feeder zone system, present along the entire 4 km deposit (Grenne 1989b). This system comprises a network of sulphide veins, which are from mm to some 10 cm thick. The feeder zone has pyrite, chalcopyrite and quartz as its main constituents, and accessory amounts of sphalerite, magnetite and iron oxides. The total width of the zone is about 100 m. Because of its high Cu content, this part of the deposit was the first to be mined at Løkken.

N021 KVIKNE–SINGSÅS Cu-Zn, Ni-Cu

Terje Bjerkgård & Morten Often (NGU)

Deposits of the Kvikne–Singsås area (N021) are hosted by the Gula Group, a predominantly sedimentary unit with an uncertain origin, in the Upper Allochthonous Trondheim Nappe Complex. The Gula Group (i.e., the Singsås Formation) is mainly composed of metasandstones and psammites, which are commonly calcareous. Turbidite facies has been indicated for parts of the unit (Nilsen 1978). The sandstones have frequent minor intercalations of black schists, especially in the central part of the group (the Kvikne area). Thin units of mafic metavolcanic rocks, 'the Gula greenstone' occur within the Gula group and are commonly associated with black schist and banded carbonaceous quartzite (Nilsen 1978). Most sulphide occurrences, such as the Børsjøhø, Røstvangen and Kvikne deposits, are confined to these assemblages. The Gula Group probably represents the outer margin of Baltica, formed after the break-up of Rodinia (Bjerkgård & Bjørlykke 1994a, Sturt et al. 1997) or part of a micro-continent, situated close to Baltica (Ihlen et al. 1997).

The **Røstvangen**, **Børsjøhø** and **Kvikne** Cu-Zn deposits (Table 7) are all closely associated with amphibolite (Rui 1973a, Nilsen & Mukherjee 1972). Whereas the Børsjøhø deposit is probably the biggest (probable ore 2 Mt at 1.8–2.0 % Cu), the Røstvangen deposit is the most recently worked and is therefore best known. About 388 000 t of ore was produced at Røstvangen, containing on average 2.65 % Cu, <1 % Zn, 43 % S and traces of Pb, with Ag and Au grades of 10–80 ppm and 0.3–2.0 ppm, respectively (Rui 1973a). The deposit consists of several small elongate, lenticular bodies, which all have their long axes parallel to regional fold axes (Rui 1973a). The same holds true for the deposits constituting the Kvikne mines, which are also closely associated with amphibolite (Nilsen & Mukherjee 1972, Nilsen 1974). About 250 000 t of ore was produced from the Kvikne mines. The average content of samples from the ore is 2.4 % Cu and 1.8 % Zn.

The **Fløttum** Cu-Zn deposit is associated with black banded quartzite and carbonaceous phyllite, but, unlike Kvikne and Røstvangen, amphibolite is absent. The deposit consists of four ore lenses, which were perhaps originally parts of one body, but were later disrupted by folding. The lenses are inclined and ruler-shaped (Nilsen 1978). The sulphides are pyrite, pyrrhotite, sphalerite, chalcopyrite and accessory galena. Close to the ore lenses there are glassy muscovite-bearing quartzitic schists, most likely formed by hydrothermal processes during ore formation. During exploration, a dipartite division was established with a footwall and a hanging-wall ore type. The hanging wall ore consists of pyrite and subordinate sphalerite, whereas the footwall ore consists of pyrrhotite, sphalerite, chalcopyrite, galena, fahlore and arsenopyrite. Total possible ore reserves are estimated to 350 000 t, with 0.96 % Cu, 4.76 % Zn and 29 ppm Ag.

The **Undal** deposit is situated in a graphitic phyllite with minor greenstone, which belongs to the so-called Undal Formation. This unit is interpreted as a tectonic mélange (Horne 1979)

Table 7. Cu-Zn deposits and occurrences in the Kvikne-Singsås metallogenic area (N021) included in the FODD database.

Deposit	Tonnage (Mt)		Cu %	Zn %	Pb %	S %	When mined	Genetic type	Reference
	Total	Mined							
Røstvangen	0.49	0.39	2.7	<1.0		43	1908–1920	VMS	Rui (1973a)
Børsjøhø	2.0	<0.01	1.8–2.0				1908–1916	VMS	Bjørlykke (1946)
Kvikne	0.25	0.25	2.4	1.8			1632–1812	VMS	Nilsen & Mukherjee (1972)
Fløttum	0.35		1.0	4.8	<0.5		Test mining	VMS	Nat. ore database
Undal	1.0	0.28	1.2	1.9		41	1952–1971	VMS	Foslie (1926)

situated between the Gula Group and the Støren Group in the Trondheim Nappe Complex. The deposit is about 600 m long and has the form of a thin ruler, about 70 m wide and 3–5 m thick. It is a pyritic ore body with subordinate chalcopyrite and sphalerite. Analysis of ore production yielded 1.15 % Cu, 1.86 % Zn, 43.2 % Fe and 41.1 % S (Foslie 1926). About 279 000 t ore was produced from the deposit, mainly between 1952 and 1971. The total tonnage of the deposit is estimated to about 1 Mt.

Magmatic Ni-Cu deposits also occur within the Gula Group, and a total of 5 deposits are listed in the NGU database. They are related to mafic intrusions of presumably Silurian age. Test mining took place on the **Vakkerlien** deposit in the southern part of the area in the 1870s. This deposit consists of a cigar shaped ore body with chalcopyrite, pentlandite and pyrrhotite. Exploration was conducted by Sulfidmalm AS from 1974, later also by Folldal Verk, and since 2004 by Sulfidmalm and Falconbridge/Blackstone Ventures, including core drilling. Blackstone (2009b) has published reserves of 400 000 t with 1 % Ni, 0.4 % Cu.

Skjækerdalen nickel mine in Verdalen was in operation in the period of 1876–1891 and was then a large nickel producer with its own smelter. The deposit occurs as magmatic sulphide dissemination in gabbroid to ultramafic fragments in a comagmatic dioritic–trondhjemitic matrix, a part of Skjækerdalen intrusive complex (436 Ma), in the northernmost part of the Gula Group. Hildreth et al. (2001), in their description of the deposit, explain the near total lack of platinum group elements (PGE) by a possible fractionation of PGE in an ultramafic cumulate in an early magma chamber.

The **Brattbakken** deposit in the northernmost part of the area N021 was discovered in 2004, shortly before it was incorporated into the Blåfjella-Skjækerfjella national park. The deposit is in a differentiated mafic-ultramafic intrusion, about 1300 x 350 m in size, in metapelites of the Gula Group. The ultramafic part of the intrusion shows in part modally layered cumulates. Grab samples yielded 1 % Ni, 1 % Cu, 0.1 % Co and 1 ppm Pt.

N022 FOLLDAL–MERÅKER Cu-Zn

Terje Bjerkgård (NGU)

The Folldal–Meråker Cu-Zn area (N022) comprises a number of VMS deposits related to immature arc development near the Baltica margin in the early Ordovician (Grenne et al. 1999). The deposits are hosted by a succession of mainly bimodal felsic and mafic volcanic and volcaniclastic rocks comprising the Fundsjø Group in the eastern part of the Upper Allochthonous Trondheim Nappe Complex. Geochemical analyses, the bimodal character of the volcanics and the large quantity of volcaniclastic rocks demonstrate that the Fundsjø Group was formed in an island arc to back-arc, marginal-basin environment.

The major deposits in the Folldal–Meråker area are the deposits at Folldal (production from 4 mines was 4.45 Mt), Sivilvangen (resources 0.4 Mt), Vingelen (probable ore 0.2 Mt), Hersjø (resources 3.0 Mt) and Killingdal (production of 3 Mt). Further north there is the smaller Mannfjell deposit (0.1 Mt produced) and several others (Table 8).

The five deposits in the **Folldal** region occur at several stratigraphic levels in the Fundsjø Group, and are hosted by different lithologies, including basalt, rhyodacite and tuffite (Bjerkgård & Bjørlykke 1994b; Fig. 43). The lowermost volcanic-hosted deposits have intense underlying alteration halos, whereas the uppermost deposits, in volcaniclastics, have a very limited alteration. The deposits in volcaniclastics are larger and have a greater width-to-thickness ratio than the volcanic-hosted ones. The deposits in volcaniclastics contain 3–8 Mt and the volcanic-hosted deposits 0.5–2 Mt of ore. The Cu contents are at 0.5–2.0 %, Zn 1.2–5.0 % and Pb 0–0.5 %, with the highest Cu contents in the mafic-hosted deposits and the highest Zn and Pb contents in the tuffite-hosted deposits (Bjerkgård & Bjørlykke 1994b). The concentration of ore deposits in the Folldal area is probably due to the intrusion of a large trondhjemitic body at the base of the volcanic sequence (Bjerkgård & Bjørlykke 1996). This intrusion, which was comagmatic with the felsic volcanics, is dated to 488 ± 2 Ma (U-Pb zircon age, Bjerkgård & Bjørlykke 1994a).

The **Sivilvangen** deposit is hosted by a tuffitic greenschist sequence with subordinate lenses of metarhyodacite and metabasalt (greenstone). Structurally above and below the tuffite, which has a thickness of 130 m, there is graphite-bearing phyllite. Extensive drilling in 1990–1991 revealed that the deposit is ruler-shaped with 0.7 % Cu and 4.3 % Zn over an average thickness of 2.2 m (Table 8). The extent of the mineralised zone is not completely constrained, but its limited thickness reduces its economic potential.

The **Vingelen** deposit is in the structurally upper part of an approximately 200-m-thick unit of tuffitic greenschist. There are two thin plates (1–3 m) of massive sphalerite-pyrite mineralisation

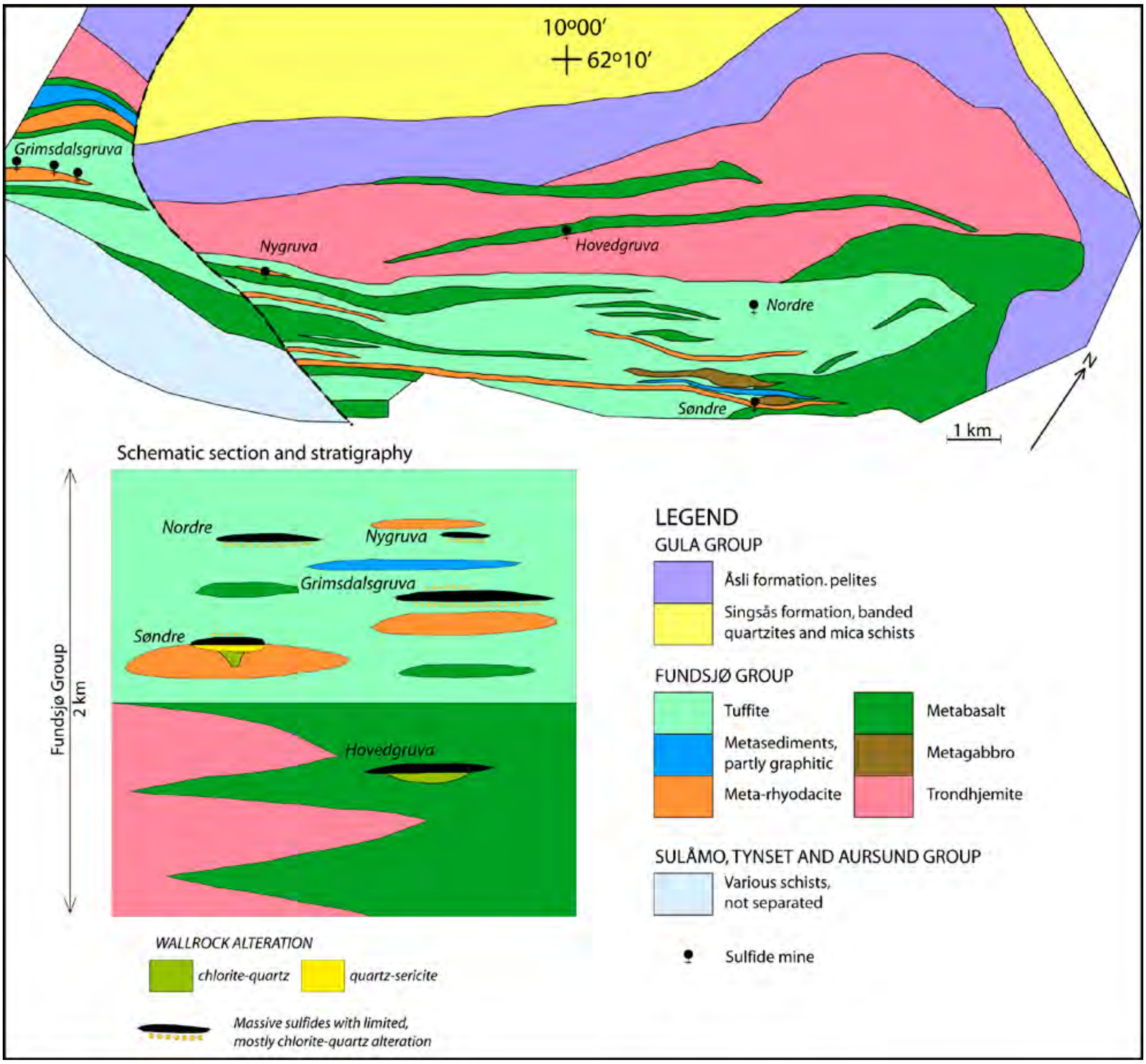


Figure 43. Geology and schematic section of the Folldal Ore District. (Modified from Bjerkgård & Bjørlykke 1996).

(Fig. 44), which are probably connected at depth (Bjerkgård 1989). On the basis of limited drilling, the deposit contains 0.2 Mt of ore. The deposit is not delimited, however. Average contents, based on surface sampling, are 1.3 % Cu and 3.8 % Zn.

The **Hersjø** deposit is in massive greenstone, mainly composed of dark green hornblende and feldspar with subordinate chlorite, epidote and calcite. Around the ore lenses, this rock has been altered to dark chlorite schist, commonly with lenses and layers enriched in quartz ± feldspar. Subordinate lithologies in the area include felsic volcanic rock (quartz keratophyre), gabbro and pillow basalt. Diamond drilling and geophysics have identified a resource of 2.99 Mt of Cu-Zn ore with 1.70 % Cu and 1.40 % Zn (Bjerkgård 2007). The resource comprises three major ore lenses, of which the A lens contains 68 %, B 22 %, and C 10 % of the resource (Fig. 45). All the major ore lenses are open to depth, but because of the steep plunge of the ore axes (70°), very long holes are needed to investigate their down-plunge extension.

Figure 44. A mineralised block from the Vingelen deposit, showing primary banded ore with light pyrite-chalcopyrite bands alternating with dark sphalerite-pyrite bands. Size of block approximately 50 x 50 cm. Photo: T. Bjerkgård, NGU.

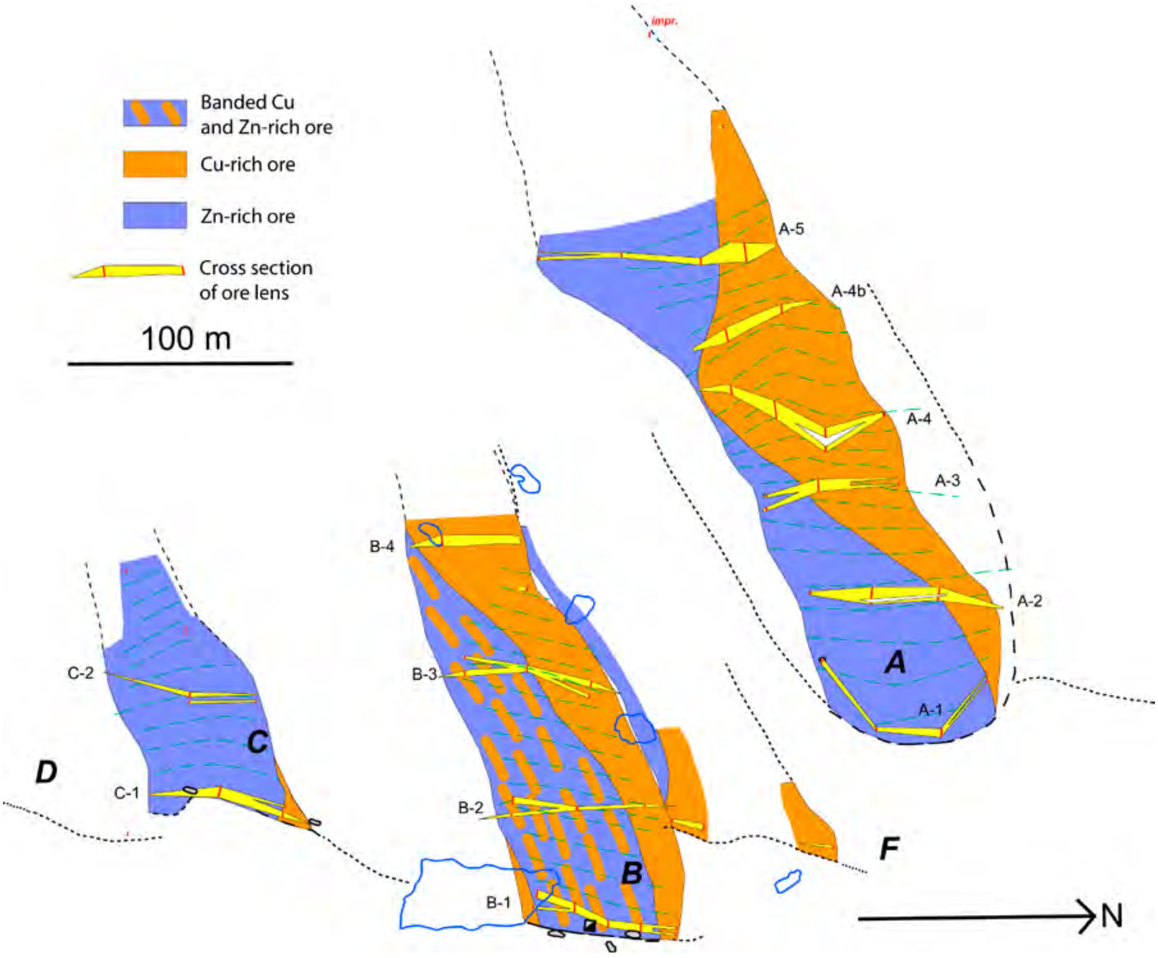


Figure 45. The general distribution of Cu- and Zn-dominated ore in the A, B, C and F lenses in the Hersjø deposit, based on data from diamond drilling. The ore lenses are shown projected to the surface (from Bjerkgård 2007).

The **Killingdal** deposit is hosted by massive greenstone, locally with relict pillow structures. There also are subordinate thin layers of felsic metavolcanic rocks in the region (Rui 1973b, Birkeland 1986). The deposit consists of two ore bodies, the Main Ore Body and the North Ore Body (Fig. 46). They are both strongly elongated, with approximately lens-shaped cross sections (Fig. 47), and occur in the hinge of a regional-scale, isoclinal fold structure (Rui 1973b). The ore bodies are parallel for about 2500 m of the known length and have a mean axial plunge of about 30° W.

At higher levels, the width of the Main Ore Body varies at 40–80 m, and the ore body has a mean thickness of about 3.5 m, with a maximum at 10–12 m. Towards the deeper part of the mine, however, the width of the ore body gradually narrows and its thickness is drastically reduced until the massive ore passes into impregnated schists in the deepest levels. The cross section of the North Orebody is considerably less than that of the Main Ore Body, and it has been exploited to a lesser extent. In the massive ore, pyrite is by far the dominant mineral, which, together with sphalerite and chalcopyrite generally accounts for more than 90 % by weight of the ore. The principal gangue minerals are quartz and muscovite. Mineral banding parallel or subparallel to the ore walls is usually present, with darker bands richer in sphalerite. Bands of pyrrhotite-rich ore up to a couple of centimetres in thickness are locally found near the hanging wall.

The wallrocks associated with the Main Ore Body can be divided into distinctive types according to the distribution and chemical and mineralogical composition of the rocks. Inwards, successively enveloping the ore (Fig. 47), these are: (1) ordinary hornblende schist, (2) chlorite schist, and (3) quartz-muscovite schist. The North Ore Body is correspondingly enveloped by (1) ordinary phyllite, (2) chlorite schist, and (3) quartz-muscovite schist. Parallel to the strike of the schistosity the massive ores typically finger out into the quartz-muscovite schist or chlorite schist, which in turn apparently finger out into each other and finally fade out into the ordinary country rocks (hornblende schist and phyllite). Assays of grab samples and drill core show that the Main Ore Body is rather homogeneous in composition,

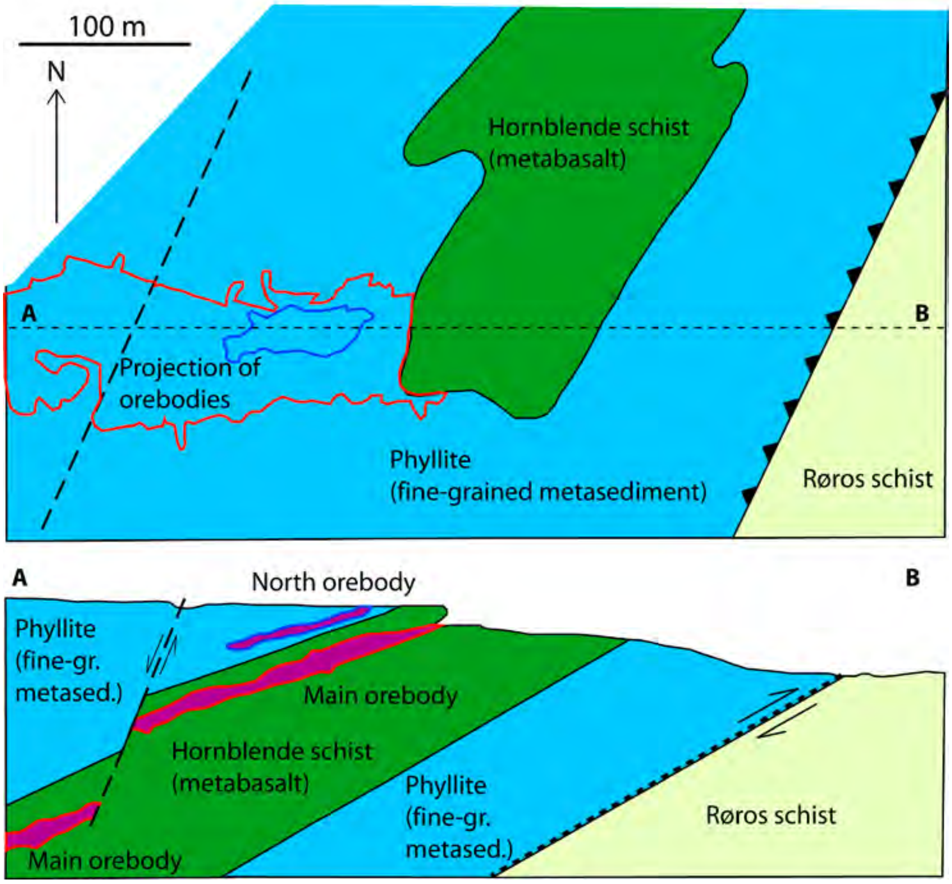


Figure 46. Geological details and E-W cross section of the easternmost part of the Killingdal deposit (modified from Rui 1973b).

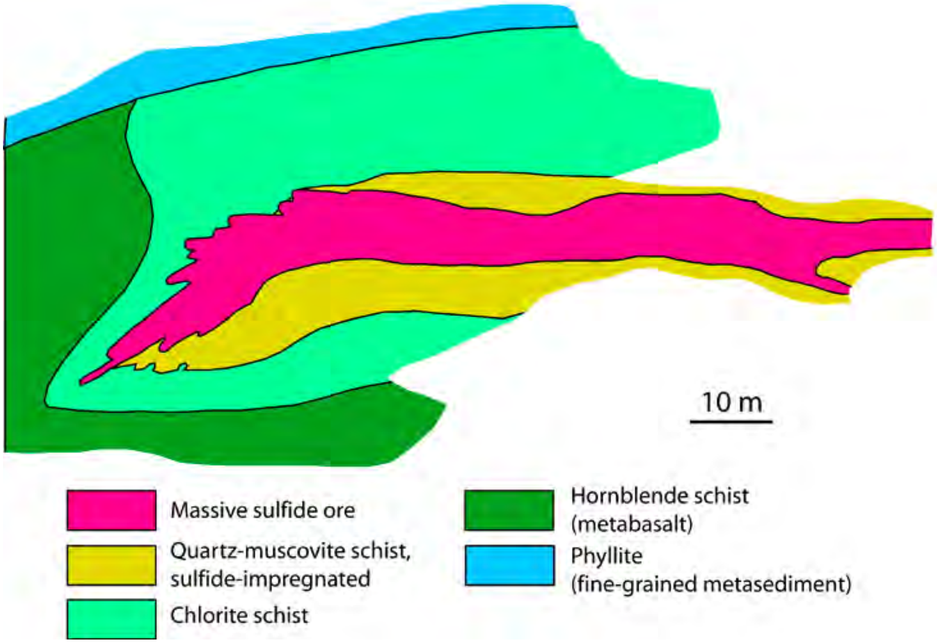


Figure 47. N–S cross section of the Main Ore Body at level 45, which is about 2000 m down dip along the orebody at Killingdal (modified from Rui 1973b).

Table 8. Deposits and occurrences in the Folldal-Meråker metallogenic area (N022) included in the FODD database.

Deposit	Tonnage (Mt)		Cu %	Zn %	Pb %	S %	When mined	Genetic type	Reference
	Total	Mined							
N. Geitryggen	3	2.5	1.3	3.2			1920–1926, 1936–1970	VMS	Bjerkgård & Bjørlykke (1994b)
S. Geitryggen	> 0.5	0.5	0.8	2.4			1770–1847, 1952–1965	VMS	Bjerkgård & Bjørlykke (1994b)
Folldal	2	1.15	1.9	1.1			1748–1940 (discont.)	VMS	Bjerkgård & Bjørlykke (1994b)
Nygruva	0.5	0.3	0.85	3.5			1783–1952 (discont.)	VMS	Bjerkgård & Bjørlykke (1994b)
Grimsdalen	8.3		0.5	2.3			Test mining	VMS	Bjerkgård & Bjørlykke (1994b)
Sivilvangen	0.4	<0.01	0.69	4.31			Test mining	VMS	Nat. ore database
Vingelen	0.2	0.03	1.3	3.8			1723–1835 (discont.)	VMS	Bjerkgård (1989)
Hersjø	2.99	<0.01	1.7	1.4			1670–1699	VMS	Bjerkgård (2007)
Killingdal	3	2.96	1.7	5.5	0.4	45	1677–1986 (discont.)	VMS	Birkeland (1986)
Mannfjell	0.1	0.1	1.8	5.3		28.5	1901–1918	VMS	Nat. ore database

with a higher bulk sulphide to gangue ratio than in the North Ore Body. Production from the latter was also higher in zinc and lower in copper than the Main Ore Body. The mine was worked to a depth of 1400 m along the dip, and about 3 Mt with 1.7 % Cu, 5.5 % Zn, 0.4 % Pb and 45 % S was produced during more than 300 years of mining (Table 8).

The small **Mannfjell** deposit is hosted by felsic metavolcanic rocks and generally overlain by banded tuffite (Grenne et al. 1995). Above a feeder zone consisting of pyritic veins, there is a semimassive to massive layer of pyrite with subordinate chalcopyrite and sphalerite. The ore layer has an extent of about 450 m and a thickness of generally less than 2 m, but occasionally up to 4 m. The deposit varies in its content of Zn and Cu, but during the last mining period an average content of 1.8 % Cu and 5.3 % Zn over a thickness of 0.5–2 m was reported. Later analyses have shown some enrichment of gold, averaging 1 ppm, and even higher in prospects along strike from the main deposit.

N023 RØROS–TYDAL Zn-Cu

Terje Bjerkgård (NGU)

The Røros Ore District (Fig. 48) was a major copper producer in Norway during 1644–1977; more than 6.5 Mt of ore was produced from 12 main mines during the 333 years of mining. The major deposits include the Storwartz, Quintus and Olav mines in the eastern part of the district (the Storwartz Ore Field), and the Kongens, Sextus, Lergruvbakken and Mugg mines in the northwestern part of the district (the Nordgruve Ore Field). Individual mined deposits comprised up to 3 Mt of sulphide ore and contained on average about 2.7 % Cu and 4.2–5 % Zn (Bjerkgård et al. 1999). The zinc-rich ores were only partly exploited, and it is calculated that 250 000–300 000 t of zinc was wasted during the mining operations (Bøckman 1942).

The Røros Ore District is in the southeastern part of the Upper Allochthon of the Caledonides. The ores are hosted by the Aursund Group – a unit mainly comprising metagraywacke with lesser amounts of tuffite, metabasalt and gabbroic sills and dykes, representing a marginal-basin environment, probably formed close to Baltica. It could have formed during the late stages of closure of the Iapetus Ocean in the Late Ordovician to Early Silurian (Grenne et al. 1999). The sediments of the Aursund Group have been divided into two lithological units: the Røsjø and Røros Formations (Rui & Bakke 1975). The Røsjø Formation is present in the western part of the district, mainly comprising metagreywacke and quartz-biotite phyllite with thin bands of hornblende-bearing, quartz-rich tuffaceous sediment. The Nordgruve Ore Field is situated in this unit. The Røros Formation comprises the eastern part of the district and consists of calcareous metagreywacke, rhythmically alternating with gray carbonaceous phyllite on a metre scale. Graded beds and cross bedding are common features, showing that the sequence is the right way up. The Storwartz Ore Field and the Klinkenberg deposit are situated in this unit. Both units contain numerous gabbros, mainly as extended, sill-like intrusions, concordant with the surrounding sediments. They have lengths up to several kilometres, and are 20–50 m, rarely up to 100 m thick.

There are five major deposits in the *Nordgruve Ore Field*: **Kongens–Rødalen**, **Mugg**, **Lergruvbakken**, **Christianus Sextus**, and **Fjellsjø** (Fig. 49; Table 9). Despite most of these deposits being dominated by zinc, they were generally mined for copper, with the exception of Lergruvbakken, where zinc was the major product. Mugg is very different from the other deposits in the Nordgruve Ore Field, being mainly a chalcopyrite-pyrrhotite deposit with subordinate amounts of sphalerite

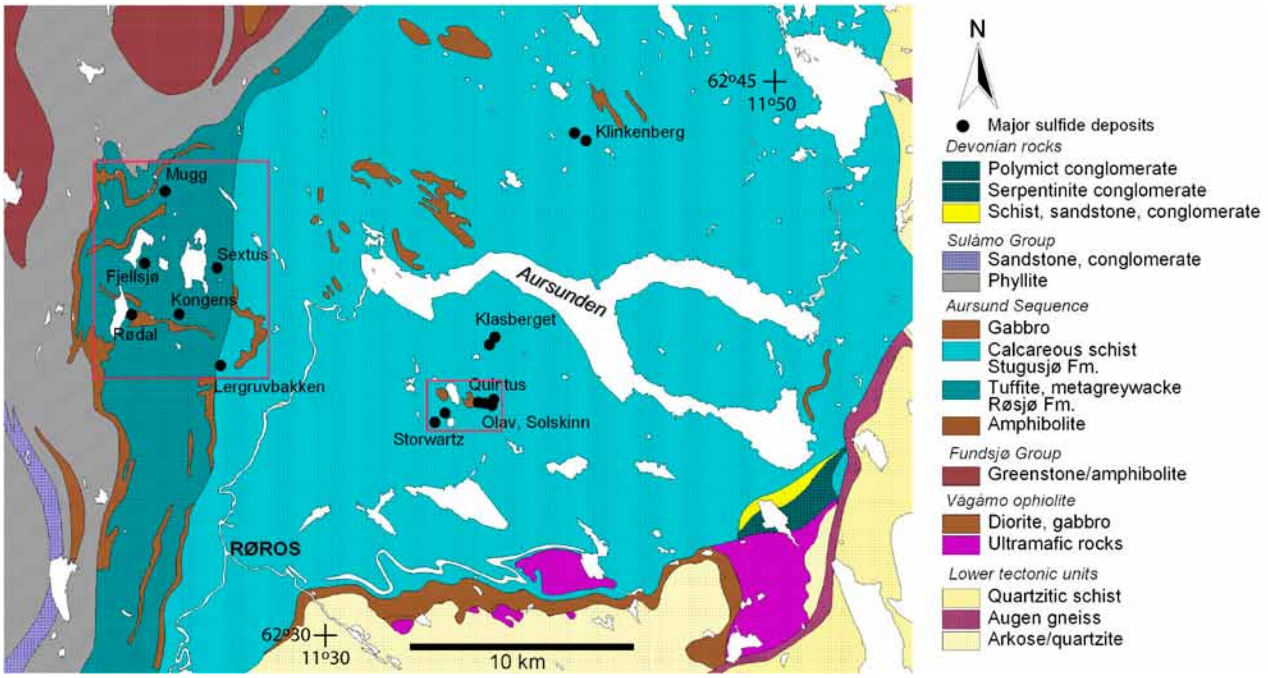


Figure 48. Geology of the Røros Ore District. Rectangles indicate the areas of Figures 49 and 50.

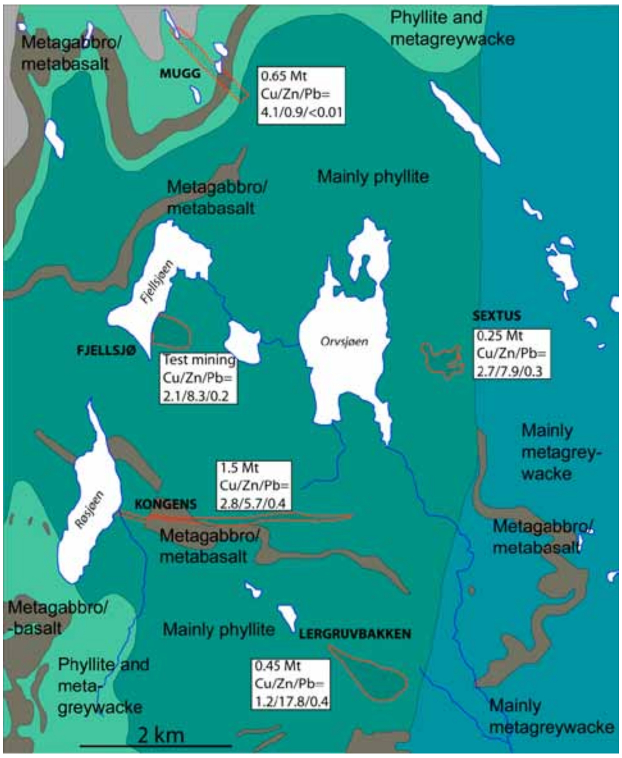


Figure 49. Geology and ore deposits in the Nordgruve Ore Field. The red lines are horizontal projection of the ore bodies. The numbers are ore production figures (Mt) and in-situ metal contents (%). White areas are lakes and blue lines are rivers.

and only trace amounts of galena. The massive parts of the deposits, especially the zinc-rich domains, are characterised by banding on a mm to cm scale, generally of sphalerite- and pyrite-rich bands, but bands enriched in chalcopyrite and/or pyrrhotite also occur. Especially at Mugg, Fjellsjø and Rødalen, the ores contain abundant fragments of quartz and schist millimetres to several centimetres in diameter. These fragments are partially rounded and show that the ore bodies have been strongly tectonised and later recrystallised, a texture known as "durchbewegung" (Vokes 1969).

The **Kongens** ore body is more than 2.5 km long and is connected to the Rødalen orebody situated another 500 m further west. The extreme elongation is due to tight folding along a subhorizontal fold axis. Mining was mainly carried out on the copper-enriched parts of the deposit, beneath the massive zinc ore. This can be seen in a 700-m-long open pit where copper-rich ore was concentrated in the fold structures and mined via small adits and shafts. About 1.5 Mt of copper ore was produced from the Kongens deposit. In addition, there was production of pyrite.

The massive ore is from 10 cm to >1 m thick and locally there are two or even three parallel sulphide layers. The ore is fine-grained, banded and consists of pyrite, pyrrhotite and sphalerite with subordinate chalcopyrite and galena. Quartz-chlorite schist and quartz-sericite schist underlie the ore layers, generally with thin stringers and impregnation of sulphides, mainly pyrite, pyrrhotite and chalcopyrite in varying proportions. Close to and above the ore layers there is a thick unit of psammite, locally with primary graded bedding preserved, showing that the sequence is generally the right way up. The extent of the alteration below the ore layers is unknown, but the outcrops in the pit indicate that it must form a zone at least 20 m thick.

The **Christianus Sextus** mine is located about 2.5 km northwest of Kongens mine, and consists of two thin flat-lying, plate-like ore bodies 10–15 m apart. The upper zone predominantly consists of pyrite and sphalerite, whereas the lower zone is enriched in pyrrhotite and chalcopyrite. Only about 250 000 t of ore was produced from the deposit, in several periods of mining between 1723 and 1940. The massive ore is surrounded by quartz-sericite schist with weak to strong impregnation of pyrite with minor sphalerite and scattered grains of chalcopyrite. This grades downwards into a zone of sericite-chlorite schist and quartz-chlorite schist with weak impregnation, mainly of chalcopyrite. This alteration extends down towards the lower ore zone.

The **Mugg** deposit is at a higher stratigraphic level than the Sextus deposit. It forms a ruler about 2.4 km long and 60–150 m wide, but only 0.1 to 1.5 m thick. As at Kongens, the extreme elongation is due to folding about a subhorizontal fold axis. About 650 000 t of ore was taken out of the mine between 1770 and 1919. The deposit mainly consists of pyrrhotite-chalcopyrite mineralisation with subordinate sphalerite and pyrite. Locally, magnetite forms a major part of the ore. Fragments of quartz and schist, typically subrounded, are a very characteristic feature of the ore. These features, together with a generally irregularly veined ore, show that the ore body is strongly tectonised.

The **Fjellsjø** deposit is a thin, relatively flat-laying plate, about 2000 x 300 m in area, located between 30–80 m below the surface. The deposit has only been subject to test mining. It contains 1.5–2 Mt of mineralisation. Drilling has shown the presence of another zone of massive ore about 35 m below the main deposit, but probably of limited extent. The main ore type consists of pyrite and sphalerite, with subordinate amounts of chalcopyrite and pyrrhotite. A less common type consists of pyrrhotite, chalcopyrite and sphalerite with rounded 1–5 cm fragments of pyrite, quartz and schist. Chlorite schist and quartz-sericite schist occur associated with bands of massive ore.

Lergruvbakken is an underground deposit consisting of several thin plates of pyrite-sphalerite ore at variable, but generally shallow levels below the ground. Two of the plates (called A and C ore) were mined in the period 1973–1977. The two plates were originally connected, but are now dissected by a major fault zone. The plates are 0.6 m thick and cover an area of 850 x 100–300 m. With a height of the stopes of 1.7 m, the original reserves were 940 000 t, of which about 450 000 t was mined.

The *Storwartz Ore Field* is located in the Røros Formation. It comprises six deposits lying E–W one after the other, over a distance of about 3100 m, and with a total width of 100–300 m (Fig. 50). As in the Nordgruve Ore Field, the ore bodies form shallow, flat-laying, typically 1–2-m-thick plates, but with locally thicker parts due to folding. The elongate shape of the ore field is due to folding about a subhorizontal SW-trending axis. Late steeply-dipping faults crosscut the ore field, and have locally disrupted the ore bodies.

About 4 Mt of ore was mined from the deposits in the Storwartz Ore Field during 1645–1972 (Table 9). The main product was copper, together with pyrite. The western **Old** and **New Storwartz** deposits predominantly consist of pyrrhotite and sphalerite (Fig. 51), with substantial amounts of galena. The amounts of pyrite and chalcopyrite vary to a large degree. Main non-sulphides are calcite, plagioclase, quartz and chlorite, whereas sericite and biotite are subordinate phases. Strong deformation of the ore is evident in many places in the form of rounded fragments of psammite, and of plagioclase crystals.

The eastern **Quintus–Hestkletten**, **Olav** and **Sol-**

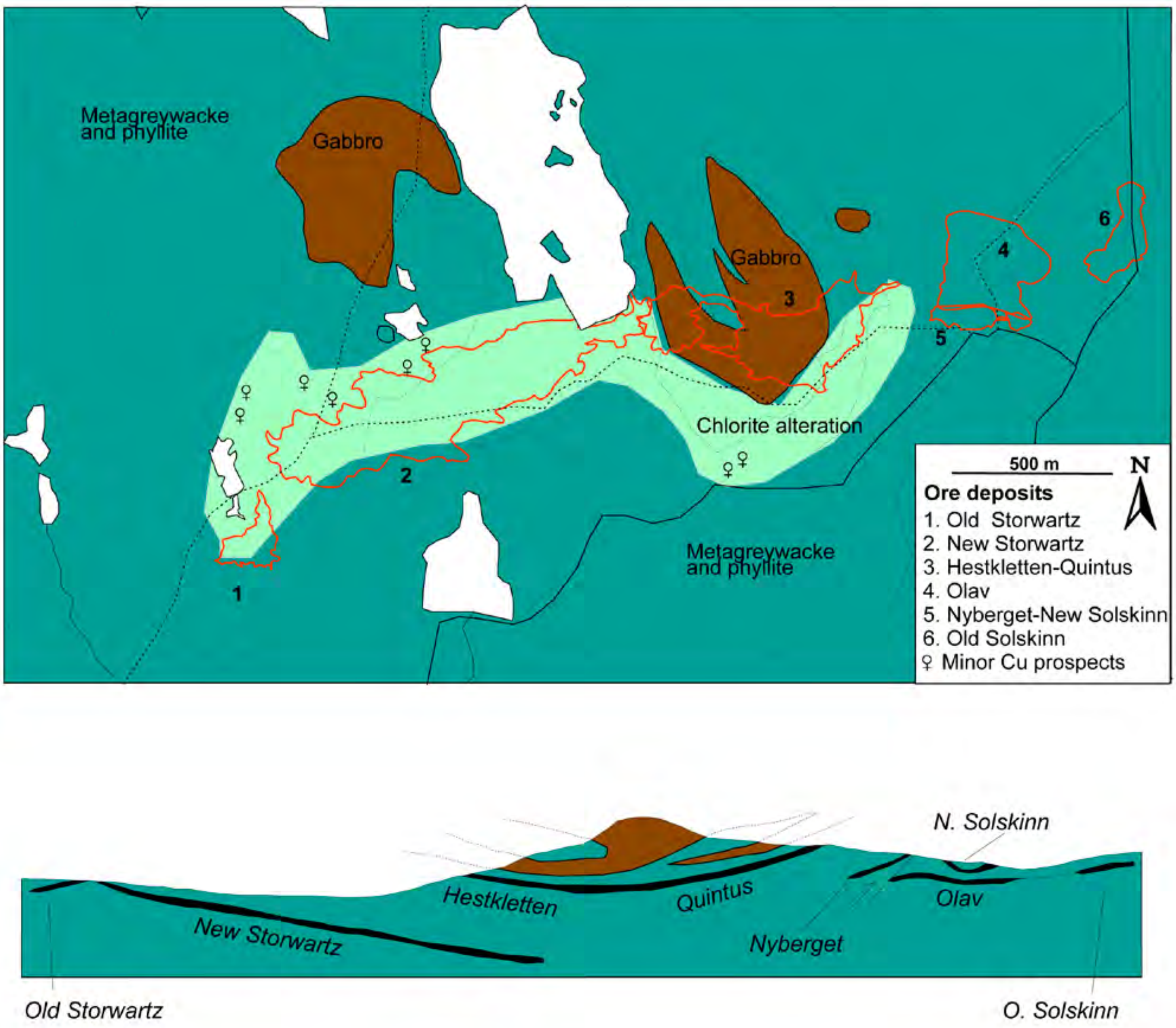


Figure 50. Geology of the Storwartz Ore Field with the projected outline of the deposits and the extent of chlorite alteration. A schematic cross section along the length of the field is also presented.

skinn deposits predominantly consist of pyrrhotite and chalcopyrite with subordinate to major amounts of sphalerite (Fig. 51). Pyrite is generally a subordinate mineral. Major non-sulphides are quartz and chlorite, whereas garnet and biotite are the most important subordinate phases. An extensive zone of quartz-chlorite alteration underlies the Storwartz and Quintus–Hestkletten deposits. This zone contains numerous small showings with Cu mineralisation. The showings contain up to 1-m-thick ore lenses and veins with massive pyrrhotite-chalcopyrite mineralisation.

Taking the Storwartz ore field as a whole, the deposits from east to west show a very distinct pattern with respect to zonation in the base metals from Cu-rich deposits in the east (Solskinn, Olav and Quintus) grading into Zn- and Pb-rich deposits in the west (the two Storwartz deposits). Together with the presence of an extensive and continuous chlorite alteration zone beneath the deposits, this is an argument in favour of the ore bodies in the Storwartz field originally being one deposit, with the zonation reflecting distance from the high-T vent site(s). Taking into account the tonnages of the deposits and the *in situ* ore grades, the proposed single deposit contained about 5 Mt of ore with an average grade of 3 % Cu and 9.4 % Zn, excluding eroded parts between the present deposits.

Smaller deposits in a similar geological setting were mined north of the Røros ore district. They are typically cupriferous with local gold or zinc enrichments. The largest of these, the **Kjøli** deposit, produced 250 000 t of cupriferous pyrite ore. Further north, in the Meråker area, the **Lillefjell** deposit produced 107 000 t with 5 % Cu and 4.5 % Zn.

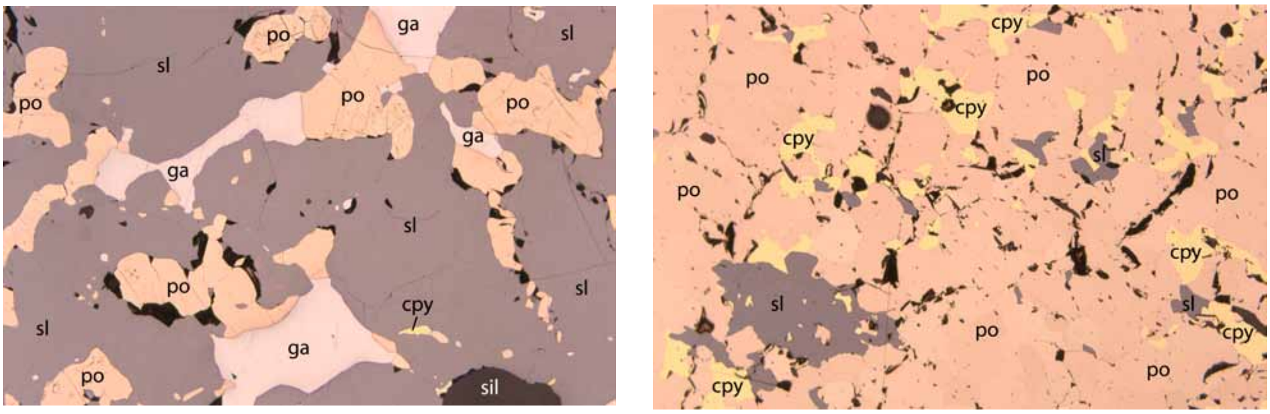


Figure 51. Photomicrographs of typical ore texture in the Old Storwartz deposit (left) and Olav deposit (right). Sizes of the sections are 1.2 x 1.2 mm and 2.4 x 3.0 mm, respectively. cppy = chalcopyrite, ga = galena, po = pyrrhotite, sil = silicate, sl = sphalerite.

Table 9. Deposits and occurrences in the Røros-Tydal metallogenic area (N023) included in the FODD database (all data from the Norwegian national ore database).

Deposit	Tonnage (Mt)		Cu %	Zn %	Pb %	Ag g/t	When mined	Genetic type
	Total	Mined						
Kongens-Rødalen	3	1.5	2.8	5.7	0.4	23	1657–1940 (discont.)	VMS
Christianus Sextus		0.25	2.7	7.9	0.3	14	1723–1940 (discont.)	VMS
Mugg		0.65	4.1	0.9	<0.01	12	1770–1919	VMS
Fjellsjø	1.5–2		2.1	8.3	0.2	11	Test mining	VMS
Lergruvbakken	0.94	0.45	1.2	17.8	0.4	17	1973–1977	VMS
Old/New Storwartz	1.7	1.62	1.6	11.1	1.3	25	1645–1919	VMS
Quintus – Hestkletten		0.75	2.5	6.2	0.4	13	1691–1770	VMS
Olav, Solskinn	1.51	1.34	4.3	2.5	0.02	9	1660–1972 (several periods)	VMS
Kjøli		0.25	2.9	0.02	<0.01		1773–1919	VMS
Lillefjell		0.11	5.0	4.5			1760–1895	VMS

N024 FOSDALEN Fe

Jan Sverre Sandstad (NGU)

The Fosdalen metallogenic area (N024) is a more than 150 km long and up to 10 km wide, NE-trending zone NW of Trondheimsfjord. It is part of the Smøla–Snåsa terrane, which is assumed to comprise mature arc volcanosedimentary sequences and their plutonic counterparts (Grenne et al. 1999). Tectonostratigraphically, the area is part of the Køli Nappe Complex in the Upper Allochthon of the Caledonides. The area contains several magnetite- to pyrite-dominated deposits, some with minor amounts of chalcopyrite. These are hosted by shoshonitic lavas, rhyolites and various pyroclastic rocks (Grenne et al. 1999).

Fosdalen is the largest deposit and the only one that has given rise to any significant production. Mining was carried out in the period 1906–1997 and more than 35 Mt of ore was produced, carrying 50–70 % magnetite, 3 % cobaltiferous pyrite (0.25 % Co) and minor amounts of chalcopyrite (Grenne et al. 1999). Nearly 16 Mt of magnetite concentrate was produced, along with pyrite and copper concentrates that were produced when marketing conditions were favourable (Carstens 1955, Smith 1995). The mine was very close to an all-year, ice-free harbour.

The mineralisation at Fosdalen is hosted by the Fosdal Group, which consists of diorite, chlorite-epidote-hornblende schist, 'quartz schist', marbles and calc-silicate schist (Fig. 52). The rocks are strongly sheared due to deformation along the Møre–Trøndelag Fault Zone, and primary features of the host rock are difficult to recognize. However, minor epidote blebs in the chlorite-epidote-hornblende schist are assumed to repre-

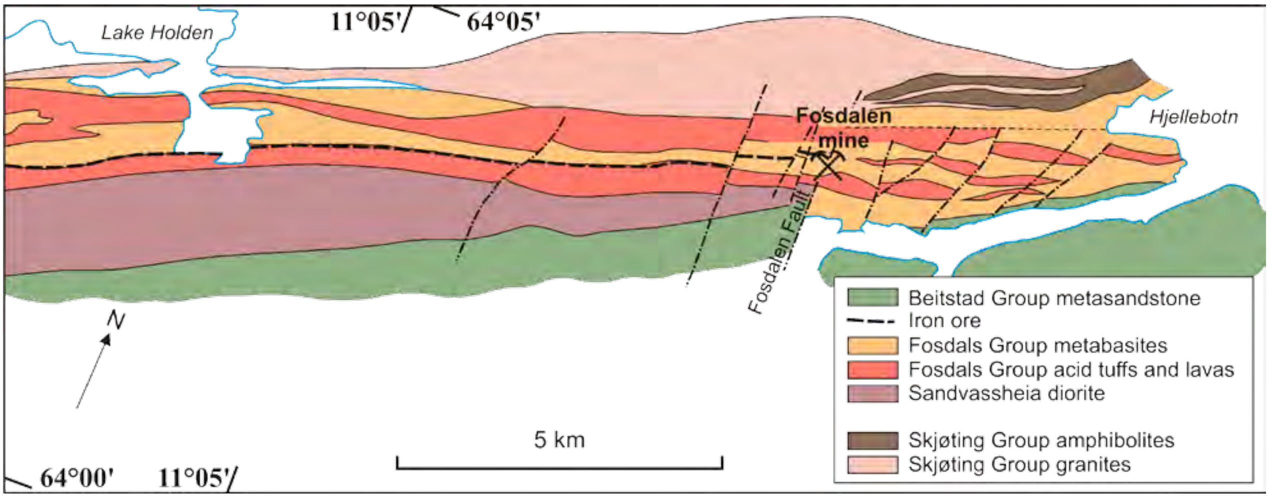


Figure 52. Simplified geological map of the Fosdalen district showing the distribution of the magnetite unit (Smith 1995, Grenne et al. 1999).

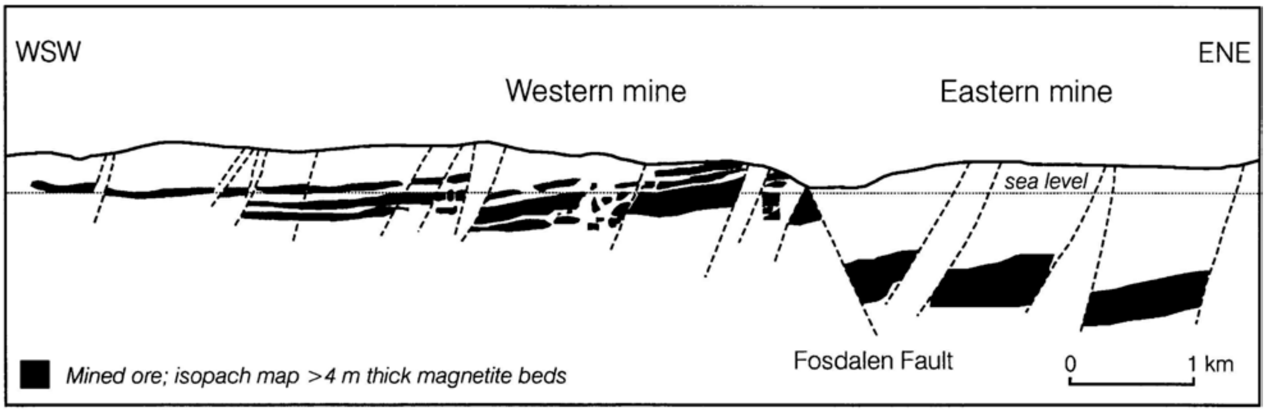


Figure 53. Section along strike though the Fosdalen mine showing the distribution of magnetite beds > 4 m thick (Smith 1995).

sent amygdales in metabasalts (Smith 1995). The 'quartz schist' comprises a variety of rocks, including porphyritic rocks, interpreted as a metamorphosed sequence of crystal tuffs interbedded with metasediments.

The exploitation of the magnetite mineralisation at Fosdalen was carried out over a strike length of 12 km. The orientation of the ore zone is ENE–WSW with a steep dip to the SSE. The footwall contact to the metabasalts is generally sharp, whereas the hanging-wall contact to the 'quartz schist' is more gradual. The Fe ore is banded and several magnetite-rich bands comprise the ore unit. The magnetite bodies are lens-shaped, generally 200 m long and wide and up 10 m thick, and the average thickness is 2–3 m. The ore bodies are separated by steeply dipping NNE–striking normal faults. A major fault zone separates the ore bodies of the Western mine from those of the Eastern mine, with a downthrow of the eastern ore bodies of around 700 m (Fig. 53).

As early as in the 1950s, the iron mineralisation at Fosdalen was interpreted as having been formed by 'exhalative' processes in a submarine volcanic environment, possibly as an oxide facies deposition produced during massive sulphide mineralisation (Carstens 1955).

N025 GRONG-STEKENJOKK Cu-Zn

Jan Sverre Sandstad (NGU), Anders Hallberg (SGU)

The Grong-Stekenjokk area in central Norway and west-central Sweden is one of the most important areas for Cu-Zn(-Pb) VMS ores in the Caledonides. Four mines have been operated, Stekenjokk, Skorovas, Joma and Gjersvik, with a total production of 24.5 Mt in the period 1952–1998.

Tectonostratigraphically, area N025 is part of the Køli Nappe Complex in the Upper Allochthon of the Caledonides. The western part comprises the Gjersvik Nappe overlying the Orklump/Leipikvattnet Nappe with the Stikke and Gelvenållo Nappes further to the northeast and across the Norwegian-Swedish border. The stratigraphically inverted Gjersvik Nappe consists of metavolcanic rocks of the Skorovass Complex (Gjersvik Group) and metasedimentary rocks of the Limingen Group, assumed to represent an immature arc sequence (Sandstad et al. 1997, Grenne et al. 2000). The underlying Orklump Nappe comprises a sequence of predominantly pelagic sediments and basalts in an oceanic setting (Grenne et al. 2000). The mineralised parts of the Köli Nappe complex in Sweden, the Stikke and Gelvenåkko nappes, consist of the Remdalen group, the Stekenjokk Quartz-Keratophyres, the Lasterfjället Greenschist and the Blåsjön Phyllite lithostratigraphic units (Stephens 1986). The Stekenjokk Quartz-Keratophyre and the Blåsjön Phyllite can be stratigraphically correlated with the Gjersvik Group and the Limingen Group of the Gjersvik Nappe (Stephens 1986).

Although the deposits are thought to have been developed in different palaeotectonic settings, they are included in the same metallogenic province. The Joma deposit is hosted entirely by metabasalts in a sequence of predominantly pelagic metasediments in an oceanic setting. The other VMS deposits listed in Table 10 are hosted by metavolcanic rocks of basaltic to rhyodacitic composition, the Skorovass Complex and the Stekenjokk Quartz-Keratophyres.

The **Joma** deposit is located in mafic metavolcanic rocks of the Røyrvik Group (Fig. 54). The sequence is structurally overturned and deformed by three phases of deformation related to the nappe emplacement (Reinsbakken 1986, Odling 1988). The greenstones are underlain by recrystallised ribbon chert and graphitic phyllites, which sit on a thick sequence of quartz and calcareous phyllites. The greenstones are interpreted as having formed in an ocean island, probably in an off-axis setting. The massive sulphide deposit occurs at the interface between an older volcanic-intrusive complex and a younger volcanic-volcaniclastic sequence, which show WPB and MORB affinities, respectively. The feeder zone to the massive ore comprises extensive albitisation, chloritisation and quartz-sericite alteration associated with sulphide dissemination and stockwork veining.

The ore body has a double arc-formed dish shape that is roughly wedge shaped in cross section, being thickest in the east, adjacent to the feeder zone (Reinsbakken 1986). A general sulphide stratigraphy shows compositional changes from a thin Cu-rich (chalcopyrite-pyrrhotite) layer at the base, thinning westwards away from the feeder zone and intercalated with numerous

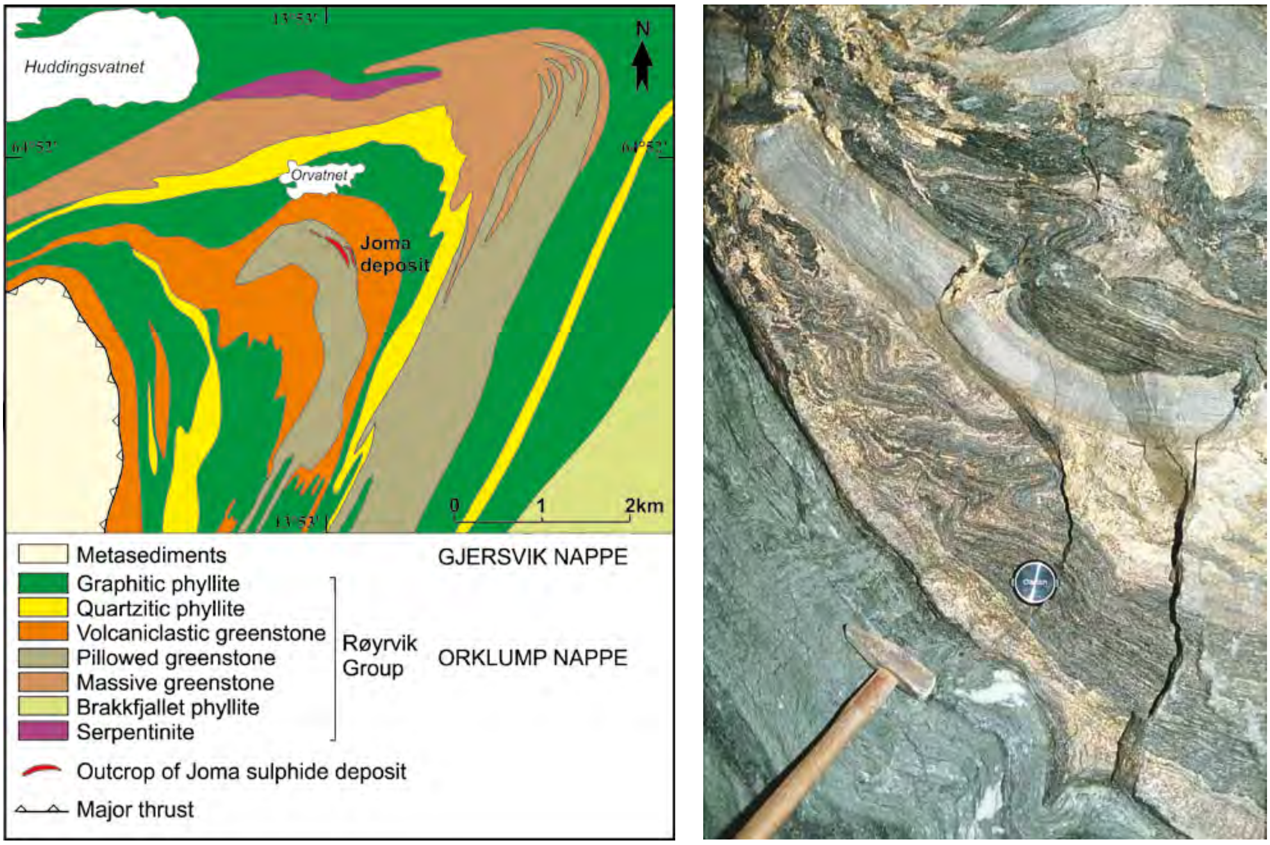


Figure 54. Geological map of the Joma region after Odling (1988). Banded Zn-rich pyritic ore at Joma. Photo: A. Reinsbakken.

thin layers of magnetite, chlorite schist and albitite, and overlain by massive pyrite. At the eastern flank of the ore body, the feeder zone mineralisation is overlain by Zn-rich pyritic ore. The most Cu-rich ore is a tectonic breccia, which contains fragments of quartz, carbonate, pyrite and magnetite in a chalcopyrite-pyrrhotite matrix. Primary sulphide-breccia ore types also exist, and a palinspatic reconstruction of the Joma deposit suggests that the massive sulphides were deposited in a submarine environment, on top and adjacent to a major growth fault (Reinsbakken 1986).

The Early Ordovician Skorovass Complex (SC) is composed of submarine volcanic and plutonic rocks, unconformably overlain by psammitic metasedimentary rocks of the Limingen Group (Fig. 55). The volcanic part of the SC, the Bjørkvatnet Formation, is divided into three stratigraphic members (Sandstad et al. 1997; Grenne et al. 2000). The Lower Member consists of a sequence of basaltic lavas and subordinate basaltic andesites. The Middle Member comprises strongly fractionated Fe-Ti basalts followed by a heterogeneous unit of feldspar-phyric, low-K rhyodacite flows, basaltic andesites and volcaniclastic rocks. The Upper Member consists of primitive Mg-rich, pillowed and massive basalts, subordinate quartz-phyric volcanic rocks and calcareous tuffites. Geochemical data indicate a subduction affinity for the whole volcanic sequence. The Lower Member can be related to the early stages of ensimatic arc construction, whereas the higher units formed in response to rifting processes within the arc complex.

Massive sulphides are abundant in the rift-related part of the volcanic succession, particularly in the Middle Member at Skorovass. The earliest, Cu-Zn dominated ores (e.g., **Skorovas**, **Gjersvik**) occur between the Fe-Ti basalts and the overlying low-K rhyodacites. Continuous hydrothermal activity through the Middle Member is manifested by deposits with higher Zn/Cu ratios and Pb contents at higher stratigraphic levels (e.g., **Visletten**, **Godejord**), a feature that may be related to the increased felsic magmatic activity with time (Sandstad et al. 1997). Minor gabbro bodies related to the primitive metabasalts of the Upper Member contain massive or disseminated Cu-Ni sulphides with significant PGE+Au enrichment in the **Stormyrplutten** and **Lillefjellklumpen** occurrences (Grenne et al. 1999).

The **Skorovas** deposit was discovered in 1873 and was in operation from 1952 to 1984, with a total production of 5.6 Mt that until 1976 consist-

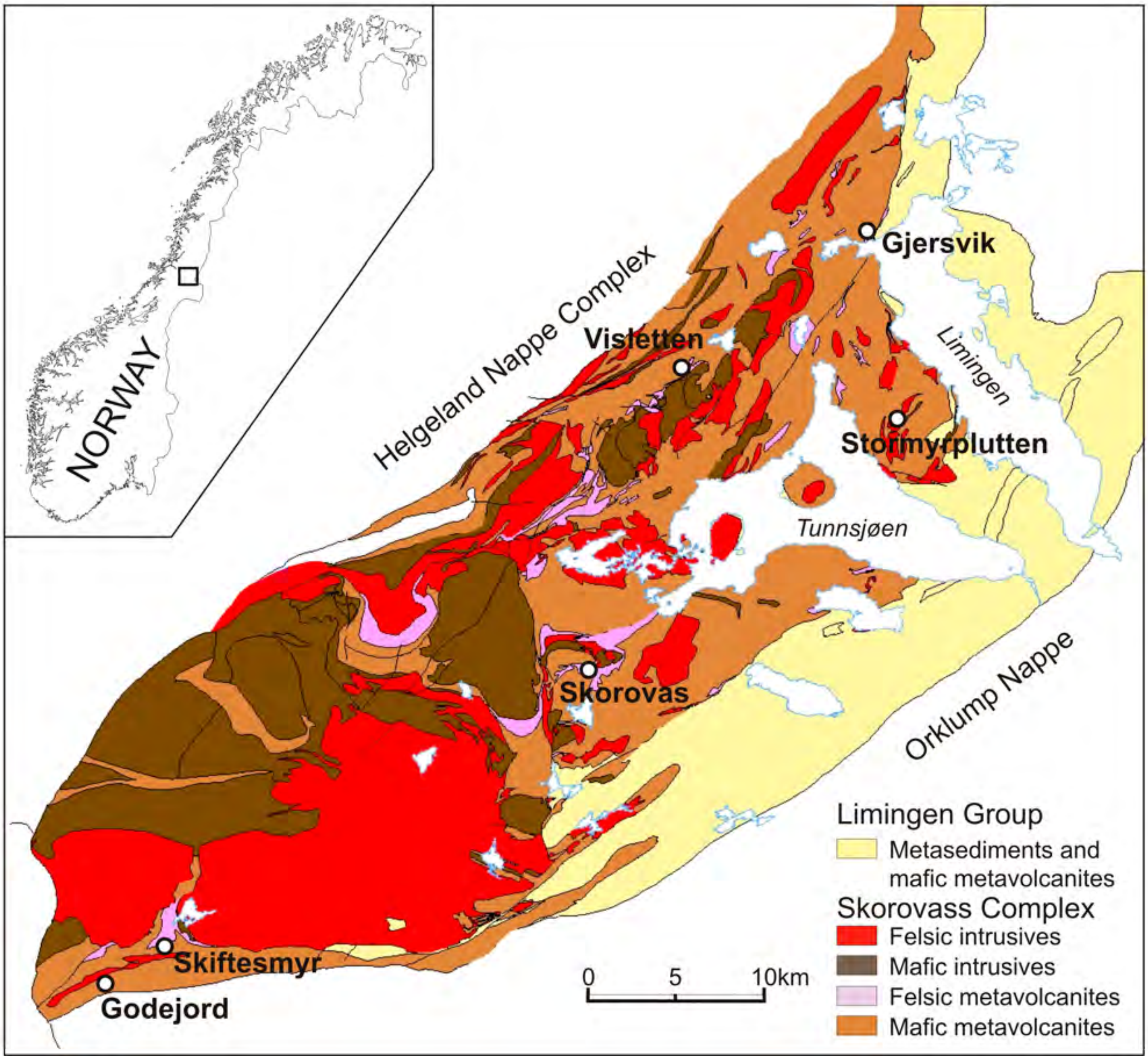


Figure 55. Simplified geological map of the Gjersvik Nappe showing the location of the major VMS deposits and the Stormyrplutten Ni-Cu occurrence.

ed of pyritic ore. During the final operating years, Cu and Zn were exploited. Remaining *in situ* reserves at the closure were 1.3 Mt in the 'Southern Orebody' (Reinsbakken 1992; Table 10).

The Skorovas deposit consists of a north–south-orientated mineralised zone, about 800–900 m long, 200–300 m wide and, at maximum, 50 m thick. The ore zone is subparallel to early fold structures and plunges gently to the south at its northern extension, is more flat within the central parts and then rises gently at the southern extension. It comprises an *en echelon* array of closely spaced, elongated, flat-lying massive sulphide lenses. In between, minor ore lenses occur within strongly sheared rocks that trend in a south-eastern direction, which represents the transport direction of the larger nappe structures (Reinsbakken 1992). The mineralisation is almost completely metamorphosed, as primary textures are only rarely preserved. A pronounced zonation in the distribution of Cu and Zn exists. The ore minerals are, in decreasing order of abundance: pyrite, chalcopyrite, sphalerite, and magnetite and accessories including galena, tennantite, arsenopyrite and hematite. The main gangue minerals are quartz, calcite and chlorite.

The northernmost part of the deposit is pyrite-dominated and consists of a thick zone of disseminated and veined sulphides within a strongly schistose, chlorite-quartz rich rock that is interpreted to represent the central, top part of the feeder-zone. The mineralisation continues southward abruptly into a series of massive pyrite lenses. The northern, major parts of the Main and East ore bodies are dominantly pyritic and contain only minor amounts of Cu and Zn, but grade southwards into more base metal-rich ores. These ore bodies occur above Fe-Ti rich metabasalts of the Middle Member and are overlain by differentiated basaltic andesites and andesites. The southern, mined ore lenses (SE and SW ore bodies) are locally Zn-rich and are interpreted as having formed at upper stratigraphic levels, above felsic flows and pyroclastics.

The **Gjersvik** deposit was discovered in 1909. Small-scale test mining was performed prior to full-scale production in the period from 1993–1998. Total reserves were 1.6 Mt at 1.7 % Cu and 1.0 % Zn, and only trace amounts of Pb and precious metals. Production was based on 0.5 Mt grading 2.15 % Cu and 0.60 % Zn as a satellite deposit for the Joma mine.

The present form of the deposit is an asymmetric trough or spoon-shaped body situated in a synformal D_3 structure, which plunges gently to the south and deforms earlier, tight to isoclinal recumbent folds in the ore (Reinsbakken 1986). The massive ore zone is up to 8 m thick and is composed of a series of sulphide layers or lenses that are separated by thin chloritic zones. The major part of this is a pyritic Cu-dominated facies with varying amounts of pyrrhotite, magnetite, chalcopyrite, and sphalerite in a carbonate-quartz-chlorite gangue. A lens of very Zn-rich pyritic ore (10–20 % Zn) occurs 10–20 m above the main ore.

Recent work (Sandstad et al. 1997, Grenne et al. 2000) has indicated that the deposit is located within the Middle Member of the Bjørkvatnet Formation, i.e. a stratigraphic position similar to that of the Skorovas deposit. The main ore level was originally underlain by altered Fe-Ti-rich basalts, which are now preserved only locally due to tectonic relationships. The hanging wall comprises similar basaltic lavas together with felsic rocks of pyroclastic and flow origin typical of the upper parts of the Middle Member. The upper, Zn-rich ore occurs at the contact between a basaltic and an overlying felsic unit. Sulphide veining and alteration (chloritisation, albitisation and quartz-sericite alteration) in the hanging wall of the main ore level is thought to be largely related to this upper ore level.

Massive sulphides at **Skiftesmyr** mainly consist of pyritic Zn-Cu ore, which occurs as layers or a continuous series of ore lenses forming a 2–20-m-thick, plate-like orebody overlain by lenses of magnetite-bearing metachert. The main gangue minerals are quartz, chlorite and calcite. Both footwall and hanging-wall rocks are strongly affected by quartz-sericitic, albitic and chloritic alteration with variable amounts of sulphide veins and dissemination. The ore body shows a marked lateral zonation, with Cu-dominated ore concentrated in the eastern and upper levels of the ore body and Zn-rich ore in the western parts and at depth. It contains 2.75 Mt grading about 1.23 % Cu, 1.86 % Zn, 11 g/t Ag and 0.4 g/t Au calculated at a cut-off of 1 % Cu equivalents (Table 10). According to underground mining plans reported in 1992 by Norsulfid A/S (Lindeman 1992), a total of 2.684 Mt of ore was planned to be extracted (cut-off 1 % Cu equivalents), grading 1.08 % Cu, 1.63 % Zn, 8.65 ppm Ag, 0.31 ppm Au and 34.6 % S. The reduced tonnage and grades quoted result from ore being tied up in pillars and from waste rock dilution.

The **Visletten** deposit comprises a massive ore zone with a thickness of up to 3 m consisting of pyrite with layers rich in sphalerite and subordinate galena, minor chalcopyrite and metachert. Reserves have been calculated at 0.8 Mt with 0.9 % Cu and 3.9 % Zn. Zinc-rich layers carry up to 1 % Pb and are significantly enriched in Ag and Au (up to 90 and 2 g/t, respectively). The massive sulphide ore is underlain by a sequence of basaltic lavas that are extensively chloritised and sulphide-veined below the massive ore level. The stratigraphic hanging wall comprises quartz-phyric felsic flows, overlain by pillow lavas. The distal part of the ore unit is associated with thin beds of magnetite-bearing chert.

The **Godejord** deposit is located in the southern part of the Grong district. The ore level is 5 to 10 m thick and comprises massive to banded and disseminated sulphides in a variably tuffaceous, calcareous and cherty host. It occurs in the upper part of a thick sequence dominated by tuffaceous or epiclastic sediments with interlayered felsic effusives. The upper part of this succession contains abundant exhalite units, some of which are rich in fine-grained garnet and carry up to 12 % MnO (Grenne & Erichsen 1996). The ore lies stratigraphically on top of a 10-m-thick layer of magnetite-bearing chert with local Mn enrichment, and is separated from an overlying basaltic unit by a thin zone of calcareous sediments similar to those below the ore body (Grenne 1995). The richer parts of the laterally extensive Godejord zone have been estimated to contain about 0.1 Mt with 0.8 % Cu, 6.9 % Zn, 0.2 % Pb, 20 g/t Ag and 0.8 g/t Au calculated at a cut-off of 2 % Cu equivalent (Grenne & Erichsen 1996). The actual massive and semimassive ore, however, is considerably richer and is known for its high contents of silver and gold and its unusual mineralogy, including Fe-poor sphalerite, fahlore, Cu-Ag±Te sulphides,

Table 10. Deposits and occurrences in the Grong metallogenic area (N025) included in the FODD database.

Deposit	Tonnage (Mt) Total	Tonnage (Mt) Mined	Cu %	Zn %	Pb %	Ni %	When mined	Reference
Joma	22.5	11.453	1.49*	1.45*			1972–1998	Norsulfid A/S, Grong Gruber
Skorovas	6.9	5.6	1.14*	2.71*			1952–1984	Reinsbakken (1986)
Gjersvik	1.62	0.5	2.15*	0.5*			1993–1998	Norsulfid A/S, Grong Gruber
Skiftesmyr	2.75		1.23	1.86				Norsulfid A/S
Visletten	0.78		0.92	3.86				Norsulfid A/S
Godejord	0.1		0.8	6.9	0.2			Grenne & Erichsen (1996)
Stormyrplutten	0.2		0.5			0.08		Larsen & Grenne (1995)
Stekenjokk	17.1	7.0	1.35	3.22	0.36		1976–1988	Stephens et al. (1978)
Jormlien	0.00	0.00002	0.40	6.00	0.10		1919	Stephens et al. (1978)
Levimalmen	5.00		1.40	1.60	0.10			Stephens et al. (1978)
Unna Gaisartjåkko	1.00		0.80	0.50	-			Stephens et al. (1978)
Ankarvattnet	0.80		0.50	5.50	0.37			Stephens et al. (1978)
Remdalen	0.70		1.43	2.74	0.04			Stephens et al. (1978)
Usmeten	0.25		1.28	0.31	-			Stephens et al. (1978)
Skidträskbäcken	0.23		0.71	1.53	0.04			Stephens et al. (1978)
Beitsetjenjunje	0.20		0.97	1.00	0.16			Stephens et al. (1978)
Tjokkola	0.17		0.89	2.20	0.10			Stephens et al. (1978)
Tjåter	0.15		1.00	4.80	1.90			Stephens et al. (1978)
Storbäcksdalen Västra	0.15		1.20	6.30	2.40			Stephens et al. (1978)
Rikarbäcken	0.15		0.80	4.30	1.10			Stephens et al. (1978)
Skidträskbäcken N	0.14		0.46	0.10	0.07			Stephens et al. (1978)
Björkvattnet	0.13		0.73	0.40	0.05			Stephens et al. (1978)
Abelvattnet	0.07		0.90	0.07	-			Stephens et al. (1978)
Daningen	0.05		9.85	0.60	0.00			Stephens et al. (1978)
Njeretjakke	10.00					0.28		Stephens et al. (1978)

* Average grades of mined ore

Cu-Sn sulphides and native gold (Bergstøl & Vokes 1974). Recent studies have shown that parts of the ore zone contain also notable amounts of barite (Grenne & Erichsen 1996).

The most intensely mineralised part of the Swedish section of the Grong-Stekenjokk area is the **Stekenjokk** subarea (N025.1) with the Stekenjokk, Levi and a number of other deposits included in the Fennoscandian Ore Deposit Database. The **Stekenjokk** deposit and the nearby and stratigraphically correlated **Levi** deposit are hosted by volcanic rocks mainly of felsic composition that were deposited as submarine ash flows and subvolcanic intrusions (Zachrisson 1986a). The volcanic rocks in the stratigraphic footwall of the ore have been strongly altered. Overlying the volcanic rocks is a thin layer of graphitic phyllite tentatively correlated, on the basis on high contents of U, Mo and V, to the Cambrian-Ordovician alum shale occurring as platform cover at the Caledonian Front (Sundblad & Gee 1985). The ores at Stekenjokk and Levi consist of two different types, a massive stratabound pyritic ore and an irregularly disseminated pyrrhotitic ore, the latter interpreted to represent the stringer zone to the massive ore. Both massive and disseminated ores contains varying proportions of pyrite, pyrrhotite, chalcopyrite, sphalerite and galena. Ore and host rocks at Stekenjokk and Levi have been multiply folded and elongated into the present shape (Zachrisson 1986b).

Sulphide mineralisation at Stekenjokk was first identified at the beginning of the 20th century when sulphide-bearing boulders were found in the area. Subsequent drilling in 1918–1921 and 1952–1963 outlined the ore and mining started in 1975 (Zachrisson 1986a). Mining was terminated in 1988 due to low metal prices after the production of 7 Mt of ore. In 2006, IGE announced combined reserves and resources for Stekenjokk and Levi at 10 Mt (IGE 2006).

N026 BINDAL Au

Peter Ihlen (NGU)

The Bindal metallogenic area (N026) is in the central northwestern part of the Scandinavian Caledonides. It is part of a much wider area containing abundant, small epigenetic deposits of precious metals and base-metal sulphides. They show a strong spatial relationship with the Late Ordovician to Early Silurian Bindal Batholith (BB, Nordgulen et al. 1993) intruding amphibolite-facies country rocks of the Helgeland Nappe Complex (HNC) of the Uppermost Allochthon. Although W±Au and Zn-Pb-Cu skarn deposits are locally present, the deposits mainly comprise polymetallic sulphide veins containing variable proportions of Au, Ag, As, Pb, Cu, Zn, Fe, Sb, Bi, W, U and Th (Ihlen 1993). Native gold and electrum are predominantly found associated with arsenopyrite and/or Pb-Sb-sulphosalt veins in the contact zone of the main granitoid massifs of the BB. Veins composed of similar mineral assemblages yield generally low gold grades (<1 ppm Au) when occurring at a distance from the intrusive contact.

The deposits in the Bindal area are typical representatives of orogenic gold deposits. They mainly comprise shear-related Au-As veins hosted by the Early Silurian Oksdal granite massif as well as granitic dykes and metamorphogenic quartz veins occurring in its supracrustal country rocks (Fig. 56). The gold deposits in the province are assumed to have formed at the end of the Silurian continent-continent collision (Scandian orogeny) and associated nappe emplacement and obduction of the BB (Nordgulen et al. 1993), but prior to late extension related to the tectonic collapse of the nappe pile in the Devonian (Ihlen 1993, 1995).

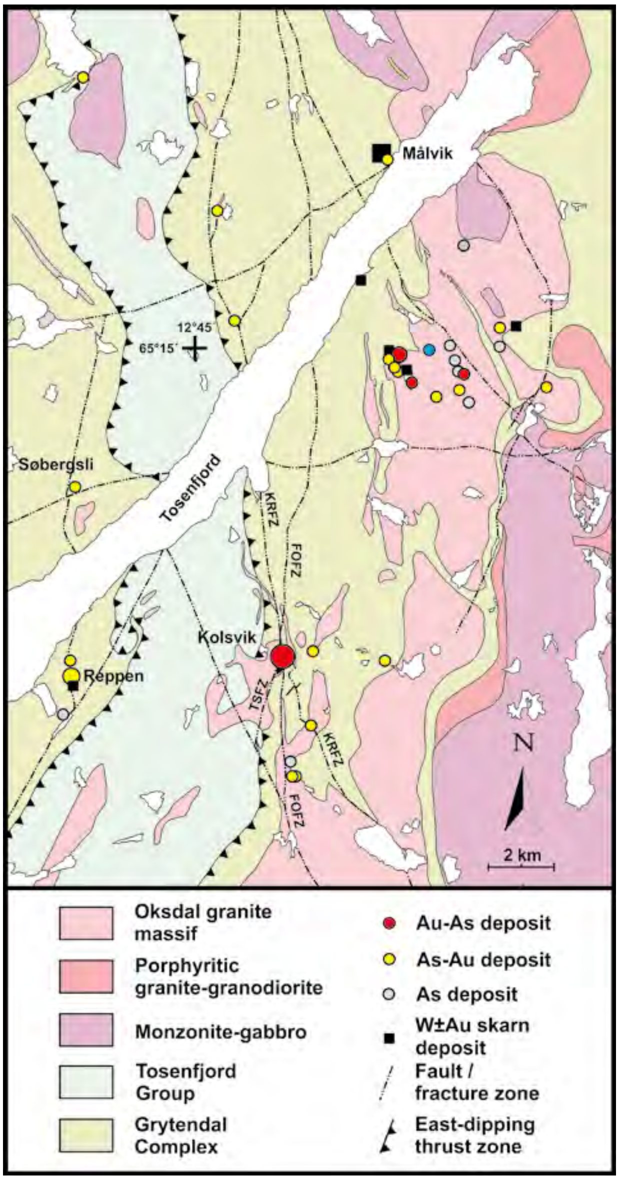


Figure 56. Simplified geological map of the Bindal area showing the distribution of auriferous deposits with size of symbols indicating their importance. Map redrawn from Ihlen (1993).

Gold was discovered at **Kolsvik** in about 1910 by a local farmer, Konrad Kolsvik. This led to extensive exploration in the area in the following years when a number of auriferous veins were discovered, mainly by Boliden AB during the first half of the 20th century. Most of them were found in the interior of and in the endocontact of the Oksdal granite massif, which intrudes amphibolite-facies supracrustal rocks of the Grytendal Complex and the Tosenfjord Group characterised by the presence of abundant granitoid dykes. The Grytendal complex comprises dominantly sillimanite- and kyanite-grade migmatitic two-mica gneisses hosting small bodies of anatectic granites and units of calc-silicate gneiss, amphibolite, marble and quartzite. The Tosenfjord Group constitutes a separate nappe unit within the Grytendal Complex and is composed of meta-sandstone, hornblende schist, calc-silicate gneiss, marble and polymict conglomerate which unconformably overlie a basement of harzburgite and dunite occurring as small bodies along the base of the nappe (Thorsnes & Løseth 1991).

Most of the deposits in the area N026 comprise one or two parallel, steeply-dipping mineralised shear zones intersecting grey, coarse- to medium-grained two-mica granites and granodiorites of the Oksdal granite massif. These shear zones rarely exceed 75 m in length and 1 m in width. The direction of the veins varies from ENE–WSW via E–W to ESE–WNW. However, major deposits such as Kolsvik and Reppen occur associated with regional N–S to NNE-trending shear zones.

The Kolsvik deposit in the centre of the area has been investigated by several companies since its discovery in the early 20th century. Several thousand metres of core have been drilled, together with the construction of several hundred metres of exploratory adits and minor underground workings. NGU, who conducted a detailed geological survey of the deposit, estimated the potential ore reserves on the basis of previous drill-core analyses from A/S Sulfidmalm and Terra Mining AS to about 0.85 Mt with highly variable gold grades over 1–2 m true width of the ore zones. About 0.2 Mt of these potential reserves were suggested to exceed 7 g/t Au (Ihlen 1993). Gexco Norge AS discovered additional ore veins during its investigations in the period 2003–2009.

The mineralisation is connected to the steeply east-dipping Kolsvikbogen–Ringvatn Fault Zone (KRFZ), which can be followed for more than 20 km in a N–S direction through the Oksdal granite massif and its metasedimentary country rocks (Figs. 56 and 57). The rocks along the fault zone exhibit deformation structures suggestive of early ductile and intermediate-stage brittle dextral shearing and late ductile shearing in conjunction with reactivation of the KRFZ and associated ore structures as normal faults during Devonian extension. The gold mineralisation is related to the intermediate stage and seems restricted to a 950-m-long segment of the KRFZ in the roof of the granite pluton. In this region, the KRFZ bifurcates into a number of ore-bearing splays designated the B, C, D and F ore zones (Fig. 57), as the fault follows and partly penetrates the interfingering contact between granitoid-veined supracrustals of the Grytendal Complex and the two-mica granites that are intruded by small bodies and dykes of leucogranite and late leucotonalitic dykes. These leucocratic intrusions, which are the main host-rock for the gold-arsenopyrite vein mineralisation, crosscut the D3 mylonite zones in the late Silurian two-mica granite of the B zone. There, the mylonites and undeformed leucocratic dykes carry superimposed auriferous arsenopyrite veins showing no signs of ductile shearing. The supracrustals, which behaved mainly ductilely

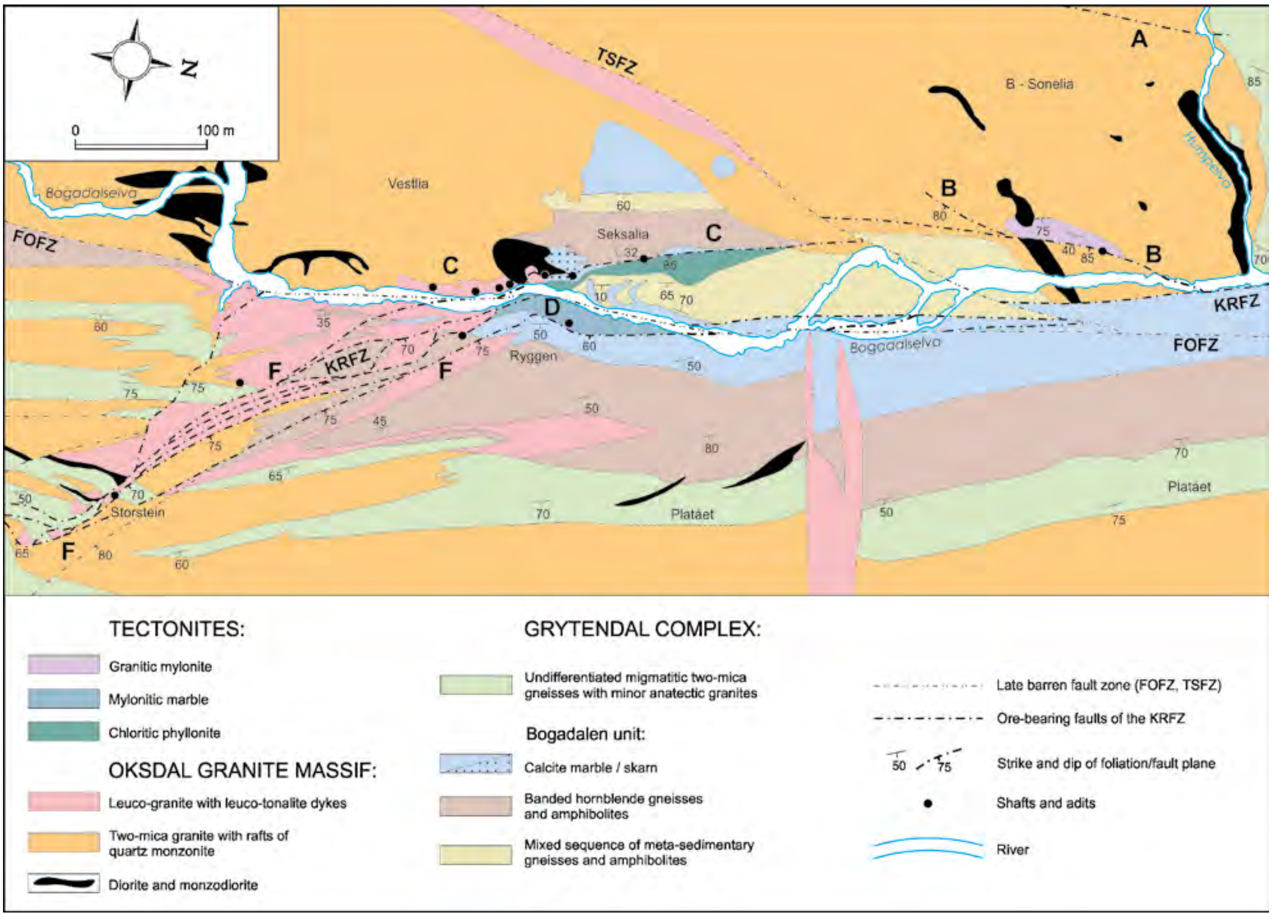


Figure 57. Simplified geological map of the Kolsvik deposit redrawn from Ihlen (1993). Capital letters indicate the different mineralised segments of the fault and fracture zones.

during the brittle deformation of the granites, are only weakly mineralised, and comprise variable migmatitic biotite gneisses of the Grytendal Complex, which includes the east-dipping Bogadalen unit composed of marbles, amphibolites, calc-silicate and hornblende gneisses. Core logging gives indications that the bifurcated segment of the fault zone (950 m long) converges both to the north and south as well as down-dip (150 m) to form a single fault zone. The Finnlia–Oksdalen fault zone (FOFZ) and the Tverrelva–Skavvassfjell fault zone (TSFZ), both of regional extent, dextrally offset the KRFZ. Both the FOFZ and the TSFZ are enveloped by strong chlorite alteration which, along the TSFZ branch, occurs associated with strong silicification and quartz breccias (TSFZ) containing only accessory arsenopyrite. It appears to have developed subsequent to the main auriferous event.

Gold-arsenopyrite mineralisation is found scattered in the granites over a wide area, but mainly on the footwall side of the KRFZ. The best and most continuous gold mineralisation, however, occurs in areas where the KRFZ intersects leucogranites and -tonalites, that is, in the southern and central parts of the bifurcated fault zone. The 0.5–5 m wide ore zones, commonly containing economic grades of gold (3–10 g/t, max.1200 g/t), occur along the individual faults and splays of the KRFZ and in the immediately adjacent, fractured and brecciated granites. Arsenopyrite is the dominant ore mineral and carrier of native gold. It forms massive to semimassive veins, breccia cement and a stockwork of thin veins, which intersect both undeformed and mylonitic two-mica granites, as well as sheared synplutonic glassy and milky quartz veins in them. Arsenopyrite is rarely accompanied by any co-precipitated gangue minerals such as quartz. It also occurs as disseminated aggregates in the leuco-granites or as fine-grained dissemination in black ultracataclastic quartz veins along the faults and in the matrix of quartz-cemented breccia veins. Only 0.5 % of the registered arsenopyrite veins in the drill core are hosted by supracrustals, mainly by amphibolite.

The native gold contains 4–30 % Ag. Although it locally occurs as visible grains (<1 mm) along shear planes in the milky quartz veins, it is normally found intergrown with arsenopyrite as microscopic grains (1–50 µm). It is rarely encountered along fractures in the arsenopyrite crystals, even when the latter are strongly fractured by later reactivation of the mineralised structures. This, and the presence of abundant inclusions of native gold (1–10 µm) in arsenopyrite, suggests that the two minerals co-precipitated. The arsenopyrite crystals also occur intergrown with minor scheelite and contain inclusions of galena, rutile and, rarely, Bi-tellurides. They locally show fractures and interstices filled with galena, chalcopyrite, bismuthinite, native bismuth, Bi-Sb sulphosalts (giessenite and kobellite) and/or several unidentified Pb-Bi and Au-Bi sulphides. The massive arsenopyrite veins are intersected by quartz-chlorite-pyrite veins, which post-date the latest event of extensional ductile shearing. The latest mineralisation event is characterised by marcasite forming zoned crystals around cores of uraninite or thorite.

The gold mineralisation was formed subsequent to episodes of skarn alteration, silicification and muscovitisation of the granites and adjacent country rocks. It seems to be coeval with the development of late quartz breccias and fracture-bound sericite alteration, which are widespread in the leucogranites but less pronounced in the surrounding two-mica granites. Breccias, occurring as veins and small bodies without any apparent structural control, may have formed by hydraulic fracturing. Post-ore hydrothermal activity includes chlorite alteration and veining, and late stilbite-calcite-chlorite breccias and veins, all associated with several episodes of extensional tectonism.

The **Reppen** deposit in the western part of the area (Fig. 56) comprises mineralisation of Au, As, Sb, Pb and Zn outcropping over a distance of about 1 km in the hanging wall of a regional N-trending fault zone intersecting granite-veined supracrustals of the Grytendal complex. The Søbergsli Au-As deposit is possibly related to the fault extension north of Tosenfjord. This steeply-dipping reverse fault (55–70° E) separates migmatitic mica gneisses in the west from banded calcitic marbles in the east at Reppen. The gneisses and granite dykes in them show mylonite and cataclastite development along the fault plane. The marble in the hanging wall of the fault is the main ore-hosting unit, having a strike and a dip of 040–065° and 20–55°, respectively, and intersected by a dense network of granite sills and flat-lying interconnecting dykes 1–15 m thick. The sills and dykes are frequently pervasively fractured and brecciated. Hydrothermal activity during this brittle deformation generated quartz breccias, a stockwork of quartz veins and narrow single veins as well as fracture-bound silicification of the granites locally grading into 1–5-m-thick lenses of massive quartz. The gold mineralisation occurs superimposed on the silicified and quartz-veined sills mainly along their margins and locally in the immediately adjacent marbles.

It comprises semimassive veinlets and dissemination of co-precipitated arsenopyrite, pyrite and native gold. Both the quartz veining and the arsenopyrite mineralisation decrease in intensity away from the fault zone, and cease after about 150 m towards the east. The Reppen ore is characterised by shoots rich in jamesonite and boulangerite which, like the other sulphides, contain inclusions of native gold occasionally filling micro-fractures. Work conducted by A/S Sulfidmalm in 1982–1983 on large samples from the old trenches indicate 5–7 g/t Au over 4–5 m. The tonnage was considered to be about 1 Mt. Core drilling also revealed the presence of garnet-clinopyroxene skarns in the marbles at depth. These contain pyrrhotite mineralisation with enhanced contents of scheelite and gold (0.1–0.3 g/t Au). Similar skarn mineralisation, with up to 5 g/t Au, is also found elsewhere in the HNC.

The **Målvik** tungsten deposit in the northeastern part of the area comprises scheelite mineralisation which occasionally yields 1–2 ppm Au together with enhanced contents of As and Bi. Scheelite as dissemination and veinlets occurs together with coprecipitated epidote and amphibole in plagioclase-clinopyroxene and garnet skarns. The skarns replace hornblende-biotite gneisses with units of calcitic marbles (Skaarup 1974, James et al. 1993). The up to 60-m-wide and 900-m-long heterogeneous skarn zone with highly variable contents of scheelite is intersected by numerous granite dykes locally containing fractures coated by auriferous arsenopyrite.

N027 VEFSN (RALLKATT) Fe

Rognvald Boyd (NGU)

The iron deposits in the Vefsn metallogenic area (N027) are on the southern side of Ranafjord, about 60 km SW of the Rana iron district in the Dunderlandsdal valley (N029). Søvegjarto (1977) regarded the Vefsn lithologies, both the ores and their host rocks, as a continuation of those in Dunderlandsdal. Solli & Nordgulen (2008) indicate that both belong to the lowermost nappes within the Uppermost Allochthon of the Caledonides. This correlation implies that the Vefsn deposits were also deposited during the Neoproterozoic, at ca. 660 Ma (Melezhik et al. 2003). Over twenty mineral occurrences are known from area N027, ranging from quite small showings to a deposit with resources of 30 Mt. Several of the deposits have been known since the late 1800s. All the deposits of any significance were investigated using geophysical methods and geological mapping by Rana Gruber (see Rana iron ore district) in the 1970s, but none was then found to merit drilling. Only one of these, **Rallkatt**, has been included in the FODD.

The ores in the Vefsn area differ from those in the Rana area in the following respects: 1) They are exclusively magnetite-haematite ores, containing 0.15–0.3 % P. No apatite-bearing magnetite occurrences have been found. 2) Most of the occurrences are in a sequence of mica schists, garnetiferous below the ores, and actinolite-carbonate-bearing above, the schists themselves occurring in a sequence dominated by dolomitic and calcitic marbles: this has broad similarities to the ores in the Rana district. 3) Several of the occurrences, though probably of a similar origin to the normal metasediment-hosted ones, occur as lenses in later dioritic and granodioritic intrusives of, as yet, unknown ages.

The three most important deposits in area N027 are **Fuglestrand**, with resources of >13 Mt, Rallkatt with 19 Mt and **Seljeli** with 30 Mt of potential ore. Fuglestrand contains 37 %, Rallkatt 30 % and Seljeli 19 % Fe_{tot}. The phosphorus concentration is <0.3 % in all three. Magnetite is the predominant ore mineral at Fuglestrand, with lesser haematite, while the reverse is the case at Seljeli, and at Rallkatt, the amounts are approximately equal. The dominant gangue minerals at Fuglestrand and Rallkatt are quartz, amphibole, epidote and calcite, and at Seljeli quartz, calcite, amphibole, biotite, chlorite and epidote.

N028 RANA–HEMNES Zn-Pb-Cu

Terje Bjerkgård (NGU), Anders Hallberg (SGU)

The Rana–Hemnes Zn-Pb-Cu area (N028) covers a large domain around the Okstindan mountains in Nordland, Norway and Västerbotten, Sweden. In the area, there are two major sulphide deposits: Bleikvassli and Mofjell, as well as numerous smaller deposits, especially in the Mofjell district. The deposits are situated in the Rödingsfjäll Nappe Complex in the Uppermost Allochthon of the Scandinavian Caledonides (Bjerkgård et al. 1997). The hosting lithologies are metasedimentary sequences with minor intercalations of mafic and felsic metavolcanic rocks. According to Grenne et al. (1999), most of the sequences were probably deposited on the margin of the Laurentian plate during rifting of Rodinia and development of an Atlantic-type or passive margin. This seems to hold true for the southern part of the area, where there are thick units of alumina-rich kyanite-garnet mica schist, calcareous mica schist, quartz-feldspar schist, dolomite and calcite marble, divided into two groups separated by an unconformity, the Anders Larsa and Kongsfjell Groups (Ramberg 1967). The main part of the Kongsfjell group is characterised by high-Al kyanite-garnet mica schists, probably clay-rich sediments deposited under low-energy conditions in a deeper marine environment. Metabasalts in the units have a MORB to transitional MORB character (Bjerkgård et al. 1997). The depositional age of the sediments is 590–600 Ma according to Sr-isotope data on the marbles (Bjerkgård et al. 1995). During both Caledonian and pre-Caledonian events, the lithologies were strongly deformed, folded and metamorphosed at middle- to upper-amphibolite facies (Ramberg 1967, Brattli 1996).

The sediment-hosted **Bleikvassli** Zn-Pb(-Cu) deposit is in the southern part of the area N028. About 5.0 Mt of ore grading about 0.15 % Cu, 4.0 % Zn, 2 % Pb, and 25 g/t Ag was mined from 1957 to 1997. The deposit is structurally at the top of the Kongsfjell Group, very close to the Anders Larsa Group, in mainly muscovite-kyanite schists and quartz-feldspar gneisses (Fig. 58). Structurally below the deposit is a thick and laterally persistent unit of amphibolite, which either represents a large gabbroic sill or a massive volcanic flow. Chemical analyses also indicate that some of the quartz-feldspar gneisses are felsic volcanics, including the units associated with the deposit (Bjerkgård 1999).

The ore body consists of a discontinuous layer of massive, semimassive and disseminated sulphides, is more than 1500 m long, up to 300 m wide and up to 20 m thick in fold hinges. Average *in situ* values based on more than 1400 drill hole analyses are 0.27 % Cu, 5.17 % Zn, 2.72 % Pb, 45 g/t Ag and 0.21 g/t Au. The average iron content is 16.9 %, showing that it is a semi-massive ore body (op. cit.). The ore is generally concordant with the wallrocks, but crosscutting relationships also occur, especially near fold hinges, due to remobilization. Three types of sulphide ore are recognised at Bleikvassli: 1) massive pyrite ore, 2) massive pyrrhotite ore and 3) mobilisate-type veins and veinlets, mainly in the wallrocks (Vokes 1963). The pyrrhotite ore is enriched in Cu compared to the pyrite ore (Vokes 1962, 1963, Bjerkgård 1999). The mobilisates are enriched in galena, chalcopyrite, sulphosalts, silver and gold. The distribution of the two main ore types shows a very consistent pattern: The pyrrhotite ore occurs mainly in the deeper, southern part of the deposit, whereas the pyrite ore is mainly restricted to the upper, northern part of the deposit. Vokes (1963) suggested that the pyrite and pyrrhotite ores represent syngenetic compositional variations, noting a zonation from Cu-rich pyrrhotite ore to pyrite ore with lesser Cu, structurally upwards from footwall to hanging wall, but he also observed reverse zonation patterns. Skauli (1992) interpreted thin bands of veined pyrrhotite ore as relicts of a primary stringer zone. It has been suggested that the observed unconformity between the Kongsfjell and Anders Larsa Groups represents a pathway for both the volcanics and the hydrothermal solutions forming the Bleikvassli deposit (Bjerkgård et al. 1997).

The **Gräskevardo** (Gräskovardo) deposit in Sweden occurs in a broadly similar stratigraphic position as the Bleikvassli deposit and is also hosted by sediments (Stephens et al. 1978). The disseminated ore consists of pyrrhotite, pyrite, galena, sphalerite, chalcopyrite and magnetite and can be traced for at least 4 km along strike (Sundblad 1982). Similar Bleikvassli, Gräskevardo is a Zn>Pb>Cu deposit with 0.1 Mt with 0.35 % Cu, 3.49 % Zn, 1.23 % Pb as determined from four samples from the deposit (Sundblad 1982).

The Mofjell subarea (N028.1) makes up the northern part of the Hemnes-Rana area. The area comprises numerous smaller and larger sulphide deposits situated in the volcanosedimentary Mofjell Group. Many of these have high grades of base metals, silver and/or gold. The favourable geological setting (arc with bimodal igneous rocks and large amounts of sediments), and the high number of sulphide occurrences show that this is an area with a high potential for new economic discoveries. The Mofjell Group (Søvegjarto et al. 1988) is dominated by quite massive grey gneisses with persistent layers of amphibolite and aluminous biotite and muscovite gneisses (Marker 1983). The grey gneisses represent partly greywacke-type sediments, and partly felsic metavolcanic rocks. Parts of the commonly garnet-bearing amphibolites contain pods and stripes of calc-silicate rock (interpreted as pillow lavas). The biotite and muscovite gneisses are generally rich in quartz and aluminosilicates (staurolite, kyanite) in addition to mica. They may form separate, generally persistent layers, but grade into each other with changing proportions of biotite and muscovite.

The biotite (-hornblende) and muscovite gneisses invariably contain disseminated pyrite and are important for hosting all the stratabound Zn-Pb-Cu sulphide occurrences recorded in the Mofjell Group, including those of the Mofjell mine. Several stratigraphic levels with zones of exhalites and pyrite mineralisation can be traced for several kilometres along strike. Based on limited lithogeochemical studies of the amphibolites, it has been suggested that the Mofjell Group was formed in a volcanic-arc or back-arc environment (Bjerkgård et al. 1997). This group has a tectonic contact to the underlying units.

The **Mofjellet** Zn-Pb (Cu) deposit produced 4.35 Mt of ore with average grades of 3.61 % Zn, 0.71 % Pb and 0.31 % Cu in the period 1928–1987. The average silver and gold contents in the mainly semimassive ore were around 10 and 0.3 ppm, respectively. In the last years before the mine was closed down, high gold grades were encountered in diamond drilling (up to 7 ppm in a 1.4 m interval). The deposit consists of three ruler-shaped ore bodies situated more or less on top of each other (Fig. 59). The ore bodies have a maximum width of about 100 metres. The two upper lenses (lenses I and II) are connected through tight folding in a generally north-facing fold structure, the so-called AKP structure.

This very important structure can be followed along the entire length of the ore body. Lens III forms a separate ore body on the lower limb of this major north-facing fold structure. The de-

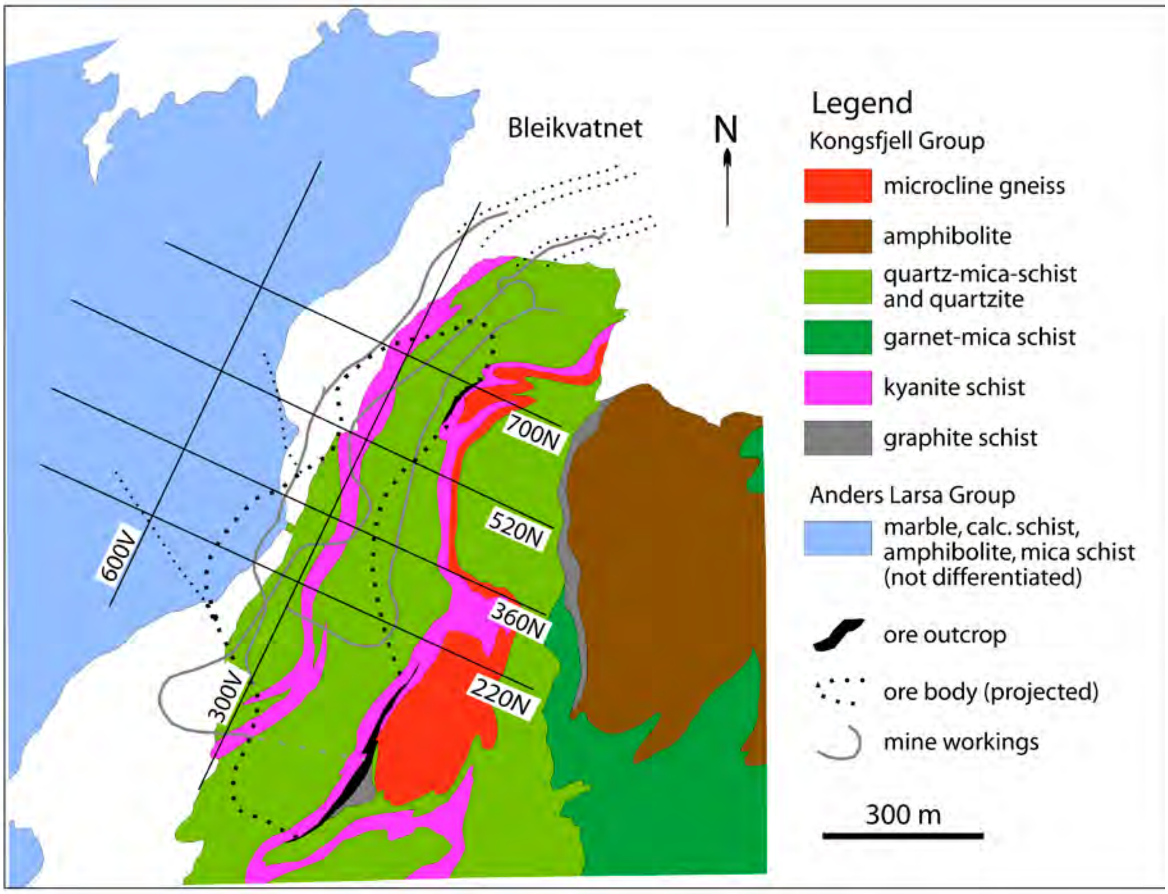


Figure 58. The Bleikvassli deposit: Geology and horizontal projection of the ore body (dotted lines).

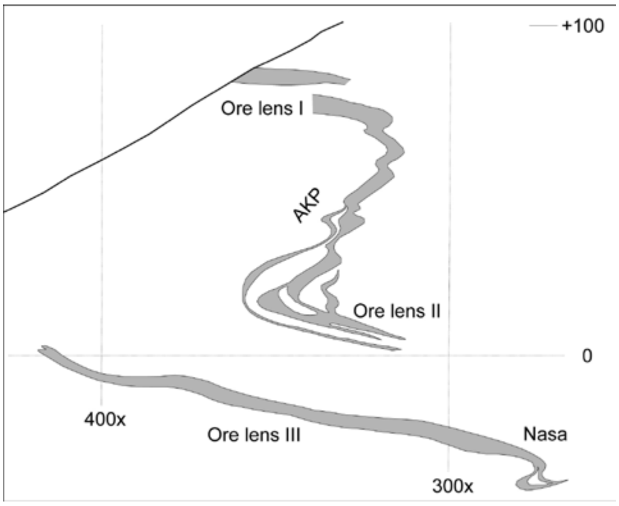


Figure 59. Schematic N–S profile from the westernmost part of the Mofjell deposit, showing the general structure and division of the deposit into individual ore lenses. The grid is 100 x 100 m.

posit consists of alternating semimassive ore layers, layers of sulphide disseminations and layers of wall rock at a metre scale or less. The ore layers rarely contain as much as 50 % sulphides. The most important ore minerals are pyrite and sphalerite, whereas galena, chalcopyrite and pyrrhotite occur in subordinate amounts. Various sulphosalts, arsenopyrite, native antimony and gold-silver alloys are found in variable, but generally accessory amounts. Important gangue minerals include quartz, biotite, muscovite, calc-silicates (epidote, amphibole, diopside, garnet), calcite, plagioclase, and magnetite.

In many cases, coarse sulphides form dissemination and semimassive veins, overprinting the more fine-grained sulphide layers or are injected into layers of wall rock. These coarse sulphides have much higher contents of galena, chalcopyrite and sulphosalts, and commonly lower contents of sphalerite and pyrite, than the ordinary ore layers, and were apparently formed by remobilisation of sulphides from the original layers. Based on the features of the ore, including structure, mineralogy and associated lithologies, the Mofjell deposit most probably represents a syngenetic, exhalative hydrothermal mineralisation, formed at or near the seafloor during the Neoproterozoic.

Several smaller deposits of similar type as the Mofjell deposit are present further east in the Mofjell area. The largest of these are shown in Figure 60. There is also an ongoing exploration campaign to find new economic deposits in addition to that at Mofjell. To the west, across the Rana Fjord, is the **Båsmo** deposit (just outside the high potential area, Fig. 60). This deposit is hosted by garnet-chlorite schist probably belonging to the Plurdal Group. Båsmo was mined for pyrite and 1.85 Mt was produced, giving a concentrate containing 49 % S, 44 % Fe, 0.4 % Cu and 0.4 % Zn from ore with 20 % S, 0.13 % Cu and 0.14 % Zn.

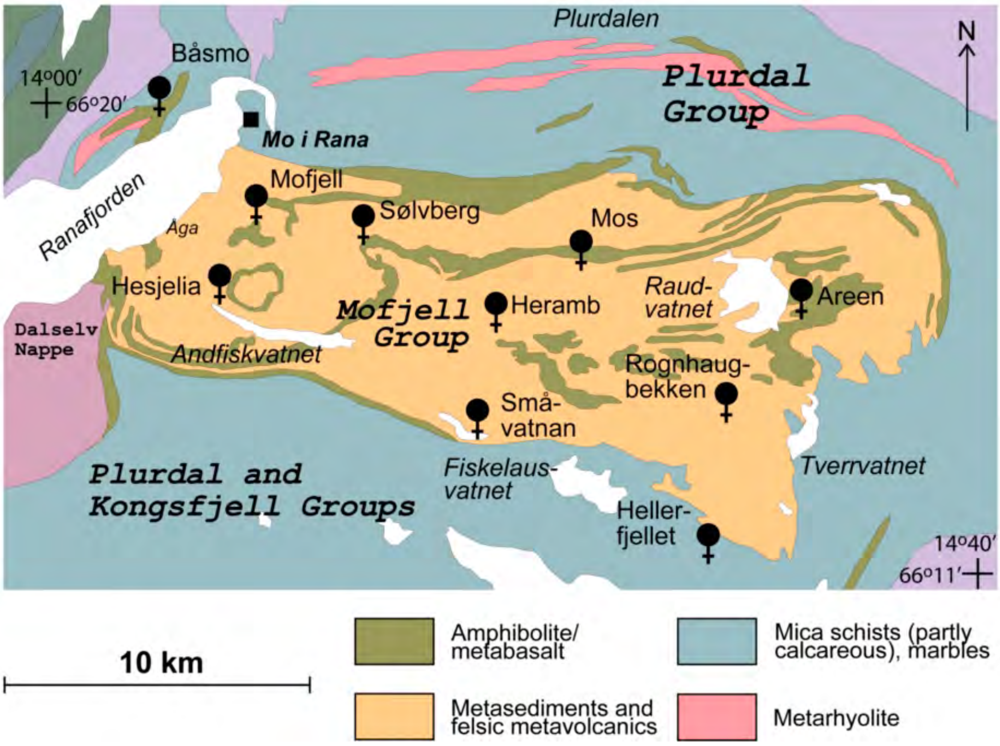


Figure 60. Geology and major sulphide deposits in the Mofjell region.

N029 RANA Fe

Rognvald Boyd (NGU)

The iron deposits in the Dunderlandsdal valley in Rana (N029) were well known prior to 1799, when an iron works in southern Norway was awarded mining rights for the area (http://www.ranagruber.no/). In 1901, the iron works were bought by the Edison Ore Milling Syndicate, established by Thomas Alva Edison in order to exploit patents he held on the magnetic separation of iron ore. An open-pit mine was established at Ørtvann near the village of Storforshei, 32 km north of Mo i Rana by the Dunderland Iron Ore Company in 1902, and production of iron-ore briquettes began in 1906, but was terminated after two years for environmental reasons. Sporadic production followed until 1937 when Rana Gruber AS was founded by A/S Sydvaranger and the German Vereinigte Stahlwerke. After WWII, the company was taken over by the Norwegian government and later, in 1961, incorporated into A/S Norsk Jernverk, a fully integrated pig iron producer. Pig iron production ceased in 1989, but Rana Gruber had, by then, developed a range of speciality products based on iron ore: powder metallurgy, coal washing, water purification, and chemical-technical uses. In 1990, Rana Gruber became the first company in the world to produce advanced

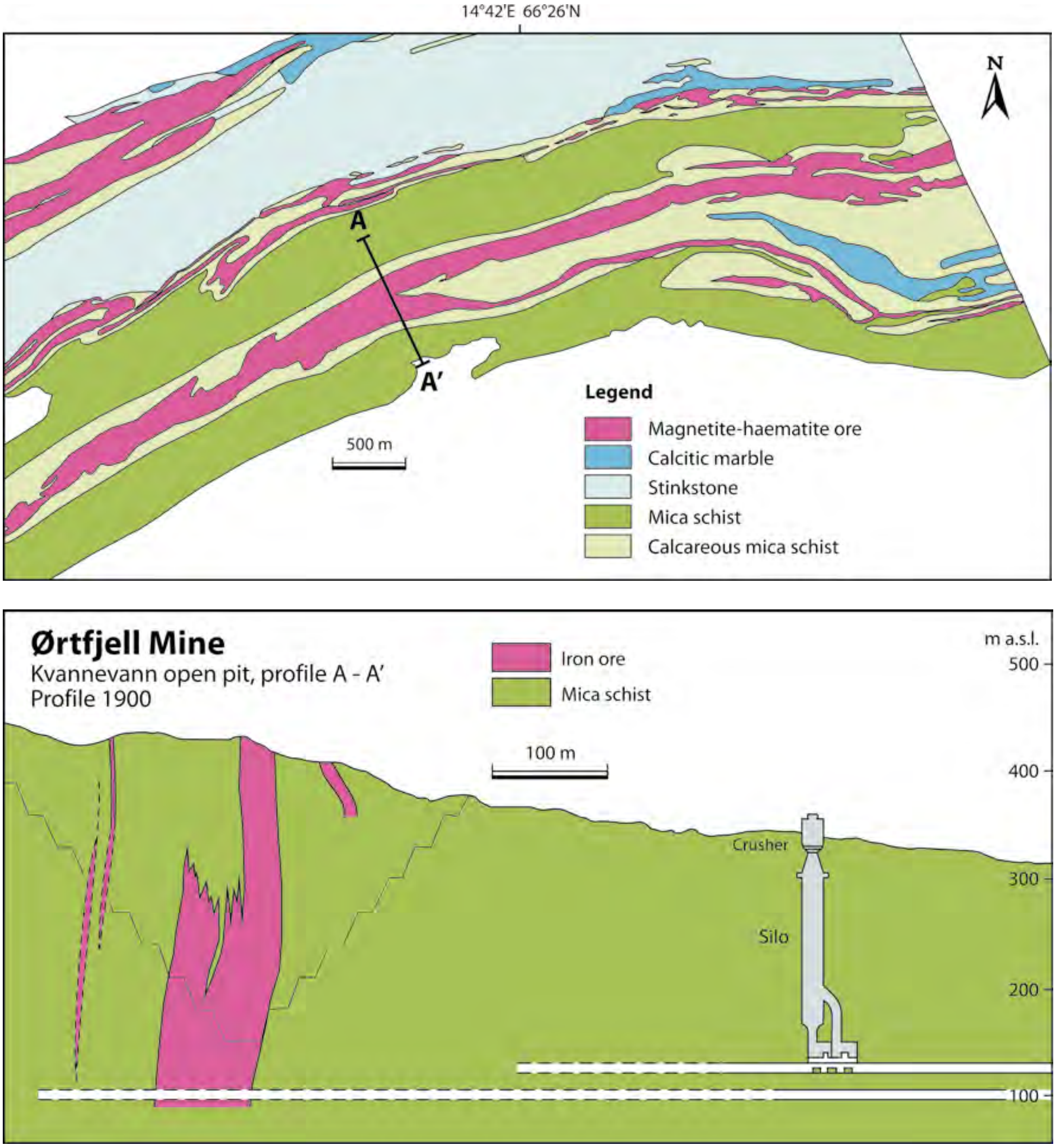


Figure 61. Surface map and cross section of the Kvannevann ore body (http://www.ranagruber.no/).

natural black iron oxide pigments from magnetite superconcentrates. Total production from the early 20th century to the present is thought to have been about 100 Mt, grading from 33 to 37 % Fe.

The iron ore units belong to the Ørtfjell Group, part of the Ramnåli Nappe, which itself is part of the Rødingsfjell Nappe Complex (Gjelle & Søvegjarto 2004). The immediate host rocks of the mineralisation are mica schists of various types, but the schists themselves occur in a sequence dominated by dolomitic and calcitic marble several hundred metres thick. The sequence hosting the ore extends from Mosjøen in the south almost to Tromsø in the north (see also N027 and N034), and is thought to have been deposited in Neoproterozoic times, at ca. 660 Ma (Melezhik et al. 2003). Two main ore units are known, ranging in thickness from a few metres to 30 m (Bugge 1978b): 1) an upper magnetite-haematite ore, containing 0.15–0.3 % P, and 2) a lower apatite-bearing magnetite ore containing 0.8–1 % P. Both units contain several ore bodies, the most important ones belonging to the upper unit. These include the **Ørtfjell** deposit, by far the largest in the district, which includes the Kvannevann mine, currently producing roughly 2.1 Mt/a. Mining at the current level (Fig. 61) will allow production until 2023. The magnetite:haematite ratio averages 2:1 at Ørtfjell, but ranges down to 1:10 in other deposits within the upper unit. Where haematite is dominant, the gangue minerals are quartz, calcite, epidote and biotite, and where magnetite is dominant, the gangue minerals are quartz, calcite, biotite, hornblende and grünerite (Bugge 1978b). Bands of pyrrhotite up to 1 m thick are present at the margins of the ores, and minor amounts of pyrite are common. The upper unit is also enriched in manganese, commonly containing 5–10 % MnO.

N030 SULITJELMA Cu-Zn

Terje Bjerkgård (NGU), Anders Hallberg (SGU)

The Sulitjelma area (N030) includes more than 20 deposits with a total tonnage in excess of 35 Mt (Cook et al. 1990). The average grades of the 25 Mt mined from 11 deposits between 1887 and 1991 are 1.84 % Cu and 0.86 % Zn (Table 11). Contents of precious metals are 10 g/t Ag and 0.25 g/t Au (Cook et al. 1990). The Norwegian deposits within the N030 are concentrated in an area of 25 km^2, and are at varying stratigraphic-structural levels in the Otervann Volcanic Formation (Cook et al. 1990), also known as the Sulitjelma Amphibolites, in the Upper Allochthon Køli Nappe Complex (Fig. 62).

The palaeotectonic setting of the volcanic rocks is disputed. According to Boyle (1989), the volcanic rocks form the extrusive part of the Sulitjelma ophiolite complex, underlain by sheeted dikes of the Mietjerpakte Intrusive Complex and below that being the Sulitjelma Gabbro Complex. Inclusions of Precambrian gneiss in the Sulitjelma Gabbro have been interpreted to show that the ophiolite complex represents a fragment of an ensialic marginal basin (Cook et al. 1990). The gabbro has been dated to 437 ± 2 Ma (Pedersen et al. 1991), and because of the cogenetic relationships between the young gabbro and the volcanic rocks, it has been argued that the term ophiolite complex is inappropriate (Grenne et al. 1999). Structurally below the volcanic rocks, there is a thick sedimentary sequence of schists, the Furulund Group, which contains fossils of Upper Ordovician to Lower Silurian age (Spjeldnæs 1985). The whole rock package has been folded isoclinally, leading to a large-scale repetition of sedimentary and volcanic units. This also means that the ore units are repeated (Cook et al. 1990).

The volcanic pile is divided into several units, and the sulphide deposits are found at different levels within these units (Fig. 63). The deposits are further divided into a Southern and a Northern Ore Field. The **Jakobsbakken**, **Sagmo** and **Anna** deposits are in the Southern Ore Field (Fig. 62). Jakobsbakken is the most zinc-rich of the deposits, containing 4.5 Mt of ore with 1.55 % Cu and 2.42 % Zn. It also is at a structurally lower position than the other two, closer to the underlying Furulund Schist.

Most of the deposits are in the Northern Ore Field. The **Ny-Sulitjelma** and **Bursi** deposits are the structurally lowest in this ore field, and are situated between overlying metabasalts of the so-called Giken Amphibolite Unit and the Furulund Schist (Cook et al. 1990). Structurally higher up in the Giken Amphibolite Unit is the Hankabakken–Palmberg ore zone. The largest of the deposits in the Sulitjelma field, **Giken**, is situ-

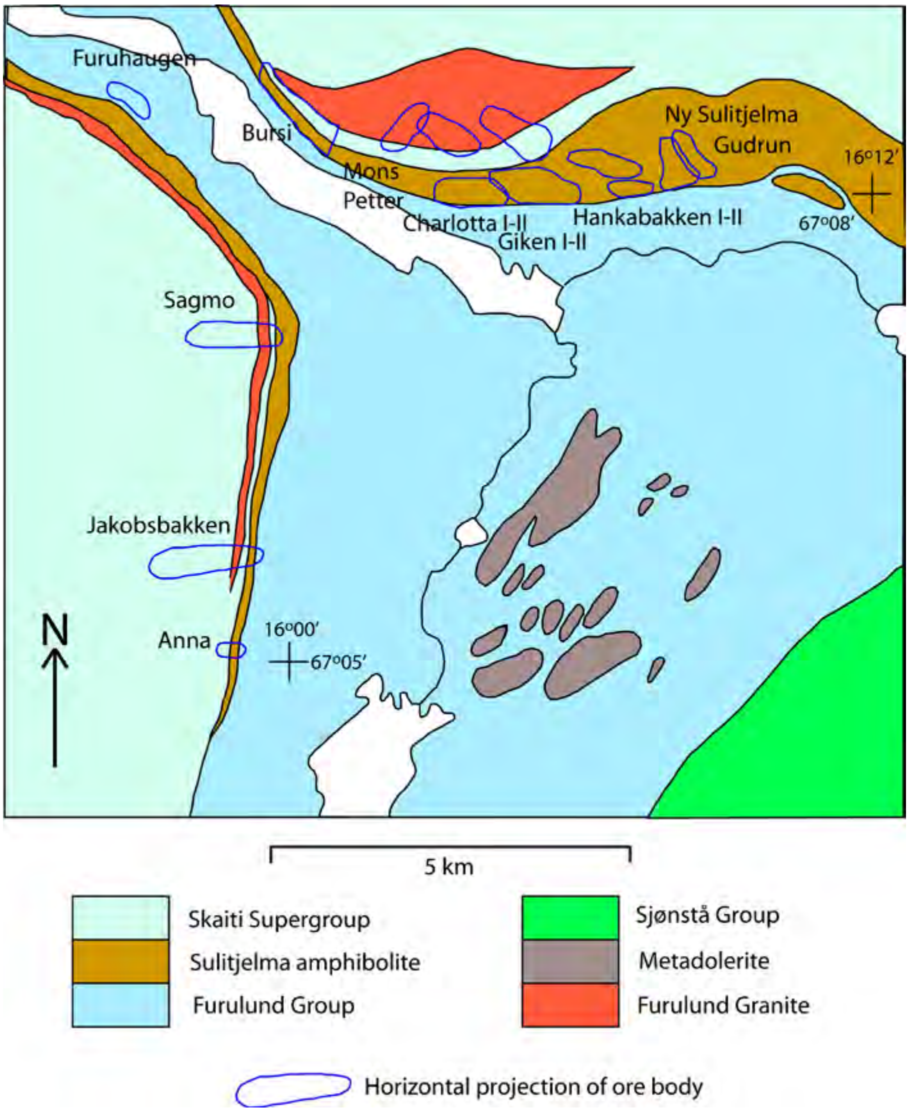


Figure 62. Geology and ore deposits in the Sulitjelma Ore District. The outlines of the main deposits are shown as horizontal projections (in blue line) (modified from Cook et al. 1990).

ated structurally above the Giken Amphibolite Unit and below a schist unit (the Leirelva Schist) equivalent to the Furulund Schist. The Giken deposit contained 10.5 Mt of ore, of which 5.8 Mt was mined, containing 2.25 % Cu and 0.7 % Zn. Further up structurally is the **Charlotta** deposit, which is located at the contact between the Leirelva Schist and the Lower Amphibolite Unit. It is possible that this is the same level as the Sagmo deposit in the Southern Ore Field. The **Mons Petter** deposit is the structurally highest ore zone in the Northern Ore Field, and is situated between the Lower and Middle Amphibolite Unit. The

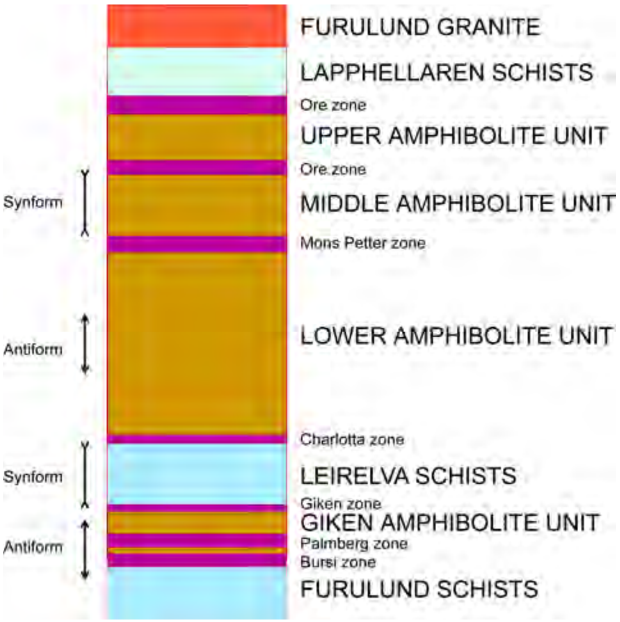


Figure 63. Stratigraphic column of the Sulitjelma Amphibolite Group in the Northern Ore Field, indicating the structural levels of the main horizons hosting sulphide ore bodies (from Cook et al. 1990).

Table 11. Massive sulphide deposits in the Sulitjelma metallogenic area (N030). All data from the Norwegian national ore database except Jervas (from Stephens et al. 1978).

Deposit	Total tonnage (Mt)	Mined (Mt)	Reserves (Mt)	Cu %	Zn %
Giken	10.5	5.8	4.7	2.25	0.7
Jakobsbakken	4.5	4.47	0.03	1.55	2.42
Charlotta	3	3	0	2	0.58
Ny-Sulitjelma	2.59	2.59	0	1.99	0.55
Mons Petter	2.5	2.5	0	1.75	0.48
Hankabakken	2.49	1.99	0.5	1.4	0.4
Sagmo	1.9	1.9	0	1.6	0.23
Bursi	1.845	1.83	0.015	1.5	0.31
Gudrun	0.71	0.71	0	1.49	0.55
Furuhaugen	0.52	0.37	0.15	1.65	
Anna	0.29	0.29	0	3.86	
Fjelds	0.25	0	0.25	1.5	
Jervas	~10	-		0.46	0.07

westernmost, small **Furuhaugen** deposit (0.52 Mt) has an uncertain structural position; it may occur even at a higher stratigraphic level than Mons Petter.

The **Jervas** deposit is in Sweden, around 30 km south of the Sulitjelma deposits, within rocks of similar age and at a similar stratigraphic position. Historic resource estimates give about 10 Mt with 0.46 % Cu, 0.07 % Zn and 0.03 % Pb, most of the ore occurring as dissemination in altered rocks (Grip & Frietsch 1973, Stephens et al. 1978).

Polyphase deformation with a high degree of folding and amphibolite-grade metamorphism has obliterated most primary textures and mineralogical zonation patterns in the Sulitjelma metallogenic area. However, several of the deposits are underlain by alteration zones, and display zonation in base metals in accordance with classical VMS type deposits (Cook et al. 1990).

N031 LOFOTEN Fe-Ti

Peter Ihlen (NGU)

The Lofoten metallogenic area (N031) is part of a NE-trending belt of titaniferous mafic intrusions, which extend from Andøya in the north via Vesterålen (N033 Selvåg) to the westernmost islands of Lofoten in the south. Fe-Ti-oxide deposits in the Lofoten area are mainly confined to the Flakstadøy Anorthosite Complex (FAC). Subordinate beach-sand deposits are additional constituents of this metallogenic area and reflect the enhanced background levels of Fe-Ti oxides in the Quaternary tills, as well as in their high-grade metamorphic and plutonic source rocks.

Beach-sand deposits are especially widespread along the western side of Moskenesøy, where the beaches are facing the North Atlantic. One of them, the Kalvika deposit comprises several-metres-thick sequences composed of alternating 1–2 cm layers of black Fe-Ti-oxide sand and light grey quartz-feldspar sand. The total content of Fe-Ti oxides in the sand is estimated to about 25 %.

Orthomagmatic deposits occur associated with the FAC, which represents a 15-km-long and up to 3-km-wide NE–SW-trending intrusion along the eastern coast of Flakstadøy. The magma generating the FAC was emplaced as a plagioclase-rich crystal mush that crystallised under polybaric conditions at 9–4 kbar and 1185–1140 °C, which is similar to many massif-type anorthosite complexes (Markl et al. 1998). It intrudes banded and migmatitic supracrustals affected by high-grade metamorphism (Fig. 64). The original western gabbroic margin of the FAC has been obliterated by the emplacement of a somewhat younger massif of mangerites (Markl et al. 1998). Similar anorthosites and mangerites in the eastern part of Lofoten yield U-Pb ages (zircon) at about 1.79 Ga, whereas charnockites where formed at 1.84 Ga (Corfu 2000).

The FAC can be subdivided into three units, of which the two lower units show igneous layering dipping 15°–65° east. They comprise a lower inhomogeneous gabbro-norite unit, an intermediate leuco-troctolite unit and an upper anorthosite unit (Romey 1971). The Fe-Ti oxide ores explored in the past are only developed in the lower and intermediate unit, where irregularly distributed patches of low-grade sulphide dissemination also occur, partly overlapping the Fe-Ti ore zones. The sulphides comprise mainly pyrrhotite intergrown with accessory pentlandite (Carstens 1957). Presence of chalcopyrite is indicated by whole-rock analyses conducted by NGU yielding less than 0.06 % Ni and 0.15 % Cu.

The lower unit is up to 2 km wide and is, according to the description given by Romey (op. cit.), composed of a multitude of gabbroic, noritic and anorthositic rocks of highly variable colour index and grain size. It is predominantly composed of isotropic coarse-grained leuconorites with a colour index of 20–30 %. In some areas it contains more than 10 % of disseminated Fe-Ti oxides, which also occur enriched along thin pyroxenitic layers. The leuconorite carries scattered megacrysts of plagioclase (5–20 cm), which becomes

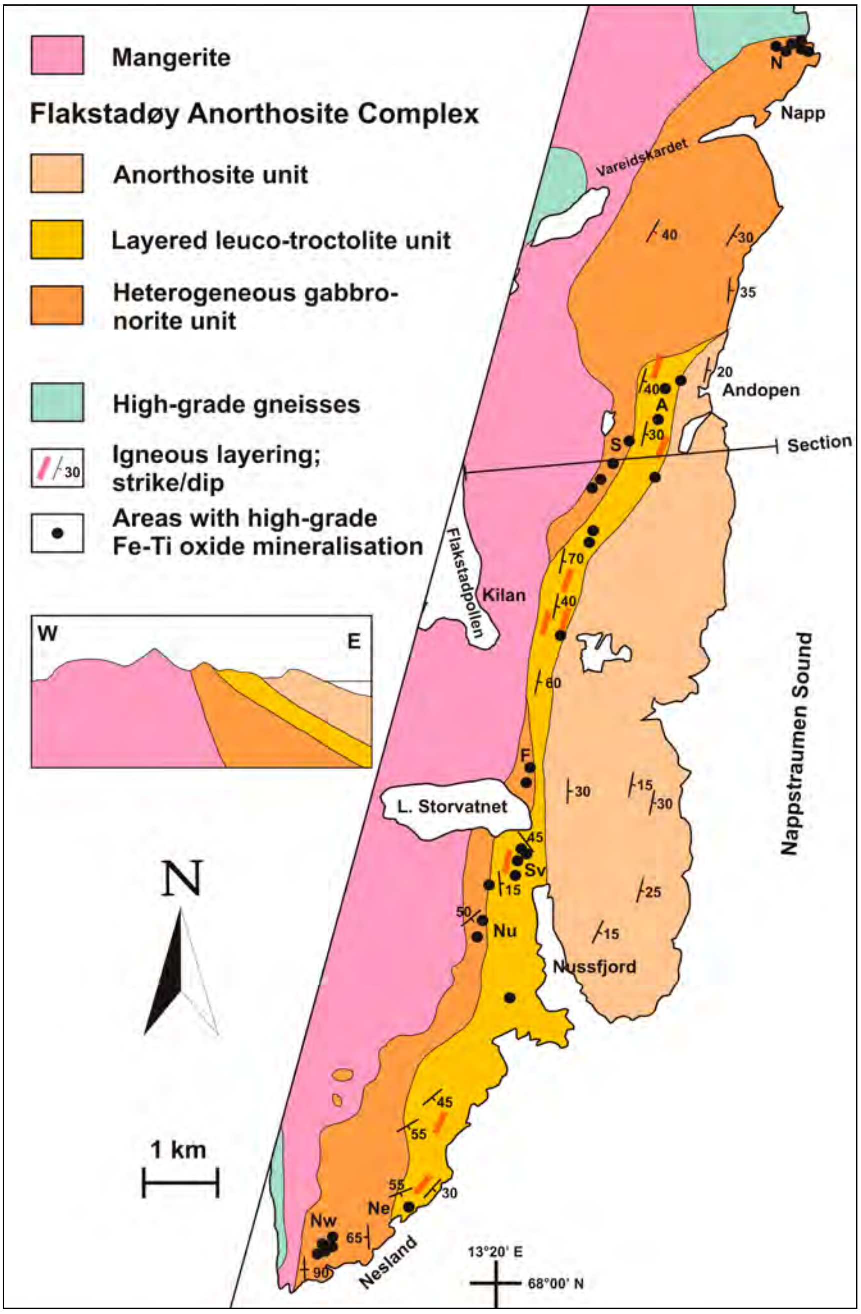


Figure 64. Geological map of the Flakstadøy Anorthosite Complex compiled from Romey (1971) and Markl et al. (1998). The high-grade areas comprise: A = Andopen, F = Fiskefjellet, N = Napp, Ne = Nesland, east, Nu = Nussfjord, Nw = Nesland, west, S = Sørdalen, Sv = Svadet and WN = Nesland-west

densely spaced along the border of an underlying footwall zone occupied by fine- to coarse-grained isotropic gabbros Nesland (west) and hypersthene gabbros (Napp) (Fig. 64).

The gabbros are strongly enriched in Fe-Ti oxides, which are mainly composed of magnetite and subordinate hemoilmenite. The former contain exsolution lamellae of spinel and minor ilmenite, whereas the latter contain lamellae of hematite and accessory corundum (Carstens 1957). The mineralised areas at Napp, Sørdal, Fiskefjellet, Nussfjord and Nesland, each 10 000–50 000 m^2 in size, comprise gabbros with dissemination of magnetite+ilmenite (10–15 %) and frequently containing several-metres-wide layered zones composed of magnetite-pyroxenite layers (15–80 % magnetite + ilmenite) alternating with layers of leucogabbro, anorthosite and unmineralised pyroxenite. Metre-thick pods of massive magnetite ore are also occasionally encountered. The spacing, abundance of Fe-Ti oxides, and thickness of the mineralised layers vary considerably in both the lower and intermediate unit. The individual layers are normally from a few mm up to 1 m thick and rarely extend for more than a few tens of metres along strike.

The intermediate unit is 200–500 m thick and composed of coarse-grained leuco-troctolites that show gradational contacts with both the upper anorthosite unit and the lower gabbro-norite unit (Romey op. cit., Markl et al. op. cit.). In contrast to the lower unit, the abundance of disseminated Fe-Ti oxides is much lower in the isotropic leucotroctolites, which, however, contain a higher frequency of areas with igneous layering. The Fe-Ti mineralisation at Andopen, Svadet and Nesland, is mainly confined to several-metres-thick, layered zones locally attaining a thickness of 20 m. The mineralisation comprises densely spaced semi-massive to massive cumulate layers of magnetite-ilmenite alternating with, and grading into, olivine-rich peridotitic layers with dense dissemination of oxides. The layers are generally 1–20 cm thick and alternate with layers of anorthosite, olivine-norite, mela- and leucotroctolite, peridotite and minor dunite with low contents of Fe-Ti oxides. Lenses of massive ore with thicknesses in the range 1–3 m are less widespread. Grab samples of sulphidic Fe-Ti ores from Andopen contain, according to old reports, 52–57 % Fe, 7–10 % TiO_2, 0.29–0.33 % V and 0.66–1.14 % Cu.

The upper unit is exposed as a 2-km-wide zone of very coarse-grained anorthosites, which grade from anorthositic norites in the lower part of the unit via noritic anorthosites to true anorthosites in the upper eastern part. The anorthositic rocks contain only minor amounts of disseminated Fe-Ti oxides.

The Fe-Ti occurrences in the FAC have never been explored in detail, and the average grades of the described Fe-Ti zones are unknown. However, magnetite concentrates have been extracted from large test samples from the Napp and Andopen deposits in the lower and intermediate unit, respectively. The magnetite-hypersthene gabbro at Napp yielded concentrates with 64.69–66.36 % Fe, 1.8–3.9 % TiO_2 and 0.37–0.40 % V, whereas the magnetite-pyroxenite layers gave concentrates with 64.71 % Fe, 2.60–2.87 % TiO_2 and 0.42–0.46 % V. The magnetite-rich layers at Andopen contain magnetite with 3.3–3.5 % TiO_2 and 0.34–0.46 % V (Carstens 1957).

N032 RÅNA Ni-Cu

Rognvald Boyd (NGU)

The Råna intrusion (metallogenic area N032), located 30 km SW of Narvik in the Nordland county, is one of a suite of intrusions and ophiolite complexes in the Scandinavian Caledonides that all have very similar ages, that of Råna being 437 +1/-2 Ma (Tucker et al. 1990). The emplacement of these bodies is interpreted to be due to a period of extension immediately prior to continent–continent collision in the Scandian Orogeny (Andréasson et al. 2003). Two of the suites, Råna and Skjækerdalen, carry Ni-Cu mineralisation. Råna is the intrusion with the highest proportion of ultramafic rocks and the most magnesian olivine. It appears to be the only intrusion in which the crystallisation order olivine-orthopyroxene-plagioclase-clinopyroxene is dominant.

The Råna intrusion is located within the Narvik Nappe complex in the Upper Allochthon of the Caledonides. Structural relationships within and around the intrusion (Fig. 65) make it clear that the country rocks were exposed to at least one phase of isoclinal folding prior to emplacement of the mafic magma, and that the intrusion and its country rocks were subjected to at least three deformation phases and amphibolite-facies metamorphism after solidification. The surface expression of the intrusion and gravity data indicate that it has the overall form of an inverted cone, its deepest part, also containing the highest proportion of ultramafic rocks, being on the northwestern and northern margins, where predominantly ultramafic rocks extend to at least 2.5 km below sea level. Southern and central parts of the intrusion, east of Storvatnet, do not extend to any great depth below sea level and contain no significant component of ultramafic rocks. The crudely conical form probably is a result of tectonic compression, bringing originally subhorizontal cumulate layers close to the N margin of the intrusion into a subvertical position. There are also clear indications, in drill-hole profiles from the Bruvann region in the northwestern part of the body (Figs. 65 and 66) and in certain outcrops, of instability and intrusive relationships within the magma chamber prior to its complete solidification.

The Tverrfjell klippe, east of lake Storvatnet (Fig. 65), the only near-surface part of the intrusion to show classical layering features, lies in an open E-trending synform. Synformal structures also exist in the southwestern part of the intrusion, but these are tight to isoclinal and are probably linked to a zone of compression and shearing, which extends eastwards along Eiterdal, structurally above the Tverrfjell klippe and possibly postdating the fold that defines the Tverrfjell structure. There are clear indications of a SE-directed thrusting along the NW margin of the intrusion, the most important being the "block" extending from Bruvann to Råna, which is bounded to the SE by a series of shear zones with which several EM anomalies are associated (Singsaas 1973). These, and possibly earlier stages of movement, have resulted in the incorporation of extensive sheets of country rock, some of which are graphite- and sulphide-bearing, into the intrusion. The youngest tectonic features seen are subvertical N-striking faults, thin shear zones and fractures, among them the faults that displace the southern contact of the Tverrfjell klippe, and probably structures that influence the location of Lake Storvatn.

The geometry of the NW part of the intrusion is compatible with the theory that the ultramafic cumulates at Arnes (Fig. 65) represent the northern limb of an antiformal structure, cored by intrusive norite, and with an inverted sequence from country rock, through marginal norite (Basal Series) and into the Ultramafic Series defining the structure (Lamberg 2005). Remains of the "uppermost" part of the Ultramafic Series are exposed on the top of Arneshesten, and its continuation forms the southern limb of the antiform in the Bruvann area. The Ultramafic Series in the Bruvann area forms two blocks separated by a SW-trending hinge fault (Fig. 65). The ultramafic units in the eastern block dip southwards, forming the northern limb of a synform with a shallow westward plunge. The ultramafic units west of the hinge fault dip north-northwestwards and are

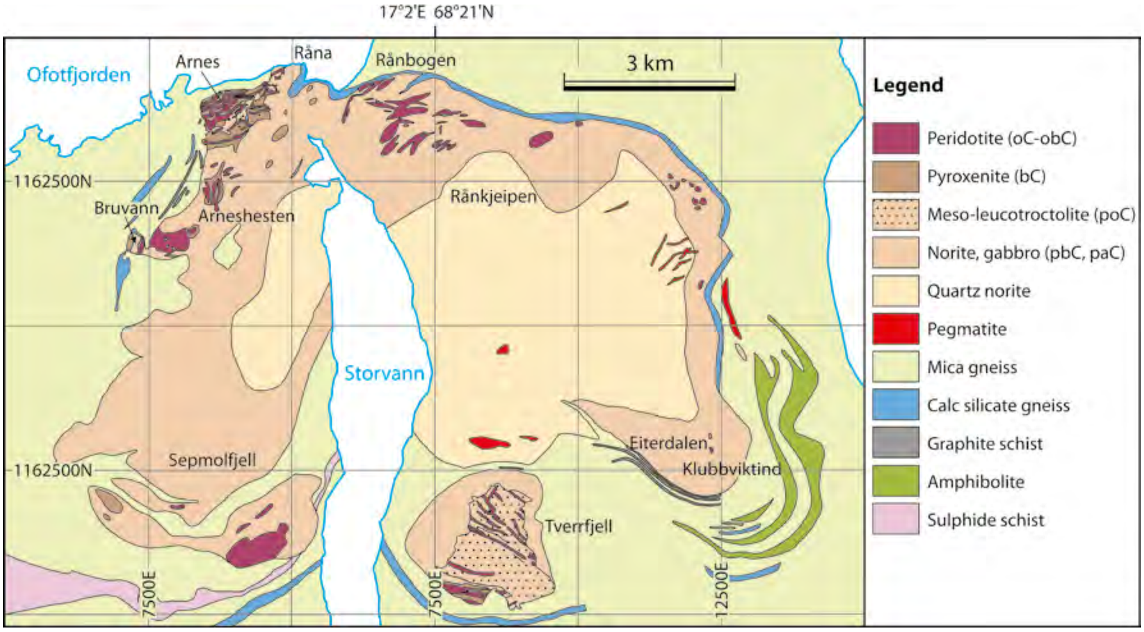


Figure 65. Geology of the Råna intrusion, from Lamberg (2005), after Boyd & Mathiesen (1979), Barnes (1986) and Karppanen et al. (1999).

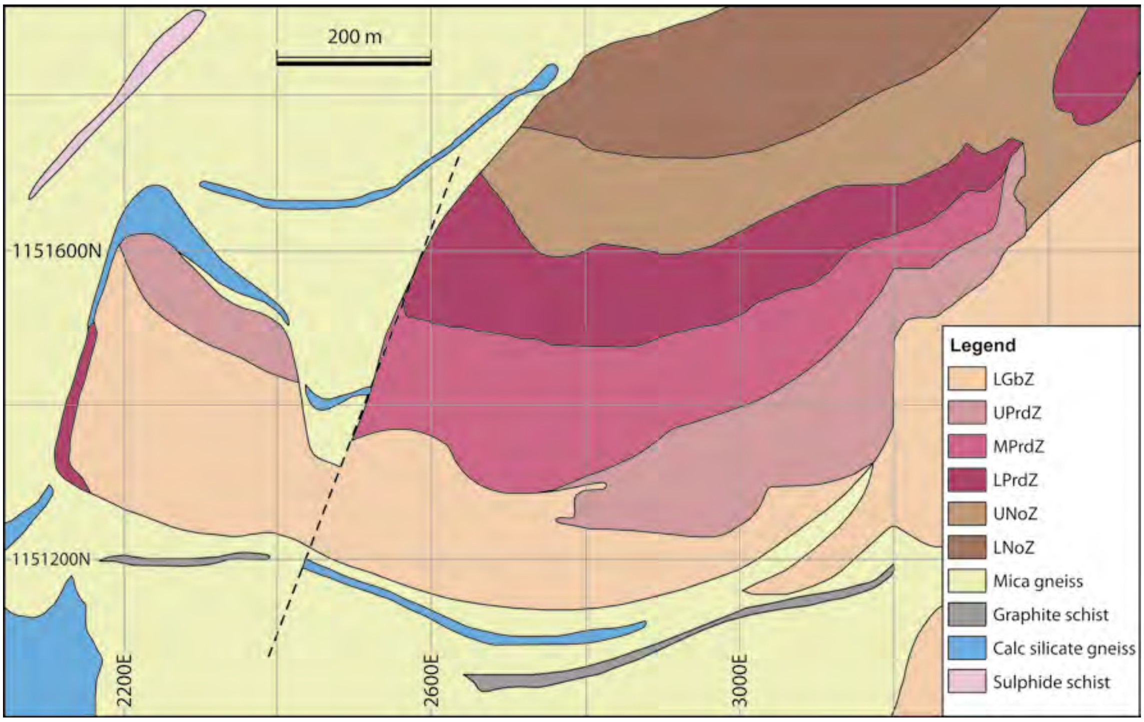


Figure 66. Geological map of the Bruvann area (Lamberg 2005, modified after Boyd & Mathiesen 1979 and Karppanen et al. 1999).

seen in drill hole profiles to be clearly intersected by the westward continuation of the norite block, which forms a ridge north of the ultramafic units on the eastern side of the hinge fault.

There are several ways of explaining these relationships. The following explanation differs from that of Lamberg (2005): 1) Formation of the Basal and Ultramafic Series on the inward-dipping floor of a magma chamber in the form of an inverted cone. 2) Compression from the NW, leading to the overturning of the northern margin of the chamber and thrusting of the NW block of the intrusion to the SE before the Norite Series had completely crystallised. 3) Upward intrusion of norite into the now inverted Ultramafic Series. 4) Continued thrusting of the NW block of the intrusion to the SE, along shear zones on the SE side of Arneshesten. This tectonic stage also led to the development of shear zones along internal contacts (e.g., the contacts between the norite core and the Ultramafic Series) and to the incorporation of slices of country rock into the intrusion. This stage coincided with amphibolite facies metamorphism, which, although clearly seen in the shear zones, left large volumes of mafic and ultramafic rock with their original textures and mineralogy. 5) Late-stage, possibly near-brittle shearing and faulting, including the hinge fault at Bruvann. There is a consensus between Boyd & Mathiesen (1979), Boyd (1980) and Lamberg (2005) that the Ultramafic Series is dominated by products of the following crystallisation order: olivine-orthopyroxene-plagioclase-clinopyroxene. Certain magma pulses, especially at higher levels, show clinopyroxene before plagioclase. Barnes (1986) concluded that the primary magma was a primitive olivine tholeiite with about 12 % MgO.

The earliest exploration activities in the Råna intrusion took place almost 100 years ago (Foslie 1921, 1922). Numerous exploration campaigns have been carried out, especially in the **Bruvann** region. The general form of the northwestern part of the intrusion and of most of the mineralisation in the Bruvann area became clear during an exploration campaign funded by Stavanger Staal (1970–75) and by special governmental funding (1977–81), implemented by the Geological Survey of Norway. Subsequently, the Bruvann ore body was mined (1989–2001) by Nickel og Olivin, in which Outokumpu Oy had a majority ownership from late 1995. In addition to Ni-Cu concentrate, the intrusion has yielded the following products: 1) olivine from Bruvann was tested for use as a flux in iron-ore pellets in the early 1980s, 2) norite and pyroxenite from Bruvann have been produced for use as hard-rock aggregate, and 3) the pegmatite north of Tverrfjell has been a source of high-purity quartz.

The Bruvann occurrence is characterised by the assemblage pyrrhotite+pentlandite+chalcopyrite±pyrite occurring interstitially in olivine±orthopyroxene cumulates and grading up to 0.8 % sulphide-bound Ni. Locally, the dissemination grades into massive sulphide containing up to 5 % Ni. Prior to mining, reserves were calculated as 43 Mt with 0.33 % sulphide Ni, 0.08 % Cu and 0.01 % Co (cut-off 0.15 % sulphide Ni). The tonnage mined during 1989–2001 was 8.2 Mt grading 0.52 % Ni at a cut-off in the range 0.43−0.47 % depending on the nickel price (Scandinavian Highlands 2009). The remaining ore has been calculated as 9.15 Mt grading 0.36 % Ni (cut-off at 0.30 % Ni) or alternatively 5.5 Mt grading 0.39 % Ni (cut-off at 0.35 % Ni) (Scandinavian Highlands 2009). Platinum metals grades are in the low ppb range (<5 ppb), whereas gold values up to 75.6 ppb have been recorded (Boyd et al. 1987). Recalculated to content in total sulphides, the highest precious metal values, in a sample of weak dissemination, contained 175 ppb Pt, 251 ppb Pd and 3246 ppb Au. The concentrations of precious metals are abnormally low in relation to those of Ni and Cu, leading to the conclusion (Barnes 1987) that the magma was depleted in precious metals by the removal of a small amount of sulphides (implicitly enriched in precious metals) prior to saturation of the sulphides, which are now present at or near the surface of the intrusion.

As shown in Figure 66, graphitic schists are a common feature in the vicinity of the intrusion, also occurring as slices in shear zones within the intrusion. Ramdohr (1969) shows an illustration of Bruvann in which graphite occurs in sulphide dissemination in olivine cumulate. Sulphur isotope data (Boyd & Mathiesen 1979) do not suggest that external sources of sulphur had more than a very local impact at Råna. Lamberg (2005) believes that other geochemical indicators (O and Sm-Nd isotopes) support an important role for crustal contamination, also with black schists.

Several of the earliest prospect pits are in the Rånbogen region close to the northern margin of the Råna intrusion. The most prominent mineralisation in this area is semi-massive to massive sulphide associated with black schist and occurring in ENE-trending shear zones. All available data on this occurrence suggest that the Ni content in the sulphide phase is <2 %, which is only 20–25 % of the values for the Bruvann ore. Data from Barnes (1987) suggest that the Rånbogen occurrence contains approximately 9 ppb Pt, 6 ppb Pd and 4.5 ppb Au which, because the host rocks are much more sulphide-rich, gives contents in the sulphide phase <10 % of those at Bruvann.

The **Eiterdal** occurrence is located on the outer contact of the intrusion near the base of a steep rock wall SW of the mountain Klubbviktind in the SE corner of the intrusion. The occurrence is hosted by an olivine norite at a sheared contact with calc-silicate rock containing graphitic schist. The norite contains several types of mineralisation, including blebby sulphide and interstitial mineralisation transitional to more massive sulphide. Barnes (1987) suggests that this occurrence is similar in composition to that found at Rånbogen.

N033 SELVÅG Fe-Ti

Are Korneliussen (NGU)

Massive and disseminated Fe-Ti deposits occur in gabbros and anorthosites emplaced into Palaeoproterozoic supracrustal rocks and Archaean gneisses within the Selvåg area (N033). A major Fe-Ti deposit occurs in the layered Selvåg gabbroic intrusion (Fig. 67; Priesemann & Krause 1985). This intrusion contains cumulate layers of magnetite and ilmenite. An overview of the geology of the area has been given by Griffin et al. (1978).

The **Selvåg** deposit (Priesemann & Krause 1985) is a part of the Eidet–Hovden Palaeoproterozoic layered mafic intrusion that crystallised under granulite-facies conditions within a series of migmatitic gneisses. The deposit, which consists of a northern and a southern ore body separated by a fault, is within modally layered cumulates of three types: (1) low-grade disseminated Fe-Ti oxides in fairly uniform cumulates, (2) medium-grade ore in a heterogeneous cumulate sequence, with from 8 vol.% Fe-Ti oxides in mesocratic cumulates to 30 vol.% within pyroxenite layers, with an average of 20 vol.%, and (3) high-grade ore with 30 vol.% Fe-Ti oxides within pyroxenite layers. The main resource is associated with the northern ore body, particularly in its eastern part, facing the Selvågdalen valley. The ore is composed of titanomagnetite, ilmenite and sulphides (mainly pyrrhotite), with titanomagnetite as the main ore constituent. The resource is 44 Mt defined by core drilling and categorised as probable ore at 25 % Fe, 2.5 % Ti and 0.15 % V. The vanadium content in magnetite concentrates is about 0.6 wt.% V_2O_3.

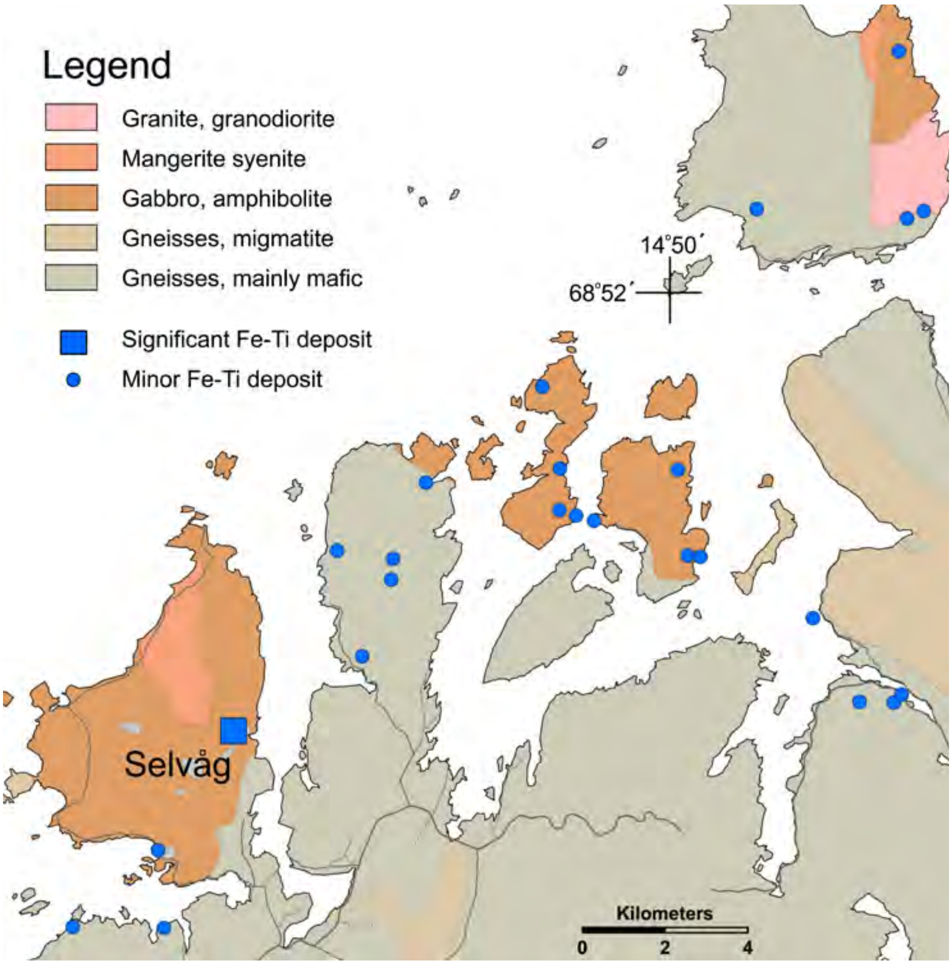


Figure 67. Registered Fe-Ti deposits and occurrences in NW Vesterålen.

N034 TROMS Fe

Jan Sverre Sandstad (NGU)

The Troms metallogenic area (N034) contains over 180 iron deposits and occurrences (Fig. 68). They represent the northernmost extension of the numerous iron oxide deposits from south of Mosjøen to Tromsø in the north, a distance of more than 500 km, and include the metallogenic areas Vefsn (N026) and Rana (N028). The iron oxide beds are extensive, several km long along strike. Exploration was carried out in the region in several periods during the 20th century. However, substantial production has not been carried out in any of these deposits, mainly due to their somewhat low Fe content.

The stratabound-stratiform iron oxide deposits occur in metasedimentary rocks in the lowermost nappes within the Uppermost Allochthon of the Caledonides (Grenne et al. 1999). The host rocks are dominantly calcareous mica schists and marbles, whereas quartzite and metavolcanic rocks occur locally. The sequence is thought to have been deposited in Neoproterozoic times, at ca. 660 Ma based on isotope analyses of marbles (Melezhik et al. 2003). Magnetite and hematite occur in various proportions, both within and between different deposits, and apatite-bearing iron oxide deposits are common (0.8–1.0 % P; Søvegjarto 1977). Manganese contents of the sediment-hosted Caledonian iron oxide ores are fairly low as a whole (0.15–0.40 %), but in certain ores in the Troms area the Mn content can be as high as 15 %, mainly present as spessartine garnet, less importantly as mangano-calcite (Foslie 1949). Locally, magnetite contains 1–3 % MnO. The iron oxide ores have been assumed to be of sedimentary origin, but amphibolitic host rocks in some areas suggest that volcanic processes may also have affected mineralisation (Grenne et al. 1999). Four of the iron oxide deposits in the area are included in FODD: Andørja, Espenes (Sørreisa), Gunnarheimen (Lavangen) and Mosan (Fig. 68; Table 12).

The largest and best-studied deposit is **Andørja**, which is located close to the sea on the island of Andørja. It was discovered around 1910, but the most extensive exploration was carried out by Christiania Spigerverk A/S during 1957–1963 (Wanvik 1983). In total, 125 holes with a combined length of 14,147 m were drilled. Beneficiation tests were performed in 1991–1992 and 1998–1999, but the iron concentrate was not found suitable for special products similar to those for the Rana area ores (Lindahl 1999). The banded iron ore occurs within a 70–180-m-thick amphibolite, probably a metavolcanic rock, and comprises several ore lenses and beds that are 3–20 m thick. Locally, they are densely spaced and could be mined together over a 50 m thickness. The average Fe content is 25 % total Fe, with 18 % magnetic Fe and 1 % P. Magnetite is the only iron oxide observed in the ore. Common gangue minerals are hornblende, oligoclase, biotite, quartz, and locally some garnet (Lindahl 1999). The total tonnage is estimated to 70 Mt. The minor **Mosan** deposit nearby contains 7.2 Mt of magnetite ore (15.5 % magnetic Fe) hosted by amphibolite.

The **Gunnarheimen** deposit constitutes the northern part of the Lavangen phosphorous iron-oxide deposits. The magnetite-bearing formation is 200 m thick and consists of mainly calcareous mica schist and marble. Magnetite occurs disseminated in 0.5–5-m-thick lenses over a strike length of more than 3 km in mica schist. The average total Fe content is 25 %, with 18 % magnetic Fe and around 1 % P.

Espenes is the most significant deposit in the Sørreisa region. Iron exploration at Sørreisa commenced in 1903, and minor trenching and test mining was conducted over a strike length of 6–7 km in a ten-year period. Drilling in 1939 revealed a magnetite-bearing sequence with an average thickness of 25 m having an average grade of 23 % total Fe, 16 % magnetic Fe, and 0.8 % P. The host rock is a calcareous quartz-amphibole-biotite schist underlying a major unit of calcite marble.

Other important iron oxide districts within the Troms metallogenic area include Salangen, Bogen and Håfjell. The latter deposits occur at two different levels in the stratigraphy, the upper con-

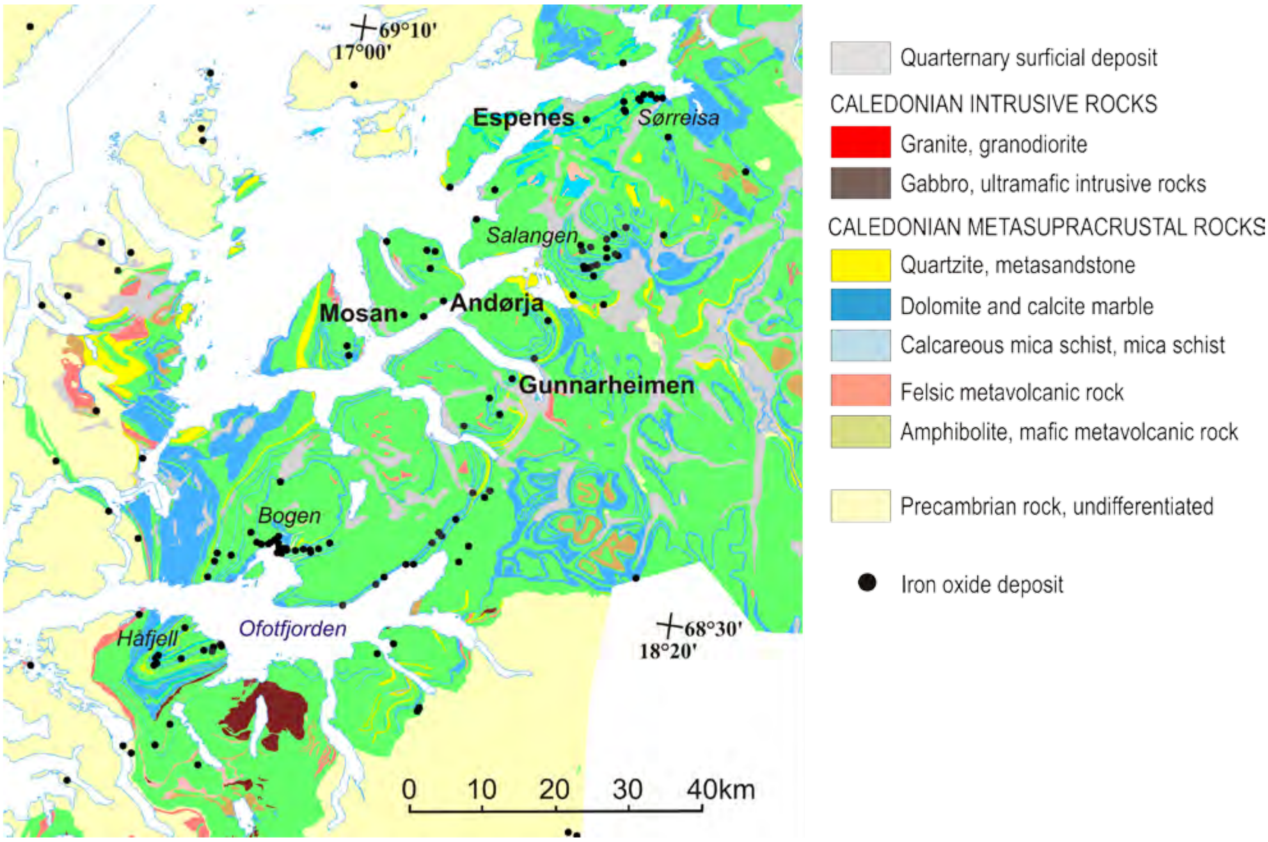


Figure 68. Geological map of Caledonian rocks showing the distribution of iron-(manganese) deposits between Håfjell and Sørreisa in the Troms Fe metallogenic area (N034).

taining Mn-enriched ores (Foslie 1949). Minor deposits also occur east of the metallogenic area N034, probably at a lower level of the Caledonian tectonostratigraphy. They may also represent tectonic repetitions.

Table 12. Deposits and occurrences in the Troms area (N034) included in the FODD database.

Deposit	Ore tonnage (Mt)	Fe %	Magnetic Fe %	P %	Reference
Andørja	74–91	25	18	1	Lindahl (1999) and references therein
Mosan	7.2		14.5–22.1	0.8	National ore database
Gunnarheimen	13.5	24.6	18	1.0	National ore database
Espenes	6.6	23	16	0.8	National ore database

N035 VADDAS–BIRTAVARRE Cu-Zn

Terje Bjerkgård (NGU)

The Vaddas–Birtavarre area (N035) is south of Nordreisa in Troms County. The area includes several semimassive to massive sulphide deposits at three stratigraphic levels in the Oksfjord Group of the Vaddas Nappe in the Upper Allochthon Reisa Nappe Complex (Lindahl et al. 2005). The lower boundary of the Oksfjord Group is marked by an unconformity to the underlying metasedimentary Kvænangen Group, whereas the upper boundary is a thrust contact to the overlying Kåfjord Nappe. The Oksfjord Group is dominated by pelitic metasediments, but also includes a greenstone unit, the Loftani Greenstone Member, which partly comprises pillow basalts (Fig. 69). The greenstone unit is in the lower part of the group in the area around Vaddas, where it attains a thickness of up to 500 m. The major sulphide deposits in the Vaddas district (Table 13) are located on top of the Loftani Greenstone Member, except one deposit, Rieppe, which is in the lower part of the Greenstone. Smaller sulphide deposits occur in a greywacke succession above the greenstone in the Vaddas district, in a similar stratigraphic position as the major deposits at Birtavarre some 30 km to the south (Vokes 1957). The upper part of the Oksfjord Group is a monotonous greywacke unit, known as the Ankerlia Formation (Lindahl et al. 2005).

The **Vaddas** occurrence crops out as 25 small showings SW of Vaddas, on a mountainside 500–750 m a.s.l. Several kilometres of exploration tunnels have been driven from seven adits (named A–G). There is continuous outcrop of ore over a length of about 1000 m between adits B and E,

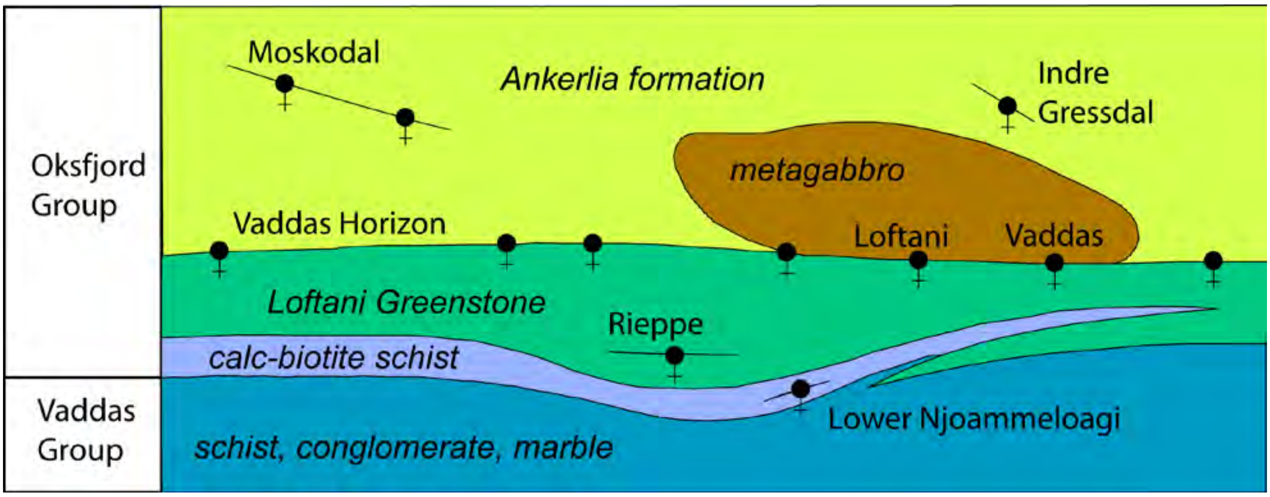


Figure 69. Schematic geology and locations of the sulphide occurrences in the Vaddas region (modified from Lindahl et al. 2005).

Table 13. Deposits and occurrences in the Vaddas-Birtavarre metallogenic area (N035) included in the FODD database.

Deposit	Tonnage (Mt)		Cu %	Zn %	When mined	Genetic type	Reference
	Total	Mined					
Vaddas	1.42	0.72	1.4	<0.1	1900–1957 (discont.)	VMS	Lindahl (1974)
Rieppe	3.0		0.5	2	Test mining	VMS	Lindahl (1974)
Sabetjok	0.3–0.4	0.014	1.2		1914–1919	VMS	Vokes (1957)
Skaide	0.06–0.08	0.024	3.1		1911–1919	VMS	Vokes (1957)
Moskogaissa 115	0.065	0.065	4.5–8		1898–1919	VMS	Vokes (1957)

whereas the ore is concealed between adits A and B (length of 400 m), partly because of a fault with a 20-m throw on the ore zone. The ore is not massive throughout and varies in height in a 50-m-wide zone. An *en echelon* pattern of ore concentration along the zone is apparent from geophysical data. The average thickness of the ore varies from 0.7 m (assaying 1.4 % Cu) in adit D to 2.8 m (1.8 % Cu) in adit E. It is a pyrrhotite-pyrite ore with clasts of greenstone and quartz fragments forming the host rock. The zinc content is generally very low, <0.1 % Zn. The contents of Ag and Au also are low. So-called massive ore contains 40–60 % sulphides, corresponding to approximately 25 % S. The deposit has been evaluated for mining several times, especially if combined with the larger Rieppe deposit (see below). Resource calculations show a reserve of 715 000 t at 1.37 % Cu with an ore thickness of 1.5 m or 853 000 t at 1.1 % Cu with a thickness of 2.0 m (Lindahl 1974).

The **Rieppe** deposit is about 8 km south of Vaddas. It is located south of a major fault, the Rieppe Fault Zone, which has a vertical throw of 800 m. The mineralisation has an along-strike extent in outcrop of about 2 km, part of it in a high vertical cliff. The deposit is within the Loftani Greenstone Member, at a lower level than the Vaddas zone. The deposit is concordant with the surrounding host rock. It is strongly tectonised, containing fragments of greenschist commonly altered to talc. The mineralisation consists of pyrrhotite with varying amounts of chalcopyrite and sphalerite, whereas pyrite is generally an accessory phase. The strong deformation leads to a very large variation in metal content and ore thickness (2–20 m). Lenses of barren wallrock up to several metres in size form inclusions in the ore, as well as greenschist fragments with sulphide impregnation (Lindahl 1974, Lindahl et al. 2005).

The Rieppe deposit has an identified resource of 3 Mt at 0.5 % Cu and 2 % Zn (at 0.2 % Cu cut-off). Below the main zone, there is an additional probable resource of 1 Mt at 0.4 % Cu. Gold is not an economic element in the ore, but the silver content in the copper concentrate is 48 g/t. Flotation tests have shown that also talc may be exploited from the deposit (Digre 1972, Lindahl et al. 2005).

A number of small Cu-Zn deposits occur in the metasedimentary Ankerlia Formation in the valley Kåfjorddalen, some 30 km SW of Vaddas. Collectively these deposits are known as **Birtavarre**, and these are pyrrhotite-chalcopyrite occurrences normally with low contents of zinc. During 1899–1919, about 110 000 t of copper ore was produced, mainly from the three mines Moskogaissa 115, Sabetjok and Skaide (Vokes 1957). The deposits are at different stratigraphic levels within the Ankerlia Formation, partly associated with small greenstone bodies (Lindahl et al. 2005). The stratigraphically lowermost is **Sabetjok**. Only 14 000 t of Cu ore was mined from the deposit before it was closed in 1919. At the same level, about 2 km ESE of Sabetjok, is the small working known as Birtavarre Høyfjell. On the basis of geophysics which showed strong anomalies between the two workings, drilling was carried out in the 1950s. This identified a possible resource of 300 000–400 000 at 1.20 % Cu with an average thickness of 1.4 m (Vokes 1957).

The **Skaide** deposit is associated with amphibolites stratigraphically above Sabetjok. Skaide is quite far from the other deposits, 10.5 km NE of Moskogaissa 115. About 24 000 t of ore with 4.4–6.2 % Cu was produced between 1911 and 1919. The Skaide ore contained much more zinc than the other deposits, was also somewhat richer in copper, and contained a lower proportion of pyrrhotite. Only the richest part of the ore was exploited, leaving a so-called "concentrating ore" with 2–2.5 % Cu in the ground. The mineralised plate has an extent of 200 x 80 m. With an average thickness of 1–1.5 m, and a specific gravity of 3.5 g/ cm^3, it corresponds to an initial resource of only 56 000–84 000 t (Vokes 1957).

Moskogaissa 115 was the largest of the deposits worked in the Birtavarre region, about 300 m long and 60 m wide. With an average thickness of about 1 m, approximately 60 000–70 000 t of Cu ore was mined with 4.5–6 % and up to 8 % Cu (Vokes 1957). About 1200 metres to the west is **Moskogaissa 117** which produced some 3000 t of ore with 6 % Cu, and 900 m to the east is **no. 111**, which produced only 1800 t of Cu ore. A geophysical survey and drilling in the area in the 1950s revealed no further resources, and showed that an old 100 000 t of resources in the Moskogaissa 111 deposit probably does not exist (Vokes 1957).

N036 KAUTOKEINO Au-Cu

Jan Sverre Sandstad (NGU)

The Kautokeino metallogenic area (N036) covers the western half of the Kautokeino greenstone belt (KkGB) which is overlain by Caledonian Nappe rocks in the north. The area N036 is 25–35 km wide and is transected by the Bothnian–Kvænangen Fault Complex. It is bounded by the Čignaljåkka–Boaganjávri Lineament in the west and the Soadnjujávri–Bajasjávri Fault in the east (Olesen & Sandstad 1993). To the south, in the territory of Finland, area N036 is bounded by Svecofennian (Haparanda Suite?) granitoids. The eastern part of the KkGB is not included in area N036. It is dominated by platform-type metasediments, and minor stratiform sulphide deposits mainly comprising Fe sulphides with low contents of base metals.

The KkGB is the westernmost of the Palaeoproterozoic greenstone belts in inner Finnmark, Norway. The supracrustal sequences comprise metavolcanic rocks varying in composition from tholeiitic to komatiitic, and clastic metasedimentary units deposited during extensional events. The supracrustal rocks are cut by quartz monzonitic to granitic intrusives, and were strongly deformed during the Svecofennian orogeny. Although the geochronological constraints are weak, the rocks are mainly assumed to have been deposited between 2.4–1.85 Ma ago (Lahtinen et al. 2008). However, the lowermost stratigraphic metavolcanic sequence, the Goldinvarri (Gål'denvarri) Formation, has an Archaean age according to U-Pb dating of zircon of 2769 ± 9 Ma (A. Solli, pers. comm. 2009). It is unconformably overlain by conglomerate of the Masi Formation that mainly comprises quartzitic rocks. The main body of the greenstone belt is dominated by overlying tholeiitic metavolcanic rocks defined into several formations (Siedlecka et al. 1985). These rocks are dominated by mafic tuffs and tuffites, but basaltic lavas and metadolerites are also common. They show a gradual transition to shale and siltstone, and the youngest sequence comprises coarse clastic sandstones.

Gold-copper and copper mineralisation is widespread in the area, but only one deposit, Bidjovagge, in the northernmost part of area N036, has been exploited and is included in the FODD. In addition, there are numerous prospects that have been and are currently under exploration. They are mainly confined to the western part of the greenstone belt, which is transected by the Bothnian–Kvænangen Fault Complex (Olesen & Sandstad 1993). This NNW-trending fault complex comprises several steeply dipping shear zones with associated mineralisation.

The **Bidjovagge** gold-copper deposit is located in the northwesternmost part of the KkGB, about 40 km NNW of Kautokeino town. The deposit consists of several lens-shaped ore bodies over a strike length of 2.5 km: 13 of these have been mined, in two periods. Copper mineralisation was first discovered in the area in 1952, and preliminary investigations were carried out by Boliden. NGU carried out extensive investigations in 1956–1965 and identified 3.6 Mt of ore with 1.8 % Cu. Mining in the period 1971–1975 by Fangel & Co and A/S Sydvaranger produced 430 000 t of ore, yielding 23 000 t copper concentrate. Outokumpu Co mined 1.95 Mt of ore with average grades of 1.2 % Cu and 4 g/t Au in the second mining period, 1985–1991.

The Bidjovagge region comprises a sequence of tuffites, graphitic schist and carbonates intruded by doleritic sills (Bjørlykke et al. 1987). It is folded into an upright antiform, which is sheared, especially along the eastern limb (Bjørlykke et al. 1993) (Fig. 70). Syenodioritic dikes occur as lenses in the shear zone (Fig. 71). Two periods of mineralisation have been identified (Bjørlykke et al. 1993). An early stage of gold mineralisation within brittle-ductile structures pre-dates the syenodioritic dikes, and a late copper-rich stage within brittle structures. The Au-Cu mineralisation is in albite felsites, where the graphitic schist has been oxidised along dilatational structures in the shear zone (Fig. 72). The mineralising fluids were highly saline and CO_2-rich (Ettner et al. 1994). The mineralisation is Palaeoproterozoic, post-peak metamorphic in age. U-Pb dating of davidite yielded 1885 ± 18 Ma and uraninite 1837 ± 8 Ma at Bidjovagge (Cumming et al. 1993). Native gold is fine-grained, commonly in the range 15–30 µm. The ore has been subdivided into three major types that warranted different processing during mining (Ekberg & Sotka 1991):

Copper ore that comprises 2–5 % Cu and typically less than 1–2 ppm Au. Chalcopyrite and, to a lesser extent, bornite occur in sulphide-rich carbonate veins. The main, C ore body is an example of this type.

Gold ore with 5–20 ppm Au and 0.1–0.5 % Cu. The mineralisation occurs as dissemination of gold in sheared and brecciated albite felsites and partly in quartz veinlets. In addition to albite, the ore contains quartz, actinolite, sulphides (pyrite, pyrrhotite and chalcopyrite), tellurides, davidite

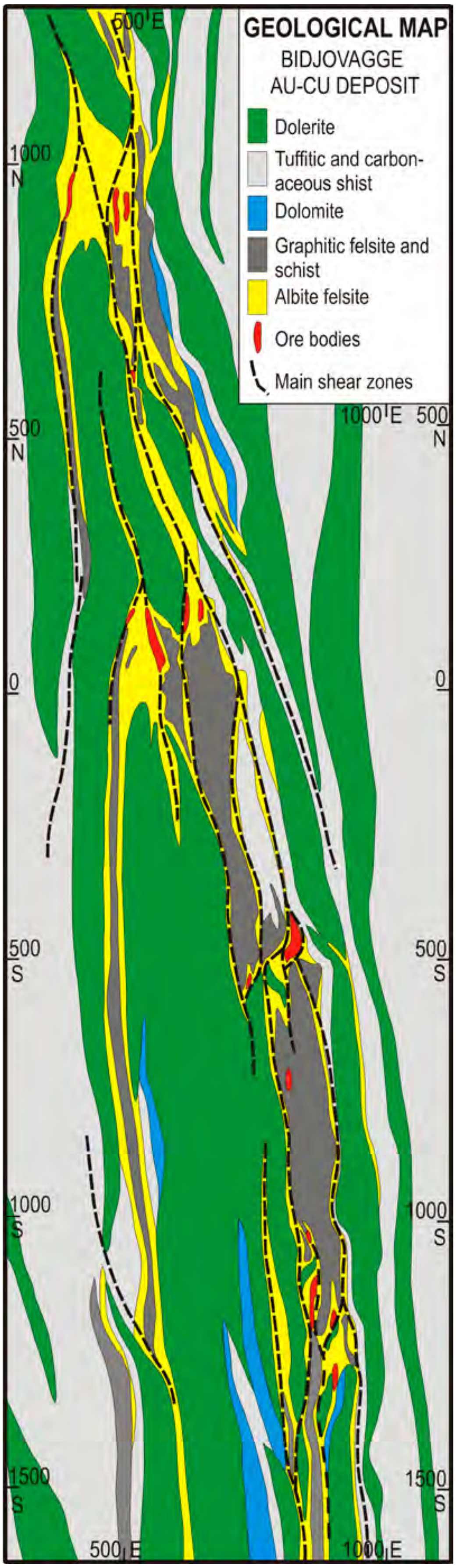


Figure 70. Geological map of the Bidjovagge region modified from Nilsen & Bjørlykke (1991). The local coordinates are in metres. The deposit is at 69.280888°N, 22.491639°E.

Figure 71. Sheared graphitic schist, albite felsite and syenodioritic dike in the D open pit in the Bidjovagge Au-Cu deposit (The pit is currently flooded, 2011). Photo: J. S. Sandstad, NGU.

Figure 72. Copper-gold mineralised albite felsite at Bidjovagge. The lens cap is 5 cm in diameter. Photo: J. S. Sandstad, NGU.

and native gold. This ore type occurs in the Eva and in the upper part of D ore body.

Gold-telluride ore is structurally similar to the gold ore, but the gold mainly occurs in tellurides (calaverite). The K ore body exemplifies this ore type.

Drilling has lately been carried out in the northernmost part of the mining area, and some positive intersections have been recorded. The present indicated resource given by Arctic Gold (2011) is 1.36 Mt with 2.74 g/t Au and 1.21 % Cu, and marginal ore at the dump from the previous mining comprises 0.3 Mt with 1.8 ppm Au and 0.6 % Cu. The Bidjovagge deposit can be classified as orogenic gold with atypical metal association, which is common in Palaeoproterozoic supracrustal belts in the northern part of the Fennoscandian shield (Eilu et al. 2007).

N037 KARASJOK–LAKSELV Ni-Cu-PGE

Rognvald Boyd (NGU), Pasi Eilu (GTK)

The Karasjok–Lakselv metallogenic area (N037) comprises the N-trending Palaeoproterozoic Karasjok greenstone belt (KjGB) in Norway and the Pulju and Nirroselkä komatiite-dominated sequences in the northern part of the Central Lapland greenstone belt (CLGB) in Finland. The rocks of the Pulju schist belt and Nirroselkä, respectively, form SW- and SE-trending, arm-like extensions into the bulk of area N037 defined by the entire KjGB. The KjGB and CLGB form an obvious geological continuum, where KjGB sequences form, or are replaced by, similar units of the CLGB near the Finnish-Norwegian border (e.g., Lehtonen et al. 1998, Koistinen et al. 2001).

Mafic to ultramafic intrusives, commonly small (<10 km in maximum surface dimension), occur at different levels in the KjGB: several of these host Ni-Cu-PGE mineralisation and have drawn the attention of exploration companies. In the Finnish part of area N037, the nickel mineralisation (Table 14) explored by mining companies since the 1960s is closely associated and hosted by komatiites (Papunen et al. 1977, Papunen 1998).

The **Karenhaugen** intrusion is located 4 km SE of the southeasternmost part of the Porsanger Fjord. The intrusion is about 1 km long and up to 80 m thick at the exposed levels. The intrusion is a metapyroxenite, largely consisting of isotropic amphibolites cut by numerous narrow shear zones, leading to a locally strong foliation (Davidsen 1994). Volumetrically subordinate parts of the body contain 20–30 % plagioclase and there are lenses and aggregates of quartz related to shear zones. Locally, the rock contains significant concentrations of chalcocite with inclusions of bornite: these phases occur in concentrations that can exceed 10 %. Chalcopyrite is present as a subsidiary phase and several platinum group minerals occur in trace amounts (Nilsson & Larsen 1998): the latter include phases in the solid so-

Table 14. Deposits and occurrences in the metallogenic area N037 included in the FODD database.

Subarea, Occurrence	Tonnage (Mt)	Au g/t	Co %	Cu %	Ni %	Pd g/t	Pt g/t	Main host rock	Reference
Gallujav'ri	Potentially large*	**	0.01	0.2	0.13	0.2	0.2	Peridotite	Nilsson & Often (2005)
Karenhaugen	1			0.6		0.9	0.3	Pyroxenite	Ludvigsen et al. (1990), Ludvigsen (1993)
Porsvann	Showing*	0.1–0.3	**	0.01–0.5	**	**	**	Pyroxenite	Ludvigsen (1993), Tertiary Minerals (2001)
Pulju Ni (N037.1)									
Hotinvaara	1.267		0.03	<0.1	0.43	**	**	Komatiite	Inkinen et al. (1984), Papunen (1998)
Iso-Siettelöjoki	0.5		0.05	0.01	0.29	**	**	Komatiite	Papunen (1976, 1998)

* No tonnage data available for the deposit

** May contain significant grades of the metal lution series between stibiopalladinite (Pd_5Sb_2)/merteite ($Pd_{11}Sb_4$–Pd_8Sb_3) and arsenopalladinite ($Pd_8(As,Sb)_3$)/stillwaterite (Pd_8As_3), a range of complex arsenides, native palladium, sperrylite ($PtAs_2$) and several new phases. The grades reach 10 ppm Pt+Pd, with palladium exceeding platinum by factors of four to ten (Nilsson & Often 1990, unpublished data). Ludvigsen et al. (1990), on the basis of data from seven drill holes, modelled an open-pit mine that contained 700 000 t of ore averaging 0.57 % Cu, 0.87 ppm Pd, and 0.31 ppm Pt: they concluded that higher grades and tonnages, potentially from other nearby deposits, would be needed to make such a target economically interesting.

The **Porsvann** intrusion is located just south of Lakselv and 1 km E of the E6 highway. The intrusion has dimensions similar to Karenhaugen, but it shows a transition from metapyroxenite to metagabbro, indicating an overall layering. NGU drilled four holes totalling 357.5 m in the body in 1992. The sulphides and other metallic minerals found in polished sections are pyrrhotite (major phase, >10 %): pyrite, pentlandite, chalcopyrite and magnetite (subsidiary phases (1–10 %). The grades reach 13 ppm Pt + Pd with a Pd:Pt ratio of 3.3–4.3. Gold grades are 0.1–0.3 ppm. The best drill hole intersections contained 43 m grading 1.2 ppm Pt+Pd, including 15.2 m at 2.1 ppm (Tertiary Minerals 2001). Copper grades are generally in the range 100–5000 ppm, in some sections lower than those of Pd (Ludvigsen 1993).

