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MINERAL RESOURCES IN THE ARCTIC

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MINERAL RESOURCES IN THE ARCTIC

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PREFACE

Morten Smelror

The Arctic is one of Earth's few remaining frontier areas. This huge area contains some of the largest known provinces of natural resources, including world-class petroleum-bearing basins, metallogenic provinces and mineral deposits, among them several of the world's largest diamond mines. Major new discoveries are still being made in the Arctic, both beyond the regions that are already well known and within provinces where there are already operating mines, where the use of modern exploration methods has revealed "new" ore bodies underneath surface Quaternary deposits or at greater depths in the Earth's crust. Increasing focus on, and development of the Arctic region creates a rapidly growing need for effective assessment of the resource potential of the region. Such an assessment must be based on compilation and evaluation of updated knowledge of the geology of prospective areas and of known deposits.

The Geological Survey of Norway (NGU) held an informal dialogue about possible implementation of a mineral resource project in the Arctic with potential partners in the course of 2011. Having been given a positive response, NGU invited representatives of the geological surveys of the countries of the Arctic region to an inaugural, consultative meeting, held in Toronto in March, 2012 in conjunction with the annual Prospectors and Developers Association of Canada Convention (PDAC). A consensus on the general form of the project was achieved and the first regular meeting of the group of geoscientists who have had a major role in implementation of the project took place in Copenhagen in December 2012. NGU had, prior to that meeting, been granted funding by the Ministry of Foreign Affairs of Norway to support coordination of the project and publication of its products.

Interest in the Arctic will continue to grow in the years ahead of us. Cooperation on compilation of modern geological and geophysical data is a neccessary step towards a common understanding of the potential for natural resources in the Arctic regions. This Preface gives me the opportunity to acknowledge the positive support of the leaders of our partner organizations in this project and the outstanding efforts of the geoscientists who have participated in achieving its aims. The financial support of the Ministry of Foreign Affairs of Norway is gratefully acknowledged.

The fiery skies of the winter, the summer nights' miraculous sun.
Walk against the wind. Climb mountains.
Look to the North.
More often.

Rolf Jacobsen
(from: North in the World, 2002)

CONTENTS

INTRODUCTION

Geoscientific maps of the Arctic

The first initiative for cooperation on a series of circum-Arctic geological and geophysical maps was undertaken by the Russian Ministry of Natural Resources and Ecology and by the Russian Federal Agency of Mineral Resources (Rosnedra) in 2003 (Petrov and Smelror, 2014). The objective was to produce digital geological and geophysical maps for the Arctic region at a scale of 1:5,000,000. A consortium of national agencies from Canada, Denmark, Finland, Norway, Russia, Sweden and the USA signed an agreement on the cooperation two years later (Petrov & Smelror, 2014). This volume is one of the products from a project, the Circum-Arctic Mineral Resources project, which was among the original aims of the participating organizations and is the most recent to be implemented:

- Geological Map of the Arctic (Harrison et al., 2008)
- Magnetic and Gravity Anomaly Maps of the Arctic (Gaina et al., 2011)
- Tectonic Map of the Arctic at scale 1:5M (Petrov et al., 2013, http://vsegei.ru/en/intcooperation/temar-5000/)
- Mineral Resources in the Arctic (this work)

Compilations of the type provided by the first three Circum-Arctic projects are important steps in updating scientific knowledge, in improving knowledge of the development of the Earth's Crust and in providing background information, which is relevant in assessment of the potential for mineral resources, not least in relation to energy resources in offshore sedimentary basins.

Why consider the mineral potential of the Arctic?

The High Arctic has attracted attention from explorers at least since the three voyages of Willem Barents in the late 16thC. Barents' aim was to search for what we now know as the Northeast Passage or, in Russia, as the Northern Sea Route (Figure 1). Barents visited Bear Island, Svalbard and Novaya Zemlya but none of the voyages penetrated the region east of the Kara Sea (Figure 2). The first commercial exploitation in the High Arctic began early in the following century with the establishment of Dutch and English whaling stations on Svalbard. The whaling expeditions discovered coal on Spitsbergen, the main island in the Svalbard archipelago, as early as 1610 and used the coal on their ships (Dallmann, 2015): serious exploration and long-term exploitation of the coal deposits began approximately three hundred years later. Mining of metallic ores has been important in the southern parts of the Nordic region as early as the 9thC (at Falun) and, by the 19thC had become one of the most important industries in northern parts of Norway and Sweden. Mineral exploration and subsequent mining developed throughout the Arctic in the latter part of the 19thC and the first decades of the 20thC, becoming the most important industry in many parts of the Arctic by the latter half of the 20thC. The aim of this work is to give readers an overview of some of the most important mineral deposits on land in the Arctic, not of energy resources such as coal, but of metals and diamonds.

The case for the timeliness of the Circum-Arctic Mineral Resource project rests on many factors:

- Heightened national, regional and international focus on the Arctic including numerous research projects of many kinds.
- National projects on the mineral potential of the Arctic regions of several countries, including Canada, Greenland, the Nordic countries and Russia. These projects involve documentation of mineral potential as part of the basis for assessment of the development potential of the regions covered.
- The continuing discovery of major new deposits in the Arctic, some in known metallogenic

provinces but others in regions not previously recognized as having a major mineral potential.

- Concern relating to access to certain critical mineral resources, some of which are known to occur in the Arctic: assessments of critical raw materials in Europe, the USA and other countries are among the expressions of this concern (European Commission, 2014, US Department of Energy, 2011).
- Improved access due to the more consistent, longer-term opening of shipping lanes such as the North-East Passage (also known as the Northern Sea Route), the North-West Passage and the Arctic Bridge (from Churchill to Murmansk), combined with greater access to ice-classified cargo vessels and ice-breakers.
- Article 7 of the Protocol on Environmental Protection to the Antarctic Treaty (http://www.ats.aq/documents/recatt/att006_e.pdf) which was signed in 1991 bans all mineral resource activities on the Antarctic continent except those related to scientific research. The Arctic Region is thus, on a global scale