The **Gallujavri** intrusion is about 20 km NNW of Karasjok and 3.5 km E of the lake Iddjajavri (Nattvann). The intrusion was investigated by A/S Sydvaranger (later ASPRO) in the period 1976–1982. The investigations included geochemical sampling, ground geophysics, geological mapping, minor core drilling and mineralogical studies on sulphide-bearing samples. The geological survey (NGU) carried out fieldwork in the area in 1987 and 1988 in the context of a regional study of mafic and ultramafic intrusions in the Karasjok Greenstone Belt. This work focused on rock geochemistry and on the nature of the PGE mineralisation. The intrusion is about 5 km long and 500 m wide at its broadest, in the north, becoming narrower southwards. Weak sulphide mineralisation has been found in drill holes in the northern part of the body, along the eastern margin, and in the southern part of the body. Sulphide enrichments have also been found on the surface in the northeastern part of the intrusion. The mineralisation is hosted by variably altered peridotite and pyroxenite and generally consists of variation between homogeneous, fine-grained dissemination and more patchy, medium-grained dissemination. Accumulations associated with tremolite-carbonate veins are less common. The sulphides and other metallic minerals found in polished sections from the occurrence are (NGU, Ore database – R. Hagen and L.P. Nilsson, unpublished data) as follows. Major phases (>10 %): pentlandite, pyrrhotite and chalcopyrite; subsidiary phases (1–10 %): violarite (Ni_2FeS_4), mackinawite ($(Fe,Ni)_{1.1}S$), pyrite, bravoite ($(Ni,Fe)S_2$) and magnetite; accessory phases (<1 %): altaite (PbTe), hessite, electrum, native gold, haematite, chromite, ilmenite, barite, arsenopyrite (FeAsS), niccolite (NiAs), cubanite ($CuFe_2S_3$), marcasite (FeS_2), covellite (CuS), rutile, sphalerite and melonite ($NiTe_2$). Heavy-mineral concentrates of mineralised outcropping rock samples have yielded values of up to 2.3 ppm Pt, 23 ppm Pd and 9.9 ppm Au. However, distinct platinum-group minerals were not found in these concentrates, suggesting that the PGE are sulphide-bound. The highest Au, Pt and Pd values occurred in a concentrate that was also rich in arsenopyrite. In 2003, Tertiary Minerals drilled an additional three holes on a combined IP and magnetic anomaly associated with an Ni-Cu-(PGE) sulphide occurrence hosted in a metaolivine cumulate (Nilsson & Often 2005).

The Ni occurrences of area N037 in Finland are all hosted by Palaeoproterozoic komatiites (Papunen 1976 and 1998, Papunen et al. 1977, Puustinen et al. 1995). The Pulju region is seen to have such a potential for economic komatiite-hosted nickel that a subarea of high exploration potential (N037.1) is drawn in the Fennoscandian metallogenic map. Within this subarea, there are two occurrences with a resource estimate (Table 15) and tens of other indications of nickel mineralisation. The SE arm of area N037, the Nirroselkä region, also contains numbers of nickel indications, but no deposits of any size have so far been found there. The Pulju and Nirroselkä nickel occurrences are typical for komatiite-hosted systems: they contain significant sulphidic Ni but are poor in Cu, and the main ore minerals are pentlandite and pyrrhotite (Papunen et al. 1977, Papunen 1998). During metamorphism, orogenic fluids may have enhanced the sulphidic Ni content of the occurrences (Papunen 1998).

N038 KARASJOK Au, Cu

Peter Ihlen (NGU)

The Palaeoproterozoic Karasjok Greenstone Belt (KjGB), roughly equalling the Karasjok metallogenic area (N038), has been the site of intermittent gold exploration since the first discovery of placer gold in the vicinity of Karasjok in 1866 (Reusch 1902). It comprises amphibolites-facies volcanosedimentary rocks hosting komatiite-associated banded iron formation and Ni-Cu-PGE mineralisation in ultramafic-mafic intrusions. The KjGB constitutes an east-dipping tectonic wedge between the Archaean Jergul Gneiss Complex with its cover of quartzites in the west and the overlying allocthonous Tanaelv Complex in the east (Fig. 73; Braathen & Davidsen 2000).

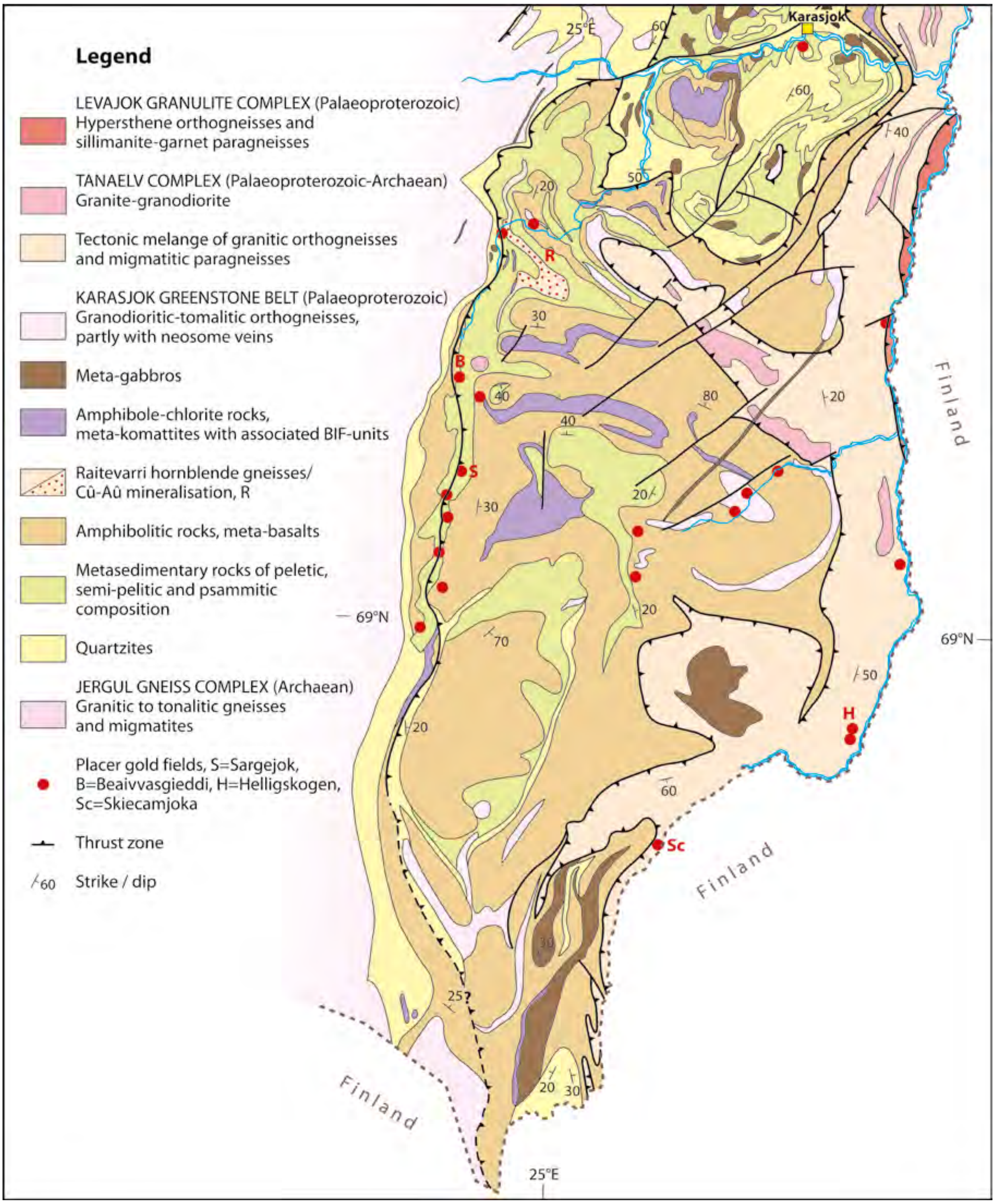


Figure 73. Geological map of the KjGB south of Karasjok showing the distribution of placer gold fields and the low-grade epigenetic Cu-Au mineralisation at Raitevarri. Geology redrawn from Siedlecka & Roberts (1996).

Placer gold has been detected in a number of river valleys south of Karasjok (Bjørlykke 1966). It almost invariably occurs along rivers (Fig. 73) that dissect the more than 3–5-m-thick Quaternary deposits down to the underlying bedrock. However, the gravel of the present riverbanks is generally low in gold, which is mainly found concentrated in old river channels 1–10 m above the water level of the present rivers. The auriferous gravels along these channels largely represent reworked basal tills, which partly fill open fractures in exposed rocks. The basal till at **Sargejok** contains up to 8 g/m^3 Au, including up to 17-g gold nuggets (~1 cm^3, Bjørlykke 1966).

Detailed investigations of the 10–20-m-thick Quaternary deposits in the Sargejok gold field revealed the presence of five individual till units separated by waterlain sediments and palaeosols (Fig. 74; Olsen et al. 1996). All till units contain abundant gold grains, which increase in abundance from the upper unit towards the lowermost (Often et al. 1990). The latter unit overlies a locally gold-rich tillitised gravel bed resting directly on Sargejok schists. The gravel bed may represent a proglacial glaciofluvial outwash from the same glacier that deposited the overlying basal till (ST 5 in Fig. 74). The age of this glacial event possibly exceeds 300 ka (Olsen et al. 1996).

Remnants of preglacial (Tertiary?) deep weathering (saprolites/regoliths) occurring in many of the gold fields was suggested as a potential source for the commonly coarse placer gold and nuggets (Ihlen 2005). The Sargejok schists in the gold field show in most localities signs of deep weathering down to a depth of 30 m. They comprise a sequence of sheared quartz-carbonate-veined chlorite-muscovite schists, which host a thin unit of foliated biotite amphibolite with patchy mineralisation of chalcocite and bornite. Analyses of cores from 6 drill holes gave maximum contents of 0.1 % Cu over 1.5 m and 134 ppb Au over 1.0 m for the unweathered schists. However, higher gold values (226 and 789 ppb Au) were recorded from a fracture-bound weathering zone (Often et al. 1990). The low gold values in the unweathered schists give no clear indications that saprolite gold may have formed during deep weathering and was later incorporated into the basal tills during glaciation.

The presence of sperrylite, native platinum and chromite in the basal till (Bjørlykke 1966) may rather indicate externally derived gold, for example, from metakomatiites occurring abundantly in adjacent areas (Often et al. 1990). In the Helligskogen and Skiecamjoka gold field, 1–5-mm grains of native gold have been found along fractures in 5–7-mm quartzofeldspatic clasts (Bjørlykke 1966), suggesting the presence of gold mineralisation in the surrounding granitic rocks of the Tanaelv Complex (Fig. 73). In addition, Reusch (1902) found along the Karasjok river at Beaivvasgieddi a boulder and small pebbles of "sandstone" containing veinlets and disseminated grains of gold. This could indicate that the metasandstones or the quartzites which the river crosses up-stream may host gold mineralisation. However, despite considerable exploration work conducted over the last 3–4 decades, no high-grade gold has been found in any of these potential lithological units or elsewhere in the KjGB.

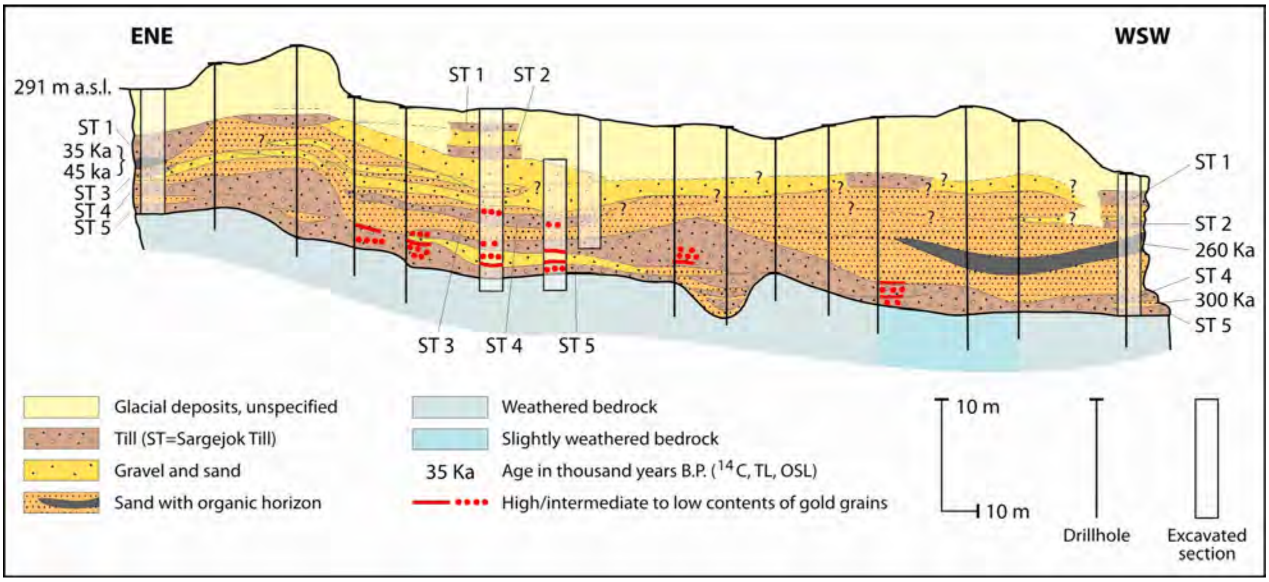


Figure 74. Section showing the stratigraphy of Quaternary deposits in the Sargejok gold field, with the distribution of drill holes and excavations. Redrawn from Often et al. (1990) and Olsen et al. (1996).

Thus, the source of placer gold in the Karasjok area is still enigmatic.

Cu mineralisation with associated low-grade gold (0.1–1 g/t Au) is found in several places along the basal thrust zone of the KjGB, including the mineralisation at Sargejok. The low-grade **Raitevarri** Cu-Au deposit in the hanging wall of the basal thrust zone covers an area of about 10 km^2. It occurs inside a 0.3–1-km-wide and more than 16-km-long unit of partly garnetiferous quartz-hornblende-plagioclase-biotite-chlorite gneisses, which are characterised by unoriented sheets of hornblende (graben texture) and gradational borders with enclaves of amphibolite and zones of quartz-kyanite-muscovite schists. The mineralisation, which comprises irregularly distributed weak dissemination of sulphides (<1–10 vol.%), is mainly developed in the hinge zone of a tight antiform structure (Fig. 73), where the muscovite schists mainly contain pyrite and the biotite-chlorite-plagioclase gneisses mainly pyrrhotite and chalcopyrite. Subordinate and accessory minerals include anhydrite, sphalerite, galena, native gold, chalcocite, bornite, covellite, native copper, molybdenite, arsenopyrite, pentlandite, mackinawite, barite and tellurides of Ag, Bi and Pb (B. Røsholt and M. Often, pers. comm. 1986).

A/S Sydvaranger discovered the Raitevarri deposit in 1969 and drilled eight holes in 1973 and 1976. RTZ drilled 9 holes in 1994 and Store Norske Gull AS is presently exploring the deposit. The RTZ reports (Coppard 1994) suggest that the Cu grades are invariably below 0.8 % Cu in 1-m sections, and the Au concentrations rarely exceed 0.5 g/t. The best sections so far published include 20.5 m with 0.43 % Cu (SV DDH 5), 5 m with 0.18 % Cu and 0.1 ppm Au (RTZ DDH 6) and 4 m with 0.06 % Cu and 0.53 ppm Au (RTZ DDH 3) (Coppard 1994). Native gold is erratically distributed and is extremely fine-grained (1–4 µm; M. Often, pers. comm. 1986). It mainly occurs in the biotite-chlorite-plagioclase gneiss and in muscovite-quartz schist, commonly in conjunction with chalcopyrite-pyrrhotite dissemination and enhanced levels of arsenopyrite. The genesis of the deposit is uncertain, and both syngenetic and epigenetic models have been proposed (Often 1985, Bjørlykke et al. 1985, Ihlen et al. 1993, Eilu & Ojala 2011).

N039 ALTA–REPPARFJORD Cu-Au

Jan Sverre Sandstad (NGU)

The Alta–Repparfjord area (N039) comprises three tectonic windows that form large basement culminations within the Caledonides of west Finnmark: the Alta–Kvænangen, Alteneset and Repparfjord–Komagfjord Tectonic Windows. The stratigraphic sequences and geological evolution within the windows are largely similar, although some differences exist (Siedlecka et al. 1985). The windows are all dominated by copper±gold deposits of various types (Table 15); both volcanic- and sediment-hosted and deposits of epigenetic and syngenetic origin occur, although the genesis is not constrained for all deposits (Bjørlykke et al. 1985, Sandstad 1986).

The supracrustal sequences of the windows predominantly comprise metavolcanic rocks varying in composition from calc-alkaline to tholeiitic, and clastic metasedimentary rocks deposited during extensional events. They are intruded by mafic and minor ultramafic and felsic igneous rocks. Geochronological constraints are scarce, but the supracrustals are assumed to be primarily of Palaeoproterozoic age. However, the lowermost stratigraphic sequences in the Repparfjord–Komagfjord window may be Archaean in age, as suggested by comparison with similar sequences in inner Finnmark (see section N036). The Palaeoproterozoic rocks are overlain by thin sequences of Neoproterozoic sediments. The basement rocks are overthrust by allochthonous rocks of the Caledonian Nappe Complexes and have suffered multiphase deformation during the Svecokarelian and Caledonian Orogenies.

The **Kåfjord** deposit is the largest Cu vein deposit within the Alta–Kvænangen Window. It is located west of Alta, in the lowermost Kvenvik Formation. The formation is at least 2 km thick and consists of tholeiitic lavas and volcaniclastic rocks with minor gabbroic sills and beds of graphitic schist and carbonate. The Kåfjord mine commenced production in 1827 and was the first large industrial operation in northern Fennoscandia until it closed down in 1878. During 1843–1878, around 62 000 t of cobbed ore with around 5 % Cu was produced (Moberg 1968). Regular production was carried out again in 1895–1908,

Figure 75. Mine dumps and a copper mineralised quartz-carbonate vein in greenstone at Kåfjord. Photos: J. S. Sandstad, NGU.

with a total production of about 5000–6000 tonnes of metallic copper.

The Cu mineralisation at Kåfjord occurs as quartz-carbonate veins in brecciated metagabbro and metabasalt (Fig. 75). A subhorizontal shear zone is located less than 100 m above these veins and truncates the brecciated rocks (Mørk 1970). Several irregular veins, which are 100–350 m long and 0.5–4 m thick, have been exploited over an area around 2.5 km in a N–S direction. The veins mainly comprise quartz, calcite and ferrous dolomite. Chalcopyrite and pyrite occur as clusters and dissemination, and haematite and magnetite are also locally present (Bjørlykke et al. 1985).

Mørk (1970) proposed an epigenetic, post- or syntectonic origin for the Cu mineralisation. An alternative hypothesis that regards the mineralisation as epithermal and synvolcanic has yet to be tested (Bjørlykke et al. 1985). Similar vein deposits occur in the western part of the Alta–Kvænangen Window at Middavarre and Bergmark (Vik 1985). Stratabound Cu mineralisation in fine-grained albite felsites that are partly graphite bearing also occurs at Bergmark. Minor Cu vein deposits or occurrences are also common in the metavolcanic rocks in the Altenes window.

The **Raipas** Cu deposit is the best known of the several copper occurrences in the Storviknes Formation,which overlies the metavolcanic rocks of the Kvenvik Formation within the Alta–Kvænangen Window. The Storviknes Formation is 600 m thick and comprises a 200-m-thick dolomite unit with interbedded siltstone and a lower red and a upper grey siltstone. Tidal channels, stromatolites and palaeokarst are present in the upper part of the dolomite and indicate deposition in a tidal-flat environment (Vik 1986).

The main copper mineralisation in Raipas is in the matrix of karst breccias in the upper part of the massive dolomite (Fig. 76), and as disseminated

Figure 76. Old mine openings and dumps, and Cu-bearing carbonate breccia at Raipas. Photos: J. S. Sandstad, NGU.

in thin dolomite beds in siltstone and in conglomerates at the top of the dolomite (Vik 1985, 1986). The mineralisation is copper-dominated, although cobalt occurs locally, for example, at Borras. The main ore minerals are chalcopyrite, bornite, digenite and chalcocite, and in minor amounts, fahlore and linneaite-series minerals (Vik 1986). Dolomite and minor barite are the gangue minerals. The thickness of the mineralised breccia bodies at Raipas varies from 1–5 m, with a maximum width of 20–25 m and a length of 60 m. The Raipas copper deposit shows similarities both with red-bed copper and karst-related lead-zinc deposits (Vik 1986). The Raipas deposit produced 12 500 t of ore between 1837 and 1870 with an average grade of 6.7 % Cu (Vokes 1955, Moberg 1968).

The Nussir–Saltvatn subarea (N039.1), within the Repparfjord–Komagfjord tectonic window, is distinguished as the area with highest potential of new discoveries in the Alta–Repparfjord area, primarily due to the potential for large sediment-hosted Cu deposits (Fig. 77; Table 15). The Repparfjord (Ulveryggen) deposit was mined in 1972–1979 and is, together with the major Nussir deposit, currently under evaluation. These deposits are similar to globally major sediment-hosted copper deposits, such as those in the Copperbelt in Central Africa and the Kupferschiefer in Central Europe (Sandstad 2010). Additionally, there are several minor historical mines and prospects within area N039.1 where Cu±Au occur in shear zone-hosted quartz-carbonate veins in mainly metavolcanic rocks, for example at Porsa, Bachke and Vesterdalen (Viola et al. 2008).

The **Repparfjord** copper deposit is hosted by sandstone and conglomerate in the lowermost part of the Saltvatn Group (Fig. 77), which is an approximately 2.5-km-thick sequence of predominantly clastic metasedimentary rocks. The occurrence was discovered around 1900. The Swedish company Nordiska Grufaktiebolag started exploration in 1903 with trenching and the digging of minor adits, but defined the ore as uneconomic at that time. The Canadian company Invex drilled 2358 m in 1955–1957, before A/S National Industri acquired the rights in 1960. The Geological Survey of Norway carried out extensive exploration and drilling in the 1960s, and 10 Mt of ore with an average grade of 0.72 % Cu was identified. Folldal Verk A/S acquired the rights in 1970 and mined about 3 Mt with an average grade of 0.66 % Cu in 1972–1979 from four open pits (Fig. 78).

Copper mineralisation at Repparfjord is hosted by a heterogeneous metasedimentary package comprising metasandstone, metaconglomeratic sandstone and metasiltstone of the Ulveryggen Formation (Fig. 78). The deposit consists of sev-

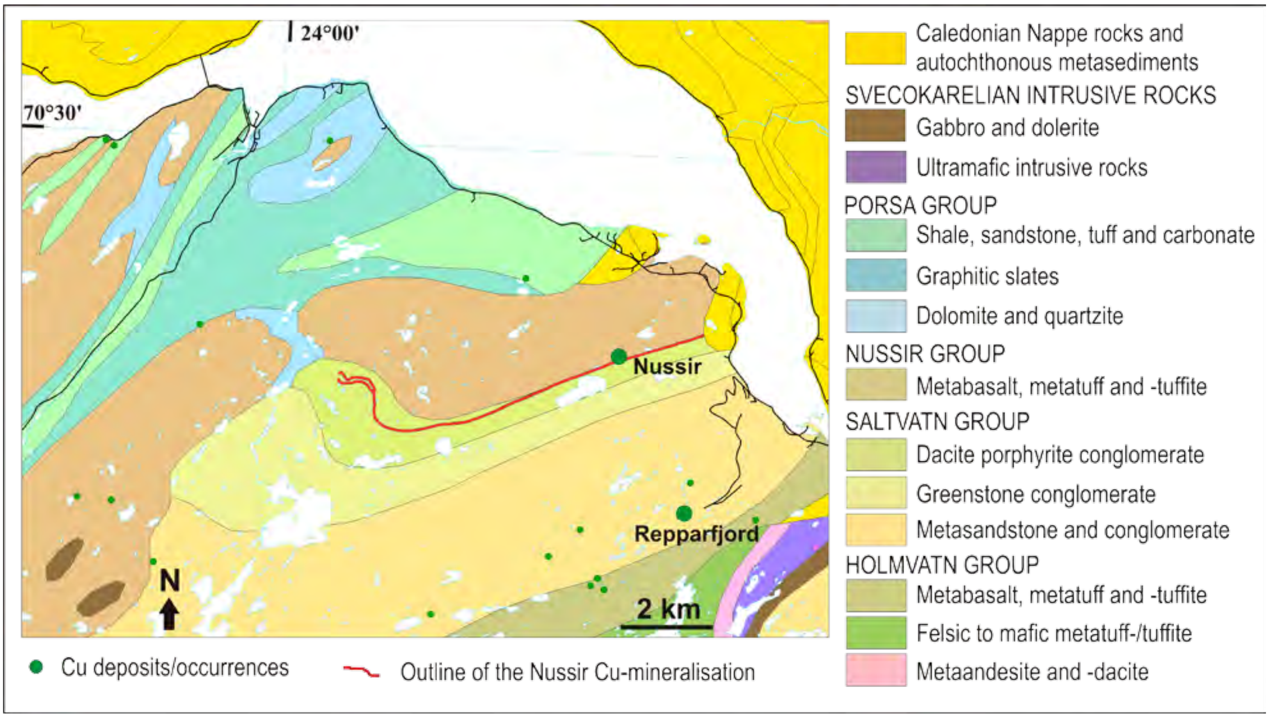


Figure 77. Geological map of the Nussir–Saltvatn subarea (N039.1) with copper deposits marked with green circles. The major copper deposits are Repparfjord (Ulveryggen) and Nussir, and the outline of the Nussir copper deposit is also shown with a red line.

Figure 78. The 'Vestfelt' pit and copper mineralisation in partly sheared metasandstone at the Repparfjord copper deposit. Photos: G. Viola.

eral diffuse, lens-shaped ore bodies, 100–400 m long and 10–100 m wide, over a strike length of about 1.8 km in the ENE–WSW direction. The main ore minerals are chalcopyrite, bornite and chalcocite, mainly occurring as dissemination and, to a lesser extent, in cracks and veinlets in the host rocks.

The genesis of the occurrence has been intensely discussed, with both syngenetic (sedimentary or diagenetic) and epigenetic processes proposed (Fabricius 1979, Stribrny 1985). However, recent investigations also suggest a strong tectonic control of the higher-grade copper ore (Sandstad et al. 2007).

The **Nussir** copper deposit was discovered in 1979, and was mapped at the surface and sparsely drilled over a strike length of 9 km in the 1980s and 1990s (Nilsen 1993). Nussir ASA was established in 2005, and an extensive drilling programme commenced in 2006. A total of 109 holes with total length of 15,600 m have been drilled (by the end of 2010). A detailed helicopter-borne geophysical survey has also been conducted. A scoping study was completed in October 2009, and the indicated and inferred resource defined is 25.5 Mt at 1.16 % Cu with elevated Au and PGE grades (Table 15). The resource is open at depth (http://www.nussir.no/).

The copper mineralisation occurs in a thin sequence of dolomite, schist and sandstone (Figs. 77 and 79), on top of the coarse clastic metasediments of the Saltvatn Group. The extent of the mineralised zone is about 9 km along the ENE-trending strike. The dip is 50–60° to the NNW and the average width 3–4 m. It has been drilled to a depth of around 500 m below the surface. The host rock and mineralogy vary along strike. In the western, more folded part of the sequence, chalcopyrite dominates in dolomite, whereas in the east bornite and chalcocite are hosted by schist and siltstone, and the deposit has elevated contents of precious metals.

Figure 79. A 3-m-wide outcrop of copper mineralisation in dolomite at Nussir. Photo from www.nussir.no.

The **Porsa** copper deposit consists of two parallel, steeply dipping, W-trending carbonate-quartz veins, called Greville and Parallel (Fig. 80), hosted by greenstones of the Svartfjell Formation of the Nussir Group (Pharaoh et al. 1983). Well-preserved pillow lavas and other primary structures are present in the greenstones between the veins. The Cu-rich veins are about 100 m long, 3–10 m thick and around 150 m apart. The veins have been exploited to a depth of nearly 100 m during 1905–1911 and 1918–1931.

The main ore minerals at Porsa comprise aggregates and thin lenses and bands of chalcopyrite, pyrite and magnetite (pseudomorphs of haematite). The major gangue mineral is calcite with minor amounts of quartz, albite, actinolite and

Figure 80. Left: Copper-mineralised calcite vein at Porsa. The central part of the vein is strongly foliated and sheared, whereas the vein texture is structureless and massive at the edges. Right: Chalcopyrite-magnetite band and aggregates in a foliated calcite vein crosscut by undeformed, copper-barren calcite-vein at right. Porsa, boulder at the Parallel vein. Diameter of the coin is 21 mm. Photos: J. S. Sandstad, NGU.

Table 15. Deposits and occurrences in the Alta–Repparfjord metallogenic area (N039) included in the FODD database.

Occurrence (Alternative name)	**Ore tonnage (Mt)**	**Cu %**	**Co %**	**Au g/t**	**Ag g/t**	**When mined**	**Genetic type**	**Reference**
Nussir	25.5	1.16		0.13	18		Stratabound clastic-hosted	Nussir ASA (2010)
Repparfjord (Ulveryggen)	3.1* 7.5**	0.66 0.81				1972–1979	Stratabound clastic-hosted	Nussir ASA (2010)
Porsa	0.1	2				1905–1911 1918–1931	Vein copper	
Bachke	0.25	1.95				1900–1906 1928–1931	Vein copper	
Vesterdalen	showing						Shear zone Au-Cu	
Raipas	0.013	6.7				1837–1870	MVT Cu	Vokes (1955)
Kåfjord	0.2	2	0.02			1826–1908	Vein copper	

* Mined ore, **Indicated and inferred resources (Nussir ASA, Sept. 2010)

chlorite. Accessory ore minerals include sphalerite, scheelite and covelline. Hydrothermal alteration of the greenstones comprises chloritisation, carbonatisation and albitisation. The formation of the veins occurred along a NE-striking, brittle-ductile dextral shear zone (Viola et al. 2008).

The **Bachke** deposit was discovered in 1900 and mining was carried out periodically by several companies until 1931. Four parallel quartz-carbonate veins up to 100 m long and 1–1.5 m thick have been exploited. The veins are hosted by greenstones of the Nussir Group, have a NW strike and a variable but generally steep dip. The main sulphide minerals are chalcopyrite and pyrite, and magnetite and haematite occur in subordinate amounts. Krause (1980) described uraninite as an accessory mineral in crosscutting veinlets. The vein matrix is composed of quartz, calcite, albite, chlorite and wallrock fragments.

Copper mineralisation in the **Vesterdalen** prospect was discovered in the early 1900s. Several minor exploration campaigns have been carried out due to elevated gold values associated with the copper occurrence, which is hosted by a sequence of impure dolomite and reddish siltstone that overlie the Nussir Group greenstones. The copper occurrence comprises dissemination, aggregates and veinlets, and the copper mineralogy is very complex. Digenite seems to dominate, but bornite, chalcocite, covelline and malachite also occur. Analysed samples yield values in the range of 0.64–9.76 % Cu and 0.2–16.4 g/t Au. In addition, elevated molybdenum contents have been detected, with 0.9 % Mo as the maximum value. The molybdenum mineral present is powellite ($CaMoO_4$; Viola et al. 2008). Accessory minerals include brannerite, orthobrannerite and uraninite. The genesis of the mineralisation is not well understood in this extensively covered area. High f_{O2} during mineralisation is suggested by the presence of barite and uranium minerals.

N040 SØR-VARANGER Fe

Peter Ihlen (NGU)

The Neoarchaean iron deposits in the Sør-Varanger metallogenic area (N040) are banded iron formations (BIF) interpreted as exhalative sedimentary ores by Bugge (1960b). They constitute characteristic members of the supracrustal sequences of the Sørvaranger–Kola terrane, which is unconformably overlain by the Palaeoproterozoic Polmak and Pasvik Greenstone Belts, being overthrust by the Inari Terrane in the southwest. The Archaean rocks in the Sør-Varanger province are mainly comprised of grey, amphibolite to granulite-facies ortho- and paragneisses, which

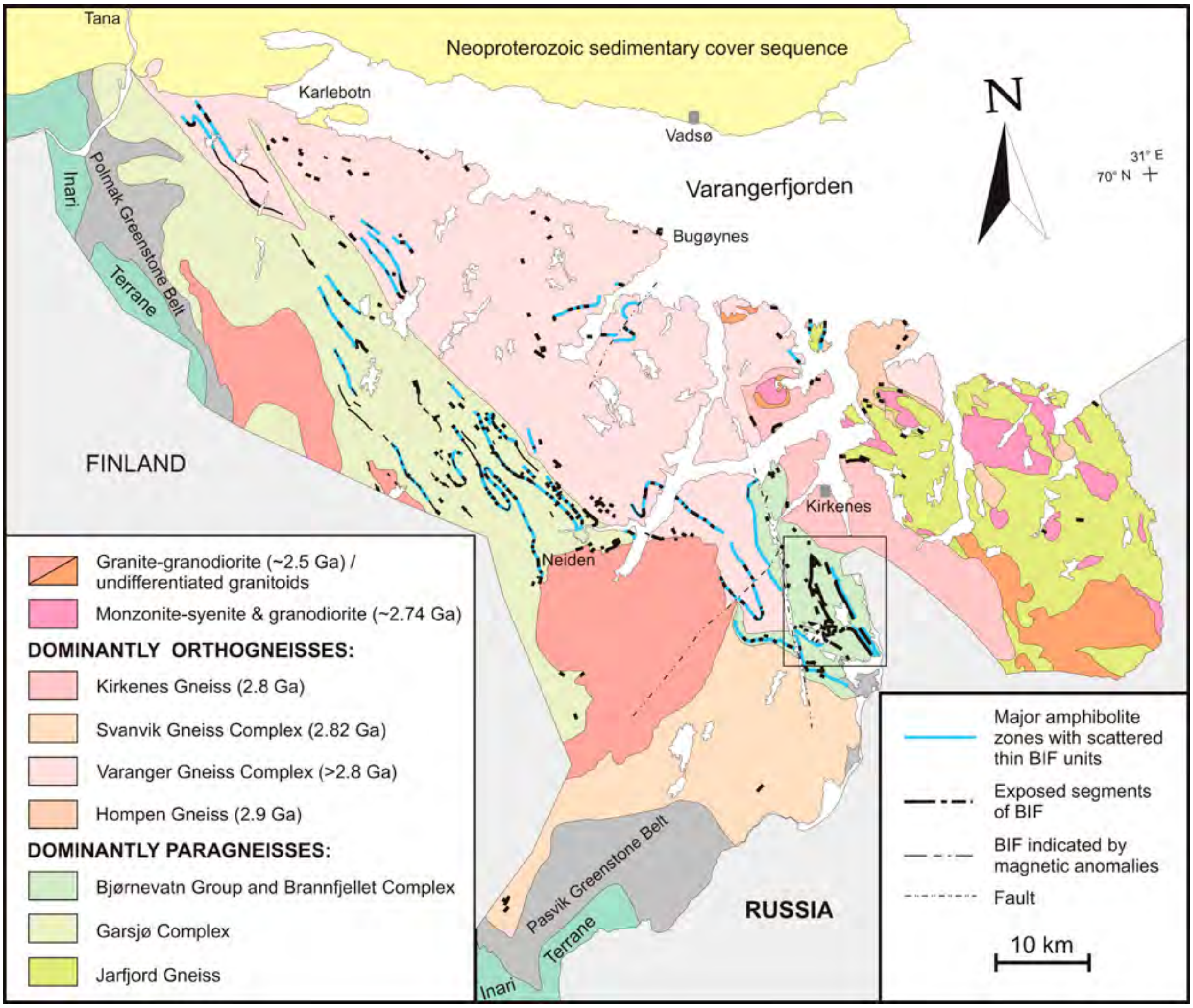


Figure 81. Geological map of the Sørvaranger province showing the distribution of BIF units. Terminology of the gneiss units is after Dobrzhinetskaya et al. (1995). Compilation of the BIF occurrences is based on Wiik (1966), Iversen and Krill (1990, 1991), Iversen and Nilsson (1991), Nilsson and Iversen (1991), Siedlecka and Roberts (1996) and unpublished field data from Ø. Nordgulen, M. Heim, E., Iversen, and L. P. Nilsson. The rectangle indicates the area shown in Figure 82.

are subdivided into a number of different tectonic megaunits (Fig. 81) predominantly composed of either strongly deformed volcanosedimentary sequences or of TTG-type orthogneiss complexes, some with small enclaves of mineralised paragneisses (Siedlecka & Nordgulen 1996, Dobrzhinetskaya et al. 1995).

The individual lithotectonic units were largely formed and amalgamated into their present position during 2.90–2.73 Ga and prior to the intrusion of lateorogenic granite plutons, for example the Neiden granite at ca. 2.5 Ga (Dobrzhinetskaya et al. 1995; Levchenkov et al. 1995). Geochronological data presented by the latter authors indicate that most of the supracrustals and the BIF units were deposited at about 2.8 Ga.

The supracrustal gneiss complexes hosting the BIF deposits as presented in Figure 81 are dominantly composed of metasedimentary rocks of pelitic, semipelitic and psammitic composition. They generally only contain subordinate sequences of mafic to intermediate metavolcanic rocks which are, however, important carriers of the BIF units, especially those containing Fe-rich amphibolite members (Siedlecka et al. 1985, Dobrzhinetskaya et al. 1995). The BIF deposits in the area vary considerably in mineralogy, type of banding, and size. They commonly show banding on a mm to dm scale. The individual bands are mainly composed of one to three of the following minerals: magnetite, quartz, hornblende, grünerite-cummingtonite, biotite, and garnet, as well as locally diopside and hypersthene (Wiik 1966, Siedlecka et al. 1985). According to the type of mineralogical banding, they can be subdivided into typical oxide-facies BIF composed of alternating bands of quartz and magnetite, which may grade into silicate-facies types containing bands of magnetite and Fe-rich silicates. Although the BIF units are strongly deformed, causing tectonic dismembering and changes in the original thicknesses, they were most probably deposited at different levels in the original volcanosedimentary sequences. The BIF ores in the Garsjø Group and in the Jarfjord

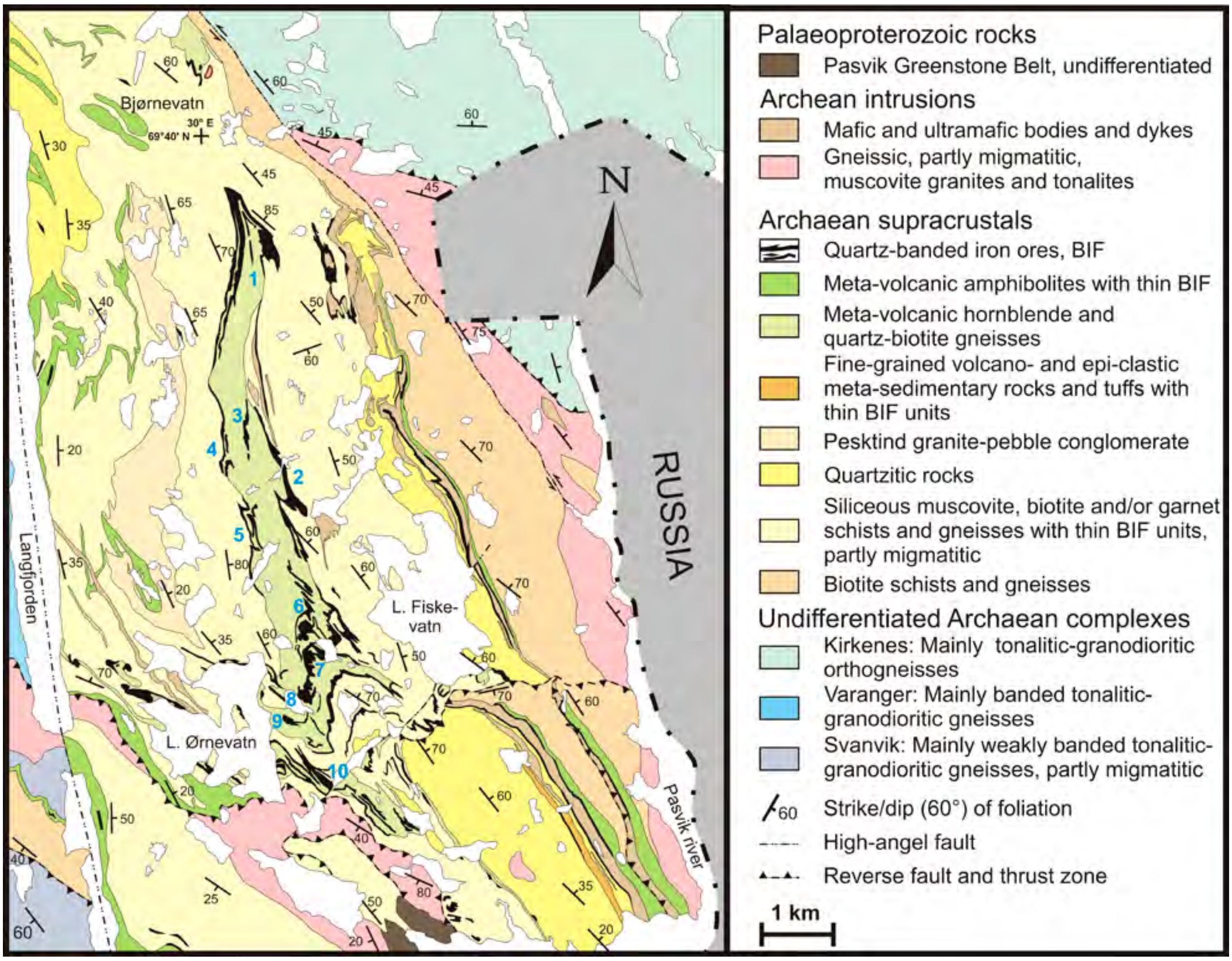


Figure 82. Geological map of the Bjørnevatn subarea, compiled from Iversen and Krill (1990) and Iversen and Nilsson (1991). Resource estimates are based on the ore bodies: 1) Bjørnevatn, 2) Tverrdalen, 3) Grundtjern, 4) Søstervann, 5) Bjørnefjell, 6) Fisketind, east, 7) Fisketind, SW, 8) Jerntoppen, 9) Hyttemalmen, and 10) Kjellmannsåsen.

Gneiss frequently comprise silicate-facies ores. They are normally 1–15 m thick and commonly constitute several-kilometre-long trains of lenses with the strike length of the individual ore bodies rarely exceeding a few hundred metres. Only the oxide-facies units occurring in the Bjørnevatn Group (Dobrzhinetskaya et al. 1995) have dimensions suitable for exploitation.

In the south, area N040 extends into Finnish territory. A few small occurrences of oxide- to silicate-facies BIF have been detected there, in settings similar to those in the Norwegian part of the area. There are no resource estimates of Finnish occurrences, which have as a group been referred to as the Vätsäri iron occurrences by Lehto and Niiniskorpi (1977) and Saltikoff et al. (2006).

The **Bjørnevatn** subarea (N040.1, Fig. 82) contains the largest accumulation of BIF ores in the Sør-Varanger metallogenic area. The BIF units of the presently mined ore field were first discovered by the Commissioner of Mines, Tellef Dahll, in 1865 (Dahll 1891), but exploration in the area started nearly forty years later in 1906. Full-scale mining commenced in 1910 by A/S Sydvaranger and continued until 1997. During this period, open pit and subordinate underground mining gave a total production of over 200 Mt of ore with about 30 % Fe (magnetic). In 2009, Sydvaranger Gruve AS reopened the deposit and is presently mining two of the ore bodies (**Hyttemalmen** and **Kjellmannsåsen**) with proven ore reserves of 20 Mt containing 34 % Fe (total). In addition, the company has defined 10 individual ore bodies for future mining with total resources (proven+indicated+ inferred) of 449 Mt with 31 % Fe (total) (Northern Iron 2010).

The ore bodies are part of the Bjørnevatn Group, which comprises formations predominantly composed of quartzite, conglomerate, siliceous mica schist and gneiss, as well as biotite-rich mica schist and mafic to intermediate metavolcanic rocks with major BIF units. The metavolcanic rocks contain two levels of BIF ores that occur interlayered with and separated by sequences of hornblende and quartz-biotite gneisses, as well as magnetite-rich amphibolites, locally with pillow structures. These rocks are interpreted as andesitic, dacitic and basaltic volcanic rocks, respectively (Bugge 1978b; Siedlecka et al. 1985). The ore zones and their wall rocks are crosscut by lateorogenic granite dykes and Mesoproterozoic dolerite dykes (1300–1200 Ma, Siedlecka & Nordgulen 1996), not shown in Figures 81 and 82.

The ore bodies of the upper BIF level have been the main target for open-pit mining both in the past and present. The shape of the ore bodies shown in Figure 82 is the ultimate result of three phases of isoclinal to tight folding. In the northern part of the mining field, the distribution of the ores is governed by a moderately SE-plunging synform overturned towards the west. They may reach a thickness of nearly 200 m and a strike-length in the range of 1–5 km. The upper BIF usually contains 30–35 % Fe (magnetic) (>50 % magnetite) and the lower BIF 10–30 % Fe (magnetic) (Siedlecka et al. 1985). The ores consist of alternating magnetite- and quartz-dominated bands (2–10 mm thick). Additional minerals in the BIF include hornblende, grünerite, epidote, biotite and hematite, together with traces of pyrite and chalcopyrite that are mainly confined to the magnetite bands. In some parts of the mining field, the BIF comprises nearly monomineralic bands of hornblende and grünerite.

In the southernmost part of the mining field, both the amphibolitic rocks and the ore zones thin out and start to interfinger with arenitic to pelitic metasedimentary rocks locally grading into conglomeratic units with pebbles of BIF and tonalite in a magnetite-rich matrix. These features indicate transformation to shallow-water palaeoconditions.

Correlation of iron ores in the Bjørnevatn Group with quartz-banded iron ores elsewhere in the supracrustal sequences of the Sør-Varanger province have been discussed by Bugge (1960b, 1978b) and Siedlecka et al. (1985). The up to 1-km-long and 1–15-m-thick units of banded iron ores occurring in the supracrustals of the Garsjø Group and Jarfjord Gneiss, as well as in small enclaves inside the plutonic rocks of the Varanger, Kirkenes, Hompen and Svanvik Gneiss Complexes (Fig. 82), have many features in common, including a small size, close association with thin units of Fe-rich amphibolites (ferrobasalts), variable wallrock lithologies, and lenticular banding with highly variable thickness and spacing of the magnetite, quartz, grünerite, and/or biotite-garnet bands. Although the Fe-rich amphibolites associated with the iron ores in the Sør-Varanger metallogenic area show similar major and trace element chemistry and REE characteristics (Dobrzhinetskaya et al. 1995), the wall-rock sequences frequently differ, reflecting variations in the depositional environments with respect to distance from volcanic centres and the degree of syn-depositional influx of volcanoclastic and epiclastic sediments.

REFERENCES

Aggerholm, V. 1979. En geologisk undersøgelse af nogle vanadiumholdige jern-titan forekomster i Bamble-Formasjonen i Syd-Norge. Speciale, Aarhus universitet. 138 p. (in Danish)

Åhäll, K. I. & Daly, J. S. 1985. Late Presveconorwegian magmatism in the Østfold–Marstrand belt, Bohuslän, SW Sweden. In: Tobi, A. C. & Touret, J. L. R. (eds) The deep Proterozoic crust in the North Atlantic Provinces, Reidel, 359–367.

Andersen, T., Griffin, W. L. & Pearson, N. J. 2002. Crustal evolution in the SW part of the Baltic Shield: the Hf isotope evidence. Journal of Petrology 43, 1725–1747.

Andersen, T., Griffin, W. L., Jackson, S. E., Knudsen, T.-L. & Pearson, N. J. 2004. Mid-Proterozoic magmatic arc evolution at the southwest margin of the Baltic shield. Lithos 73, 289–318.

Andersen, T., Griffin, W. L. & Sylvester, A. G. 2007. Sveconorwegian crustal underplating in southwestern Fennoscandia: LAM-ICPMS U-Pb and Lu-Hf isotope evidence from granites and gneisses in Telemark, southern Norway. Lithos 93, 273–287.

Andréasson, P. G., Gee, D. G., Whitehouse, M. J. & Schöberg, H. 2003. Subduction-flip during Iapetus Ocean closure and Baltica-Laurentia collision, Scandinavian Caledonides. Terra Nova 15, 362–369.

Arctic Gold 2011. Reopening of the Bidjovagge gold-copper mine. 4 p. Available at: http://www.arcticgold.se/

Austrheim, H. 1987. Eclogitisation of lower crustal granulites by fluid migration through shear zones. Earth Planetary Science Letters 81, 221–232.

Austrheim, H. & Griffin, W.-L. 1985. Shear deformation and eclogite formation within granulite-facies anorthosites of the Bergen Arcs, Western Norway. Chemical Geology 50, 267–281.

Barnes, S.- J. 1986. Investigation of the potential of the Tverrfjell portion of the Råna intrusion for platinum group element mineralization. Norges geologiske undersøkelse, Report 86.201. 169 p.

Barnes, S.-J. 1987. Unusual nickel and copper to noble-metal ratios from the Råna Layered Intrusion, northern Norway. Norsk Geologisk Tidsskrift 67, 215–231.

Barnes, S.-J. 1989. Sulphide segregation history of the Tverrfjell portion of the Råna Layered Intrusion. In: Prendergast, M. D. & Jones, M. J. (eds) Magmatic Sulphide – the Zimbabwe Volume, 107–116.

Barnes, S.-J., Boyd, R., Korneliussen, A., Nilsson, L. P., Often, M., Pedersen, R. B. & Robins, B. 1988. The use of mantle normalization and metal ratios in discriminating between the effects of partial melting, crystal fractionation and sulphide segregation on platinum group elements, gold, nickel and copper: Examples from Norway. In: Prichard, H. M., Potts, P. J., Bowles, J. F. W. & Cribb, S. J. (eds) Geo-Platinum -87. London: Elsevier, 113–143.

Berg, B. I. 2006. Moisesberg i Fyresdal, 1541–1549. Novus Forlag og Norsk Bergverksmuseum, Oslo 2006. 400 p. (in Norwegian with English summary).

Bergstøl, S. & Vokes F. M. 1974. Stromeyerite and Mckinstryite from the Godejord poly-metallic sulphide deposit, central Norwegian Caledonides. Mineralium Deposita 9, 325–337.

Berthelsen, A., Olerud, S. & Sigmond, E. M. O. 1996. Geologisk kart over Norge, berggrunnskart Oslo 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Bingen, B., Birkeland, A., Nordgulen, Ø. & Sigmond, E. M. O. 2001a. Correlation of supracrustal sequences and origin of terranes in the Sveconorwegian orogen of SW Scandinavia: SIMS data on zircon in clastic metasediments. Precambrian Research 108, 293–318.

Bingen, B., Davis, W. J. & Austrheim, H. 2001b. Zircon U-Pb geochronology in the Bergen arc eclogites and their Proterozoic protoliths, and implications for the pre-Scandian evolution of the Caledonides in western Norway. Geological Society of America, Bulletin 113, 640–649.

Bingen, B. & Stein, H. J. 2003. Molybdenite Re-Os dating of biotite dehydration melting in the Rogaland high-temperature granulites, S Norway. Earth and Planetary Science Letters 208, 181–195.

Bingen, B., Skår, Ø., Marker, M., Sigmond, E. M. O., Nordgulen, Ø., Ragnhildstveit, J., Mansfeld, J., Tucker, R. D. & Liegeois, J.-P. 2005. Timing of continental building in the Sveconorwegian orogen, SW Scandinavia. Norwegian Journal of Geology 85, 87–116.

Bingen, B., Stein, H. J., Boagerts, M., Bolle, O. & Mansfeld, J. 2006. Molybdenite Re-Os dating constraints gravitational collapse of the Sveconorwegian orogen, SW Scandinavia. Lithos 87, 328–346.

Bingen, B. & Stein, H. J. 2007. Fra gruvedrift til geoturisme. Nye aldersdateringer forteller den geologiske historien. GEO, Magasin for Geomiljøet, Juni 2007 (4), 24–28. (in Norwegian)

Bingen, B., Davis, W. J., Hamilton, M. A., Stein, H. J., Engvik, A. K., Skår, Ø. & Nordgulen, Ø. 2008a. Geochronology of high-grade metamorphism in the Sveconorwegian belt, S Norway: U-Pb, Th-Pb and Re-Os data. Norwegian Journal of Geology 88, 13–42.

Bingen, B., Nordgulen, Ø. & Viola, G. 2008b. A four-phase model for the Sveconorwegian orogeny, SW Scandinavia. Norwegian Journal of Geology 88, 43–72.

Binns, R. A. 1967. Barroisite-bearing eclogite from Naustdal, Sogn og Fjordane, Norway. Journal of Petrology 8, 349–371.

Birkeland, A. 1986. Mineralogisk og geokjemisk undersøkelse av Killingdal gruver, Sør-Trøndelag. M. Scient. Thesis, University of Oslo. 158 p. (in Norwegian)

Bjerkgård, T. 1989. Regionalgeologiske undersøkelser i Vingelenfeltet, Nord-Østerdalen, i det sørlige Trondheimsfeltet, med henblikk på sulfidmineraliseringene. Cand. Scient. Thesis, University of Oslo. 191 p. (in Norwegian)

Bjerkgård, T. 1999. Metal distribution and formation of the Bleikvassli Zn-Pb-(Cu) deposit, Nordland, Norway. In: Stanley et al. (eds) Mineral Deposits: Processes to Processing, London, 22–25 August, 1999, 931–934.

Bjerkgård, T. 2007. The Hersjø ore deposit, evaluation of ore potential. Norges geologiske undersøkelse, Report 2007.023. 33 p.

Bjerkgård, T. & Bjørlykke, A. 1994a. Geology of the Folldal area, southern Trondheim Region Caledonides, Norway. Norges geologiske undersøkelse, Bulletin 426, 53–75.

Bjerkgård, T. & Bjørlykke, A. 1994b. The stratabound sulphide deposits in the Folldal area, Southern Trondheim region, Norway. Norsk Geologisk Tidsskrift 74, 213–237.

Bjerkgård, T., Larsen, R.B. & Marker, M. 1995. Regional Geology of the Okstindene Area, the Rödingsfjäll Nappe Complex, Nordland, Norway. Norges geologiske undersøkelse, Rapport 95.153.

Bjerkgård, T. & Bjørlykke A. 1996. Sulphide deposits in Folldal, Southern Trondheim Region Caledonides, Norway. Source of metals and wall-rock alterations related to host rocks. Economic Geology 91, 676–696.

Bjerkgård, T., Larsen, R. B. & Marker, M. 1997. Regional setting of the Bleikvassli Zn-Pb deposit in Nordland, Norway: Norges geologiske undersøkelse, Bulletin 433, 34–35.

Bjerkgård, T., Sandstad, J. S. & Sturt, B. A. 1999. Massive sulphide deposits in the south-eastern Trondheim region Caledonides, Norway: a review. In: Stanley et al. (eds) Mineral Deposits: Processes to Processing, London, 22–25 August, 1999, 935–938.

Bjørlykke, A., Olerud, S. & Sandstad, J. S. 1985. Metallogeny of Finnmark, North Norway. Norges geologiske undersøkelse, Bulletin 403, 183–196.

Bjørlykke, A., Hagen, R. & Söderholm, K. 1987. Bidjovagge Copper-Gold Deposit in Finnmark, Northern Norway. Economic Geology 82, 2059–2075.

Bjørlykke, A, Nilsen, K., Anttonen, R. & Ekberg, M. 1993. Geological setting of the Bidjovagge deposit and related gold-copper deposits on the northern part of the Baltic Shield. In: Maurice, Y.T. (ed.) Proceedings 8th Quadrenn. IAGOD Symposium, Ottawa, Canada, 1990, 667–680.

Bjørlykke, H. 1946. Foreløpig rapport over geologiske undersøkelser ved Røstvangen grube og tilhørende gruber og skjerp ved Børsjøhø. BA Report 4463. 9 p. (in Norwegian)

Bjørlykke, H. 1947. Flåt nickel mine. Norges geologiske undersøkelse, Bulletin168b, 1–39.

Bjørlykke, H. 1949. Hosanger nikkelgruve. Norges geologiske undersøkelse, Bulletin 172. 37 p. (in Norwegian)

Bjørlykke, H. 1966. De alluviale gullforekomster i indre Finnmark. Norges geologiske undersøkelse 236, 5–66. (in Norwegian)

Blackstone Ventures Inc. 2009a. Hosanger project. 4 p. Available at: http://www.blv.ca/s/Hosanger.asp.

Blackstone Ventures Inc. 2009b. Available at: www.blv.ca

Blackstone Ventures Inc. 2010a. Available at: http://www.blv.ca/s/Bamble.asp

Blackstone Ventures Inc. 2010b. Available at: http://www.blv.ca/s/Ertelien.asp

Bøckman, K. L. 1942. Rørosviddas malmforekomster. In: Rørosbok-komiteen (ed.) Rørosboka, 1. bind. Trondheim, 53–71. (in Norwegian)

Bodart, D. E. 1968. On the paragenesis of albitites. Norsk Geologisk Tidsskrift 48, 269–280.

Boundy, T. M., Fountain, D. M. & Austrheim, H. 1992. Structural development and petrofabrics of eclogite facies shear zones, Bergen arcs, western Norway: implications for deep crustal deformation processes, Journal of Metamorphic Geology 10, 127–146.

Boyd, R. 1980. Geologisk oversiktsrapport, Bruvannsfeltet, Ballangen kommune, Nordland. Norges geologiske undersøkelse rapport 1582 A, 4 volumes. 45 p + 53 maps. (in Norwegian)

Boyd, R. & Mathiesen, C. O. 1979. The nickel mineralization of the Råna mafic intrusion, Nordland, Norway. Canadian Mineralogist 17, 287–298.

Boyd, R. & Nixon, F. 1985. Norwegian nickel deposits: a review. Geological Survey of Finland, Bulletin 333, 363–394.

Boyd, R., McDade, J. M., Millard, H. T. & Page, N. J. 1987. Platinum metal geochemistry of the Bruvann nickel-copper deposit, Råna, North Norway. Norsk Geologisk Tidsskrift 67, 205–213.

Boyd, R., Barnes, S.-J. & Grønlie, A. 1988. Noble metal geochemistry of some Ni-Cu deposits in the Sveconorwegian and Caledonian orogens in Norway. In: Prichard, H., Bowles, J. & Potts, P. (eds) Geoplatinum '87 Symposium Volume. Elsevier, 145–158.

Boyle, A. P. 1989. The geochemistry of the Sulitjelma ophiolite and associated basic volcanics: Tectonic implications. In: Gayer, R. A. (ed.) The Caledonide geology of Scandinavia. London: Graham and Trottman, 153–163.

Braathen, A. & Davidsen, B. 2000. Structure and stratigraphy of the Palaeoproterozoic Karasjok Greenstone Belt, North Norway–regional implications. Norsk Geologisk Tidsskrift 80, 33–50.

Brattli, B. 1996. Structures and metamorphism at Brygfjell–Simafjell within the Rödingsfjället Nappe Complex, Nordland, Norway. Norges geologiske undersøkelse, Bulletin 431, 19–32.

Brickwood, J. D. 1986. The geology and mineralogy of some Fe-Cu-Ni sulphide deposits in the Bamble area, Norway. Norsk Geologisk Tidsskrift 66, 189–208.

Brøgger W. C. 1935. On several Archean rocks from the south coast of Norway. II. The south Norwegian hyperites and their metasomatism. Skrifter Norsk Vitenskaps-Akademi i Oslo, Matematisk-Naturvitenskapelig Klasse 1. 421 p.

Bugge, A. 1963. Norges molybdenforekomster. Norges geologiske undersøkelse 217. 134 p. (in Norwegian)

Bugge, C. 1917. Kongsbergfeltets geologi. Norges geologiske undersøkelse 82. 272 p. (in Norwegian)

Bugge, J. A. W. 1960a. Skarn iron ore deposits in the Arendal district. In: Vokes, F. M. (ed.) Mines in south and central Norway. International Geological Congress, XXI session, Oslo 1960, Guide to excursion no. C10, 26–38

Bugge, J. A. W. 1960b. Precambrian of eastern Finnmark. In: Holtedahl, O. (ed). Geology of Norway. Norges geologiske undersøkelse 208, 78–92.

Bugge, J. A. W. 1978a. Kongsberg–Bamble Complex. In: Bowie et al. (eds) Mineral deposits of Europe, vol. 1: North-West Europe. London: Institution of Mining and Metallurgy and Mineralogical Society, 213–217.

Bugge. J. A. W. 1978b. Norway. In: Bowie, S. H. U., Kvalheim, A. & Haslam, H. W. (eds) Mineral deposits of Europe, v. 1, North-west Europe. London: Institution of Mining and Metallurgy/Mineral Society, 199–249.

Carstens, H. 1955. Jernmalmene i det vestlige Trondheimsfelt og forhold til kisforekomstene. Norsk Geologisk Tidsskrift 35, 211–221. (in Norwegian)

Carstens, H. 1957. Investigations of titaniferous iron ore deposits. Part II: Gabbro, anorthosite and titaniferous iron ore on Flakstadøy in Lofoten, northern Norway. Det Kongelige Norske Videnskaps Selskapers Skrifter 1957, no. 4, 1–24.

Charlier, B., Duchesne, J.-C. & Vander Auwera, J. 2006. Magma chamber processes in the Tellnes ilmenite deposit (Rogaland Anorthosite Province, SW Norway) and the formation of Fe-Ti ores in massif-type anorthosites. Chemical Geology 234, 264–290.

Charlier, B., Skår, Ø., Korneliussen, A., Duchesne, J. C. & Vander Auwera, J. 2007. Ilmenite composition in the Tellnes Fe-Ti deposit, SW Norway: fractional crystallization, postcumulus evolution and ilmenite-zircon relation. Contributions to Mineralogy and Petrology 154, 119–134.

Chernet, T. 1999. Effect of mineralogy and texture in the TiO_2 pigment production process of the Tellnes ilmenite concentrate. Mineralogy and Petrology 67, 21–32.

Chernet, T. 2003. Effect of mineralogy and texture of sand and hard rock ilmenite in TiO_2 pigments production by the sulfate process, a case study on Australian ilmenite concentrate and Tellnes ilmenite concentrate, Norway. In: Duchesne, J.-C. & Korneliussen, A. (eds) Ilmenite deposits and their geological environment. Norges geologiske undersøkelse, Special Publication 9, 45–46.

Cook, N. J., Halls, C. & Kaspersen, P. 1990. The geology of the Sulitjelma ore field, Northern Norway – some new interpretations. Economic Geology 85, 1720–1737.

Coppard, J. 1994. Norway-Rai'tevarre. 1994 year end report. Directorate of Mines (BV) report 4025. 10 p.

Corfu, F. 2000. U-Pb zircon geochronology of the Lofoten-Vesterålen AMCG-complex, northern Norway. 24. Nordic Geological Winter Meeting, Trondheim, Norway, abstract volume, Geonytt Nr. 1, p. 53.

Cosca, M. A., Mezger, K. & Essene, E. J. 1998. The Baltica–Laurentia Connection: Sveconorwegian (Grenvillian) Metamorphism, Cooling, and Unroofing in the Bamble Sector, Norway. Journal of Geology 106, 539–552.

Cumming, G. L., Krstic, D., Bjørlykke, A. & Aasen, H. 1993. Further analysis of radiogenic minerals from the Bidjovagge gold-copper deposit, Finnmark, northern Norway. Mineralogy and Petrology 47, 361–369.

Cuthbert, S. J. 1985. Petrology and tectonic settings of relatively low-temperature eclogites and related rocks in the Dalsfjord area, Sunnfjord, West Norway. PhD thesis, University of Sheffield.

Dahll, T. 1891. Om fjeldbygningen i Finmarken og guldets forekomst sammesteds. Norges geologiske undersøkelse 4, 1-21. (in Norwegian)

Dalsegg, E., Elvebakk, H., Gellein, J. & Kihle, O. 1999. Gravity measurements in eclogite mapping, Naustdal, Sogn og Fjordane. Norges geologiske undersøkelse, Report 99.124. 30 p.

Davidsen, B. 1994. Stratigrafi, petrologi og geokjemi med vekt på komatiittiske bergarter innen den nordligste del av Karasjok grønnsteinsbelte, Brennelv, Finnmark. Unpublished cand. scient. thesis, University of Tromsø. 380 p. + 6 app. + 1 map enclosure. (in Norwegian)

de Haas, G. J. L. M., Nijland, T. G., Andersen, T. & Corfu, F. 2002. New constraints on timing of deposition and metamorphism in the Bamble sector, south Norway: zircon and titanite U-Pb data from the Nelaug area. GFF 124, 73–78.

Digre, M. 1972. Orienterende flotasjonsforsøk med malmprøver fra Rieppe. Internal report A/S Bleikvassli Gruber. (in Norwegian)

Dobrzhinetskaya, L. F., Nordgulen, Ø., Vetrin, V. R., Cobbing, J. & Sturt, B. A. 1995. Correlation of the Archaean rocks between the Sørvaranger area, Norway, and the Kola Peninsula, Russia (Baltic Shield). Norges geologiske undersøkelse, Special Publication 7, 7–27.

Dons, J. A. 1963. De prekambriske bergarter i Telemark, I Gruber og skjerp innen gradteigskart E36V Kviteseid. Norges geologiske undersøkelse 216, 1–80. (in Norwegian)

Duchesne, J. C. 1987. The Bjerkreim–Sokndal massif. In: Maijer, C. & Padget, P. (eds) The geology of southernmost Norway. Norges geologiske undersøkelse, Special Publication 1, 56–59.

Duchesne, J. C. 1999. Fe-Ti deposits in Rogaland anorthosites (South Norway): geochemical characteristics and problems of interpretation. Mineralium Deposita 34, 182–198.

Duchesne, J.-C. (ed.) 2001. The Rogaland Intrusive Massifs, an excursion guide. Norges geologiske undersøkelse, Report 2001.29. 137 p.

Duchesne, J. C., Maquil, R. & Demaiffe, D. 1985. The Rogaland anorthosites: facts and speculations. In: Toby, A. C. & Touret, J. L. R. (eds) The deep Proterozoic crust in the North Atlantic provinces. NATO Adv. Stud. Inst., Reidel, Dordrecht, C158, 449–476.

Duchesne, J. C. & Hertogen, J. 1988. Le magma parental du lopolith de Bjerkreim–Sokndal (Norvège méridionale). C.R. Acad. Sci. Paris 306, 45–48.

Duchesne, J.-C. & Korneliussen, A. (eds) 2003. Ilmenite deposits and their geological environment. Norges geologiske undersøkelse, Special Publication 9. 134 p.

Dunning, G. R. & Pedersen, R. B. 1988. U/Pb ages of ophiolites and arc-related plutons of the Norwegian Caledonides: implications for the development of Iapetus. Contributions to Mineralogy and Petrology 98, 13–23.

Eidsvig, P. 1971. Geofysiske målinger, Hosanger, Østerøy. Norges geologiske undersøkelse, Rapport 967. 11 p. (in Norwegian)

Eilu, P., Pankka, H., Keinänen, V., Kortelainen, V., Niiranen, T. & Pulkkinen, E. 2007. Characteristics of gold mineralization in the greenstone belts of northern Finland. In: Ojala, V. J. (ed.) Gold in the Central Lapland Greenstone Belt, Finland. Geological Survey of Finland, Special Paper 44, 57–106.

Eilu, P. & Ojala, V. J. 2011. Cu-Au mineralisation at Raitevarri, Karasjok greenstone belt, northern Norway. In: Barra, F., Reich, M., Campos, E. & Tornos, F. (eds) Let's Talk Ore Deposits. Proceedings of the Eleventh Biennial SGA Meeting, 26–29 September 2011, Antofagasta, Chile. Ediciones Universidad Catolica del Norte, Antofagasta, Chile, 351–353.

Ekberg, M. & Sotka, P. 1991. Production mineralogy and selective mining at Bidjovagge mine, northern Norway. International Conference on Applied Mineralogy, Pretoria, South Africa.

Elvebakk, H., Gellein, J. & Furuhaug, L. 1999. Gravity measurements in eclogite mapping, Naustdal, Sogn og Fjordane. Norges geologiske undersøkelse, Report 99.046. 52 p.

Engvik, A. K., Austrheim, H. & Andersen, T. B. 2000. Structural, mineralogical and petrophysical effects on deep crustal rocks of fluid-limited polymetamorphism, Western Gneiss Region, Norway. Journal of Geological Society, London, 157, 121–134.

Engvik, A. K., Mezger, K., Wortelkamp, S., Bast, R., Corfu, F., Korneliussen, A., Ihlen, P., Bingen,B. & Austrheim, H. 2010. Metasomatism of gabbro – mineral replacement and element mobilization during amphibolite facies metamorphism. Journal of Metamorphic Geology 29, 399–423.

Eskola, P. 1921. On the eclogites on Norway. Skr. Nor. Vid. Akad. Oslo, Kl. 1 No. 8, 1–118.

Ettner, D. C., Bjørlykke, A. & Andersen, T. 1994. A fluid inclusion and stable isotope study of the Proterozoic Bidjovagge, Au-Cu deposit, Finnmark, Northern Norway. Mineralium Deposita 29, 16–29.

Fabricius, J. 1979. Kobberforekomsten på Ulveryggen, Finnmark, Norge. Dansk geologisk Forening, Årsskrift for 1979, 107–110. (in Danish)

Foslie, S. 1921. Field observations in Northern Norway bearing on magmatic differentiation. Journal of Geology 29, 701–719.

Foslie, S. 1922. Raana norittfelt. Differentiation ved squeezing. Norges geologiske undersøkelse 87, III. 52 p. (in Norwegian with English summary).

Foslie, S. 1926. Norges svovelkisforekomster. Norges geologiske undersøkelse 127, 1–122. (in Norwegian)

Foslie, S. 1949. Håfjellsmulden i Ofoten og dens sedimentære jern-mangan-malmer. Norges geologiske undersøkelse 174. 129 p. (in Norwegian)

Foslie, S. 1955. Kisdistriktet Varaldsøy–Ølve i Hardanger og bergverksdriftens historie. Norges geologiske undersøkelse 147, 1–106. (in Norwegian)

Foslie, S. & Johnson Høst, M. 1932. Platina i sulfidisk nikkelmalm. Norges geologiske undersøkelse, Bulletin 137. 71 p.

Gale, G. H. & Roberts, D. 1974. Trace element geochemistry of Norwegian lower Palaeozoic basic volcanics and its tectonic implications. Earth Planetary Science Letters 22, 380–390.

Gammon, J. B. 1966. Fahlbands in the Precambrian of Southern Norway. Economic Geology 61, 174–188.

Gautneb, H. & Sæther, O. M. 2009. A compilation of previously published geochemical data on the lower Cambro-Silurian sedimentary sequence, including the alum shales in the Oslo region. Norges geologiske undersøkelse, Report 2009.053. 25 p.

Geis, H. P. 1957. Vorkommen von Pyrite und Kupferkies auf Karmøy, Norwegen. BA Report 3116A+B. 100 p. (in German)

Geis, H. P. 1965. 100 Jahre Vigsnes Kobberverk. Tidsskrift for kjemi, bergvesen og metallurgi, 8–9, 194–202. (in German)

Geis, H. P. 1971. A short description of the iron-titanium provinces in Norway with special reference to those in production. Miner. Sci. Eng. July 1971, 14–24.

Gierth, E. & Krause, H. 1973. Die ilmenittlagerstätte Tellnes (Südnorwegen). Norsk geologisk tidskrift 53, 359–402.

Gjelle, S. & Søvegjarto, U. 2004. Ranas fjell og gruver. En beskrivelse av berggrunnen på kartbladene Mo i Rana og Storforshei. Norges geologiske undersøkelse Gråsteinen 9. 63 p. (in Norwegian)

Green, J. C. 1956. Geology of the Storkollen–Blankenberg area, Kragerø, Norway. Norsk Geologisk Tidsskrift 36, 89–140.

Grenne, T. 1986. Ophiolite-hosted Cu-Zn deposits at Løkken and Høydal, Trondheim Nappe Complex, Upper Allochthon. In: Stephens, M. B. (ed.) Stratabound sulphide deposits in the central Scandinavian Caledonides. Sveriges Geologiska Undersökning Ca 60, 55–64.

Grenne, T. 1989a. Magmatic evolution of the Løkken SSZ ophiolite, Norwegian Caledonides: Relationships between anomalous lavas and high-level intrusions. Geological Journal 24, 251–274.

Grenne, T. 1989b. The feeder zone to the Løkken ophiolite-hosted massive sulphide deposit and related mineralizations in the central Norwegian Caledonides. Economic Geology 84, 2173–2195.

Grenne, T. 1995. Kjerneboring i Godejord 1994. Norges geologiske undersøkelse Rapport 95.101. 22 p. (in Norwegian)

Grenne T., Grammeltvedt, G., & Vokes F. M. 1980. Cyprus-type sulphide deposits in the western Trondheim district, Central Norwegian Caledonides. Proceedings of the international ophiolite symposium 1979, Cyprus. Nicosia, Cyprus Ministry Agriculture Natural Resources, Geological Survey Department, 727–743.

Grenne, T. & Lagerblad, B. 1985. The Fundsjø Group, central Norway: a lower Palaeozoic island arc sequence, geochemistry and regional implications. In: Gee, D. G. & Sturt, B. A. (eds) The Caledonide orogen – Scandinavia and related areas. Chichester: Wiley, 745–760.

Grenne, T. & Vokes, F. M. 1990. Sea-floor sulphides at the Høydal volcanogenic deposit, Central Norwegian Caledonides. Economic Geology 85, 344–359.

Grenne, T., Hertogen, J., Solli, A., Birkeland, A., Erichsen, E. & Sandstad, J. S. 1995. The sequential development of magmatic and ore-forming processes in the Fundsjø Group, Meråker district, Central Norway. Norges geologiske undersøkelse 427, 108–111.

Grenne, T. & Erichsen, E. 1996. 3D-modellering, tonnasje- og gehaltberegning av Godejordforekomsten, Grong, Nord-Trøndelag. Norges geologiske undersøkelse Rapport 96.024. 41 p. (in Norwegian)

Grenne, T., Ihlen P. M. & Vokes, F. M. 1999. Scandinavian Caledonide Metallogeny in a plate tectonic perspective. Mineralium Deposita 34, 422–471.

Grenne, T., Heim, M., Reinsbakken, A. & Sandstad, J. S. 2000. Arc rifting and ore formation in the Early Ordovician Skorovass complex, Central Norway. 24. Nordiske geologiske vintermøtet, Trondheim 2000. Geonytt nr. 1.

Griffin, W. L., Taylor, P. N., Hakkinen, J. W., Heier, K. S., Iden, I. K., Krogh, E. J., Malm, O., Olsen, K. I., Ormaasen, D. E. & Tveten, E. 1978. Archaean and Proterozoic crustal evolution in Lofoten–Vesterålen, N Norway. Journal of the Geological Society of London 135, 629–647.

Grip, E. & Frietsch, R. 1973. Malm i Sverige 2, Norra Sverige. Almqvist & Wiksell Läromedel AB, Stockholm. 295 p. (in Swedish)

Gvein, Ø. 1977. Rapport vedrørende A/S Sydvaranger avd. Vigsnes kobbergruver, Rogaland, BV 1384. 59 p. (in Norwegian)

Helland, A. 1900. Bergverksdrift og stenbrytning i Norge. Naturen, 342–346. (in Norwegian)

Hildreth, S. C., Grenne, T. & Sharp, W. E. 2001. Genesis of Ni-Cu sulphide ore at the Skjækerdalen intrusive complex, central Norway. Norwegian Journal of Geology 81, 49–58.

Horne, G. S. 1979. Mélange in the Trondheim Nappes suggests a new tectonic model for the central Norwegian Caledonides. Nature 281, 267–270.

Hornemann, H. H. 1936. Report on the cobalt mines at Modum, collected from different sources. Norges geologiske undersøkelse Bergarkivet, report BA 596. 17 p.

IGE 2006. Available at: www.ige.se

Ihlen, P. M. 1986a. The metallogeny of the Kongsberg distric. In: Olerud, S. & Ihlen, P. M. (eds) Metallogeny associated with the Oslo Paleorift. 7th IAGOD symposium, Excursion guide no 1, Sveriges geologiska undersökning Ser. Ca 59, 30–32.

Ihlen, P. M. 1986b. The geological evolution and metallogeny of the Oslo Paleorift. In: Olerud, S. & Ihlen, P. M. (eds) Metallogeny associated with the Oslo Paleorift. 7th IAGOD symposium, Excursion guide no 1, Sveriges geologiska undersökning Ser. Ca 59, 6–17.

Ihlen, P. M. 1986c. Late Proterozoic gold deposits of the Eidsvoll-Odalen distict, southeast Norway. TERRA cognita 6, p. 538.

Ihlen, P. M. 1993. The Kolsvik Au-As deposit, Bindal, North-Central Norway. I: Corelogs. Norges geologiske undersøkelse, Report 93.003. 322 p.

Ihlen, P. M. 1995. Gold mineralization in relation to batholith magmatism in the Helgeland nappe complex and its immediate substrate, the Caledonides of north-central Norway. Grønlands geologiske undersøgelse. Open file series no. 95–10; Gold mineralization in the Nordic countries and Greenland, 42–46.

Ihlen, P. M. 1999. Gold deposits in Norway – a review. In: Cook, N. J. & Sundblad, K. (eds) Gold '99 Trondheim.

Precambrian gold in the Fennoscandian and Ukrainian Shield and related areas. NGU and NTNU Trondheim, 96–99.

Ihlen, P. M. 2005. Gold deposits in the Karelian Craton and potential exploration targets in the Karasjok Greenstone Belt. Norges geologiske undersøkelse, Report 2005.076. 55 p.

Ihlen, P. M. & Vokes, F. M. 1978. Metallogeny associated with the Oslo rifting. In: Dons, J. A. & Larsen, B. T. (eds) The Oslo paleorift. A review and guide to excursions. Norges geologiske undersøkelse 337, 123–142.

Ihlen, P. M., Ineson, P. R. & Mitchell, J. G. 1978. K/Ar dating of clay-mineral alteration associated with ore deposition in the northern part of Oslo Region. In: Neumann, E.-R. & Ramberg, I. B. (eds) Petrology and Geoshemistry of Coninental Rifts. Dordrecht: D. Reidel Publishing Company, 255–264.

Ihlen, P. M., Ineson, P. R., Mitchell, J. G. & Vokes, F. M. 1984. K-Ar dating of dolerite dykes in the Kongsberg-Fiskum District, Norway, and their relationship with the silver and base metal veins. Norsk Geologisk Tidsskrift 64, 87–96.

Ihlen, P. M. & Nordum, F. S. 1986. The Kongsberg mining area – a road log. In: Olerud, S. & Ihlen, P. M. (eds) Metallogeny associated with the Oslo Paleorift. 7th IAGOD symposium, Excursion guide no 1, Sveriges geologiska undersökning Ser. Ca 59, 33–38.

Ihlen, P. M., Often, M. & Marker, M. 1993. The geology of the Late Archaean sequence at Khisovaara, Russian Karelia, and associated metasomatites: Implications for the interpretation of the Raitevarre Cu-Au deposit in the Karasjok Greenstone Belt, North Norway. 1st International Barents Symposium 21–24 Oct. 1993, Kirkenes, Norway. Norges geologiske undersøkelse, Abstract volume. (in English and Russian).

Ihlen, P. M., Grenne, T. & Vokes, F. M. 1997. The metallogenic evolution of the Scandinavian Caledonides. Transactions Institution Mining Metallurgy section B: Applied earth science, 106, B194–B203.

Inkinen, O., Ilvonen, E. & Pelkonen, R. 1984. Puljun liuskejakson ja Hotinvaaran tutkimukset 1982–1984. Outokumpu Oy Report, 001/2742/OI,EI,RP/84/21. 54 p. + 64 app. (in Finnish)

Iversen, E. & Krill, A. G. 1990. Kirkenes, bedrock map 2434-2, 1:50 000, preliminary edition. Norges geologiske undersøkelse.

Iversen, E. & Krill, A. G. 1991. Bøkfjorden, bedrock map 2434-1, 1:50 000, preliminary edition. Norges geologiske undersøkelse.

Iversen, E. & Nilsson, L. P. 1991. Høybuktmoen, bedrock map 2434-3, 1:50 000, preliminary edition. Norges geologiske undersøkelse.

James, D. W., Mitchell, J. G., Ineson, R. & Nordgulen, Ø. 1993. Geology and K/Ar chronology of the Målvika scheelite skarns, Central Norwegian Caledonides. Norges geologiske undersøkelse, Bulletin 424, 65–74.

Jensen, R. 1972. Hosangerfeltet, Østerøy, Hordaland. Elkem A/S intern rapport. Norges geologiske undersøkelse Ba 4732. 5 p. (in Norwegian)

Johansen, H. & Segalstad, T. V. 1985. Gangmineraldannelser i Kongsberg sølvforekomst. In: Nye malmtyper i Norge. Malmgeologisk Symposium, BVLI – Bergforskningen, Trondheim, p. 99. (in Norwegian)

Jolivet, L., Raimbourg, H., Labrousse, L., Avigad, D., Leroy, Y., Austrheim, H. & Andersen, T. B. 2005. Softening trigerred by eclogitization, the first step toward exhumation during continental subduction. Earth Planetary Science Letters 237, 532–547.

Jonsson, S. 1992. Eldre bergverksdrift i Sokndal. Titania A/S's røtter og tidlige historie. Ilmenitten jubileumsnummer i anledning Titania A/S 90 år (1902–1992), 1–21. (in Norwegian)

Jøsang, O. 1966. Geologiske og petrografiske undersøkelser i Modumfeltet. Norges geologiske undersøkelse 235, 1–171. (in Norwegian)

Karppanen, T., Lamberg, P. & Pietilä, R. 1999. The Nikkel og Olivin a s Exploration Project. Years 1996–1998. Final Report. Unpublished internal report of Outokumpu Base Metals, 30. March 1999. 33 p.

Keilhau, B. M. 1836. Om det forrige guldverk i Eidsvold, et bruddstykke. Nyt Mag. f. Naturv. 11, 259–276. (in Norwegian)

Kjerulf, T. & Dahll, T. 1861. Om jernertsenes forekomst ved Arendal, Næsøy, Kragerø. Nyt Mag. F. Naturv. 11, 293–359. (in Norwegian)

Koistinen, T., Stephens, M. B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comps) 2001. Geological map of the Fennoscandian Shield, 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia.

Korneliussen, A. & Furuhaug, L. 1993. Ødegården rutilforekomst: En rutilførende skapolittomvandlet gabbro ved Ødegårdens Verk, Bamble. Norges geologiske undersøkelse, Rapport 93.078 (in Norwegian)

Korneliussen, A. & Furuhaug, L. 2000. On the rutile deposits Ramsgrønova, Orkheia, Ødegården and Lindvikkollen, S. Norway. Norges geologiske undersøkelse, Report 2000.123. 35 p.

Korneliussen, A., Austrheim, H., Eriksen, E., Furuhaug, L., Lauritsen, T., Rønning, J. S. & Røste, J. 1990. Rutilforekomster på Holsnøy, Meland kommune, Hordaland. Norges geologiske undersøkelse, Report 90.008. 45 p. (in Norwegian)

Korneliussen, A., Austrheim, H., Furuhaug, L., Lauritsen, T. & Torbergsen, K. 1991. Husebø rutilforekomst, Meland kommune, Hordaland. Norges geologiske undersøkelse, Rapport 91.159. 28 p. (in Norwegian)

Korneliussen, A., Braathen, A., Erambert, M., Lutro, O. & Ragnhildstveit, J. 1998. The geology of the Engebøfjell eclogite deposit and its regional setting. Norges geologiske undersøkelse, Rapport 98.081. 121 p.

Korneliussen, A., McEnroe, S. A., Nilsson, L. P., Schiellerup, H., Gautneb, H., Meyer, G. B. & Størseth, L. R. 2000a. An overview of titanium deposits in Norway. Norges geologiske undersøkelse, Bulletin 436, 27–38.

Korneliussen, A., McLimans, R., Braathen, A., Erambert, M., Lutro, O. & Ragnhildstveit, J. 2000b. Rutile in eclogites as a mineral resource in the Sunnfjord Region, western Norway. Norges geologiske undersøkelse, Bulletin 436, 39–47.

Krause, M. 1980. Some uranium mineralisations in the Raipas Suite of the Komagfjord tectonic window, Finnmark, Norway. Norges geologiske undersøkelse 355, 49–52.

Krause, H., Gierth, E. & Schott, W. 1985. Ti-Fe deposits in the South Rogaland Igneous Complex, with special reference to the Åna–Sira anorthosite massif. Norges geologiske undersøkelse, Bulletin 402, 25–37.

Krogh, E. J. 1980. Geochemistry and petrology of glaucophane-bearing eclogites and associated rocks from

Sunnfjord, Western Norway. Lithos 13, 355–380.

Krupp, R. & Krupp, G. 1985. Geological setting of the Tverrfjell copper/zinc deposit, Central Norway. Geologische Rundschau 74, 467–482.

Kullerud, K. 2003. Geochemistry and mineralogy of the Tellnes ilmenite ore body. In: Duchesne, J.-C. & Korneliussen, A. (eds) Ilmenite deposits and their geological environment. Norges geologiske undersøkelse, Special Publication 9, 70–71.

Kvale, A. 1960. The nappe area of the Caledonides in Western Norway. Norges geologiske undersøkelse, Bulletin 212e. 43 p.

Laajoki, K., Corfu, F. & Andersen, T. 2002. Lithostratigraphy and U-Pb geochronology of the Telemark supracrustals in the Bandak–Sauland area, Telemark, South Norway. Norwegian Journal of Geology 82, 119–138.

Lahtinen, R., Garde, A. A. & Melezhik, V. A. 2008. Palaeoproterozoic evolution of Fennoscandia and Greenland. Episodes 31, 20–28.

Lamberg, P. 2005. From genetic concepts to practice – lithogeochemical identification of Ni-Cu mineralised intrusions and localisation of the ore. Geological Survey of Finland, Bulletin 402. 264 p.

Larsen, R. B. & Grenne, T. 1995. Character and tectonic setting of an Ordovician boninite hosted Cu-Ni-PGE ore in the Norwegian Caledonides. Transactions of the Institute of Mining and Metallurgy, Section B104, 87–98.

Lauritsen, T. 1992. Magnetiske bakkemålinger ved Ødegårdens Verk, Bamble, Telemark. Norges geologiske undersøkelse Rapport 92.218. (in Norwegian)

Lehto, T. & Niiniskorpi, V. 1977. The iron formations of northern and eastern Finland. Geological Survey of Finland, Report of Investigations 23. 49 p.

Lehtonen, M. I., Airo, M.-L., Eilu, P., Hanski, E., Kortelainen, V., Lanne, E., Manninen, T., Rastas, P., Räsänen, J. & Virransalo, P. 1998. Kittilän vihreäkivialueen geologia. Lapin vulkaniittiprojektin raportti. Summary: The stratigraphy, petrology and geochemistry of the Kittilä greenstone area, northern Finland. A report of the Lapland Volcanite Project. Geological Survey of Finland, Report of Investigation 140. 144 p.

Levchenkov, O. A., Levsky, L. K., Nordgulen, Ø., Dobrzhinetskaya, L. F., Vetrin, V. R., Cobbing, J., Nielsson, L. P. & Sturt, B. A. 1995. U-Pb zircon ages from Sørvaranger, Norway, and the western part of the Kola Peninsula, Russia. Norges geologiske undersøkelse, Special Publication 7, 29–47.

Lindahl, I. 1974. Økonomisk geologi og prospektering i Vaddas-Rieppe feltet, Nord-Troms. Ph.D. thesis, NTH. (in Norwegian)

Lindahl, I. 1999. Jernmalmen på Andørja, Ibestad kommune – Vurdering av kvalitet på superslig og apatittkonsentrat. Norges geologiske undersøkelse, Rapport 99.115. 20 p. (in Norwegian)

Lindahl, I., Stevens, B. P. J. & Zwaan, K. B. 2005. The geology of the Váddás area, Troms: a key to our understanding of the Upper Allochthon in the Caledonides of northern Norway. Norges geologiske undersøkelse, Bulletin 445, 5–43.

Lindeman, E. 1992. Underjordisk drift i Skiftesmyr. Bergvesenet Rapport BV2883. (in Norwegian)

Ludvigsen, E. 1993. Karenhaugforekomsten: det økonomiske potensialet. SINTEF rapport, STF36 F93077. (in Norwegian)

Ludvigsen, E., Nielsen, K. & Sandvik, K. L. 1990. Karenhaugforekomsten: det økonomiske potensialet. SINTEF rapport, STF36 F90045. (in Norwegian)

Lundquist, T. 1979. The Precambrian of Sweden. Sveriges geologiska undersökning, C 768. 87 p.

Lutro, O. & Tveten, E. 1996. Geologisk kart over Norge, berggrunnskart Årdal M 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Lutro, O. & Nordgulen, Ø. 2008. Oslofeltet, berggrunnskart M 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Lysberg, K. B. 1976. Geologi og mineralisering ved Knaben molybdengruber. Thesis Universitetet i Bergen. 84 p. (in Norwegian)

Marker, M. 1983. Caledonian and pre-Caledonian geology of the Mofjell area, Nordland, Norway. Unpublished PhD thesis, University of Copenhagen.

Marker, M., Schiellerup, H., Meyer, G. B., Robins, B. & Bolle, O. 2003. The Rogaland Anorthosite Province. Geological map 1:75000. Norges geologiske undersøkelse, Special Publication 9, 109–116.

Markl, G., Frost, B. R. & Bucher, K. 1998. The origin of anorthosites and related rocks from the Lofoten islands, northern Norway. I. Field relations and estimation of intrinsic variables. Journal of Petrology 39, 1425–1452.

Mathiesen, C. O. 1978. Vurdering av Hosanger nikkelfelt, Østerøy i Hordaland. Norges geologiske undersøkelse, Rapport 1650/44A. 6 p. (in Norwegian)

McEnroe, S. A., Robinson, P. & Panish, P. 1996. Rock-magnetic properties, oxide mineralogy, and mineral chemistry in relation to aeromagnetic interpretation and the search for ilmenite reserves. Norges geologiske undersøkelse, Report 96.060. 148 p.

McEnroe, S. A., Robinson, P. & Panish, P. 2000. Chemical and petrographic characterisation of ilmenite and magnetite of oxide-rich cumulates in the Sokndal Region, Rogaland, Norway. Norges geologiske undersøkelse, Bulletin 436, 49–56.

Meinich, L. 1879. Om forekomsten av nikkelmalm i Smålenene. Nyt Magazin for Naturvidenskaperne, Bind 24, 125–137 + 1 plansje. (in Norwegian)

Meinich, L. & Vogt, J. H. L. 1903. Les gisements de nickel de Romsaas, Smaalenene, Norvège. Norges geologiske undersøkelse Bergarkivet rapport nr 1428. 9 p. (in French)

Melezhik, V. A., Zwaan, B. K., Motuza, G., Roberts, D., Solli, A., Fallick, A. E., Gorokhov, I. M. & Kusnetzov, A. B. 2003. New insights into the geology of high-grade Caledonian marbles based on isotope chemostratigraphy. Norwegian Journal of Geology 83, 209–242.

Meyer, G. B, Schiellerup, H. & Tegner, C. 2002. Chemical characterisation of ilmenite, magnetite and apatite in the Bjerkreim–Sokndal Layered Intrusion, Rogaland, South Norway. Norges geologiske undersøkelse, Report 2002.042. 25 p.

Moberg, A. 1968. Kopparverket i Kåfjord, ett bidrag til Nordkalottens historia. Norrbottens Museum. 143 p. (in Swedish)

Mørk, K. 1970. En geologisk undersøkelse av området omkring Kåfjord Kobbergruve, Kåfjord i Alta, Finnmark. Thesis University of Oslo. 115 p. (in Norwegian)

Munz, I. A., Yardley, B. W. D., Banks, D. A. & Wayne, D. 1995. Deep penetration of sedimentary fluids in basement rocks from southern Norway: Evidence from hydrocarbon and brine inclusions in quartz veins. Geochimica et Cosmochimica Acta, 59, 239–254.

Neumann, H. 1944. Silver deposits at Kongsberg. Norges geologiske undersøkelse 162. 133 p.

Nilsen, K. S. 1993. Nussir kobberforekomst i Kvalsund, Finnmark. Malmgeologisk symposium Kongsberg 19-20/11 1992. Bergindustriens Landsforening og Norsk Bergindustriforening. 7 p. (in Norwegian)

Nilsen, K. S. & Bjørlykke, A. 1991. Geological setting of the Bidjovagge gold-copper deposits, Finnmark, northern Norway. Geologiska Förenings Förhandlingar 113, 60–61.

Nilsen, O. 1974. Mafic and ultramafic inclusions from the initial (Cambrian?) volcanism in the central Trondheim Region, Norway. Norsk Geologisk Tidsskrift 54, 337–359.

Nilsen, O. 1978. Caledonian sulphide deposits and minor iron-formations from the southern Trondheim region, Norway. Norges geologiske undersøkelse, Bulletin 340, 35–85.

Nilsen, O. & Mukherjee, A. D. 1972. Geology of the Kvikne mines with special reference to the sulphide ore mineralization. Norsk Geologisk Tidsskrift 52, 151–192.

Nilsson, L. P. & Iversen, E. 1991. Neiden, bedrock map 2334-2, 1:50 000, preliminary edition. Geological Survey of Norway.

Nilsson, L. P. & Larsen, R. B. 1998. Edle mineraler i mafiske og ultramafiske bergarter – en oppsummering av platinagruppe mineraler (PGM) funnet i Norge i de senere år. In: Nordrum, F. S. (ed.) Kongsberg mineralsymposium 1998, 40–49. (in Norwegian)

Nilsson, L. P. & Often, M. 2005. A summary report on the Ni-Cu-PGE occurrences and their host rocks in the Precambrian of Finnmark, Northern Norway. Norges geologiske undersøkelse, Report 2005.85. 79 p.

Nordgulen, Ø. 1999. Geologisk kart over Norge, berggrunnskart Hamar 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Nordgulen, Ø., Bickford, M.E., Nissen, A.L. & Wortman, G.L. 1993. U-Pb zircon ages from the Bindal Batholith, and the tectonic history of the Helgeland Nappe Complex, Scandinavian Caledonides. Journal Geological Society London 150, 771–783.

Northern Iron 2010. Sydvaranger Iron Project. Available at: www.northerniron.com.au

Nussir ASA 2010. Available at: www.nussir.no

Odling, N. E. 1988. Deformation of the Joma sulphide deposit, Caledonides of Nord-Trøndelag, Norway. In: Zachrisson, E. (ed.) Proceedings of the 7th Quadrennial IAGOD Symposium, Luleå, Sweden. Stuttgart: E. Schweizerbart'sche, Verlagsbuchhandlung, 513–524.

Often, M. 1985. The Early Proterozoic Karasjok Greenstone Belt, Norway: a preliminary description of lithology, stratigraphy and mineralisation. Norges geologiske undersøkelse, Bulletin 403, 75–88.

Often, M., Olsen, L. & Lyså, A. 1990. Statusrapport over undersøkelsene i Sargejåk gullfelt, Finnmark. Norges geologiske undersøkelse, Rapport 90.045. 21 p. (in Norwegian)

Olesen, O. & Sandstad, J. S. 1993. Interpretation of the Proterozoic Kautokeino Greenstone Belt, Finnmark, Norway from combined geophysical and geological data. Norges geologiske undersøkelse, Bulletin 425, 43–64.

Olsen, L., Mejdahl, V. & Selvik, S. F. 1996. Middle and Late Pleistocene stratigraphy, chronology and glacial history in Finnmark, North Norway. Norges geologiske undersøkelse, Bulletin 429, 1–111.

Padget, P. & Brekke, H. 1996. Geologisk kart over Norge, berggrunnskart Arendal – 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Papunen, H. 1976. Lapin nikkeliprojekti. Kohteet 1–171. Pohjois-Suomen malmigeologinen toimikunta, Projekti 11. Geological Survey of Finland, unpublished report X134/PSMT-P11-76-2. (in Finnish)

Papunen, H. 1998. Geology and ultramafic rocks of the Paleoproterozoic Pulju greenstone belt, western Lapland. Technical Report 6.5. Brite-EuRam BE-1117 GeoNickel. University of Turku, Department of Geology. 57 p.

Papunen, H., Ilvonen, E., Idman, H., Pihlaja, P., Neuvonen, K. J. & Talvitie, J. 1977. The ultramafics of Lapland. Geological Survey of Finland, Report of Investigation 23. 87 p.

Pedersen, F. D. 1986. An outline of the geology of the Hurdal area and the Nordli granite molybdenite deposit. In: Olerud, S. & Ihlen, P. M. (eds) Metallogeny associated with the Oslo Paleorift. 7th IAGOD symposium, Excursion guide no 1, Sveriges geologiska undersökning Ser. Ca 59, 18–23.

Pedersen, R. B. & Furnes, H. 1991. Geology, magmatic affinity and geotectonic environment of some Caledonian ophiolites in Norway. Journal of Geodynamics 13, 183–203.

Pedersen, R. B., Furnes, H. & Dunning, G. 1991. A U/Pb age for the Sulitjelma Gabbro, north Norway: Further evidence for the development of a Caledonian marginal basin in Ashgill–Llandovery time. Geological Magazine 128, 141–153.

Pedersen, R. B. & Dunning, G. R. 1997. Evolution of arc crust and relations between contrasting sources: U-Pb (age), Nd and Sr isotope systematics of the ophiolitic terrain of SW Norway. Contributions to Mineralogy and Petrology 128, 1–15.

Pedersen, S. & Konnerup-Madsen, J. 2000. Geology of the Setesdalen area, South Norway: Implications for the Sveconorwegian evolution of South Norway. Bulletin of the Geological Society of Denmark 46, 181–201.

Pedersen, S., Andersen, T., Konnerup-Madsen, J. & Griffin, W. L. 2009. Recurrent Mesoproterozoic continental magmatism in South-Central Norway. International Journal of Earth Sciences 98, 1151–1171.

Petersen, J. S & Jensen, S. M. 1995. Bleka gold fields in Telemark, South Norway. In: Ihlen, P. M., Pedersen, M. & Stendal, H. (eds) Gold mineralization in the Nordic countries and Greenland. Extended abstracts and Fieldtrip guide, Grønland Geologiske Undersøgelse Open File Series 95/10, 62–64.

Pharaoh, T. C., Ramsay, D. M. & Jansen, Ø. 1983. Stratigraphy and structure of the northern part of the Repparfjord–Komagfjord window, Finnmark, northern Norway. Norges geologiske undersøkelse 377, 1–45.

Priesemann, F.-D. & Krause, H. 1985. The Selvåg deposit: A Proterozoic magmatic Fe-Ti-V occurrence on Vesterålen, Northern Norway. Norges geologiske undersøkelse, Bulletin 402, 51–64.

Puustinen, K., Saltikoff, B. & Tontti, M. 1995. Distribution and metallogenic types of nickel deposits in Finland. Geological Survey of Finland, Report of Investigation 132. 38 p.

Ragnhildstveit, J. & Helliksen, D. 1997. Geologisk kart over Norge, berggrunnskart Bergen, 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Ragnhildstveit, J. & Nilsen, K. 1998. Geological map of the area south of Dalsfjord, bedrock map, scale 1:50 000. Norges geologiske undersøkelse.

Ramberg, I. 1967. Kongsfjell-områdets geologi, en petrografisk og strukturell undersøkelse i Helgeland, Nord-Norge. Norges geologiske undersøkelse 240. 152 p. (in Norwegian)

Ramdohr, P. 1969. The ore minerals and their intergrowths.

Oxford: Pergamon Press. 1176 p.

Rana Gruber AS 2010. Available at: www.ranagruber.no.

Reddick Consulting Inc. 2009. Technical Report on Resource Estimates for the Ertelien, Stormyra and Dalen Deposits, Southern Norway. Prepared for Blackstone Ventures Inc. NI 43-101 Report. 99 p.

Reinsbakken, A. 1986. The Joma Cu-Zn massive sulphide deposit hosted by mafic metavolcanic rocks. In: Stephens M. B. (ed.) Stratabound sulphide deposits in the central Scandinavian Caledonides. Sveriges Geologiska Undersökning Ca 60, 50–54.

Reinsbakken, A. 1992. The Skorovass volcanogenic massive sulphide deposit – volcanostratigraphy, petrochemistry, hydrothermal alteration and paleotectonic setting. Dr.ing. Thesis, UNIT–NTH. 363 p.

Reusch, H. 1902. Fra det indre av Finnmarken. Norges geologiske undersøkelse 36, 5–64. (in Norwegian)

Roberts, D. & Tucker, R. D. 1998. Late Cambrian U-Pb zircon age of a metatrondhjemite from Ytterøya, Trondheimsfjorden, Central Norwegian Caledonides. Norsk Geologisk Tidsskrift 78, 253–258.

Robins, B., Tumyr, O., Tysseland, M. & Garmann, L. B. 1997. The Bjerkreim–Sokndal layered intrusion, Rogaland, SW Norway: Evidence from marginal rocks for a jotunite parent magma. Lithos 39, 121–133.

Romey, W. D. 1971. Basic igneous complex, mangerite, and high grade gneisses of Flakstadøy, Lofoten, Northern Norway: I. Field relations and speculations on origin. Norsk Geologisk Tidsskrift 51, 33–61.

Rui, I. J. 1973a. Geology and structures of the Røstvangen sulphide deposit in the Kvikne district, central Norwegian Caledonides. Norsk Geologisk Tidsskrift 53, 433–442.

Rui, I. J. 1973b. Structural control and wall rock alteration at Killingdal mine, Central Norwegian Caledonides: Economic Geology 68, 859–883.

Rui, I. J. & Bakke, I. 1975. Stratabound sulphide mineralization in the Kjøli Area, Røros District, Norwegian Caledonides. Norsk Geologisk Tidsskrift 55, 51–75.

Saltikoff, B., Puustinen, K. & Tontti, M. 2006. Metallogenic zones and metallic mineral deposits in Finland: explanation to the Metallogenic map of Finland. Geological Survey of Finland, Special Paper 35. 66 p.

Sandstad, J. S. (ed.) 1986. Proterozoic copper mineralizations in northern Norway. Sveriges geologiska undersökning Ser. Ca 64, Excursion guide no. 6. 22 p.

Sandstad, J. S. 2010. Microscope and SEM (scanning electron microscope) investigations of thin sections from the Nussir Copper deposit. Norges geologiske undersøkelse, Report 2010.025. 55 p.

Sandstad, J. S., Reinsbakken, A. & Grenne, T. 1997. The Skorovass complex, Central Norwegian Caledonides: Massive sulphides in an Early Ordovician immature arc setting. F. M. Vokes Anniversary Symposium, Trondheim, Norway.

Sandstad, J. S., Viola, G. & Nilsson, L. P. 2007. Reconnaissance structural geological mapping and field XRF-analyses of the Ulveryggen copper deposit, Finnmark, Norway. Norges geologiske undersøkelse, Report 2007.64. 16 p.

Sanetra, S. 1985. The Rødsand Fe-Ti-V deposits, Møre, Western Norway. Norges geologiske undersøkelse, Bulletin 402, 39–49.

Scandinavian Highlands 2009. Available at: scandinavianhighlands.com/index.php?id=1477

Schärer, U., Wilmart, E. & Duchesne, J. C. 1996. The short duration and anorogenic character of anorthosite magmatism: U-Pb dating of the Rogaland complex, Norway. Earth and Planetary Science Letters 139, 335–350.

Scheerer, T. 1845. Om nikkelens forekomst i Norge. Nyt Mag. For Naturvidenskaberne 4, 91–96. (in Norwegian)

Schiellerup, H., Meyer, G. B., Tegner, C., Robins, B. & Korneliussen, A. 2001. Resources of apatite, ilmenite and magnetite in the Bjerkreim Sokndal Layered Intrusion, Rogaland, South Norway. Norges geologiske undersøkelse, Report 2001.092. 33 p.

Schiellerup, H., Korneliussen, A., Heldal, T., Marker, M., Bjerkgård, T. & Nilsson, L.-P. 2003. Mineral resources in the Rogaland Anorthosite Province, South Norway: origins, history and recent developments. Norges geologiske undersøkelse, Special Publication 9, 117–135.

Schønwandt, H. K. & Petersen, J. S. 1983. Continental rifting and porphyry-molybdenum occurrences in the Oslo region, Norway. Tectonophysics 94, 609–631.

Scott, J. L. 1992. Mineralization in the Karmøy ophiolite, Southwest Norway. M.Sci. Thesis, Memorial University of Newfoundland. 221 p.

Segalstad, T. V. 1985. Sølvdannelse i Kongsberg sølvforekomst. In: Nye malmtyper i Norge. Malmgeologisk Symposium, BVLI – Bergforskningen, Trondheim, p. 100. (in Norwegian)

Siedlecka, A., Iversen, E., Krill, A. G., Lieungh, B., Often, M., Sandstad, J. S. & Solli, A. 1985. Lithostratigraphy and correlation of the Archaean and Early Proterozoic rocks of the Finnmarksvidda and Sørvaranger district. Norges geologiske undersøkelse, Bulletin 403, 7–36.

Siedlecka, A. & Nordgulen, Ø. 1996. Geologisk kart over Norge, berggrunnskart Kirkenes, M 1:250 000. Norges geologiske undersøkelse. (in Norwegian)

Siedlecka, A. & Roberts, D. 1996. Finnmark Fylke. Berggrunnsgeologi M 1:500 000. Norges geologiske undersøkelse. (in Norwegian)

Singsaas, P. 1973. El.magn. bakkemålinger Bruvann, Råna. Norges geologiske undersøkelse, Rapport 1110. 13 p. (in Norwegian)

Skaarup, P. 1974. Strata-bound scheelite mineralisation in skarns and gneisses from the Bindal area, Northern Norway. Mineralium Deposita 9, 299–308.

Skauli, H. 1992. On the formation of Zn-Pb deposits; a case study of the Bleikvassli deposit, Northern Norway. Unpublished Ph.D thesis, University of Oslo.

Smith, P. M. 1995. Geological setting of mineralization along the Verran Fault Zone, central Norway. PhD Thesis, University of London. 304 p.

Solli, A. & Nordgulen, Ø. 2008. Bedrock map of Norway and the Caledonides in Sweden and Finland – 1:2 000 000. Norges geologiske undersøkelse.

Søvegjarto, U. 1977. Kaledonske jernmalmer i Nordland. In: Bjørlykke, A., Lindahl, I. & Vokes, F. M. (eds) Kaledonske malmforekomster. Trondheim: BVLI's Tekniske Virksomhet, 95–106. (in Norwegian)

Søvegjarto U., Marker, M., Graversen, O. & Gjelle, S. 1988. Berggrunnskart Mo i Rana 1927 I – M 1: 50000. Norges geologiske undersøkelse. (in Norwegian)

Spjeldnæs, N. 1985. Biostratigraphy of the Scandinavian Caledonides. In: Gee, D. G. & Sturt, B. A. (eds): The Caledonide orogen – Scandinavia and related areas. Chichester: Wiley, 317–329.

Stein, H.J., Bingen, B., Yang, G. & Ihlen, P. 2008. Re-Os dating of pyrite generations and late hydrocarbons associated with gold deposits – post-Sveconorwegian construction of Norway's Eidsvoll Au deposit: 33rd International

Geological Congress (IGC), 6–14 August 2008, Oslo, electronic abstract 1353034.

Stephens, M. B. (ed.) 1986. Stratabound sulphide deposits in the Central Scandinavian Caledonides. Sveriges geologiska undersökning Ser Ca 60. 68 p.

Stephens, M. B., Zachrisson, E. & Thelander, T. 1978. Compilation and bibliography of stratabound sulphide deposits in the Swedish Caledonides, Sveriges geologiska undersökning, prospekteringsrapport brap 81566. 37 p.

Støren, R. 1909. Romsås grube. Geologisk gruvekart i plan og profil, 1:1000. Norges geologiske undersøkelse Bergarkivet, kart nr. K 1087. (in Norwegian)

Stribrny, B. 1985. The Conglomerate-hosted Repparfjord Copper Ore Deposit, Finnmark, Norway. Berlin-Stuttgart: Monograph Series on Mineral Deposits, 24. 75 p.

Sturt, B. A., Ramsay, D. M. & Bjerkgård, T. 1997. Revisions of the tectonostratigraphy of the Otta–Røros tract. Norges geologiske undersøkelse, Bulletin 433, 8–9.

Sundblad, K. 1982. Distribution of gahnite-bearing sulphidic deposits in the Scandinavian Caledonides. Transactions of the Institution of Mining and Metallurgy, Section B Applied earth science 91, B214–B218.

Sundblad, K. & Gee, D. G. 1985. Occurrence of a uraniferous-vanadiniferous graphitic phyllite in the Köli Nappes of the Stekenjokk area, central Swedish Caledonides. Geologiska Föreningens i Stockholm Förhandlingar 106, 269–274.

Sundblad, K., Ihlen, P. M. & Alm, E. 1995. Gold deposits in southern Norway and Sweden. Excursion guide. In: Ihlen, P. M. Pedersen, M. & Stendal, H. (eds) Gold mineralization in the Nordic countries and Greenland – Extended abstracts and field trip guid, Open File Ser. Grønlands geologiske undersøgelse 95/10, 121–181.

Sundvoll, B., Neumann, E.-R., Larsen, B. T. & Tuen, E. 1990. Age relations among Oslo Rift magmatic rocks: implications for tectonic and magmatic modelling. Tectonophysics 178, 67–87.

Sylvester, A. G. 1964. The Precambrian rocks of the Telemark area in south central Norway; III, Geology of the Vrådal granite. Norsk Geologisk Tidsskrift 78, 445–482.

Telstø, L. 2005. Fluid types and migration pathways in the Mylonite Zone during the formation of auriferous base-metal vein deposits in the Eidsvoll-Odalen district, southeastern Norway. Doctoral thesis, NTNU 2005: 129. 204 p.

Tertiary Minerals 2001. Press release 8 May 2001. Available at: www.tertiaryminerals.com/news080501.htm

Thorsnes, T. & Løseth, H. 1991. Tectonstratigraphy in the Velfjord-Tosen region, southwestern part of the Helgeland Nappe Complex, Central Norwegian Caledonides. Norges geologiske undersøkelse, Bulletin 421, 1–18.

Tucker, R. D., Boyd, R. & Barnes, S.-J. 1990. A U–Pb zircon age for the Råna Intrusion, northern Norway: new evidence of basic magmatism in the Scandinavian Caledonides in Early Silurian time. Norsk Geologisk Tidsskrift 70, 229–239.

Vik, E. 1985. En geologisk undersøkelse av kobbermineraliseringene i Alta–Kvænangen-vinduet, Troms og Finnmark. Unpublished PhD thesis, NTH Univ. Trondheim. 300 p. (in Norwegian)

Vik, E. 1986. The Raipas copper deposit. In: Sandstad, J. S. (ed.) Proterozoic copper mineralizations in northern Norway. Sveriges geologiska undersökning Ser. Ca 64, Excursion guide no. 6, 9–13.

Viola, G. & Henderson, I. 2010. Inclined transpression at the toe of an arcuate thrust: an example from the Precambrian 'Mylonite Zone' of the Sveconorwegian orogen. In: Law, R. D., Butler, R. W. H., Holdsworth, R. E., Krabbendam, M. & Strachan, R. A. (eds) Continental tectonics and mountain building: the legacy of Peach and Horne. Geological Society London, Special Publication 335, 715–737.

Viola, G., Sandstad, J. S., Nilsson, L. P. & Heincke, B. 2008. Structural and ore geological studies in the northwestern part of the Repparfjord Window, Kvalsund, Finnmark, Norway. Norges geologiske undersøkelse, Report 2008.29. 93 p.

Vogt, J. H. L. 1902. Om nikkel, navnlig om muligheten at gjenoptage den norske bergverksdrift på nikkel. Teknisk Ukeblad 1901–02, 1–40. Særtrykk. (in Norwegian)

Vogt, J. H. L. 1910. Norges jernmalmforekomster. Norges geologiske undersøkelse 51. 225 p. (in Norwegian)

Vokes, F. M. 1955. Observations at the Raipas mine, Alta, Finnmark. Norges geologiske undersøkelse 191, 103–114.

Vokes, F. M. 1957. The copper deposits of the Birtavarre district, Troms, northern Norway. Norges geologiske undersøkelse 199. 239 p.

Vokes, F. M. 1962. Mineral parageneses of the massive sulphide ore bodies of the Caledonides of Norway. Economic Geology 57, 890–903.

Vokes, F. M. 1963. Geological studies on the Caledonian pyritic zinc-lead orebody at Bleikvassli, Nordland, Norway. Norges geologiske undersøkelse 222. 126 p.

Vokes, F. M. 1969. A review of the metamorphism of sulphide deposits: Earth Science Reviews 5, 99–143.

Wanvik, J. E. 1983. Andørja magnetittforekomster. Oppsummerende rapport til Bergmesteren vedrørende Elkems utgåtte mutinger. Rapport BV 1356. (in Norwegian)

Wiik, V. H. 1966. Petrological studies of the Neiden granite complex. Norges geologiske undersøkelse 237, 5–99.

Wilson, J. R., Robins, B., Nielsen, F. M., Duchesne, J. C. & Vander Auwera, J. 1996. The Bjerkreim–Sokndal layered intrusion, Southwest Norway. In: Cawthorn, R. G. (ed.) Layered intrusions, Elsevier, 231–256.

Wulff, P. 1996. En befaring af circa 100 mineraliseringer i Sunnhordland, SV-Norge. Norges geologiske undersøkelse, Rapport 96.139. 100 p. (in Danish)

Wulff, P. & Stendahl, H. 1995. Gold in Sunnhordland, the Caledonides of southwestern Norway. In: Ihlen P. M., Pedersen, M. & Stendal, H. (eds) Gold mineralization in the Nordic countries and Greenland. Extended abstracts and Fieldtrip guide, Grønland Geologiske Undersøgelse Open File Series 95/10, 116–119.

Zachrisson, E. 1986a. The Stekenjokk Zn-Cu(-Pb) massive sulphide deposit in a bimodal metavolcanic sequence. In: Stephens, M. B. (ed.) Stratabound sulphide deposits in the Central Scandinavian Caledonides. Sveriges geologiska undersökning Ca 60, 34–41.

Zachrisson, E. 1986b. The structural setting of the Stekenjokk ore bodies, Central Swedish Caledonides. Economic Geology 66, 641–652.

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 139–206, 2012

METALLOGENIC AREAS IN SWEDEN

Hallberg, A., Bergman, T., Gonzalez, J., Larsson, D., Morris, G. A., Perdahl, J. A., Ripa, M., Niiranen, T. & Eilu, P. 2012. Metallogenic areas in Sweden. *Geological Survey of Finland, Special Paper 53, 139–206,* 35 figures and 18 tables.

The metallogeny of Sweden is summarised in forty-one metallogenic areas covering approximately 22% of the country's area. Each metallogenic area is characterised by its particular set of important metals, defined by past production, metal resources, known deposits and the estimated potential for future mineral discoveries. Base metals (Cu, Zn, Pb, Mo, Ni, Co) are the dominant commodity in 15 of the areas, ferrous metals (Fe, Mn, Ti ,V, Cr) in 13 areas, energy metals (U) in 6 areas, precious metals (Au, Ag) in 4 areas and special metals (W, REE) in 3 of the areas. Most of the metallogenic areas are characterised by more than one metal group.

The most significant and economically most important metallogenic areas overlap with the four classic ore districts in Sweden: Northern Norrbotten in northernmost Sweden, the Skellefte district in north-central Sweden, Bergslagen in south-central Sweden, and the Caledonides along the border with Norway. Most of the mineral wealth in Sweden was formed in the Palaeoproterozoic Era; Kiruna-type Fe-apatite deposits, porphyry copper deposits and skarn iron deposits formed 2.1–1.86 Ga ago in Northern Norrbotten, while volcanogenic massive sulphide deposits and orogenic gold deposits in the Skellefte district and Fe-apatite deposits, skarn iron deposits and volcanogenic massive sulphide deposits in Bergslagen formed 1.91-1.89 Ga ago. Sediment-hosted base-metal deposits and volcanogenic massive sulphide deposits formed in the Neoproterozoic to Early Palaeozoic make up the most important deposits in the Caledonides.

Keywords (GeoRef Thesaurus, AGI): metallogenic provinces, mineral resources, metal ores, mines, production, Paleozoic, Proterozoic, Sweden

Anders Hallberg, Torbjörn Bergman, Julio Gonzalez, George Morris,
Magnus Ripa
Geological Survey of Sweden, P.O. Box 670, SE-751 28 Uppsala, Sweden

Daniel Larsson, Jan-Anders Perdahl
Geological Survey of Sweden, Mineral Resources Information Office, Skolgatan 11, SE 930 70 Malå, Sweden

Tero Niiranen
Geological Survey of Finland, P.O. Box 77, FI-96101 Rovaniemi, Finland

Pasi Eilu
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

E-mail: anders.hallberg@sgu.se

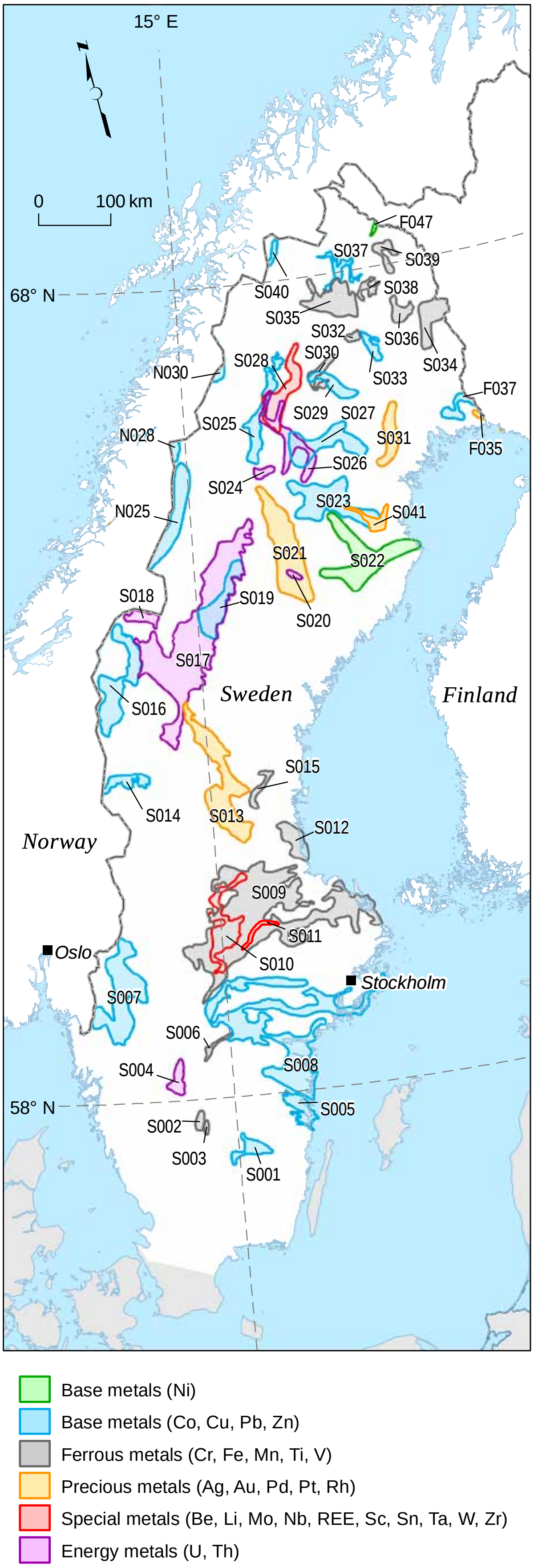


Figure 1. Index map of metallogenic areas in Sweden. The names of the metallogenic areas are listed in Table 1. Note that areas coded to Norway (N) and Finland (F) are described in the sections for these countries.

Table 1. List of the metallogenic areas in Sweden.

Code	Area name, main metals
S001	Vetlanda Cu, Ni, Au
S002	Taberg Fe, Ti, V
S003	Spexeryd Mn
S004	Billingen U, V, Mo
S005	Gladhammar–Västervik Cu, Co, U, REE, Fe
S006	Bölet Mn
S007	Dalsland–Värmland Cu, Ag, U, Au, Fe, Mn
S008	Southern Bergslagen Zn, Pb, Fe, Co, Ni
S009	Northern Bergslagen Fe, Cu, Zn, Pb, Ag
S010	Western Bergslagen W, Mo
S011	Riddarhyttan REE, Fe
S012	Hamrånge Fe, Cu, W
S013	Överturingen–Los Au, Zn, U
S014	Vassbo Pb, Zn
S015	Dellen–Ljusdal V
S016	Sylarna Cu, Zn, Pb, Ag
S017	Caledonian Black Shale U, V, Mo
S018	Hotangen U
S019	Dorotea Pb, Zn, Ag
S020	Björkråmyran U
S021	Gold Line Au
S022	Lappvattnet Ni, Cu
S023	Skellefte District Zn, Cu, Pb, Ag, Au
S024	Duobblon U
S025	Laisvall Pb, Zn, Ag
S026	Arjeplog–Arvidsjaur U
S027	Radnejaur–Moskosel Cu, Au, Zn, Pb, Ag
S028	Rappen–Ultevis Mo, Cu, Au
S029	Vaikijaur Cu, Mo, Au
S030	Kallak Fe, Mn, Cu, Au
S031	Boden Au, Ag, Cu
S032	Gällivare–Malmberget Fe
S033	Aitik–Nautanen Cu, Au
S034	Pajala–Kolari Fe, Cu, Au
S035	Kiruna Fe, Cu, Au
S036	Tärendö Fe, Zn, Cu
S037	Viscaria–Sautusvaara Cu, Fe, Au, Zn, Ag, Co
S038	Vittangi Fe, Cu, Au, Co, Mo
S039	Lannavaara Fe, Cu
S040	Sjangeli Cu, Ag, Au, U
S041	Skellefte District Gold Au

The metallogenic areas id-coded to neighbouring countries are listed and described in the respective country sections of this book.

S001 VETLANDA, Cu-Au, Ni-Cu-Co

Torbjörn Bergman (SGU)

The Vetlanda metallogenic area (Fig. 1, Table 1) is located in south-eastern Sweden and constitutes part of the Oskarshamn–Jönköping Belt (Mansfeld et al. 2005). The belt is geographically well defined and comprises 1820 to 1830 Ma metamorphic rocks, calc-alkaline intrusions, and volcanic and sedimentary rocks. It is surrounded by 1770 to 1810 Ma granites and monzonites belonging to the Transscandinavian Igneous Belt.

Area S001 includes 9 historical mines and more than 30 known metal occurrences of various types (Table 2). The majority of the deposits were mined in the late 19th century, and mining in the area ceased in the early part of the 20th century. Important historical mines include the Kleva gabbro-hosted Ni-Cu deposit, the Ädelfors Au quartz vein deposit, the Fredriksberg basalt-hosted Cu deposit and the Sunnerskog Cu skarn deposit. The deposits are all small and the tonnage of each is generally less than 0.05 Mt. The largest mine is Kleva with a mined tonnage of 0.055 Mt.

The **Kleva** Ni-Cu-Co deposit is hosted by a gabbronoritic intrusion, 2.5 km wide and 6.5 km long (Nilsson 1985). The ore minerals are Ni-bearing pyrrhotite, chalcopyrite and pyrite. The mineralisation is massive and breccia matrix ore, and low-grade dissemination within the gabbro (Nilsson 1985). The mined ore averaged around 1.9% Ni, 0.8% Cu and 0.2% Co (SGU Mineralmarknaden 2007). More recent analyses from outcrops and dumps have given 2.8% Ni, 1.2% Cu and 0.3% Co in the sulphide phase of the ore (Nilsson 1985).

The **Ädelfors** auriferous quartz veins were probably discovered by the middle of the 16th century. Mining started in 1749 and the deposit was mined in several workings during short periods until 1916. The quartz veins are generally narrow, less than 0.5 m wide (Tegengren 1924). The deepest working in the area, Adolf Fredriksgruvan, is mined down to 310 m depth. In total, 141 kg of Au have been extracted from Ädelfors. The auriferous quartz veins are hosted by mafic volcanic rocks belonging to the Oskarshamn–Jönköping Belt (Mansfeld 1996). The gold-bearing mineral assemblage is dominated by pyrite, chalcopyrite and pyrrhotite. In addition, a strong positive correlation between Au, native Bi and bismuthinite has been detected at Ädelfors (Bergman 1986).

Mining at **Sunnerskog** had started by the 17th century and continued intermittently until 1894. The deposit was mined down to 44 m depth (Tegengren 1924). The copper content in the ore is less than 1% (Tegengren 1924). The exact tonnage of the deposit is not known, but is most likely less than 0.05 Mt. The Sunnerskog Cu skarn deposit is hosted by fine-grained metasedimentary rocks belonging to the Oskarshamn–Jönköping Belt. The skarn mineral assemblage is coarse-grained and dominated by grossular-andradite garnet, diopside-hedenbergite pyroxene, quartz, epidote and wollastonite. The dominant Cu minerals are chalcocite and digenite. Native Cu, covellite and scheelite are present in small amounts (Wahlström & Sundblad 1986). Wahlström & Sundblad (1986) have suggested that the deposit is of the contact metasomatic type genetically related to a granitic source.

The **Fredriksbergs** Cu-Zn-Pb deposit is situated in the south-western part of the Vetlanda area (S001) and is hosted by tholeiitic metabasalts (Mansfeld et al. 2005). The ore minerals are chalcopyrite, pyrrhotite, sphalerite and galena. Mining at Fredriksberg started in 1769 and continued intermittently until 1939. In the Fredriksberg area, there are 20 mine shafts and prospects. The largest mine, Mossgruvan, has been mined down to

Table 2. Metal mines in the S001 Vetlanda metallogenic area. Data on the produced tonnage and years of reported production from 'Official Statistics of Sweden, Metal and Mining Industries'.

Deposit(s)	**When mined**	**Mined (Mt)**	**Au ppm**	**Co %**	**Cu %**	**Fe %**	**Mo %**	**Ni %**	**Ti %**	**Zn %**
Ädelfors gruvor	1890–1916	0.00722	3.1							
Inglamåla gruvor	1845–1916	0.00443				40.0			7.0	
Kleva gruva	1845–1919	0.05465		0.2	0.8			1.90		
Fredriksbergsgruvorna	1905–1938	0.00358			1.0					5.0
Virserum	1892–1918	0.00241			0.7			0.88		
Skedegruvan	1905–1905	0.00004								
Rikagruvan	1935–1938	0.00003								5.0
Viktorsgruvan	1884–1918	0.00002					3.0			

95 m depth. Other mines include Krongruvan and Borrbänksgruvan. Documentation of ore grades is uncertain. The average grade is estimated at 1% Cu (Tegengren 1924, Shaikh et al. 1989). Locally, for example, at Borrbänksgruvan, the Zn content is up to 5%. Gold is also present and, according to Tegengren (1924), 'copper concentrate' from Mossgruvan contained up to 60 ppm Au.

S002 TABERG Fe-Ti-V

Daniel Larsson (SGU)

The Taberg metallogenic area (Smålands Taberg) hosts the largest accumulation of Fe-Ti-V ore in Southern Sweden: the **Smålands Taberg** Fe-Ti-V deposit (Fig. 2). The deposit is hosted by, and apparently associated with, an olivine diabase that makes up a part of the Taberg igneous complex, dated at 1204.3 ± 1.8 Ma (Lu-Hf isochron, Larsson & Söderlund 2005).

The Smålands Taberg deposit (Fig. 2) is within or near the 10- to 25-km-wide, N-trending Protogine Zone (PZ), a tectonic lineament probably established by ca. 1.7 Ga as a discontinuity in the crust at a boundary between ca. 1.7 and ca. 1.8 Ga terrains (Gorbatschev & Bogdanova 2004, and references therein). The medium-grained, dark olivine dolerite associated with the deposit has commonly been called *hyperite*. The complex extends for about 1 km in a NW direction and about 400 m NE at its widest section. It has the shape of a plug or a funnel, and its hardness and resistance to weathering has caused the rock to stand out as an elevated hill with steep sides reaching roughly 150 m above the surroundings.

Figure 2. The Smålands Taberg Fe-Ti-V deposit in 1994, seen from the east. Copyright: Lund University.

Iron ore at Taberg was mined intermittently from the Middle Ages until 1960. Although the average Fe content is as low as 31.4% and, to a significant extent, the iron is in silicates, it was considered to be of very good quality due to a homogeneous character and the absence of impurities such as sulphides. Later on, it was also valued for its relatively high content of V. The highest output was reached in 1943 when >200 000 tons of ore was mined. Most of the mining took place in open cuts and only went underground during the later years. The total tonnage of the deposit is estimated at 150 Mt (Shaikh et al. 1989).

The mineralisation at Taberg is made up of magmatic cumulates consisting of 40 to 60% olivine, about 30% magnetite with exsolution lamellae of ilmenite and pleonaste, 5 to 25% plagioclase, and coronitic orthopyroxene and amphibole. Ulvöspinel locally occurs as exsolution lamellae in magnetite. In the literature, this type of mineralisation, or rock type, is called magnetite olivinite, cumberlandite, or magnetite-rich melatroctolite if the plagioclase content exceeds 10%. Hjelmqvist (1950) distinguished between plagioclase-rich and plagioclase-poor magnetite olivinite at Taberg. The plagioclase-poor variety is by definition an ultramafic rock. The distribution of the two types is irregular and no distinct layering is seen. A rare feature at Taberg is a magnetitite or *iron band* as it was called by the miners. The oxide minerals in the magnetitite are similar to the magnetite olivinite, although constituting about 90% of the assemblage, with the remainder being mainly olivine with traces of plagioclase and biotite. The magnetitite was preferentially sought out for mining and was found in the western part of the ore body. It occurred as bands with thicknesses of up to 15 cm (Tilas 1760). It is similar to magnetitite found in the Bushveld igneous complex, South Africa, which is mined for its V content. The V content of the magnetite at Taberg is, however, about 0.5%, whereas the average content found in the magnetite from the Bushveld complex is about 1%.

Two additional Fe deposits similar to Taberg are known in southern Sweden. They share the same tectonic setting and have similar rock associations. The southernmost occurrence is exposed at Långhult, about 90 km south of Taberg, and the northernmost occurrence is found near Ransberg, about 90 km north of Taberg. What sets Taberg apart from the other two deposits is its exceptionally large size, whereas the deposits at Långhult and Ransberg are confined to small, approx. 5 by 10-m-wide open pits. The Smålands Taberg Company drove five drill holes through the deposit during the early 1940s, confirming that nearly the entire Taberg hill consists of ore. This drill core is no longer available. The Taberg hill is presently a nature reserve and an important recreational area for the inhabitants of the nearby Taberg community. An aeromagnetic anomaly in the southern part of Lake Vättern north of Taberg has intermittently been investigated, as it is considered to represent a possible occurrence of a layered intrusion or potentially a deposit similar to Taberg.

S003 SPEXERYD Mn

Torbjörn Bergman (SGU)

The Spexeryd metallogenic area is defined on the basis of the presence of more than 20 small Mn deposits along a 2 km, approximately N-trending line. The occurrences are breccia-hosted and situated in the southern extension of the major fault zone defining the depression containing Lake Vättern. The deposits at Spexeryd are similar to those in the Bölet area (S006) 100 km to the north. The **Spexeryd** and **Bölet** deposits were referred to as the ‘Vättern graben deposits’ by Andreasson et al. (1987). The Mn occurrences at Spexeryd were discovered in 1825 and the first mine was in production by 1829. The production continued in the area, almost without a break, until 1954. Total production was 0.4 Mt of ore with grades of up to 50% Mn (Shaik et al. 1989). The Spexeryd mine is, despite the limited production, the largest Mn producer in Sweden. The brecciated host rock of the Spexeryd deposits belongs to the 1810–1770 Ma Transscandinavian Igneous Belt. The age of mineralisation and brecciation is, however, estimated at ca. 250 Ma (Shaik et al. 1989). The dominating ore mineral is braunite, which occurs in an intimate mix with barite, calcite, quartz and fluorite (Tegengren 1924). In addition, minor amounts of manganite, pyrolusite and hausmannite have been detected in the ore.

S004 BILLINGEN U

Anders Hallberg (SGU)

Palaeozoic sedimentary rocks containing U-bearing black shales of upper Cambrian to lower Ordovician age once covered large parts of the Fennoscandian Shield. Today, remnants of these rocks are found in outliers throughout southern and central Sweden, along the margins of the Caledonides and in the Gulf of Bothnia (Andersson et al. 1985).

At Billingen, in one of the outliers of the Palaeozoic rocks in south-central Sweden, a more than 150-m-thick sequence of Cambrian to Silurian sandstones, shales and limestones is covered by dolerite of presumed Permian age (Fig. 3). Uranium mineralisation, with up to 300 g/t of U, occurs in middle Cambrian to lowermost Ordovician black shales (Andersson et al. 1985). The black shales also contain minor bituminous limestone (stinkstone) as lenses and carbonaceous rich layers and lenses (*kolm*).

Drilling during the 1950s showed that the **Ranstad** area at Billingen carried the richest U mineralisation. The mineable U-rich zone is less than 4 m thick with an average grade of 305 g/t U. The sequence consists of black shale (92–94%), bitu-

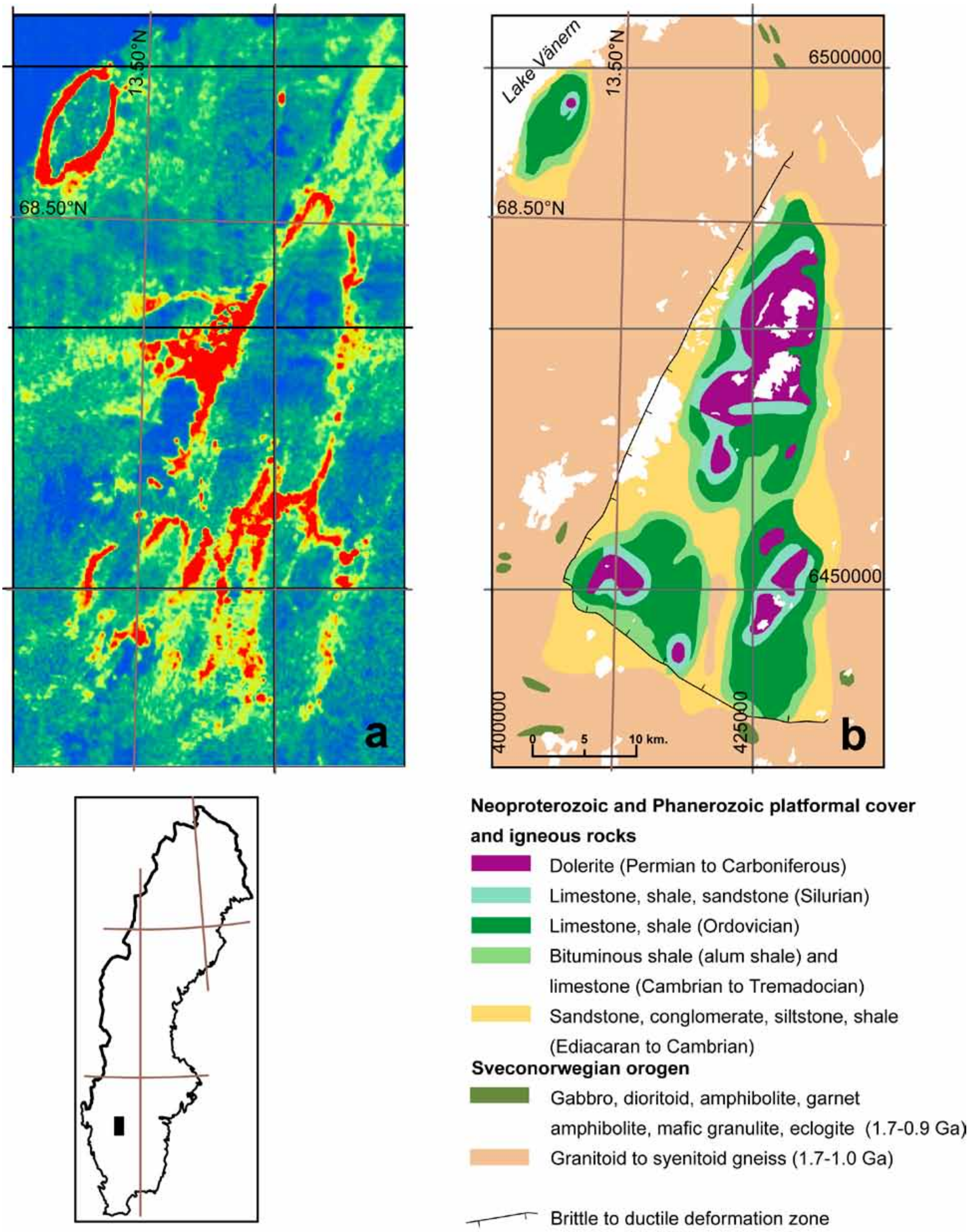


Figure 3. a. Map showing U radiation measured by airborne geophysics in the Billingen area. A red colour indicates higher radiation from uranium in rocks and sediments on the ground. Note that the radiation is screened by water-covered areas (lakes and wetlands).
b. Geological map of the Billingen area with flat-lying Phanerozoic platformal cover rocks resting on top of the Precambrian basement. Geology from the digital ‘Bedrock Sweden 1M 2010’. The easily eroded Phanerozoic rocks have been protected by a flat-lying dolerite sill. The Kinnekulle area (not mentioned in the text), located in the northwestern part of the maps, also consists of flat-lying Phanerozoic platformal cover rocks and shows a similar U-radiation pattern.

minous limestone (4–6%) and carbon-rich layers (2%), where the latter may contain up to 5000 g/t U (Andersson et al. 1985). The total reserves, as estimated in the 1970s, are around 900 000 t of uranium, of which 300 000 t were considered to be exploitable (Gustafsson 2007). Test mining between 1965 and 1969 produced about 120 tons of U at a low recovery grade of 60–70%.

Uranium exploration in Sweden was aborted in the early 1980s, but recently exploration companies have again shown an interest in the Billingen area. Today, the Ranstad deposit is not considered as economically mineable but forms an ore resource of 8.2 Bt @ 213 g/t U (Andersson et al. 1985). According to the classification of the International Atomic Energy Agency (IAEA), the U mineralisation at Billingen is a black shale deposit (OECD 2006).

S005 GLADHAMMAR–VÄSTERVIK Cu, Co, U, REE, Fe

Anders Hallberg (SGU)

The Västervik area (Fig. 4) contains several small Fe, Cu and U deposits (Uytenbogaardt 1960, Bruun et al. 1991), a few of which have been mined in historical time. The produced tonnage is low. Several of the Fe deposits are associated with REE and U, and several of the Cu deposits are associated with Co and, locally, with Ag and Au. All the deposits in the area are hosted by metasedimentary rocks, usually quartzites, belonging to the Västervik Formation.

The geology of the Västervik area is dominated by metamorphosed sedimentary rocks, mostly quartzites and meta-arkoses, commonly with well-preserved cross-bedding, mud cracks and

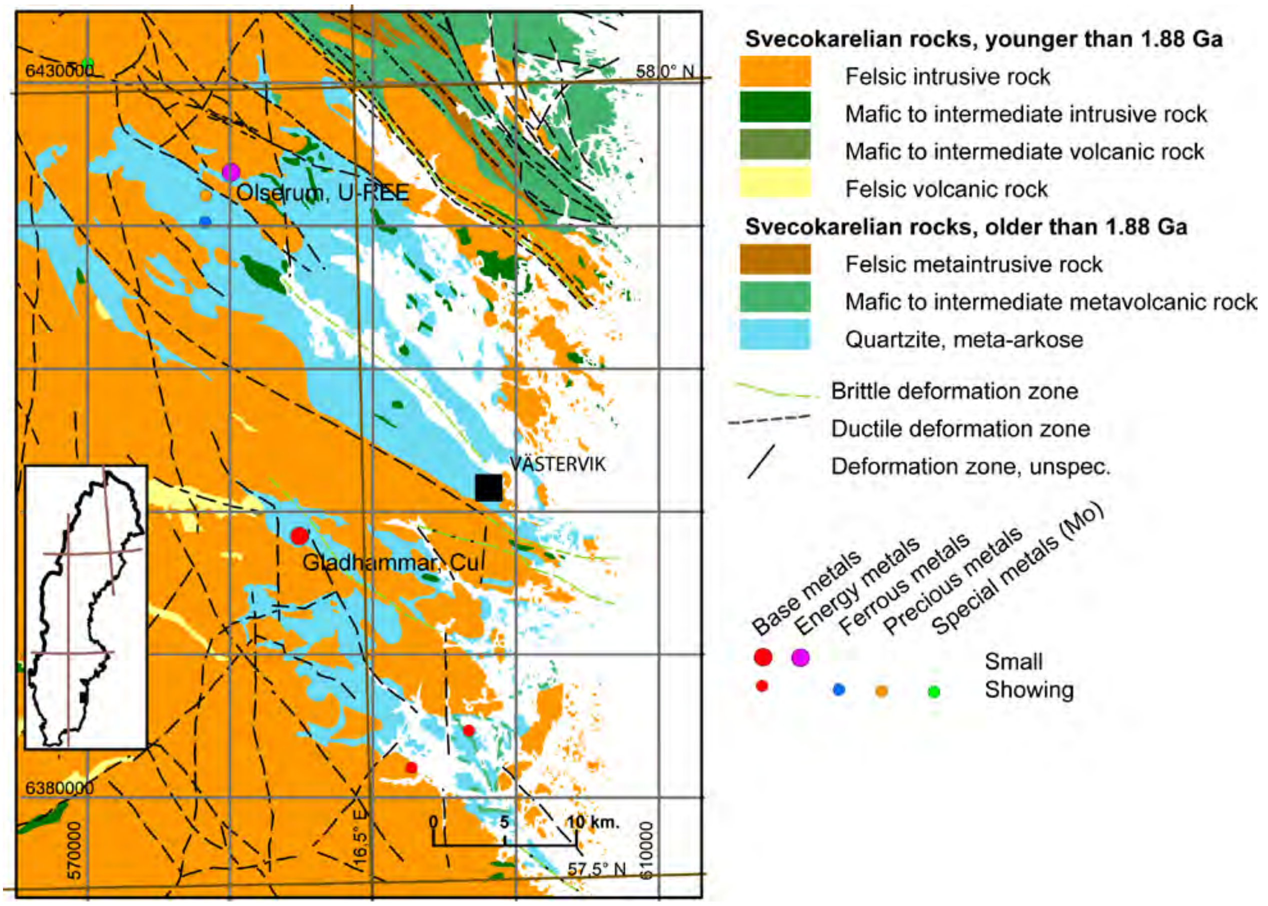


Figure 4. Simplified geological map of the Västervik area from Wik et al. (2005). All of the occurrences discussed in the text are within the quartzites and arkoses, Palaeoproterozoic in age (shown in blue colour). The grids shown are SWEREF-99 and Latitude-Longitude. Note that the size category 'Occurrences' contains deposits of the category 'Showing' in the Fennoscandian Ore Deposit Database.

other evidence for deposition in a deltaic-tidal flat environment (Gavelin 1984). Detrital-zircon age determinations, identifying at least five different source-rock ages, indicate that the quartzites were deposited at ca. 1882 to 1850 Ma (Sultan & Plink-Björklund 2006).

The deposits at **Gladhammar** were being mined for Fe by the 16th century. Mining for Cu started during the 17th century, and for Co at the end of the 18th century. Intermittent mining with a small production continued until 1892, when the mines were closed. More recently, exploration at Gladhammar has discovered Au. Genetically, the Cu-Co mineralisation at Gladhammar has been described as a Palaeoproterozoic sediment-hosted copper deposit with veins formed during regional deformation. The mines at Gladhammar are known for their rare mineral assemblages and are the type localities for lindströmite ($Pb_3Cu_3Bi_7S_{15}$), hammarite ($Pb_2Cu_2Bi_4S_9$) and gladite ($PbCuBi_5S_9$).

S006 BÖLET Mn

Torbjörn Bergman (SGU)

The Bölet metallogenic area lies immediately to the northwest of Lake Vättern. The metallogenic area is defined based on the presence of more than 50 manganese deposits along a 50 km, approximately NE-trending line. The oldest written documentation of the Bölet deposit dates back to the late 17th century. Deposits were periodically mined until 1857. After that time, mining was sporadic and the last period of exploitation was during World War II.

Most of the deposits are situated in the **Bölet** ore field, in the central part of the metallogenic area, close to the western shore of Lake Vättern. The Bölet ore field comprises more than 40 small workings within an area of 1 x 0.3 km. The largest working in the area is Vretgruvan, which has been mined to a depth of 240 m along an ore zone with an average width of 1.5 m. The total production in the area is estimated at 0.05 Mt, with an average ore grade of 30% Mn (Magnusson 1973).

The Mn occurrences are breccia-hosted and follow fault zones related to the major Lake Vättern fault (Andreasson et al. 1987). The deposits at Bölet are of similar type to the occurrences at Spexeryd, 100 km to the south, southeast of Lake Vättern (metallogenic area S003). The dominant ore minerals at Bölet are manganite and pyrolusite (Fig. 8g) which occur in an intimate mix with barite, calcite and fluorite (Tegengren 1924).

S007 DALSLAND–VÄRMLAND Cu-Ag, U, Au, Fe-Mn

Anders Hallberg (SGU)

The Dalsland–Värmland area is polymetallic (Table 3), with several sediment-hosted Cu deposits, quartz veins with Cu, Mn-Fe veins, disseminated Ni in ultramafic rocks and Au-rich quartz veins (Wik et al. 2002). The area broadly overlaps with the Mjösa–Vänern Mineral Belt of Bingen et al. (2008). Although the style, setting and metallogeny of the individual deposits vary, it appears that most of the deposits were formed broadly contemporaneously during the later stages of the Sveconorwegian orogeny, at around 1 Ga (Alm 2000, Stein et al. 2000). Several deposits have been mined in the past, but the only one that has been in production in recent times is **Harnäs**, where 71 000 t @ 2 g/t Au were mined from 1993 to 1997. The largest unexploited resource is in the **Dingelviken** sediment-hosted Cu-Ag deposit, from which 27.5 Mt @ 0.77% Cu and 22 g/t Au as well as elevated gallium contents has been reported (Thelander & Hammergren 1985, Hammergren 1989).

Most of the rocks in the Dalsland–Värmland area (Fig. 5) belong to the Idefjorden terrane (Bingen et al. 2008) and consist of 1.64–1.52 Ga plutonic, volcanic and sedimentary rocks formed along the Laurentia–Baltica margin. Subsequent sedimentation in a marine environment formed the Dal Group at around 1.2 Ga. The northernmost part of the Dalsland–Värmland area be-

Table 3. Deposits in the Dalsland–Värmland area (S007). Data on the produced tonnage, years of production and most of the metal grades from 'Official Statistics of Sweden, Metal and Mining Industries'. Resources for Dingelvik and Henneviken are from Dalia Mining AB (www.daliamining.se). Resources include reserves.

Deposit	**When mined**	**Resources (Mt)**	**Mined (Mt)**	**Ag ppm**	**Au ppm**	**Cu %**	**Mn %**	**Pb %**	**Zn %**
Sediment-hosted copper									
Stora Strand	1905–1925	0.75	0.01	25	0.8	1.5			
Henneviken	not exploited	2.35				1.1			
Dingelvik	not exploited	27.5		22		0.8			
Manganese mines									
Kesebolsgruvan	1917–1944		0.04				33.2		
Vikensfältet	1882–1918		0.00329				22.0		
Rolfsbyfältet	1894–1918		0.00183				22.1		
Kingebols mangangruva	1918–1918		0.00020				22.0		
Base & precious metal veins									
Knollegruvan	1872–1872		0.0001	15		2.0		2.3	
Vingenäs	1882–1905		0.0001	644	0.8	6.9			
Bortans koppargruva	1892–1917		0.0016			4.8			
Mangens Storgruva	1898–1909		0.0014		1.2	7.0			
Åmotfors koppargruva	1918–1918		0.00001			6.2			
Harnäs	1993–1997		0.07	31	4.6	0.1		1.5	
Vassviksgruvan	1872–1918		0.001361	1600		10.7		11.5	
Ånimskogsgruva	1898–1899		0.00109	230	0.1	1.6		0.01	0.01
Glava koppargruvor	1916–1918		0.00054	63	4.0	1.4		1.9	
Slädekärr	1907–1907		0.00012	205		0.4		0.4	

longs to the so-called Eastern segment (Bingen et al. 2008) and consists of deformed and metamorphosed plutonic rocks. While the host rocks are different, the deposits are broadly similar to the other deposits of the area. All of the host rocks in the Dalsland–Värmland area were affected by the Sveconorwegian orogeny at 1.14–0.90 Ga ago. The deformation that occurred during the waning stages of the orogeny is believed to have produced most of the vein deposits in the area, whereas the sediment-hosted deposits may have been formed earlier.

It is noteworthy that the Dalsland–Värmland area bears several similarities with area N007 Telemark Cu in Norway some 200 km to the WNW. The rock types are similar, they were formed at broadly the same time and both areas carry copper deposits.

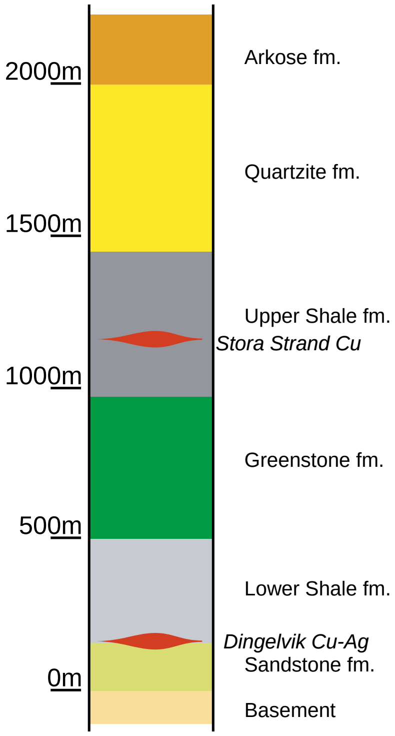


Figure 5. Simplified stratigraphic column of the Dalsland Group showing the stratigraphic location of the sediment-hosted copper occurrences in the area (red in the column).

THE BERGSLAGEN REGION

Anders Hallberg and Magnus Ripa (SGU)

The Bergslagen mining district (Figs. 6 and 7) in south-central Sweden makes up the south-western part of the Svecokarelian orogen in the Palaeoproterozoic Fennoscandian Shield (Stephens et al. 2009). The intensely mineralised district forms one of Sweden's most important provinces for the exploitation of metallic mineral resources. More than 4400 Fe, 700 sulphide, 95 special metal (mainly W) and a few precious metal deposits are known from the area.

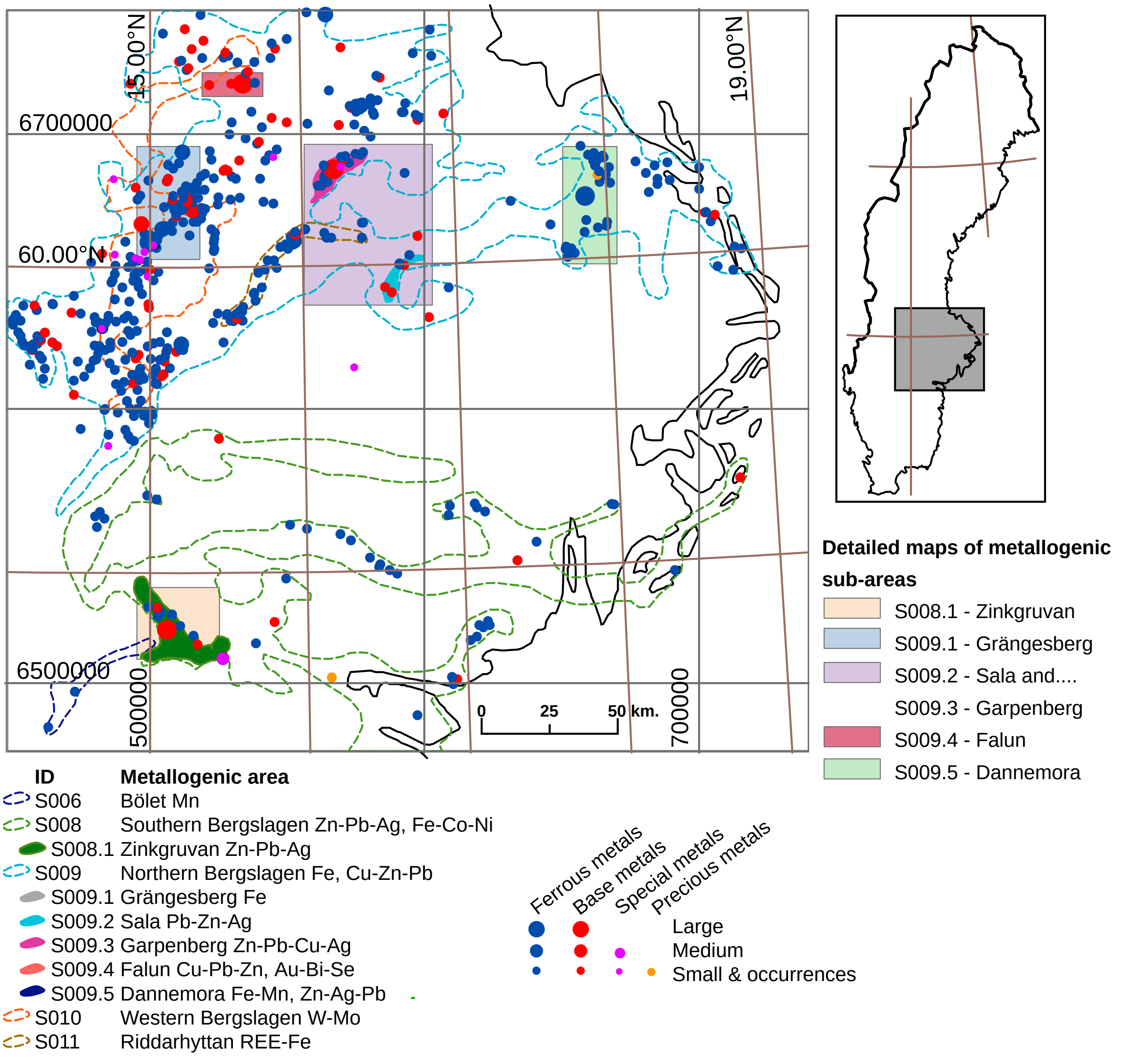


Figure 6. Map showing deposits occurring in the Fennoscandian Ore Deposit Database and the location of metallogenic areas in Bergslagen. The locations of more detailed maps for the metallogenic subareas and their surroundings are shown as boxes (Figs. 10, 11, 13, 15 and 16). Grids shown are SWEREF-99 and Latitude-Longitude.

Genetic deposit types and subtypes defined from the area include (Figs. 8 and 9):

- Banded iron formations (variably quartz-banded iron oxides, locally with other silicate bands)
- Skarn iron ore (magnetite with variably skarn-altered carbonates and silicates)
    - Mn-poor skarn iron ore and crystalline carbonate rock
    - Mn-rich skarn iron ore and crystalline carbonate rock
- Apatite-iron ore (iron oxides with apatite and some skarn)
- Sulphide ore (base metals, locally associated with skarn iron)
    - Stratiform, ash-siltstone-associated Zn-Pb-Ag (Åmmeberg-type)
    - Stratabound, podiform, skarn-limestone-associated Zn-Pb-Ag(-Cu-Au) (Falun type)
- Manganese ore (Mn oxides)
    - Stratiform Mn analogue to skarn iron ore
    - Breccia-hosted Mn
- Special and precious metals
    - W oxides (scheelite in skarn and wolframite and scheelite in quartz veins)
    - REE in iron ore
    - Molybdenite, porphyry-style or in skarn

To the west and southwest, the district is bound-

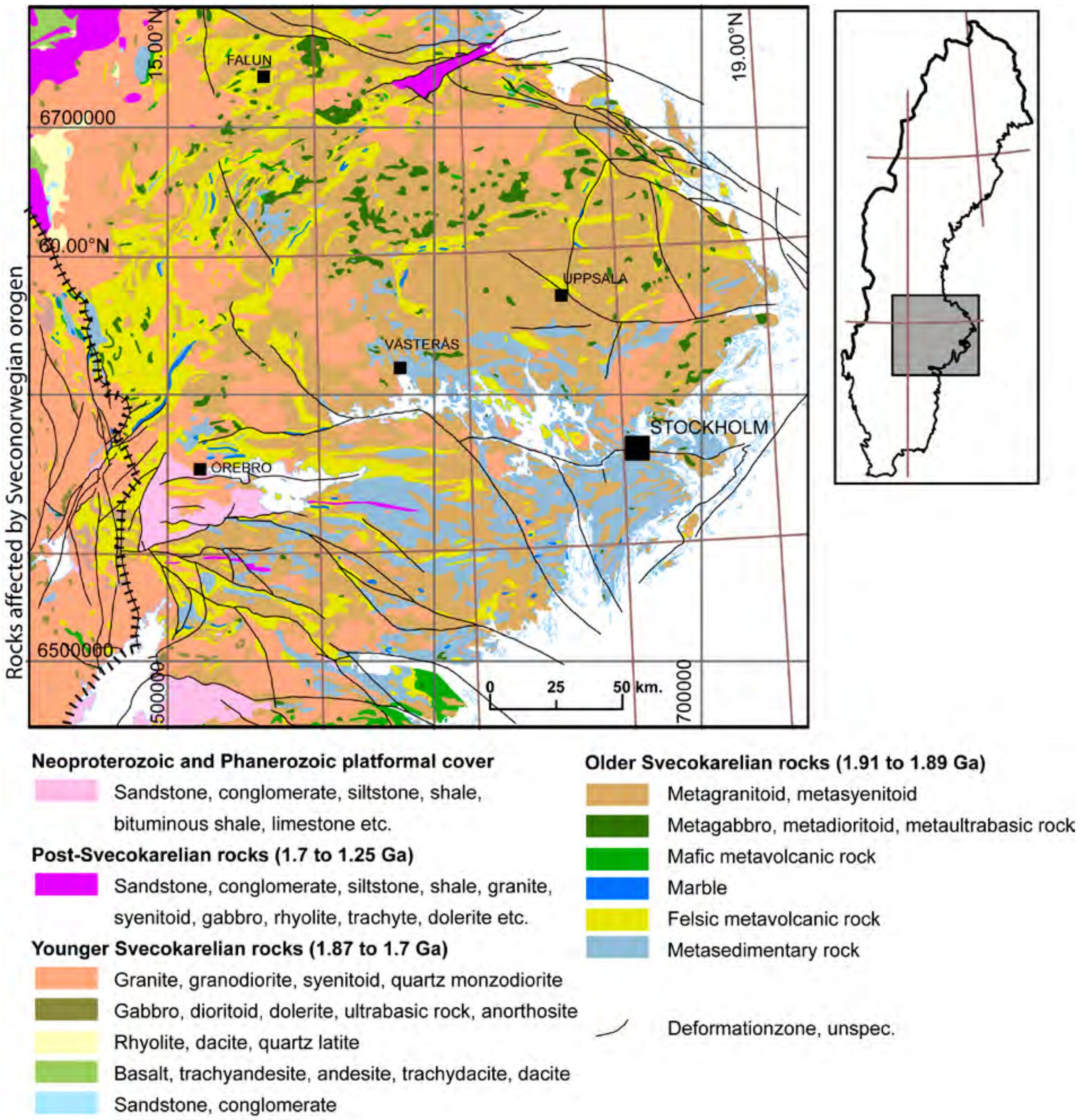


Figure 7. Simplified geological map of the Bergslagen district from Stephens et al. (2009). The outlined area in the western margin of the map indicates Palaeoproterozoic rocks affected by the Sveconorwegian orogeny. Grids shown are SWEREF-99 and Latitude-Longitude.

ed by younger batholiths, to the north by major northwest-trending, crustal-scale shear zones and to the east by the Baltic Sea (Stephens et al. 2009; Fig. 7). It may possibly be correlated across the Baltic Sea to southwestern Finland (to metallogenic area F001, Orijärvi, and possibly to F004, Häme, in Finland).

Most of the metal deposits occur in felsic metavolcanic rocks, associated with organogenic, crystalline, carbonate rocks and calc-silicate

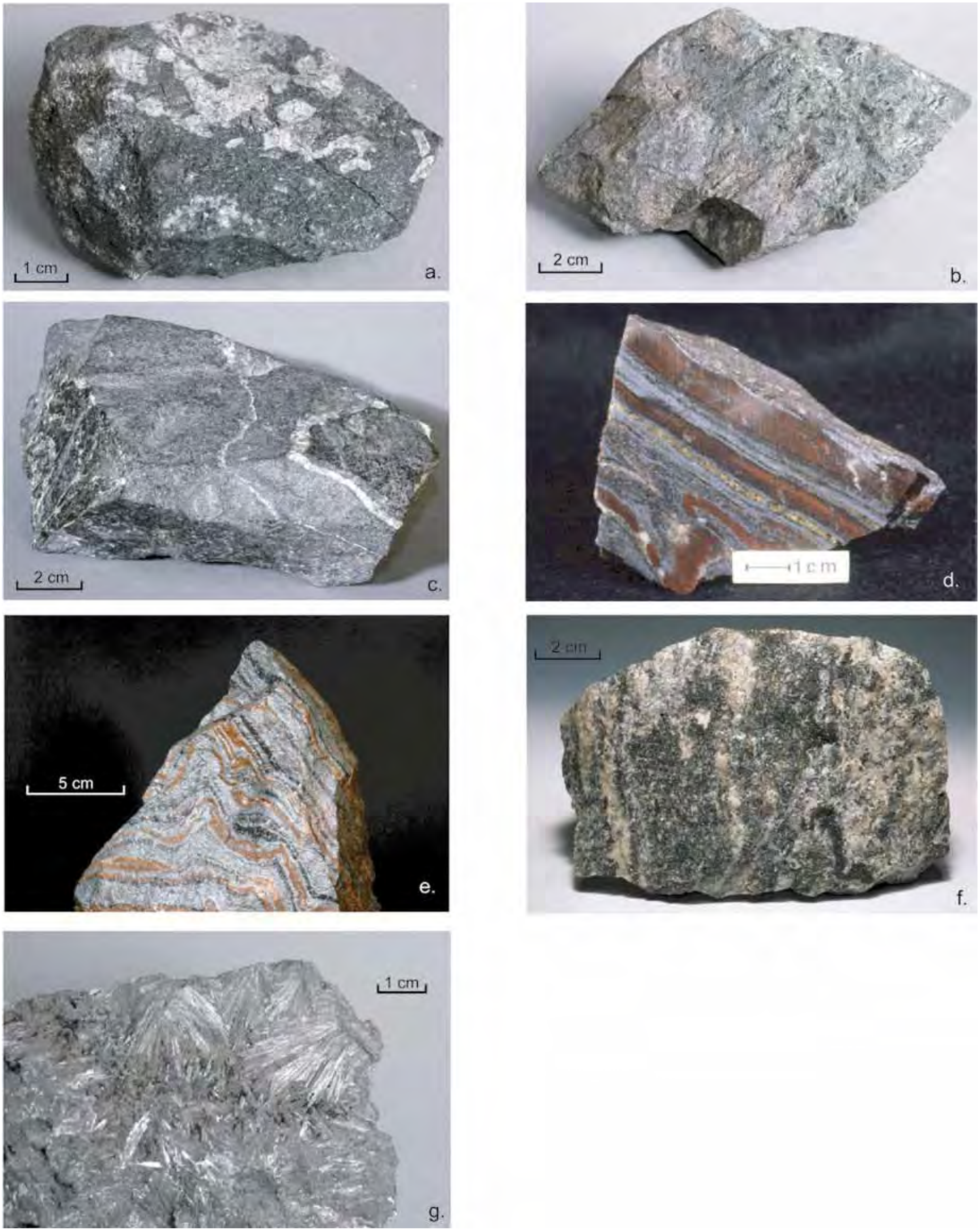


Figure 8. Examples of ferrous, mainly iron, ores from Bergslagen (Stephens et al. 2009). a. Apatite-bearing magnetite ore, Grängesberg deposit. b. Actinolite-garnet-magnetite skarn from Mn-poor skarn, Persberg deposit. c. Dannemorite-knebelite-magnetite skarn from Mn-rich skarns, Dannemora deposit. d. Jasper-hematite layered banded iron formation, Pershytte district. e. Banded iron formation, Striberg deposit. f. Banded dolomitic marble impregnated by hausmannite, Långban deposit. g. Manganite (MnO(OH)), Bölet deposit. Figure f: photo: Erik Jonsson (SGU), sample NRM 31128, copyright: Naturhistoriska riksmuseet. Other photos: Torbjörn Bergman, SGU.

(skarn) rocks 1900 to 1800 Ma in age (Allen et al. 1996a). In a few places, the basement to the metavolcanic rocks, consisting of turbiditic metagreywacke grading upward into quartzitic rocks, is exposed (Lundström et al. 1998). A sequence of clastic metasedimentary rocks, meta-argillite, quartzite and metaconglomerate lies stratigraphically above the volcanic rocks. Supracrustal rocks were intruded by several suites of igneous rocks, of which the oldest, a granitoid-dioritoid-gabbroid suite, is broadly contemporaneous with the metavolcanic rocks. The supracrustal rocks and the older intrusive suite were affected by Svecokarelian deformation and metamorphism (Stephens et al. 2009).

On the metallogenic map of the Fennoscandian Shield (Fig. 6), the Bergslagen region is covered by two major metallogenic areas, Southern and Northern Bergslagen (S008 and S009 respectively), and by two smaller areas, Western Bergslagen W-Mo (S010) and Riddarhyttan REE-Fe (S011). The division into two major areas is based upon differences in the character of the supracrustal rocks, where the northern area is strongly dominated by felsic metavolcanic rocks, whereas the southern area has broadly equal proportions of felsic metavolcanic and metasedimentary rocks. Further, differences in metallogeny occur between these two areas. Hence, four metallogenic areas with 6 subareas, each with a different char-

Figure 9. Examples of base, special and precious metal ores from Bergslagen (Stephens et al. 2009). a. Layered sphalerite-dominated ore, Zinkgruvan deposit. b. Semi-massive, chalcopyrite-pyrite ore, Falu deposit. c. Molybdenite in granite, Bispbergsklack deposit. d. Pyroxene-hornblende-scheelite skarn, Yxsjöberg deposit. e. Wolframite breccia, Baggetorp deposit. f. Native gold in a quartz vein, Falu base metal deposit; this specimen was collected by A.E. Törnebohm in 1898 and is archived at SGU. Photos: Torbjörn Bergman, SGU.

acter, are defined and are marked on the map as follows: S008.1 Zinkgruvan Zn-Pb-Ag, S009.1 Grängesberg Fe, S009.2 Sala Pb-Zn-Ag, S009.3 Garpenberg Zn-Pb-Cu-Ag, S009.4 Falun Cu-Pb-Zn, Au-Bi-Se, and S009.5 Dannemora Fe-Mn, Zn-Ag-Pb. Please note that the subareas S009.4 and S009.5 have an area of less than 20 km^2 each and are, for typographical reasons, not shown on the printed metallogenic map of Fennoscandia. Both areas can, however, be found on the Web version of the map.

S008 SOUTHERN BERGSLAGEN Zn-Pb-Ag, Fe-Co-Ni

Anders Hallberg (SGU)

In the Southern Bergslagen area (Fig. 6), there are about 900 iron, 400 sulphide, and a few precious metal (Au, Ag) and special metal (mainly W) occurrences (Table 4). All of the ferrous metal deposit types that are typical for the Bergslagen district, with the exception of apatite-iron deposits, are represented in the region. The economically most important deposit today is the **Zinkgruvan** Zn-Pb-(Ag-Cu) mine with >50 Mt of combined resources, reserves and mined ore (Table 4).

The metal-rich rocks in the Southern Bergslagen area consist of ca. 1900 Ma felsic metavolcanic rocks and broadly coeval migmatised metasedimentary rocks (Stephens et al. 2009). The supracrustal rocks consist of about 60% metavolcanic and 40% metasedimentary rocks. Approximately one third of the metavolcanic rocks are basic in character and mainly found in the southeastern part of the area. Only a fraction of the supracrustal rocks are carbonates, but they host the majority of metal deposits. The supracrustal rocks have been intruded by several generations of intrusions (Stephens et al. 2009).

In subarea S008.1 (Fig. 10), the most important deposit is Zinkgruvan with reserves, resources and mined tonnage of 50 Mt @ 8% Zn, 3.5% Pb and 70 g/t Ag plus an additional tonnage of a recently identified Cu ore with reserves and resources of nearly 4 Mt @ 2.7% Cu, 0.8% Zn and 30 g/t Ag (Lundin Mining 2010a). While the Zinkgruvan deposit has been known since the 16th century, large-scale mining commenced in 1857 and is ongoing with an annual rate of about 1 Mt of ore (Lundin Mining 2010b).

The Zn-Pb mineralisation at Zinkgruvan has a distinctive, less than 20-m-thick stratification, an

Table 4. Selection of deposits in the Southern Bergslagen metallogenic area (S008). Data on the produced tonnage, years of production and metal grades for smaller base metal deposits and all of the ferrous metal deposits are from ‘Official Statistics of Sweden, Metal and Mining Industries’. Reserves, resources and metal grades for Zinkgruvan and Zinkgruvan Cu are from Lundin Mining (www.lundinmining.com). In addition to those listed, there are another 50 base-, ferrous- and special metal deposits in the FODD for area S008. Resources include reserves.

Deposit(s)	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Co %	Cu %	Pb %	Zn %	Fe %	Mn %
Base metal deposits										
Zinkgruvan	1849–	19.30	31.36	70			3.5	8.0		
Zinkgruvan Cu	2010–	3.91	0.03	30		2.7		0.4		
Bersbo gruvfält	1874–1919, 1930		0.13			2.0				
Venafältet	1875–1908		0.21		0.2					
Ferrous metal deposits										
Kantorps gruvor	1845–1967		6.37						43.8	
Nartorps gruvor	1845–1927		0.72						49.5	0.2
Stavsfältet	1845–1967		0.71						36.8	2.6
Klara gruvor	1907–1962		0.53						56.2	
Förola	1845–1966		0.45						44.9	2.5
Asköfältet	1868–1946		0.39						26.6	
Utö gruvor	1845–1940		0.28						28.4	
Skottvångsgruvor	1846–1933		0.10						53.4	

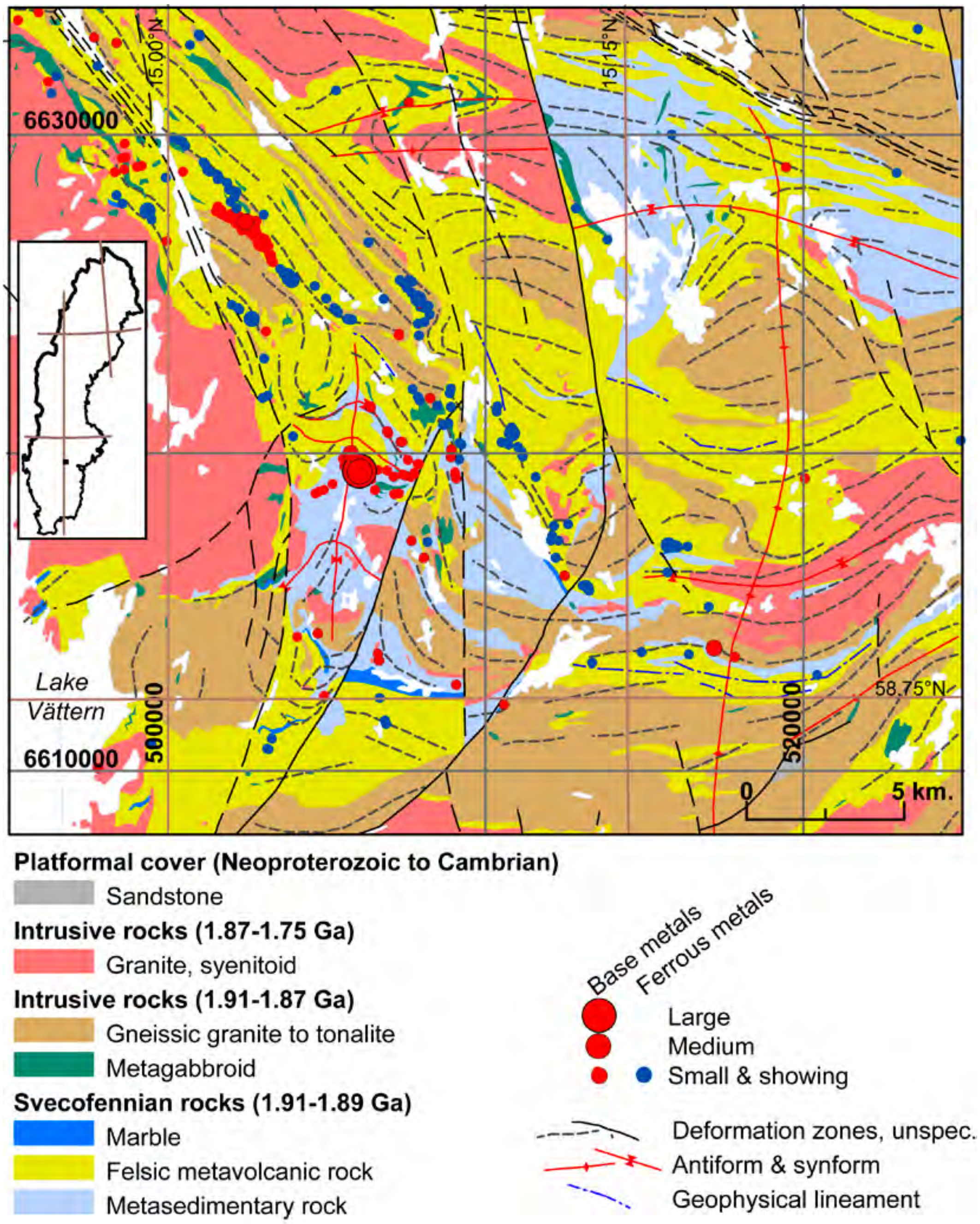


Figure 10. Geological map of the Zinkgruvan area with the locations of base and ferrous metal deposits. Simplified from Stephens et al. (2009). The location of the Zinkgruvan mine is indicated by a large red dot. For the location of the map area, see Figure 6.

extent of 5 km along strike and a known depth to 1300 m (Hedström et al. 1989). In the central part of the mine, the ore zone is underlain by Cu mineralisation as veins and dissemination in crystalline carbonate rock. The deposit is hosted by a volcanosedimentary complex consisting of felsic metatuffites mixed with chemical precipitates. The host rocks and the ore were folded and metamorphosed at upper-amphibolite facies conditions during the Svecokarelian orogeny. Hedström et al. (1989) interpreted the depositional environment of the sulphide mineralisation as a subsiding marine basin active at the end of the volcanic activity and distal from volcanic centres. Hydrothermal fluids circulated within the thick volcanosedimentary pile and vented heavy metal-bearing brines at the bottom of the sea. The characteristics of the deposit are between those of volcanogenic sulphide (VMS) and sediment-hosted, exhalative Zn-Pb deposits (SEDEX).

Other deposits in the Zinkgruvan subarea include the Vena mining field with about 200 small

Cu-Co workings (Wikström & Karis 1989). Mining at Vena commenced at ca. 1770 and the total documented production during the 19th century was less than 500 000 tons of ore at an unknown grade. The mines in the Vena field have been a major Co producer in Sweden.

S009 NORTHERN BERGSLAGEN Fe, Cu-Zn-Pb

Anders Hallberg and Magnus Ripa (SGU)

Nearly half of all Swedish deposits listed in the Fennoscandian Ore Deposit Database (FODD) are located in the Northern Bergslagen metallogenic area (Tables 5 and 6). In this metal-rich province, there has been continuous mining for more than 1000 years, perhaps close to 2000 years. More than 380 ferrous-metal deposits are listed in the FODD. Most of these are Fe deposits, but in about 30 of them Mn was either an important by-product or the main commodity. There are 70 base metal deposits, three of which are presently in operation, and around 60 W and Mo deposits. Precious-metal deposits are nearly absent in the area. In addition to the 470 deposits listed in the FODD, more than 5000 metal occurrences are documented in the Mineral Resource Database at the Geological Survey of Sweden. Most of these are similar to those listed in the FODD, but smaller. The total amount of produced metals and metals in reserves and resources in the S009 area is

Table 5. Selection of large, medium and small base-metal deposits in the Northern Bergslagen metallogenic area (S009). Data on the produced tonnage, years of production and most of the metal grades are from 'Official Statistics of Sweden, Metal and Mining Industries'. Data for the Garpenbergsfältet from Boliden (2008), for Lovisagruvan from Stephens et al. (2009), and for the Bunsås deposit from Viking Mineral AB (2011). In addition to those listed, there are 50 smaller base-metal deposits in the Fennoscandian Ore Deposit Database. Resources include reserves.

Deposit(s)	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Au ppm	Cu %	Pb %	Zn %
Mines in production								
Garpenbergsfältet	1876–	51.20	33.72	51	0.1	0.1	1.8	5.0
Lovisagruvan	1992–	0.4	0.12				7.0	11.0
Closed mines								
Falu gruva	1280–1992		11.39*	18	3.0	3.0	1.5	4.0
Saxberget	1882–1988		6.43	42	0.4	0.9	2.2	7.1
Stollbergsmalmen	1874–1981		3.48	20			5.0	3.0
Kaveltorps gruvor	1874–1971		1.21			0.5	3.7	7.2
Svärdsjö gruva	1887–1989		1.04	66	0.4	0.6	1.5	4.5
Ryllshyttegruvan	1888–1937		0.83					2.0
Ljusnarsbergsfältet	1874–1975		0.76				2.5	3.5
Sala gruva	1837–1962		0.73	150			1.0	12.0
Kalvbäcksfältet	1901–1963		0.56	100	0.3	0.1	3.6	8.3
Lövåsfältet	1874–1954		0.31				4.0	2.0
Mårshyttefältet	1906–1919		0.21			2.0		
Tomtebogruvan	1914–1968		0.12			4.4		
Skytt- och Näverbergsgruvorna	1890–1948		0.10					35.0
Hällefors silvergruva	1878–1978		0.07	350				33.0
Kallmorbergsföltet	1881–1931		0.07	300		9.7	25.0	16.0
Håkansbodafältet	1881–1954		0.05			2.5		
Gruvberget	1909–1989		0.05	200			4.5	10.0
Dannemorafältet	1880–1928		0.04					41.1
Riddarhytte odalutmål	1892–1930		0.03			7.7		12.0
Dammbergsgruvan	1905–1917		0.02					40.0
Bunsås koppargruva	1881–1920	0.96	0.01	18	0.4	0.5		1.9

* The total mined tonnage from the Falu mine only refers to the time period from which statistical information on ore production is available (1874 to 1992). Prior to 1874, only raw copper production data are available; see Figure 14.

0.49 Mt Cu, 5.7 Mt Zn, 2.2 Mt Pb, 358 Mt Fe, 46 t Au and 5185 t Ag; the precious metals are largely considered as by-products in most deposits.

The vast majority of the deposits in the Northern Bergslagen area are hosted by Palaeoproterozoic (c. 1900 Ma) supracrustal rocks (Figs. 10–16), mainly volcanic rocks and variably skarn-altered carbonate rocks (Stephens et al. 2009, Allen et al. 1996a). The metavolcanic rocks are predominantly felsic (85% of the surface area), whereas mafic metavolcanic rocks are less frequent. The remaining 15% are dominated by metasedimentary rocks, greywackes, argillites, minor quartzites and carbonate rocks (about 1%).

Table 6. Selection of larger ferrous metal deposits in the Northern Bergslagen metallogenic area (S009). Data on the produced tonnage, years of production, and Fe and Mn grades are from 'Official Statistics of Sweden, Metal and Mining Industries'. Resources for the Grängesberg Mining District and for the Norrberg-Morberg-Kallmorberg ore field are from Grängesberg Iron AB (2011), resources for Dannemora are from Dannemora Mineral AB (2011) and historical resources for the unexploited Kölen deposit are from Carlsson (1979). In addition to those listed, there are another 400 smaller ferrous metal deposits in the Fennoscandian Ore Deposit Database with a combined reported production of 46 Mt of iron ore. Resources include reserves.

Deposit(s)	When mined	Resources (Mt)	Mined (Mt)	Fe %	Mn %
Grängesberg mining district	1783–1989	120.30	132.58	60.3	0.2
Dannemorafältet	1845–1992	61.36	27.63	42.9	1.7
Kölen		70.00		40.0	
Norrberg-Morberg-Kallmorbergsfälten	1858–1902	42.80	18.99	42.4	0.1
Stråssa	1858–1982		28.12	31.7	0.1
Risbergsfältet	1783–1979		20.51	43.8	
Håksbergsfältet	1858–1979		19.79	33.2	0.2
Blötbergsfältet	1859–1979		15.96	50.9	0.3
Idkerbergsfältet	1860–1977		11.04	63.1	0.1
Stripafältet	1858–1977		12.53	48.9	0.1
Riddarhytte odalutmål	1858–1979		8.42	37.1	0.4
Persbergs odalfält	1845–1977		7.14	47.7	0.2
Stribergs gruvfält	1858–1967		7.02	48.2	
Ställbergs- Haggruvefältet	1870–1977		6.60	50.2	4.5
Vintjärnsfältet	1858–1978		6.21	39.1	0.5
Källfallsfältet	1897–1967		5.74	48.0	
Klackberg-Kolningsbergsfälten	1858–1967		5.27	45.3	3.9
Intrångets gruvor	1912–1969		5.14	46.8	0.2
Pershytte-Bergsgruvefältet	1858–1967		4.91	44.6	
Eskilsbacks-Mimerfälten	1874–1979		4.86	41.4	0.4
Tuna Hästbergsfältet	1858–1968		4.73	33.1	4.3
Basttjärnsfältet	1875–1978		4.02	43.9	3.9
Dalkarlsbergs odalfält	1858–1961		3.86	54.1	
Ramhälls gruvor	1845–1975		3.66	35.2	1.5
Sköttgruve- och Mossgruvefält	1868–1972		3.41	49.8	0.7
Vingesbackegruvan	1950–1980		3.40	42.7	0.4
Nybergsfältet	1858–1967		3.39	44.7	
Herrängsfältet	1845–1961		2.92	33.0	
Lekombergsfältet	1867–1945		2.84	49.8	
Semlafältet	1859–1967		2.75	40.5	
Smältarmossen	1872–1979		2.71	43.9	
Getbacks- och Rödbergsfälten	1860–1963		2.70	37.6	
Finnmossegruvorna	1858–1973		2.52	53.6	
Ormbergsfältet	1783–1926		2.45	61.0	
Nyängsfältet	1845–1966		2.26	44.9	1.4

S009.1 Grängesberg Fe

The Fe ores in Bergslagen have, on the basis on their metallurgical properties, been divided into apatite-rich iron deposits, with P contents >0.2%, and non-apatite iron deposits, with P contents considerably less than 0.2% (Geijer & Magnusson 1944). Apatite-iron ores in Bergslagen are found in a restricted belt, S009.1 Grängesberg, in the northwestern part of the Bergslagen district (Figs. 11 and 12). Within this belt there are four major apatite-iron ore fields, **Grängesberg**, **Blötberget**, **Fredmundberg** and **Lekomberga**, each of which has several ore bodies. The Idkerberget apatite iron-ore, a type of ore similar to those in the subarea S009.1, is located some 20 km to the north, but a proper geological correlation between the Grängesberg subarea and the Idkerberget deposit

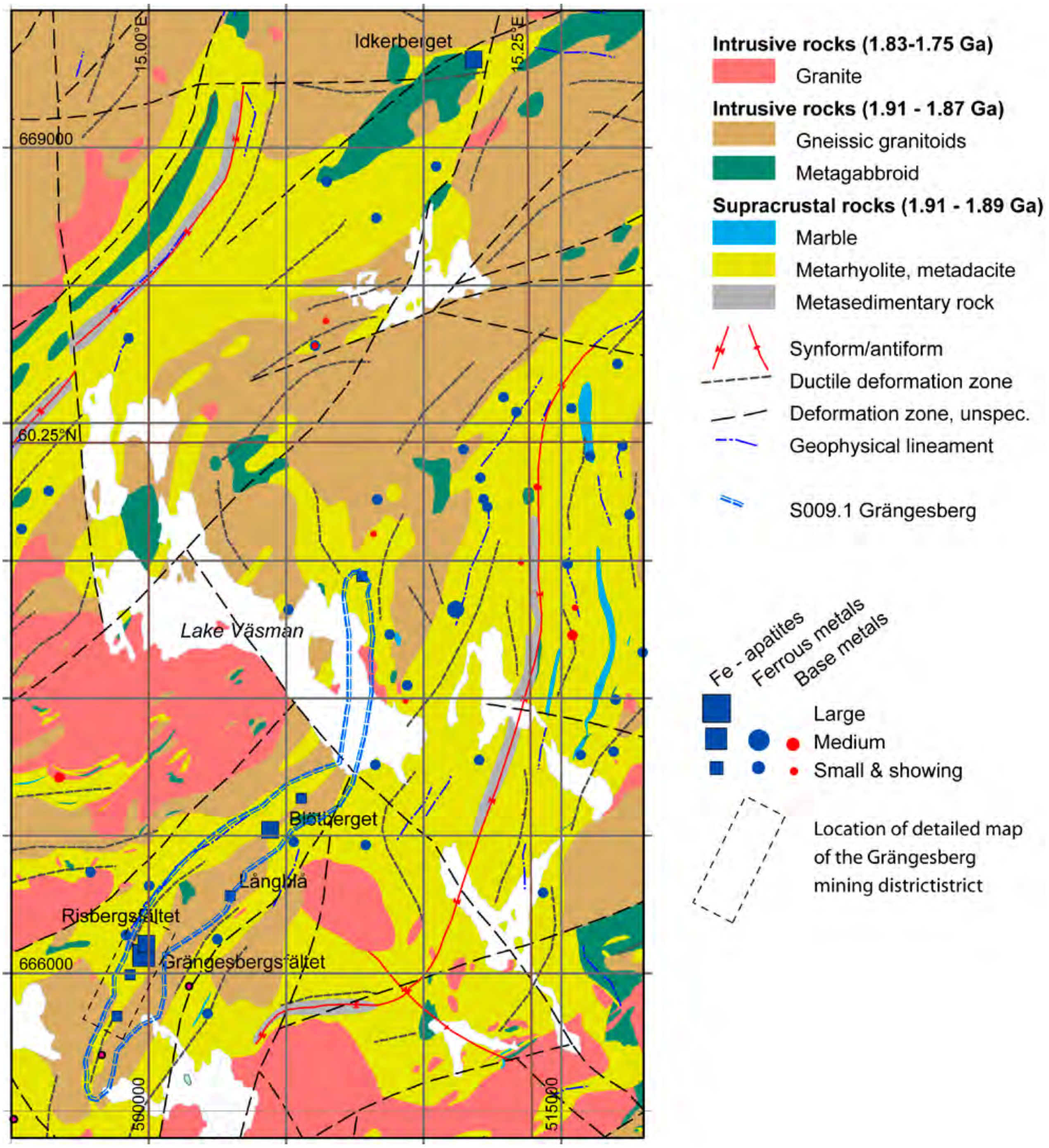


Figure 11. Geological map of part of the western Bergslagen area (S009), where the apatite iron ores are located. Simplified from Stephens et al. (2009). For the location of the map area, see Figure 6.

cannot be made from the available information. In addition, there are some minor apatite-iron deposits outside these mining fields and several non-apatite iron deposits within the area.

The **Grängesberg** deposit, the largest apatite-iron ore deposit in Bergslagen, is the third largest iron deposit in Sweden by production. It is third in size after the giant Kirunavaara and Malmberget deposits of northern Sweden. It is also the largest known metal deposit in the Bergslagen district, and the southernmost of the known apatite-iron deposits of Kiruna-type in Sweden.

The major ore body at Grängesberg extends 1500 m along strike and is up to 100 m wide (Magnusson 1938). It has been mined down to 650 m depth, but is geophysically constrained to extend down to at least 1500 m. The ore consists of massive magnetite (80%) and hematite (20%) with a few percent of apatite. Hematite is restricted towards the structural hanging wall and makes up the western part of the ore body. The iron ore is hosted by Na-altered dacitic metavolcanic rocks, dated to 1904 ± 8 Ma (Hallberg et al. 2008). Ore and host rocks have been intruded by several generations of mafic dikes and pegmatites (Looström 1939).

Less than 100 m to the west of the Grängesberg ore body (Fig. 12), similar but smaller ores

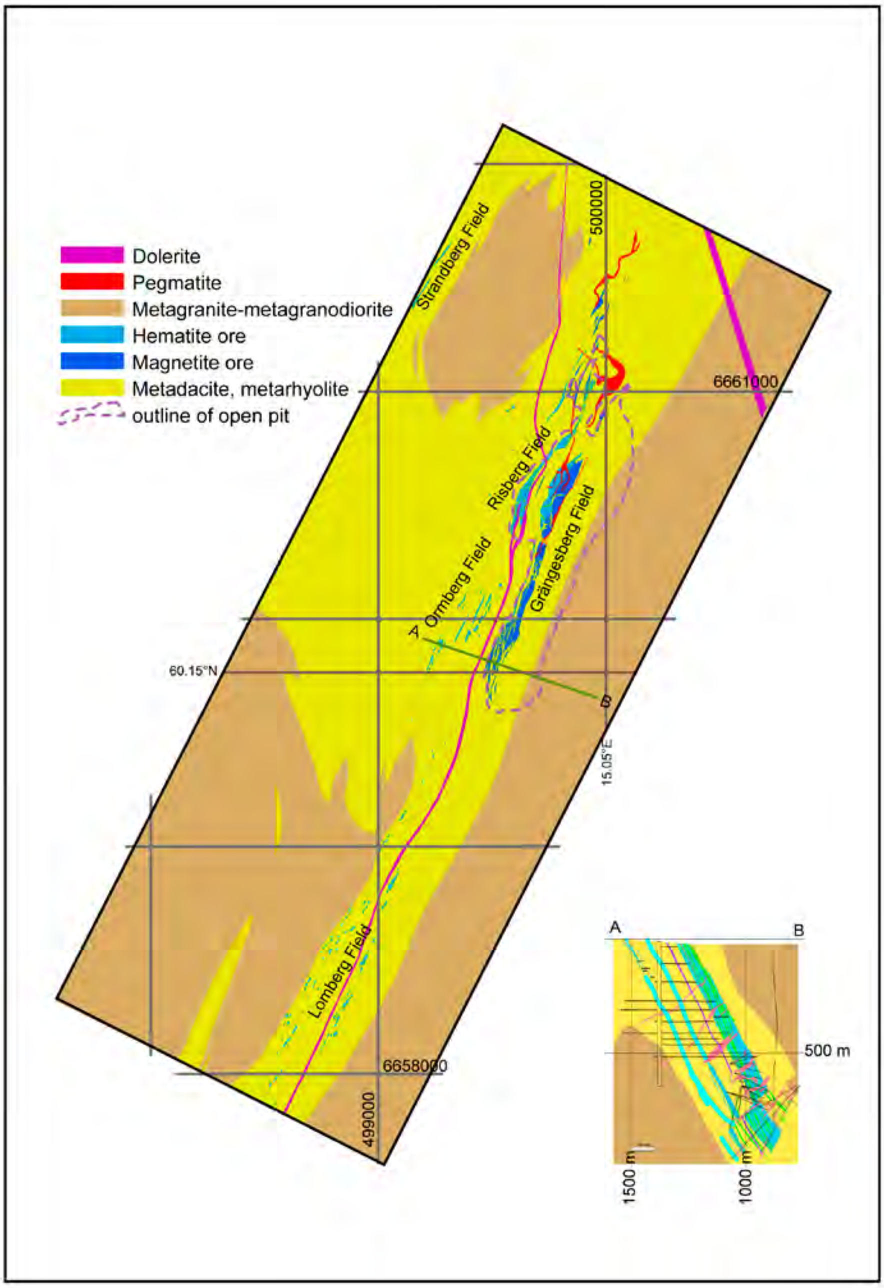


Figure 12. Geological map of the Grängesberg mining district with a profile across the southern part of the Grängesberg deposit (Lönnfallet). From Hallberg et al. (2008).

of the **Risberg** field are found (Hedberg 1907). They carry somewhat more hematite, whereas the P contents are similar to those at Grängesberg. Further to the southwest and along strike from the Risberg field lies the **Ormberg** field (Hedberg 1907). The ores at Ormberg are dominated by hematite and the P content is significantly lower than at Risberg and Grängesberg. Still further to the southwest lies the **Lomberget** field (Hedberg 1907), where disseminated apatite-bearing hematite and magnetite ores have been mined in the past. Five kilometres northeast of Grängesberg are the Blötberget and Fredmundberget fields and about 10 km further to the north lies the Lekomberg field (Geijer & Magnusson 1944). The northernmost apatite-iron ore field in the Bergslagen metallogenic district is Idkerberget, 27 km to the north of Grängesberg (Geijer & Magnusson 1944).

S009.2 Sala Pb-Zn-Ag

The **Sala** silver mine is the only deposit of any importance in Bergslagen, where Ag has been the main commodity for most of the production time. Mining started in the early 16th century and ended in 1962 (Fig. 13). During the latter years, Zn rather than Ag was the main commodity. The amount of Ag extracted from the mine during the about 450 years of operation is impossible to estimate exactly. However, more detailed production statistics from 1837 to 1962 give 0.7 Mt @ 150 g/t Ag, 1% Pb and 12% Zn (Table 5). It should be noted that the upper part of the deposit was more Ag-rich and the lower more Zn-rich and that available statistics only show the last 130 years of

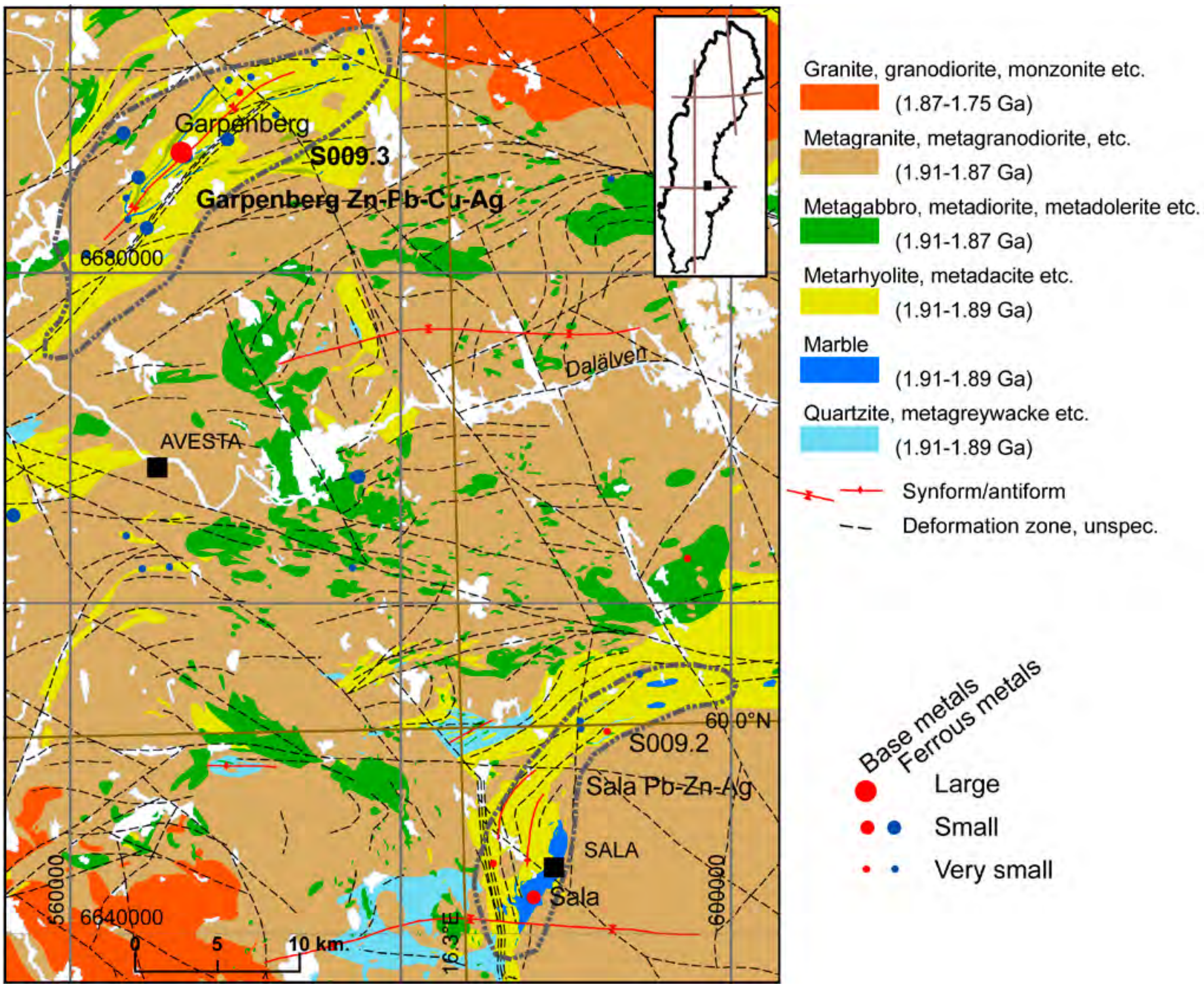


Figure 13. Geological map of the Sala-Garpenberg area in central Bergslagen. Boundaries of the metallogenic subareas S009.2 (Sala) and S009.3 (Garpenberg) are shown by grey dashed lines. Map simplified from Stephens et al. (2009).

mining. Thus, the Zn grade may be overestimated and Ag grade underestimated. Extremely high Ag grades, at 1 000 g/t and more are reported from the early days of mining. In those days, however, the Ag ore was mined and sorted by hand, leading to the high grades in assays.

The ore at Sala is hosted by a diopside-actinolite-tremolite skarn together with talc, serpentine and chlorite in a dolomitic marble (Jansson 2007). More Zn-rich parts of the deposit occurring at depth are normally not associated with skarn but with marble. The ore minerals include Ag-rich galena, argentite and sphalerite. Minor phases present are geochronite, boulangerite, cinnabar, mercury, silver amalgams and chalcopyrite. The ore bodies pinch out at depth and seem to disappear at around 300 m. In the vicinity of the Sala deposit, there are several Pb-Zn deposits within thinner marble layers, some of which have been mined in the past.

S009.3 Garpenberg Zn-Pb-Ag-Cu

Garpenberg is the largest massive sulphide deposit in Sweden with a total tonnage (production, reserves and resources) of 85 Mt @ 5.01% Zn, 1.83% Pb, 0.06% Cu, 51 g/t Ag and 0.1 g/t Au (Boliden 2011a). It consists of several ore bodies that are interpreted as having been emplaced in a dolomitic limestone (Allen et al. 1996a). Multiple folding and faulting have further redistributed and separated them. The oldest part of the Garpenberg mine (Garpenberg odalfält) was mined for Cu in the 13th century, but Zn later became the most important commodity (Magnusson 1973). In 1972, the Garpenberg Norra mine, about 3 km to the north, was opened. The two mines were eventually connected through an underground drift and since then may be considered as one. During the last decade, several new blind ore bodies have been discovered to the east of the interconnecting drift. These include the Lappberget, Dammsjön, Kasperbo and Kvarnberget, discoveries that have increased the reserves and resources significantly (Allen et al. 2010).

The deposit consist of lenses and pods of sulphides with varying proportions of pyrite, sphalerite, galena, chalcopyrite and pyrrhotite hosted in calc-silicate rocks (tremolite skarn) and mica schists (Christofferson et al. 1986). A more Cu-rich mineralisation forms a network of chalcopyrite-pyrite-pyrrhotite-bearing quartz and quartz-fluorite veins in the quartz-mica-altered stratigraphic footwall. The deposit is interpreted to be a synvolcanic subsurface replacement mineralization in limestone with the Cu mineralisation as a stringer to the Zn-Pb ore. In the Garpenberg Norra deposit, stromatolitic structures indicate an organogenic origin for the limestone (Allen et al. 1996a).

The Garpenberg supracrustal inlier, broadly covering the same area as the S009.3 metallogenic area (Fig. 13) that is hosting the Garpenberg deposits, also hosts other Zn-Pb deposits and skarn iron deposits in carbonate rocks. At one of these, the Ryllshyttan Zn-Pb-Ag-magnetite deposit, it has been shown that both sulphide and magnetite mineralisation took place by replacement of carbonate rocks (Jansson 2009). Dating of critical lithologies has shown that the mineralisation is broadly contemporary with volcanism in the area, i.e. the mineralisation is epigenetic but broadly synvolcanic.

S009.4 Falun Cu-Pb-Zn, Au-Bi-Se

The **Falu mine** is one of the oldest mines in the country and has been in operation for a millennium. It has gained an almost mythical importance in both the Swedish society and mining history. Historically, it is without question the most important mineral deposit in Sweden. While it is impossible to obtain any exact figures on total ore production and grades of the deposit, it is estimated that during its lifetime 28 Mt of ore at 2–4% Cu, 4% Zn, 1.5% Pb, 13–24 g/t Ag and 2–4 g/t Au has been mined (Fig. 14). The tonnage data given in the FODD, 11.4 Mt of ore, only include the documented production from 1874 to the closure of the mine in 1992.

In the mine, three types of mineralisation have been worked: a massive pyrite-dominated sulphide ore with sphalerite, galena and chalcopyrite (Fig. 9b); a Cu-Au stringer ore in intensely altered rocks; and younger Au-mineralised quartz veins (Fig. 9f).

The deposit is hosted by metavolcanic rocks (Fig. 15), largely altered to mica schists and so-called ore quartzites, along with marble and skarn (Lasskogen 2010). The rocks were intruded by quartz-phyric subvolcanic intrusions and mafic dikes, then metamorphosed to upper amphibolite facies and experienced several phases of folding and faulting. The deposit has been interpreted as a stratabound volcanic-associated skarn sulphide

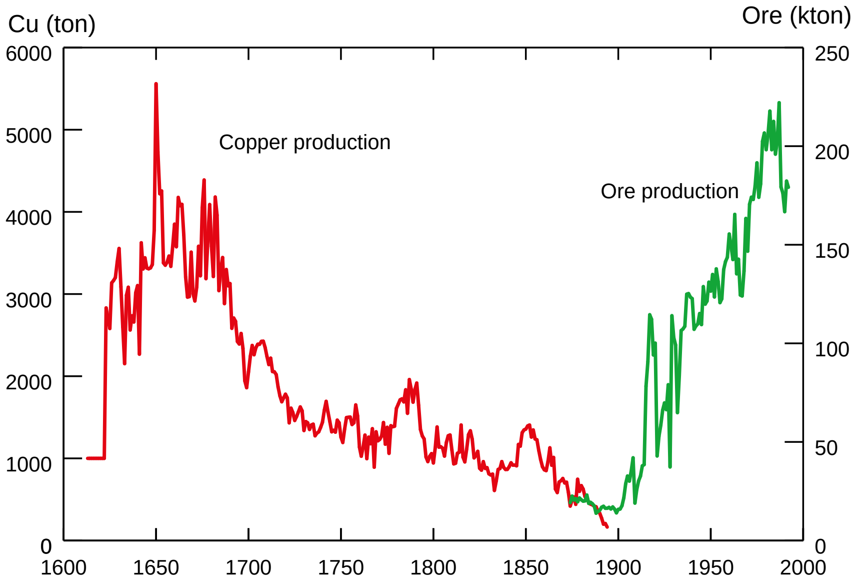


Figure 14. Documented copper production (1612–1894, red) and ore production (1874–1992, green) from the Falu mine. Note the peak in copper production in the 17th century. Data on copper production are from Tegengren (1924), and data on ore production from the Official Statistics of Sweden, Metal and Mining Industries.

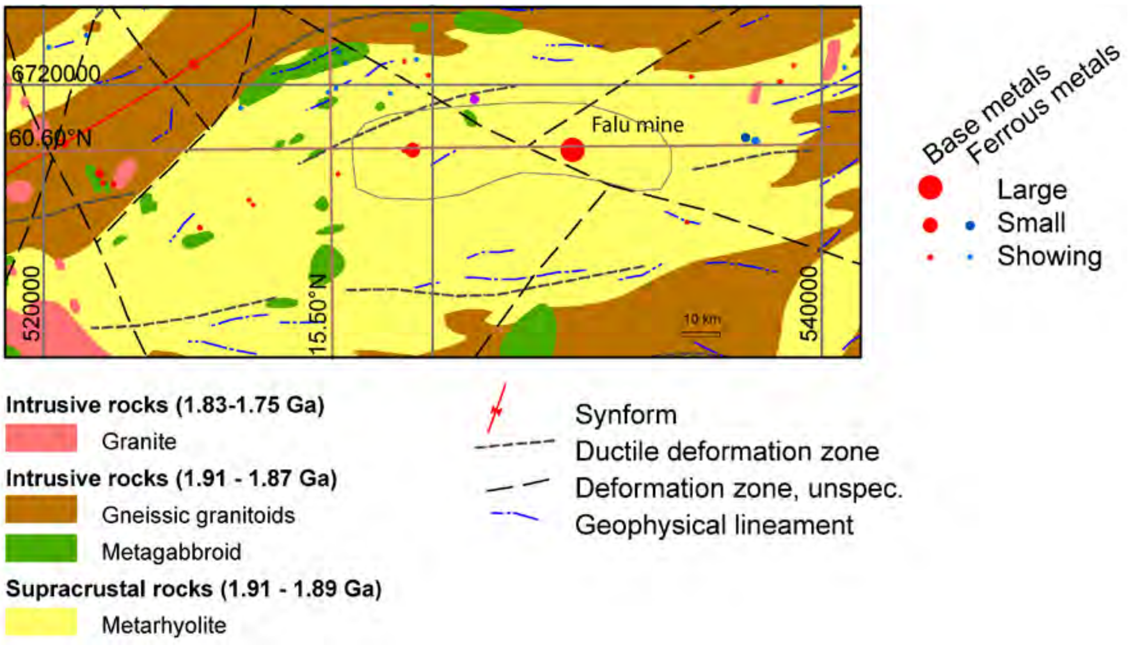


Figure 15. Geological map of the Falu region. Boundaries of the metallogenic subarea S009.4 (Falun) are indicated by a thin black line in the central part of the figure. Please note that this subarea does not appear on the printed Metallogenic Map of the Fennoscandian Shield (Eilu et al. 2009).

deposit (Allen et al. 1996a).

About 40 km west of Falun are the Skytt and Näverberg mines. According to available descriptions, they are similar to the Falu deposit, but significantly smaller with a total production amounting to less than 0.1 Mt (Table 5).

S009.5 Dannemora Fe-Mn, Zn-Ag-Pb

Dannemora, which consists of about 25 individual ore bodies, is the largest skarn-iron deposit in the Bergslagen district. Mining at Dannemora has probably taken place since the 13th century, although the first written document on the mine dates from 1481. In the early days, the mining focused on a minor Zn-Pb sulphide occurrence. However, during the 16th century, products from iron-ore mining became the main commodity. It is estimated that the total iron ore production until the closure of the mine in 1992 was 54.3 Mt @ 52% Fe and 2–3% Mn (Allen et al. 1996a). The lower

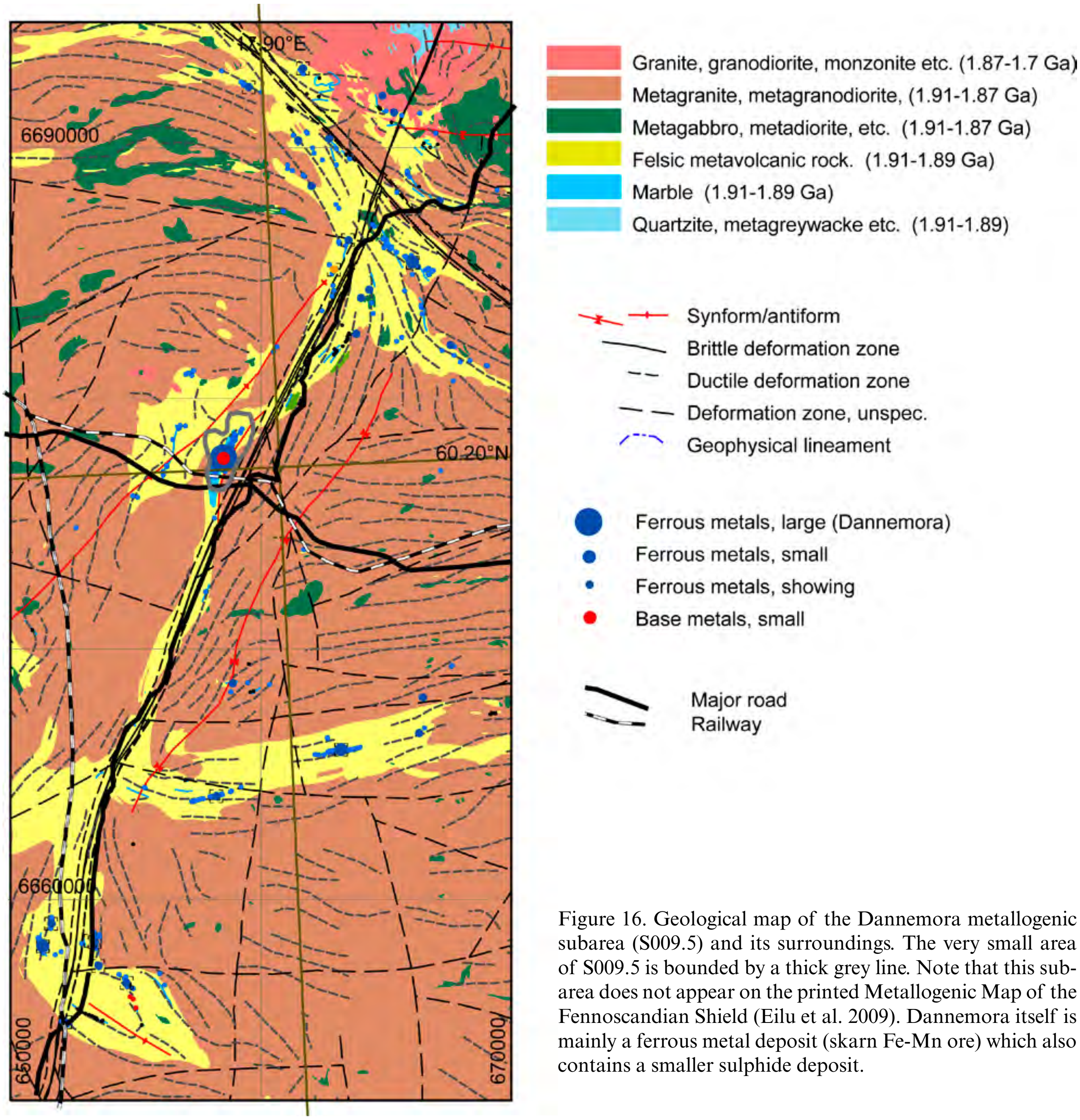


Figure 16. Geological map of the Dannemora metallogenic subarea (S009.5) and its surroundings. The very small area of S009.5 is bounded by a thick grey line. Note that this subarea does not appear on the printed Metallogenic Map of the Fennoscandian Shield (Eilu et al. 2009). Dannemora itself is mainly a ferrous metal deposit (skarn Fe-Mn ore) which also contains a smaller sulphide deposit.

production figure given in Table 6 is from the period when proper statistical information is available (from 1845 to the closure of the mine). In 2005, the company Dannemora Mineral AB was formed with the aim to re-open the mine. The company has so far delivered iron ore to a number of different European smelter companies for testing.

The Fe deposit at Dannemora consists of massive and stratabound magnetite associated with Mn minerals (Fig. 8c), diopside, actinolite, chlorite and serpentine (Lager 2001). The ore also contains calcite, dolomite, siderite and rhodochrosite. It was traditionally divided into Mn-rich and Mn-poor varieties, where the Mn content of the skarn was 1–6% and less than 1%, respectively. In parts of the deposit, the magnetite itself is manganiferous.

The deposit is hosted by dolomitic or calcitic marble and skarn, which in turn is hosted by metavolcanic rocks with an age of ca. 1.9 Ga (Fig. 16). A large part of the latter consist of thinly bedded or laminated pyroclastic material, but volcanoclastic breccias have also been recognised in part of the stratigraphy. Of particular palaeo-environmental interest is the evidence of evaporites in the carbonate sequence (Lager 2001). The deposit is interpreted to have formed in a caldera setting with sedimentation in an open marine, lagoonal and saline environments (Lager 2001). These conditions caused the depositional sequences of volcaniclastic tidal deposits, dolomitic carbonate, sabkha and salt pan deposits to form. The latter may have functioned as traps for metal precipitation from hydrothermal solutions. Due to later deformation, the ore and its host rocks today form a NNE-trending, steeply dipping structure, called the Dannemora syncline. The rocks were metamorphosed under greenschist-facies conditions and several original structures and textures are preserved (Dahlin & Sjöström 2010).

S010 WESTERN BERGSLAGEN W-Mo

Torbjörn Bergman

The Western Bergslagen metallogenic area largely overlaps with the northern Bergslagen metallogenic area (S009; Fig. 6). The main difference between S009 and S010 is that the latter is defined by the presence of more than 100 known W and Mo occurrences and deposits.

The majority of the W occurrences are minor and only a few have been mined, including **Yxsjöberg**, **Sandudden**, **Wigström** and **Elgfall** (Ohlsson 1979). The most prominent occurrence is Yxsjöberg, with an estimated tonnage of 5 Mt at 0.3 to 0.4% W. It was mined until 1989 and was then the largest tungsten deposit in Scandinavia (Ohlsson 1979). Production data for Yxsjöberg probably also includes the ore mined from the nearby Sandudden deposit. The Elgfall and Wigström deposits (both less than 0.2 Mt of ore) were mined during two short periods (1970–1971 and 1978–1981, respectively) as satellite bodies to the Yxsjöberg deposit (Andersson 1986, Bergman 1994).

All known W occurrences in area S010 are skarn deposits hosted by the Svecofennian, 1910–1890 Ma, felsic metavolcanic and crystalline carbonate rocks. The occurrences are mostly concordant or subparallel to bedding. Crystalline carbonate rock is generally found as remnants in the skarn but is, in some deposits, completely replaced by skarn. Scheelite, generally with a significant component of powellite ($CaMoO_4$), is the only economically important tungsten mineral (Ohlsson 1979). The skarn assemblages consist of grossularite-andradite garnet, hedenbergite-diopside pyroxene and hornblende (Fig. 9d). Scapolite, vesuvianite and wollastonite are important constituents in some deposits, for example at Wigström and Elgfall (Ohlsson 1979, Bergman 1994). Fluorite is common in many deposits, and a strong positive correlation between fluorine and tungsten contents is noted in the Yxsjöberg deposit (Ohlsson 1979), where fluorite was extracted as a by-product.

The presence of molybdenite is also a common feature in the tungsten skarn deposits and, in many places, for example in the **Hörken** deposit (Hübner 1971), scheelite and molybdenite occur in approximately equal proportions. In general, other sulphide minerals are only present in subordinate amounts. An exception is the Yxsjöberg deposit, where significant amounts of pyrrhotite and chalcopyrite are present and, in fact, the deposit was originally opened as a copper mine. At Wigström, sphalerite is common together with pyrrhotite and molybdenite (Bergman 1994).

Molybdenum deposits of the ‘Climax-type’, in which molybdenite is hosted by late-Svecofennian, 1.8 Ga granites and pegmatites, also occur in the area (Fig. 9c). Examples are the **Bispbergsklack**, **Pingstaberg** and **Uddgruvan** deposits. All are minor (<0.1 Mt of ore) and have never had any significant economic importance. The total molybdenum production from the Swedish deposits is about 0.2 Mt of MoS_2, of which more than 50% originates from Uddgruvan in the vicinity of Grängesberg. Most of these deposits were mined during World War II, and no mining has been carried out after that period.

S011 RIDDARHYTTAN REE-Fe

Anders Hallberg (SGU)

The Riddarhyttan district (Fig. 6) hosts more than 300 skarn Fe deposits and a few sulphide deposits, about 40 of which are included in the Fennoscandian Ore Deposit database (FODD). Of particular interest, and the reason for defining a separate metallogenic area for the Riddarhyttan district, is that several of the skarn iron ores (Table 7) carry high contents of rare earth elements (REE) that have been mined in the past (Geijer 1961, Gustafsson 1990, Andersson 2004). During 1860–1919, about 160 t of cerite ore (REE ore) was produced from the Nya Bastnäs mine. In 1923, an additional 825 t was extracted from the waste dumps. The grade of the ore is unknown. The Fe ore production from the area S011 is in the order of 95 Mt @ 42% Fe, making it a significant producer in the Bergslagen region. The total production from base metal deposits is about 0.1 Mt of Cu-Pb-Zn-Ag ore.

The mineralised Riddarhyttan district is hosted by a supracrustal enclave that stretches from the Riddarhyttan deposit in the southwest to the Myresjö mines in the northeast (Andersson 2004). The supracrustal belt mainly consists of felsic metavolcanic rocks surrounded by intrusive rocks in the east, and intrusive and supracrustal rocks in the west. The host rocks may be correlated to carbonate-dominated supracrustal rocks in the Nora area some 40 km to the southwest, where REE mineralisation occurs at Rödbergfältet.

The REE occurrences are in skarns replacing dolomitic carbonate rocks and are associated with tremolite and talc (Geijer 1936, 1961, Geijer & Magnusson 1944). The main REE-bearing minerals are allanite and cerite, while other REE phases include ferriallanite, törnebohmite and bastnäsite (Table 8; Andersson 2004). The Bastnäs mine is the type locality for the latter mineral. Sulphide minerals, mostly chalcopyrite, bismuthinite and molybdenite, are commonly associated with the REE occurrences. Most authors agree that the REE occurrences in the area are epigenetic replacement deposits.

Table 7. REE-bearing Fe deposits within the Riddarhyttan metallogenic area (S011) (Geijer 1936, Andersson 2004).

Deposit	Included in a mining field in FODD
Johannagruvan	Bojmossfältet
Kallmoragruvan	Kallmorbergsfältet
Malmkärrafältet	Malmkärragruvan
Nya Bastnäs	Riddarhytte odalutmål
Rödbergsgruvan	-
Södra Hackspikgruvan	Smörbergfältet
Tallgruvan	Sundsgruve-Hubergsgruvefälten
Åsgruvan	Getbacks- och Rödbergsfälten
Östanmossgruvan	Getbacks- och Rödbergsfälten

Table 8. REE minerals in the Bastnäs-type deposits, from Andersson (2004).

Mineral	Formula
Allanite-(Ce)	$(Ce,La)CaFeAl_2[Si_2O_7][SiO_4]O(OH)$
Bastnäsite-(Ce)	$(Ce,La)CO_3F$
Bastnäsite-(La)	$(La,Ca)CO_3F$
Cerianite	CeO_2
Cerite-(Ce)	$(Ce,La,Nd,Ca)_9(Mg,Fe)Si_7O_{24}(O,OH,F)_7$
Dissakisite-(Ce)	$Ca(Ce,La)MgAl_2[Si_2O_7][SiO_4]O(OH)$
Dollaseite-(Ce)	$Ca(Ce,La)Mg_2Al[Si_2O_7][SiO_4]F(OH)$
Ferriallanite-(Ce)	$(Ce,La)CaFeAlFe[Si_2O_7][SiO_4]O(OH)$
Fluocerite-(Ce)	$(Ce,La)F_3$
Fluocerite-(La)	$(La,Ce)F_3$
Fluorbritholite-(Ce)	$Ca_2(Ce,Nd)_3[SiO_4]_3F$
‘Fluorbritholite-(Y)’	$Ca_2(Y,REE)_3[SiO_4]_3F$
Gadolinite-(Ce)	$(Ce,Nd)_2FeBe_2Si_2O_{10}$
Gadolinite-(Y)	$(Y,REE)_2FeBe_2Si_2O_{10}$
Håleniusite-(La)	$(La,Ce)OF$
Lanthanite-(Ce)	$(Ce,La)(CO_3)_3$ x 8 H_2O
Parisite-(Ce)	$Ca(Ce,La)_2(CO_3)_3F_2$
Percleveite-(Ce)	$(Ce,La)_2Si_2O_7$
Törnebohmite-(Ce)	$(Ce,La)_2Al[SiO_4]_2(OH)$
Västmanlandite-(Ce)	$(Ce,La)_3CaAl_2(Mg,Fe)_2[Si_2O_7][SiO_4]_3(F,O)(OH)_2$

S012 HAMRÅNGE Fe, Cu, W

Anders Hallberg (SGU)

The Hamrånge metallogenic area (S012) hosts several skarn-type iron deposits, similar to those found in the Bergslagen district, but in an area that is separated from the Bergslagen district proper by several major WNW-trending faults and shear zones (Fig. 17). Scheelite mineralisation associated with the iron ore has been detected in several deposits, and sulphides are often found together with the iron ores (Wik et al. 2009). Several scheelite- and copper-bearing boulders are known from the area (Jönsson & Mattsson 1984). The only deposit qualifying for the Fennoscandian Ore Deposit Database is the Magmyrgruvan mine, with a documented production from intermittent mining between 1845 and 1905 of 7000 t @ 59% Fe.

Most of the iron deposits occur in supracrustal enclaves in the Ljusdal granite, dated to 1843

Ma (Delin 1993), but iron deposits also occur within a larger enclave of supracrustal rocks in the southern part of the Hamrånge area. The geology of the ore-bearing supracrustal rocks in the Hamrånge area is best known in the southern part of the area, where it consists of a volcanic sequence of mafic to felsic volcanic rocks (tuffs, tuffites, lavas and volcanic breccias) with intercalated carbonates overlain by argillites and quartzites (Jönsson & Mattsson 1984, Bergman et al. 2008, Ogenhall 2010). The volcanic sequence has been dated at 1888 ± 6 Ma and the overlying quartzites were deposited after 1855 ± 10 Ma (Ogenhall 2010). The supracrustal sequence is cut by several generations of intrusive rocks. In the northern part of the area, supracrustal rocks of similar compositions are found as small enclaves in granites of the Ljusdal batholith (1.87–1.82 Ma). The area was later affected by at least two phases of deformation.

During exploration for gold in the 1980s in the Hamrånge area, the State Mining Property Commission (NSG) found several arsenopyrite-bearing and gold-rich boulders with grades of up to 12.4 g/t Au (Thelander 1987). A subsequent drilling programme revealed that the mineralisation occurs as dissemination in layers parallel to the banding of felsic to intermediate metavolcanic rocks. In the richest part, a 1.2-m-thick layer carried 8.8 g/t Au down to 30 m below the surface.

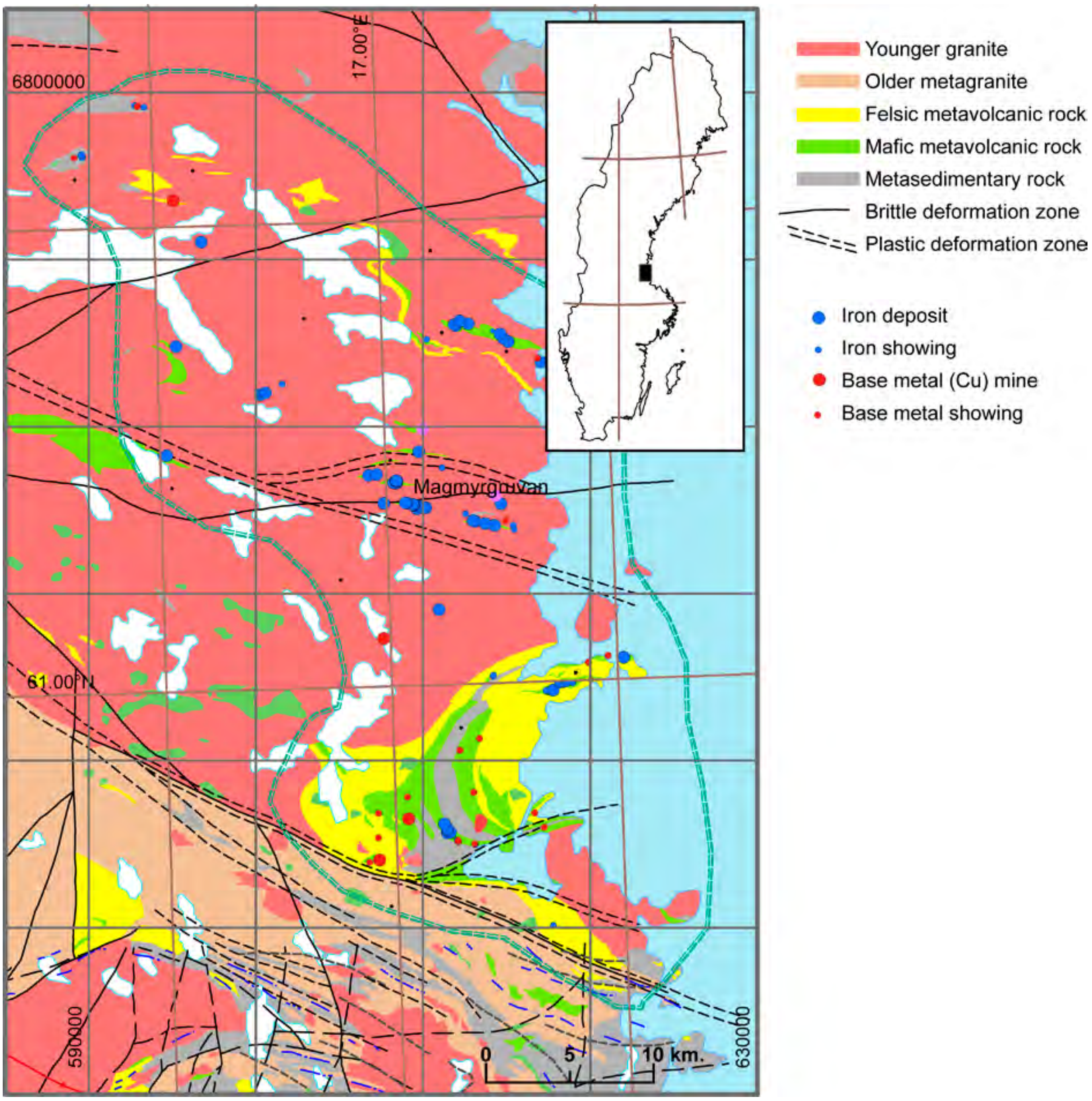


Figure 17. Geological map of the Hamrånge metallogenic area (S012), with the locations of mineral deposits from the SGU Mineral Resource database. The green dashed double line indicates the extent of the area S012. Map simplified from Wik et al. (2009).

It was, however, concluded that the occurrences were uneconomic and the project was terminated at the end of the 1980s. In recent years, several exploration companies have worked in the area, but no new discoveries have been reported.

S013 ÖVERTURINGEN–LOS Au, Zn, U

Jan-Anders Perdahl (SGU)

The Överturingen–Los area has a mixed metallogeny with epithermal Au-Cu, structurally controlled Co-Cu, massive sulphide Zn-Pb-Cu-Au, stratiform Fe oxide, and both granite- and shear zone-related U-Th occurrences.

The metallogenic area is situated within the southwestern part of the 1.97–1.87 Ga Bothnian Basin, north of the Bergslagen district (Lundqvist 1987). The Bothnian basin is dominated by metasedimentary rocks with minor intercalated metavolcanic rocks. The volcanosedimentary sequence was intruded by the 1843 Ma Ljusdal granite (Delin 1993). The rocks were strongly affected by NW- to NNW-trending shear zones of the so-called Storsjö–Edsbyn deformation zone (Mattsson & Elming 2001).

The **Enåsen** epithermal Au-Cu deposit occurs within strongly deformed upper amphibolite-facies supracrustal rocks (Nysten & Annersten 1985). The occurrence consists of disseminated chalcopyrite and gold in a topaz-bearing quartz-sillimanite gneiss, which is in turn hosted by quartz-feldspar and quartz-mica gneisses (Hallberg 1994). The deposit is interpreted as a strongly deformed and metamorphosed high-sulphidation epithermal deposit of Palaeoproterozoic age (Hallberg & Fallick 1994). Open pit mining started in 1984, in 1989 it progressed to underground operation, and the mine was closed in 1991. The total production was 1.7 Mt ore at 3 ppm Au.

The **Tjärnberget** Zn-Pb-Cu massive and disseminated sulphide deposit is bounded by a shear zone (Lundqvist et al. 1986). The massive ore is dominated by pyrite, pyrrhotite and sphalerite with galena and chalcopyrite in minor amounts. The impregnation-style mineralisation of dominantly chalcopyrite and galena is mainly found in alteration zones rich in tremolite and actinolite. The bedrock in the area comprises mafic and intermediate volcanic rocks with intercalated sedimentary or volcaniclastic rocks.

Deposits at the historic Los Co-Cu mines are structurally controlled and are defined by disseminated mineralisation in shear zones and fissure fillings within amphibolites (Tegengren 1924, Lundqvist 1968). The ore minerals are pyrrhotite, pyrite, smaltite, chalcopyrite, bismuthinite, native bismuth and rare gersdorffite. A gersdorffite sample from Los led to the discovery of nickel as an element by Cronstedt in 1751. Mining at the Los Co-Cu mines took place during the 18th century, and since the tonnage and grade are unknown, the Los deposit has not been included in the Fennoscandian Ore Deposit Database.

S014 VASSBO Pb-Zn

Anders Hallberg (SGU)

Sandstone-hosted, disseminated Pb-(Zn) deposits occur in Neoproterozic to Lower Cambrian sedimentary rocks along the eastern front of the Scandinavian Caledonides (Fig. 18). The deposits in the Vassbo area are the southernmost of this type in Sweden.

The sandstone-hosted, disseminated Pb-(Zn) ore in the Vassbo area has been mined at two deposits, **Vassbo** and **Guttusjö** (Table 9), but several minor prospects of a similar type of mineralisation are known in the area. During mining activities between 1956 and 1982, the Vassbo deposit produced 4.9 Mt of ore and the Guttusjö deposit 0.08 Mt. Pre-production grades were estimated at 6% Pb, 0.3% Zn and 20 g/t Ag at Vassbo and 3.5% Pb at Guttusjö (Tegengren 1962, Stephens et al. 1979). A third deposit in the Vassbo area for which grade and tonnage estimates are available is **Sågliden**, with about 13 Mt @ 1.6% Pb (Stephens et al. 1979). For the other sandstone-hosted Pb-Zn deposits in the area no data are available.

The mineralised sandstone at Vassbo is Lower

Cambrian in age and rests on the Precambrian basement (Tegengren 1962, Christofferson et al. 1979). It is structurally overlain by nappes formed during the Caledonian orogeny. In the Vassbo area, the basement consists of felsic volcanic rocks (ca. 1.7 Ga), sandstones of Mezoproterozoic age, and dolerites (ca. 1.2 Ga). Further to the north, the mineralised sandstones are covered by Caledonian nappes. The main Pb-(Zn) mineralisation consists of disseminated galena with minor amounts of sphalerite and is located in the upper parts of the Vassbo Formation, some tens of metres above the basement. Weaker mineralisation also exists below the main ore body but still within the Vassbo Formation, and also in the underlying basal conglomerates. Parts of the ore are richer in sphalerite. Sulphides occupy pore space in the sandstone, and thus the possible upper grade is controlled by the volume of the pore space. It has been suggested that the mineralisation took place through penetration of the sedimentary sequence by metalliferous solutions preferentially flowing along low-pressure conduits provided by the thicker sandstones. (Christofferson et al. 1979)

Table 9. Sandstone-hosted Pb-(Zn) deposits of the Laisvall-type in the Vassbo metallogenic area (S014). Data on mined tonnage and grade from the 'Official Statistics of Sweden, Metal and Mining Industries'. Resources for Sågliden from Stephens et al. (1979).

Deposit	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Pb %	Zn %
Vassbogruvan	1956–1982		4.91	20	4.6	0.3
Guttusjögruvan	1978–1981		0.08		3.5	
Sågliden		13			1.6	

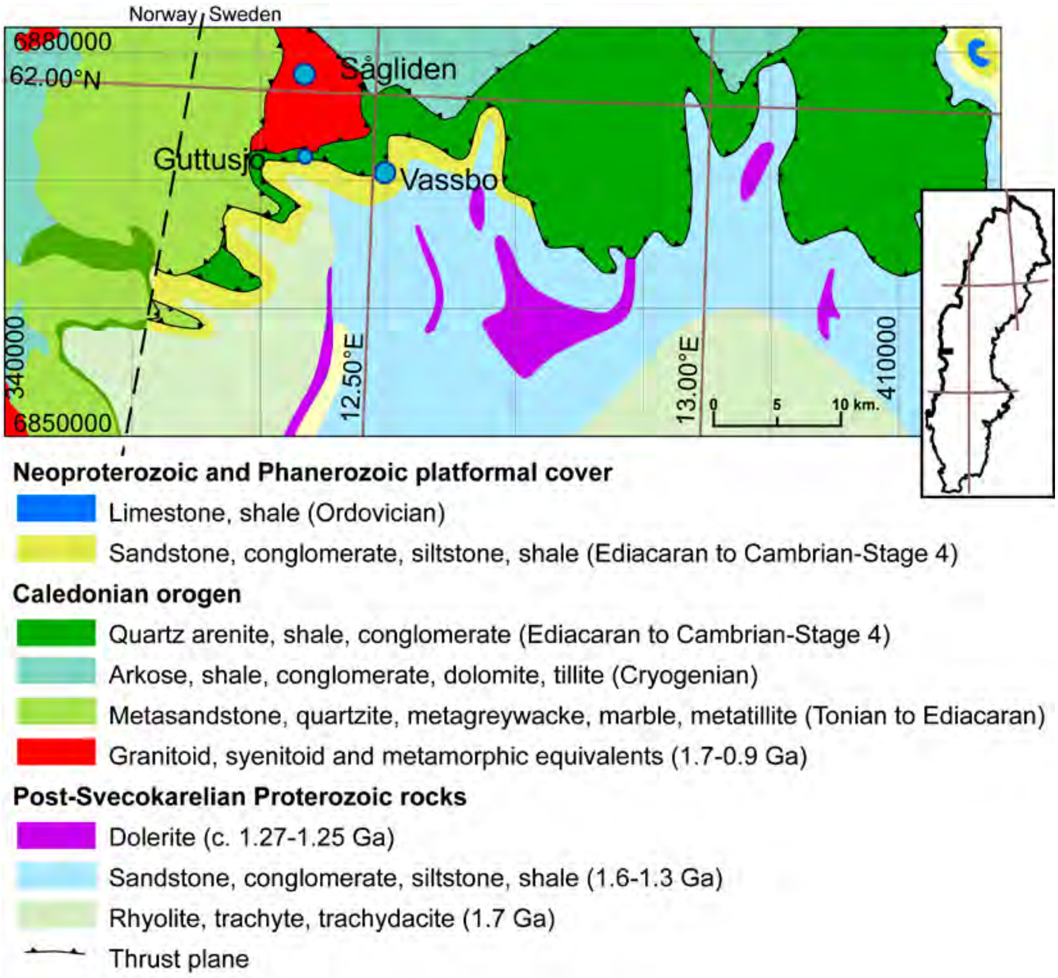


Figure 18. Geological map of the Vassbo metallogenic area (S014), with location of the three sandstone-hosted Pb-(Zn) deposits included in the Fennoscandian Ore Deposit Database. Map simplified from the SGU's Bedrock Sweden 1M 2010 (Swedish side) and Koistinen et al. (2001) (Norwegian side).

S015 DELLEN–LJUSDAL Fe-Ti-V

Anders Hallberg (SGU)

Palaeoproterozoic mafic intrusive rocks (ca. 1850 Ma) in central Sweden show Fe-Ti-V grades that are, in places, above normal for such rocks and, locally, Fe-Ti-V deposits have been formed (Table 10). Within the Dellen–Ljusdal area, several gabbro-hosted Fe-Ti-V deposits have been identified (Lundegårdh 1956, Wik et al. 2009). The metals are most likely of magmatic origin and mineralisation was broadly synchronous with the host-rock crystallisation (Lundegårdh 1956). The deposits within the Dellen–Ljusdal area were mined on a small scale for iron during the 18th and 19th centuries, but the iron produced turned out to be of poor quality and mining was terminated. It was later discovered that the deposits are V bearing. Exploration in the 1980s produced resource estimates for four of the deposits (Andersson 1982, Lindblom & Ros 1983, Wik et al. 2009). More than 60 Fe-Ti-V occurrences are known from the area, about half of which lie in now-abandoned minor workings (Wik et al. 2009).

The **Sumåssjön** V(-Fe-Ti) deposit was test-mined for iron between 1730 and 1790, and a further mining attempt was made at the end of 1870s. The high V content of the ore led to exploration activities in 1980s with extensive drilling, and the existence of an E-striking ore body with 21 Mt @ 0.223% V was documented (Andersson 1982). Vanadium is mainly bound to disseminated magnetite in medium- to fine-grained norite. The footwall consists of a granite and the hanging wall is a coarse-grained norite. The **Kramstafältet** ore field comprises at least 20 individual deposits, which host excavations from historic small-scale mining, in a mafic intrusion with a 1.5 x 0.75 km surface exposure (Wik et al. 2009). The intrusion is dominated by gabbro, but in parts it has a more noritic composition with occurrences of V- and Ti-bearing magnetite with ilmenite lamellae. The **Simesvallen** deposit is in a 35- to 70-m-wide, locally hornblende-altered, orthopyroxene-bearing gabbro (Wik et al. 2009). The main ore minerals are V-bearing magnetite and ilmenite.

Table 10. Deposits in the Dellen-Ljusdal area (S015). Resources include reserves.

Deposit	When mined	Resources (Mt)	Mined (Mt)	Fe %	Ti %	V %	References
Kramstafältet	1919–1919		0.0005				Official Statistics of Sweden, Metal and Mining Industries
Masugnsberget		1.1				0.19	Lagergren (1983)
Simesvallen		2.5			2.2	0.19	Lindblom & Persson (1993)
Sumåssjön		21		20.0	3.7	0.22	Andersson (1982)

S016 SYLARNA Cu

Anders Hallberg (SGU)

The Sylarna metallogenic area (Fig. 19) contains several small Cu occurrences (Table 11) from the Bjelke ore field (Bjelkes gruvfält) in the north to Skarvarna in the south, a distance of over 100 km. A few of the deposits (the Fröå, Bjelke and Brattvallen ore fields) were mined in the past, but their combined production was less than 60 000 t @ 0.5–1.5% Cu. Historic resource estimates for the Sylarna and Grufvålsgruvorna deposits are 3.8 Mt @ 0.72% Cu and 0.5 Mt @ 0.3% Cu, respectively. For the smaller and less well documented Grunddörrsstöten, Skarvarna and Åsvallen deposits, historic resource estimates report >50 000 t @ 1.5% Cu. (Stephens et al. 1979)

The majority of the occurrences in the Sylarna area are Cu(-Zn) deposits hosted by epidote-altered rocks (Karis & Strömberg 1998, Zachrisson & Eriksson 1981). The mineralised rocks are hosted by a metasedimentary sequence composed of mica schists, argillitic rocks and carbonate-rich arkoses, and by amphibolites. These were deposited in Neoproterozoic to Early Palaeozoic times, and today constitute a part of the Seve nappes of the Caledonian orogeny (Karis & Strömberg

1998). Detailed mapping has shown that several of the deposits are located at the same stratigraphic level in the sedimentary succession. The host rocks to the Skarvarna deposit in the south can, for example, be correlated to the Grufvålsgruvorna and the Vargtjärnsstöten deposits 45 km away from the former. The deposits in the northern part of the Sylarna area, including the

Table 11. Copper deposits in the Sylarna metallogenic area (S016). Resource includes reserves.

Deposit(s)	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Au ppm	Cu %	Pb %	Zn %	References
Fröå malmfält	1874–1919		0.054688			1.00		1.50	1
Bjelkes gruvfält	1874–1911		0.004050	5	0.1	1.52	0.01	1.37	1
Brattvallen	1876–1878		0.000300	5	0.1	0.53	0.01	0.02	1
Åsvallen		0.04		5	0.1	1.38		0.14	2
Skarvarna		0.05		5	0.1	1.58	0.01	0.08	2
Gröndörrsstöten, N		0.05		5		1.50		0.13	2
Grufvålsgruvorna		0.50				0.30			2
Sylarna		3.80				0.72			2

1 Official Statistics of Sweden, Metal and Mining industries
2 Stephens et al. (1979)

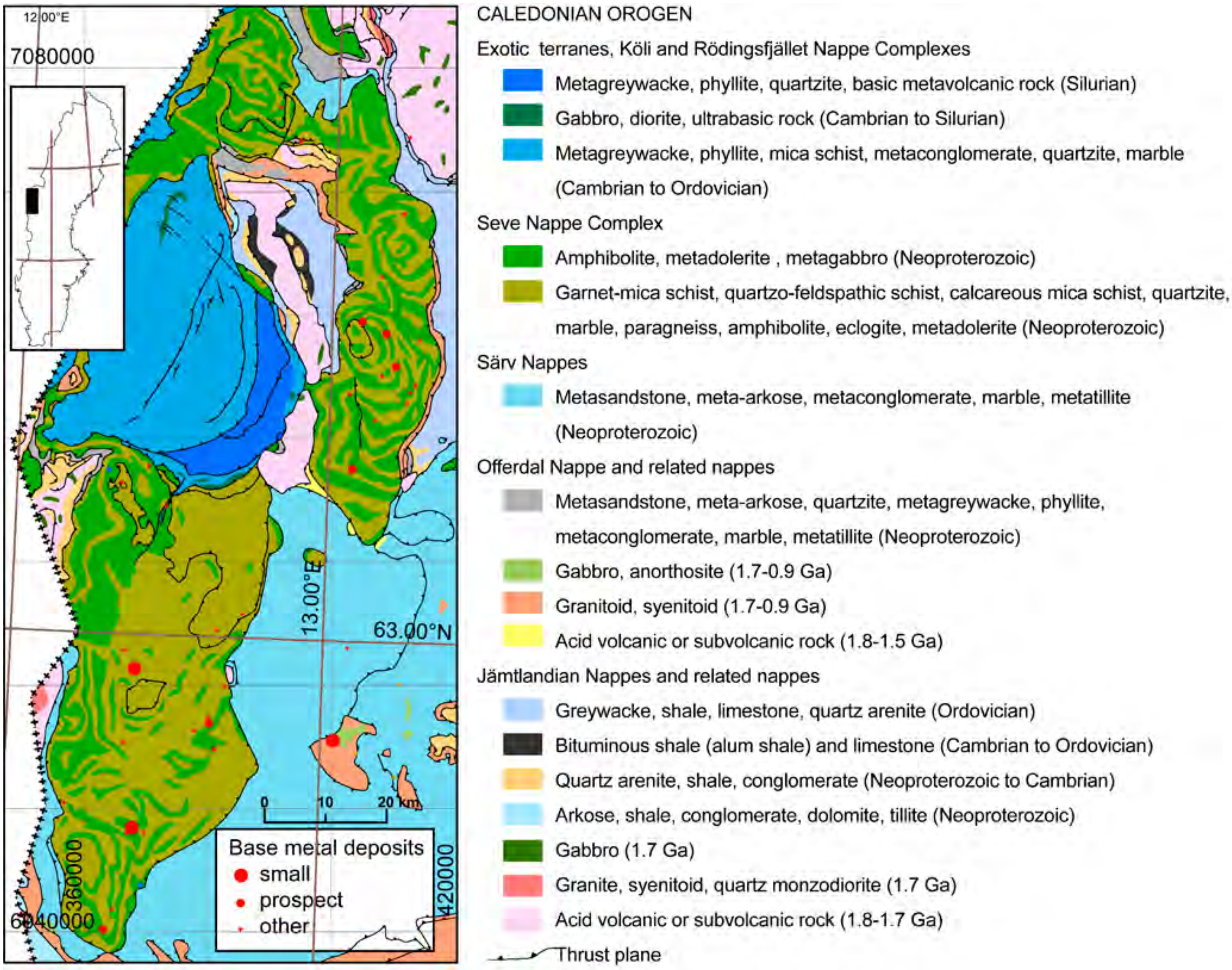


Figure 19. Geological map of the Seve thrust complex in the Scandinavian Caledonides in western Jämtland County, with the locations of copper deposits included in the Fennoscandian Ore Deposit Database. Geology from SGU's Bedrock Sweden 1M 2010.

Åsvallen, Fröå, Brattvallen and Bjelke ore fields, are interpreted as sitting at the same stratigraphic level that can be followed for 30 km along strike (Karis & Strömberg 1998).

The extremely large extent of the mineralised rocks and their setting within the sedimentary succession suggests that the Cu(-Zn) occurrences in the Sylarna area belong to the category of sediment-hosted Cu deposits. It is noteworthy that sediment-hosted Cu deposits have also been found in eastern Greenland in rocks that may once have been deposited together with the rocks in the Seve nappe during the breakup of the Rodinia supercontinent (Weihed et al. 2008, Nystuen et al. 2008). These are, in turn, broadly similar in age to the large Cu deposits of the Katanga province in Congo.

S017 CALEDONIAN BLACK SHALE U-Mo-V

Anders Hallberg (SGU)

Lower Palaeozoic U-rich sedimentary rocks once covered large parts of the Fennoscandian Shield. Today, remnants of them are found in outliers within the southern and central parts of Sweden along the margins of, and within nappes in the Caledonides, and in the Gulf of Bothnia (Andersson et al. 1985).

Within the Caledonian Black Shale area, two types of sediment-hosted U deposits occur. The mineralisation at **Myrviken** is similar in age (Middle Cambrian to Lower Ordovician) and shares characteristics with sediment-hosted U deposits elsewhere in Sweden, for example at Billingen (metallogenic area S004 Billingen) and Kinnekulle, and they are all classified as black shale deposits by the International Atomic Energy Association (IAEA). The other deposit type, exemplified by **Tåsjö**, is hosted by P-rich sandstones of Lower Ordovician age and is classified as a phosphorite type by the IAEA.

The Palaeozoic sedimentary rocks in nappes of the Caledonides and along the eastern margin of the mountain range have been explored for U in the past. Average grades in the 150- to 180-m-thick black shale are in the order of 10% organic C, 1500–1600 g/t V and 180 g/t U, whereas thinner parts may have slightly higher U and V contents together with 400–450 g/t Mo (Andersson et al. 1985). By comparison, in the phosphorite-type deposits, a 2- to 3-m-thick layer with a surface extent of more than 35 km^2 and with 200–250 g/t U and 3% P_2O_5, has been identified (Armands 1970).

The sediments of the host sequence were deposited in basins along the western margin of the Fennoscandian platform (Gee et al. 2008). These basins started to form during the initial breakup of Rodinia in the late Tonian to Cryogenian (c. 850 Ma) (Nystuen et al. 2008). The breakup led to the separation of the Fennoscandian and Laurentian Shields and the formation of the Iapetus ocean. In the Lower Ordovician period, the two continents started to converge, and in mid-Silurian to Lower Devonian times they collided. During the collision, rocks from the Proterozoic basement, the Neoproterozoic to Palaeozoic sediments and outboard oceanic volcanic terranes were thrust onto the Fennoscandian Shield, forming the present nappes (Gee et al. 2008).

Uranium mineralisation in the Tåsjö subarea (S017.1) was discovered in the mid-1950s. The area was further explored in the 1970s by the Geological Survey of Sweden and by the companies Stora Kopparberg and Boliden (Armands 1970). In an area of 500 km^2, approximately 100 holes were drilled, of which around 25 crossed the U-rich layer. Historic resource estimates for the whole field gave 40 000 t U and 6 Mt P_2O_5, of which about 1200 t of uranium and 180 000 t of P_2O_5 were considered to be covered by less than 50 m of overburden (Gustafsson 1979). The U-rich rocks at Tåsjö consist of a 3- to 10-m-thick layer of phosphatic and calcareous sandstone of Lower Ordovician age. Most of the U mineralisation is associated with apatite, which makes up 9–20% of the rocks (Gee 1972).

Palaeozoic black shales (alum shales) in the Myrviken subarea (S017.2) are broadly similar in age and composition to those in south-central Sweden, but the metamorphic grade is somewhat higher (Gee 1979). The stratigraphy consists of Lower Cambrian sandstone that passes upwards into conglomerates, commonly phosphorite-bearing, which are in turn overlain by a grey siltstone that grades into the black shales in the middle and upper (Furongian) Cambrian. Some black shales also occur in the Lower Ordovician. The black shales may be traced across the Caledonides in nappes to the Norwegian border (Gee 1979).

The geology of the black shales in the Myrviken area is well known due to extensive exploration (27 drill holes) conducted by the State Mining Property Commission (NSG) in the 1970s and early 1980s (Gustafsson 1979, Gee 1979, Andersson et al. 1985). The black shale has, on average, 10.4% organic ca. In certain 20–30-m-thick layers, the organic C content may reach 13–14% and U 200–400 g/t. Recent exploration in the area (now called Viken) report an inferred resource of 685 Mt @ 0.017% U_3O_8 (corresponding to a U content of 144 g/t), 0.03% Ni, 0.29% V_2O_5 and 0.036% MoO_3 (Continental Precious Metals 2012). The Upper Cambrian black shale was tectonically thickened by Silurian thrusting and folding from 20–30 m to approximately 180 m near the village of Myrviken.

S018 HOTAGEN U

Anders Hallberg (SGU)

The Hotagen U district lies within and adjacent to the Olden window in the Scandinavian Caledonides and carries a large number of U occurrences. The rocks in the window are dominated by Proterozoic felsic volcanic, sedimentary and granitic rocks with numerous dolerite dikes. In a few places, thin autochthonous layers of Neoproterozoic to Silurian sedimentary rocks rest on the Proterozoic basement (Stephens et al. 2005). The Proterozoic rocks were affected by Caledonian deformation, which formed major mylonite zones that divide the rocks into imbricate slices, brecciated the granites and gave them a gently doming form.

A large number of U occurrences occur throughout the rocks of the Olden window and adjacent areas, although there are two areas of particular interest, the northwestern and northeastern parts (Troeng 1982, Wilson & Åkerblom 1980, 1982). Occurrences in the northwestern area are dominated by veins crosscutting all the rocks, including the Lower Palaeozoic metasedimentary rocks. The veins postdate the Caledonian thrusting and are thus Late Silurian or younger. Occurrences in the northeastern area consist of mineralised veins and disseminated mineralisation in a fractured and altered granite. The U mineralisation consists of pitchblende, commonly associated with fluorite and galena with radiogenic Pb. An interesting feature is that all occurrences are within 100 m of dolerites and that the dolerites mostly show weak radioactive anomalies along their contacts.

At present (2011), exploration activity is ongoing at the Kläppibäcken deposit in the northeastern area, from where Mawson Resources has reported a measured and indicated resource of 1.95 Mt @ 0.077% U_3O_8 (Mawson Resources 2010).

S019 DOROTEA Pb-Zn

Anders Hallberg

Sandstone-hosted disseminated Pb-Zn deposits occur in Neoproterozoic to Lower Cambrian metasedimentary rocks along the eastern front of the Scandinavian Caledonides (Grip & Frietsch 1973). In the Dorotea metallogenic area (S019), several sandstone-hosted Pb-Zn occurrences are known, most of them minor. The two largest are **Lövstrand** and **Bellviksberg** (Chelle-Michou 2008). Historic resource estimates made by Boliden Mineral indicate that the Lövstrand deposit has 10 Mt @ 2.4% Pb and the Bellviksberg deposit 1 Mt @ 5.3% Pb + Zn and 21 g/t Ag (Grip 1978). A more recent estimate for the Bellviksberg deposit gave 1.66 Mt @ 5.35% Pb, 0.23% Zn and 21 g/t Ag (Chelle-Michou 2008). A resource estimate is also available for the Granberget deposit a few kilometres to the south of Bellviksberg: 1.73 Mt @ 3.9% Pb, 0.4% Zn and 14 g/t Ag. For the other known deposits in the Dorotea area, no resource estimates are available. None of the deposits in area S019 have yet been subject to exploitation.

In the Dorotea area, Pb-Zn mineralisation occurs within the Ström quartzite, a rock unit believed to be broadly equivalent to the rocks hosting the Laisvall mineralisation, but occurring in lower allochthone nappes of the Caledonides (Gee et al.

1978). The nappes were formed during an eastward thrusting of the Caledonian orogeny and are, in the Dorotea area, resting on alum shales that are slightly younger than the Ström quartzite. This means that the deposits were formed to the west of their present position. A minimum displacement of 40 km along the thrust has been suggested (Chelle-Michou 2008).

The nappe is tectonically disturbed and consists of several slices separated by faults. The deformation also broke the initially stratiform mineralisation into slices, making resource estimations difficult. A reconstruction of the original stratigraphy of the Ström quartzite shows a lower unit of Varangerian tillites and an upper unit of Lower Cambrian sandstones. The latter unit hosts the Pb-Zn occurrence. Comparison with undisturbed, autochthonous stratigraphies elsewhere in the Caledonides suggests that the middle Cambrian alum shale that today makes up the autochthonous basement to the Ström quartzite must have originally been deposited on top of it (Chelle-Michou 2008). In the Bellviksberg area, the main part of the mineralisation occurs in less tectonically disturbed rocks and predominantly in the coarser-grained units that are usually richer in organic matter and less compacted (Chelle-Michou 2008).

S020 BJÖRKRÅMYRAN U

Jan-Anders Perdahl

The Björkråmyran metallogenic area (Fig. 20) has been defined around the **Björkråmyran** U deposit, the largest occurrence of this mineralisation type. However, similar U deposits are found in many locations in central Sweden over an area too large to be defined as a single metallogenic area.

An airborne radiometric survey in 1982 led to the recognition of area S020 (Kullman 1985a). Several boulder trains were found and subsequent drilling resulted in the discovery of the Björkråmyran deposit. Boulder trains with similar mineralisation are found in a 100-km radius from Björkråmyran, but were not properly followed up before the U exploration programme was closed down in the early 1980s. The mineralisation at Björkråmyran is tectonically controlled, occurring within E- to SE-trending shear fractures (Kullman 1989). The host rocks are coarse porphyritic Revsund-type granite and supracrustal rocks, mainly metagreywackes. These are characterised by strong Na enrichment and are almost devoid of K. Uranium is located in a metamict U-Zr-Si-bearing compound. Other elements enriched at Björkråmyran are Nb, Y, Th, Mo, Pb and Cl. A historic ore resource estimate indicates 1.33 Mt @ 0.099% U using a cut-off of 250 g/t U (Kullman 1985b).

S021 GOLD LINE Au

Jan-Anders Perdahl (SGU)

‘The Gold Line’ was the original name of a geochemical gold anomaly detected in a regional till survey in northern Västerbotten County in the late 1980s (Lindroos 1989). Since then, several gold occurrences and large amounts of As-Au-mineralised boulders have been found in the area. Two mines have been in production: **Blaiken** Zn-Au (closed in 2007) and **Svartliden** Au, still in production. Most of the Au-deposits in the Gold Line metallogenic area are considered to be orogenic gold deposits.

The geology of the Gold Line metallogenic area (Fig. 20) consists of metasedimentary rocks and metabasalts of the Bothnian Supergroup, which was intruded by several phases of granitoids (Kathol & Weihed 2005). The metabasalts were emplaced as sills or submarine lava flows. Pillow lavas, spilites and volcanoclastic breccias are common. Granodiorites intruded at an early stage of the orogeny and were deformed together with the supracrustal rocks. Late- to post-orogenic granites (Revsund-type granites) occur as large massifs in the region.

In 2005, the Svartliden Au deposit was put

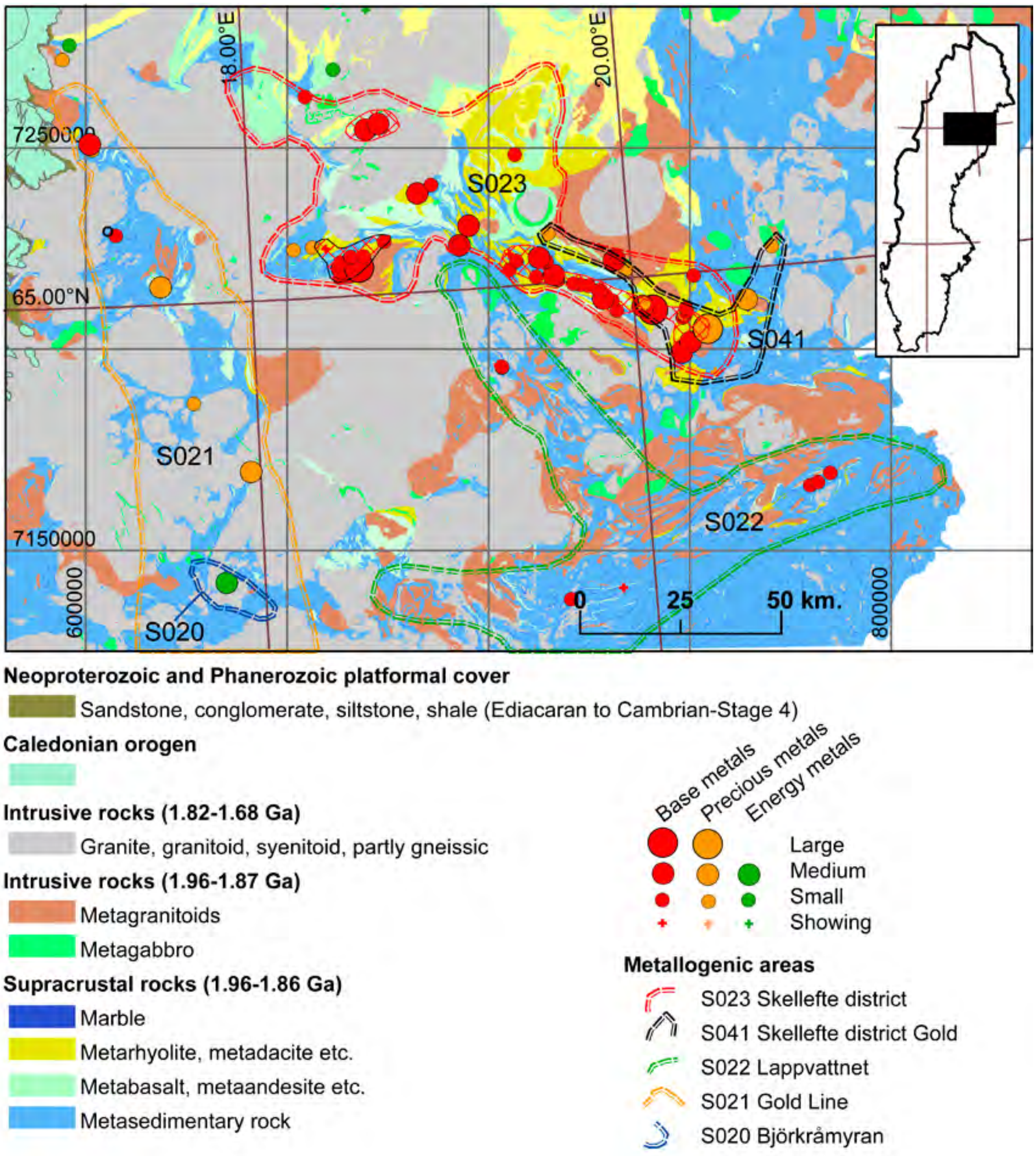


Figure 20. Geological map of north-central Sweden with the locations of metallogenic areas S020–S023 and S041, and of base-, precious- and energy-metal deposits included in the Fennoscandian Ore Deposit Database. Map simplified from Kathol & Weihed (2005).

into production. It has an annual production of around 0.3 Mt @ 4 g/t Au and has, up to March 2011, produced 251 471 oz. of gold. The deposit comprises epigenetic Au and Ag in hydrothermally altered, ductile shear zones that have been metamorphosed to mid-amphibolite facies. Minerals detected in the ore include native silver, native gold, electrum, actinolite, grunerite, diopside, amphibole, pyroxene, löllingite, arsenopyrite, native bismuth and pyrrhotite (Eklund 2007).

The mineralisation at **Fäboliden** is mainly hosted by arsenopyrite-bearing quartz veins within a roughly N-striking, steeply dipping shear zone cutting amphibolite facies volcano-sedimentary host rocks (Bark 2005, 2008). The narrow belt of supracrustal rocks is surrounded by Revsund granites. The gold is fine-grained (2–40 µm) and closely associated with arsenopyrite-löllingite and stibnite, and is found in fractures and as inclusions in the arsenopyrite-löllingite grains. Gold also occurs as free grains in the silicate matrix of the host rock.

S022 LAPPVATTNET Ni-Cu

Anders Hallberg (SGU)

The Lappvattnet metallogenic area (Fig. 20) contains at least 30 Ni deposits (Åkerman 1987, Nilsson 1985). For nine of these there is a historical resource estimate, and these deposits are found in the Fennoscandian Ore Deposit database (Table 12). One deposit (**Lappvattnet**) has been test-mined, whereas the other deposits have not been exploited in any way. The combined resources for all nine deposits are 6.37 Mt @ 0.60% Ni, 0.16% Cu and 0.02% Co.

The Ni-Cu mineralisation occurs as disseminated veinlets and massive ore hosted in metamorphosed Palaeoproterozoic mafic to ultramafic intrusive rocks (dunites, peridotites and picrites). Ore minerals include chalcopyrite, pentlandite and in places mackinawite, sphalerite, gersdorffite and sperrylite. The ultramafic intrusives occur as small bodies within metamorphosed sediments, mainly greywackes, also of Palaeoproterozoic age. Most of the mafic to ultramafic intrusives are within an east–northeast-trending, 15-km-broad and 100-km-long zone, the so-called Nickel Line (Åkerman 1987). There are also a few Ni deposits hosted by mafic to ultramafic intrusions north of the Nickel Line (Nilsson 1985). The mineralisation, together with the host rocks, has been metamorphosed and deformed, and intruded by several generations of granitites through syenitoids and gabbros (Kathol & Weihed 2005).

Table 12. Ni-Cu(-Co) deposits in the Lappvattnet metallogenic area (S022). The Lappvattnet deposit has undergone to small-scale test mining; the other deposits are unexploited. Data on tonnage and grade from Åkerman (1987). Resources include reserves.

Deposit	Resources (Mt)	Co %	Cu %	Ni %
Lappvattnet	1.00	0.02	0.21	1.00
Rörmyrberget	4.24	0.02	0.06	0.61
Mjövattnet	0.17	0.02	0.19	1.29
Njuggträskliden	0.58	0.04	0.26	0.71
Brännorna	0.35	0.02	0.04	0.63
Gårkälen	0.04	0.04	0.18	0.40

S023 SKELLEFTE DISTRICT Zn-Cu-Pb-Ag-Au

Anders Hallberg (SGU)

The Skellefte district in northern Sweden (Fig. 20) is one of the most prominent gold and base-metal districts in the Fennoscandian Shield. It is usually defined as a 140-km-long and 50-km-wide, WNW-trending, Palaeoproterozoic (1.96–1.86 Ga) magmatic region with a large number of pyritic massive sulphide deposits hosted by metavolcanic rocks (Allen et al. 1996b, Kathol & Weihed 2005, Rickard 1986). About 150 precious and base-metal deposits are known from metallogenic area S023. About 30 of these have been in production since 1924, when the first mine was opened (Boliden 2011a). Today (2011), there are four active mines. Approximately 30 additional deposits with historical mineral resources, as well as modern resource data, have not yet been exploited. The total production from the district during 1924–2009 was 105 Mt @ 2.4 g/t Au, 60 g/t Ag, 0.94% Cu, 4.6% Zn and 0.5% Pb. The remaining reserves and resources are 7.45 Mt and 25 Mt, respectively, at somewhat lower grades. This information is mainly from Boliden (2011a), and is according to the JORC code. The more significant gold deposits of the Skellefte region are described in section S041, below.

Most of the deposits are massive to semi-massive, complex pyritic Zn-Cu-Pb±Au,Ag occurrences, generally located in the upper parts of the metavolcanic sequence close to overlying metasedimentary rocks (Allen et al. 1996b). Economically important exceptions, for example the Boliden and the Kristineberg deposits, occur at lower stratigraphic levels. Low-grade porphyry Cu, one Ni and numerous sub-economical Au-As quartz vein deposits have also been reported from the district (Grip & Frietsch 1973, Weihed et al. 1992, Kathol & Weihed 2005). A selection of the larger deposits is listed in Table 13 and some of them are further described below.

Mineralised metavolcanic rocks of the metallogenic area (the Skellefte Group) are generally overlain by metasedimentary rocks. In detail, however, the stratigraphy of the supracrustal rocks is complex with large variations across and along the district (Allen et al. 1996b). The basement to the supracrustal sequences is not exposed. The supracrustal rocks were intruded by a broadly coeval intrusive suite, deformed, metamorphosed and subsequently intruded by a younger suite, the so-called Revsund granites (1.82–1.68 Ga). To the south, the Skellefte district is bordered by metasedimentary rocks belonging to the Bothnian basin. To the north, there is a less well-defined boundary against the Arvidsjaur Group, which predominantly consists of continental volcanic rocks, with minor metasedimentary and intrusive rocks (Kathol & Weihed 2005).

Base-metal and gold mineralisation at **Boliden** (subarea S023.1) occurs in massive arsenopyrite ore, massive pyrite+pyrrhotite ore, as veins and as disseminated mineralisation within intensely altered rocks below the massive sulphide ore, and in brecciated parts of the massive sulphide ore (Figs. 21–23). Ore-related hydrothermal activity forms a symmetric pattern around the ore with a central zone of intense alteration (andalusite+sericite+quartz) surrounded by less altered rocks (sericite+chlorite) that grades into a chlorite schist more distal to the ore (Nilsson 1968, Bergman Weihed et al. 1996). The massive ore, the altered rocks and the veins all crosscut the local stratigraphy. The deposit is exceptional among the Skellefte district massive sulphide deposits in terms of its extremely high Au grade (15.5 ppm), high As concentration and intense alteration. These features may suggest an alternative genesis for the deposit, and an epithermal high-sulphidation model, possibly overprinted by an orogenic gold-type event, has been suggested (Bergman Weihed et al. 1996).

The **Kristineberg** massive sulphide deposit (subarea S023.2) was discovered in 1918, making it one of the first known deposits in the Skellefte district (Du Rietz 1953). Production at Kristineberg started in 1935 and is still on-going (Fig. 24). According to official statistics, the mine has, up to 2009, produced 25 Mt @ 1.0% Cu, 3.64% Zn, 0.24% Pb, 1.24 g/t Au and 36 g/t Ag. The ore consists of two main massive sulphide zones, the A and the B ores, in addition to the Einarsson zone of Cu- and Au-rich stockwork ores with sulphide lenses in altered and deformed rocks (Årebäck et al. 2005). Ore zones are hosted by hydrothermally altered felsic to intermediate metavolcanic rocks. The deposit was formed at a lower stratigraphic level within the Skellefte Group than other deposits in area S023, including the nearby **Rävliden** and **Rävlidmyran** deposits. The mineralisation of the A and B zones is interpreted as synvolcanic massive sulphide type, whereas the Einarsson zone, within

Table 13. Larger base metal deposits in the Skellefte District metallogenic area (S023). Data are from the 'Official Statistics of Sweden, Metal and Mining Industries' and company reports. Please note that the Boliden deposit is also included in the Skellefte District Gold metallogenic area (S041). Resources include reserves.

Deposit	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Au ppm	Cu %	Pb %	Zn %	Reference
Kristineberg	1935–	8.54	25.43	48	1.2	1.1	0.3	6.1	1, 2
Renström	1948–	5.66	10.48	151	2.8	0.8	1.4	7.3	1, 2
Boliden	1926–1967	-	8.35	50	15.5	1.4	0.3	0.9	1
Storliden	2002–2008	-	1.55	30	0.3	4.0		10.0	1, 3
Rakkejaur	1934–1988	-	0.72	45	1.0	0.3	0.2	2.3	1
Långsele	1951–1991	-	11.20	25	0.9	0.6	0.3	3.9	1
Rävliden	1936–1991	-	7.54	90	0.5	1.0	0.8	4.2	1
Adakfältet	1932–1977	0.66	6.35			0.8	0.1	3.0	1, 5
Udden	1971–1990	-	5.95	39	0.8	0.5	0.3	4.8	1
Rudtjebäcken	1947–1975	1.01	4.74	10	0.3	0.9	0.1	3.0	1, 6
Petiknäs södra	1989–2007	-	5.40	102	2.4	0.9	0.9	4.9	1, 2
Maurliden Västra	2000–	2.84	2.22	49	0.9	0.2	0.4	3.4	1, 2
Långdal	1950–1999	-	4.48	160	1.9	0.1	1.7	5.7	1
Näsliden	1963–1989	-	4.03	37	1.4	1.2	0.3	2.9	1
Norrliden Norra		2.34		43	0.54	0.7	0.3	2.9	4
40 smaller deposits		13.74	6.05						

1. Official Statistics of Sweden, Metal and Mining industries
2. Boliden (2009)
3. Lundin Mining (2008)
4. Gold Ore Resources (2011)
5. Boliden Mineral Adak closure map (in the archives of the Mining Inspectorate of Sweden)
6. Boliden Mineral Rudtjebäcken closure map (in the archives of the Mining Inspectorate of Sweden)

strongly altered, andalusite-bearing rocks and rich Au-Cu dissemination, lacks clear evidence of a synvolcanic origin.

Mineralisation in the Adak subarea (S023.3) was discovered in 1930 during regional exploration conducted by the Geological Survey of Sweden (Ljung 1974). Mining started in 1934 and the last mine in the area closed in 1976. The Adak field consists of the **Adak**, **Lindsköld**, **Karlsson östra**, **Karlsson södra** and **Brännmyran** mines. In total, 6.35 Mt @ 0.80% Cu, 3% Zn, 0.1% Pb and some silver and gold were extracted between 1934 and 1976. The Rudtjebäcken deposit, a few kilometres to the east, was in operation from 1947 to 1975 and produced 2.96 Mt @ 0.92% Cu, 2.96% Zn, 0.1% Pb as well as some Au and Ag (Table 13).

Mineralisation in the Adak field consists of chalcopyrite, sphalerite, arsenopyrite, galena, pyrite and pyrrhotite, occurring as massive bodies, veins and disseminations within altered mafic to felsic metavolcanic rocks with carbonate interlayers (Ljung 1974). In addition to base metals and associated low-grade precious metals, the deposits of the Adak field contain Co-bearing pyrite and arsenopyrite. The deposits are also among the most Se-rich in the Skellefte district, and grades of In have been demonstrated.

Most of the deposits in the Adak subarea are in hydrothermally altered felsic volcanic rocks of the Skellefte Group. The altered rocks include cummingtonite-cordierite-anthophyllite microgneiss, cordierite-biotite-chlorite schist and calc-silicate assemblages (Ljung 1974). They constitute the oldest part of the area and occur in the core of a large dome structure, the Adak dome. The altered and ore-bearing rocks are overlain by less altered, mafic metavolcanic rocks of the same group. Granitoids belonging to the Adak suite separate the Adak area from the main Skellefte District (Kathol & Weihed 2005).

Figure 21. Aerial photo of the Boliden deposit, looking east. The open pit is in the centre of the photo. The waste-rock deposit at the Björkdal gold mine seen as a white area close to the horizon in the upper left side of the photo. Copyright: Boliden Mineral AB.

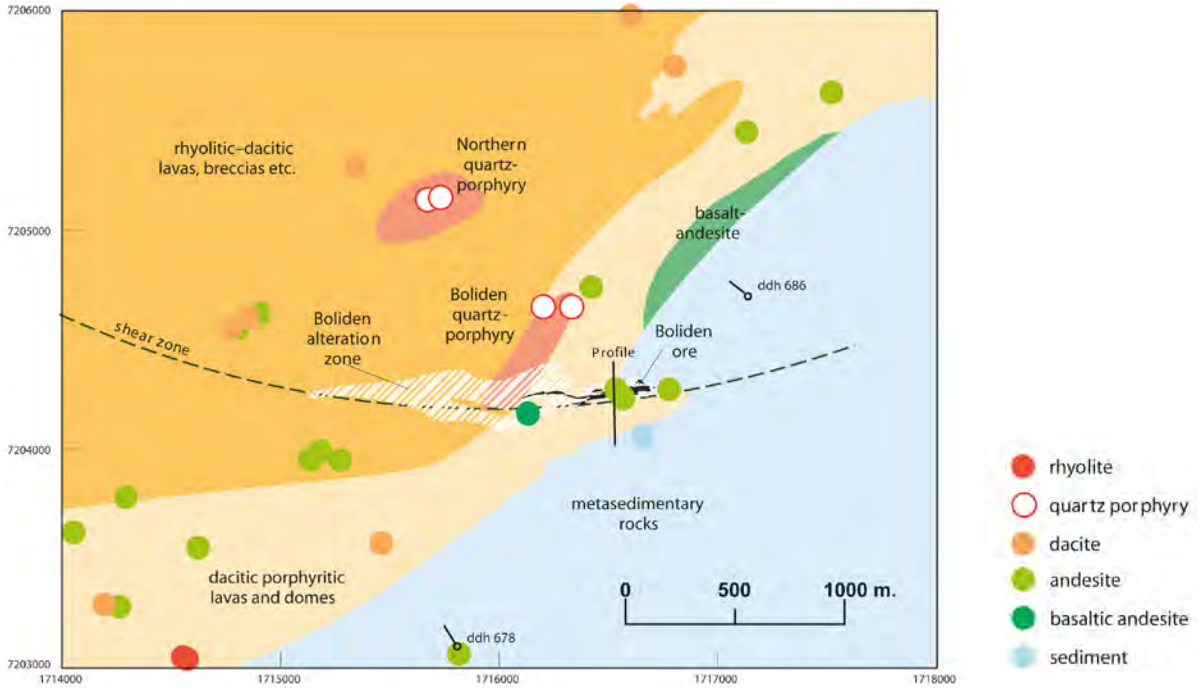


Figure 22. Geological map of the Boliden area (Hallberg 2001). 'Profile' and the short vertical black line indicate the location of the section shown in Figure 23. Coordinates in Swedish national grid RT 90. North up.

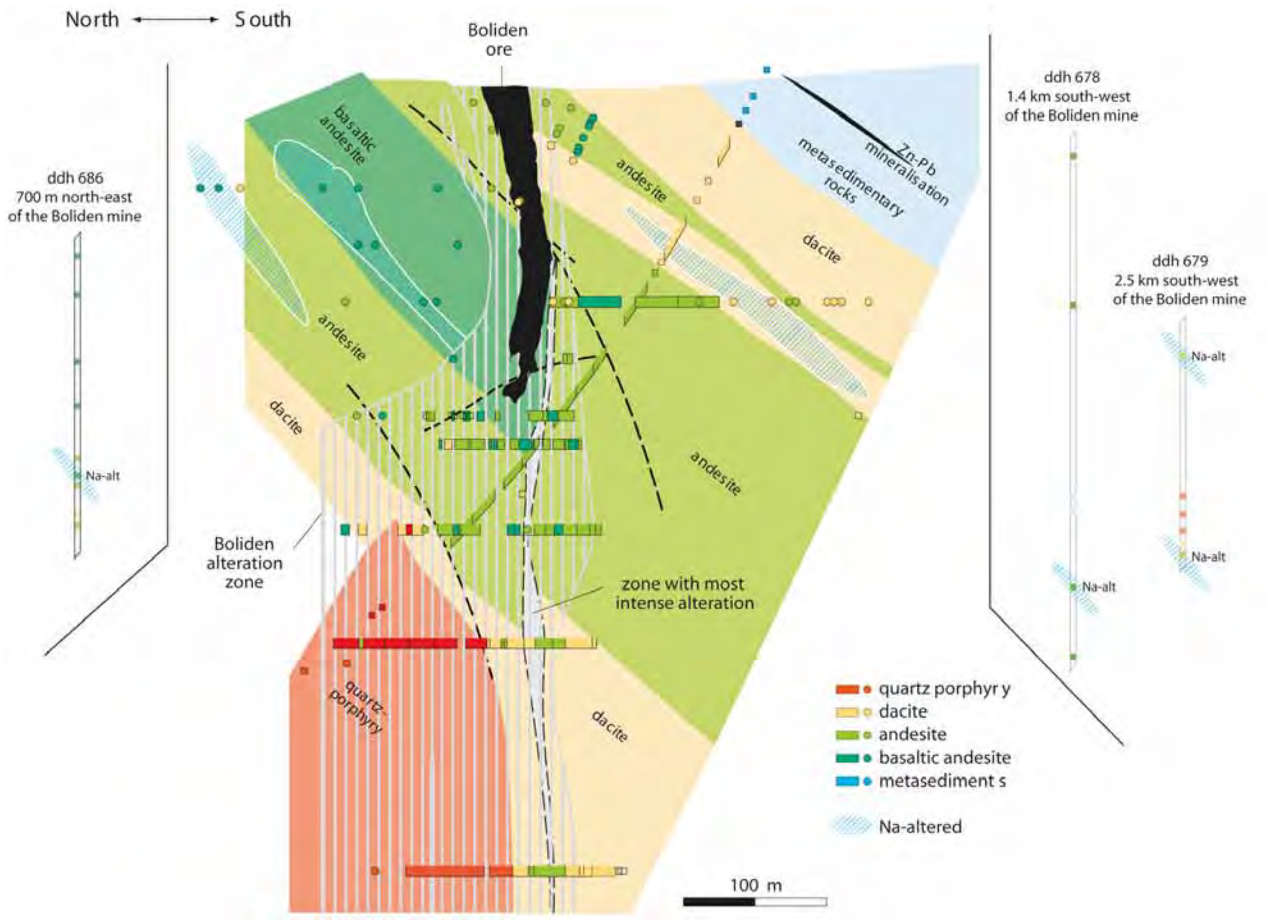


Figure 23. Vertical section across the Boliden deposit (Hallberg 2001). Modified and reinterpreted from Ödman (1941) and Bergman Weihed et al. (1996). Coloured bars and dots show the position and classified rock composition. Areas with light blue tight hatching indicate the position of rock samples that show sodic alteration. Light grey vertical hatching around and below the Boliden ore indicates a domain of variable alteration. The location of the section is shown in Figure 22.

Figure 24. Aerial photo of the Kristineberg deposit with open pits and the head frame. Copyright: Boliden Mineral AB.

S024 DOBBLON U

Anders Hallberg (SGU)

Mineralisation in the Dobblon metallogenic area represents a different and metallogenetically important type compared to other uranium mineralisations in the region. Uranium occurrences at **Dobblon** (Duobblon) are stratabound, disseminated, within a 60-m-thick, extensive ignimbrite unit characterised by numerous cavities (Lindroos 1979). The unit is composed of at least three ash flows showing varying degrees of welding and having intercalated conglomerates. The mineralised ignimbrite unit rests on basal breccias on top of a granite of the Revsund type. Overlying the ignimbrite is red-bed type tuffaceous sandstone and polymict conglomerates, which are in turn capped by rhyolitic metavolcanic rocks dated at 1800 Ma (Skiöld 1988).

Rich U mineralisation is found in lithophysae-bearing ignimbrite in several 2000-m-long and 1- to 25-m-thick horizons (Smellie 1982). There is a tendency for higher grades down-dip, suggesting a rolling front enrichment due to leaching and deposition of U. Mineralisation consists of disseminated fine-grained pitchblende and complex uranotitanates associated with Fe-Ti-Mn oxides. Minor amounts of U also occur in primary minerals such as titanite, apatite and zircon. Reported grades are on average 200–300 g/t U (Lindroos 1979). Basal breccias underlying the ignimbrite also carry some U in fracture fillings. Preliminary estimates produced during exploration in the 1970s indicate about 4000 t of U in ores with 300 g/t (Lindroos 1979). A recent evaluation of the inferred resources suggests 13.8 Mt @ 0.03% U_3O_8, and thus largely confirms the older data (Mawson Resources 2011). Several other uranium occurrences have been found in the area.

S025 LAISVALL Pb-Zn-Ag

Anders Hallberg (SGU)

Sandstone-hosted, disseminated, lead-zinc mineralisation occurs in Neoproterozic to Lower Cambrian metasedimentary rocks along the eastern front of the Scandinavian Caledonides (Fig. 25, Table 14). The largest and best-described of them is **Laisvall** (Rickard et al. 1979), wherefrom nearly 65 Mt @ 4.6% Pb, 0.6% Zn and some Ag was extracted during 1943–2001. Two similar, unexploited Pb-Zn deposits have been identified in the vicinity of Laisvall. They are **Maiva**, with about 1 Mt of ore, 7 km to the northeast of Laisvall, and **Niepsurt** with 1.75 Mt of ore located less than 10 km to the south (Lilljequist 1973). Within the Laisvall area, there are another 15 known sandstone-hosted Pb-Zn deposits (Grip & Frietsch 1973).

The mineralisation at Laisvall consists of stratabound galena and sphalerite filling the pore space in the sandstones (Rickard et al. 1979, Casanova 2010). Gangue minerals that are interpreted to be associated with the mineralisation event include calcite, barite and fluorite. The mineralised rocks belong to the Såvvovare Formation (together with the Akkerselet Fm., the Såvvovare Fm. forms the previously used Laisvall Fm., see Fig. 25) with the most intense mineralisation in the Lower sandstone (Kautsky Member), whereas less intense mineralisation occurs in the Upper sandstone or Nadok Member. In addition, there is minor mineralisation in sandstones of the Neoproterozoic Ackerselet Formation (Casanova 2010).

The autochthonous sedimentary sequence at Laisvall rests unconformably on a weathered surface of Palaeoproterozoic (1.87–1.66 Ga) granitoids to syenites. The lowest part of the sedimentary sequence consists of conglomerates, whereas the top of the sequence consists of alum shale. The Neoproterozoic and younger sedimentary successions hosting the Pb-Zn occurrences of Laisvall type were formed during crustal extension and formation of sedimentary basins along the margins of continental Baltica (Gee et al. 2008). During the subsequent collision between Baltica and Laurentia in the Silurian, parts of these successions were thrust eastwards onto Baltica, forming nappes.

Table 14. Sandstone-hosted Pb-(Zn) deposits in the Laisvall metallogenic area (S025). Resources include reserves.

Deposit	When mined	Resources (Mt)	Mined (Mt)	Ag ppm	Pb %	Zn %	Reference
Laisvall	1943–2001	-	64.49	11	3.8	0.3	Official Statistics of Sweden, Metal and Mining Industries
Maiva		1.00		10	5.1	0.1	Grip & Frietsch (1973)
Niepsurt		1.75		8	3.2	0.3	Mineral deposit register

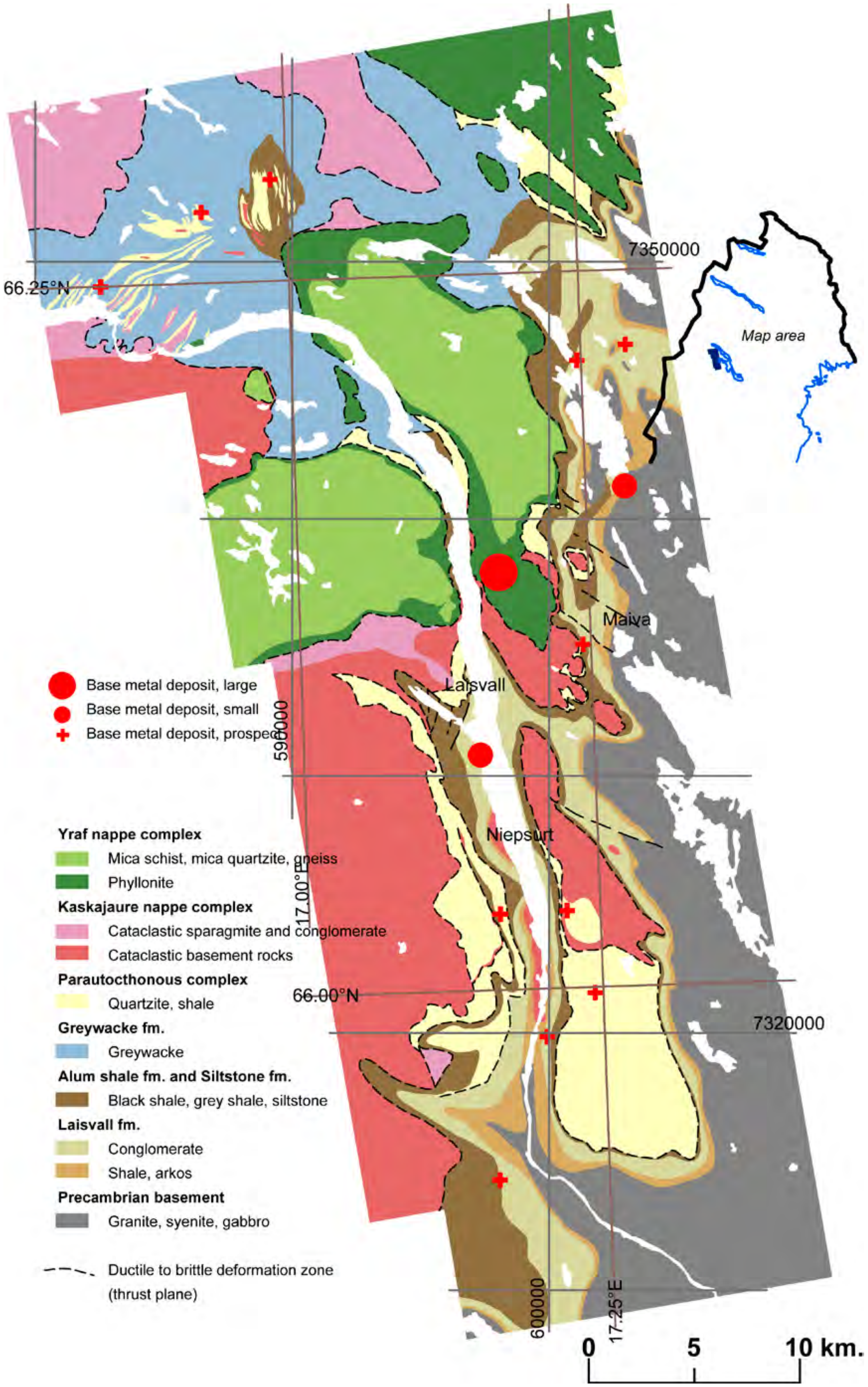


Figure 25. Geological map of the southern part of the Laisvall metallogenic area (S025). The map shows the major sandstone-hosted Pb-(Zn) deposits included in the Fennoscandian Ore Deposit Database, as well as smaller deposits of the same type from SGU's Mineral Resource Database. The map has been digitised from Lilljequist (1973).

S026 ARJEPLOG–ARVIDSJAUR U

Jan-Anders Perdahl

Mineralisation in the Arjeplog–Arvidsjaur metallogenic area is epigenetic and took place during peak Svecokarelian metamorphism at ca. 1.75 Ga (Öhlander 1986a). It is associated with Na metasomatism, and occurs in the Arvidsjaur area in 'episyenites' and at Arjeplog in metavolcanic rocks.

The largest of the deposits is **Pleutajokk**, which was test-mined between 1980 and 1981. The bedrock at Pleutajokk consists of a sequence of rhyolitic metavolcanic rocks (Gustafsson 1981). Post-volcanic, deep-seated faults were generated, some of which controlled the emplacement of dolerite intrusions. These lithologies were subsequently intruded by granites accompanied by numerous pegmatites. The granites and the pegmatites are, like the older rhyolites, anomalously rich in U and Th. Uranium minerals occur in fractures confined to elongated structures. Alteration at Pleutajokk also resulted in Na enrichment, whereas K (and to some extent Si) was depleted.

At **Skuppesavon**, mineralisation occurs in felsic volcanic rocks which were partly Na altered and, in places, contain notable amounts of calc-silicate minerals (Smellie & Laurikko 1984). The volcanic rocks were intruded by mafic dykes. Uranium mineralisation occurs partly as impregnation and partly as fracture fillings.

A U enrichment at **Björklund** occurs as disseminated uraninite together with fracture and fissure infilling mineralisation in leucocratic (Storavan) granite (Öhlander 1986a). An initial pervasive metasomatic phase, the extent of which was controlled by local structural weaknesses and variations in rock permeability, is characterised by enrichment of Na and Ca coupled with depletion of K (episyenitisation). Oxidising uraniferous hydrothermal solutions later penetrated along zones of weakness previously opened by the Ca- and Na-rich fluids.

S027 RADNEJAUR–MOSKOSEL Cu-Au-Zn-Pb-Ag

Jan-Anders Perdahl

The Radnejaur–Moskosel metallogenic area is divided into the eastern Moskosel part, where the only deposit that has been subject to mining (Laver) occurs, and the western Radnejaur part from which some smaller copper occurrences and numerous copper-rich boulders are known.

The Moskosel part is characterised by large volumes of intermediate to felsic metavolcanic rocks, which represent the lower part of the Arvidsjaur volcanic sequence resting on metasedimentary rocks. The **Laver** Cu-Ag-(Zn) deposit is of vein and breccia style, which cut the host rock in various directions forming an irregular network (Ödman 1943). Disseminated ore is common between the veinlets. Chalcopyrite and pyrrhotite are the dominant ore minerals, and high concentrations of sphalerite may be observed in places. In certain portions of the ore bodies, concentrations of arsenopyrite are also observed. Chlorite and biotite alteration are common, whereas minor amounts of garnet, epidote, gahnite and tourmaline are less frequent. The Laver deposit was in production between 1934 and 1946.

The mineral potential of the Radnejaur part was discovered in the 1950s when road construction led to the discovery of Cu-rich boulders. More than a thousand boulders have been recorded, but only minor occurrences have been found in outcrops so far. The largest base-metal deposit is **Lulepotten** which, according to Beowulf Mining (2011), has an inferred resource of 5.4 Mt @ 0.8% Cu and 0.3 g/t Au. The mineralisation is tectonically controlled and occurs as impregnation in mafic to intermediate volcanic rocks following the schistosity, and as joint fill in the granite (Grip 1978). The main ore minerals are chalcopyrite and bornite, with lesser amounts of chalcocite and hematite. Magnetite is fairly abundant and causes a marked magnetic anomaly at the site. The main gangue minerals are quartz and carbonates, with minor amounts of tourmaline and fluorite (Grip 1978). Several boulder trains have been found, indicating the presence of breccia style Cu-Zn-Pb and calc-silicate-hosted Zn-Pb deposits. Only narrow mineralised zones have, however, been intersected by drilling (Padget et al. 1969, Walser 1980).

The **Jerfojaur** Ti deposit consists of several lenses of titaniferous iron ore (magnetite and ilmenite), which occur in the eastern part of a gabbroic massif with an age of 1880 to 1860 Ma. The mineralised lenses are up to 35 m wide. Reserves have been estimated at about 6 Mt @ 15–20% Fe and 5–7% TiO_2 (Grip 1978). Another intrusion-related mineralisation is the molybdenite occurrence at **Kåtaberget**, which was discovered by a private prospector in 1970. The mineralised aplite is relatively coarse grained and grades without sharp contacts into a coarse-grained grey granite. The molybdenite occurs as irregularly distributed coarse aggregates over a large area, but the overall average grade is low. Fluorite is common and small quantities of pyrite and chalcopyrite are present (Öhlander 1986b).

S028 RAPPEN–ULTEVIS Mo, Cu, Au

Jan-Anders Perdahl (SGU)

The Rappen–Ultevis metallogenic area is one of the most polymetallic districts in Sweden, with several known Mn, Fe-Mn, Cu, Zn, Pb, Mo, Au, Ag, W and a few Be and Sn deposits. Uranium deposits occurring within the Rappen–Ultevis region are described in section S0026, above. Area S028 is poorly documented due to limited exploration and mapping. Information on grades and tonnage of the deposits is generally missing, and only few of the deposits are therefore included in the Fennoscandian Ore Deposit Database. Geologically, the Rappen–Ultevis area is characterised by a volcanic sequence (1880 to 1860 Ma in age) resting on older metasedimentary rocks. The volcanic period was followed by large-scale rifting and the formation of sediment-filled basins at around 1850 Ma. The area was later intruded by several generations of granites.

In the southern part of area S028, within the so-called Arjeplog district, there are several Fe-Mn-bearing skarn iron deposits. From south to north, these include the **Sakka**, **Skomern**, **Rebak**, **Rappen** and **Hejka** (Frietsch 1969). Stratiform manganiferous iron ores consist of magnetite-rich bands alternating with calc-silicate layers. The dominant ore mineral is magnetite, but minor amounts of hematite also occur. Common calc-silicate minerals are garnet, tremolite-actinolite and epidote. Average grades of the deposits are 26% Fe, 0.4–7% Mn and 0.03% P (Frietsch 1969).

In the northern part of the area, within the Ultevis district, there are several stratiform Mn-(Fe) deposits hosted by felsic to intermediate metavolcanic rocks and, occasionally, by metasedimentary rocks (Quezada 1979). The Ultevis district also hosts Zn, Pb, W, U, barite and fluorite occurrences, mainly in tuffaceous sedimentary units (Quezada 1979).

At **Björntjärn**, **Allebuoda Lilla** and **Maldok**, several disseminated molybdenite occurrences have been found in granites, aplites and tuffaceous rocks, as well as scheelite in calc-silicate rocks (Hill 1981, 1984, Öhlander 1986b). The Björntjärn (Allebuoda Stora) deposit is bound by a 10-m-wide and approximately 250-m-long aplitic dike. The footwall rock consists of a 5-m-wide greenstone. A resource calculation in 1981 gave an inferred reserve of 1.8 Mt @ 0.12% Mo (Hill 1981). More Mo mineralisation has been detected at **Skarjaviken** (Walser & Einarsson 1982).

Galena-sphalerite-chalcopyrite-pyrite occurrences, associated with fluorite, have been found at **Askelluokta** and **Kiuri** (Carlon 1984). At Kiuri, an Ag deposit was mined for a short period during the early 18th century.

S029 VAIKIJAUR Cu, Mo, Au

Anders Hallberg

Several disseminated, intrusive-hosted Cu-Au-Fe oxide occurrences were found during regional exploration in the southern part of Norrbotten County in the 1960s (Sundbergh & Niva 1981). Occurrences with grades of up to 2.5% Cu and 1–2 g/t Au over many metres were intersected by diamond drilling. However, due to the limited extent of the exploration and drilling, proper ore resource estimates could not be made on them.

Two of the most intensely explored occurrences are **Vaikijaur** and Iekelvare (Weihed 2001). The Vaikijaur occurrence is hosted by a granite

(Weihed 2001, Lundmark 1983). The mineralisation partly consists of pyrite and partly of high-magnetic zones with magnetite, pyrite, chalcopyrite and some molybdenite. In places, it is associated with a quartz-sulphide stockwork. The high-magnetic zones carry the highest grades of Cu and Au, with maxima at 5% Cu and 7 g/t Au over one-metre intercepts. Mineralisation is associated with potassic alteration (K feldspar + biotite) overprinted by irregular propylitic and phyllic alteration zones (Lundmark 2003). The hosting Jokkmokk granitoid has been dated at 1880 Ma, and Re-Os dating of molybdenite indicates an age of mineralisation between 1890 and 1870 Ma (Lundmark et al. 2005). At least two generations of mafic dykes and pegmatites intruded the host rock. Vaikijaur is interpreted as a porphyry-style deposit (Lundmark 2003).

At **Iekelvare**, the mineralisation is associated with a foliated diorite intruding a granite (Weihed 2001) and largely occurs as scattered veinlets of chalcopyrite and pyrite. Accessory minerals include sphalerite, galena and molybdenite. There is magnetite throughout the deposit. In more intensely mineralised parts, the host rocks are visibly bleached due to alteration. Two small Mo occurrences in the area, **Maddåive** (Einarsson & Minell 1984) and **Druggegruvan** (Theolin 1962), were mined during the 1940s producing a limited amount of ore.

S030 KALLAK Fe, Mn, Cu, Au

Anders Hallberg

The Kallak area hosts several iron deposits (Table 15), none of which have been exploited (Frietsch 1997). The combined ore resources for six of the deposits down to 225 m, calculated from gravimetric and ground-magnetometric survey, are 189 Mt @ 30–38% Fe (Johansson 1980, Frietsch 1997). A limited number of drill cores, 7 driven in 1948 and an additional 6 in the early 1970s, show that the iron ore consist of magnetite with subordinate amounts of hematite and that it contains Mn (0.47%) and traces of chalcopyrite (Eriksson 1983, Frietsch 1997). None of the cores go deeper than 200 m, and the sulphide mineralisation has not been further investigated (Frietsch 1997).

At **Kallak**, the best-known deposit in the area, magnetite and hematite occur interlayered with quartz and feldspar with accessory hornblende, diopside and chlorite in a 1-km-long and up to 300-m-wide zone (Eriksson 1983). Magnetite is the dominant Fe oxide. The host rock is garnet and epidote skarn, but there are no sharp boundaries between the ore and the host (Grip & Frietsch 1973). The Fe-mineralised zone is in felsic to intermediate metavolcanic rocks believed to be 1.88–1.86 Ga in age, although there are no modern isotope dates for the rocks to confirm this age. The rocks have been deformed and metamorphosed to banded gneisses. The supracrustals were intruded by several generations of both mafic and felsic intrusive rocks. The Fe occurrences in the Kallak area have been interpreted as quartz-banded iron ores (Proterozoic banded iron formation) by Frietsch (1997).

Table 15. Ore tonnage estimated from geophysical survey of iron deposits in the Kallak metallogenic area (S030). All data are from Johansson (1980) and Frietsch (1997). Resources include reserves.

Deposit	Resources (Mt)	Fe %	Mn %	Ti %
Åkosjägge	75.00	30.0		
Kallak	50.00	38.5	0.4	0.1
Kallak Södra	23.00	30.0	0.2	
Akkihaure	12.00	30*		
Parkijaure	23.00	38.5		
Parkijaure Södra	6.00	35.0		

* Estimated Fe grade

S031 BODEN Au, Ag, Cu

Anders Hallberg

The sharp rise in gold prices in the late 1970s initiated exploration for gold in Sweden as well as in the rest of the world. Due to the known presence of arsenopyrite-bearing boulders and outcrops in the area, and after evaluation by the Swedish State Mining Property Commission (NSG) of available data, the Boden area was selected as one of several promising areas for gold exploration (Lilljequist 1981, Carlson et al. 1983). Exploration in the early 1980s identified a number of Au-As-mineralised targets and several were drilled in the mid-1980s (Lundmark 1984, 1985). However, the results were poor, and shortly after the first drilling campaigns all exploration in the area by the NSG was terminated. At the beginning of 1990, the area was included in a regional till-geochemical survey. The results of this project confirmed that the area does show positive Au anomalies. A few years later, all government-funded exploration in Sweden ended, and very little exploration has since been carried out in the area. The gold-bearing boulders and the Au anomalous till still remain to be explained.

S032 GÄLLIVARE–MALMBERGET Fe

Julio Gonzalez and Anders Hallberg (SGU)

The Gällivare–Malmberget metallogenic area contains the second largest iron deposit in Sweden, **Malmberget**, as well as several smaller deposits (Figs. 26 and 27). All of the deposits in the area are apatite-iron ores (Bergman et al. 2001, Grip & Frietsch 1973, Geijer 1930).

The iron deposits are hosted by metamorphosed and deformed felsic metavolcanic rocks with an age of 1960–1860 Ma (Bergman et al. 2001, Witschard 1996). The rocks are broadly similar in age and composition to those hosting the Kiruna iron deposit (subarea S035.1). Lens-shaped mafic rock enclaves that are found close to the iron ores are believed to be metamorphosed and deformed dykes, sills and extrusives. The felsic metavolcanic host rocks were later intruded by Lina granites with an age of 1830–1750 Ma (Bergman et al. 2001, Witschard 1996). Numerous smaller granite bodies also crosscut the iron mineralisation. Felsic metavolcanic rocks hosting the iron deposits are commonly rich in K feldspar, whereas albite-rich rocks occur locally as hosts to ore. Mafic rocks affected by alteration are usually biotite- and scapolite-rich (Bergman et al. 2001). Geijer (1930) described another alteration assemblage in the footwall to the mineralisation with sillimanite, muscovite and quartz. Deposits in the Malmberget area have, together with the host felsic metavolcanic rocks, mafic rocks and younger granite-pegmatite dikes, been strongly affected by ductile deformation forming the present shape of the deposits. Several ore lenses are boudinaged in the plunge direction (Geijer 1930). The fact that younger dikes, believed to belong to the younger granite-pegmatite association, are likewise deformed suggests that deformation took place after ca. 1800 Ma (Bergman et al. 2001).

Most of the deposits within the Gällivare–Malmberget area occur in the Malmberget ore field, which consists of several iron ore bodies. In the western and northern part of the Malmberget ore field, the ore forms an almost continuous horizon, whereas the eastern part it is made up of several isolated lenses of iron ore. The western and northern parts of the deposit consist of magnetite and hematite, and commonly show apatite banding. Mineralisation in the eastern part is magnetite dominated and not as rich in apatite. Apatite, amphibole, pyroxene and biotite form the gangue in the ore, and pyrite, chalcopyrite, bornite, and molybdenite can be found locally as accessory phases.

The deposits in the Malmberget area were probably known by the 17th century, but it was not until technical development (the Thomas process for treating P-rich iron ore) and infrastructure, in the form of railway to Luleå, that large-scale iron ore production commenced. From 1885 to 1905 the production of lump ore increased from less than 100 tons/year to 1 million tons/year. The total tonnage of the Malmberget deposit (production, reserves and resources) is estimated at 930 Mt @ 51.1% Fe and 0.5% P. By the end of 2009, about 510 Mt of ore had been produced.

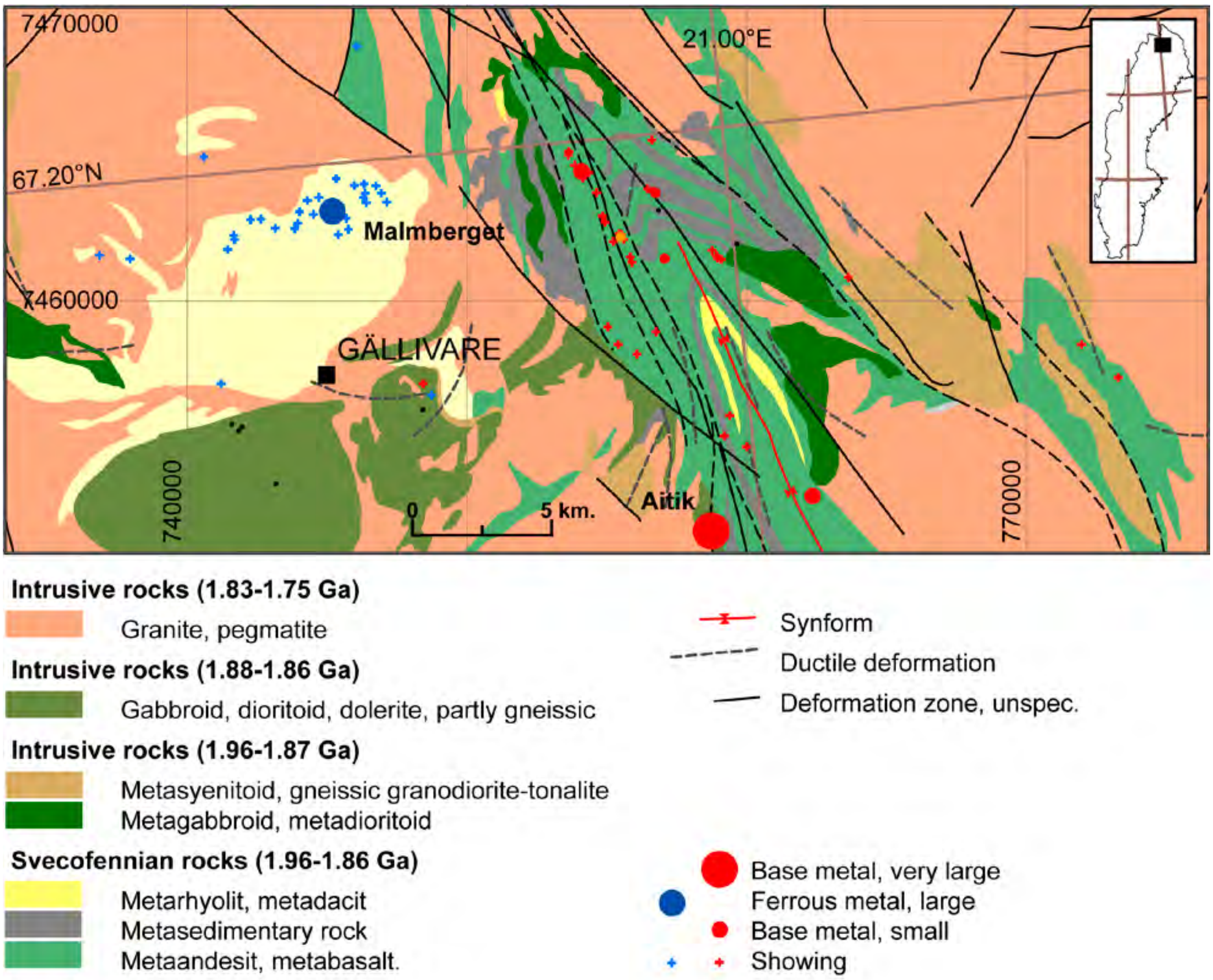


Figure 26. Geological map of the Gällivare area with the locations of deposits included in the Fennoscandian Ore Deposit Database and also smaller occurrences from SGU's Mineral Deposit Database. Simplified from Bergman et al. (2001). The grids shown are SWEREF-99 and Latitude-Longitude.

Figure 27. Aerial photo of 'Kaptensgropen' at Malmberget, looking north. Kaptensgropen is the abandoned open pit of the Kaptensgruvan mine. Below the Kaptensgruvan open pit are the Kapten and Fabian ore bodies, where mining currently takes place at a depth of 855 m below the surface. Head frames in the photograph serve other ore bodies of the Malmberget deposit. Copyright: LKAB.

S033 AITIK–NAUTANEN Cu-Au

Anders Hallberg (SGU)

From a modest production of less than 1 Mt during 1968, the first year of operation, the **Aitik** Cu-Au-Ag deposit (Figs. 26 and 28) will in a few years have increased its annual production from the present 18 Mt to 36 Mt. The accumulated production by the end of 2009 was 502 Mt @ 0.4% Cu, 0.2 g/t Au and 4 g/t Ag. Reported reserves and resources stand at 733 Mt @ 0.25% Cu, 0.14 g/t Au, 1.6 g/t Ag and 30 g/t Mo, and 1717 Mt @ 0.19% Cu, 0.11 g/t Au, 1.03 g/t Ag and 24 g/t Mo respectively (Boliden 2011a).

The main ore at Aitik is hosted by a biotite-sericite schist or gneiss and amphibole-biotite gneiss (Zweifel 1976, Monro 1988). The precursor to the altered, metamorphosed and deformed host rock is not clear, but it is believed to be a Svecofennian volcaniclastic rock belonging to the Porphyrite Group (Bergman et al. 2001, Wanhainen & Martinsson 1999). The mineralisation consists of veinlet and disseminated chalcopyrite, pyrite, pyrrhotite and magnetite in hydrothermally altered, metamorphosed and strongly deformed rocks. Accessory minerals include bornite, chalcocite, malachite, molybdenite, sphalerite, galena, arsenopyrite, scheelite and uraninite.

In the footwall, there is a deformed subvolcanic intrusion of quartz monzodiorite, with sub-economic Cu grades, dated at 1873 ± 24 Ma (Witschard 1996) and 1887 ± 8 Ma (Wanhainen et al. 2006). The intrusion and the volcaniclastic rocks were affected by ore-related potassic alteration. Aitik is interpreted as a Palaeoproterozoic porphyry Cu deposit formed at ca. 1890 Ma and overprinted by an iron oxide mineralisation some 100 million years later (Wanhainen 2005).

A deposit similar to Aitik with respect to the style of mineralisation, grades and host rocks, but of much smaller size, is at **Liikavaara East**, less than 4 km to the ENE of Aitik (Zweifel 1976). Further to the north, in the so-called Nautanen trend, several small Cu occurrences are found, including **Nautanen**, **Ferrum**, **Fridhem** and **Liikavaara** (Bergman et al. 2001). They occur as disseminated, veinlet and locally massive lenses and veins of chalcopyrite (± magnetite) hosted by deformed supracrustal rocks with an age of ca. 1900 Ma.

Figure 28. Aerial photo looking north showing the Aitik open pit. Copyright: Boliden Mineral AB.

S034 PAJALA–KOLARI Fe, Cu Au

Jan-Anders Perdahl (SGU), Anders Hallberg (SGU), Tero Niiranen (GTK), Pasi Eilu (GTK)

The metallogenic area S034 is defined by the presence of skarn-hosted iron oxide occurrences with minor copper and gold within the N-S trending Baltic–Bothnian Megashear (BBM, Berthelsen & Marker 1986). The area covers large parts of the Pajala and Kolari municipalities, in the west (Sweden) and east (Finland) respectively, along the international border in Lapland. In Lapland the BBM is also known by the name Pajala Shear Zone (PSZ). To the east and west, area S034 is bound by the outer margins of the shear and fault zone array defining the PSZ. To the north and south the metallogenic area extends as far as indications of skarn-hosted Fe (± Cu-Au) mineralisation have, so far, been detected (Fig. 29).

The supracrustal rocks of the Pajala–Kolari area consist of the 2.44–2.05 Ga Karelian sequence of rift-related tholeiitic meta-volcanic rocks and associated mica schists, quartzites, graphitic schists, and dolomitic marbles, and of the 1.89–1.77 Ga Svecofennian sequence of molasse-type quartzites, conglomerates and mica schists (Hiltunen 1982, Bergman et al. 2001, Väänänen & Lehtonen 2001, Niiranen et al. 2007). In western part of the area (Pajala), the Svecofennian sequence also contains felsic volcanic units similar to the Porphyrite Group in the Kiruna area. In Sweden, the oldest rocks of area S034 are believed to be meta-arenites in the easternmost part of the Pajala area, close to the Finnish border, which have been suggested to belong to the Kovo Group (2.4–2.3 Ga). The rest of the Karelian sequence in Sweden belongs to the Greenstone Group (2.3–1.96 Ga), which corresponds to the uppermost Kuusamo Group and the Savukoski and Sodankylä groups in northern Finland. The

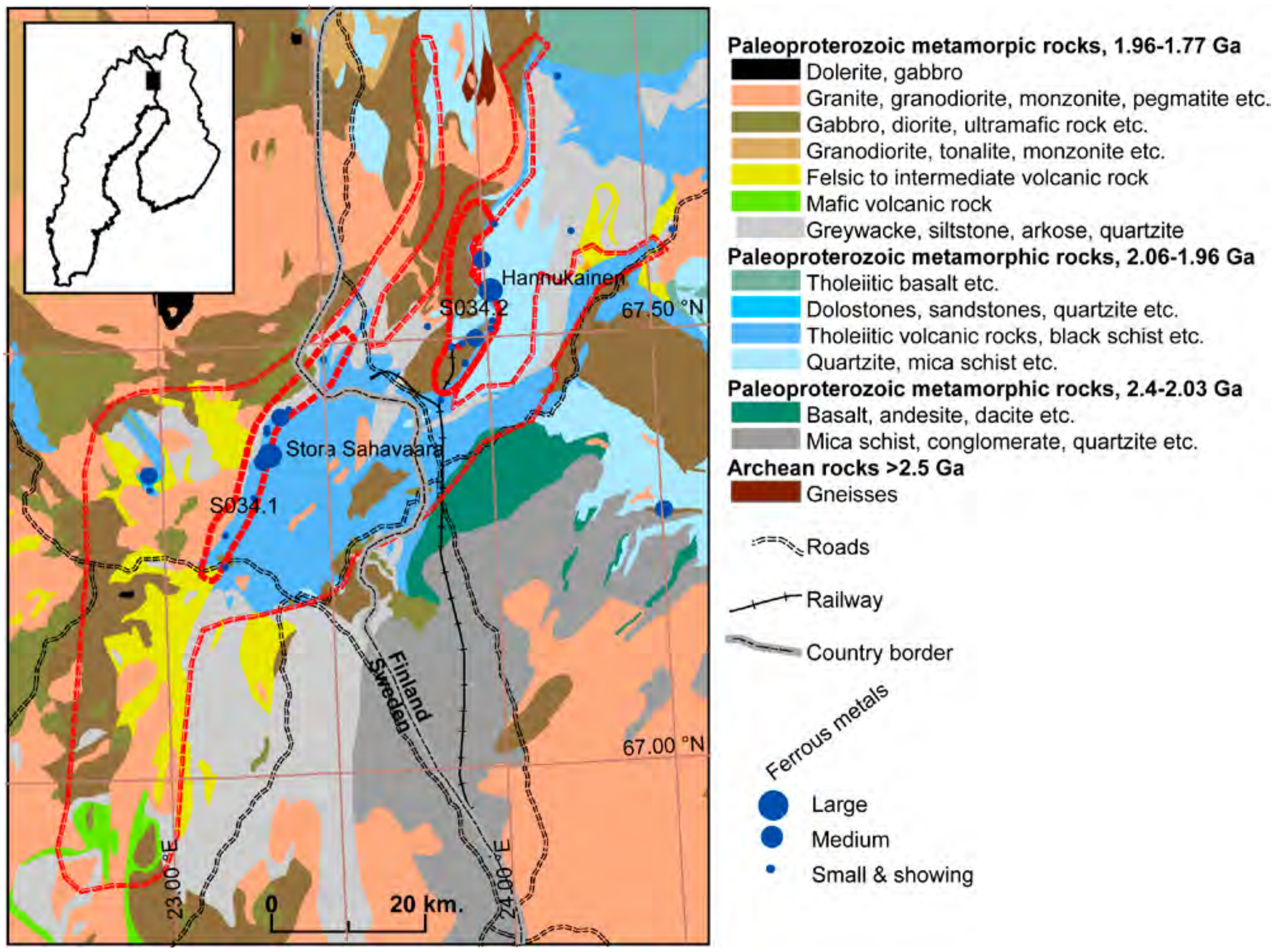


Figure 29. Geological map of the Pajala–Kolari metallogenic area (S034, red dashed double line) and its surroundings, with deposits included in the Fennoscandian Ore Deposit Database. Boundaries of the subareas Kaunisvaara (S034.1) and Kolari (S034.2) in the central and NE parts of area S034, respectively, are indicated by thick dashed lines. Map simplified from Koistinen et al. (2001).

Greenstone Group, and in particular its carbonate rocks, act as host to most of the iron ores in the Kaunisvaara subarea (S034.1).

The Karelian sequence is crosscut by 2.2–2.0 Ga mafic dykes and synorogenic 1.89–1.86 Ga Haparanda Suite mafic to felsic intrusives (e.g., Hiltunen 1982, Bergman et al. 2001, Väänänen & Lehtonen 2001, Niiranen et al. 2007). The Haparanda intrusives are broadly contemporaneous with the Svecofennian metavolcanic rocks. Felsic intrusives of 1.82–1.77 Ga in age represent the youngest magmatic stage in the area (Väänänen & Lehtonen 2001, Niiranen et al. 2007). The bedrock was subjected to deformation and metamorphism during the Svecofennian orogenic stages between 1.91 Ga and 1.77 Ga, with three different ductile deformation stages recognised in the region (e.g., Hölttä et al. 2007). The D1 and D2 phases probably took place during 1.91–1.86 Ga, and the D3 between 1.84 and 1.79 Ga (Sorjonen-Ward et al. 1992, Hölttä et al. 2007, Patison 2007). Peak metamorphic conditions in area S034 vary from upper-greenschist to upper-amphibolite facies and were probably reached during the D2 stage (Hölttä et al. 2007, Patison 2007).

Area S034 can be characterised by iron oxide–copper–gold (IOCG) mineralisation, as defined by Hitzman et al. (1992). There is, however, no consensus on the genetic type of the Fe ± Cu-Au deposits of the region. The deposits can be classified as skarns using the definition of skarn strictly in its descriptive sense based on the mineralogy, and free of genetic interpretations, as proposed by Einaudi et al. (1981). In the Swedish part of area S034, the iron oxide deposits are hosted by skarns overprinting dolomitic marbles. In the Finnish part, there are a number of deposits that are not skarn hosted, but the iron oxides, iron sulphides, copper and gold occur as disseminated mineralisation or breccia infill in variably altered country rocks. Magnetite also forms massive bodies. The deposits occur at various levels in the local stratigraphy. In the Swedish part, they are located in the uppermost part of the Karelian sequence, near to the contact to the Svecofennian sedimentary rocks. In the Finnish part, most of the deposits occur in the mafic metavolcanic rocks, but examples are also known within the Svecofennian sequence and within the Haparanda Suite diorites. All the deposits display a clear structural control (Hiltunen 1982, Niiranen et al. 2007). On the other hand, the structural control of the deposit geology is either poorly described or apparently lacking in the Swedish part of the area, although Niiranen et al. (2007) and Nykänen et al. (2008) stress that all deposits are close to the PSZ shear and fault zones. No intrusions occur close to the Swedish deposits (except at Pellivuoma), whereas in Finland the deposits typically occur near to or within the Haparanda Suite intrusives. The age data suggest that the mineralisation postdates the Haparanda Suite intrusive stage by ca. 60 Ma. Thus, no causative intrusion can be linked to either the Swedish or the Finnish deposits (Niiranen et al. 2007).

At least 25 drilling-indicated iron ± copper-gold deposits are known within area S034 (Hiltunen 1982, Frietsch 1997, Niiranen et al. 2007). The deposits vary in style, being typically massive to semi-massive to disseminated magnetite bodies. Most are only weakly enriched in Cu and Au. However, in some deposits, about 1% Cu and 0.5–1 ppm Au grades are common in drill intercepts. Typically, the elevated Cu and Au grades only occur in discrete parts of the larger iron oxide bodies. The Cu and Au grades in resource estimates are therefore low, as is shown in Table 16. A relatively high sulphur content (0.5–2.5% S) is a common feature for most ores (Northland Resources 2007, Baker & Lepley 2010). The dominant sulphide minerals are pyrrhotite and pyrite. Small amounts of chalcopyrite occur as dissemination and veinlets. Gold and copper have a strong positive correlation in nearly all cases investigated.

The **Kaunisvaara subarea** (S034.1) includes several iron deposits (Table 16, Fig. 30) hosted in a NE-trending, steeply northwest dipping greenstone sequence. The mafic metavolcanic rocks can be followed across the border into Finland, where similar rocks and iron occurrences are found. Similar mineralised greenstone belts with similar depositional ages can be found at several localities across the Northern Sweden, and the greenstones in the Kaunisvaara region have been tentatively correlated with the Kiruna greenstone belt some 140 km to the west (Bergman et al. 2001).

Outcrops in subarea S034.1 are very rare. Most of the geological information for the area comes from magnetic and electromagnetic surveys, drilling and trenching. The lowermost lithological unit at Kaunisvaara is part of the Greenstone Group and consists of metamorphosed tuffs and agglomerates, and amphibolites (Padget 1977). This formation is believed to have been deposited 2.06–1.95 Ga ago. The basement of the Kaunisvaara greenstones is not exposed. Greenstones are overlain by a sequence locally called the Iron Formation (IF), which consist of phyllites (commonly graphite-rich), carbonate rocks (mostly dolomitic), calc-silicate rocks (skarn) and iron ores. The IF is in turn overlain by the Phyllite Formation, which is made up of alternating bands of

Table 16. Iron ± copper-gold deposits, with a resource estimate exceeding 2 Mt, in the Pajala-Kolari metallogenic area (S034).

Subarea, **Deposit**	**Tonnage (Mt)**	**Mined (Mt)**	**Fe %**	**Cu %**	**Au ppm**	**References**
Kaunisvaara (S034.1)						
Mannakorpi	20		25			Hiltunen (1982)
Palotieva	8.7		24.2	0.05		Lindroos et al. (1972), Baker & Lepley (2010)
Pellivuoma	95.14		29.9			Ros et al. (1980), Northland Resources (2010c)
Ruutijärvi 2	8.3		40.9			Lindroos & Johansson (1972)
Stora Sahavaara	88.3		42.3			www.northland.eu
Östra Sahavaara	4		40.5	0.03		Lindroos (1972)
Södra Sahavaara	19.6		32.1	0.05		Lindroos (1972)
Suksivuoma	3.5		43.5			Frietsch (1997)
Tapuli	116.1		26.1			Lindroos et al. (1972), Baker & Lepley (2010)
Kolari (S034.2)						
Hannukainen	202.5	4.56	33.1	0.16	0.05	Hiltunen (1982), Northland Resources (2010a)
Kuervitikko	45		22.9	0.16	0.17	Northland Resources (2010a)
Rautuvaara Mine	13.3	11.6	46.8	0.2		Hiltunen (1982)
Rautuvaara- SW[2]	4.5		42.7	0.15		Hiltunen (1982), Niiranen et al. (2007)
Rautuvaara-Cu	2.8		21.8	0.48	0.2	Hiltunen (1982), Niiranen et al. (2007)
Rytijänkkä	0.4[1]		37			Hugg & Heiskanen (1983)
Taporova	7		28			Hiltunen (1982)

1 Massive ore of 0.4 Mt plus disseminated magnetite mineralisation of about 200 Mt at 20–25 % Fe (Hugg & Heiskanen 1983).
2 Mined tonnage not reported, but is probably included in the ore mined from Rautuvaara Mine.

quartzite and phyllite. Thin layers of calc-silicate rocks are present in a few places within the Phyllite Formation, but this member does not contain any significant mineralisation. (Lindroos 1974)

All of the iron occurrences in the Kaunisvaara subarea, from **Karhujärvi** in the south to **Mannakorpi** in Finland, are located within the IF. The lowest member of the IF, resting directly on the local greenstones, is a grey to brownish, thinly bedded phyllite. The thickness of this phyllite is around 150 m at Sahavaara, but becomes thicker to the north. Within this phyllite there are two 10–40-m-thick layers with skarn iron ores and dolomite. The Södra and Östra Sahavaara deposits lie within this unit (Lindroos 1974, Lundberg 1967). The grey to brownish phyllite is overlain by a graphite- and iron sulphide-rich phyllite. The high content of sulphides and graphite gives the rocks a high conductivity, which makes them easily detectable by electromagnetic survey. Interbedded in the graphitic phyllite are a few lenses, 1–25 m thick, of scapolite-bearing calc-silicate rocks. The graphite phyllite member is overlain by the main iron ore-bearing unit of the region, a sequence consisting of dolomite and calc-silicate rocks, and iron ore. The larger deposits in the district, **Stora Sahavaara**, **Ruutijärvi**, **Tapuli** and **Palotieva**, are within this unit (Lindroos 1974). The thickness of the dolomite-skarn-iron ore unit varies from a few metres in the south to more than 300 m in the area around the Tapuli deposit. The relative content of iron ore, skarn and dolomite varies considerably. At Sahavaara, the unit is dominated by iron ore with some skarn, at Tapuli skarn dominates over iron ore, whereas drill holes to the south of Tapuli show the unit to be dominated by dolomite with some skarn but no iron ore. (Lindroos 1974)

The iron ore is entirely made up of magnetite and skarn minerals, and haematite is very rare or absent. Two main types of skarn exist (Lundberg 1967, Lindroos 1972, Lindroos et al. 1972): 1) a serpentine skarn that makes up the gangue or wraps around the iron ore, and 2) a diopside-tremolite skarn that forms a zone between the iron ore and the hanging-wall metasedimentary units, or occurs between the iron ore–serpentine mass and the dolomite. All serpentine is retrograde, replacing tremolite-diopside and all other high-temperature skarns.

Stora Sahavaara is the largest deposit in the Kaunisvaara subarea (Frietsch 1997, Northland Resources 2007, Northland Resources 2010d). The stratiform deposit forms an arcuate 1300-m-long by 40-m-thick body that strikes NE and dips 50–70° to the northwest. The bulk of the deposit consists of magnetite and serpentine in diopside-tremolite rocks. There is very little carbonate rock at Stora Sahavaara. Estimates of the ore resources made in the 1960s gave 82 Mt @ 41.0% Fe, 0.08% Cu and 2.5% S to a depth of 435 m (Lundberg 1967). Recent assessment has increased the resource, as shown in Table 16.

The Tapuli iron deposit is the second largest by tonnage in the Kaunisvaara subarea, but has

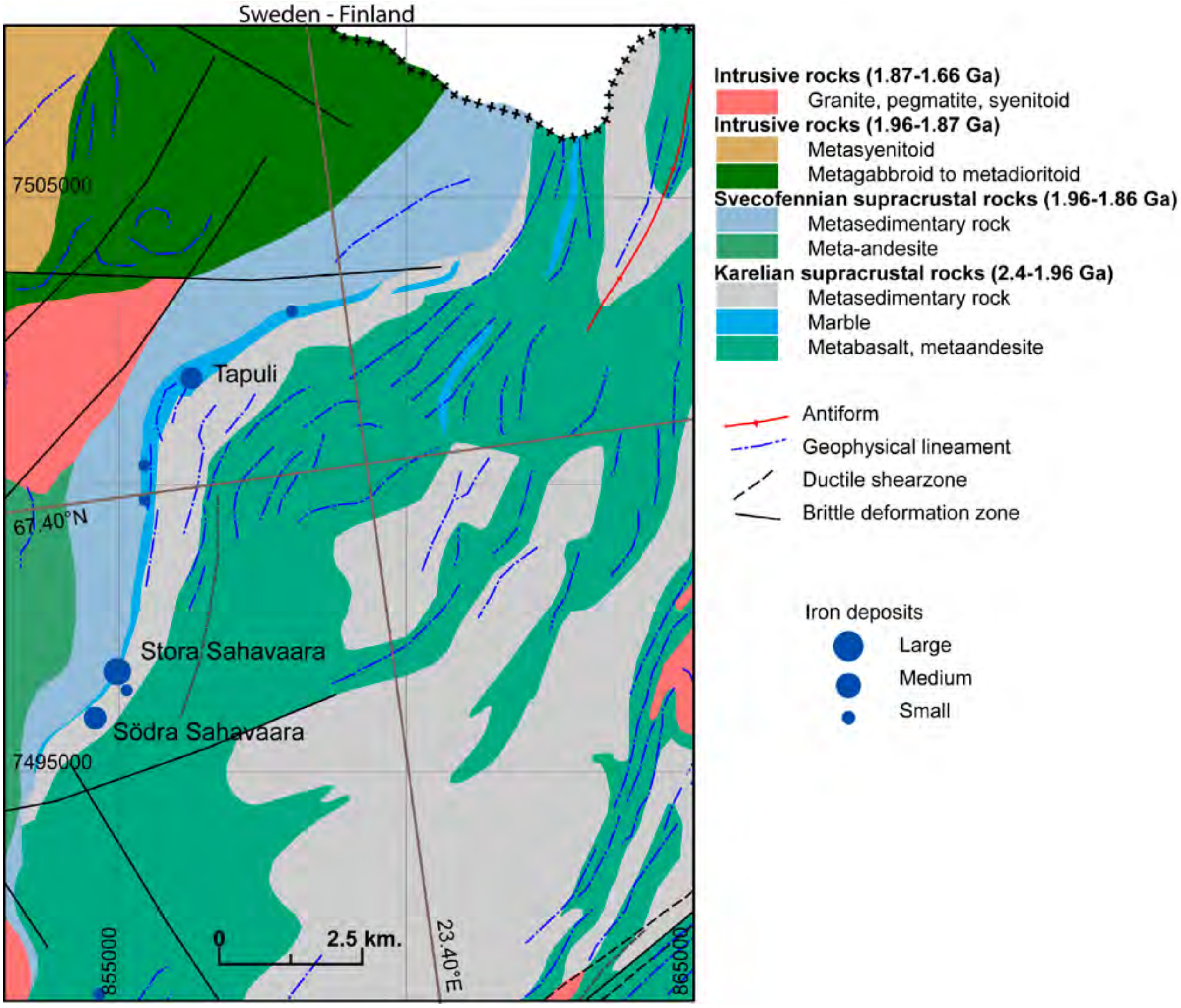


Figure 30. Geological map of the Swedish part of the Pajala–Kolari metallogenic area (S034) showing the locations of major deposits in the Fennoscandian Ore Deposit Database. Map simplified from Bergman et al. (2001).

a lower Fe grade (Table 16). Similar to the other deposits in the area, the ore body consists of stratiform layers or lenses with a northeastern strike and a dip at 50–65° to the NW. Most of the ore has accumulated in a fold structure where the ore continues to at least 300 m depth. The proportion of gangue to magnetite is much larger at Tapuli compared to other large iron deposits in area S034; hence the low Fe content of the ore. Another important difference is the low sulphide content of the ore, on average <0.2% S. A reserve of 60 Mt @ 29.3% Fe was identified in the 1960s (Lindroos et al. 1972). Recent resource calculations give measured resources of 52 Mt @ 27.04% Fe, indicated reserves of 49 Mt @ 25.11% Fe, and inferred reserves of 21.9 Mt @ 24.5% Fe (Baker & Lepley 2010, Northland Resources 2010b).

Some 15–20 km WSW of the Kaunisvaara subarea is the **Pellivuoma** iron occurrence. The setting of the Pellivuoma ore bodies, host rocks, ore and gangue minerals, and the relations between the local rock units is similar to that in subarea S034.1, except that the deposit is located next to a granite intrusion (Ros et al. 1980; Northland Resources 2010c).

The **Kolari subarea** (S034.2) deposits differ in several ways from the Pajala deposits. The deposits in subarea S034.2 occur at varying levels in the stratigraphy, including the Svecofennian sequence. In addition, some deposits are hosted partly or entirely in variably altered Haparanda Suite diorite intrusions. The Kolari deposits locally contain significant Cu-Au grades, whereas the Pajala deposits are generally low in Cu and barren with respect to gold. The deposits are enveloped by extensive alteration haloes. Typically, the proximal alteration is calc-silicate (Ca-clinopyroxene and actinolite), which overprints earlier sodic (albite) alteration (Hiltunen 1982, Niiranen et al. 2007). In some disseminated (e.g., Rautuvaara-Cu) and breccia-type deposits, the proximal alteration is dominated by potassic alteration (biotite-K feldspar) rather than calc-silicates, which overprints the sodic assemblages. **Taporova** is an exception to all the other deposits in area S034, as it contains significant amounts of haematite in addition to magnetite (Hugg & Heiskanen 1983).

The best known deposit in the Finnish part of area S034 is **Hannukainen**. It consists of five lenticular semi-massive ore bodies hosted by intensely altered mafic metavolcanic rock and diorite (Figs. 31 and 32). The deposit is structurally controlled by a W- to SW-dipping thrust zone. The long axes of the ore bodies plunge at about 25° to the SW. Mineralisation at Hannukainen took place in multiple stages between 1.86–1.77 Ga, probably during 1.82–1.79 Ga (Hiltunen 1982, Niiranen et al. 2007).

The **Rautuvaara-Cu** deposit forms an end member of the various iron oxide ± Cu-Au deposits of area S034. The deposit is not skarn type (s.l.), but consists of a disseminated magnetite-Cu-Au mineralisation hosted by intensely altered mafic metavolcanic rocks and Haparanda Suite diorites (Hiltunen 1982, Niiranen et al. 2007). The lenticular occurrence is hosted by the steeply SE-dipping Rautuvaara shear zone, which also hosts two other iron oxide ± Cu-Au occurrences, **Rautuvaara-NE** and **Rautuvaara-SE**. The latter two were partially mined as part of the main operation at the **Rautuvaara Mine**. The dominant proximal alteration at Rautuvaara-Cu is defined by the assemblage albite-cummingtonite-biotite. There are skarn veins within the deposit, but they are typically unmineralised. Similar types of occurrence in subarea S034.2 have been detected at **Rautuoja**, in parts of the **SW-Rautuvaara**, and at **Kuervitikko**.

The **Kuervitikko** deposit is located approximately 4 km north of Hannukainen. The deposit consists of two or three lenticular ore bodies hosted by the same thrust zone as the Hannukainen deposit. The style of mineralisation in the Kuervitikko ore bodies varies from Hannukainen-type semimassive, skarn-hosted magnetite ± Cu-Au ore, to Rautuvaara-Cu -type disseminated magnetite ± Cu-Au ore hosted by intensely albite-biotite altered diorite and mafic metavolcanic rock (Hiltunen 1982, Niiranen et al. 2007).

Figure 31. The Hannukainen mine site in 2009. View to the ENE. Photo: courtesy of Northland Resources.

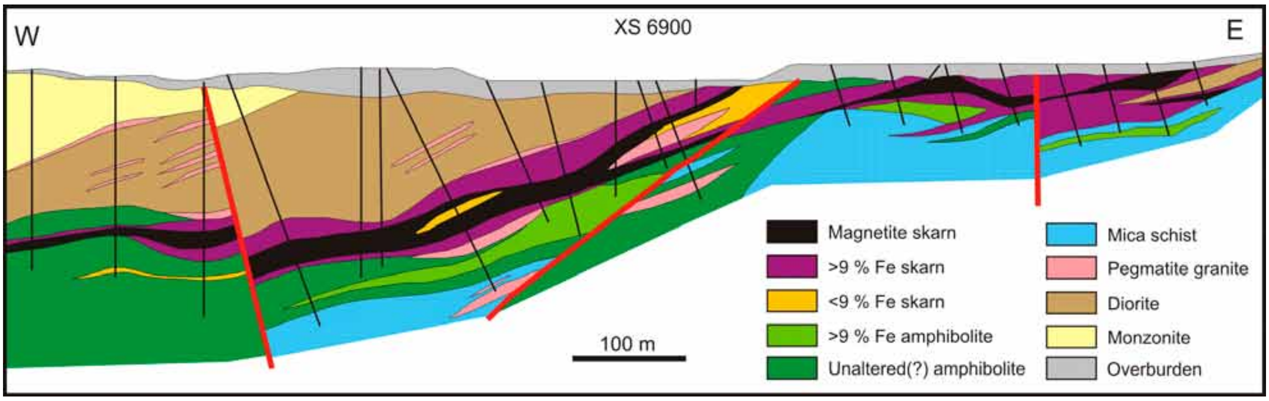


Figure 32. Section 6900 across the Hannukainen deposit. Red lines indicate faults, black lines are drill-hole traces. Based on a figure provided by Northland Resources in January 2011.

S035 KIRUNA Fe, Cu, Au

Anders Hallberg (SGU)

Economically, the most important deposit type in the Kiruna metallogenic area (Fig. 33; Table 17) is apatite-iron ore, of which the giant ore at **Kirunavaara** is in a category by itself, being the only world-class deposit in Sweden. The Kirunavaara deposit (Fig. 34) has been known since the 17th century, but large-scale mining did not start until the arrival of infrastructure, in the form of railways, to Luleå at the Baltic Sea and to Narvik on the Atlantic coast, during the first years of the 20th century. From modest and intermittent mining in the 19th century through the last 110 years of large-scale mining, 940 Mt of iron ore @ 61% Fe have been produced. Present day reserves and resources are 684 Mt and 328 Mt, respectively, giving a total tonnage of the Kirunavaara deposit of nearly 2 Gt (LKAB 2011). The area also has several large-scale historical producers (Fig. 35), including **Luossavaara** to the north along strike from the Kirunavaara deposit. Luossavaara produced 21.4 Mt between 1858 and 1985. Other deposits in the vicinity of Kirunavaara are **Nukutus** (4.2 Mt) and **Huukivaara** (2.4 Mt). A few km to the E of Kirunavaara lies the **Tuolluvaara** deposit, in operation between 1902 and 1982 with a total production of 25.4 Mt. The **Mertainen** deposit is located 30 km to the ESE. During the short lifetime of this mine, from 1956 to 1959, the deposit produced 0.4 Mt of iron ore. A large unexploited resource, the blind Lappmalmen deposit, is located 2 km east of the Luossavaara deposit (Fig. 35).

All mined iron deposits are apatite-bearing. The majority of the about 20 unexploited deposits in the area also belong to this type. In addition, there are more than 60 predominantly apatite-iron deposits for which no ore resource estimates have been carried out (Bergman et al. 2001, Frietsch 1997, Grip & Frietsch 1973). Most of the apatite-iron deposits are also enriched in rare earth elements (REE), which are mainly concentrated in the apatite (Frietsch & Perdahl 1995).

The apatite-iron deposits occur in, or have a spatial relation to the Porphyry Group, a bimodal sequence of mafic and felsic metavolcanic rocks and metasedimentary rocks, or in a few cases in the underlying Porphyrite Group, which predominantly consists of meta-andesites (Bergman et al. 2001). These rocks were deposited between 1.96 and 1.86 Ga. In the Kirunavaara area, the Porphyry Group is overlain by the Lower Hauki Group, which consists of quartz-sericite altered metavolcanic and metasedimentary rocks (Parak 1975). In most cases, magnetite is the dominant mineral and apatite, actinolite, albite and scapolite constitute the gangue. A few deposits are hematite-dominated and there the gangue consists of apatite, quartz and carbonates. In general, the hematite-dominated deposits are found higher in the stratigraphy of the Porphyry Group.

The Kiruna area also hosts small epigenetic Cu deposits. These are mainly hosted by the Greenstone Group rocks, which form the basement to the Porphyrite and Porphyry groups. The only deposit of this kind that has been mined in recent times is Pahtohavare (Martinsson 1997), which is immediately outside the Kiruna metallogenic area. The **Rakkurijärvi** Cu deposit, a few km S of Kirunavaara, has recently been subject of detailed exploration (Smith et al. 2007). Other deposits of this kind include **Tjårrojåkka**, where part of the

Cu occurrence is hosted by an apatite-iron ore (Edfelt 2007), and the **Sierkavara** (Pikkujärvi) deposit (Weihed 2001, Hedin 1988).

About 50% of all iron ore that has been mined in Sweden and 65% of all reported iron ore reserves come from deposits that are located within the 75 km^2 that constitutes the **Kirunavaara subarea** (S035.1). The single largest deposit is Kirunavaara itself, which is considered a world-class deposit. It is a tabular ore body that can be followed for about 5 km along strike, is up to 100 m thick and has been shown to extend to a depth of more than 1300 m (Parak 1975, Bergman et al. 2001). Calculations based upon geophysical measurements indicate that the ore body continues below a depth of 1500 m. The ore is at the contact between a thick sequence of trachyandesitic lava flows and the overlying rhyodacitic pyroclastic rocks. The entire sequence strikes N–S and dips steeply to the E. The massive magnetite-apatite ore grades into magnetite-actinolite breccias towards the wall rocks. The P content of the ore varies and shows a bimodal distribution of either <0.05% or >1.0%.

In the faulted southern end of the Kirunavaara deposit, three small ore bodies, Konsuln, Sigrid

Table 17. Reserves, resources and produced tonnage for ferrous and base-metal deposits in the Kiruna metallogenic area (S035). Deposits without dates for production are unexploited. Resources include reserves.

Deposit	When mined	Resources (Mt)	Mined (Mt)	Total (Mt)	Fe %	Mn %	Ag ppm	Au ppm	Cu %	References
Apatite iron ore										
Kirunavaara	1864–	993.0	940.3	1933.3	60	0.08				1,2
Lappmalmen		260.0		260.0	47					5
Mertainen	1956–1959		0.4	0.4	55.5					2
Pattok		62.4		62.4	44					6
Tjårrojåkka		51.0		51.0	51.5					6
Ekströmsberg		41.6		41.6	52					6
Painirova syd		36.0		36.0	30					3
Tuolluvaara	1902–1982		25.4	25.4	64.6	0.04				2
Luossavaara	1846–1987		21.4	21.4	60	0.07				2
Renhagen		11.3		11.3	33.7					4
Eustilljåkk		5.0		5.0	37.5					4
Nukutus	1964–1986		4.2	4.2	48.9	0.07				2
Tjåorika		2.5		2.5	57					3
Haukivaara	1965–1972		2.4	2.4	51.2	0.06				2
Gäddmyr		0.2		0.2	68					4
Skarn iron ore										
Rakkurijoki		74.5		74.5	39.7					6
Rakkurijärvi Fe		69.6		69.6	29					6
Altavaara Norra		7.1		7.1	25.8					4
Altavaara Södra		0.1		0.1	20					4
Altavaara Östra		0.1		0.1	25					4
Laukujärvi Fe		3.7		3.7	33.5					4
Salmivaara		16.0		16.0	33.5					4
Årosjåkk		2.7		2.7	28.3					4
Other types of Fe deposits										
Poultsa		31.5		31.5	34.3					4
Fe ores total				2662.0						
Base metal deposits										
Sierkavare				5.0					0.61	7
Tjårrojåkka Cu				3.2					0.87	8
Lieteksavo				0.1			46	1.3	6.80	9

1 LKAB (2011)
2 Official Statistics of Sweden, Metal and Mining Industries
3 Grip & Frietsch (1973)
4 Frietsch (1997)
5 LKAB Press release 2006, www.lkab.com
6 Scandinavian Resources (2011)
7 Holme (1986)
8 Ros (1979)
9 Lindblad (1985)

and Viktor, are situated. To the north, the mineralisation may be followed at depth under Lake Luossajärvi (today partly drained). Two kilometres further north is the Luossavaara deposit, showing the same characteristics as Kirunavaara. At the surface, Luossavaara can be traced for 1200 m along strike.

Deposits occurring further to the north, **Nukutus** and **Henry**, are so-called Per Geijer ores (Geijer 1919, Frietsch 1997). The Per Geijer ores differ from the larger deposits, located further down in the stratigraphy, in size, in iron oxide and gangue mineralogy, and in alteration style. In general, they contain more apatite and hematite; locally, hematite is the dominant oxide. Gangue consists of quartz and sericite and, in places, also carbonates and albite. These deposits occur in the upper parts of the Porphyry Group, stratigraphically above the Kirunavaara and Luossavaara deposits. The **Rektorn** and **Haukivaara** deposits, to the east of Kirunavaara, are Per Geijer ores. The blind **Lappmalmen** deposit, discovered in the 1960s, shows the same characteristics as the Per Geijer ores (Parak 1969).

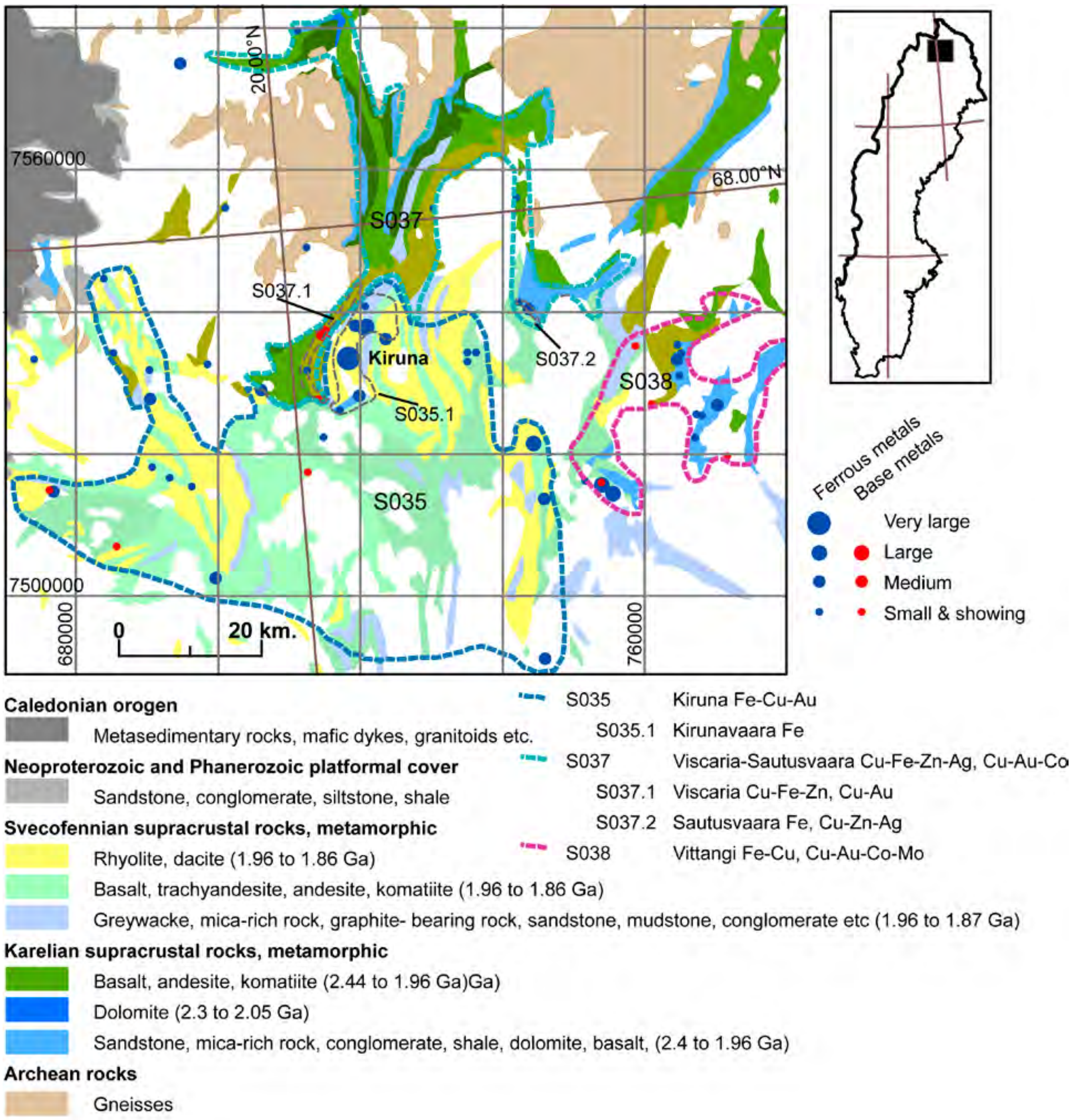


Figure 33. Geological map of part of Northern Sweden. Three metallogenic areas, Kiruna (S035), Viscaria–Sautusvaara (S037) and Vittangi (S038), subareas (with thin dashed boundary lines) and major metal deposits of the region are shown. Geological map simplified from SGU's digital Bedrock Sweden 1M 2010.

Figure 34. Panoramic view of the Kiruna iron ore deposit looking south. The outcropping iron ore (all exploited) was located on the eastern (left) side of the mountain in the left-centre part of the photo. The iron ore dips steeply (60–70°) to the east (left) under the town of Kiruna. The plume of smoke in the centre of the image comes from the pelletisation plant. Copyright: LKAB.

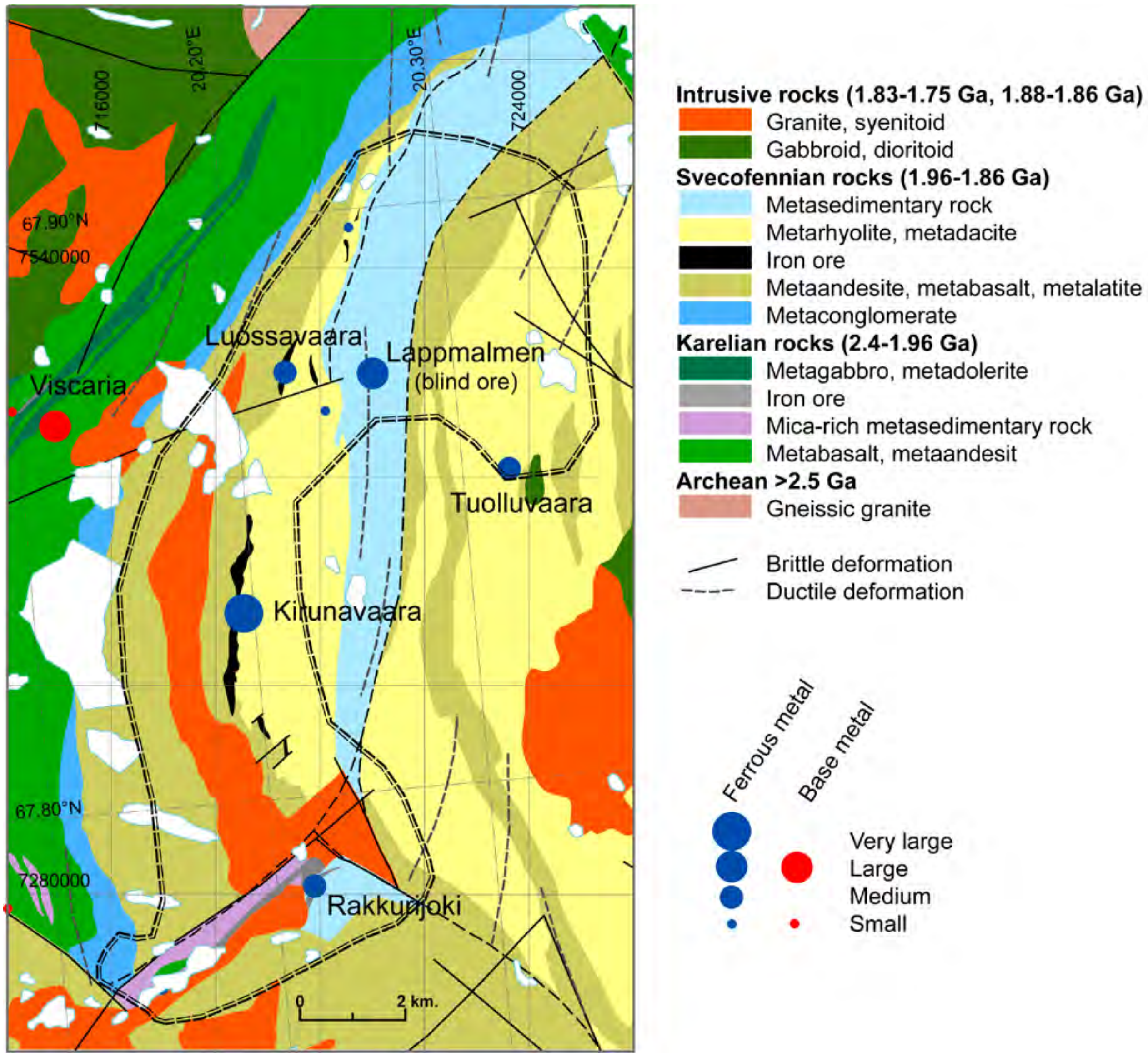


Figure 35. Geological map of the Kiirunavaara subarea (S035.1, black dashed double line) with surroundings, and major deposits of the region included in the Fennoscandian Ore Deposit Database. The Viscaria base metal deposit (in metallogenic area S037) on the left. Note that Lappmalmen is a blind deposit and its position is shown as a surface projection of the deep-seated ore. Geological map simplified from Bergman et al. (2001).

S036 TÄRENDÖ Fe, Zn-Cu

Julio Gonzalez and Anders Hallberg

The metal deposits in the Tärendö area were already known by 1644. Between 1846 and 1861, approximately 120 tons of iron ore of unknown grade was produced from the Junosuando deposits. None of the other iron deposits in the area have been exploited.

The Tärendö metallogenic area contains several iron deposits including **Tornefors**, **Vähävaara**, **Junosuando** and **Leppäjoki** (Frietsch 1997). Both skarn iron ores and quartz-banded iron ores are present in the area. The supracrustal rocks of the Tärendö area consist of thick sequences of mafic metavolcanic rocks with intercalated pelitic schist, graphitic schist, quartzite and carbonates belonging to the Greenstone Group, locally named the Veikkavaara Greenstone Group. These have been dated at between 2400 and 1960 Ma. These rocks are overlain by the Pahakurkkio Group dominated by metasedimentary rocks, which in turn are overlain by mafic to felsic metavolcanic rocks with an age between 1960 and 1860 Ma (Padget 1970, Bergman et al. 2001). Most of the iron deposits in the Tärendö area are in the upper parts of the Veikkavaara Greenstone Group and in the lower parts of the Pahakurkkio Group (Frietsch 1997). The supracrustal rocks have been intruded by several generations of granitoids to gabbroids (Bergman et al. 2001).

The skarn iron deposits of the Tärendö area are typically hosted by carbonate rocks intercalated in the greenstones. They are composed of magnetite, which is commonly Mg bearing, tremolite, actinolite, diopside, phlogopite, biotite, serpentine and some hornblende. The calc-magnesium silicates are either evenly distributed throughout the iron ore or occur as layers within the ore. Small amounts of pyrite, pyrrhotite and, locally, chalcopyrite occur.

The quartz-banded iron occurrences are in a stratigraphic position similar to the skarn iron ores, but are usually made up of quartzites with magnetite and Fe-Mg-Mn silicates: hornblende, grunerite, clinoenstatite, hedenbergite and garnet. The deposits commonly contain some sulphides and minor amounts of manganese. The phosphorous content in both the skarn iron deposits and the quartz-banded deposits is generally very low.

S037 VISCARIA–SAUTUSVAARA Cu, Fe, Au, Zn, Ag, Co

Jan-Anders Perdahl

The Viscaria–Sautusvaara metallogenic area (Fig. 33) contains several large stratiform iron and copper deposits hosted by volcano-sedimentary sequences of the Kiruna Greenstone Group (2400–1960 Ma). The main rock types in the Kiruna Greenstone Group are metabasalts, graphite-bearing meta-argillites, crystalline carbonate rocks and ultramafic rocks (Martinsson 1997).

The **Viscaria** deposit consists of several stacked units showing a variation from magnetite-bearing Cu-rich sulphide ore in the A zone to sulphide poor magnetite ore in the B and D zones (Martinsson 1997). The economically important A zone is in a marble between two units of black schist, on top of a volcaniclastic unit and immediately below pillow lavas. It is capped by an extensive thin chert unit. The ore consists of fine-grained chalcopyrite, magnetite, pyrrhotite and minor sphalerite. The ore minerals are disseminated or form thin intercalations and semi-massive accumulations. According to Martinsson (1997), the ore was formed by fissure-controlled exhalative events in a fault-controlled basin.

The iron ore zone at **Sautusvaara** is approximately 2500 m long and strikes NW–SE. The deposit consists of two ore bodies separated by a fault (Hallgren 1970). The smaller northern ore body has been estimated to have 13.3 Mt @ 42.1% Fe. The southern ore body has 42.1 Mt @ 37.2% Fe and can be followed 1100 m along strike. It consists of bands of magnetite and skarn minerals (diopside and tremolite) and, in places, chlorite and biotite are also abundant. The dominant sulphide mineral is pyrite, generally occurring as fissure veins. At least two generations of pyrite occur and the content of cobalt in the coarse-grained pyrite varies between 1.1–1.6% Co. Traces of chalcopyrite and pyrrhotite have been detected. The rock underlying the iron ore zone is a well-stratified scapolite-diopside-biotite-bearing sediment. This unit is underlain by graphite-bearing schists and minor marble (skarn). These rocks are stratigraphically situated in the upper part of the Kiruna Greenstone Group.

The **Tjavelk** deposit is a magnetite skarn iron ore, which is approximately 800 m long and up to 30 m wide. It is estimated to have 6.8 Mt @ 35% Fe, 3.6% S and 0.12% Cu (Frietsch 1979). The skarn is composed of tremolite-actinolite and serpentine with a banded pattern in places. Sulphide minerals are pyrrhotite, pyrite and chalcopyrite. Apatite is relatively common both as impregnations and as schlieren in the magnetite ore. The average phosphorus content is 1.3% P, the highest found in a skarn iron ore in northern Sweden.

The **Pahtohavare** deposit SW of Kiruna comprises three epigenetic Cu-Au ore bodies (Martinsson 1997). Two of them have been mined (the Southern and the Southeastern ores). The ore bodies are located in an antiformal structure, bordered towards south by a shear zone (Martinsson 1997). Southern Pahtohavare is the largest ore body, with a maximum length of 270 m and a thickness of up to 25 m. It is in an altered black schist unit close to a thick mafic sill. Early albitisation of tuffite along the contact of the sill was later overprinted by ore-related alteration. Adjacent black schist was albitised and its graphite replaced resulting to a rock commonly called ‘albite fels’. The main ore minerals, chalcopyrite and pyrite, mainly form veinlets and breccia fill in the albite rock. The third ore body at Pahtohavare, Central, consists mainly of secondary Cu minerals.

S038 VITTANGI Fe, Cu, Au, Co, Mo

Julio Gonzalez (SGU)

The Vittangi metallogenic area (Fig. 33) hosts several large apatite-iron, skarn-iron and a few smaller Cu(-Co) deposits. The oldest rocks in the Vittangi area are the volcano-sedimentary sequences belonging to the Vittangi Greenstone Group (2400 to 1960 Ma in age), rocks broadly equivalent to the Kiruna Greenstone Group in the Kiruna area (Eriksson & Hallgren 1975, Martinsson 1993, Bergman et al. 2001). The lower part of the Vittangi Greenstone Group comprises metamorphosed mafic volcanic rocks and ultramafic dykes. Within the upper parts of the Vittangi Greenstone Group, there are several deposits of calc-silicate-bearing (skarn) iron deposits in metasedimentary rocks. The occurrences consist of magnetite associated with tremolite-actinolite, diopside, calcite, chlorite, serpentine and talc. A layered or banded structure is common.

The skarn iron ores are mainly found further to the north and east in the Vittangi area. Most of them are hosted by rocks of the Kiruna Greenstone Group. **Vathanvaara**, hosted by metasediments of the Vittangi Greenstone Group, is the largest skarn iron deposit in the Vittangi area, with a tonnage of 28 Mt @ 39.4% Fe, 0.049% P and 2.91% S (Frietsch 1997). The ore and host rocks are locally strongly fractured and (superficially) kaolin-weathered to a depth of at least 100 m. The deposit consists of magnetite with some amphibole. A dark serpentine-bearing ore may also be present. Mineralisation is rich in pyrite and pyrrhotite, and small amounts of chalcopyrite occur sporadically. The host rock is a layered graphite-bearing biotite schist. Subordinate to the schist is a scapolite-bearing quartzite with magnetite impregnations. The deposit has not been exploited.

The Vittangi Greenstone Group was overlain by a sequence of Svecofennian (1960 to 1860 Ma in age) volcanosedimentary rocks (Bergman et al. 2001). These rocks, similar in age and composition to the Porphyry and Porphyrite groups in the Kiruna district, some 40 km to the northwest, are host to all the apatite-iron deposits in area S038 and are mainly found in the southwestern and western part of the metallogenic area. The supracrustal rocks were intruded by granites, tonalities and gabbroic rocks between 1890 and 1870 Ma.

Leveäniemi is the largest apatite-iron deposit in area S038 with a total tonnage (resources and mined tonnage) of 168 Mt @ 55.4% Fe and 0.45% P (Frietsch 1966, 1997, LKAB 2010), making it the third largest iron deposit in Northern Norrbotten. The Leveäniemi deposit was mined from 1964 to 1982 and LKAB is presently (2011) planning to reopen the mine. The deposit is dominated by massive magnetite ore, massive hematite ore and calcite-rich magnetite ore. Large volumes of magnetite breccia (not included in the resources) occur in an up to 100-m-wide zone in the surrounding biotite schist. The contacts between massive ores and ore breccias are mostly distinct.

The nearby **Gruvberget** apatite-iron deposit (Frietsch 1966), geologically similar to Leväniemi, was recently put into production by LKAB. In older days, vein-hosted copper was mined at Gruvberget. During intermittent production between 1644 and 1785, about 1740 tons of raw copper was produced (Tegengren 1924).

The **Kiskamavaara** Cu-Co deposit comprises disseminated and fissure-fill mineralisation of cobalt-bearing pyrite, chalcopyrite, magnetite, hematite and minor amounts of bornite and molybdenite. The host rocks consist of metamorphosed rhyolitic tuffs, intermediate tuffs and mafic volcanic rocks belonging to the Porphyrite Group. Historic ore resource calculations give 3.42 Mt @ 0.37% Cu and 0.09% Co at Kiskamavaara (Persson 1982).

S039 LANNAVAARA Fe-Zn, Cu, Co

Julio Gonzalez and Anders Hallberg

The most important deposits in the Lannavaara metallogenic area are two iron occurrences associated with calc-silicate rocks: Teltaja with 43 Mt @ 41% Fe and Kevus with 38.8 Mt @ 28% Fe (Frietsch 1985, 1997). The Huornaisenvuoma Zn-Pb-Au deposit is close to the two former deposits (Bergman et al. 2001). It is the only Zn-Pb deposit of any economic significance in northern Norrbotten. In the poorly explored and exposed northern part of area S039, there are several smaller iron deposits. None of the deposits within the Lannavaara area have been mined. Supracrustal rocks in the Lannavaara area range from Karelian (2400 to 1960 Ma) supracrustal rocks of the Kovo and Greenstone groups, overlain by Svecofennian metasedimentary and metavolcanic rocks (Ambros 1980, Bergman et al. 2001). The supracrustal rocks are cut by several generations of intrusions ranging from granites to gabbros.

The **Huornaisenvuoma** sulphide deposit is hosted by a thick dolomite unit in the upper part of the Greenstone Group (Frietsch et al. 1997). It consists of sphalerite, magnetite and pyrite occurring both as disseminated mineralisation and as almost massive layers. The deposit generally has a thickness of 1–2 m and its maximum length is 950 m. The country rocks comprise metamorphosed mafic tuff and tuffite, manganiferous iron formations and black schist. These volcanic and sedimentary rocks were metamorphosed under middle to upper amphibolite facies conditions. The historical resource estimate for Huornaisenvuoma is 0.56 Mt @ 4.8% Zn, 1.7% Pb, 0.2% Cu and 12 ppm Ag (Frietsch 1991).

The **Kevus** iron deposit is composed of magnetite with diopside, scapolite and hornblende (Frietsch 1997). The tuffitic metabasalt host is impregnated with magnetite. In addition to iron, the deposit carries manganese (0.2–0.5% Mn) and some copper (>0.1% Cu). The deposit and the host rock were intensely brecciated and deformed by subsequent tectonic activity.

The **Teltaja** iron deposit consists of magnetite and hematite in cherty rocks with minor calc-silicate minerals belonging to the Greenstone Group sequence (Frietsch 1985). The deposit is made up of two mineralised units. The first consists of a 70-m-wide magnetite-hematite body with an average iron content of 47% Fe, hosted by jaspilitic quartzite (jaspilite). The second is a 15-m-wide calc-silicate-bearing magnetite-dominated ore body with an average content of 33% Fe. The latter ore body has an anomalously high Mn content (Ambros 1980). The deposit is almost totally devoid of sulphides.

S040 SJANGELI Cu, Ag, Au, U

Jan-Anders Perdahl

The Sjangeli metallogenic area occurs as two mineralised windows in the Swedish Caledonides, close to Lake Torneträsk. The Kuokkel window lies immediately west of the lake and the Sjangeli window a few kilometres further to the west. The Precambrian rocks in these windows form a large dome-shaped antiform, the top of which has been removed by pre-Caledonian erosion. The rocks were affected by the Caledonian orogeny to varying degrees.

In the Sjangeli window, the Proterozoic sedimentary rocks and amphibolites are isoclinally folded (Romer 1987, 1988). Neoproterozoic arkoses and sandstones lie discordantly on these rocks. Copper mineralisation is found in three areas within the window (**Sjangeli**, **Valfojokk** and **Unna Alakats**) detected in more than 300 exploration pits and trenches. The mineralisation occurs as veins and impregnation parallel to the strike of the amphibolites and the adjacent sediments (Romer 1987). Dominant ore minerals are bornite, chalcopyrite and chalcocite with secondary copper minerals (malachite and azurite). The ore minerals are accompanied by epidote, quartz, calcite and amphibole. The mineralisation is genetically connected to the Vassijaure granite, which cuts the amphibolites and sedimentary rocks (Romer 1988). The Sjangeli copper field has been known since 1696. Mining operations started on a small scale in 1698, and several attempts to exploit the thin but rich ore lenses followed, the last attempt in 1863. In 1905, large-scale test mining was carried out and 4000 tons of ore was extracted (Fredriksson 1982).

The Kopparåsen (Kuokkel) area has for a long time attracted the attention of economic geologists. Copper and zinc occurrences were discovered there in 1897 and were intensely investigated during the following twenty years. In 1963, radioactive anomalies were detected in the area and investigated first by AB Atomenergi and, during 1968–1970, by the Geological Survey of Sweden (Adamek 1975).

The Kopparåsen greenstone belt, also known as the Kuokkel Group, is built up of a sequence of steeply inclined metamorphosed volcanic and sedimentary rocks. The ca. 2300 Ma mafic volcanic rocks largely consist of tuffs and tuffites together with sediments. Narrow zones with impregnations of uraninite, magnetite, pyrite, pyrrhotite, chalcopyrite, bornite, galena, sphalerite, gersdorffite, arsenopyrite and molybdenite occur in banded metatuff, graphite schist and chert (Adamek 1975). The mineralisation is considered to be of volcanic-sedimentary origin.

S041 SKELLEFTE DISTRICT GOLD Au

Anders Hallberg

More than 50% of all the gold that has been produced in Sweden comes from a restricted area in Northern Sweden that covers the eastern part of the Skellefte District (S023) and adjacent areas to the east (Fig. 20). The individual deposits that define the metallogenic area S041 show different characteristics, have different host rocks, and were most likely formed at different times and by different processes (Table 18), but collectively they point out the gold potential of the area. Geologically, area S041 can be divided into a western and an eastern part. The geology of the western part was briefly described in previous section S023. Geology of the eastern part is dominated by metasedimentary rocks, including marble, belonging to the Bothnia basin (Kathol & Weihed 2005). Rocks intruding the western part are also seen in the eastern part, where younger S-type granites and pegmatites (1830–1750 Ma) are also found. The **Boliden** Au-Cu-As deposit, the largest and by far the economically most important deposit in the Skellefte District, is described in a previous section (S023). Other economically important deposits are described below.

The **Åkerberg** gold deposit consists of a zone of east–west-trending, subvertical centimetres-wide gold-bearing quartz veins in a layered gabbro (Mattson 1991, Dahlenborg 2007). The mineralised zone is 10–30 m wide and 350 m long, and can be followed to a depth of around 150 m. Outside the mineralised zone, the quartz veins pinch out to altered veinlets and eventually disappear further to the east. The western end of the mineralised zone is not exposed, as it is covered by a younger pegmatite.

The **Björkdal** gold deposit is located at the contact between an intrusive granodiorite to tonalite and supracrustal rocks belonging to the Skellefte Group. Gold mineralisation consists of cm- to m-wide, subvertical, auriferous quartz veins within the granodiorite (Weihed et al. 2003, Gold Ore Resources 2011). The veins mainly trend NE and NNE. The gold occurs as both free milling and associated with pyrite.

The **Åkulla Östra** deposit is in an area with several small massive sulphide deposits that have been mined in the past. It was known at an early stage that the deeper part of the Åkulla Östra mine carried auriferous quartz veins in altered rocks (Grip & Frietsch 1973). Recently, part of the underlying rocks have been drilled and resources of 2.78 Mt @ 4.1 g/t Au and 186 g/t Te have been reported. The access to the mineralisation will be from the nearby **Kankberg** mine ('Kankberg nya' in Table 18; Boliden 2011b).

The **Tallberg** deposit is interpreted as a Palaeoproterozoic porphyry copper deposit hosted by a 1.9-Ga granitoid (Weihed 1992a, 1992b). The deposit is low of grade, 0.27% Cu and 0.2 g/t Au, but the large tonnage (Table 18) could make it mineable in the future.

The **Holmtjärn gamla** (Old Holmtjärn) deposit was found in the early 1920s and was mined out in two years. The upper parts of the ore were strongly weathered and carried gold grades of more than 1 000 g/t Au. The massive arsenopyrite and pyrite ore beneath the weathered zone also showed high gold grades (Grip & Frietsch 1973). Although no detailed description exists, it seems from the available information that Holmtjärn gamla in many ways resembles the Boliden deposit.

Throughout the Skellefte district gold metallogenic area, several gold- and arsenopyrite-bearing quartz veins have been found (Högbom 1937, Grip & Frietsch 1973). In a few places they have been mined on a small scale in the past, but the small tonnage and scattered gold make them uneconomic.

Table 18. Gold deposits in metallogenic area S041 classified according to the assumed genetic type. Note that some of the deposits are also included in metallogenic area S023 (Skellefte District).

Deposit	When mined	Resources (Mt)	Reserves (Mt)	Mined (Mt)	Total (Mt)	Au ppm	Ag ppm	Te ppm	References
Gold-rich VMS									
Boliden	1926–1967			8.35	8.35	15.5	50		1
Kankberg	1966–1997			1.1566	1.16	2.6	52		1
Petiknäs södra	1989–2007			5.4	5.4	2.4	102		2
Renström	1948–	3.41	1.76	11.02	16.19	2.8	151		1, 3
Petiknäs norra		2.23			2.23	3.6	48.8		3
Åkulla Västra	1938–1957			0.98	0.98	0.7	12		1
Holmtjärn nya	1984–1992			0.46	0.46	7.4	92		1
Holmtjärn gamla	1924–1925			0.0004	0.0004	100			1
Porphyry copper									
Tallberg		44			44.00	0.2	1		4
Orogenic gold									
Björkdal	1988–	33.7	4.025	15.32	53.02	1.8			5
Åkerberg	1989–2001			1.48	1.48	3.0			1
Other type(s)									
Åkulla Östra	1997–1998			0.2	0.2	4.1	16		2
Älgträsk		4.2			4.2	3.1	6		3
Krångfors	1934–1934			0.00006	0.00006	30.0			1
Kankberg nya		0.689	2.78		3.47	4.1		186	3, 6

1 Official Statistics of Sweden, Metal and Mining Industries
2 Boliden (2008)
3 Boliden (2011a)
4 Weihed (1992b)
5 Gold Ore Resources (2011)
6 Boliden (2011b)

REFERENCES

Adamek, P. M. 1975. Geology and mineralogy of the Kopparåsen uraninite-sulphide mineralization. Norrbotten County, Sweden. Geological Survey of Sweden, serie C 712. 69 p.

Åkerman, C. 1987. Summary of results from nickel prospecting. A consulting report. Sveriges Geologiska AB, prospekteringsrapport, prap87007. 70 p.

Allen, R. L., Lundström, I., Ripa, M., Simeonov, A. & Christofferson, H. 1996a. Regional volcanic facies interpretation of 1.9 Ga metasediment- and metavolcanic-hosted Zn-Pb-Ag(-Cu-Au) sulfide and Fe oxide ores, Bergslagen region, Sweden. Economic Geology 91, 979–1008.

Allen, R. L., Weihed, P. & Svensson, S. Å. 1996b. Setting of Zn-Cu-Au-Ag massive sulfide deposits in the evolution and facies architecture of a 1.9 Ga marine volcanic arc, Skellefte district, Sweden. Economic Geology 91, 1022–1053.

Allen, R., Danielsson, S., Eklund, D., Fagerström, P., Jonsson, R., Lundstam, E., Munck, M., Nilsson, P. & Pantze, R. 2010. Discovery and geology of the Lappberget Zn-Pb-Ag-(Cu, Au) deposit, Bergslagen Sweden. In: Nakrem, H. A., Harstad, A. O. & Haukdal, G. (eds) 29th Nordic Geological Winter Meeting, Oslo, January 11–13, NGF Abstracts and Proceedings of the Geological Society of Norway 1, p. 4.

Alm, E. 2000. Sveconorwegian metallogenesis in Sweden. Meddelanden från Stockholms universitets Institution för geologi och geokemi 307, 1–17.

Ambros, M. 1980. Beskrivning till berggrundskartorna Lannavaara NV, NO, SV, SO och Karesuando SV, SO. Sveriges geologiska undersökning, serie Af 25–30. 111 p. (in Swedish)

Andersson, A., Dahlman, B., Gee, D. G. & Snäll, S. 1985. The Scandinavian alum shales. Sveriges geologiska undersökning, serie Ca 56. 50 p.

Andersson, L. G. 1982. Malmberäkning – Sumåssjön. LKAB Prospektering AB, rapport Grb 285. 6 p. (in Swedish)

Andersson, L. G. 1986. The Wigström tungsten deposit. In: Lundström, I. & Papunen, H. (eds) Mineral deposits of southwestern Finland and the Bergslagen province, Sweden. 7th IAGOD symposium and Nordkalott project meeting, excursion guide No. 3. Sveriges geologiska undersökning, serie Ca 61, p. 41.

Andersson, U. B. (ed.) 2004. The Bastnäs-type REE mineralisations in north-western Bergslagen, Sweden – a summary with geological background and excursion guide. Sveriges geologiska undersökning, Rapporter och meddelanden 119. 34 p.

Andreasson, P.-G., Solyom, Z. & Johansson, I. 1987. Geotectonic significance of Mn-Fe-Ba and Pb-Zn-Cu-Ag mineralizations along the Sveconorwegian–Grenvillian front in Scandinavia. Economic Geology 82, 201–207.

Årebäck, H., Barrett, T. J., Abrahamsson, S. & Fagerström, P. 2005. The Palaeoproterozoic Kristineberg VMS deposit, Skellefte district, northern Sweden, part I: geology. Mineralium Deposita 40, 351–367.

Armands, G. 1970. A uranium-bearing layer from the Lower Ordovician, Sweden. Geologiska Föreningens i Stockholm Förhandlingar (GFF) 92, 481–490.

Baker, H. & Lepley, B. 2010. Mineral resource estimate for the Tapuli iron deposit, Pajala municipality, Norrbotten County, Sweden. SRK Consulting, Project U3871. 178 p.

Bark, G. 2005. Genesis and tectonic setting of the hypozonal Fäboliden orogenic gold deposit, northern Sweden. Licentiate thesis 2005:73, Luleå University of Technology. 7 p.

Bark, G. 2008. On the origin of the Fäboliden orogenic gold deposit, northern Sweden. PhD thesis 2008:7, Luleå University of Technology, Division of Ore Geology and Applied Geophysics. 20 p.

Beowulf Mining 2011. Available at: www.beowulfmining.net

Bergman, S., Kübler, L. & Martinsson, O. 2001. Description of regional geological and geophysical maps of northern Norrbotten County (east of the Caledonian orogen). Sveriges geologiska undersökning, serie Ba 56. 110 p.

Bergman, S., Högdahl, K., Nironen, M., Ogenhall, E., Sjöström, H., Lundqvist, L. & Lahtinen, R. 2008. Timing of Palaeoproterozoic intre-orogenic sedimentation in the central Fennoscandian Shield; evidence from detrital zircon in metasandstone. Precambrian Research 161, 231–249.

Bergman, T. 1986. Mineralogisk-mineralkemisk undersökning av Ädelfors guldfyndighet, norra Småland. Unpublished thesis, Stockholm University. 41 p. (in Swedish)

Bergman, T. 1994. The Wigström deposit western Bergslagen, Sweden: A contact metasomatic tungsten skarn deposit related to a late Svecofennian granite. Abstract 21st Nordic geological winter meeting, Tekniska Högskolan i Luleå, p. 21.

Bergman Weihed, J., Bergström, U. & Weihed, P. 1996. Geology, tectonic setting, and origin of the Paleoproterozoic Boliden Au-Cu-As deposit, Skellefte district, Northern Sweden. Economic Geology 91, 1073–1097.

Berthelsen, A. & Marker, M. 1986. 1.9–1.8 Ga old strike-slip megashears in the Baltic Shield, and their plate tectonic implications. Tectonophysics 128, 163–181.

Bingen, B., Andersson, J., Söderlund, U. & Möller, C. 2008. The Mesoproterozoic in the Nordic countries. Episodes 31, 29–34.

Boliden 2008. Annual report 2007. Available at: www.boliden.com

Boliden 2009. Annual report 2008. Available at: www.boliden.com

Boliden 2011a. Annual Report 2010. Available at: www.boliden.com

Boliden 2011b. Press release 24 February 2011. Available at: www.boliden.com

Bruun, Å., Sundberg, A., Wik, N.-G., Kornfält, K.-A., Wikman, H. & Wikström, A. 1991. Malmer; industriella mineral och bergarter i Kalmar län. Sveriges geologiska undersökning, Rapporter och meddelanden 65. 176 p. (in Swedish)

Carlon, C. J. 1984. The BP-LKAB-Jokkmokk mineral joint venture Tjåmotis; Jokkmokk; Swedish Lappland. Comments, notes and recommendations (June–September 1984). LKAB Prospektering AB, prospekteringsrapport bsg84-372. 80 p.

Carlson, L., Fjellström, M., Lundqvist, A. & Niva, B. 1983. Guld i Älvsbynområdet. Sveriges Geologiska AB, prospekteringsrapport, prap83025. 23 p. (in Swedish)

Carlsson, E. 1979. Kölen-malmen ”överlistad” – storfynd i Svärdsjö, Jernkontorets Annaler med Bergsmannen 163, 2/79, 54–56. (in Swedish)

Casanova, V. 2010. Geological and geophysical characteristics of the Pb-Zn sandstone-hosted autochthonous Laisvall deposit in the perspective of regional exploration of the Swedish Caledonian Front. Master thesis 2010:039, Luleå University of Technology. 32 p.

Chelle-Michou, C. 2008. Geology and Mineralization of the Bellviksberg Sandstone-Hosted Pb(-Zn) Deposit, Dorotea Area, Sweden. Master thesis 2008:054 PB, Luleå University of Technology. 54 p.

Christofferson, H., Wallin, B., Selkman, S. & Rickard, D. T. 1979. Mineralization controls in the sandstone lead-zinc deposits at Vassbo, Sweden. Economic Geology 74, 1239–1249.

Christofferson, H., Lundström, I. & Vivallo, W. 1986. The Garpenberg area and zinc-lead-copper deposit. In: Lundström, I. & Papunen, H. (eds) Mineral deposits of Southwestern Finland and the Bergslagen province, Sweden. Sveriges geologiska undersökning, serie Ca 61. 44 p.

Continental Precious Metals 2012. The Viken Licence. Available at: www.czqminerals.com.

Dahlenborg, L. 2007. A Rock Magnetic Study of the Åkerberg Gold Deposit, Northern Sweden. Examensarbeten i geologi vid Lunds universitet, Nr. 208. 32 p.

Dahlin, P. & Sjöström, H. 2010. Structure and stratigraphy of the Dannemora inlier, eastern Bergslagen Region, Primary volcanic textures, geochemistry and deformation. Department of Earth Sciences, Uppsala University. 33 p.

Dannemora Mineral AB 2011. Annual Report 2010. 82 p. Available at: www.dannemoramineral.se

Delin, H. 1993. The radiometric age of the Ljusdal granodiorite of central Sweden. In: Lundqvist, T. (ed.) Radiometric dating results. Geological Survey of Sweden. Sveriges geologiska undersökning, serie C 823, 13–16.

Du Rietz, T. 1953. Geology and Ores of the Kristineberg Deposit, Vesterbotten, Sweden. Sveriges geologiska undersökning, serie C 524. 91 p.

Edfelt, Å. 2007. The Tjårrojåkka Apatite-Iron and Cu (-Au) Deposits, Northern Sweden – Products of One Ore Forming Event. PhD thesis 2007:17, Luleå University of Technology, Department of Chemical Engineering and Geosciences, Division of Ore Geology and Applied Geophysics. 167 p.

Eilu, P., Bergman, T., Bjerkgård, T., Feoktistov, V., Hallberg, A., Ihlen, P. M., Korneliussen, A., Korsakova. M., Krasotkin, S., Muradymov, G., Nurmi, P. A., Often, M., Perdahl, J.-A., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. (comp.) 2009. Metallogenic Map of the Fennoscandian Shield, 1:2 000 000. Geological Survey of Finland, Geological Survey of Norway, Geological Survey of Sweden, The Federal Agency of Use of Mineral Resources of the Ministry of Natural Resources and Ecology of the Russian Federation.

Einarsson, Ö. & Minell, H. 1984. Slutrapport över uppföljningsarbeten 1983 Arvidsjaur och Moskosel. Sveriges Geologiska AB, prospekteringsrapport, prap84028. 20 p. (in Swedish)

Einaudi, M.T., Meinert, L. D. & Newberry, R. J. 1981. Skarn deposits. Economic Geology, 75th Anniversary Volume, 317–391.

Eklund, D. 2007. Mineralogy of the hypozonal Svartliden gold deposit, northern Sweden, with emphasis on the composition and paragenetic relations of electrum. Undergraduate thesis MN3, Department of Earth Sciences, Uppsala University. Vol. 139. 34 p.

Eriksson, B. & Hallgren, U. 1975. Beskrivning till berggrundskartbladen Vittangi NV, NO, SV, SO. Sveriges geologiska undersökning, serie Af 13–16. 203 p. (in Swedish)

Eriksson, T. 1983. Järnmalmen vid Björkholmen i Jokkmokk socken. Sveriges geologiska undersökning, prospekteringsrapport, brap83801. 13 p. (in Swedish)

Fredriksson, G. 1982. Geologisk rapport: Rekognoscering av Sjangeli- och Unna Allakas-fältens kopparmineraliseringar, Norrbottensfjällen. LKAB Prospektering AB, rapport pro8222. 13 p. (in Swedish)

Frietsch, R. 1966. Berggrund och malmer i Svappavaarafältet, norra Sverige. Sveriges geologiska undersökning, serie C 604. 282 p. (in Swedish)

Frietsch, R. 1969. P.M. rörande järnmalmsfyndigheterna Sakka, Skomern, Rebak, Rappen och Hejka. Sveriges geologiska undersökning, prospekteringsrapport, brap576. 12 p. (in Swedish)

Frietsch, R. F. 1979. Järnmalmsfyndigheten Tjavelk. Redogörelse för resultaten av SGU:s undersökningar 1968–69. Sveriges geologiska underökning, prospekteringsrapport, brap79507. 9 p. (in Swedish)

Frietsch, R. 1985. The Lannavaara iron ores, northern Sweden. Sveriges geologiska undersökning, serie C 807. 55 p.

Frietsch, R. 1997. The Iron Ore Inventory Programme 1963−1972 in Norrbotten County. Sveriges geologiska undersökning, rapporter och meddelanden 92. 77 p.

Frietsch, R. & Perdahl, J.-A. 1995. Rare earth elements in apatite and magnetite in Kiruna-type iron ores and some other iron ore type. Ore Geology Reviews 9, 489–510.

Frietsch, R., Tuisku, P., Martinsson, O. & Perdahl, J.-A. 1997. Early Proterozoic Cu-(Au) and Fe ore deposits associated with regional Na-Cl metasomatism in northern Fennoscandia. Ore Geology Reviews 12, 1–34.

Gavelin, S. 1984. The Västervik area in south-eastern Sweden. Studies in Proterozoic sedimentation, high-grade metamorphism and granitization. Sveriges geologiska undersökning, serie Ba 32. 171 p.

Gee, D. G. 1972. The regional context of the Tåsjö uranium project, Caledonian Front, Central Sweden. Sveriges geologiska undersökning, serie C 671. 36 p.

Gee, D. G. 1979. Projekt alunskiffer. Sammanfattning av undersökningar fram till 1978-12-31. Sveriges geologiska undersökning, prospekteringsrapport, brap79511. 28 p. (in Swedish)

Gee, D. G., Kumpulainen, R. A. & Thelander, T. 1978. The Tåsjön decollement, central Swedish Caledonides. Sveriges geologiska undersökning, serie C 742. 35 p.

Gee, D. G., Fossen, H., Henriksen, N. & Higgins, A. K. 2008. From the Early Paleozoic Platforms of Baltica and Laurentia to the Caledonide Orogen of Scandinavia and Greenland. Episodes 31, 44–51.

Geijer, P. 1919. Rapport över undersökningsarbeten å Nokutusvaara malmfält och Rektorsmalmen sommaren 1918. Sveriges geologiska undersökning, prospekteringsrapport, brap00806. 21 p. (in Swedish)

Geijer, P. 1930. Gällivare malmfält. Sveriges geologiska undersökning, serie Ca 22. 115 p. (in Swedish)

Geijer, P. 1936. Norbergs berggrund och malmfyndigheter. Sveriges geologiska undersökning, serie Ca 24. 162 p. (in Swedish)

Geijer P. 1961. The geological significance of the cerium mineral occurrences of the Bastnästype in Central Sweden. Arkiv för Mineralogi och Geologi 3(4), 99–105

Geijer, P. & Magnusson, N. H. 1944. De mellansvenska järnmalmernas geologi. Sveriges geologiska undersökning, serie Ca 35. 654 p. (in Swedish)

Gold Ore Resources 2011. Operations. Available at: www.goldoreresources.com

Gorbatschev, R. & Bogdanova, S. 2004. The Protogine Zone south of Lake Vättern: a major lithospheric boundary in the Baltic Shield. Geologiska Föreningen i Stockholm Förhandlingar (GFF) 126, 22–23.

Grängesberg Iron AB 2011. Operations. Available at: www.grangesberg.com

Grip, E. 1978. Sweden. In: Bowie, S. H. U. Kvalheim, A. & Haslam, H. W. (eds) Mineral Deposits in Europe, vol. 1. Northwest Europe. London: Institution of Mining and Metallurgy. 362 p.

Grip, E. & Frietsch, R. 1973. Malm i Sverige 2 Norra Sverige. Almqvist & Wiksell. 295 p. (in Swedish)

Gustafsson, B. 1979. Uranuppslag inom Norrbotten och Västerbotten 1979. Sveriges geologiska undersökning, prospekteringsrapport, brap79056. 23 p. (in Swedish)

Gustafsson, B. 1981. Uranium exploration in the N. Västerbotten – S. Norrbotten province, northern Sweden. Uranium Exploration Case Histories, Proceedings of an advisory group meeting on case histories of uranium exploration jointly organized by the International Atomic Energy Agency and the OECD Nuclear Energy Agency and held in Vienna, 26–29 November 1979, 333–350.

Gustafsson, B. 1990. Sällsynta jordartsmetaller i Sverige. Sveriges Geologiska AB, prospekteringsrapport, prap90024. 36 p. (in Swedish)

Gustafsson, B. 2007. Uran i Sverige och världen. Geologiskt forum 55, 30–32. (in Swedish)

Hallberg, A. 1994. The Enåsen gold deposit, central Sweden: 1. A Palaeoproterozoic high-sulphidation epithermal gold mineralization. Mineralium Deposita 29, 150–162.

Hallberg, A. 2001. Rock classification, magmatic affinity and hydrothermal alteration at Boliden, Skellefte district, Sweden – a desk-top approach to whole rock geochemistry. In: Weihed, P. (ed.) Economic geology research, Volume 1 1999–2000. Sverige geologiska undersökning, serie C 833, 93–131.

Hallberg, A. & Fallick, A. E. 1994. The Enåsen gold deposit, central Sweden: 2. Light element stable isotope evidence of premetamorphic hydrothermal activity. Mineralium Deposita 29, 163–169.

Hallberg, A., Rimsa, A. & Hellström, F. 2008. Age of the host-rock to the Grängesberg apatite-iron ore. Sveriges geologiska undersökning, rapport 2008:27, 19–22.

Hallgren, U. G. 1970. Sautusvaara järnmalmsfyndighet rapport rörande resultaten av SGU:s undersökningar under åren 1961–1967. Sveriges geologiska underökning, prospekteringsrapport, brap00893. 110 p. (in Swedish)

Hammergren, P. 1989. En sedimentknuten stratiform koppar- och silvermineralisering i Dalsland, Sverige. Sveriges Geologiska AB, prospekteringsrapport, prap89508. 36 p. (in Swedish)

Hedberg, N. 1907. Grängesberg. En gruffältsbeskrivning. Jernkontorets Annaler 62, 67–125. (in Swedish)

Hedin, J.-O. 1988. Sjiska granitområde. Slutrapport stödetapp III. LKAB Prospektering AB, prospekteringsrapport K8801. 7 p. (in Swedish)

Hedström, P., Simeonov, A. & Malmström, L. 1989. The Zinkgruvan ore deposit, south-central Sweden: A Proterozoic, proximal Zn-Pb-Ag deposit in distal volcanic facies. Economic Geology 84, 1235–1261.

Hill, T. 1981. Allebuouda Molybden, malmberäkning av ”Stora Malmen”. LKAB prospekteringsrapport, pro8115. 70 p. (in Swedish)

Hill, T. 1984. Slutrapport. Projekt Arjeplog, objekt Maldok. LKAB Prospektering AB, prospekteringsrapport S8436. 111 p. (in Swedish)

Hiltunen, A. 1982. The Precambrian geology and skarn iron ores of the Rautuvaara area, northern Finland: Geological Survey of Finland, Bulletin 318. 133 p.

Hitzman, M. W., Oreskes, N. & Einaudi, M. T. 1992. Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits. Precambrian Research 58, 241–287.

Hjelmqvist, S. 1950. The titaniferous iron-ore deposit of Taberg in the south of Sweden. Sveriges geologiska undersökning, serie C 512. 55 p.

Högbom A. 1937. Skelleftefältet, med angränsande delar av Västerbottens och Norrbottens län, en översikt av berggrund och malmförekomster. SGU C 389. 122 p.

Holme, K. 1986. Preliminär tonnageberäkning på Sierkavare kopparmineralisering. LKAB Prospektering, prospekteringsrapport, K8634. 5 p. (in Swedish)

Hölttä, P., Väisänen, M., Väänänen, J. & Manninen, T. 2007. Paleoproterozoic metamorphism and deformation in central Lapland, Finland. Geological Survey of Finland, Special Paper 44, 7–56.

Hübner, H. 1971. Molybdenum and tungsten occurrences in Sweden. Sveriges geologiska undersökning, serie Ca 46. 29 p.

Hugg, R. & Heiskanen, V. 1983. Suomen rautamalmiesiintymät, malmiutumat ja malmiviitteet. Rautaruukki Oy OU 2/79, RAETSU Report 8.2.1983. 412 p. (in Finnish)

Jansson, N. 2007. A Structural and Ore Geological study of the Palaeoproterozoic Stratabound Sala Zn-Pb-Ag deposit, Bergslagen, Sweden. Undergraduate thesis, Department of Earth Sciences, Uppsala University, 148. 82 p.

Jansson, N. 2009. The origin of the Ryllshyttan stratabound Zn-Pb-Ag-(Cu) + magnetite deposit, Garpenberg, Bergslagen, Sweden. Licentiate thesis, Luleå University of Technology. 37 p.

Johansson, R. 1980. Jokkmokkområdets järnmalmer – Geofysisk tolkning med malmberäkning. Sveriges geologiska undersökning, prospekteringsrapport, brap86005. 14 p. (in Swedish)

Jönsson, M. & Mattsson, C. 1984. Prospektering i Söderhamns kommun 1983. LKAB Prospektering AB rapport bsg 353. 137 p. (in Swedish)

Karis, L. & Strömberg, A. G. B. 1998. Beskrivning till berggrundskartan över Jämtlands län, del 2: Fjälldelen. Sveriges geologiska undersökning serie Ca 53:2. 236 p. (in Swedish with English summary)

Kathol, B. & Weihed, P. (eds) 2005. Description of regional geological and geophysical maps of the Skellefte District and surrounding areas. Sveriges geologiska undersökning, serie Ba 57. 197 p.

Koistinen, T., Stephens, M.B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comp.) 2001. Geological map of the Fennoscandian Shield, 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, Moscow: Ministry of Natural Resources of Russia.

Kullman, F. 1985a. PM angående uranprospektering i Åseleområdet 1985. Sverige Geologiska AB, prospekteringsrapport, IRAP85040. 19 p. (in Swedish)

Kullman, F. 1985b. Björkråmyran. Malmberäkning 1985. Sveriges Geologiska AB, prospekteringsrapport, IRAP85039. 36 p. (in Swedish)

Kullman, F. 1989. A uranium-zirconium mineralization in Revsund granite at Björkråmyran, Northern Sweden. Uranium Deposits in Magmatic and Metamorphic Rocks. Proceedings of a Technical Committee Meeting of Uranium Deposits in Magmatic and Metamorphic Rocks, organized by the International Atomic Energy Agency and held in Salamanca, 29 September – 3 October 1986, 45–56.

Lager, I. 2001. The geology of the Palaeoproterozoic limestone-hosted Dannemora iron deposit, Sweden. Sveriges geologiska undersökning, Rapporter och meddelanden 107. 49 p.

Lagergren, L. 1983. Vanadin-titanfyndigheten Masugnsberget, resultat av borrning. Sveriges Geologiska AB, prospekteringsrapport, prap83534. (in Swedish)

Larsson, D. & Söderlund, U. 2005. Lu-Hf apatite geochronology of mafic cumulates: An example from a Fe-Ti mineralization at Smålands Taberg, southern Sweden. Chemical Geology 224, 201–211.

Lasskogen, J. 2010. Volcanological and volcano-sedimentary facies stratigraphical interpretation of the Falun Cu-Zn-Pb-(Ag-Au) sulphide deposit, Bergslagen district, Sweden. Master thesis, Luleå University of Technology, Division of Ore Geology. 104 p.

Lilljequist, R. 1973. Caledonian geology of the Laisvall area, Southern Norrbotten, Swedish Lapland. Sveriges geologiska undersökning, serie C 691. 43 p.

Lilljequist, R. 1981. Preliminära undersökningar av guldinnehållet inom skilda geologiska miljöer av Norrbottens berggrund. Sveriges geologiska undersökning, prospekteringsrapport, brap81039. 43 p. (in Swedish)

Lindblad, K. 1985. Kiruna västra, lägesrapport. LKAB Prospektering, prospekteringsrapport, K8533. 8 p. (in Swedish)

Lindblom, L. & Persson, G. 1983. Vanadin-titanfyndigheten Simesvallen Resultat av borrning samt mineralogisk undersökning. Sveriges Geologiska AB, prospekteringsrapport, prap83524. 31 p. (in Swedish)

Lindblom, L. & Ros, F. 1983. Vanadin-titanfyndigheten Gruvberget. Sveriges Geologiska AB, prospekteringsrapport, prap83560. 47 p. (in Swedish)

Lindroos, H. 1972. PM Angående Kaunisvaara malmstråk. Sveriges geologiska undersökning, brap763. (in Swedish)

Lindroos, H. 1974. The stratigraphy of the Kaunisvaara iron ore district, northern Sweden. Sveriges geologiska undersökning, serie C 695. 18 p.

Lindroos, H. 1979. Översiktlig geologi och malmberäkning av uranfyndigheten Duobblon. Sveriges geologiska undersökning, prospekteringsrapport, brap79047. 92 p.

Lindroos, H. 1989. Gold exploration in the Juktan area, 1989. Sveriges Geologiska AB, prospekteringsrapport, prap89536.

Lindroos, H. & Johansson, K. 1972. Ruutijärvi järnmalmsfyndighet. Rapport rörande resultaten av SGU:s undersökningar under åren 1963–1971. Sveriges geologiska undersökning, brap762. (in Swedish)

Lindroos, H., Nylund, B. & Johansson, K. I. 1972. Tapuli och Palotieva järnmalmsfyndigheter. Rapport rörande resultaten av SGU:s undersökningar under åren 1963–1969. Sveriges geologiska undersökning, brap764.

Ljung, S. 1974. Adak-Lindsköld och Brännmyrangruvorna inom Adakfältet. Sveriges geologiska undersökning, serie C 701. 94 p. (in Swedish)

LKAB 2010. Annual Report 2009. Available at: www.lkab.com

LKAB 2011. Annual Report 2010. Available at: www.lkab.com

Looström, R. 1939. Lönnfallet. Southernmost Part of the Export Field at Grängesberg. Sveriges geologiska undersökning, serie C 428. 30 p.

Lundberg, B. 1967. The Stora Sahavaara iron ore deposit, Kaunisvaara, Northern Sweden. Sveriges geologiska undersökning, serie C 620. 37 p.

Lundegårdh, P. H. 1956. The titaniferous ore-bearing gabbro of Helsingland, central Sweden, Sveriges geologiska undersökning, serie C 549. 34 p.

Lundin Mining 2008. Annual report 2007. Available at: www.lundinmining.com

Lundin Mining 2010a. Reserves & Resources, June 30 2010. Available at: www.lundinmining.com

Lundin Mining 2010b. Production statistics. Available at: www.lundinmining.com

Lundmark, C. 1983. Vaikijaur. Resultat av borrningsarbeten okt–dec 1982. Sveriges Geologiska AB, prospekteringsrapport, prap83048. 8 p. (in Swedish)

Lundmark, C. 1984. Finnträsket – borrning 1984. Sveriges Geologiska AB, prospekteringsrapport, prap84113. 32 p. (in Swedish)

Lundmark, C. 1985. Stavsträsk – områdets geologi och resultat från 1984 års diamantborrning. Sveriges Geologiska AB, prospekteringsrapport, prap85026. 13 p. (in Swedish)

Lundmark, C. 2003. Vaikijaur, a palaeoproteroic Cu-Au porphyry style mineralization in the Jokkmokk granitoid at the Archaean–Proterozoic boundary in northern Sweden. Licentiate thesis 2003:5, Luleå University of Technology. 69 p.

Lundmark, C., Stein, H. & Weihed, P. 2005. The geology and Re–Os geochronology of the Palaeoproterozoic Vaikijaur Cu-Au(-Mo) porphyry-style deposit in the Jokkmokk granitoid, northern Sweden. Mineralium Deposita 40, 396–408.

Lundqvist, T. 1968. Precambrian geology of the Los–Hamra region central Sweden. Sveriges geologiska undersökning, serie Ba 23. 255 p.

Lundqvist, T. 1987. Early Svecofennian stratigraphy of southern and central Norrland, Sweden, and the possible existence of an Archaean basement west of the Svecokarelides. Precambrian Research 35, 343–352.

Lundqvist, T., Willden, M., Kresten, P. & Sundblad, K. 1986. The Enåsen Au deposit and the Alnö alkaline complex. Sveriges geologiska undersökning, serie Ca 67. 22 p.

Lundström, I., Allen, R. L., Persson, P. O. & Ripa, M. 1998. Stratigraphies and depositional ages of Svecofennian, Palaeoproterozoic metavolcanic rocks in E. Svealand and Bergslagen, south central Sweden. GFF 120, 315–320.

Magnusson, N. H. 1938. Neue Untersuchungen innerhalb des Grängesberg-feldes. Sveriges geologiska undersökning, serie C 418. 44 p. (in German)

Magnusson, N. H. 1973. Malm i Sverige 1, mellersta och södra Sverige. Stockholm: Almqvist & Wiksell. 320 p. (in Swedish)

Mansfeld, J. 1996. Geological, geochemical and geochronological evidence for a new Palaeoproterozoic terrain in southeastern Sweden. Precambrian Research 77, 91–103.

Mansfeld, J., Beunk, F. & Barling. J. 2005. 1.83–1.82 Ga formation of a juvenile volcanic arc – implications from U-Pb and Sm-Nd analyses of the Oskarshamn-Jönköping Belt, southeastern Sweden. Geologiska Föreningen i Stockholm Förhandlingar (GFF) 127, 149–157.

Martinsson, O. 1993. Stratigraphy of greenstones in the eastern part of northern Norrbotten. In: Martinsson, O., Perdahl, J.-A. & Bergman, J.: Greenstone and porphyry hosted ore deposits in northern Norrbotten, NUTEK Project nr 92-00752P, 1–5.

Martinsson, O. 1997. Tectonic setting and metallogeny of the Kiruna greenstones. PhD thesis 1997:19, Luleå University of Technology. 162 p.

Mattson, B. 1991. Mineralmarknaden Tema: Krom. Sveriges geologiska undersökning, Periodiska Publikationer 1991:1, 32–34. (in Swedish)

Mattsson, H. & Elming, S.-Å. 2001. Magnetic fabrics and paleomagnetism of the Storsjö-Edsbyn deformation zone. Precambrian Research 107, 265–281.

Mawson Resources 2010. Kläppibäcken Uranium Project. Available at: www.mawsonresources.com

Mawson Resources 2011. Uranium projects, Duobblon uranium project. Available at: www.mawsonresources.com

Monro, D. 1988. The geology and genesis of the Aitik Cu-Au deposit, arctic Sweden. PhD thesis, Department of Geology, University College, Cardiff. 386 p.

Niiranen, T., Poutiainen, M. & Mänttäri, I. 2007. Geology, geochemistry, fluid inclusion characteristics, and U–Pb age studies on iron oxide–Cu–Au deposits in the Kolari region, northern Finland. Ore Geology Reviews 30, 75–105.

Nilsson, C. A. 1968. Wall rock alteration at the Boliden deposit, Sweden. Economic Geology 63, 472–494.

Nilsson, G. 1985. Nickel-copper deposits in Sweden. In: Papunen, H. & Gorbunov, G. I. (eds): Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geological Survey of Finland, Bulletin 333, 313–362.

Northland Resources 2007. Press release 23 Aug. 2007. Available at: www.northland.eu

Northland Resources 2010a. Press release 12 May 2010. Available at: www.northland.eu

Northland Resources 2010b. Tapuli. Project presentation at: www.northland.eu/s/Tapuli.asp

Northland Resources 2010c. Pellivuoma. Project presentation at: http://www.northland.eu/s/Pellivuoma.asp

Northland Resources 2010d. Sahavaara. Project presentation at: http://www.northland.eu/s/Sahavaara.asp

Nykänen, V., Groves, D. O., Ojala, V. J., Eilu, P. & Gardoll, S. 2008. Reconnaissance-scale conceptual fuzzy-logic prospectivity modelling for iron oxide copper – gold deposits in the northern Fennoscandian Shield, Finland. Australian Journal of Earth Sciences 55, 25–38.

Nysten, P. & Annersten, H. 1985. The gold mineralization at Enåsen, central Sweden. Geologiska Föreningens i Stockholm Förhandlingar (GFF) 106, 245–256.

Nystuen, J. P., Andresen, A., Kumpulainen, R. A. & Siedlecka, A. 2008. Neoproterozoic basin evolution in Fennoscandia, East Greenland and Svalbard. Episodes 31, 35–43.

Ödman, O. H. 1941. Geology and Ores of the Boliden Deposit, Sweden. Sveriges geologiska undersökning, serie C 438. 190 p.

Ödman, O. H. 1943. Geology of the copper deposit at Laver, N. Sweden. Sveriges geologiska undersökning, serie C 452. 35 p.

OECD 2006. Uranium 2005: Resources, Production and Demand. A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency. 388 p.

Ogenhall, E. 2010. Geological evolution of the supracrustal Palaeoproterozoic Hamrånge Group: a Svecofennian case study. Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 738. 53 p.

Öhlander, B. 1986a. Uranium occurrences in the Arvidsjaur district. In: Öhlander, B. (ed.) Proterozoic mineralizations associated with granitoids in northern Sweden. 7th IAGOD Symposium and Nordkalott project meeting. Sveriges geologiska undersökning, serie Ca 65, 20–21.

Öhlander, B. 1986b. Proterozoic mineralizations associated with granitoids in Northern Sweden. Sveriges geologiska undersökning, serie Ca 65. 41 p.

Ohlsson, L.-G. 1979. Tungsten occurrences in Sweden. Economic Geology 74, 1012–1034.

Padget, P. 1970. Beskrivning till berggrundskartbladen Tärendö NV, NO, SV, SO. Sveriges geologiska undersökning, serie Af 5–8, 95 p. (in Swedish)

Padget, P. 1977. Beskrivning till berggrundskartbladen Pajala NV, NO, SV, SO, Sveriges geologiska undersökning, serie Af 21–24. 36 p. (in Swedish)

Padget, P., Ek, J. & Eriksson L. 1969. Vargisträsk, a case history in ore prospecting. Geoexploration 7, 163–175.

Parak, T. 1969. Nya undersökningar inom Kirunafältets norra del. Geologiska Föreningen i Stockholm, Förhandlingar (GFF) 91, 34–51. (in Swedish)

Parak, T. 1975. The origin of the Kiruna Iron ores. Sveriges geologiska undersökning, serie C 709. 209 p.

Patison, N. J. 2007. Structural controls on gold mineralisation in the Central Lapland Greenstone Belt. Geological Survey of Finland, Special Paper 44, 105–122.

Persson, G. 1982. Kiskamavaara tonnageberäkning på koppar och kobolt. Sveriges geologiska undersökning, prospekteringsrapport, brap82509. 5 p. (in Swedish)

Quezada, R. 1979. Ultevisfältet preliminär geologisk rapport. Sveriges geologiska undersökning, prospekteringsrapport, brap79009. 10 p. (in Swedish)

Rickard D. (ed.) 1986. The Skellefte Field. Sveriges geologiska undersökning, serie Ca 62. 54 p.

Rickard, D. T., Willdén, M. Y., Marinder, N.-E. & Donnelly, T. H. 1979. Studies on the genesis of the Laisvall sandstone lead-zinc deposit, Sweden. Economic Geology 74, 1255–1285.

Romer, R. 1987. The Sjangeli area. LKAB Prospektering AB, rapport, K8724. 34 p.

Romer, R. 1988. Disturbance of Pb, Sr and Nd isotope system related to medium and low grade metamorphism illustrated with data from the polymetamorphic early proterozoic (Romback)-Sjangeli basement window of the Caledonian of Sweden. PhD thesis 1988:65D, Technical University of Luleå. 10 p.

Ros, F. 1979. Tjårrojåkka kopparmalmsfyndighet, Sveriges geologiska undersökning, prospekteringsrapport, brap82567. 13 p. (in Swedish)

Ros, F., Nylund, B. & Oldeberg, H. 1980. Pellivuoma Järnmalmsfyndighet, Rapport rörande resultaten av SGU:s undersökningar under åren 1964–1971. Sveriges geologiska undersökning, brap80011. (in Swedish)

Scandinavian Resources 2011. Press release. www.scandinavianresources.com

SGU Mineralmarknaden 2007. Tema: Nickel. Sveriges geologiska undersökning, Periodisk publikation 2007:1, p. 86. (in Swedish)

Shaikh, N. A., Persson, L., Sundberg, A. & Wik, N.-G. 1989. Malmer, industriella mineral och bergarter i Jönkopings län. Sveriges geologiska undersökning, Rapporter och meddelanden 50. 127 p. (in Swedish)

Skiöld, T. 1988. Implications of new U-Pb zircon chronology to early Proterozoic crustal accretion in northern Sweden. Precambrian Research 38, 147–164.

Smellie, J. A. T. 1982. The mineralogy and genesis of uranium in rhyolitic ignimbrites of Precambrian age from Duobblon, Sweden. Mineralogical Magazine 46, 187–199.

Smellie, J. A. T. & Laurikko, J. 1984. Skuppesavon, Northern Sweden: A uranium mineralisation associated with alkali metasomatism. Mineralium Deposita 19, 183–192.

Smith, M., Coppard, J., Herrington, R. & Stein, H. 2007. The Geology of the Rakkurijärvi Cu-(Au) Prospect, Norrbotten: A New Iron Oxide-Copper-Gold Deposit in Northern Sweden. Economic Geology 102, 393–414.

Sorjonen-Ward, P., Nurmi, P., Härkönen, I. & Pankka, H. 1992. Epigenetic gold mineralization and tectonic evolution of a lower Proterozoic greenstone terrain in the northern Fennoscandian (Baltic) Shield. In: Sarkar, S. C. (ed.) Metallogeny Related to Tectonics of the Proterozoic Mobile Belts. New Delhi: Oxford & IBH Publishing, 37–52.

Stein, H. J., Morgan, J. W. & Scherstén, A. 2000. Re-Os dating of low-level highly radiogenic (LLHR) sulfides: The Harnäs gold deposit, Southwest Sweden, records continental-scale tectonic events. Economic Geology 95, 1657–1671.

Stephens, M. B., Thelander, T. & Zachrisson, E. 1979. Compilation and bibliography of stratabound sulphide deposits in the Swedish Caledonides. Sveriges geologiska undersökning, berggrundsrapport, brap81566. 37 p.

Stephens, M. B., Thelander, T. & Karis, L. 2005. Bedrock map 20E Hotagen NV, scale 1:50 000. Sveriges geologiska undersökning, serie Ai 178.

Stephens, M. B., Ripa, M., Lundström, I., Persson, L., Berg-

man, T., Ahl, M., Wahlgren, C.-H., Persson, P.-O. & Wickström, L. 2009. Synthesis of the bedrock geology in the Bergslagen region, Fennoscandian Shield, south-central Sweden. Sveriges geologiska undersökning, serie Ba 58. 259 p.

Sultan, L. & Plink-Björklund, P. 2006. Depositional environments at a Palaeoproterozoic continental margin, Västervik Basin, SE Sweden. Precambrian Research 145, 243–271.

Sundbergh, S. & Niva, B. 1981. Vaikijaur. Sveriges geologiska undersökning, prospekteringsrapport, brap81006. 27 p. (in Swedish)

Tegengren, F. 1924. Sveriges ädlare malmer och bergverk. Sveriges geologiska undersökning, serie Ca 17. 406 p. (in Swedish)

Tegengren, F. R. 1962. Vassbo blymalmsfyndighet i Idre och dess geologiska inramning Sveriges geologiska undersökning, serie C 586. 61 p. (in Swedish with English summary)

Thelander, T. 1987. Hamrånge slutrapport 1987. Sveriges Geologiska AB, prospekteringsrapport, prap87539. 37 p. (in Swedish)

Thelander, T. & Hammergren, P. 1985. Prospekteringsarbeten inom projekt Dingelvik 1984 med tonnage- och haltberäkningar. Sveriges Geologiska AB, prospekteringsrapport, prap85503. 19 p. (in Swedish)

Theolin, A. 1962. Malm- och mineralfyndigheter inom Jokkmokk, Arvidsjaur och Arjeplogs socknar, Norrbottens län. Sveriges geologiska undersökning, prospekteringsrapport, brap00673. 8 p. (in Swedish)

Tilas, D. 1760. Tabergs järnmalmsberg i Småland, Jönköpings landshöfdingedöme, Tveta härad, Månsarpa socken, på Kåperyds bergsmans-hemmans ägor: beskrifvit i September månad 1757, Kongl. Vetenskaps-Academiens Handlingar för 1760, 21, 14–29. (in Swedish)

Troeng, B. 1982. Uranium-rich granites in the Olden window, Sweden. Mineralogical Magazine 46, 217–226.

Uytenbogaardt, W. 1960. Uranium mineralization in the Västervik area. International Geological Congress. Report of the Twenty-First Session, Norden 15, 114–122.

Väänänen, J. & Lehtonen, M. I. 2001. U-Pb isotopic age determinations from the Kolari–Muonio area, western Finnish Lapland. Geological Survey of Finland, Special Paper 33, 85–93.

Viking Mineral AB 2011. Projects; Bunsås. Available at: www.wikingmineral.se

Wahlström, M. & Sundblad, K. 1986. The Sunnerskog Cu-(W-Mo) deposit – A Proterozoic cordilleran-type skarn mineralization in southeastern Sweden. Terra Cognita 6:3, p. 521.

Walser G. 1980. Tjärrovare – Prospekteringsinsatser 1968–1980. Sveriges geologiska undersökning, prospekteringsrapport, brap80020. 31 p.

Walser, G. & Einarsson, Ö. 1982. The geological context of molybdenum occurrences in the southern Norrbotten region, northern Sweden. Geologische Rundschau 71, 213–229.

Wanhainen, C. 2005. On the Origin and Evolution of the Palaeoproterozoic Aitik Cu-Au-Ag Deposit, Northern Sweden. PhD thesis 2005:36, Luleå University of Technology, Department of Chemical Engineering and Geosciences. 151 p.

Wanhainen, C. & Martinsson, O. 1999. Geochemical characteristics of host rocks to the Aitik Cu-Au deposit, Gellivare area, northern Sweden. Proceedings of the Fifth Biennial SGA Meeting and 10. IAGOD Quadrennial Symposium, London, 22–25.8.1999, 1443–1446.

Wanhainen, C., Billström, K. & Martinsson, O. 2006. Age, petrology and geochemistry of the porphyritic Aitik intrusion, and its relation to the dissaminated Aitik Cu-Au-Ag deposit, northern Sweden. GFF 128, 273–286.

Weihed, P. 1992a. Geology and genesis of the Early Proterozoic Tallberg porphyry type deposit, Skellefte district, northern Sweden. Geologiska Institutionen, Chalmers Tekniska Högskola – Göteborgs Universitet vol. A 72, 1–147.

Weihed, P. 1992b. Lithogeochemistry, metal and alteration zoning in the Proterozoic Tallberg porphyry-type deposit, northern Sweden. Journal of Geochemical Exploration 42, 301–325.

Weihed, P. 2001. A review of Palaeoproterozoic intrusive hosted Cu-Au-Fe-oxide deposits in northern Sweden. In: Weihed. P. (ed.) Economic Geology Research 1, 1999–2000. Sveriges geologiska undersökning, serie C 833, 4–32.

Weihed, P., Bergman, J. & Bergström, U. 1992. Metallogeny and tectonic evolution of the Early Proterozoic Skellefte district, northern Sweden. Precambrian Research 58, 143–167.

Weihed, P., Bergman Weihed, J. & Sorjonen-Ward, P. 2003. Structural evolution of the Björkdal gold deposit, Skellefte district, northern Sweden: Implications for Early Proterozoic mesothermal gold in the late stage of the Svecokarelian orogen. Economic Geology 98, 1291–1309.

Weihed, P., Eilu, P., Larsen, R. B., Stendal, H. & Tontti, M. 2008. Metallic mineral deposits in the Nordic countries. Episodes 31, 125–132.

Wik, N.-G., Lundqvist, I., Selinus, O., Sivhed, U., Sundberg, A. & Wikström, A. 2002. Malmer, industriella mineral och bergarter i Västra Götalands län, inklusive kommunerna Habo och Mullsjö. Sveriges geologiska undersökning, Rapporter och meddelanden 108. 255 p. (in Swedish)

Wik, N.-G., Bergström, U., Bruun, Å., Claeson, D., Jelinek, C., Juhojuntti, N., Kero, L., Lundqvist, L., Stephens, M. B., Sukotjo, S. & Wikman, H. 2005. Beskrivning till regional berggrundskarta över Kalmar län. Sveriges geologiska undersökning Ba 66. 50 p. (in Swedish)

Wik, N.-G., Albrecht, L., Bergman, S., Kübler, L. & Sundberg, A. 2009. Malmer, industriella mineral och bergarter i Gävleborgs län. Sveriges geologiska undersökning, Rapporter och meddelanden 130. 310 p. (English summary)

Wikström A. & Karis L. 1989. Beskrivning till berggrundskartorna Finspång NO, SO, NV, SV. Sveriges geologiska undersökning, Af 162, 163, 164, 165. 186 p. (in Swedish, with English summary)

Wilson, M. R. & Åkerblom, G. V. 1980. Uranium enriched granites in Sweden. Sveriges geologiska undersökning, Rappporter och meddelanden 19. 31 p.

Wilson, M. R. & Åkerblom, G. V. 1982. Geological setting and geochemistry of uranium rich granites in the Proterozoic of Sweden. Mineralogical Magazine 46, 233–245.

Witschard, F. 1996. Berggrundskartan 28K Gällivare SV, skala 1:50 000. Sveriges geologiska undersökning, serie Ai 100.

Zachrisson, E. & Eriksson, L. 1981. Kopparmineraliseringen Sylarna. Sveriges geologiska undersökning, prospekteringrapport, brap81547. 32 p. (in Swedish)

Zweifel, H. 1976. Aitik – geological documentation of a disseminated copper deposit. Sveriges geologiska undersökning, serie C 720. 79 p.

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 207–342, 2012

METALLOGENIC AREAS IN FINLAND

Eilu, P., Ahtola, T., Äikäs, O., Halkoaho, T., Heikura, P., Hulkki, H., Iljina, M., Juopperi, H., Karinen, T., Kärkkäinen, N., Konnunaho, J., Kontinen, A., Kontoniemi, O., Korkiakoski, E., Korsakova, M., Kuivasaari, T., Kyläkoski, M., Makkonen, H., Niiranen, T., Nikander, J., Nykänen, V., Perdahl, J.-A., Pohjolainen, E., Räsänen, J., Sorjonen-Ward, P., Tiainen, M., Tontti, M., Torppa, A. & Västi, K. 2012. Metallogenic areas in Finland. *Geological Survey of Finland, Special Paper 53, 207–342*, 90 figures and 43 tables.

Forty-seven metallogenic areas have been identified in Finland. Of these, 10 areas are dominantly potential for ferrous metals (Fe, Ti, V, Cr), 11 for precious metals (Au, Pd, Pt), 11 for nickel, 8 for copper, zinc and/or lead, 4 for metals mostly used in advanced technologies ('high-tech metals' Be, Li, Nb, REE, Ta), and 3 for uranium. Many of the metallogenic areas are potential for more than just one major group of metals. The Finnish metallogenic areas include more than 30 different genetic types of metal deposits. By past production and present resources, the most significant deposit types include: mafic intrusion-hosted Ti-Fe-V (e.g., Mustavaara deposit at Koillismaa), mafic to ultramafic hosted Cr (Kemi), IOCG-style Fe±Cu,Au (Hannukainen deposit in the Pajala-Kolari area), magmatic Ni-Cu-PGE (Portimo, Koillismaa, Hitura and Kotalahti areas, and Kevitsa and Sakatti deposits), orogenic gold (Kittilä), and VMS (Vihanti-Pyhäsalmi). Highly significant are also the unique deposit types of Outokumpu Cu-Co and Talvivaara Ni-Zn-Cu-Co. Most of the known metal endowment of Finland was formed during the Palaeoproterozoic Era, during 2.45–1.92 Ga multi-stage rifting and the 1.9–1.8 Ga Svecofennian orogeny. Detected metal endowment in the Archaean is relatively low with minor komatiite-related Ni (Kuhmo) and orogenic gold deposits (Ilomantsi). Carbonatite-hosted Nb-REE at Sokli, dated to ca. 365 Ma, is the main post-Svecofennian metal deposit known from Finland.

Keywords (GeoRef Thesaurus, AGI): metallogenic provinces, mineral resources, metal ores, mines, production, Paleozoic, Proterozoic, Archean, Finland

Timo Ahtola, Pasi Eilu, Niilo Kärkkäinen, Markku Tiainen, Mikko Tontti
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

Olli Äikäs, Tapio Halkoaho, Asko Kontinen, Tapio Kuivasaari, Jarmo Nikander, Esa Pohjolainen, Peter Sorjonen-Ward, Akseli Torppa, Kaj Västi
Geological Survey of Finland, P.O. Box 1237, FI-70211 Kuopio, Finland

Olavi Kontoniemi
Geological Survey of Finland, P.O. Box 97, FI-67101 Kokkola, Finland

Pertti Heikura, Helena Hulkki, Markku Iljina, Heikki Juopperi, Tuomo Karinen, Jukka Konnunaho, Esko Korkiakoski, Markus Kyläkoski[†], Tero Niiranen, Vesa Nykänen, Jorma Räsänen
Geological Survey of Finland, P.O. Box 77, FI-96101 Rovaniemi, Finland
[†] Deceased

Hannu Makkonen
Belvedere Mining Oy, Kummuntie 8, FI-85560 Ainastalo, Finland
Present address: Geological Survey of Finland, P.O. Box 77, FI-96101 Rovaniemi, Finland

Margarita Korsakova
State Company Mineral, Detskaya str., 26 liter A office 4H, 199106 St. Petersburg, Russia

Jan-Anders Perdahl
Geological Survey of Sweden, Mineral Resources Information Office, Skolgatan 11, 93070 Malå, Sweden

E-mail: pasi.eilu@gtk.fi

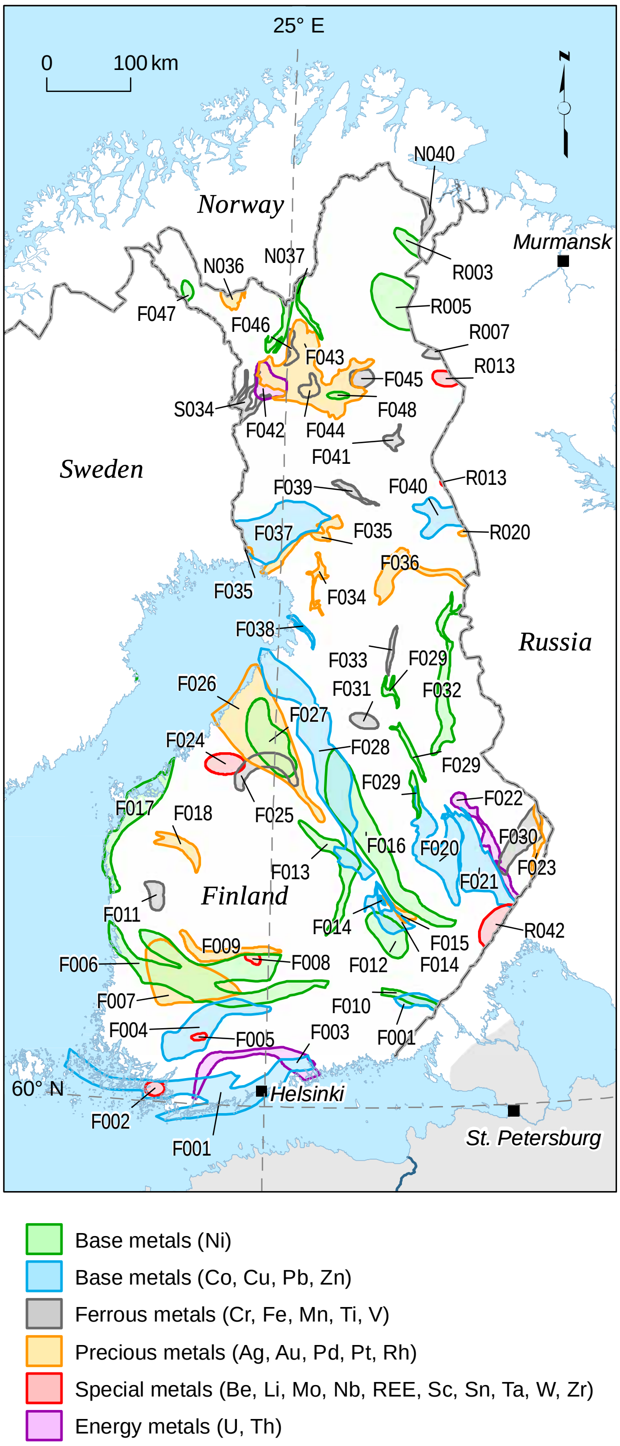


Figure 1. Index map of metallogenic areas in Finland. The names of the metallogenic areas are listed in Table 1. Note that areas coded to Norway (N), Sweden (S) and Russia (R) are described in sections for these countries.

Table 1. List of the metallogenic areas in Finland.

Code	Area name, main metals
F001	Orijärvi Zn, Cu, Ag, Pb
F002	Kemiö Ta, Be
F003	Palmottu U
F004	Häme Zn, Au, Ag
F005	Somero Li
F006	Vammala Ni, Co, Cu
F007	Pirkkala Au
F008	Eräjärvi Ta, Li, Be
F009	Tampere Au, Cu
F010	Telkkälä Ni, Co
F011	Peräkorpi Ti
F012	Puumala Ni, Co
F013	Ilmolahti Ni, Co, Cu
F014	Virtasalmi Cu
F015	Rantasalmi Au
F016	Kotalahti Ni, Co
F017	Oravainen Ni, Co
F018	Seinäjoki Au, Sb
F020	Outokumpu Co, Cu
F021	Hammaslahti Cu, Zn
F022	Koli U
F023	Ilomantsi Au
F024	Emmes Li
F025	Koivusaarenneva Ti, V
F026	Laivakangas Au, Cu
F027	Hitura Ni, Co
F028	Vihanti-Pyhäsalmi Zn, Cu
F029	Talvivaara Ni, Co, Zn
F030	Huhus Fe
F031	Otanmäki V, Fe, Ti
F032	Kuhmo Ni, Ag, Au
F033	Pääkkö Fe
F034	Oijärvi Au, Ag
F035	Portimo PGE, Cr, Ni
F036	Koillismaa PGE, V, Ni, Fe, Cu
F037	Peräpohja Cu, Co, Fe
F038	Haukipudas Zn, Cu
F039	Misi Fe, V
F040	Kuusamo-Kuolajärvi Co, Au
F041	Jauratsi Fe
F042	Kesänkitunturi U
F043	Kittilä Au, Cu
F044	Porkonen-Pahtavaara Fe, Mn
F045	Koitelainen Cr, V, PGE
F046	Pyhäjärvi V, Fe, Ti
F047	Ruossakero Ni, Co
F048	Sattasvaara Ni

The metallogenic areas id-coded to the neighbouring countries (Fig. 1) are listed and described in the respective country sections of this book.

F001 ORIJÄRVi Zn-Cu

Pasi Eilu & Mikko Tontti (GTK)

The Orijärvi area (F001; Fig. 1, Table 1) is within the southern half of the E-trending Uusimaa supracrustal belt and has a possible extension to the northeast across the Vyborg rapakivi batholith (Fig. 1). Area F001 (Fig. 2) is bounded to the north by the Häme volcanic belt, by the unmineralised northern half of the Uusimaa supracrustal belt, and in its eastern extension by the unmineralised supracrustal and intrusive rocks of the Saimaa-Lahdenpohja area. The southern boundary of the Orijärvi area is somewhere under the Gulf of Finland and, hence, not exactly known. Thus, the location of the boundary of area F001 drawn in the Fennoscandian metallogenic map is simply an educated guess based on information gathered from those areas of the Uusimaa belt that are dry land. In the west, the metallogenic area ends at the contact between the Uusimaa supracrustal belt and the Åland rapakivi massif. The rocks and mineral deposits of area F001 are largely similar to those in the Bergslagen region in central Sweden, and the Orijärvi area and the Uusimaa belt are commonly seen as an eastern extension of Bergslagen (Latvalahti 1979, Kähkönen 2005, Weihed et al. 2005). For example, by using the geological and metallogenic maps of Fennoscandia (e.g., Koistinen et al. 2001, Eilu et al. 2009) and geotectonic interpretations (e.g. Lahtinen et al. 2005), one may attempt to combine Bergslagen and Uusimaa supracrustal belts and the Bergslagen (S008, S009) and Orijärvi (F001) metallogenic areas.

The Uusimaa belt is formed by supracrustal and synvolcanic intrusive rocks at 1895–1875 Ma intruded by late-orogenic granitoids at about 1830–1810 Ma (Väisänen et al. 2002, Skyttä et al. 2005, Väisänen & Kirkland 2008). The 1895–1875 Ma igneous rocks show bimodal trends and dominantly calc-alkaline affinity, especially in the areas near VMS deposits. The region was affected by multiple stages of deformation and regional metamorphism during the Svecofennian orogeny, peaking at ca. 1880–1870 and 1830–1815 Ga (Kähkönen 2005, Skyttä et al. 2005, Väisänen &

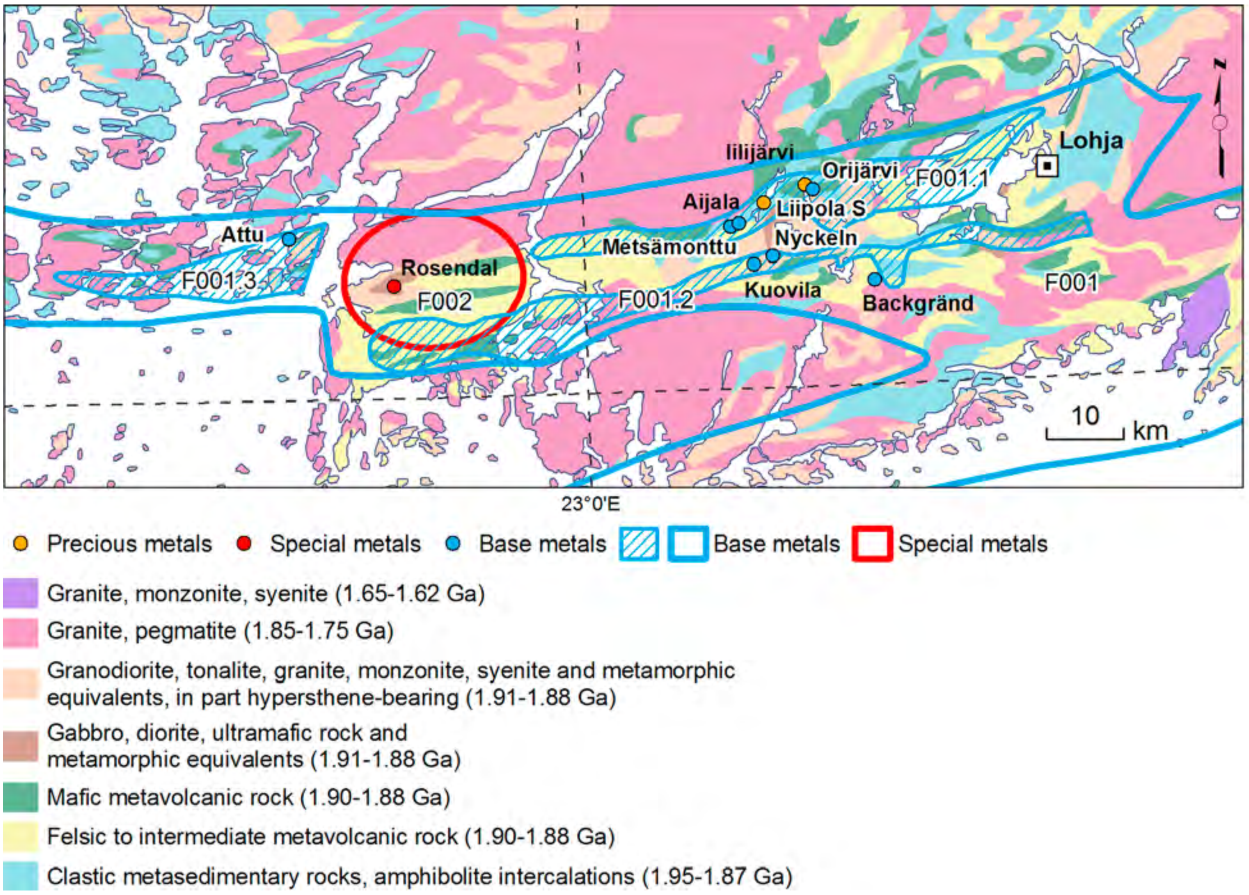


Figure 2. Geology of the central parts of the Orijärvi (F001) and Kemiö (F002) metallogenic areas, with the most significant base, precious and special metal occurrences of the region. Geology is from Koistinen et al. (2001).

Kirkland 2008). Most of the metallic mineralisation in the region (Fig. 2) is associated with the ca. 1895–1891 Ma rocks of the Aijala and Kuovila subareas (F001.1 and F001.2, respectively).

Four styles of metallic mineralisation has been detected within the Orijärvi area (Mikkola 1966, Latvalahti 1979, Mäkelä 1989, Saltikoff et al. 2006, Eilu 2007): 1) Zn-Cu±Pb,Au VMS (Aijala, Metsämonttu, Orijärvi), 2) possible epithermal Au±Cu (north-central F001), 3) banded iron formations (Jussarö, Nyhamn), and 4) skarn iron ores (minor occurrences along the entire Orijärvi area).

Aijala, **Metsämonttu** and **Orijärvi** (Table 2, Figs. 3 and 4) are the main mines of the Orijärvi area, and form the core of the Aijala subarea (F001.1). They all belong to the VMS type of mineralisation (Latvalahti 1979, Colley & Westra 1987, Mäkelä 1989): They are closely related to intensely altered felsic to mafic volcanic rocks and chemical sedimentary units (iron formation and chert). Alteration is characterised by the loss of Na and Ca and enrichment of K, Fe and Mg. The most typical altered rocks include cordierite-mica, cordierite-anthophyllite, and andalusite-cordierite-muscovite gneisses, and tremolite±diopside skarn reflecting metamorphosed equivalents of volcanic rocks altered in submarine VMS systems. The main ore minerals include in variable degrees chalcopyrite, sphalerite, galena, pyrite, pyrrhotite and fahlore. The base metal occurrences in the Kuovila and Attu subareas are largely similar to those in the Aijala subarea (Hangala 1987, Mäkelä 1989, Skyttä 2005).

The gold occurrences in the Orijärvi area and its surroundings, of which only **Iilijärvi** is listed below (Table 2), mostly show features fitting Au-rich VMS or epithermal mineralisation (Eilu 2007 and references therein). This suggests that they are premetamorphic and possibly closely related to the base metal deposits of the region. Some of the occurrences seem to be gold only, whereas others show enrichment in Au, Ag and base metals. The best investigated of the gold occurrences is Iilijärvi, one kilometre northwest from the Orijärvi mine (Fig. 3). The ore at Iilijärvi is chiefly hosted either by felsic metavolcanic rocks that have been altered and recrystallised into quartz rock or the main host is a metamorphosed chert (Colley & Westra 1987, Mäkelä 1989, Smith et al. 1992). In any case, andalusite-cordierite-muscovite gneiss derived from felsic volcanic rock and cordierite-anthophyllite gneiss derived from mafic volcanic rock surround and partially host the gold mineralisation. In addition to the style of alteration, its metal association and Au/Ag ratio, as well as the setting close to VMS deposits, strongly point towards a pre-metamorphic timing and gold-rich VMS or submarine epithermal style for mineralisation at Iilijärvi. Other gold occurrences are less easy to classify, but indications of an orogenic style of mineralisation remain rare, and may be due to remobilisation of ore minerals and the high degree of deformation and regional metamorphism.

Iron deposits in the Orijärvi area are probably all chemical sediments in primary origin. Many are still easily recognised as magnetite-quartz-Fe

Table 2. Base and precious metal deposits and occurrences in the Orijärvi area (F001). Only cases with a resource estimate available are shown.

Subarea **Occurrence**	**Tonnage (Mt)**	**Ag g/t**	**Au g/t**	**Cu %**	**Pb %**	**Zn %**	**When mined****	**Reference**
Aijala Zn-Pb-Cu±Au (F001.1)								
Iilijärvi	0.045	30	4	0.6	0.6	1.3	1788, 1884	Mäkelä (1989)
Metsämonttu	1.508*	25	1.43	0.28	0.74	3.34	1951–1974	Latvalahti (1979)
Aijala	0.835*	14	0.7	1.59		0.66	1670´s–1958	Latvalahti (1979)
Orijärvi	0.925*	40	0.4	1.3	1.03	3.32	1758–1954	Latvalahti (1979)
Kuovila Zn-Pb-Cu (F001.2)								
Backgränd	0.046	65		0.54	0.8	1.37		Mäkelä (1989)
Kuovila	0.01	6			0.4	1.4		Skyttä et al. (2005)
Liipola S	0.024	112				0.69		Mäkelä (1989)
Attu Zn-Pb-Cu (F001.3)								
Attu	4.32	43		0.16	1.05	1.76	1630, 1891	Hangala (1987)
Outside the subareas								
Salo-Issakka	1.8	14		0.33		1.65		Papunen (1990)

* Only the mined amount is reported.

** Mining has taken place in several time intervals.

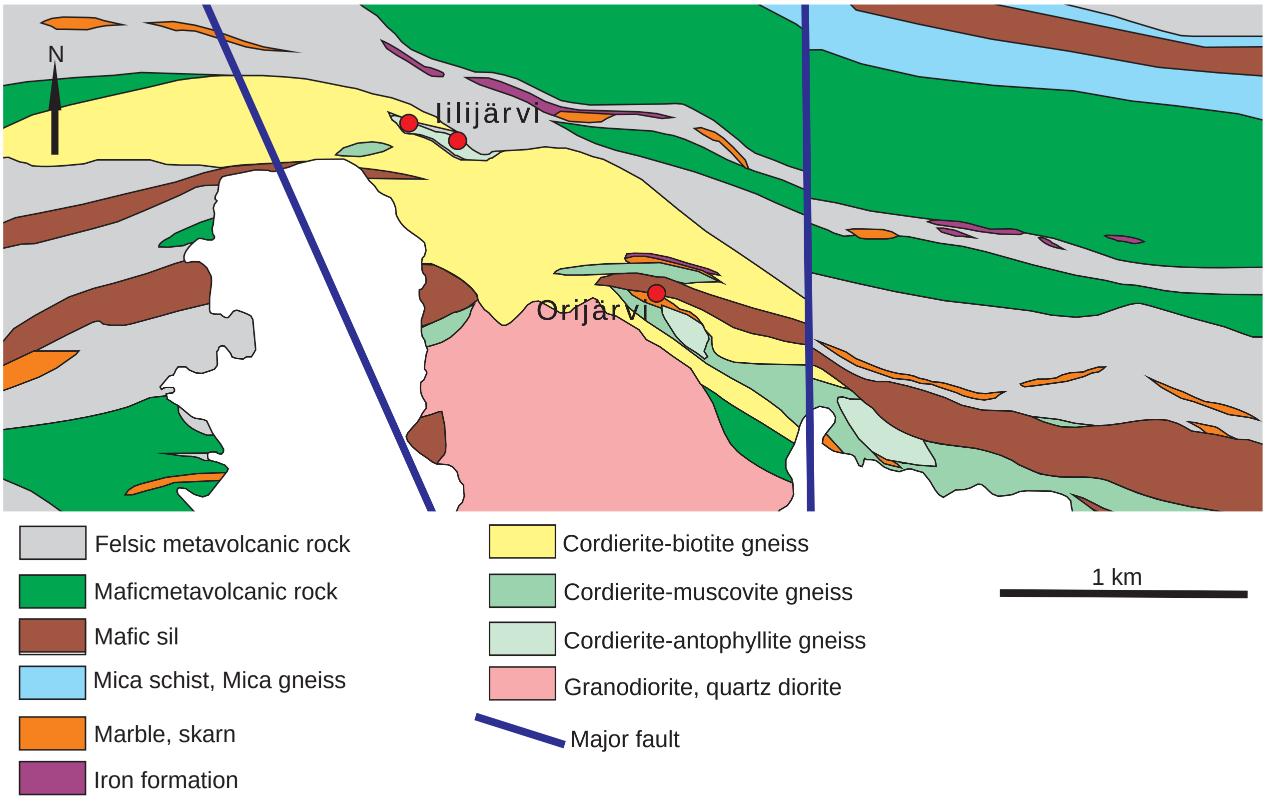


Figure 3. Surface geology of the Orijärvi-Iilijärvi region after Mäkelä (1989). The Orijärvi mine is at 60.229°N, 23.539°E.

Figure 4. Metsämonttu mine site during operation. Photo: Outokumpu Oy.

Table 3. Selected iron deposits and occurrences in the Orijärvi area (F001) and its surroundings in the Uusimaa belt.

Occurrence	Tonnage (Mt)	Fe %	Ti %	When mined**	Genetic type	Reference
Jussarö	28	28	0.09	1834–1967	BIF	Mikkola (1966), Puustinen (2003)
Nyhamn	10	20		1959	BIF	Saltikoff et al. (2006)
Sillböle	0.035*	30		1744–1866	Skarn	Saltikoff et al. (2006)
Ojamo	0.012*	45		1542–1838	Skarn	Saltikoff et al. (2006)

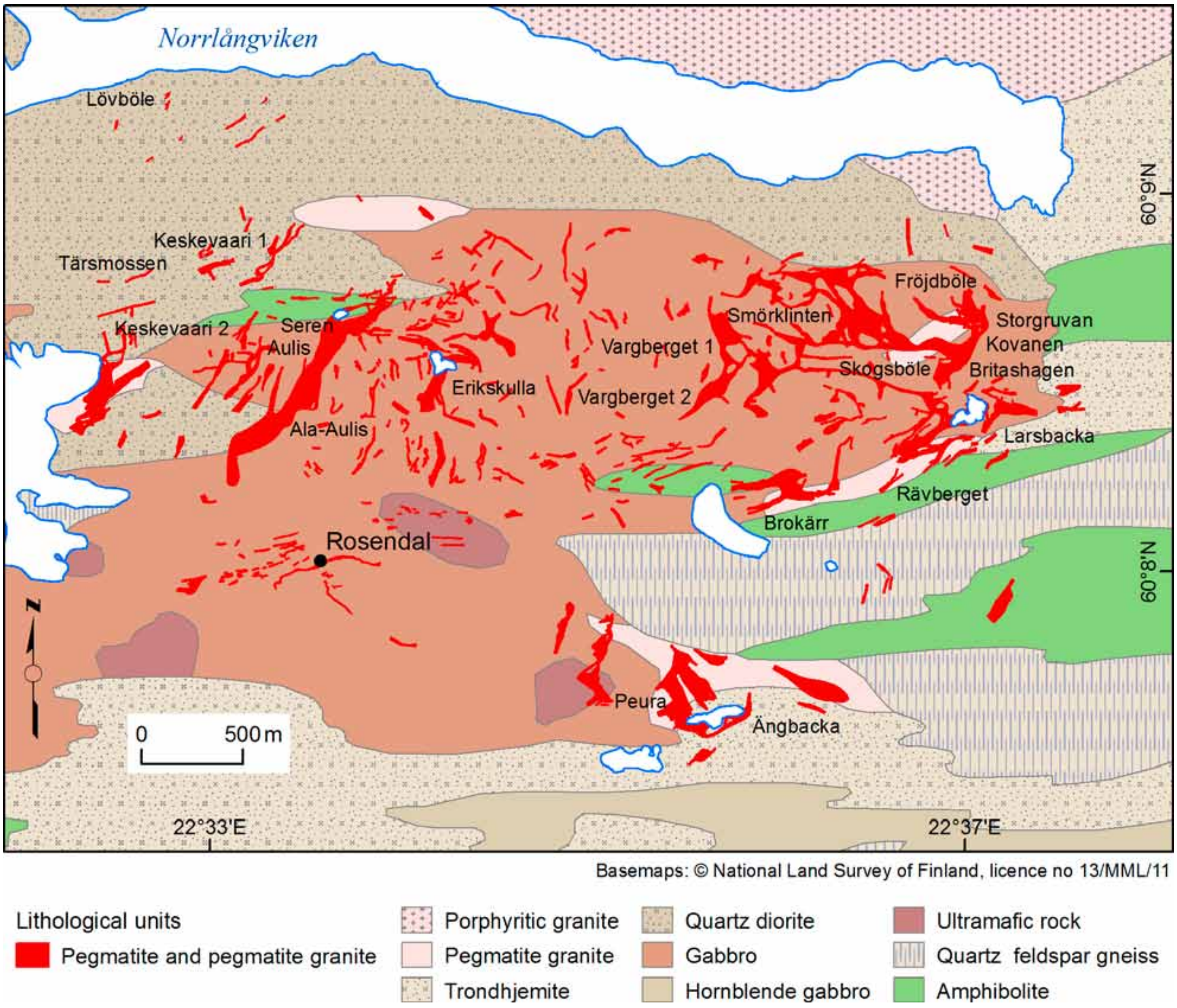
* Only the mined amount is reported.
** Mining has taken place in several time intervals, except at Nyhamn.

silicate banded iron formations, such as the magnetite ores at **Jussarö** and **Nyhamn**, and the numerous small iron occurrences within the Aijala and Kuovila subzones (e.g., Mäkelä 1989, Skyttä et al. 2005). A number of small iron occurrences, including those mined during the 16th to 19th centuries (Table 3), have traditionally been classified as skarns (Mäkelä 1989). They are, however, not skarns *sensu stricto* (i.e. formed in contact with and due to an intrusion), but multiply deformed iron formation units that suffered metamorphic skarnification and recrystallisation in contact with chemically reactive lithological units, such as marbles, or are recrystallised carbonate-facies iron formations (Mäkelä 1989).

F002 KEMIÖ Ta

Pasi Eilu (GTK)

The Kemiö metallogenic area (F002) is in the western part of the Uusimaa supracrustal belt (Fig. 2). The extent of area F002 is defined by the presence of a late-orogenic granitic, complex pegmatite swarm (Lindroos et al. 1996) with a significant potential for feldspar, quartz, tantalum and beryllium exploitation. Feldspar and quartz have been exploited from the Kemiö pegmatites



Basemaps: © National Land Survey of Finland, licence no 13/MML/11

Figure 5. Geology of the central part of the Kemiö pegmatite region (metallogenic area F002), including the Rosendal Ta deposit, SW Finland. Pegmatites according to mapping by R. Alviola, in 1996–2002; geology based on the GTK digital bedrock database. Small white areas are lakes, the larger two are sea.

since the 17th century, with a total cumulative mining of about 5 Mt of pegmatite (Puustinen 2003). Minor volumes of beryl and columbite-tantalite have also been recovered (Puustinen 2003), but within the last 20 years the pegmatites have been explored as significant sources of tantalum metal.

The Rosendal deposit (Fig. 5) has an inferred resource of 1.3 Mt at 0.021 % Ta, 0.014 % Be and 0.08 % Sn (Alviola 1997). The deposit also contains recoverable albite, quartz and muscovite (Tertiary Minerals 2001). This resource estimate only covers the uppermost 50 m of one dyke. There are several similar, albeit apparently smaller, dykes at Rosendal, within an area 1 km long and 500 m wide. The mineral assemblage at Rosendal comprises microcline, albite, quartz, tapiolite, tantalite, chrysoberyl, beryl and cassiterite. The resource at Rosendal and known Ta-Nb mineral pegmatites in the region indicate that area F002 may have a significant, largely untested, Ta potential.

F003 PALMOTTU U

Esa Pohjolainen & Olli Äikäs (GTK)

The Palmottu area (F003) is a south-opening arc extending from the central to northern and eastern parts of the Uusimaa supracrustal belt. The high uranium contents of the bedrock and groundwater in the Uusimaa region are radiometrically and geochemically distinguishable. In particular, the uranium content of the late orogenic, 1.84–1.79 Ga, granites of southern Finland is relatively high. The main U-bearing minerals in the occurrences are uraninite, monazite, uranothorite, zircon, allanite and apatite (Räisänen 1989, Cuney et al. 2008).

Several uranium and thorium occurrences are known from the migmatised Uusimaa belt (Fig. 6); most of them are hosted by granitic and pegmatitic parts of the migmatites (Räisänen 1989). Many occurrences (e.g. Palmottu) have been discovered by means of aeroradiometric gamma anomalies in granitic areas (Seppänen 1985). All the known occurrences are small and their uranium grade is low (Table 4). Uranium occurrences of area F003 are mainly associated with late-orogenic granites (1.84–1.79 Ga) in migmatites. U-Pb analyses of uraninites and allanites from the eastern part of the area indicate uranium remobilisation and enrichment during the Ordovician, ca. 450 Ma ago (Vaasjoki et al. 2002). Monazite gives a concordant age of 1793 Ma at Palmottu; this date can be considered as the age of U mineralisation at the site (Vaasjoki 1996).

Most of the uranium occurrences in the western part of area F003 are related to the granitic dykes and lenses in migmatitic mica gneisses. The occurrences are located along the marginal zone of the late-orogenic Perniö granite and in paragneisses forming country rocks to the granite (garnet-bearing mica gneiss, quartz-feldspar gneiss and pyroxene-bearing charnockite). GTK discovered the **Palmottu** deposit at Nummi-Pusula (80 km NW of Helsinki) in 1979. Palmottu is an intrusive uranium deposit, rich in thorium (U/Th about 2:1). Two types of uraniferous dykes are present: 1) granite pegmatites and 2) sheared, quartz-rich granite with biotite accumulations (Räisänen 1989). Palmottu is on the southern limb near the crest of a large fold with a vertical, approximately E-W trending axial plane (Kuivamäki et al. 1991). The fractures now hosting the U-rich granitic dykes may have been opened during folding (Räisänen 1989), and the dykes were probably derived from the late-orogenic Perniö granite.

At Palmottu, uranium mainly occurs as disseminated uraninite typically associated with biotite accumulations in the granitic dykes of migmatitic mica gneisses. The main uranium and thorium minerals are uraninite and monazite. An alteration rim mainly consisting of coffinite ($USiO_4$) frequently surrounds uraninite grains. Conventional U-Pb dating of uraninite gave discordant ages (indicating the loss of lead) between 1678 and 1741 Ma (Ruskeeniemi et al. 1994). The only U^{6+} mineral identified is uranophane, occurring as a fracture fill (Kaija et al. 2000). Molybdenite occurs in small amounts. In total, 62 holes (9093 m) were drilled during 1981–1984 at Palmottu. The main ore body is discontinuous with a total length of 400 m and thickness from 1 to 15 m (Räisänen 1991). The mineralisation continues from the surface to a depth of at least 400 m.

In the eastern part of area F003, numerous uranium occurrences have been localised, mainly by ground and airborne radiometrics. Two uranium-rich boulders (glacial erratics) were found by Imatran Voima Oy (IVO) at **Alho**, northwest of Porvoo, in 1956 (boulder IVO-9: 36 % U_3O_8) and in 1957 (IVO-99: 12 % U_3O_8). The main minerals of boulder IVO-9 are uraninite, calcite, quartz, hematite and chlorite (Appelqvist & Kinnunen 1977). Uraninite is botryoidal, usually surrounded by carbonate. The bedrock source of the Alho boulders has not been discovered.

IVO had a field laboratory for milling and concentration tests at **Lakeakallio** (Fig. 6). From the Lakeakallio uranium occurrence, the company mined 557 tonnes of ore with a grade of 0.11 % U_3O_8 in 1958–1959. The host rock is granite that contains coarse-grained garnet and biotite nests. The country rocks are migmatitic mica gneiss and hornblende gneiss. The dominant ore minerals are uraninite, molybdenite and pyrite. Zircon and monazite are the radioactive accessories. Uraninite occurs at the grain margins of the gangue, and has a grain size of 0.2–0.4 mm. Remobilised uraninite has been found in microcracks around the primary uraninite. Milling and concentration tests at the IVO Lakeakallio field laboratory were also carried out on material from other occurrences known at the time from the eastern part of area F003.

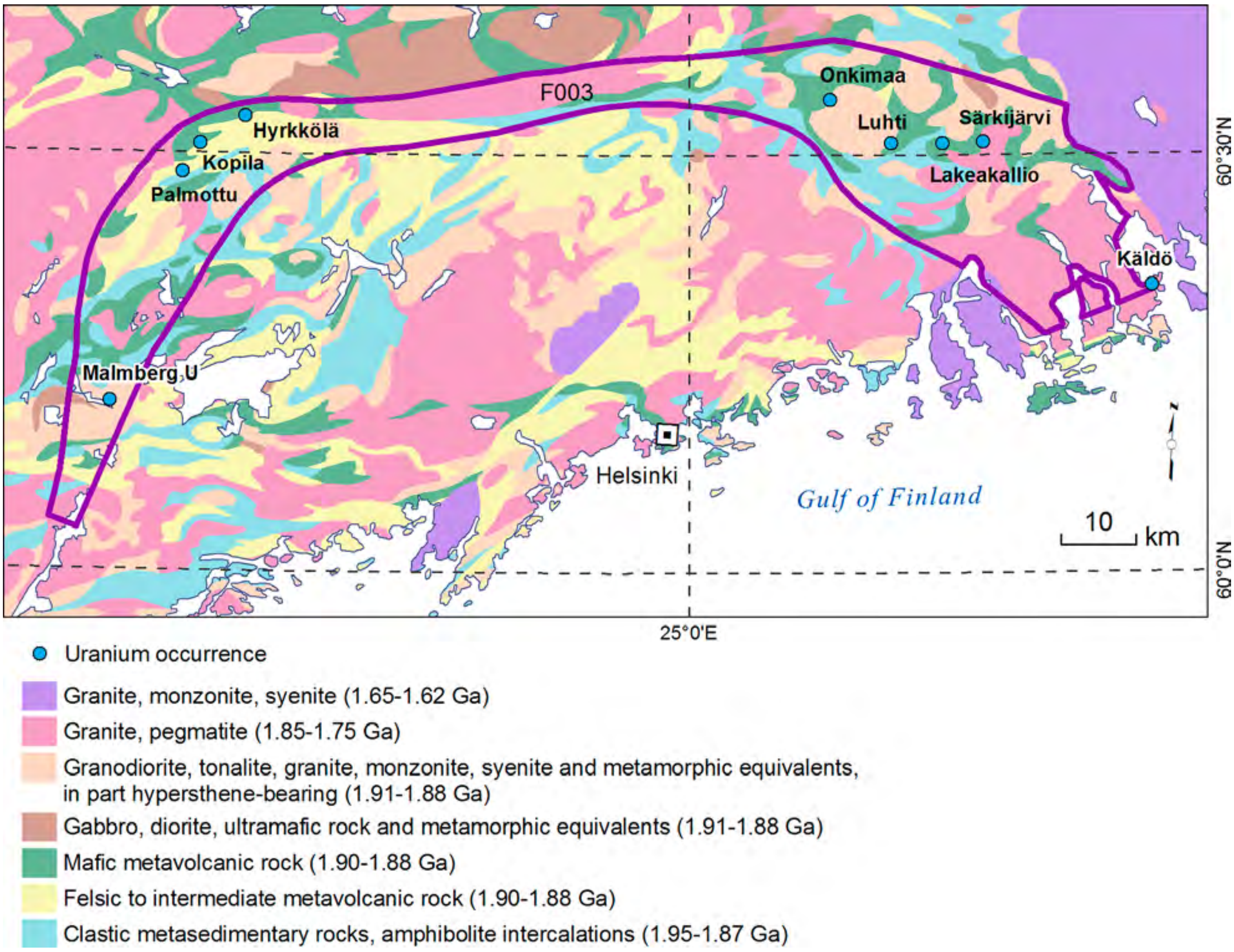


Figure 6. Geology of the Palmottu metallogenic area (F003) with selected uranium occurrences. Geology is based on Koistinen et al. (2001).

Table 4. Uranium occurrences with a resource estimate in the metallogenic area F003.

Occurrence	Ore tonnage (Mt)	U %	Main ore minerals	Reference
Lakeakallio	0.0006*	0.11	Uraninite, molybdenite	Appelqvist & Kinnunen (1977)
Onkimaa	2.7	0.01	Uraninite, zircon	Appelqvist (1974), Räisänen (1989)
Palmottu	1.018	0.11	Uraninite, monazite	Räisänen (1989), Kaija et al. (2003)

* Only the mined amount has been reported.

The **Onkimaa** uranium occurrence at Mäntsälä was discovered by GTK in 1972 (Appelqvist 1980). The mineralised rock is coarse-grained, almost a pegmatitic granite or granodiorite forming the neosome of migmatite. The radioactive minerals at Onkimaa are uraninite and zircon. Molybdenite is encountered in small amounts. Uraninite occurs as euhedral grains (0.15–0.25 mm in size) at grain boundaries and as inclusions in light-coloured gangue minerals.

F004 HÄME Au, Zn-Cu

Pasi Eilu & Niilo Kärkkäinen (GTK)

The Häme metallogenic area (F004) is within the WSW-trending Häme volcanic belt. The Häme area (Fig. 7) is bounded to the north by the Pirkanmaa migmatite belt (also called the Vammala migmatite zone), to the NW and W by barren areas of the Häme volcanic belt, and to the east and south by the Uusimaa supracrustal belt. The exact boundaries of area F004 can be questioned, however, as it is not very clear where the boundary between the Häme and Uusimaa supracrustal belts lie (Kähkönen 2005, Väisänen & Westerlund 2007), and the extent of gold and base metal potential along the Häme volcanic belt appears to gradually fade out to the west. Only the boundary to the north is distinct, where it coincides with the clear boundary (a major fault zone) between the Häme volcanic belt and the Pirkanmaa migmatite belt (Tiainen & Viita 1994, Vaasjoki et al. 2005).

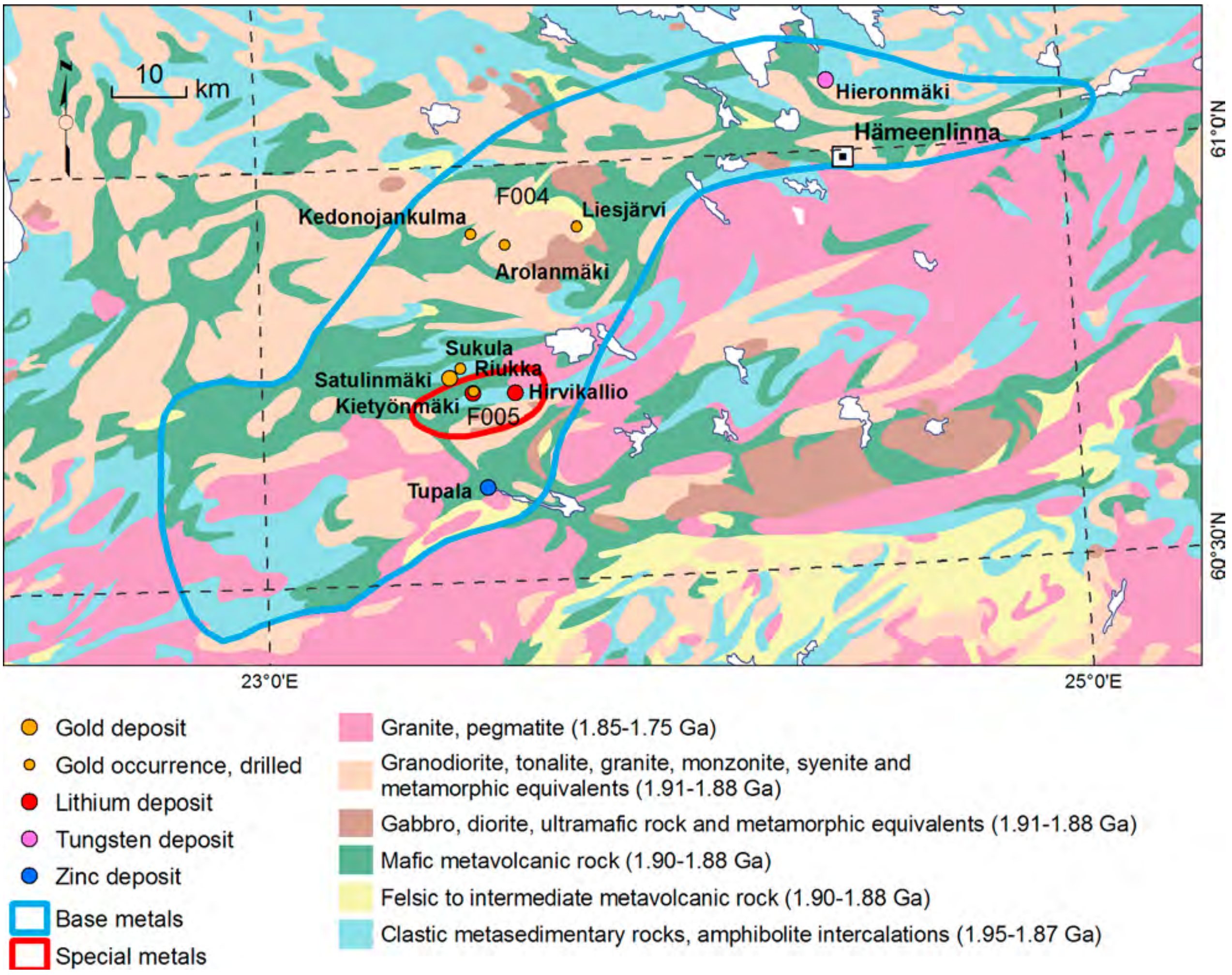


Figure 7. Geology of the Häme Au, Zn-Cu (F004) and Somero Li (F005) metallogenic areas and their immediate surroundings with the most significant metal occurrences and drilling-indicated gold occurrences. Geology is based on Koistinen et al. (2001).

Volcanic and sedimentary rocks, with intermediate volcanic rocks dominating, form the Häme volcanic belt. Age dating suggests that at least some of the supracrustal rocks were deposited at about 1880 Ga (Saalmann et al. 2009). The belt has been intruded by the ca. 1880 Ma I-type synvolcanic and synorogenic and the ca. 1830–1810 Ma S-type late-orogenic granitoids (Hakkarainen 1994, Tiainen & Viita 1994, Kähkönen 2005). According to Kähkönen (2005), the 1890–1880 Ma igneous rocks in Häme indicate an arc setting less evolved than within the Tampere schist belt or most of the Uusimaa supracrustal belt, and have a medium-K basaltic to rhyolitic composition. Like nearly all of southern Finland, the region has been affected by multiple stages of deformation and regional metamorphism during the Svecofennian orogeny, peaking at ca. 1880–1860 and 1830–1800 Ga (Kähkönen 2005, Saalmann et al. 2009).

Three or four styles of metallic mineralisation define the Häme metallogenic area (Mäkelä 1980, Mäkelä 1989, Papunen 1990, Peuraniemi 1992, Tiainen & Viita 1994, Eilu 2007, Kärkkäinen 2007, Saalmann et al. 2009, Tiainen et al. 2011): 1) Zn-Cu±Pb VMS (Tupala), 2) skarn(?) tungsten ores (Hieronmäki), 3) orogenic gold Au±Cu (Satulinmäki?), and 4) possibly epithermal or porphyry-related Cu±Au (Kedonojankulma).

Scattered VMS-style, Zn-Pb-Ag±Cu mineralisation occurs throughout the Häme area. The occurrences are intimately related to condierite±anthophyllite rocks and sericite schists, indicating metamorphosed equivalents of mafic to felsic volcanic rocks altered in submarine hydrothermal systems (Mäkelä 1980, Mäkelä 1989, Papunen 1990, Tiainen & Viita 1994). Only one occurrence, **Tupala**, has so far been determined to contain a tonnage large enough to warrant resource estimation (Table 5, Fig. 8). Tupala is a stratabound, partially remobilised, zinc-silver deposit hosted by intermediate and felsic volcanic rocks at a contact zone between intermediate and mafic volcanic rock sequences (Mäkelä 1989, Tiainen & Viita 1994).

The gold occurrences in area F004 may all

Table 5. Selected base and precious metal deposits and occurrences in the Häme Au, Zn-Cu area (F004).

Occurrence	Tonnage (Mt)	Ag g/t	Au g/t	Pb %	W %	Zn %	Genetic type	Reference
Tupala	0.76	39		0.71		3.86	VMS	Mäkelä (1989)
Satulinmäki	0.36		2.34				Epithermal or orogenic	Kärkkäinen et al. (2006), Koistinen (2006)
Hieronmäki	0.063				0.32		Skarn?	Peuraniemi (1992)

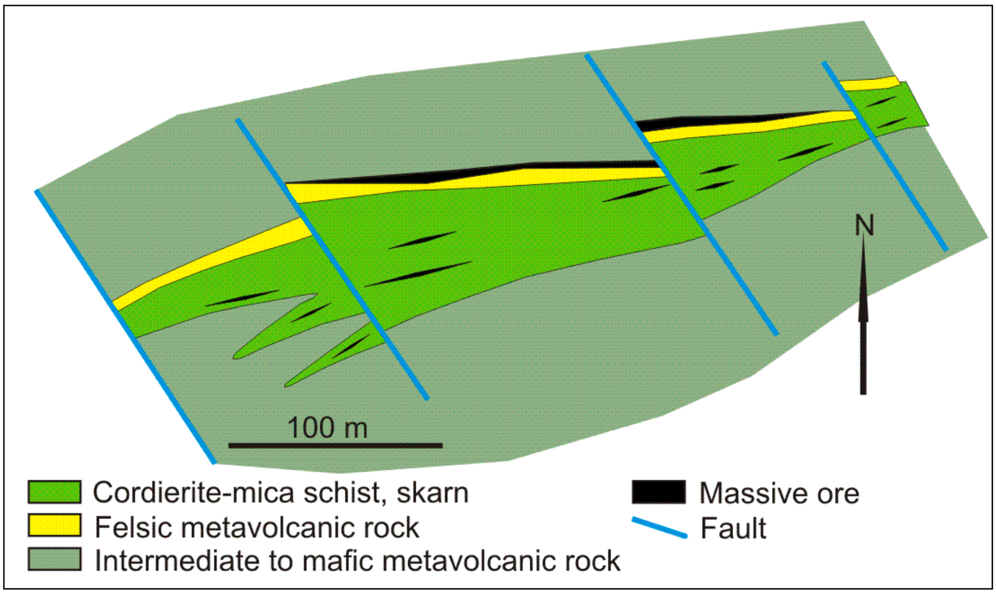


Figure 8. Surface geology at the Tupala Ag-Zn-Pb occurrence (after Mäkelä 1989).

represent the orogenic type or both orogenic and epithermal (or other syngenetic intrusion-related) types. Most of the exploration in the region has been carried out in the western parts of the Häme area (Kärkkäinen 2007), where the **Satulinmäki** deposit (Table 4) is the most extensively investigated of all gold targets. Recent structural geological studies at Satulinmäki (Kärkkäinen et al. 2006, Kärkkäinen 2007, Saalmann 2007, Saalmann et al. 2009) indicate that it is controlled by post-peak deformation structures and that mineralisation took place in possibly two stages of structural evolution of the area. Radiometric dating (hornblende Ar-Ar and zircon U-Pb) of auriferous quartz veins also suggests a late-orogenic timing (between 1.82 and 1.79 Ga; Saalmann et al. 2009). Satulinmäki, and similar occurrences within a few kilometres of it, are hosted by the locally most competent rock units, felsic dykes, and gold occurs closely associated with tourmaline- and arsenopyrite-rich quartz veins. A strong positive correlation occurs between Au, As, Bi, Sb and Te, and the most intensely altered host rock (Perälä 2003, Kärkkäinen et al. 2006, Kärkkäinen 2007). A similar style of mineralisation has also been detected in other localities near Satulinmäki (Saalmann 2007, Saalmann et al. 2009). Gold and gold-copper occurrences have additionally been detected elsewhere in area F004, and it has been suggested (Tiainen et al. 2011) that there are porphyry-type Cu-Au deposits in the area. Metamorphosed epithermal types of deposits are also possible.

The third obvious type of mineralisation in the Häme area is tungsten mineralisation, of which the **Hieronmäki** deposit is most extensively investigated (Table 5). Even at Hieronmäki, the available reporting is minor: the deposit may well be of skarn type (diopside, vesuvianite, garnet and calcite form the gangue), is enriched in As, Co, S, W and Zn, and is in a mafic to intermediate volcanic setting, but little more is known about it.

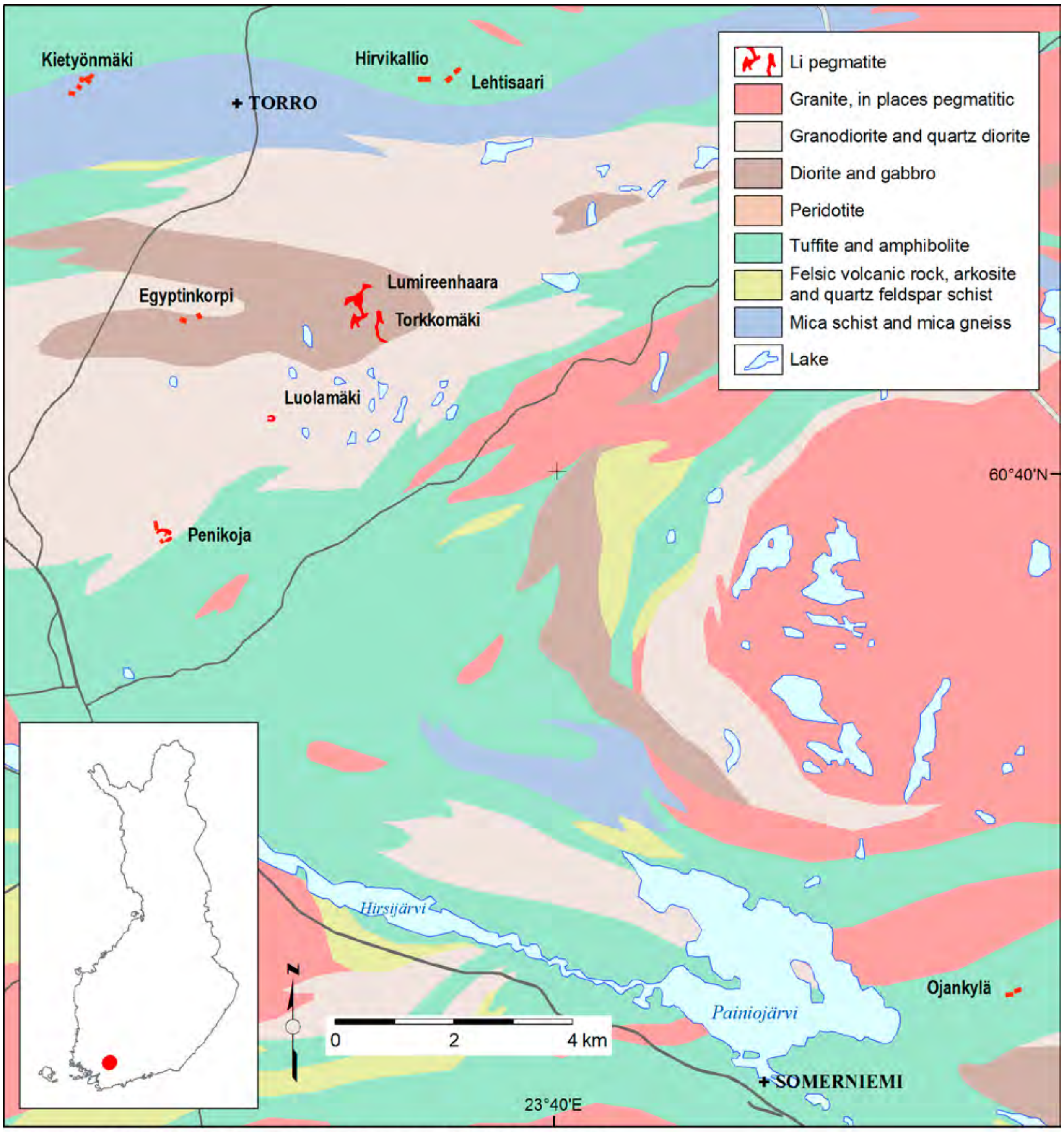
F005 SOMERO Li

Timo Ahtola (GTK)

The Somero rare metal pegmatite region (metallogenic area F005) is in the Häme volcanic belt between the towns of Tammela and Somero in SW Finland (Figs. 7 and 9). The Häme belt mainly consists of volcanic rocks intercalated with minor greywackes and metapelitic units. Syntectonic plutonic rocks of gabbroic, dioritic, granodioritic and tonalitic composition and late-tectonic K-granites and pegmatitic dykes (Saalmann et al. 2009) intrude the succession. The rocks were metamorphosed in amphibolite-facies conditions with the metamorphic grade increasing to the south leading to local migmatisation and partial melting. Late-tectonic potassic granites and pegmatitic dykes are the youngest magmatic rocks of the Häme volcanic belt (Saalmann 2007).

In the Somero area (approx. 400 km^2), at least 56 rare metal pegmatites are known. Of these, at least nine contain lithium silicates and phosphates including cookeite, elbaite, heterosite-siclerite, lepidolite, lithiophilite, petalite, spodumene, triphylite and Li-Fe micas (Vesasalo 1959, Saikkonen 1981, Alviola 1989, 2004). According to Alviola (2003), these lithium pegmatites belong to the LCT (Li, Cs, Ta) family of Černý (1998). It is probable that there are still several unexposed lithium pegmatites in the region, to be discovered in the future.

The two largest lithium occurrences in the area are the Hirvikallio petalite pegmatite and the Kietyönmäki spodumene pegmatite (Table 6). Hirvikallio, the largest known petalite pegmatite dyke in Finland, is vertical, 170 m long, 5–25 m wide, and its average Li_2O content is 1.78 %. The lithium reserve total about 200 000 tonnes, estimated to the depth of 50 m. The pegmatite contains petalite accumulations 0.5–2 m in size in albitic aplite (Alviola 1989). The size of individual petalite crystals varies from 2 to 50 cm. The Kietyönmäki dyke swarm is composed of half a dozen Li pegmatite dykes and some pegmatite granites. In all but one of the pegmatites, petalite is completely altered to SQI (spodumene+quartz intergrowth). During 1987–1988, GTK drilled 17 holes in the Kietyönmäki dyke swarm. The largest dyke at Kietyönmäki is almost vertical, about 200 m long and 10 m wide (Alviola 1989).



Basemaps: © National Land Survey of Finland, licence no MML/VIR/TIPA/217/10

Figure 9. Rare metal pegmatites ('Li pegmatite' in the legend) in the central parts of the Somero area (F005), also called the Somero-Tammela rare metal province (map modified from Alviola et al. 2004).

Table 6. Rare metal occurrences with a resource estimate in the Somero Li area (F005).

Occurrence	Tonnage (Mt)	Li %	Sn %	Ta %	No. of dykes	References
Kietyönmäki	0.4	0.55	0.016	0.003	>5	Alviola (1989, 1993)
Hirvikallio	0.15	0.83			One	Vesasalo (1959), Saikkonen (1981)

F006 VAMMALA Ni

Markku Tiainen (GTK)

The arcuate, W- to NW-trending, Vammala Ni area (F006) is within the Pirkanmaa migmatite suite paragneisses (i.e., Pirkanmaa migmatite belt). Area F006 is bounded to the north by the Tampere schist belt and Central Finland Granitoid Complex, to the SW by the Satakunta Mesoproterozoic sandstone formation and to the south by Southern Finland supersuite. In the east, the area narrows and ends at the Vyborg rapakivi massif. Although not shown here, the Ni-potential area may in fact continue further to the northeast, towards the Kotalahti nickel area (F016). For more details of the geology of the Pirkanmaa migmatite belt, see the description of the Pirkkala metallogenic area (F007).

The narrow core areas of area F006 (Fig. 10), the Pori–Vammala and Kylmäkoski subareas (F006.1 and F006.2, respectively), have been delineated according to the spatial distribution of the known Ni deposits and occurrences and the favourable geology for intrusive-type Ni deposits (Papunen 1980, Häkli & Vormisto 1985, Gaál 1985, Mäkinen 1987, Liipo et al. 1997, Makkonen et al. 2010). The subareas include all nickel mines and known unexploited, economic and subeconomic, Ni deposits of area F006

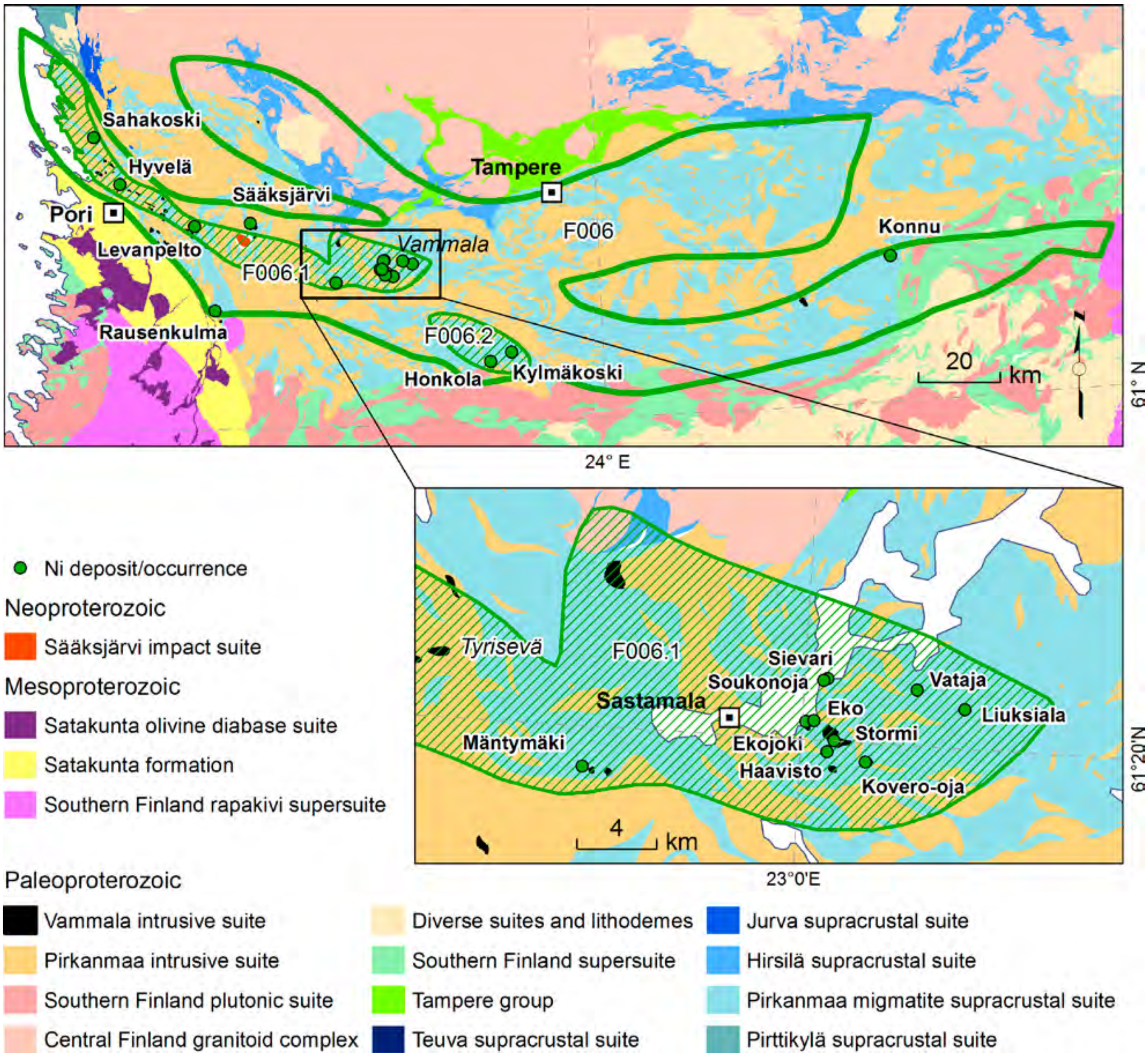


Figure 10. Geology of the Vammala Ni area (F006), with the Pori-Vammala and Kylmäkoski metallogenic subareas (F006.1 and F006.2, respectively), and the most significant nickel-copper occurrences of the region. Geology is from the GTK digital bedrock database.

(Table 7; Saltikoff et al. 2006). The gap between Pori–Vammala and Kylmäkoski subareas is due to granitoid-dominated geology and does not have significant indications of Ni deposits or ultramafic intrusions (Matisto 1973). The subareas are geologically essentially similar, although the number of ultramafic cumulate occurrences in the surroundings of Sastamala is much higher than in the Kylmäkoski subarea. The subareas are characterised by nickel-copper occurrences hosted by synorogenic differentiated ultramafic intrusions in a high-grade metamorphic, polydeformed, throndhjemitic schollen migmatite domain, in originally pelitic to psammitic sediments with sulphide interlayers. The mineralised intrusions are small, typically less than 0.5 km wide, olivine cumulates of arc-type tholeiitic basaltic magma. Dunitic and peridotitic basal layers of the intrusions typically host the sulphide occurrences (Fig. 11; Peltonen 1995, Lamberg 2005). In places, for example at Ekojoki, the core of the intrusion is mineralised (Lamberg 2005). The main ore minerals in the Vammala-type deposits are pyrrhotite, pentlandite and chalcopyrite. Sulphides occur as dissemination or matrix ore occupying the intercumulus of olivine cumulate (Fig. 12). Typical metal contents are 0.4–0.7 % Ni and 0.2–0.5 % Cu (Table 7). The PGE contents are low, except at Ekojoki, where PGE contents up to 1.6 ppm have been detected (Lamberg 2005). Three nickel deposits, **Kylmäkoski**, **Kovero-oja** and **Stormi**, were exploited in the Vammala Ni area during 1971–1994, yielding a combined total of 8.1 Mt of ore averaging 0.67 % Ni and 0.42 % Cu (Liipo et al. 1997). The majority of the ore, 7.4 Mt, was produced from the Stormi deposit.

The **Pori–Vammala subarea** (F006.1) includes two mined deposits, Stormi (Vammala) and Kovero-oja, four sub-economic deposits, namely Ekojoki, Mäntymäki, Hyvelä and Sahakoski, and a group of significant occurrences, including Sääksjärvi, Rausenkulma, Soukko, Liuksiala, Haavisto and Levanpelto (Fig. 10). In addition to the intrusions know to be mineralised, the subarea includes ultramafic intrusions that have the potential for nickel deposits. For example, the large serpentinised pyroxenite-peridotite Tyrisevä intrusion may, according to the mineral chemistry, be mineralised (Peltonen & Jokinen 2002).

The composition of the ultramafic intrusions changes along strike of the subarea from east to west. The intrusions near Stormi are mainly peridotitic and dunitic, whereas in the western part, near Pori, the intrusions seem to include more of the gabroidic and pyroxene-bearing phases and less of the dunitic phase. For example, the Hyvelä deposit is hosted by noritic pyroxene-cummingtonite gabbro and does not include substantial ultramafic phases (Stenberg & Häkli 1985), and the Sahakoski deposit is hosted by a lherzolite-norite intrusion (Mäkinen 1987).

By far the biggest deposit in area F006 is Stormi (Table 7). The ore is hosted by an ultramafic cumulate-textured intrusion at the bottom of the three-layered ultramafic Vammala complex, in the core of a regional F2–F3 antiform (Fig. 11; Häkli &Vormisto 1985, Peltonen 1995, Kilpeläinen 1998, Lamberg 2005). The three main units of the Vammala complex are: 1) a 70-m-thick upper serpentinite, 2) a 100-m-thick intermediate metapicrite

Table 7. Intrusion-hosted Ni-Cu deposits and occurrences with a resource estimate in the Vammala Ni Area (F006).

Subarea Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	When mined	Main host rock	Reference
Pori–Vammala Ni-Cu (F006.1)							
Ekojoki	1.19	0.02	0.42	0.51		Dunite	Dragon Mining (2007)
Hyvelä	0.807	0.03	0.26	0.52		Norite	Suomen Nikkeli (2006)
Kovero-oja	1.56	0.02	0.33	0.4	1975–1977	Peridotite	Grundström (1973)
Liuksiala	0.05		0.2	0.3		Peridotite	Grundström (1991a)
Mäntymäki	0.466	0.01	0.2	0.73		Lherzolite	Suomen Nikkeli (2006)
Rausenkulma	0.375	0.02	0.49	0.36		Peridotite	Grundström (1999)
Sääksjärvi	3.5	0.03	0.33	0.24		Peridotite	Heikkilä-Harinen (1977a)
Sahakoski	1.6	0.03	0.19	0.65		Peridotite	Belvedere Resources (2006)
Soukko	0.05		0.25	0.44		Peridotite	Grundström (1991b)
Stormi	9	0.04	0.41	0.6	1975–1994	Dunite	Liipo et al. (1997)
Kylmäkoski Ni-Cu (F006.2)							
Kylmäkoski	0.69*	0.01	0.48	0.5	1971–1974	Peridotite	Papunen (1980)

* Only the mined amount is reported.

layer (cortlandite) with metasedimentary intercalations, and 3) a 100-m-thick lower cumulate-textured layered ultramafic Stormi intrusion.

The lower layered ultramafic Stormi intrusion consists of a 2–20-m-thick pyroxenitic and peridotitic marginal series and an almost 100-m-thick dunitic layered series (Lamberg 2005). The layered series consists of olivine, olivine-chromite, olivine-sulphide and olivine-sulphide-chromite cumulates, also including orbicular peridotite at the bottom of the intrusion. The nickel-copper ore is mainly hosted by the dunitic subzones of the layered series, but also in places by the marginal peridotites and pyroxenites (Fig. 11). Offset-type mineralisation has been encountered as massive sulphide veins in the mica gneiss country rocks of the ultramafic intrusion. The main ore minerals, as coexisting phases in the ore, are monoclinic pyrrhotite, pentlandite and chalcopyrite. Hexagonal pyrrhotite occurs as inclusions in the monoclinic pyrrhotite. The nickel content of olivine (Fo_{75-85}) varies from 500 to 3000 ppm (Mäkinen & Makkonen 2004), which indicates the deposition of a nickel-bearing sulphide phase from the magma.

The Kylmäkoski subarea (F006.2) includes one mined deposit, Kylmäkoski, the small drilled occurrence of Honkola, and a few indications of nickel mineralisation, both mineralised erratics and outcrops including large ultramafic fragments or sills. The Kylmäkoski deposit is hosted by a peridotitic-dunitic intrusion 260 x 100 m wide and 80 m thick. The deposit consists of pentlandite-pyrrhotite-chalcopyrite dissemination as an intercumulus phase in olivine and olivine-pyroxene cumulates (Papunen 1985). In addition to Ni, Cu and Co, elevated PGE contents have been observed at Kylmäkoski as arsenides (Gervilla et al. 1998)

Several mafic-ultramafic intrusions have been explored outside the Pori-Vammala and Kylmäkoski subareas, but no economic deposits have been found so far. For example, the small Konnu nickel occurrence at Padasjoki, in the easternmost part of area F006, is hosted by a pyroxenite-perodotite sill, indicating the continuation of the Vammala metallogenic area to the east (Kärkkäinen et al. 2003, Tiainen et al. 2007).

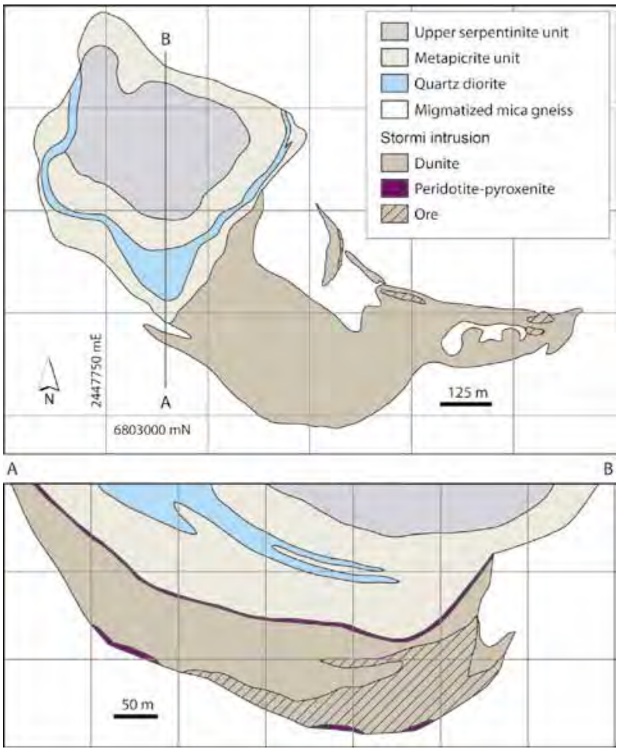


Figure 11. The Vammala ultramafic complex, modified after Häkli and Vormisto (1985) and Lamberg (2005). Surface plan (upper) and cross section (lower) along the line A–B. Grid according to Finnish national KKJ coordinates.

Figure 12. Pyrrhotite-pentladite ore in peridotite at Stormi. Scanned image by Hannu Makkonen, GTK.

F007 PIRKKALA Au

Pasi Eilu & Niilo Kärkkäinen (GTK)

The Pirkkala Au area (F007) is defined by the extent of orogenic gold mineralisation within the Pirkanmaa migmatite belt in SW Finland (Fig. 1). To the north, metallogenic area F007 is clearly bounded by the distinct boundary between the Pirkanmaa migmatite belt and Tampere schist belt, and to the south by the less-distinct boundary between the Pirkanmaa migmatites and the Häme volcanic belt, respectively. To the east and west its boundaries are vague: perhaps the metallogenic area should be open along strike at both ends.

The turbidite-dominated Pirkanmaa migmatite belt is a Svecofennian subduction zone complex pushed towards the present north, below the Tampere schist belt (Kähkönen 2005). In addition to turbiditic mica schist and gneisses, the belt contains minor volumes of black schists, mafic lavas (max age 1.92 Ga), arenites, conglomerates and chert. The area was intruded by synorogenic, ca. 1.89 Ga, mafic-ultramafic, and extensive, ca. 1.88 Ga, tonalites, and metamorphosed under high-T amphibolite facies conditions peaking at about 1.88 Ga (Kilpeläinen 1998, Peltonen 1995 and 2005, Nironen 2005, Saalmann et al. 2010). The region suffered another major stage of deformation and metamorphism during 1.83–1.80 Ga (Kähkönen 2005, Saalmann et al. 2010).

The Pirkkala metallogenic area is characterised by orogenic gold mineralisation; other types of gold mineralisation have not so far been identified in the region (Eilu 2007, Kärkkäinen 2007). Area 007 partially overlaps the Vammala Ni area (F006), and the mineralisation in both took place due to Svecofennian orogenic processes. However, there is only partial regional overlap, no local spatial overlap between the mineralisation types, they are possibly separated by 30–80 Ma in age, and the exact mineralisation processes are very different; hence, two distinct metallogenic areas have been defined within the Pirkanmaa migmatite belt.

Eilu (2007) lists 13 drilling-indicated gold occurrences (at least 1 m @ ≥1 g/t Au) from the Pirkkala area. The present number of known occurrences is close to 20 and seems to increase every year as exploration extends into new areas (Kärkkäinen 2007, Eilu 2012a). Despite the regionally extensive exploration, enough drilling to define a resource estimate has only been carried out at two localities (Table 8). Mica gneiss or synorogenic intermediate intrusive rocks host most of the occurrences in the area. All are gold-only occurrences with a distinct structural control by local shear zones and the hosts typically being the locally most competent lithological units (e.g., Saalmann et al. 2010). The dominant sulphides are pyrite, pyrrhotite, arsenopyrite and löllingite, and the gold occurs both in quartz veins and in the immediate wallrocks of these veins.

The largest known deposit in area F007 is **Jokisivu**, where the current *in situ* resource estimate is 12 t of gold at an average grade of 6.5 g/t Au (Dragon Mining 2010). The two main ore bodies at Jokisivu comprise several auriferous quartz vein arrays surrounded by altered host rock (Figs. 13 and 14). The deposit is controlled by a conjugate set of brittle-ductile shear zones between two major NW-trending shear zones in upper-amphibolite facies rocks (Luukkonen 1994). Most of the gold (90 %) occurs as free native grains chiefly in quartz veins and vein selvages, is locally related to arsenopyrite, and commonly occurs with the minor tellurides (Luukkonen 1994, M. Kilpelä, pers. comm. 13 May 2006). Visible gold commonly occurs in quartz veins. According to age dating and structural interpretation by Saalmann et al. (2010), the hosting diorite at Jokisivu has an age of ca. 1.88 Ga, whereas the mineralisation took place during ca. 1.80 Ga regional-scale granite magmatism and shear zone development. The dominant alteration mineral assemblage diopside-garnet-hornblende-labradorite (Grönholm 2006) suggests mineralisation under mid-amphibolite facies PT conditions.

Table 8. Orogenic gold deposits with a resource estimate in the Pirkkala Au area (F007).

Occurrence	Tonnage (Mt)	Au g/t	Main ore minerals	Host rocks	Reference
Jokisivu	1.831[1]	6.5	Pyrrhotite, arsenopyrite, löllingite	Diorite, mafic volcanic rock	Grönholm (2006), Dragon Mining (2010)
Kaapelinkulma	0.161	6.2	Pyrrhotite, arsenopyrite, löllingite	Quartz diorite, tonalite	Rosenberg (1997), Dragon Mining (2009)

1) Mining started at Jokisivu in 2009.

Figure 13. Jokisivu open pit in September 2009. Photo: Pasi Eilu, GTK.

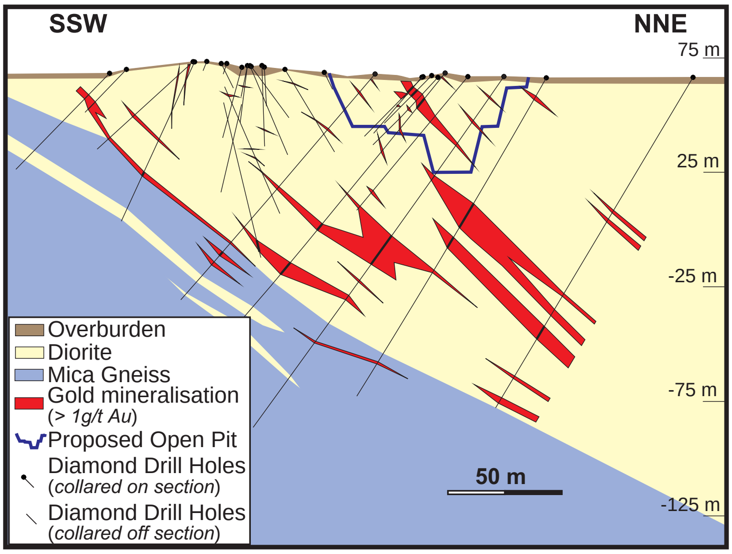


Figure 14. Section across the Kujankallio lodes of the Jokisivu gold deposit. Image: courtesy of Polar Mining, 2009.

F008 ERÄJÄRVI Ta-Li-Be

Pasi Eilu (GTK)

The Eräjärvi metallogenic area (F008) is in the NE margin of the Pirkanmaa migmatite belt, immediately to the south of the Tampere schist belt (Fig 15). Area F008 is defined by the presence of late-orogenic (ca. 1.80 Ga) LCT type of complex pegmatites best known for their numerous Li and Be minerals and Fe-Mn phosphates (e.g., Volborth 1960, Lahti 1981, 1987). More than 70 complex and numerous simple pegmatite dykes are known from the area. The pegmatites are enriched in B, Be, Li, Nb, Sn and Ta (Lahti 1981, Alviola 2004). About 30 pegmatite dykes have been exploited, on a small scale, for quartz, feldspar, muscovite, beryl, amblygonite, and columbite-tantalite, from about 1910 to 1966 (Puustinen 2003). So far, no significant Ta resource has been detected, but area F008 remains potential for rare metals, including Be, Li, Nb and Ta.

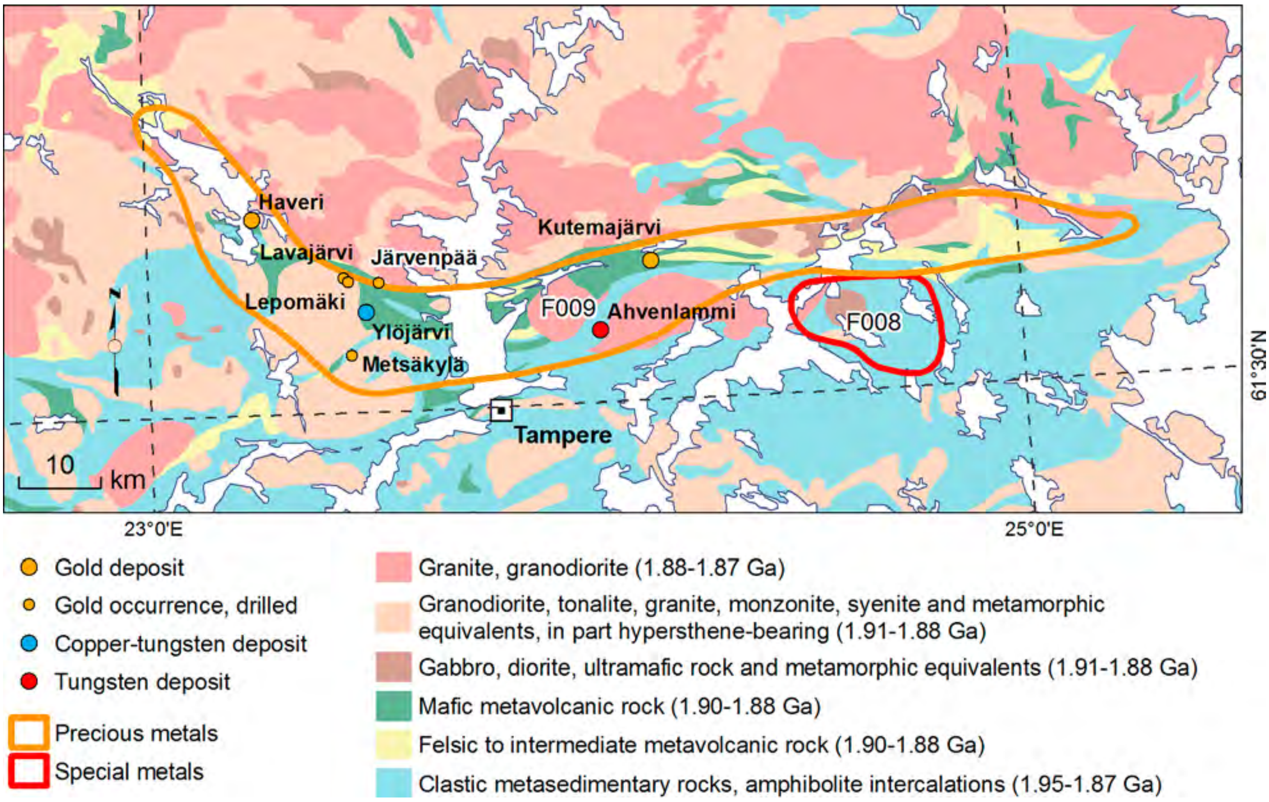


Figure 15. Geology of the Eräjärvi (F008) and Tampere (F009) metallogenic areas and their surroundings, with the most significant metallic deposits and drilling-indicated gold occurrences. Geology from Koistinen et al. (2001).

F009 TAMPERE Au, Cu

Pasi Eilu (GTK)

The Tampere area (F009) comprises the E-trending Tampere schist belt and its possible extension to the east and northeast. Metallogenic area F009 is bounded to the north by the Central Finland Granitoid Complex and to the south by the Pirkanmaa (migmatite) belt (Fig. 15). The Tampere schist belt is formed by supracrustal rocks formed during ca. 1905–1889 Ma and deformed and metamorphosed by 1.88 Ga, indicating a very rapid evolution for the area (Kähkönen 2005). The oldest unit seem to be the ca. 1905 Ma, primitive, EMORB basaltic volcanic rocks at Haveri. However, most of the supracrustals have an arc-like affinity and comprise medium- to high-K intermediate to felsic volcanic and volcaniclastic rocks and turbidites (Kähkönen 2005). The belt has been intruded by hypabyssal (synvolcanic?) porphyries and synkinematic (1.89–1.87 Ga) granitoid batholiths (Nironen 2005).

At least six types of metallic mineralisation have been detected within the Tampere area (Himmi et al. 1979, Mäkelä 1980, Luukkonen 1994, Poutiainen & Grönholm 1996, Talikka & Mänttäri 2005, Eilu 2007, 2012a, 2012b): 1) gold-copper VMS (Haveri), 2) metamorphosed epithermal gold (Kutemajärvi), 3) porphyry- or granitoid-related breccia pipe copper-tungsten (Ylöjärvi, Ahvenlammi?), 4) orogenic gold (western Tampere belt), 5) granitoid-related gold (along Hämeenkyrö batholith margin, western Tampere belt), and 6) zinc VMS (central and western Tampere belt). The latter three styles of mineralisation have only been detected as tiny showings and are not further considered here. Porphyry Cu±Au deposits may occur near high-sulphidation epithermal gold deposits (Hedenquist et al. 1996) and granitoid-related breccia-hosted copper deposits (e.g., Paull et al. 1990). However, no distinct porphyry deposits have so far been detected from the Tampere area.

Haveri (Fig. 17) was the first mine in Finland where gold was among the main commodities (Table 9). The deposit is in the westernmost part of area F009 (Fig. 15), hosted by mafic lava and hyaloclastite, and is stratiform on a large (>100 m) scale (Fig. 16). The host rocks belong to the oldest unit of the Tampere schist belt. The main ore minerals at Haveri are pyrrhotite, chalcopyrite, and magnetite. Gold occurs both closely associated with chalcopyrite and in silicified zones with low copper grades, but is restricted throughout to the domain of sulphide mineralisation. The following genetic types have been suggested for the deposit: VMS, IOCG, and VMS copper overprinted by orogenic gold mineralisation (Mäkelä 1980, Karvinen 2003, Strauss 2004). However, most of the evidence supports the hypothesis of a metamorphosed and deformed gold-rich VMS-style stringer-zone mineralisation, possibly originally resembling the Hellyer deposit in Tasmania (Schardt et al. 2001) as summarised by Eilu et al. (2004) and Eilu (2011b). The present setting of the deposit seems to be in a fold closure (Nironen 1994), suggesting at least some degree of remobilisation of the sulphides from their primary sitings and, hence, obscuring its genetic type.

The **Ylöjärvi** Cu-W(-Ag-As-Au) deposit (Clark 1965, Himmi et al. 1979) is in the western part of the Tampere schist belt (Fig. 15). The ore is in two subvertical, discordant, tourmaline breccia pipes 150 m apart in intermediate tuffite and plagioclase porphyry (Fig. 18). In the area, there also are smaller, unexploited breccia bodies (pipes?) of a similar style. The matrix of the breccia is composed of tourmaline with smaller, variable volumes of ore and other gangue minerals. The major ore minerals at Ylöjärvi are arsenopyrite, chalcopyrite and scheelite. The deposit is about 200–400 m from the Hämeenkyrö synorogenic granodiorite batholith, and research in the area suggests that the mineralising fluids were derived from the batholith, and that the deposit is genetically close to porphyry copper mineralisation (e.g., Himmi et al. 1979).

The **Ahvenlammi** tungsten deposit is in the easternmost part of the Tampere metallogenic area, in supracrustal rocks probably belonging to the Tampere schist belt. Scheelite occurs at Ahvenlammi in quartz and scheelite-only veins, and as dissemination and fracture-fill in greywacke (Luukkonen 1994). The occurrence could be related to the local granites and, hence, go broadly into the same genetic category as the Ylöjärvi deposit.

Kutemajärvi (Orivesi) is the third mine in the Tampere area. It is within a >30 km long, E-trending, variably sericitised zone close to the northern boundary of the Tampere schist belt, with the Järvenpää gold prospect, from which no resource has been reported (Eilu 2007, Eilu 2012a). These occurrences best fit into the category of (metamorphosed) high-sulphidation epithermal gold deposits (Hedenquist et al. 1996), as 1) they are characterised by intense sericitisation, which at Kutema surrounds the ore bodies hosted by metasomatic quartz rock, 2) the proximal alteration zone is surrounded by pyrophyllite-andalusite-quartz rock (Fig. 19), 3) the silicified and sericitised rocks are characterised by intense depletion of nearly all major and trace elements, but enriched in Ag, Au, As, Bi, F, S, Si and Te, 4) the proximal alteration assemblages contain minor amounts of F- and P-rich minerals (e.g. apatite, fluorite, topaz and lazulite), and 5) there are no indications of K or CO_2 enrichment (Luukkonen 1994, Poutiainen & Grönholm, 1996, Talikka & Mänttäri 2005). The geological setting characterised by potentially subaerial, intermediate to felsic volcanism (Kähkönen 2005) is also favourable for an epithermal mineralising system. Epithermal systems commonly do not survive orogeny, as they are easily eroded. However, similar alteration sequences and metal associations have been described, for example, at the Hope Brook (Newfoundland, Canada) and Brewer (Carolina slate belt, USA), where the rocks have been metamorphosed under upper-greenschist or lower-amphibolite facies conditions (Dube et al. 1998, Ayuso et al. 2005). At Kutemajärvi, a possible source for the mineralising fluids is the hypabyssal porphyry immediately to the north of the deposit (Fig. 19), in contact with the alteration halo around the gold deposit (Talikka & Mänttäri 2005).

Table 9. Deposits and occurrences in the Tampere area (F009) included in the FODD database.

Occurrence (Alternative name)	**Tonnage (Mt)**	**Ag g/t**	**Au g/t**	**Cu %**	**W %**	**When mined**	**Genetic type**	**Reference**
Haveri	26.26*		1	0.5		1842–1865, 1942–1962	VMS	Mäkelä (1980), Lappland Goldminers (2008)
Ylöjärvi (Paroinen)	4.013**	13.9	0.04	0.75	0.11	1943–1966	Porphyry?	Clark (1965), Himmi et al. (1979)
Kutemajärvi (Orivesi)	2.78		8.9			1990, 1994–2003, 2007–	Epithermal	Poutiainen & Grönholm (1996)
Ahvenlammi	1.12				0.16		Skarn?	Luukkonen (2004)

* Mined 1.56 Mt @ 2.82 ppm Au, 0.37 % Cu (Mäkelä 1980).
** Only the mined amount is anywhere reported.

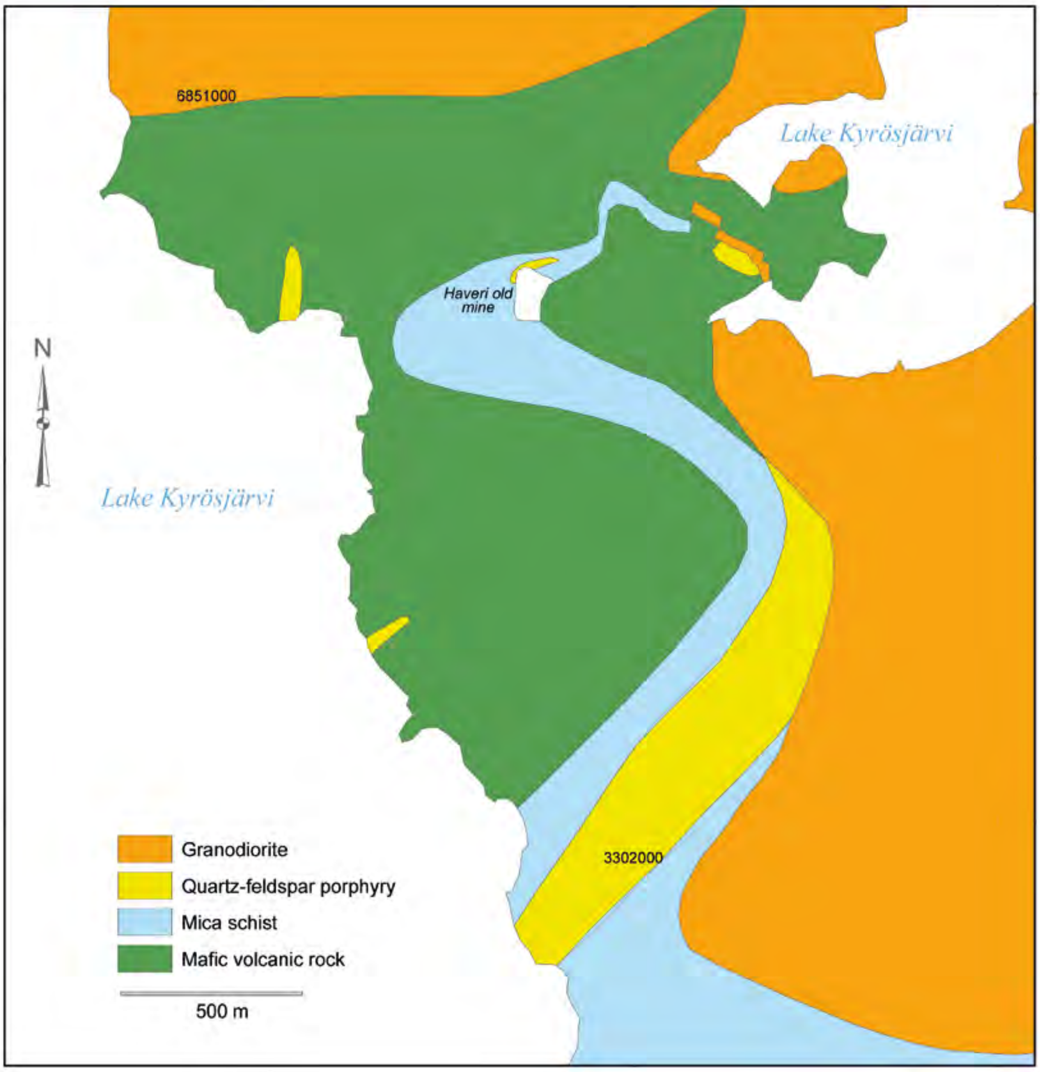


Figure 16. Haveri area, according to Strauss (2004). Possibly, most of what is marked as mica schist in this map is in fact spilitised mafic volcanic rock, especially within the area <500 m from the old mine. Coordinates according to the Finnish National YKJ grid. The Haveri old pit is at 61.713°N, 23.244°E.

Figure 17. The old open pit at Haveri, with the headframe in the background, in November 2004. View to the north; photo: Pasi Eilu, GTK.

Figure 18. Ylöjärvi mine during operation in 1960s. The mine is at 61.609°N, 23.500°E. Photo: courtesy of Outokumpu Oy.

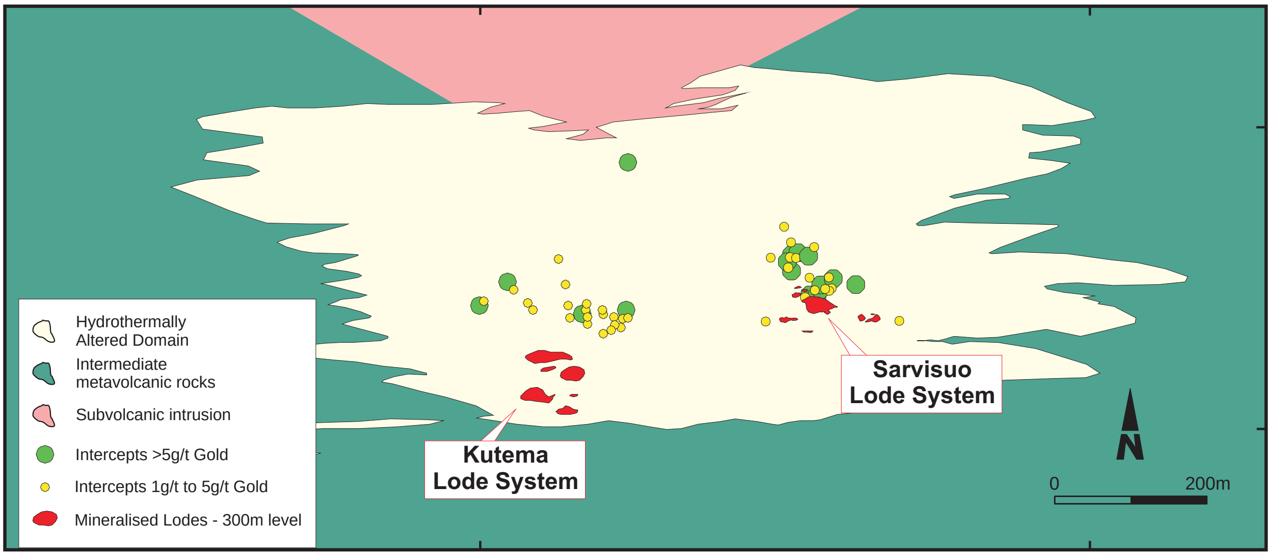


Figure 19. Surface geology of Orivesi gold mine and its immediate surroundings. The Kutema Lode System is at 61.653°N, 24.157°E. Image: Polar Mining, 2009.

F010 TELKKÄLÄ Ni-Cu

Hannu Makkonen (Belvedere Mining Oy)

The WNW-trending, Telkkälä Ni-Cu area (F010) is within the southern part of the Saimaa-Lahdenpohja metaturbidite-synorogenic intrusive area. Area F010 (Fig. 20) is defined by the presence of nickeliferous, ca. 1.89–1.88 Ga, synorogenic mafic-ultramafic intrusions. It is bounded to the north by Svecofennian metaturbidites and synorogenic granitoids and to the south by the Mesoproterozoic Vyborg rapakivi massif. Among the synorogenic gabbros, hornblende varieties predominate, but norites are also present (Häkli 1985). Area F010 is related to a distinct positive gravimetric anomaly; the known nickel deposits are in the southern part of this anomaly. The domain covering the so far discovered nickel deposits (Table 10) and their immediate surroundings defines an area of high potential of discoveries, which we here call the Telkkä Ni subarea (F010.1).

The most important deposit so far discovered in the area F010 is **Telkkälä** (Fig. 21). It is hosted by a differentiated mafic-ultramafic intrusion composed of a cummingtonite gabbro-norite-perknite outer part and of a peridotitic core. The intrusion is located within veined migmatitic and schollen-migmatitic garnet-cordierite-mica gneisses. The horizontal dimensions of the Telkkälä intrusion are 50 x 150 metres and the depth is about 50 metres. In addition to this, there is a 200-m-long peridotite at the depth of 110–225 m, hosting the deep ore. The Telkkälä intrusion was intruded before or during the main stage of regional deformation and metamorphism, D_2, of the area.

The Telkkälä deposit consists of three ore bodies: 1) surface ore, including massive ore in peridotite and perknite, as well as network and disseminated ore in cummingtonite gabbro, 2) offset ore made by a major massive sulphide vein, and 3) deep ore, consisting of massive, network and disseminated ore in peridotite and norite and massive ore in the contact zone of norite and peridotite. The main ore minerals are pyrrhotite,

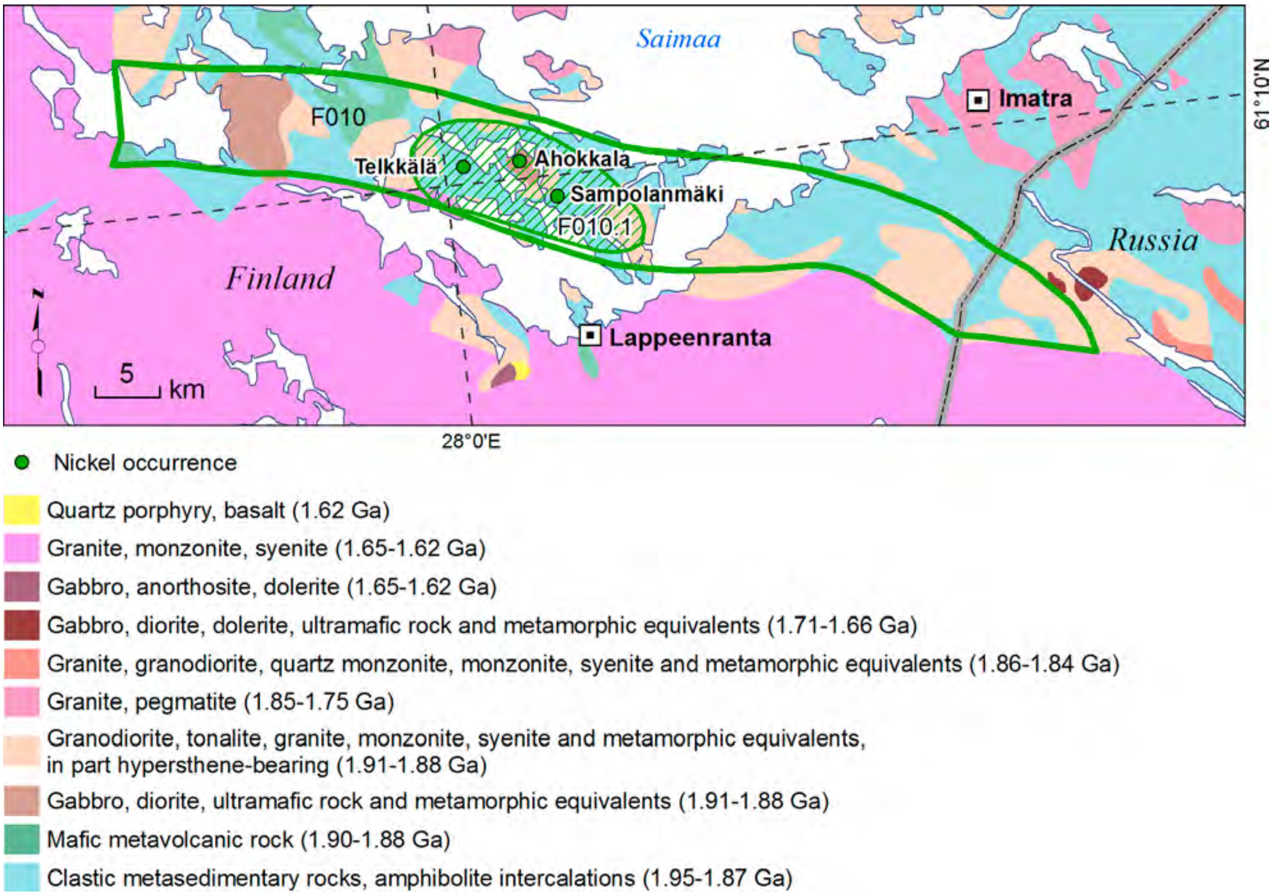


Figure 20. Geology of the Telkkälä Ni-Cu metallogenic area (F010), with the Telkkä metallogenic subarea (F010.1), and the most significant nickel-copper occurrences of the area (Table 10). Geology is from Koistinen et al. (2001).

pentlandite and chalcopyrite. According to Häkli et al. (1975), the massive and breccia ores were formed in the cooling stage of the intrusion, when the increased hydraulic pressure brecciated the rocks and sulphide liquid invaded the open spaces. Copper-rich sulphide liquid, which segregated from the bulk of the sulphide liquid, produced chalcopyrite stringers of the second generation. An alternative explanation for the massive ores is that sulphides were remobilised during the D_2–D_3 deformation stages and emplaced into D_3 shear structures, forming the massive sulphide ore. The Telkkälä deposit was mined in two phases, first the surface ore in 1969–1970 (211 331 tonnes at 1.06 % Ni and 0.29 % Cu), and then the deep ore in 1988–1992 (394 065 t at 1.41 % Ni and 0.35 % Cu) (Isomäki 1992, 1994).

Table 10. Mafic-ultramafic intrusion-hosted Ni-Cu deposits and occurrences in the Telkkälä Ni-Cu area (F010). All deposits with a resource estimate are within subarea F010.1.

Occurrence	**Tonnage (Mt)**	**Co %**	**Cu %**	**Ni %**	**When mined**	**Main host rock**	**Reference**
Telkkälä	0.605*	0.05	0.33	1.29	1969–1970, 1988–1992	Peridotite, gabbro	Isomäki (1992)
Ahokkala	0.02		0.2	1.25		Norite	Kärkkäinen et al. (2003)
Sampolanmäki	0.03		0.2	0.4		Gabbro	Kärkkäinen et al. (2003)

* Only the mined amount is reported

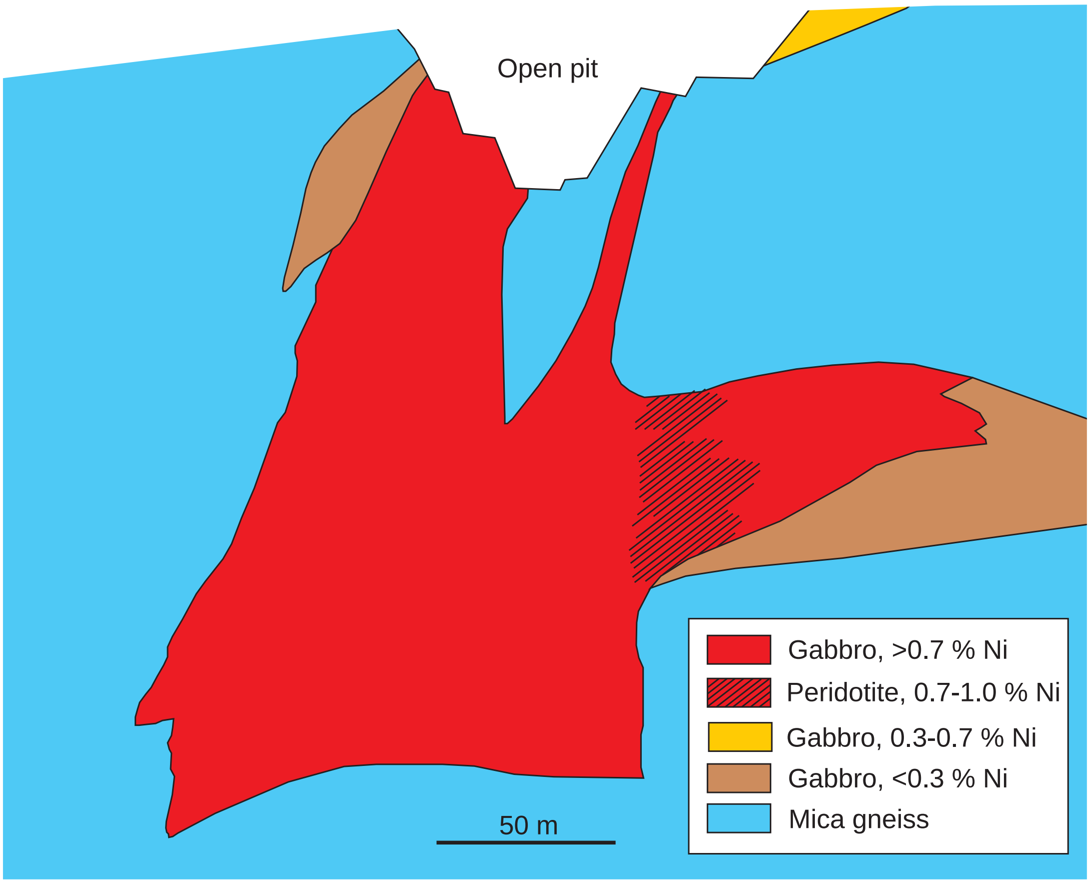


Figure 21. Geology of the Telkkälä nickel mine, at 61.1794°N, 28.0275°E. Modified from Eeronheimo and Pietilä (1988).

F011 PERÄKORPI Ti

Niilo Kärkkäinen (GTK)

The Peräkorpi Ti area (F011) comprises a cluster of Ti, P and Fe-rich gabbro intrusions within the westernmost corner of the Central Finland Granitoid Complex (Fig. 22). The Central Finland Granitoid Complex belongs to primitive arc complex of Central Finland and is composed of collision-related intrusions (1.89–1.87 Ga) and granitic intrusions (1.88 Ga) post-dating the main stage of crustal thickening (Korsman et al. 1997). The Peräkorpi Ti area is composed of several P-Ti-Fe-rich mafic intrusions at the contact zone between the postorogenic Lauhavuori granite in the west and the synorogenic granodiorite-dominant area in the east (Fig. 22). Peltonen (2005) classified the Peräkorpi Ti-Fe-P gabbros into Group III in his three-part division of the Svecofennian mafic-ultramafic intrusions. Their geochemical characteristics are similar to anorogenic gabbros, and they form a bimodal magmatic suite with potassium-rich granites. Perämaa and Lauhavuori granite intrusions are probably related to same geotectonic event, a mature postorogenic type of magmatism (Peltonen 2005).

There are three major intrusions: Perämaa (Peräkorpi) at Honkajoki, and Kauhajärvi and Lumikangas at Kauhajoki (Fig. 22, Table 11). Apatite-rich Ti-Fe occurrences also occur in geophysical anomalies at Kirveskylä near Kauhajärvi and at Hyyppä near Lumikangas (Huuskonen & Kärkkäinen 1994). At Ratuskylä, there is an analogous anomaly under thick overburden. The length of these intrusions varies between 2 and 10 km and the width between 1 and 3 km. All of these intrusions are quite similar in hosting low-grade apatite-ilmenite-ilmenomagnetite deposits with an average of about 20 wt% of the three ore minerals combined. Ilmenite is mainly igneous and occurs as separate grains, although much of ilmenite also occurs as lamellas in magnetite (ilmenomagnetite). The normative ratio of ilmenite to magnetite averages 1.5. Perämaa and Kauhajärvi show distinct differentiation from peridotite to anorthosite, whereas Lumikangas is composed of rather homogeneous layered gabbro and monzogabro.

The **Kauhajärvi** intrusion (Fig. 23) has a thin,

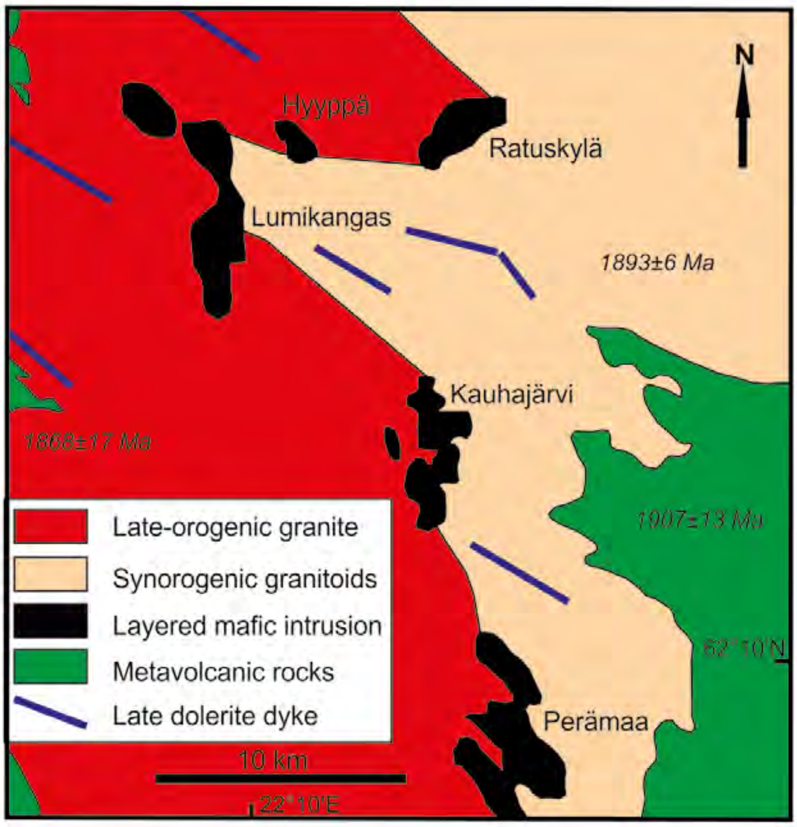


Figure 22. Geology of the central parts of the Peräkorpi metallogenic area (F011) and the most significant titanium occurrences of the area (based on Kärkkäinen & Appelqvist 1999). Numbers in italics indicate igneous ages in Ma for the rocks that are labelled.

poorly-layered, gently-dipping, basal zone (50 m thick) of gabbro. It is crystallised from a rather primitive magma under relatively low f_{O2} conditions. The voluminous, modally well-layered main zone (>400 m) is composed of peridotite, olivine gabbro, gabbronorite, gabbro and anorthosite, and represents more evolved parental magma that crystallised under relatively high f_{O2} conditions (Kärkkäinen & Appelqvist 1999). The Fe-Ti oxides and apatite are concentrated in several layers that are up to tens of metres thick and contain 4–8 % TiO_2, 19–40 % Fe_2O_3 and 1–3.6 % P_2O_5. Ilmenite, apatite and Ti magnetite (ilmenomagnetite) have crystallised coevally with mafic silicates (olivine, pyroxenes) from an early intrusive stage, and are common throughout the intrusion. The Ti/Fe ratio, TiO_2/Fe_2O_3 = 0.16–0.20, does not vary across the stratigraphy of the intrusion. The small variation in the Fe/Mg ratio and the high abundance of apatite (2–8 %) throughout the main zone, without a clear stratigraphic variation, indicate that iron and phosphorus were enriched together with titanium in the parental magma. A high P in magma allowed the crystallisation of ilmenite under relatively oxidising conditions.

The drilled part of the 5 km long **Lumikangas** magnetic and gravity anomaly, 15 km northwest of the Kauhajärvi gabbro, comprises gently-dipping (30° to the E) layered mafic intrusion characterised by uniformly high P_2O_5 and TiO_2, a rather high K_2O, and low Cr contents, a high normative alkali feldspar content, and coeval crystallisation of apatite, Fe-Ti oxides and mafic silicates (Sarapää et al. 2006a). Its composition varies from dark oxide gabbro (>10 % ilmenite and magnetite) to apatite-rich leucogabbro and monzogabbro in the upper part of the intrusion. The oxide-rich part is 1200 m long, 300 m wide and 200 m thick, and contains 19 % of ore minerals: 8.7 wt% ilmenite (up to 21 wt%), 5.4 % apatite (up to 17 wt%) and 4.8 wt% magnetite (up to 17 wt%).

Table 11. Ilmenite-magnetite-apatite occurrences with a resource estimate from the Peräkorpi area (F011). All are hosted by a layered intrusion.

Occurrence	Tonnage (Mt)	Ti %	Main host rock	References
Perämaa	200*	3.2	Peridotite	Pakarinen (1984)
Kauhajärvi	9.6	6.6	Peridotite	Kärkkäinen (1999), Kärkkäinen & Appelqvist (1999)
Lumikangas	230*	2.8	Monzogabbro	Sarapää et al. (2006a, 2006b)

* Due to the low density of drilling, only a rough estimate is available.

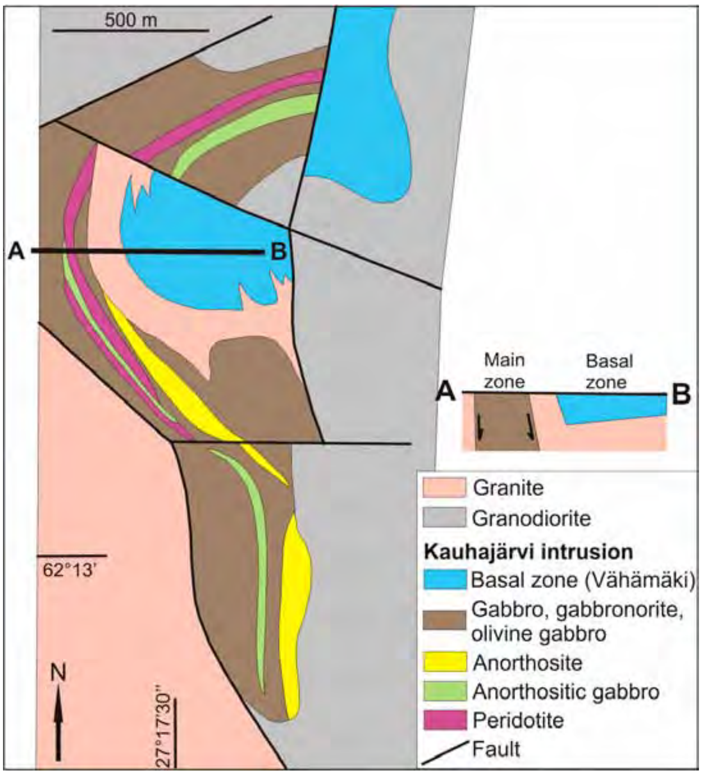


Figure 23. Geology of the Kauhajärvi gabbro (based on Kärkkäinen & Appelqvist 1999).

F012 PUUMALA Ni-Cu

Hannu Makkonen (Belvedere Mining Oy)

The NW-trending Puumala Ni-Cu area (F012) is entirely within the Saimaa-Lahdenpohja metaturbidite-synorogenic intrusive area (Fig. 24). It comprises a set of mineralised tholeiitic mafic-ultramafic intrusions surrounded by metaturbidites and synorogenic granitoids. The metallogenic area includes two small subareas with high potential for discoveries: Niinimäki Ni (F012.1) and Kekonen Ni (F012.2). They differ distinctly in their country rocks. The Niinimäki subarea is located within a granulite facies garnet-cordierite-(sillimanite) gneiss area, representing the 1830 Ma thermal metamorphism with K granites (e.g., Korsman et al. 1988). This younger metamorphic event largely destroyed the fingerprints of the earlier ca. 1.89 Ga metamorphic event. The Kekonen subarea, by contrast, is characterised by country rocks typical for the Kotalahti Ni area, that is, variously migmatised metaturbidites and synorogenic, mainly tonalitic granitoids. Despite the currently different environment, the mafic-ultramafic intrusions and related deposits in both subareas were originally similar (Makkonen 1996).

The Niinimäki subarea (F012.1) includes nickel deposits and occurrences of the Luonteri-Heiskalanmäki belt and the **Niinimäki** deposit to east (Fig. 24). The eastern boundary of the area, and thus of the Puumala Ni-Cu area, may extended some tens of kilometres to the east-southeast from Niinimäki, where there are a few small Ni-Cu occurrences (e.g. **Kitula** and several deposits at Partalansaari). The latter are, however, outside any designated metallogenic area in the map by Eilu et al. (2009).

The N-trending Luonteri-Heiskalanmäki belt is 2 km wide and 15 km long. The dip of the metasedimentary units and embedded sill-like intrusions is steep. The stratigraphic footwall of the intrusions, where the Ni-Cu deposits are located, is towards the east (Makkonen 1996). The largest intrusions are over 2 km long but narrow. The most important deposits include, from south to north, **Pihlajasalo**, **Rietsalo** and **Heiskalanmäki** (Table 12). In addition, several showings have been found and, on the basis of glacial erratic boulder data, at least a few are still to be found. The PGE contents of the ore are anomalously high at Rietsalo (up to 1 m @ 1.2 g/t Pt) and Heiskalanmäki (0.19 g/t Pt, 0.29 g/t Pd) compared to a typical Svecofennian Ni-Cu deposit (Makkonen 1996a).

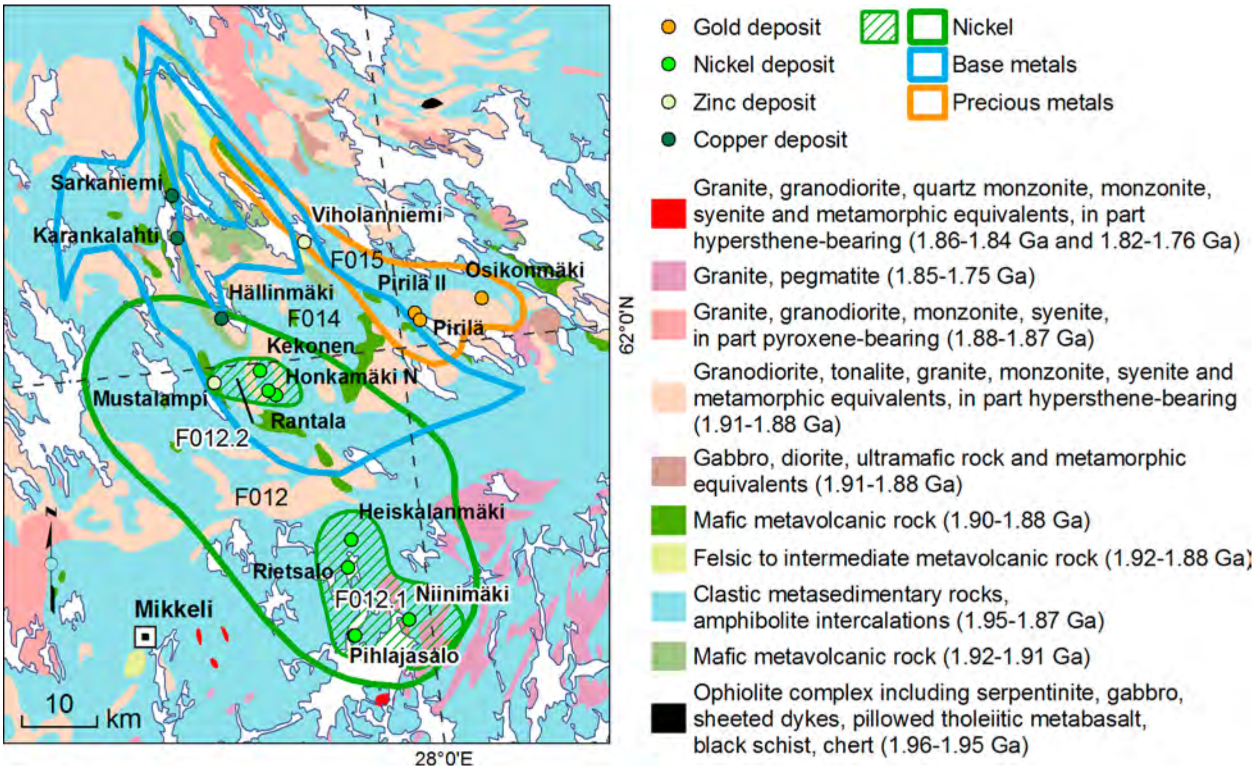


Figure 24. Geology of the Puumala Ni (F012), Virtasalmi Cu (F014) and Rantasalmi Au (F015) metallogenic areas with the most significant nickel, copper and gold occurrences of the area. Geology is from Koistinen et al. (2001).

Around the **Niinimäki** intrusion itself, the dip of the metasedimentary units is shallow or subhorizontal. Consequently, the mafic-ultramafic intrusions are not as elongated as in the Luonteri-Heiskalanmäki belt. The following description for the Niinimäki intrusion and deposit is slightly modified from Makkonen et al. (2008). The horizontal section of the Niinimäki intrusion at the 100 m level is 1 x 2 km and the total thickness is 300 m (Fig. 25). At the surface, the intrusion only occupies an area of 1 km^2, the intrusion being partly overlain by mica gneiss. The layering and schistosity in the surrounding gneisses conforms with the intrusion contacts.

The Niinimäki intrusion mainly consists of gabbro. Because of the high metamorphic grade, there are no primary magmatic minerals left, the main mineral phases being metamorphic orthopyroxene and plagioclase, or in places hornblende and biotite. In mineralised zones near peridotite, the gabbro is altered and the main minerals are plagioclase, chlorite, serpentine and biotite. Peridotite occurs as 50–150 m thick layers with sharp contacts within the gabbro near the stratigraphic footwall of the intrusion. In contrast to the gabbro, olivine and orthopyroxene are the predominant primary magmatic minerals in the peridotite. The ultramafic rock can thus be classified as a harzburgite. Olivine is partly serpentinised and clinoamphibole occurs as an alteration product after orthopyroxene. Minor pyroxenite, composed of orthopyroxene and clinoamphibole, is associated with the peridotite. Small amounts of tonalite also occur within the intrusion, possibly representing the latest differentiates (Makkonen 1997). Country rock contamination is shown, for example, by a high LREE content, high Zr/MgO ratio, and low ε_{Nd} (1.9 Ga) value of 1.0 ± 0.4. *In situ* nickel depletion is found in olivine, and nickel depletion is also shown by the whole rock Ni–MgO ratio (Makkonen 1996). Nickel orebodies occur at the western margin of the intrusion, hosted by both gabbro and peridotite (Table 12). Disseminated sulphides (pyrrhotite, pentlandite, chalcopyrite) occur in the harzburgite and disseminated, net-textured and massive sulphides in the altered gabbro. Near the surface, the gabbro-hosted ore is altered to pyrite-violarite ore (Makkonen & Forss 1994, 1995)

The Kekonen subarea (F012.2) includes three Ni-Cu deposits (Table 12) and a few occurrences without a resource estimate. In addition, there are a few unexplored, relatively large intrusions that could host nickel deposits. Schollen migmatites, typical country rocks for the Svecofennian Ni-bearing intrusions, exist near the **Kekonen** deposit. The petrology of the Saarijärvi intrusion, just south of Kekonen, has been studied by Pietikäinen (1986) and Makkonen (1996). It is an example of a Ni-potential intrusion with Ni depletion and contamination features (enriched LREE, ε_{Nd} (1.9 Ga) 0.4 ± 0.3). Drilling intersects of 0.7 % Ni have been reported in the Saarijärvi intrusion, but no distinct ore body has so far been identified. The Kekonen deposit includes portions where PGE and Au contents are anomalously high (0.45 m @ 0.15 g/t Pd, 0.21 g/t Au; Makkonen 1996a, Makkonen 1996).

Table 12. Mafic-ultramafic intrusion-hosted Ni-Cu occurrences with a resource estimate in the Puumala Ni-Cu area (F012).

Subarea **Occurrence**	**Tonnage (Mt)**	**Co %**	**Cu %**	**Ni %**	**Main host rock**	**Reference**
Niinimäki Ni (F012.1)						
Niinimäki peridotite	2.4	0.016	0.13	0.36	Harzburgite	Makkonen & Forss (1995)
Niinimäki gabbro	0.223	0.043	0.27	0.87	Metagabbro	Makkonen & Forss (1994, 1995)
Rietsalo	0.056	0.015	0.53	0.53	Gabbro	Makkonen (1996a)
Heiskalanmäki	0.055	0.015	0.25	0.55	Gabbro	Makkonen (1995)
Pihlajasalo 1	0.01	0.023	0.24	1.14	Perknite	Makkonen & Mursu (2004)
Pihlajasalo 2	0.01	0.012	0.22	0.55	Gabbro	Makkonen (1996b)
Kekonen Ni (F012.2)						
Kekonen	0.056	0.02	0.21	0.54	Olivine gabbronorite	Makkonen (1985, 1996)
Honkamäki	0.01	0.02	0.2	0.35	Hornblendite	Makkonen (1992a)
Rantala	0.02		0.34	0.53	Picrite	Makkonen (1996a)

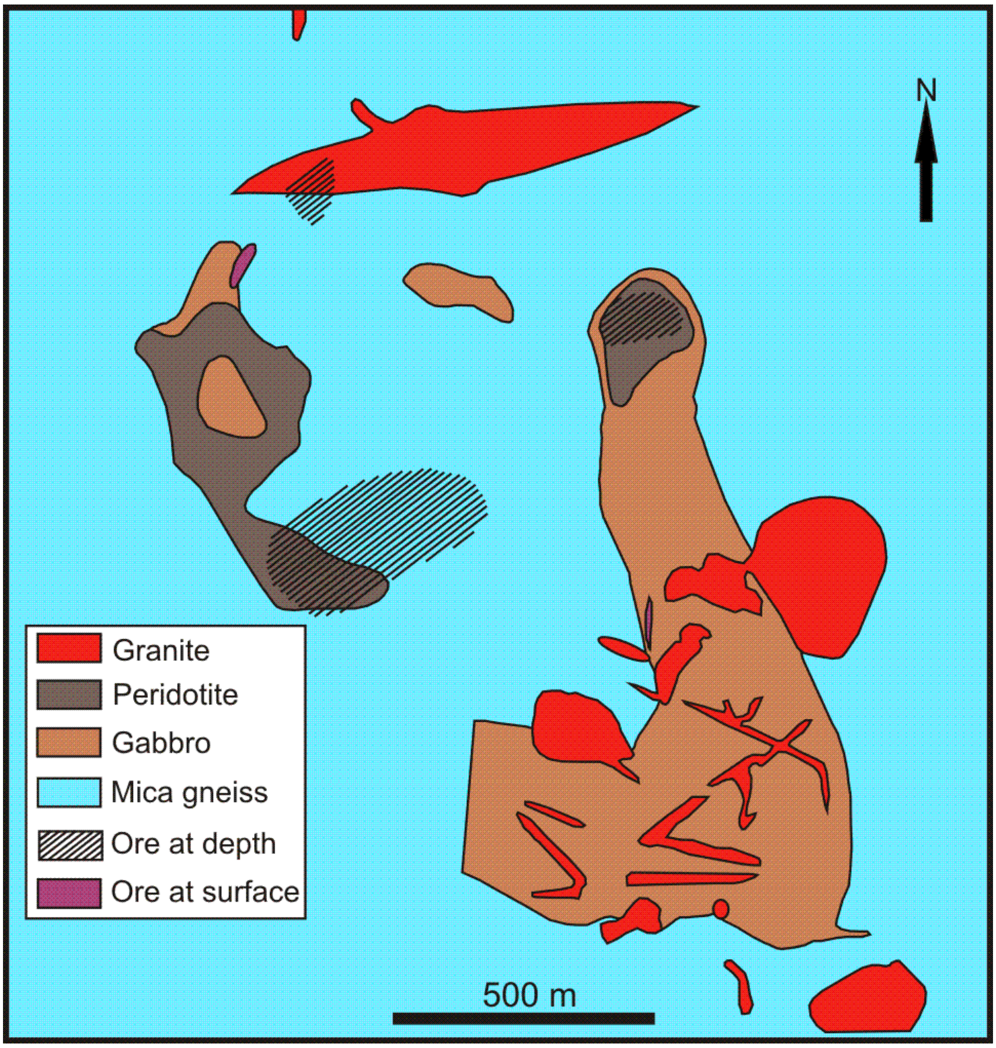


Figure 25. Geology of the Niinimäki nickel deposit, located at 61.6766°N, 27.945°E. Modified from Makkonen & Forss (1995) and Grundström (1998), mapped by J. Vilen (GTK) in 1997.

F013 ILMOLAHTI Ni-Cu

Hannu Makkonen (Belvedere RMining Oy)

The NW-trending Ilmolahti Ni-Cu area (F013) is a west-opening arcuate belt near the eastern margin of the Central Finland Granitoid Complex (Fig. 1). It contains scattered nickeliferous mafic-ultramafic intrusions surrounded by metaturbidites and synorogenic granitoids. Most of the deposits are of low nickel grade. Deposits in the middle of area F013, such as **Törmälä** (Kontoniemi & Forss 1999) and **Mäkisalo**, are in the Rautalampi granulite domain. Within area F013, only the Törmälä deposit is close to being economic based on its nickel grade and ore amount (Table 13).

The Rautalampi granulite domain, about 40 km west of the Archaean craton, belongs to the contact area between the Central Finland Granitoid Complex and the Savo schist belt. The central part of the Törmälä region forms a structural dome, with gneissic tonalites (1.93–1.91 Ga) in the centre, together with the mafic-ultramafic rocks (Lahtinen 1994, Pääjärvi 2000). The tonalites are the oldest rocks in the area, which means that the mafic-ultramafic intrusions occur stratigraphically at the lowest level in the area. In addition to the Törmälä and Majasaari intrusions, several relatively large, unexplored intrusions occur within or near the structural dome.

The Törmälä gabbro-peridotite intrusion has a surface extent of around 50 x 150 m. The thickness of the body is up to 40 m and it dips gently to the NW. The contacts with the surrounding tonalite gneisses are tectonised. The main rock types are olivine gabbronorite and plagioclase-bearing lherzolite, whereas coarse-grained gabbronorite and pyroxenite are found along the intrusion margins. The central part of the intrusive body is slightly more mafic (higher whole-rock Mg-number and higher Fo) than the margins. Sulphides (pyrrhotite, pentlandite, chalcopyrite) occur in varying amounts as coarse-grained disseminations and breccias throughout the intrusion body. The highest sulphide concentrations are found near the footwall contact. (Makkonen et al. 2008)

Country rock contamination features typical for Svecofennian nickeliferous intrusions are not obvious at Törmälä. This is probably because in most of the Svecofennian nickel-rich intrusions the country rock is mica gneiss, whereas at Törmälä it is tonalitic gneiss. The ε_{Nd} (1.88 Ga) value in the Törmälä peridotite is 1.2–1.4 ± 0.4, whereas much lower values are common in other analysed intrusions within the Svecofennian domain (Makkonen & Huhma 2007). Nickel depletion is distinct in both olivine and whole rock at Törmälä (Makkonen et al. 2008).

Table 13. Mafic-ultramafic intrusion-hosted Ni-Cu deposits and occurrences in the Ilmolahti Ni-Cu area (F013).

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	Main host rock	Reference
Ilmolahti	0.21	0.04	0.28	0.37	Peridotite	Papunen & Vorma (1985)
Mäkisalo	0.104	0.03	0.28	0.43	Gabbro	Kontoniemi & Forss (2001)
Ohensalo	0.137		0.29	0.24	Gabbro	Heikkilä-Harinen (1977b)
Törmälä	0.116	0.03	0.33	0.6	Gabbro	Heino (1999), Kontoniemi & Forss (1999)

F014 VIRTASALMI Cu

Kaj Västi (GTK)

The Virtasalmi Cu area (F014) is located in the northwestern corner of the Saimaa Schist area. It is bordered in the west by the Central Finland Granitoid Complex and in the east by the Savo Schist Belt. It overlaps the Puumala Ni area (F012) in the south and the Rantasalmi Au area in the east (F015) (Fig. 24).

Area F014 comprises NW-trending supracrustal (1.92–1.90 Ga) and synorogenic plutonic (1.90–1.88 Ga) rocks affected by polyphase deformation and upper-amphibolite to granulite facies metamorphism. Supracrustal rocks are mafic to intermediate metavolcanic and metasedimentary rocks. Metavolcanic rocks are mainly amphibolites, diopside amphibolites and iron-rich skarn rocks, which contain andradite, diopside-hedenbergite, epidote, magnetite and locally scapolite. In places, there are marble intercalations in the amphibolites. Metasedimentary rocks in the region include mica gneiss and mica schist (Lawrie 1987, 1992, Pekkarinen 2002).

The relatively small metallogenic area F014 is characterised by the Virtasalmi-type (Hällinmäki-type) amphibolite and iron-rich garnet skarn hosted Cu deposits, which typically contain only traces of other base metals. The mineralised skarns probably are metamorphosed equivalents of altered and metamorphosed mafic volcanic rocks and ore formed in sea floor-related hydrothermal systems, and the ores could therefore be classified into the VMS (*sensu lato*) category of mineralisation (Lawrie 1987, 1992).

All Cu occurrences in the area comprise disseminated, brecciated and locally massive sulphide mineralisation (Fig. 26). The brecciated ore type occurs as mesh-like structures or lenses and is related to skarn rocks. Disseminated ore mainly occurs in diopside amphibolites (Hyvärinen 1969, Lawrie 1987, Pekkarinen 2002). Chalcopyrite is practically the only Cu-bearing sulphide, although in places there also is cubanite. Pyrrhotite, pyrite and magnetite also occur as major ore minerals. Only the **Hällinmäki** (Virtasalmi) deposit has been exploited (Fig. 27). Other Cu occurrences listed in Table 14 are prospects where resources and Cu contents vary between 0.003–0.37 Mt and 1.0–2.85 %, respectively.

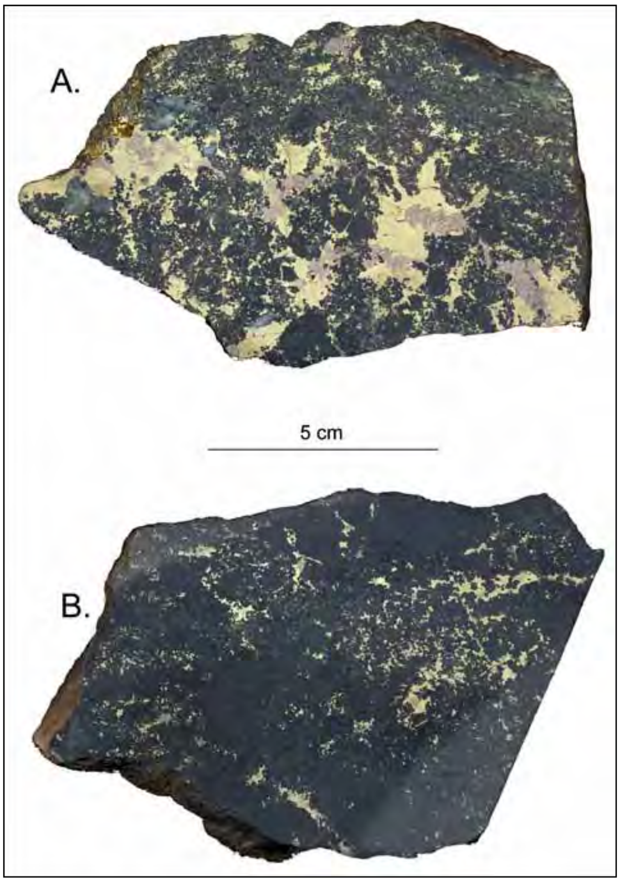


Figure 26. A) Chalcopyrite (yellow), and pyrrhotite (brown) in andradite skarn. B) Disseminated chalcopyrite with minor pyrrhotite in diopside amphibolite. Both images at the same scale. Scanned image by Kaj Västi, GTK.

The now exhausted volcanogenic-exhalative Hällinmäki deposit comprised five ore bodies (Fig. 28), was about 500 m long and 2–30 m wide, and extended to the depth of 350 m (Hyvärinen 1969, Pulkkinen 1985, Lawrie 1987). The polydeformed stratabound deposit with the subjacent stockwork zone is located on the eastern limb of a large, northerly plunging F2 antiform. This structure is refolded around the hinge of a major, upright F3, open to tight fold, the axial plane of which trends NW–SE through the area (Lawrie 1987). The interlayering of mafic metavolcanic rocks with marbles and clastic metasedimentary rocks and enrichment in incompatible elements suggest an intracratonic rift geotectonic setting for the Cu deposit. The deposit also shows lateral zoning with a marked increase in magnetite to the SE, where silicate facies iron formation occurs at the same level as the Cu mineralisation. Extensive hydrothermal alteration was coeval with exhalative mineralisation (Lawrie 1987).

On the fringes of area F014 there are a few zinc occurrences dissimilar to the Virtasalmi-type Cu. The former are hosted by felsic to intermediate volcanic rocks, quartz-carbonate rock and mica gneiss and contain about 0.3–2.9 % zinc and only minor amounts of copper. In addition, the Viholanniemi deposit also contains some lead (0.64 %), silver and gold (Table 14).

Figure 27. Hällinmäki (Virtasalmi) open pit on 27 September 2007, at 62.0576°N, 27.552°E. Photo: Kaj Västi, GTK.

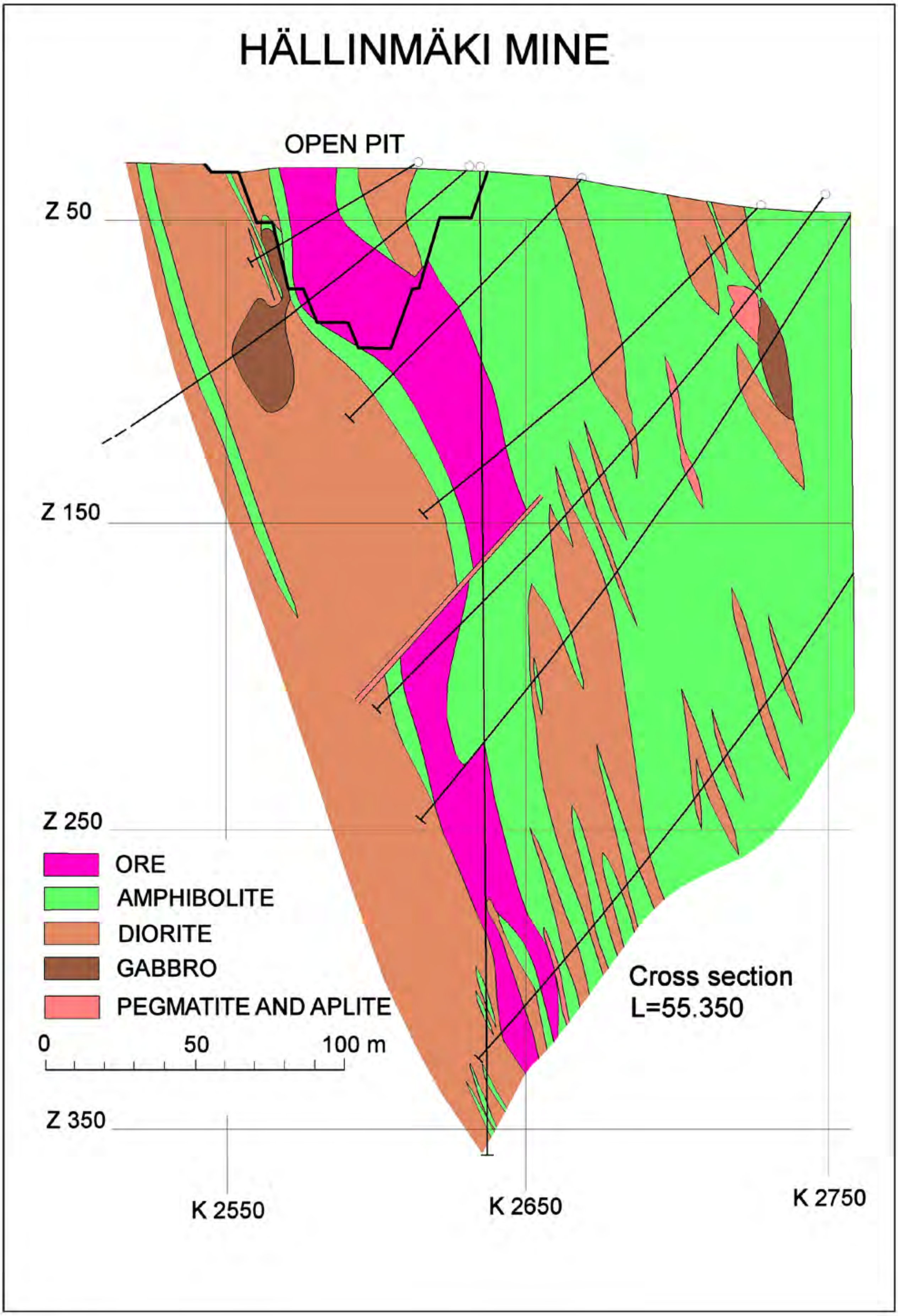


Figure 28. Section across the ore body A of the Hällinmäki mine. View to the NW. Modified from Vaajoensuu et al. (1978).

Table 14. Copper and zinc occurrences in metallogenic area F014.

Occurrence (Alternative name)	Tonnage Mt	Cu %	Zn %	Ag g/t	Au g/t	Main host rock	Reference
Virtasalmi-type Cu occurrences							
Hällinmäki (Virtasalmi)	4.2*	0.73			0.1	Garnet skarn, Amphibolite	Hyvärinen (1969), Pulkkinen (1985), Lawrie (1987)
Karankalahti	0.37	1.02				Garnet-diopside-epidote skarn, Amphibolite	Grundström et al. (1986)
Sarkaniemi	0.029–0.086	2.85				Garnet-epidote skarn, Amphibolite	Grundström (1979)
Karhuniemi	0.013–0.018	0.5–0.6				Garnet skarn, Amphibolite	Grundström (1976)
Lari	0.003–0.005	1.28				Garnet skarn	Hyvärinen (1969), Grundström (1977a)
Sahinjoki	0.003	1.0				Amphibolite, Diopside-epidote skarn	Grundström (1977b)
Zinc occurrences							
Viholanniemi S	0.19	0.19	2.31	26	0.7	Quartz-carbonate rock	Makkonen (1991a, 1991b)
Viholanniemi N	0.058	0.12	1.97	105	1.1	Quartz-carbonate rock	Makkonen (1991a, 1991b)
Mustalampi S	0.0105		5.6			Felsic to intermediate volcanic rock	Makkonen (1989)
Mustalampi N	0.0255		1.75			Felsic to intermediate volcanic rock	Makkonen (1989)

* Mined in 1966–1983; only the mined amount and grade has been reported.

F015 RANTASALMI Au

Pasi Eilu and Olavi Kontoniemi (GTK)

The Rantasalmi Au area (F015) is a NW-trending domain along the Kolkonjärvi Shear Zone (KSZ), a boundary between the Savo and the Saimaa Schist areas. The KSZ is one of the major transcurrent, possibly transcrustal faults of the 50–100 km wide, NW-trending Raahe-Ladoga suture zone between the Karelian and Svecofennian terranes in Finland (Korsman 1988). In the SW, area F015 overlaps with the Virtasalmi Cu area (F014) and in the NE it is close to and follows the strike of the SW boundary of the Kotalahti Ni area (F016) (Fig. 24).

Three occurrences with a resource estimate are known from the area F015 (Table 15): the main deposit, **Osikonmäki**, is clearly of the orogenic type (Kontoniemi 1998a, 1998b), whereas the **Pirilä** deposits may be orogenic or of the metamorphosed syngenetic type. The Osikonmäki deposit (Fig. 29) comprises several complex ore bodies (e.g. Osikko E and W) in a synkinematic tonalite (intrusion dated to 1887 ± 5 Ma; Vaasjoki & Kontoniemi 1991). The ore bodies comprise

Table 15. Gold deposits in the Rantasalmi metallogenic area (F015).

Occurrence	Tonnage (Mt)	Ag g/t	Au g/t	Cu %	Pb %	Host rocks	Reference
Osikko E	2.0		3.0			Tonalite	Kontoniemi & Ekdahl (1990),
	1.8		3.2				Parkkinen (1992),
	3.0		1.65				Belvedere Resources (2011)
Osikko W	0.09		4.9			Tonalite	Kontoniemi (1992)
Pirilä	0.3	32	6.5	0.18	0.76	Intermediate volcanic rock	Makkonen & Ekdahl (1988), Parkkinen (2003)
Pirilä II	0.03		2.7			Intermediate volcanic rock	Makkonen (1987), Makkonen & Ekdahl (1988)

both auriferous quartz veins and mineralised host rock and form, at least, a 3-km-long mineralised domain in the E-trending, south-dipping Osikonmäki shear zone (Kontoniemi 1998a, 1998b). The mineralisation is related to peak deformation, but appears to have been metamorphosed under upper-amphibolite facies conditions. Native gold chiefly occurs with Bi-Se-Te minerals at Osikonmäki, as inclusions and at grain boundaries within and between arsenopyrite, löllingite, quartz and plagioclase (Kontoniemi et al. 1991).

The Pirilä occurrence is a single-lode gold deposit also enriched in silver and base metals. It comprises auriferous arsenopyrite-quartz veins and intensely altered host rock in a major fold hinge in intermediate metavolcanic rock (Makkonen 1987, Makkonen & Ekdahl 1988). Gold and electrum inclusions are primarily near the contact between arsenopyrite and löllingite at Pirilä, but submicroscopic gold also occurs in löllingite (Makkonen & Ekdahl 1988).

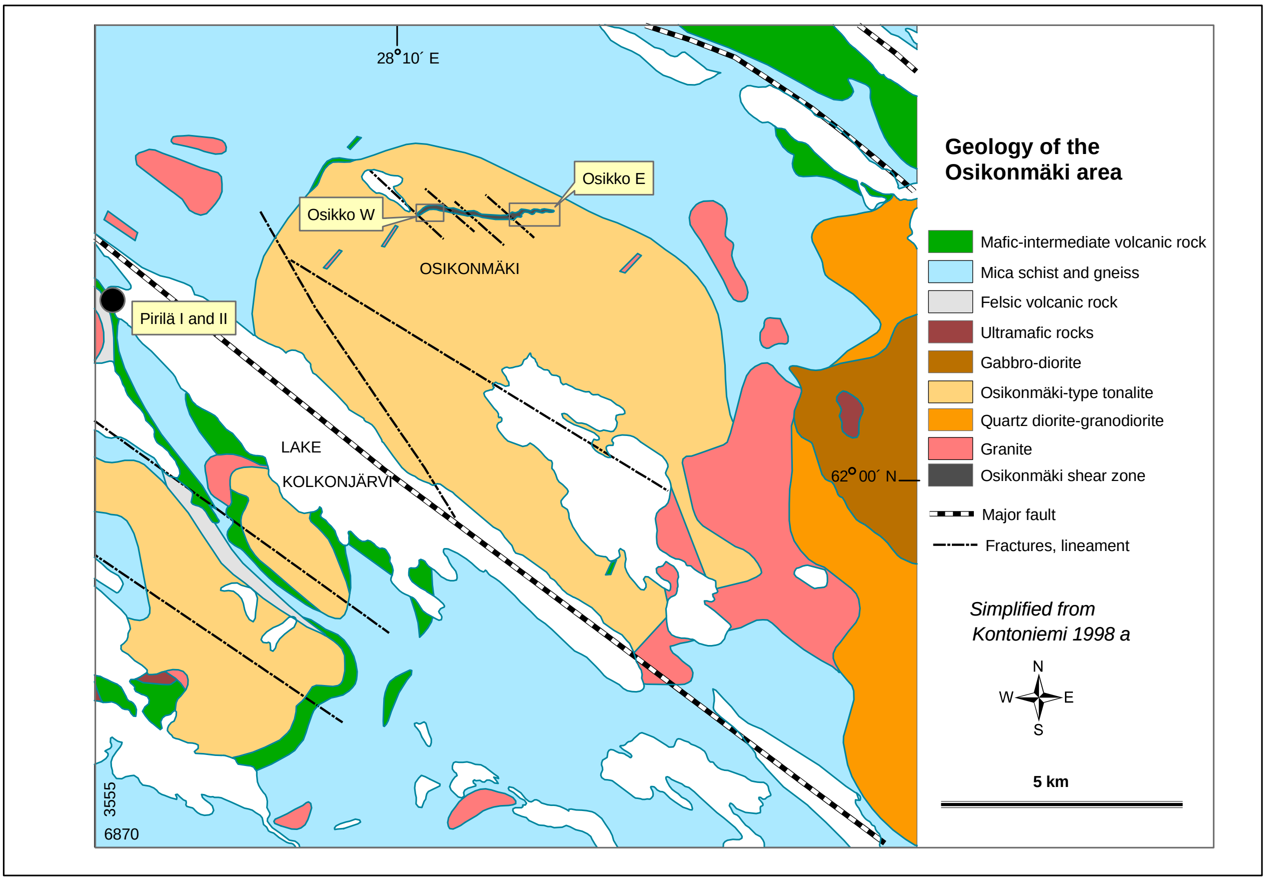


Figure 29. Geological map of the Osikonmäki–Pirilä region within metallogenic area F015 (simplified from Kontoniemi 1998a).

F016 KOTALAHTI Ni

Hannu Makkonen (Belvedere Mining Oy)

The NW-trending Kotalahti Ni area (F016) is entirely within the Savo supracrustal belt (Fig. 30). It is bounded to the northeast by the Archaean craton margin and to the southwest by the Central Finland Granitoid Complex. The exact boundaries of area F016 can be questioned, however, because the nickel-potential intrusions appear to simply gradually fade out to the southwest. The boundary to the northeast is more distinct, as the intrusion of Svecofennian nickel-rich magma took place in the craton margin zone, and did not significantly extend into the Archaean domain.

The Savo supracrustal belt is mainly formed by migmatised mica gneisses of greywacke and mudrock origin. Felsic and mafic volcanic rocks, as well as graphite schists and gneisses, are locally

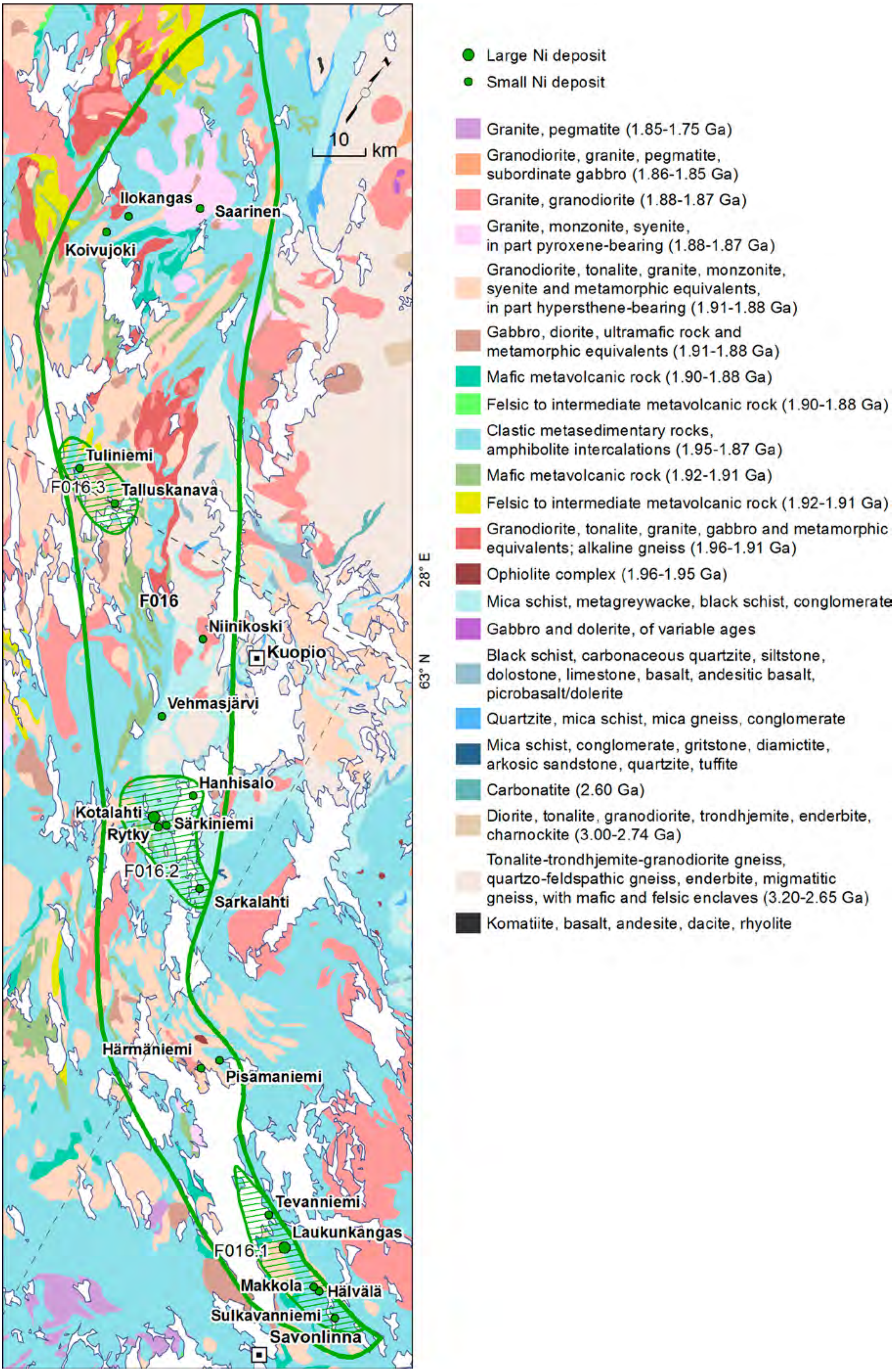


Figure 30. Geology of the Kotalahti Ni area (F016) with the Laukunkangas (F016.1), Kotala (F016.2) and Tallus (F016.3) metallogenic subareas, and the most significant nickel-copper occurrences of the region. Geology is based on the GTK digital bedrock database.

abundant (Kähkönen 2005). Volcanic rocks form major belts, but also occur as narrow discontinuous belts or limited occurrences within both metasedimentary and intrusive complexes. The volcanic rocks belong to ca. 1.92 Ga bimodal and to 1.88 Ga mafic-intermediate age groups (Kousa & Lundquist 2000). The former, forming the primitive arc complex of central Finland, are economically important due to massive sulphide deposits (metallogenic area F028). The 1.88 Ga nickel-rich mafic-ultramafic intrusions mostly occur within the mica gneiss, but also within and at the contact zone of the Archaean gneiss, as in the Kotalahti area (Fig. 31).

The following description of the metamorphism and deformation of the Savo belt is mainly from Kähkönen (2005). The eastern parts of the Savo belt, in particular, are characterised by fault-bounded blocks with variable metamorphic and structural histories. The metamorphic grade varies from medium-T amphibolite facies (550–600 °C) to granulite facies (800–880 °C) at pressures of 5 ± 1 kbar. The metamorphic evolution culminated close to a main phase of granitoid magmatism at ca. 1885 Ma. Deformation was polyphase and in many places produced complex interference patterns. The two earliest folding phases produced isoclinal to tight recumbent folds with east-to-northeast vergence; a regionally pervasive foliation or gneissose banding also developed during these phases. A third folding phase turned the flat-lying structures subvertical and resulted in approximately N-oriented elongate antiforms and synforms, which cover the structure of the Savo belt. Open curving of the axial planes of these folds is largely due to a fourth phase of deformation. North-striking dextral shear zones are related to the third phase, whereas a system of NE-striking sinistral and S-striking dextral zones characterises the fourth deformation phase.

Most of the mafic-ultramafic Ni-potential intrusions in area F016 are rather small, with roughly 10 km as the maximum dimension at the present erosion level. Typically, the maximum horizontal dimension is less than 2 km. The intrusions are composed of a differentiation series from ultramafic to gabbroic (locally to dioritic and quartz dioritic) rocks. Intrusions composed solely of ultramafic rocks exist but are rare. Intrusions are mainly in areas of higher metamorphic grade than the surrounding region, and thus in a relatively deep crustal section. These potential areas are commonly within local gravimetric highs because of the abundance of the mafic-ultramafic rocks themselves and because of the relatively dense minerals of the country rocks.

The intrusion of Ni-rich magma took place in early D_2 (e.g. Mäkinen & Makkonen 2004, Peltonen 2005), and thus into flat-lying rock units. This is important to note from the exploration point of view. In most of the studied intrusions within the Kotalahti belt, it has been possible to recognise the stratigraphic footwall of the intrusion as the most promising locality for nickel ore in an intrusion (e.g. Forss et al. 1999, Makkonen et al. 2003). According to Makkonen (2005), the magma intruded within a high-temperature shear zone between a large magma reservoir and a D_2 imbrication zone. Peltonen (2005) emphasised the importance of transtensional shear systems developed at the continental margin, which locally facilitated the ascent of melts along subvertical shear zones. Within shear zones, magmas are expected to rise faster and undergo less fractionation during emplacement, thus retaining a high nickel potential. The parental magma for the intrusions was EMORB-type tholeiitic basalt with an MgO content of 10–15 % (Makkonen & Huhma 2007, Barnes et al. 2009).

Most of the intrusions show evidence of wall rock or country rock contamination indicated, for example, by elevated LREE and low to negative ε_{Nd} in peridotites and a distinct nickel depletion (Mäkinen & Makkonen 2004, Lamberg 2005, Makkonen & Huhma 2007, Makkonen et al. 2008). These features have successfully been used in exploration within metallogenic area F016. In some intrusions however, it is obvious that the early-formed sulphides with nickel have been left at lower crustal levels than the present intrusion body, which makes the lithogeochemical exploration for Ni deposits complicated.

Typical nickel ore in the area F016 is composed of pyrrhotite, pentlandite and chalcopyrite. The ore is disseminated, network-textured or massive. The nickel content in massive ores can be 5–10 %. The Ni/Cu ratio is usually 1.5–3.5 and the Ni content in the sulphide fraction varies from 1–10 %, being mostly 3–8%. This large range reflects the variable amount of external sulphur assimilated by the mafic magma. PGE contents are typically low and show a distinct negative Pt anomaly in the mantle/chondrite normalised PGE pattern. Offset ores have been the economic backbone for many deposits in the Kotalahti area. These are ore bodies that occur outside the main host intrusion, usually enclosed by the country rocks. Typical offset ore mainly comprises massive and network sulphides, and has a high nickel content. Opinions on the origin of the offset ore bodies range from synmagmatic deposition to tectonic remobilisation of the sulphides.

Some of the most important ore indications for nickel exploration in the Kotalahti Ni area (F016) include the following:

- The intrusions can usually be found on local gravimetric highs, also below the gneisses.
- A positive magnetic anomaly usually exists, formed by monoclinic pyrrhotite or peridotitic host rock.
- All economic deposits include *peridotitic* differentiates as host rocks.
- The nickel ore locates in the stratigraphic footwall of the intrusion.
- The existence of offset ore seems to be a rule.

Kotalahti and **Laukunkangas** deposits are economically the most important in area F016 (Table 16). Both are hosted by a differentiated intrusion, but at Kotalahti the deformation history and probably also the emplacement history is more complex (cf. Papunen 2003). The Kotalahti deposit is of high importance for the Finnish nickel industry because its discovery in 1954 and opening of the mine in 1959 led to the establishment of a nickel smelter at Harjavalta in the 1960s.

The Kotala subarea (F016.2) is in the craton margin, partly within the Archaean area (Fig. 31). Kotalahti and Rytky intrusions are within the Kotalahti Dome, which is composed of Archaean gneiss surrounded by a Palaeoproterozoic craton-margin supracrustal sequence. The Kotalahti intrusion is a subvertical sheet with a length of approximately 1.3 km and a maximum width of 200 m. The southernmost intrusive body extends downwards to a depth of more than 1000 m (Papunen 2003). The wall rocks of the intrusion mainly consist of Archaean gneisses (Fig. 31). The U-Pb zircon age obtained for a gabbro in the Kotalahti intrusion is 1883 ± 6 Ma (Gaál 1980).

The rock types at **Kotalahti** range from olivine and olivine-enstatite cumulates to orthopyroxenites, poikilitic gabbros, ophitic gabbronorites and diorites (Papunen 2003). Among the peridotitic rocks, coarse-grained lherzolite is in the stratigraphic footwall and is overlain by medium-grained lherzolite (Mäkinen & Makkonen 2004). The ore bodies from north to south include Mertakoski, Välimalmio, Vehka and Huuhtijärvi. A separate massive offset, called the Jussi ore body, is present as a subvertical slab in the black-schist and calc-silicate wall rock some 150 m east of the Vehka ore body. The Jussi ore body extends to a depth of more than 1000 metres. Disseminated sulphides are common in ultramafic rocks and poikilitic gabbros, whereas ophitic gabbros and diorites are almost barren. Breccia-type sulphides occur as irregular masses, commonly along the contacts in the thinner central part of the intrusion (Papunen 2003). The Kotalahti deposit is similar in geology, host rocks and ore composition to the neighbouring Rytky deposit.

In the recent study by Seppä (2009), the peridotitic host rock of the Kotalahti deposit was found to be layered. Layering is seen in the gradual change of, for example, the Mg number, MgO and whole rock Ni/Co values towards the intrusion contact. In addition, in the Jussi ore body, layered peridotite was found as the host rock. These facts suggest that at Kotalahti the intrusion also originally formed a subhorizontal body, which was later folded into a subvertical setting. Inevitably, this gives new ideas for further exploration at Kotalahti.

The average composition for different ore types at Kotalahti is given in Table 17. According to Papunen and Vorma (1985), the Kotalahti ore averages 0.70 % Ni, 0.27 % Cu, 0.03 % Co and 4.00 % S. The main sulphide minerals are pyrrhotite, pentlandite and chalcopyrite; in the Jussi ore body, pyrite also is significant. In the disseminated ores, pyrrhotite is troilite and hexagonal pyrrhotite in composition, whereas in the breccia ores (vein network ores) and in the Jussi ore body in particular, the monoclinic variant predominates. Gersdorffite, mackinawite and argentian pentlandite are the common accessory sulphides. The Jussi ore body also contains portions rich in millerite and bornite (Papunen & Koskinen 1985). The PGE content of the Kotalahti ore is insignificant. There is a distinct negative Pt anomaly in the PGE pattern (Papunen 1989, Makkonen & Halkoaho 2007). The $\delta^{34}S$ in ores hosted by the ultramafic rocks is +1.4 to +2.6 ‰ and in the Jussi orebody +1.4 to +2.8 ‰ (Papunen & Mäkelä 1980).

The Laukunkangas subarea (F016.1) in the southeastern end of the Kotalahti Ni area forms a distinct concentration of nickel-copper deposits in a linear belt, which is characterised by an intense positive gravimetric anomaly. It has been suggested that the nickeliferous intrusions here follow the primary craton margin at the time of the emplacement of the mafic magma similarly, for example, to the Thompson Belt in Canada (e.g., Makkonen 2008). The **Laukunkangas** and **Hälvälä** deposits of subarea F016.1 have been mined (Table 16). On the basis of glacial erratic boulder data, the Laukunkangas subarea still has good potential for new deposits. The Tallus subarea (F016.3) includes two minor, low-grade deposits, **Talluskanava** and **Tuliniemi**. Based on the boulder data, however, more deposits could be found from subarea F016.3.

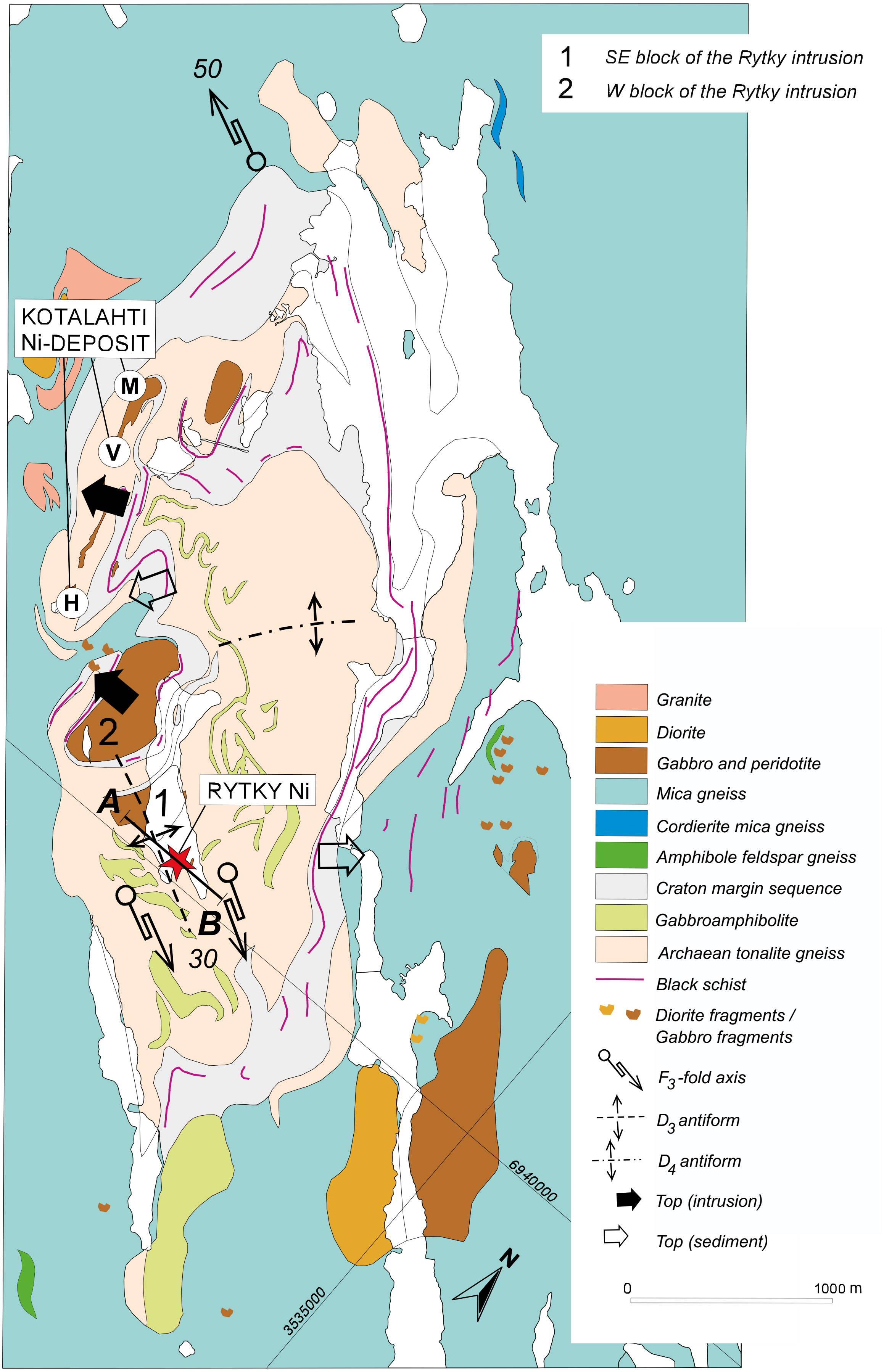


Figure 31. Kotalahti Dome geology. M = Mertakoski ore body, V = Vehka orebody, H = Huuhtijärvi ore body (Mäkinen & Makkonen 2004).

Table 16. Magmatic intrusion-hosted Ni-Cu deposits and occurrences with a resource estimate in the Kotalahti metallogenic area (F016).

Subarea **Occurrence**	**Tonnage (Mt)**	**Co %**	**Cu %**	**Ni %**	**When mined**	**Main host rock**	**Reference**
Laukunkangas Ni (F016.1)							
Sulkavanniemi	0.194		0.09	0.32		Norite	Puustjärvi (1987)
Hälvälä	0.448	0.075	0.36	1.5	1988–1992	Mica gneiss	Eeronheimo (1985a)
Makkola	0.526	0.034	0.18	0.52		Pyroxenite	Eeronheimo (1985b)
Laukunkangas	7.9	0.03	0.20	0.72	1984–1994	Harzburgite	Grundström (1985), Juhava et al. (1989), Puustinen et al. (1995)
Tevanniemi	0.182	0.03	0.15	0.63		Olivine gabbronorite	Eeronheimo (1988)
Kotala Ni (F016.2)							
Sarkalahti	0.19	0.03	0.33	1.02		Peridotite	Papunen & Vorma (1985), Belvedere (2006)
Rytky	1.54	0.03	0.29	0.71		Lherzolite	Suomen Nikkeli (2007)
Särkiniemi	0.292	0.06	0.53	0.91	2007–2008	Peridotite	Kontoniemi & Forss (1997)
Kotalahti*	12.36	0.03	0.26	0.66	1959–1987	Peridotite, Pyroxenite	Puustinen et al. (1995)
Hanhisalo	0.143	0.02	0.2	0.61		Gabbro	Kontoniemi & Forss (1998)
Niinikoski	0.083	0.045	0.13	0.43		Gabbro	Makkonen (2002)
Vehmasjärvi	0.036	0.06	0.69	0.94		Peridotite	Makkonen & Forss (1999)
Koivujoki	0.025		0.3	0.94		Peridotite	Ekdahl (1993)
Tallus Ni (F016.3)							
Talluskanava	0.15	0.02	0.19	0.33		Peridotite	Nurmi (1976), Papunen & Vorma (1985)
Tuliniemi	0.09		0.15	0.34		Norite	Ekdahl (1993)

* Only the mined amount and grades have been reported.

Table 17. Chemical composition of different ore types at Kotalahti calculated to 100 % sulphides (in weight %); from Papunen and Koskinen (1985).

Ore type	**Ni %**	**Cu %**	**Co %**
Disseminated ore in peridotite	9.81	2.90	0.41
Disseminated ore in pyroxenite	9.19	2.79	0.45
Disseminated ore in perknite	8.41	2.86	0.40
Disseminated sulphides in diorite and quartz diorite	1.37	1.54	0.38
Breccia ore, Mertakoski ore body	6.53	2.75	
Breccia ore, Välimalmi ore body	6.14	2.05	
Breccia ore, Vehka ore body	6.38	1.74	
Breccia ore, Huuhtijärvi ore body	6.65	2.10	
Breccia ore, Jussi ore body	11.23	6.47	

F017 ORAVAINEN Ni

Markku Tiainen (GTK)

The N-trending Oravainen Ni area (F017) is an east-opening arcuate belt along the eastern shore of the Gulf of Bothnia in western Finland (Fig. 1). It is defined by the presence of scattered nickeliferous mafic-ultramafic intrusions surrounded by metaturbidites of the Western Finland supersuite and strongly deformed migmatites of the Vaasa Complex. Two different types of nickel deposits have been found in area F017: a typical Svecofennian synorogenic intrusion-hosted type represented by the Oravainen deposit, and a possibly younger, diabase-hosted type at Petolahti (Table 18).

The **Oravainen** Ni deposit (Fig. 32) is hosted by a pipe-formed ultramafic intrusion within the strongly deformed, migmatitic Oravainen paragneisses of the Vaasa Complex (Isohanni 1985a, Mäkitie 2000, Sipilä et. al. 2008, GTK internal bedrock database). Two roundish pipe-formed nickel bearing ultramafic intrusions, interpreted by Isohanni (1985a) as feeding channels for the ultramafic magma, have been observed in the Oravainen area. The ultramafic intrusion hosting the nickel deposit has been referred to as ‘Ni ultramafite’ and the other, weakly mineralised intrusion as ‘B ultramafite’.

The Ni ultramafite is a 90 x 30 m oval at the surface, sub-vertical, plunging at 70° to the east and extending to a depth of at least 250 m (Isohanni 1985a). Its composition varies concentrically from a dunitic core to peridotite and pyroxenite at the margins. The main rock type of the intrusion is peridotite. The best sulphide mineralisation is in the dunitic core, and the metal grades decrease towards the margins. The roundish, 60 x 40 m wide, B ultramafite is about 50 m SW of the

Table 18. Mafic-ultramafic intrusion-hosted Ni deposits and occurrences in the Oravainen metallogenic area.

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	Pd g/t	Pt g/t	When mined	Reference
Petolahti	0.2358	0.02	0.38	0.47	0.6	0.1	1972–1973	Himmi (1975), Sipilä et al. (1985)
Oravainen	1.3	0.03	0.16	0.95				Isohanni (1985a)

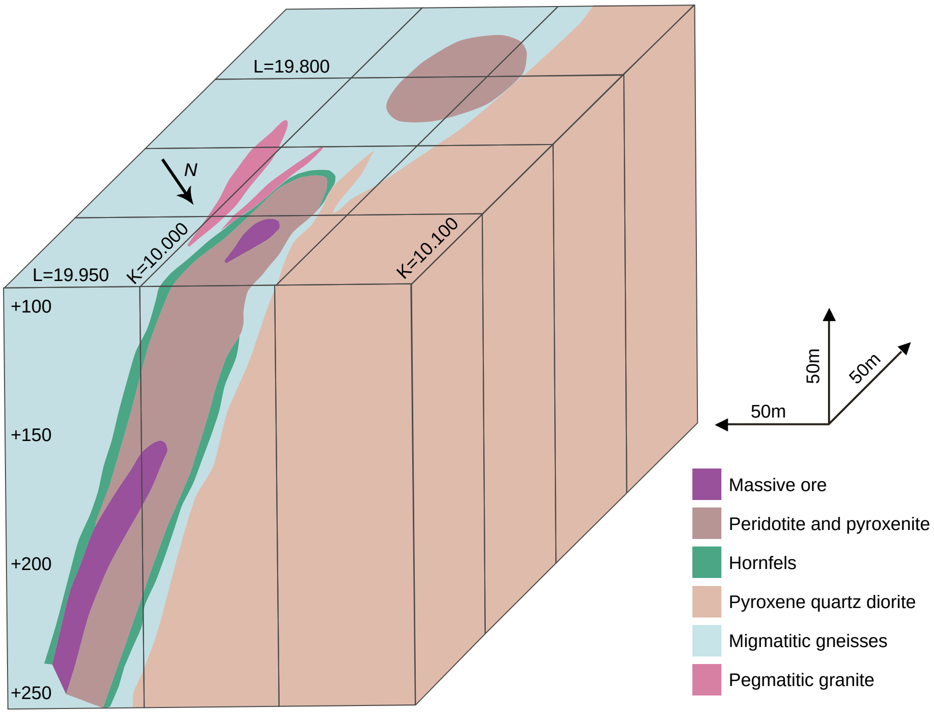


Figure 32. Geology of the Oravainen intrusion and nickel deposit, located at 63.320°N, 22.311°E (Isohanni 1985a). Grid is in 50 m intervals.

Ni ultramafite. The former is mainly composed of peridotite and is less distinctly differentiated. There is only weak sulphide dissemination in the B ultramafite, in the margins of the intrusion.

Dunite at Oravainen contains rare enstatite and augite relicts, whereas olivine is completely serpentinised. The grain size of the olivine pseudomorphs is 0.1–2 mm; augite and enstatite grains are larger and they show a poikilitic texture in relation to olivine. Peridotite is the main rock type of both intrusions and is composed of small euhedral olivine grains, medium- to coarse-grained, subhedral, poikilitic enstatite, and anhedral augite. Some phlogopite and amphibole has also been interpreted to be primary. Serpentine, amphiboles, phlogopite, chlorite, talc and carbonate occur as alteration products. Around the sulphide-rich parts, the euhedral olivine and poikilitic enstatite occur locally as silicate nodules up to 10 mm in diameter in the sulphide matrix. Pyroxenites have been encountered at the NE end of the Ni ultramafite intrusion and commonly form a narrow seam in the transitional zone between hornfels and peridotite. In the pyroxenite, enstatite occurs as euhedral prismatic grains up to 6 mm in size, augite is anhedral and phlogopite occurs as large, ragged, commonly poikilitic grains. The Fo content of the olivine varies from 70.2 % to 84.6 %. The highest Fo contents have been encountered in B ultramafite and in the SW part of Ni ultramafite. The extensive variation in the Ni content of olivine is typical for a mineralised intrusion.

In both intrusions at Oravainen, the sulphides occur as fine- to medium-grained dissemination and small blebs, typically as matrix ore containing olivine pseudomorphs as embedded euhedral grains (Isohanni 1985a). In the Ni ultramafite, the sulphides locally form a network texture (Fig. 33), and in the dunitic even almost differentiate massive ore. Main sulphide minerals are pyrrhotite, pentlandite and chalcopyrite. Cubanite, mackinawite and violarite are also encountered in the central part of Ni ultramafite. Magnetite occurs both in the sulphide mineralisation and as an alteration product of olivine. In the sulphide phase, magnetite occasionally appears as intergrowths with pyrite. Chromite has been encountered as euhedral mineral grains and as intergrowths with pyrrhotite. Arsenides (gersdorffite, niccolite, maucherite) have been encountered as fine-grained dissemination and as fillings in microcracks. Pyrrhotite occurs as large grains, including the monoclinic type and a combination of hexagonal pyrrhotite and troilite. Pentlandite mainly occurs as 3–4 mm grains, and a minor amount as small grains and as exsolution lamellae in pyrrhotite. Chalcopyrite mainly occurs as large grains together with other sulphides. The Ni value of the sulphide phase is 4.0–14.76 % Ni, and the Ni/Cu ratio is 3.5–6.6. On average, the nickel value of the sulphide phase is 5.55 % Ni and the Ni/Cu ratio is 5.8.

The **Petolahti** Ni-Cu deposit is hosted by a diabase dyke 600–700 m long and 7–70 m wide enveloped by biotite paragneisses of the Pirttikylä suite of the Western Finland supersuite (Sipilä et.

Figure 33. Pyrrhotite-pentlandite ore in peridotite at Oravainen. Sample from an erratic boulder. Scanned image, GTK.

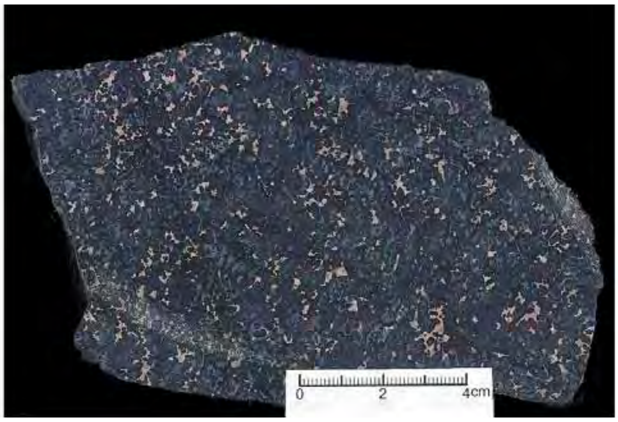


Figure 34. Disseminated pyrrhotite-pentlandite ore at Petolahti. Scanned image, GTK.

al. 1985). Sipilä et al. (1985) interpreted the Petolahti diabase as belonging to the subjotnian Häme diabase group, whereas Lehtonen et al. (2005) regarded it as one of the Svecofennian orogenic mafic-ultramafic intrusions of 1.89–1.88 Ga in age.

The main ore types at Petolahti include disseminated sulphides and sulphide veins in olivine diabase and sulphide dissemination in wall rock (Figs. 34 and 35). The sulphide dissemination in olivine diabase occurs as interstitial blebs of 0.2–4 mm in diameter between the silicates. The main sulphides are pyrrhotite, chalcopyrite and pentlandite. Pyrite has only been encountered in the wall rocks. Ilmenomagnetite and ilmenite occur as a uniform dissemination in the diabase, whereas magnetite occurs as secondary mineral with the sulphides. Pyrrhotite is almost always enveloped by pentlandite and chalcopyrite. The sulphides segregated at the same time with the differentiation of the magma, which resulted in the formation of olivine diabase, pyroxene diabase and finally quartz diabase. The sulphide veins in the olivine diabase crystallised from the residual sulphide melt. The exsolution textures of pyrrhotite, chalcopyrite and pentlandite indicate that the sulphides crystallised as a solid solution at a high temperature and a fairly low water pressure, and that they were exsolved when the temperature dropped (Sipilä et al. 1985).

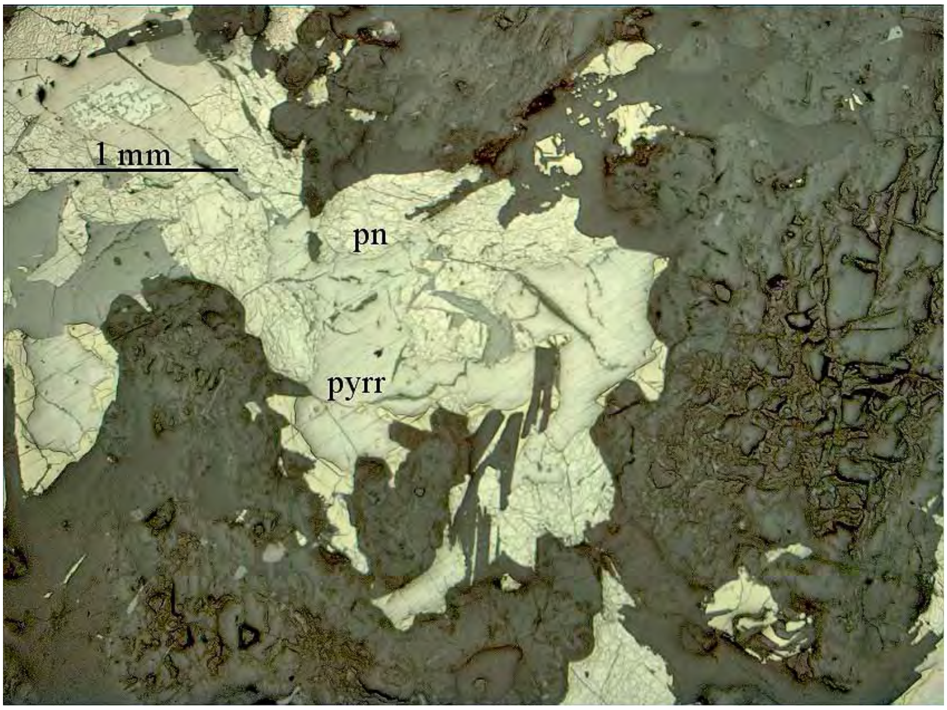


Figure 35. Pyrrhotite-pentlandite ore (pyrr, pn, respectively) in olivine diabase at Petolahti. Photo: Hannu Makkonen, GTK.

F018 SEINÄJOKI Au-Sb

Pasi Eilu and Niilo Kärkkäinen (GTK)

The Seinäjoki Au-Sb area (F018) is defined by the extent of orogenic gold±antimony mineralisation within the southern part of the Pohjanmaa supracrustal belt (Fig. 36). To the east and west its boundaries are vague: the metallogenic area should perhaps be open along strike at both ends.

The Pohjanmaa supracrustal belt comprises 1.91–1.88 Ga turbiditic greywackes and volcanic rocks of various compositions (Kähkönen 2005, Lehtonen et al. 2005). The belt is composed of two different volcanic associations (Mäkitie & Lahti 1991). A scattered zone of calc-alkaline intermediate volcanic and subvolcanic rocks occurs on the southern border of the Pohjanmaa Belt close to the Central Finland Granitoid Complex. Separated by a greywacke basin close to the Vaasa Granite, there is a volcanic belt composed of tholeiitic volcanic rocks associated with black shales, marbles and cherts. The regional metamorphic grade is at mid- and upper-amphibolite facies in the region, and is characterised by high pressure (garnet, sillimanite present) in the northern part and by low pressure (andalusite, cordierite present) in the southern part of the belt (Mäkitie 2000). Regional metamorphism peaked at 1.89–1.88 Ga when the region also was intruded by synkinematic granitoids (Mäkitie et al. 1999, Nironen 2005).

Area F018 is characterised by orogenic gold and gold-antimony mineralisation in bedrock (Eilu 2007) and by numerous Au and Sb anomaly fields in till (Lestinen et al. 1991). About ten Au and Au-Sb occurrences are known from the area (Pääkkönen 1966, Eilu & Pankka 2009), but only for three (Table 19) has enough work been done for a preliminary resource estimate. **Kalliosalo** is the best-known Au-Sb deposit in Finland. It comprises auriferous quartz vein arrays in a plagioclase porphyry. The deposit is controlled by a discordant shear zone and is close to a regional NW-trending shear zone. Part of the gold is in aurostibite, and native antimony is the main Sb carrier. A significant part of the native gold occurs as inclusions in löllingite-arsenopyrite (Appelqvist 1993). **Timanttimaa** is a typical orogenic gold-only occurrence close to a NE-trending shear zone. It comprises an auriferous quartz vein network in felsic plagioclase porphyry and tonalite with predominantly free gold in quartz veins (Kärkkäinen 1993).

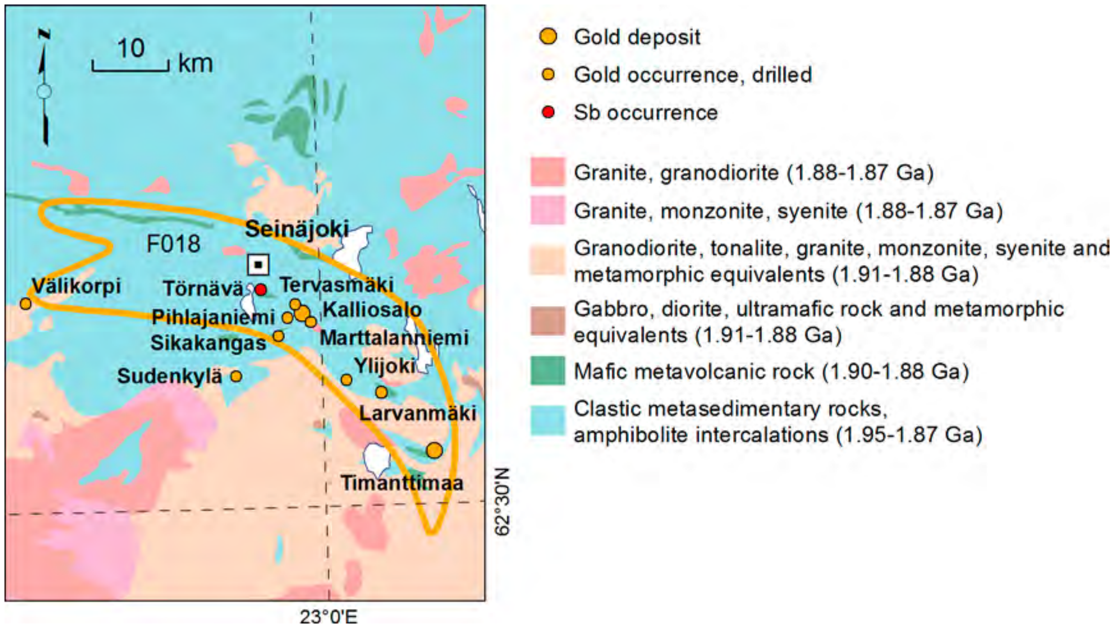


Figure 36. Seinäjoki Au-Sb (F018) metallogenic area, and the most significant gold±antimony occurrences of the region. Geology is from Koistinen et al. (2001).

Table 19. Gold±antimony deposits in the Seinäjoki metallogenic area (F018).

Occurrence	Tonnage (Mt)	Au g/t	Sb %	Main ore minerals	Host rocks	Reference
Sikakangas	0.171	1.32		Arsenopyrite, pyrrhotite	Plagioclase porphyry	Isomaa et al. (2010)
Timanttimaa	1.0	1		Pyrrhotite, arsenopyrite	Felsic volcanic rock	Kärkkäinen (1993)
Kalliosalo	0.3 1.04	1	0.85 0.41	Arsenopyrite, antimony, löllingite, stibnite, aurostibite, pyrrhotite	Plagioclase porphyry	Saltikoff (1980), Tyni (1983), Appelqvist (1993)
Törnävä E Törnävä W	0.2 0.3	<1	1.37 0.57	Pyrrhotite, antimony, gudmundite, stibnite	Mica gneiss, Mica schist	Pääkkönen (1966)

F020 OUTOKUMPU Cu-Co, Ni

Asko Kontinen (GTK)

The Outokumpu area (F020) is within the Palaeoproterozoic North Karelia Schist Belt (Fig. 37). The Outokumpu area is defined by the boundaries of the Outokumpu Allochthon (also known as the 'Outokumpu Nappe Complex' or 'Outokumpu Nappe'), which contains serpentinite bodies with the diagnostic host-rock assemblage of the polymetallic and polygenetic, Outokumpu-type copper-cobalt-zinc and Kokka-type nickel mineralisation. The boundaries of the Outokumpu Allochton as they are shown in Figure 37 are generalised after delineations presented in Koistinen (1981), Park & Bowes (1983), Gaal & Parkkinen (1993) and Kontinen et al. (2006).

The Outokumpu Allochthon is >85% composed of schistose, medium- to high- grade metaturbiditic wackes and pelites, which are typically sand-dominated, medium to thinly bedded and lack psephitic interbeds or channellisation. No metavolcanic rocks as intercalations or synsedimentary magmatic intrusions are found in the primarily turbidite sequence, which is apparently kilometres thick. Relatively deep-water deposition of the turbidites has been proposed, probably at continental slope-rise fans in a passive margin type environment (Kontinen & Sorjonen-Ward 1991, Peltonen et al. 2008, Lahtinen et al. 2009). The wacke schist contains layers of black schists (black turbidite muds), especially in the presumably lowermost parts of the allochton (Loukola-Ruskeeniemi 1999, Kontinen et al. 2006). Apart from abundant graphite (5–10%), these carbonaceous schists also commonly contain plentiful iron sulphides (5–20 wt%), and are strongly enriched in Ni, Cu and Zn relative to the upper crust. Redox-sensitive metals such as Sb, Se, Mo, V and U also occur at elevated concentrations. The cobalt content is systematically relatively low, 33 ppm on average. The Mo, V, U plus high S enrichment in the black shale intervals imply at least periodically anoxic-sulphidic depositional conditions, but also a generally oxygenated atmosphere at the time of the Outokumpu deposition ca. 1.95–1.91 Ga ago.

Wacke sediments in the Outokumpu Allochthon were deposited subsequent to 1920 ± 20 Ma, which is the age of their youngest dated detrital zircon grains (Lahtinen et al. 2009). The black schist interleaved lower units of the Outokumpu Allochthon host numerous fault-bound (exotic) bodies of serpentinite (after mantle peridotites) with variable component of 1.96 Ga gabbroic, basaltic and plagiogranitic rocks. These bodies are interpreted as fragments of 1.95 Ga mafic-ultramafic oceanic floor/crust that became tectonically incorporated among the turbidite sediments during the early obduction of the Outokumpu Allochthon at ca. 1.90 Ga (Peltonen et al. 2008). Serpentinites in the ophiolite fragments show at their margins the omnipresent listwaenite to birbirite alteration. Where ideally developed, the alteration zonation is as follows, from proximal to distal parts: 1–5 m of carbonate rock, 1–10 m of carbonate-silica rock, and 1–50 m of silica rock (birbirite). These zones are metamorphosed and recrystallised to carbonate-tremolite±olivine, tremolite±diopside and quartz rock, respectively. Thick alteration zones are typically flanked by thick zones of sulphide-rich black schist.

Some of the Outokumpu area serpentinite bodies host in their carbonate-silica alteration envelopes massive-semimassive Cu-Co-Zn (Figs. 38 and 39) and disseminated Ni sulphides of the Outokumpu and Kokka type, respectively. Of these

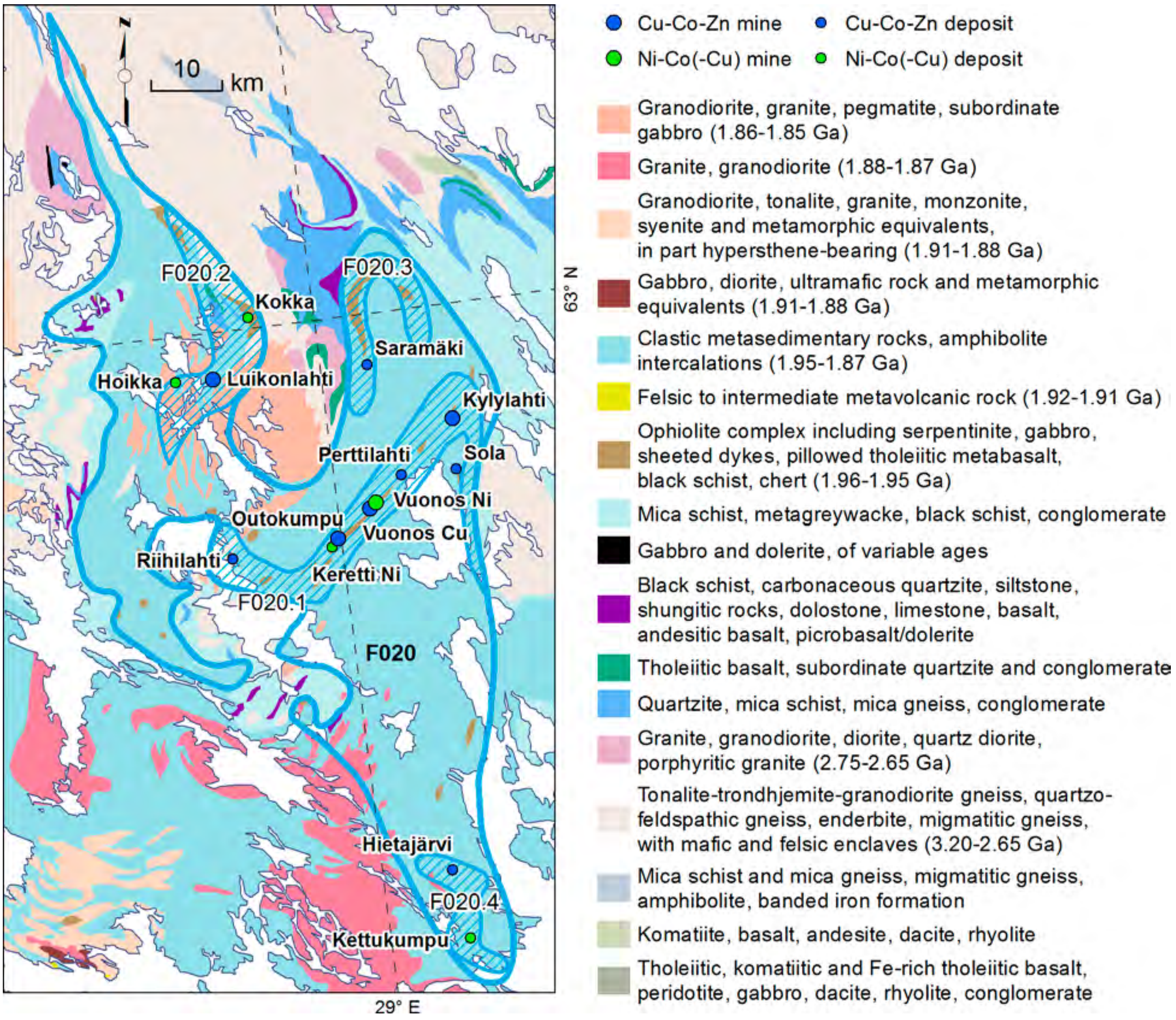


Figure 37. Geology of the Outokumpu Cu-Co, Ni (F020) metallogenic area and the metallogenic subareas, and the most significant base metal occurrences of area F020. Geology based on Koistinen et al. (2001).

two mineralisation types, the economically far more significant Outokumpu Co-Cu (Table 20) is in all cases found with a parallel zone of Ni-dominated mineralisation in the hosting skarn-quartz rocks. In contrast, the Kokka Ni also widely occurs in environments without any Cu-Co mineralisation. Weak Ni mineralisation is, in fact, a ubiquitous feature of the Outokumpu alteration assemblage, which systematically contains 1500–3000 ppm Ni in pyrrhotite and pentlandite. The concept of Kokka-type Ni mineralisation refers to rambled zones of more elevated Ni contents and Ni sulphides within the alteration zones, commonly in locations of intense shearing and in proximity to highly sulphidic black schists (Huhma 1975).

The metallogenic subareas of F020 are defined by distinct deposit clusters (Fig. 37). Between the subareas, there are no other differences between the deposits besides the deposit size and metamorphic grade (Kontinen et al. 2006, Peltonen et al. 2008). In the Keretti subarea (F020.1), the metamorphic grade is lowest in the NE at **Kylylahti** (lower-amphibolite facies) and highest in the SW at **Riihilahti** (upper-amphibolite facies). At Kylylahti (Fig. 39), the sulphide bodies are predominantly pyritic and show elevated contents of such more 'volatile' elements as As, Sb and Hg, whereas at Riihilahti, ore bodies are thoroughly pyrrhotitic with much lower Sb, As and Hg. The metamorphic control (cf., Vaasjoki et al. 1974) also shows up in that at Kylylahti a large part of Co is in pyrite, whereas at Riihilahti nearly all cobalt is in pentlandite. The large **Outokumpu** deposit is partly pyritic and relatively rich in As and Au, whereas the thinner, smaller Vuonos and **Perttilahti** deposits (Table 20) are thoroughly pyrrhotitic and low in As and Au. The Luikonlahti and Hietajärvi subareas are in mid- to upper-amphibolite facies environments, and their deposits are thus totally recrystallised to metamorphic granoblastic texture, and are thoroughly pyrrhotitic and very low in As and Au. The effects of metamorphism on the Kokka type Ni occurrences are restricted mainly to a grain size increase and increased remobilisation of the sulphides into blotches and veinlets.

The Outokumpu Co-Cu type is interpreted polygenetic with a primary inhalative-exhalative Cu-Co-Zn mineralisation event(s) ca. 1.95 Ga, in a hot spring environment in spreading zones or leaky transforms in a predominantly ultramafic ocean floor (Peltonen et al. 2008). The Ni mineralisation in the carbonate-silica alteration assemblage occurred during the ca. 1.90 Ga obduction of the ophiolite fragments, inside the host turbidite sediments, when low T (<200°C) carbonaceous and sulphidic fluids altered the outer margins of the ultramafic bodies to sulphide-bearing carbonate to quartz rocks. Nickel originally in ferromagnesian mantle minerals, such as olivine, was during this process relocated into sulphides. The exceptionally high Ni content in the Co-Cu type ores (Table 20) is interpreted to reflect early syntectonic interaction of the Cu-Co protosulphides with the Ni sulphides, by simple 'mechanical' mixing of the two sulphide end members or by fluid-assisted diffusion or the transport of Ni from the Ni occurrences into the Cu-Co bodies. Later syntectonic solid-state remobilisation and concentration of the Cu-Co-Zn-Ni sulphides into fault-controlled positions completed the geometric style of the Outokumpu type deposits as thin (1–15 m) and narrow (50–450 m) but long (1– >5 km) sheets. In such serpentinite bodies or ophiolite fragments that obducted without any Cu-Co protosulphides, only rambled local Ni enrichments of the Kokka type were generated in structurally favourable positions.

From the exploration standpoint, besides the probability of Outokumpu type Cu-Co deposits only occuring in a fraction of the observed serpentinite bodies (those obducted with Cu-Co protosulphides), one should also note that, on the basis of Pb isotope compositions, the commonly accompanying black shales did not significantly contribute to the genesis and metal budgets of the ore bodies (Peltonen et al. 2008). Experience from past exploration confirms this inference, as the black schists and their characters, such as metal tenors and ratios, have nowhere been observed to be useful vectors to the Cu-Co ores. However, the genesis of the Outokumpu alteration assemblage and Kokka-type Ni occurrences involved the influx of S and some rare metals, such as As, Sb and Pb, from the black shales.

Table 20. Metallic mineral deposits with a resource estimate in the Outokumpu Cu-Co, Ni Area (F020).

Subarea, **Occurrence**	**Tonnage (Mt)**	**Mined (Mt)**	**Ag g/t**	**Au g/t**	**Co %**	**Cu %**	**Ni %**	**Zn %**	**Reference[1]**
Keretti (F020.1)									
Keretti Ni	1.76			0.15	0.11	0.39	0.46	0.2	Parkkinen & Reino (1985)
Outokumpu	28.5[2]	28.5	8.9	0.8	0.24	3.8	0.12	1.07	Huhma & Huhma (1970)
Vuonos Cu	5.89[2]	5.89	11	0.1	0.15	2.45	0.13	1.6	Huhma & Huhma (1970)
Vuonos Ni	5.5[2]	5.5	0.3		0.03	0.04	0.2		Parkkinen & Reino (1985)
Sola	0.1				0.1	2	0.15	1	Huhma & Huhma (1970)
Perttilahti	1.324				0.15	2.15	0.14	1.89	Huhma & Huhma (1970)
Riihilahti	0.7		6	0.3	0.09	0.72	0.03	0.09	Parkkinen (1997)
Kylylahti	8.4			0.68	0.29	1.25	0.20	0.54	Universal Resources (2010)
Luikonlahti (F020.2)									
Luikonlahti	7.7[2]	7.7			0.12	1.2	0.09	0.65	Eskelinen et al. (1983)
Kokka	2.47					0.01	0.35		Parkkinen (1997)
Hoikka	0.2				0.04	0.5	0.15		Parkkinen (1997)
Saramäki (F020.3)									
Saramäki	3.4				0.09	0.71	0.05	0.63	Parkkinen (1997)
Hietajärvi (F020.4)									
Kettukumpu	0.4				0.07	0.44	0.18	0.1	Parkkinen (1997)
Hietajärvi	0.34		0.7		0.15	0.71	0.18	1.21	Huhma & Huhma (1970)

[1] References in addition to Kontinen et al. (2006) and Peltonen et al. (2008).

[2] Only the mined amount has been reported.

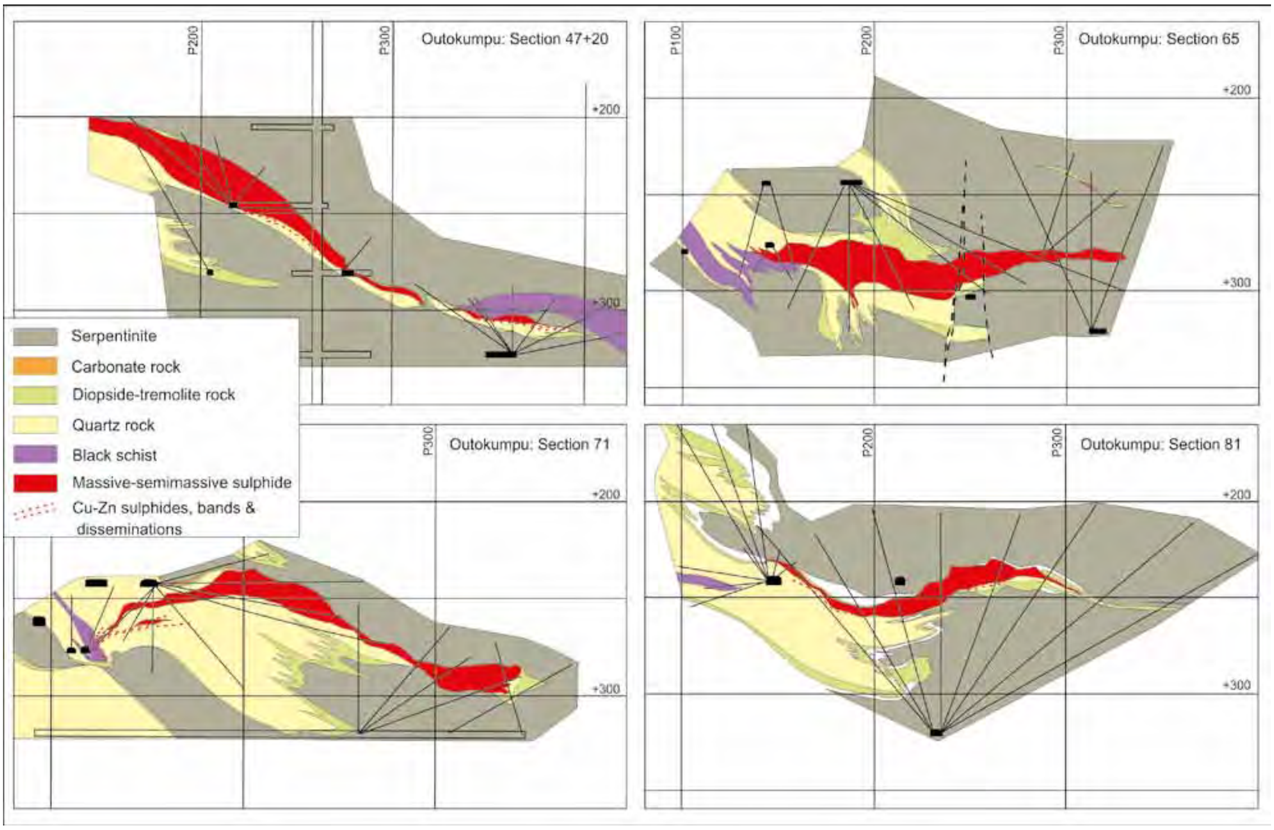


Figure 38. Sections across the SW part of the Outokumpu Cu-Co-Zn deposit, located at 62.7245°N, 28.992°E. Numbers on the right (+100, +200, +300) indicate reference levels in metres, small black polygons indicate underground drives and the black diagonal lines are drill hole traces. View to the NE. Modified from Kontinen et al. (2006).

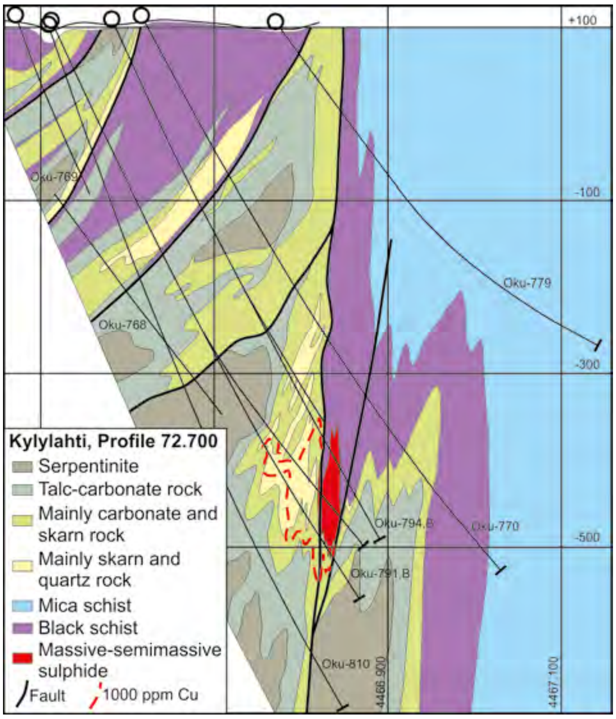


Figure 39. Geological section across the deeper parts of the Kylylahti Cu-Co deposit (62.8558°N, 29.3453°E) and its wallrocks. Numbers on the right (+100, -100, etc.) indicate reference levels in metres. Codes of the type 'Oku-810' are drill hole numbers. Modified from Kontinen et al. (2006).

F021 HAMMASLAHTI Cu-Zn

Kaj Västi (GTK)

The extent of the Hammaslahti metallogenic area (F021) is defined by the estimated extent of the apparently diagnostic rock sequence for the Hammaslahti-style copper-zinc mineralisation (Figs. 1 and 40). The diagnostic sequence includes both mafic volcanic and turbiditic sedimentary units of the Höytiäinen Belt (Vaasjoki et al. 2005). The extent of metallogenic area F021 is defined by the

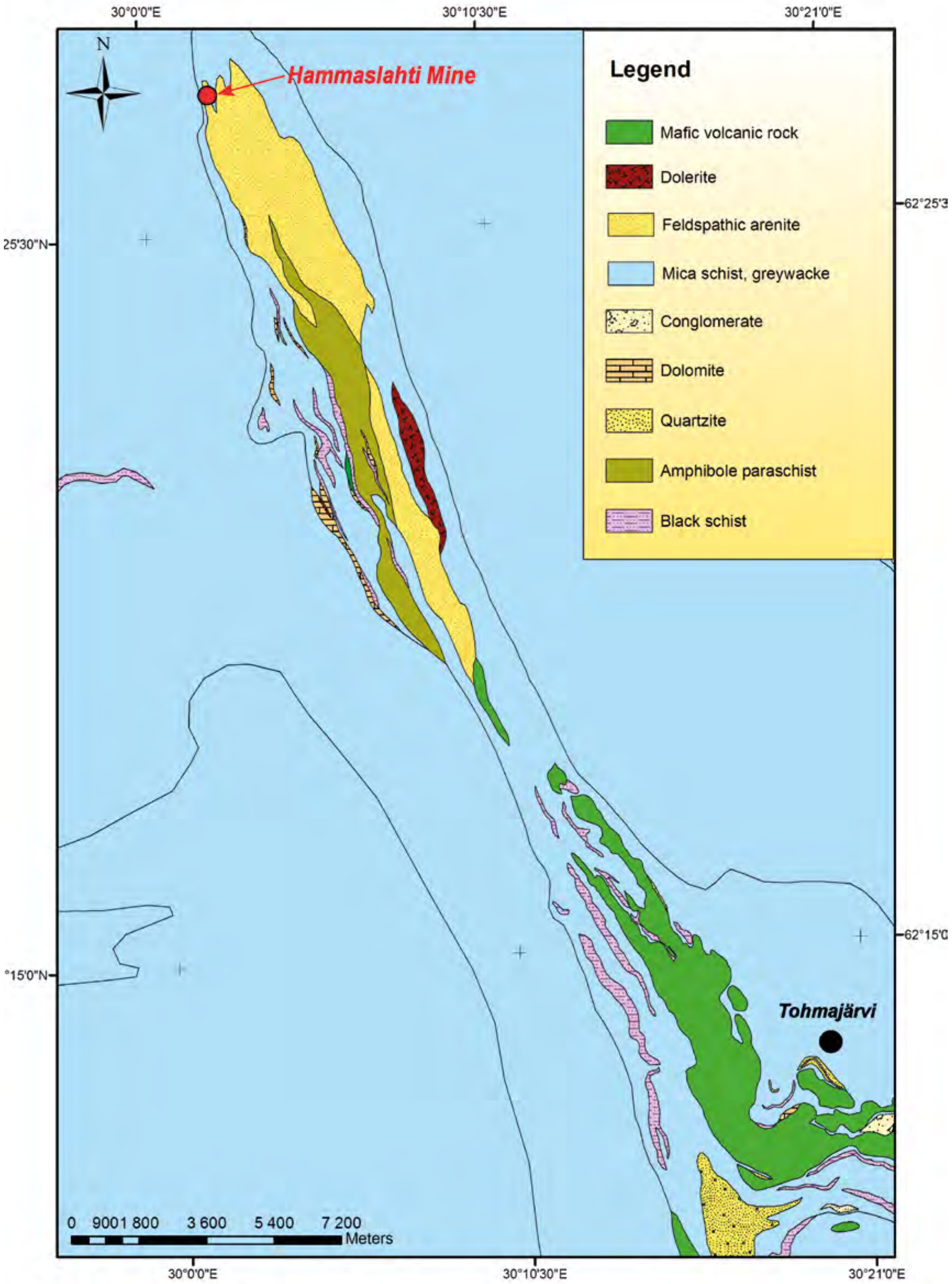


Figure 40. Geology of the central parts of the Hammaslahti metallogenic area (F021). Geological map is based on the GTK digital bedrock database.

extent of the diagnostic lithological sequence, as seen in the outcrop and estimated from low-altitude aerogeophysical surveys by GTK (Eilu et al. 2009, Damsten 2010a, b).

Bedrock of metallogenic area F021 mainly comprises coarse- to fine-grained metasedimentary rocks. Tholeiitic metabasalts, which are interpreted to have erupted in a rifted basin, form a large igneous complex in the Tohmajärvi region some 20 km SE of the Hammaslahti mine (Nykänen 1971, Ward 1987). The Hammaslahti Cu deposit itself is located on the northwestern margin of a 2-km-wide and 8-km-long NNW-trending arkosite formation which, after a short break, can be traced for about 10 km to the SSE (Fig. 40). Partly within and on the western margin of the arkosite formation, there is a 12-km-long conglomerate formation. These coarse-grained metasedimentary rocks are, in turn, enclosed by a relatively thin mica schist-phyllite shell and a thicker greywacke formation. Black schist, skarn rock, dolomitic marble and amphibolite intercalations are common both in conglomerate and mica schist-phyllite units. About 12 km east of the Hammaslahti mine, area F021 is bounded by the Archaean basement complex.

The **Hammaslahti** Cu-Zn deposit consists of three ore bodies (S, N and Z) hosted by hydrothermally altered quartz greywacke and arkosite. In places, the deposit is closely related to black schist and tremolite skarn (Karppanen 1986, Hämäläinen 1987, Loukola-Ruskeeniemi et al. 1992, Rantala, 2011). According to Kousa et al. (2008), the deposit probably represents a subseafloor hydrothermal system distal to contemporaneous mafic magmatism. The irregular and elongated ore bodies occur in an *en echelon* pattern in a N-trending zone, dipping steeply to the W with a plunge of 25–30° to the south. Alteration in and around the ore is characterised by depletion of Ca, Na, K, Sr and Rb and enrichment of S, Fe, Cu, Zn and Au (Loukola-Ruskeeniemi et al. 1991). The S and N ore bodies mainly consist of remobilised breccia ore, a stringer-like impregnation network and banded breccia, with local high-grade chalcopyrite concentrations. Pyrrhotite and chalcopyrite are the major sulphides in the S and N ore bodies. The Z ore body, lying further to the north, differs from the other lodes in that sphalerite, in addition to chalcopyrite and pyrite, is one of the major ore minerals. Galena, cubanite, mackinawite and arsenopyrite are minor sulphides in the ore (Karppanen 1986, Hämäläinen 1987). The pre-mining assessment of the ore resources indicated 4 Mt at 1.0 % Cu (Hyvärinen 1970) or, according to Koistinen (1971), >5 Mt @ about 1 % Cu. However, when mining operations ended in 1986, a total of 7 Mt of ore containing 1.16 % Cu had been produced (Loukola-Ruskeeniemi et al. 1992). In addition, the Z orebody yielded 0.28 Mt @ 1.55 % Zn, 0.52 % Cu, 0.59 ppm Au and 5.2 ppm Ag (Hämäläinen 1987). Of all the three ore bodies, the southernmost (S) was of the highest value, accounting for 70 % of the total ore reserves.

F022 KOLI U

Olli Äikäs (GTK)

The Koli U area (F022) is a narrow, NW-trending belt following the boundary between the Palaeoproterozoic Höytiäinen Belt and the Archaean Eastern Finland Complex (Fig. 41). Area F022 comprises basal quartzites and conglomerates in the lowermost part of the Höytiäinen Belt, above and at the unconformity against the largely Neoarchaean TTG-rocks of the basement (Äikäs & Sarikkola 1987, Vaasjoki et al. 2005). Area F022 extends for 140 km from Värtsilä in the SE (at the Finnish-Russian border) to Juuka in the NW.

Archaean granitoids near the Proterozoic unconformity are characterised by monzogranites and stromatic migmatites with potassic granite leucosomes; the youngest granitoids are 2.63 Ga in age (Sorjonen-Ward & Luukkonen 2005). A large part of these granitoids show enhanced radioactivity in airborne geophysical data. In the sedimentary sequence above the unconformity, the NW part (Koli belt) is mainly composed of arenites known as the Herajärvi Group (Kohonen & Marmo 1992), whereas the SE part (Kiihtelysvaara-Värtsilä belt) contains a highly variable suite of sedimentary and mafic volcanic units, including dolomitic marble and black schist (Pekkarinen 1979, Pekkarinen & Lukkarinen 1991). The counterpart of the Herajärvi Group is absent or markedly thinner in the SE; on the other hand, marble and black schist are absent in the NW. The mafic Koli sill complex, which intrudes both the Archaean basement and part of the overlying Herajärvi Group, was emplaced at about 2220

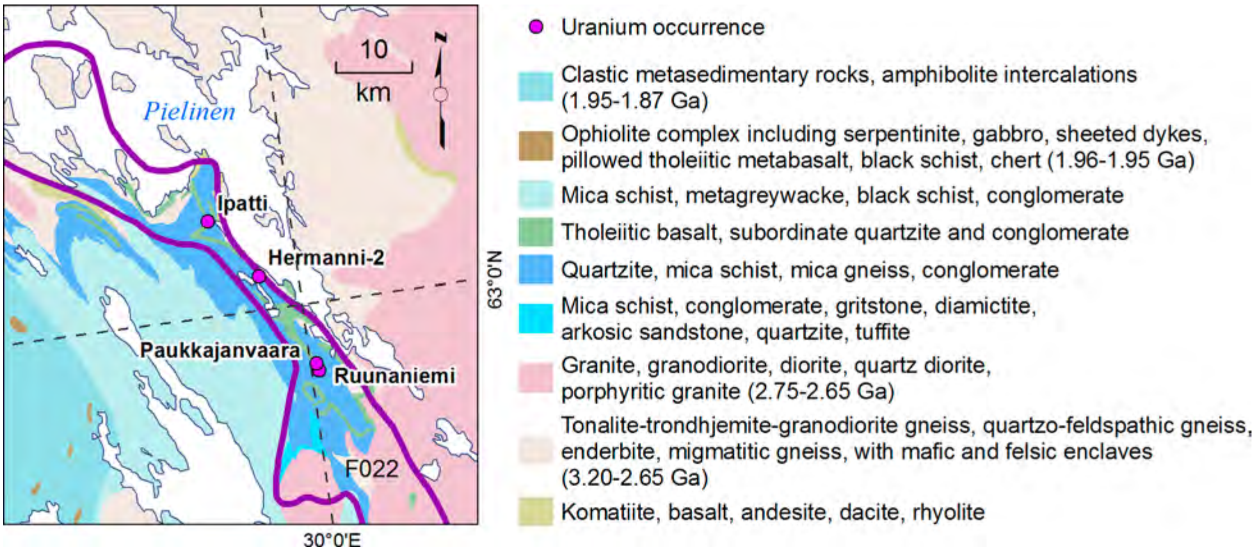


Figure 41. Central parts of the Koli metallogenic area (F022). Geology simplified from the GTK digital bedrock map database.

Ma. Tholeiitic dyke swarms of age groups 2.1 Ga and 1.98 Ga (Vuollo & Huhma 2005) cut the Archaean basement and the overlying basal units of the Höytiäinen belt. With the epicontinental sedimentary rocks deposited at the craton margin, the Koli U area represents an orogenic foreland setting with respect to Svecofennian NE-vergent thrusting.

In its NW part, area F022 contains minor deposits and occurrences of uranium in the Herajärvi Group metasedimentary rocks, commonly showing a close spatial association between uranium and mafic dykes (Piirainen 1968, Äikäs & Sarikkola 1987, Pekkarinen et al. 2006). In the SE part, occurrences of thorium and uranium in quartz-pebble conglomerates are known both in the basal and upper parts of the sedimentary pile. In addition, showings of uranium ± molybdenum have been drilled in the Archaean basement adjacent to the Proterozoic unconformity (Pekkarinen 1979). Structural and thermochronological constraints indicate that the Koli U area has experienced lower-amphibolite facies PT conditions, and remained at elevated temperatures until at least 1.82 Ga. Therefore, late-orogenic retrograde hydrothermal processes are a plausible mechanism for mobilisation of uranium (Sorjonen-Ward & Äikäs 2008).

The styles of uranium mineralisation within area F022 range from primary stratiform conglomerate and sandstone occurrences to epigenetic veins and breccia infills in and along mafic dykes in the Proterozoic host rocks (Äikäs & Sarikkola 1987). The main uranium minerals in these occurrences are pitchblende and uranophane. In the Archaean basement, uranium occurs as uraninite in metasomatic pegmatoid pockets, possibly related to Palaeoproterozoic events of mineralisation (Pekkarinen 1979). Pilot-scale mining and milling was carried out at **Paukkajanvaara** from 1958 to 1961, with 0.04 Mt ore at 0.14 % U treated in 1960−1961.

F023 ILOMANTSI Au, Mo

Peter Sorjonen-Ward (GTK), Margarita Korsakova (SC Mineral)

The Ilomantsi metallogenic area (F023) comprises the N-trending eastern part of the Ilomantsi greenstone belt and the immediately surrounding country rocks (Fig. 42). The Finnish part of the area is also known as the Hattu schist belt (e.g., Sorjonen-Ward 1993).

The eastern part of the Ilomantsi greenstone belt is similar to those Neoarchaean greenstone belts in Canada, Australia, Brazil, India and southern Africa in which peak metamorphic conditions were in the lower-amphibolite facies (e.g., Eckstrand et al. 1996, Goldfarb et al. 2001). The

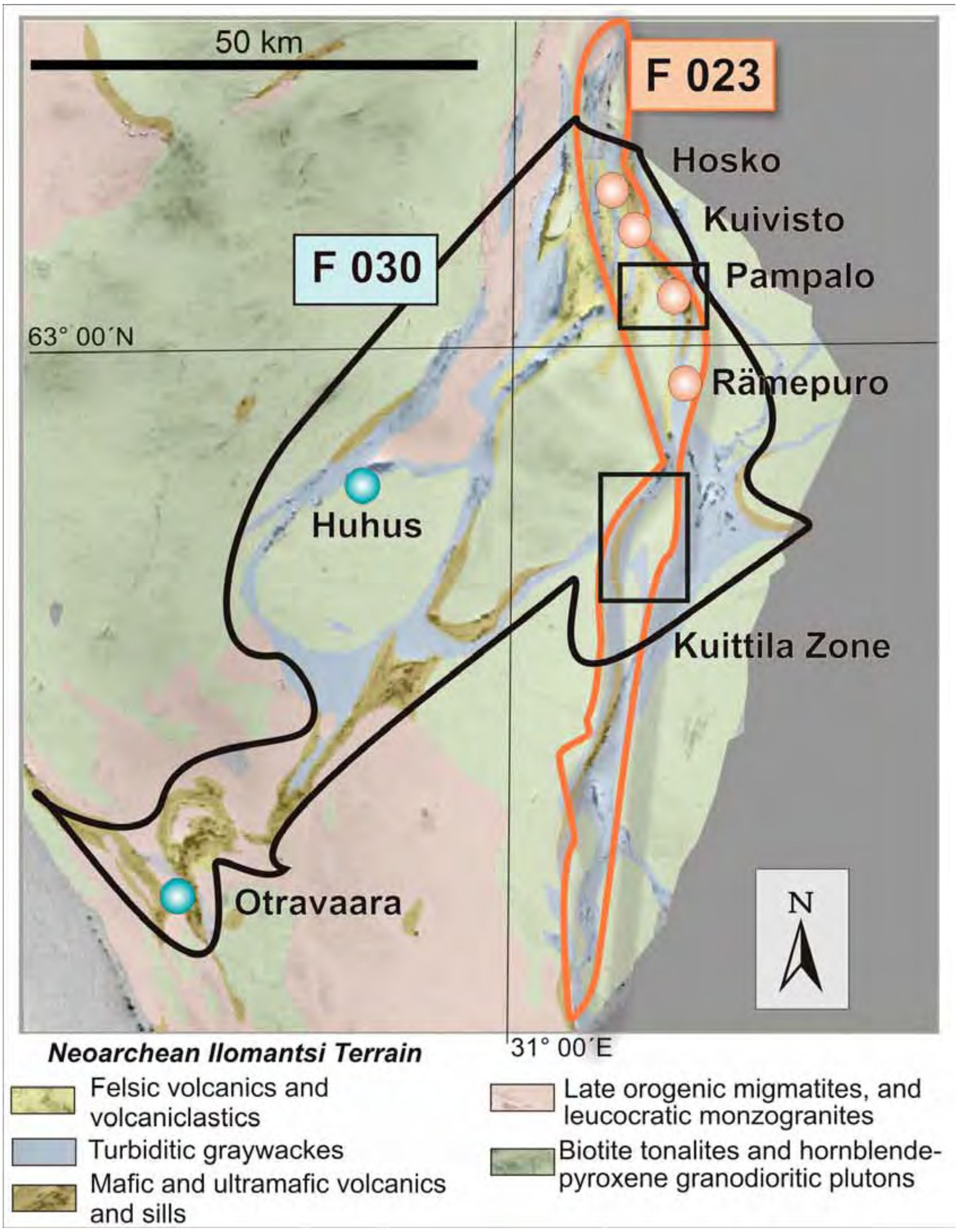


Figure 42. Simplified geological map of the Neoarchaean Ilomantsi greenstone belt and surroundings, indicating principal Au and Fe occurrences in metallogenic areas F023 (Ilomantsi, Finnish part only) and F030 (Huhus), respectively. The black rectangle enclosing Pampalo indicates the location of Figure 44a, and the larger black rectangle indicates the location of a more detailed map of the Kuittila Zone (Fig. 45). Geology based on the GTK bedrock database. Aeromagnetic map based on GTK survey data in the background. Proterozoic rocks in the lower left corner in light grey, Russian territory on right in dark grey.

Ilomantsi greenstones are dominated by felsic to intermediate epi- and volcaniclastic rocks with intercalations of tholeiitic and komatiitic volcanic rocks, BIF, and felsic to intermediate porphyries (Sorjonen-Ward 1993, Sorjonen-Ward & Luukkonen 2005, Feoktistov et al. 2007). Isotopic constraints indicate that the supracrustal sequence was deposited during a brief time around 2.76–2.75 Ga and was intruded by felsic to intermediate granitoids and porphyries with ages from 2746 to 2725 Ma (Vaasjoki et al. 1993, Sorjonen-Ward & Luukkonen 2005). The greenstone sequence thus represents one of the youngest Archaean supracrustal units in the Fennoscandian Shield, and was deformed and metamorphosed simultaneously with and shortly after depositions, at 2.74–2.63 Ga, thus coinciding with the global Neoarchaean orogenic event.

The most important metallic commodity in the Ilomantsi area is orogenic gold, but there are also indications of Mo-W mineralisation in the granitoids intruding the greenstone belt (Nurmi et al. 1993, Luukkonen et al. 2002, Raw Mineral Base of the Republic of Karelia 2005, Eilu 2007). Gold mineralisation and accompanying hydrothermal alteration in the Hattu schist belt coincides with well-defined narrow high-strain zones, delineating the generally N-S trending Hattu Au subarea (F023.1) (Fig. 42). Magnetite-quartz and sulphide-quartz banded iron formations are also present within the eastern part of the Ilomantsi greenstone belt. However, the most significant BIF occurrences are within the western branch of the greenstone belt, defined here as a separate metallogenic area (Huhus Fe, F030) and discussed in a separate section below.

Gold mineralisation at Ilomantsi is rather typical of the orogenic category as defined by Groves (1993) and Goldfarb et al. (2001). Each of the occurrences is characterised by a strong structural control and gold is, at present, the sole commodity of economic interest. Typical metal-enrichment associations at both district and prospect scales include Au-As-Sb-Te-W±B, with Au/Ag >1; quartz veining is abundant, although sulphides, which comprise 1–3 vol%, are more common as dissemination dispersed through altered rocks. Gold commonly occurs in a native form, with the dominant sulphide ore minerals being pyrite, pyrrhotite and arsenopyrite, the latter being more typical of the turbidite-hosted Hosko (or Valkeasuo) occurrence in the northernmost part of area F023. Alteration is in many places subtle, although pervasive, and typically includes carbonate, potassic alteration (sericite and biotite) chlorite and tourmaline (Nurmi et al. 1993, Rasilainen 1996, Poutiainen & Partamies 2003). The occurrences are predominantly within N–S and NW-trending ductile shear zones, and mineralisation has been found in nearly all rock types present within the greenstone belt: intermediate volcaniclastic to clastic rocks, komatiitic to basaltic volcanic rocks, granitoids, and quartz-feldspar porphyries (Nurmi et al. 1993, Eilu 2007). Mesoscopic and microstructural evidence indicates that the gold mineralisation was mostly likely concurrent with alternating ductile and brittle rock behaviour under peak-metamorphic conditions (Sorjonen-Ward 1993); this deformation event is correlated with the regional-scale syn-D3 to D4 phase recognised throughout eastern Finland, between 2.72–2.69 Ga (Sorjonen-Ward & Luukkonen 2005).

In total, 16 gold occurrences with ore-grade intersections have so far been indicated by drilling in the Finnish part of the Ilomantsi area (Eilu 2007), and several further occurrences have been drilled in the Russian part of the area. However, resource estimates have only been reported for seven occurrences (Table 21). Test mining was undertaken at Pampalo in two stages during 1996–1999, when 1784 kg of gold was produced from 0.1258 Mt of ore (Figs. 43 and 44), and full-scale production started at the mine in early 2011 (Endomines 2011). Gold exploration within area F023 has only been systematically undertaken in the central parts of the area covered by subarea F023.1. Therefore, the potential for further discoveries within the region as rather high.

Molybdenum mineralisation in area F023 is most prominent in its southernmost part, with 10.93 Mt (at 0.03 % Mo) at Jalonvaara. The Jalonvaara deposit is confined to endo- and exo-contacts of a small porphyry granite massif. Indications of Mo ± W mineralisation have also been detected in other parts of the Ilomantsi metallogenic area, for example at Kuittila (Fig. 45), in the central part of subarea F023.1. The style of molybdenum mineralisation varies from quartz vein networks and molybdenite dissemination in granitoids to pyrite-molybdenite dissemination in sericite schist associated with granite (Kojonen et al. 1993, Nurmi et al. 1993, Raw Mineral Base of the Republic of Karelia 2005). Textural relationships at Kuittila indicate that laminated quartz-tourmaline-albite veins containing molybdenite and scheelite form geometrically regular networks that are locally disrupted by ductile shear zones with sericitic alteration and quartz-carbonate-pyrite veins, containing gold (Sorjonen-Ward 1993). It is therefore concluded that the Mo±W mineralisation was a late-stage magmatic event, subsequently overprinted by syntectonic gold mineralisation. Isotopic dating of zircon from the Kuittila Tonalite (Vaasjoki et al. 1993) and molybdenite from veins (Stein et al. 1998) are consistent with, but do not unequivocally demonstrate these age relationships. Moreover, the auriferous shear zones at Kuittila contain scheelite, whereas the distribution of scheelite in the Pampalo deposit has proven to be a practical qualitative vector for gold mineralisation (Esa Sandberg, pers. comm. 2006).

Table 21. Orogenic gold occurrences with a reported resource within the Ilomantsi metallogenic area (F023).

Occurrence	**Tonnage (Mt)**	**Au g/t**	**Main ore minerals**	**Main host rock**	**Reference**
Kuittila	0.275	2.58	Pyrite, pyrrhotite	Tonalite	Damsten (1990)
Kuivisto	0.1	4	Pyrrhotite, pyrite	Intermediate volcaniclastic schist	Heino et al. (1995), Parkkinen (2003)
Muurinsuo	0.997	1.8	Pyrrhotite, pyrite	Felsic to intermediate sediments	Rasilainen (1996), Endomines (2009)
Pampalo	1.6488	4.3	Pyrite	Intermediate volcaniclastic schist	Nurmi et al. (1993), Rasilainen (1996), Endomines (2010b)
Rämepuro	0.223	4.2	Pyrrhotite, pyrite	Tonalitic porphyry dyke	Ojala et al. (1990), Nurmi et al. (1993), Endomines (2009)
Soanvaara	0.5	3	Pyrite, chalcopyrite	Chlorite-mica schist	Raw Mineral Base of the Republic of Karelia (2005)
Valkeasuo	1.077	2.8	Pyrrhotite, arsenopyrite	Felsic to intermediate volcaniclastic schists	Heino et al. (1995), Endomines (2009)

Figure 43. The Pampalo mine site in summer 2010. Photo: Seppo Huttunen, courtesy of Endomines Ab.

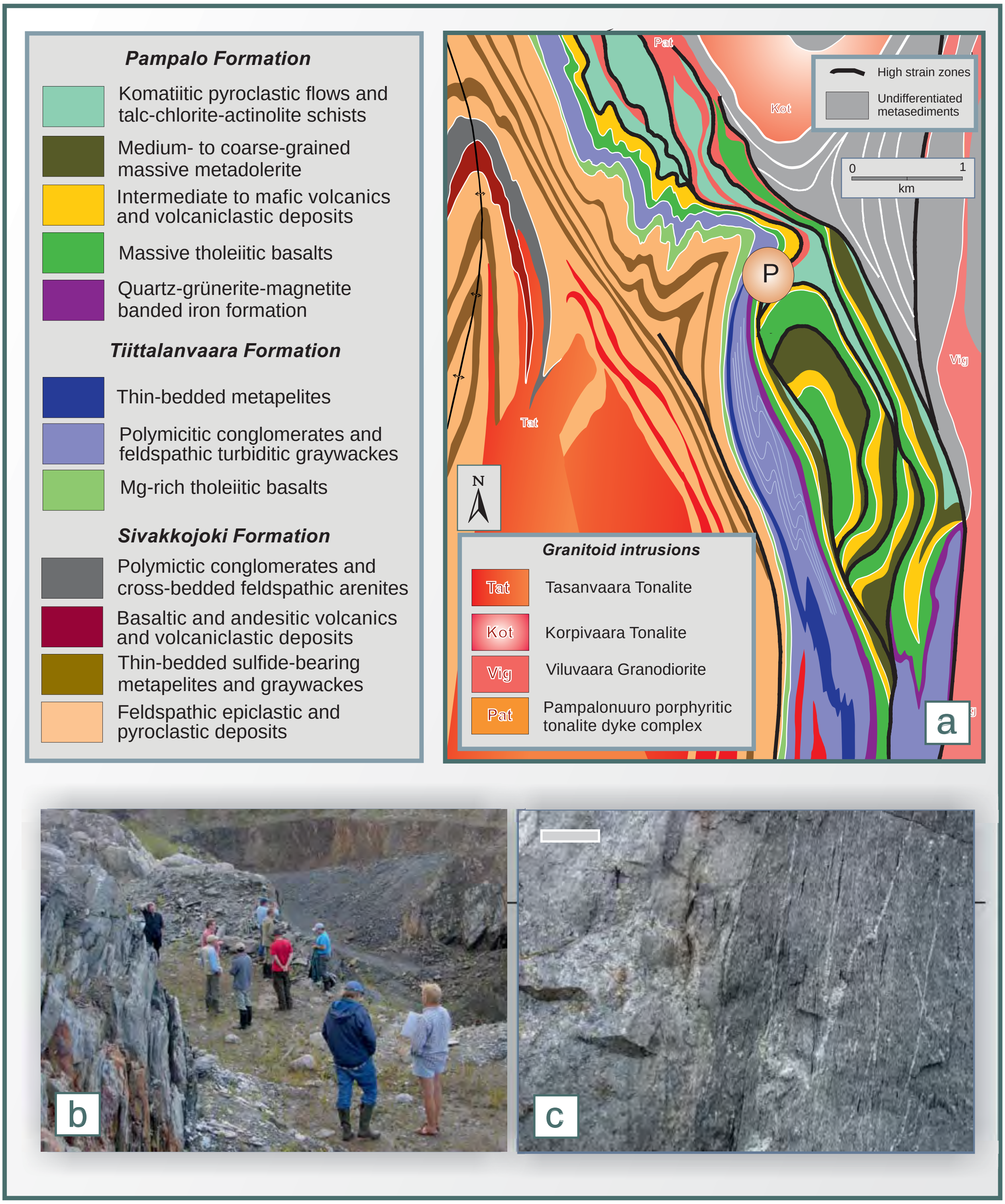


Figure 44. (a) Stratigraphic setting of the Pampalo Zone in the northern part of the Hattu schist belt (see location in Fig. 42); location of the Pampalo gold deposit indicated by the symbol P. (b) View towards the southwest into the Pampalo open pit. The entrance to the decline into to the underground mine is at the right margin, to the right of project geologist Esa Sandberg (wearing shorts and sandals). Outcrops in the foreground at left are talc-chlorite schists of the hanging wall, immediately east of the main lodes. The far wall beyond the decline shows a steep westerly dip in a mafic volcanic and banded iron formation defining the footwall to the deposit (WGS84 coordinates 62° 59´8”N 31° 15´ 58”E). (c) Typical example of ore-grade material, in which sulphides and gold are disseminated through strongly foliated and veined rock of intermediate composition, inferred to have been derived from a volcaniclastic protolith. Scale bar is approximately 5 cm. Photos: Peter Sorjonen-Ward, GTK.

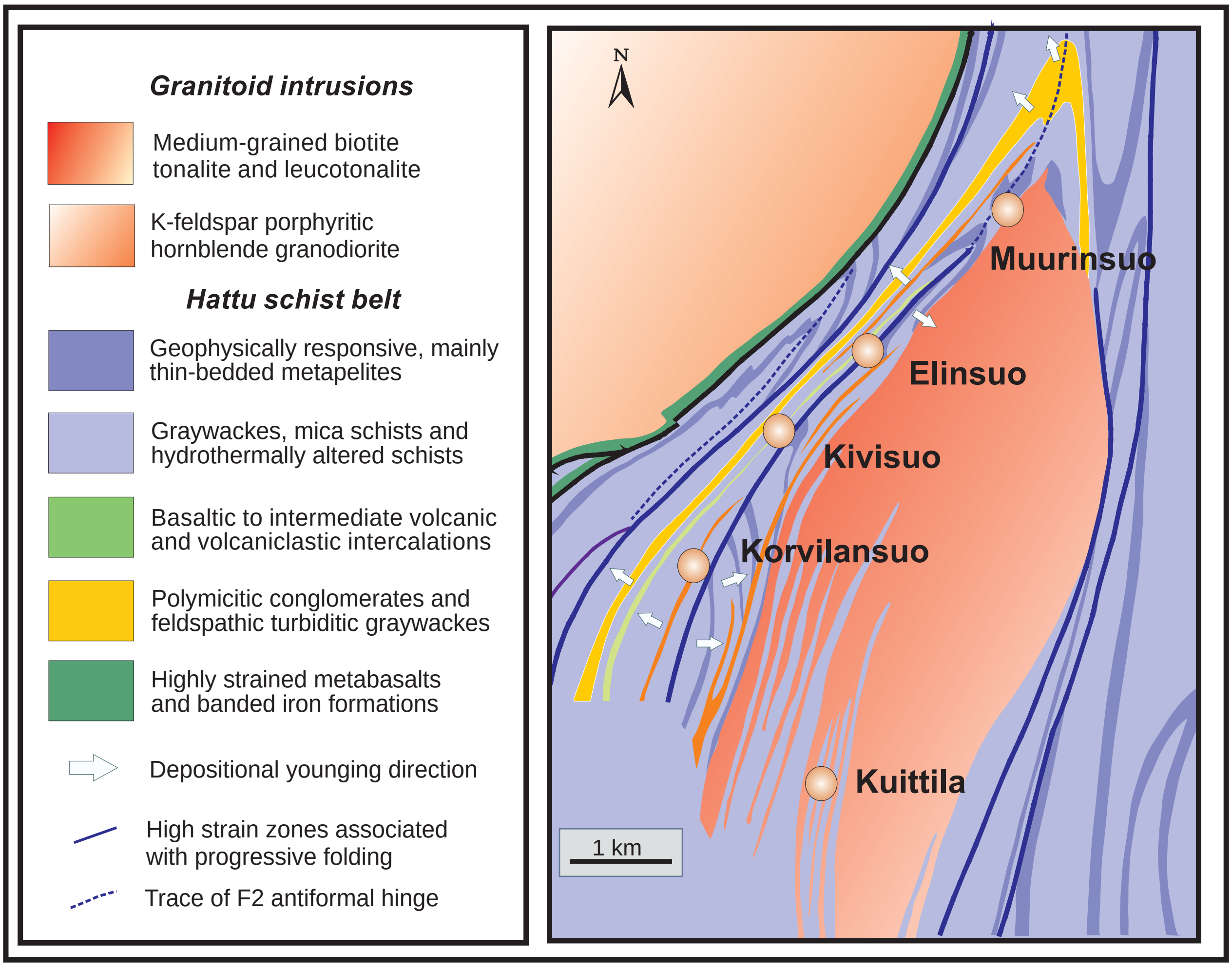


Figure 45. Geological map of the Kuittila Zone, showing the asymmetric distribution of gold occurrences along and within the western margin of the Kuittila Tonalite. Dots mark drilling-indicated gold occurrences, two of which (Kuittila and Muurinsuo) have been drilled sufficiently to permit provisional resource estimation. The location of the Kuittila occurrence is 62.773°N, 31.199°E.

F024 EMMES Li

Timo Ahtola (GTK)

The Emmes (Kaustinen or Kruunupyy–Ullava) 500 km^2 Li area (F024) is a part of the Pohjanmaa schist belt (Fig. 46). Alviola et al. (2001) suggested that lithium pegmatites in area F024 belong to the albite-spodumene subgroup of the LCT (Li, Cs, Ta) pegmatite family of Černy and Ercit (2005). These Palaeoproterozoic 1.79 Ga (U-Pb columbite age) albite-spodumene pegmatites crosscut the Svecofennian 1.95–1.88 Ga supracrustal rocks composed of greywackes and mica schists with intercalations of sulphide-bearing black schist and volcanic metasedimentary rock (Alviola et al. 2001). The regional metamorphic grade varies from lower- to upper-amphibolite facies. The LCT pegmatites in the area are younger than the 1.89–1.88 Ga peak of regional metamorphism (Mäkitie et al. 2001).

The average mineral composition of the spodumene pegmatites in the Emmes area is 32 % quartz, 30 % albite, 20 % spodumene, 13 % microcline and 5 % mica, with accessory volumes of columbite, triphylite, beryl, tourmaline, apatite and garnet (Ahtola et al. 2010a, 2010b). The dykes are 200–400 m long, some are very narrow, but others up to 10–25 m wide (Fig. 47). The area is mostly covered by glacial till and postglacial sediments, and none of the dykes discovered so far were originally exposed. Spodumene occurs as long and quite thin laths. Its colour varies from colourless or grey to green and brownish red. The average Li_2O content of the pegmatites is around 1 %. The best known and the biggest lithium deposit is Länttä, presently held by Keliber Oy (Table 22). Exploration since the 1960s in the region indicates that, in addition to those so far discovered, the area probably contains dozens of spodumene pegmatite dykes. Hence, the spodumene pegmatites of area F024 potentially form the largest lithium resource in the EU area.

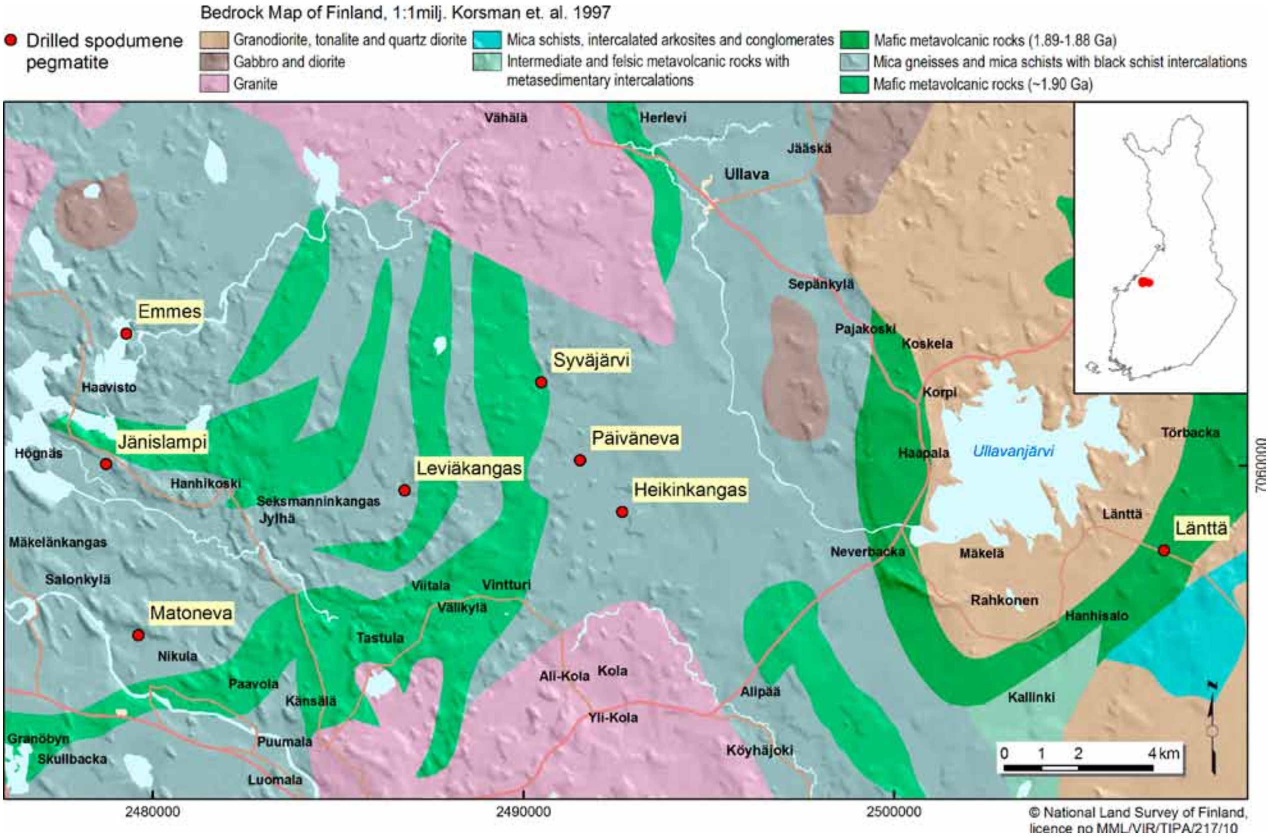


Figure 46. Bedrock of the central parts of the Emmes Li area and drilled spodumene pegmatites in the area. Geology according to Korsman et al. (1997), main roads in red, lakes and rivers in pale blue, digital elevation model in the background. Coordinates according to the Finnish national KKJ grid. The Emmes deposit is at 63.671°N, 23.580°E.

Table 22. Rare metal occurrences with a resource estimate in the Emmes Li area (F024).

Occurrence	Tonnage (Mt)	Be %	Li %	Ta %	No. of dykes	Reference
Emmes	1.1		0.54			Säynäjärvi (1972)
Länttä	2.95		0.43	0.0065	One	Grøndahl (2009)
Leviäkangas	2.1	0.0067	0.33	0.0059	One	Ahtola et al. (2010a)
Syväjärvi	2.6	0.0053	0.46	0.0021	Several	Ahtola et al. (2010b)

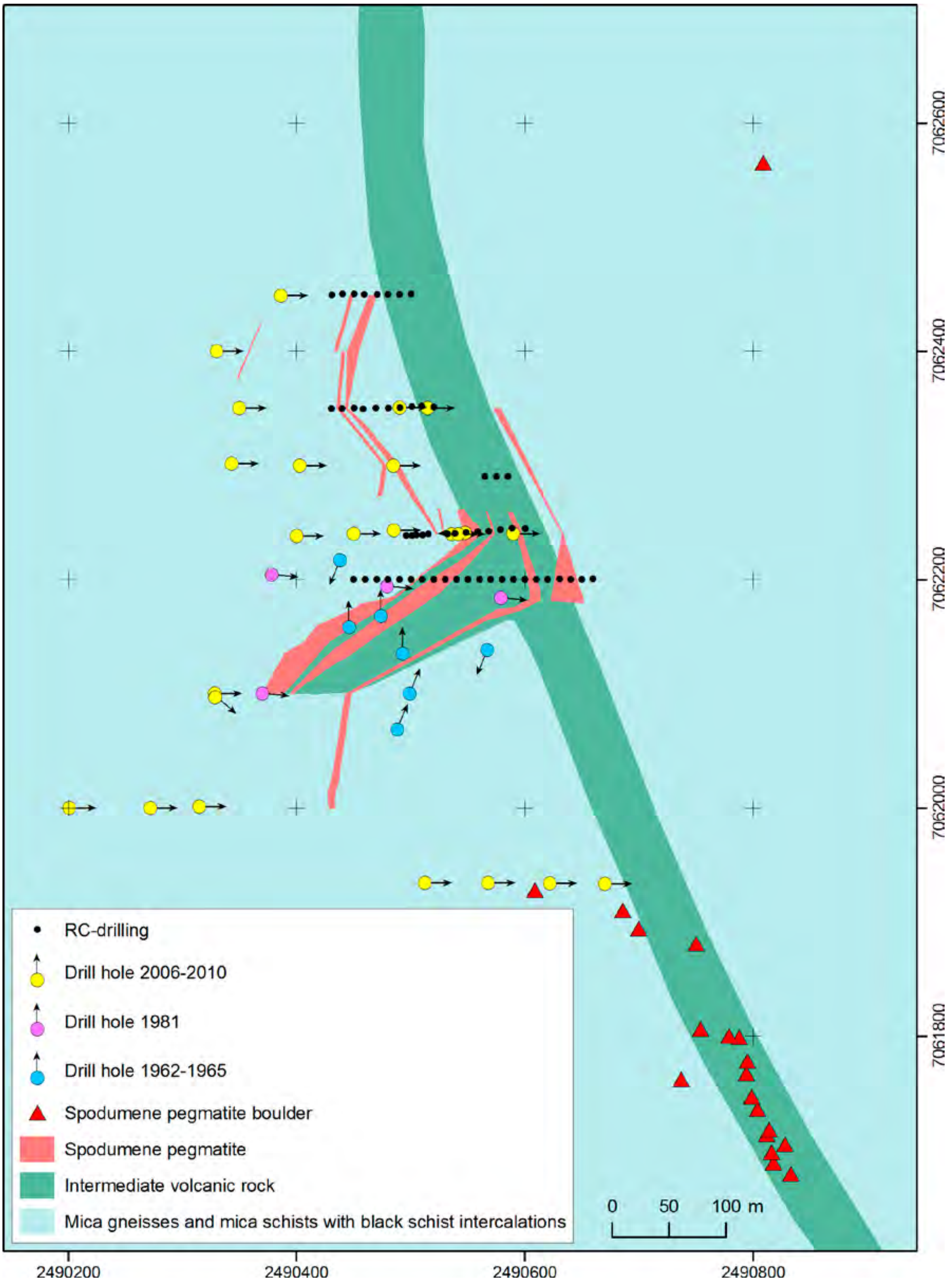


Figure 47. Geology the Syväjärvi spodumene pegmatite area (Ahtola et al. 2010b). Coordinates according to Finnish national KKJ grid. The Syväjärvi deposit is at 63.396°N, 23.484°E.

F025 KOIVUSAARENNEVA Ti

Niilo Kärkkäinen (GTK)

The Koivusaarenneva Ti area (F025) comprises a chain of ilmenite-rich gabbro intrusions on the northwestern part of the Central Finland Granitoid Complex (CFGC), close to the Pohjanmaa supracrustal belt (Fig. 48). Mafic intrusions have been found here in regional geophysical surveys, indicated by gravity and magnetic highs in an area with only a few outcrops.

The mafic intrusions of area F025 were emplaced at 1881 Ma into tonalitic bedrock, and belong to a larger gabbro province interpreted to have been formed in tensional zones in the vicinity or margin of convergent plate boundaries in the Kälviä-Halsua region, western Finland (Kärkkäinen & Bornhorst 2003). The most common rock types in these intrusions are medium-grained gabbro, gabbronorite and pyroxenite, all characterised by Fe-Ti oxides. The rocks have been recrystallised under regional metamorphism at mid-amphibolite facies PT conditions. This has resulted in almost all pyroxene being uralitised and the plagioclase mainly being oligoclase. Common features of these intrusions include their small size and layered structure, mainly gabbroic composition, pyroxenite as the most mafic rock type, the occurrence of igneous ilmenite and magnetite, the absence or a low content of apatite, low MgO in ilmenite and high V in magnetite (Kärkkäinen & Bornhorst 2003). Five ilmenite deposits (Table 23) in area F025 are presently (2011) being explored by Kalvinit Oy (a subsidiary of Endomines Oy), and a mining concession has been applied for.

The main ilmenite deposit of area F025 is hosted by the **Koivusaarenneva** gabbro, which is a 3-km-long, 0.5–1-km-thick, sill-like intrusion. Koistinen (1996) estimated it to contain 44 Mt of mineralised rock with 15 % ilmenite and 6 % vanadiniferous magnetite (0.6 % V in magnetite). Koivusaarenneva gabbro can be divided into three zones, lower, middle and upper (Fig. 49), and the characteristic minerals in these zones are ilmenomagnetite, ilmenite and apatite, respectively (Kärkkäinen & Bornhorst 2003). The main rock type in all zones is a metamorphosed gabbro or gabbronorite. The lower zone contains minor ilmenite-rich layers with abundant ilmenomagnetite. The TiO_2/Fe_2O_{3TOT} ratio is constant at 0.2 for all rock types in the lower zone. The middle zone contains a 1.5-km-long, 50–60 m thick, Ti-mineralised layer that grades at 8–48 % ilmenite and 2–25 % magnetite (Fig. 50). The average ratio of ilmenite to magnetite is 4:1. The TiO_2/Fe_2O_{3TOT} ra-

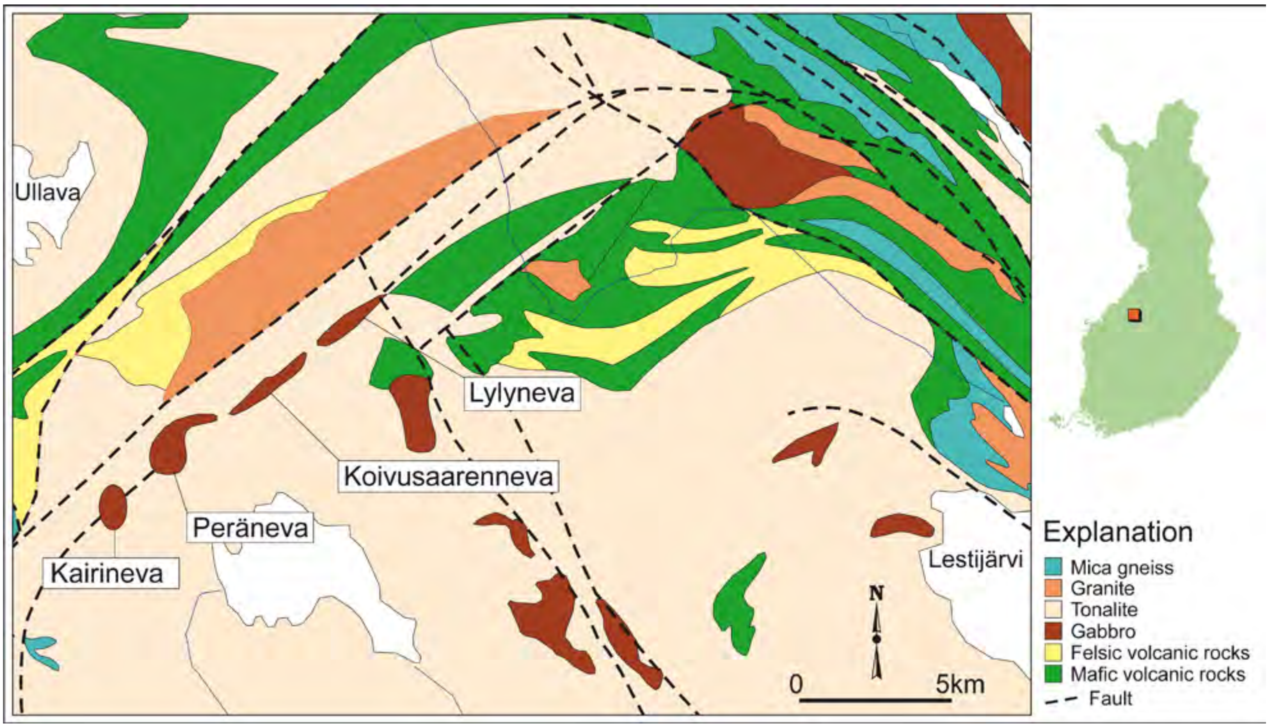


Figure 48. Geology of central parts of the Koivusaarenneva metallogenic area (F025); named are the most significant known titanium occurrences of the region (Kärkkäinen & Bornhorst 2003). The Koivusaarenneva intrusion is at 63.586°N, 24.239°E.

tio of the middle zone is 0.23–0.50. Ilmenite is the dominant Fe-Ti oxide in the upper zone, which consists of P-rich gabbro and leucogabbro.

The mineralogy of the Fe-Ti oxides varies according to the stratigraphic position, but is constant along the strike within each stratigraphic unit at Koivusaarenneva. Magmatic ilmenite (Fig. 51) dominates in the middle and the upper zones, and is also common in the lower zone where part of the ilmenite occurs as exsolution lamellae in titanomagnetite (Kärkkäinen & Bornhorst 2003). The grain size of the ilmenite and magnetite is 0.1–1.2 mm. Metamorphic processes have only slightly affected the ore mineralogy, most importantly by causing recrystallisation of titanomagnetite (ulvospinel) to ilmenomagnetite. Ilmenite is low in MgO (<0.5 %) and Cr (<100 ppm), whereas the V content of magnetite is high (0.6 %); locally, the Cr content in magnetite is also relatively high (Table 24).

The chemical composition and cryptic layering of the three zones at Koivusaarenneva suggest crystallisation from successive pulses of Ti-rich tholeiitic magma. The parent magmas for the lower and middle zones are similar. The lower zone is interpreted to have been generated by relatively closed-system fractional crystallisation, and based on the common ilmenomagnetite, under relatively high oxygen fugacity (Kärkkäinen & Bornhorst 2003). The upper zone has also been generated by relatively closed-system fractional crystallisation, but the parental magma was far more evolved, although primarily similar to magma of the two lower zones.

The genesis of the Fe-Ti oxide-rich layers in the middle zone can be explained by deposition from several magma pulses in an open system, because of the small volume of the rock in the middle zone (Kärkkäinen & Bornhorst 2000). The middle zone may represent a channel for magma flow

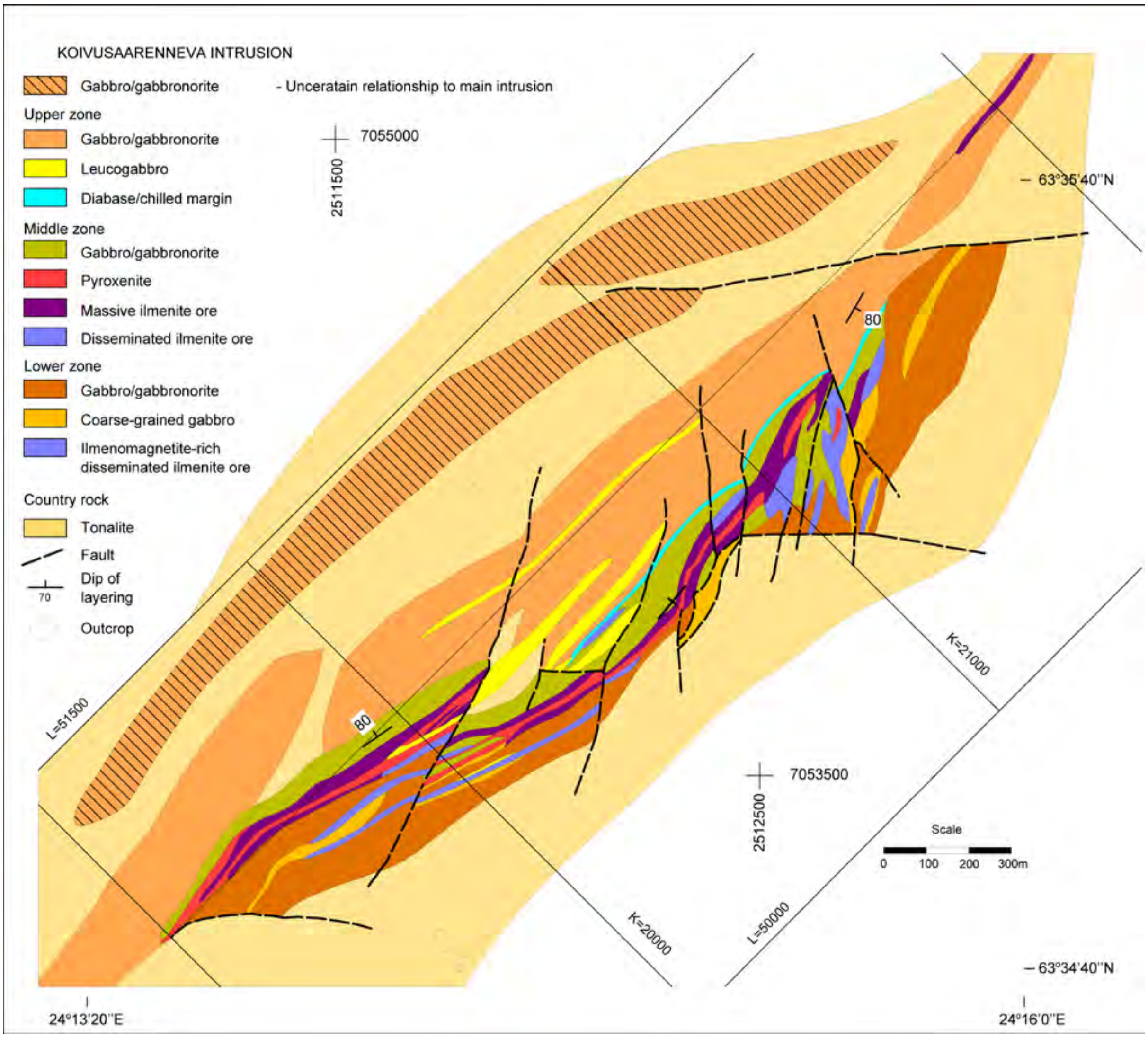


Figure 49. Surface geology of the Koivusaarenneva gabbro (Kärkkäinen & Bornhorst 2003).

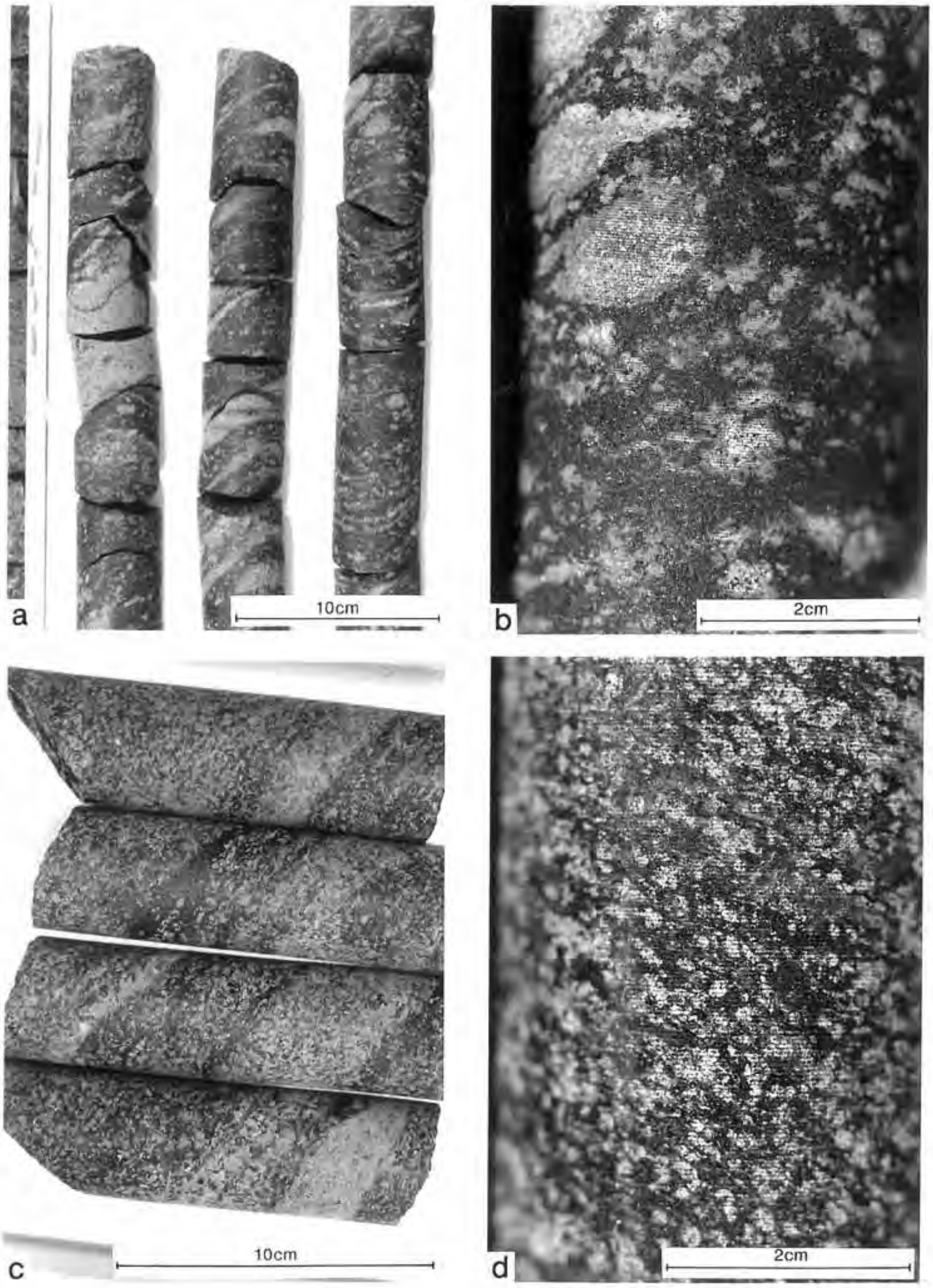


Figure 50. Ilmenite ore in drill core; middle zone of the Koivusaarenneva intrusion. Photo: Niilo Kärkkäinen, GTK.

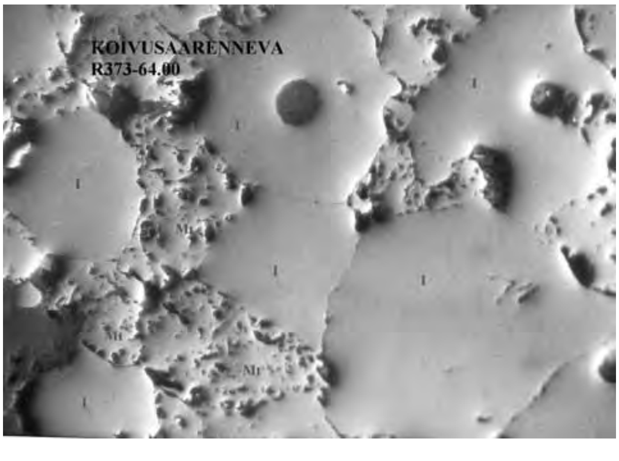


Figure 51. Photomicrograph of the Koivusaarenneva ore. Grain size of ilmenite is 0.5–3 mm. Field of view 10 mm. Image: Niilo Kärkkäinen, GTK.

where the large mass of oxides was trapped and accumulated in favourable localities within the channelways from multiple magma pulses. Ti-rich melt droplets or suspended oxides were removed from a Ti-saturated magma and sank to the floor of a shallow magma chamber to form the mineral deposit composed of a Fe-Ti oxide-rich matrix between a silicate framework. The Ti- and Fe-depleted magma then flowed out of the poorly crystallised intrusion and was replaced by a new pulse of Ti-saturated parent magma (Kärkkäinen & Bornhorst 2003).

The **Kaireneva** and **Peräneva** gabbro bodies were found in a regional gravity survey (6–7 points/km^2) and drilling (Sarapää et al. 2003). The hosts to ilmenite ore at Kaireneva are poorly layered, homogenous gabbro and gabbronorite (Sarapää et al. 2003). Peräneva is a complex intrusion system between Koivusaarenneva and Kaireneva (Sarapää & Kärkkäinen 2001). **Lylyneva** is characterised by apatite-rich ilmenite-magnetite ore lenses (Sarapää & Kärkkäinen 2003).

Economically, the most favourable intrusions for ilmenite are those among several interconnected intrusions, as is the case within the Koivusaarenneva Ti area. The magma-flow genesis (Kärkkäinen & Bornhorst 2003) for Ti mineralisation in area F025 is supported by the fact that the Koivusaarenneva gabbro is a member in a chain of small intrusions, three of which, Lylyneva, Peräneva, and Kaireneva, also host ilmenite deposits. Hence, there is potential for further discoveries in the area. Such discoveries essentially require gravity surveys with at least seven survey points per km^2.

Table 23. Ilmenite-magnetite occurrences with a resource estimate in the Koivusaarenneva metallogenic area (F025). All are hosted by a layered mafic intrusion.

Occurrence	Tonnage (Mt)	TiO_2 %	Main host rock	Reference
Koivusaarenneva				
indicated	32	7.8	Gabbronorite, Pyroxenite	Endomines (2010a)
inferred	30	6.7		
Kaireneva (Kairineva)				
indicated	6.4	10.0	Gabbronorite	Endomines (2010a)
inferred	0.1	7.3		
Peräneva				
inferred	2.9	9.3	Gabbronorite	Endomines (2010a)
Lylyneva				
inferred	1.7	15.5	Gabbronorite	Endomines (2010a)
Riutta				
Inferred	0.8	8.9	Gabbronorite	Endomines (2010a)

Table 24. Electron microprobe analyses of ilmenite and magnetite from the Koivusaarenneva gabbro (Kärkkäinen & Bornhorst 2003). Sample codes indicate the drill hole (R373) and downhole depth in metres.

Mineral Zone Sample	Ilmenite Middle Zone R373, 142.59	Ilmenite Middle Zone R373, 163.90	Magnetite Middle Zone R373, 183.18
FeO_{TOT}	47.67	47.34	88.92
TiO_2	48.30	49.64	0.05
MnO	1.35	0.62	0.00
MgO	0.17	1.02	0.00
Cr_2O_3	0.02	0.01	3.04
V_2O_3	0.22	0.29	3.15
SiO2	0.04	0.02	0.04
Al_2O_3	0.05	0.05	0.19
CaO	0.02	0.00	0.00
NiO	0.01	0.02	0.05
ZnO	0.03	0.01	0.05
Total	97.88	99.02	97.43

F026 LAIVAKANGAS Au

Kaj Västi, Jarmo Nikander, Olavi Kontoniemi, Pasi Eilu (GTK)

The Laivakangas Au area (F026) is located in the NW part of the NW-trending Raahe–Ladoga suture zone between the Karelian and Svecofennian terranes in Finland (Korsman 1988). Area F026 is considered to extend for about 200 km along the Raahe–Ladoga suture (Figs. 1 and 52). It is located immediately to the SW of the Vihanti-Pyhäsalmi Zn area (F028). In its central part, it overlaps the Hitura Ni area (F027) and Koivusaarenneva Ti-V area (F025).

At least two major styles of mineralisation can be defined from area F026: orogenic gold, and porphyry Cu-Au and porphyry Mo (Table 25). Most of the known 30 drilling-indicated Au occurrences (Eilu & Pankka 2009) appear to belong to the orogenic gold category. A few occurrences have most of their features more akin to the porphyry style, at least those three listed in that category in Table 25.

Only one to ten holes have been drilled into most of the known gold occurrences in area F026. A few of the occurrences, especially those listed in Table 25, have been shown to be more promising and been drilled more thoroughly. A full feasibility study for the Laivakangas (Laiva) deposit was completed in 2010, and gold production started in 2011 (Nordic Mines 2010). Other occurrences mentioned below are or have been under extensive exploration during the past few years. Gold deposits in the region are typically hosted by quartz diorite, tonalite, ophitic (hypabyssal) gabbro or intermediate to mafic metavolcanic rock. In places, mica gneiss, mica schist and felsic schist also host the mineralisation (Table 25).

The **Laivakangas** deposit is hosted by silicified shear zones and quartz veins within quartz diorite and intermediate to mafic metavolcanic rock (Luukas et al. 2004, Nordic Mines 2009). The deposit is cut by post-mineralisation granite. Gold mostly occurs as native and in minor amounts in maldonite as inclusions in arsenopyrite, löllingite and gangue. The generally east–west-striking mineralised vein swarms dip steeply to the south. The horizontal dimensions of the deposit are 1.3 by 1.2 km; the deposit is open at the depth of 300 m. According to the feasibility study, the measured and indicated mineral reserve amounts to 11.7 Mt at 1.86 ppm Au. In addition, there is a measured and indicated resource of 4.9 Mt at 1.83 ppm Au (Nordic Mines 2010).

The **Kopsa** deposit has historically been interpreted as a porphyry gold-copper mineralisation, possibly overprinted by later brittle style epigenetic auriferous quartz vein mineralisation (Eilu & Pankka 2009). Ore minerals occur within the Kopsa intrusion (quartz diorite – granodiorite) as compact sulphide veins and stringers in connection with quartz veins. Commonly, the ore minerals are near the contact of veins and within fractures cutting the quartz veins. The main ore minerals are pyrrhotite, arsenopyrite and chalcopyrite and occasionally löllingite. Gold (electrum) and related Bi and Bi-Te minerals occur in both the arsenic and silicate phases as inclusions (in löllingite, arsenopyrite, quartz) and along sulphide and silicate grain boundaries (Eilu & Pankka 2009, Kontoniemi 2009).

The **Hirsikangas** deposit is in a contact area of the Himanka volcanic rocks and pelitic schists, hosted by a ‘felsic schist’ that probably comprises strongly sheared and altered porphyry and greywacke. Regional prograde metamorphism at Hirsikangas took place under amphibolite facies conditions, and the most characteristic metamorphic minerals in the metasedimentary rocks include biotite, andalusite and fibrolitic sillimanite (Kontoniemi & Mursu 2006). To the NW of Hirsikangas, dextral folding is possibly associated with a strike-slip shear system. Ductile-brittle shears are focused within vertical *en echelon* lenses of felsic schist, and the orientation of the lenses follows the strike of the ductile shears and perhaps also the axial plane of shear folding. Principal ore minerals are pyrrhotite, arsenopyrite and löllingite with accessory ilmenite, sphalerite, chalcopyrite, scheelite and native gold. Gold and related minerals typically occur at grain boundaries of and fractures in silicate grains, rarely also associated with sulphide minerals (Kontoniemi & Mursu 2006).

Subarea F026.1 has been defined around the known deposits of **Ängeslampi**, **Ängesneva** and **Vesiperä** (Fig. 52). In addition to these three with resource data, nine gold occurrences have so far been found by drilling in the rather small area of F026.1 (Eilu & Pankka 2009 and references therein). All occurrences of the subarea have been classified into the orogenic gold category. They seem to mostly be hosted by the locally most competent rock type, a hypabyssal gabbro, and all occurring close to or within subsidiary shear zones of one of the major NW-trending shear zones of the Raahe–Ladoga suture. Native gold occurs associated with arsenopyrite, löllingite and gangue

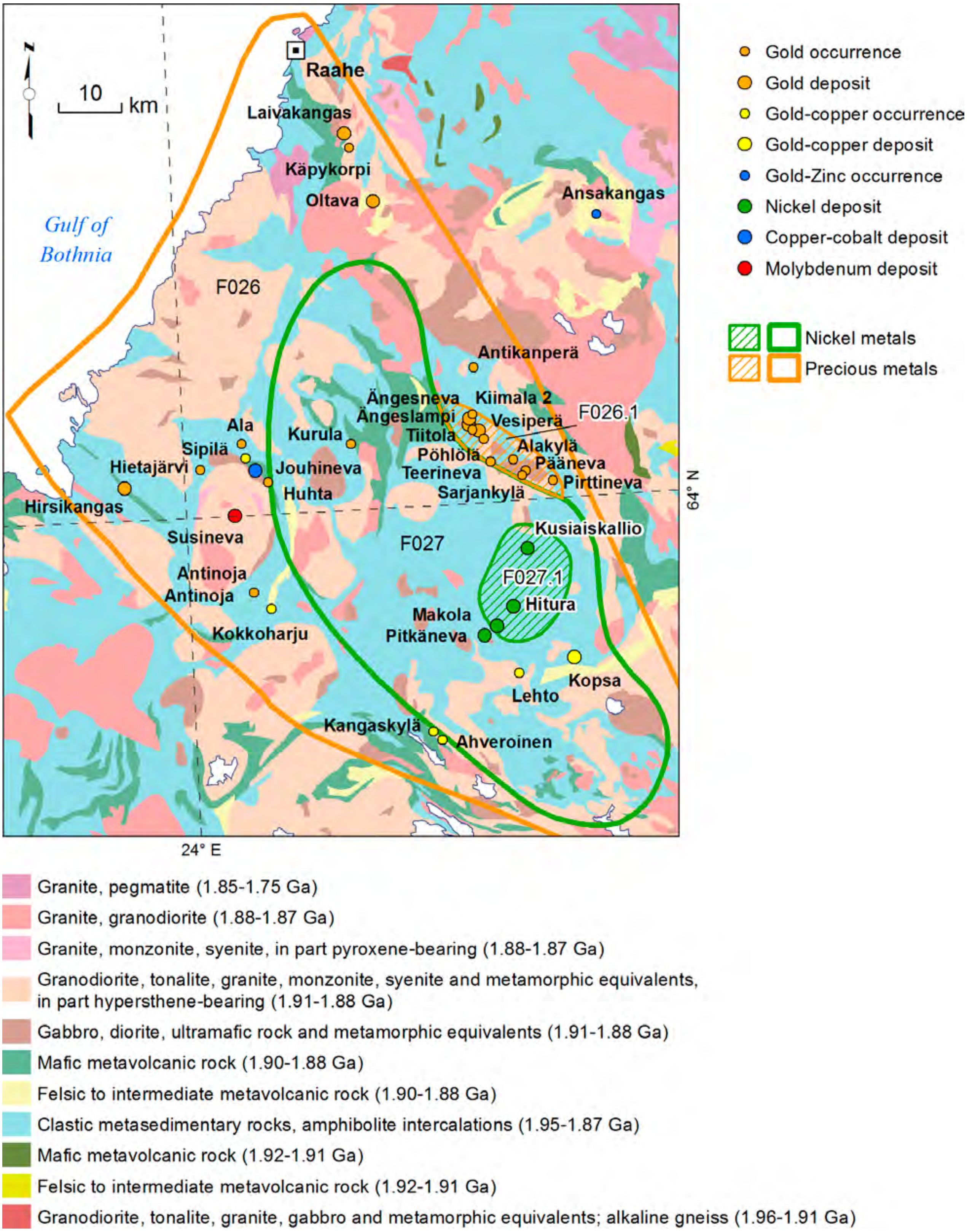


Figure 52. Hitura Ni (F027) and Laivakangas Au (F026) metallogenic areas with the most significant metal deposits of the region. Geology is from Koistinen et al. (2001).

in quartz veins and biotitised host rocks. More discoveries, and increases in the known resources, are expected from this area 20 km long and 2–5 km wide with ongoing exploration.

Table 25. Selected metal deposits in the Laivakangas Au area (F026).

Occurrence (Alternative name)	Tonnage (Mt)	Au g/t	Co %	Cu %	Mo %	Main host rock	Reference
Orogenic gold							
Ängeslampi	0.27	3.1		0.14		Hypabyssal gabbro*	Sipilä (1988)
Ängesneva	3.85	1.19				Hypabyssal gabbro*	Västi (1991a), Belvedere Resources (2010a)
Hirsikangas	5.675	1.25				Felsic schist	Kontoniemi & Mursu (2006), Belvedere Resources (2009)
Laivakangas (Laiva)	20.73	1.88				Quartz diorite, Mafic volc. rock	Nordic Mines (2010)
Oltava**	0.000718	30				Quartz diorite, Mica gneiss	Nikander (1999)
Vesiperä	0.3	2.5				Hypabyssal gabbro*	Västi (1991b)
Porphyry Cu-Au, porphyry Mo							
Jouhineva	0.45	0.88	0.18	0.81		Meta-andesite	Isohanni (1984, 1985b)
Kopsa	25	0.57		0.18		Tonalite	Gaál & Isohanni (1979)
Susineva	0.3				0.04	Granodiorite	Gaál & Isohanni (1979)

* The rock type has also commonly been called ‘plagioclase porphyry’
** Resource data available for only one lode

F027 HITURA Ni

Hannu Makkonen (Belvedere Mining Oy)

The Hitura metallogenic area (F027) is close to the NW end of the Raahe–Ladoga suture in western Finland. Its extent is defined by nickel indications around the known deposits near the boundary between the Savo and Pohjanmaa supracrustal belts (Fig. 52). The Hitura area is completely inside the Laivakangas Au area (F027) and partially overlaps the Koivusaarenneva Ti area (F025). However, there is no local spatial overlap between the mineralisation types, and the exact mineralising processes are different. Hence, three distinct metallogenic areas have been defined within the region (Fig. 52).

The main rock types in the area F027 are mica gneiss and mica schist, the latter mainly occurring in the western part of the area. The metasedimentary rocks are of lower metamorphic grade in the western part and have been interpreted as stratigraphically younger. The metamorphic grade in the eastern part is at upper-amphibolite facies, which peaked at D_2 and produced various types of migmatites, including schollen migmatite typical of the Svecofennian nickel areas. Schollen migmatites are most common within the Hitura-Makola subarea (F027.1). Another similar region is at Reisjärvi, in the southern part of area F027. These regions, probably representing the deepest crustal sections and including numerous nickel-bearing glacial erratics, are the most potential areas for new discoveries within the F027 (Kousa et al. 2000, Makkonen 2005).

There are five nickel deposits (Table 26), more than five drilling-indicated occurrences and a large number of other indications, mainly glacial erratics, of nickel mineralisation in area F027, listed in the GTK mineral deposit and ore indication databases. These all belong to the mafic-ultramafic intrusion-hosted subtype of the magmatic nickel deposit category, and are of Svecofennian synorogenic age, ca. 1.88 Ga. The parent magma for these deposits was tholeiitic basalt with an MgO content of 10–15 %. Area F027 is similar to the Vammala Ni area (F006) in that the intrusions are mainly peridotitic and commonly serpentinised. In contrast, in the Kotalahti Ni area (F016), the intrusions are mainly of differentiated gabbro-peridotite type. This fact gives challenges for exploration in the Hitura and Vammala areas, because of the important *negative* gravimetric anomalies and complicated magnetic anomalies (remanent magnetism) due to the serpentinites potentially hosting nickel deposits (Peltonen 2005).

The **Hitura** ultramafic complex consists of three separate, closely-spaced serpentinite massifs surrounded by migmatised mica gneiss (Figs. 53 and 54). In addition to migmatised gneisses, a belt of sulphide- and graphite-bearing schists and mylonitic rocks not far from the Hitura body characterises the immediate environment. The horizontal extent of the ultramafic complex is 0.3 km by 1.3 km. The deepest drilling intersections are at the level of about 800 m. Geophysical surveys indicate that the intrusion continues to at least 1000 m below the surface. The core of the complex is serpentinite, and marginal zones are amphibole-rich ultramafic rocks. Pegmatitic dykes, with an age of 1877 ± 2 Ma, are not uncommon (Isohanni et al. 1985).

The contacts of the Hitura complex against gneissic wall rocks are commonly tectonic. The contact zone is characterised by dislocated mafic blocks, erratic wall-rock inclusions and, locally, by massive sulphide lumps in a soft talc-rich matrix, indicating late-tectonic movements and faults. The gneiss near the contact ("contact gneiss") is typically homogenised and contains small garnet crystals and large pale dots of feldspars and quartz. Pyrrhotite dissemination is common in the gneisses near the serpentinite body. Some small serpentinite tongues in mica gneisses, partly nickel mineralised, are found in the western side of the Hitura massive. Shear zones with narrow mica gneiss tongues separate the three ultramafic massifs (Meriläinen et al. 2008).

Several nickel ore bodies occur in the contact zones and in the core of the North Hitura serpentinite massif. From west to east, the ore bodies in the contacts are Länsimalmi, Pohjoiskaari, Koilliskaari and Itämalmi. In the centre of the North Hitura, there is the Keskitappi (Central Core) ore body. In the massif between the core and the contacts, there is low-grade nickel mineralisation. Possible mineral resources of the Middle and South Hitura massifs are not exactly known (Meriläinen et al. 2008). The main ore minerals at Hitura are pyrrhotite and pentlandite but, in places, vallerite, mackinawite, chalcopyrite and cubanite are abundant. Pentlandite is the main nickel-bearing mineral, but mackinawite containing up to 6% Ni is locally also important. Copper is mainly in vallerite, but locally Cu is also hosted by chalcopyrite and cubanite. Many accessory minerals have been identified at the site, such as pyrite, violarite, maucherite, niccoline, gersdorffite and millerite. Pyrite only occurs in joints with carbonates. Platinum minerals, such as sperrylite, michenerite, irarsite, iridarsenite and hollingworthite, have also been detected (Meriläinen et al. 2008).

Table 26. Magmatic intrusion-hosted Ni-Cu deposits and occurrences in the Hitura Ni area (F027). Only deposits for which there is a public resource estimate are included. For the fifth, Räihäneva, resource information has not been published.

Occurrence	Tonnage (Mt)	Co %	Cu %	Ni %	When mined	Main host rock	Reference
Hitura	19.36[1, 2]	0.02	0.18	0.52	1970–	Dunite	Kuisma (1985), Belvedere Resources (2010b)
Makola	1.08	0.05	0.44	0.74	1941–1954	Dunite	Geol. Surv. Finland Ore Deposit Database
Pitkäneva	1.7	0.02	0.06	0.22		Peridotite	Papunen & Vorma (1985)
Kusiaiskallio	0.798		0.14	0.22		Gabbro-Peridotite	Papunen & Vorma (1985)

1 Mined until the end of 2011: 16 Mt; NI 43-101 compliant reserves are 1.32 Mt @ 0.67 % Ni, 0.24 % Cu, resources (measured + indicated) 2.422 Mt @ 0.66 % Ni, 0.22 % Cu, inferred resource 0.615 Mt @ 0.67 % Ni, 0.29 % Cu (Belvedere Resources 2010b).

2 The ore also contains roughly 0.1 ppm Pt and 0.1 ppm Pd (Kojonen et al. 2003).

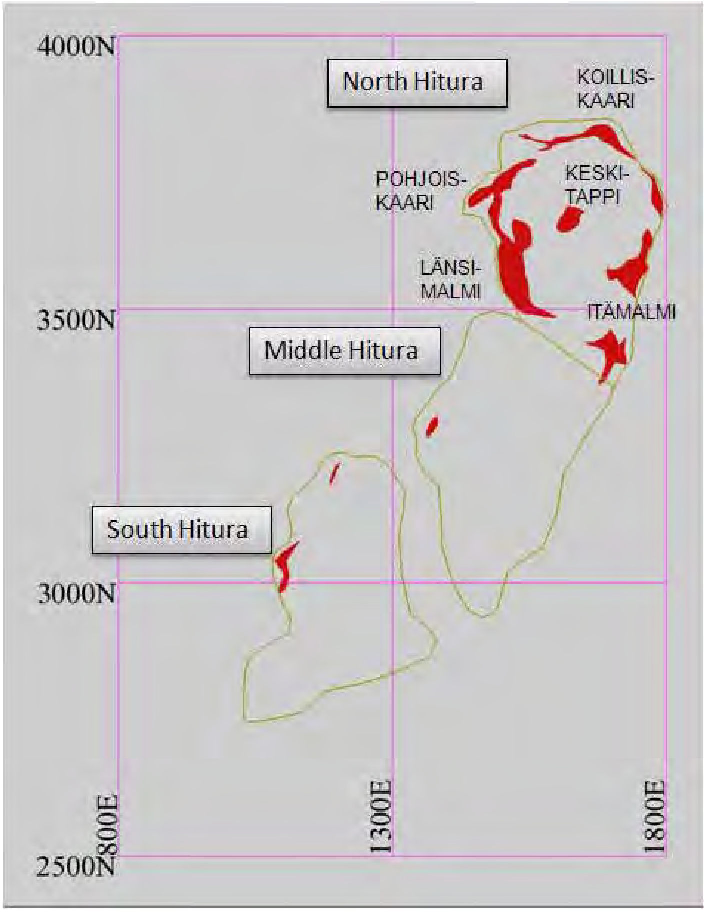


Figure 53. Geology of the Hitura nickel deposit (200 m level). Ore in red, intrusion borders in green. Surpac figure by H. Makkonen.

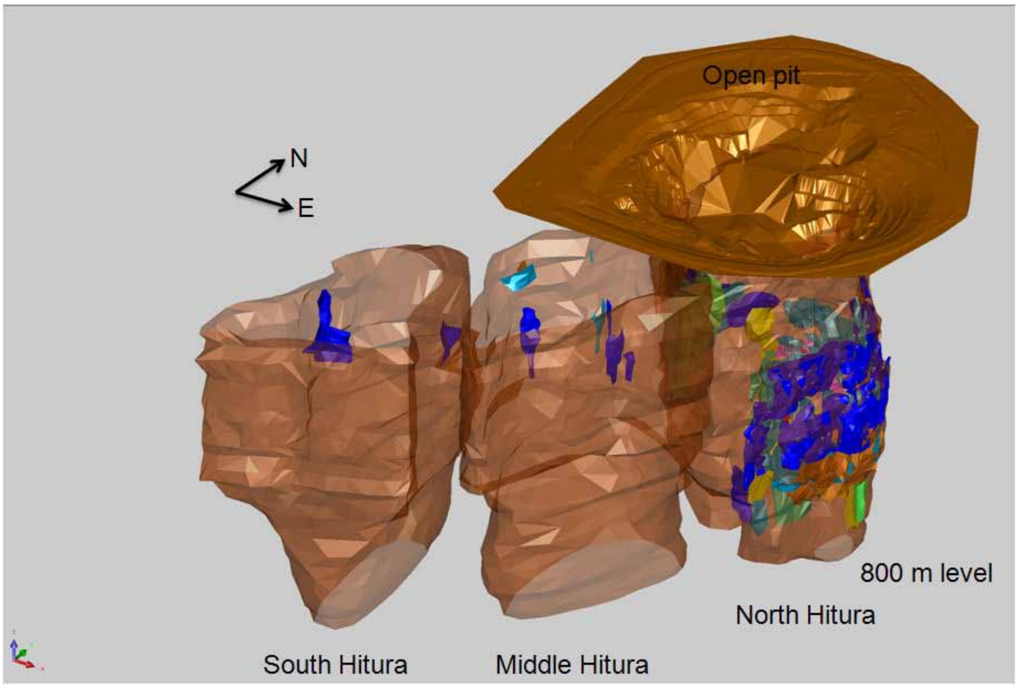


Figure 54. Hitura deposit looking from the SE. Open pit (at its maximum depth of 170 m in 1990) and intrusion bodies in brown, underground ore body solids in blue, yellow, green and brown. The North Hitura body is known to continue to at least 800 m from the surface, but the depth of the South and Middle Hitura bodies is unknown. Surpac figure by H. Makkonen.

F028 VIHANTI–PYHÄSALMI Zn-Cu

Kaj Västi (GTK)

The Vihanti–Pyhäsalmi area (F028) is located on the NE edge of the Svecofennian domain (Figs. 1 and 55), in the NW part of the Raahe–Ladoga suture, previously commonly called the Main Sulphide Ore Belt of Finland (Kahma 1973). The Raahe–Ladoga suture has been described as a collisional boundary zone between Proterozoic and Archaean domains (Lahtinen 1994). The Vihanti–Pyhäsalmi area comprises the central part of the northwestern Savo schist belt (Vaasjoki et al. 2005) and is 10–40 km wide and about 300 km long. In the SE part, it partly overlaps the Kotalahti Ni area (F016). The Laivakangas Au area (F026) and the Hitura Ni area (F027) are immediately to the SW of the Vihanti–Pyhäsalmi area (Fig. 1).

Most of the massive sulphide deposits in the area F028 are hosted by metavolcanic rocks, locally also by metasedimentary rocks, in a Palaeoproterozoic island arc environment, close to the Archaean Karelian craton. In the Pyhäsalmi region (subarea F028.3), volcanic activity started in an extensional continental margin with felsic volcanism and continued in a rifted marine environment with mafic volcanism. Large-scale hydrothermal alteration and mineralisation occurred close to the centres of mafic volcanism. Without a longer hiatus, volcanic activity continued with more calc-alkaline volcanism (Kousa et al. 1997). In the northwestern end of the area, in subarea F028.1, volcanogenic rocks are predominantly intermediate and mafic in composition. An essential part of this rock assemblage is composed of what is called the Lampinsaari-type rock association comprising felsic metavolcanic rocks, skarns and graphite tuffs (Luukas et al. 2004). According to Rauhamäki et al. (1980), volcanic activity within subarea F028.1 took place in two stages. The earlier cycle started under marine conditions and comprised felsic volcanic rocks and chemically precipitated carbonate rocks, and is characterised by the formation of Lampinsaari-type ore bodies. The deposition of volcanic and carbonate rocks continued concurrently with ore formation, culminating in the stages of zinc ore deposition. After mineralisation, more felsic volcanic rocks were erupted during the later cycle. Graphite tuff between the zinc ore and the later volcanic cycle refers to reducing conditions (op. cit.).

The Vihanti–Pyhäsalmi metallogenic area includes a great number of Zn-Cu deposits and prospects. It is particularly known from the two world-class VMS-type Zn deposits at **Pyhäsalmi** and **Vihanti** (Figs. 56 and 57), but there also are a few smaller mines and a number of unexploited deposits and occurrences. Currently, only the Pyhäsalmi mine is active. Within the vicinity, there are three smaller mined VMS-type deposits: **Mullikkoräme**, **Ruostesuo** and **Kangasjärvi** (Table 27).

In the northwestern part of area F028, only the Vihanti (Lampinsaari) deposit has been exploited (Fig. 57). The deposit consists of five types of mineralisation: zinc, copper, pyrite, lead-silver-gold and uranium-phosphorous ore. According to Autere et al. (1991), the U-P type is the oldest, whereas the Pb-Ag and Zn ores are the youngest. The Zn ores, hosted by dolomite and skarn rock, were by far the most important ore types for the economy of the mine, containing over 75 % of the total ore resource. The U-P mineralisation with over 1 Mt of low grade ore has never been exploited. In addition to the Vihanti deposit, there are a couple of smaller unexploited deposits (Table 27) in subarea F028.1. Although intense exploration has been carried out in the Vihanti district, only minor showings have so far been detected.

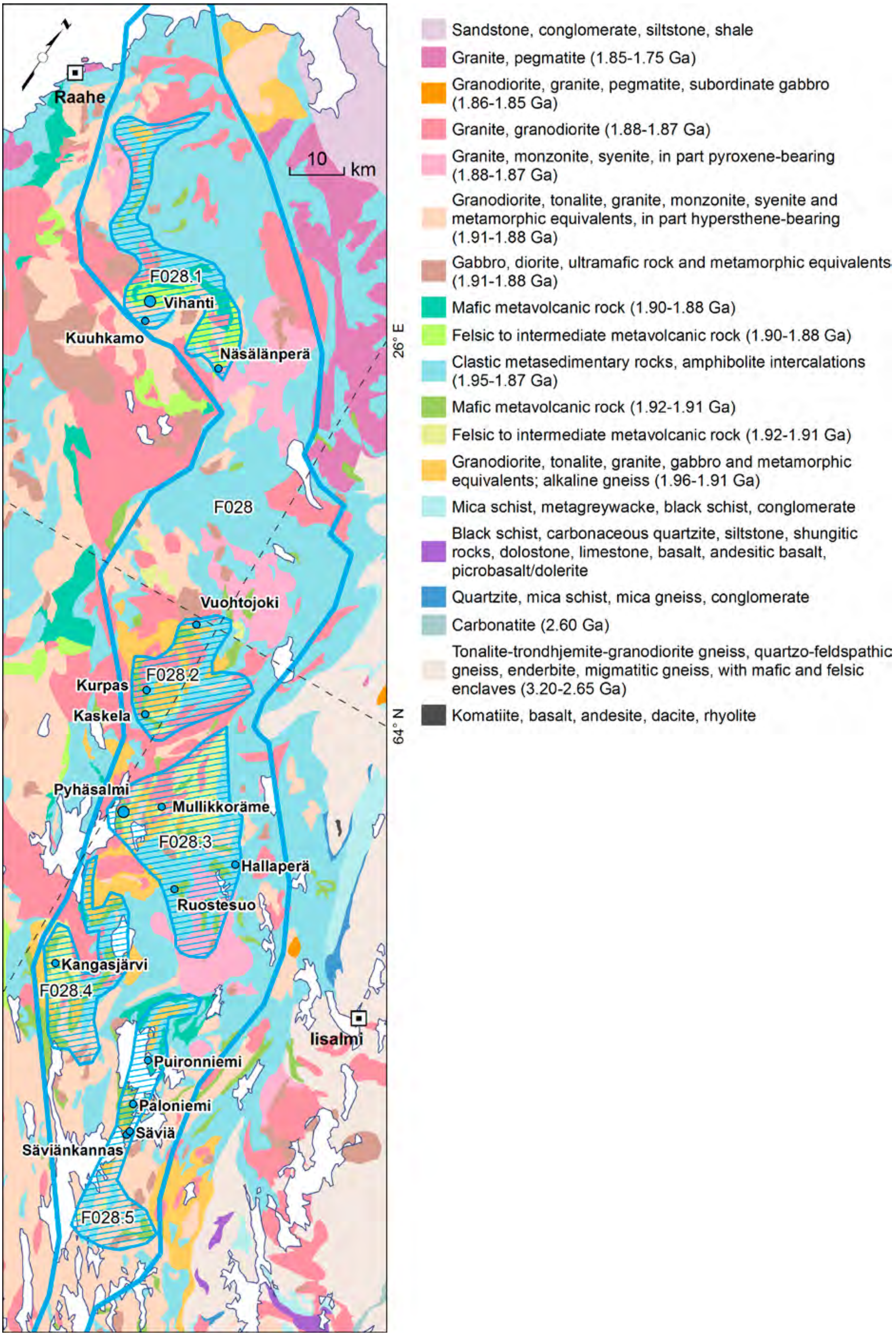


Figure 55. Geology of the Vihanti–Pyhäsalmi metallogenic area (F028), with the most significant base metal occurrences. Geology simplified from the GTK digital bedrock map database.

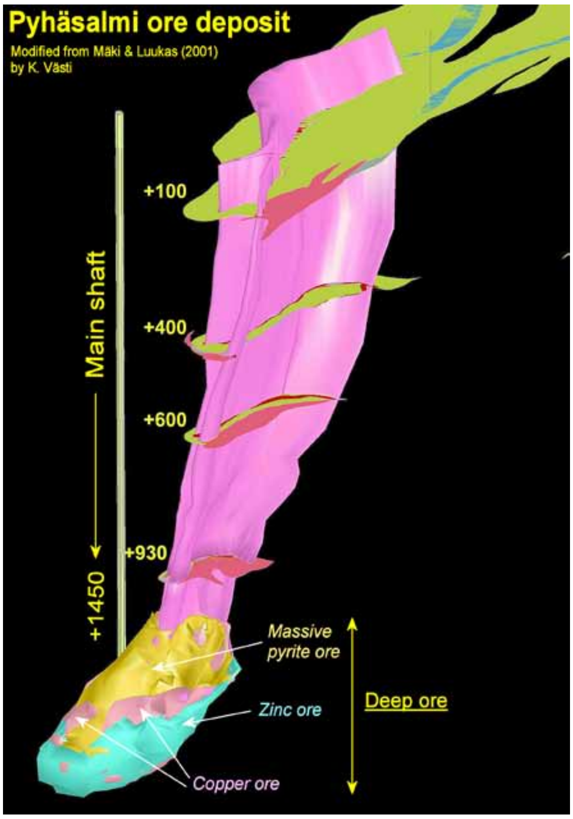


Figure 56. A 3D model of the Pyhäsalmi Zn-Cu deposit viewed from the southeast. The deep ore was discovered on 19 December 1996 (Luukkonen et al. 2000).

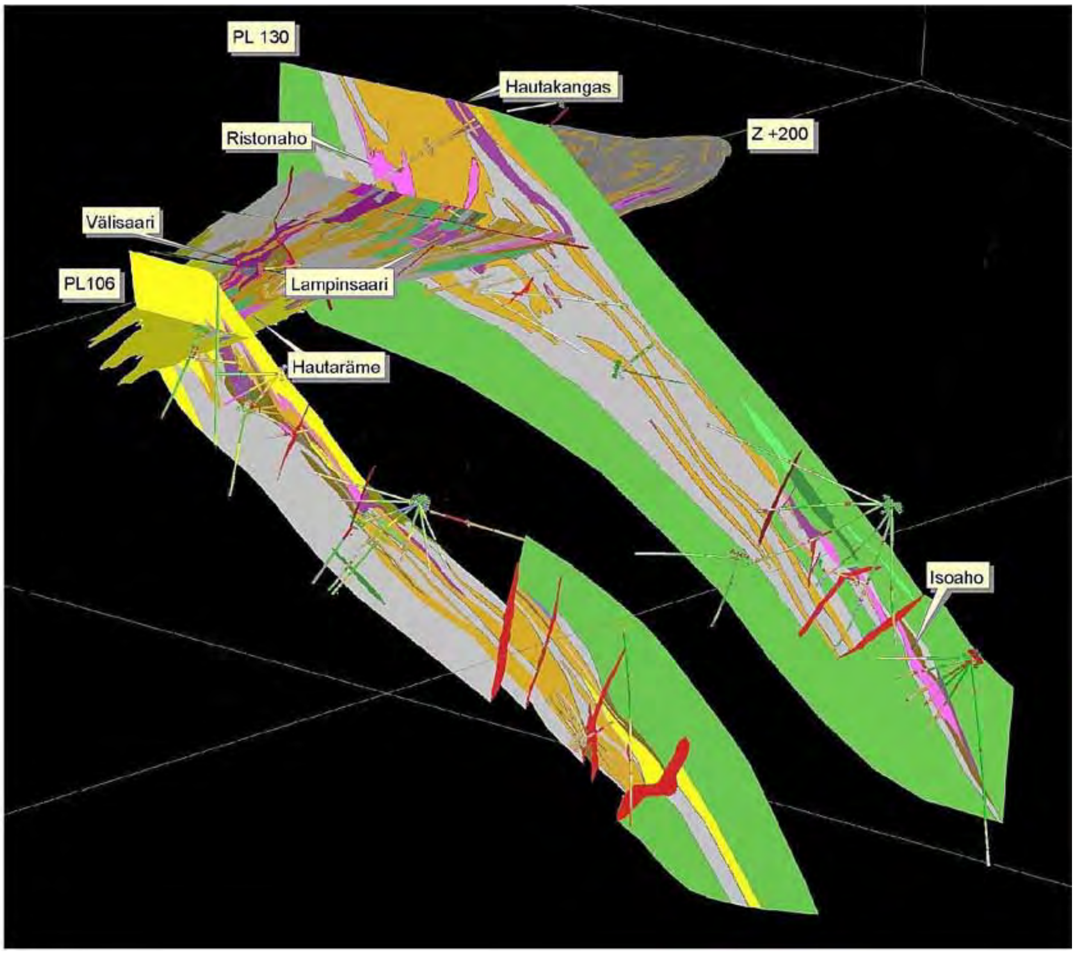


Figure 57. Geological cross sections of the Vihanti mine, looking from the southwest (Kousa & Luukas 2004). Intermediate volcanic rock (possibly tuffite) is indicated in green, skarn-banded felsic volcanic rock in grey, skarn and dolomite in orange, cordierite-sillimanite gneiss in yellow, younger dikes in red, pyrite ore in dark purple and zinc ore in pale purple.

Table 027. Selected Zn-Cu deposits in the Vihanti–Pyhäsalmi area (F028). Note that all host rocks are metamorphosed.

Occurrence	Tonnage Mt	Mining	Zn %	Cu %	Pb %	Ag g/t	Au g/t	Main host rocks	Reference
Vihanti, mined	28.1	1954–1992	5.12	0.48	0.36	25	0.49	Dolomitic marble, Skarn	Kousa et al. (1997)
Vihanti, resource	9.164		0.36	0.34				Dolomitic marble, Skarn	Outokumpu (1992)
Pyhäsalmi, mined*	45.6	1962–	2.5	0.9		14	0.4	Rhyolitic tuff and lava	T. Mäki (pers. comm. 2010)
Pyhäsalmi, resource**	19.8		2.2	0.5		14	0.3	Rhyolitic tuff and lava	Inmet Mining (2010)
Mullikkoräme, mined	1.148	1990–2000	6.1	0.3	0.7	45	1.0	Fels. volc. rock, Dolomitic marble	Luukas et al. (2005)
Mullikkoräme, resource***	2.815		7.4	0.3	0.7	59	0.7	Fels. volc. rock, Dolomitic marble	Puustjärvi (1992)
Ruostesuo, mined	0.24	1988–1990	2.63	0.3		8	0.3	Rhyolite, Basalt	Reino et al. (1992)
Ruostesuo, resource***	2.769		1.72	0.38		9.9	0.38	Rhyolite, Basalt	Kousa et al. (1997)
Kangasjärvi, mined	0.086	1986	5.12	0.06		5.0	0.3	Rhyolite	Roberts et al. (2004)
Kangasjärvi, resource***	0.3		5.4	0.06	0.02	5	0.3	Rhyolite	Puustjärvi (1992)
Säviä Cu ore bodies	4.0			1.1		5–15	0.2	Felsic pyroclastic rock	Laitakari (1968), Kousa et al. (1997)
Säviä Zn ore bodies	1.0		2.0	0.23		7.5		Felsic pyroclastic rock	Laitakari (1968), Kousa et al. (1997)
Hallaperä	3.1		0.98	0.47		12	0.3	Mica gneiss, Tonalite	Helovuori (1980)
Vuohtojoki	0.7		2.6	0.3		8	0.2	Felsic tuffite, Cordierite gneiss	Puustjärvi (1992), Marttila (2001)
Kaskela	0.124		3.9	0.4	0.1	12		Felsic tuffite	Puustjärvi (1994)
Kurpas	0.4		0.55	0.63				Mafic volcanic rock	Puustjärvi (1992)
Kuuhkamo	0.25		4.0					Diopside skarn, Cordierite gneiss	Pekkarinen (1990)
Näsälänperä	0.1		2.0	0.05		15		Felsic volcanic rock	Mäkelä (1980)

* Mined 1962–2009

** Ore reserves and resources estimated as at end of 2009

*** Remaining global resource

F029 TALVIVAARA Ni-Zn-Cu

Asko Kontinen (GTK)

Most of the Talvivaara area (F029) is within the N-S trending, Palaeoproterozoic, Kainuu supracrustal belt (Laajoki 1991, 2005). Its extent is defined by the areal distribution of the known Talvivaara-type polymetallic deposits and occurrences and their host rock assemblages, outlining two clusters in the central and southern part of the Kainuu belt, and one in the northernmost part of the North Karelia schist belt in the south (Fig. 58).

The main components of the Proterozoic strata in the Kainuu belt are: (1) Sumi-Sariola and Jatuli stage, 2.5–2.1 Ga, cratonic and epicratonic, dominantly quartz-arenite sequences, (2) Lower Kaleva stage, 2.1–1.95 Ga, riftogenous wacke-pelite sequences, and (3) Upper Kaleva stage, 1.95–1.90 Ga, deep-water turbidite wackes and pelites (Kontinen 1986b, 1987, Laajoki 2005). Of these sequences, the two older ones are autochthonous, whereas the third is at least partly located in allochthonous units carrying fault-bound, exotic ophiolithic fragments of 1.95 Ga oceanic crust (Peltonen et al. 2008 and references therein). The Kainuu belt was deformed and metamorphosed in multiple medium- to low-pressure, low- to medium-temperature events during the 1.91–1.78 Ga Svecofennian orogenesis.

The Talvivaara-type deposits occur in association with sulphide- and metal-rich carbonaceous (now graphitic) sediments. Carbonaceous sediments first appear in the Karelian record as thin layers in the topmost 2.1 Ga dolomitic and tuffaceous strata of the Jatuli sequence. They become abundant in the upper parts of the Lower Kaleva sequence, which are characterised by quartz-rich wackes and pelites, locally with phosphorite-banded silicate-magnetite iron formation intercalations. Layers of carbon- and sulphide-rich sediments are also common in the deeper-water turbidites of the Upper Kaleva stage. Graphitic-sulphidic metasedimentary units in both of the Kaleva sequences are, on average, strongly enriched relative to average upper crust in redox-sensitive metals, such as As, Fe, Mo, Sb, Se, V and U, and also in the base metals Cu, Zn and Ni (Loukola-Ruskeeniemi 1999). The pattern of metal enrichment is similar to that in many Phanerozoic metal-enriched black shales, especially in those deposited in large oxic-anoxic stratified restricted-marine basins or ocean-wide during so-called oceanic anoxic events. These basins were characterised by a high settling flux of organic matter and bio-trapped and particle-adsorbed metals, and their enhanced retention in slowly accumulating anoxic-sulphidic bottom sediments (e.g. Algeo & Maynard 2004, Tribovillard et al. 2006). The source of metals was ultimately in the global ocean water that during the anoxic events may, however, have been enriched in metals relative to the modern standard, ultimately probably related to coevally intensified submarine plume-related volcanic activity (Condie et al. 2001, Kerr 2005).

Compared to the average Kalevian black schist, black schists in the Talvivaara-type deposits have similar concentrations of the more redox-sensitive elements, such as V (650 ppm), Mo (60 ppm), Se and U (15 ppm), but several times more Ni (6.3 x 350 ppm), Co (5.7 x 35 ppm), Cu (4.3 x 300 ppm) and Zn (3.3 x 1500 ppm) (Loukola-Ruskeeniemi 1999, Kontinen et al. 2006, Talvivaara Mining Company 2010). The manganese concentration is also elevated (7.5 x 400 ppm). Although a hydrothermal hot spring source of the excess base metals has been proposed (Ervamaa & Heino 1980, Loukola-Ruskeeniemi 1991, Loukola-Ruskeeniemi & Heino 1996), the high degree of enrichment, especially in the hydrothermally relatively immobile Ni, is a problem that is not yet satisfactorily explained. Some clues can be seen in the following characteristics of the Talvivaara occurrences:

The mineralised units of area F029 seem to be stratabound and stratigraphically controlled, occurring in particularly highly graphitic (5–15 wt% graphite-bound C) and sulphidic (5–30 % S mainly in pyrrhotite and pyrite) mud-dominated units, in several cases immediately above and locally interbedded in phosphorite-chert-black shale sequences intercalated with silicate- and oxide-facies iron formations. There are no volcanic intercalations or igneous intrusions in the mineralised units or underlying metasediments. There is little evidence of such aspects as obvious leach zones in the footwall sedimentary units or distinct metal zonation in the mineralised units themselves. In the largest of the known deposits, Talvivaara, the mineralised unit is roughly 12 km along its exposed length and is surprisingly uniform in its metal content and ratios. All the known mineralised units show a similar enrichment in C, Fe, S and redox-sensitive metals to the background 'barren' black shales. Mineralised muds also show Co/Ni, Cu/Ni or Zn/Ni ratios broadly similar to the accompanying 'barren' black schists, or black shales of area F029 in general, with no tendency in these rations towards high values, in contrast to the typical sea-floor hydrothermal Cu+Zn±Pb (e.g. Goodfellow et al. 1999) or sediment-hosted Cu±Zn±Pb±Co±Ni deposits (e.g. Jowett et al. 1986, Cailteaux et al. 2005 and cited references).

Other chemical indicators of hydrothermal metal contribution, such as significant positive Eu anomalies in chondrite and shale-normalised REE patterns (e.g. Douville et al. 1999, Bodeï et al. 2008), are also lacking in the Talvivaara ore (Kontinen, unpublished data).

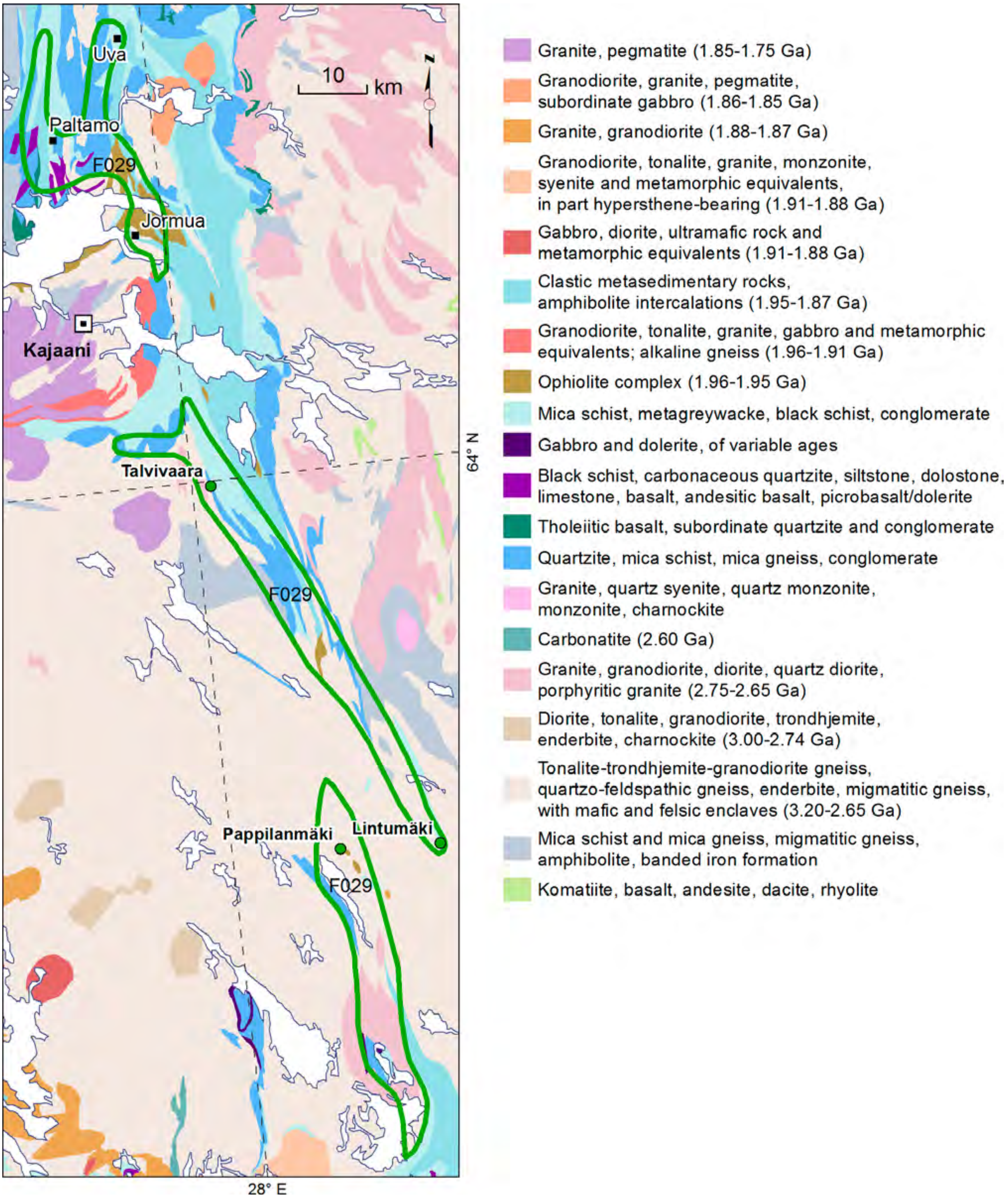


Figure 58. Geology of the Talvivaara metallogenic area (F029), and the base metal occurrences with a resource estimate in the area. Geology is from the GTK digital bedrock database.

When combined, the above features point to synsedimentary metal enrichment, most likely by the very same mechanisms that produced the metal enrichment in the associated 'barren' graphitic metasedimentary units, but under a water column that for one reason or another was apparently temporally and distinctly enriched in Ni, Co, Cu and Zn. The elevated Mn and Fe provide support for effective cycling of Mn and Fe hydroxides-oxihydroxides over basinal redoxclines also probably contributing to the high base metal levels. High Fe±Mn and S, as at Talvivaara, probably require (far-field as no near-field are present) hydrothermal sources of Fe, Mn and S. On the other hand, the uniformly high Ni/Cu (1.9 ± 0.6) and Ni/Zn (0.5 ± 0.1) ratios (based on data in Heino 1986) provide evidence for the origin of the base metals in a well-mixed and very large, probably oceanic seawater-type reservoir (presently Ni/Cu = 2.5 and Ni/Zn = 0.7; Li 2000). Although a synsedimentary origin, probably as inferred above, seems the most likely genetic scenario, large-scale diagenetic-early metamorphic enrichment in the base metals cannot yet be excluded as an alternative, although less likely model.

Talvivaara-type deposits have often been genetically and stratigraphically correlated with the ultramafic-associated Outokumpu-type Co-Cu-Zn-Ag±Au semimassive-massive sulphide deposits (e.g. Mäkelä 1981, Loukola-Ruskeeniemi 1999). However, several observations counter such a relationship. For example, the lead isotope composition of whole rocks and galena from Talvivaara and Outokumpu are highly different, suggesting different metal sources (Peltonen et al. 2008). Moreover, the maturity and sources of the contained epiclastic materials seem quite different; the Talvivaara formation comprises highly weathered quartz-rich materials from Archaean and/or recycled Archaean sources, whereas Outokumpu greywackes and interbedded black shales seem to derive from a predominantly Proterozoic (1.98–1.92 Ga) source (Kontinen et al. 2006, Lahtinen et al. 2009).

The giant **Talvivaara** deposit is located in the central part of area F029 (Figs. 58 and 59). The deposit has an exposed strike length of about 12 km. It comprises one or two originally <50 m thick layers of strongly metal-enriched, massive to laminated, graphite- and sulphide-rich muds intercalated with layers centimetres to metres thick of thinly bedded to laminar pyritic muds and carbonate rocks that are now metamorphosed and recrystallised to coarse-grained carbonate-diopside-tremolite calc-silicate rocks (Ervamaa & Heino 1980, Loukola-Ruskeeniemi & Heino 1996). Upright compressional folding and related reverse faulting in a late stage of the tectonic deformation significantly contributed to the volumes of minable ores by tectonically thickening and piling up the mineralised rock (Figs. 59 and 60). The present sulphide mineral assemblage of the ore is pyrrhotite-pyrite-sphalerite-chalcopyrite-pentlandite±alabandite. Nickel, which holds 80 % of the total metal value of the deposit, is located in pyrrhotite (21 %) and its pentlandite exsolutions (71 %) (Riekkola-Vanhanen 2010). Although only a negligible host to Ni, (metamorphic) pyrite contains the main part of the total Co in the deposit.

Based on drill core observations, at its footwall contacts the Talvivaara formation abruptly grades with the appearance of quartz wacke interbeds into a unit of quartz wackes originally at least hundreds of metres thick with subordinate interlayers of graphitic-sulphidic phyllite, metacarbonate rocks and mass-low conglomerate. The hanging-wall contact of the ore involves a rapid shift to black shale-intercalated, graphite-rich feldspathic wackes (the Kuikkalampi formation), possibly representing a shift to the Upper Kaleva deposition. In its middle part, the Talvivaara deposit is overlain by a small klippe (Viteikko; Figs. 59 and 60) of the allochthonous Upper Kaleva turbidites with thin lenses of talc-carbonate altered ophiolithic mantle peridotites spread all along its basal contact.

Distinct features of the other Talvivaara-type occurrences include the metal-rich graphitic and sulphidic schists in the Jormua region lying almost directly on an Archaean gneissic basement, separated from the latter only by a thin (<100 m) layer of conglomerate and quartz wacke (Rastas 1969, Ervamaa 1974). In the Paltamo region (Fig. 58), the mineralised sediments occur intercalated with mass-waste psephite layers rich in dolomite and mafic volcanic rock boulders from the immediately underlying uppermost Jatulian strata (Heino 1982, Kärki 1988). In the Uva region, quartz wacke-intercalated metal-rich black shales are immediately above wackes and muds with thin layers of chert-banded silicate-magnetite iron formation (Kontinen 1986a, 1986b). In the Rautavaara region, at **Pappilanmäki**, mineralised black metasedimentary rocks sit on mylonitised basement gneisses and alternate with layers of chert-banded silicate iron formation that are centimetres to metres in thickness (Sipilä 1984, Lauri Pekkarinen, pers. comm. 2010).

The currently mined giant Talvivaara deposit (Fig. 61) in the central part of area F029 is presently the only economically exploitable Talvivaara-type deposit. However, many of the

Ni-Cu-Co-Zn occurrences detected in area F029 have a potential for at least a few tens of millions of tonnes of Talvivaara-grade ore (Heino 1982, Sipilä 1984, Vanne 1984, Äikäs 1996). At present, only three of these occurrences have been studied to the extent that there is a publicised resource estimate for them (Table F028).

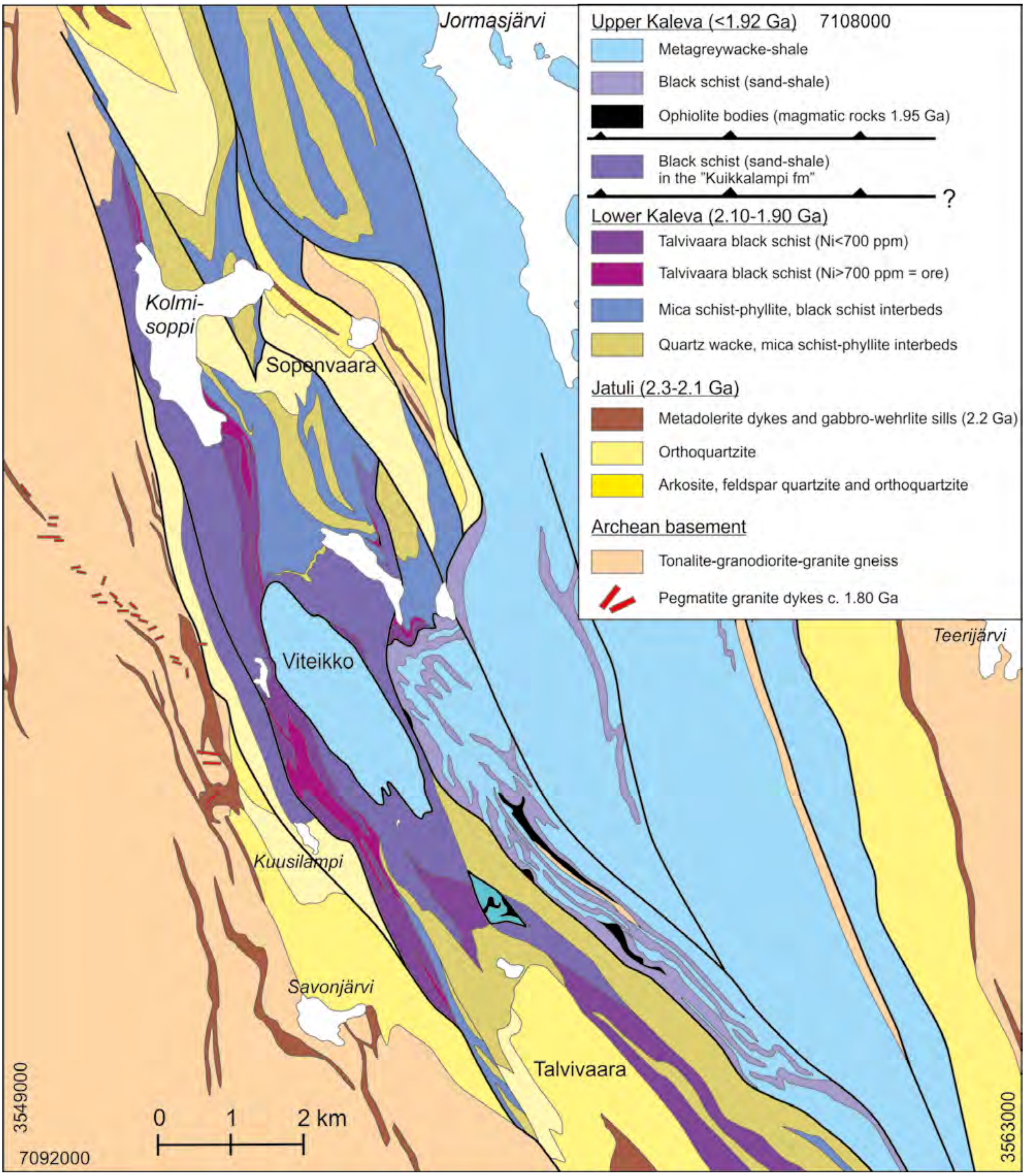


Figure 59. Surface geology at the Talvivaara deposit (defined by Ni >700 ppm) and its surroundings. Mapping and interpretation by Asko Kontinen, GTK. North up, grid: Finnish national YKJ.

Table 28. Metallic mineral deposits with a resource estimate in the Talvivaara Ni area (F029). All deposits are hosted by graphitic metaturbidites.

Occurrence	Tonnage (Mt)	Mined	Ag g/t	Co %	Cu %	Ni %	Mn %	Zn %	Reference[1,2]
Lintumäki	4				0.09	0.18		0.4	Geol. Surv. Finland Ore Deposit Database
Pappilanmäki (R1)	34.26			0.01	0.10	0.19		0.39	Western Areas (2011)
Talvivaara	1577	2007–	2	0.02	0.13	0.22	0.3	0.49	Talvivaara Mining Company (2010)

1 References in addition to Kontinen et al. (2006) and Peltonen et al. (2008).
2 Data on Ag and Mn concentrations at Talvivaara from Heino (1986)

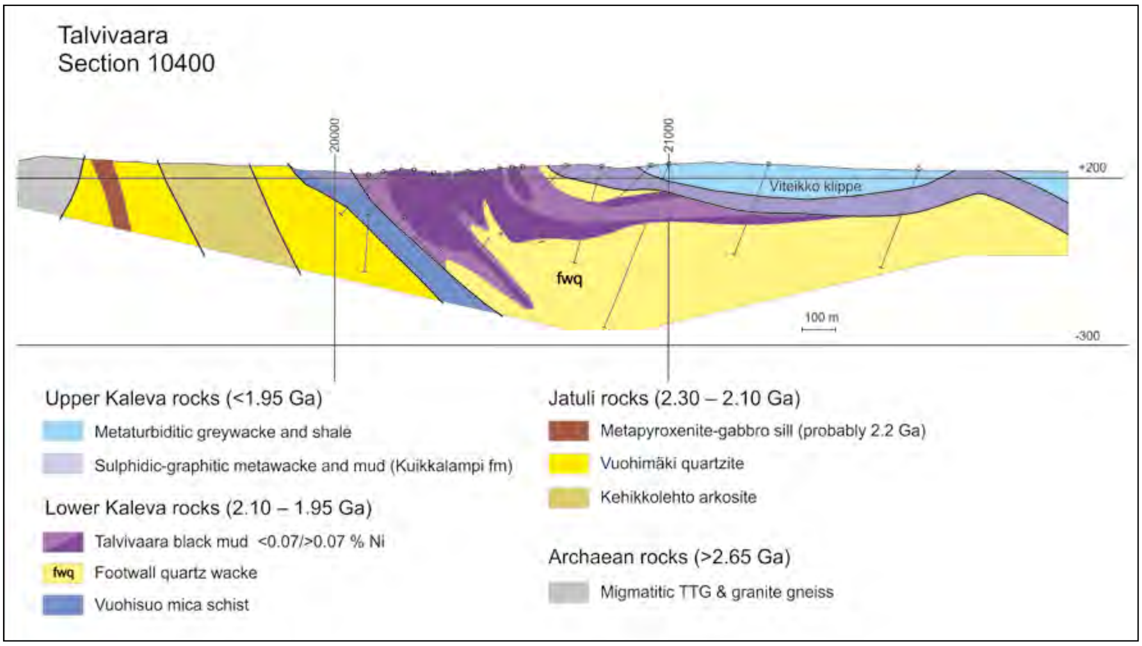


Figure 60. Section across the Talvivaara deposit at the Kuusilampi ore body. Mapping and interpretation by Asko Kontinen, GTK. View to the NNW.

Figure 61. Talvivaara mine site in 2010; view to the SE. The extent of the excavated area is 0.7 x 2.5 km. Photo courtesy Talvivaara Mining Co.

F030 HUHUS Fe

Peter Sorjonen-Ward (GTK)

The Huhus Fe area (F030) comprises the central and western parts of the Ilomantsi greenstone belt (Fig. 42). The Ilomantsi greenstone belt is dominated by felsic to intermediate epi- and volcaniclastic rocks with associated felsic to intermediate volcanic and subvolcanic units, and intercalations of tholeiitic and komatiitic volcanic rocks, and banded iron formation (BIF) (Sorjonen-Ward 1993, Sorjonen-Ward & Luukkonen 2005). The generally distinct geophysical signatures of the latter rock types indicate that they are widely distributed, and facilitate lithostratigraphic interpretation in poorly exposed terrain (Fig. 62). The supracrustal rocks appear to have been deposited and erupted over a relatively brief period around 2.76−2.75 Ga, and were intruded by granitoids with ages from 2746 to 2725 Ma (Sorjonen-Ward & Luukkonen 2005). The greenstones were metamorphosed and deformed during ca. 2.72–2.65 Ga, that is, during the global Neoarchaean orogenic event. Peak-metamorphic conditions within area F030 are predominantly at amphibolite facies, with characteristic mineral assemblages in BIFs including garnet and grünerite or ferroactinolite. The region experienced a greenschist facies metamorphic overprint during the Palaeoproterozoic Svecofennian orogeny, with dynamic recrystallisation of mineral fabrics, but only minor tectonic reworking. However, structurally focussed retrograde fluid-rock interaction has in many places modified the magnetic signature of the Archaean rocks (Sorjonen-Ward 1993).

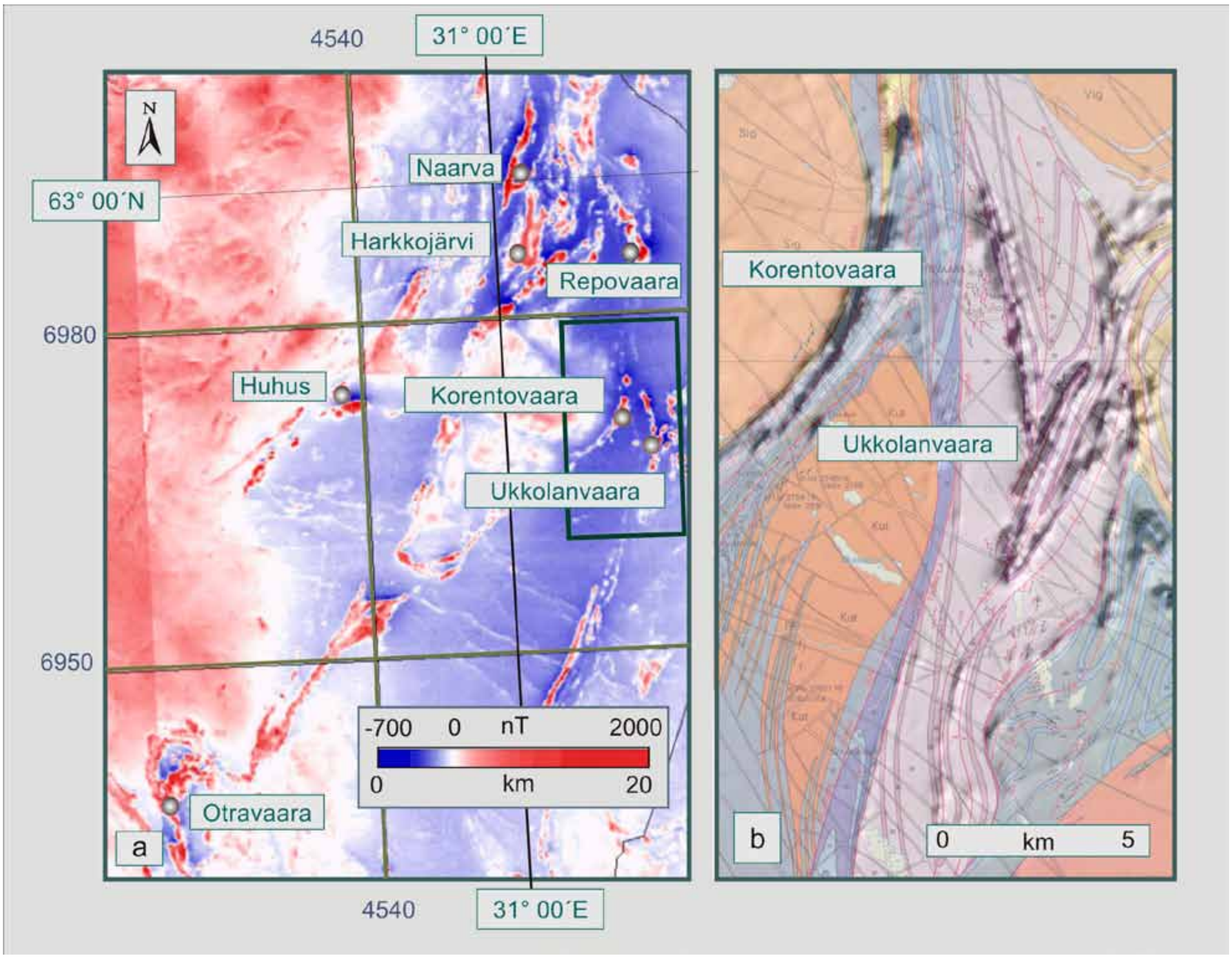


Figure 62. (a) Total magnetic intensity image of the area F030 and surroundings (red shades indicating anomaly maxima), including the Ilomantsi greenstone belt, indicating a correlation between anomalies and stratigraphically confined BIF occurrences (grey dots; Table 29). The grid corresponds to the Finnish national KKJ grid. (b) Southern part of the Hattu schist belt, showing magnetic anomalies due to the Korentovaara and Ukkolanvaara BIFs, intercalated within the turbiditic sediments of the Korvilansuo (blue hues) and Ukkolanvaara (purple hues) Formations, respectively. Orange hues indicate granitoids. Aeromagnetic maps based on GTK survey data.

The BIFs of the Ilomantsi greenstone belt were the subject of reconnaissance resource assessment by Rautaruukki Oy in the 1970s to 1980s (Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983). The BIFs typically comprise alternating units of magnetite-, sulphide- and silicate-dominated BIF associated with diverse rock types, including mica schists of epi- to volcaniclastic origin, and felsic and mafic volcanic rocks (Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983, Laajoki 1985). Many of the smaller Fe occurrences are stratigraphically associated with felsic and mafic volcanic horizons that show evidence of exhalative or subseafloor hydrothermal alteration; these may show lateral, along-strike variations in intensity, ranging from garnet-epidote-grünerite-arsenopyrite assemblages to weakly altered sediments containing actinolite and disseminated sulphide (Sorjonen-Ward 1993). Lehto and Niiniskorpi (1977) also discriminated between grünerite-dominated oxide facies, containing abundant garnet and Fe-hornblende, and Fe-hornblende-dominated assemblages, with biotite and chlorite, occurring more typically in metagraywackes. In these two facies, much of the iron is bound in sulphides or silicates rather than in more readily exploitable oxides. However, both of these facies types appear to be transitional to more classical BIF in which silica-rich layers alternate with magnetite-rich bands (Fig. 63).

Chemical analyses and mineralogical documentation are available for numerous Fe occurrences in area F030, and many have also been been delineated with ground geophysical surveys. However, only a few occurrences have been drilled, with mineral resource estimates being, at least in part, based on the dimensions and magnitude of geophysical anomalies (Table 29).

Within the Hattu schist belt, which forms the eastern branch of the Ilomantsi greenstone belt (Fig. 62), the stratigraphic context of iron formations is better constrained than in the Huhus area itself (Sorjonen-Ward 1993). There appears to be a distinct BIF unit at the transition from an upwards-fining coarse clastic sequence containing polymictic conglomerates of felsic provenance (Tiittalanvaara Formation) and the mafic and ultramafic eruptive units of the overlying Pampalo Formation. This iron formation unit is also present in the hanging wall of the Pampalo Au deposit (Sorjonen-Ward 1993), where local sulphidation has occurred in association with synorogenic hydrothermal alteration. Niiniskorpi (1975) and Lehto and Niiniskorpi (1977) defined the BIFs in this area as the **Repovaara** occurrence, for which a resource estimate of 2.2 Mt has been quoted (Hugg & Heiskanen 1983). In the southern part of the Hattu schist belt, the **Korentovaara** and **Ukkolanvaara** occurrences (Table 29) are intercalated within turbiditic metagraywackes, with lesser amounts of mafic material (Laajoki & Lavikainen 1977), which were interpreted by Sorjonen-Ward (1993) as more distal with respect to principal volcanic centres.

The **Huhus** deposits, from which area F030 takes its name, are blanketed by extensive glaciofluvial deposits, so that their extent and character has only been delineated by geophysical surveys, with limited till geochemistry and bedrock drilling (Kurki 1980). The BIFs are within a poorly understood sequence that includes mafic amphibolites, banded metasediments and felsic units that are most likely of volcanic or subvolcanic intrusive origin: the latter rocks are associated with Zn-Pb mineralisation that has been drilled in several places (Kurki 1980). A preliminary resource estimate, to depths of 100 m and 500 m (Table 29), has been provided for two separate ore lenses (Sipilä 1964, Hugg & Heiskanen 1983).

Magnetic anomalies associated with BIFs have also been mapped elsewhere in the western part of area F030, but their stratigraphic context and extent is not well-constrained. The **Naarva** BIF occurrences have been mapped along the eastern and western margin of the Naarva Granodiorite, over a total distance of 2.8–3.0 km, with a thickness of up to 200 m. Ore grade intersections in two narrow lenses form the basis for a resource estimate of 0.6 Mt. At **Harkkojärvi**, drilling has indicated the presence of BIF units overlying a metasedimentary sequence that also includes felsic porphyries.

In the southwestern part of area F030, a few small deposits of pyritic ore have been discovered, which were exploited for sulphur (total production 0.022 Mt with maximum concentrations of 47.8 % Fe and 36.6 % S) at the beginning of the 20th century (e.g., Saksela 1951, Männikkö et al. 1987). These occurrences are hosted by felsic volcanic rocks within the Otravaara Formation and are likely to record subseafloor volcanic-related hydrothermal processes, although remobilisation during subsequent deformation is also likely. The paucity of metals other than Fe, apart from local Zn anomalies, nevertheless led Männikkö et al. (1987) to interpret the deposits as chemogenic sulphide-facies iron formations. However, the sporadic presence of other ore minerals, including pyrrhotite, marcasite, pentlandite and chalcopyrite at both Otravaara and Harkkojärvi, suggests a possible affinity between the two, and is consistent with hydrothermal alteration processes.

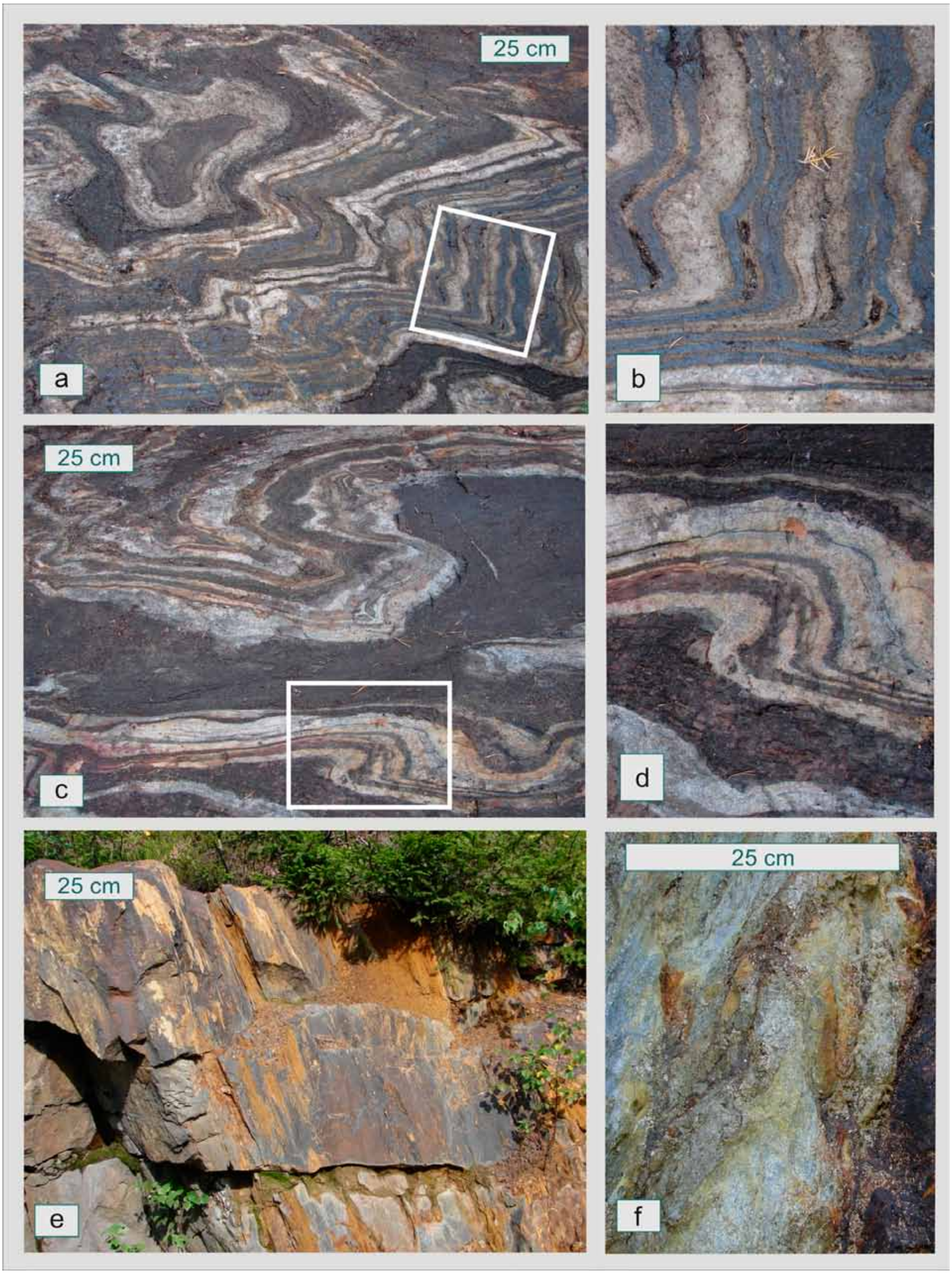


Figure 63. Examples of BIFs from the Ukkolanvaara occurrence (which is better exposed than other locations); (a) rhythmic alternation of silica-rich and magnetite bands, intercalated with more pelitic fine-grained layers, defining a spectacular refold interference pattern; (b) detail of silica-rich and magnetite bands; refolded fold illustrating distinct alternation between rhythmic BIF couplets and intercalated fine-grained pelitic and mafic sediments; (d) detail from (c) showing silicic and magnetite bands alternating with a mafic layer containing coarse porphyroblastic garnet (location at 62º49.905'N, 31º16.898'E). Figures (e) and (f) from the Otravaara sulphide-facies iron formation, showing hydrothermally altered felsic volcanic rocks and a detailed view with disseminated pyrite in strongly foliated sericitic schists (location at 62º34.6464'N, 30º23.0173'E). Photos: Peter Sorjonen-Ward, GTK.

Table 29. Iron occurrences with a reported resource within the Huhus area (F030).

Occurrence	**Tonnage (Mt)**	**Fe %**	**Main ore minerals**	**References**
Huhus (100 m)[1]	7.2	25.9	Magnetite	Sipilä (1964), Hugg & Heiskanen (1983)
Huhus (500 m)[1]	36.4	25.9	Magnetite	Sipilä (1964), Hugg & Heiskanen (1983)
Harkkojärvi	1.3	n.a.	Magnetite	Hugg & Heiskanen (1983)
Naarva	0.6	22.5	Magnetite	Hugg & Heiskanen (1983)
Repovaara	2.2	22.5	Magnetite	Hugg & Heiskanen (1983)
Korentovaara	1.1	<23	Magnetite	Hugg & Heiskanen (1983)
Ukkolanvaara	1.1	n.a.	Magnetite	Hugg & Heiskanen (1983)
Otravaara	0.022	<47	Pyrite	Saksela (1951), Männikkö et al. (1987)

1 Resource estimated to the depths of 100 m and 500 m below surface.

F031 OTANMÄKI V-Ti-Fe

Tapio Kuivasaari, Akseli Torppa, Olli Äikäs, Pasi Eilu (GTK)

The Otanmäki V-Ti-Fe area (F031) is defined by several vanadium-rich magnetite-ilmenite deposits in a Palaeoproterozoic belt of orthoamphibolite-gabbro-anorthosite intrusives and alkaline granitoids along the boundary between the Archaean Pudasjärvi and Iisalmi blocks, immediately to the west of the Palaeoproterozoic Kainuu schist belt (Figs. 1 and 64). In addition to ferrous metals, area F031 is a potential source for REE, Zr and Nb in gneissic alkaline granitoids. The belt of intrusive alkaline granitoids extends a few tens of kilometres to the east of area F031. Hence, there remains a possibility that the metallogenic area is also significantly larger, extending to the east of what is now drawn on the Fennoscandian metallogenic map.

The ferrous-metal deposits in the Otanmäki area are magmatic magnetite-ilmenite ores in deformed and metamorphosed gabbros of ca. 2060 Ma in age (Talvitie & Paarma 1980). Due to recrystallisation, ilmenite and magnetite occur as discrete, separate grains (Pääkkönen 1956), which was a significant advantage in processing the ore when the Otanmäki and Vuorokas deposits were mined. In total, about 31 Mt of ore was mined from these two deposits (Puustinen 2003). This means that there still remains at least 16 Mt of reserves and an additional 3 Mt of resources at Otanmäki and Vuorokas (Illi et al. 1985) for future exploitation (Table 30).

Both Otanmäki and Vuorokas are composed of a number of ore lenses in a domain about 2 km long (Fig. 65). The lenses are subvertical, 2–200 m long and 3–50 m thick. The main minerals are magnetite and ilmenite, in a ratio of about 2:1. The V content in magnetite is 0.62 %. Pyrite comprises 1–2 % of the ore (Pääkkönen 1956, Illi et al. 1985). The gangue minerals are chlorite, hornblende and plagioclase. The processing plant at Otanmäki produced magnetite, ilmenite and pyrite concentrates and vanadium pentoxide (from the vanadium plant). For the economy of the mine, V_2O_5 was the main product for most of the mine life (Stigzelius et al. 1970, Illi et al. 1985). During the lifespan of the mine and the plant, a total of 7.6 Mt iron concentrate, 3.8 Mt ilmenite concentrate, 0.2 Mt pyrite concentrate and 55 545 tons of V_2O_5 were produced (Illi et al. 1985).

Another style of metallic mineralisation within area F031 is defined by rare metal and REE occurrences mainly associated with alkaline gneisses. In Table 30, this style of mineralisation is represented by the Katajakangas deposit, hosted by alkali-metasomatised gneisses in Archaean granitic protoliths (Hugg 1985, Puumalainen 1986). Other rare metal-REE occurrences have also been detected in area F031, but a resource estimate has only been reported for Katajakangas. The known occurrences are elongated bodies characterised by sericitic alteration, a spatial relationship with pegmatites, and an ore mineral assemblage including fergusonite (Nb, Y, HREE), allanite (LREE), columbite-tantalite (Nb), magnetite, zircon and traces of sulphides (Hugg 1985, Äikäs 1990).

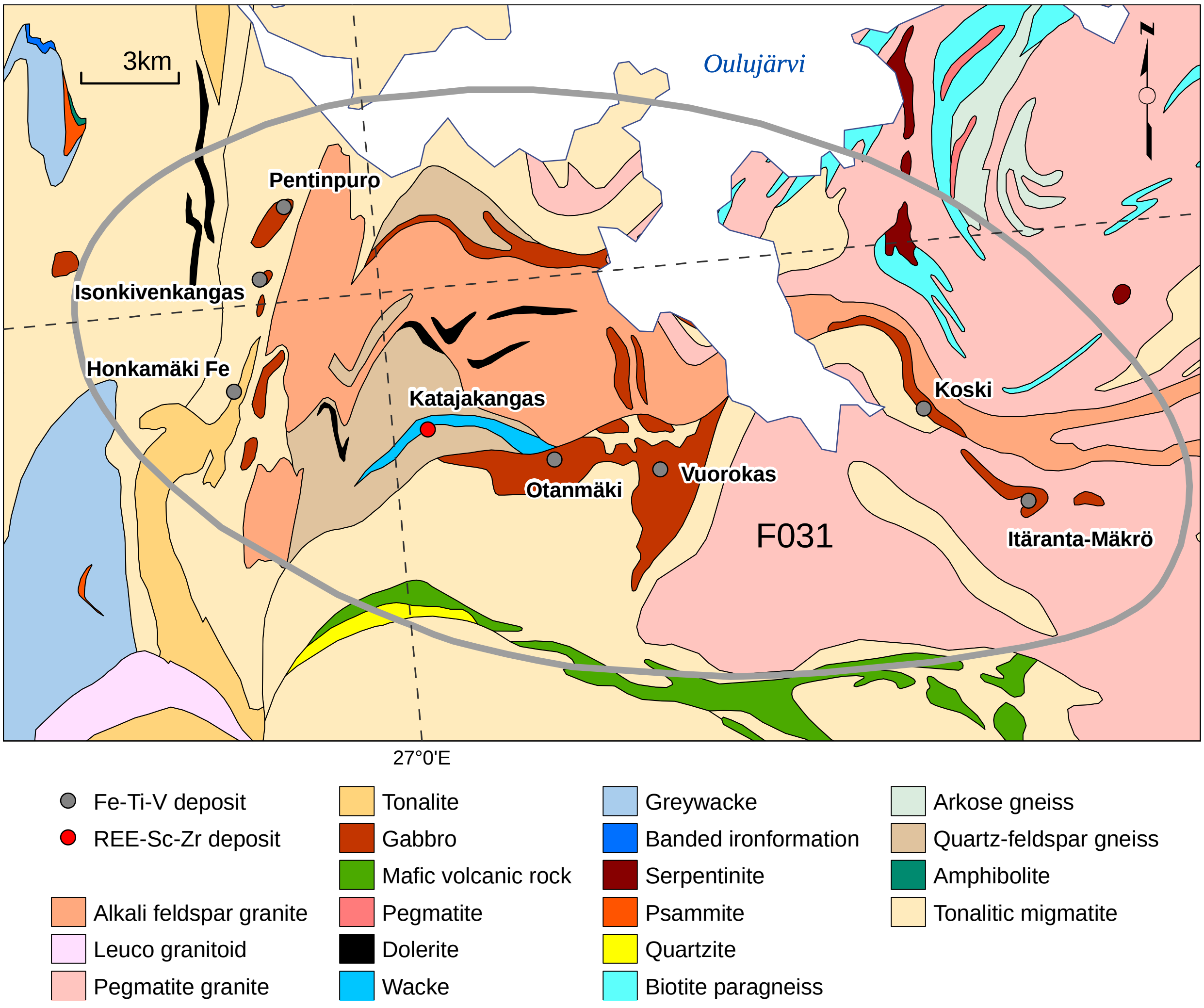


Figure 64. Otanmäki metallogenic area (F031) and its most significant metal deposits. Geology based on the GTK digital bedrock database.

Table 30. Metallic mineral deposits with a resource estimate in the Otanmäki V-Ti-Fe area (F031). Tonnage gives the total size, mined and all remaining resources and reserves.

Occurrence	**Tonnage (Mt)**	**Mined**	**Fe %**	**Ti %**	**V %**	**Nb %**	**REE %**	**Zr %**	**Reference**
Honkamäki Fe	17		30						Hugg & Heiskanen (1983)
Isonkiven-kangas	0.1		19.68		0.17				Hugg & Heiskanen (1983)
Itäranta-Mäkrö	0.15		30.29	6.78	0.25				Kinnunen (1979a)
Katajakangas	0.46					0.53	2.4	0.84	Hugg (1985)
Koski	1.09		29	7.02	0.24				Kinnunen (1979b)
Otanmäki	42	1949–1985	33.92	7.57	0.26				Pääkkönen (1956), Illi et al. (1985)
Pentinpuro	3		34.8	7	0.22				Hugg & Heiskanen (1983)
Vuorokas	8	1965–1985	32.5	5.5	0.26				Hugg & Heiskanen (1983)

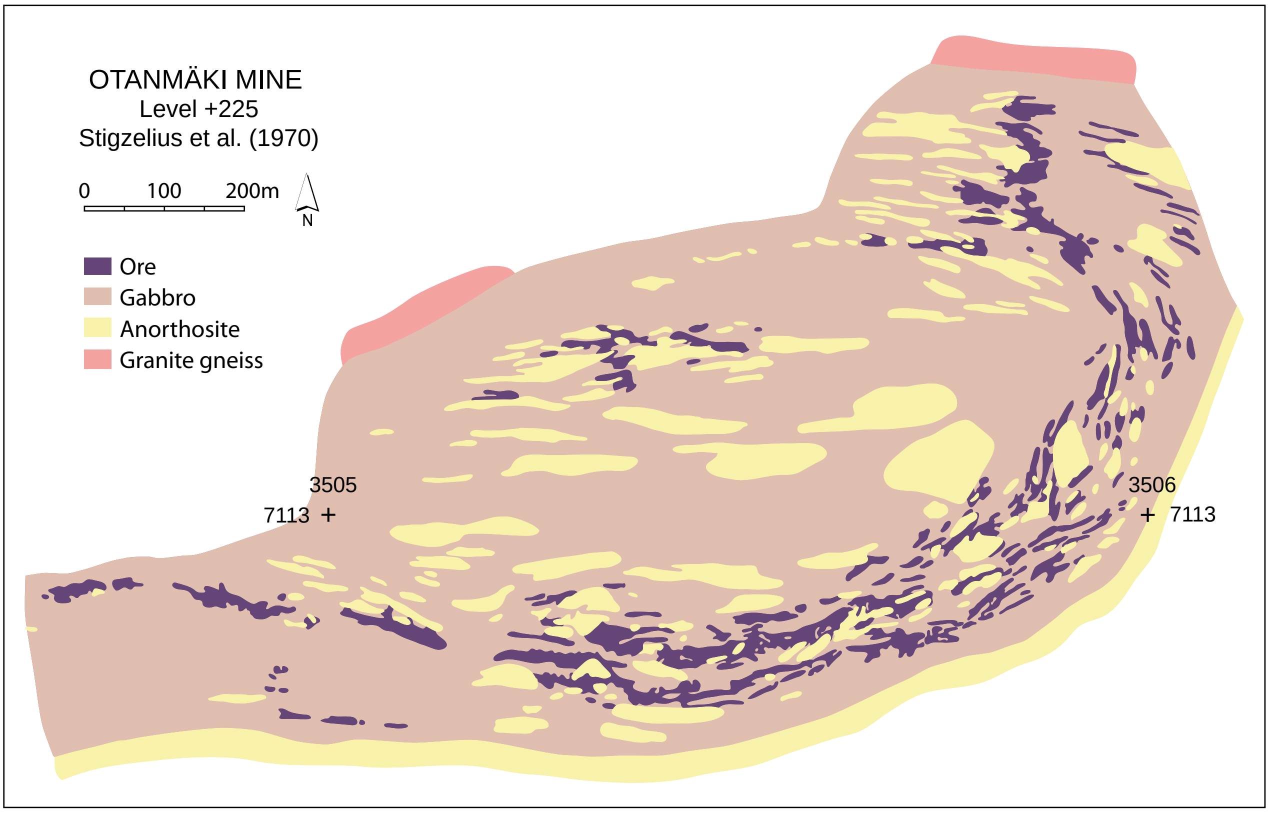


Figure 65. Geology at the Otanmäki Fe-Ti-V deposit and its immediate surroundings at the 255 m level of the mine (original by Ole Lindholm in 1965, in Lindholm & Anttonen 1980). National YKJ coordinates shown on the map. The deposit is at 64.117°N, 27.100°E.

F032 KUHMO Ni, Ag, Au

Tapio Halkoaho & Pasi Eilu (GTK)

The Kuhmo metallogenic area (F032) comprises, from south to north, the Archaean Tipasjärvi, Kuhmo and Suomussalmi greenstone belts and the immediate country rocks of these belts (Fig. 66).

The greenstone belts of the Kuhmo area are similar to Neoarchaean greenstone belts in Canada, Australia, Brazil, India and southern Africa, which are known for their numerous and large gold and komatiite-related nickel deposits (e.g. Eckstrand et al. 1996, Goldfarb et al. 2001). The greenstone belt array defining area F032 is north-trending, typically less than 10 km wide, and characterised by tholeiitic and komatiitic volcanic rocks, together with related intrusive and subvolcanic cumulates, and minor felsic volcanic and volcaniclastic units possibly formed in a rift setting (Luukkonen 1992). The margins of the greenstone belts comprise 3000–2800 Ma metavolcanic rocks, and the central parts are chiefly formed by 2800–2750 Ma tholeiitic and komatiitic metavolcanic rocks. Metasedimentary rocks only dominate in the south. The latter are chiefly greywacke-like, volcanogenic, and possibly 2740–2700 Ma in age (Luukkonen 1992, Sorjonen-Ward & Luukkonen 2005). The country rocks of the greenstones are Neoarchaean granitoids that are mostly 2760–2690 Ma in age.

The three main styles of metallic mineralisation in the Kuhmo area are 1) komatiite-related Ni(-Cu-PGE), 2) orogenic gold and 3) VMS or epithermal Ag-Zn-Pb (Papunen et al. 1989, Pietikäinen et al. 2000, Halkoaho et al. 2000, Luukkonen et al. 2002). The domains potential for these deposit types largely overlap; they only locally deviate at scales of up to a few kilometres. Hence, only subareas for the highest potential for these deposit types have been drawn (Eilu et al. 2009). Magnetite-quartz and sulphide-quartz banded iron formation also are present within the

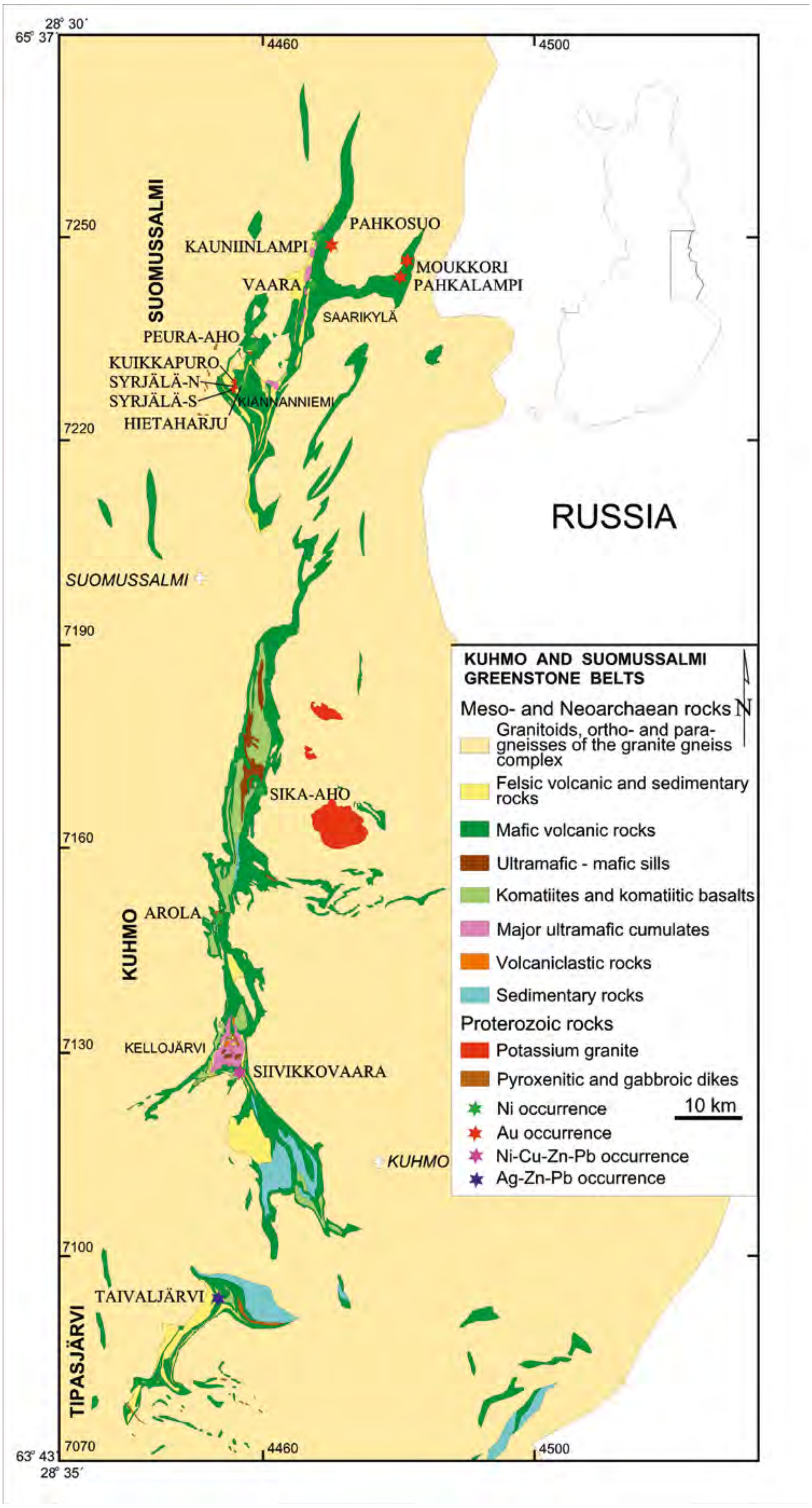


Figure 66. Geology of the Tipasjärvi, Kuhmo and Suomussalmi greenstone belts and metallic deposits with a resource estimate. The metallogenic area F032 essentially covers the area of these three greenstone belts. Geology is based on Korsman et al. (1997). North up.

Table 31. Nickel deposits with a resource estimate in the Kuhmo metallogenic area (F032).

Subarea, Occurrence	Tonnage (Mt)	Ni %	Cu %	Co %	Pd g/t	Pt g/t	Main host rock	Reference
Kuhmo F032.3								
Arola	1.5	0.46	0.01				Altered mafic lava*	Vulcan Resources (2007)
Sika-aho	0.175	0.66					Chlorite-quartz-sericite-carbonate schist	Heino (1998)
Siivikkovaara	0.1	0.3	0.33	0.015			Plagioclase-bearing amphibole rock	Makkonen & Halkoaho (2007)
Suomussalmi F032.5								
Hietaharju	1.083	0.8	0.4	0.05	1.17	0.49	Basaltic komatiite	Vulcan Resources (2009)
Peura-aho	0.495	0.6	0.27	0.04	0.58	0.27	Basaltic komatiite	Vulcan Resources (2009)
Vaara	8.241	0.32	0.02	0.01	0.14	0.07	Komatiite	Vulcan Resources (2009)
Kauniinlampi	0.5	0.45					Komatiite	Halkoaho et al. (2000)

* Quartz-carbonate-chlorite schist

greenstone belts, but these deposits are so small (1–20 m wide) that no resource estimate is available for them (Hugg & Heiskanen 1983).

Nickel deposits of area F032 can be divided into three genetic groups (Makkonen & Halkoaho 2007): 1) 'normal' magmatic komatiite-komatiitic basalt nickel deposits (Vaara, Peura-aho and Hietaharju), 2) nickel deposits that have been created by secondary, younger tectonometamorphic processes and where nickel is not in its primary magmatic position (Kauniinlampi, Sika-aho and Arola) and 3) polymetallic hydrothermal-like deposits, similar to those presently forming in black smoker environments on the sea floor (Siivikkovaara, Table 31).

The disseminated type of nickel mineralisation in the **Vaara** komatiite cumulate lens (Figs. 66 and 67) is hosted by olivine ortho- to mesocumulate in the Suomussalmi belt. In this occurrence, all chalcophile elements follow each other, unlike in the mobilised type. The sulphide dissemination of Vaara has a very high Ni/S ratio. The sulphides are considered to have formed as the result of crustal sulphide contamination of komatiitic magma. Major ore minerals include millerite, pyrite, violarite, Ni-rich pentlandite and chalcopyrite, whereas minor ore minerals include magnetite, chromite, galena, sperrylite, merenskyite and hollingworthite. Serpentinisation and host rock alteration has upgraded the quality of disseminated sulphides through the oxidation of iron of primary sulphides. Compared to the Australian komatiitic nickel deposits, the PGE tenors are abnormally high (Halkoaho et al. 2000; Table 31).

The **Sika-aho** disseminated nickel deposit is located in the Kuhmo greenstone belt. Sika-aho is of the mobilised ore type, but its nickel source is probably komatiitic. Its host rock is intensely foliated and anomalously SiO_2-rich chlorite-quartz-sericite-carbonate schist, which is situated between altered komatiitic cumulates and chlorite schist, which are surrounded by a series of volcanosedimentary rocks (Heino 1998, Luukkonen et al. 1998 and 2002). Major ore minerals are pentlandite and pyrrhotite. Pentlandite occurs as individual grains, intergrown with pyrrhotite, and inclusions and exsolutions in pyrrhotite. Minor ore minerals are Ni-Fe arsenides (Heino 1998). The Sika-aho deposit is 80 m long, 1–9 m wide and at least 150 m deep (max. 200 m). The 0.175 Mt resource (Table 31) is based on a 0.35 % Ni cut-off and contains 2.42 % S (Heino 1998, Luukkonen et al. 1998 and 2002).

Gold mineralisation within F032 is of the orogenic type as defined by Groves (1993). Typical characteristics of the occurrences include the following: the structure is the single most important control for mineralisation, gold is the sole potential commodity, the metal association (elements most commonly enriched) is Au-As-Sb-Te-W, Au/Ag >1, quartz veining is abundant, sulphide contents are at 1–3 vol%, the dominant ore minerals are pyrrhotite, arsenopyrite and pyrite, gold occurs in the native form, and carbonatisation and potassic alteration (sericitisation and biotitisation) haloes surround mineralisation (Heino 2000, Pietikäinen et al. 2000, Parkkinen 2001). The occurrences are closely related to N-, NW- and NE-trending fault and shear zones, and are hosted by practically all supracrustal rock types detected in the greenstone belts: komatiitic to basaltic volcanic rocks, quartz-feldspar porphyries and intermediate volcaniclastic to clastic rocks (Eilu 2007). The timing of gold mineralisation in the area is suggested to be syn-D3 to D4 of the local deformation stages, that is, during 2.70–2.65 Ga (Luukkonen 2001, J. Ojala, pers. comm. 2002). The metallogenic subareas Kuhmo Au (F032.2) and Tormua Au (F032.4) include nearly all known gold occurrences in the Kuhmo area (Fig. 66). The subareas follow the N to NNW trends of the main shear zones of the Kuhmo and Suomussalmi greenstone belts.

In total, 22 gold occurrences with ore-grade material have so far been indicated by drilling in the Kuhmo area (Eilu 2007). Of these, there is a reported resource for only six cases. None of the deposits have been exploited. This partly reflects the small volume of exploration effort, but may also suggest that the occurrences are relatively small, although some do have high gold grades and could thus be suitable for small-scale mining (Table 32, Fig. 68).

A few Ag-Zn-Pb occurrences have been discovered in the Kuhmo area. Of these, there is a resource estimate only for the test-mined **Taivaljärvi** 4.617 Mt at 113 g/t Ag, 0.02 ppm Au, 0.36 % Pb, and 0.72 % Zn (Sotkamo Silver 2011). Taivaljärvi is hosted by felsic and intermediate volcanic rocks, associated with intense Na depletion and the formation of K mica, biotite, garnet, tremolite, cordierite and ankerite in various parts of the alteration halo. The mineralisation is clearly syngenetic, either of VMS or epithermal type (Papunen et al. 1989). Taivaljärvi and other indications of similar styles of mineralisation define the Taivaljärvi Ag-Zn metallogenic subarea (F032.1) in the southern part of the Kuhmo area (Fig. 66). A similar style of mineralisation has also been detected along the N-S strike of the Kuhmo area, within both the Kuhmo and Suomussalmi greenstone belts (Kopperoinen & Tuokko 1988). However, Taivaljärvi still is the only one shown to contain any significant ore tonnage.

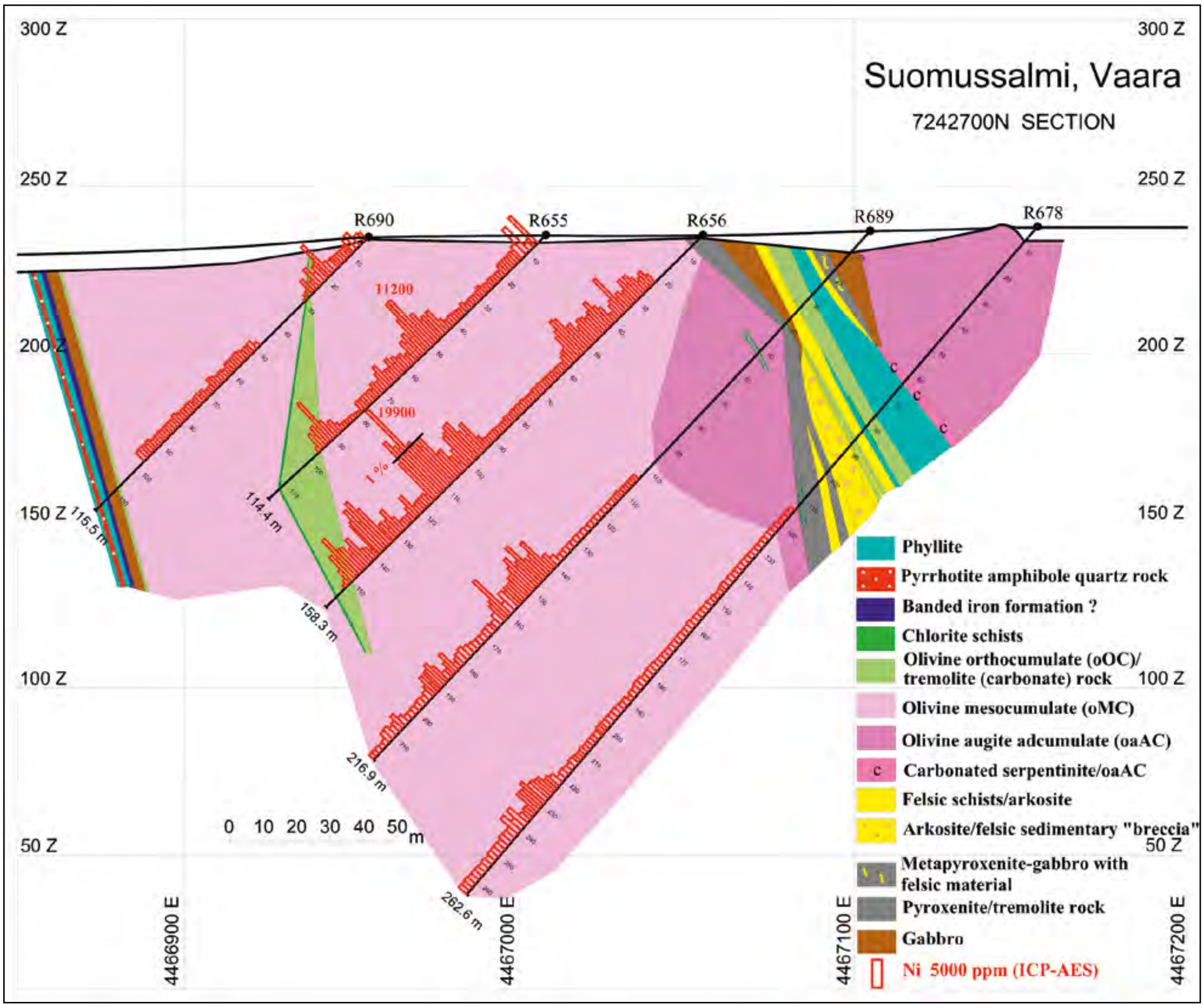


Figure 67. The southernmost drill-hole profile across the Vaara nickel occurrence with Ni content variation; view to the north (Halkoaho et al. 2000). The deposit is at 65.2794°, 29.2906°E.

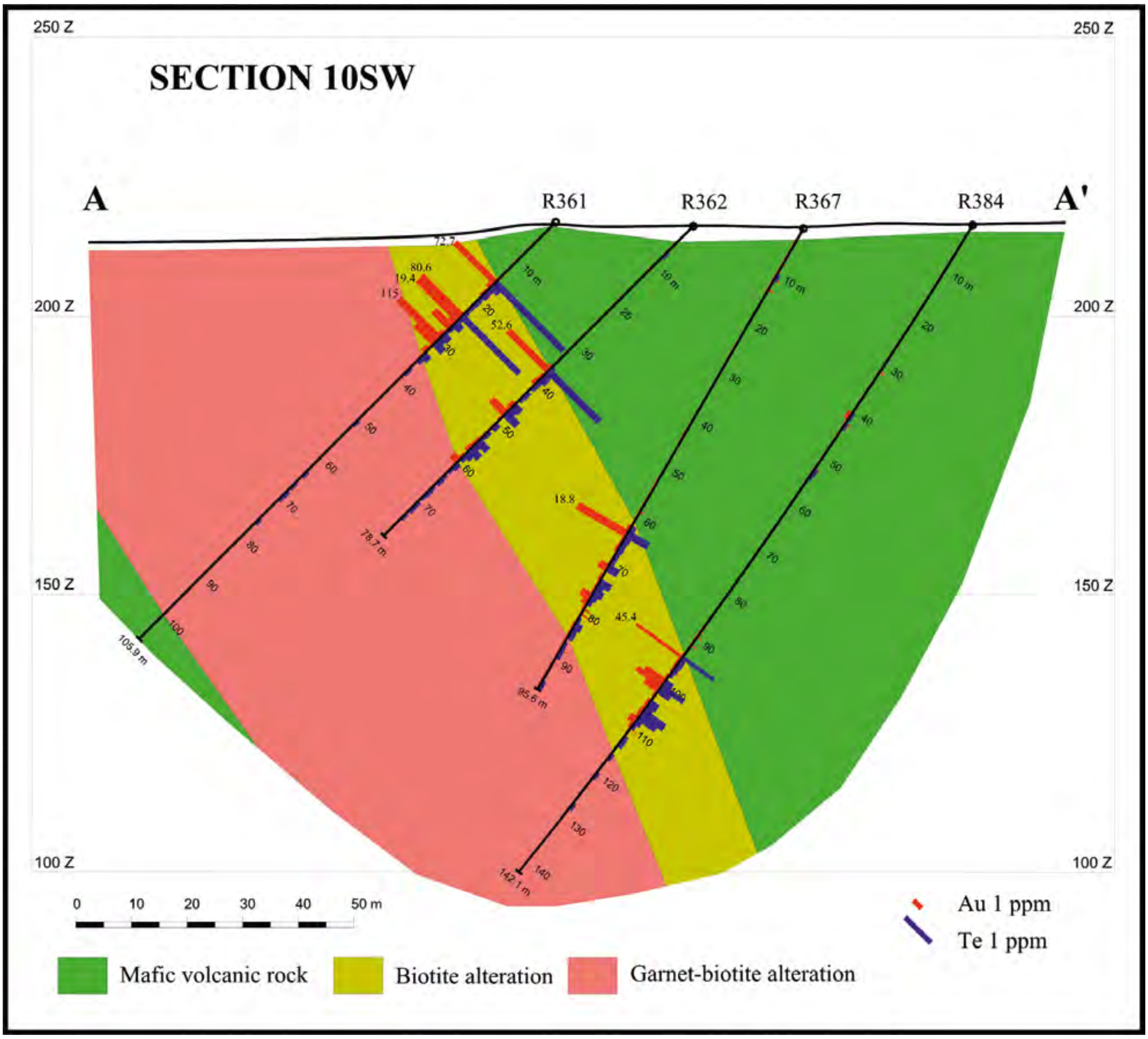


Figure 68. A drilled section across the Kuikkapuro gold occurrence, at 65.15171°N, 29.0553°E. View to NW. From Pietikäinen et al. (2000).

Table 32. Gold occurrences with a reported resource within the Kuhmo metallogenic area; all are within the Tormua subarea (F032.4).

Occurrence	Tonnage (Mt)	Au g/t	Main host rock	Reference
Kuikkapuro	0.054	14.6	Mafic volcanic rock	Heino (2000)
Moukkori	0.024	10.6	Mafic volcanic rock	Parkkinen (2001)
Pahkalampi	0.25	3.5	Mafic volcanic rock	Nordic Mines (2007)
Pahkosuo	0.098	1.55	Mafic volcanic rock	Heino (2001)
Syrjälä-N	0.057	1.55	Intermediate agglomerate	Pietikäinen et al. (2000)
Syrjälä-S	0.090	1.15	Intermediate agglomerate, quartz sericite rock	Pietikäinen et al. (2000)

F033 PÄÄKKÖ Fe

Mikko Tontti (GTK)

The Pääkkö Fe area (F033) is within the western part of the Kainuu schist belt (Fig. 69). The extent of N-trending metallogenic area F031 is defined by the presence of banded iron formation in the Central Puolanka Group of the N-trending Kainuu belt. The age of the Central Puolanka Group is uncertain: either the rocks are Neoarchaean or Palaeoproterozoic. The age of the Pääkkö Fe deposits is uncertain (Sakko & Laajoki 1975, Huhma et al. 2000).

The **Pääkkö** area includes several superior-type iron formations around Väyrylänkylä at Puolanka (Table 33), in the northern part of the Kainuu schist belt (Saltikoff et al. 2006). The deposits are within a roughly 10-km-long sedimentary sequence that consists of tuffites, dolomitic marbles, black shales, phyllites, metadiabases, quartzites and iron formations. In places, the rocks are so intensely weathered that kaolinite occurrences characterise the area (Laajoki 1975a, 1975b).

The dominant iron formation type is grunerite-rich quartz-magnetite(-hematite-goethite-) banded, representing a mix of oxide- and silicate-facies types. In addition, quartz-siderite-banded carbonate-facies type and iron-rich black schists and phyllites of the sulphide-facies category have been encountered in the region (Niiniskorpi 1975, Ervamaa & Laajoki 1977, Laajoki & Saikkonen 1977, Lehto & Niiniskorpi 1977, Gehör 1994a). The iron formations are relatively rich in REE and their REE distribution patterns show depletion of Ce. This is due to regularly occurring apatite, which is interpreted to be of marine origin (Laajoki 1975b). The **Tuomivaara** deposit, beyond any distinct metallogenic area, 50 km SSE along strike from Pääkkö, has very similar features to the Fe deposits of area F033 (Makkonen 1975, Gehör 1994b).

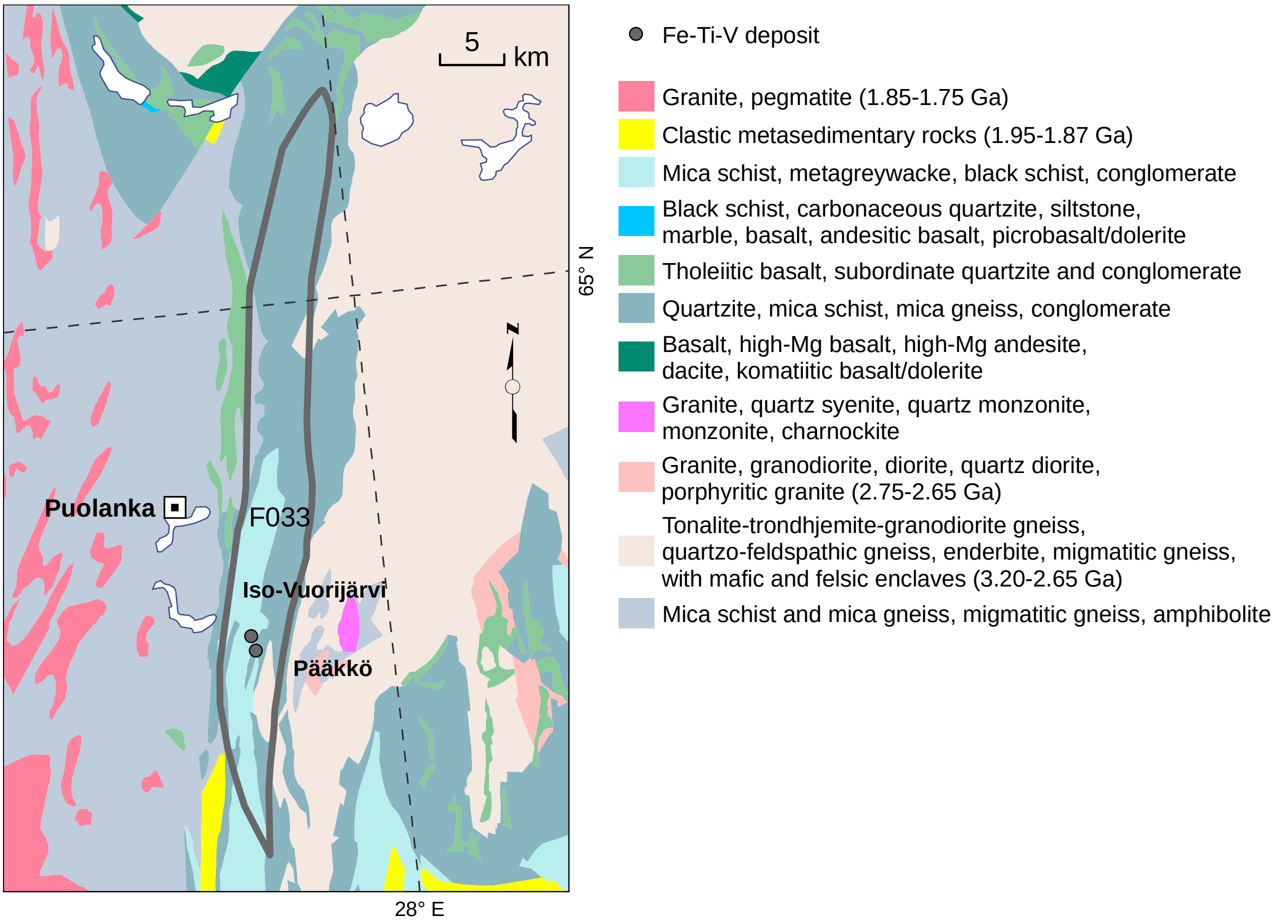


Figure 69. Geology of the Pääkkö Fe area (F033) and its immediate surroundings, with locations of the main iron occurrences. Geology based on the GTK digital bedrock database.

Table 33. Iron occurrences with a reported resource within the Pääkkö area (F033). For comparison, data on the Tuomivaara deposit are also included. All occurrences listed are of banded iron formation type.

Occurrence	Tonnage (Mt)[1]	Fe %	Mn %	P %	Ti %	V %	Main ore minerals	Reference
Iso-Vuorijärvi	5.9	26	0.05	1.04	0.04	0.02	Magnetite, siderite	Ervamaa (1977), Hugg & Heiskanen (1983)
Pääkkö	16.4	26	0.06	1.11	0.06	0.03	Magnetite, siderite	Ervamaa (1977), Hugg & Heiskanen (1983)
Tuomivaara	39	27		0.2–2.0			Magnetite, siderite	Makkonen (1975), Gehör & Havola (1988)

1) The resource is calculated only to the depth of 100 m below the surface.

F034 OIJÄRVI Au

Heikki Juopperi, Jukka Konnunaho & Pasi Eilu (GTK)

The Oijärvi area (F034) covers most of the Archaean, north-trending Oijärvi–Yli-Ii greenstone belt (Figs. 1 and 70). In geological maps, the Oijärvi and Yli-Ii greenstones appear as separate entities in the north and south, respectively, but recent aeromagnetic surveys by GTK suggest a continuum of greenstones between the two parts.

The greenstones of metallogenic area F034 are within the western part of the Meso- to Neoarchaean Pudasjärvi complex in western Finland (Sorjonen-Ward & Luukkonen 2005, Vaasjoki et al. 2005). Little is known about the geology of these poorly exposed regions: they appear as typical small Archaean greenstone sequence within an extensive TTG terrain, a setting that can be encountered in any craton. The belts are formed by komatiitic to tholeiitic volcanic rocks and fine-grained clastic sedimentary rocks (Tolppi 1999, Juopperi et al. 2001, Sorjonen-Ward & Luukkonen 2005, Rossi & Konnunaho 2006, Sarapää et al. 2008). Most of the greenstones are strongly altered and sheared. The sequences are intruded by small synorogenic granitoids and felsic porphyry dykes, and cross cut by Palaeoproterozoic dolerites. The regional metamorphic grade in the Oijärvi belt is mid- to upper-greenschist facies, whereas amphibolite-facies conditions seem to prevail in the southern extension of area F034 (Tolppi 1999, Juopperi et al. 2001).

Two styles of metallic mineralisation have been detected in the Oijärvi Au area: 1) orogenic gold, and 2) possibly epithermal Au-Ag-Zn-Pb (Juopperi & Karvinen 1999, Tolppi 1999, Rossi 2000, Juopperi et al. 2001, Rossi & Konnunaho 2006, Sarapää et al. 2008). The domains potential for these deposit types probably overlap; hence, only one metallogenic area has been defined for the greenstone belt. Work by Rossi and Konnunaho (2006) demonstrated that the Yli-Ii greenstones host similar gold-potential shear zones to the Oijärvi greenstones.

Orogenic gold occurrences within area F034 are controlled by the main along-strike shear zones of the greenstone belt. The occurrences are hosted by mafic and ultramafic volcanic rocks and felsic dykes, are within a carbonation and sericitisation envelope, contain 1–3 vol% pyrite and free native gold, and are enriched in Au, Ba, Bi, CO_2, K, Li, Rb, S and Te, and show grades up to 10 g/t Au per metre of drill core (Tolppi 1999, Juopperi et al. 2001). The **Kylmäkangas** occurrence (Fig. 71), in the central part of the Oijärvi greenstone belt, deviates from this pattern: the potential commodity association is Au-Ag-Cu-Pb-Zn, the Au/Ag ratio is 0.1−0.2, the occurrence is hosted by intensely silicified, dacitic to rhyolitic quartz-feldspar porphyry, and the very fine-grained native gold in quartz is associated with electrum and hessite (Rossi 2000, Juopperi et al. 2001). Local quartz veins at Kylmäkangas are barren. The style of alteration, siting of gold, Au/Ag ratio, and metal association together suggest that Kylmäkangas is a high-sulphidation epithermal occurrence metamorphosed under upper-greenschist facies conditions. The published mineral resource at Kylmäkangas is 1.924 Mt at 4.07 ppm Au (Agnico-Eagle 2010).

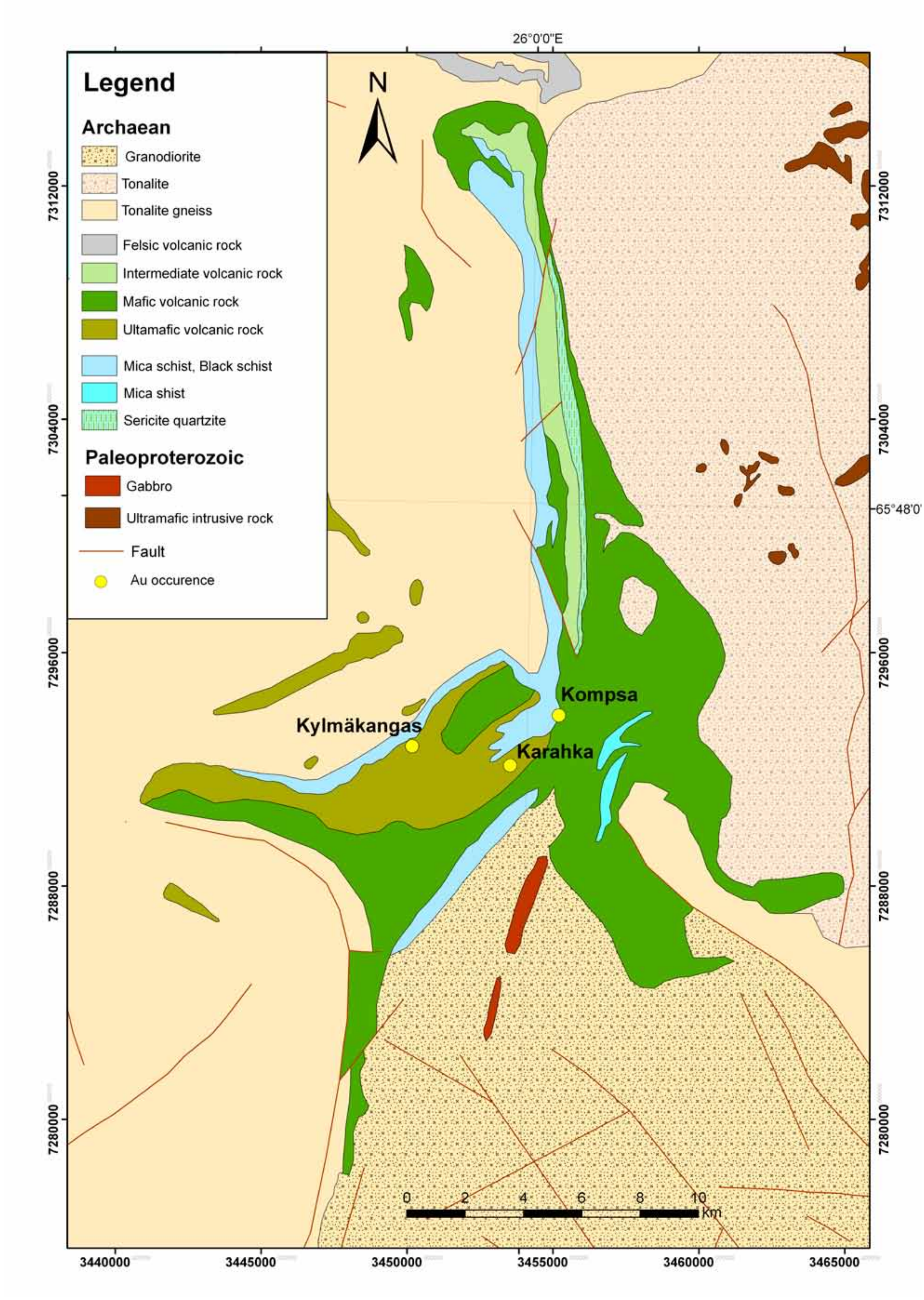


Figure 70. Geology of the northern part of the Oijärvi greenstone belt and locations of drilling-indicated gold occurrences in the area. Geology from GTK digital map database, gold occurrences from Eilu & Pankka (2009).

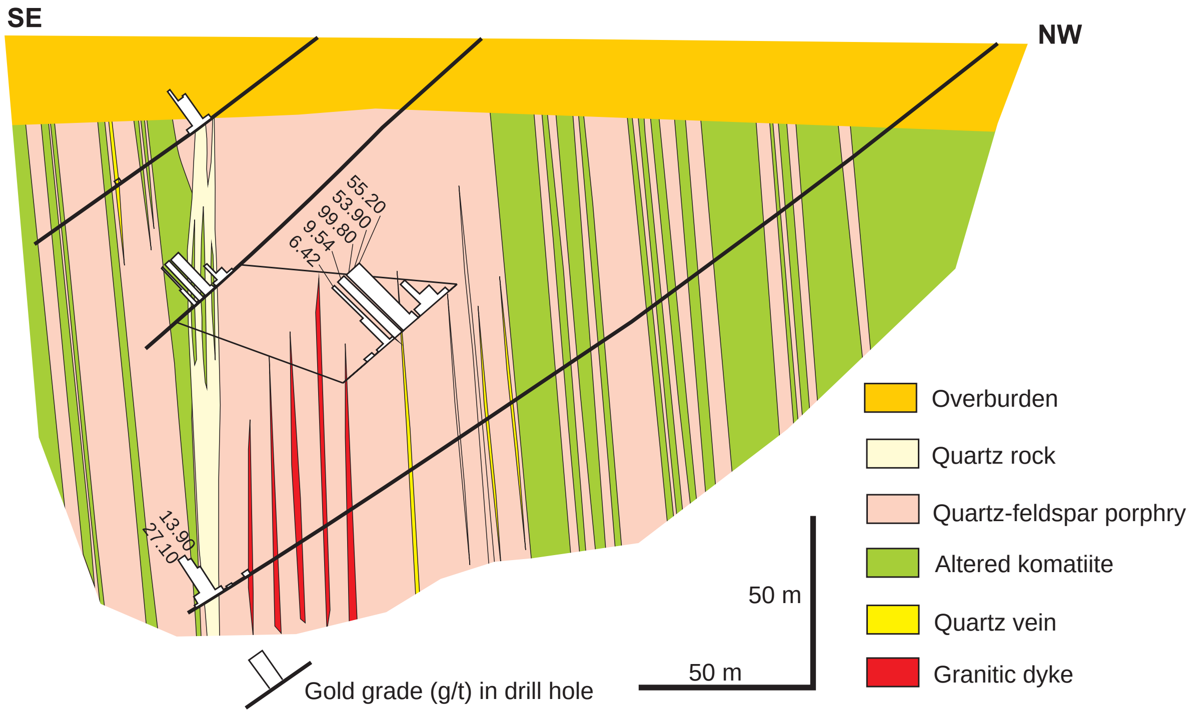


Figure 71. A drilled section across the Kylmäkangas gold occurrence, at 65.7264°N, 25.911°E. From Juopperi et al. (2001). Gold grades are given in g/t.

F035 PORTIMO Cr, PGE-Ni

Tapio Halkoaho & Markku Iljina (GTK)

The Portimo metallogenic area (F035) is defined by the Tornio, Kemi, Penikat and Portimo layered intrusions and their immediate country rocks in SW Lapland (Fig. 72). The mineralised layered intrusions are mafic to ultramafic in composition and have an age of ca. 2.44 Ga (Perttunen & Vaasjoki 2001). They straddle along the boundary between the Archaean Pudasjärvi complex and the Palaeoproterozoic Peräpohja schist belt, in a siting analogous to all layered intrusions of similar age within the Fennoscandian shield (Alapieti et al. 1990, Iljina & Hanski 2005). The intrusions and their metal deposits are described below in geographic order, from west to east.

The *Tornio intrusion* is the westernmost layered intrusion of the Portimo area and extends across the Finnish-Swedish border, about 25 km NW from Kemi. The 6-km-long and 0.4–0.5-km-wide intrusion dips at 65–75° to the NE. It contains several thin chromitite layers, where the Cr_2O_3 content varies between 26 and 32 %, FeO_{tot} between 22 and 28 % and Cr/Fe between 0.9 and 1.2 (Söderholm & Inkinen 1982).

The *Kemi intrusion* contains the sole mine presently active within the Finnish layered intrusions, the **Kemi** chromium mine (Table 34; Fig. 73; Alapieti et al. 1989a, Alapieti & Huhtelin 2005, Huhtelin 2008). The deposit was found by GTK in 1959, and mining started by Outokumpu in 1966 as an open-pit operation. Underground mining started at Kemi in 2005. The chromitite layer parallels the basal contact zone of the Kemi intrusion and is known over the whole length of the intrusive complex. In the central part of the intrusion, the basal chromitite layer widens into a thick chromitite accumulation. The chromite-rich unit has an average dip of 70° to the NW. The thickness of the main chromitite unit is from a few metres to over 160 metres and averages at 40 m. The lower contact of the chromitite unit lies stratigraphically 50–100 m above the basal contact of the complex. The top of the main chromitite unit is layered in structure, the hanging-wall contact of the ore being sharp, whereas the lower part is brecciated and characterised by gradually diminishing chromite dissemination towards the bottom of the intrusion, accompanied by irregular ore lumps. The average Cr/Fe ratio in the ore is 1.6. According to a recent seismic reflection survey in the area, the intrusion extends to a depth of 2–3 km, possibly to 4 km, and the chromitite unit may extend down to 2–2.5 km or more (Outokumpu 2010). This would mean much larger resources than what is presented in Table 34.

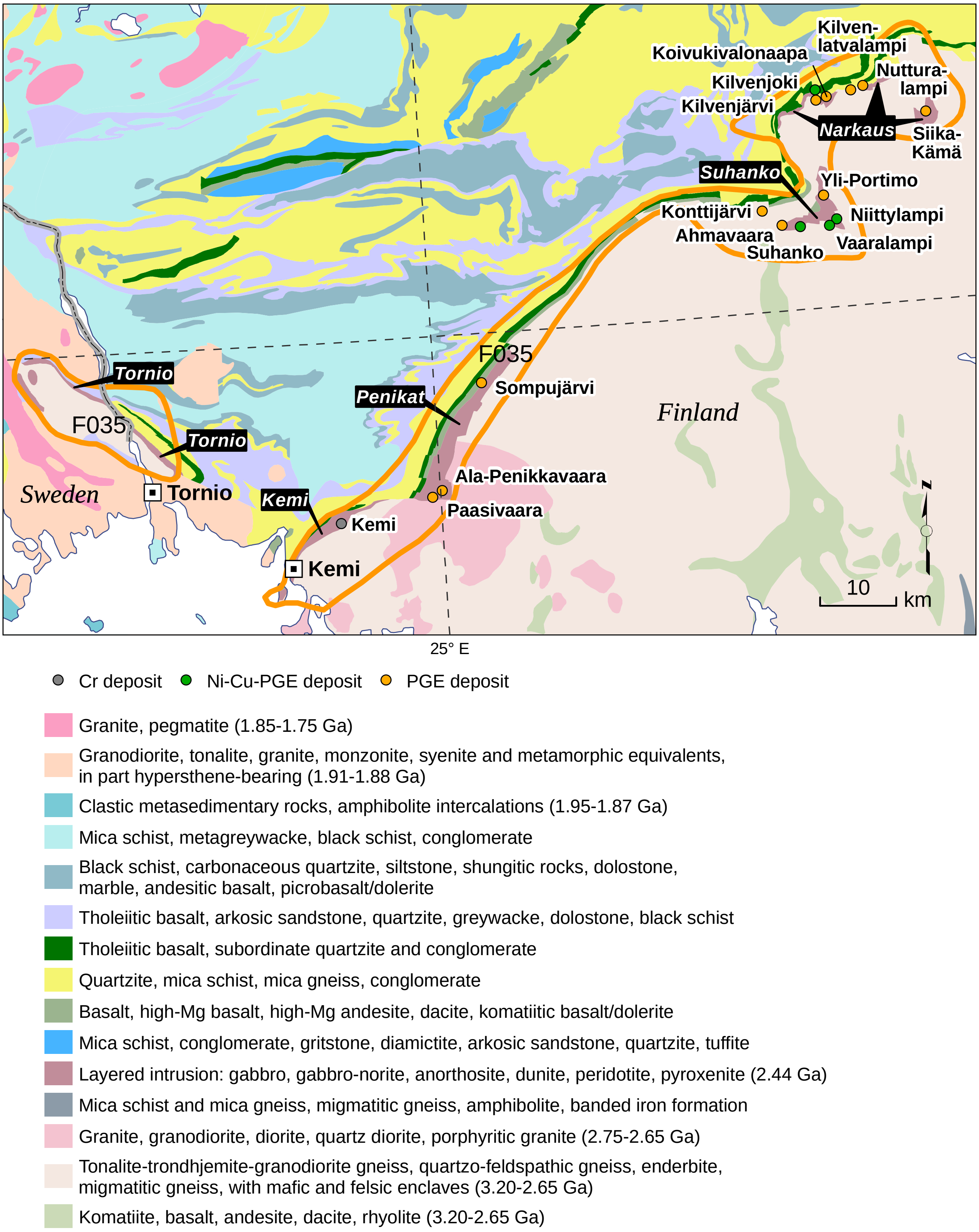


Figure 72. Geology of the Portimo metallogenic area (F035), main layered intrusions (white font in black background), and locations of the main PGE±Ni-Cu and Cr occurrences in the region. Note that the Tornio intrusion extends across the Finnish–Swedish border. Geology is from the GTK digital bedrock database and from Koistinen et al. (2001).

Figure 73. The Kemi mine in 2008. Kemi is the only Cr producer within the EU. Photo: courtesy of Outokumpu Oy.

The *Penikat intrusion* is about 25 km NE from Kemi. It dips to the NW with an angle of about 40–70° (Alapieti & Lahtinen 1986, 1989, 2002, Alapieti et al. 1990, Huhtelin et al. 1990, Halkoaho 1993, Halkoaho et al. 2005). Three well-explored reef-type PGE occurrences are known within the intrusion: 1) *Sompujärvi (SJ) Reef* at the contact between megacyclic units III (boninitic-like, Cr-rich magma type) and IV (tholeiitic like, Cr-poorer magma type), 2) *Ala-Penikka (AP) Reef* at the lower part of megacyclic unit IV, and 3) *Paasivaara (PV) Reef* at the contact between megacyclic units IV and V (Table 34). In the sulphide-bearing AP and PV reefs, the dominant sulphide assemblage is pyrrhotite-chalcopyrite-pentlandite. In the SJ reef, base metal-free chromite and silicate variants are dominant. The silicate mineralogy of the reefs is dependent on the host rock type. Base metal-bearing reefs generally contain 0.8–2 vol% sulphides and their typical metal contents range at approximately 0.06–0.24 % Ni and 0.11–0.36 % Cu. The base metal-free chromite reefs normally contain less than 0.05 % S and Cu, and about 0.08 % Ni, including the silicate-bound Ni (Alapieti & Lahtinen 2002). The silicate reefs have very low S and Cu contents, at < 0.02 % and <0.015 %, respectively, all Ni is in silicates, and the Cr content is normally low, below 0.05 % (Halkoaho 1993).

The SJ Reef is roughly 1 m thick and has a total precious metal grade (3PGE+Au) of 1–10 ppm. In certain places, for example in Kirakkajuppura, at northernmost end of the intrusion, the total precious metal grade is several hundreds of ppm. The AP reef is typically 0.2–0.4 m thick with grades at about 5 ppm 3PGE+Au. In the pothole parts of the AP reef, the best drill intercept so far detected is 20 m at 0.3–12 ppm 3PGE+Au. The average thickness of the PV reef is about 1 m and the 3PGE+Au grade <10 ppm (Alapieti & Lahtinen 1986, Halkoaho et al. 1990a, 1990b, 2005, Huhtelin et al. 1990, Alapieti and Lahtinen 2002). The lower part (megacyclic units I–III) of the Penikat intrusion also contains several thin chromitite layers (Alapieti & Lahtinen 1986 and 1989, Alapieti et al. 1990, Halkoaho 1993).

The Portimo Complex consists of the *Suhanko* and *Narkaus intrusions*. It hosts a variety of PGE mineralisation including (Alapieti et al. 1989b, Huhtelin et al. 1989, Lahtinen et al. 1989, Iljina 1994, 2005):

- PGE-rich Cu-Ni-Fe sulphide dissemination in the marginal series of the Suhanko and Konttijärvi intrusions.
- Predominantly massive pyrrhotite deposits located close to the basal contact of the Suhanko intrusion.

- Rytikangas Reef in the layered series of the Suhanko intrusion.
- Siika-Kämä Reef in the Narkaus layered series.
- Offset Cu-PGE mineralisation below the Narkaus intrusion.

The offset metal enrichment and the first two styles of mineralisation represent a contact-type mineralisation in the immediate vicinity of the basal contact of the intrusions, whereas the reef types form stratiform enrichments well inside the layered sequences.

Disseminated PGE-rich base-metal sulphide zones, normally 10–30 m thick, occur throughout the marginal series of the Konttijärvi and Suhanko intrusions (Fig. 74; Table 34). Their distribution is apparently erratic and they generally extend from the lower peridotitic layer of the marginal series downwards for some 30 m into the basement. The Pt+Pd contents vary from only weakly anomalous values to 2 ppm for most of the marginal series of the Suhanko intrusion, but are up to >10 ppm in several sites in the **Konttijärvi** and **Ahmavaara** deposits. Sulphides have also accumulated to form massive concentrations in the Suhanko intrusion. Similar to the disseminated sulphides, the massive sulphides have much higher PGE, Ni and Cu concentrations at Ahmavaara compared to the other massive sulphide deposits hosted by the Suhanko Intrusion.

The offset mineralisation is sporadically distributed in the basement gneisses and granites below the Narkaus intrusion. The largest and the best-known are below the Kilvenjärvi block. These form a cluster of ore bodies (all offset occurrences listed in Table 34). The offset mineralisation represents the richest PGE deposit type within the region, with Pt+Pd contents up to 100 ppm. An offset occurrence is predominantly a Pd deposit, as it has a much higher Pd/Pt ratio than any other PGE deposit of area F035, and is extremely low in Os, Ir, Ru, and Rh. Furthermore, it is extremely irregular in form, containing disseminated sulphide-PGM ‘clouds’, massive sulphide veins or bodies, and breccias in which sulphide veins brecciate the country-rock granitoids. The proportions of base-metal sulphides and PGM are highly variable, but the massive sulphide bodies are generally richer in PGE. In general terms, the more sulphide-rich occurrences are closer to the basal contact of the intrusion and those poorer in sulphides are encountered in a wider zone below the intrusion

The **Siika-Kämä Reef** (Table 34) of the *Narkaus intrusion* is most commonly located at the base of MCU III, but in places it may lie somewhat below that or in the middle of the olivine cumulate layer of MCU III. Chlorite-amphibole schist similar to that in the Sompujärvi Reef in the Penikat Intrusion commonly hosts the Siika-Kämä Reef. In some parts of the reef, the PGE mineralisation is accompanied by chromite seams or chromite dissemination. The thickness of the reef varies from less than one metre to several metres, and many drill holes penetrate a number of mineralised layers separated by PGE-poor layers up to several metres thick. Mineralisation at Siika-Kämä is among the most sulphide-deficient within the Portimo Complex, in some places containing no visible sulphides at all, and rarely exceeding a whole-rock sulphur content of 1 wt%.

Table 34. PGE±Ni-Cu and Cr deposits with a resource estimate in the Portimo metallogenic area (F035).

Occurrence	Tonnage (Mt)	Cr %	Au g/t	Pd g/t	Pt g/t	Cu %	Ni %	Deposit subtype	References
Kemi	160.1[1]	19							Outokumpu Oy, Annual Reports for 2004–2010
Sompujärvi	6.7[2]		0.1	3.08	5.36			Reef	Reino et al. (1993)
Ahmavaara	187		0.1	0.82	0.17	0.17	0.09	Contact	Puritch et al. (2007)
Konttijärvi	75.3		0.07	0.95	0.27	0.1	0.05	Contact	Puritch et al. (2007)
Niittylampi	1.04			0.68	0.27	0.49	0.67	Contact	Lahtinen (1986)
Suhanko	1.0		0.04	0.9	0.2	0.31	0.27	Contact	Lahtinen (1986)
Vaaralampi	32		0.06	0.55	0.2	0.2	0.31	Contact	Reino et al. (1978), Holland (2011)
Siika-Kämä	43.1		0.08	2.7	0.72	0.11	0.08	Reef	Gold Fields (2003)
Kilvenjärvi	0.7		0.8	7.27	1.12	2.74		Offset	Outokumpu (1987)
Kilven-latvalampi	3.2			1.4	0.5	0.5		Offset	Saltikoff et al. (2000)
Kilvenjoki	0.175		0.84	2.5	0.06	6.11	0.28	Offset	Outokumpu (1987)

[1] Includes 37.1 Mt of ore mined by the end of 2010.

[2] Later drilling shows much more extent for and perhaps about 35 Mt of mineralised rock with similar grades as for the 6.7 Mt.

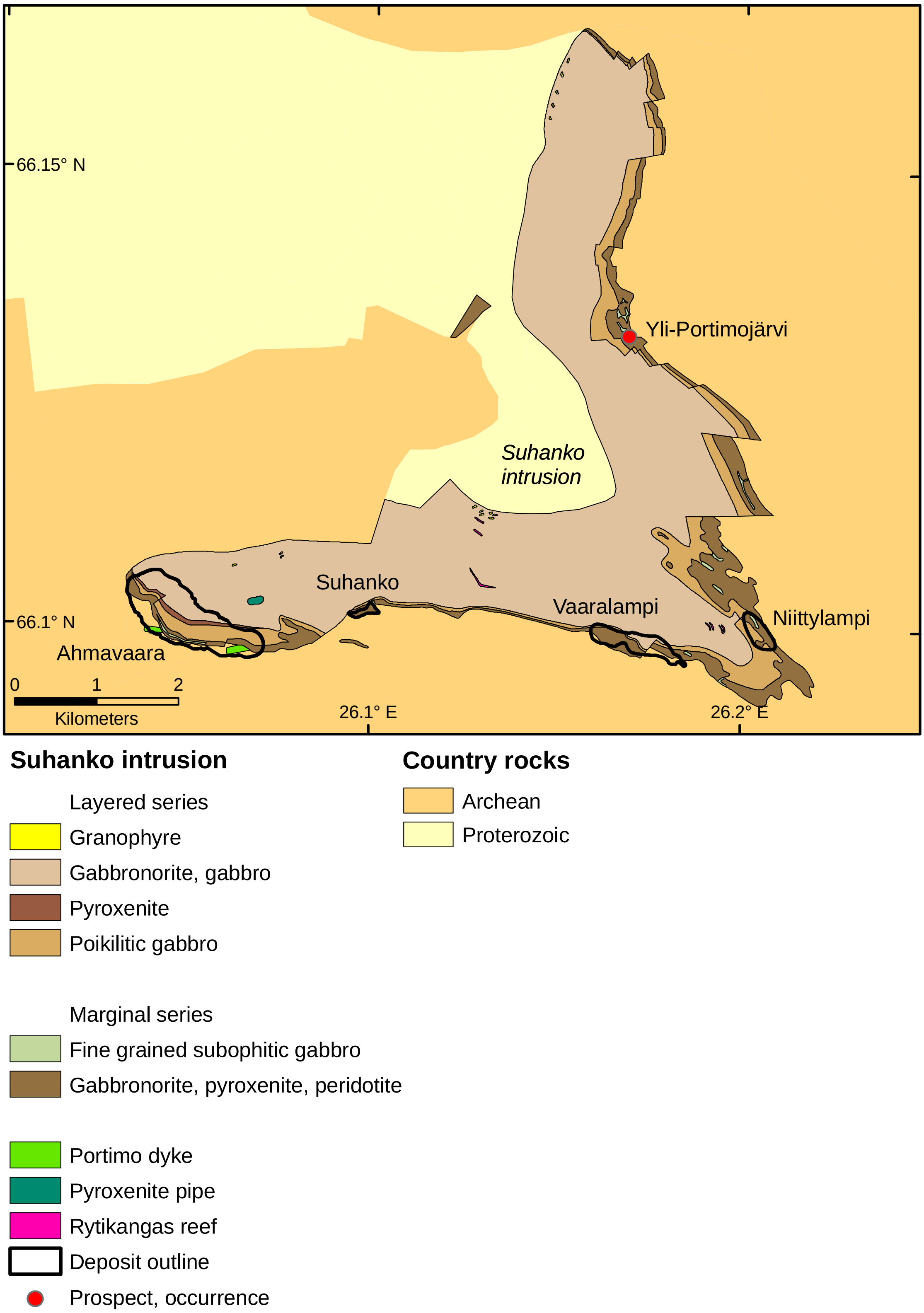


Figure 74. Geology of the Suhanko intrusion, with contact-type PGE deposits within the intrusion, after Rasilainen et al. (2010).

F036 KOILLISMAA PGE-Ni-Cu, Vi-Fe-Ti

Tuomo Karinen (GTK)

The Koillismaa metallogenic area (F036) is defined by the layered intrusions of the Koillismaa–Näränkävaara Complex and their immediate country rocks, in eastern Finland, about 150 km northeast of the city of Oulu (Fig. 75). The intrusive complex comprises the Koillismaa Intrusion, the Näränkävaara Intrusion, and a strong positive gravity anomaly (regarded as a major dyke at depth) that connects the western and eastern parts of the complex. The westernmost part of the complex (the Koillismaa Intrusion) consists of separate bodies that represent blocks of a single, sheet-like layered intrusion. These blocks straddle the boundary between the Archaean Eastern Finland complex and the Palaeoproterozoic Kuusamo schist belt, whilst the Näränkävaara Intrusion is surrounded by rocks of the Archaean basement complex. (Alapieti 1982, Alapieti & Lahtinen 2002, Iljina & Hanski 2005, Karinen 2010). The layered intrusions of the Koillismaa-Näränkävaara Complex are mafic to ultramafic in composition and have an age of ca. 2.44 Ga (Alapieti 1982).

The Koillismaa–Näränkävaara Complex hosts two principal types of metallic mineralisation. Both types are located in the Koillismaa Intrusion, but since the Näränkävaara Intrusion is of the same 2.44 Ga age, the metallogenic zone is also extended to the eastern part of the complex. The mineralisation types are:

- PGE-rich Cu-Ni-sulphide occurrences in the layered and marginal series of the Koillismaa Intrusion (Alapieti 1982, Alapieti & Lahtinen 2002, Iljina & Hanski 2005, Karinen 2010). Due

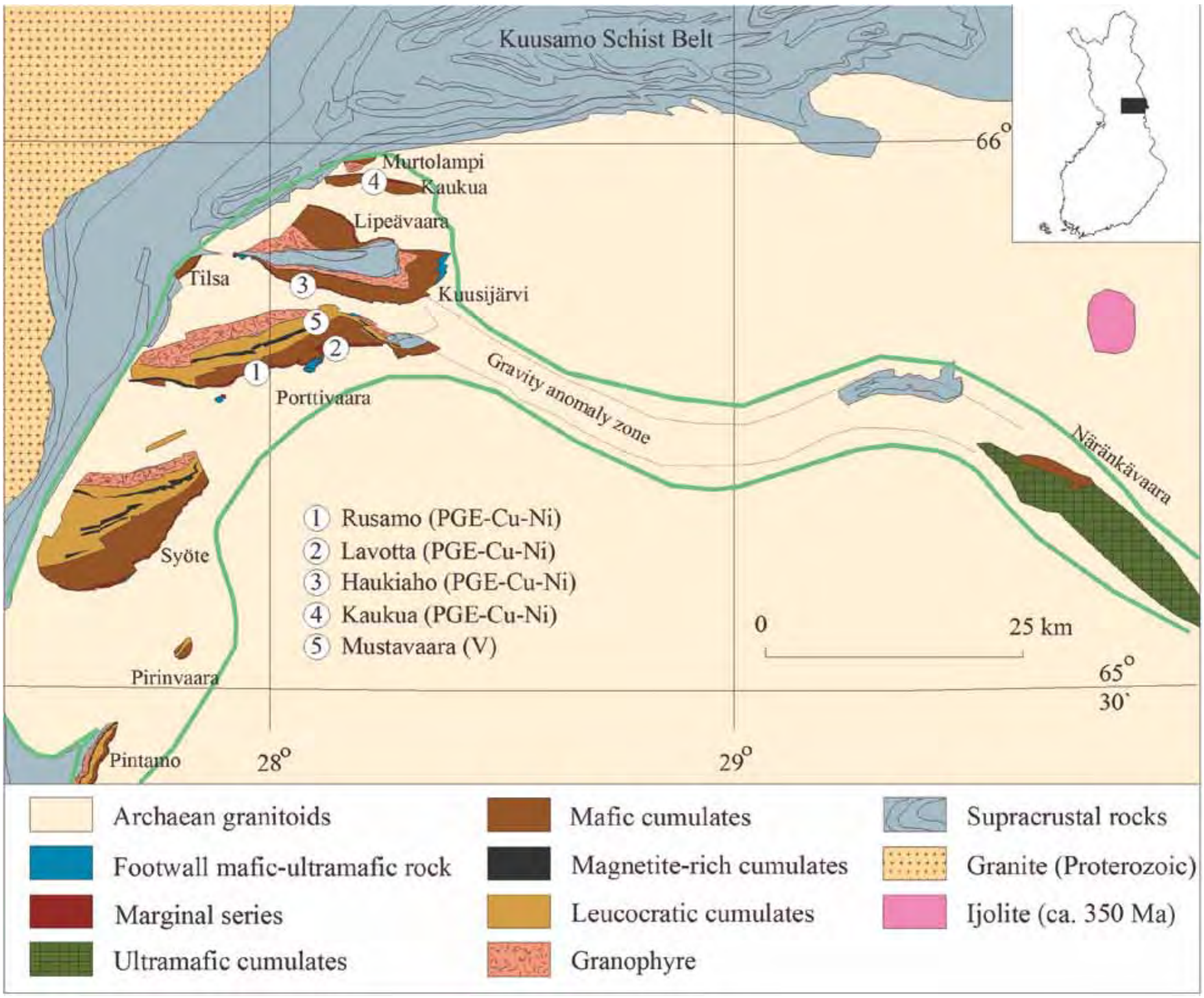


Figure 75. Geological map of the Koillismaa metallogenic area (F036), the boundaries of which are marked here by a green line. The intrusive blocks of the 2.44 Ga layered intrusions and the main metallic mineral deposits of the area are named. The 'Gravity anomaly zone' is explained in the text. The map is based on Karinen (2010).

to their location in the intrusion stratigraphy, the occurrences of the layered series represent reef-type and the occurrences of the marginal series represent contact-type PGE mineralisation.

- An orthomagmatic V-Ti-Fe-rich layer in magnetite gabbro subzone of the layered series of the Koillismaa Intrusion (Juopperi 1977, Alapieti 1982, Iljina & Hanski 2005, Karinen 2010). This type of mineralisation is represented by the Mustavaara vanadium mine (Juopperi 1977, Alapieti 1982), which so far is the only deposit that has been mined (1976–1985) within area F036.

There is one known reef-type occurrence in the Koillismaa Intrusion. It is sub-economic and is located in the middle part of the intrusion stratigraphy, in the contact of two subzones of the layered series. The mineralisation is usually less than 30 m in stratigraphic thickness and is sporadically distributed in location and in the amount of sulphides. Another feature of the mineralisation is the occurrence of metre-sized noncumulus-textured gabbronoritic bodies adjacent to the sulphide-bearing rocks. The principal sulphide minerals are pyrrhotite, chalcopyrite and pentlandite, which occur disseminated together with relatively low-temperature minerals in cm-sized pockets of clusters. The PGE grade correlates positively with the amount of these clusters. The mineralisation, referred to as the Rometölväs Reef (RT Reef), has been found from the Pirinvaara, Syöte, Porttivaara and Kuusijärvi blocks (Piispanen & Tarkian 1984, Karinen 2010).

The marginal series of the Koillismaa Intrusion is up to 200 m thick and displays a distinct basal reversal where the cumulates grade upwards in the stratigraphy from gabbroic to ultramafic rocks. The chalcophile metals-enriched domain is usually concentrated in the middle part of the marginal series, in the place where the rock grades from mafic to ultramafic. The mineralised part is typically 15–40 m thick and has gradational upper and lower contacts. Sulphides comprise 1–5 vol% of the rock and mostly occur as fine dissemination in the interstices of silicate grains. The principal sulphide minerals are pyrrhotite, chalcopyrite, pentlandite and, in places, pyrite. (Alapieti 1982, Karinen 2010)

The Koillismaa Intrusion has generally been regarded as target with greater potential for contact-type than the reef-type PGE-Cu-Ni mineralisation. In Table 35, all the PGE occurrences are of contact type. Of these, the Kaukua occurrence is worth mentioning, since there the PGE grades appear to be higher in comparison to other known contact-type occurrences of area F036 (Nortec Ventures 2009a, 2009b, Nortec Minerals 2010, 2011).

The **Mustavaara** vanadium deposit is in the magnetite gabbro layer of the upper part of the layered series of the Koillismaa Intrusion (magnetite-rich cumulates in Fig. 75). The layer is uniform and can be traced in almost every block of the intrusion. In the Mustavaara mine, the magnetite gabbro layer is about 240 m thick, strikes nearly east–west and generally dips at about 40° to the north (Juopperi 1977, Alapieti 1982, Karinen 2010). The grades of Fe, Ti and V in the magnetite gabbro show a positive correlation with the amount of the ilmenomagnetite, which is an oxide phase that originally crystallised as titaniferous magnetite, but which later during the subsolidus phase reacted to form composite grains of fine ilmenite lamellae and V-bearing magnetite host. In the Mustavaara mine, the amount of oxide was used to divide the magnetite gabbro into four distinct layers, of which the three lower ones made up the ore. The lowest ore layer was about 5 m thick and contained 25–35 vol% oxide minerals and 0.38 % V (0.68 % V_2O_5), whereas the middle layer, 15–50 m in thickness, was poorest in oxides at about 15 vol% with 0.22% V (0.39 % V_2O_5). The upper layer of ore varied from 10 to 40 m in thickness and contained 0.26 % V (0.46 % V_2O_5). During mining, one significant challenge to over-

Table 35. Deposit list of the Koillismaa Intrusion. Examples of PGE-Ni-Cu and V deposits with a resource estimate in the Koillismaa area (F036).

Occurrence	Tonnage (Mt)	Au g/t	Pd g/t	Pt g/t	Cu %	Ni %	Ti %	V %	References
Haukiaho	27.0	0.22	0.55	0.21	0.36	0.24			Iljina et al. (2005)
Kaukua	12.112	0.08	0.71	0.25	0.15	0.10			Nortec Minerals (2011)
Lavotta	3	0.2	0.26	0.18	0.26	0.21			Lahtinen (1983), Iljina (2004)
Rusamo	1.5	0.15	0.38	0.27	0.39	0.24			Lahtinen (1983), Iljina (2004)
Mustavaara	43.5[1]						5	0.2	Puustinen (2003), Adriana Resources (2006)

[1] Includes 13.5 Mt of ore mined during 1976–1985.

come was the optimisation of the production line to gain the maximum V-grade with the minimum amount of ilmenite lamellae in the magnetic concentrate. The mine started in 1976 and operated until 1985. An open pit 1800 m in length resulted, varying in width from 130 to 290 m and in depth from 50 to 135 m (Juopperi 1977). The mine produced 13.446 Mt of ore at 0.2 % V (0.36 % V_2O_5). The tonnage given in Table 35 only covers the uppermost 100 m of ore; drilling indicates that the deposit probably extends beyond 200 m depth.

F037 PERÄPOHJA Cu-Co

Markus Kyläkoski & Pasi Eilu (GTK), Jan-Anders Perdahl (SGU)

The Peräpohja area (F037) covers the main parts of Peräpohja Schist Belt (PSB) (age ca. 2.4–1.9 Ga; Perttunen & Vaasjoki 2001) in Finland and parts of the similar-aged supracrustal rocks in Sweden, immediately to the north of the Portimo metallogenic area (F035, Fig. 72). These schist belts, metamorphosed chiefly under upper-greenschist to lower-amphibolite facies conditions, comprise well-preserved volcano-sedimentary sequences deposited in intracontinental to open marine environments. Their evolution generally follows that of the other Karelian schist belts of the Fennoscandian shield (Hanski & Huhma 2005, Lahtinen et al. 2005).

Only a few mineral deposits have been detected from area F037. These include the mafic volcanic- and dolomite-hosted Vähäjoki deposit of possibly iron oxide-copper-gold (IOCG) class (Eilu et al. 2007), a few quartz-carbonate vein-hosted and dolerite-associated Cu-Au occurrences possibly of the orogenic gold class (Eilu 2007), and enigmatic bonanza-grade Au-U occurrences in the central northern part of the area (Rompas, Rumavuoma and others; Hudson et al. 2011). Of these, only one in Finland and two in Sweden have been test mined (Table 36).

Although intermittent exploration has been conducted since its discovery in 1943, the **Vähäjoki** deposit has so far proven uneconomic. Vähäjoki comprises a set of magnetite ore bodies aligned in a N-trending zone (Fig. 76). In total, 14 magnetite ore bodies have been assessed at Vähäjoki; these have a combined resource of 10.5 Mt of iron ore with a variable copper, cobalt and gold content. The best gold lodes are 0.1 Mt, 0.23 Mt and 1.0 Mt in size and contain 0.5 g/t Au, 0.03–0.5 % Co and 0.05–1 % Cu. In addition, there are at least 15 magnetite bodies that are not included in the resource estimate (Korvuo 1982).

Besides the deposits listed above, the PSB contains a number of small Cu occurrences and showings through most of the stratigraphic column. Host rocks range from siliciclastic and carbonaceous sediments to mafic volcanic rocks and dolerite sills (Mikkola 1949, Isomaa & Sandgren 2006, Kyläkoski 2009). The dominant Cu sulphide is chalcocite. Bornite and chalcopyrite are typically associated, and local occurrences of metallic copper are also known. Anomalous Co and Au contents commonly accompany Cu, an association that is also depicted in regional and local till geochemistry (e.g., Koivisto 1984, Rossi 1992). Some or all of these occurrences may belong to the 'clastic sediment-hosted stratiform Cu' deposit class or their close associates (Kyläkoski 2007, 2009). In addition, molybdenum occurrences and indications are known from the northern part of the PSB (e.g., Yletyinen 1967).

In Sweden, burghers from Tornio discovered two copper deposits in 1640, Bruksberget and

Table 36. Deposits and occurrences in the Finnish part of the area F037 included in the FODD database. No grade and tonnage data are available for the historic mines in Sweden.

Occurrence	Tonnage (Mt)	Au g/t	Co g/t	Cu %	Fe %	When mined	Genetic type	Reference
Kivimaa	0.023*	5.3		1.87		1969	Orogenic?	Aulanko (1968), Rouhunkoski & Isokangas (1974)
Vähäjoki	10.5**	0.2	0.03	0.17	39.4		IOCG?	Korvuo (1982), Liipo & Laajoki (1991)

* Mined 18 000 tonnes.

** Includes perhaps a half of the all magnetite ore bodies detected at Vähäjoki.

Stora Pahtavaara (Taipale) from the present area F037. The deposits were test mined shortly after, and there has been small-scale mining during different periods since then, last attempt ending in 1844 (Awebro et al. 1986). The mineralisation comprises chalcopyrite and bornite dissemination in quartz-carbonate veins within amphibolite (Lindbergson & Kautsky 1961) situated in fuchsite-bearing Karelian quartzites.

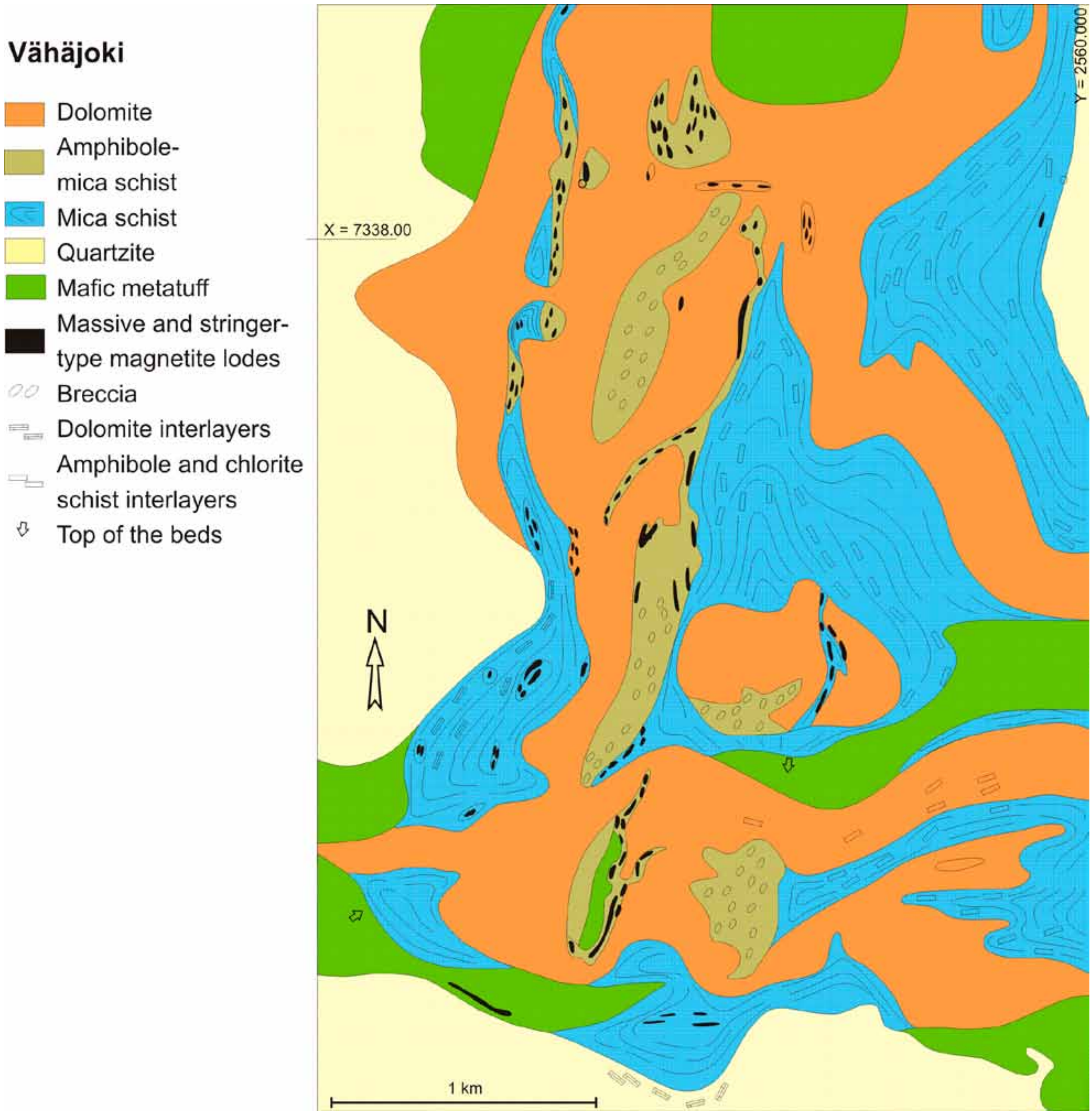


Figure 76. Geology at Vähäjoki, after Liipo and Laajoki (1991). The Au-Co-Cu mineralisation is apparently irregularly hosted by the magnetite lodes. Map coordinates are according to Finnish National Grid, Zone 2, metric values; the most intensely explored ore bodies at 7336000, 2558000 which is equivalent to 66.111°N, 25.279°E.

F038 HAUKIPUDAS Zn

Esko Korkiakoski & Pertti Heikura (GTK)

The Haukipudas Zn area (F038) is within the southwestern part of the Northern Ostrobothnia volcano-sedimentary belt (NOB) in western Finland. The NW-trending area F038 is defined by the interpreted extent of the most zinc deposit-potential part of the lowermost units of the NOB (Fig. 77).

The Palaeoproterozoic NOB covers an area of approximately 2500 km^2. The stratigraphy presented below is from the GTK digital bedrock database and parallel to Korkiakoski (2002). To the north it is bordered by Archaean basement gneisses, whereas the western and southwestern margins are delineated by younger (1830 Ma) Svecofennian granites and unmetamorphosed Muhos and Hailuoto Formations (600–1200 Ma). The NOB predominantly consists of coarse- to fine-grained turbiditic metasedimentary units (greywackes, mica schists and phyllites) and intercalated sulphidic black schists. They represent folded and, at least partly, overthrusted Lower-Kaleva (2060–1950 Ma) sequences grading from fine-grained deepwater accumulations (phyllite-black schist-mafic volcanic rock-chert association) to more coarse-grained greywackes with some conglomerate lenses representing proximal turbidite basin deposits. The turbiditic rocks are underlain by partly skarn-altered dolomite, black schist and MORB-type mafic volcanic sequences. Interestingly, some of the volcanic rocks belonging to the

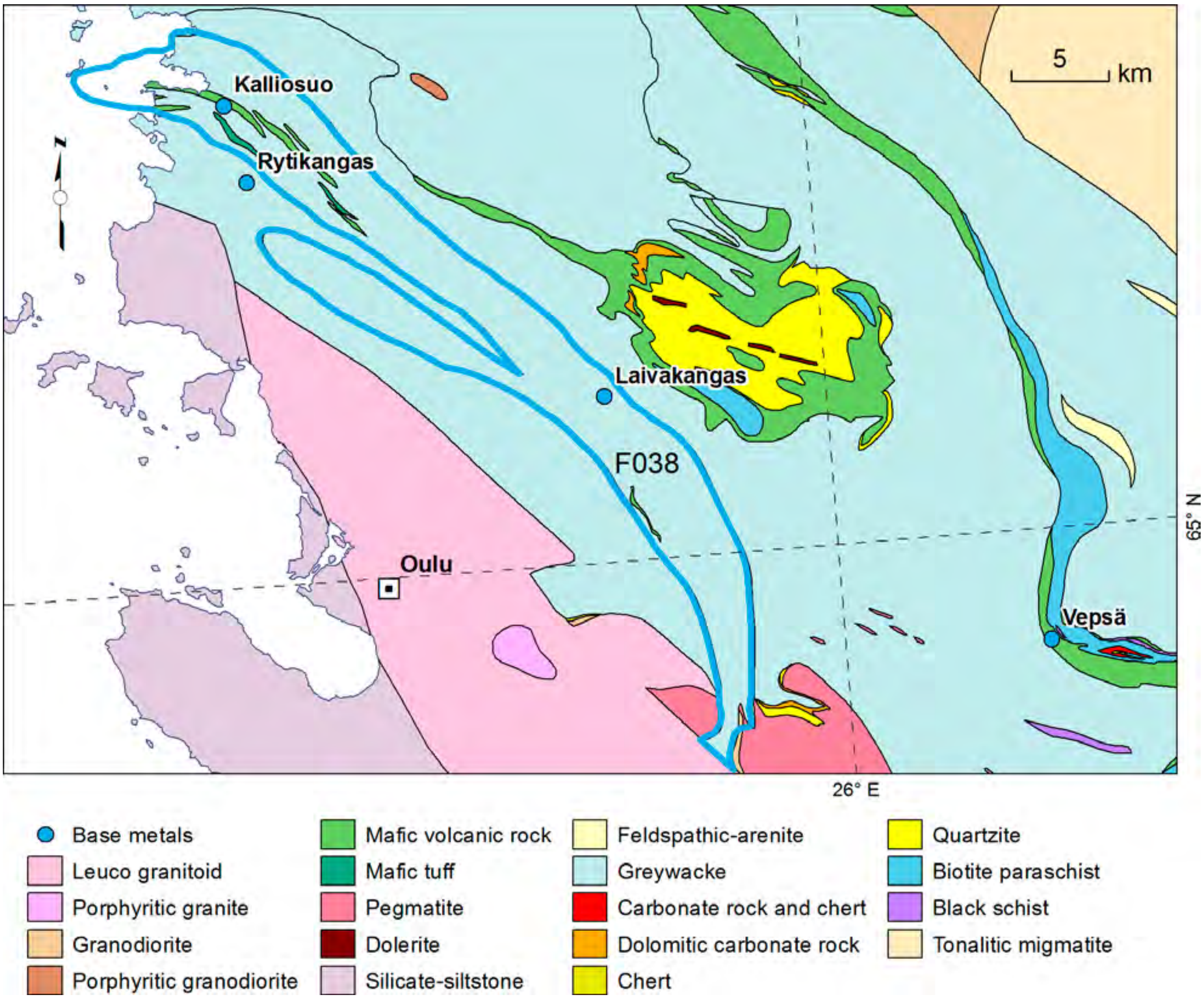


Figure 77. Geology of the Haukipudas Zn area (F038) and its immediate surroundings, with locations of zinc occurrences so far detected in the metallogenic area and the entire Northern Ostrobothnia volcano-sedimentary belt. Geology based on the GTK digital bedrock database.

Haukipudas Formation, in the lower part of the NOB, are komatiitic in composition. The oldest metasedimentary units occurring in the southern part of metallogenic area F038 consist of Jatulian (2300–2100 Ma) conglomerates and arkosites accumulated on the Archaean basement complex. The quartzites of the Koiteli Formation surrounded by turbiditic sediments are thought to be Jatulian in age.

The accumulated geological, geochemical and geophysical data clearly indicate that the NOB, especially its SW part, which is here defined as the Haukipudas metallogenic area (F038), is potential for sediment-hosted (SEDEX) zinc-copper and lead-silver sulphide deposits (Korkiakoski 2002). The rocks belonging to phyllite-black schist-mafic volcanic rock-chert association are locally hydrothermally altered and form economically the most interesting exploration targets for SEDEX-type deposits. This is indicated by a number of known ore-grade boulders and a few drill intercepts from the area (Vanhanen 1995). In addition, anomalous Pb-Ag values have been detected from the shallow-marine black schist-dolomite association from area F038 (Ahtonen 1996). So far, no economic deposits have been located within the NOB. This may partly be related to the fact that abundant sulphidic black schists of the area produce strong geochemical and geophysical anomalies, making it difficult to distinguish the possible ore-related anomalies from those caused by barren schists.

F039 MISI Fe

Tero Niiranen (GTK)

The NW-trending Misi Fe area (F039) covers the northeastern part of the Peräpohja schist belt in southern Lapland (Fig. 1). The boundaries of area F039 are essentially defined by low-altitude aeromagnetic data, as there are very few outcrops beyond the central parts of the area F039. To the north and east, the area is bounded by the Central Lapland granitoid complex, and to the southwest and northeast by clastic sedimentary, dominantly arkositic, sequences of the Peräpohja belt (Fig. 78).

The bedrock of the Misi metallogenic area consists of a 2.3–2.1 Ga supracrustal sequence of quartzites, dolomitic marbles, mafic metavolcanic rocks and mica schists that are locally overlain by ≤1.98 Ga quartz-feldspar schists and bimodal metatuffs (Hanski 2002, Niiranen et al. 2003, Hanski et al. 2005). The 2.20–2.12 Ga gabbros and 1.80–1.77 Ga granitoids comprise the intrusives of the area (Hanski et al. 2001a, Niiranen et al. 2005). Area F039 was subjected to multiphase deformation and up to amphibolite facies metamorphism during the Svecofennian orogenic events in 1.90–1.77 Ga.

Several small magnetite occurrences are known in area F039 (Table 37). Nuutilainen (1969) lists 13 drilling-defined magnetite occurrences in the belt. The magnetite occurrences are lenticular- to irregular-shaped replacement bodies and veins hosted by tremolite- and serpentine-dominated skarns. All of the known occurrences are within highly albitised varieties of 2.20–2.12 Ga gabbros or located at the contacts of the albitised gabbros and the 2.3–2.1 Ga quartzite-dolomitic marble sequence (Niiranen et al. 2003). The chemical composition of the magnetite occurrences indicates that they are Ti, P, and S poor and enriched in V (Nuutilainen 1969).

Niiranen et al. (2005) proposed a metasomatic origin for the Misi magnetite deposits. In their model, the iron was precipitated from deep circulating high-salinity brines that also caused the widespread albitisation and iron depletion of the mafic country rocks. U-Pb age dating of the albitised wall rocks of the Raajärvi deposit indicates that the albitisation took place at 2.06–2.01 Ga (Niiranen et al. 2005). This suggests that the mineralisation slightly post-dates the intrusion of the gabbros in the region. Figure 79 shows the geology of the Raajärvi deposit as an example of the magnetite deposits in the Misi belt.

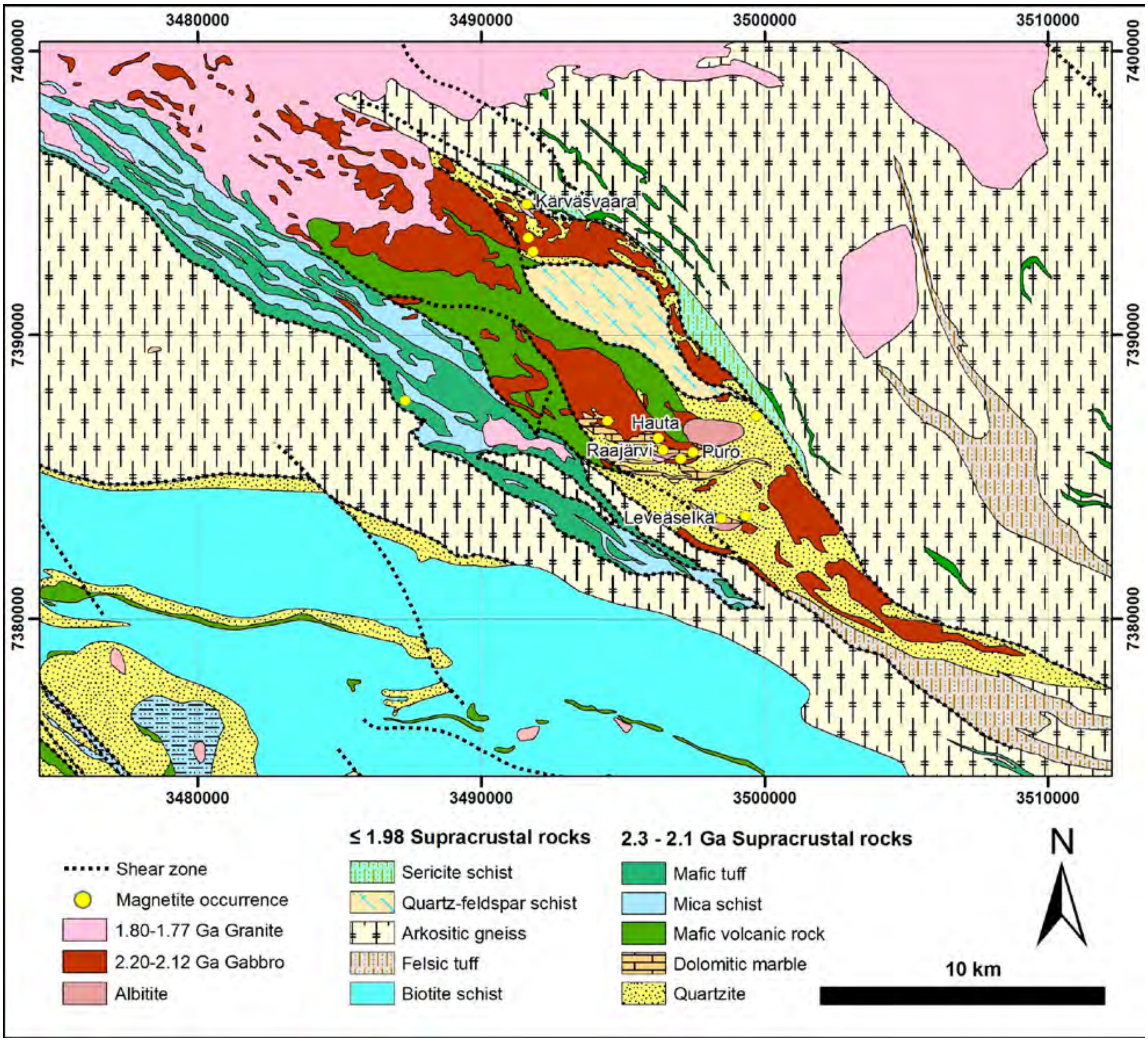


Figure 78. Geology of the Misi metallogenic area (F039) and surroundings, with metallic deposits that have a resource estimate. Metallogenic area F039 essentially covers the NW-trending gabbro-rich supracrustal belt in the centre of the map. Geology is from the GTK digital bedrock database.

Table 37. Iron deposits with a resource estimate in the Misi area (F039).

Occurrence	Tonnage (Mt)	Mined (Mt)	Fe %	When mined	Main host rock	Reference (in addition to Nuutilainen 1969)
Leveäselkä	1.3	1.1	47	1972–1974	Serpentine skarn	Hugg & Heiskanen (1983)
Puro	1	0.06	53.9	1966–1967	Tremolite skarn	Hugg & Heiskanen (1983)
Raajärvi	6.55	5.12	46	1961–1975	Tremolite skarn	Puustinen (2003)
Kärväsvaara	1.35	0.93	52.1	1958–1967	Tremolite skarn	Puustinen (2003)
Hauta	0.24		34.8		Tremolite skarn	Hugg & Heiskanen (1983)

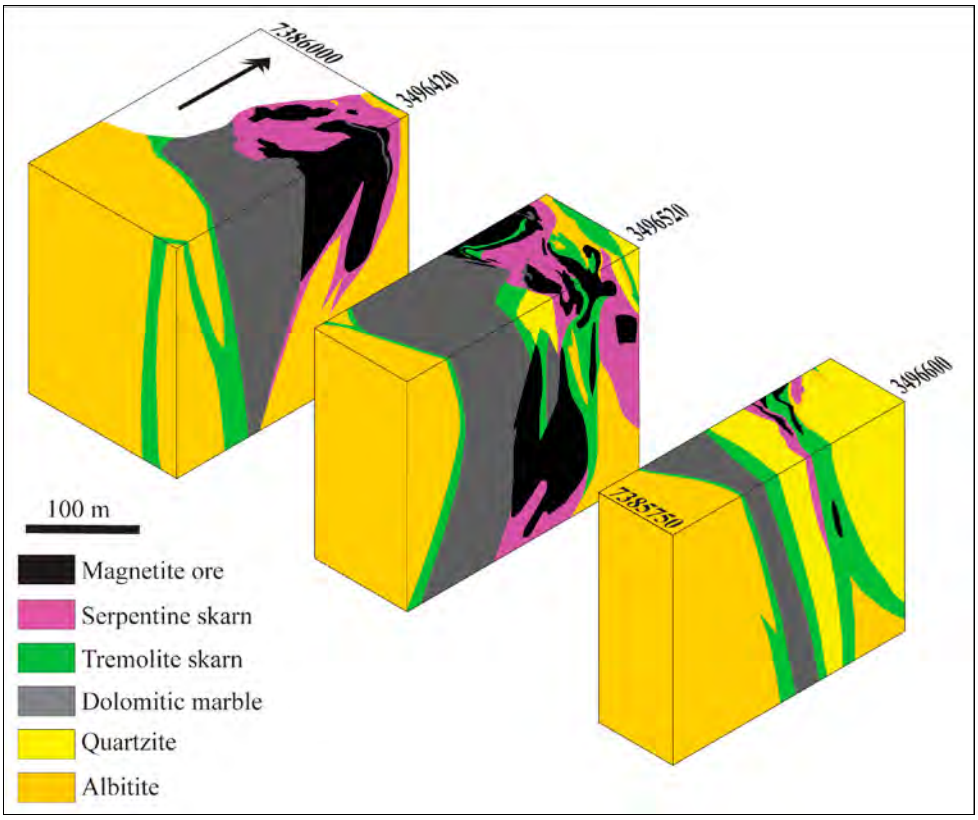


Figure 79. Sectioned 3D geology of the Raajärvi deposit, located at 66.5646°N, 26.9157°E. Modified after Niiranen et al. (2003) and unpublished Rautaruukki data. Coordinate system: Finnish national KKJ3. The arrow points to the north.

F040 KUUSAMO-KUOLAJÄRVI Co-Au

Pasi Eilu (GTK), Margarita Korsakova (SC Mineral), Olli Äikäs (GTK)

The Kuusamo-Kuolajärvi metallogenic area (F040) covers the central and eastern parts of the Kuusamo-Paanajärvi and Salla-Kuolajärvi Palaeoproterozoic schist (greenstone) belts, across the Finnish-Russian border (Figs. 1 and 80). In the north, area F040 is bounded by the Salla greenstones, in the east by Archaean granite-greenstone terrain, in the southeast by the ca 2.45 Ga Olanga layered intrusions, and in the south and west by higher-metamorphic grade supracrustals of the Kuusamo schist belt. The latter two boundaries are defined by a gradual decrease in indications of Au-Co and U mineralisation, whereas the other boundaries of F040 are rather sharp.

The Kuusamo-Paanajärvi and Salla-Kuolajärvi belts (KKB) form the southeastern part of the Lapland greenstones, which extend for >500 km across the northern Fennoscandian shield. The KKB was formed, at least in its central parts, in an intracratonic failed rift setting related to the breakup of the Archaean Karelian craton (Hanski & Huhma 2005). The rocks of the belt comprise clastic sedimentary and volcaniclastic rocks with abundant indications of evaporates, and three or four stages of mafic volcanism and associated mafic sills and dikes, all deposited or intruded between ca. 2.44 and 1.90 Ga (Dain & Ivanov 1978, Pankka 1992, Räsänen & Vaasjoki 2001, Vanhanen 2001, Afanas'eva 2003, Feoktistov et al. 2007). The rocks were probably subjected to the same orogenic stages as the Central Lapland greenstone belt, during the Palaeoproterozoic (see the description of metallogenic area F043). During the compressive epochs (1.91–1.88, 1.85–1.79 Ga), the degree of regional metamorphism varied from upper-greenschist to upper-amphibolite facies within the KKB (Silvennoinen 1991). The highest metamorphic grade was attained in the west and northwest, near the contact with the Central Lapland Granite Complex. From there, the metamorphic grade at the present surface decreases towards the central parts of the belt, which also hosts all gold occurrences. From the central parts, the metamorphic grade again increases to-

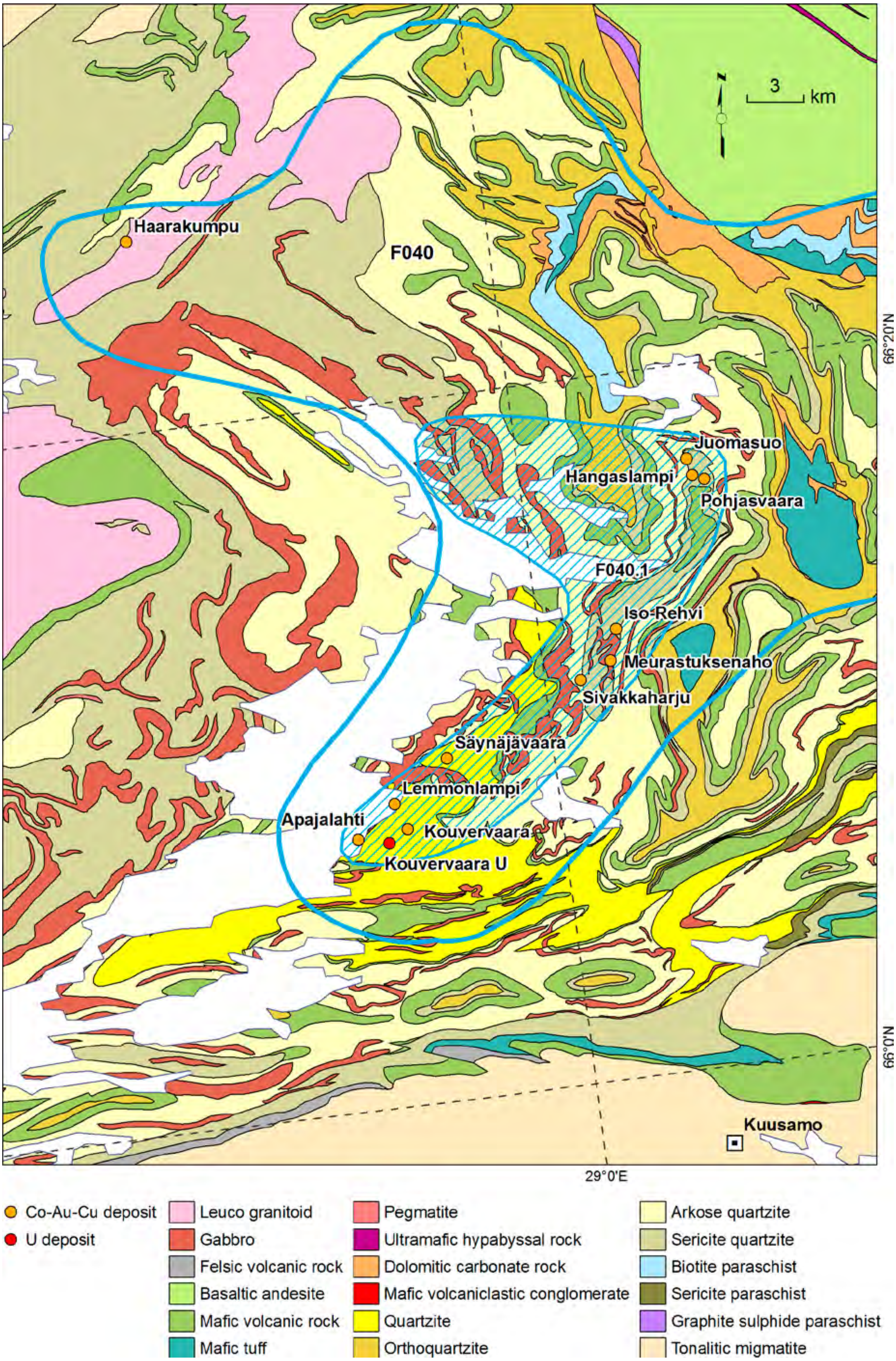


Figure 80. Geology of the western part of the Kuusamo-Kuolajärvi metallogenic area (F040), including the Kuusamo subarea (F040.1), and metallic deposits with a resource estimate in the region. Geology is based on the GTK digital bedrock database.

wards the eastern flank of the belt.

The main styles of metallic mineralisation in metallogenic area F040 are epigenetic Au-Co-Cu±U and stratabound clastic-hosted U (Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001). Models of orogenic gold with atypical metal association, iron oxide-copper-gold (IOCG), epithermal and syngenetic style have all been suggested for the Au-Co-Cu±U occurrences within area F040 (Dain & Ivanov 1978, Bezrukov 1989, Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001, D.I. Groves, pers. comm. 2006, Eilu & Pankka 2009). The timing and parts of alteration seem to fit with the orogenic style of mineralisation. Alteration, metal association and the mineralising fluid(s) fit best with the IOCG hypothesis. Mineralising fluid(s), metal association, rift−shelf tectonic setting, indications of very early deformation, and host rock associations are consistent with the syngenetic (pre-metamorphic) hypothesis. Structural control and gold fineness fit with all of the genetic styles proposed.

The region covered by subarea F040.1 is most intensely explored and investigated within the Kuusamo-Kuolajärvi area. In addition to those listed in Table 38, there are many more Au-, Au-Co-Cu- and U-mineralised occurrences within the entire F040, many of these explored to some extent, both in Finland and Russia, but there is no tonnage information on them. The general sequence of alteration related to Au-Co-Cu±U deposits within the F040.1 is reported as follows (Pankka 1992, Pankka & Vanhanen 1992, Vanhanen 2001): Albitisation is the most extensive alteration type and is, apparently, premetamorphic. Albitisation is followed by a sequence of syn- to late-metamorphic(?) alteration stages. The first of them is the Mg-Fe metasomatism, which is closely related to gold mineralisation and indicated by the formation of chlorite, tremolite-actinolite, magnetite, chloritoid, talc and Fe sulphides. The next stage is K±S metasomatism, indicated by biotite and sericite ± pyrite and additional(?) gold mineralisation and ductile deformation. This is followed by a stage of carbonation, silicification, further gold mineralisation (or remobilisation) and brittle deformation. These uncertainties in the timing of alteration and mineralisation are one of the major reasons why the genetic type of metallic mineralisation is largely uncertain within area F040.

The largest known deposit within area F040 is **Juomasuo** in the central Kuusamo schist belt, within subarea F040.1 (Fig. 81). Test mining of 17.6 t of ore took place in 1992. Exploration resumed at site in 2010, and the deposit now has an *in situ* resource of 8060 kg gold and 1964 t cobalt (Dragon Mining 2011a; Table 38). The deposit is enriched in Au, Cu, Mo, Ni, REE and U. It is hosted by albitised, biotitised and sulphidised mafic volcanic rock and sericite quartzite. Juomasuo comprises one major and a number of smaller lodes controlled by a NW-trending fault crossing an axial culmination in a NE-trending anticline. Native gold is chiefly associated with Bi and Te minerals as inclusions in pyrite, cobaltite and uraninite, between silicates, and in tiny Au-Bi-Te rich veinlets oriented parallel to foliation and enveloped by silicates. (Pankka 1992, Vanhanen 2001)

The **Maiskoe** gold-only deposit is in the northern part of F040, in Russia. The deposit is hosted by Jatulian andesitic basalt and gabbro-pyroxenite sills and dykes intruded into the basalt (Fig. 82). According to gravimetric data, the deposit is in the exocontact of a concealed granitoid massif and close to two parallel thrust zones. The occurrence is hosted by two quartz veins in sheared and altered rock. The mineralised veins are traced along the strike for 2.5–3.8 km and to a depth for 60–80 m. Veins have a lens-shaped form with pinches and swells. Major ore minerals are sulphides, which form banded and locally nested impregnation (0.5–1.0 % on average). In decreasing order, the ore minerals are: chalcopyrite, pyrrhotite, cobaltite, cubanite, mackinawite, galena, sphalerite, nickel tellurides, lead and gold. Native gold is associated with a telluride-galena assemblage. The gold content in the veins shows an extreme variation from traces to 580 g/t Au. In mineralised localities south of Maiskoe, the gold content varies from 0.1–0.5 g/t Au to 90 g/t Au. The Maiskoe deposit was mined in 1995–1997 and 51 kg of gold was produced. (Dain & Ivanov 1978, Bezrukov 1989, Afanas'eva 2003)

Stratabound clastic-hosted uranium deposits have been detected in subarea F040.1 and elsewhere in the Finnish part of area F040. However, there is a resource estimate only for **Kouvervaara U** (Table 38), and even this estimate appears to be based on scarce data. The Kouvervaara sandstone-type uranium occurrence is subvertical, more than 3 km long, but only a few centimetres to some metres thick, and it is cut by several faults (Vanhanen 1989a). The uranium grade varies from 0.05 % to 0.217 % and averages 0.0385 % per metre of drill core, and the average thickness is 4 m (Vanhanen 1989a, Wallis 2006). Due to a small number of drill hole intercepts, the tonnage given in Table 38 is only provisional. The occurrence is possibly of the roll-front type; it is associated with albitisation and the contact between sericite schist and arkose quartzite (Pankka & Vanhanen 1992).

Table 38. Gold-cobalt and uranium deposits and occurrences in the Kuusamo-Kuolajärvi Au-Co, U area (F040) having a reported resource estimate.

***Subarea,* Occurrence**	**Tonnage (Mt)**	**Au g/t**	**Co %**	**Cu %**	**U %**	**Main host rocks**	**Reference**
Kuusamo subarea (F040.1)							
Kouvervaara U	0.3*				0.04	Sericite quartzite	Vanhanen (1989a), Pankka & Vanhanen (1992), Wallis (2006)
Apajalahti	0.1	10				Sericite quartzite	Pankka (1992), Vanhanen (2001)
Iso-Rehvi	0.04	4	0.05	0.10		Phyllite	Vanhanen (1991, 2001)
Juomasuo	1.42	5.7	0.15	0.03		Mafic volcanic rock	Vanhanen (2001), Dragon Mining (2011a)
Kouvervaara	1.58	0.4	0.2	0.2		Sericite quartzite	Tarvainen (1985), Pankka (1992), Vanhanen (2001)
Hangaslampi	0.278	6.2	0.1	0.1	0.03	Sandy siltstone	Vanhanen (2001), Dragon Mining (2011a)
Säynäjävaara	0.4	1	0.06	0.02		Sericite schist	Vanhanen (2001), Pankka et al. (1991), Pankka (1992)
Pohjasvaara	0.095	4.9	0.1	0.3		Sericite schist	Vanhanen (2001), Dragon Mining (2011a)
Sivakkaharju	0.047	7.5	0.03	0.12	0.03	Sericite schist	Vanhanen (2001), Dragon Mining (2004)
Lemmonlampi	0.09	0.35	0.3	0.4		Dolerite	Pankka et al. (1991), Vanhanen (2001)
Meurastuksenaho	0.366	3.6	0.25	0.28		Sericite quartzite	Vanhanen (1989b, 2001), Dragon Mining (2011a)
Outside subarea F040.1							
Maiskoe	0.1	7.6				Volcanic rock	Bezrukov (1989)
Haarakumpu	4.68		0.17	0.34		Supracrustal rocks	Vartiainen (1984)

* Grade and tonnage based on limited data only.

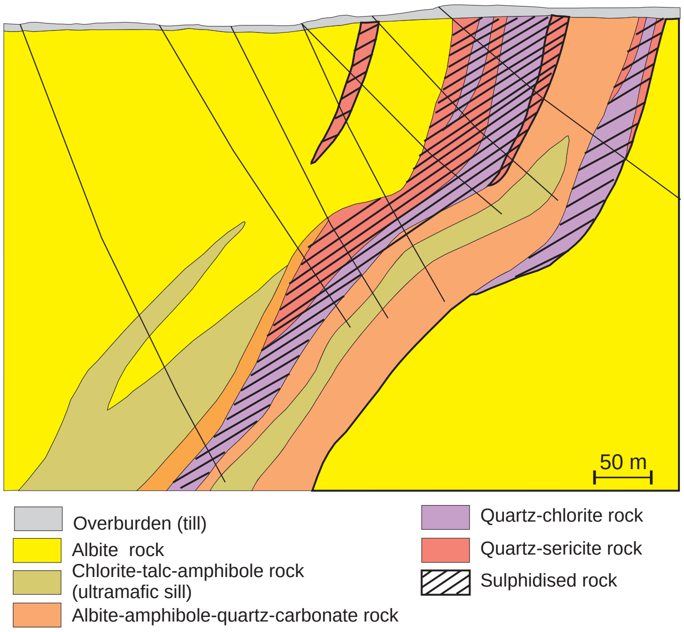


Figure 81. Section across the Juomasuo cobalt-gold deposit, after Pankka (1992). View to the NW. The deposit is at 66.2888°N, 29.1995°E.

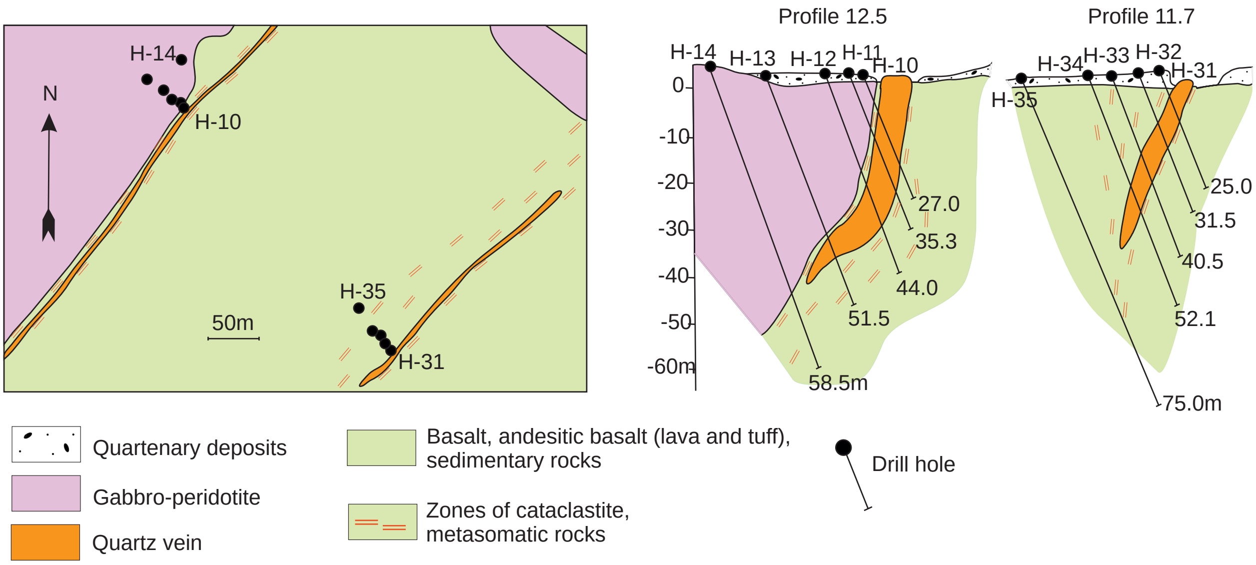


Figure 82. Geological map and sections across the Maiskoe gold deposit. Modified from the publication Raw Mineral Base of the Republic of Karelia (2005). The deposit is at 66.633°N, 29.717°E.

F041 JAURATSI Fe

Jorma Räsänen (GTK)

The Jauratsi Fe area (F041) is in the eastern part of Central Lapland greenstone belt (CLGB), where it comprises the area of the Siulionpalo Formation and its extensions to the north and southeast (Figs. 1 and 83). The Jauratsi area is bounded by a tectonic contact to the northeast, to the volcanic rocks of the >2.43 Ga Salla Group and to the 2.44 Ga Akanvaara layered intrusion (Mutanen 1997). Elsewhere, area F041 is bounded by the volcanic and sedimentary rocks of the Sodankylä Group, which are cut by a mafic dyke yielding a zircon age of 2070 ± 5 Ma (Räsänen & Huhma 2001).

The Siulionpalo Formation (Fig. 83), which in CLGB lithostratigraphy is the lowest unit of the 2.15–2.05 Ga Savukoski Group, lies immediately above the mafic volcanic rocks of the Sodankylä Group. It is overlain by the ca. 2.05–2.0(?) Ga Sattasvaara-type komatiites (Räsänen et al. 1995), locally called the Kummitsoiva Formation and the Kummitsoiva komatiite complex (Saverikko 1983). The lithology is comparable to the Matarakoski and Sattasvaara Formations, respectively, at Sodankylä in central CLGB. The Siulionpalo Formation essentially comprises oxide- to sulphide-facies iron formation. It consists of black, sulphide-rich schist and banded iron formation units associated with minor, mainly tuffitic, felsic volcanic rocks.

The main deposits of area F041 are composed of banded haematite-magnetite deposits, which are associated with iron sulphide-rich schists, have a lateritic goethite-rich cover, and were first described by Rieck et al. (1967). The **Jauratsi** iron deposit (Fig. 83, Table 39) locally contains relatively high Cu and Zn concentrations, up to 0.09 % and 0.4 %, respectively (Kerkkonen 1982). Potential mineral resources at the Jauratsi deposit have been estimated at more than 20 million tonnes (Korkalo 2006). The **Reposelkä** deposit is in a sulphide-facies iron formation (Table 39). To the south of Jauratsi is the **Vesilaskujänkä** VMS-style Cu-Co occurrence, associated with highly albitised felsic tuffites and sulphidic black schist.

Table 39. Metallic mineral deposits with a resource estimate in the Jauratsi Fe area (F041).

Occurrence	Tonnage (Mt)	Co %	Cu %	Fe %	Ni %	S %	Zn %	References (in addition to Kerkkonen 1982)
Jauratsi	16.5		0.03	27	0.05	17.8	0.06	Hugg & Heiskanen (1983)
Reposelkä	26			15		15		Roos (1982)
Vesilaskujänkä	1.8	0.01	0.35	12	0.02	8.1		Saltikoff et al. (2000)

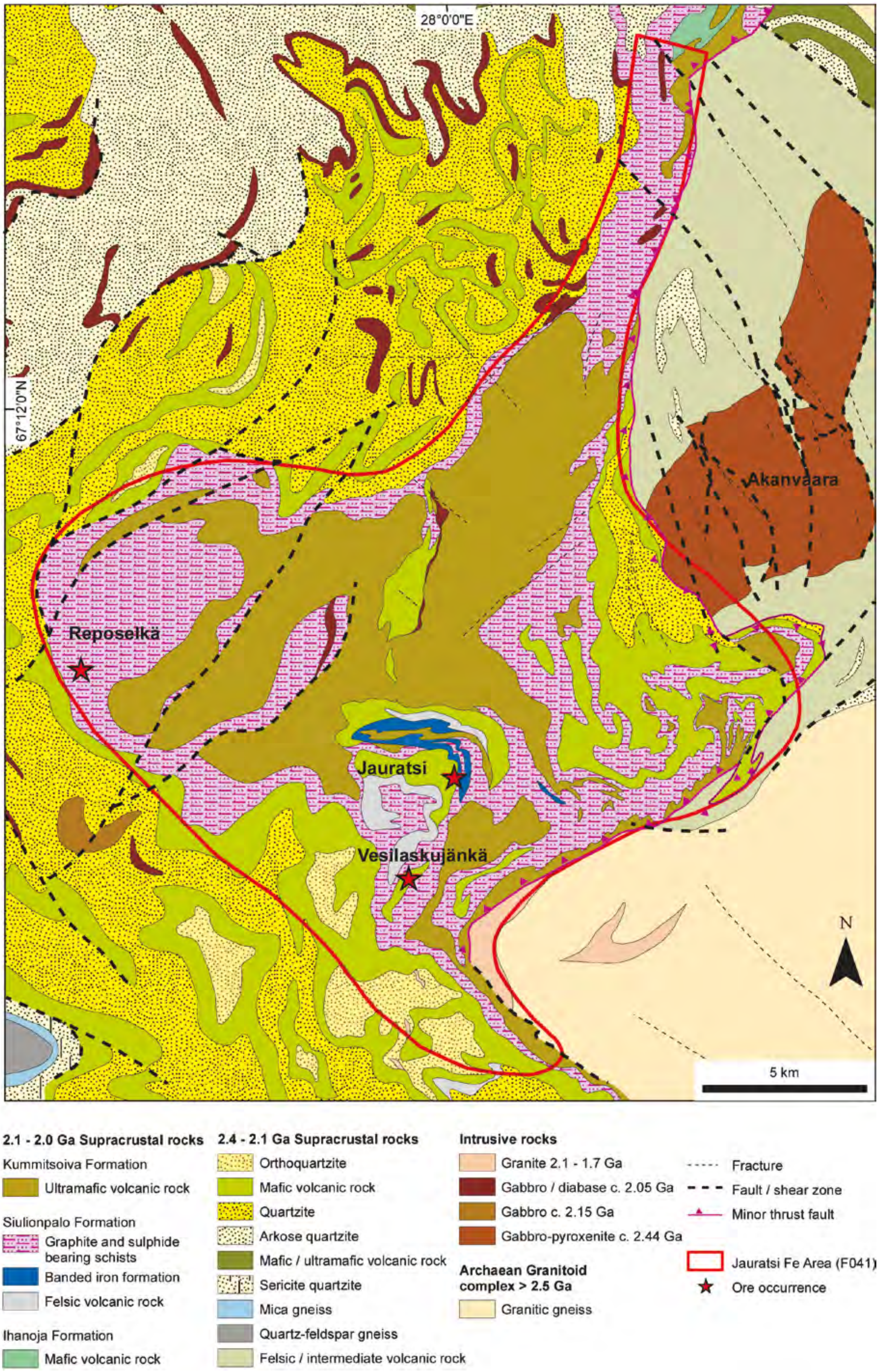


Figure 83. The Siulionpalo Formation and geology of the Jauratsi Fe area (F041) and its surroundings. Geology simplified from the GTK digital bedrock map database.

F042 KESÄNKITUNTURI U

Esa Pohjolainen (GTK)

The Kesänkitunturi U area (F042) is in the SW part of the Central Lapland greenstone belt (CLGB) (Figs. 1 and 84). The metallogenic area covers rocks of the Savukoski and Kumpu groups of the CLGB. Uranium deposit classes detected in the area include the sandstone and vein types. Four occurrences are known, and a mineral resource has been defined for two of them, Kesänkitunturi and Pahtavuoma.

The **Kesänkitunturi** metamorphosed sandstone deposit is hosted by sericite quartzite of the Ylläs formation, which rests disconformably on top of older schists and is discordantly overlain by younger clastics of the ca. 1.80–1.88 Ga Kumpu group (Lehtonen et al. 1998, GTK digital bedrock map database). *In situ* resources of Kesänkitunturi are 950 t U, with an average grade of 0.065 % U for 1.4 Mt of ore. Uranium occurs as uraninite in cement between quartz blastoclasts in the quartzite. The rock contains torbernite as a secondary uranium mineral; chalcopyrite and pyrite are also encountered. The deposit is completely within the Pallas-Yllästunturi National Park.

The **Pahtavuoma** vein-type deposit consists of three ore bodies in fine-grained metasedimentary rocks of the Matarakoski formation in the 2.15–2.05 Ga Savukoski group of the CLGB. The lodes are thin, subvertical sets of veins and lenses, with thicknesses varying from a few centimetres to several metres. The lengths and depths of the lodes are 100 m. Each lode is composed of more than one parallel vein, where uranium occurs in rich pods or nests. *In situ* resources in the two best bodies are 500 t U, with an average grade 0.39 % U. The main U-bearing mineral is uraninite, which forms intergrowth structures with pyrrhotite and molybdenite (Korkalo 2006). In addition to U, the 0.14 Mt occurrence is enriched in Ag (avg. 24 g/t), Co (0.01 %), Cu (0.24 %) and Pb (0.09 %). The uraniferous veins at Pahtavuoma are connected to shear zones or fractures younger than the main deformational event of the CLGB.

Uraninite-bearing veins also are present at **Laavivuoma**, 1.5 km west of Pahtavuoma. Uraninite occurs as roundish or angular grains in veins with brown amphibole, quartz and molybdenite. The uraninite grains are partly fractured due to subsequent deformation, grain fractures are filled by quartz. Uraninite also occurs as bands, in the cement of microbreccia, and as inclusions with magnetite and ilmenite inside brown amphibole. Colloform pitchblende occurs in veins and clusters with silicates and fine-grained molybdenite (Pääkkönen 1988).

The **Aakenusvaara** occurrence is located 10 km east of the Pahtavuoma deposit. Pebbles of uraniferous biotite schist were identified in outcrops of radioactive conglomerate about 5 km to the SE from the Aakenusvaara occurrence. A subsequent search for the provenance of this type of mineralized rock led to the discovery of the Aakenusvaara occurrence. It is located in the Pittarova formation metasediments and metavolcanic rocks of the Savukoski group of the CLGB, 2 km SE of the Saattopora gold mine. Uraninite occurs as roundish grains with a variable degree of alteration, as dissemination and as chains of grains in biotite schist layers. Pitchblende fills microcracks, which cut all preceding mineral phases in the biotite schist (Pääkkönen 1989).

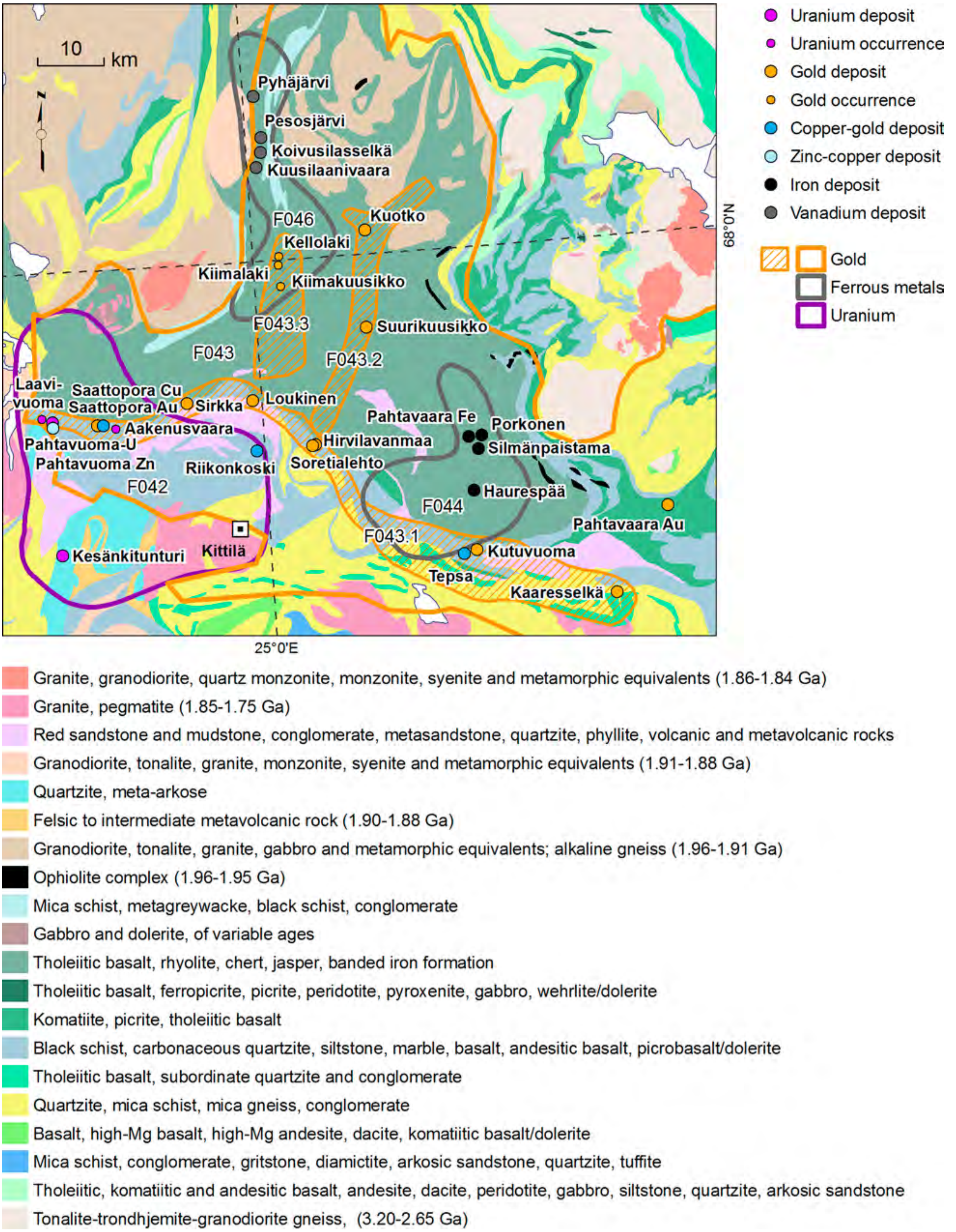


Figure 84. Geology of Central Lapland, metallogenic areas F042, F043, F044 and F046, and metallic deposits with a resource estimate. Geology is from the GTK digital bedrock map database.

F043 KITTILÄ Au, Cu

Pasi Eilu, Tero Niiranen, Helena Hulkki, Vesa Nykänen (GTK)

The Kittilä metallogenic area (F043) covers most of the Central Lapland greenstone belt (CLGB). It extends from the Pajala Shear Zone in the west to Sodankylä in the southeast, north of Koitelainen intrusion in the northeast, and to the Central Lapland Granitoid Complex in the south (Fig. 84). The boundaries of area F043, other than that to the west, are not exact, as indications of gold mineralisation just appear to gradually fade out.

The Central Lapland greenstone belt (CLGB) is the largest mafic volcanic-dominated province preserved in Fennoscandia. It extends from the Norwegian border in the northwest to the Salla greenstones near the Russian border in the southeast. The belt was initially formed in an intracratonic rift setting related to the breakup of the Archaean Karelian craton (Hanski & Huhma 2005). The sequence starts with bimodal komatiitic and felsic volcanic rocks, dated at ca. 2.45 Ga, which overlie unconformably the Archaean basement and represent the onset of rifting (Peltonen et al. 1988, Lehtonen et al. 1998, Manninen et al. 2001). This was followed by 300–400 Ma of deposition of quartzite, turbidite, carbonate rock, iron formation, graphitic schist and basalt, intermittently intruded by mafic dykes and sills dated at ca. 2.2 Ga, 2.10 Ga, and 2.05 Ga (Huhma 1986, Lehtonen et al. 1998, Vaasjoki 2001). Rifting culminated in extensive mafic and ultramafic volcanism and the formation of oceanic crust at about 1.97 Ga. Fragments of oceanic crust were subsequently emplaced back onto the Karelian craton, as indicated within the CLBG by the Nuttio ophiolites (Hanski & Huhma 2005). The emplacement of the ophiolites was followed by the main compressional deformation associated with the Svecofennian synorogenic plutonism, between 1.92–1.86 Ga (Vaasjoki 2001, Lahtinen et al. 2005). Deformational evolution of the CLGB during 1.92–1.77 Ga apparently took place as follows (Ward et al. 1989, Sorjonen-Ward et al. 1992, Mänttäri 1995, Lahtinen et al. 2005, Patison 2007): D_1 and D_2 during 1.92–1.88 Ga, D_3 either during 1.92–1.88 Ga or 1.84–1.79, and the latest, completely brittle D_4 in ca. 1.77 Ga or slightly post-1.77 Ga. Note, however, that the timing for the deformation stages is chiefly indirect, with very few robust radiometric dates setting definite values for any of the stages; in particular, the timing of D_3 is poorly constrained (Lahtinen et al. 2005, Patison 2007). Saalmann and Niiranen (2010) list five deformation stages for the Hanhimaa and western Sirkka Shear Zone areas, with D_1–D_4 being mostly ductile and D_5 brittle. Somewhat similar geotectonic evolution to that for the CLGB can be envisioned for both the Kuusamo and Peräpohja belts for the entire Proterozoic (e.g., Lahtinen et al. 2005).

The main styles of metallic mineralisation in the area F043 are orogenic gold and seafloor-style (syngenetic) zinc-copper deposits (Inkinen 1979, Korkiakoski 1992, Korvuo 1997, Eilu et al. 2007). The orogenic gold type (Table 40) can be further divided into gold-only and gold-copper subtypes. In addition, the gold palaeoplacers of the <1.88 Ga Kumpu Group molasse sequence overlying the greenstone sequences (Härkönen 1984) can be regarded as belonging to area F043, and their gold is probably derived from the orogenic and/or syngenetic occurrences in the region.

Gold mineralisation within area F043 is of the orogenic type as defined by Groves (1993), and the entire CLGB is in many aspects, except for age, similar to Neoarchaean greenstone belts elsewhere in the world rich in orogenic gold mineralisation. Typical characteristics of the occurrences include the following: the structure is the single most important control for mineralisation, Au/Ag >1, quartz veining is abundant, the sulphide contents are at 1–3 vol%, the dominant ore minerals are pyrite, arsenopyrite and pyrrhotite, gold mostly occurs in the native form, carbonatisation, sericitisation and biotitisation haloes surround mineralisation, and most occurrences are in lower- to mid-greenschist facies rocks (Härkönen et al. 1999, Eilu et al. 2007, Patison 2007, Patison et al. 2007). In addition to structure, another significant factor in locally controlling gold mineralisation is the tuffite and phyllite units pervasively albitised (± carbonated) in the early stages of the regional evolution. During the later orogenic stages, these were the locally most competent units, which thus provided the best sites for local dilation, veining and mineralisation (e.g. Grönholm 1999, Saalmann & Niiranen 2010).

Many of the occurrences of area F043 are of the gold-only style, but about a half of the occurrences also contain Co, Cu and/or Ni as a potential commodity (Table 40). This has been explained by the latter belonging to the subcategory of 'anomalous metal association' as defined by Goldfarb et al. (2001) for similar deposits at, for example, Sabie–Pilgrim's Rest in South Africa, and Tennant Creek, Pine Creek and Telfer in Australia. The gold-only orogenic mineralisation derives

Table 40. Gold±copper deposits and occurrences in the Kittilä metallogenic area (F043) having a reported resource estimate.

Subarea, Occurrence	Tonnage (Mt)	Mined (Mt)	Au g/t	Co %	Cu %	Ni %	Genetic type	Reference
Sirkka Au-Cu (F043.1)								
Hirvilavanmaa	0.11		2.9				Orogenic	Härkönen & Keinänen (1989)
Kaaresselkä	0.3		5		nr		Orogenic	Pulkkinen (1999)
Kutuvuoma	0.068	tm	6.7				Orogenic	Anttonen (1995), Korkalo (2006)
Loukinen[1]	0.114		0.5		nr	0.45	Orogenic	Holma & Keinänen (2007)
Riikonkoski[2]	9.45		nr		0.45		Orogenic[2]	Yletyinen & Nenonen (1972)
Saattopora Au[3]	2.163	2.163	2.9		0.25		Orogenic	Korvuo (1997), Eilu et al. (2007)
Saattopora Cu	11.6		0.25	0.01	0.62	0.1	Orogenic[2]	Lehtinen (1987), Korkalo (2006)
Sirkka	0.25	tm	0.8	0.1	0.38	0.32	Orogenic[2]	Vesanto (1978)
Soretialehto	0.013		3.5				Orogenic	Keinänen & Holma (2001)
Suurikuusikko Au (F043.2)								
Suurikuusikko (Kittilä Mine)	58.64	2.2[4]	3.74				Orogenic	Härkönen et al. (1999), Patison et al. (2007) , Agnico-Eagle (2011)
Kuotko	1.116		3.4				Orogenic	Härkönen & Keinänen (1989), Agnico-Eagle (2011)
Beyond the subareas								
Pahtavaara Au	4.3	3.5	2.7				Orogenic or syngenetic	Korkiakoski (1992), Lappland Goldminers (2010)

nr Not reported in the resource estimate, but analysed drill intercepts indicate that the deposit contains, at least in parts, several g/t gold (if Cu reported) or 0.1–2 % copper (if Au reported).
tm Small-scale test mining only.
1 Four or five ore bodies known, some probably with higher gold and lower base metal grades, but only one with a reported resource estimate.
2 Either a syngenetic Cu deposit overprinted by orogenic gold mineralisation or an orogenic deposit with an anomalous metal association.
3 Only the mined tonnage has been reported; there are probably resources at depth, but their volume is unknown.
4 Mining in 2008–2010 (Mining Registry official statistics and Agnico-Eagle annual reports)

from low-salinity orogenic fluids devoid of base metals, whereas the orogenic Au-Cu±Co±Ni±Ag mineralisation derives from moderate- to high-salinity orogenic fluids formed in an intracratonic setting of evaporate-bearing, volcanosedimentary sequences locally rich in base metals subjected to orogenic processes (Groves 1993, Goldfarb et al. 2001). Obviously, both low- and moderate-salinity fluids have been active within the CLGB, which indeed has all the above-mentioned features for moderately saline, base metal-enriched fluids to be formed (e.g., Hanski & Huhma 2005).

Despite multiple efforts (Mänttäri 1995, Sorjonen-Ward et al. 1992, 2003, Rastas et al. 2001), the dating of gold mineralisation in northern Finland is not well constrained. Most or all of orogenic gold mineralisation apparently took place during a continent-continent collision epoch of the evolution of the Fennoscandian shield, at 1.85–1.79 Ga. However, some orogenic mineralisation may be related to the earlier compressional stage, the microcontinent accretion, at 1.92–1.88 Ga, as is implied by the preliminary Re-Os data from Suurikuusikko. Saalmann and Niiranen (2010) suggest that a significant part of gold mineralisation postdates the 1.79–1.77 Ga Nattanen-type granites.

Three subareas with a high potential of discovery of gold deposits have been defined for F043: Sirkka, Suurikuusikko and Hanhimaa (F043.1, F043.2, F043.3, respectively; Figure 84). The worm-shaped Sirkka Subarea covers the west- to northwest-trending Sirkka Shear Zone and its subsidiary faults: there are more than 30 drilling-indicated occurrences, of which one (**Saattopora**; Fig. 85) has been mined, and two (**Kutuvuoma**, **Sirkka**) test mined. A few are gold-only occurrences, but most cases include Cu and some also Co and Ni as potential commodities. Quartz-carbonate±albite veining is extensive, the dominant hosts are komatiite, intermediate tuffite and phyllite, and pre-gold albitisation is common in tuffite and phyllite (Korvuo 1997, Pulkkinen 1999, Hulkki & Keinänen 2007, Eilu & Pankka 2009). Occurrences within the Sirkka Subarea are, in most aspects, similar to the Pahtohavare and Bidjovagge copper-gold deposits in Sweden (S037) and Norway (N036), respectively (Ettner et al. 1994, Lindblom et al. 1996).

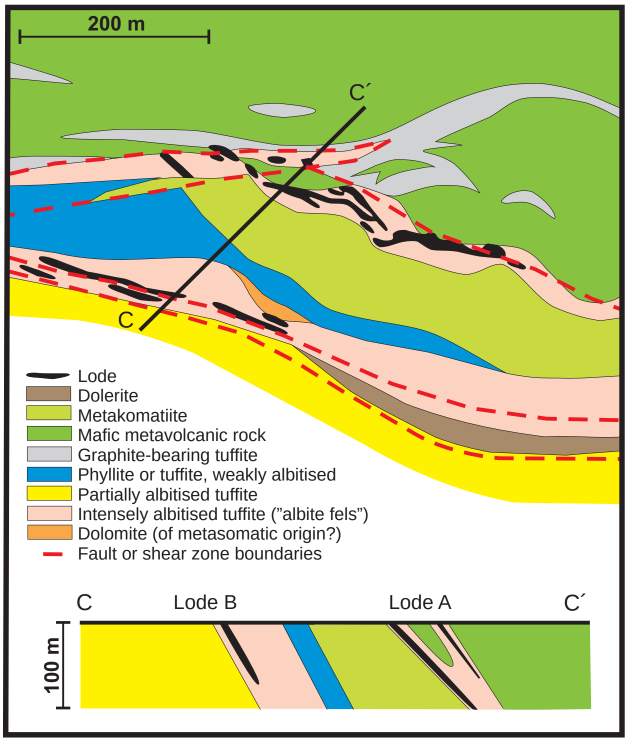


Figure 85. Geological map and a section across the Saattopora deposit. Note the presence of all lodes within the most intensely albitised tuffite, that is, within the locally most competent rock unit. Modified from Korvuo (1997).

The Suurikuusikko subarea (F043.2) comprises the north- to northeast-trending Kiistala Shear Zone and its immediate surroundings (Fig. 84). It includes the **Suurikuusikko** (Kittilä mine) and **Kuotko** gold deposits. They are structurally controlled gold-only occurrences in greenstones, and characterised by carbonate-biotite-graphite-chlorite alteration. At Suurikuusikko (Fig. 86), nearly all of the gold is refractory, bound in arsenopyrite and pyrite, whereas free native gold dominates at Kuotko (Härkönen & Keinänen 1989, Härkönen et al. 1999, Patison et al. 2007). Exploration data summarised by Eilu and Pankka (2009) show that subarea F043.2 must be regarded as having a great potential for further discoveries, as practically all drilling within the shear zone system, both along strike and to the depth of >1 km, has intercepted high gold grades.

The Hanhimaa subarea (F043.3; Fig. 84) contains the most recent gold discoveries in northern Finland. The subarea F043.3 is N- to NE-trending, containing the 20-km-long Hanhimaa Shear Zone (HSZ) with its subsidiary faults and surrounding bedrock. Interestingly, the shear and fault system is parallel to the Kiistala Shear Zone. The gold potential in the Hanhimaa subarea was

Figure 86. Aerial view of the Suurikuusikko (Kittilä) mine site in September 2010. The ore zone is visible as a dark grey band in the middle of the main open pit. The small Rouravaara open pit is at upper left. View to the NE. Photo: courtesy of Agnico-Eagle Mines Ltd.

identified in 2002. Since then, three gold prospects (Kiimalaki, Kellolaki and Kiimakuusikko) have been located within the 100–200 metre wide domain of strongly sheared and hydrothermally multiply altered greenstones and felsic dykes within the HSZ proper and in subsidiary faults to it (Dragon Mining 2009, 2011b, Saalmann & Niiranen 2010). The metal association in the drill intercepts varies from gold-only through Au-Ag to Au-Ag-Pb-Zn-Sb-Cu, suggesting orogenic gold mineralisation with both normal and anomalous metal association plus a possibility of syngenetic (VMS-style?) base-metal mineralisation overprinted by orogenic gold system(s) (Dragon Mining 2009 and 2011b). Nearly all exploration, and all drilling, has so far been performed for a small part of subarea F043.3. This suggests that much more is still to be discovered within the subarea.

The **Pahtavaara** gold deposit (Fig. 87) in the southeastern part of area F043 is somewhat an enigma. It has many of the alteration characteristics of amphibolite-facies orogenic gold deposits and an obvious structural control, but has an anomalous barite-gold association and a very high fineness (>99.5 % Au) of gold (Kojonen & Johanson 1988, Korkiakoski 1992). The geometry of high-grade quartz-barite lenses and amphibole rock bodies relative to biotite-rich alteration zones is also anomalous. Pahtavaara may well be a metamorphosed seafloor alteration system with ore lenses as either carbonate- and barite-bearing cherts or quartz-carbonate-barite veins. The gold may have been introduced later, but its grain size, textural position (nearly all is free, native, and occurs with silicates, not sulphides) and high fineness point to a pre-peak metamorphic timing, which is highly anomalous for orogenic gold.

There are a number of VMS-style (or other syngenetic type) base-metal occurrences in the southern part of the Kittilä area. Most of them are obviously small, have seen only minor drilling, and have no resource estimate. The main exception is the **Pahtavuoma** copper-zinc deposit, near the SW corner of area F043, containing 21.4 Mt at 0.3 % Cu, 0.67 % Zn, 0.03 % Co and 10 g/t Ag (Inkinen 1979, Korvuo 1997). The deposit is open at the depth of 300–400 m. Pahtavuoma comprises six zinc-rich and four copper-rich ore bodies. In two periods during 1974–1993, 0.3 Mt of copper ore was test mined at Pahtavuoma at grades of 1.07% Cu and 26 ppm Ag (Puustinen 1995). As suggested in Table 40, a number of low-grade syngenetic(?) base-metal occurrences may have been overprinted by orogenic gold mineralisation within area F043. This is one of the possible reasons, in addition to the moderate-salinity orogenic fluids and extensive supracrustal sequences with highly variable rock types and multiple deformation, why there are so many polymetallic occurrences in northern Finland where the processes of mineralisation and genetic types of the ores are difficult to determine.

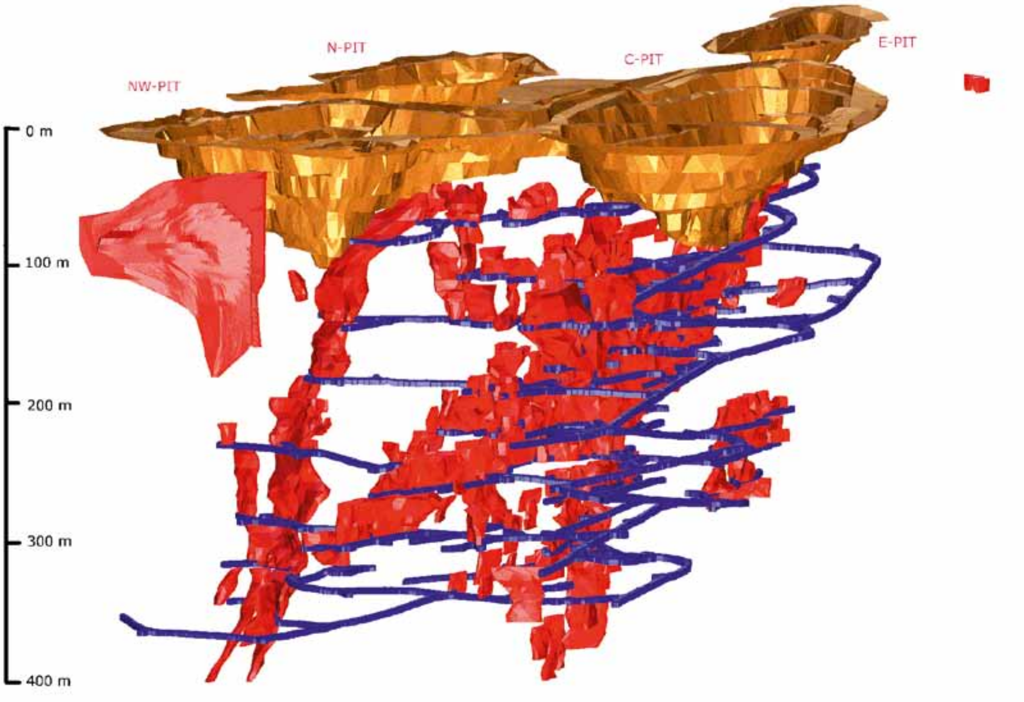


Figure 87. Open pits (brown), underground drives (blue) and ore bodies as of December 2010 in the Pahtavaara gold mine. View to the NE. Image: courtesy of Lappland Goldminers AB.

F044 PORKONEN-PAHTAVAARA Fe-Mn

Helena Hulkki & Tuomo Karinen (GTK)

The Porkonen-Pahtavaara area (F044) is in the Palaeoproterozoic Central Lapland greenstone belt (CLGB), entirely inside the Kittilä metallogenic area (F043) (Fig. 84). Extent of metallogenic area F044 is defined by the presence of chemical sediments of the Porkonen Formation of the Kittilä Group of the CLGB (Lehtonen et al. 1998). These chemical sediments predominantly comprise alternating layers of chert, iron-rich minerals and graphite, and they are commonly mixed on a fine scale with volcaniclastic material (Paakkola & Gehör 1988). Besides the chemical sediments, the Porkonen Formation comprises graphitic tuffaceous schists and mafic lavas. The geological evolution of the region is briefly described in the description of metallogenic area F043.

Oxide-, carbonate- silicate- and sulphide-facies iron formation occur area F044. Typically, the oxide facies is in the lower, carbonate facies in the mid- and sulphide facies in the upper part of the sequence. Abundant manganese characterises the carbonate-facies iron formation, as is the case in the **Silmänpaistama** deposit (Table 41). The sequence also contains phosphorite bands a few millimetres thick (Paakkola 1971, Gehör 1994). All deposits are deformed and metamorphosed under lower- to mid-greenschist facies conditions, and are fine-grained. Hence, and due to being rather small, they have never been exploited, except their jasper been used as a decorative stone to a small extent (Kinnunen 1982), even though they have intermittently been explored for more than 150 years (Saltikoff et al. 2006).

Table 41. Iron occurrences with a reported resource within the Porkonen-Pahtavaara metallogenic area (F044). The data are from Paakkola (1971), Hugg & Heiskanen (1983) and Gehör (1994).

Occurrence	Tonnage (Mt)1	Fe %	Mn %	Main ore minerals
Haurespää	15.3	33		Magnetite, goethite, haematite, siderite
Pahtavaara Fe	14	30		Magnetite, goethite, haematite
Porkonen	9	30		Magnetite, goethite, haematite
Silmänpaistama	7	21.4	5.9	Siderite, manganosiderite, magnetite, goethite, haematite

F045 KOITELAINEN Cr, V, PGE

Markku Iljina, Tuomo Karinen, Pasi Eilu (GTK)

The Koitelainen area (F045) covers the Koitelainen intrusion in Central Lapland (Figs. 1 and 88). Koitelainen is the largest of the ca. 2.45 Ga mafic to ultramafic layered intrusions that occur near the Archaean-Proterozoic boundary in the northern parts of the Fennoscandian shield. The intrusion is subhorizontal, 26 x 29 km in horizontal extent and roughly 3 km in thickness (Mutanen 1997). The emplacement of the 2.45 Ga intrusions is part of a large plume-related rifting event (Mu-

Table 42. Metallic mineral deposits and occurrences in the Koitelainen metallogenic area (F045) having a reported resource estimate.

Occurrence	Tonnage (Mt)	Cr %	PGE g/t[2]	Pd g/t	Pt g/t	V %	Main host rock	Reference
Koitelainen LC	2[1]	15.7		0.9	0.48	nd	Chromitite	Mutanen (1989, 1997)
Koitelainen UC	70	14.4	1.1			0.4	Chromitite	Mutanen (1989, 1997)
Koitelainen V	15					0.2	Gabbro	Mutanen (1989, 1997)

1 The deposit is probably much larger, as three to six LC layers seem to extend for at least 20 km along strike (Mutanen 1997); however, due to minor drilling, the total tonnage cannot be reliably estimated.

2 'PGE g/t' indicates the combined Pd and Pt content.

nd The chromite is reported to be V-rich, but the V content of the occurrence is not reported (Mutanen 1997).

tanen & Huhma 2001, Alapieti 2005). This event belongs to a global episode of igneous activity at the beginning of the Proterozoic that produced several layered intrusions and mafic dyke swarms on other cratons, and was, at least in Fennoscandia, related to the initial breakup of an Archaean craton (Alapieti & Lahtinen 2002, Hanski et al. 2001b, Iljina & Hanski 2005).

Mineralisation at Koitelainen is stratiform. There are two major, sulphide-free, PGE-enriched chromite reefs (**Koitelainen UC** and **Koitelainen LC,** Table 42) possibly extending across the entire intrusion, and a V-rich gabbro (**Koitelainen V**). Both of the chromite reefs are enriched in vanadium. Although the intrusion hosts a V-rich magnetite gabbro, the UC reef still is the most significant V mineralisation within the intrusion. The main V mineral in the UC and LC reefs is chromite and in the gabbro magnetite. The Koitelainen V deposit is a magnetite gabbro 40 m thick, located in the middle part of the upper third of the intrusion. The UC reef has a varying thickness of 0.8–2.2 m and, at surface, it extends along strike for 60 km. The LC reef layers occur within 60 m of the stratigraphy of the intrusion, and are known for about 20 km along strike. (Mutanen 1989, 1997)

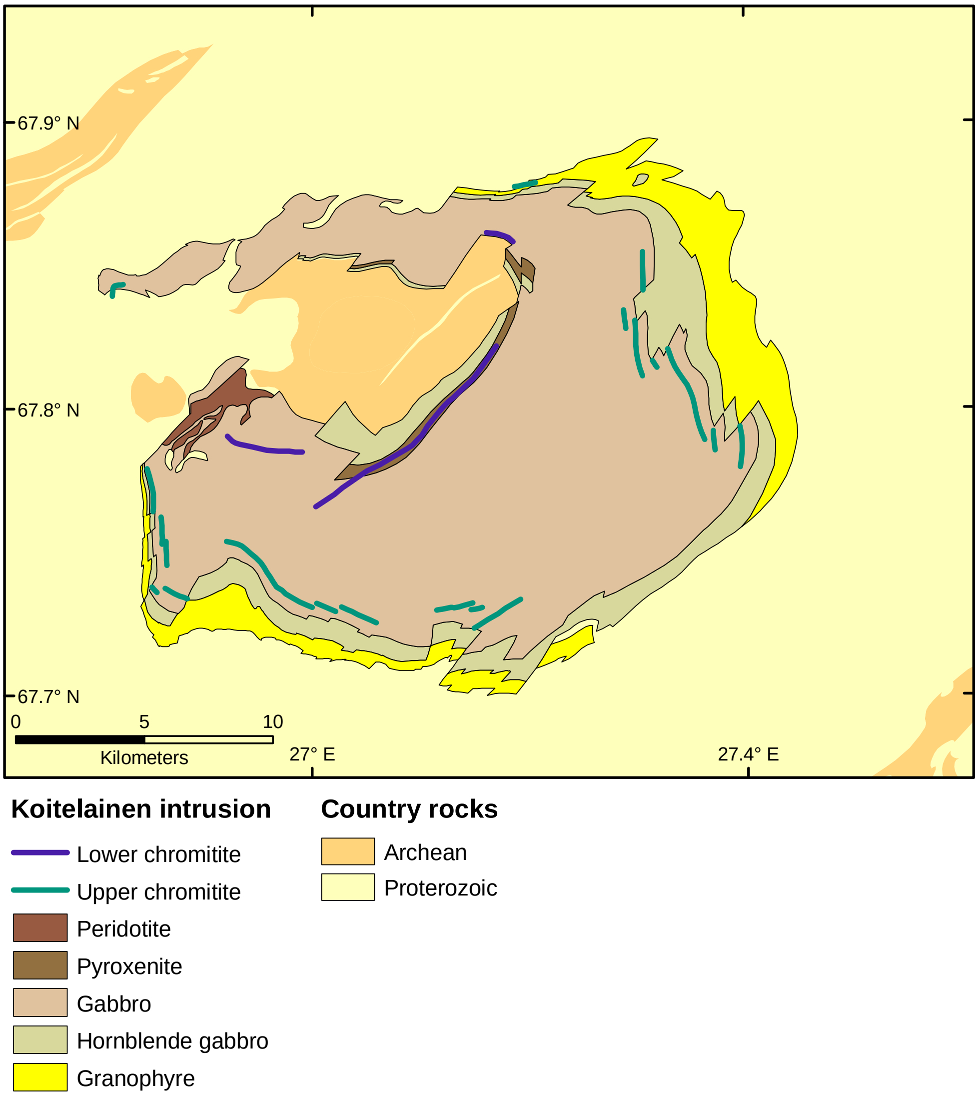


Figure 88. Geology of the Koitelainen intrusion and its immediate surroundings, after Rasilainen et al. (2010). 'Lower chromitite' and 'Upper chromitite' indicate the surface exposures of the Koitelainen LC and Koitelainen UC deposits, respectively.

F046 PYHÄJÄRVI V-Ti-Fe

Tuomo Karinen & Pasi Eilu (GTK)

The Pyhäjärvi area (F046) is located in the northern part of the Palaeoproterozoic Central Lapland greenstone belt (CLGB), almost entirely inside the Kittilä metallogenic area (F043) (Fig. 84). The extent of metallogenic area F046 is defined by the presence of V ± Ti-Fe occurrences in highly altered and deformed, medium-grained mafic rocks running along the N- to NE-trending contact of the supracrustal rocks and monzonitic intrusion (Makkonen et al. 1968, Lehto & Niiniskorpi 1977, Hugg & Heiskanen 1983). The supracrustal rocks belong to the 2.1–2.0 Ga Kittilä Group in the lithostratigraphic division of the CLGB. There is no age determination for the monzonitic intrusion, but it is assumed to belong to the 1.89–1.86 Ga Haparanda suite (Lehtonen et al. 1998).

Very little information is available on the F046 deposits (Table 43), as only minor exploration has been carried out in the area. The vanadium ore occurs as semimassive-massive oxide veins and dissemination in amphibolite. Immediately to the west of the amphibolites, there are gabbroic rocks, but there is no knowledge of how the ore is related to these gabbros; for instance, there is not enough data to show whether the ore could possibly represent residual liquid of the gabbros. Furthermore, there is no idea how the hosting amphibolite and the gabbros are related to the monzonitic intrusion. Individual vanadium ore veins are a few centimetres to 2.5 m wide. Ore bodies are 50–400 m long, 5–15 m wide and eastward gently dipping, open at depths of 100–300 m. The main ore minerals in all vanadium (± Ti-Fe) occurrences are ilmenite and magnetite, which occur disseminated and as subparallel veins in the host rock (Makkonen et al. 1968, Hugg & Heiskanen 1983). The main gangue in the ore veins is chlorite. The grades in the Pyhäjärvi occurrence (two samples from the old drill cores) have recently been checked by GTK with the following results: 0.61–0.70 % V (1.09–1.25 % V_2O_5), 10.6–11.0 % TiO_2 and 62.5–68.7 wt% Fe_2O_3 and 0.015–0.018 % Co, with no REE or precious metals detected. The grades are similar to those originally reported from these drill cores.

Table 43. The V-Ti-Fe occurrences with a reported resource within the Pyhäjärvi metallogenic area (F046).

Occurrence	Tonnage (Mt)1	Fe %	Ti %	V %	References
Kuusilaanivaara	0.25			0.4	Makkonen et al. (1968), Hugg & Heiskanen (1983)
Koivusilasselkä	0.85	25–30		0.31	Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)
Pesosjärvi	0.70			0.22	Makkonen et al. (1968), Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)
Pyhäjärvi	2.70*	25	3	0.4	Makkonen et al. (1968), Lehto & Niiniskorpi (1977), Hugg & Heiskanen (1983)

* Makkonen et al. (1968) suggested that the total amount of ore to the depth of 400 m could be about 6.0 Mt.

F047 RUOSSAKERO Ni

Tuomo Karinen, Jukka Konnunaho (GTK), Jan-Anders Perdahl (SGU)

The Ruossakero metallogenic area (F047) is in the northwesternmost Finland and in the adjacent part of Sweden. It is defined by the extent of the Archaean, komatiite-bearing greenstones, and the presence of layered intrusions potentially containing PGE deposits near the Archaean–Proterozoic boundary (Figs. 1 and 89).

In Finland, the metallogenic area includes two Ni-enriched domains, Ruossakero and Sarvisoaivi, where the mineral occurrences are associated to ultramafic bodies in the Archaean, komatiite-dominated greenstones. The Ruossakero domain is a zone of ultramafic komatiitic (serpentinite, dunite and minor pyroxenite) bodies 4-km-long and 1-km-wide. At Sarvisoaivi, a few km to the west of Ruossakero, the main hosting body is 700 m x 700 m wide and 200–300 m thick. Geophysical studies and bedrock mapping indicate another ultramafic body (SE-trending, about 1 km long, 3.5–35 m thick) within the Sarvisoaivi domain (Isomaa 1982).

The Ruossakero nickel deposit has a surface extension of 340 m x 100 m and a thickness of 100 m. Isomaa (1988) estimated that the deposit hosts 5.44 Mt @ 0.53 % Ni (cut off at 0.4 wt%). The preliminary feasibility study in 1996 suggested an open-pittable 1.6 Mt @ 0.61 % Ni (0.5 % Ni cut off) (Lahtinen 1996). At 0.3 % Ni cut off, the deposit could be 35.6 Mt with 0.42 % or 0.33 % Ni, depending on calculation method used (Lahtinen 1996). Pyrite and millerite are the principal ore minerals in the deposit. They occur as dissemination together with minor chalcopyrite in three distinct subzones that vary in thickness from 4 to 42 metres (average thickness 24 m).

To the south, several mafic-ultramafic bodies have been found within the poorly explored Archaean province north of Kiruna in Sweden, but no mineral resource estimates have been made for them. A few of these are within the domain of metallogenic area F047. One of the largest intrusions is Kurkovare, being at least 6 km long and up to 940 m wide. The intrusion is mainly medium-grained consisting of anthophyllite, tremolite, chlorite, talc, olivine and serpentine. The northernmost part is altered to soapstone. The magnesium content varies between 30 and 40 % MgO, nickel between 0.10 and 0.38 % Ni (mainly silica bonded), and chromium between 0.4 and 2.4 % with an average of 0.78 % Cr (Lilljequist 1980). Geophysical surveys suggest the presence of additional mafic-ultramafic intrusions in the neighbourhood, within the Swedish part of area F047.

The relationship between the intrusions and the known komatiitic volcanic rocks is unclear for most cases within the Ruossakero metallogenic area. However, the presence of the 2.44 Ga Kaamajoki-Tshokkoaivi layered intrusion in the Finnish part (Heikura et al. 2004) indicates that not all Ni-Co-(PGE) potential of the area F047 is confined to Archaean komatiites.

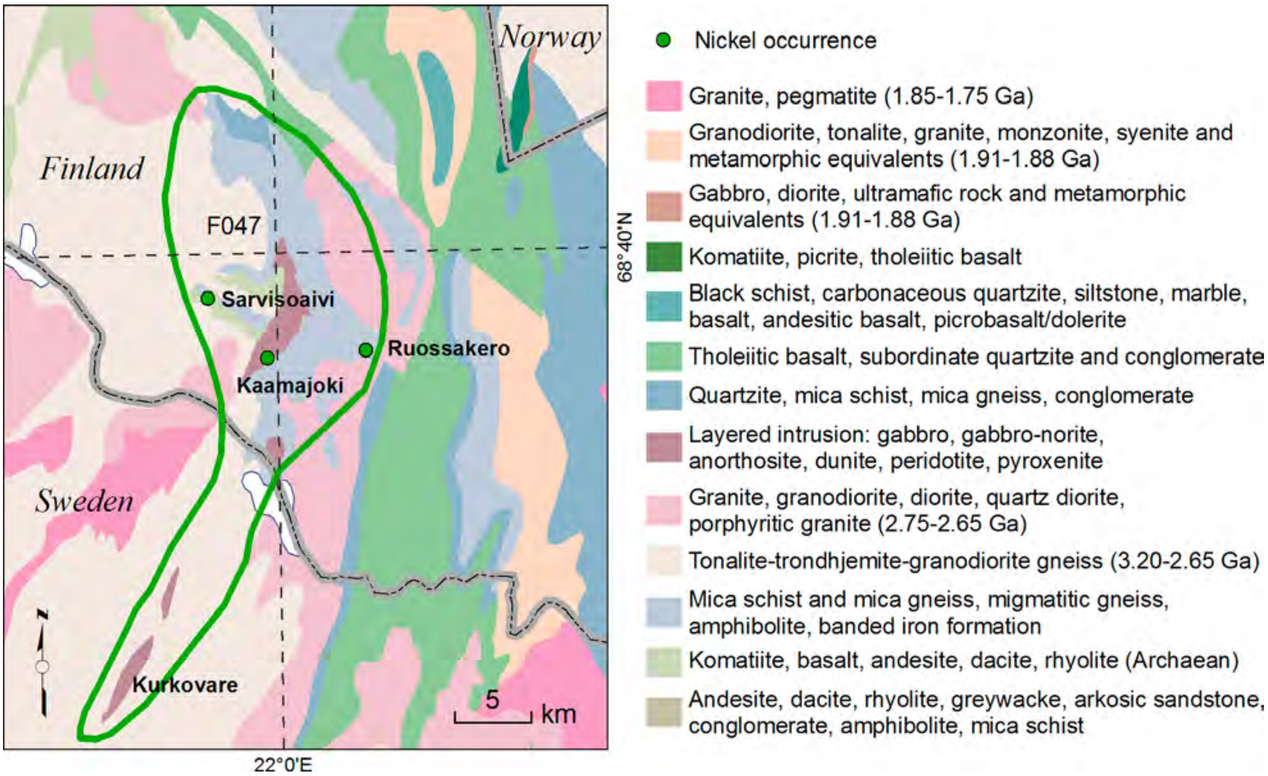


Figure 89. Geological map of the Ruossakero metallogenic area (F047). Geology based on Koistinen et al. (2001).

F048 SATTASVAARA Ni

Jorma Räsänen (GTK)

The Sattasvaara metallogenic area (F048) is in the central part of Central Lapland greenstone belt (CLGB), where it covers the essential parts of the Sattasvaara Formation (Figs. 1 and 90). The Sattasvaara Formation is composed of komatiites and picrites constituting the upper part of the Savukoski Group, whereas the lower part is dominated by graphite- and sulphide-bearing schists of the Matarakoski Formation, which includes the first manifestation of extensive black schists in the Palaeoproterozoic lithostratigraphy of the Central Lapland greenstone belt (Räsänen et al. 1995). According to mineral assemblages (amphibole+cholorite±biotite), the rocks of area F048 are metamorphosed under greenschist-facies conditions and, though their primary mineralogy is changed, primary volcanic textures and structures are well preserved.

The general outline of the CLGB is given by Hanski and Huhma (2005) and in the description of the Kittilä area (F043). The Sattasvaara Formation comprises ultramafic and mafic komatiites and minor basalts, which lie on the sulphide-rich black schists of the approximately 2.15–2.05 Ga Matarakoski Formation (e.g. Saverikko 1985, Korkiakoski 1992, Lehtonen et al. 1998, Räsänen 1996, 2005). In the Sattasvaara metallogenic area, komatiites occur in an E-trending synclinal structure nearly 10 km wide and 40 km long. A large proportion of the volcanic rocks are pillow lavas and fragmental rocks, but massive lava flows and sill-like ultramafic to mafic cumulates are also present. So far, there are no reliable radiometric age data for the volcanic rocks of the Sattasvaara Formation, but one of its branches continues far into northern Norway, where Krill et al. (1985) have reported a Sm-Nd age of 2085 ± 85 Ma from the komatiites. The Kevitsa mafic-ultramafic intrusion is enclosed by sulphide-bearing black schists of the Matarakoski Formation immediately to the east of area F048 (Fig. 90), and yields an age of about 2050 Ma (Sm-Nd 2052 ± 25 Ma and U-Pb 2057 ± 5 Ma; Huhma et al. 1996, Mutanen 1997).

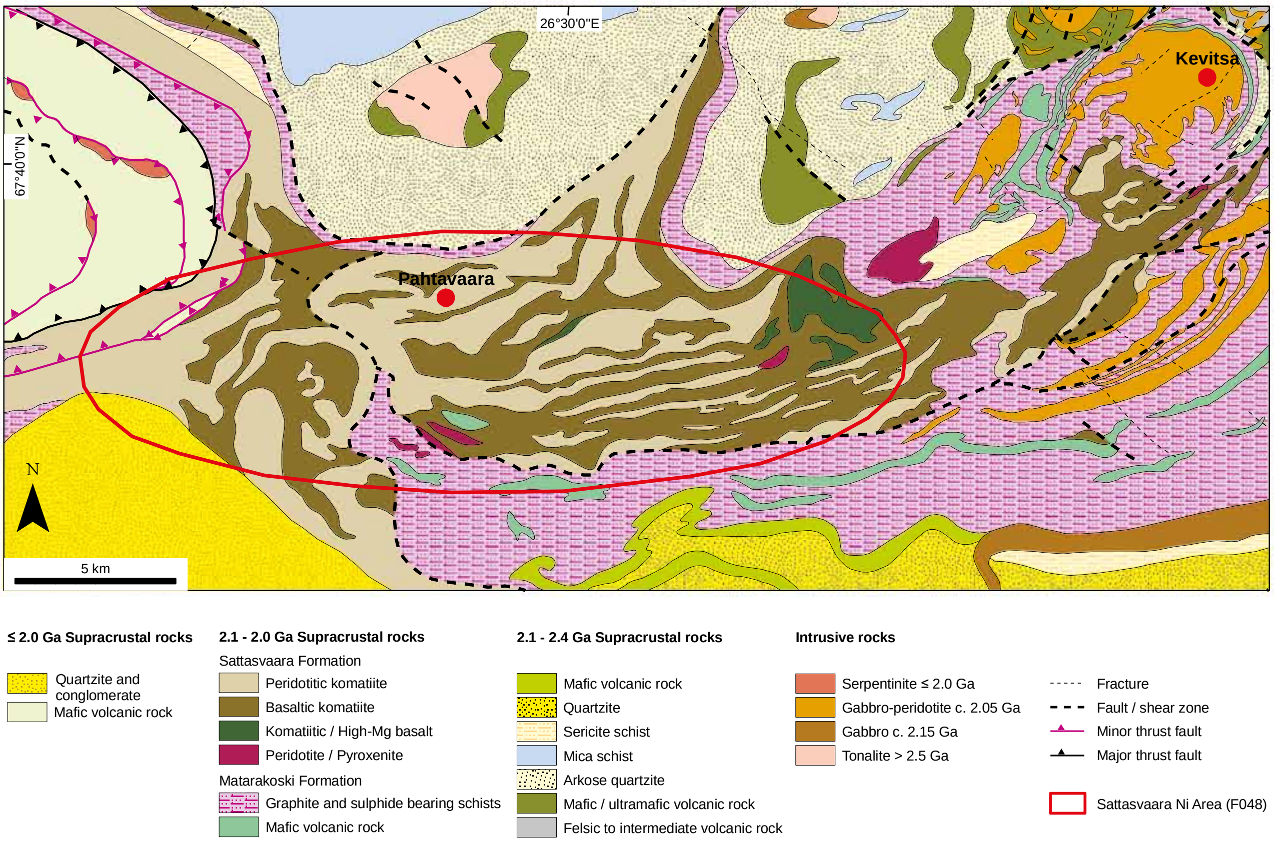


Figure 90. Sattasvaara metallogenic area (F048) in the Central Lapland greenstone belt. Geology simplified from the GTK digital bedrock map database. For reference, the locations of the Pahtavaara gold mine (Fig. 84) and the intrusion-hosted Kevitsa Ni-Cu-PGE mine are also shown.

The presence of abundant komatiites with underlying sulphidic schists in area F048 suggests a significant potential for komatiite-hosted Ni (±Cu±PGE) mineralisation. On GTK's geochemical maps (Salminen 1995), the komatiite area shows a distinct Ni anomaly which on low-altitude airborne geophysical maps appears as a high magnetic anomaly surrounded by a high electromagnetic anomaly which, for one, is induced by schists. The schists providing an important stratigraphic key horizon compose the Matarakoski Formation, which is a complex volcano-sedimentary sequence including sulphide-rich black schists, quartzites and greywacke-like schists with felsic to intermediate volcanic rocks. It also contains mafic volcanic rocks. These are intruded by sill-like ultramafic to mafic cumulates and overlain by komatiites of the Sattasvaara Formation, which form a comagmatic suite ranging from peridotitic komatiites to more evolved basaltic komatiites and komatiitic/high-Mg basalts (7–37 % MgO, 0.2–1.3 % TiO_2), also including Ti-rich volcanic rocks classified as picrites (12–18 % MgO, 1.5–2.0 % TiO_2), and named as a komatiite-picrite association by Hanski et al. (2001c). This rock association is highly potential for Ni mineralisation. It broadly resembles the roughly coeval Proterozoic rocks of the Cape Smith Belt in Canada, where several komatiite-hosted Ni (±Cu±PGE) deposits have been found in the Raglan Formation (e.g., Arndt 1982, St-Onge & Lucas 1994, Lesher 1999, Jowitt et al. 2010). Moreover, sulphidic sedimentary and felsic to intermediate volcanic rocks constitute substrates to the Proterozoic Ni deposits at Pechenga in north-west Russia (e.g., Abzalov & Both 1997, Barnes et al. 2001, Foster 2003), and to the Archaean komatiite-hosted nickel sulphide deposits in Western Australia (e.g. Groves et al. 1986, Frost & Groves 1989, Cowden & Roberts 1990, Lesher & Arndt 1995, Fiorentini et al. 2006).

No nickel sulphide deposit with a resource has so far been reported from the Sattasvaara area. However, there is a large disseminated Ni-Cu-PGE deposit in the **Kevitsa** mafic-ultramafic intrusion, which lies in the same lithology as the volcanic rocks of the Sattasvaara Formation (Fig. 90), although not considered as comagmatic with the Sattasvaara komatiites. The mineral resource at Kevitsa is 275 Mt @ 0.3 % Ni, 0.41 % Cu, 0.015 % Co, 0.15 g/t Pd, 0.2 g/t Pt and 0.11 g/t Au (First Quantum Minerals 2011). In addition, there is the recent ultramafic-hosted Ni-Cu discovery at **Sakatti**, to the SE of area F048 (Coppard 2011).

SIGNIFICANT DEPOSITS NOT INCLUDED IN ANY METALLOGENIC AREA

Pasi Eilu (GTK)

There are two significant mineral deposits in Finland that could not be connected to any metallogenic areas described above. These are briefly described in this section.

The **Korsnäs** Pb-REE deposit in westernmost Finland is geographically inside the Oravainen Ni Area (F017). Korsnäs is a unique deposit hosted by a large, N-trending, calcite-diopside-barite-fluorite-allanite vein (or a carbonatite dyke) that cuts the local Svecofennian mica gneisses (Isokangas 1978). It was mined between 1959 and 1972 and yielded some 0.87 Mt of ore averaging 3.6 % Pb. Allanite and a few other REE minerals (Papunen & Lindsjö 1972) also made the deposit prospective for REE. During the pilot production of an REE concentrate, the ore proved to contain 0.83 % RE_2O_3. In the immediate vicinity of the Korsnäs mine there is also a group of unexploited, 1–20-m-wide carbonate veins or dykes that may contain significant REE grades (Rehtijärvi & Kinnunen 1979).

The **Akanvaara** Cr-V-Ti-PGE deposit has an analogous geological setting and internal structure to that of Koitelainen (F045). It is hosted by a mafic layered intrusion, with a surface area of about 50 km^2 (Fig. 83). Structurally, it is a block-faulted monocline with a general dip towards the southeast. The immediate floor consists of felsic volcanic rocks, and the lowermost exposed roof rocks are felsic volcanic rocks. The intrusion hosts Cr, V, Ti, PGE and Au occurrences. At least 23 chromitite layers and numerous chromitite bands of uncertain continuity have been located. The thickness of the chromitite layers and sub-layers ranges from a few centimetres up to 3 metres, and they define three potentially large deposits (Mutanen 1998). Chromitites with proven metallurgical properties and substantial amounts of vanadium also contain a range of complex platinum-group mineral associations (Mutanen 1997, 1998, 2005, Alapieti & Lahtinen 2002). U-Pb analyses of zircons from the Akanvaara gabbroic rocks give an age of 2436 Ma, whereas the granophyre cap has an age of 2420 Ma (Mutanen & Huhma 2001). The Os and Nd isotopic systematics of the intrusion point to the existence of coeval, crustally contaminated komatiitic volcanism (Hanski et al. 2001b).

REFERENCES

Abzalov, M. Z. & Both, R. A. 1997. The Pechenga Ni-Cu deposits, Russia: data on PGE and Au distribution and sulphur isotope compositions. Mineralogy and Petrology 61, 119–143.

Adriana Resources 2006. Press release 10 July 2006. Available at: www.adrianaresources.com.

Afanas'eva, E. N. 2003. Sostavlenie prognozno-metallogeničeskoi karty na blagorodnye metally v Pana-Kuolajarvinskom progibe. Otčet VSEGEI.

Agnico-Eagle 2010. Press release 17 February 2010. Available at: www.agnico-eagle.com

Agnico-Eagle 2011. Media release 28 April 2011. Available at: www.agnico-eagle.com.

Ahtola, T., Kuusela, J., Koistinen, E., Seppänen, H. Hatakka, T. & Lohva, J. 2010a. Report of investigations on the Leviäkangas lithium pegmatite deposit in Kaustinen, Western Finland. Geological Survey of Finland, unpublished report M19/2323/2010/32. 59 p.

Ahtola, T., Kuusela, J., Koistinen, E., Seppänen, H. Hatakka, T. & Lohva, J. 2010b. Report of investigations on the Syväjärvi lithium pegmatite deposit in Kaustinen, Western Finland. Geological Survey of Finland, unpublished report M19/2323/2010/44. 49 p.

Ahtonen, N. 1996. Pohjois-Pohjanmaan liuskejakson mustaliuskeiden geokemia, mineralogia ja petrofysiikka malminetsinnän kannalta. MSc thesis, University of Oulu. Department of Geosciences and Astronomy. 78 p. (in Finnish)

Äikäs, O. 1990. Torium- ja niobi-lantanidimalmiaiheet Vuolijoen Otanmäessä. Geological Survey of Finland, unpublished report M19/3431/-90/1/60. 28 p. (in Finnish)

Äikäs, O. 1996. Sinkkimalmitutkimukset Juankosken kunnassa valtausalueilla Topilanmäki 1–2 (kaivosrekisteri nrot 5311/1–2) vuosina 1933–1995. Geological Survey of Finland, unpublished report M06/3333/-96/1/10. 9 p. (in Finnish)

Äikäs, O. & Sarikkola, R. 1987. Uranium in lower Proterozoic conglomerates of the Koli area, eastern Finland. In: Uranium deposits in Proterozoic quartz-pebble conglomerates: Report of the Working Group on Uranium Geology, IAEA TECDOC 427, 189–234.

Alapieti, T. 1982. The Koillismaa layered igneous complex, Finland − its structure, mineralogy and geochemistry, with emphasis on the distribution of chromium. Geological Survey of Finland, Bulletin 319. 116 p., 1 app. map.

Alapieti, T. 2005. Early Palaeoproterozoic (2.5−2.4 Ga) Tornio–Näränkävaara Layered Intrusion Belt and Related Chrome and Platinum-group Element Mineralization, Northern Finland. Geological Survey of Finland Guide 51a, 5−11.

Alapieti, T. & Lahtinen J. 1986. Stratigraphy, petrology, and platinum-group element mineralization of the early Proterozoic Penikat layered intrusion, Northern Finland. Economic Geology 81, 1126–1136.

Alapieti, T., Lahtinen, J. Huhma, H., Hänninen, E., Piirainen, T. A. & Sivonen, S. J. 1989b. Platinum-group element-bearing Cu-Ni sulphide mineralization in the marginal series of the early Proterozoic Suhanko-Konttijärvi layered intrusion, Northern Finland. In: Prendergast, M. D., Jones, M. J. (eds), Magmatic sulphides – Zimbabwe volume, London: IMM, 177–187.

Alapieti, T.T., Kujanpää, J., Lahtinen, J.J. & Papunen, H. 1989a. The Kemi stratiform chromitite deposit, Northern Finland. Economic Geology 84, 1057–1077.

Alapieti, T. T. & Lahtinen J. J. 1989. Early Proterozoic layered intrusions in the northeastern part of the Fennoscandian shield. In: Alapieti T. (ed.) 5th International Platinum Symposium. Guide to the post-symposium field trip, 1989. Geological Survey of Finland, Guide 29, 3–41.

Alapieti, T. T., Filén, B. A., Lahtinen, J. J., Lavrov, M. M., Smolkin, V. F. & Voitsekhovsky, S. N. 1990. Early Proterozoic layered intrusions in the northeastern part of the Fennoscandian shield. Miner. Petrol. 42, 1–22.

Alapieti, T. T. & Lahtinen, J. J. 2002. Platinum-group element mineralization in layered intrusions of northern Finland and the Kola Peninsula, Russia. In: Cabri, L. J. (ed.) The geology, geochemistry, mineralogy and mineral beneficiation of platinum-group elements. CIM, Special Volume 54, 507–546.

Alapieti, T. T. & Huhtelin, T. 2005. The Kemi intrusion and associated chromite deposit. Geological Survey of Finland, Guide 51a, 13–32.

Algeo, T. J. & Maynard, J. B. 2004. Trace-element behaviour and redox facies in core shales of Upper Pennsylvanian Kansas-type cyclothems. Chemical Geology 206, 289–318.

Alviola, R. 1989. The granitic pegmatites of the Somero-Tammela area. In: Symposium Precambrian granitoids. Petrogenesis, geochemistry and metallogeny, August 14−17, 1989, Helsinki, Finland. Excursion C1: Late-orogenic and synorogenic Svecofennian granitoids and associated pegmatites of southern Finland. Geological Survey of Finland, Guide 26, 16–25.

Alviola, R. 1993. Tutkimustyöselostus Tammelan kunnassa, valtausalueella Kietyönmäki 1, kaiv. rek. N:o 3991/1, suoritetuista teollisuusmineraalitutkimuksista. Geological Survey of Finland, unpublished report M06/2024/-93/1/85. 7 p. (in Finnish)

Alviola, R. 1997. Tutkimustyöselostus Dragsjärdin kunnassa, valtausalueella Rosendal 1, kaiv. rek. n:o 4556/1, suoritetuista tutkimuksista vuosina 1986–1997. Geological Survey of Finland, unpublished report M06/2012/97/1/85. 11 p. (in Finnish)

Alviola, R. 2003. Pegmatiittien malmipotentiaalista Suomessa. Geological Survey of Finland, unpublished report M10/03/1/85. 5 p. (in Finnish)

Alviola, R. 2004. Oriveden Seppälä-Viitaniemi alueen pegmatiittitutkimus. Geological Survey of Finland, unpublished report M19/2141/2004/1/85. 9 p. 60 app. (in Finnish)

Alviola, R., Mänttäri, I., Mäkitie, H. & Vaasjoki, M. 2001.

Svecofennian rare-element granitic pegmatites of the Ostrobothnia region, western Finland; their metamorphic environment and time of intrusion. Geological Survey of Finland, Special Paper 30, 9–29.

Alviola, R., Keskisaari, K., Kujala-Tammi, M.-R., Ajlani, M. & Väätäinen, J. 2004. Granite pegmatites of Forssa-Somero pegmatite field. Guide map. Espoo: Geological Survey of Finland.

Anttonen, R. 1995. Tutkimukset Kittilän Kutuvuomassa 1993–1995 (Report on exploration at Kutuvuoma, Kittilä, in 1993–1995). Outokumpu Oy Finnmines, Report 001/371112/RSA/95. 5 p. (in Finnish)

Appelqvist, H. 1974. Selostus geologisen tutkimuslaitoksen uraanitutkimuksista Mäntsälän Onkimaalla vuosina 1972–1974. Geological Survey of Finland, unpublished report M19/2044/74/4/10. 12 p. (in Finnish)

Appelqvist, H. 1980. Kaivoslain mukainen tutkimustyöselostus kaiv. rek. n:o 2440/1–2. KTM Report n:o 107/460/74. 7 p. (in Finnish)

Appelqvist, H. 1993. Ore mineralogy in the Proterozoic Kalliosalo gold occurrence, western Finland, with preliminary data on an unspecified mineral, $Ag_3Au_3Sb_{10}S_{10}$. Geological Survey of Finland, Special Paper 18, 37–44.

Appelqvist, H. & Kinnunen, K. 1977. Raportti geologisen tutkimuslaitoksen uraanitutkimuksista Askolan-Porvoon alueella 1976–1977. Geological Survey of Finland, unpublished report M19/3022/77/1/10. 12 p. (in Finnish)

Arndt, N. T. 1982. Proterozoic spinifex-textured basalts of Gilmour Island, Hudson Bay. Geological Survey of Canada 82-1A, 137–142.

Aulanko, H. 1968. Tervolan Kivimaan Cu-Au-esiintymän hyväksikäyttö. Outokumpu Oy, Report 035/2631/HA/68-69. 7 p. (in Finnish)

Autere, I., Pelkonen, K. & Pulkkinen K. 1991. Outokumpu Finnmines Oy:n Vihannin kaivos. Summary: Outokumpu Finnmines Oy's Vihanti zinc mine. Vuoriteollisuus – Bergshanteringen 49, 81–88.

Awebro, K, Bäärnhielm, G., Claezon Johansson, H., Hedlund, L. G., Håkansson, H., Roslund, Y., Sirviö, J., Westerberg, J. O. & Åkerlund, Å. 1986. Kalix kopparbruk, ett projektprogram II. Stockholm: Studia Laplandica 7. (in Swedish)

Ayuso, R. A., Wooden, J. L., Foley, N. K., Seal, R. R. & Sinha, A. K. 2005. U-Pb zircon ages and Pb isotope geochemistry of gold deposits in the Carolina Slate Belt of South Carolina. Economic Geology 100, 225–252.

Barnes, S.-J., Melezhik, V. A. & Sokolov, S. V. 2001. The composition and mode of formation of the Pechenga nickel deposits, Kola peninsula, northwestern Russia. The Canadian Mineralogist 39, 447–471.

Barnes, S.-J., Makkonen, H. V., Dowling, S. E., Hill, R. E. T. & Peltonen, P. 2009. The 1. 88 Ga Kotalahti and Vammala nickel belts, Finland: geochemistry of the mafic and ultramafic metavolcanic rocks. Bulletin of the Geological Society of Finland 81, 103–141.

Belvedere Resources 2006. Press release 31 October 2006.

Belvedere Resources 2009. Press release 1 December 2009. Available at: www.belvedere-resources.com.

Belvedere Resources 2010a. Belvedere announces Indicated Resource Estimate for the K1(Ängesneva) occurrence on the Kiimala gold property Press release 2 June 2010.

Belvedere Resources 2010b. Belvedere's extends Reserve Base at Hitura Nickel Mine – Revised. Press release in 13 October 2010.

Belvedere Resources 2011. Press release 01/02/2011.

Bezrukov, V. J. 1989. Otčet o rezultatah poiskovyh i poiskovoocenočnyh rabot na Maiskom zolotorudnom projavlenii v 1985–88 g.g. SZTGF.

Bodeï, S., Buatier, M., Steinmann, M., Adatte, T. & Wheat, C. G. 2008. Characterisation of metalliferous sediment from low-temperature hydrothermal environment on the eastern Flank of the East Pacific Rise. Marine Geology 250, 128–141.

Cailteaux, J. L. H., Kampunzu, A. B., Lerouge, C., Kaputo, A. K. & Milesi, J. P. 2005. Genesis of sediment-hosted stratiform copper-cobalt deposits, central African Copperbelt. Journal of African Earth Sciences 42, 134–158.

Černý, P. 1998. Magmatic vs. metamorphic derivation of rare-element granitic pegmatites. Krystalinikum 24, 7−36.

Černý, P. & Ercit, T. S. 2005. The classification of granitic pegmatites revisited. Canadian Mineralogist 43, 2005–2026.

Clark, A. H. 1965. The composition and conditions of formation of arsenopyrite and löllingite in the Ylöjärvi copper-tungsten deposit, southwest Finland. Bulletin de la Commission Géologique de Finlande 217. 56 p.

Colley H. & Westra, L. 1987. The volcano-tectonic setting and mineralisation of the early Proterozoic Kemiö-Orijärvi-Lohja belt, SW Finland. In: Pharaoh, T. C., Beckinsale, R. D. & Rickard, D. (eds) Geochemistry and Mineralisations of Proterozoic Volcanic Suites. Oxford: Blackwell. Geological Society of London Special Publications 33, 95−107.

Condie, K. C., DesMarais, D. J. & Abbot, D. 2001. Precambrian superplumes and supercontinents: a record in black shales, carbon isotopes, and paleoclimates? Precambrian Research 106, 239–260.

Coppard, J. 2011. The Sakatti discovery, northern Finland. 8th Fennoscandian Exploration and Mining. Programme and Abstracts, 1–3 Nov 2011, Levi, Lapland, Finland, 38–39.

Cowden, A. & Roberts, D.E. 1990. Komatiite hosted nickel sulfide deposits, Kambalda. In: Hughes, F. E. (ed.) Geology of the Mineral Deposits of Australia and Papua New Guinea. The Australasian Institute of Mining and Metallurgy, Melbourne, Australia, 567–581.

Cuney, M., Brouand, M., Lauri, L., Rämö, T., Kister, P. & Caillat, C. 2008. Accessory mineral paragenesis and U potential of late orogenic potassic granites of southern Finland [Electronic resource]. In: 33rd International Geological Congress, 6-14 August 2008, Oslo, Norway: abstract CD-ROM. 1 p. Optical disc (CD-ROM).

Dain, A. D. & Ivanov, A. N. 1978. Otčet o rezultatah poiskovyh rabot na zoloto, provedenyh v zapadnoi časti Severo-Karel'skoi sinklinornoi zony v 1975–78 g.g. SZTGF. (in Russian)

Damsten, M. 1990. Tutkimustyöselostus Ilomantsin kunnassa valtausalueilla Kuittila 1–3, kaiv. rek. n:ot 3808 ja 3956, suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/4244/-90/1/10. 9 p. (in Finnish)

Damsten, M. 2010a. Tohmajärven Muskon kairaukset vuonna 2008 karttalehdellä 4232 05. Geological Survey of Finland, unpublished report M19/4232/2010/30. 14 p. (in Finnish)

Damsten, M. 2010b. Tohmajärvi-Joensuu välisen liuskevyöhykkeen kairauksetkarttalehdillä 4223, 4241 ja 4232 vuonna 2009. Geological Survey of Finland, unpublished report M19/4232/2010/31. 18 p. (in Finnish)

Douville, E., Bienvenu, P., Charlou, J. L., Donval, J. P., Fouquet, Y., Appriou, P. & Gamo, T. 1999. Yttrium and rare earth elements in fluids from various deep-sea hydrothermal systems. Geochimica et Cosmochimica Acta 63, 627–643.

Dragon Mining 2004. Annual Report 2003. Perth, Australia. 46 p. Available at: www.dragon-mining.com.au

Dragon Mining 2007. Press release 17 August 2007.

Dragon Mining 2009. Annual Report 2008. Perth, Australia. 102 p.

Dragon Mining 2010. Press release 5 March 2010.

Dragon Mining 2011a. Significant increase in the resource of the Juomasuo gold deposit at Kuusamo gold project. Press release 12 January 2011. Available at: www.dragon-mining.com.au

Dragon Mining 2011b. Hanhimaa Gold Project. Available at: http://www.dragon-mining.com.au/-Northern-Finland-.html

Dube, B., Dunning, G. & Lauziere, K. 1998. Geology of the Hope Brook mine, Newfoundland, Canada: a preserved Late Proterozoic high-sulphidation epithermal gold deposit and its implications for exploration. Economic Geology 93, 405–436.

Eckstrand, O. R., Sinclair, W. D. & Thorpe, R. I. 1996. Geology of Canadian Mineral Deposit Types. Geological Survey of Canada, Geology of Canada 8. 640 p.

Eeronheimo, J. 1985a. Kairaus- ja malmiarvioraportti Kerimäki, Hälvälä. Outokumpu Oy, Report 030/4211 08/JJE/1985. (in Finnish)

Eeronheimo, J. 1985b. Kaivoslain 19 §:n mukainen tutkimustyöselostus, Kerimäki, Makkola. Ukonmäki ja Ukonmäki 2, kaivosrekisterinumerot 2932/1 ja 3432/1. Outokumpu Oy, Report 080/4211 08/JJE/1985. 4 p. (in Finnish)

Eeronheimo, J. 1988. Kaivoslain 19 §:n mukainen tutkimustyöselostus Savonlinna/Tevanniemi, kaivosrekisterinumero 3894/1, NiCu. Outokumpu Oy, Report 080/421106B/JJE/1988. 3 p. (in Finnish)

Eeronheimo, J. & Pietilä, R 1988. Yhteenveto Taipalsaaren Telkkälän Ni-Cu-esiintymän tutkimuksista vuoden 1985 jälkeen. Outokumpu Oy, Report 001/313405D/JJE,RMP/1988. 12 p. 41 App. (in Finnish)

Eilu, P. 2007. FINGOLD: Brief descriptions of all drilling-indicated gold occurrences in Finland − the 2007 data. Geological Survey of Finland, Report of Investigation 166. 35 p.

Eilu, P. 2012a. Gold mineralisation in southwestern Finland. Geological Survey of Finland, Special Paper 52. In press.

Eilu, P. 2012b. Haveri copper-gold deposit: genetic considerations. Geological Survey of Finland, Special Paper 52. In press.

Eilu, P. Ojala, J., Ruotoistenmäki, T. & Sorjonen-Ward, P. 2004. Preliminary geophysical and geological assessment of gold-copper mineralisation at Haveri, southern Finland. Geological Survey of Finland, unpublished report CM19/2124/2004/2/10. 37 p.

Eilu, P., Pankka, H., Keinänen, V., Kortelainen, V., Niiranen, T. & Pulkkinen, E. 2007. Characteristics of gold mineralisation in the greenstone belts of northern Finland. Geological Survey of Finland, Special Paper 44, 57–106.

Eilu, P. & Pankka, H. 2009. FINGOLD – A public database on gold deposits in Finland. Version 1.0. Geological Survey of Finland. Digital data product 4. Optical disc (CD-ROM).

Eilu, P., Bergman, T., Bjerkgård, T., Feoktistov, V., Hallberg, A., Ihlen, P.M., Korneliussen, A., Korsakova. M., Krasotkin, S., Muradymov, G., Nurmi, P. A., Often, M., Perdahl, J.-A., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. (comps.) 2009. Metallogenic Map of the Fennoscandian Shield, 1:2,000,000. Geological Survey of Finland, Geological Survey of Norway, Geological Survey of Sweden, The Federal Agency of Use of Mineral Resources of the Ministry of Natural Resources and Ecology of the Russian Federation.

Ekdahl, E. 1993. Early Proterozoic Karelian and Svecofennian formations and the evolution of the Raahe-Ladoga Ore Zone, based on the Pielavesi area, central Finland. Geological Survey of Finland, Bulletin 373. 137 p.

Endomines 2009. Nya beräkningar av mineraltillgångarna i förekomster längs den Karelska Guldlinjen. Pressmedelande 28 April 2009. (in Swedish) Available at: www.endomines.com

Endomines 2010a. Exploration and Development of Ilmenite Deposits. Available at: www.endomines.com.

Endomines 2010b. Pampalo Gold Mine ore reserve tonnage increased by 50% and gold content by 11%. Press release 27 September 2010. Available at: www.endomines.com

Endomines 2011. Endomines commences production at the Pampalo Gold Mine. Press release 8 February 2011. Available at: www.endomines.com

Ervamaa, P. 1974. Selostus Saviniemessä 1972 suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M19/3434/74/6/10. 5 p. (in Finnish)

Ervamaa, P. 1977. Selostus Puolangan kunnassa sijaitsevilla Vihajärvi 1 ja Vuorijärvi 1 nimisillä valtausalueilla suoritetuista tutkimustöistä ja niiden tuloksista. Geological Survey of Finland, unpublished report 8 Nov. 1977. 1 p. 2 App. (in Finnish)

Ervamaa, P. & Laajoki, K. 1977. Puolangan Väyrylänkylän prekambristen rautamuodostumien geologiasta. Abstract: On the geology of the Precambrian iron formations in Väyrylänkylä, Puolanka. Geological Survey of Finland, Report of Investigations 27. 66 p.

Ervamaa, P. & Heino, T. 1980. Sotkamon Talvivaaran nikkeli-kupari-sinkki-esiintymän tutkimukset. Geological Survey of Finland, unpublished report M19/3344/80/1/10. 73 p. (in Finnish)

Eskelinen, E., Huopaniemi, P. & Tyni, M. 1983. Myllykoski Oy:n Luikonlahden kuparikaivos 1968–1983. Vuoriteollisuus 41, 94–98 (in Finnish)

Ettner, D. C., Björlykke, A. & Andersen, T. 1994. Fluid evolution and Au-Cu genesis along a shear zone: a regional fluid inclusion study of shear zone-hosted alteration and gold and copper mineralization in the Kautokeino greenstone belt, Finnmark, Norway. Mineralium Deposita 29, 16–29.

Feoktistov, V. P., Korsakova, M. A., Krasotkin, S. J. & Stromov, V. A. 2007. Metallogeničeskaja karta rossiskoi časti Fennoskandinavskogo ŝčita 1:1 000 000. Otčet VSEGEI. 313 p.

Fiorentini, M. L., Bekker, A., Rumble, D., Barley, M. E. & Beresford, S. W. 2006. Multiple S isotope study indicates footwall hydrothermal exhalative massive sulfides were the major sulfur source for Archean komatiite-hosted magmatic nickel-sulfides from Western Australia and Canada. Geochimica et Cosmochimica Acta 70, Issue 18, Supplement 1, A174.

First Quantum Minerals 2011. Press release 30 March 2011.

Forss, H., Kontoniemi, O., Lempiäinen, R., Luukas, J., Makkonen, H. & Mäkinen, J. 1999. Ni-vyöhyke ja 1. 9 Ga magmatismi -hankkeen (12204) toiminta vuosina 1992–1998 Tervo–Varkaus -alueella. Geological Survey of Finland, unpublished report M19/3241/99/1/10. 152 p. (in Finnish)

Foster, J. G. 2003. The Pechenga Ore Deposits: Russia. New

Frontiers in Research on Magmatic Nis-PGE Mineralization, Centre for Global Metallogeny, University of Western Australia, February 2003, 129–136.

Frost, K. M. & Groves, D. I. 1989. Ocellar units at Kambalda: evidence for sediment assimilation by komatiite lavas. In: Prendergast, M. D. & Jones, M. J. (eds) Magmatic Sulfides: the Zimbabwe Volume. London: Institute of Mining and Metallurgy, 207–214.

Gaál, G. 1980. Geological setting and intrusion tectonics of the Kotalahti nickel-copper deposit, Finland. Bulletin of the Geological Society of Finland 52, 101–128.

Gaál, G. 1985. Nickel metallogeny related to tectonics. In: Nickel-copper deposits of the Baltic Shield and Scandinavian Caledonides. Geological Survey of Finland, Bulletin 333, 143–155.

Gaál, G. & Isohanni, M. 1979. Characteristics of igneous intrusions and various wall rocks in some Precambrian porphyry copper-molybdenum deposits in Pohjanmaa, Finland. Economic Geology 74, 1198–1210.

Gaál, G. & Parkkinen, J. 1993. Early Proterozoic ophiolite-hosted copper-zinc-cobalt deposits of the Outokumpu type. In: Kirkham R. V., Sinclair, W. D., Thorpe, R. I. & Duke, J. M. (eds) Mineral Deposit Modeling. Geological Association of Canada, Special Paper 40, 335–341.

Gehör, S. 1994. REE distribution in the phosphorite bands within the Paleoproterozoic Tuomivaara and Pahtavaara iron-formations, central and northern Finland. Geological Survey of Finland, Special Paper 19, 71–83.

Gehör, S. 1994a. The Palaeoproterozoic iron-formations in Central Lapland and Kainuu, Finland, with special reference to their depositional environment and metamorphism. Res Terrae, Ser. A 9. 186 p.

Gehör, S. 1994b. REE distribution in the phosphorite bands within the Paleoproterozoic Tuomivaara and Pahtavaara iron-formations, central and northern Finland. Geological Survey of Finland. Special Paper 19, 71–83.

Gehör, S. & Havola, M. 1988. The depositional environment of the early Proterozoic Tuomivaara iron-formation and associated metasediments, eastern Finland. Geological Survey of Finland, Special Paper 5, 109–133.

Gervilla, F., Papunen, H., Kojonen, K. & Johanson, B. 1998. Platinum-, palladium- and gold-rich arsenide ores from the Kylmäkoski Ni-Cu deposit (Vammala Nickel Belt, SW Finland). Mineralogy and Petrology 64, 163–185.

Gold Fields 2003. Press release July 2003.

Goldfarb, R. J., Groves, D. I. & Gardoll, S. 2001. Orogenic gold and geologic time: a global synthesis. Ore Geology Reviews 18, 1–75.

Goodfellow, W. D., Zierenberg, R. A. & ODP Leg 169 Shipboard Science Party 1999. Genesis of massive sulfide deposits at sediment-covered spreading ridges. In: Barrie, C. T. & Hannington, M. D. (eds) Volcanic-associated massive sulfide deposits: progress and examples in modern and ancient settings. Reviews in Economic Geology 8, 297–324.

Grøndahl, L. K. 2009. Keliber Oy – A European entry to the lithium industry. Available at: www.keliber.no/getfile.php/Filer/Investors/Company%20presentations/Santiago_handout_January_2009.pdf

Grönholm, P. 1999. The mesothermal Saattopora copper-gold deposit in the Palaeoproterozoic Central Lapland greenstone belt, Northern Finland. In: Cook, N. J. & Sundblad, K. (eds) Precambrian gold in the Fennoscandian and Ukrainian Shields and related areas. Gold '99 Trondheim, Norway, 4–6 May 1999. Trondheim: Geological Survey of Norway, p. 83.

Grönholm, P. 2006. The Jokisivu gold deposit, southwest Finland. Geol. Soc. Finland, Bull. Spec Issue 1, p. 42.

Groves, D. I. 1993. The crustal continuum model for late-Archaean lode-gold deposits of the Yilgarn Block, Western Australia. Mineralium Deposita 28, 366–374.

Groves, D. I., Korkiakoski, E. A., McNaughton, N. J., Lesher, C. M. & Cowden, A. 1986. Thermal erosion by komatiites at Kambalda, Western Australia and the genesis of nickel ores. Nature 319, 136–139.

Grundström, L. 1973. Selostus Tyrvään Kovero-ojan kaivospiiriin haettavalla alueella vuosina 1960–1973 suoritetuista malminetsintätutkimuksista. Included in the claim report of the claim n:o 2024. Outokumpu Oy Report 30.3.1973. 3 p., 19 app. (in Finnish)

Grundström, L. 1976. Syväkairaustutkimukset Virtasalmen Karhuniemessä v. 1976. Outokumpu Oy, Kotalahden kaivos, Report 030/3231 12/LG/76. 4 p., 19 app. (in Finnish)

Grundström, L. 1977a. Syväkairaustutkimukset Hällinmäen Larin (Litmanen) alueella v. 1976. Outokumpu Oy, Kotalahden kaivos, Report 030/3231 09/LG/77. 5 p., 25 app. (in Finnish)

Grundström, L. 1977b. Geologiset tutkimukset Virtasalmen Sahinjoen alueella v. 1976–1977. Outokumpu Oy, Kotalahden kaivos, Report 001/3231 09D/LG/77. 7 p., 20 app. (in Finnish)

Grundström, L. 1979. Geologiset tutkimukset Pieksämäen mlk:n Sarkaniemessä. Outokumpu Oy, Malminetsintä, Report 001/3232 08/LG/1979. 10 p., 24 app. (in Finnish)

Grundström, L. 1985. The Laukunkangas nickel-copper deposit. Geological Survey of Finland, Bulletin 333, 240-256.

Grundström, L. 1991a. KTM tutkimustyöselostus, Kaiv. rek.nro 4098/1. Outokumpu Oy Report 080/2121 10/LG/1991. 6 p. 13 App. (in Finnish)

Grundström, L. 1991b. Kaivoslain 19§:n mukainen tutkimustyöselostus Soukko-nimisestä valtausalueesta Vammalan kaupungissa, Turun- ja Porin läänissä, kaivosrekisterinumero 3809/1. Outokumpu Oy, Report 080/2121 07/LG/1991. 8 p., 32 app. (in Finnish)

Grundström, L. 1998. Kaivoslain 19 §:n mukainen tutkimustyöselostus Mikkelin läänissä, Juvan kunnassa valtausalueilla Niinimäki 1,3,4 ja 5, kaivosrekisterinumerot 4842/1, 5452/1, 5520/1 ja 6380/1 suoritetuista malmitutkimuksista. Outokumpu Mining Oy, Report 080/3144 05/LG/1998. (in Finnish)

Grundström, L. 1999. Kaivoslain 19§:n mukainen tutkimustyöselostus ... Rausenkulma 1 -nimisellä valtausalueella, kaivosrekisterinumero 4654/1, suoritetuista malmitutkimuksista. Outokumpu Oy, Report 080/1134 09/LG/1999. 5 p., 16 app. (in Finnish)

Grundström, L., Koistinen, T. & Vihreäpuu, U. 1986. Tutkimusraportti, Virtasalmi, Karankalahti 1979–1985. Outokumpu Oy, Malminetsintä, Report 030/3232 07/LG, TJK, UMV/1986. 5 p., 7 app. (in Finnish)

Hakkarainen, G. 1994. Geology and geochemistry of the Hämeenlinna-Somero volcanic belt, southwestern Finland: a Paleoproterozoic island arc. Geological Survey of Finland, Special Paper 19, 85–100.

Häkli, T. A. 1985. The Telkkälä nickel deposit. Geological Survey of Finland, Bulletin 333, 257–263.

Häkli, T. A., Huhma, M., Viluksela, E. & Vuorelainen, Y. 1975. A minor Ni-Cu-deposit at Telkkälä, SE-Finland. Bulletin of the Geological Society of Finland 47, 55–70.

Häkli, T. A. & Vormisto, K. 1985. The Vammala nickel deposit. Geological Survey of Finland, Bulletin 333, 273–286.

Halkoaho, T. 1993. The Sompujärvi and Ala-Penikka PGE reefs in the Penikat layered intrusion, northern Finland: implications for PGE reef-forming processes. Acta Univ. Ouluensis. Ser. A, Scientiae Rerum Naturalium 249. 122 p.

Halkoaho, T.A.A., Alapieti, T.T. & Lahtinen, J.J. 1990a. The Sompujärvi PGE Reef in the Penikat layered intrusion, Northern Finland. Mineralogy and Petrology 42, 39–55.

Halkoaho, T.A.A., Alapieti, T.T., Lahtinen, J.J. & Lerssi, J.M. 1990b. The Ala-Penikka PGE Reefs in the Penikat layered intrusion, Northern Finland. Mineralogy and Petrology 42, 23–38.

Halkoaho, T., Koistinen, E., Luukkonen, E., Niskanen, M., Pietikäinen, K. & Tenhola, M. 2000. The Vaara–Kauniinlampi komatiitic nickel prospects in Suomussalmi, Eastern Finland (register numbers of claims 5376/1, 5376/2, 5789/1, 5789/2, 6171/1, 6271/1, 6273/1, 6676/1, 6770/1 and 6938/1). Geological Survey of Finland, unpublished report CM06/4513-4514/2000/1. 37 p.

Halkoaho, T., Alapieti, T. T. & Huhtelin, T. 2005. The Sompujärvi, Ala-Penikka and Paasivaara PGE reefs in the Penikat layered intrusion, northern Finland. Geological Survey of Finland, Guide 51a, 33–76.

Hämäläinen, I. 1987. Hammaslahden sinkkimalmi. MSc Thesis, University of Turku, Department of Geology. 110 p. (in Finnish)

Hangala, L. 1987. The early Proterozoic Zn-Pb-Cu massive sulfide deposit at Attu, SW Finland. Geological Survey of Finland, Bulletin 341. 61 p.

Hanski, E. 2002. Vikajärvi. Geological Map of Finland 1:100 000, Pre-Quaternary Rocks, Sheet 3614. Geological Survey of Finland.

Hanski, E., Huhma, H. & Vaasjoki, M. 2001a. Geochronology of northern Finland: A summary and discussion. Geological Survey of Finland, Special Paper 33, 255–279.

Hanski, E., Walker, R. J., Huhma, H. & Suominen, I. 2001b. The Os and Nd isotopic systematics of c. 2.44 Ga Akanvaara and Koitelainen mafic layered intrusions in northern Finland. Precambrian Research 109, 73–102.

Hanski, E., Huhma, H., Rastas, P. & Kamenetsky, V. S. 2001c. The Palaeoproterozoic komatiite-picrite association of Finnish Lapland. Journal of Petrology 42, 855–876.

Hanski, E. & Huhma, H. 2005. Central Lapland greenstone belt. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 139–194.

Hanski, E., Huhma, H. & Perttunen, V. 2005. SIMS U-Pb, Sm-Nd isotope and geochemical study of an arkosite-amphibolite suite, Peräpohja Schist Belt: evidence for ca. 1.98 Ga A-type felsic magmatism in northern Finland. Bulletin of the Geological Society of Finland 77, 5–29.

Härkönen, I. 1984. The gold bearing conglomerates of Kaarestunturi, Central Finnish Lapland. In: Foster, R. P. (ed.) Gold '82; the Geology, Geochemistry and Genesis of Gold Deposits. Geological Society of Zimbabwe, Special Publication 1, 239–247.

Härkönen, I. & Keinänen, V. 1989. Exploration of structurally controlled gold deposits in the Central Lapland greenstone belt. Geological Survey of Finland, Special Paper 10, 79–82.

Härkönen, I., Kojonen, K. & Johanson, B. 1999. The Early Proterozoic Suurikuusikko refractory gold deposit, Kittilä, Western Finnish Lapland. In: Mineral Deposits: Processes to Processing. Proceedings of the Fifth Biennial SGA Meeting. Balkema, 159−162.

Hedenquist, J. W., Izawa, E., Arribas, A. & White, N. C. 1996. Epithermal gold deposits: Styles, characteristics, and exploration. Resource Geology Special Publication 1. 16 p.

Heikkilä-Harinen, R. 1977a. Paraisten Kalkki Oy, Report 1977-02-25. (in Finnish)

Heikkilä-Harinen, R. 1977b. Tutkimustyöselostus Oy Malminetsijä Ab:n valtausalueella Siika 1, suoritetuista tutkimustöistä ja niiden tuloksista. Paraisten Kalkki Oy, Report 23.2.1977. (in Finnish)

Heikura, P., Iljina, M., Isomaa, J. & Salmirinne, H. 2004. Tutkimustyöselostus valtausalueilla Kaamajoki 1–4, 6 ja 7 sekä Tshokkoaivi 1 Enontekiön kunnassa suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/1832, 1834/2004/1/10. 17 p. (in Finnish)

Heino, T. 1982. Tutkimustyöselostus Paltamon kunnassa valtausalueilla Haapaselkä 1 ja 2 sekä Horkanlampi 1, kaiv rek. n:o 3130 suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/3432/-82/1/10. 5 p., 5 app. (in Finnish)

Heino, T. 1986. Tutkimustyöselostus Sotkamon kunnassa valtausalueilla Kolmisoppi 1, kaiv.rek.n:o 2819, Kuusilampi 1 ja 2, kaiv.rek.n:o 2838, Kuusilampi 3, kaiv.rek.n:o 2863 ja Kaivoslampi 1, kaiv.rek.n:o 3335 Geological Survey of Finland, unpublished report M06/3344/-86/1/10. 21 p. (in Finnish)

Heino, T. 1998. Hyrynsalmi, Puistola 1 (kaivosrekisteri N:o 5657/1) ja Paatola 1 (kaivosrekisteri N:o 5619/1) nikkeliesiintymän mineraalivarantoarvio. Geological Survey of Finland, unpublished report CM19/4421/98/1/10. 33 p. (in Finnish)

Heino, T. 1999. Rautalampi, Törmälä 1 (kaivosrekisteri N:o 6615/1) nikkeliesiintymän mineraalivarantoarvio. Geological Survey of Finland, unpublished report M19/3223/99/1/10. 3 p. (in Finnish)

Heino, T. 2000. Mineral Resource Assessment of the Kuikkapuro 1 (mine. reg. N:o 6748/1), Kuikkapuro 2 (N:o 6841/1), Kuikkapuro 3 (N:o 6880/1), Kuikkapuro 4 (N:o 6880/2) and Kuikkapuro 5 (N:o 6912/1) gold mineralization, Geological Survey of Finland, unpublished report CM19/4511/2000/1.

Heino, T. 2001. Mineral Resource Assessment of the Pahkosuo gold mineralization, claims Pahkosuo (mine reg. N:o 5621/1), Pahkosuo 2 (N:o 6272/1), Pahkosuo 3 (N:o 6272/2) and Pahkosuo 4 (N:o 6410/1). Geological Survey of Finland, unpublished report M19/4513/2001/1. 3 p.

Heino, T., Hartikainen, A., Koistinen, E. & Niskanen, M. 1995. Report on exploration in Ilomantsi in 1992-1995, within claims Sivakko 1 (Mine Register no. 5188/1), Korpilampi 1-2 (5402/1-2), Korpi 1-4 (5356/1-4), Kuivisto 1 (5210/1), Kuivisto 2-3 (5356/5-6), Pihlajavaara 1-2 (5511/2-3) and Valkeasuo 1-2 (4853/1, 5511/1). Geological Survey of Finland, unpublished report M06/4333/-95/1/10. 17 p.

Helovuori, O. 1980. Tutkimustyöselostus koskien Kuopion läänin Kiuruveden kunnassa sijaitsevaa Hallaperän malmiesiintymää. Outokumpu Oy, Malminetsintä, Report 080/3323 06/OH/80. 3 p., 24 app. (in Finnish)

Himmi, R. 1975. Outokumpu Oy:n Korsnäsin ja Petolahden kaivosten vaiheita. Vuoriteollisuus 33, 35–38. (in Finnish)

Himmi, R., Huhma, M. & Häkli, T. A. 1979. Mineralogy and metal distribution in the copper-tungsten deposit at Ylöjärvi, Southwest Finland. Economic Geology 74, 1183–1197.

Holland, N. 2011. Towards Five Million Ounces. Presentation in The BMO Capital Markets 2011 Global Metals & Mining Conference, Hollywood, Florida, February 27 to March 2, 2011. Available at: http://www.goldfields.co.za/pdf/27022011_bmo_capital_markets.pdf.

Holma, M. & Keinänen, V. 2007. The Levijärvi-Loukinen gold occurrence: An example of orogenic gold mineralisation with atypical metal association. Geological Survey of Finland, Special Paper 44, 163–184.

Hudson, M., Lees, M., Vanhanen, E. & Dahlenborg, L. 2011. Rompas Au-U prospect. In: Active and ongoing gold exploration and mining in Northern Finland. Excursion guide, 18–20 August 2011. 25th International Applied Geochemistry Symposium 2011, 22–26 August 2011 Rovaniemi, Finland. Vuorimiesyhdistys – Finnish Association of Mining and Metallurgical Engineers, Serie B, Nro B92-7, 36–41.

Hugg, R. 1985. Katajakangas, geologinen malmiarvio. Rautaruukki Oy, report OU12/85. (in Finnish)

Hugg, R. & Heiskanen, V. 1983. Suomen rautamalmiesiintymät, malmiutumat ja malmiviitteet. Rautaruukki Oy OU 2/79, RAETSU Report 8.2.1983. 412 p. (in Finnish)

Huhma, A. 1975. Outokummun, Polvijärven ja Sivakkavaaran kartta-alueiden kallioperä. Summary: Precambrian rocks of the Outokumpu, Polvijärvi and Sivakkavaara map-sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 4222, 4224 and 4311. Geological Survey of Finland. 151 p.

Huhma, A. & Huhma, M. 1970. Contribution to the geology and geochemistry of the Outokumpu region. Bulletin of the Geological Society of Finland 42, 57–88.

Huhma, H. 1986. Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland. Geological Survey of Finland, Bulletin 337. 48 p.

Huhma, H., Mutanen, T., Hanski, E., Räsänen, J., Manninen, T., Lehtonen, M., Rastas, P., & Juopperi, H. 1996. Isotopic evidence for contrasting sources of the prolonged Palaeoproterozoic mafic-ultramafic magmatism in Central Finnish Lapland. In: IGCP project 336 symposium in Rovaniemi, Finland, August 21–23, 1996: program and abstracts. University of Turku, Division of Geology and Mineralogy, Publication 33, p. 17.

Huhma, H., Kontinen, A. & Laajoki, K. 2000. Age of the metavolcanic-sedimentary units of the Central Puolanka Group, Kainuu schist belt, Finland. In: 24. Nordiske Geologiske Vintermøte, Trondheim 6–9. januar 2000. Geonytt (1), 87–88.

Huhtelin, T. 2008. Day 6: The Kemi Layered Intrusion and the Kemi chrome mine. In Ojala, J. and Iljina, M. Metallogeny and tectonic evolution of the Northern Fennoscandian Shield. Guidebook to 33 IGC excursion No 15, August 15th – 21st, 2008. 99–104.

Huhtelin, T. A., Alapieti, T. T. & Lahtinen, J. J. 1990. The Paasivaara PGE Reef in the Penikat layered intrusion, Northern Finland. Mineralogy and Petrology 42, 57–70.

Huhtelin, T.A., Lahtinen, J.J., Alapieti, T.T., Korvuo, E. & Sotka, P. 1989. The Narkaus Intrusion and related PGE and sulphide mineralizations. Geological Survey of Finland. Guide 29, 145–161.

Hulkki, H. & Keinänen, V. 2007. The alteration and fluid inclusion characteristics of the Hirvilavanmaa gold deposit, Central Lapland Greenstone Belt, Finland. Geological Survey of Finland, Special Paper 44, 135–151.

Huuskonen, M. & Kärkkäinen, N. 1994. TiP-gabrojen etsintäohjelma Lauhavuoren graniitin ympäristössä: korkealentomagneettiset häiriöt ja Kauhajoen Hyypän intruusion tutkimukset. Geological Survey of Finland, unpublished report M19/1234/94/1/10. 13 p. (in Finnish)

Hyvärinen, L. 1969. On the geology of the copper ore field in the Virtasalmi area, eastern Finland. Bulletin de la Commission Géologique de Finlande 240. 82 p.

Hyvärinen L. 1970. Selostus Pyhäselän kunnan Lähdekorven kupariesiintymän malmitutkimuksista vv. 1967–1970. Geological Survey of Finland, Report M19/4241/70/1/10. 35 p. (in Finnish)

Iljina, M. 1994. The Portimo layered igneous complex – with emphasis on diverse sulphide and platinum-group element deposits. Acta Univ. Ouluensis. Ser. A 258. 158 p.

Iljina, M. 2004. Mineral exploration report of relinquished claims Koskiaho 1–2, Kuusi 4–23, Maaselkä 1–14, Murto 1–2 and Portti 1–37. Geological Survey of Finland, unpublished report M06/3543/2004/1/10. 16 p

Iljina, M. 2005. Portimo layered igneous complex. Geological Survey of Finland, Guide 51a, 76–100.

Iljina, M. & Hanski, E. 2005. Layered mafic intrusions of the Tornio–Näränkävaara belt. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds), Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 101–138.

Iljina, M., Heikura, P., Salmirinne, H. 2005. The Haukiaho and Kaukua PGE-Cu-Ni-Au prospects in the Koillismaa Layered Igneous Complex, Finland. Geological Survey of Finland, unpublished report CM06/3543,3544/2005/1/10.

Illi, J., Lindholm, O., Levanto, U.-M., Nikula, J., Pöyliö, E. & Vuoristo, E. 1985. Otanmäen kaivos. Vuoriteollisuus 1985 (2), 98–107. (English summary)

Inkinen, O. 1979. Copper, zinc, and uranium occurrences at Pahtavuoma in the Kittilä greenstone complex, northern Finland. Economic Geology 74, 1153–1165.

Inmet Mining 2010. Annual Report 2009. Available at: www.inmetmining.com

Isohanni, M. 1984. Malminetsintätyöt Kalajoen Jouhinevalla vuosina 1981–1984, 2342 02, 05. Outokumpu Oy, Report 001/2342/MAI/84. 2 p. (in Finnish)

Isohanni, M. 1985a. The Oravainen nickel occurrence in western Finland. Geological Survey of Finland, Bulletin 333, 189–210.

Isohanni, M. 1985b. Granitoidit, niiden geologia ja malminmuodostus. Geological Survey of Finland, Report of Investigations 69, 38–48. (in Finnish)

Isohanni, M., Ohenoja, V. & Papunen, H. 1985. Geology and nickel-copper ores of the Nivala area. Geological Survey of Finland, Bulletin 333, 211–228.

Isokangas, P. 1978. Finland. In: Bowie, S. H. U., Kvalheim, A. & Haslam, H. W. (eds) Mineral deposits of Europe, Volume 1 – Northwest Europe. London: The Institution of Mining and Metallurgy & The Mineralogical Society, 39–92.

Isomaa, J. 1982. Nikkelimalmitutkimukset Sarvisoaivin alueella Enontekiöllä vuosina 1978–1980. Geological Survey of Finland, unpublished report M19/1832/-82/1/10. 44 p. (in Finnish)

Isomaa, J. 1988. Tutkimustyöselostus Enontekiön kunnassa valtausalueella Ruossakero 1, 2 ja 3, kaiv. rek. n:o 3451/1-3 suoritetuista malmitutkimuksista vuosina 1983–1986. Geological Survey of Finland, unpublished report M06/1834/-88/1/10. 6 p. (in Finnish)

Isomaa, J. & Sandgren, E. 2006. Malmitutkimukset Rovaniemen kaupungin Muurolan Kuusivaarassa vuosina 2003 ja 2005. Geological Survey of Finland, unpublished report M19/2633/2006/1/10. 13 p. (in Finnish)

Isomaa, J., Koistinen, E. & Kärkkäinen, N. 2010. Sikakangas gold prospect at Seinäjoki, Western Finland. Geological Survey of Finland, unpublished report M19/2222/2010/55. 62 p.

Isomäki O.-P. 1992. Taipalsaaren Telkkälän Ni-Cu-malmiesiintymän syvämalmion geologiaa. Outokumpu Oy, Report. (in Finnish)

Isomäki, O.-P. 1994. The Hälvälä and Telkkälä nickel-copper mines. Geologi 46, 112–114.

Jowett, E. G., Rydzewski, A. & Jowett, R. J. 1986. The Kupferschiefer Cu-Ag ore deposits in Poland: a re-appraisal of the evidence of their origin and presentation of a new genetic model. Canadian Journal of Earth Science 24, 2016–2037.

Jowitt, S. M., Keays, R. R. & Peck, D. C. 2010. New Insights into the Geology and Mineral Potential of the West Raglan Ni-Cu-PGE Project, Cape Smith Fold Belt, Quebec. 11th International Platinum Symposium, June 21–24, 2010. Ontario Geological Survey, Miscellaneous Release-Data 269.

Juhava, R., Karppanen, T. & Papunen, H. 1989. The Enonkoski Ni-Cu deposit. Geological Survey of Finland, Guide 29, 257–263.

Juopperi, A. 1977. The magnetite gabbro and related Mustavaara vanadium ore deposit in the Porttivaara layered intrusion, north-eastern Finland. Geological Survey of Finland, Bulletin 288. 68 p.

Juopperi, H. & Karvinen A. 1999. Report on gold exploration during 1996-1999 carried out in Kuivaniemi Commune, expl. leases Karahkalehto 1 (mine reg. no. 6279/1), Konivesakot 1 (mine reg. no. 6276/2), Kompsa 1 ja 2 (mine reg. nos. 6751/1 and 2) and Välikangas 2 (mine reg. no. 6846/2) (in Finnish with English summary). Geological Survey of Finland, unpublished report C/M06/3521/99/2/10.

Juopperi, H, Karvinen, A. & Rossi, S. 2001. The Oijärvi gold prospects in Northern Finland. Summary. Geol. Surv. Finland. Available at: http://en.gtk.fi/ExplorationFinland/Tender/Oijarvi/oijarvi.htm

Kähkönen, Y. 2005. Svecofennian supracrustal rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 343–406.

Kahma, A. 1973. The main metallogenic features of Finland. Geological Survey of Finland, Bulletin 265. 28 p.

Kaija, J., Blomqvist, R., Suksi, J. & Rasilainen, K. 2000. The Palmottu Natural Analogue Project, Summary Report 1996-1999. The behaviour of natural radionuclides in and around uranium deposits, Nr. 13. Geological Survey of Finland, Report YST-102. 92 p.

Kaija, J., Rasilainen, K. & Blomqvist, R. 2003. IAEA Coordinated Research Project (CRP) "The use of selected safety indicators (concentrations, fluxes) in the assessment of radioactive waste disposal". Report 6: Site-specific natural geochemical concentrations and fluxes at the Palmottu U-Th mineralisation (Finland) for use as indicators of nuclear waste repository safety. Geological Survey of Finland, Report YST-114. 45 p.

Karinen, T. 2010. The Koillismaa Intrusion, northeastern Finland – Evidence for PGE reef forming processes in the layered series. Geological Survey of Finland, Bulletin 404. 176 p.

Kärki, A. 1988. Stratigraphy of the Kainuu Schist Belt and palaeosedimentology of its Kalevian metasediments at Melalahti, northern Finland. In: Laajoki, K. & Paakkola, J. (eds) Sedimentology of the Precambrian formations in eastern and northern Finland. Geological Survey of Finland, Special Paper 5, 149–164.

Kärkkäinen, N. 1993. Kultamalminetsintää Peräseinäjoen ja Alavuden Timanttimaalla vuosina 1987–1991. Geological Survey of Finland, unpublished report M19/2223/-92/1/10. 25 p. (in Finnish)

Kärkkäinen, N. 1999. Tutkimustyöseloste Kauhajoen alueen malmitutkimuksista, koskien valtausalueita Vähämäki 2, kaivosrekisteri nro 4653/, ja Vähämäki 3, kaivosrekisteri nro 5006/1. Geological Survey of Finland, unpublished report M06/1234/-99/1/10. 8 p. (in Finnish)

Kärkkäinen, N. 2007. Hanke 2901003. Etelä- ja Länsi-Suomen kultavarojen kartoitus. Loppuraportti toiminnasta 2002–2007. Geological Survey of Finland, unpublished report M10.4/2007/10/71. 27 p., 7 app. (in Finnish) http://arkisto.gsf.fi/m10/m10_4_2007_10_71.pdf

Kärkkäinen, N & Appelqvist, H. 1999. Genesis of a low-grade apatite-ilmenite-magnetite deposit in the Kauhajärvi gabbro, western Finland. Mineralium Deposita 34, 754–769.

Kärkkäinen, N. & Bornhorst, T. J. 2000. Magma flow genetic model for titanium ore in a small mafic intrusion. In: Geological Society of America 2000 Annual Meeting and Exposition, Reno, Nevada, November 13–16, 2000. Geological Society of America. Abstracts with Programs 32, A-426.

Kärkkäinen, N. & Bornhorst, T. J. 2003. The Svecofennian gabbro-hosted Koivusaarenneva magmatic ilmenite deposit, Kälviä, Finland. Mineralium Deposita 38, 169–184.

Kärkkäinen, N., Lehto, T., Tiainen, M., Jokinen, T., Nironen, M., Peltonen, P. & Valli, T. 2003. Etelä- ja Länsi-Suomen kaarikompleksi, kullan ja nikkelin etsintä vuosina 1998–2002. Geological Survey of Finland, unpublished report M19/21,12/2003/1/10. 118 p. (in Finnish)

Kärkkäinen, N., Jokinen, T. & Koistinen, E. 2006. Satulinmäki gold prospect at Somero, SW Finland. Geological Survey of Finland, unpublished report M 19/2024/2006/1/10. 55 p.

Karppanen, T. 1986. The Hammaslahti mine. In: Kojonen, K. (ed.) Prospecting in areas of glaciated terrain 1986: guide to the field excursion for the symposium in eastern Finland, September 3–5, 1986. Geological Survey of Finland, Guide 17, 34–40.

Karvinen, W. O. 2003. Northern Lion's Haveri gold mine project, Viljakkala, Finland. In: Final Program and Event Documentation. 4th Fennoscandian Exploration and Mining Congress, 4–5 December, Rovaniemi, Finland. European Union, European Regional Development Fund. Unpaginated.

Keinänen, V. & Holma, M. J. 2001. Levijärvi and Soretialehto – two epigenetic lode-gold deposits controlled by the Sirkka thrust zone within the Paleoproterozoic Central Lapland Greenstone Belt, Kittilä, northern Finland. In: Williams, P. J. (ed.) A Hydrothermal Odyssey. May 17–19th, 2001, Townsville. Extended abstracts. EGRU and JCU, 102–103.

Kerkkonen, O. 1982. Keminniemen tutkimukset. Lapin Malmi, Report 030/3644/OK/82. 70 p. (in Finnish)

Kerr, A. C. 2005. Oceanic LIPs: The Kiss of Death. Elements 1, 289–292.

Kilpeläinen, T. 1998. Evolution and 3D modelling of structural and metamorphic patterns of the Palaeoproterozoic crust in the Tampere-Vammala area, southern Finland. Geological Survey of Finland, Bulletin 397. 124 p.

Kinnunen, A. 1979a. Itäranta, Mäkrö. Vanadiinirautamalmiesiintymä. Geologinen malmiarvio. Rautaruukki Oy, Report OU 11/79. 9 p., 12 app. (in Finnish)

Kinnunen, A. 1979b. Otanmäki, Itäranta. Kosken vanadiinirautamalmiesiintymän tunnustelukairaus. Rautaruukki Oy, Report OU 18/79. 6 p., 11 app. (in Finnish)

Kinnunen, K. 1982. Primary sedimentary features in Kittilä jasper, Finnish Lapland. Bulletin of the Geological Society of Finland 54, 69–76.

Kohonen, J. & Marmo, J. 1992. Proterozoic lithostratigraphy and sedimentation of Sariola and Jatuli-type rocks in the Nunnanlahti – Koli – Kaltimo area, eastern Finland; implications for regional basin evolution models. Geological Survey of Finland Bulletin 364. 67p.

Koistinen, E. 1996. Kälviän Koivusaarennevan ilmeniittiesiintymän mineraalivarantoarvio. Geological Survey of Finland, unpublished report, M19/2341/96/1. 20 p., 104 app. (in Finnish)

Koistinen, E. 2006. 3-D modelling and minerals resource assessment of the Satulinmäki gold deposit. Geological Survey of Finland, unpublished report CQ19/2024/2006/1.

Koistinen, T. 1971. Tiedonanto: Hammaslahden kuparimalmi. Outokumpu Oy, Report 001/4241/TK/71. 4 p., 3 app. (in Finnish)

Koistinen, T. J. 1981. Structural evolution of an early Proterozoic stratabound Cu-Co-Zn deposit, Outokumpu, Finland. Transactions of the Royal Society of Edinburgh: Earth Sciences 72, 115–158.

Koistinen, T., Stephens, M. B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comps.) 2001. Geological map of the Fennoscandian Shield 1:2 000 000. Espoo: Geological Survey of Finland.

Koivisto, T. 1984. Geokemialliset tarkistustutkimukset Peräpohjan liuskealueella: Moreenigeokemialliset kultatutkimukset Kivimaan ja Vinsan tunnettujen Cu-Au juonimuodostumien ympäristössä. Tutk. rap. nro 1. Geological Survey of Finland, unpublished report S/41/2544/1/1984. 19 p. (in Finnish)

Kojonen, K. & Johanson, B. 1988. Pahtavaaran Au-malmiaiheen malmimineraaleista (Ore minerals in the Pahtavuoma deposit). Geological Survey of Finland, unpublished report M40/3714/-88/1/41.2. 2 p. (in Finnish)

Kojonen, K., Johanson, B., O'Brien, H. E. & Pakkanen, L. 1993. Mineralogy of gold occurrences in the late Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 233–271.

Kojonen, K., Isomäki, O.-P., Pulkkinen, K. & Knauf, V. 2003. Mineral processing of base metal sulphides and platinum group minerals (PGM) at the Proterozoic Hitura Ni-Cu-PGE deposit, western Finland. In: Applied mineralogy '03, Helsinki, Finland, March 17–18, 2003, 4 p. Minerals Engineering International. Optical disc (CD-ROM).

Kontinen, A. 1986a. Kallioperäyksikön kairaukset, Ristijärvi, Hongikkokangas, 3443 Hyrynsalmi. geological Survey of Finland, unpublished report K/1986/2, 28–29. (in Finnish)

Kontinen, A., 1986b. Early Proterozoic stratigraphy and sedimentation in the Hyrynsalmi area, eastern Finland. In: Sokolov, V. A. & Heiskanen, K. I. (eds) Early Proterozoic of the Baltic Shield. Proceedings of the Finnish – Soviet Symposium held in Petrozavodsk 19–27th August, 1986. Committee for Scientific and Technical co-operation between Finland and Soviet Union, Petrozavodsk, 75–103.

Kontinen, A. 1987. An early Proterozoic ophiolite – the Jormua mafic-ultramafic complex, northern Finland. Precambrian Research 35, 313–341.

Kontinen, A. & Sorjonen-Ward, P. 1991. Geochemistry of metagraywackes and metapelites from the Palaeoproterozoic Nuasjärvi Group, Kainuu schist belt and the Savo province, North Karelia : implications for provenance, lithostratigraphic correlation and depositonal setting. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1989–1990. Geological Survey of Finland. Special Paper 12, 21–22.

Kontinen, A., Peltonen, P. & Huhma H. 2006. Description and genetic modelling of the Outokumpu-type rock assemblage and associated sulphide deposits. Final technical report for GEOMEX JV, Workspace "Geology". Geological Survey of Finland, unpublished report M10.4/2006/1. 378 p.

Kontoniemi, O. 1992. Tutkimustyöselostus Rantasalmen kunnassa valtausalueilla Osikko 1, kaiv. rek. nro 4048/1, Osikko 2, kaiv. rek. nro 4295/1, Osikko 3, kaiv. rek. nro 4367/1 ja Osikko 4, kaiv. rek. nro 4668/1, suoritetuista kultamalmitutkimuksista. 14 s., 8 liites. Geological Survey of Finland, unpublished report M06/3233/92/1/10. 14 p. (in Finnish)

Kontoniemi, O. 1998a. An overview of the geology in the Osikonmäki area, Rantasalmi, southeastern Finland: Especially as a promising environment for epigenetic gold mineralization. Geological Survey of Finland, Special Paper 25, 7–18.

Kontoniemi, O. 1998b. Geological setting and characteristics of the Palaeoproterozoic tonalite-hosted Osikonmäki gold deposit, southeastern Finland. Geological Survey of Finland, Special Paper 25, 39−80.

Kontoniemi, O. 2009. Ore mineralogy and structural features of the Kopsa deposit. Geological Survey of Finland. Internal report for Finn-Nickel Oy. 31 p.

Kontoniemi, O. & Ekdahl, E. 1990. Tonalite-hosted early Proterozoic gold deposit at Osikonmäki, southeastern Finland. Bulletin of the Geological Society of Finland 62, 61–70.

Kontoniemi, O., Johanson, B., Kojonen, K. & Pakkanen, L. 1991. Ore mineralogy of the Osikonmäki gold deposit, Rantasalmi, southeastern Finland. Geological Survey of Finland, Special Paper 12, 81–89.

Kontoniemi, O. & Forss, H. 1997. Tutkimustyöselostus Leppävirran kunnassa valtausalueilla Särki 1 (kaiv.rek. nro 5422/1) ja Särki 2 (kaiv.rek.nro 5422/2) suoritetuista nikkelimalmitutkimuksista vuosina 1993–1996. Geological Survey of Finland, unpublished report M06/3241/-97/2/10. 14 p. (in Finnish)

Kontoniemi, O. & Forss, H. 1998. Tutkimustyöselostus Leppävirran kunnassa valtausalueilla Hanhi 1 (kaiv. rek.nro 5473/1) ja Hanhi 2 (kaiv.rek.nro 5771/1) suoritetuista nikkelimalmitutkimuksista vuosina 1993−1996. Geological Survey of Finland, unpublished report M06/3241/98/1/10. 13 p. (in Finnish)

Kontoniemi, O. & Forss, H. 1999. Tutkimustyöselostus Rautalammin kunnassa valtausalueilla Törmälä 1 (kaiv. rek. nro 6615/1) ja Vilosensaari 1 (kaiv. rek. nro 6615/2) suoritetuista nikkelimalmitutkimuksista vuosina 1996-1999. Geological Survey of Finland, unpublished report M06/3223/99/1/10. 15 p. (in Finnish)

Kontoniemi, O. & Forss, H. 2001. Tutkimustyöselostus Rautalammin kunnassa valtausalueella Mäkisalo 1 (kaiv. rek. nro 6671/1) suoritetuista nikkelimalmitutkimuksista vuosina 1997–2000. Geological Survey of Finland, unpublished report M06/3223/2001/1/10. 18 p., 6 app.

Kontoniemi, O. & Mursu, J. 2006. Hirsikangas gold prospect in Himanka, western Finland. Claim areas Hirsi 1 and 2 (7847/1 and 8036/1). Geological Survey of Finland, unpublished report M19/2413/2006/1/10. 32 p., 8 app.

Kopperoinen, T. & Tuokko, I. 1988. The Ala-Luoma and Taivaljärvi Zn-Pb-Ag-Au deposits, eastern Finland. Geological Survey of Finland, Special Paper 4, 131–144.

Korkalo, T. 2006. Gold and copper deposits in Central Lapland, northern Finland, with special reference to their exploration and exploitation. Acta Universitatis Oulensis, Series A, Scientiae Rerum Naturalium 461. 122 p. Available at: http://herkules.oulu.fi/isbn951428108X/

Korkiakoski, E. 1992. Geology and geochemistry of the metakomatiite hosted Pahtavaara gold deposit in Sodankylä, northern Finland, with emphasis on hydrothermal alteration. Geological Survey of Finland, Bulletin 360. 96 p.

Korkiakoski, E. 2002. Pohjois-Pohjanmaan liuskealueen sinkki-kupari-lyijy-hopea- ja kultamalmitutkimukset vuosina 1990–1999. Summary: Exploration of zinc, copper, lead, silver and gold deposits in the Northern Ostrobothnian scist belt in 1990–1999. Geological Survey of Finland, unpublished report M19/2533/2534/3511/3422/3524/2002/1/10. 71 p.

Korsman, K. 1988. Tectonometamorphic evolution of the Raahe-Ladoga zone, Introduction. Geological Survey of Finland, Bulletin 343, 5–6.

Korsman, K., Niemelä, R. & Wasenius, P. 1988. Multistage evolution of the Proterozoic crust in the Savo schist belt, eastern Finland. In: Tectono-metamorphic evolution of the Raahe-Ladoga zone. Geological Survey of Finland, Bulletin 343, 89–96.

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds) 1997. Bedrock map of Finland 1:1 000 000. Espoo: Geological Survey of Finland.

Korvuo, E. 1982. Vähäjoen rautamalmialueen tutkimukset 1979-1982. Lapin Malmi Oy, Report. (in Finnish)

Korvuo, E. 1997. The Saattopora gold ore and the Pahtavuoma Cu Zn U occurrences in the Kittilä region, northern Finland. In: Geological Survey of Finland, Guide 43, 21–25.

Kousa, J., Luukas, J., Mäki, T., Ekdahl, E., Pelkonen, K., Papunen, H., Isomäki, O-P., Penttilä, V-J., & Nurmi, P. 1997. Geology and mineral deposits of central Ostrobothnia. Geological Survey of Finland, Guide 41, 43–67.

Kousa, J. & Lundqvist, Th. 2000. Meso- and Neoproterozoic cover rocks of the Svecofennian Domain. Geological Survey of Finland, Special Paper 28, 75–76.

Kousa, J., Lukkarinen, H. & Lundqvist, T. 2000. Proterozoic crystalline rocks. In: Description to the bedrock map of central Fennoscandia (Mid-Norden). Geological Survey of Finland, Special Paper 28, 25–75.

Kousa, J. & Luukas, J. 2004. Vihannin ympäristön kallioperä- ja malmitutkimukset vuosina 1992–2003. Geological Survey of Finland, unpublished report M10.4/2004/2. 140 p. (in Finnish)

Kousa, J., Luukas, J., Nikander, J., Kontinen, A. & Sorjonen-Ward, P. 2008. Paleoproterozoic volcanic-related mineral systems along the Karelian cratonic boundary in Finland. Proceedings of the 33rd International Geological Congress, Oslo, 6–14 August 2008. 2 p.

Krill, A. G., Bergh, S., Lindahl, I., Mearns, E. W., Often, M., Olerud, S., Olesen, O., Sandstad, J.S., Siedlecka, A. & Solli, A. 1985. Rb-Sr, U-Pb and Sm-Nd isotopic dates from Precambrian rocks of Finnmark. Norges geologiske undersökelse, Bulletin 403, 37–54.

Kuisma, M. 1985. Kuparikaivoksesta suuryhtiöksi, Outokumpu 1910–1985. Outokumpu Oy, Forssan kirjapaino Oy, Forssa. 463 p. (in Finnish)

Kuivamäki, A., Paananen, M. & Kurimo, M. 1991. Structural modelling of bedrock around the Palmottu U-deposit : progress report 1990. Geological Survey of Finland, Report YST-72. 31 p., 32 app.

Kurki, J. 1980. Kaivoslain 19§:n mukainen tutkimustyöselostus, Ilomantsi, Huhus, kaiv.rek.n:o 2713/1. Outokumpu Oy Exploration, Report 080/4242 12C/JAK/80. 3 p. (in Finnish)

Kyläkoski, M. 2007. Nickel, Copper and Platinum-Group Element Ore Potential of the Jouttiaapa Formation, a ca. 2.1 Ga Palaeoproteroizoic Continental Flood Basalt Sequence in the Peräpohja Belt, Northern Finland. Licentiate Thesis, Department of Geology, University of Oulu. 209 p. (in Finnish, Figure and Table captions in English)

Kyläkoski, M. 2009. Basin scale alteration features and their implications for ore formation in the Palaeoproterozoic Peräpohja Schist Belt, Northwestern Finland. In: Smart science for exploration and mining: proceedings of the 10th Biennial SGA Meeting, Townsville, Australia, 17th-20th August 2009. Townsville: James Cook University, 457–459.

Laajoki, K. 1975a. On the stratigraphic position of kaolin in Väyrylänkylä, South Puolanka area, Finland. Bulletin of the Geological Society of Finland 47, 83–91.

Laajoki, K. 1975b. Rare-earth elements in Precambrian iron formations in Väyrylänkylä, South Puolanka area, Finland. Bulletin of the Geological Society of Finland 47, 93–107.

Laajoki, K. 1985. Precambrian banded iron formations of Finland. Krystallikum 18, 75−95.

Laajoki, K. 1991. Stratigraphy of the northern end of the early Proterozoic (Karelian) Kainuu Schist Belt and associated gneiss complexes, Finland. Geological Survey of Finland, Bulletin 358. 105 p.

Laajoki, K. 2005. Karelian supracrustal rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amstredam: Elsevier, 279–341.

Laajoki, K. & Lavikainen, S. 1977. Rare-earth elements in the Archean iron formation and associated schists in Ukkolanvaara, Ilomantsi, SE Finland. Bulletin of the Geological Society of Finland 49, 105–123.

Laajoki, K. & Saikkonen, R. 1977. On the geology and geochemistry of the Precambrian iron formations in Väyrylänkylä, South Puolanka area, Finland. Geological Survey of Finland, Bulletin 292. 137 p.

Lahti, S. I. 1981. On the granitic pegmatites of the Eräjärvi area in Orivesi, southern Finland. Geological Survey of Finland, Bulletin 314. 82 p.

Lahti, S. I. 1987. The granitoids and pegmatites of the Eräjärvi area. Geological Survey of Finland, Guide 26, 26–36 p.

Lahti, S.I. 2000. Compositional variation in columbite-tantalite minerals from different types of granitic pegmatites of the Eräjärvi district, South Finland. Journal of the Czech Geological Society 45, 107–118.

Lahtinen, J. 1983. Yhteenveto Koillismaan kerrosintruusiokompleksin platinatutkimuksista. Outokumpu Oy, Report 001/3541, 3543, 4523/JJL/83/5. 22 p., 20 app. (in Finnish)

Lahtinen, J. 1986. Ni-Cu-PGE-mineralisaation tutkimukset; arvio malmimahdollisuuksista. Ranua, Ahmavaara. Outokumpu Oy report, 001/3522/JJL/87/1. (in Finnish)

Lahtinen, J. 1996. Nickel mineral resource estimate of the Ruossakero nickel deposit, Enontekiö, northwestern Finland. Lapin Malmi Oy, Report 035/1834/JJL/96. 21 p.

Lahtinen, J.J., Alapieti, T.T., Halkoaho, T.A.A., Huhtelin, T.A. & Iljina, M.J. 1989. PGE mineralization in the Tornio–Näränkävaara layered intrusion belt. Geological Survey of Finland. Guide 29, 43–58.

Lahtinen, R. 1994. Crustal evolution of the Svecofennian and Karelian domains during 2.1–1.79 Ga, with special emphasis on the geochemistry and origin of 1.93–1.91 Ga gneissic tonalites and associated supracrustal rocks in the Rautalampi area, central Finland. Geological Survey of Finland, Bulletin 378. 128 p.

Lahtinen, R., Korja, A. & Nironen, M. 2005. Palaeoproterozoic tectonic evolution. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 481–532.

Lahtinen, R., Huhma, H., Kontinen, A., Kohonen, J. & Sorjonen-Ward, P. 2009. New constraints for the source characteristics, deposition and age of the 2.1–1.9 Ga metasedimentary cover at the western margin of the Karelian Province. Precambrian Research 176, 77–93.

Laitakari, A. 1968. Säviän kupariesiintymän geologiasta. Geological Survey of Finland, unpublished report M17/Plv-68/2. 71 p. (in Finnish)

Lamberg, P. 2005. From genetic concepts to practice – lithogeochemical identification of Ni-Cu mineralised intrusions and localisation of the ore. Geological Survey of Finland, Bulletin 402. 264 p., CD-ROM.

Lappland Goldminers 2008. Press release 1 July 2008. Available at: www.lapplandgoldminers.se

Lappland Goldminers 2010. Press release 17 February 2010.

Latvalahti, U. 1979. Cu-Zn-Pb ores in the Aijala-Orijärvi area, southwestern Finland. Economic Geology 74, 1035–1059.

Lawrie, K. C. 1987. The origin, nature and tectonic significance of the Hällinmäki Cu-deposit, Virtasalmi District, South-central Finland. PhD thesis, Glasgow University. 297 p.

Lawrie, K. C. 1992. Geochemical characterization of a polyphase deformed, altered and high grade metamorphosed volcanic terrane: implications for the tectonic setting of the Svecofennides, south-central Finland. Precambrian Research 59, 171–205.

Lehtinen, M. 1987. Kittilän tutkimusalue: Saattopora. In: H. Papunen (ed.) Lapin vulkaniittien tutkimusprojekti. Loppuraportti. Department of Geology, University of Turku, Report, 47–53. (in Finnish)

Lehto, T. & Niiniskorpi, V. 1977. The iron formations of northern and eastern Finland. Geological Survey of Finland, Report of Investigations 23. 49 p

Lehtonen, M., Airo, M.-L., Eilu, P., Hanski, E., Kortelainen, V., Lanne, E., Manninen, T., Rastas, P., Räsänen, J. & Virransalo, P. 1998. The stratigraphy, petrology and geochemistry of the Kittilä greenstone area, northern Finland: a report of the Lapland Volcanite Project. Geological Survey of Finland, Report of Investigation 140. 144 p.

Lehtonen, M. I., Kujala, H., Kärkkäinen, N., Lehtonen, A., Mäkitie, H., Mänttäri, I., Virransalo, P. & Vuokko, J. 2005. Etelä-Pohjanmaan liuskealueen kallioperä. Summary: Pre-Quaternary rocks of the South Ostrobothnian Schist Belt. Geological Survey of Finland, Report of Investigations 158. 155 p., 1 app. map.

Lesher, C. M (ed.) 1999. Komatiitic peridotite-hosted Ni–Cu–(PGE) deposits of the Raglan area, Cape Smith Belt, New Québec. Guidebook Series 2, Mineral Exploration Research Centre, Laurentian University, Sudbury. 212 p.

Lesher, C. M. & Arndt, N. T. 1995. REE and Nd isotope geochemistry, petrogenesis and volcanic evolution of contaminated komatiites at Kambalda, Western Australia. Lithos 34, 127–157.

Lestinen, P., Kontas, E., Niskavaara, H. & Virtasalo, J. 1991. Till geochemistry of gold, arsenic and antimony in the Seinäjoki district, western Finland. Journal of Geochemical Exploration 39, 343−361.

Li, Y. H. 2000. A Compendium of Geochemistry: from Solar Nebula to the Human Brain. New Jersey, Princeton: Princeton University Press.

Liipo, J. & Laajoki, K. 1991. Mineralogy, geochemistry and metamorphism of the early Proterozoic Vähäjoki iron ores, northern Finland. Bulletin of the Geological Society of Finland 63, 69–85.

Liipo, J., Papunen, H., Kilpeläinen, T. & Lamberg, P. 1997. The Stormi ultramafic complex and associated Ni-Cu deposits. Geological Survey of Finland, Guide 44, 12–15.

Lilljequist, R. 1980. Ultrabasitstråken Keukiskero och Kurkovare. Geological Survey of Sweden, exploration report BRAP 80026. (in Swedish)

Lindbergson, K. A. & Kautsky, G. 1961. Sveriges geol. undersökning med uppgift om kända mineralförekomster inom Nederkalix kommun. Geological Survey of Sweden, Report BRAP 599. (in Swedish)

Lindblom, S., Broman, C. & Martinsson, O. 1996. Magmatic-hydrothermal fluids in the Pahtohavare Cu-Au deposit in greenstone at Kiruna, Sweden. Mineralium Deposita 31, 307–318.

Lindholm, O. & Anttonen, R. 1980. Geology of the Otanmäki mine. In: Precambrian ores of Finland: guide to excursions 078 A+C, Part 2 (Finland). Espoo: Geological Survey of Finland, 25–33.

Lindroos, A., Romer, R. L., Ehlers, C. & Alviola, R. 1996. Late-orogenic Svecofennian deformation in southwestern Finland constrained by pegmatite emplacement ages. Terra Nova 8, 567–574.

Loukola-Ruskeeniemi, K. 1991. Geochemical evidence for the hydrothermal origin of sulphur, base metals and gold in Proterozoic metamorphosed black shales, Kainuu and Outokumpu areas, Finland. Mineralium Deposita 26, 152–164.

Loukola-Ruskeeniemi, K. 1999. Origin of black shales and the serpentinite-associated Cu-Zn-Co ores at Outokumpu, Finland. Economic Geology 94, 1007–1028.

Loukola-Ruskeeniemi, K., Gaál, G. & Karppanen, T. 1991. Geochemistry, structure and genesis of the Hammaslahti copper mine – explorational tools for a sediment-hosted massive sulphide deposit. Geological Survey of Finland, Special Paper 12, 101–106.

Loukola-Ruskeeniemi, K., Gaál, G. & Karppanen, T. 1992. Geochemical and structural characteristics of a sediment-hosted copper deposit at Hammaslahti, Finland: comparison with Besshi-type massive sulphide deposits. In: Maurice, Y. T. (ed.) Proceedings of the Eight Quadrennial IAGOD Symposium, Ottawa, Canada, August 12–18, 1990. Stuttgart: E. Schweizerbart'sche Verlagsbuchhandlung, 551–569.

Loukola-Ruskeeniemi, K. & Heino, T. 1996. Geochemistry and genesis of the black shale-hosted Ni-Cu-Zn deposit at Talvivaara, Finland. Economic Geology 91, 80–110.

Luukas, J., Kousa, J., Nikander, J. & Ruotsalainen, A. 2004. Raahe–Laatokka -vyöhykkeen luoteisosan kallioperä Länsi-Suomessa. In: Kousa, J. & Luukas, J. (eds) Vihannin ympäristön kallioperä- ja malmitutkimukset vuosina

1992–2003. Geological Survey of Finland, unpublished report M10.4/2004/2, 6–37. (in Finnish)

Luukas, J., Mäki, T., Kousa, J. & Nikander, J. 2005. Comparison between the Paleoproterozoic Svecofennian volcanic sequences and the major VMS-deposits (Pyhäsalmi and Vihanti) in the Raahe–Ladoga Zone, central Finland. PowerPoint presentation at the annual GAC-MAC-CSPG-CSSS meeting, Halifax 2005. Program volume 30.

Luukkonen, A. 1994. Main geochemical features, metallogeny and hydrothermal alteration phenomena of certain gold and gold tin tungsten prospects in southern Finland. Geological Survey of Finland, Bulletin 377. 153 p.

Luukkonen, E. 1992. Late Archaean and Early Proterozoic structural evolution in the Kuhmo–Suomussalmi Terrain, eastern Finland. Annales Universitatis Turkuensis. Ser. A. II 78, 1–37.

Luukkonen, E. 2001. Lentiiran kartta-alueen kallioperä. Suumary: Pre-Quaternary rocks of the Lentiira map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 4414 and 4432. Geological Survey of Finland. 68 p.

Luukkonen, E., Heino, T., Niskanen, M. & Tenhola, M. 1998. Tutkimustyöselostus Hyrynsalmen kunnassa valtausalueilla Kaivolampi 1–2 (kaiv. rek. no 6143/3 ja 6143/2), Puistola 1–2 (kaiv. rek. no 5657/1 ja 6143/1), Paatola 1–2 (kaiv. rek. no 5619/1 ja 5619/2), Kiviharju 1–2 (kaiv. rek. no 5986/3 ja 5986/4), Siltajoki 1 (kaiv.rek.no 5986/2), Jokiperänaho 1–2 (kaiv.rek.no 5656/1 ja 6119/1), Rinneaho 1 (kaiv.rek.no 5657/3) ja Hietaniemi 1–2 (kaiv.rek. no 5657/2 ja 5986/1) suoritetuista kulta- ja nikkelimalmitutkimuksista vuosina 1993–1997. Geological Survey of Finland, unpublished report M06/4421/98/1/10. 20 p. (in Finnish)

Luukkonen, E., Halkoaho, T., Hartikainen, A., Heino, T., Niskanen, M., Pietikäinen, K. & Tenhola, M. 2002. Itä-Suomen arkeeiset alueet -hankkeen (12201 ja 210 5000) toiminta vuosina 1992-2001 Suomussalmen, Hyrynsalmen, Kuhmon, Nurmeksen, Rautavaaran, Valtimon, Lieksan, Ilomantsin, Kiihtelysvaaran, Enon, Kontiolahden, Tohmajärven ja Tuupovaaran alueella. Geological Survey of Finland, unpublished report M19/4513/2002/1. 265 p. (in Finnish)

Luukkonen, K., Mäki, T., Perä, P. & Niiranen, S. 2000. Pyhäsalmen uusi kaivos. Vuoriteollisuus – Bergshanteringen 58, 16–20. (in Finnish)

Mäkelä, K. 1980. Geochemistry and origin of Haveri and Kiipu, Proterozoic strata-bound volcanogenic gold-copper and zinc mineralizations from southwestern Finland. Geological Survey of Finland, Bulletin 310. 79 p.

Mäkelä, K. 1981. Outokumpu-tyyppisten malmien esiintymismahdollisuuksista Itä- ja Pohjois-Suomessa. Summary: On the potential of finding Outokumpu-type ore deposits in East- and North-Finland. Geologi 33, 17–20.

Mäkelä, T. 1980. Tutkimusraportti. Rantsila, Näsälänperä 3412 05, 2434 08. Outokumpu Oy, Vihannin kaivos, Report 001/3412, 2434/TVM/80. 7 p., 17 app. (in Finnish)

Mäkelä, U. 1989. Geological and geochemical environments of Precambrian sulphide deposits in southwestern Finland. Annales Academiae Scientiarum Fennicae. Series A. III. Geologica-Geographica 151. 102 p.

Mäkinen, J. 1987. Geochemical characteristics of Svecokarelidic mafic-ultramafic intrusions associated with Ni-Cu occurrences in Finland. Geological Survey of Finland, Bulletin 342. 109 p.

Mäkinen, J. & Makkonen, H. V. 2004. Petrology and structure of the Palaeoproterozoic (1.9 Ga) Rytky nickel sulphide deposit, central Finland: a comparison with the Kotalahti nickel deposit. Mineralium Deposita 39, 405–421.

Mäkitie, H. 2000. Granitoids (1.89–1.87 Ga), diatexites (1.89–1.88 Ga) and granitic pegmatites (1.80–1.79 Ga), and structural-metamorphic evolution in the Seinäjoki region, western Finland. Geological Survey of Finland, Espoo. 161 p.

Mäkitie, H. & Lahti, S. I. 1991. Seinäjoen kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Seinäjoki map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 2222. Geological Survey of Finland. 60 p.

Mäkitie, H., Kärkkäinen, N., Lahti, S. I. & Lehtonen, M.I. 1999. Chemical and modal composition of granitoids in three different geological units, South-Pohjanmaa, western Finland. Geological Survey of Finland, Special Paper 27, 7–19.

Mäkitie, H., Kärkkäinen, N., Lahti, S. I. & Alviola, R. 2001. Compositional variation of granitic pegmatites in relation to regional metamorphism in the Seinäjoki region, Western Finland, Geological Survey of Finland, Special Paper 30, 31–59.

Makkonen, H. 1985. Tutkimustyöselostus Juvan kunnassa valtausalueella Saarijärvi 1–2 kaiv. rek. n:o 3426 suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/3231/-85/1/10. 5 p. (in Finnish)

Makkonen, H. 1987. Tutkimustyöselostus Rantasalmen kunnassa valtausalueilla Pirilä 2 ja 3, kaiv. rek. n:o 3682/1−2, suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/3233/-87/1/10. 5 p. (in Finnish)

Makkonen, H. 1989. Mustalammen sinkkiesiintymän tutkimukset vuosina 1986–1988, valtausalueella Mustalampi 1, kaiv. rek. no 4345/1. Geological Survey of Finland, unpublished report M19/3231/-89/3/10. 27 p. (in Finnish)

Makkonen, H. 1991a. Viholanniemen Zn-esiintymän tutkimukset Joroisissa vuosina 1984–1988. Geological Survey of Finland, unpublished report M19/3234/-91/1/10. 25 p. (in Finnish)

Makkonen, H. 1991b. Tutkimustyöselostus Joroisten kunnassa valtausalueella Viholanniemi 1–3, kaiv. rek. n:o 4014/1–3, suoritetuista tutkimuksista. Geological Survey of Finland, unpublished report M06/3234/-91/1/10. 11 p. (in Finnish)

Makkonen, H. 1992a. Honkamäen Ni-Cu -esiintymän, kaiv. rek.num. 4678/1, tutkimukset Juvalla, vuosina 1989-1991. Geological Survey of Finland, unpublished report M06/3231/-92/2/10. 5 p., 5 app. (in Finnish)

Makkonen, H. 1995. Tutkimustyöselostus Juvan kunnassa valtausalueella Heiskalanmäki 1 kaiv. rek. n:o 4889/1 suoritetuista nikkelimalmitutkimuksista vuosina 1980-1981. Geological Survey of Finland, unpublished report M06/3144/96/2/10. 9 p. (in Finnish)

Makkonen, H. 1996a Tutkimustyöselostus Anttolan kunnassa valtausalueella Pihlajasalo 1 (kaivosrekisterinumero 4714/1) suoritetuista nikkelimalmitutkimuksista vuosina 1989-1990. Geological Survey of Finland, unpublished report M06/3144/-96/1/10. 9 p. (English summary)

Makkonen, H. 1996b. Tutkimustyöselostus Juvan kunnassa valtausalueella Saarijärvi 1-2 (kaivosrekisterinro 4725/1) suoritetuista nikkelimalmitutkimuksista vuonna 1991. Geological Survey of Finland, unpublished report, M06/3231/96/1/10. 3 p. (in Finnish)

Makkonen, H. 2002. Tutkimustyöselostus Kuopion kaupungissa valtausalueella Niinikoski 1 (kaiv. rek. nro 6777/1) suoritetuista nikkelimalmitutkimuksista vuosina 1996–

2000. Geological Survey of Finland, unpublished report M06/3242/2002/1/10. 13 p. (in Finnish)

Makkonen, H. 2008. Nickel sulfide deposition during 1. 88 Ga – examples from the orogenic Kotalahti Nickel Belt compared with the Thompson and Cape Smith Nickel Belts. In: 33rd International Geological Congress, 6–14 August 2008, Oslo, Norway: abstract CD-ROM. 1 p. Optical disc (CD-ROM).

Makkonen, H. & Ekdahl, E. 1988. Petrology and structure of the early Proterozoic Pirilä gold deposit in southeastern Finland. Bulletin of the Geological Society of Finland 60, 55−66.

Makkonen, H. & Forss, H. 1994. Raportti Juvan Niinimäen nikkeliesiintymästä, valtausalue Niinimäki 2. Geological Survey of Finland, unpublished report M06/3144/94/1/10. 17 p. (in Finnish)

Makkonen, H. & Forss, H. 1995. Tutkimustyöselostus Juvan kunnassa valtausalueilla Niinimäki 1 (kaiv.rek.no 4842/1), Niinimäki 3 (kaiv.rek.no 5452/1) ja Niinimäki 4 (kaiv.rek.no 5520/1) suoritetuista nikkelimalmitutkimuksista 1990–1995. Geological Survey of Finland, unpublished report M06/3144/95/1/10. 15 p. (in Finnish)

Makkonen, H. & Forss, H. 1999. Tutkimustyöselostus Kuopion ja Karttulan kunnissa valtausalueilla Vehmasjoki 1 (kaiv. rek. nro 6329/1), Vehmasjoki 4 (kaiv. rek. nro 6371/1), Vehmasjoki 5 (kaiv. rek. nro 6502/1) ja Vehmasjoki 6 (kaiv. rek. nro 6502/2) suoritetuista nikkelimalmitutkimuksista vuosina 1996-1998. Geological Survey of Finland, unpublished report M06/3242/99/1/10. 12 p. (in Finnish)

Makkonen, H., Kontoniemi, O., Lempiäinen, R., Lestinen, P., Mursu, J. & Mäkinen, J. 2003. Raahe-Laatokka-vyöhyke, nikkelin ja kullan etsintä-hankkeen (2108001) toiminta vuosina 1999–2003. Geological Survey of Finland, unpublished report M 10.4/2003/5/10. 90 p. (in Finnish)

Makkonen, H. & Mursu, J. 2004. Nikkelimalmitutkimukset Anttolan Pihlajasalon kohteessa vuosina 2000 ja 2001. Geological Survey of Finland, unpublished report M19/3144/2004/1/10. 5 p. 6 App. (English summary)

Makkonen, H. & Halkoaho, T. 2007. Whole rock analytical data (XRF, REE, PGE) for several Svecofennian (1.9 Ga) and Archean (2.8 Ga) nickel deposits in eastern Finland. Geological Survey of Finland, unpublished report M19/3241/2007/10/32. 49 p.

Makkonen, H., Halkoaho, T., Tiainen, M., Iljina, M., Ahtonen, N., Toropainen, E., Jokisaari, R., Turunen, R. & Laaksonen, M. 2010. FINNICKEL – a public database on nickel deposits in Finland. Version 1.1. Digital data product 11. Geological Survey of Finland. Optical disc (CD-ROM).

Makkonen, H. V. 1996. 1.9 Ga tholeiitic magmatism and related Ni–Cu deposition in the Juva area, SE Finland. Geological Survey of Finland, Bulletin 386. 101 p.

Makkonen, H. V. 1997. Composition of olivine as an exploration tool in the Niinimäki intrusion, SE Finland. In: Proceedings of the Fourth Biennial SGA Meeting, Turku/Finland/11-13 August 1997. Rotterdam: A. A. Balkema, 467–469.

Makkonen, H. V. 2005. Intrusion model for Svecofennian (1.9 Ga) mafic-ultramafic intrusions in Finland. Geological Survey of Finland, Special Paper 38, 11–14.

Makkonen, H. V. & Huhma, H. 2007. Sm-Nd data for mafic-ultramafic intrusions in the Svecofennian (1.88 Ga) Kotalahti Nickel Belt, Finland – implications for crustal contamination at the Archaean/Proterozoic boundary. Bulletin of the Geological Society of Finland 79, 175–201.

Makkonen, H. V., Mäkinen, J. & Kontoniemi, O. 2008. Geochemical discrimination between barren and mineralized intrusions in the Svecofennian (1.9 Ga) Kotalahti Nickel Belt, Finland. Ore Geol. Rev. 33, 101–114.

Makkonen, V. 1975. Tuomivaaran alueen tutkimukset, kaivosrekisterinumero 2229/1. Rautaruukki Oy Malminetsintä, Report 5.11.1975. (in Finnish)

Makkonen, V., Hiltunen, A. & Nuutilainen, J. 1968. Silaskairan vanadiinimalmi. Selostus kenttätutkimuksista vv. 1966–1967. Rautaruukki Oy, Report Ro, 4/68. 20 p., 5 app. (in Finnish)

Männikkö, K. H., Määttä, T. T., Ojala, V. J. & Tuukki, P. A. 1987. Otravaaran rikkikiisumalmin ja sen ympäristön geologia. University of Oulu, Department of Geology. Pohjois-Karjalan malmiprojekti. Report 4. 78 p. (in Finnish)

Manninen. T., Pihlaja, P. & Huhma, H. 2001. U-Pb geochronology of the Peurasuvanto area, northern Finland. Geological Survey of Finland, Special Paper 33, 189–200.

Mänttäri, I. 1995. Lead isotope characteristics of epigenetic gold mineralization in the Palaeoproterozoic Lapland greenstone belt, northern Finland. Geological Survey of Finland, Bulletin 381. 70 p.

Marttila, E. 2001. Kärsämäen kartta-alueen kallioperä. Pre-Quaternary Rocks of the Kärsämäki map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 3322. Geological Survey of Finland. 42 p., 1 app.

Matisto, A. 1973. Toijala. Geological Map of Finland 1:100 000, Pre-Quarternary Rocks, Sheet 2114. Geological Survey of Finland.

Meriläinen, M., Ekberg, M., Lovén, P., Koivistoinen, P., Hakola, J. & Strauss, T. 2008. Updated Reserve and Resource Estimate of the Hitura Nickel Mine in Central Finland. Belvedere Resources, National Instrument 43-101 Technical Report. 65 p.

Mikkola, A. 1949. Kemin näytteet. Geological Survey of Finland, unpublished report M17/Ke/48/1. (in Finnish)

Mikkola. A. 1966. Jussarön malmiesiintymä. English summary: Jussarö ore field. Vuoriteollisuus 24 (2), 55−61.

Mutanen, T. 1989. Koitelainen intrusion and Keivitsa-Satovaara Complex. Geological Survey of Finland, Guide 28. 49 p.

Mutanen, T. 1997. Geology and ore petrology of the Akanvaara and Koitelainen mafic layered intrusions and the Keivitsa-Satovaara layered complex, northern Finland. Geological Survey of Finland, Bulletin 395. 233 p.

Mutanen, T. 1998. Akanvaaran intruusion kromi-, kromivanadiini-, vanadiini-, ja platinametalli-kultaesiintymät. English summary: Cr, Cr-V, V, and PGE occurrences in the AkanvaarA intrusion. Geological Survey of Finland, unpublished report M06/3644/-98/1/10. 94 p., 10 app.

Mutanen, T. 2005. The Akanvaara intrusion and the Keivitsa-Satovaara Complex, with stops at Kaikkivaltiaanlehto and Rantavaara intrusions: field trip guidebook. Geological Survey of Finland, Guide 51b. 124 p.

Mutanen, T. & Huhma, H. 2001. U-Pb geochronology of the Koitelainen, Akanvaara and Keivitsa layered intrusions and related rocks. Geological Survey of Finland, Special Paper 33, 229–246.

Niiniskorpi, V. 1975. Raportti Lapin rautamalmien horisonttisidonnaisuus-projektin tutkimuksista Itä-Suomessa vuosina 1972−1975. Pohjois-Suomen malmigeologinen toimikunta, Kauppa- ja teollisuusministeriö, Tunnus PSMT-P10-76-3. (in Finnish)

Niiranen, T., Hanski, E. & Eilu, P. 2003. General geology, alteration, and iron deposits in the Palaeoproterozoic Misi region, northern Finland. Bulletin of the Geological Society of Finland 75, 69–92.

Niiranen, T., Mänttäri, I., Poutiainen, M., Oliver, N. H. S. & Miller, J. A. 2005. Genesis of Palaeoproterozoic iron skarns in the Misi region, northern Finland. Mineralium Deposita 40, 192–217.

Nikander, J. 1999. Tutkimustyöselostus Pyhäjoen kunnassa valtausalueella Oltava 1 (kaiv. rek. nro 6809/1) suoritetuista kultamalmitutkimuksista vuosina 1998 ja 1999. Geological Survey of Finland, unpublished report M06/2432/-99/1/10. (in Finnish)

Nironen, M. 1994. Structural control and (re)mobilization of the extinct Haveri Au-Cu deposit, southern Finland. Bulletin of the Geological Society of Finland 66, 39–44.

Nironen, M. 2005. Proterozoic orogenic granitoid rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 443–480.

Nordic Mines 2007. Pressmeddelande den 17 april 2007.

Nordic Mines 2009. Laiva gold plant feasibility study, vol. 2. Ore reserve and mine, 07.10.2009. Available at: www.nordicmines.se.

Nordic Mines 2010. Press release, Uppsala, 10 March, 2010. Available at: www.nordicmines.se

Nortec Ventures 2009a. Press release 9 March 2009. Available at: www.nortecventures.com

Nortec Ventures 2009b. Press release 22 June 2009. Available at: www.nortecventures.com

Nortec Minerals 2010. Press release 13 October 2010. Available at: www.nortecminerals.com

Nortec Minerals 2011. Press release 22 February 2011. Available at: www.nortecminerals.com

Nurmi, A. 1976. Talluskanava: nickel, copper and cobalt in till. Journal of Geochemical Exploration 5, 344–349.

Nurmi, P. A., Sorjonen Ward, P. & Damsten, M. 1993. Geological setting, characteristics and exploration history of mesothermal gold occurrences in the late Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 193−231.

Nuutilainen, J. 1969. On the geology of the Misi iron ore province, northern Finland. Ann. Acad. Sci. Fenn. Ser A III 96. 98 p.

Nykänen, O. 1971. On the Karelides in the Tohmajärvi area, eastern Finland. Bulletin of The Geological Society of Finland 43, 93–108.

Ojala, V. J., Pekkarinen, L. J., Piirainen, T. & Tuukki, P. 1990. The Archaean gold mineralization in Rämepuro, Ilomantsi greenstone belt, eastern Finland. Terra Nova 2, 240−244.

Outokumpu 1992. Internal company report. (in Finnish)

Outokumpu Oy 1987. Malminetsintä XXVII vuosikertomus 1986. Outokumpu Oy Report, Espoo. (in Finnish)

Outokumpu Oyj 2010. Annual Report 2009. Available at: http://ar.outokumpu.com/2009.

Pääjärvi, A. 2000. Rautalammin ja Karttulan kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Rautalampi and Karttula map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 3223 and 3224. Geological Survey of Finland. 81 p.

Paakkola, J. 1971. The volcanic complex and associated manganiferous iron formation of the Porkonen-Pahtavaara area in Finnish Lapland. Geological Survey of Finland, Bulletin 247. 83 p.

Paakkola, J. & Gehör, S. 1988. The lithofacies associations and sedimentary structures of the iron-formations in the early Proterozoic Kittilä Greenstone Belt, northern Finland. Geological Survey of Finland, Special Paper 5, 213–238.

Pääkkönen, K. 1988. Tutkimustyöselostus Kittilän ja Muonion kunnissa valtausalueilla Kolvakero 1-3, kaiv.rek. n:o 3315 sekä Laavivuoma 1-2 ja Kolvakero 4, kaiv.rek. n:o 3572 suor. malmitutkimuksista vv. 1982–1985. Geological Survey of Finland, unpublished report M06/2741/-88/1/60. 6 p. (in Finnish)

Pääkkönen, K. 1989. Uraanimalmitutkimukset Aakenusvaaran länsiosassa Kittilässä 1981–82. Geological Survey of Finland, unpublished report M19/2741/-89/1/60. 22 p. (in Finnish)

Pääkkönen, V. 1956. Otanmäki, the ilmenite-magnetite ore field in Finland. Bulletin de la Commission Géologique de Finlande 171. 71 p.

Pääkkönen, V. 1966. On the geology and mineralogy of the occurrence of native antimony at Seinäjoki, Finland. Bulletin de la Commission geologique de Finlande 225. 71 p.

Pakarinen, J. 1984. Raportti Honkajoella, Kauhajoella ja Karvialla 15. 4. 1983 - 29. 2. 1984 suoritetuista fosforititaani-rauta-malmitutkimuksista. Geological Survey of Finland, unpublished report M19/1234/84/1/10. 49 p. (in Finnish)

Pankka, H. 1992. Geology and mineralogy of Au Co U deposits in the Proterozoic Kuusamo volcanosedimentary belt, northeastern Finland. PhD thesis, Geology. Michigan Technological University. 233 p.

Pankka, H., Puustinen, K. & Vanhanen, E. 1991. Kuusamon liuskealueen kulta-koboltti-uraaniesiintymät. Summary: Au-Co-U deposits in the Kuusamo volcano-sedimentary belt, Finland. Geological Survey of Finland, Report of Investigation 101. 53 p.

Pankka, H. S. & Vanhanen, E. J. 1992. Early Proterozoic Au Co U mineralization in the Kuusamo district, northeastern Finland. Precambrian Research 58, 387–400.

Papunen, H. 1980. The Kylmäkoski nickel-copper deposit in southwestern Finland. Bulletin of the Geological Society of Finland 52, 129–145.

Papunen, H. 1985. The Kylmäkoski nickel-copper deposit. Geological Survey of Finland, Bulletin 333, 264–273.

Papunen, H. 1989. Platinum-group elements in metamorphosed Ni-Cu deposits in Finland. In: Magmatic sulphides – the Zimbabwe volume. London: The Institution of Mining and Metallurgy, 165–176.

Papunen, H. (ed.) 1990. Sinkkiprojektin loppuraportti. University of Turku, Institute of Geology and Mineralogy, Publication 22. 143 p. (in Finnish)

Papunen, H. 2003. Ni-Cu sulfide deposits in mafic-ultramafic orogenic intrusions - examples from the Svecofennian areas, Finland. In: Eliopoulos, D. G. et al. (eds) Mineral exploration and sustainable development: proceedings of the Seventh Biennial SGA Meeting, Athens, Greece, 24-28 August 2003. Vol. 1. Rotterdam: Millpress, 551–554.

Papunen, H. & Lindsjö, O. 1972. Apatite, monazite and allanite: three rare earth minerals from Korsnäs, Finland. Bulletin of the Geological Society of Finland 44, 123–129.

Papunen, H. & Mäkelä, M. 1980. Sulfur isotopes in Finnish nickel-copper occurrences. Bulletin of the Geological Society of Finland 52, 55–66.

Papunen, H. & Koskinen, J. 1985. Geology of the Kotalahti nickel-copper ore. Geological Survey of Finland, Bulletin 333, 228–240.

Papunen, H. & Vorma, A. 1985. Nickel deposits in Finland, a review. Geological Survey of Finland, Bulletin 333, 123–144.

Papunen, H., Kopperoinen, T. & Tuokko, I. 1989. The Taivaljärvi Ag-Zn deposit in the Archean greenstone belt, eastern Finland. Economic Geology 84, 1262–1276.

Park A. F. & Bowes, D. R. 1983. Basement-cover relationships during polyphase deformation in the Svecokarelides of the Kaavi distinct, eastern Finland. Transactions of the Royal Society of Edinburgh: Earth Sciences 74, 95–118.

Parkkinen, J. 1992. Osikonmäki: Kultaesiintymän rakennegeologinen mallitus ja mineraalivarantoarvion tarkistus. Geological Survey of Finland, unpublished report M19/3233/92/1/10. 12 p. (in Finnish)

Parkkinen, J. 1997. An outline of the history of exploration and mining in the Outokumpu district. Geological Survey of Finland, Guide 42, 27–28.

Parkkinen, J. 2001. Quality control of mineral resource estimates: Laivakangas, Hosko, Kuivisto E, Other, Osikonmäki, Pirilä, Housuvaara, Pahkalampi. Geological Survey of Finland, Report. 27 p.

Parkkinen, J. 2003. Update of quality control of mineral resource estimate, 2003. Geological Survey of Finland, unpublished report CM19/2332/2003/1/10.

Parkkinen, J. & Reino, J. 1985. Nickel occurrences of the Outokumpu type at Vuonos and Keretti. Geological Survey of Finland, Bulletin 333, 178–188.

Patison, N. J. 2007. Structural controls on gold mineralisation in the Central Lapland Greenstone Belt. Geological Survey of Finland, Special Paper 44, 105–122.

Patison, N. J., Salamis, G. & Kortelainen, V. J. 2007. The Suurikuusikko gold deposit: Project development summary of northern Europe's largest gold resource. Geological Survey of Finland, Special Paper 44, 123–134.

Paull, P. L., Hodkinson, I. P., Morrison, G. W. & Teale, G. S. 1990. Mount Leyshon gold deposit. Hughes, F. E. (ed.) Geology of the Mineral deposits of Australia and Papua New Guinea. Melbourne: Australian Institute of Mining and Metallurgy, 1471–1481.

Pekkarinen, L. 1990. Kaivoslain 19§:n mukainen tutkimustyöselostus, Vihanti, Kuuhkamo, 2434 05, kaivosrekisteri nro 3648/1–2. Outokumpu mining, Finnmines, Report 080/2434 05/LP/90. 2 p., 4 app. (in Finnish)

Pekkarinen, L. 2002. Haukivuoren ja Pieksämäen kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Haukivuori and Pieksämäki map-sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 3231 and 3232. Geological Survey of Finland. 98 p.

Pekkarinen, L. J. 1979. The Karelian formations and their depositional basement in the Kiihtelysvaara – Värtsilä area, east Finland. Geological Survey of Finland Bulletin 301. 141p.

Pekkarinen, L. J. & Lukkarinen, H. 1991. Palaeoproterozoic volcanism in the Kiihtelysvaara-Tohmajärvi district, eastern Finland. Geological Survey of Finland, Bulletin 357. 30 p.

Pekkarinen, L. J., Kohonen, J., Vuollo, J. & Äikäs, O. 2006. Kolin kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Koli map-sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 4313. Geological Survey of Finland. 116 p.

Peltonen, P. 1995. Petrogenesis of ultramafic rocks in the Vammala Nickel Belt: Implications for crustal evolution of the early Proterozoic Svecofennian arc terrane. Lithos, 34, 253–274.

Peltonen, P. 2005. Svecofennian mafic-ultramafic intrusions. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 407–442.

Peltonen, P. & Jokinen, T. 2002. Tutkimustyöselostus Äetsän kunnassa Tyrisevän alueella suoritetuista malminetsintätutkimuksista vuosina 1998–2001. Geological Survey of Finland, unpublished report M19/2121/2002/2. 17 p. (in Finnish)

Peltonen, P., Kontinen, A., Huhma, H. & Kuronen, U. 2008. Outokumpu revisited: new mineral deposit model for the mantle peridotite-associated Cu-Co-Zn-Ni-Ag-Au sulphide deposits. Ore Geology Reviews 33, 559–617.

Peltonen, P. T., Manninen, T. & Pihlaja, P. 1988. The late Archean volcaniclastic Rookkiaapa formation in Peurasuvanto, northern Finland. Geological Survey of Finland, Special Paper 5, 165–176.

Perälä, A. 2003. Someron Satulinmäen Au-esiintymän geologia, geokemia ja mineralogia. MSc thesis, Department of Geosciences, University of Oulu. 57 p. (in Finnish)

Perttunen, V. & Vaasjoki, M. 2001. U-Pb geochronology of the Peräpohja Schist Belt, northwestern Finland. Geological Survey of Finland, Special Paper 33, 45–84.

Peuraniemi, V. 1992. Hieronmäki: W, Sn, Cu and Zn concentrations of till near a scheelite mineralization in hilly region. Handbook of Exploration Geochemistry 5. Amsterdam: Elsevier. 277–282.

Pietikäinen, K. 1986. Juvan Saarijärven peridotiittien malmipotentiaalista. MSc thesis, University of Turku, Department of Geology. 72 p. (in Finnish)

Pietikäinen, K., Hartikainen, A., Niskanen, M. & Tenhola, M. 2000. The gold prospects: Kuikka, Syrjälä N, Syrjälä S and Tupakkiloma in Kiannaniemi, Suomussalmi, Eastern Finland (register numbers of claims 6318/1, 6318/2, 6318/3, 6748/1, 6841/1, 6880/1, 6880/2, 6912/1 and claim reservation 77/2000. Geological Survey of Finland, unpublished report CM06/4511/2000/1. 25 p.

Piirainen, T. 1968. Die Petrologie und die Uranlagerstätten des Koli-Kaltimogebiets im finnischen Nordkarelien. Bulletin de la Commission Géologique de Finlande 237. 99 p.

Piispanen, R. & Tarkian, M. 1984. Cu-Ni-PGE Mineralization at Rometölväs, Koillismaa Layered Igneous Complex, Finland. Mineralium Deposita 19, 105–111.

Poutiainen, M. & Grönholm, P. 1996. Hydrothermal fluid evolution of the Palaeoproterozoic Kutemajärvi gold telluride deposit, Southwest Finland. Economic Geology 91, 1335–1353.

Poutiainen, M. & Partamies, S. 2003. Fluid evolution of the late Archaean Rämepuro gold deposit in Ilomantsi greenstone belt in eastern Finland. Mineralium Deposita. 38, 196−207.

Pulkkinen, E. 1999. Summary report. The Kaaresselkä gold and copper prospects, Sodankylä, Finnish Lapland. Geological Survey of Finland, unpublished report C/M 06/3714/-99/2.

Pulkkinen, J. 1985. Yhteenveto Virtasalmen kaivoksen toiminnasta vuosina 1966–1984. Outokumpu Oy, Kotalahden kaivos, unpublished company report. 7 p. (in Finnish)

Puritch, E., Ewert, W., Brown, F. H. & King, D. 2007. Technical report, mineral resource estimate, and preliminary economic assessment (scoping study) of the Suhanko Project, northern Finland, for North American Palladium Ltd. Aker Kvaerner, P&E Consultants Inc., and F.H. Brown. NI-43-101F1 Technical report and Scoping Study. Report No 135. 199 p.

Puumalainen, V.-M. 1986. Otanmäen liuskealueen ja sen ympäristön kivilajit ja rakenne. MSc thesis, University of Oulu, Department of Geology. 53 p. (in Finnish)

Puustinen, K. 1995. Suomen malmikaivokset vuosina 1530–1994. Geological Survey of Finland, unpublished report M10.1/-95/1. 96 p. (in Finnish)

Puustinen, K. 2003. Suomen kaivosteollisuus ja mineraalisten raaka-aineiden tuotanto vuosina 1530–2001, historiallinen katsaus erityisesti tuotantolukujen valossa. Geological Survey of Finland, unpublished report M10.1/2003/3. 578 p. (in Finnish)

Puustinen, K., Saltikoff, B. & Tontti, M. 1995. Distribution and metallogenic types of nickel deposits in Finland. Geological Survey of Finland, Report of Investigations 132. 38 p.

Puustjärvi, H. 1987. Kaivoslain 19 §:n mukainen tutkimustyöselostus. Kerimäki, Sulkavanniemi, kaivosrekisterinumero 3544/1. Outokumpu Oy, Report 080/4211 11AB, 4211 08CD/HOP/87. 3 p. (in Finnish)

Puustjärvi, H. 1992. Massiivisten sulfidimalmien sulfidimalmien tutkimukset Pyhäsalmen ympäristössä. In: Ekdahl, E. (ed.) Suomen kallioperän kehitys ja raaka-ainevarat. Symposio Oulussa 1.2.10.1992. Vuorimiesyhdistys – Bergsmannaföreningen r.y. Sarja B 51, 80–93. (in Finnish)

Puustjärvi, H. 1994. Kaivoslain 19§:n mukainen tutkimustyöselostus, Pyhäsalmi, Kaskela, kaiv. rek. no 4301/1. Outokumpu mining, Finnmines, Report 080/3322 07D/HOP/1994. 3 p., 6 app. (in Finnish)

Räisänen, E. 1989. Uraniferous granitic veins in the Svecofennian schist belt in Nummi-Pusula, southern Finland. In: Uranium deposits in magmatic and metamorphic rocks: proceedings of a technical committee meeting, Salamanca, 29 September – 3 October 1986. Vienna: International Atomic Energy Agency, 37–44.

Räisänen E. 1991. Tutkimustyöselostus ja malmiarvio Nummi-Pusulan kunnassa valtausalueilla Palmottu 1–2, kaiv. rek. N:o 3243 suoritetuista uraanimalmitutkimuksista. Geological Survey of Finland, unpublished report M06/2023/-91/10. 11 p. (in Finnish)

Rantala, E. 2011. Hammaslahden malmi ja sen 3D-mallintaminen. MSc. thesis, University of Turku, Department of Geology. 49 p., 3 app. (in Finnish)

Räsänen, J. 1996. Palaeovolcanology of the Sattasvaara komatiites, northern Finland: evidence for emplacement in a shallow water environment. In: IGCP project 336 symposium in Rovaniemi, Finland, August 21–23, 1996: program and abstracts. University of Turku, Division of Geology and Mineralogy, Publication 33, 69–70.

Räsänen, J. 2005. SANI-hankkeessa vuosina 2002–2004 tehdyt geologiset tutkimukset (Geological investigations of the SANI project in 2002–2004). Geological Survey of Finland, unpublished report K 21.42/2004/4. 28 p. (in Finnish)

Räsänen, J. & Huhma, H. 2001. U-Pb datings in the Sodankylä schist area, central Finnish Lapland. Geological Survey of Finland, Special Paper 33, 153–188.

Räsänen, J. & Vaasjoki, M. 2001. The U-Pb age of a felsic gneiss in the Kuusamo Schist Area: reappraisal of local lithostratigraphy and possible regional correlations. Geological Survey of Finland, Special Paper 33, 143–152.

Räsänen, J., Hanski, E., Juopperi, H., Kortelainen, V., Lanne, E., Lehtonen, M. I., Manninen, T., Rastas, P. & Väänänen, J. 1995. New straticraphical map of central Finnish Lapland. The 22nd Nordic Geological Winter Meeting, 8–11 January, 1996, Turku, Finland, Abstracts, p. 182.

Rasilainen, K. 1996. Alteration geochemistry of gold occurrences in the late Archean Hattu Schist Belt, Ilomantsi, Eastern Finland. Academic dissertation: synopsis and four research papers. Geological Survey of Finland. 140 p.

Rasilainen, K., Eilu, P., Halkoaho, T., Iljina, M. & Karinen, T. 2010. Quantitative mineral resource assessment of nickel, copper, platinum, palladium and gold in undiscovered PGE deposits in mafic-ultramafic layered intrusions in Finland. Geological Survey of Finland, Report of Investigations 180. 300 p.

Rastas, P. 1969. Jormuan emäksinen kompleksi. MSc thesis, Department of Geology, University of Turku. 102 p. (in Finnish)

Rastas, P., Huhma, H., Hanski, E., Lehtonen, M. I., Härkönen, I., Kortelainen, V., Mänttäri, I. & Paakkola, J. 2001. U-Pb isotopic studies on the Kittilä greenstone area, Central Lapland, Finland. Geological Survey of Finland, Special Paper 33, 95–141.

Rauhamäki, E., Mäkelä, T. & Isomäki, O.-P. 1980. Geology of the Vihanti mine. In: Häkli, T. A. (ed.) Precambrian ores of Finland; Guide to excursions 078 A+C, Part 2 (Finland), 180-190. 26th International Geological Congress, Paris 1980, 14–24.

Raw Mineral Base of the Republic of Karelia 2005. Karelia, Petrozavodsk. 278 p. (in Russian)

Rehtijärvi, P. & Kinnunen, K. A. 1979. Fluid and mineral inclusions and inclusion zones of cave calcite from Korsnäs Mine, western Finland. Bulletin of the Geological Society of Finland 51, 75–79.

Reino, J., Ilvonen, E. & Rekola, T. 1978. Suhanko-Pekkala -alueen tutkimuksista 1970-luvulla. Outokumpu Oy Report, 001/3522, 3524, 3611, 3613/JR, EI, TPR/78. (in Finnish)

Reino, J., Huhtala, T. & Mäki, T. 1992. Malmiarvion toteutuminen eräissä Suomen sulfidikaivoksissa. In: Parkkinen, J. (ed.) Malmiarvioseminaari 26.11.1992. Vuorimiesyhdistys. Sarja B 53, 135–152. (in Finnish)

Reino, J., Ekberg, M., Heinonen, P., Karppanen, T., Hakapää, A. & Sandberg, E. 1993. Suomen kallioperän emäksisten kivilajien malmipotentiaali. Abstract: Ore potential of basic rocks in Finland. Voimayhtiöiden ydinjätetoimikunta. Raportti YJT-93-02. Helsinki: Voimayhtiöiden ydinjätetoimikunta. 80 p.

Rieck, K., Borchert, H. & Anger, G. 1967. Lagerstättenkundliche Untersuchungen am Eisenerzvorkommen Jauratsi in Finnisch-Lappland. Bulletin de la Commission Géologique de Finlande 226. 70 p.

Riekkola-Vanhanen, M. 2010. Talvivaara Sotkamo mine – bioleaching of a polymetallic nickel ore in subartic climate. Nova Biotechnologica 10, 7–14.

Roberts, M., Oliver, N. & Lahtinen, R. 2004. Geology, lithogeochemistry and paleotectonic setting of the host sequence to the Kangasjärvi Zn-Cu deposit, central Finland: Implications for volcanogenic massive sulphide exploration in the Vihanti–Pyhäsalmi district. Bulletin of the Geological Society of Finland 76, 31–62.

Roos, S. 1982. Reposelkä 1:n tutkimukset. Tutkimustyöselostus valtausalueelta kaiv.rek. n:o 2469/1. Lapin Malmi Oy, Report 080/3642/SR/1. 1 p. (in Finnish)

Rosenberg, P. 1997. The Kaapelinkulma gold deposit, Valkeakoski. Geological Survey of Finland, Guide 44, 23–25.

Rossi, S. 1992. Tervolan alueelta tavattujen moreenigeokemian ja lohkareiden kulta-, kupari- ja kobolttiviitteiden malmipotentiaalin arviointi, kuvaus kesällä 1992 suoritetuista tutkimuksista ja niiden alustavista tuloksista. Geological Survey of Finland, unpublished report M19/2633/-92/2/10. 11 p. (in Finnish)

Rossi, S. 2000. Report on gold exploration during 1999–2000 carried out in Kuivaniemi Commune, expl. leases Välikangas 1, (mine reg. no. 6846/1) and Kylmäkangas 1 (mine reg. no. 7002/1). Geological Survey of Finland, unpublished report C/M06/3521/2000/2/10. (in Finnish with English summary)

Rossi, S. & Konnunaho, J. 2006. Malminetsinnälliset kallioperätutkimukset Yli-Iin kunnassa Oulun läänissä vuosina 2001–2004. Geological Survey of Finland, unpublished report M19/3512/2006/1/10. 50 p., 231 app. (in Finnish)

Rouhunkoski, P. & Isokangas, P. 1974. The copper-gold vein deposit of Kivimaa at Tervola, N-Finland. Bulletin of the Geological Society of Finland 46, 29–35.

Ruskeeniemi, T., Blomqvist, R. & Ahonen, L. 1994. Uraninite and its alteration at Palmottu - a possible natural analogue for spent fuel under reducing conditions. In: The Palmottu Analogue Project, Progress Report 1993. The behaviour of natural radionuclides in and around uranium deposits, Nr. 7. Geological Survey of Finland, YST-85, 53–64.

Saalmann, K. 2007. Structural control on gold mineralization in the Satulinmäki and Riukka prospects, Häme Schist Belt, southern Finland. Bulletin of the Geological Society of Finland 79, 69–93.

Saalmann, K., Mänttäri, I., Ruffet, G. & Whitehouse, M. J. 2009. Age and tectonic framework of structurally controlled Palaeoproterozoic gold mineralization in the Häme belt of southern Finland. Precambrian Research 174, 53–77.

Saalmann, K. & Niiranen, T. 2010. Hydrothermal alteration and structural control on gold deposition in the Hanhimaa shear zone and western part of the Sirkka Line. Geological Survey of Finland, unpublished report M19/2741/2010/58. 30 p.

Saalmann, K., Mänttäri, I., Peltonen, P., Whitehouse, M. J., Grönholm, P. & Talikka, M. 2010. Geochronology and structural relationships of mesothermal gold mineralization in the Palaeoproterozoic Jokisivu prospect, southern Finland. Geological Magazine 147, 551–569.

Saikkonen, R. 1981. Hirvikallion petaliittiesiintymä, Tammela. Oy Lohja Ab, Malminetsintä. Report 12.1.1981. (in Finnish)

Sakko, M. & Laajoki, K. 1975. Whole rock Pb-Pb isochron age for the Pääkkö iron formation in Väyrylänkylä, South Puolanka area, Finland. Bulletin of the Geological Society of Finland 47, 113–116.

Saksela, M. 1951. Späthydrothermale Bildungen im Kieserz von Otravaara, Ostfinnland. Geological Survey of Finland, Bulletin 154, 115–122.

Salminen, R. (ed.) 1995. Alueellinen geokemiallinen kartoitus Suomessa 1982–1994. Summary: Regional geochemical mapping in Finland in 1982–1994. Geological Survey of Finland, Report of Investigations 130. 47 p., 24 app. maps.

Saltikoff, B. 1980. Nurmon Kalliosalon antimoniesiintymän malmimäärä. Geological Survey of Finland, unpublished report M19/2222/-80/2/10.1. 4 p., 12 app. (in Finnish)

Saltikoff, B., Puustinen, K. & Tontti, M. 2000. Metallic mineral deposits of Finland: explanatory remarks to the Mineral deposits map of Finland. Geological Survey of Finland, Guide 49. 29 p.

Saltikoff, B., Puustinen, K. & Tontti, M. 2006. Metallogenic zones and metallic mineral deposits in Finland: explanation to the Metallogenic map of Finland. Geological Survey of Finland, Special Paper 35. 66 p.

Sarapää, O. & Kärkkäinen, N. 2001. Report of investigations of the Peräneva ilmenite deposit in Kälviä, claim areas Peräneva and Peräneva 2, 6341/1 and 6828/1, in 1997–2000. Geological Survey of Finland, unpublished report M06/2341/2001/1. 5p., 1 app.

Sarapää, O. & Kärkkäinen, N. 2003. Tutkimustyöselostus Toholammen kunnassa valtausalueella Lylyneva 1–2 (kaivosrekisterinumero 6141/1–2) suoritetuista ilmeniittitutkimuksista vuosina 1994–1997. Geological Survey of Finland, unpublished report M 06/2341/2003/1. 34 p. (in Finnish)

Sarapää, O., Ahtola, T., Reinikainen, J., & Seppänen, H. 2003. Industrial mineral potential in Finland. Geological Survey of Finland, Special Paper 36, 5–12.

Sarapää, O., Kärkkäinen, N., Chernet, T., Lohva, J. & Ahtola, T. 2006a. Exploration results and mineralogical studies on the Lumikangas apatite-ilmenite gabbro, Kauhajoki, western Finland. Geological Survey of Finland, Special Paper 38, 31–41.

Sarapää, O., Kärkkäinen, N., Chernet, T., Lohva, J. & Ahtola, T. 2006b. Tutkimustyöselostus Kauhajoen kunnassa valtausalueella Lumikangas (Kaivosrekisterinumero 7741/1) suoritetuista ilmeniitti-apatiittitutkimuksista vuosina 2002–2004. Geological Survey of Finland, unpublished report M06/1234/2006/1/10. 21 p. (in Finnish)

Sarapää, O., Pankka, H., Hulkki, H., Karvinen, A., Keinänen, V., Pulkkinen, E., Lahti, I., Salmirinne, H. & Sarala, P. 2008. Pohjois-Suomen kultavarojen kartoitus vuosina 2003–2008. Loppuraportti. Hanke 2108002, 2901005. Geological Survey of Finland, unpublished report M10.4/2008/77. 91 p. (in Finnish)

Saverikko, M. 1983. The Kummitsoiva komatiite complex and its satellites in northern Finland. Bulletin of the Geological Society of Finland 55, 111–139.

Saverikko, M. 1985. The pyroclastic Komatiite complex at Sattasvaara in northern Finland. Bulletin of the Geological Society of Finland 57, 55–87.

Säynäjärvi, K. 1972. Emmesin spodumenipegmatiittiesiintymä (Kaiv.rek.nro. 1940/1a). Partek Oy Ab Report. 3 p. (in Finnish)

Schardt, C., Cooke, D. R., Gemmell, J. B. & Large, R. R. 2001. Geochemical Modelling of the Zoned Footwall Alteration Pipe, Hellyer Volcanic-Hosted Massive Sulfide Deposit, Western Tasmania, Australia. Economic Geology 96, 1037–1054

Seppä, V.-M. 2009. Kotalahden alueen nikkeliesiintymät. MSc thesis, Geology and Mineralogy, University of Turku. 79 p. (in Finnish)

Seppänen, H. 1985. Raportti aeroradiometristen gammasäteilyanomalioiden maastotarkistuksista 1984. Geological Survey of Finland, unpublished report M19/2013/-85/1/60. 6 p. (in Finnish)

Silvennoinen, A. 1991. Kuusamon ja Rukatunturin kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Kuusamo and Rukatunturi map-sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 4524+4542 and 4613. Geological Survey of Finland. 62 p.

Sipilä, E. 1964. Selostus Huhuksen rautamalmin tutkimuksista. Oy Malminetsijä Ab Report 21.9.1964. 2 p. (in Finnish)

Sipilä, E. 1984. Tutkimusselostus Rautavaaran kunnassa valtausalueella Pappilanmäki 1, kaiv.rek. n:o 3044/1 suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/3343/-78-80/1/10. 16 p. (in Finnish)

Sipilä, E., 1988. Kultatutkimukset valtausalueella Ängeslampi 1 (kaiv. rek. n:o 3981/1). Geological Survey of Finland, unpublished report M06/2433/-88/1/10. 4 p., 9 app. (in Finnish)

Sipilä, P., Ervamaa, P. & Papunen, H. 1985. The Petolahti nickel-copper occurrence. Geological Survey of Finland, Bulletin 333, 293–303.

Sipilä, P., Kujala, H. & Torssonen, M. 2008. Oravaisten-Lapuan-Alahärmän kallioperä. Abstract: Pre-Quaternary rocks of the Oravainen-Lapua-Alahärmä area. Geological Survey of Finland, Report of Investigation 170. 40 p.

Skyttä, P., Käpyaho, A. & Mänttäri, I. 2005. Supracrustal rocks in the Kuovila area, suothwestern Finland: structural evolution, geochemical characteristics and the age of volcanism. Bulletin of the Geological Society of Finland 77, 129–150.

Smith, M. S. & Dymek, R. F. & Schneiderman, J. S. 1992. Implications of trace element geochemistry for the origin of cordierite-orthoamphibole rocks from Orijärvi, SW Finland. Journal of Geology 100, 545−559.

Söderholm, K. & Inkinen, O. 1982. The Tornio layered intrusion – a recently discovered intrusion with chromitite horizons in northern Finland. Bulletin of the Geological Society of Finland 54, 15–24.

Sorjonen-Ward, P. 1993. An overview of structural evolution and lithic units within and intruding the late Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 9−102.

Sorjonen-Ward, P., Nurmi, P., Härkönen, I. & Pankka, H. 1992. Epigenetic gold mineralization and tectonic evolution of a lower Proterozoic greenstone terrain in the northern Fennoscandian (Baltic) Shield. In: Sarkar, S. C. (ed.) Metallogeny Related to Tectonics of the Proterozoic Mobile Belts. New Delhi: Oxford & IBH Publishing, 37–52.

Sorjonen-Ward, P., Ojala, V. J. & Airo, M.-L. 2003. Structural modelling and magmatic expression of hydrothermal alteration in the Paleoproterozoic Lapland greenstone belt, northern Fennoscandian Shield. In: Eliopoulos, D. G. et al. (eds) Mineral Exploration and Sustainable Development. Proceedings of the Seventh Biennial SGA Meeting, Athens, Greece, 24–28. August 2003. Rotterdam: Millpress, 1107–1110.

Sorjonen-Ward, P. & Luukkonen, E. J. 2005. Archean rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 19–99.

Sorjonen-Ward, P. & Äikäs, O. 2008. Structural framework and event history relevant to uranium mineralization near the Palaeoproterozoic-Archean unconformity in southeastern Finland. Abstract, 33rd International Geological Congress (MRD 19 Uranium Deposits), Oslo, August 2008.

Sotkamo Silver 2011. Press release 14 Feb 2011. NI 43-101 compliant mineral resource, cut off at 50 g/t Ag eq.

Stein, H. J., Sundblad, K., Markey, R. J., Morgan, J. W. & Motuza, G. 1998. Re-Os ages for Archean molybdenite and pyrite, Kuittila-Kivisuo, Finland and Proterozoic molybdenite, Kabeliai, Lithuania: testing the chronometre in a metamorphic and metasomatic setting. Mineralium Deposita 33, 329–345.

Stenberg, A. & Häkli, T. A. 1985. The Hyvelä nickel-copper occurrence. Geological Survey of Finland, Bulletin 333, 287–293.

Stigzelius, H., Laatio, G., Ervamaa, P., Paarma, H., Piirainen, T., Makkonen, V. & Airas K. 1970. Oulun läänin malmi-, teollisuusmineraali- ja kalkkikiviesiintymät. Oulun läänin teollisuustoimikunta, Esitykset ja osamietinnöt 13. 185 p. (in Finnish)

St-Onge, M. R. & Lucas, S. B. 1994. Controls on the regional distribution of iron–nickel–copper–platinum-group element sulfide mineralization in the eastern Cape Smith Belt, Quebec. Canadian Journal of Earth Sciences, 31, 206–218.

Strauss, T. A. L. 2004. The geology of the Proterozoic Haveri Au-Cu deposit, southern Finland. PhD thesis, Rhodes University. 306 p.

Suomen Nikkeli 2006. Available at: www.nikkeli.fi/documents/mining/Mantymaki%20nickel%20deposit.pdf. Acessed in 24 October 2006.

Suomen Nikkeli 2007. Press release 1 March 2007.

Talikka, M. & Mänttäri, I. 2005. Pukala intrusion, its age and connection to hydrothermal alteration in Orivesi, southwestern Finland. Bulletin of the Geological Society of Finland 77, 165–180.

Talvitie, J. & Paarma, H. 1980. On Precambrian basic magmatism and the Ti-Fe ore formation in central and northern Finland. Geological Survey of Finland, Bulletin 307, 98–107.

Talvivaara Mining Company 2010. Press release 27 October 2010. Available at: http://www.talvivaara.com

Tarvainen, T. 1985. Kuusamon Kouvervaaran Co-Au-esiintymän malmiarvio. Geological Survey of Finland, Finland, unpublished report M19/4522/-85/1/10. 85 p. (in Finnish)

Tertiary Minerals 2001. Press release 4 October 2001.

Tianen, M. & Viita, H. 1994. Determination of ore potential areas in the Häme belt, southwestern Finland, by integration of geological, geophysical and till geochemical data. Geological Survey of Finland, Report of Investigation 125. 49 p.

Tiainen, M., Valjus, T., Nyholm, T. & Huhta, P. 2007. Malmitutkimukset (Ni-Cu) Padasjoen Nyystölän kunnassa, Konnun tutkimuskohteessa 1997–2003. Geological Survey of Finland, unpublished report M19/2143/2007/10/103. 30 p., 134 App. (in Finnish)

Tiainen, M., Kärkkäinen, N., Koistinen, E., Pakkanen, L. & Sipilä, P. 2011. Kedonojankulma: a recently discovered Palaeoproterozoic porphyry-type Cu-Au deposit in Southern Finland. In: Barra, F., Reich, M., Campos, E & Tornos, F. (eds) Let's Talk Ore Deposits. Proceedings of the Eleventh Biennial SGA Meeting, 26–29 September 2011, Antofagasta, Chile. Ediciones Universidad Catolica del Norte, Antofagasta, Chile, 393–395.

Tolppi, T. 1999. Metavulkaniittien geokemia ja hydrotermінen muuttuminen Karahkalehdossa Oijärven arkeeisella liuskejaksolla. MSc thesis, Department of Geology, University of Oulu. 80 p. (in Finnish)

Tribovillard, N., Algeo, T. J., Lyons, T. & Riboulleau, A. 2006. Trace metals as paleoredox and paleoproductivity proxies: An update. Chemical Geology 232, 12–32.

Tyni, M. 1983. Nurmon Kalliosalon antimoni-kultaesiintymän malmiarvio. Myllykoski Oy, Report. (in Finnish)

Universal Resources 2010. Press release, 2 August 2010.

Vaajoensuu, K., Grundström, L. & Astorga, T. 1978. Virtasalmi mine, mining technique. Outokumpu Oy Finland, Mining, Milling and Metallurgical Division. Unpublished company report. 15 p.

Vaasjoki, M. 1996. U-Pb dating of monazite from Palmottu. Geological Survey of Finland, Report 15.8.1996. 2 p.

Vaasjoki, M. (ed.) 2001. Radiometric age determinations from Finnish Lapland and their bearing on the timing of Precambrian volcano-sedimentary sequences. Geological Survey of Finland, Special Paper 33. 279 p.

Vaasjoki, M. & Kontoniemi, O. 1991. Isotopic studies from the Proterozoic Osikonmäki gold prospect at Rantasalmi, southeastern Finland. Geological Survey of Finland, Special Paper 12, 53–57.

Vaasjoki, M., Sorjonen-Ward, P. & Lavikainen, S. 1993. U-Pb age determinations and sulfide Pb-Pb characteristics from the late Archaean Hattu schist belt, Ilomantsi, eastern Finland. Geological Survey of Finland, Special Paper 17, 103–131.

Vaasjoki, M., Appelqvist, H. & Kinnunen, K. A. 2002. Paleozoic remobilisation and enrichment of Proterozoic uranium mineralisation in the East-Uusimaa area, Finland. In: Lithosphere 2002: Second Symposium on the Structure, Composition and Evolution of the Lithosphere in Finland, Espoo, Otaniemi, November 12-13, 2002: programme and extended abstracts. Institute of Seismology. University of Helsinki. Report S-42, p. 139.

Vaasjoki, M., Korsman, K. & Koistinen, T. 2005. Overview. In: Lehtinen, M., Nurmi, P. A. & Rämö O. T. (eds) The Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 1–18.

Vaasjoki, O., Häkli, T. A. & Tontti, M. 1974. The effect of cobalt on the thermal stability of pentlandite. Economic Geology 69, 549–551.

Väisänen, M., Mänttäri, I. & Hölttä, P. 2002. Svecofennian magmatic and metamorphic evolution in southwestern Finland as revealed by U-Pb zircon SIMS geochronology. Precambrian Research 116, 111−127.

Väisänen, M. & Westerlund, G. 2007. Palaeoproterozoic mafic and intermediate metavolcanic rocks in the Turku area, SW Finland. Bulletin of the Geological Society of Finland, 79, 127–141.

Väisänen, M. & Kirkland, C. L. 2008. U-Th-Pb zircon geochronology on igneous rocks in the Toija and Salittu Formations, Orijärvi area, southwestern Finland: constraints on the age of volcanism and metamorphism. Bulletin of the Geological Society of Finland 80, 73–87.

Vanhanen, E. 1989a. Kuusamon Kouvervaaran uraaniesiintymän malmitutkimukset vuosina 1979–1987. Geological Survey of Finland, unpublished report M19/4522/-89/1/10. 16 p, 34 app. (in Finnish)

Vanhanen, E. 1989b. Kuusamon Meurastuksenahon koboltti-kultaesiintymän malmitutkimukset 1984–1986. Geological Survey of Finland, unpublished report M19/4611/-89/1/10. 19 p. (in Finnish)

Vanhanen, E. 1991. Tutkimustyöselostus Kuusamossa valtausalueella Iso-Rehvi 1, kaiv. rek. n:o 4442, malmitutkimuksista vuosina 1988–1989. Geological Survey of Finland, unpublished report M06/4611/-91/1/10. 4 p. (in Finnish)

Vanhanen, E. 1995. Pohjois-Pohjanmaan liuskealueen sinkki-lyijyhopeamalmitutkimukset vuosina 1990-1993. English summary: Exploration of zinc, lead and silver deposits in northern Ostrobothnia Schist Area in 1990-1993. Geological Survey of Finland, unpublished report M19/2533,3422,3511/-95/1/10. 18 p.

Vanhanen, E. 2001. Geology, mineralogy and geochemistry of the Fe-Co-Au-(U) deposits in the Paleoproterozoic Kuusamo Schist Belt, northeastern Finland. Geological Survey of Finland, Bulletin 399. 229 p.

Vanne, J. 1984. Tutkimustyöselostus Rautavaaran kunnassa valtausalueella Lintumäki 1–2, Kaiv. Rek. N:o 3237/1–2 suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/4321/-84/1/10. 9 p., 2 app. (in Finnish)

Vartiainen, H. 1984. Haarakummun Co-Cu-mineralisaation alustava malmiarvio. Lapin Malmi, Report 030/4612/HV/84/6. 7 p., 23 app. (in Finnish)

Västi, K. 1991a. Tutkimustyöselostus Haapaveden kunnassa valtausalueella Kiimala 1, kaiv. rek. n:o 4125/1, ja Kiimala 2, kaiv. rek. n:o 4267/1, suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/2433/-91/2/10. 3 p., 9 app. (in Finnish)

Västi, K. 1991b. Tutkimustyöselostus Haapaveden kunnassa valtausalueella Vesiperä 1, kaiv. rek. nro 3853/1, suoritetuista malmitutkimuksista. Geological Survey of Finland, unpublished report M06/2433/-91/1/10. 3 p., 4 app. (in Finnish)

Vesanto, J. 1978. Sirkan malmi ja sitä ympäröivä kallioperä (Sirkka gold deposit and the surrounding bedrock). MSc thesis, Department of Geology, University of Oulu. 89 p. (in Finnish)

Vesasalo, A. 1959. On the petalite occurrences of Tammela, SW Finland. Bulletin of the Geological Society of Finland 31, 59–74.

Volborth, A. 1960. Gediegen wismutantimon und andere Erzmineralien im Li-Be-Pegmatit von Viitaniemi, Eräjärvi, Zentralfinnland. Neues Jahrbuch für Mineralogie, Abhandlungen 94, 140–149.

Vulcan Resources 2007. Press release in 26 April 2007.

Vulcan Resources 2009. Press release 23 October 2009.

Vuollo, J. & Huhma, H. 2005. Palaeoproterozoic mafic dykes in NE Finland. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) The Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 195–236.

Wallis, C. S. 2006. Technical report on the Kouvervaara uranium property, Finland. Prepared for Cooper Minerals Inc. NI 43-101 Report. Scott Wilson RPA Inc. 24 p. Available at: http://www.cooperminerals.com/pdf/43-101_KouvervaaraREV.pdf

Ward, P. 1987. Early Proterozoic deposition and deformation at the Karelian craton margin in southeastern Finland. Precambrian Research 35, 71–93.

Ward, P., Härkönen, I. & Pankka, H. S. 1989. Structural studies in the Lapland greenstone belt, northern Finland and their application to gold mineralization: Geological Survey of Finland, Special Paper 10, 71–78.

Weihed, P., Arndt, N., Billström, C., Duchesne, J. C, Eilu, P., Martinsson, O., Papunen, H. & Lahtinen R. 2005. Precambrian geodynamics and ore formation: the Fennoscandian Shield. Ore Geology Reviews 27, 273–322.

Western Areas 2011. Activities report for the period ending 31 March 2011. 19 p. Available at: www.westernareas.com.au

Yletyinen, V. 1967. Ylitornion Kivilompolon molybdeenihohde-esiintymästä. Summary: On the molybdenum prospect at Kivilompolo in Ylitornio, northern Finland. Geological Survey of Finland, Geotechnical Publications 73. 21 p.

Yletyinen, V. & Nenonen, E. 1972. Selostus malmitutkimuksista Kittilän Riikonkoskella vuosina 1969–1972. Geological Survey of Finland, unpublished report M19/2734/72/1/10. 32 p. (in Finnish)

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 343–395, 2012

METALLOGENIC AREAS IN RUSSIAN PART OF THE FENNOSCANDIAN SHIELD

Korsakova, M., Krasotkin, S., Stromov, V., Iljina, M., Lauri, L. & Nilsson, N. P. 2012. Metallogenic areas in Russian part of the Fennoscandian shield. *Geological Survey of Finland, Special Paper 53,* 343–395, 35 figures and 23 tables.

There are 40 major metallogenic areas within the Russian part of the Fennoscandian shield. Of these, 14 areas show potential dominantly for ferrous metals (Fe, Mn, Ti, V, Cr), 12 for precious metals (Au, Pd, Pt), 6 for nickel, 5 for metals mostly used in modern, advanced technologies ('high-tech metals' Li, Nb, REE, Sn, Ta, Zr), but only 3 for copper, zinc and/or lead. However, a number of the areas are potential for more than one major group of metals. More than 20 genetic types of metal deposits are known from the area. By past production and present resources, the most significant deposits and areas include: BIF (Kostomuksha), carbonatite and peralkaline intrusion associated rare metal (Kola Province), and the mafic intrusion-hosted Ti-Fe±V, Cr and Ni-Cu-PGE (Pechenga, Zaimandrovskaya, Burakovka). Nearly all known deposits are either Archaean (especially the BIF), Palaeoproterozoic or Devonian (Kola and Northern Karelia) in age. There also is a large number of gold-potential metallogenic areas, some with geology largely similar to that in significant gold mine camps else where in the world, whereas very little gold mining has so far taken place. This suggest that, with more exploration, also the Russian part of Fennoscandia may eventually emerge as a significant gold producer. The situation may be similar from a few other metals, too.

Keywords (GeoRef Thesaurus, AGI): metallogenic provinces, mineral resources, metal ores, mines, Devonian, Precambrian, Republic of Karelia, Murmansk Region, Russian Federation

Margarita Korsakova, Stanislav Krasotkin
State Company Mineral, Detskaya str., 26 liter A office 4H, 199106 St. Petersburg, Russia

Victor Stromov[†]
VSEGEI, Sredny Prospekt 74, 199108 St. Petersburg, Russia
[†] Deceased

Markku Iljina, Laura Lauri
Geological Survey of Finland, P.O. Box 77, FI-96101 Rovaniemi, Finland

Lars Petter Nilsson
Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway

E-mail: krasotkin@scmin.spb.ru

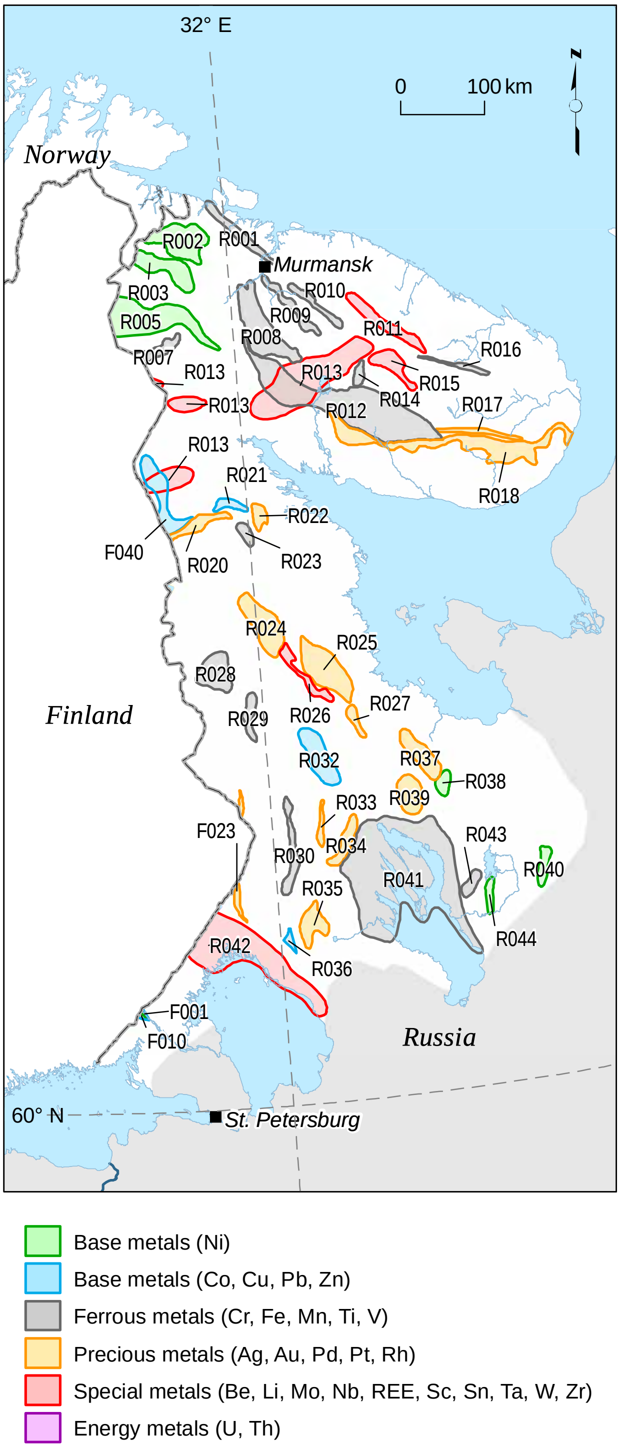


Figure 1. Index map of metallogenic areas in NW Russia. The names of the metallogenic areas are listed in Table 1.

Table 1. List of the metallogenic areas in NW Russia.

Code	Area name, main metals
R001	Uraguba-Murmansk Fe
R002	Pechenga Ni, Cu, PGE, Co, Au
R003	Allarechka Ni, Cu
R005	Lotta Ni, Cu
R007	Korvatundra Cr
R008	Zaimandrovskaya Fe, Ti
R009	Sholtanyavr Fe
R010	Pinkelyavr Fe
R011	Porosozero-Voron'ya Li, Nb, Ta
R012	Imandra-Varzuga Cr, PGE, Ni, Cu
R013	Kovdor-Lovozero REE, Nb, Li, Be, Zr
R014	Tsaginskaya V, Fe, Ti
R015	West Keyvy Zr, Nb
R016	Kuroptevskaya V, Fe, Ti
R017	Purnachskaya Au
R018	South Varzuga Au
R020	Olanga PGE
R021	Kukas Cu
R022	Vinchozero Au
R023	Eletozaro Ti, Fe, V, Nb
R024	Shombozero Au
R025	Lehta Au, Cu
R026	Päävaara-Lobash Mo, Au
R027	Parandovo-Nadvoiza Au, Mo, Cu
R028	Kostomuksha Fe, Au
R029	Bolshozero Fe, Au
R030	Gimoly Fe, U
R032	Elmozero-Segozero Pb, Cu
R033	Jangozero Au, Cu
R034	Pedrolapi-Elmus Au, Cu, Zn
R035	Hautovaara-Shotozero Au, Pb, Zn, Ta, Nb, Ni
R036	Tulomozero Zn, Pb, Fe
R037	Pulozero Au
R038	Kamennozero Ni, Zn, Cu
R039	South Vygozero Au, Ni, Cr
R040	Voloshovo Ni, Au, Cu
R041	Onega V, Ti, U, PGE, Cu, Au
R042	Northern Ladoga Sn, Zn, Pb, U, Au, W, Fe, V
R043	Burakovka Cr, PGE, Ni
R044	Matkalahta Ni

The metallogenic areas id-coded to the neighbouring countries are listed and described in the respective country sections of this book.

R001 URAGUBA–MURMANSK Fe

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Uraguba–Murmansk Fe area (R001) is in the northwestern part of the suture zone between the large Murmansk and Central Kola terrains (Fig. 1, Table 1). The suture is represented by relics of a 3000–2500 Ma greenstone belt comprising metavolcanic rocks, intrusives of mafic and ultramafic composition, blocks of metasedimentary rocks, zones of dynamic metamorphism and granitoid massifs. (Feoktistov et al. 2007)

Area R001 is characterised by stratiform iron mineralisation. The small Nerpichie deposit and a number of BIF showings (Lisiya gora, Srednyaya zalezh and others) are known in the andesite-rhyolite formation rocks. The Nerpichie deposit comprises BIF lenses 200–1500 m long and 11–65 m thick, where the average Fe content is 29%. Based on preliminary exploration conducted at one of the sites, the reserves were estimated at 35 Mt of ore. The total estimated resources of ferriferous ore in the area are about 312 Mt. The conducted economic evaluation (Malyshev 1985) suggests that, at present, there are no economic BIF ores in area R001. Hence, the exploration prospects for the region are estimated as weak, despite large prognostic resources of iron ore.

R002 PECHENGA Cu-Ni-PGE-Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Pechenga Cu-Ni-PGE-Au area (R002) is bordered on the south by the Inari-Allarechka granite-amphibole block, and covers the Pechenga riftogenic greenstones and the westernmost part of the Titovo schist and gneiss belt. The Pechenga Palaeoproterozoic (2500–1800 Ma) trough structure (greenstone belt) is formed by a thick effusive cover of basaltoids with minor intercalations of quartzite, sandstone, dolomite, phyllite and tuffite. Gabbro-wehrlite intrusions 1970 Ma in age occur in the thickest part of the sedimentary sequence. Large layered peridotite-pyroxenite-gabbronorite massifs (2505 and 2496 Ma in age) and Ludikovian (2100–1920 Ma) gabbro-norite-pyroxenite-peridotite massifs occur in the granite-gneiss formations of the Titovo belt (3200–2500 Ma). These intrusions are genetically related to rifting (Feoktistov et al. 2007). Magmatic Ni-Cu-PGE and epithermal gold types of mineralisation have been detected in area R002, which includes the subareas North Pechenga (R002.1), General-skaya (R002.2), Karikyavr (R002.3) and South-Pechenga (R002.4).

The North Pechenga subarea (R002.1) is within the Pechenga riftogenic trough and is confined to the thick sequence of volcanogenic rocks (the “productive strata”). Volcano-sedimentary rocks in the subarea include sandstone, phyllite and tuffite, hosting more than 200 massifs of gabbro and wehrlite. Copper-nickel mineralisation is genetically and spatially related to these massifs (Table 2). The intrusions have a lens-shaped form and occur concordantly with their country rocks. The length of the intrusive bodies varies from 200 to 5000 m and thickness from a few metres to 700 m. Altogether, 12 deposits of sulphidic Cu-Ni ore are known; six of them are presently under mining and one is abandoned (Gorbunov et al. 1999). The ore bodies have an extent along the strike of 600–1500 m, along dip 500–2100 m, and have a thickness from 5–20 to 70–200 m (Fig. 2). Sulphides occur as impregnated, massive and breccia veins. Impregnated ore is in peridotite of near-bottom parts of gabbro-norite intrusions, whereas massive and breccia vein ore is confined to deformed zones between the lower contacts of the massifs and the underlying volcanosedimentary rocks. Average metal grades in the Pechenga deposits are 0.51–2.6% Ni, 0.26–1.4% Cu, and 0.018–0.08% Co. Elevated contents of Au (0.1–3.4 g/t) and PGE (0.03–0.43 g/t) are also present. The main ore minerals are pyrrhotite, pentlandite, chalcopyrite and pyrite. The North Pechenga subarea has been studied in detail to the depth of 800–1000 m, but in the authors’ opinion, the probability of finding new commercial targets here at accessible depths is still rather high (Stromov 1987).

The General`skaya subarea (R002.2) is related to the large, layered **General’skaya** peridotite-pyroxenite-gabbronorite massif, 2496–2505 Ma in age. The massif is located in the contact zone between the Archaean granite-gneiss basement and the Palaeoproterozoic volcano-sedimentary rocks of the Pechenga rift. The intrusion has a wedge form elongated in a northwestern direction and is discordant relative to its country rocks. The length of the massif is 4 km and the width 2–3 km. The intrusion plunges gently, at 10–30°, under the Pechenga formations. It is thought that the exposed massif represents a small part of a large pluton. The General'skaya intrusion belongs to the rhythmically layered type and a "critical zone" of 100–200 m thick, represented by plagioclase-bronzite-olivine cumulates, is distinguished within it. Sulphide mineralisation of the 'critical zone' is represented by weak impregnation (3–5%) of chalcopyrite, pyrrhotite and pentlandite. This zone includes units 1–10 m thick with an increased platinum content (up to 3.5 g/t; Table 2). According to electric survey data, four electroconductivity targets with a low sulphide content running westward for 800–900 m are distinguished in the 'critical zone' (Grohovskaya et al. 1996). Platinoid resources are estimated at 120 t, and potential of the area for economic sulphidic platinum mineralisation is considered as modest.

The Karikyavr Ni-Cu subarea (R002.3) is defined by a zone of mafic-ultramafic intrusions in Lopian granite-gneisses of the Pechenga trough. Within the area, there are more than 20 gabbro-norite-pyroxenite-peridotite massifs 2500–2400 Ma in age. The intrusions comprise, from the bottom upwards, the following zones: peridotite, pyroxenite, gabbro-norite and gabbro. Individual intrusions are 100–500 m long, and from a few metres to 200 m thick. The rocks are strongly altered by amphibolisation, serpentinisation and biotitisation. In the area, there is one medium-sized sulphide deposit, **Karikyavr**, and a number of showings (**Rovno**, **Saken**, etc.; Table 2). Sulphide-bearing zones are confined to the footwall of the massifs. Ore is mainly impregnated and brecciated with contents of 0.5–2.0% Ni, 0.2–0.5% Cu and 0.1–3.0g/t platinoids (Gorbunov et al. 1999). The massifs are underexplored, with the exception of the Karikyavr-1 massif. The potential for further discoveries in the area is estimated as moderate.

The South Pechenga Au subarea (R002.4) is located in the southern wing of the Pechenga

Table 2. Deposit and showings in the Pechenga area (R002) included in the FODD database. Information is based on Gorbunov et al. (1999) and Korovkin et al. (2003), unless otherwise indicated.

Name	Ore tonnage (Mt)	Au, g/t	Co %	Cu %	Ni %	PGE g/t	Pd g/t	Pt g/t	Genetic type	Additional references
North Pechenga subarea (R002.1)										
Pakhtajarvi	28.67			0.3	0.75				Magmatic	
Sputnik	17.3	0.01	0.031	0.77	1.4	0.035			Magmatic	
Verkhnee	63.08	0.02	0.019	0.24	0.5	0.099			Magmatic	
Semiletka	17.17	0.04	0.027	0.35	0.73	0.14			Magmatic	
Kootsel'vaara-Kammikivi	34.37		0.018	0.64	1.2	0.185			Magmatic	
Kaula	14.6		0.08	1.4	2.6				Magmatic	
Zapolyarnoe	20.57	0.01	0.046	1.16	2.34	0.43			Magmatic	
Tundrovskoe	107.2	0.01	0.022	0.26	0.51	0.022			Magmatic	
Zhdanovskoe	1024.44	0.01	0.023	0.25	0.65	0.058			Magmatic	
Bystrinskoe	36.3	0.01	0.022	0.26	0.49	0.086			Magmatic	
Northern Onki	3.05			0.5	1.15				Magmatic	
Generalskaya subarea (R002.2)										
Mountain General'skaya	53.33			0.46	0.27	2.25	2.05	0.2	Magmatic	Dodin et al. (2000), Grokhovskaya et al. (1996)
Karikyavr subarea (R002.3)										
Rovno	15			0.2	0.4				Magmatic	Bakushin (1983)
Karikjavr	22.31			0.5	0.63	0.464			Magmatic	Bakushin (1983)
Karikjavr 2, 3	25			0.3	0.6				Magmatic	Bakushin (1983)
Saken	30			0.4	0.8				Magmatic	Bakushin (1983)
South Pechenga subarea (R002.4)										
Braginskoe	2	5							Epithermal	Akhmetov et al. (2004)

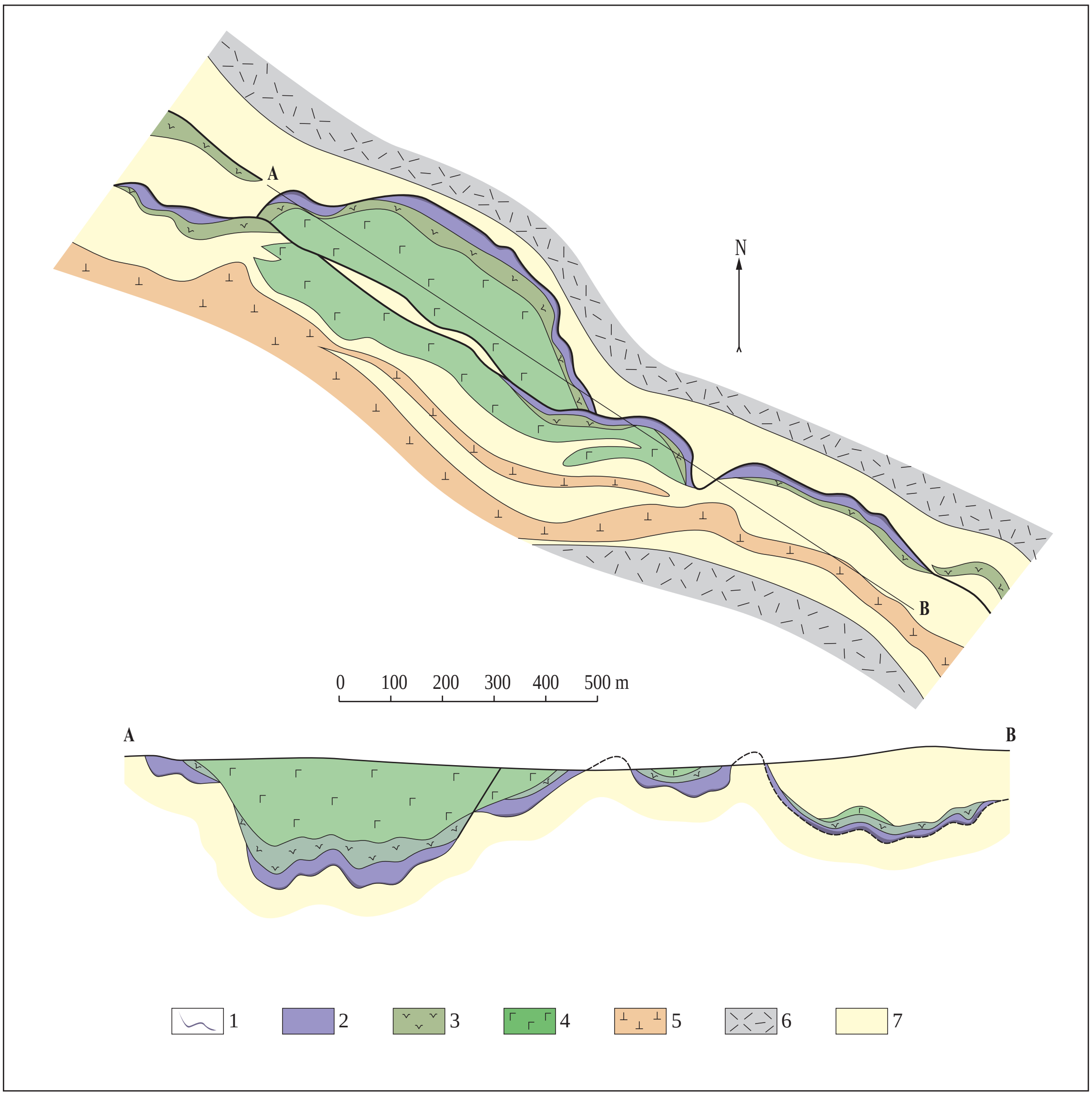


Figure 2. Geological map and long section of the Zhdanovskoe nickel deposit located at 69.422°N, 30.668°E. Legend: 1 – mineralised tectonic zone; 2 – impregnated Cu-Ni ore in altered peridotite; 3 – serpentinite and peridotite; 4 – gabbro; 5 – gabbro-diabase; 6 – effusive diabase; 7 – phyllite and sandstone; 8 – faults. Based on Gorbunov et al. (1999).

synclinorium comprising metamorphosed Kalevian volcano-sedimentary formations (1920–1800 Ma). Exploration in the subarea (R002.4) has revealed gold mineralisation in metasomatic quartz rock, andesite, dacite, carbonaceous schist, and sulphide ore (seven showings and 60 mineralised localities). The most promising gold-quartz sulphide formation is in the metasomatic quartz rocks where the gold content is up to 8 g/t (showings Ansem, Porojarvi, and others). Lenses of gold-bearing quartz rock have a length along the strike at 60–500 m and thickness from 2 to 12.5 m (Fig. 3). Taking into account the low level of exploration in the subarea and the extensive signs of gold, its potential for further discoveries is estimated as moderate (Voronyaeva 2008).

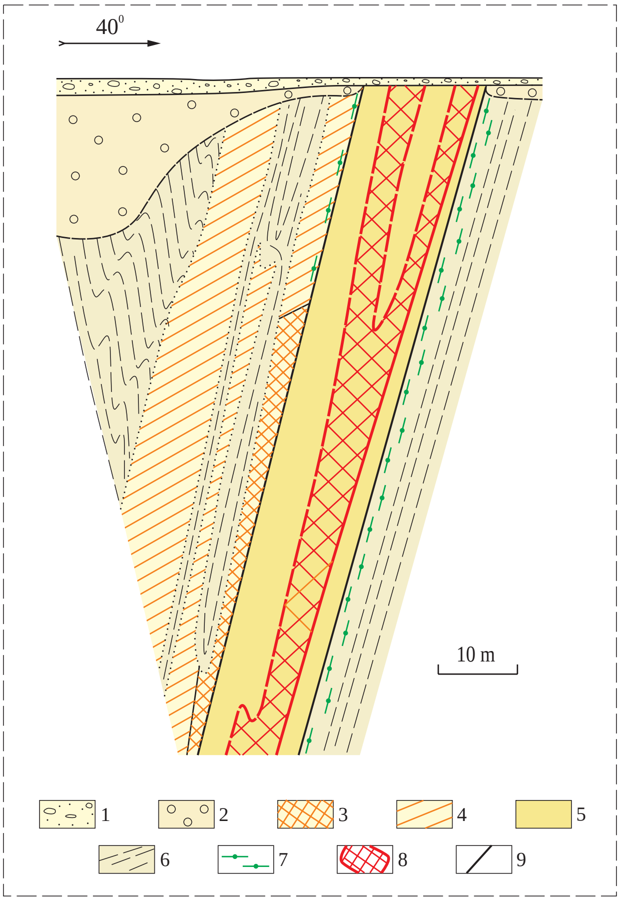


Figure 3. Geological cross-section of ore body N1 of the Ansem gold showing within the South Pechenga subarea (R002.4). Legend: 1 – Quaternary deposits; 2 – weathered schists and metasomatites; 3 – chlorite- and biotite-quartz-carbonate metasomatite; 4 – chlorite-talc-carbonate metasomatite; 5 – metasomatic quartz rock; 6 – carbonaceous shale; 7 – mylonite; quartz-chlorite, plagioclase-biotite-sericite blastomylonite; 8 – gold-bearing veins; 9 – faults. Based on Voronyaeva (2008).

R003 ALLARECHKA Cu-Ni-PGE-Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI), Markku Iljina (GTK), Lars Petter Nilsson (NGU)

The Allarechka Cu-Ni-PGE-Au area (R003) is located within the dominantly Archaean Inari–Allarechka granite-amphibolite block. The extent of area R003 is defiend by the presence of Palaeoproterozoic (2100–1920 Ma) Ni-rich mafic-ultramafic intrusions. The E-W trending area R003 extends across the Finnish-Norwegian-Russian borders, with all known deposits having a resource estimate occurring in Russia (Fig. 1). There are two subareas of known magmatic Ni-Cu-PGE deposits, Khikhnayarvi and Allarechka-Annam (Feoktistov et al. 2007).

The Khikhnayarvi subarea (R003.1) is located in the central part of R003. It includes about 80 harzburgite massifs in a granite gneiss dome-dominated region. The subarea is characterised by low-grade syngenetic Cu-Ni mineralisation, such as **Runnijoki** and **Khihnajarvi** (Table 3), with 0.17–0.45% Cu and 0.47–0.65% Ni (Goldberg 1972). Degree of exploration in subarea R003.1 is rather high and its prospects for further discoveries are estimated as low. Several small metaharzburgite intrusions exist in the extension of this subarea in South Pasvik in Norway. Exploration has been carried out in the area by various companies in several periods over the last 40 years. In the 1970s, Ni-Cu mineralised boulders were discovered at **Rømlingsås,** 10–12 km to the WSW of Runnijoki, and also found in drill cores in the 1990s by the Finnish prospector Erkki Kreivi (Nilsson & Often 2005). However, no extensive follow up work seems to have been conducted in the target area at Rømlingsås.

The Allarechka-Annam subarea (R003.2) is in the southeastern part of the Allarechka area. The subarea covers the Allarechka-Annam sutural zone at the boundary between the Lapland Granulite Belt and Inari-Allarechka block, and also the margins of some Archaean granite-gneiss domes, with a large number of ultramafic bodies (Gorbunov et al. 1985). Two medium-sized Cu-Ni deposits (the closed mines of **Vostok** and

Allarechka; Table 3) and a number of showings are known from subarea R003.2. Mineralisation is genetically and spatially related to small ultramafic massifs and is confined to their bottom part, in cases as offsets in the country rocks of the massifs. The latter have also been called 'segregated ores' (Fig. 4).

The Allarechka-Annam sutural zone located in the southwestern part of subarea R003.2 is regarded as the most promising for new discoveries within the subarea. Comparison of this region with the Ni-rich Thomson Belt in Canada undertaken by Rundkvist and Sokolova (1985) has shown that the areas have many similarities: for example, a similar position in regional geological structures, hosted by ultramafic intrusions, similarity between the Thomson Belt deposits (Pipe-2, Tomson, and others) and Vostok and Allarechka deposits, and the locations of Ni-Cu ores where the ultramafic bodies have intruded into sulphidic carbonaceous supracrustal formations. Subarea R003.2 has been extensively investigated and the probability of revealing outcropping deposits is practically excluded. However, there are many unexplored geophysical and geochemical anomalies that provide hope for discovering Cu-Ni deposits at depth. Taking into account this and the similarities with one of the richest Ni regions in the world, the potential of the subarea for further discoveries is estimated as rather high.

Table 3. Examples of Ni-Cu deposits with a resource estimate in the Allarechka metallogenic area (R003). All are hosted by harzburgite and have pyrrhotite, pentlandite and chalcopyrite as the main ore minerals. Data for all deposits are from Zak et al. (1972b), Gorbunov et al. (1999) and Korovkin et al. (2003).

Name	Ore tonnage (Mt)	Co %	Cu %	Ni %	Genetic type
Akkim	1.75		0.335	0.47	Magmatic Ni-Cu-PGE
Allarechka	2.23	0.075	1.77	3.59	Magmatic Ni-Cu-PGE
Vostok	2.34	0.028	0.95	2.1	Magmatic Ni-Cu-PGE
Khikhnajarvi	2.6		0.17	0.47	Magmatic Ni-Cu-PGE
Runnijoki	15.385		0.45	0.65	Magmatic Ni-Cu-PGE

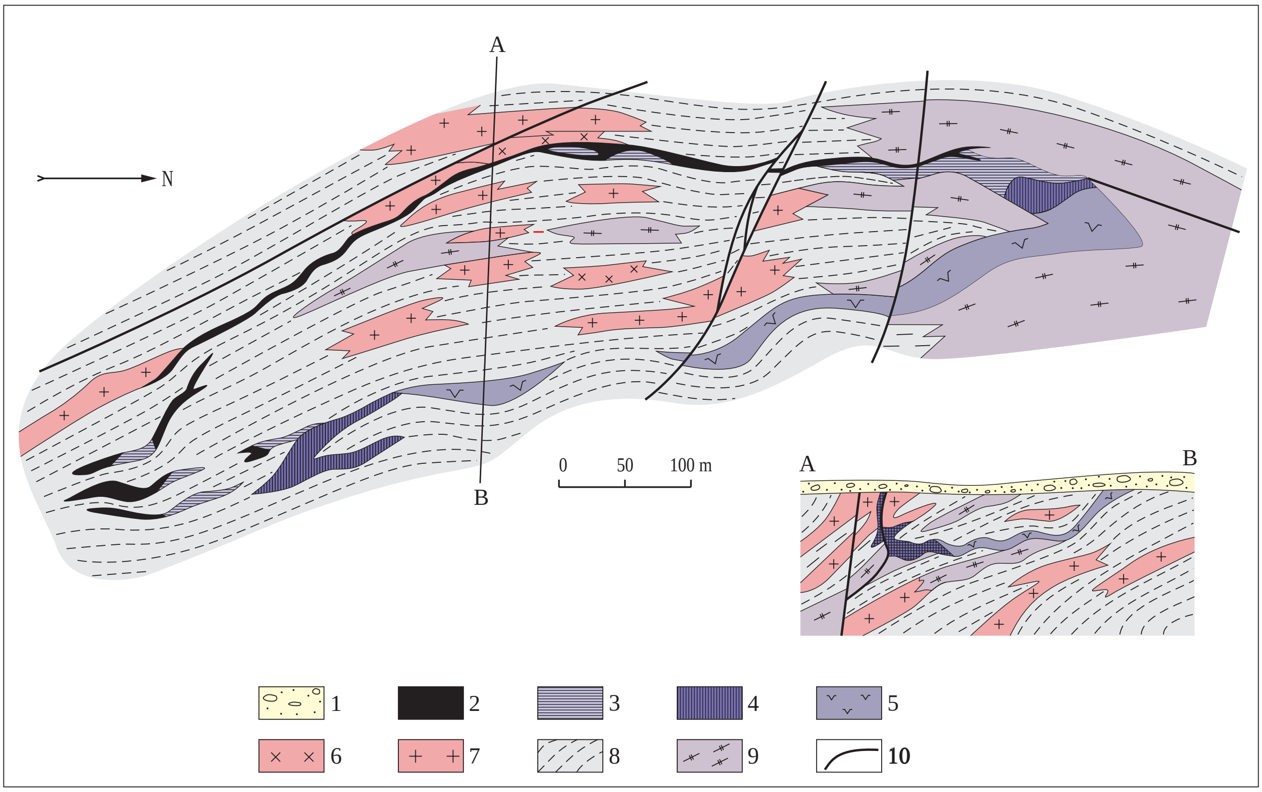


Figure 4. Geological map of the 130 m level and cross-section of the Allarechka Ni-Cu deposit. The deposit is at 69.01°N, 30.28°E. Legend: 1 - moraine; 2 – massive sulphide ore; 3 – intensively mineralised metaperidotite; 4 – mineralised metaperidotite; 5 – metaperidotite; 6 – plagiomicrocline granite-gneiss; 7 – plagioclase granite-gneiss; 8 – biotite gneiss; 9 – feldspathic amphibolite; 10 – faults. Based on Gorbunov et al. (1999).

R005 LOTTA Cu-Ni-PGE

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI), Markku Iljina (GTK)

The Lotta Cu-Ni-PGE area (R005) is located within the Lapland granulite belt. It extends across the Finnish-Russian border, with all known deposits with a resource estimate occurring in Russia (Fig. 1). The granulite belt is formed by pyroxene-plagioclase schists, garnet-quartz-feldspar rocks (felsic granulites), two-pyroxene-plagioclase schists, garnet amphibolites (mafic granulites), and large conformable massifs of diorite-enderbite, migmatite-granulite (metapelites) and diorite (e.g., Korja et al. 1996, Tuisku et al. 2006). The belt is a 7–8 km thick plate overthrusted from the north onto Belomorian rocks, and it is cut by overthrust sheets overthrusted on each other (Feoktistov et al. 2007). The granulite belt was formed under compressional conditions during regional cratonisation (sometime during 1.93–1.87 Ma) (Lahtinen et al. 2005).

Approximately 200 websterite-gabbro-norite massifs have so far been detected in the granulite belt. The distribution of the massifs is irregular, and they commonly form groups of 3–10 bodies within a few square kilometres. The horizontal extent of the massifs varies from tens of metres to 600 x 1400 m (Ozersky massif). These intrusions host the magmatic Cu-Ni-PGE mineralisation of the Lotta area.

The central part of the Lotta area contains the Lovnozero subarea (R005.1) with the **Lovnozerskoe** Cu-Ni deposit (Table 4) and more than 20 websterite-gabbro-norite massifs (Gorbunov et al. 1985). The Lovnozerskoe deposit represents a combination of several spatially contiguous lens- and bed-shaped massifs with veined, impregnated and massive sulphide mineralisation in 22 ore bodies. The 10–50 m thick ore bodies dip at 40° to

Table 4. Examples of Ni-Cu deposits with a resource estimate in the Lotta metallogenic area (R005). All data are from Gorbunov et al. (1978) and Yakovlev et al. (1979).

Name	Ore tonnage Mt	Cu %	Ni %	Main host rock	Genetic type
Laukku	1.67*	0.3	0.515	Gabbro	Magmatic Ni-Cu-PGE
Lovnozerskoe	20.863	0.43	0.88	Norite	Magmatic Ni-Cu-PGE
Sueinlagash	2.25*	0.25	0.3	Gabbronorite	Magmatic Ni-Cu-PGE
Yunges	0.56*	0.15	0.38	Websterite	Magmatic Ni-Cu-PGE

* Due to uncertainty in the data, the deposit is in the category ‘Showing’ in the Fennoscandian deposit database.

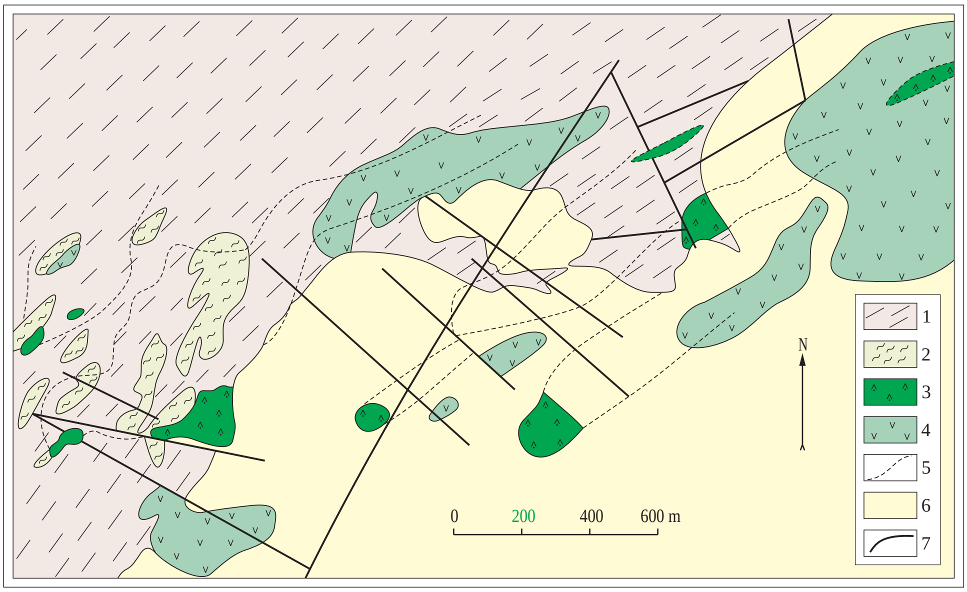


Figure 5. Geological map of the Lovnoozerskoe deposit (68.47°N, 29.85°E) and its surroundings (based on a mapping by E.K. Kozlov). The Ni-Cu deposit is at 68.47°N, 29.85°E. Legend: 1 – hypersthenic plagiogneiss; 2 – granulite; 3 – mineralised norite and gabbro-norite; 4 – barren norite and gabbro-norite; 5 – boundaries of norite bodies not exposed by erosion; 6 – Quaternary deposits; 7 – faults.

the SW, have a length along the strike 200–500 m, and are traced along the dip for 800 m (Fig. 5). In the Lovnozerskoe deposit, the best potential for finding new ore is at depth along the dip. The several deposits reported on the Russian side of the border may anticipate similar deposits to also be found in the Finnish part of area R005, which has a similar geological setting but a lower degree of exploration.

R007 KORVATUNDRA Cr, Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Korvatundra Cr, Au area (R007) is located on the southern margins of the Lapland Granulite Belt, in the Tanaelva Granulite Belt of ca. 2700 Ma in age, and defined by komatiitic to tholeiitic amphibolite and amphibole-biotite-plagioclase schists. Within the region, there also are several small ultramafic intrusions of Mesoarchaean age (Feoktistov et al. 2007). Area R007 has the greatest potential for mafic- to ultramafic-hosted Cr mineralisation, as exemplified by the **Padostundra** deposit, which has a total tonnage of 2.5 Mt and a Cr grade of 25% (Fig. 6). There also are mineralised localities of epithermal gold type (up to 2.0 g/t Au detected) in the local greenstones (Gorbacheva 2000). In the Russian part of the Korvatundra area, more than ten underexplored ultramafic massifs are known, and no exploration for gold has been conducted. In the Finnish part, very little exploration has also been performed. Due to this, the potential for discovery of mineral deposits in the area is estimated as rather high.

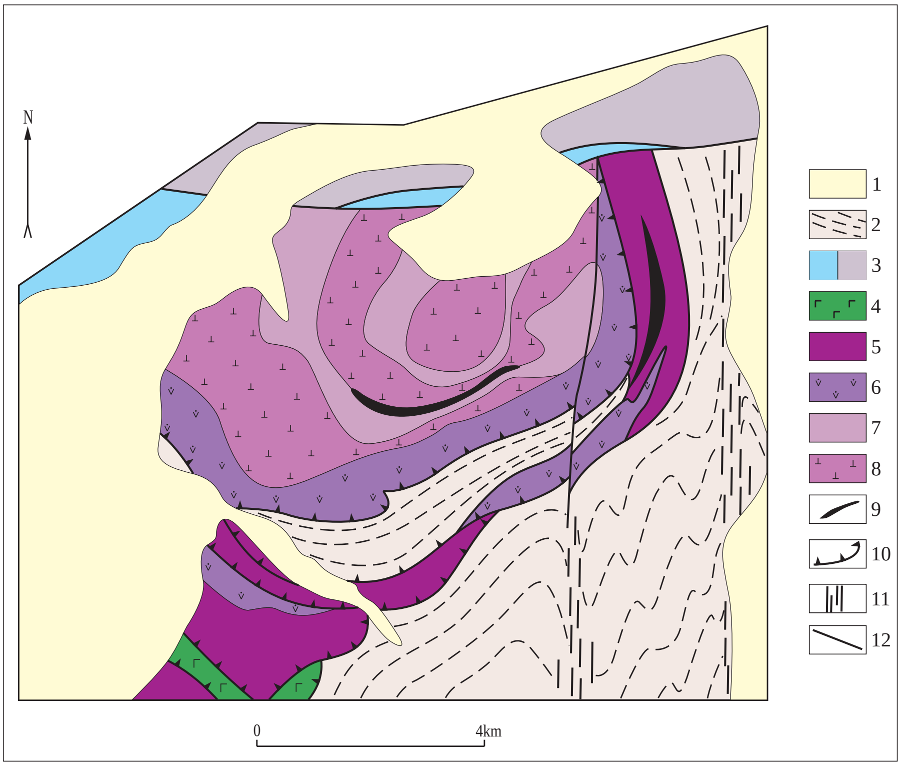


Figure 6. Geological map of the Pados massif at 68.08°N, 29.7°E. Legend: 1 – Quaternary deposits; 2 – Kola-Belomoride series gneiss; 3 – Korvatundra complex (a-gneiss; b-amphibolite); 4 – metagabbro; 5–8 ultramafic rocks of the Pados massif: 5 – apodunite serpentinite, 6 – harzburgite, 7 – dunite, 8 – bronzitite; 9 – zone of magnesian schist; 10 – thrust lines; 11 – shear zone; 12 – faults. Based on Pozhilenko et al. (2002).

R008 ZAIMANDROVSKAYA Fe-Ti

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Zaimandrovskaya metallogenic area (R008) is in the central part of the Kola Peninsula. The degree of exploration in the area is satisfactory. Geologically, the area is confined to the Central Kola Mesoarchaean (3200–2800 Ma) zone formed by rocks of old metamorphic basement comprising BIF, amphibolite, micaceous gneiss and schist, and massifs of migmatite-plagiogranite and migmatite-diorite-enderbite of lower to mid-Lopian age (Feoktistov et al. 2007). The large Palaeoproterozoic alkaline gabbroid intrusion of Gremyakha-Vyrmes containing Fe-Ti mineralisation also occurs within the area (Pozhilenko et al. 2002). Two types of mineralisation have been detected in the area: 1) stratiform iron, and 2) mafic intrusion-hosted Ti-Fe±V (Table 5).

The Gremyakha-Vyrmes Ti-Fe subarea (R008.1) is located in the northern part of the Zaimandrovskaya area and is confined to a large (205 km^2) massif of alkaline gabbroid 1973 Ma in age (Fig. 7). The massif is elongated to the NW and is 19 km long and 4–6 km wide. The massif formed during three stages of intrusion with which the following series of rocks are related: 1) peridotite-pyroxenite-gabbro-anorthosite and ankerite-pulaskite, which form the southern part of the massif, 2) a plate-shaped body of nepheline syenite-juvite-ijolite with a size of 4 x 1.5 km, and 3) alkaline granosyenite-alkaline granite forming the NE part of the massif. Within the massif, two Ti deposits, **Gremyakha-Vyrmes** and **South-Eastern Gremyakha** (Table 5) have been explored. The Ti mineralisation is related to a layered peridotite-pyroxenite-gabbro-anorthosite complex. The Gremyakha-Vyrmes deposit consists of six plate- to lens-shaped bodies of apatite-ilmenite-titanomagnetite ore with a length of 1100–2500 m and a thickness of 10–200 m. In addition to Ti and Fe, the deposit also contains 3.37% P_2O_5. The South-Eastern Gremyakha deposit comprises two ore bodies 800 and 400 m long, and 66–250 m and 10–40 m thick, respectively. The TiO_2 content of the ore varies from 10 to 15.3%, averaging at 13.35%.

The Olenegorsk Fe subarea (R008.2) is located in the southern part of area R008, and includes 10 BIF deposits, five of them under active mining (Table 5). All the deposits are confined to amphibolite-gneiss sequences, which comprise (from the bottom upwards): 1) biotite gneiss, hornblende-biotite gneiss, metaconglomerate, 2) hornblende amphibolite with gneiss, 3) ferriferous flinty rock (BIF), and 4) amphibolite and biotite gneiss and leptite (Goryainov 1976). The BIF mainly occurs as

Table 5. Deposit and showings in the Zaimandrovskaya area (R008) included in the FODD database. Information on Fe-Ti deposits is based on Osokin (1987) and Korovkin et al. (2003), and on straform iron deposits on Goryainov (1976) and Pozhilenko et al. (2002).

Name	Ore tonnage (Mt)	When mined	Fe %	TiO_2 %	Genetic type
Gremyakha-Vyrmes subarea (R008.1)					
Gremyakha-Vyrmes	340.09		21	7.02	Mafic intrusion-hosted
South-Eastern Gremyakha	86.986		28.3	13.35	Mafic intrusion-hosted
Olenegorsk Fe subarea (R008.2)					
Aivar	666.9		29.6		Stratiform iron
Svintsovotundrovskoe	84.4		31.1		Stratiform iron
Olenegorskoe	487.98	1954–	30.6		Stratiform iron
Kurkenpakhk	46.26		30.1		Stratiform iron
South Kakhozerskoe	45.54		29.1		Stratiform iron
Komsomol’skoe	166.12	1989–	29.2		Stratiform iron
Kirovogorskoe	266.32	1978–	30.3		Stratiform iron
XV Oktyabr’skoi Revolyutsii	64.44	1986–	29.7		Stratiform iron
Professor Bauman	61	1986–	30.6		Stratiform iron
Pechegubskoe	141.558		33		Stratiform iron
Deposits outside subareas					
Volch’etundrovskoe	108.1		22.09		Stratiform iron

actinolite-(grunerite-pyroxene-)-magnetite chert. Less commonly, predominantly in the **Olenegorskoe** deposit, the BIF is an actinolite-hematite-magnetite chert. The BIF bodies occur conformably and have a plate- or lens-shaped form with a thickness to length ratio from 1:20 to 1:40. The ore bodies are steeply dipping (60–70º), their length along the strike varies from 100 to 3000 m and their thickness from a few metres to 300 m, and they have been traced to the depth of 300–1500 m. Iron content of ore is 29.0–31.0% (Fig. 8). Prognostic resources are estimated at >1000 Mt of iron ore, but the main resource belongs to deep parts (>500 m), where exploitation is possible only by underground methods.

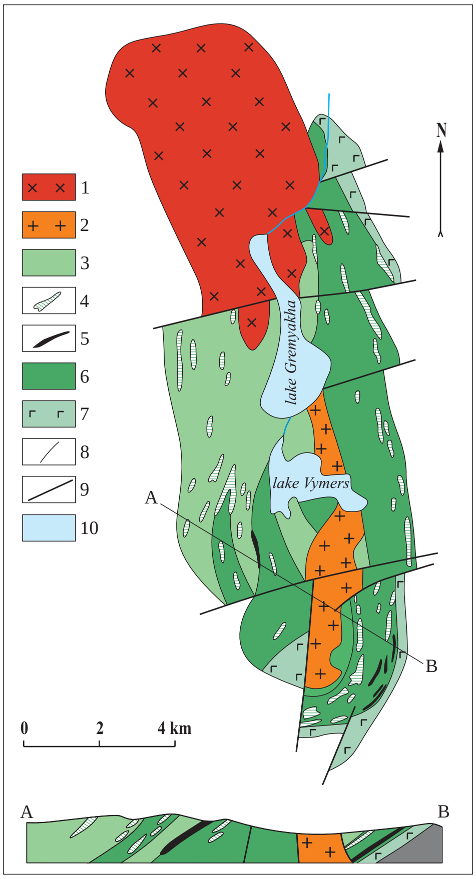


Figure 7. Geological map of Gremyakha-Vyrmes massif, located at 68.67°N, 32.5°E. Legend: 1 – alkaline granite and alkaline granosyenite; 2 – nepheline syenite, ijolite, urtite, melteigite, jacupirangite, juvite, malignite, foyaite, aegirinite; 3 – ilmenite-apatite, alkaline gabbro, pulaskite, akerite; 4 – peridotite, pyroxenite, olivinite with ilmenite-titanomagnetite mineralisation; 5 – high-grade ilmenite-titanomagnetite ore; 6 – gabbro, gabbro-anorthosite, anorthosite; 7 – gabbro and gabbro-norite; 8 – boundaries between complexes (a) and country rock (b); 9 – faults; 10 – lakes. Based on Gorbunov et al. (1981).

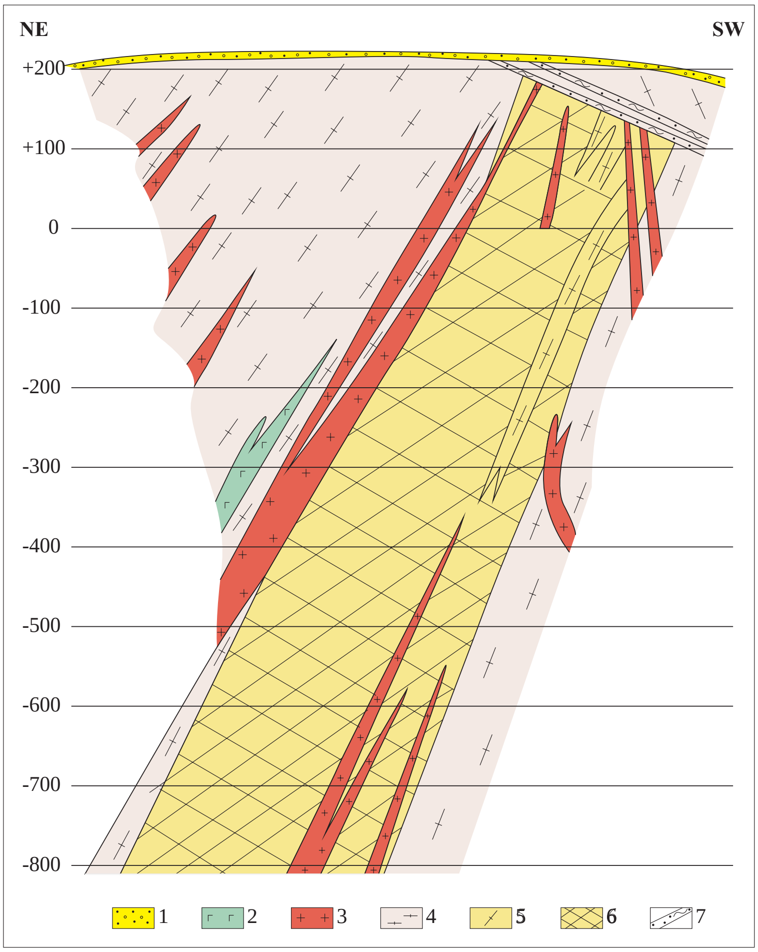


Figure 8. Geological cross-section of the Olenegorskoe deposit, located at 68.15°N, 33.17°E. The levels are in metres. Legend: 1 – moraine; 2 – gabbro-norite; 3 – granite; 4 – leucocratic, biotite, and amphibole-biotite gneisses; 5 – metachert (barren and weakly-mineralised); 6 – quartzite amphibole-magnetite, amphibole-hematite-magnetite; 7 – mylonite of tectonic zone. Based on Korovkin et al. (2003).

R009 SHOLTYAVR Fe

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Sholtyavr Fe area (R009) is to northwest of the Zaimandrovskaya area and is confined to the Mesoarchaean Central Kola belt. The region is composed of gneissic amphibolite, hornblende gneiss, mica gneiss, and migmatitic plagiogranite and diorite-enderbite intrusions of early to mid-Lopian age (3200–2500 Ma) (Feoktistov et al. 2007). Area R009 is characterised by stratiform iron mineralisation (BIF). The **Sholtjavr** deposit comprises bipyroxene-magnetite chert hosted by schist and garnet-biotite gneiss. The six known ore bodies are 500–1500 m long, 30–40 m thick and have been traced to the depth of 300 m. Total tonnage is 126.4 Mt, and iron content of ore is 21% (Goryainov 1976, Malyshev, 1985, Pozhilenko et al. 2002). The further resource potential of area R009 is related to underexplored outcrops of hypersthene-amphibole-magnetite chert widely occurring in the area.

R010 PINKEL'YAVR Fe

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The NW-trending, 80 km long and 5–8 km wide Pinkel'yavr Fe area (R010) is to the northeast of the Sholtyavr area. The area is formed by gneiss, amphibolite, schists, and migmatitic plagiogranite and migmatite-diorite-enderbite intrusions of Mesoarchaean age (3200–2800 Ma) (Feoktistov et al. 2007). Area R010 is characterised by stratiform iron mineralisation. Two deposits, **Pinkel'yavr** and **Gora Polovinnaya**, occur in the area. In addition, a few outcrops of hornblende-diopside BIF with ore-grade material are known, but have not been explored to any significant extent (Dmitriev 1983). The 193 Mt Pinkel'yavr deposit located in the head-stream of the Teriberka river, is formed by a series of BIF lenses 100–400 m long and 100–140 m thick with an average Fe content of 22.6% (Goryainov 1976, Pozhilenko et al. 2002). The Gora Polovinnaya deposit in the interstream area of Chudzjok and Voron'ya rivers consists of BIF units 2500–3700 m long and 10–80 m thick, where the average Fe content is 23.09% in 147 Mt of ore (Goryainov 1976). Despite large ore reserves and resources (in total about 300 Mt), taking into account the low Fe content of the ore, exploitation and discovery prospects of the area could be estimated as low.

R011 POROSOZERO-VORON'YA Li, Nb, Ta

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Porosozero-Voron'ya Li-Nb-Ta area (R011) is located in the northwestern part of the Kola Peninsula, confined to the suture zone between the Murmansk and Central Kola blocks. A major part of the sutural zone on the present erosional level consists of mid- to late Lopian formations (3000–2500 Ma), which are relics of the elongated Uraguba-Kolmozero greenstone belt, affected by Mesoarchaean granite intrusion, metamorphism and deformation. Area R011 is confined to the central part of the Polmos-Porosozero greenstone belt. The greenstone belt is composed of volcano-sedimentary rocks. Its lower parts are formed by a basal sedimentary sand-greywacke sequence, which is overlain by metamorphosed tholeiitic basalt and peridotitic komatiite flows. Upward in the section there is a basalt-andesite-dacite sequence, and the section is terminated by aluminiferous gneiss and schist (a terrigenous sequence). The greenstone belt rocks metamorphosed under high-temperature amphibole facies conditions (Feoktistov et al. 2007).

Granitoids are widespread within area R011. Among the granitoids, there is a late Lopian (2745–2733 Ma) plagiogranite-granite complex related to the culmination stage of the evolution of the greenstone belt. Epithermal gold mineralisation has been detected, as well as widely developed granitic pegmatite-related mineralisation related to a leucocratic granite complex of the protocollisional stage (Ivanova 1974). Within the area, four deposits and a number of prospective showings of rare metals (Li, Cs, Ta) and rare earth elements in pegmatite, and Au and Mo showings are known (Table 6). Two prospective subareas, Voron'ya (R011.1) and Kolmozero (R011.2), are distinguished in the area. The Porosozero-Voron'ya metallogenic area is characterised by a high productivity potential, but due to the absence of infrastructure, the explored deposits have not been mined.

The Voron'ya Li-Ta, Au subarea (R011.1) is located in the northwestern part of the Porosozero-Voron'ya area. The subarea hosts the **Voron'etundrovskoe**, **Ohmyl'k** and **Polmostundrovskoe** deposits, a number of showings of rare metal pegmatite, and potentially prospective showings of Au and Cu-Mo ore. A typical example of a rare metal target in the subarea is Palmostundrovskoe, where 12 *en echelon* -like discordant pegmatite dykes are located in an area of 6 km^2. The dykes are 1000–1300 m long, 3–30 m thick, and are traced along the dip for 200–300 m. The pegmatites are composed of quartz, albite, spodumene (20–50%) and microcline. The average Li content is 1.25%, and the deposit has reserves of 844,000 t of Li$_2$O. Gold showings (**Nyalm I, II** and **Oleninskoe**) are of the gold-sulphide-quartz type (Bezrukov 1985a), and comprise quartz veins, stockworks and mineralised zones of host rock. Gold content varies from 0.6 to 7.0 g/t (Fig. 9). The porphyry-style Cu-Mo occurrence **Pellapahk** is located in the contact zone between quartz porphyry and aluminiferous schist. It comprises a vein stockwork of 2000 m x 40–190 m in size, and has 0.062% Mo, 0.25% Cu, and 1.09 g/t Au (Fig. 10) (Bezrukov, 1985a).

The Kolmozero Li subarea (R011.2) is located in the SE part of Porosozero-Voron'ya area, and has the same metallogenic features as the Voron`inskaya subarea: rare metals and gold (Table 6). The large **Kolmozerskoe** rare metals deposit is in the subarea. It is confined to a gabbro-anorthosite massif as a set of pegmatite dykes with a length along strike at 500–2800 m. The dykes are traced to the depth of 200–300 m, and their thickness is 1–70 m. Mineralised localities and geochemical halos of gold have also been revealed in the subarea.

Table 6. Deposits and showings in the Porosozero-Voron'ya area (R011) included in the FODD database. Information is based on Pozhilenko et al. (2002) for all deposits; in addition, data on the granitic pegmatite type of deposits are from Belolipetskii et al. (1992) and Korovkin et al. (2003).

Name	Ore tonnage (Mt)	Ag g/t	Au g/t	Be %	Cu %	LiO$_2$ %	Mo %	Nb g/t	Ta$_2$O$_5$ g/t	Genetic type
Voron'ya subarea (R011.1)										
Voron'etundrovskoe	0.6					1.03			340	Granitic pegmatite
Mountain Okhmyl'k	8.454					0.33			90	Granitic pegmatite
Polmosttundrovsoe	28.936			0.027		1.25		70	39	Granitic pegmatite
Nyal'm-1	1.2		6.7	0.058						Orogenic gold
Nyal'm-2	0.919		3.7							Orogenic gold
Oleninskoe	2.58		3.1							Orogenic gold
Pellapahk	667.741	2.12	1.09		0.25		0.062			Porphyry
Kolmozero subarea (R011.2)										
Olenii ridge	1.125					0.8			150	Granitic pegmatite
Mudajok	0.3					0.3			100	Granitic pegmatite
Kolmozerskoe	74.04			0.019		1.14		110	91	Granitic pegmatite

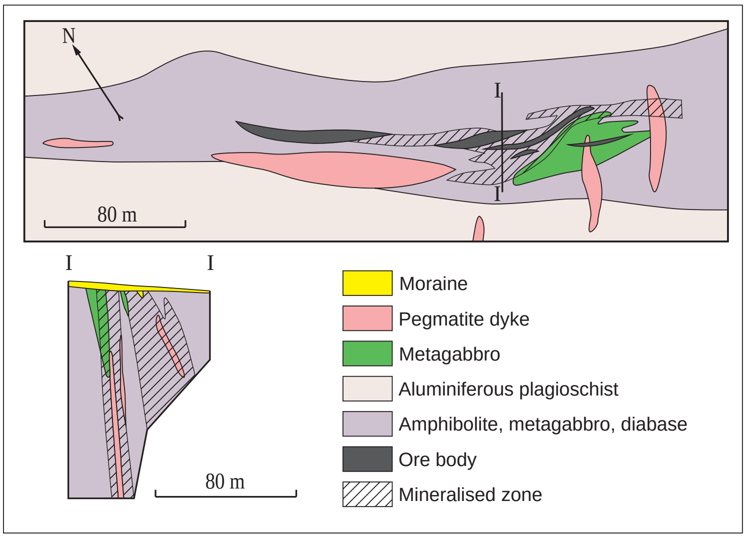


Figure 9. Geological map and a cross section of the Oleninskoe gold occurrence, located at 68.47°N, 35.66°E. Based on Pozhilenko et al. (2002).

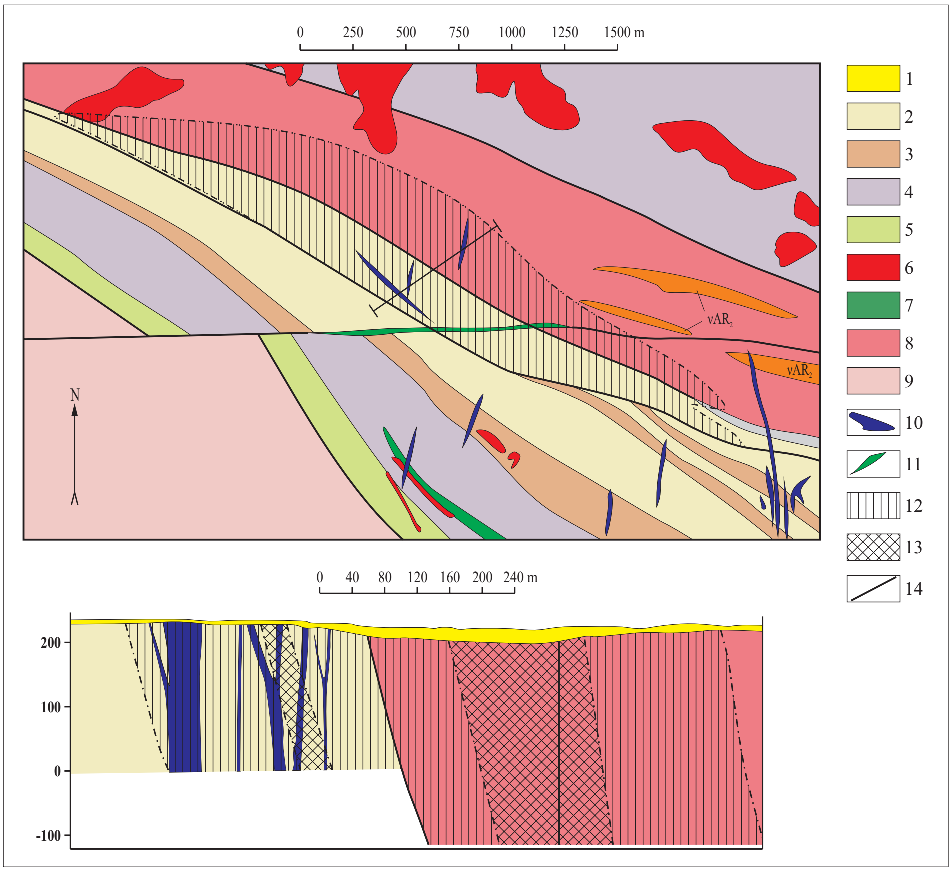


Figure 10. Geological map of the Pellapahk Mo-Cu occurrence, located at 68.5°N, 35.6°E. Legend: 1 – Quaternary deposits; 2 – biotite-staurolite plagioschist (Chervurtsk complex); 3 – schistose porphyroid (Voron'yatundracomplex); 4 – amfibolite (Polmostundra complex); 5 – garnet-biotite gneiss and schist (Lyavozero complex); 6 – plagiomicrocline granite and granite-pegmatite; 7 – metagabbro; 8 – quartz porphyry; 9 – plagiomicrocline gneiss-granite; 10 – dolerite dyke; 11 – olivine gabbro dyke; 12 – mineralised zone; 13 – ore body; 14 – faults. Based on Pozhilenko et al. (2002).

R012 IMANDRA-VARZUGA Cr, Ni-Cu-PGE, Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Imandra-Varzuga Cr, Ni-Cu-PGE, Au area (R012) is located in the southern part of the Kola Peninsula. It covers the western part of the Palaeoproterozoic Imandra-Varzuga rift-related greenstone belt and the Archaean bedrock immediately around the Proterozoic belt. The Imandra-Varzuga belt is formed by metamorphosed volcano-sedimentary formations of Sariolian to Ludikovian age (2400–1920 Ma). Intrusive magmatism in area R012 is represented by small bodies of barren gabbro-peridotite and large, mineralised, layered intrusions of peridotite-pyroxenite-gabbro-norite located at the boundary between the Archaean and Palaeoproterozoic rocks (Feoktistov et al. 2007).

Three types of mineralisation have been detected in the region: 1) mafic to ultramafic hosted Cr, 2) magmatic Ni-Cu-PGE, and 3) orogenic gold. Four subareas are distinguished in area R012: Monchegorsk, Nearby Khibiny (Prikhibinskyi), Fedorovo-Pana and Panarechka-Varzuga.

The Monchegorsk subarea (R012.1) is in the northwesternmost part of the Imandra-Varzuga metallogenic area. The subarea consists of the large Monchepluton (2496–2505 Ma) and Monchetundra (2467–2540 Ma) intrusions, and a number of smaller peridotite-pyroxenite-gabbro-norite massifs. These layered intrusions contain magmatic Ni-Cu-PGE and mafic to ultramafic hosted Cr types of mineralisation.

Monchepluton is a layered mafic-ultramafic intrusion composed of (from the bottom upwards) gabbro-norite, peridotite, with pyroxenite and peridotite interlayers, pyroxenite, norite, norite-gabbro-norite and gabbro-anorthosite. Before the Second World War, Cu-Ni deposits (**Nittis-Kumuzhya-Travyanaya** (NKT), **Sopcheozerskoe**, **Njudaivench**; Table 7) were discovered in the massif (Fig. 11). The richest vein ore at NKT has been mined out. The other deposits of disseminated and nest-disseminated low-grade ore, despite large tonnage, have not been exploited (Korovkin et al. 2003). As a result of exploration in 1984–1992 in the ultramafic part of Monchepluton, the **Sopcheozerskoe** chromite deposit was found. The deposit comprises a plate-shaped body 1300–1400 m long, 150–280 m wide, and from 3 to 32.5 m thick (Fig. 12). The average content of Cr_2O_5 in the ore is 24.2% in a resource of 5.6 Mt (Galkin et al. 2001).

During recent years, special attention in subarea R012.1 has been paid to platinum mineralisation in the layered massifs. As a result, an increased content of platinoids in the Cu-Ni ore of the Monchegorsk deposit was detected, and platinum-bearing low-grade sulphide mineralisation was discovered in the upper parts of the Njudaivench deposit, in the rocks of the neighbouring Monchetundra massif (Loipishnjun site). The total PGE content of the disseminated and nested to disseminated Cu-Ni ore is 0.5–4.9 g/t, and in the vein ore 5.0–6.0 g/t (up to 30.0 g/t). Low-grade sulphide mineralisation contains 0.5–4.0 g/t of platinoids (Dodin et al. 2000).

The Nearby Khibiny subarea (R012.2) is also in the northwestern part of the Imandra-Varzuga metallogenic area, to the southwest of the Khibiny nepheline-syenite pluton. The subarea includes a northwestern fragment of the Mesoproterozoic Imandra-Varzuga belt with immediate Archaean country rocks, and layered peridotite-pyroxenite-gabbro-norite massifs. The ore potential of the subarea is mainly defined by the presence of mafic to ultramafic hosted Cr mineralisation in the layered massifs. These massifs contain the medium-sized **Bolshaya Varaka** deposit and the smaller **Chernorechenskoe**, **Tikozerskoe** and **Devichetundrovskoe** occurrences (Dokuchaeva et al. 1992). The Bolshaya Varaka deposit is hosted by the large Sumian Umbarechensk massif. There are two lens-shaped ore bodies with a length of 100–120 m along the strike, 80–100 m along the dip and a thickness of 3.0–11.8 m. The ore consists of disseminated, massive and banded varieties, and has an average content of 25% Cr_2O_5. The mineral composition of the ore is chrome-spinellide, amphibole, and plagioclase. Several gold showings have been detected in subarea R012.2 (e.g., 33 km and Izvestkovyi quarry). These are hosted by carbonaceous volcano-sedimentary rocks of the Ilmozero suite, which has undergone cataclasis, foliation, silicification and chloritisation. The gold content of the showings varies from 0.15 to 1–3 g/t.

The Fedorovo-Pana subarea (R012.3) is in northeastern part of the Imandra-Varzuga area. Geologically, the subarea is within the large (490 km^2), 2501–2487 Ma, Fedorovo-Pana layered mafic-ultramafic massif. The massif comprises three blocks bounded by major faults: 1) West Pana, 2) Fedorova on the western edge of the intrusion, and 3) East Pana (Fig. 13). Field and geophysical observations along the boundary between Imandra-Varzuga greenstone belt and the

Archaean basement indicate presence of two additional igneous massifs. These massifs are 8–10 km long, 1–3 km thick, and composed of gabbro and norite. Magmatic Cu-Ni-PGE mineralisation characterises the subarea R012.2 (Dodin et al. 2000). In section across the marginal zone of the Fedorova Tundra (= **Fedorovotundrovskoe**) deposit, there are gabbro-norite and gabbro zones. Platinum mineralisation is hosted by the lower gabbro-norite zone. The ore zone is >3 km long, 1 km wide, and 10–30 m thick. The platinoid content varies from a few hundred ppb to 4 g/t, Ni content is 0.1% and Cu 0.15–0.25%.

The West Pana block is formed, from the bottom to the top, by marginal, norite and gabbro-norite zones. There are two layered units, separated from each other in cross section for 1.5–2.0 km, hosting platinum mineralisation. These layered units comprise interbedding norite, gabbro-norite, leucogabbro and anorthosite. The lower layered unit is traced for 10–13 km and has a thickness from 1 to 50 m. Within this unit, there are lens-shaped platinum-rich bodies 100–300 m long and 0.1–4.0 m thick with an average Pt content of 4.6 g/t. The upper layered unit is characterised by a very uneven distribution of platinoids from 0.1 to 4.0 g/t (maximum 40.0 g/t). Some ore bodies are 0.2–2.0 m thick and a few tens of metres long (Fig. 14).

The East Pana block is the most difficult to reach and the least studied part of the Fedorovo-Pana massif. Within this block, unlike in the West Pana block, there are zones of gabbro-norite (600 m) and thick (up to 2000 m) gabbro. The lower gabbro-norite zone hosts platinum-mineralised localities. Mineralisation is characterised by a high (up to 40.0 g/t) platinoid content and a thickness of 0.5–4.0 m.

The Panarechka-Varzuga Au subarea (R012.4) is located in the southern part of the Imandra-Varzuga greenstone belt, and is formed by basaltic and andesitic basalt lava and tuff, dolomite, carbonaceous schist and sandstone. Gold showings, gold-mineralised localities and geochemical Au anomalies have been detected in black schist sequences (at Solenoozero and Polisar) and in intermediate to felsic lava and tuff (at Panarechka). Mineralisation is of the epithermal gold type and is hosted by metasomatic sericite-carbonate-albite-quartz and albite-quartz-carbonate rocks. Typical ore minerals are native gold, pyrite, chalcopyrite, galena and sphalerite. The gold content of black schist-hosted occurrences varies from 0.1 to 1.8 g/t, and in felsic lavas and tuffs from 1.05 to 12.0 g/t (Pozhilenko et al. 2002).

Numerous Cu showings, hosted by basaltic lava, tuff and tuffite, are also known from the subarea R012.4. The domain of Cu mineralisation extends for 70 km and is 1.5–3.0 km wide. Mineralisation is nested to disseminated in the effusives and is confined to quartz veins and veinlets. The main ore mineral is native copper, whereas cuprite, bornite and chalcocite are less common. According to the intensity of native copper dissemination, bodies 10–80 m long, 1–10 m thick with a Cu content from 0.2–0.5 to 1.0–2.0% are defined. This type of mineralisation has not been extensively studied in the region (Borisov 1990).

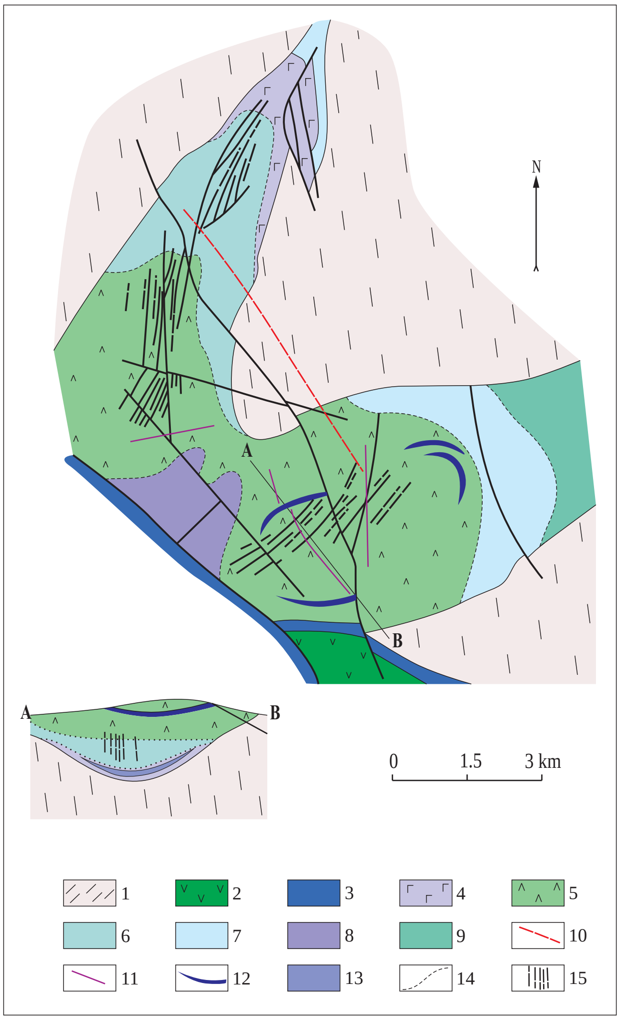


Figure 11. Geological and structural map of the Monchegorsk pluton (Nittis-Kumuzhya-Travyanaya and Sopcha massifs). Legend: 1 – Archaean gneiss; 2 – metagabbro and metagabbro-norite; 3 – zone of alternation of basic and ultramafic rocks with metagabbroid of the Moncha Main ridge; 4 – peridotite; 5 – pyroxenite; 6 – zone of alternation of pyroxenite and peridotite; 7 – feldspathic pyroxenite; 8 – olivinite; 9 – melanocratic norite; 10 – quartz porphyry dyke; 11 – diabase dyke; 12 – disseminated ore of the Sopcha mountain; 13 – disseminated ore in the basal part of the intrusion; 14 – lithological unit boundaries within the pluton; 15 – ore veins. Based on Pozhilenko et al. (2002).

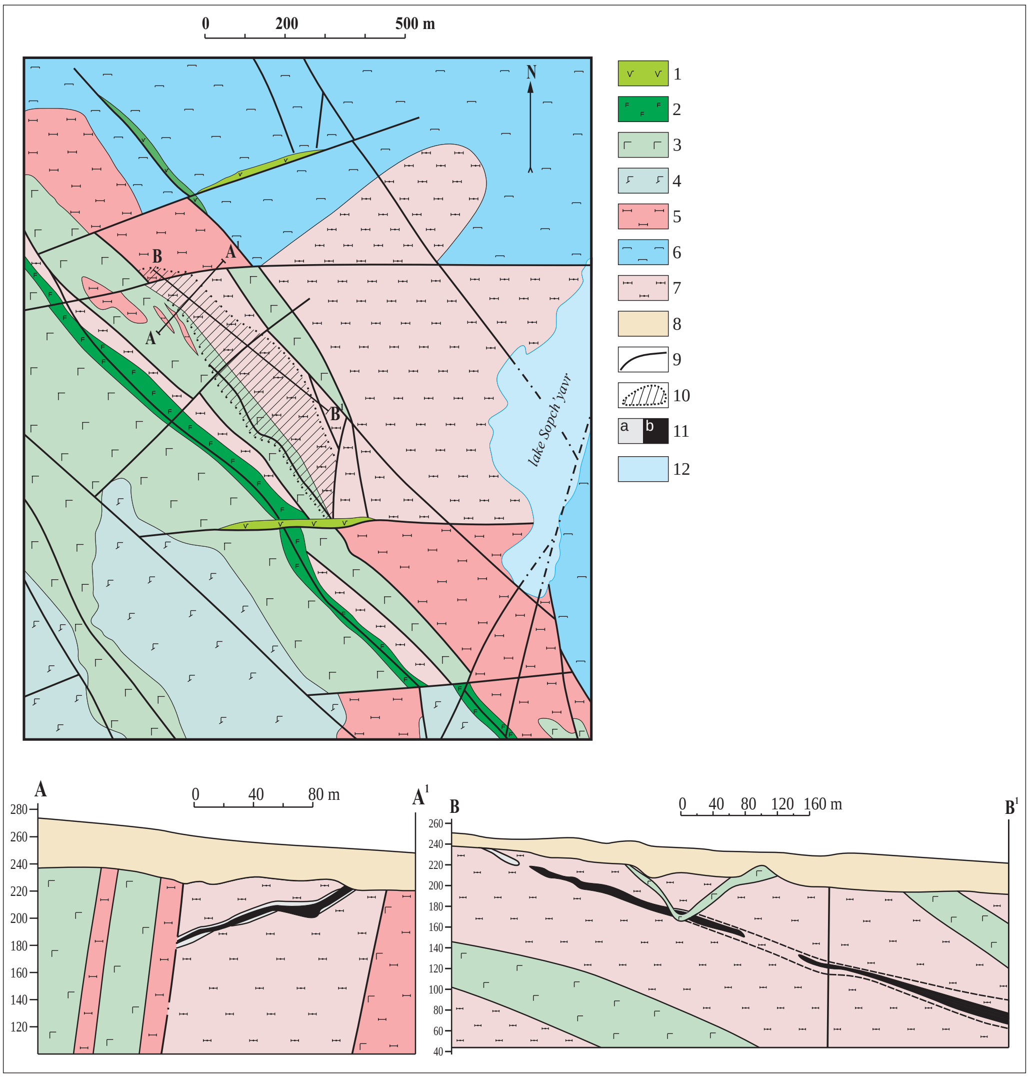


Figure 12. Geological map of the Sopcheozerskoe chromite deposit (67.88°N, 32.75°E) and its surroundings. Legend: 1 – diabase; 2 – gabbro with titanomagnetite; 3 – gabbroid, gabbro; 4 – metagabbroid; 5 – peridotite; 6 – pyroxenite; 7 – dunite and peridotite; 8 – Quaternary deposits; 9 – faults; 10 – surface projection of the traced part of chromite ore at depth; 11 – chromite ore in cross sections: a – <30% Cr_2O_5; b – >30% Cr_2O_5; 12 – lakes. Based on Pozhilenko et al. (2002).

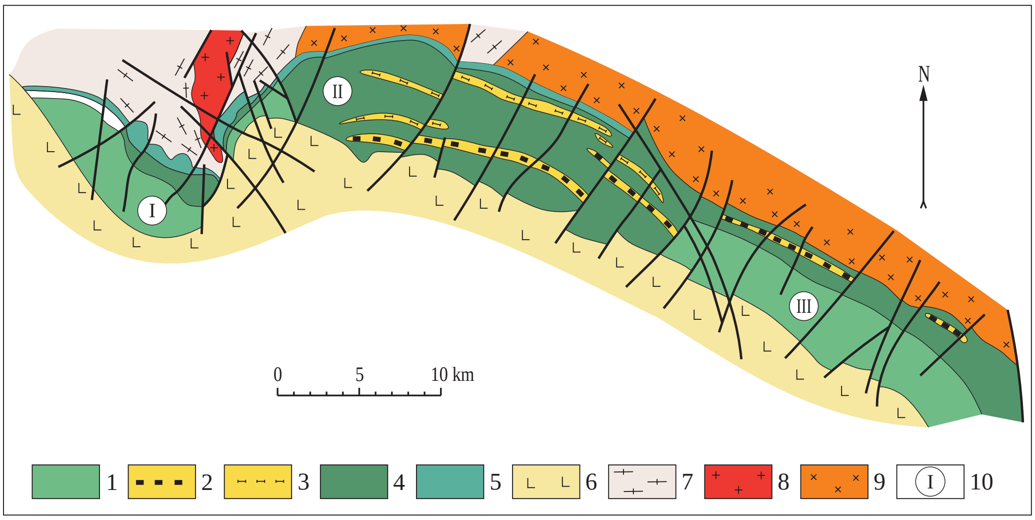


Figure 13. Geological map of the Fedorovo-Pana massif. Legend: 1 – gabbro; 2 – upper platinum-bearing reef; 3 – lower platinum-bearing reef; 4 – gabbronorite; 5 – norite; 6 – basaltoid; 7 – granite-gneiss; 8 – granitoid; 9 – alkaline granite; 10 – blocks of the massif (in circles): I West Pana; II Fedorovotundra (mineralisation at 67.51°N, 35°E); III East Pana. Based on Dodin et al. (2000).

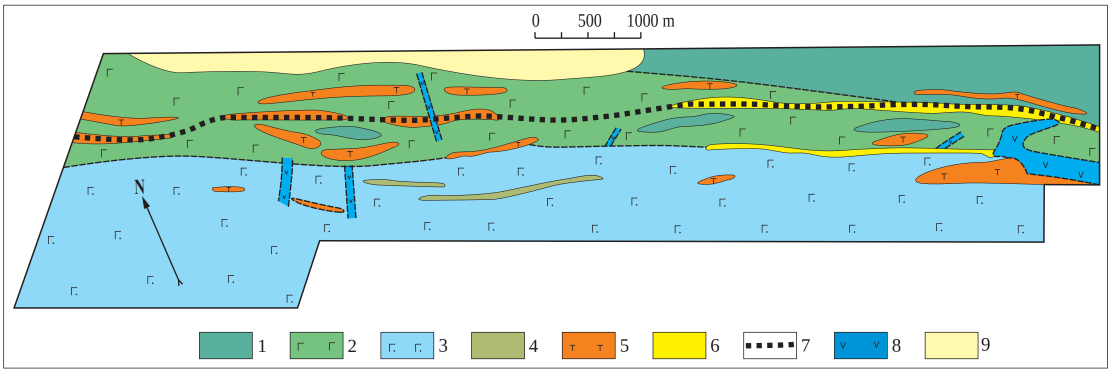


Figure 14. Geological map of the Malaya Pana showing (West Pana block). Legend: 1 – norite; 2 – equigranular quartz gabbronorite; 3 – melanocratic porphyric gabbronorite; 4 – leucocratic gabbronorite; 5 – pegmatoidal metagabbroid; 6 – alternation of gabbronorite, norite, and anorthosite; 7 – northern platinum reef (67.53°N, 35.27°E); 8 – magnetite-bearing diabase; 9 - Quaternary deposits. Based on Pozhilenko et al. (2002).

Table 7. Deposit and showings in the Imandra-Varzuga area (R012) included in the FODD database.

Name	**Ore tonnage (Mt)**	**Ag g/t**	**Au g/t**	**Co %**	**Cr %**	**Cu %**	**Ni %**	**PGE g/t**	**Genetic type**	**References**
Monchegorsk subarea (R012.1)										
NKT	8.16	5.2	2.2	0.23		2.9	5.1		Magmatic Ni-Cu-PGE	Gorbunov et al. (1981), Korovkin et al. (2003)
Njudaivench	13.2					0.2	0.24		Magmatic Ni-Cu-PGE	Gorbunov et al. (1981), Korovkin et al. (2003)
Sopchuaivench	131.2			0.014		0.17	0.33		Magmatic Ni-Cu-PGE	Gorbunov et al. (1981), Korovkin et al. (2003)
Sopcheozerskoe	5.2				14.6				Mafic to ultram. hosted Cr	Gorbunov et al. (1981), Korovkin et al. (2003)
Sopcha (lode ores)	0.71	5.2	2.2	0.15		2.06	3.23		Magmatic Ni-Cu-PGE	Gorbunov et al. (1981), Korovkin et al. (2003)
Monchetundorvskoe	38							2.5	Magmatic Ni-Cu-PGE	Korovkin et al. (2003)
Nearby Khibiny (Prikhibinskyi) subarea (R012.2)										
Devich'etundrovsoe	8.4				14.1				Mafic to ultram. hosted Cr	Dokuchaeva et al. (1992)
Tikozerskoe	29				13				Mafic to ultram. hosted Cr	Dokuchaeva et al. (1992), Pozhilenko et al. (2002)
Bol'shaya Varaka	25.2				14.1				Mafic to ultram. hosted Cr	Dokuchaeva et al. (1992), Galkin et al. 2001
Chernorechenskoe	7				17.9				Mafic to ultram. hosted Cr	Dokuchaeva et al. (1992), Pozhilenko et al. (2002)
Fedorovo-Pana subarea (R012.3)										
Western Panskoe	22.852					0.25	0.1	3.65	Magmatic Ni-Cu-PGE	Dodin et al. (2000), Korovkin et al. (2003)
Fedorovotundrovskoe	26.275					0.15	0.1	1.37	Magmatic Ni-Cu-PGE	Dodin et al. (2000), Korovkin et al. (2003)
Vostochno-Panskoe	12.79					0.17	0.23	13.2	Magmatic Ni-Cu-PGE	Dodin et al. (2000), Korovkin et al. (2003)

R013 KOVDOR-LOVOZERO REE, Nb, Li, Be, Zr

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI), Laura Lauri (GTK)

The Kovdor-Lovozero REE, Ta, Nb, Zr, Ti, Fe area (R013) extends across the Kola, Murmansk and Karelia blocks covering the area of Palaeozoic alkaline magmatism (416–360 Ma) related to the processes of continental rifting. The Palaeozoic rift system in the central part of the Kola Peninsula consists of subparallel deep fault zones, ultramafic alkaline and alkaline massifs, and explosive volcanic dykes and pipes. Analysis of the distribution of alkaline magmatism has shown that the location of the largest plutons, Khibiny and Lovozero, is controlled by a triple junction of rift-related faults. The dominant northeastern trend of the metallogenic area bifurcates into two branches in the western part of the Murmansk oblast: one branch is traced to Sokli, Kovdor and Mavroguba massifs and regional alkaline dykes, another is defined by the Sallanlatvi and Vuorijarvi massifs, by a wide area of alkaline dykes of the Kandalaksha area and further to the NE by the Afrikanda, Lesnaya Varaka, Ozernaya Varaka and Salmagora intrusions. Area R0013 extends towards the northeast from the Khibiny and Lovozero plutons, as marked in the Fennoscandian metallogenic map (Eilu et al. 2009).

Two major types of mineralisation are present in area R013: 1) peralkaline rock-associated rare metal (Nb-Ta, REE, Zr), and 2) carbonatite-associated metal (Cu, Fe, Ti, V, Nb-Ta, REE, U) deposits (Table 8). Ultramafic alkaline intrusions (Kovdor, Afrikanda, Vuorijarvi and others) host titanomagnetite-apatite-phlogopite-rare metals-rare earth mineralisation. Nepheline-syenite plutons (Khibiny, Lovozero) are characterised by unique apatite deposits, as well as by rare metal and rare earth occurrences. Five metallogenic subareas have been defined for the Kovdor-Lovozero area: Lovozero, Khibiny, Afrikanda, Kovdor and Sallanlatvi-Vuorijarvi.

The Lovozero subarea (R013.1) is located in the central part of the Kovdor-Lovozero area. Spatially, it is confined to the Lovozero apatite-nepheline-syenite pluton with a size of 723 km^2. The subarea is characterised by peralkaline rock-associated rare metal mineralisation. Magmatic layering in the Lovozero massif is subhorizontal (Fig. 15). The intrusion was formed during two stages. During the first stage, the primary layered complex was formed and consists of lujavrite, foyaite and urtite. The second stage is characterised by the intrusion of eudialytic lujavrite. A differentiated complex of the first stage forms the lower part of the massif and has a thickness exceeding 5 km according to geophysical data. Eudialytic lujavrite of the second stage forms a plate-shaped body of 270 km^2 in size with a thickness of 800–1000 m. The mineral deposits in the Lovozero massif contain disseminated loparite ore in zones of urtite, foyaite, malignite and lujavrite. About 40 loparite-bearing units are known, eight of which are of industrial significance and a further nine are near-economic. At present, four deposits are under exploration: **Umbozero**, **Karnasurt**, **Kedykvypakh** and **Alluaiv** (the first two are presently mined). The main extracted ore component is loparite, a complex raw material containing Nb, Ta, REE, Sr and Th. The loparite ore is easy to dress and the technological scheme of chemical-metallurgical processing of concentrate is rather effective. Presently, only Ti, Nb and rare earths are extracted from the loparite concentrate. Strontium and thorium are not extracted, because there is no market demand (Korovkin et al. 2003). The exploration potential of the subarea is estimated as high.

The Khibiny subarea (R013.2) is in the central part of the Kovdor-Lovozero area. The subarea coincides with the very large (1346 km^2) Khibiny alkaline pluton of the apatite-nepheline syenite type. The pluton is a concentric-zonal, polyphase, equidimensional intrusion. The eastern contact of the massif is subvertical to the depth of 3–4 km and flattens out at the depth of 4–5 km. The western and southern contacts dip towards the centre at 65–70° down to the depth of 4 km. The peripheral part of the massif consists of alkaline syenite, nepheline syenite and khibinite. The central part is composed of nepheline syenite and foyaite. A bow-shaped body of ijolite-urtite, with nepheline-apatite ore, occurs between the peripheral and central parts (Zak et al. 1972a). Mineralisation in subarea R013.2 is of the peralkaline rock-associated rare metals type. Within the Khibiny pluton, 10 apatite-nepheline deposits are known, six of which are mined (Kukisvumchorr, **Yuksporskoe**, Apatitovyi tzirk, **Rasvumchorr**, **Koashvinskoe** and Niorkpakhskoe) and four are in reserve (Olenyi ruchei, Eveslogchorr, **Partomchorr** and Kuelporskoe). Of the deposits mentioned, only about half occur in the FODD (Eilu et al. 2010) and in Table 8, because metal grades are not reported from all the apatite deposits. Apatite-nepheline ores are spatially related to the ijolite-urtite complex and form units in the upper

Table 8. Deposit and showings in the Kovdor-Lovozero area (R013) included in the FODD database.

Name	**Ore tonnage Mt**	**Fe %**	**Nb %**	**REE %**	**Ta %**	**Ti %**	**Zr %**	**Genetic type**	**References**
Lovozero subarea (R013.1)									
Alluaiv	178.84		0.33	1.25	0.023	1.4		Peralkaline rock associated	Dudkin et al. (1984), Kukharenko et al. (1965)
Karnasurt	23.759		0.347	1.33	0.026	1.67		Peralkaline rock associated	Dudkin et al. (1984), Kukharenko et al. (1965)
Kedykvyrpakhk	9		0.38	1.52	0.031	1.93		Peralkaline rock associated	Dudkin et al. (1984), Kukharenko et al. (1965)
Umbozero	180.5		0.186	0.95	0.015	1.39		Peralkaline rock associated	Dudkin et al. (1984), Kukharenko et al. (1965)
Khibiny subarea (R013.2)									
Koashvinskoe	856.6			0.41				Peralkaline rock associated	Zak et al. (1972a), Pozhilenko et al. (2002)
N'orkpakhkskoe	96.864			0.39				Peralkaline rock associated	Zak et al. (1972a), Pozhilenko et al. (2002)
Partomchorr	877.4			0.2				Peralkaline rock associated	Zak et al. (1972a), Pozhilenko et al. (2002)
Rasvumchorr	350.4			0.34				Peralkaline rock associated	Zak et al. (1972a), Pozhilenko et al. (2002)
Yuksporskoe	542.2			0.38				Peralkaline rock associated	Zak et al. (1972a), Pozhilenko et al. (2002)
Afrikanda subarea (R013.3)									
Afrikanda	627.3	18		0.67		6.66		Carbonatite associated	Korovkin et al. (2003), Judin (1987)
Lesnaya Varaka	311.7	15				7.7		Carbonatite associated	Gorbunov et al. (1981)
Kovdor subarea (R013.4)									
Kovdor	1255.3	24.4					0.16	Carbonatite associated	Gorbunov et al. (1981), Korovkin et al. (2003)
Sallanlatvi-Vuorijarvi subarea (R013.5)									
Neske-Vara	6.162		0.525		0.018			Carbonatite associated	Subbotin (1990)
Sallanlatvi	71.99		0.191					Carbonatite associated	Pozhilenko et al. (2002), Serba (1962)
Deposits beyond subareas									
Sokli	250	17.5	0.21		0.005		0.13	Carbonatite associated	Vartiainen (1980), Hugg & Heiskanen (1983)

parts of the intrusion (Fig. 16). The ores are complex with high contents of P, Al, Ti, Sr, Nb and Ta. However, practically only apatite concentrate is fully extracted, whereas nepheline concentrate is extracted in only small volumes. Prospects for finding new economic deposits at an accessible depth are estimated as low within the subarea.

The Afrikanda subarea (R013.3) is located 30 km to the southwest of the Khibiny pluton and hosts a group of ultramafic alkaline intrusions (**Afrikanda**, **Lesnaya Varaka** and Ozernaya Varaka). Intrusions within subarea R013.3 have a concentric zonation (Fig. 17). Core parts are composed of olivinite and pyroxenite, whereas the alkaline rocks belong to a separate, later phase and form ring- and crescent-shaped intrusions in the peripheral zones, as well as cross-cutting veins in the central parts of massifs. Mineralisation in subarea R013.3 belongs to the carbonatite-associated type. The large Afrikanda Fe-Ti deposit is in this subarea. It is confined to an ultramafic alkaline massif with a diameter of 6.4 km (Fig. 17). The central part of the massif comprises coarse-grained pyroxenite with perovskite-titanomagnetite ores, and the peripheral part is composed of nepheline pyroxenite. At the present surface, the deposit is an oval elongated in a north-northwestern direction; in cross section it is a vertical pipe. The deposit has been explored down to 200–400 m depth, and there is no sign of ore pinching out. The average grade is 11.12% TiO_2. Minerals containing rare earth elements (dysanalyte,

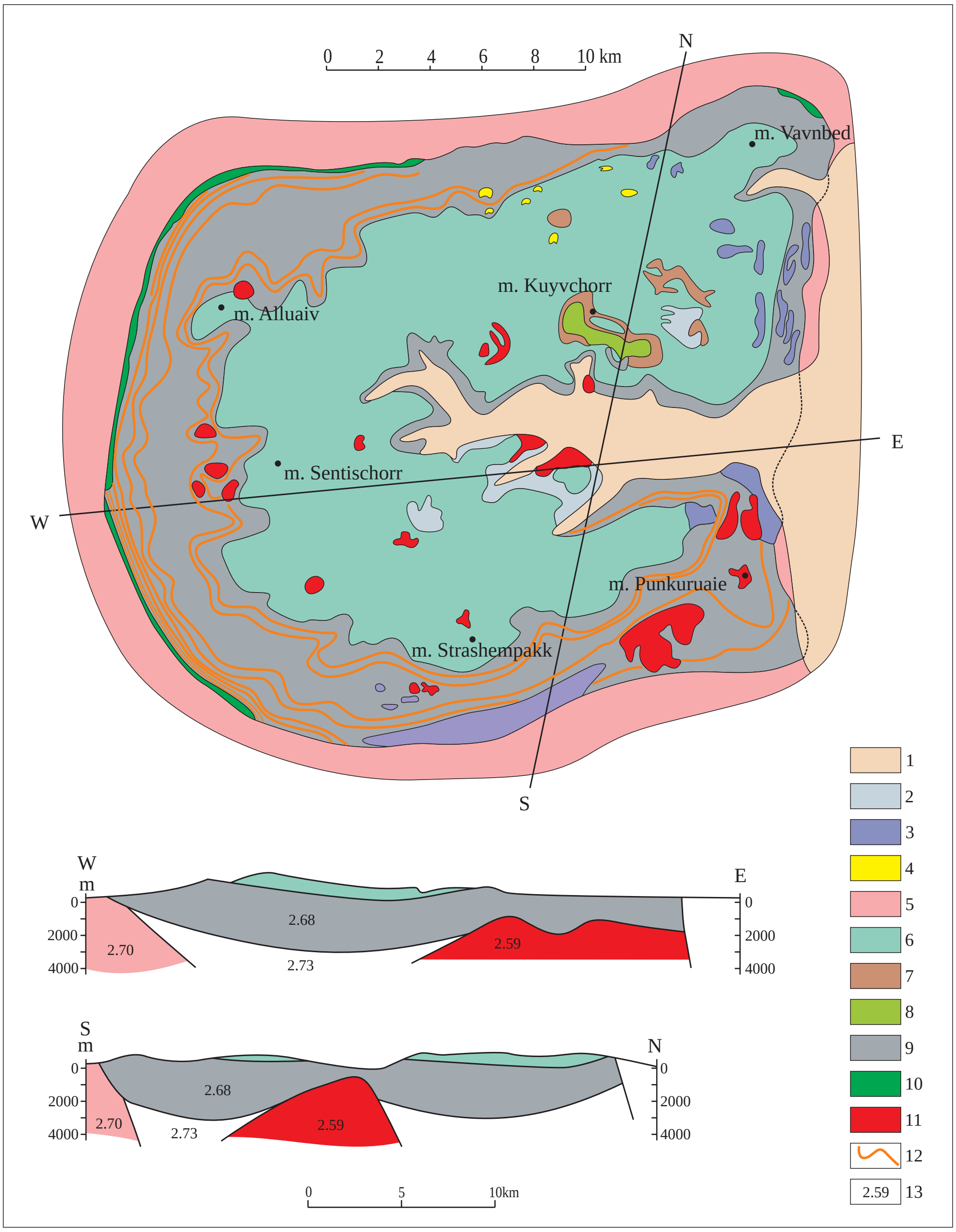


Figure 15. Geological map of Lovozero massif. Vertical scale in metres. Mt Alluaiv is at 67.81°N, 34.52°E. Legend: 1 – Quaternary deposits – Rocks of the Lovozersk Suite: 2 – phonolite, syenite-porphyry; 3 – augite porphyry and tuff; 4 – metamorphosed schist and tuff schist; 5 – biotite gneiss, granite gneiss, diorite gneiss; 6 – eudialytic lujavrite; 7 – foyaite, foyaite-lujavrite; 8 – ijolite with apatite and titanite; 9 – lujavrite, foyaite and urtite of the layered complex (alternating members); 10 – pegmatoid foyaite, lujavrite, alkaline syenite of the endocontact zone; 11 – poikilitic and inequigranular nepheline, nepheline-sodalite and nosean syenite; 12 – ore horizons of lujavrite, foyaite and urtite; 13 – rock density in g/cm^3 (for cross section). Based on Bussen and Sakharov (1972).

pyrochlore, orthite, melanocerite and others) are present as accessory phases in the ore. The thorium content of the ore is 0.67%. Analogous mineralisation occurs in other massifs of the subarea (Pozhilenko et al. 2002). At present, there is no effective industrial technology for processing such ore. Hence, despite the very large resources, the Afrikanda deposit is not mined.

The **Kovdor** subarea (R013.4) includes the large (105 km^2) Kovdor ultramafic alkaline massif. The massif is composed of alkaline ultramafic rock, foyaite and carbonatite (Fig. 18). The massif has intruded into Archaean gneisses. Beside and inside the massif, there are carbonatite bodies up to 3 km long and from several metres to a few tens of metres wide. The fenitisation zone around the massif is 0.1–1.0 km wide; in the southwest, it extends for 2.0 km beyond the massif. According to gravimetric data, the massif is a downwards narrowing column extending to the depth of 15 km (Gorbunov et al. 1981). Mineralisation in the Kovdor intrusion belongs to the carbonatite-associated type, has a complex character, and includes apatite, baddeleyite-apatite, rare metals, phlogopite and vermiculite ores. Apatite ores are in the peripheral ring zone of apatite-forsterite rock and in apatite-calcite carbonatite inside the massif. Baddeleyite-apatite-magnetite ores occur in the main unit, a large pipe-shaped carbonatite body (1300 x 200 x 800 m) within the central part of the massif, and in small (120–700 x 25–100 m) lens-shaped carbonatite bodies. Niobium ore comprises three small bodies in the centre of the carbonate core of the main unit and is composed of gummite-tetraferriphlogopite-calcite carbonatite with a high concentration of hatchettolite, zirkelite and pyrochlore. The potential for further discoveries exists in the deep parts of the subarea.

The Sallanlatvi-Vuorijarvi subarea (R013.5) is in the southwestern branch of the Kovdor-Lovozero area. Here, there are two alkaline massifs, **Sallanlatvi** and Vuorijarvi, which carry carbonatite-associated mineralisation. The mineralisation is hosted by carbonatite bodies with the main ore mineral being pyrochlore (Serba 1962, Subbotin 1990). Ore bodies of the **Neske-Vara** deposit in the Vuorijarvi massif have a vein shape, a length along the strike of 70–220 m, and a thickness of 3–12 m. The pyrochlore ore is characterised by a low (0.24%) Nb content and has not been of commercial interest. Exceptions to this are 10 ore bodies with 0.5–0.7% Nb. This high-grade ore is currently regarded as a reserve (Fig. 19; Table 8). The Sallanlatvi deposit is a pipe-shaped carbonatite body with a size of 800 x 1400 m containing low-grade pyrochlore ore (0.191% Nb) (Fig. 20). Prospects for further discoveries within the subarea are estimated as low.

The **Sokli** carbonatite intrusion hosts the only known Finnish mineral deposit that belongs to area R013. The intrusion, described by Vartiainen (1980), is a multistage, funnel-shaped pluton that consists of a fenite aureole surrounding a carbonatite massif that may be divided into a transition

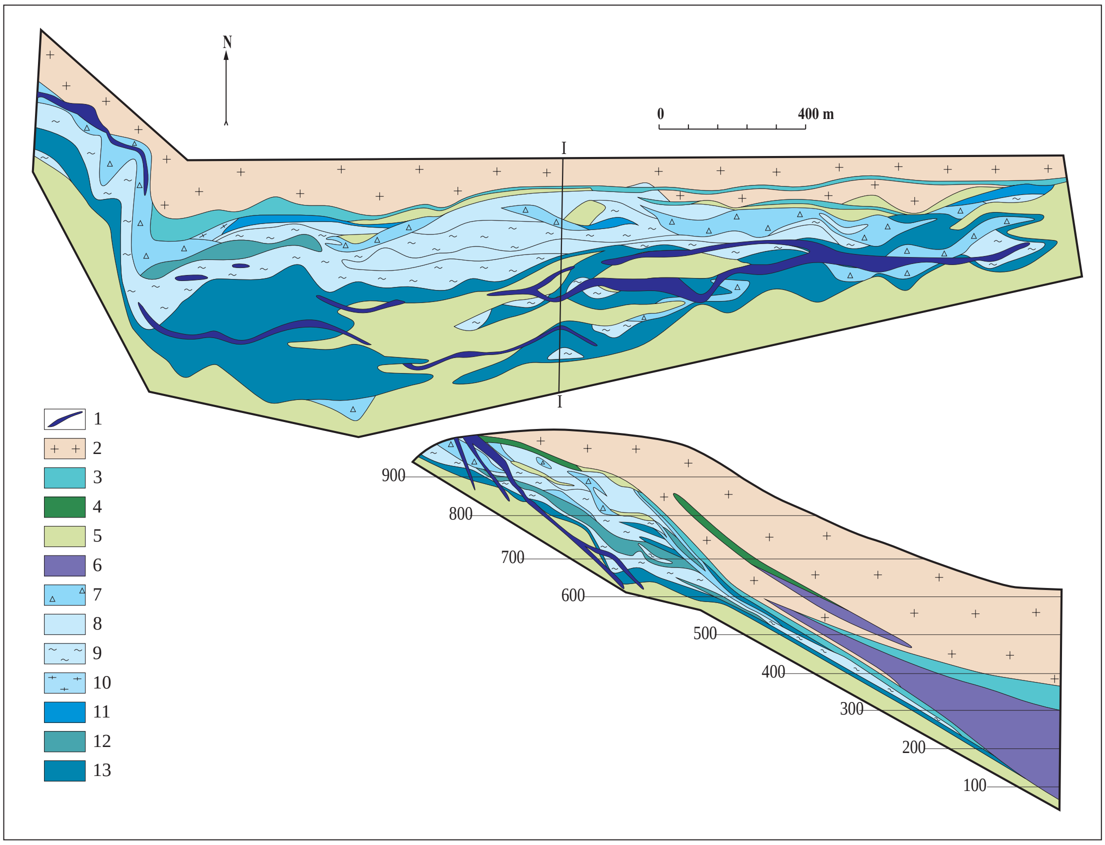


Figure 16. Geological map of Plateau Rasvumchorr deposit, located at 67.62°N, 33.87°E. All scales, also the scale for the vertical section is in metres. Legend: 1 – zones of natrolite alteration (spreusteinisation); 2 – ristschorrite; 3 – lujavrite; 4 – malignite; 5 – massive urtite; 6 – melteigite and gneissose ijolite; 7 – breccia of apatite-nepheline ore; 8 – spotted ore; 9 – lentiform-banded ore; 10 – titanite-apatite ore; 11 – massive ore; 12 – block ore; 13 – urtite with apatite (2–8% P_2O_5). Based on Pozhilenko et al. (2002).

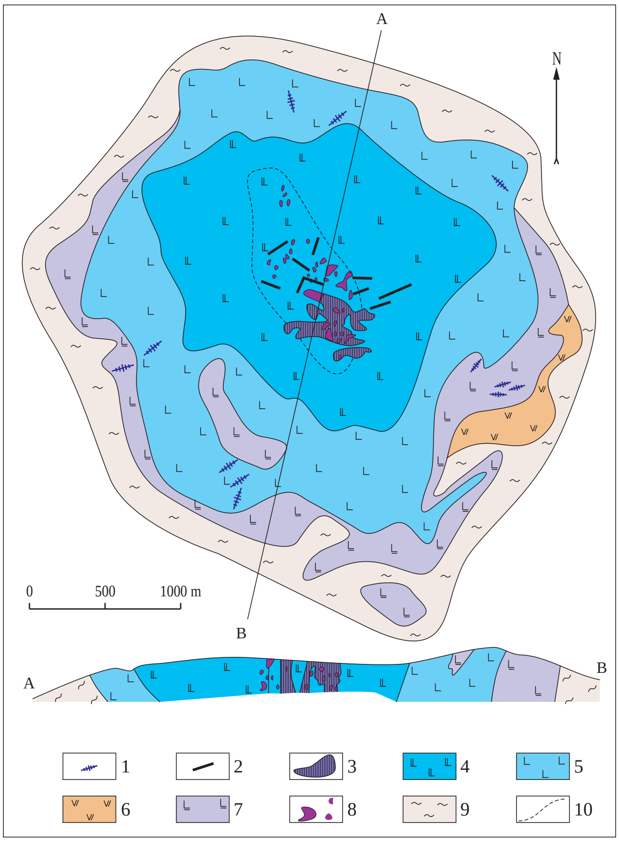


Figure 17. Geological structure of the Afrikanda massif, located at 67.47°N, 32.63°E. Legend: 1 – vein ijolite and tinguaite; 2 – alkaline pegmatite; 3 – amphibole pyroxenite ore; 4 – coarse-grained pyroxenite; 5 – fine-grained pyroxenite; 6 – melteigite; 7 – nepheline pyroxenite; 8 – olivinite; 9 – fenitised gneiss; 10 – boundary of olivinite xenolith-bearing domain. Based on Judin (1987).

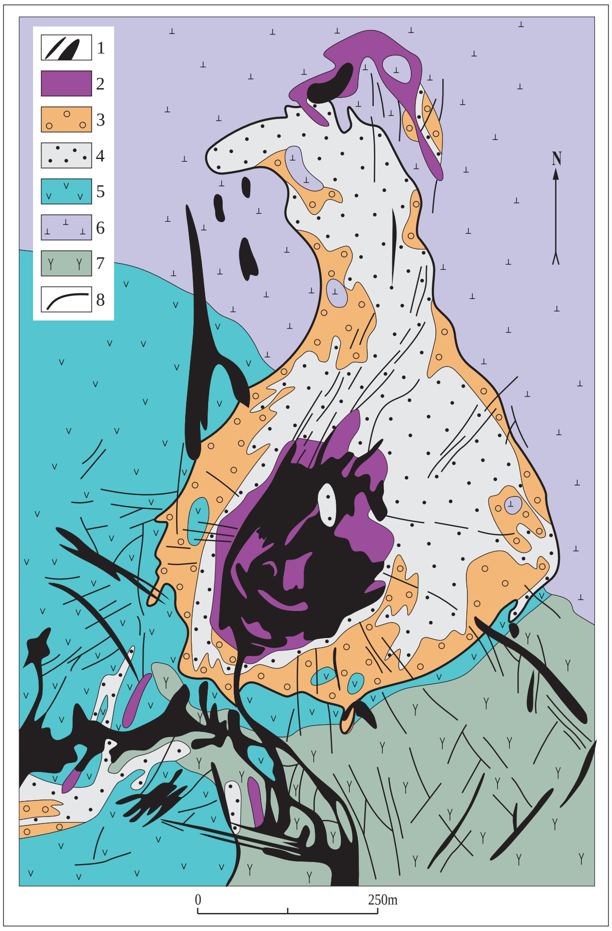


Figure 18. Geological map of the Kovdor apatite-magnetite deposit, located at 67.55°N, 30.37°E. Note that the map only shows a part of the entire Kovdor ultramafic alkaline massif. Legend: 1 – forsterite-calcite carbonatite; 2 – apatite-calcite-magnetite and calcite-forsterite-magnetite ore; 3 – apatite-forsterite rock; 4 – apatite-silicate magnetite ore; 5 – ijolite; 6 – pyroxenite; 7 – fenite; 8 – boundary of apatite-silicate-magnetite complex. Based on Dunaev (1982).

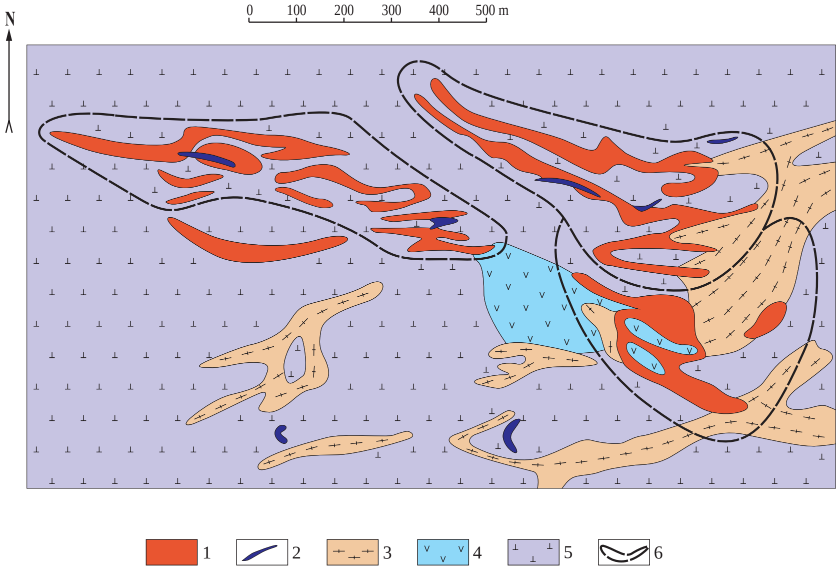


Figure 19. Geological map of the Neske-Vara rare metal deposit, located at 66.78°N, 30.17°E. Legend: 1 – rare metal carbonatite; 2 – high-grade pyrochlore ore; 3 – calcite carbonatite; 4 – ijolite; 5 – pyroxenite; 6 – contours of ore zones. Based on Pozhilenko et al. (2002).

zone of metasomatic rocks, a metacarbonatite zone and a magmatic carbonatite core (Fig. 21). The intrusion is capped by about 26 m thick regolith that constitutes the main phosphate ore. In addition to phosphate ore, the deposit contains Nb, Ta, Zr and some U. The main ore minerals in Sokli are pyrochlore, uraniferous apatite, magnetite, ancylite, rhabdophane, baddelleyite, zirconolite, fersmite and lueshite. An old resource estimate (Hugg & Heiskanen, 1983) indicates a resource of 250 Mt, with an Nb content of 2100 ppm, Ta content of 50 ppm and Zr content of 0.13% (Table 8). The Sokli deposit has not been mined.

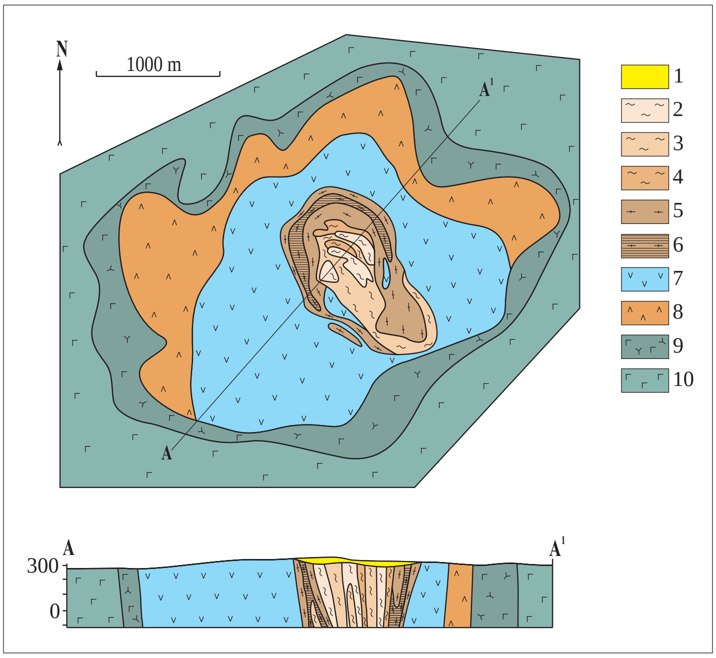


Figure 20. Geological plan map and cross section of the Sallanlatvi massif, located at 66.7°N, 29.51°E. The scale for the vertical section is also in metres. Legend: 1 – weathering crust; 2 – barite-bearing ankerite-siderite carbonatite; 3 – barite- and magnetite-bearing ankerite-dolomite carbonatite; 4 – magnesite-dolomite carbonatite; 5 – phlogopite-calcite carbonatite (weakly-mineralised); 6 – phlogopite-calcite carbonatite (enriched in lueshite and pyrochlore); 7 – ijolite; 8 – melteigite; 9 – fenitised metapicritobasalt; 10 – metapicritobasalt. Based on Subbotin (1990).

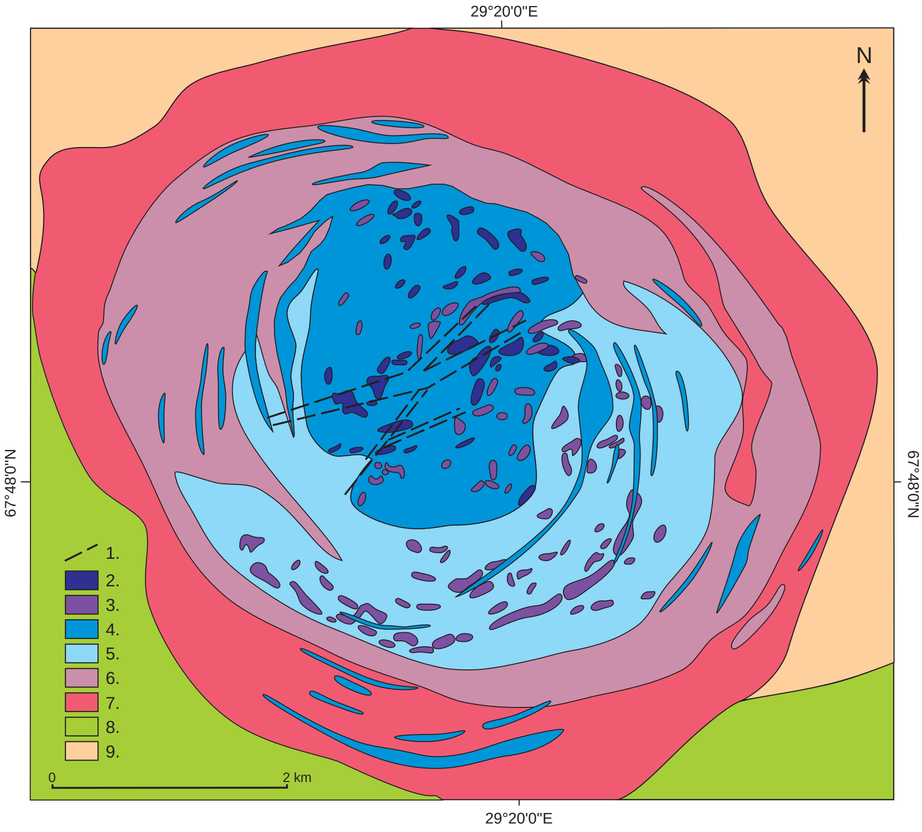


Figure 21. Geological map of the Sokli carbonatite complex (after Vartiainen, 1980). Legend: 1 – central fracture zone; 2 – magmatic phoscorite; 3 – metaphoscorite; 4 – magmatic sövite and silicosövite; 5 – metasilicosövite; 6 – metasomatite; 7 – fenite; 8 – amphibolite; 9 – tonalite gneiss.

R014 TSAGINSKAYA Ti-V-Fe

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Tsaginskaya metallogenic area (R014) is immediately to the west of the Keyvy greenstone belt. It spatially coincides with the large (288 km^2) Tsaginsk gabbro-anorthosite massif 2668 Ma in age. The massif is related to a deep meridional fault in the Archaean granite-gneiss terrain. It is a layered lopolith 23 x 6–9 km in horizontal extent and 2.5–3.0 km thick. The dip of layers is towards the centre, with an angle of 30–40° in the marginal parts and 5–10° in the centre. Marginal endocontact zones are composed of medium-grained gabbro and gabbro-norite, the central part comprises large- and gigantic-grained gabbro, anorthosite and Ti-Mgt ore, and the upper part is characterized by alternation of gabbro-anorthosite and titanomagnetite ore layers (Judin 1980).

The **Tsaginskoe** Fe-Ti-V deposit has been explored to the depth of 180 m. Ore bodies are lenses and beds of titanomagnetite ore with a length up to 20–350 m and thickness from 0.3 to 22.5 m (Fig. 22). Average metal contents in the ore are 6.2% TiO_2, 0.25% V_2O_5 and 35% Fe and the total tonnage is 53.9 Mt (Judin 1980, Pozhilenko et al. 2002). Due to lack of current effective industrial technological schemes of ore processing, the deposit is not exploited and the exploration prospects of the Tsaginskyi area are estimated as low (Korovkin et al. 2003).

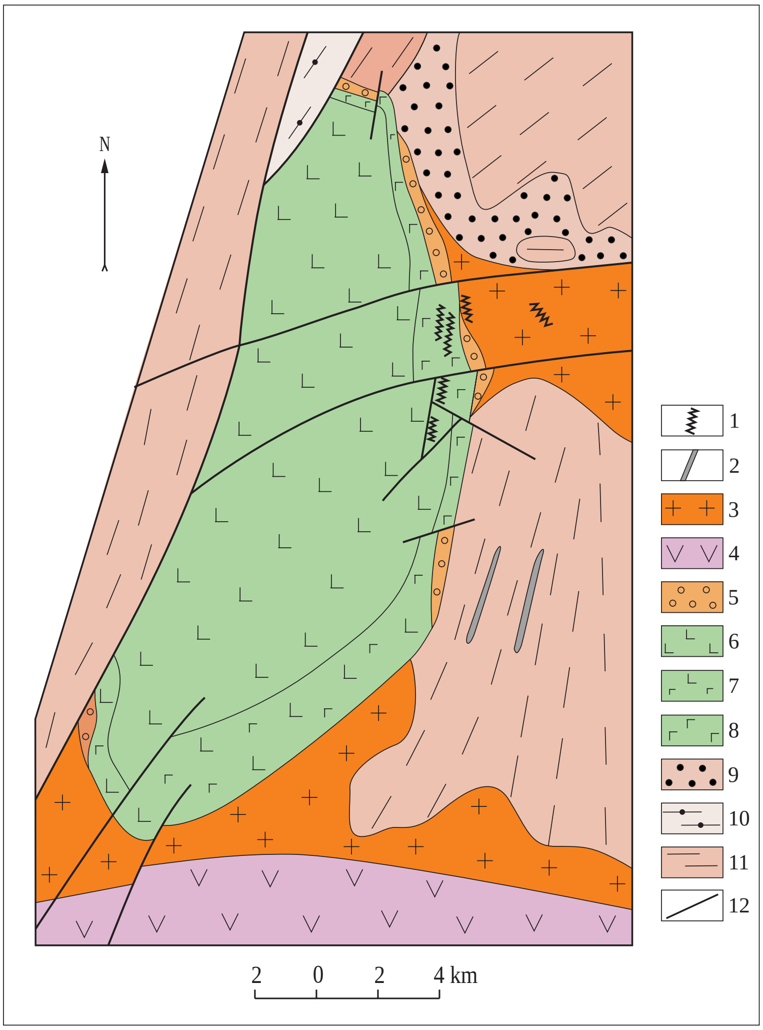


Figure 22. Geological map of the Tsaginsk gabbro-labradorite massif. Legend: 1 – olivine gabbro-norite dykes; 2 – granophyric diabase dykes; 3 – alkaline granite; 4 – mafic rocks of the Pana massif; 5 – quartz syenite and granosyenite; 6 – Tsaginsk massif: gabbro, gabbronorite, monzodiorite and monzonite of the marginal zone; 7 – Tsaginsk massif: zone of alternation of leucogabbro and gabbro-labradorite with gabbronorite and gabbro; 8 – Tsaginsk massif: leucogabbro and gabbro-labradorite; 9 – amphibole-biotite and two-mica gneiss of Kolovaisk complex; 10 – micaceous and garnet-micaceous gneiss of Volshpahk complex; 11 – complex of gneiss, granite gneiss, migmatite; 12 – faults. Based on Judin (1980).

R015 WEST KEYVY Zr, REE

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The NW-trending West Keyvy area (R015) is in the western part of the Neoarchaean Keyvy greenstone belt. Geologically, the metallogenic area is confined to an area of alkaline granites 2751–2654 Ma in age. The massifs are formed by lepidomelane-ferrohastingsite, aegirine-arfvedsonite and magnetite-aegirine granite. The granites are enriched in Zr, Y, La, Ce, and Ga, which are ac-

Table 9. Deposit and showings in the West Keyvy area (R015) included in the FODD database.

Name	Ore tonnage Mt	Nb %	REE %	Y %	Zr %	Genetic type	References
Lesnoe	1.511	0.31	0.153	0.4	1.21	Peralkaline rock associated	Korovkin et al. (2003)
Sakharjok	35.8	0.041	0.107	0.027	0.62	Peralkaline rock associated	Batieva & Bel'kov (1984), Pozhilenko et al. (2002)

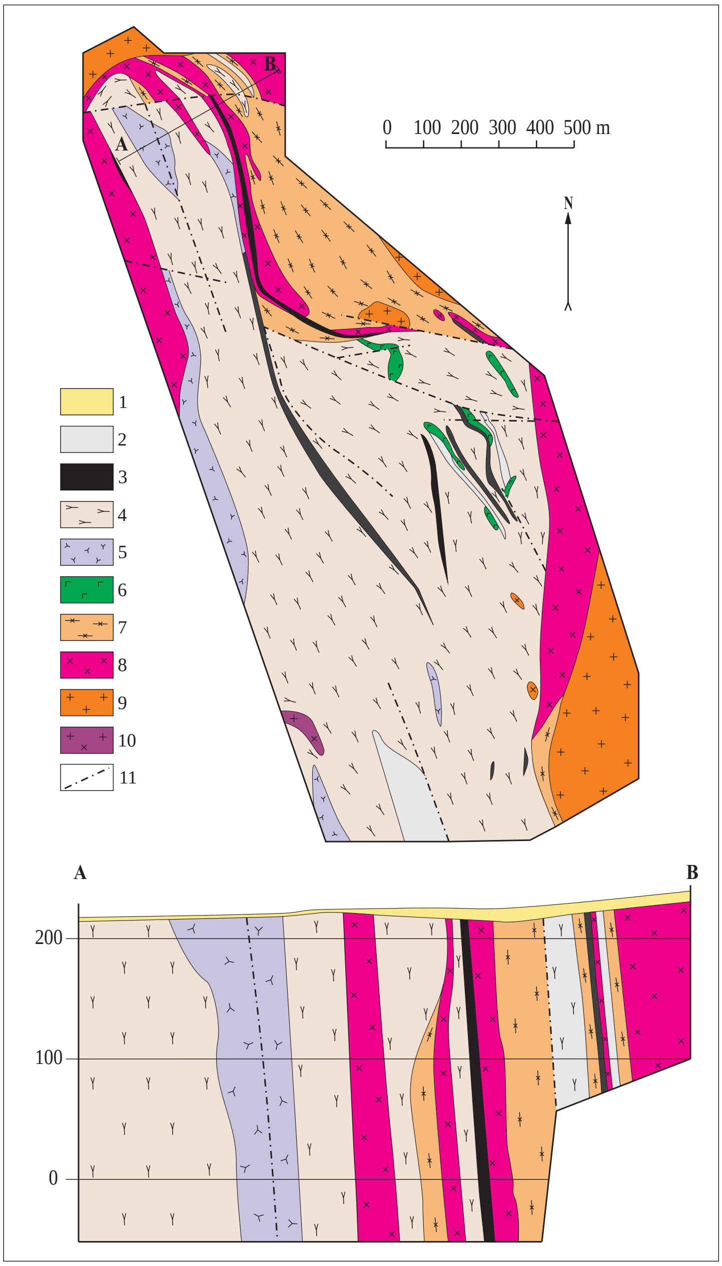


Figure 23. Geological map of the Sakharjok deposit. Legend: 1 – Quaternary deposits; 2 – albitite; 3 – britolite-zircon ore; 4 – banded nepheline syenite; 5 – recrystallised, porphyric nepheline syenite: 6 – alkaline gabbroid (essexite, theralite); 7 – banded alkaline syenite; 8 – recrystallised alkaline syenite 9 – alkaline granite; 10 –plagiogranite, diorite; 11 – faults. Based on Pozhilenko et al. (2002).

cumulated in minerals with high concentrators of these metals (zircon, monazite, fergusonite and others). The known occurrences (Table 9) are in pegmatite dykes (El'skoozerskoe), in mineralised zones of microcline-albite-quartz metasomatite in alkaline granites (Jumperuaiv) and in albitised and zeolitised endocontact zones of nepheline syenite bodies (Sakharjok) (Belolipetskyi et al. 1992). Hence, the mineralised bodies in area R015 can be classified into the category of peralkaline rock-associated rare metals deposits.

The richest mineralisation of area R015 is related to the Sakharjok alkaline and nepheline syenite massif, which is 2682–2613 Ma in age. The **Sakharjok** occurrence comprises several subparallel bodies of albitised nepheline syenite (Batieva & Bel'kov 1984), where eight ore bodies 400–1540 m long, 10–300 m wide and 15–100 m thick have been described with 0.614–1.074% ZrO_2, 0.023–0.031% Y_2O_5, and 0.051–0.065% Nb_2O_5 (Fig. 23). The large variety of rare earth and rare metals mineralisation, the wide area with alkaline granite intrusion, and the small amount of exploration work so far conducted in area R015 suggest that discoveries of significant deposits suitable for mining are possible in the area.

R016 KUROPTEVSKAYA V-Fe-Ti

Stanislav Krasotkin and Victor Stromov (VSEGEI)

The Kuroptevskaya metallogenic area (R016) is located along the boundary between the northeastern margin of the Keyvy greenstone belt and the Murmansk terrain. The Neoarchaean Keyvy belt is composed of andesite-dacite-rhyolite and dacite-rhyolite-sandstone-argillite-carbonaceous high-alumina sequences. The extent of area R016 is defined by the presence of 2668–2659 Ma gabbro-anorthosite massifs hosting Fe-Ti-V mineralisation (Feoktistov et al. 2007).

Two prospective occurrences of vanadium-bearing Ti-Mgt ore (**Kuroptevskoe** and **Magazin-Musyur**; Table 10) have been discovered in the area (Judin 1987). Kuroptevskoe is hosted by a gabbro-anorthosite massif and comprises two ore zones 2.3 and 2.8 km long and 20–80 m wide. Within the outcropping ore zones, there are several lens-shaped ore bodies 80–200 m long and 7–35 m thick. The ore bodies are composed of alternating layers of mineralised metaperidotite and metapyroxenite with bands of rich ilmenite-titanomagnetite ore. Metal contents in impregnated ore vary from 1.68–1.87% TiO_2, 0.14–0.21% V_2O_5, and 20.0–34.0% Fe. In high-grade ore, metal contents are 4.55–14.1% TiO_2, 0.15–0.32% V_2O_5 and 40–53% Fe. The Magazin-Musyur occurrence has the same mineralisation parameters as those at Kuroptevskoe. The occurrences have only been explored from the surface. Hence, they are classified as only potentially large in the FODD database. As a whole, the resource potential of area R016 is estimated at 10 Mt of TiO_2 and 840,000 tons of V_2O_5.

Table 10. Deposit and showings in the Kuroptevskaya area (R016) included in the FODD database.

Name	Ore tonnage Mt	Fe %	Ti %	V %	Genetic type	References
Kuroptevskoe	35	34	4.8	0.2	Mafic intrusion-hosted Ti-Fe±V	Pozhilenko et al. (2002), Judin (1980)
Magazin-Musyur	120	28	3.5	0.3	Mafic intrusion-hosted Ti-Fe±V	Pozhilenko et al. (2002), Judin (1980)

R017 PURNACHSKAYA Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The Purnachskaya Au area (R017) is confined to the northern wing of the Neoarchaean, 120 km long and 2–4 km wide Tersk greenstone belt. The metallogenic area comprises metamorphosed volcano-sedimentary rocks with a composition ranging from basalt to andesite and rhyolite, conglomerate, and a weathering crust at the base of the section (Feoktistov et al. 2007). Orogenic gold mineralisation characterises area R017. Gold-targeted exploration in the area has not been conducted, but during geological mapping, five gold-mineralised localities with a gold content at 0.1–1.0 g/t and signs of gold in panned samples were detected (Bezrukov 1985). As area R017 is in a Neoarchaean greenstone belt, has specific features of mineral composition, and several clear signs of gold have been detected, it is suggested that there is a rather high potential for gold deposit discoveries.

R018 SOUTH-VARZUGA Au

Stanislav Krasotkin (SC Mineral), Victor Stromov (VSEGEI)

The South Varzuga Au area (R018) is located in southern part of the Kola Peninsula, within the Neoarchaean Tersk greenstone belt. The greenstone belt and area R018 extend along the southern margin of the Palaeoproterozoic Imandra-Varzuga rift belt for 350 km (Feoktistov et al. 2007). The Tersk greenstone belt is formed by metamorphosed volcanogenic rocks of rhyolitic to andesitic and to basaltic composition, which are intruded by Palaeoproterozoic granitoid intrusions and mafic to ultramafic massifs of 2500–2400 Ma in age.

Area R018 is characterised by orogenic gold mineralisation represented by two known, potentially large occurrences (Vorgovyi and Olennyi; Table 11), 31 mineralised localities with an Au content at 0.1–4.6 g/t, and a number of geochemical Au anomalies (Bezrukov 1985). The **Vorgovyi** occurrence (Fig. 24) is confined to a shear zone that follows the system of thrust-overthrust at the boundary between the Tersk and Imandra-Varzuga belts. Ore-hosting rocks are carbonaceous volcano-sedimentary formations metamorphosed under conditions transitional between greenschist and epidote-amphibolite facies. The silicified mineralised zone is traced for 1.5 km along the strike and is 5–15 m thick. Ore minerals include arsenopyrite, pyrite, sphalerite, galena and native gold. The distribution of gold is very uneven, with concentrations varying from 0.1 to 3.09 g/t Au. To the northwest from Vorgovyi, there are two mineralised localities with a similar type of mineralisation, Fomkin ruchei and Gorelyi Bor. The **Olennyi** occurrence is in an interdome zone in biotite and amphibole-biotite schists. It is characterised by quartz veins and silicified zones. The gold content varies from 0.1 to 4.5 g/t. The occurrence is of the gold-sulphide-quartz type. The sulphides detected are pyrite, pyrrhotite and chalcopyrite. The metallogenic area R018 still is poorly explored, but has several signs of gold mineralisation. Hence, there is a significant potential for economic discoveries.

Table 11. Gold occurrences in the South Varzuga area (R018) included in the FODD database.

Name	Ore tonnage Mt	Au g/t	Genetic type	References
Olennyi	4.348	2.3	Orogenic gold	Gavrilenko & Kalinin (1997)
Vorgovyi	7.14	3.5	Orogenic gold	Pozhilenko et al. (2002)

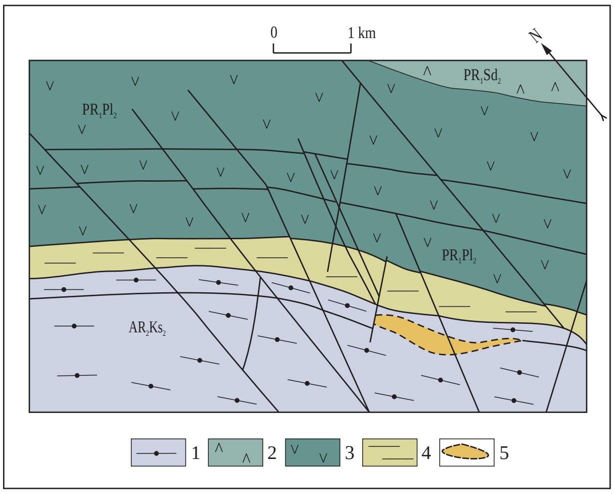


Figure 24. Structural and geological setting of the Vorgovyi gold occurrence on the boundary between the Imandra–Varzuga zone and the Tersk terrane. Legend: 1 – volcano-sedimentary rocks of the upper subcomplex of the Kisloguba complex; 2 – metaandesitic basalt of the Verhneseidorechk subcomplex; 3 – metapicrite basalt of the Verhnepolisarsk subcomplex; 4 – zone of mylonitisation and shearing composed of quartz-carbonate-chlorite-sericite schist; 5 – gold-mineralised zone. Based on Pozhilenko et al. (2002).

R020 OLANGA PGE

Margarita Korsakova (SC Mineral)

The Olanga area (R020) in Northern Karelia is defined by a band of layered intrusions on the boundary between the Palaeoproterozoic Kuusamo-Panajärvi synclinorium in the north and the Archaean Pjaozero diorite block in the south. Area R020 continues for a few kilometres into the territory of Finland, but is separated by about 40–50 km from the Koillismaa area (F036) with similar intrusions and mineral occurrences as those in the Olanga area. The Sumian (2439–2445 Ma) layered intrusions, which form the essential part of area R020, are Lukkulaisvaara, Tzipringa, Kivakka, Olanga and Kovdozero (Fig. 25), which all follow a deep NE-trending fault. They have intruded into a 2860–2720 Ma basement comprising diorite to tonalite intrusions and migmatitic granites (Feoktistov et al. 2007).

Four PGE showings have been detected from the area (Table 12). They all are within the Lukkulaisvaara massif, in microgabbronorite unit with schlieren-like pegmatoidal plagiopyroxenite-bronzitite, norite, and anorthosite, and in a zone of microgabbronorite, fine-grained norite and anorthosite interbeds. The thickness of the PGE-enriched bodies varies from 0.5–1.5 m to 50–120 m, and the length from 0.5–1.5 km to 5 km (Fig. 26). Another four PGE showings have recently been detected in the Lukkulaisvaara massif, during exploration in 2001–2004, but data on them were not available for this report.

Several PGE-mineralised localities have also been found in the Kivakka massif (Fig. 25), but there is insufficient information to calculate resources for any of them. Three lithogeochemical Pt anomalies have also been detected within the Kivakka massif (Klunin 1994), in drill holes, indicating platinoid mineralisation with a concentration of 3–6 g/t Pt. Major ore minerals of the PGE occurrences of area R020 are chalcopyrite, pyrrhotite, pentlandite. The sulphides are associated with platinum group minerals, which occur in a silicate rock matrix and include a palladium bismuth-telluride, merenskyite and kotulskite, palladium arsenides and antimonides, moncheite, sperrylite and others. Platinoid minerals are always associated with native gold and electrum.

Table 12. PGE occurrences with a reported resource within the Olanga PGE area (R020) in the Lukkulaisvaara massif. The resources shown are calculated to the depth of 300 m.

Occurrence	Ore tonnage (Mt)	Pt g/t	Pd g/t	Main host rocks	Reference
Nadezhda	1.33	1.54	5.96	Microgabbronorite	Klunin (1994)
Showing no. 15	0.6	2.5	4	Microgabbronorite	Klunin (1994)
Showing no. 2	0.7	3	6	Anorthosite	Klunin (1994)
Vostochno-critical zone	0.521	3.77	0.07	Microgabbronorite	Klunin (1994)

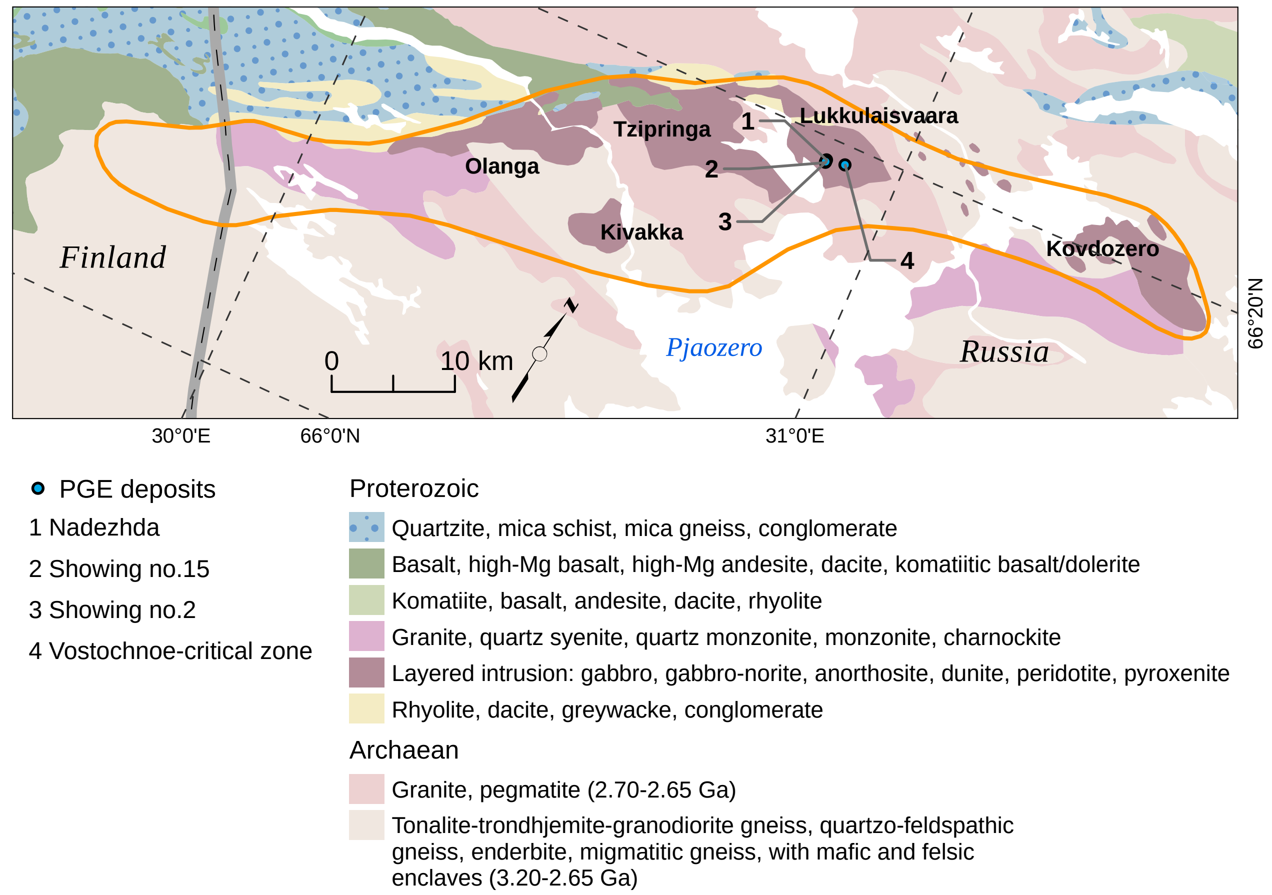


Figure 25. PGE occurrences listed in Table 12 and layered intrusions in the Olanga metallogenic area (R020). Geological map based on Koistinen et al. (2001).

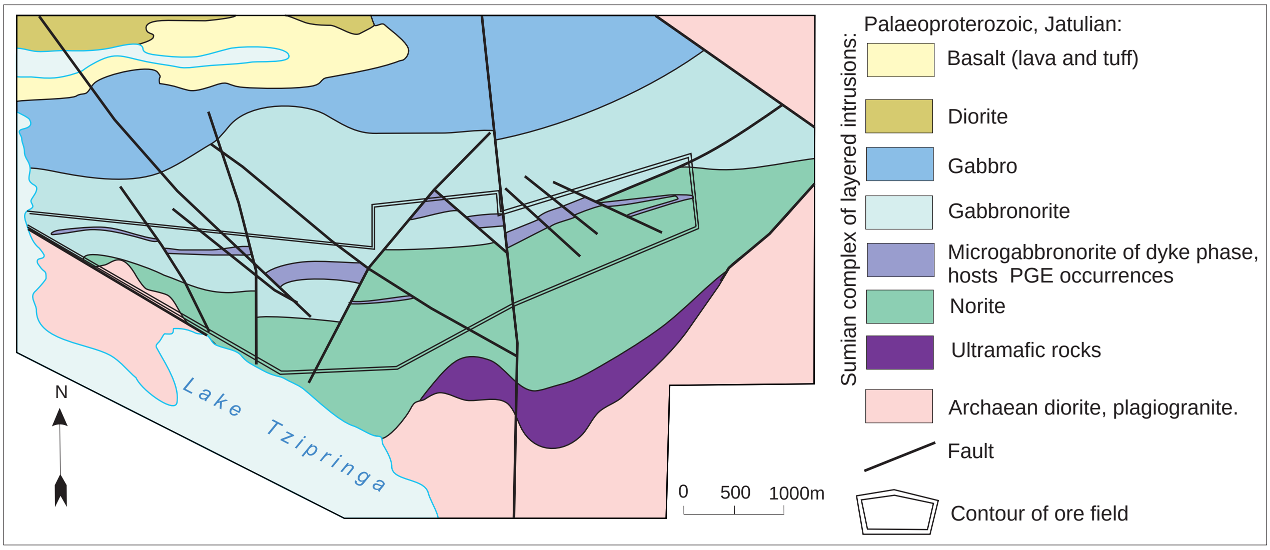


Figure 26. Geological map of Lukkulaisvaara massif. Modified from the Raw Mineral Base of the Republic of Karelia (2005). The PGE occurrences are at about 66.32°N, 30.87°E.

R021 KUKASOZERO Cu

Margarita Korsakova (SC Mineral)

The Kukasozero area (R021) in Northern Karelia is equivalent to the Kukasozero graben-syncline filled by the Palaeoproterozoic (Jatulian) conglomerate-quartzite-sandstone formation. The area is bordered by Sumian-Lopian volcanic rocks in the north and by Archaean granitoids in the south. One copper showing, **Nemittovaara-1** (Klunin & Paničev 1988), and a number of Cu-mineralised localities are known from area R021.

The Nemittovaara-I showing is confined to a NW-trending, 0.1–0.2 km wide zone of acid metasomatism cross-cutting granite, gneiss and gabbro. The metasomatite varies in mineral composition from pyrite-quartz-carbonate to magnetite-amphibolite-garnet. An ore body hosted by granite comprises a major quartz-carbonate vein 1.5 m thick and a series of parallel carbonate veinlets. Ore minerals include chalcopyrite, pyrite, bornite, sphalerite, cobalt and nickel sulphides, which form nested to scattered dissemination and veinlets of 1.5–3.0 cm in thickness. The average Cu content at Nemittovaara-I is 0.3%, and the estimated resource 56,000 t Cu.

The Cu-mineralised localities are mainly confined to Jatulian sedimentary rocks and volcanic rocks, the most studied of them being Hirvinavolok (Metallogeny of Karelia 1999). Copper mineralisation in these localities is represented by thin impregnation of chalcopyrite (up to 20–30%) and is confined to a unit of micaceous quartzite traced along all the northern and parts of the southern shores of Lake Kukas. Besides chalcopyrite, also bornite, sphalerite, pyrite, pyrrhotite, siegenite, linneite and millerite are present. Mineralised zones with thickness of 0.5–1.0 m are confined to the contacts of Sumian volcanic rock. Copper content varies from 0.8 to 5.8%, averaging 0.4%. Accessory elements are gold and silver. There are no resource estimates for these mineralised localities (Popov & Beljaev 1974). The small size of mineralised locations suggests a rather low potential for major metal deposit discoveries for area R021.

R022 VINCHOZERO Au

Margarita Korsakova (SC Mineral)

The Vinchozero Area (R022) is located in North-eastern Karelia, in the northern part of the Neoarchaean, riftogenic, dominantly N-trending, Tikshozero-Kumozero greenstone belt. The complex inner structure of the greenstone belt is characterised by a combination of linear and isometric structures of high order. The most complete section of mid- to late Lopian rocks (2880–2705 Ma) is represented here. The sequence includes komatiite to tholeiite, andesite to dacite, rhyolite, and carbonaceous andesitic basalt to basalt associations with a total thickness of about 3000 m. In addition, late Lopian (2700–2800 Ma) protocollisional plutons of mafic, intermediate and felsic composition are widely present in the area. All rocks have been subject to intense and variable hydrothermal alteration, deformation and mylonitisation related to submeridional shear zones, which were probably reactivated through the Palaeoproterozoic to the Svecofennian time (Kozhevnikov 2000, Korsakova & Ivanov 2001, Kuleshevich 2006).

No mineral deposits or showings of any significant size have been detected within the area, but there is a large number of gold-mineralised localities with accessory amounts of antimony, arsenic, and silver. Impregnated and streaky-impregnated gold-sulphide mineralisation, gold-quartz and gold-sulphide-quartz veins are present in the altered carbonaceous andesite-dacite-rhyolite and andesitic basalt to basalt sequences. Favourable factors of gold mineralisation in the area include the presence of late Lopian rhyolite, dacite and granite-porphyry dykes and granodiorite and granite porphyry intrusions. Gold and pathfinder element contents in the mineralised localities are 0.2–1.0 g/t Au, >1% As, >1% Sb, and 1–20 g/t Ag.

No gold-targeting exploration has been carried out in the Vinchozero area. However, the favourable geological situation due to the long, multistage geological evolution of the territory, from Archaean to the end of Neoproterozoic, as well as presence of various geological formations, is favourable for the localisation of gold mineralisation. The superposed processes together with direct signs of gold make it possible to consider the Vincheozero area as promising for commercial targets of orogenic gold type of mineralisation (Feoktistov et al. 2007).

R023 ELET'OZERO Ti, Fe, Nb

Margarita Korsakova (SC Mineral)

The Elet'ozero metallogenic area (R023) is located in Northern Karelia, in the eastern part of Pjaozero diorite-tonalite block, and includes two Ludikovian alkaline gabbroid massifs: Elet'ozero and Tikshozero. The Elet'ozero massif includes the **Elet'ozero** Ti deposit with minor volumes of iron, vanadium and fluorine, and the small **Elet'ozero-1** Nb-Ta-REE deposit.

Ore bodies in the Elet'ozero Ti deposit are hosted by melanocratic varieties of banded, medium-grained, olivine gabbro. The main ore minerals titanomagnetite, ilmenite and magnetite consist 20–70 vol-% of the ore. The concentrations of the main commodities are 1.3–37.5% Fe, 8–25% TiO_2, 2.6–3.0% P_2O_5, and up to 0.19% V_2O_5. The Elet'ozero-1 Nb deposit is hosted by alkaline pegmatites of the fourth phase of the Elet'ozero gabbroid massif. Mineralised zones are 0.35–9.0 m wide and enriched in pyroclore and other accessory minerals. The Nb_2O_5 content of the ore is 0.1–0.56% and Ta_2O_5 up to 0.015%. Reserves are 355 t and resources 2000 t of Nb_2O_5. (Bogachev et al. 1963).

R024 SHOMBOZERO Au

Margarita Korsakova (SC Mineral)

The Shombozero Area (R024) is located in Northern Karelia and practically covers the Shambozero synclinorium. The synclinorium comprises a complex of Palaeoproterozoic sedimentary-volcanogenic formations (in age from Sumian to Ludicovian) with sills and dykes of gabbro-dolerite and differentiated gabbro-peridotite intrusions intruding the supracrustal formations. In the marginal parts of the area, there are Neoarchaean granitoids and fragments of Archaean greenstone belts. (Feoktistov et al. 2007)

No proper deposits or showings of ore minerals have so far been revealed in the area. This can possibly be explained by the so far narrow objectives of exploration carried out in the area. Only Cu-Ni and platinoid deposits in gabbro-peridotite intrusions have been targeted, but with no discoveries. On the other hand, a geochemical heavy-mineral survey and geological mapping has indicated several gold-mineralised localities in Sumian, sheared and intensely altered, felsic volcanic rocks and Sariolian andesites and basalts in area R024. Gold-mineralised localities have also been detected in an altered fracture zone in the Archaean basement rocks in the northern margin of the Shambozero synclinorium (Ščukin, 1997, Timofeev et al. 1983). The gold content is up to 3–3.5 g/t in these localities, where no resource estimates have been performed. Besides lithogeochemical gold anomalies in bedrock, geochemical work on heavy minerals in till revealed gold in Quaternary deposits in the area. All this, together with geological formations favourable for the localization of gold mineralisation, which are analogous to Palaeoproterozoic structures developed in Finland (Kuusamo and Central Lapland greenstone belts), enables the Shambozero area to be considered promising for gold mineralisation (Feoktistov et al. 2007). At present, a geological follow-up study with an emphasis on gold is being carried out in area R024. The revealing of gold in altered and deformed rocks of all stratigraphic levels of the Palaeoproterozoic section, as well as in metasomatic blastomylonites of the Archaean basement complex, is expected.

R025 LEHTA Au, Cu

Margarita Korsakova (SC Mineral)

The Lehta metallogenic area (R025) is located in northeastern Karelia. Its boundaries coincide with boundaries of the NNW-trending Lehta synclinorium, which is 100 km long and 45 km wide in its central part, narrowing to about 3 km wide at the NW and SE ends. The synclinorium is formed by Palaeoproterozoic volcanogenic-sedimentary rocks folded in systems of complex, predominantly isoclinal folds. Their formation started in the stage of protocontinental rifts during the Sumian and Sariolian, then continued with the formation of a superimposed Jatulian trough and terminated in the stage of protooceanic rifts during the Ludikovian (Feoktistov et al. 2007).

The metallic occurrences with a resource estimate in area R025 are the gold showings **Zheleznye Vorota** and **Paiozero** and the **Shuezerskoe** copper occurrence, which has been mined in the past (Table 13). The Shuezerskoe deposit is confined to the Jatulian basalt and gabbrodolerite containing quartz, quartz-calcite and albite-calcite veins with a thickness from 0.1 m to 2–3 m. Ore minerals in veins include chalcopyrite, bornite, chalcocite, native copper, molybdenite, native gold and silver (Metallogeny of Karelia 1999, Raw Mineral Base of the Republic of Karelia 2005).

The Zheleznye Vorota gold showing is confined to the Sumian uranium-bearing polymictic and quartz conglomerate, where concordant beds and intersecting stockworks with an increased gold content are distinguished. Ore minerals include pyrite, uraninite, chalcopyrite, sphalerite, molybdenite, native bismuth, martite, limonite and hematite (Judin & Ščukin 1981). The Paiozero gold showing is located in altered cataclastic and mylonitised Sumian-Sariolian volcanic rocks and quartz veins. Ore minerals are pyrite and pyrrhotite (Afanas'eva 1997).

Within the Lehta area, there also are more than ten mineralised locations where the gold content exceeds 6–8 g/t, but due to insufficient exploration, their resource cannot be defined. They all are hosted by Sumian felsic volcanic rocks and by the overlying Sariolian mafic volcanic rocks and Jatulian conglomerate. Practically all the known gold-mineralised locations are in zones of low-temperature metasomatic alteration and brecciation. The results of several regional and local till-geochemical and heavy-mineral investigations also indicate the good potential for gold mineralisation in area R025. The same is indicated by the extensive primary and secondary dispersion haloes and enrichment zones of elements typically enriched in and around gold deposits, such as Ag, U, Bi, Fe, Co, and As. At present, investigations are being carried out in the Lehta area in metasomatically and dynamically altered Palaeoproterozoic volcanic rocks to reveal gold mineralisation in geological settings analogous to the known gold deposits and showings of Finnish Lapland.

Table 13. Deposit and showings in the Lehta area included in the FODD database.

Occurrence	Ore tonnage (Mt)	Cu %	Au g/t	Genetic type	References
Shuezerskoe	0.0037	2.43	5	Hydrothermal vein	Metallogeny of Karelia, (1999), Raw Mineral Base of the Republic of Karelia (2005)
Zheleznye Vorota	2.33		0.43	Sedex	Judin & Ščukin (1981)
Paiozero	11.67		0.6	Orogenic gold	Afanas'eva (1997)

R026 PJAVAARA-LOBASH Mo, Au

Margarita Korsakova (SC Mineral)

The Pjavaara-Lobash Area (R026) is located in the Panozero-Tungud granitoid block. It has an irregular lensoid shape, occurs along a 90 km long NW-trending shear zone, and combines several late Neoarchaean (late Lopian, 2700–2800 Ma), multiphase, granodiorite-granite-porphyry massifs intruded into mid-Lopian volcanic sequence during the protocollisional stage of continental protocrust formation (Feoktistov et al. 2007). The area includes three porphyry-type occurrences: the **Lobash** and **Päävaara** molybdenum, and the **Lobash-I** gold deposits (Table 14) related to granodiorite and granite porphyry intrusions. Mafic, intermediate and, less commonly, felsic metavolcanic and gabbroid rocks, and endocontact parts of granitoid massifs host the deposits.

The Lobash Mo deposit comprises a linear stockwork in Lopian volcanic rocks above an unexposed granite massif (Fig. 27; Judin, & Ščukin 1981, Tytyk 1991, Kuleshevich et al. 2004b). The ore body is 2 km long, 500–750 m wide and up to 200 m thick with gradual thinning at its margins. In the southern margin of the deposit, in addition to the stockwork ore, there is a gently plunging, lens-shaped, quartz-vein ore body with a lateral extent of 150–300 x 750 m and a thickness in its central parts from 40–60 to 130 m. The main ore mineral is molybdenite which occurs with accessory amounts of pyrite and traces of chalcopyrite, pyrrhotite and scheelite (Tytyk 1991). The Päävaara Mo deposit differs from Lobash in its deeper level of erosion and smaller extent of mineralisation (Raw Mineral Base of the Republic of Karelia 2005).

The Lobash-I gold deposit is 1.5 km east of the Lobash Mo deposit in a similar geological setting. The deposit is hosted by shear zones in porphyry dykes and their immediate wall rocks. It is characterised by intense silicification and sulphidation, and the ore minerals only occur in quartz and quartz-carbonate veins that irregularly saturate the host rock. There is a spatial coincidence of gold and polymetallic mineralisation at Lobash-I. The main ore minerals are galena, sphalerite, chalcopyrite and pyrrhotite. Native gold and electrum occur in association with hessite, native bismuth and bismuth telluride. It is supposed that the deposit obtained its present shape during the Svecofennian, at 1880–1850 Ma (Kuleshevich 2004b). At present, exploration and extensive drilling are being carried out at Lobash-I. This work will probably enable the presently known

Table 14. Deposits in the Pjavaara-Lobash area included in the FODD database.

Occurrence	**Ore tonnage (Mt)**	**Mo %**	**Au g/t**	**Cu %**	**Genetic type**	**References**
Päävaara	233	0.043			Porphyry	Raw Mineral Base of the Republic of Karelia (2005)
Lobash	149	0.1			Porphyry	Judin & Ščukin (1981), Tytyk (1991), Kuleshevich et al. (2004b)
Lobash-I	1.78		4.5	0.4	Porphyry	Tytyk (1998), Kuleshevich et al. (2004b)

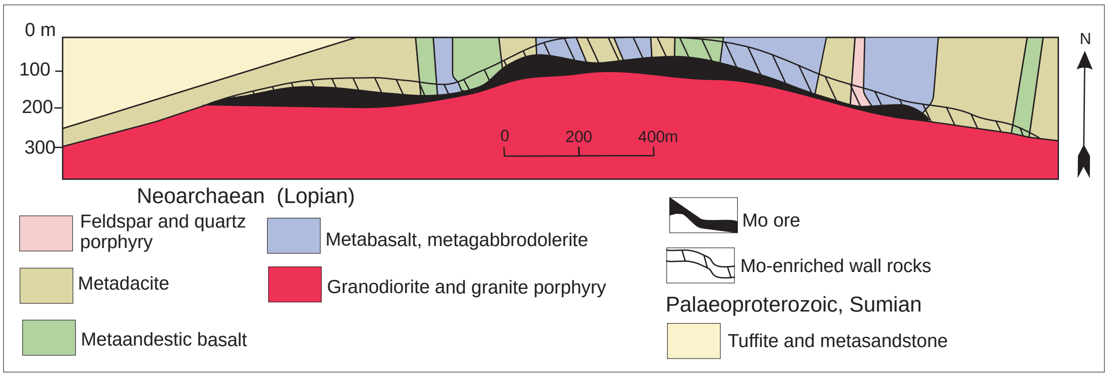


Figure 27. Schematic section across the Lobash Mo deposit, located at 64.583°N, 33.05°E (Raw Mineral Base of the Republic of Karelia 2005).

resource to be significantly increased (Table 14).

As a whole, the Pjavaara-Lobash area has rather good prospects to increase the presently known resources. This especially seems to be the case for the margins and deeper parts of the Lobash and Lobash-I deposits, and the granodiorite-granite-porphyry massifs and their country rocks in the southeastern and northwestern parts of area R026, as suggested by exploration in the area. Geochemical Au anomalies, heavy mineral anomalies in till, and the known Mo- and Au-mineralised locations also indicate the good prospectivity of the SE and NW parts of the metallogenic area.

R027 PARANDOVO-NADVOIZA Au, Mo, Cu

Margarita Korsakova (SC Mineral)

The Parandovo-Nadvoiza area (R027) covers the southeastern boundary of the Neoarchaean Pebozero-Parandovo greenstone belt formed by the association of mid-Lopian rhyolite, andesite, dacite, andesitic basalt and basalt containing thin units of carbonaceous shale and sulphide mineralisation. The late Lopian Kochkoma intrusion and associated, small, granodiorite to granite porphyry dykes and other intrusive bodies have intruded into the supracrustal sequence of the greenstone belt. In the south, the greenstone belt is overlain by Palaeoproterozoic, predominantly sedimentary formations. Extensive metasomatites of variable composition are common at the margins of the Kochkoma massif and along faults in shear and mylonite zones.

Three small metal occurrences are known within area R027: **Voitzkoe** Cu-Au, **Kochkoma** Mo and **Sumskoe** Cu (Table 15) (Judin & Ščukin 1985). The Voitzkoe deposit is in Sariolian to Jatulian sericite-quartz schist and characterised by crosscutting quartz, quartz-calcite and calcite veins. Ore minerals include chalcopyrite, chalcocite, bornite, covellite, native copper, molybdenite and native gold, which occur as thin films, fine-grained dissemination, and nuggets with a weight of up to 100 g. The deposit was mined during the 18th century when 102 t of copper and 74 kg of gold were produced (Raw Mineral Base of the Republic of Karelia 2005). The Kochkoma Mo occurrence is in the southeastern endo- and exocontact of the Kochkoma massif in tourmaline-bearing, intensely albitised granite, characterised by quartz-tourmaline veins with pyrite and arsenopyrite. Elevated gold contents occur in the veins (typically 0.1–0.5 g/t Au, max 3.8 g/t Au) (Judin & Ščukin 1985). The Sumskoe Cu occurrence is in a propylitised shear zone in Lopian intermediate to mafic volcanic rocks. The main ore mineral at Sumskoe is chalcopyrite, which occurs as dissemination and nests (Raw Mineral Base of the Republic of Karelia 2005).

Table 15. Deposit and showings in the Parandovo-Nadvoiza area (R027) included in the FODD database.

Occurrence	Ore tonnage (Mt)	Au g/t	Mo %	Cu %	Genetic type	References
Voitzkoe	0.056	1.9		1.3	Hydrothermal vein	Raw Mineral Base of the Republic of Karelia (2005)
Sumskoe	6.25			0.8	Volcanic exhalative	Raw Mineral Base of the Republic of Karelia (2005), Judin, & Ščukin (1985)
Kochkoma	3.75		0.08		Porphyry	Judin & Ščukin (1985)

R028 KOSTOMUKSHA Fe, Au

Margarita Korsakova (SC Mineral)

The Kostomuksha area (R028) is located in Western Karelia, in the northern part of the Kostomuksha-Bolsheozero greenstone belt. Area R028 has an isometric extent, but a rather complicated inner structure. Its western part is a submeridional monocline affected in the north by the Korpanga antiform. This part of the area is formed by mid-Lopian, 2843–2888 Ma, metavolcanic rocks of rhyolitic, basaltic and komatiitic composition and oceanic (riftogenic) in type. In the east, an arched syncline attached to the area is formed by late Lopian metasedimentary and felsic metavolcanic rocks of 2779 Ma in age representing formations of the continental (basinal) type. The latter part of the area is the most mineralised and is distinguished as the West-Kostomuksha subarea (R028.1). Practically all iron deposits are confined to R028.1. Late Lopian metasedimentary and felsic metavolcanic rocks cover wide areas to the east of the subarea R028.1. They form a row of local synformal structures with a submeridional strike but without any essential accumulation of iron ore. Plutonic intrusions predominantly occur in the West Kostomuksha subarea. These include small bodies of 2720 Ma granodiorite to granite porphyry and isolated bodies of gabbro-peridotite (Fig. 28).

Iron deposits in area R028 are of the stratiform (BIF) type. The two largest occurrences are **Kostomuksha** in a late Lopian metasedimentary to felsic metavolcanic sequence and the **Korpanga** in mid-Lopian rocks (Table 16). The former is under active mining, whereas the latter is presently under preparation for exploitation. In addition, there are a number of smaller deposits and showings mainly confined to the mid-Lopian metavolcanic sequence.

The Kostomuksha deposit, which has been mined since 1982, comprises the 12.5 km long and 5–300 m thick "main ore body" and the "interbedding strata", consisting of 67 ore bodies 100–670 m long and 5–80 m thick. Iron ore at Kostomuksha include the amphibole-magnetite (30–60% magnetite) and grunerite-hornblende-magnetite-quartz (20–35% magnetite) types. So far, 396.87 Mt of ore has been mined at Kostomuksha. In the Korpanga deposit, 18 ore bodies, with the same mineral composition as at Kostomuksha, have been identified. Their lateral extent varies from 150 to 2650 m and thickness from 4 to 60 m. Ore at both Kostomuksha and Korpanga is of high quality and homogeneous, practically without a change along the strike or dip.

The **Taloveis** porphyry-type gold deposit (Table 16) is related to granodiorite-granite porphyry. The gold occurs in quartz veins and stockworks as well as in metasomatically altered granitoid. The gold content of the veins is up to 10–30 g/t; in

Table 16. Deposits and showings in the Kostomuksha metallogenic area (R028) included in the FODD database.

Occurrences	Ore tonnage (Mt)	Fe %	Au g/t	References
Kostomuksha	2454.49	32.2		Rogozov (1987), Malyshev (1985), Borisova et al. (2001)
Korpanga	693.132	29.5		Moškov (1982), Ivanov & Korsakova (2005)
Zapadnoe	239.0	25.12		Šramko (1977)
Juzno-Kostomuksha	205.8	27.18		Šramko (1977)
Juzhno-Korpanga	192.192	29.92		Rogozov (1983)
Kondokskoe	169.05	30.15		Krongaus (1982, 1983)
Jugo-Zapadnoe	137.2	26.26		Šramko (1977)
Taloveis	124.0	26.61		Šramko (1977)
Valkamajarvi	120.0	27.81		Krongaus (1983)
Severo-Vostochnoe	101.0	25.92		Šramko (1977)
Severo-Kostomuksha	99.0	32.89		Šramko (1977)
Koivasozero	97.1	28.73		Krongaus (1983)
Jurikkalampi	27.3	26.48		Krongaus (1983)
Korpangijoki	22.5	30.06		Krongaus (1983)
Sorasenlampi	21.4	26.31		Krongaus (1983)
Kentozero	17.7	20.15		Krongaus (1982, 1983)
Kondokskoe	2.5		2.0	Borisova et al. (2001)
Berendey	1.33		3.0	Borisova et al. (2001), Ivanov & Korsakova (2005)
Taloveis	2.503		4.8	Furman (2001), Ivanov & Korsakova (2005)

stockworks, the grade normally is 4 g/t although in places 8 g/t. The explored gold reserve amounts to only 159 kg of the metal. There also are isolated gold showings and mineralised locations in hydrothermally altered volcanic rocks of variable composition in area R028.

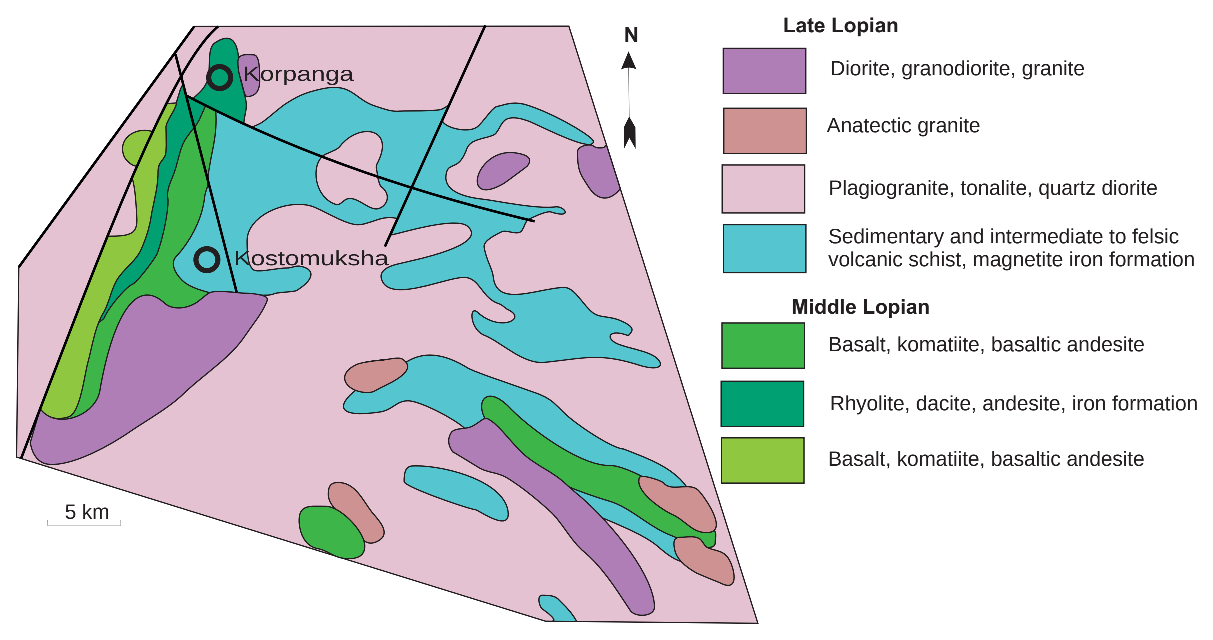


Figure 28. Geology of the Kostomuksha area (Raw Mineral Base of the Republic of Karelia 2005).

R029 BOLSHEOZERO Fe, Au

Margarita Korsakova (SC Mineral)

The Bolsheozero metallogenic area (R029) has a lensoid shape and is elongated in a submeridional direction. It is located in Western Karelia, in the southern part of the Kostomuksha-Bolsheozero greenstone belt (Feoktistov et al. 2007). Its western part is characterised by Neoarchaean (mid-Lopian) sedimentary-volcanogenic formations, and the eastern part by undivided mid- to late Lopian rocks predominantly of intermediate to felsic composition and with banded iron formation units. All these formations have been subject to intense hydrothermal alteration related to E-W trending faults, as well as migmatisation, which makes it difficult to determine their stratigraphic sequence. In the central part of area R029, mid- to late Lopian formations are covered by Palaeoproterozoic Sumian to Sariolian volcanic rocks, which form a small, superimposed, trough-like syncline. Plutonic rocks in the area are represented by several late Lopian granodiorite to granite porphyry massifs.

Within area R029, there are a number of banded iron formation occurrences, including the **Bolsheozerskoe** deposit with a reserve of 2.28 Mt of ore, and the smaller occurrences of **Severo-Bolsheozero**, **Juzhno-Bolsheozero**, **Hedozero** and **Juzhnoe**. All of them are in a sequence of felsic volcanic rocks and schists of mid-Lopian age. The predicted resource of P_1+P_2 categories for all the occurrences amounts to 243.84 Mt of ore (Raw Mineral Base of the Republic of Karelia 2005).

One gold deposit has also been detected in area R029: **Bolsheozero Au**. It is hosted by mid-Lopian silicified and pyritised felsic volcanic rocks. It has a predicted resource of the P_2 category of 3 t of gold. Several mineralised localities and high-contrast geochemical gold anomalies have been found in the area. These, together with favourable geological factors, are used in exploring for gold in the Bolsheozero metallogenic area.

R030 GIMOLY Fe, U

Margarita Korsakova (SC Mineral)

The Gimoly area (R030) is located in Western Karelia and covers the submeridional Gimoly-Sukkozero greenstone belt, which is formed by Neoarchaean (late Lopian) micaceous schists and amphibolites of sedimentary and intermediate to felsic volcanic origin, and intruded by Neoarchaean migmatitic plagiogranite (Feoktistov et al. 2007). Area R030 is characterised by BIF and vein uranium mineralisation.

The Mezhozero subarea (R030.1), characterised by banded iron formation, forms the northern part of the Gimoly area. Two iron deposits are known from subarea R030.1, **Mezhozero** and **Gimoly-I**, with a total reserve of to 77.68 Mt of ore. Magnetic anomalies of area R030 are most intense within the Mezhozero subarea, and decrease in intensity to the south, indicating a decrease in the thickness of the BIF horizons. Ten ore bodies have been identified in the Mezhozero deposit; their length is from 160 to 1140 m, thickness 10–50 m, and they have been traced to the depth of 300–375 m. The technological properties of Mezhozero and Gimoly-I iron ores are inferior to that at Kostomuksha, because the essential part of iron occurs in silicates in the R030.1 deposits, in contrast to the latter, where oxide iron dominates.

In the southern part of the area, in Neoarchaean migmatitic plagiogranite, there are two vein-type uranium showings: **Raduzhnoe** and **Hukkala**. The uranium content of these showings is low, averaging at 0.01–0.02% U. Their predicted resource of category P_2 is estimated as 91,600 t U, which is obviously an overestimate (Raw Mineral Base of the Republic of Karelia 2005).

R032 ELMOZERO-SEGOZERO Pb, Cu

Margarita Korsakova (SC Mineral)

The Elmozero-Segozero area (R032) is located in Central Karelia. It covers the northern (Elmozero) part of the Palaeoproterozoic Elmozero-Segozero syncline and extensive parts of Neo- and Mesoarchaean granitoids and greenstones surrounding the Palaeoproterozoic syncline (Feoktistov et al. 2007). Three small polymetallic deposits are known from area R032. The **Rokzhozero** copper deposit, with a prognostic resource of 12,700 t Cu, is in Mesoarchaean (mid-Lopian) felsic to intermediate metavolcanic rocks. The **Lebedevogorsk** and **Tuhkozero** Pb-Zn deposits are related to hydrothermal veins hosted by late Lopian migmatite granite. Prognostic resources for the latter combined are 130,500 tons of lead and 22,700 tons of zinc (Ganin & Bondarev 1983, Raw Mineral Base of the Republic of Karelia 2005). Within area R032 there also are many Cu-mineralised localities in the Palaeoproterozoic, Sumian to Sariolian, volcanic rocks.

R033 JANGOZERO Au, Cu

Margarita Korsakova (SC Mineral)

The Jangozero area (R033) is located in Central Karelia, on the eastern margin of the Jatulian Jangozero superimposed trough. Two gold occurrences, **Jatuly-I** and **Maimjarvi**, and the potentially large **Maimjarvi Cu** deposit are known from the area (Feoktistov et al. 2007). The gold mineralisation is in several units of quartz conglomerate, as lens-shaped bodies from 0.4 to 33 m thick, with a background gold content from 0.07 to 0.19 g/t Au. At irregular intervals, the gold content rises to 2.0–3.0 g/t Au. The highest gold grade is in the parts with superimposed metasomatic alteration and epigenetic sulphide dissemination. The predicted gold resource amounts to 18.8 t Au within area R033 (Raw Mineral Base of the Republic of Karelia 2005). The Maimjarvi Cu deposit is hosted by a layer of propylitised sandstone on its contact with narrow gabbrodolerite dykes. The copper content of the ore varies from 0.5 to 3.5%, and averages 0.8% Cu. The prognostic copper resource at Maimjarvi amounts to 162,000 tons of Cu (Raw Mineral Base of the Republic of Karelia 2005).

R034 PEDROLAMPI-ELMUS Au, Pb, Cu

Margarita Korsakova (SC Mineral)

The Pedrolampi-Elmus area (R034) is in the eastern part of Central Karelia. It covers the southern part of the Mesoarchaean (mid-Lopian) Semchensko-Urasozero greenstone belt of oceanic (riftogenic) type formed by rhyolitic to komatiitic metavolcanic rocks of 2860 Ma in age. Superimposed on the Archaean rocks are small bodies of the Jatulian volcano-sedimentary sequence comprising basalts, carbonate rocks, argillite and aleurolite.

The gold occurrences **Pedrolampi**, **Elmus** and **Talpus**, and the **Korbozero** zinc occurrence (Table 17) are in the Archaean greenstones of area R034. In addition, there is the small **Talpus-1** copper deposit in the Jatulian sedimentary rocks close to the eastern margin of the Archaean greenstones. All gold targets are in submeridional shear, brecciation and propylitisation zones in foliated felsic to intermediate volcanic rocks. The Pedrolampi gold deposit is a steeply dipping linear quartz stockwork concordant with a shear zone. The stockwork is 35–40 m wide and is traced along the strike for 400 m and along the dip for 350 m. In the stockwork, there are lens-shaped ore bodies with a gold content from 1 to 46 g/t. The ore bodies are from 1.0 to 7.0 m thick and extend along the strike and dip from a few metres to 50–70 m (Fig. 29). The Korbozero zinc occurrence is 4 km long, from 2 to 4 m thick, in a banded carbonaceous quartz-sericite schist. The Talpus-1 copper occurrence is 5 m thick and 1.6 km long. It is hosted by a Jatulian, epidotised, basalt unit enriched in pyrite and chalcopyrite.

Table 17. Deposits and showings in the Pedrolampi-Elmus area (R034) included in the FODD database.

Occurrence	Ore tonnage (Mt)	Au g/t	Cu %	Zn %	Pb %	References
Pedrolampi	0.5	5.91				Novikov (1997)
Elmus	0.476	4.2				Novikov (1997)
Talpus	1.67	3				Novikov (1997)
Korbozero	40.7			0.52	0.02	Sivaev & Goroško (1982)
Talpus-I	6.7		1.2			Sivaev & Goroško (1982)

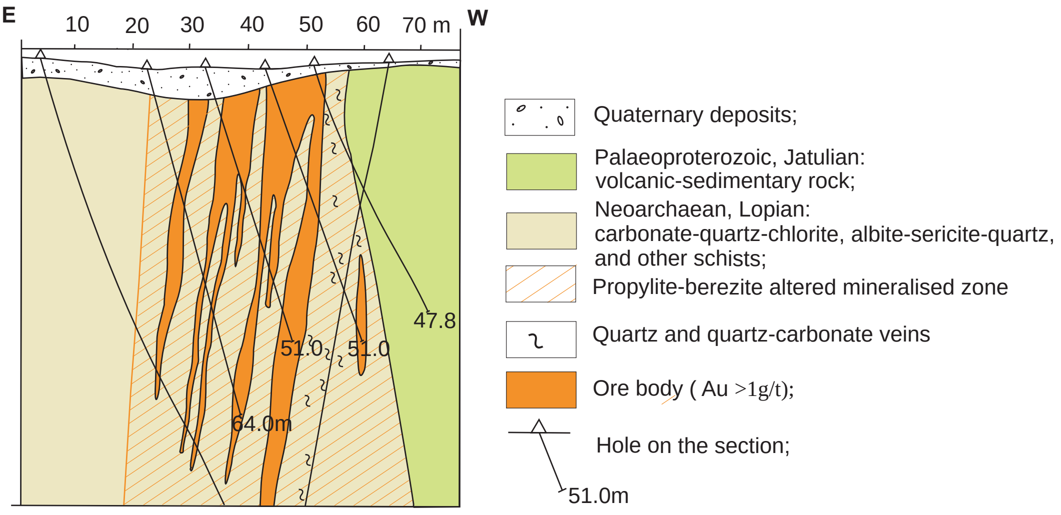


Figure 29. Section across the Pedrolampi deposit, located at 62.8°N, 33.683°E (Raw Mineral Base of the Republic of Karelia 2005).

R035 HAUTAVAARA-SHOTOZERO Au, Pb, Zn, Ta, Nb, Ni

Margarita Korsakova (SC Mineral)

The Hautavaara-Shotozero area (R035) is in the southern part of Central Karelia. It entirely covers the Archaean submeridional Hautavaara greenstone belt, includes small remnants of greenstones within TTG terrain in its eastern margins, and the northwestern margin of Ulialegi rapakivi granite massif in the south. In addition to the greenstones, Meso- and Neoarchaean peridotites to alkaline granites are widely present in area R035. The Mesoarchaean (mid-Lopian) Hautavaara greenstone belt has a complex, faulted structure caused by series of sublongitudinal and transversal faults as well as by the presence of the primary structures of the Archaean central volcanoes. The greenstones range from rhyolite through andesite and basalt to komatiite in composition. The volcanic rocks are intensely altered by metamorphic-metasomatic sulphidation, silicification, chloritisation, and carbonatisation.

The metallogenic area includes two small deposits, one potentially large deposit and seven showings, as classified in the FODD database (Table 18). The gold occurrences are hosted by rocks of variable composition, genesis and age. Nickel occurrences are present in mid-Lopian differentiated gabbro-peridotite massifs at **Hautavaara** and **Hursulskoe**. In the Hautavaara massif, there are thin lenses of Cu-Ni ore formed by liquation. The Hursulskoe Ni-Mg deposit has a complex genesis dominated by weathering processes. Lead-zinc ore has been detected at **Kainaoja** and **Detalnoe**. These are hosted by pyritic units in intermediate to felsic volcanic rocks and characterised by quartz-calcite veins and banded sulphide dissemination. Tantalum-niobium showings occur in late Lopian pegmatite dykes hosted by alkaline and subalkaline granites at **Vershinnoe** and **Vein Sluchainay**a, and in the Mesoproterozoic rapakivi granite at **Muzilampi**.

Table 18. Deposits and showings in the Hautavaara-Shotozero area (R035) included in the FODD database. All data are based on Sivaev and Goroško (1988).

Name	Au g/t	Ni %	Zn %	Pb %	Cu %	Ta %	Nb %	Ore tonnage (Mt)	Genetic type	Main host rocks
Hursula	8							1.25	Orogenic gold	Gabbroid
Njalmozero	3.9							2.56	Epithermal gold	Felsic tuffite
Tzentralnoe	5							0.8	Orogenic gold	Granite
Novye peski	10							1	Epithermal gold	Actinolite-clorite-epidote schist
Hautavaara		0.49	0.7		0.59			0.3	Magmatic	Serpentinite
Hursulskoe		0.4						1125	Polygenetic	Lizardite
Kainooja			2	2.48				0.89	Volcanic exhalative	Felsic volcanic rock
Detalnoe			14.8	1.2				0.3	Hydrothermal vein	Felsic volcanic rock
Vershinnoe						0.01		1.25	Granitic pegmatite	Pegmatite
Vein Slu-chainaja						0.015	0.015	3.3	Granitic pegmatite	Pegmatite
Muzilampi						0.0068	0.019	153	Granitic pegmatite	Rapakivi

R036 TULOMOZERO Zn, Pb, Fe

Margarita Korsakova (SC Mineral)

The small Tulomozero metallogenic area (R036) is in southeast of Central Karelia and covers a Palaeoproterozoic graben-syncline of the same name. The syncline is formed by Jatulian and Ludicovian sedimentary, volcanic and skarn rocks. Area R036 is immediately to the NE of the Salmi Rapakivi massif. Iron, zinc and lead-zinc occurrences are known within the area (Raw Mineral Base of the Republic of Karelia 2005, Feoktistov et al. 2007).

The **Tulomozero** Fe deposit is in carbonate-aleurolite strata and characterised by hematite ore with an average Fe content of 37.36%. More than 200 ore bodies with a length from 30 to 2400 m and an average thickness of 0.54 m have been detected. The ore reserve is 3.27 Mt. The deposit was mined in the 19th and the beginning of the 20th century. Processing of hematite ore was rather difficult and the cost of the produced cast-iron high. The **Kovat-Jarvi** Zn occurrence is related to skarn and is characterised by sphalerite-magnetite and magnetite ore bodies 53–208 m long and 0.31–7.9 m thick. The zinc content of the ore varies from 2.9 to 25.9%, averaging 9.75%, and the ore reserve is 6,510 tons of Zn. The **Fadein-Kel'ya** Pb-Zn deposit is characterised by carbonate-barite-quartz veins, propylite and beresite alteration, mylonitisation and shearing in granite and dolerite. The mineralised zones are 100–200 m long, 15.0–44.8 m thick, the Zn content is 0.35–12.45%, and Pb 0.2–7.11%.

R037 PULOZERO Au, Mo

Margarita Korsakova (SC Mineral)

The Pulozero metallogenic area (R037) is in Eastern Karelia, east of Lake Vygozero. It has an oval shape elongated in a northwesterly direction for 70 km and its width is 15–20 km. Area R037 covers the northern part of the Mesoarchaean Sumozero-Rybozero greenstone belt and comprises two narrow depressions divided by a ridge formed by Archaean granitoids. The mid-Lopian sequence in the depressions comprises metasedimentary and metavolcanic rocks of rhyolitic to komatiitic composition, felsic and intermediate dykes, a small granodiorite to granite porphyry, and anatectic granite intrusions. (Feoktistov et al. 2007)

Several processes of low-temperature metasomatism – beresitisation, sulphidisation, sericitisation, listvenitisation and others – commonly accompanied by shearing and cataclasis, occur widely in volcanic rocks and granitoids of area R037 (Kuleshevich 2006). No mineral occurrences with a resource estimate have been discovered in area R037, but there are numerous other indications of mineralisation. Panning of overburden has indicated the presence of molybdenite, chalcopyrite and gold. Gold and molybdenum and elements typically enriched in Au and Mo deposits (Bi, Pb, Ag, Cu) define regional and local lithogeochemical anomalies. In addition, gold mineralisation has been detected in haloes around small intrusions and granitic porphyry dykes. In such settings, the Au content is typically 0.1–0.2 g/t, but may reach 2 g/t within the granite bodies. A gold content of 0.1–0.7 g/t, locally up to 6.53 g/t Au, has also been detected in beresite and listvenite zones in volcanosedimentary rocks in the area. Another notable feature is that the geological structure of the Pulozero area has similarities with the Pjavaara-Lobash area (R026), where large Au and Mo deposits have been found (Kuleshevich et al. 2004a). Thus, in the Pulozero area, there are both direct and indirect signs of gold mineralisation. Such features are characteristic for greenstone belts, and this offers the possibility of discovering porphyry and volcanic exhalative types of mineralisation by conducting targeted exploration in the area.

R038 KAMENNOOZERO Ni, Zn, Cu

Margarita Korsakova (SC Mineral)

The Kamennoozero area (R038) is located in Eastern Karelia, in the Kamennoozero trough-shaped greenstone depression, which is the eastern branch of the Sumozero-Rybozero greenstone belt. The entire sequence of mid-Lopian, 2875–2995 Ma, volcanosedimentary formations is present here. Numerous small, late Lopian, differentiated intrusions of gabbro to peridotite in composition have intruded the sequence.

The main metallogenic potential of area R038 is in magmatic nickel deposits hosted by mafic-ultramafic intrusions, such as **Svetloozerskoe**, **Vostochno-Vozhma**, **Lebjazhinskoe**, and **Kumbuksinskoe** (Table 19; Fig. 30). In addition to intrusion-hosted occurrences, there also is nickel mineralisation in komatiites, as indicated by **Zolotoporozhskoe** and **Leschevskoe**. In the northern part of the area, there are the **Severo-Vozhma** Cu-Zn and **Verhne-Vozhma** Cu deposits, which are related to sulphide-rich strata in Lopian intermediate to felsic volcanic rocks (Fig. 31). Work conducted on the nickel deposits by the Finnish companies Outokumpu Mining Services and Kivijarvi Ltd has suggested that the presently available reserves of Cu-Ni ore are not enough for their profitable mining. However, exploration by a few Russian and foreign companies aimed to finding additional resources is continuing in the area.

Table 19. Deposits in the Kamennoozero area (R038) included in the FODD database.

Occurrence	Ni %	Cu %	Zn %	Co %	Au g/t	Ore tonnage (Mt)	Genetic type	Main host rock	References
Svetloozerskoe	0.79	0.2				5.18	Magmatic	Serpentinite	Tytyk et al. (1997)
Vostochno-Vozhma	0.8	0.22				3.095	Magmatic	Serpentinite	Tytyk et al. (1997)
Lebjazhinskoe	0.74	0.42				10.35	Magmatic	Serpentinite	Tytyk et al. (1997), Fedjuk (1998)
Kumbuksinskoe	0.7	0.26				20.83	Magmatic	Serpentinite	Fedjuk et al. (1984)
Ore body no. 4 of Vozhma massif	0.57					1.754	Magmatic	Serpentinite	Fedjuk (1998)
Leschevskoe	0.59					2.2	Magmatic	Komatiite	Furman (1989)
Zolotoporozhskoe	0.52					3.076	Magmatic	Komatiite	Tytyk et al. (1997)
Severo-Vozhma		0.28	1.7			1.52	Volcanic exhalative	Basaltic andesite	Tytyk et al. (1997)
Verhne-Vozhma		2.1				3.095	Volcanic exhalative	Sericite schist	Fedjuk et al. (1984)

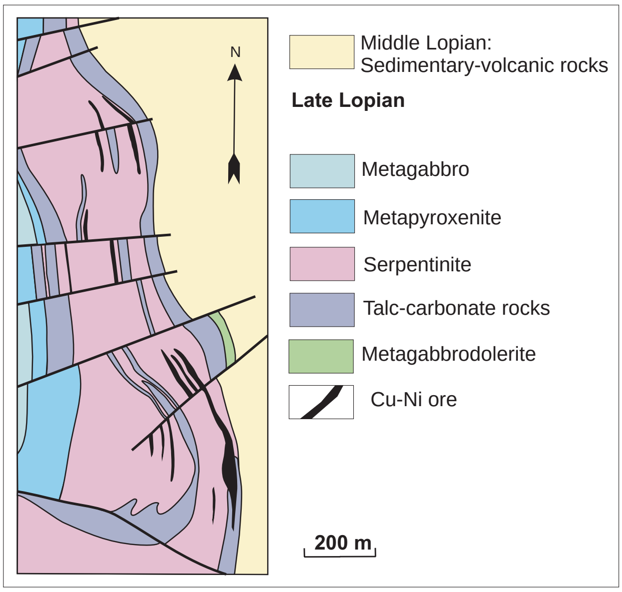


Figure 30. Geological plan of the Svetloozerskoe Cu-Ni deposit located at 63.17°N, 36.13°E (Raw Mineral Base of the Republic of Karelia 2005).

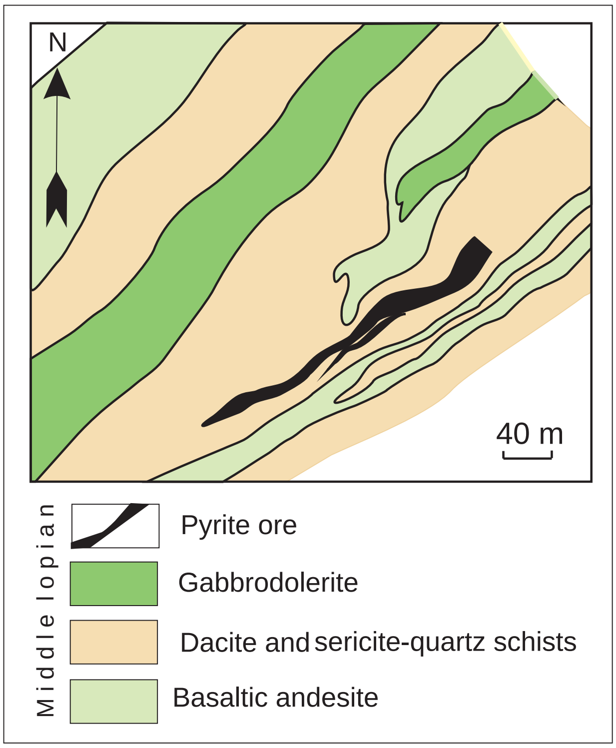


Figure 31. Geological plan of the Severo-Vozhma Cu-Zn deposit located at 63.3°N, 36.2°E (Raw Mineral Base of the Republic of Karelia 2005).

R039 SOUTH-VYGOZERO Au, Ni, Cr

Margarita Korsakova (SC Mineral)

The South Vygozero area (R039) is located in Eastern Karelia and covers the southern branch of the Sumozero-Rybozero greenstone belt. Neoarchaean (mid-Lopian, 2960–3054 Ma) volcanic rocks from rhyolitic to komatiitic in composition, and differentiated gabbro-diorite-plagiogranite and gabbro-peridotite intrusions occur in the area. The central part of area R039 is covered by Jatulian troughs and graben-synclines predominantly with metasedimentary rocks. North- and NW-trending faults and shear zones with beresite-listvenite alteration and sulphidic mineralisation are developed in the area.

All the Lopian sedimentary-volcanogenic formations altered under low-temperature conditions have potential for gold mineralisation. A similar gold potential is also present in all the plagioporphyry and granite porphyry dykes of the final phase of gabbro-diorite-plagiogranite intrusions, as well as in the late Lopian dacitic to rhyolitic dykes and sills (Judin & Vlasov 1991). There is also Cu-Ni mineralisation in komatiitic and basaltic volcanic rocks and gabbro-peridotite massifs (Table 20). In addition, Cr mineralisation is hosted by the mafic-ultramafic intrusions of the South Vygozero metallogenic area.

Two subareas of high potential for discoveries are distinguished in the area: Zalomaev (R039.1) in the west and Rybozero (R039.2) in the southwest. These subareas are defined by their high density of know deposits and other Au- and Ni-mineralised localities, extensive heavy mineral and geochemical anomalies, and abundant hydrothermally altered rocks (Feoktistov et al. 2007).

The most interesting locations for exploration in the area are the **Rybozero** gold deposits in the Rybozero subzone (R039.1), where the occurrences are in listvenitised, beresitised and silicified rocks of originally variable composition. Two ore bodies are distinguished: one 0.8–3.9 m thick and traced along the strike for 850 m and along the dip for 300 m, and another 0.8 m thick and traced along the strike for 300 m and along the dip for 150 m. At depth they pinch out. Gold occurs as both free grains and in pyrite. High contents of silver (up to 27 g/t) and arsenic (up to 0.76%) and increased Cu, Co, Bi, Te, Pb, Zn, Se, and Hg contents characterise these deposits (Judin & Vlasov 1991). Nickel deposits of area R039 are characterised by impregnated and streaky-impregnated types. The deposits occur as flat bodies with a length and width of a few hundreds of metres and a thickness of 1–15 m.

Table 20. The South Vygozero area (R039) included in the FODD database. Data from Judin & Vlasov (1991).

Occurence	Ni %	Au g/t	Cr %	Ore tonnage (Mt)	Genetic type	Main host rocks
Zalomaev subarea (R041.1)						
Severo-Konzhozerskoe	0.35			8	Magmatic Ni-Cu-PGE	Serpentinite
Juzhno-Konzhozero	0.38			4.2	Magmatic Ni-Cu-PGE	Serpentinite
Zalomaevskoe		8.5		2.35	Volcanic exhalative	Basalt
Vostochno-Zalomaevskoe		5.7		0.88	Epithermal gold	Biotite-quartz-feldspar schist
Lambozero-1	0.5			4	Magmatic Ni-Cu-PGE	Serpentinite
Rybozero subarea (R041.1)						
Rybozerskoe	0.38			5.26	Volcanic exhalative	Amphibole-mica schist
Zapadno-Rybozero	0.34			4.12	Volcanic exhalative	Amphibole-chlorite schist
Rybozero		3.0		6.67	Volcanic exhalative	Carbonate-chlorite-tremolite rock
Ladvozero			16	13	Mafic to ultramafic hosted Cr	Ultramafic plutonic rock

R040 VOLOSHOVO Ni, Cu, Au

Margarita Korsakova (SC Mineral)

The Voloshovo metallogenic area (R040) is located in the western Archangelsk oblast, which is in the southern part of the Kenozero greenstone belt, in the easternmost corner of the Fennoscandian shield. The area is mainly covered by mid-Lopian komatiitic and tholeiitic volcanic rocks with smaller areas of intermediate to felsic volcanic rocks and small bodies of gabbro-peridotite. All rocks of the area have been subject to shearing and hydrothermal alteration.

Within area R040 there is the potentially large **Voloshovskoe** Cu-Ni deposit and two small gold occurrences of **Svjatozero** and **Veshkozero**. Voloshovskoe is hosted by the three contiguous mafic-ultramafic intrusions with a total area of 5 km^2 where two types of Cu-Ni ore have been detected: 1) the dominant listvenite-hosted in the mafic to ultramafic rocks, and 2) a minor in altered basalt in the exocontacts of the massifs. The average Ni content of the ore is 0.7%, locally increasing to 2.3% (Korovkin et al. 2003). The Svjatozero gold occurrence is related to shear zones and beresite-listvenite alteration and to intermediate-felsic metavolcanic rocks in the exocontact of the massifs hosting the Voloshovskoe deposit. The Veshkozero gold occurrence is hosted by metabasalt in the exocontacts of Voloshovskoe massifs. The gold content of the occurrences is up to 1.2–3.0 g/t.

R041 ONEGA V, Ti, U, PGE, Cu, Au

Margarita Korsakova (SC Mineral)

The Onega area (R041) is in southeastern Karelia, close to the southern margin of the Karelian Craton, and represents the Palaeoproterozoic Onega riftogenic trough. It has a complex faulted structure with narrow, NW-trending, syn- and antiforms complicated by linear dislocation zones of folding and faulting. Fracturing and metasomatic alteration are genetically related to the dislocation zones, which are characterised by albitite, mica-carbonate rock and glimmerite (Savitzkii 1991, 1996).

Margins of the Onega trough are formed by Jatulian variegated basalt-carbonate-aleurolite-argillite-shungite and conglomerate-quartzite-sandstone sequences carrying Au and Cu mineralisation. Ludikovian picrite-basalt-carbonate-aleurolite formations with uranium-precious metal-vanadium-copper mineralisation occur in the anticlines. Kalevian flysch-like sandstone-aleurolite sequences with U and Cu mineralisation are present in the synclines. The supracrustal sequences are intruded by Ludikovian gabbro-dolerite sills and dykes of 1983–1984 Ma in age (Philippov et al. 2007) and by small gabbro-peridotite bodies. The former intrusions host titanomagnetite occurrences.

Within area R041 there are two large titanomagnetite, four medium-sized and three small uranium-precious metal-vanadium deposits, two small U, and two small Cu deposits (Table 21). In addition, two potentially large Cu deposits, one potentially large V deposit, and four polymetallic showings have been distinguished in the area. Practically all of the known occurrences are within the five metallogenic subareas marked in the metallogenic map: Povenetz (R041.1), Pydozhgorskaj (R041.2), Koikaryskaj (R041.3), Padma (R041.4) and West Onega (R041.5).

The most interesting location for industrial development is on the polymetallic **Pudozhgorskoe** deposit complex. There is vanadium-bearing titanomagnetite-platinoid mineralisation and uranium-precious metal-vanadium mineralisation in the locality. The V-Ti-Fe-PGE-Au deposit is confined to a layered sheet of gabbro-dolerite which has intruded into an Archaean granitoid in the northeastern margin of the Onega trough (Figs. 32 and 33). The ore body has a northwestern strike and it dips to the southwest at 15–20°. It has been traced along the strike for 25 km, and the thickness in the explored part of the intrusion varies from 130–180 m in the central parts to 40–50 m on the flanks. The intrusion is differentiated into two main zones: the lower gabbro and the upper diorite; the titanomagnetite ore occurs concordantly at the contact of these main zones. The ore is hosted by amphibole-rich gabbro-dolerite with a dense titanomagnetite dissemination forming 45–75 vol-% of the rock in the economic part and 25–45 vol-% in the margins. The prevailing thickness of the ore is 20–25 m (Fig. 33). The titanomagnetite ore has a liquation genesis and is of the early-magmatic segregation type. Besides titanomagnetite, the ore minerals include chalcopyrite, bornite, covellite, pyrite, sphalerite, galena, palladium tellurides (kotulskite, merenskyite, sop-

Table 21. Deposits and showings in the Onega area (R041) included in the FODD database. References are listed except where the data source is the Raw Mineral Base of the Republic of Karelia (2005).

Occurence	Fe %	Ti %	V %	PGE g/t	Pt g/t	Au g/t	Cu %	U %	Ore tonnage Mt	Genetic type	Host rock	References
Povenetz subarea (R041.1)												
Voronov Bor							1.3		0.777	Sedex	Quartzite	Golovanov (1994)
Vostochno-Povenetz							0.59		3.4	Volcanic exhalative	Basalt	
Pydozhgorskaj subarea (R041.2)												
Pudozhgorskoe	28.9	8.13	0.43	1.62		0.21	0.13		516.699	Magmatic	Dolerite	Trofimov & Golubev (2002)
Pelgozero	21.7	9.03	0.41						302	Magmatic	Gabbro-dolerite	Ganin & Loginov (2004)
Onezhskoe	16	2.3	0.23						2340	Magmatic	Gabbro-dolerite	Ganin & Loginov (2004)
Koikaryskaj subarea (R041.3)												
Koikarskoe		6							314.09	Magmatic	Dolerite	Trofimov & Golubev (2002)
Padma subarea (R041.4)												
Srednjaja Padma			2.35						4.59	Stratabound clastic hosted	Metasomatic rock	Petrov (1991)
Verhnjaja Padma			2.32					0.043	0.565	Stratabound clastic hosted	Siltstone	Petrov (1991)
Kosmozero			4.22						1.642	Stratabound clastic hosted	Siltstone	Petrov (1991)
Kovkozero			0.5						3.0	Stratabound clastic hosted	Siltstone	Petrov (1991)
Vesennee			3.09					0.046	2.66	Stratabound clastic hosted	Siltstone	Petrov (1991)
Tzarevskoe			2.33						3.378	Stratabound clastic hosted	Siltstone	Petrov (1991)
Velikogubskoe			0.5						0.6	Stratabound clastic hosted	Albite-carbonate rock	Petrov (1991)
Shulginovskoe			2.41						6.224	Stratabound clastic hosted	Siltstone	Petrov (1991)
West Onega subarea (R041.5)												
Lindolampi							7.9		1.65	Volcanic exhalative	Gabbro-dolerite	
Rudanskoe							1.3		13	Sedex	Sandstone	Sivaev & Goroško (1982)
Deposits outside subareas												
Pazhskoe					2.5				2.8	Magmatic	Tuffite	
Chornyi navolok						5			0.2	Clastic sedim. hosted	Quartz conglomerate	
Unitzkoe								0.161	1.242	Unconformity	Siltstone	
Ptitzefabrika								0.06	2.33	Stratabound clastic hosted	Quartzite	

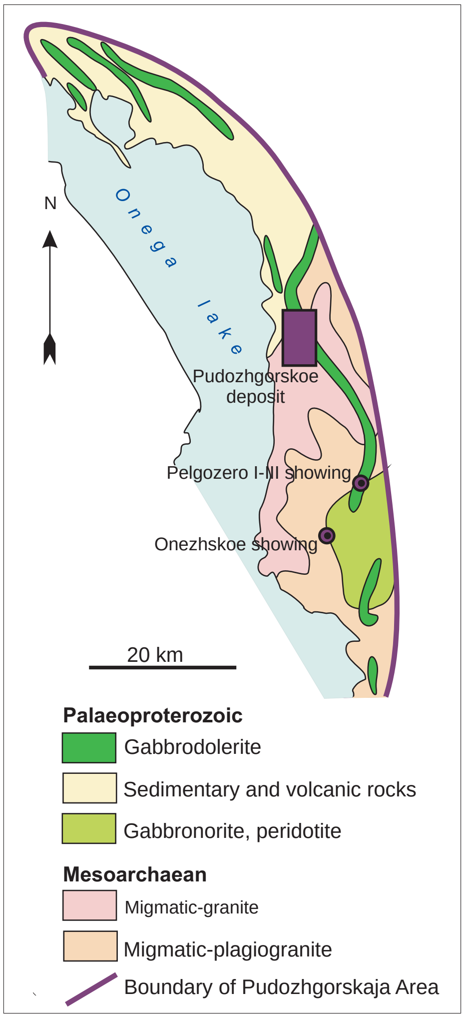


Figure 32. The Pudozhgorskaja subarea (from Feoktistov et al. 2007). The Onezhskoe showing is located at 62.04°N, 35.9°E.

cheite, keitkonite), sperrylite, and electrum. Gold-PGE mineralisation at Pudozhgorskoe is confined to the economic part of the titanomagnetite ore. The richest precious metal mineralisation (up to 2% PGE+Au) is associated with a weak sulphide impregnation (0.1–1 vol-%) and is persistent along the strike and dip of the ore. Up to the present, the deposit has not been exploited due to a lack of suitable technology for extraction of the metal association Ti, V, Fe, Pd, Pt, Au, and Cu.

Uranium-precious metal-vanadium deposits of the so-called Padma Group occur in the central part of the Onega trough. Structurally, all of the deposits are in steep strike-slip shear zones, at the contact between carbonate rock and aleurolite or shungite-bearing schists (Fig. 34). These zones are conjugated to cleavage cracks with pre- and synmineralisation alteration. Cleavage cracks are subperpendicular to rock bedding. The most vanadium-rich mineralisation is confined to the inner parts of the metasomatite. In addition to V, there are minor amounts of Ag, Au, Cu, Mo, Pd, Pt, and U in the mineralised zones.

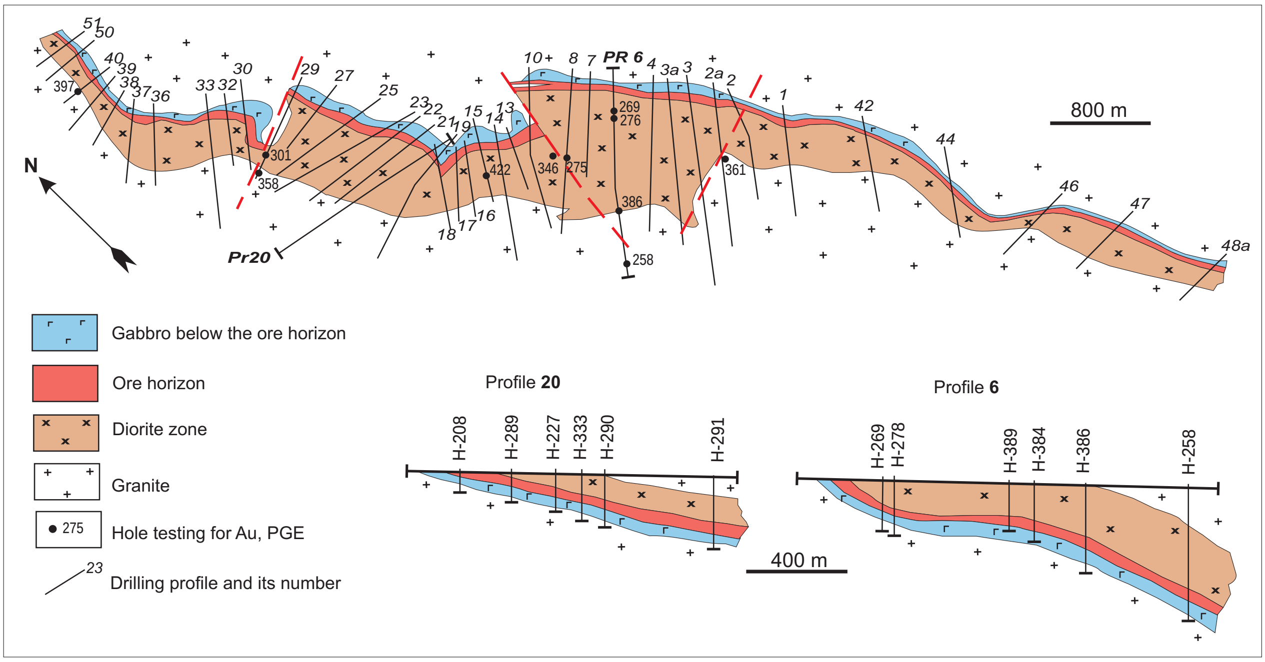


Figure 33. Geological map and cross sections of the Pudozhgorskoe V-Ti-Fe-PGE-Au deposit, located at 62.283°N, 35.9°E (from Golubev et al. 2001).

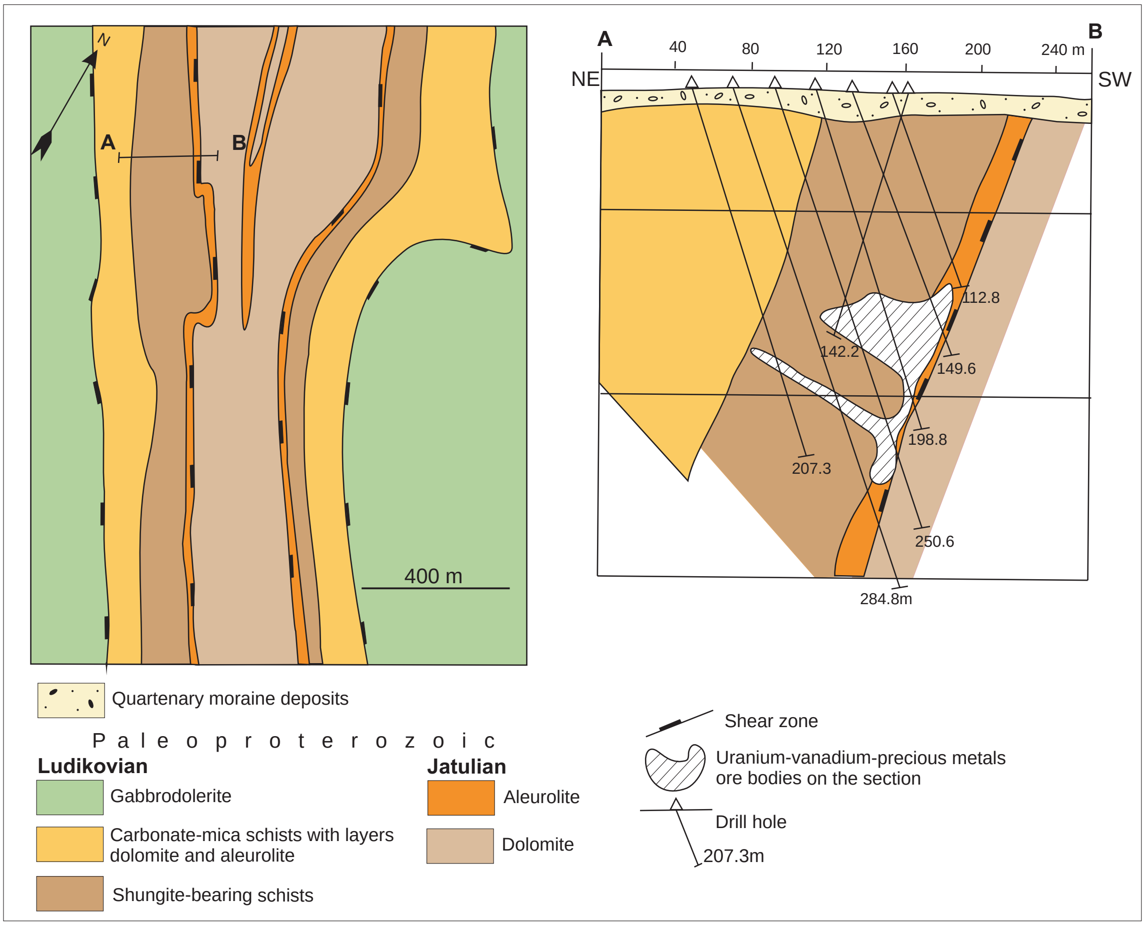


Figure 34. Local geology and a section across the Srednja Padma deposit, located at 62.366°N, 35.283°E (Raw Mineral Base of the Republic of Karelia 2005).

R042 NORTHERN LADOGA Sn-Zn-Pb, U, Au, W

Margarita Korsakova (SC Mineral)

The Northern Ladoga metallogenic area (R042) is in southwestern Karelia, in the southeastern part of the Ladoga-Bothnia suture zone between the main Archaean and Palaeoproterozoic domains of the Fennoscandian shield. In addition, Mesoproterozoic rifting and rapakivi magmatism characterises area R042. Archaean migmatite-granite domes of the area are overlain by an angular and stratigraphic unconformity by Jatulian and Ludikovian volcano-sedimentary formations. The latter are covered by extensive Kalevian flysch-like quartzite-sandstone-aleurolite-schist sequences. On the northern shore of Lake Ladoga, there is a Mesoproterozoic (mid-Riphean) trachybasalt-aleurolite-sandstone formation. Palaeoproterozoic plutons of Kalevian and Vepsian ages, with compositions from gabbro and syenite to granite, occur widely in the area. The eastern part of area R042 is dominated by the early Riphean Salmi rapakivi pluton with composition ranging from gabbro and anorthosite to granite. Calcareous and magnesian skarns, K feldspar and albite metasomatite, and greisens are common in the country rocks of the Salmi pluton.

A large number of metallic mineral deposits are known from the Northern Ladoga area (Table 22). The most important and economically promising occur in the subareas Janisjarvi (R042.1), Latvasurskaya (R042.2) and Pitkäranta (R042.3). All the known Sn and Sn-Zn occurrences are in the Pitkäranta subarea. Tin deposits are complex in composition, containing significantly enriched amounts of not just Sn, but also Zn, Ag, Cu, Fe, W, and rare metals such as indium. The number of ore bodies at **Pitkäranta** varies from 2–3 to 20–30 per deposit. The most common are tin and zinc ore bodies but, in places, there also are rare metal (with beryllium) and fluorite ore bodies. The ore bodies are flat in shape and occur concordantly with the host rocks. Their length and width varies from a few tens to a hundred metres and thickness from a few centimetres to 3–13 m.

The Latvasurskaya subarea (R042.2) is characterised by tungsten occurrences, but it also contains the **Mramornaya Gora** uranium deposit. The deposits are hosted by magnesian and calcic skarns. The tungsten occurrences are a few hundreds of metres long, but only rarely more than one metre thick. Practically all W is in disseminated scheelite in the skarns.

Gold showings in the Janisjarvi subarea (R042.1) are confined to intensely beresitised and propylitised small bodies and dykes of tonalite porphyry and to zones of shearing and beresitisation in Kalevian terrigenous rocks. In each occurrence, the ore zones contain impregnated and streaky-impregnated sulphides (arsenopyrite, chalcopyrite, pyrite) with native gold, galena, sphalerite, native silver, and bismuth minerals. The traced length of the mineralised zones is 1500–2500 m and their width 100–250 m.

Table 22. Deposits and showings in the Northern Ladoga area (R042) included in the FODD database.

Occurence	**Sn %**	**Zn %**	**Pb %**	**Au g/t**	**W %**	**U %**	**V %**	**Be %**	**Fe %**	**Ore tonnage Mt**	**Genetic type**	**Host rock**	**References**
Janisjarvi subarea (R042.1)													
Alattu				1						2.5	Epithermal gold	Tonalite	Stepanov (2004)
Janisjoki				1.64						6.7	Orogenic gold	Siltstone	Stepanov (2004)
Latvasurskaya subarea (R042.2)													
Latvasurskoe					1.13					0.295	Skarn	Pyroxene skarn	Venediktov & Fedjuk (1998)
Zapadno-Latvasurskoe					3.5					0.06	Skarn	Amphibolite	Venediktov & Fedjuk (1998)
Kommuna-rovskoe					0.9					0.1	Skarn	Pyroxene skarn	Venediktov & Fedjuk (1998)
Mensun-vaarskoe					1.5					0.07	Skarn	Pyroxene skarn	Venediktov & Fedjuk (1998)
Mramor-naya Gora						0.065				1	Skarn	Marble	Raw Mineral… (2005)
Pitkäranta subarea (R042.3)													
Jugo-Zapad-noe Lupikko	0.27	2.94						0.11		2.35	Skarn	Carbon-ate rock	Michailova (1985)
Hapunlampi	0.29									1.945	Skarn	Carbon-ate rock	Michailova (1985)
Hapunvaara	0.3	0.65								5.15	Skarn	Carbon-ate rock	Michailova (1985)
Kitelskoe	0.56	2.12								6.82	Skarn	Marble	Kudrjavzeva (1986)
Pitkäranta	0.52	3.8								46.16	Skarn	Marble	Artamonova & Duhuvskii (1989)
Ristiniemi		3								3.53	Skarn	Mica schist	Artamonova & Duhuvskii (1989)
Uksa	0.3	0.31						0.08		5.23	Skarn	Carbon-ate rock	Kudrjavzeva (1986)
Valkealampi	0.42	1.4	2.4							1.68	Skarn	Quartz-bio-tite schist	Artamonova & Duhuvskii (1989)
Deposits outside subareas													
Velimäki							0.61		15.5	130.4	Magmatic	Mica schist	Raw Mineral… (2005)
Leppjasjurja							0.27			118.5	Stratabound clastic hosted	Black schist	Artamonova & Duhuvskii (1989)
Karhu (Karkku)						0.132				5.3	Stratabound clastic hosted	Sandstone	Raw Mineral… (2005)

R043 BURAKOVKA Cr, Ni, Au, PGE

Margarita Korsakova (SC Mineral)

The Burakovka metallogenic area (R043) is located in southeastern Karelia, east of Lake Onega, within the Vodlozero granitoid block. The area occupies the northeastern part of the large 2449 Ma Burakova layered intrusion, which varies in composition from peridotite, pyroxenite and gabbro to norite. Area R043 covers two parts: Aganozero in the northeastern and Shalozero in the central part of the Burakova intrusion. There are two large metallic occurrences in area R043, the **Aganozero chromite** and the **Aganozero silicate nickel** deposits. There are also a few potentially large chromite and PGE deposits and a few apparently small PGE and gold occurrences (Table 23).

All chromite occurrences are confined to the Major Chromite Horizon, which is a sheet-like body occurring on the boundary between ultramafic and pyroxenite zones of the Burakova layered intrusion. The chromite units extend for tens of kilometres along their N-trending strike (Fig. 35), and with a true thickness varying from 0.7 to 6.3 m (Ganin & Loginov 2004). Nickel ore is confined to the dunite unit of the ultramafic zone in the central part of the Aganozero block. The productive unit is composed of hydrotalcite-lizardite serpentinites that have a higher (70–95%) content of acid-soluble Ni, Mg and Fe, metastability, porosity and electrical conductivity than other ultramafic rocks of the massif. In cross-section, the unit is a subhorizontal lens with complicated configuration and a thickness of more than 800 m (Goroško 1997). The PGE occurrences in the Burakova intrusion are confined to bands occupying distinct positions in the layered series of the massif. The thickness of these bands varies from 1 to 20 m, and their extent along strike is a few tens of kilometres (Ganin & Loginov 2004).

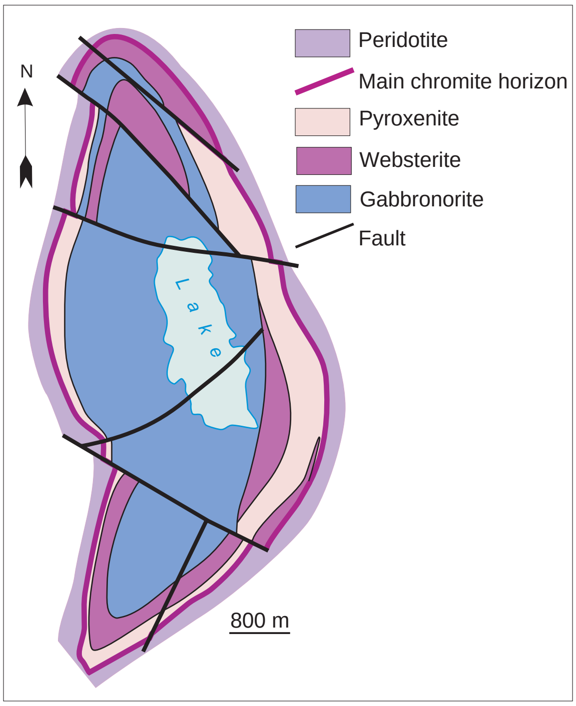


Figure 35. Geology of the Aganozero chromite deposit, located at 62.2°N, 36.516°E (Raw Mineral Base of the Republic of Karelia 2005).

Table 23. Deposits and showings in the Burakovka area (R043) included in the FOOD database. All data are from Ganin & Loginov (2004).

Occurence	**Ore tonnage (Mt)**	**Cr %**	**Ni %**	**PGE g/t**	**Au g/t**	**Mg %**	**Host rock**
Aganozero Cr	204.13	21.79		1.2	8.9		Websterite
Mezhjakozero	1.8	22			7.2		Peridotite
Shalozero Cr	245.5	15.9		0.18	0.06		Websterite
Aganozero silicate nickel (Aganozero nickel-bearing serpentinite)	2774		0.29			37	Serpentinite
Platinometal horizon “A” (Burakovskaya intrusion)	214			1.4			Gabbronorite
Horizon of banded subzone of Aganozero and Shalozero blocks	23.3			1.1	1.3		Gabbronorite
Hole no. 337	3.66				1.64		Peridotite
Gold-platinum horizon “B” Burakovka intrusion	22.65			0.6	2.49		Gabbronorite
Shalozero Au	0.845				7.1		Peridotite

R044 MATKALAHTA Ni

Margarita Korsakova (SC Mineral)

The Matkalahta metallogenic area (R044) is located in southeastern Karelia, in the southern part of the Archaean Vodlozero granitoid block. It is a narrow, riftogenic, N-trending greenstone belt formed by Neoarchaean (mid-Lopian), dominantly mafic to ultramafic volcanic rocks with minor intermediate and felsic units, intruded by small gabbro-peridotite intrusions. Area R044 has not been extensively studied, and no deposits with a resource estimate have been reported. Only one drill hole has intercepted a thin komatiite-hosted unit of Cu-Ni mineralisation with 2.4% Ni, 0.11% Cu, and 0.18% Co. This indication of mineralisation and the similarity of the Matkalahta greenstone belt with the mineralised Lopian greenstones of the Sumozero-Rybozero belt suggests that the Matkalahta area is an area of possible Ni(±Cu, Co) discoveries (Raw Mineral Base of the Republic of Karelia 2005).

REFERENCES

Afanas'eva, E. N. 1997. Otčet o rezultatah poiskov mestoroždenii zolota na Leževskoi ploščadi v Belomorskom i Kemskom raionah Karelii v 1996–1997 g.g. SZTGF. (in Russian)

Akhmetov, A. M., Voronyaev,a L. V. & Pavlov, V. A. 2004. Gold mineralization of the Yuzhno-Pechengskaya structural zone (Kola Peninsula), occurrence's types and mineable gold discovery perspectives. Regional'naya geologiya i metallogeniya. No. 20, 143–165. (in Russian)

Artamonova, N. A. & Duhuvskii, A. A. 1989. Geologičeskoe stroenie i poleznye iskopaeye Severo-Vostočnogo Priladožja. Otčet TGSZF. (in Russian)

Bakushin, E. M. 1983. Some geological features of Karikjavr Ni-bearing massifs (Kola Peninsula). Sovetskaya geologiya. No. 3. (in Russian)

Batieva, I. D. & Bel'kov, I. V. 1984. Sakharjok alkaline massif, it's rocks and minerals. Apatity: Kola Branch of Soviet Academy of Sciences press. 133 p. (in Russian)

Belolipetskyi, A. P., Britvin, S. N., Voloshin, A. V., Gordienko, V. V., Zozulya, D. R., Kozyreva, L. V., Kulakov, A. N., Mets, O. F., Petrov, S. I., Subbotin ,V. V., Subbotina, G. F., Torokhov, M. P. & Yakhonchuk, V. N. 1992. Rare metals mineralisation of the Kola metallogenic province. Preprint. Apatity. 50 p. (in Russian)

Bezrukov, V. I. 1985a. Otčet o provedenii obščih i detalnyh poiskovyh rabot na zoloto v Kolmozersko-Voroninskoi structure v 1982–1984 gg. Mončegorsk: FGU SZ FGI. 358 p. (in Russian)

Bezrukov, V. I. 1985b. Otčet o rezultatah tematičeskih rabot po ocenke perspektivnosti mestnoi mineralno-syrevoi bazy na tradicionnye dlja Murmanskoi oblasti rudnye I nerudnye poleznye iskopaemye. Mončegorsk: FGU TFI. 314 p. (in Russian)

Bogachev, A. I., Zak S. I., Safronova G. P. & Inina K. A. 1963. Geology and petrology of the Elet'ozero massif of gabbroid rocks of Karelia. Pud. RAS SSSR. L. 160 p. (in Russian)

Borisov, A. E. 1990. Volcanism and native copper mineralization in the Lower Proterozoic of the Kola Peninsula. Apatity: KSC AS USSR. 70 p. (in Russian)

Borisova, R. I., Leontev, A. I. & Korsunova, O. O. 2001. Otčet po sostavleniju komplekta kart geologičeskogo soderžanija masštaba 1:50 000 Kostomukšskogo železorudnogo raiona (listy Q-36-110-VG, Q-36-122-AB). 380 p. (in Russian)

Bussen, I. V. & Sakharov, A. S. 1972. Petrology of the Lovozero alkaline massif. Leningrad: "Nauka". 296 p. (in Russian)

Dmitriev, I. A. 1983. Otčet o rezultatah poiskovo-ocenocnyh rabot na učastke g. Polovinnaja. oz. Pinkeljavr v predelah severnoi železorudnoi zony. Apatity: FGU SZ FRI. 297 p. (in Russian)

Dodin, D. A., Chernyshev, N. M. & Iatzkevich, B. A. 2000. Platinum deposits of Russia. St. Petersburg: "Nauka". 755 p. (in Russian)

Dokuchaeva, V. S., Zhangurov, A. A. & Fedorov, Zh. A. 1992. Imandra intrusive geology and mineralisation. Sovetskaya geologia, N 10, 60–67. (in Russian)

Dudkin, O. B., Minakov, F. V., Kravchenko, M. P., Kravchenko, E. B., Kulakov, A. N., Polezhaeva, L. I., Pripachkin, V. A. & Pushkarev, J. D. 1984. Carbonatites of Khibiny. Apatity: Kola Branch of Soviet Academy of Science press. 97 p. (in Russian)

Dunaev, V. A. 1982. Kovdor deposit structure. Geology of the ore deposits 3, 28–36

Eilu, P., Bergman, T., Bjerkgård, T., Feoktistov, V. P., Hallberg, A., Korsakova, M. A., Krasotkin, S. J., Myradymov, G., Nurmi, P. A., Often, M., Perdahl, J.-A., Philippov, N. B., Sandstad, J. S., Stromov, V. A. & Tontti, M. 2009. Metallogenic map of the Fennoscandian Shield 1:2 000 000.

Eilu, P., Hallberg, A., Bergman, T., Feoktistov, V., Korsakova, M., Krasotkin, S., Lampio, E., Litvinenko, V., Nurmi, P. A., Often, M., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. 2010. Fennoscandian Ore Deposit Database. Updated 30 June 2010. Available at: http://en.gtk.fi/ExplorationFinland/fodd/.

Fedjuk, A. V., Morozov, S. A. & Furman, V. N. 1984. Otčet o detalnyh poiskah medno-nikelevyh rud v zone ležačego kontakta Vožminskogo i Kumbuksinskogo nikelenosnyh massivov (obekt Vostočnaja rudokontrolirujuščaja zona) za 1982–84 g.g. SZTGF. (in Russian)

Fedjuk, Z. N. 1998. Otčet o rezultatah poiskov dopolnitelnyh resursov medno-nikelevyh i medno-zinkovyh rud i drugih poleznyh iskopaemyh na učastke "Kivijiarvi" (Vožminskii obekt) 1995–97 g.g. SZTGF. (in Russian)

Feoktistov, V. P., Korsakova, M. A., Krasotkin, S. J. &

Stromov, V. A. 2007. Metallogeničeskaja karta rossiskoi časti Fennoskandinavskogo ŝčita 1:1 000 000. Otčet VSEGEI. 313 p. (in Russian)

Furman, V. N. 1989. Otčet o rezultatah poiskov mednonikelevyh rud, svjazanyh s komatiitami v Kostomukshskoj strukture za 1985–89 g.g. SZTGF. (in Russian)

Furman, V. N. 2001. Otčet o rezultatah poiskovyh i poiskovo-ocenočnyh rabot na zoloto, provedenyh v južnoi časti Kostomukshskoj železorudnoi struktury v 1988–2001g.g. "Sevzapgeologija". (in Russian)

Galkin, A. S., Dedjuhin, A. M., Kozyrev, S. M., Khashkovskaya, T. N. & Maksimov, V. I. 2001. Geological structure and composition of Sopcheozerskoe chromite deposit. Tzvetnye metally. #2. (in Russian)

Ganin, V. A. & Bondarev, A. P. 1983. Otčet o gruppovoi geologičeskoi semke i geologičeskomu doizučeniju masštaba 1:50 000 Elmozerskogo sinklinorija i ego obramlenija v Muezerskom, Medvežegorskom i Segežskom raionah KASSR, provedennyh v 1978–83 g.g. SZTGF. (in Russian)

Ganin, V. A. & Loginov, V. N. 2004. Otčet o rezultatah prognozno-poiskovyh rabot v predelah Burakovskogo rassloennogo intruziva i ego obramlenija. SZTGF.

Gavrilenko, B. V. & Kalinin, A. A. 1997. Mineralogical-geochemical aspects of gold and silver mineralization of Kola region. In: Gold and diamond mineralization problems of European Russia. Petrozavodsk: Karelian SC RAS press. (in Russian)

Goldberg, Ju. I. 1972. Otčet o detalnyh poiskovyh rabotah na nikel, provedennyh Allarečenskoi partiei v predelah Hihnajarvinskogo bloka v 1970–1972 gg. Apatity: FGU SZ FGI. (in Russian)

Golovanov, Ju. B. 1994. Geologičeskoe stroenie i poleznye iskopamye severo-vostočnogo kryla Onežskoi struktury i ee obramlenija. SZTGF. (in Russian)

Golubev, A. I., Trofimov, N. N., Petrov, S. V. & Filippov, N. B. 2001. Precions metals mineralisabion of Ti-Mgt ore of the Pudozhgorskoe deposit: technological characteristic, mineralogy. Geology and commercial minerals of Karelia, issue 4 Petrozavodsk, 48–62. (in Russian)

Gorbacheva, S. A. 2000. Otčet o rezultatah rabot na kompleks poleznyh iskopaemyh v zone soclenenija laplandskih granulitov i gneisov belomorskogo kompleksa v 1998–2000 gg. Monchegorsk: FGU SZ FGI. 412 p. (in Russian)

Gorbunov, G. I., Astaf'ev, J. A., Barten'ev, I. S., Goncharov, J. V. & Yakovlev, J. N. 1978. Structures of copper-nickel ore fields and deposits of the Kola Peninsula. Leningrad: "Nauka". 160 p.

Gorbunov, G. I., Bel'kov, I. V. & Makievskyi, S. I. 1981. Mineral deposits of the Kola Peninsula. Leningrad: "Nauka". 272 p.

Gorbunov, G. I., Zagorodnyi, V. G. & Robonen, V. I. 1985. Copper-nickel deposits of the Baltic Shield. Leningrad: "Nauka", 329 p.

Gorbunov, G. I., Astaf'ev, J. A., Goncharov, J. V., Korchagin, A. U., Neradovskyi, J. N., Smol'kin, V. F., Sokolov, S. V., Sharov, N. V. & Yakovlev, J. N. 1999. Copper-nickel deposits of Pechenga. M.; Pub. "Geos". 236 p. (in Russian)

Goroško, A. F. 1997. Otčet o rezultatah poiskovyh i poiskovo-ocenočnyh rabot na mestoroždenii nikelenosnyh serpentinitov v Pudožgorskom raione Respubliki Karelija, provedennyh v 1990–95 g.g. TGSZF. (in Russian)

Goryainov, P. M. 1976. Geology and genesis of the Kola Peninsula iron-silica formation. Leningrad: "Nauka". 147 p. (in Russian)

Grohovskaya, T. L., Laputina, I. P., Kuznetzov, G. S., Muravitskaya, G. N., Sokolov, S. V., Tel'nov, V. A. & Bol'shakov, A. N. 1996. Platinum-copper-nickel mineralisation of m. General`skaya layered intrusion. Geology of ore deposits 8 (3), 211–225. (in Russian)

Hugg, R. & Heiskanen, V. 1983. Suomen rautamalmiesiintymät, malmiutumat ja malmiviitteet. Rautaruukki Oy OU 2/79, RAETSU Report 8.2.1983. 412 p. (in Finnish)

Ivanov, N. M. & Korsakova, M. A. 2005. Otčet o rezultatah prognozno-poiskovyh rabot na zoloto po listam Q-35-XXX, Q-36-XXV, XXVI (Kostomukshskoj ploščad). "Sevzapgeologija". 320 p. (in Russian)

Ivanova, L. I. 1974. Otčet po sostavleniyu prognozno-metallogeničeskoi karty masštaba 1:200 000 na Li, Cs, Rb, Ta, Nb na Uragubsko-Kolmozerskoi zone pegmatitov I Kareka-Girvasskomu pegmatitovomu polju. FGU SZ FGI Monchegorsk. 347 p. (in Russian).

Judin, B. A. 1980. Gabbro-labradorite formation of the Kola Peninsula and its metallogeny. M.: "Nauka". 168 p. (in Russian)

Judin, B. A. 1987. Oxide iron-titanium ore of magmatic formations in Karelia and Kola Peninsula. Petrozavodsk: Karelia press. 213 p. (in Russian)

Judin, S. N. & Ščukin, O. N. 1981. Otčet po ocenke perspektif zolotonosnosti Lehtinskoi struktury i ee obramlenija, provedennoi Lehtinskim otrjadom v 1975–81 g.g. SZTGF. (in Russian)

Judin, S. N. & Ščukin, O. N. 1985. Otčet o gruppovoi geologičeskoi s'emke masštaba 1:50 000 Parandovo-Nadvoizkogo sinklinorija i ego obramlenija, provedennoi Nadvoizkim otrjadom v Belomorskom i Segežskom raionah KASSR v 1982–85 g.g. SZTGF. (in Russian)

Judin, S. N. & Vlasov, G. V. 1991. Otčet o rezultatah geologičeskogo doizučenija masštaba 1:50 000 s obščimi poiskami, provedennogo Južno-Vygozersoi partiei v 1986–91g.g. v Vostočnoi Karelii. SZTGF. (in Russian)

Klunin, S. F. 1994. Otčet o rezultatah poiskovyh rabot na blagorodnye metally s poputnymi poiskami almazov i drugih poleznyh iskopaemyh v predelah Olangskoi gruppy massivov, provedenyh v 1987–93 g.g. SZTGF (in Russian)

Klunin, S. F. & Paničev, V. F. 1988. Geologičeskoe stroenie i poleznye iskopaemye Panajarvinskoi zony i ee obramlenija. Otčet SZTGF. (in Russian)

Koistinen, T., Stephens, M.B., Bogatchev, V., Nordgulen, Ø., Wennerström, M. & Korhonen, J. (comp.) 2001. Geological map of the Fennoscandian Shield, 1:2,000,000. Geological Survey of Finland, Espoo: Erikoiskartat, 53. ISBN 951-690-818-7.

Korja, T., Tuisku, P., Pernu, T. & Karhu, J. 1996. Field, petrophysical and carbon isotope studies on the Lapland Granulite Belt: implications for deep continental crust. Terra Nova 8, 48–58.

Korovkin, V. A., Turyleva, L. V., Rudenko, D. G., Juravlev, A. V. & Kluchnikova, G. N. 2003. Mineral resources of the Northwest Russian Federation. Saint-Petersburg: VSEGEI Cartographic Factory. 519 p. (in Russian)

Korsakova, M. A. & Ivanov, N. M. 2001. State geological map of the Russian Federation (sheets Q-36-XV, XVI) Explanation note. 197 p. (in Russian)

Kozhevnikov, V. N. 2000. Archaean greenstone belts of the Karelian craton as accretionary orogens. Petrozavodsk: Karelian Research Center RAS. 223 p. (in Russian)

Krongaus, V. A. 1982. Otčet o rezultatah poiskovyh rabot na železnye rudy v vostočnoi časti Kostomukshskogo železorudnogo raiona za 1976–82 g.g. "Sevzapgeologija"

(in Russian)

Krongaus, V. A. 1983. Otčet o rezultatah poiskovyh rabot na železnye rudy v predelah Kostomukshskogo učastka za 1978–83 g.g. “Sevzapgeologija”. (in Russian)

Kudrjavzeva, M. F. 1986. Otčet o rezultatah poiskovyh i poiskovo-ozenočnyh rabot na Uksinskoi ploščadi, provedennyh v 1984–86 g/g/ TGSZF. (in Russian)

Kukharenko, A. A., Orlova, M. P., Bulakh, A. G. & Bagdasarov, E. A. 1965. Caledonian complex of ultramafic alkali rocks and carbonatites in Kola Peninsula. Moscow: Nedra. 550 p. (in Russian)

Kuleshevich, L. V. 2006. Evolution of the endogenous regimes of formation of gold mineralization in Karelia. Geology and commercial minerals of Karelia, issue 9. Petrozavodsk, 81–100. (in Russian)

Kuleshevich, L. V., Tytyk, V. M. & Korotaeva, N. N. 2004a. Geology and commercial minerals of Karelia, issue 7. Petrozavodsk, 111–126 p. (in Russian)

Kuleshevich, L. V., Tytyk, V. M. & Korotaeva, N. N. 2004b. Precambrian Lobash-I gold-base metal deposit, Karelia. Geology and commercial minerals of Karelia, issue 7. Petrozavodsk, 111–126. (in Russian)

Lahtinen, R., Korja, A. & Nironen, M. 2005. Palaeoproterozoic tectonic evolution. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds.) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 481–532.

Malyshev, V. P. 1985. Otčet po teme “Sostavlenie prognozno-metallogeničeskih kart na zeleznye rudy Karelo-Kolskogo regiona”. FGU SZ FGI, L. 305 p. (in Russian)

Metallogeny of Karelia 1999. Petrozavodsk: “Karelia”. 340 p. (in Russian)

Michailova, D. V. 1985. Otčet o rezultatah poiskovo-ozenočnyh rabot, provedennyh Uksinskoi partiei na učastke Jugo-Zapadnoe Ljupikko v Severnom priladože v 1982–85 g.g. TGSZF. (in Russian)

Moškov, E. I. 1982. Otčet o rezultatah detalnoi razvedki Korpangskogo mestoroždenija železnyh rud za 1977–81 g.g. “Sevzapgeologija”. (in Russian)

Nilsson, L. P. & Often, M. 2005. A summary report on the Ni-Cu-PGE occurrences and their host rocks in the Precambrian of Finnmark, Northern Norway. Norges geologiske undersøkelse Report 2005.085. 79 p.

Novikov, Ju. N. 1997. Otčet o resultatah poiskovyh i poiskovo-ozenočnyh rabot na zoloto v Zentralnoi Karelii na Elmusskoi pločšadi s podsčetom zapasov mestoroždenija Pedrolampi po kategorii C_2. SZTGF. (in Russian)

Osokin, A. S. 1987. Apatite-titanomagnetite-ilmenite ore’s position and composition in Gremyakha-Vyrmes massif. Apatity: Kola Branch of Soviet Academy of Science press. 90 p. (in Russian)

Petrov, Ju. B. 1991. Otčet Zentralno-Karelskoi partii o rezultatah poiskoyh (masštaba 1:10 000) i poiskovo-ocenočnyh rabot, provedenyh na Zaonežskoi i Unizkoi ploščadjah po geologiheskomy zadaniju 32–19 za 1988–90 g.g. Fondy GGP “Nevskgeologija”. (in Russian)

Philippov, N. B., Trofimov N. N. Golubev A. I. & Sergejev, S. A. 2007. Isotopic age data on the Koikary-Svjatnavolok and Pudozhgora sheeted intrusions. Geology and commercial minerals of Karelia, issue 9. Petrozavodsk. 49–69.

Popov, V. E. & Beljaev, K. D. 1974. Mednye mestoroždenija Baltiiskogo ščita i ih svjaz s vulkanizmom. IV IAGOD Symposium. Varna. (in Russian)

Pozhilenko, V. I., Gavrilenko, B. V., Zhirov, D. V. & Zhabin, S. V. 2002. Geology of ore areas of the Murmansk oblast. Apatity: Publ. of KSC RAS. 359 p. (in Russian)

Raw Mineral Base of the Republic of Karelia 2005. Karelia, Petrozavodsk. 278 p. (in Russian)

Rogozov, V. A. 1983. Otčet o rezultatah predvaritelnoj razvedki Južno- Korpangskogo učastka za 1980–83 g.g. s podsčetom zapasov po sostojaniju na 01.10.1983 g. “Sevzapgeologija”. (in Russian)

Rogozov, V. A. 1987. Otčet o rezultatah poiskovo-ocenočnyh rabot na podkarernyh gorizontah Kostomukshskogo mestoroždenija I prilegajužčei territorii za 1983–87 g.g. “Sevzapgeologija”. (in Russian)

Rundkvist, D. V. & Sokolova, V. N. 1985. Geology of sulphide copper-nickel deposits of the Canadian Shield. M., VIEMS. 61 p. (in Russian)

Savitzkii, A. V. 1991. Ocenka perspektiv Onežskogo rudnogo raiona na vyjvleniekrupnyh mestoroždenii kompleksnyh rud na osnove prognozno-metallogeničeskih issledovanii i sostavlenij komplekta prognoznyh kart masštaba 1:200 000. Fondy VSEGEI. (in Russian)

Savitzkii, A. V. 1996. Otčet po teme: “Ozenit perspektvy promyšlennoi platinonosnosti uglerodistyh formazii Prionežskogo raiona”. Fondy VSEGEI. (in Russian)

Ščukin, O. N. 1997. Infomacionnyi otčet o rezultatah operežajuščih gravimetričeskih rabot masštaba 1:50 000 i geohimičeskih poiskov masštaba 1:100 000 v predelah Gaikol’sko-Šombozerskogo sinklinorija i ego obramlenija v 1989–96 g.g. (in Russian)

Serba, B. I. 1962. The Sallanlatvi massif of alkaline rocks and carbonatites. In: “Magmatic formations of the Kola Peninsula”. Leningrad: AS USSR. 18 p. (in Russian)

Sivaev, V. V. & Goroško, A. F. 1982. Otčet po grunnovoi geologičeskoi semke i geologičeskomu doizučeniju masštaba 1:50 000 severo-zapadnogo kryla Onežskoi muldy i ee obramlenija, provedennyh v 1978–82 g.g. (Zentralnaja Karelija) SZTGF. (in Russian)

Sivaev, V. V. & Goroško, A. F. 1988. Geologičeskoe stroenie i poleznye iskopaemye Uljalegskogo massiva granitov rapakivi i ego obramlenija. Otčet o resultatah geologičeskoi semke masštaba 1:50 000 s srednemasštabnogo geologičeskogo kartirovanija, provedennyh Vedlozerskoi partiei v 1983–88 g.g. v Južnoi Karelii. SZTGF. (in Russian)

Šramko, G. M. 1977. Otčet o rezultatah poiskovo-ocenočnyh rabot v predelah Zapadnoi častei Kostomukshskogo rudnogo polja, provedenyh v 1974–76 g.g. “Sevzapgeologija”. (in Russian)

Stepanov, K. I. 2004. Otčet po teme: “Proizvodstvo poiskovyh pabot v predelah Sortavalskoi ploščadi (poiski mednonikelevyh, polimetalličeskih i zolotorudnyh mestoroždenii. TGSZF. (in Russian)

Stromov, V. A. 1987. Prognoznaya očenka nikelenosnosti Pečengskogo rudnogo polja na osnove paleorekonstrukcii. Otčet. Fondy FGUP VSEGEI, L. 231 p. (in Russian)

Subbotin, V. V. 1990. Structural control and mineral zonality of rare metals mineralisation of Vuorijarvi massif. In: “Alkaline magmatism of northeastern part of the Baltic Shield”. Apatity: KSC RAS, 76–78. (in Russian)

Timofeev, V. G., Filimonov, A. G., Lavrov, B. S., et al. 1983. Otčet o rezultatah aerofotogeologičeskogo kartirovanija masštaba 1:50 000 Vostočno-Karelskoi strukturnoi zony i ee obramlenija v 1974–83 g.g. (in Russian)

Trofimov, N. N. & Golubev, A. J. 2002. Otčet o naučno-issledovatelskoi rabote po “Ozenke perspektiv novyh istočnikov elementov platinovoi gruppy (EPG) v Respublike Karelija” v 1997–2002 g.g. Fondy Kar. Geologičeskogo institute. (in Russian)

Tuisku, P., Mikkola, P. & Huhma, H. 2006. Evolution of migmatitic granulite complexes: implications from Lapland Granulite Belt, Part 1: Metamorphic geology. Bulletin of the Geological Society of Finland 78, 71–105.

Tytyk, V. M. 1991. Otčet Belomorskoi partii o rezultatah predvaritel'noi razvedki mestoroždenija Lobaš, provedenoi v 1988–1991 g.g. SZTGF. (in Russian)

Tytyk, V. M. 1998. Otčet o rezultatah poiskovyh i poiskovo-ocenočnyh rabot na zolotorudnom mestoroždenii Lobaš-I, provedenyh v 1992–97 g.g. SZTGF. (in Russian)

Tytyk, V. M., Vlasov, G. V. & Fedjuk, Z. N. 1997. Otčet o rezultatah geologorazvedočnyh rabot I etapa (predvaritelnaja razvedka), provedennyh na Lebjažinskom, Svetloozerskom, Vostočno-Vožminskom i Zolotoporožskom medno-nikelevyh i Severo-Vožminskom medno-zinkovom mestoroždenijah v Segežskom i Medvežegorskom raionah RK po dogovoru s Tekobankom v 1990–1994 g.g. "Obekt Kivijiarvi". SZTGF. (in Russian)

Vartiainen, H. 1980. The petrography, mineralogy and petrochemistry of the Sokli carbonatite massif, northern Finland. Geological Survey of Finland, Bulletin 313. 126 p. (in Russian)

Venediktov, N. N. & Fedjuk, A. V. 1998. Materialy po ozenke i ucetu prognoznyh resursov tverdyh poleznyh iskopaemyh Respubliki Karelija po sostojaniju na 01.01.98 g. TGSZF. (in Russian)

Voronyaeva, L. V. 2008. Geologija i zolotonosnost Južno-Pečengskoi strukturnoi zony. Avtoreferat dissertacii na soiskanie učenoi stepeni kandidata geologo-mineralogičeskih nauk. 30 p. (in Russian)

Yakovlev, J. N., Yakovleva, A. K., Balabonin, N. L. & Orsoev, D. A. 1979. Copper-nickel ores of granulite complex. Leningrad: "Nauka". 208 p. (in Russian)

Zak , S. I., Kamenev E. A., Minakov F. V., Armand A. L., Mikheichev A. S. & Petersil'e, B. A. 1972a. Khibiny alkaline massif. Leningrad: "Nedra". 176 p. (in Russian)

Zak, S. I., Kochnev-Pervukhov, V. I. & Proskuryakov, V. V. 1972b. Ultramafic rocks of Allarechka region, it's metamorphism and mineralization. Petrozavodsk: Karelia press. 130 p. (in Russian)

Mineral deposits and metallogeny of Fennoscandia
Edited by Pasi Eilu
Geological Survey of Finland, Special Paper 53, 397–401, 2012

MAIN METALLOGENIC EVENTS IN FENNOSCANDIA: SUMMARY

Lahtinen, R., Hallberg, A., Korsakova, M., Sandstad, J. S. & Eilu, P. 2012. Main metallogenic events in Fennoscandia: summary. *Geological Survey of Finland, Special Paper 53*, 397–401, 1 table.

Keywords (GeoRef Thesaurus, AGI): metallogeny, metal ores, tectonics, Paleozoic, Proterozoic, Archean, Fennoscandia

Raimo Lahtinen, Pasi Eilu
Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland

Anders Hallberg
Geological Survey of Sweden, P.O. Box 670, SE-751 28 Uppsala, Sweden

Margarita Korsakova
State Company Mineral, Detskaya str., 26 liter A office 4H, 199106 St. Petersburg, Russia

Jan Sverre Sandstad
Geological Survey of Norway, P.O. Box 6315 Sluppen, 7491 Trondheim, Norway

Fennoscandia is the most important metal mining district of Europe and has been so for a long time. Most types of ore known to the world are present and intense exploration continues to add to the known mineral wealth of the region. Metallogenic areas within Fennoscandia are geographically rather evenly distributed, although variable in age and importance. Below, we summarise the main metallogenic events in Fennoscandia, with examples in Table 1. This overview is based on the FODD database with explanation book (Eilu et al. 2009) and discussions in Grenne et al. (1999), Weihed et al. (2005, 2008) and Lahtinen et al. (2011).

Mineable **Archaean** banded iron formations (e.g. Kostomuksha, Bjørnevatn) occur, and a number of small orogenic (and intrusion-related?) gold occurrences have been identified (e.g., Pampalo). Unlike some other Archaean areas, komatiite-hosted nickel-copper sulphide deposits are rare, and significant volcanogenic massive sulphide deposits are not known from the Archaean supracrustal belts of Fennoscandia.

The **Palaeoproterozoic** rifting stages of the Archaean continents in northern and eastern Fennoscandia have included the intrusion and extrusion of large volumes of mafic-ultramafic magmas, now seen in abundance associated with occurrences of layered intrusion-, intrusion- and some komatiite-hosted ore deposits. These deposits vary from sulphide-poor Cr, V-Ti-Fe and PGE producing systems to more sulphide-rich Ni-Cu-PGE systems. Major metal mineralisation peaks are at 2.44 Ga, 2.05 Ga and 2.0 Ga, where the last event includes the famous Pechenga Ni-Cu deposits (1.98 Ga). A number of skarn iron ore deposits, hosted by carbonate rocks, and black schists within volcaniclastic rocks, were also formed during this epoch. The significant new greenfield discovery of the Sakatti Cu-Ni-PGE deposit south of Kevitsa in Finnish Lapland shows that northern Fennoscandia is still fertile territory for new discoveries of rift-related deposits.

The 2.44 Ga layered intrusions are probably related to a failed rift and thus can be classified as intra-cratonic. Many of the 2.1–2.0 Ga deposits also are intra-cratonic in nature, although they show affinity to asthenosphere-derived mantle melts. The systems related to bimodal alkaline magmatism during craton break-up at ca. 2.05 Ga produced REE-Nb mineralisation. While the age of the very large black shale-hosted Talvivaara Ni-Zn-Co-Cu deposit is not known, it forms a unique deposit class of its own. Sedimentary exhalative or red bed-type Cu and VMS-type deposits have been found related to sag and rift phases, respectively. The Outokumpu-type deposits have a VMS-type (Co-Cu-Zn) proto-ore, formed at 1.95 Ga, but strongly modified during deformation at ca. 1.90 Ga. The Outokumpu-type Ni ores were formed during metamorphism. Some intracratonic U occurrences have been found, but none yet in mineable sizes.

The VMS districts in Fennoscandia are among the most important Palaeoproterozoic VMS-districts in the world. Deposits were formed in intra-arc extensional settings prior to basin inversion and accretion. The arc settings vary from primitive, bimodal arc complexes at 1.92 Ga (Pyhäsalmi) to the 30 million years younger Skellefte district deposits mainly formed in mature arc crust. The VMS deposits in the Bergslagen area, south-central Sweden, are similar in age to the Skellefte deposits but formed in a continental margin back-arc setting. In the Bergslagen area, a large number of economically important iron ores, mostly carbonate replacement (skarn iron ores), were also formed at this time. The economically important group of Fe-apatite ores (Kiruna, Grängesberg) formed at this time, too, in two restricted areas in northern and south-central Sweden, respectively. The northern Palaeoproterozoic part of Fennoscandian is also host to porphyry copper (Aitik) and IOCG deposits.

Palaeoproterozoic orogenic gold deposits formed at syn- to post-peak metamorphism and their timing reflects the complex orogenic evolution of Fennoscandia (Lahtinen et al. 2005). Svecofennian orogenic Ni-Cu deposits are related to mafic–ultramafic rocks intruded during transpressional collisional phases along linear belts at the margins of microcontinents. Late- to post-collisional stages include intrusion of Ti-P rich mafic magmas, pegmatites and carbonatites with minor rare-metal mineralisation.

The **Palaeo- to Mesoproterozoic** transition in Fennoscandia included the intrusion of 1.65–1.47 Ga rapakivi granites, and the Gothian (1.64–1.52) and Telemarkian accretionary events (1.52–1.48 Ga) without the formation of any significant ore deposits. Several minor Cu (Au, Ag) and Co occurrences are known in the pre-Sveconorwegian supracrustals (1.34–1.14 Ga). Similarly, the rocks formed during the Sveconorwegian orogeny (1.14–0.97 Ga) have almost no known mineralisation, except the large volumes of post-collisional anorthositic magmas hosting major Ti deposits (e.g. Tellnes) and minor synorogenic Mo deposits. Stratabound Mesoproterozoic U mineralisation is found in unmetamorphosed Mesoproterozoic sandstone in the Ladoga region, Russia.

Table 1. Main metallogenic events in Fennoscandia.

Metallogenic event and geotectonic setting	**Main metal association**	**Deposit type**	**Deposit examples**	**Metallogenic area examples**
Archaean				
2.9–2.8 Ga supracrustal belts	Fe, Ag-Zn, Ni	BIF, Epithermal, Komatiitic	Kostomuksha, Bjørnevatn, Taivaljärvi, Vaara	F030, F032, F047, N040, R028
2.9–2.7 Ga granitoids	Mo	Porphyry	Mätäsvaara, Lobash	R011, R026
2.7 Ga collision	Au, Li, Be	Orogenic gold, Granitic pegmatite	Pampalo, Taloveis, Polmostundrovskoe	F023, F032, F034, R011, R022, R028, R034
Palaeoproterozoic cratonic to rift stages of the Archaean continents				
2.50–2.44 Ga rifting	Cr, PGE-Ni-Cu, V-Ti-Fe	Layered intrusion	Kemi, Aganozero, Ahmavaara, Fedorovotundra, Mustavaara	F035, F036, F045, R002, R012, R014, R043
2.4–2.0 Ga cratonic / incipient rifting	Ni-Co-Zn, V, Cu	Black shale-hosted, SEDEX, Sediment-hosted	Talvivaara, Kovadjarv, Rudanskoe, Nussir	F029, F037, F038, N039, R036, R041
2.1–2.05 Ga rifting	Ni-Cu-PGE, V-FE-Ti, Cu-Zn, REE-Nb	Mafic-ultramafic intrusion, VMS, Alkaline intrusion	Kevitsa, Otanmäki, Viscaria, Eletozero	F021, F031, F045, F048, N037, R023, S037
2.1–2.05 Ga rifting?	Fe-(Cu)	Replacement (skarn)	Tapuli	S034
2.0 Ga rifting	Ni-Cu	Magmatic Ni-Cu	Pechenga	R002
1.95 Ga rifting	Co-Cu-Zn	VMS	Outokumpu (Keretti)	F020
1.8(–0.4) Ga cratonic	U	Unconformity U	Paukkajanvaara	F022
Palaeoproterozoic subduction-related				
1.93–1.90 Ga arcs	Zn-Cu	VMS	Pyhäsalmi, Vihanti	F028
1.91–1.88 Ga arcs; volcanic	Zn-Cu-Pb, Au, Fe	VMS, Epithermal, Replacement (skarn)	Kristineberg, Falu mine, Garpenberg, Zinkgruvan, Boliden, Dannemora	F001, F004, R042, S008, S009, S023
1.91–1.88 Ga arcs; plutonic	Fe-P, Cu-Au, Au	Kiruna-type, Porphyry, Epithermal, IOCG	Kirunavaara, Grängesberg, Aitik, Orivesi, Jänisjoki	F009, F026, N038, R042, S009, S033, S035
Palaeoproterozoic collisional				
1.91–1.90 Ga	Au, Ni-Co	Orogenic gold, Outokumpu-type Ni	Kittilä, Vorgovyi, Vuonos	F020, F043, R018
1.89–1.88 Ga	Au, Ni-Cu	Orogenic gold, Mafic-ultramafic intrusion	Bidjovagge(?), Pahtohavare(?), Björkdal, Vammala, Kotalahti	F006, F007, F015–F018, F027, N036, S037, S041
1.82–1.79 Ga	Au, Cu-Au, Fe	Orogenic gold, IOCG	Satulinmäki, Hannukainen	F004, S034

Table 1. Continued. Main metallogenic events in Fennoscandia.

Metallogenic event and geotectonic setting	**Main metal association**	**Deposit type**	**Deposit examples**	**Metallogenic area examples**
Palaeoproterozoic late- to post-collisional				
1.88–1.85 Ga	Ti-V	Mafic intrusion	Koivusaarenneva	F011, F025
1.79–1.77 Ga	Li, Nb-Ta-Be, REE-Pb	Pegmatite, carbonatite	Länttä, Rosendal, Korsnäs	F002, F005, F008, F024
1.68–1.62 Ga	Fe-Ti-V, Ni-Cu	Mafic-ultramafic intrusion	Rødsand, Espedalen	N019, N017
Meso- to Neoproterozoic				
1.6–1.14 Ga cratonic, continental margin	U, Cu, Co, Ni-Cu	Sediment-hosted, Mafic-ultramafic intrusion	Karkku, Ertelien, Skuterud	N004–N007, N009–N010, N012, R042
1.14–0.97 Ga collisional	Mo, Ni-Cu	Mafic intrusion, Felsic intrusion	Knaben, Flåt	N002–N003
Post-collisional 960–920 Ma	Fe-Ti-V	Mafic intrusion	Tellnes	N001
Neoproterozoic rift + passive margin	Zn-Pb-Cu, Fe, V-U-Mo, Nb-P-Fe	VMS, Sedimentary Fe, Shale-hosted, Carbonatite	Mofjell, Bleikvassli, Rana, Sylarna, Häggån, Fen	N028–N029, N034, S016
Phanerozoic				
500–430 Ma passive margin	V-U-Mo	Black-shale hosted	Myrviken, Tåsjö	S017
500–475 Ma island arcs and ophiolites	Zn-Cu, Cu-Zn, Fe-Cu, Ni-Cu-PGE	VMS, Ophiolite	Stekenjokk, Løkken, Joma, Fosdalen, Karmøy	N014–N015, N020–N025
435–440 Ma intraorogenic phase, mafic intrusives, ophiolites	Ni-Cu, Cu-Zn	Mafic-ultramafic intrusion, VMS	Råna, Sulitjelma, Vaddas	N032, N030, N035
430–390 Ma collisional orogeny	Pb, Ti, Au	Sandstone-hosted/metamorphic, Metamorphic, Orogenic gold	Engebøfjellet, Kolsvik, Laisvall	N016, N026, S025
post-collisional 400–360 Ma	REE, Nb, Fe, Zr	Alkaline intrusion, Ultramafic-alkaline intrusion, Carbonatite	Umbozero, Kovdor, Sokli	R013
300–240 Ma rifting; Oslo Rift	Mo, Ag	Porphyry, Hydrothermal vein	Nordli, Kongsberg	N011, N008

In **Neoproterozoic to Palaeozoic** times, the opening of the Iapetus Ocean (ca. 600 Ma) included the development of an Atlantic-type passive margin in Fennoscandia. This stage produced some stratabound-stratiform VMS Zn-Pb-Cu and sedimentary Fe ores (Rana) followed by deposition of bituminous alum shales, which now host large but low-grade V-U-Mo deposits. Arcs and marginal basins formed either outboard of the present Fennoscandia (Baltica plate) or on the Laurentian side of the Iapetus Ocean. Abundant Zn-Cu, Cu-Zn and Fe-Cu VMS deposits, with some PGE occurrences in ophiolites, and Cu-Ni-(PGE) deposits related to boninitic intrusions have been found in these arc and marginal basin settings. During initial collision, intrusion-related Ni-Cu deposits and Cu-Zn VMS deposits formed in a transtensional environment. At some time between the early Cambrian (age of host rocks) and mid-Silurian to early Devonian (faulting of mineralised rocks), the formation of a sandstone-hosted Pb deposit (Laisvall) took place.

The final Palaeozoic continent-continent collision occurred during the Scandian orogeny (ca. 430–390 Ma) and produced metamorphic rutile deposits in eclogites (Engebøfjellet). Palaeozoic post-collisional alkaline rocks are widespread in the NE part of Fennoscandia (especially in Kola), and have a good potential for Ti and rare metals (REE, Nb-Ta).

The last major metallogenic event is the Permian Oslo Rift (300–240 Ma), when porphyry Mo deposits (Nordli) were formed in alkaline to peralkaline granitic rocks. The Ag-rich calcite veins at Kongsberg are also related to this magmatic-hydrothermal event.

REFERENCES

Eilu, P., Bergman, T., Bjerkgård, T., Feoktistov, V., Hallberg, A., Ihlen, P. M., Korneliussen, A., Korsakova. M., Krasotkin, S., Muradymov, G., Nurmi, P. A., Often, M., Perdahl, J.-A., Philippov, N., Sandstad, J. S., Stromov, V. & Tontti, M. (comp.) 2009. Metallogenic Map of the Fennoscandian Shield, 1:2 000 000. Espoo: Geological Survey of Finland, Trondheim: Geological Survey of Norway, Uppsala: Geological Survey of Sweden, St. Petersburg: The Federal Agency of Use of Mineral Resources of the Ministry of Natural Resources and Ecology of the Russian Federation.

Grenne, T., Ihlen P. M. & Vokes, F. M. 1999. Scandinavian Caledonide Metallogeny in a plate tectonic perspective. Mineralium Deposita 34, 422–471.

Lahtinen, R., Korja, A. & Nironen, M. 2005. Palaeoproterozoic tectonic evolution. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield. Developments in Precambrian Geology 14. Amsterdam: Elsevier, 481–532.

Lahtinen, R., Hölttä, P., Kontinen, A., Niiranen, T., Nironen, M., Saalmann, K. & Sorjonen-Ward, P. 2011. Tectonic and metallogenic evolution of the Fennoscandian shield: key questions with emphasis in Finland. In: Nenonen, K. & Nurmi, P. A. (eds) Geoscience for society: 125th anniversary volume. Geological Survey of Finland, Special Paper 49, 23–33.

Weihed, P., Arndt, N., Billström, C., Duchesne, J. C., Eilu, P., Martinsson, O., Papunen, H. & Lahtinen R. 2005. Precambrian geodynamics and ore formation: the Fennoscandian Shield. Ore Geology Reviews 27, 273–322.

Weihed, P., Eilu, P., Larsen, R. B., Stendal, H. & Tontti, M. 2008. Metallic mineral deposits in the Nordic countries. Episodes 31, 125–132.

www.gtk.fi
info@gtk.fi

This book is the first ever compilation of mineral deposits and metallogenic areas in Fennoscandia. It describes the major metal deposits and all metallogenic domains in Norway, Sweden, Finland and NW Russia. Deposits and metallogenic areas defined by the following metals are included: Ag, Au, Be, Co, Cr, Cu, Fe, Li, Mn, Mo, Nb, Ni, Pb, Pd, Pt, Rh, REE, Sc, Sn, Ta, Ti, U, V, W, Y, Zn, and Zr. The metallogenic areas are tracts of probable future metal ore discoveries in northern Europe. The publication can be used in selecting strategic areas for mineral exploration and for research in economic geology. It also is an instrument for land-use planning and political decision-making. Thereby, it acts as a tool for fulfilling the requirements set by the raw materials policy of the European Union and by the countries in the region. This is a joint product of the geological surveys of Finland, Norway, Russia (VSEGEI and SC Mineral) and Sweden.

ISBN 978-952-217-174-0 (paperback)
ISBN 978-952-217-175-7 (PDF)
ISSN 0782-8535
9 789522 171740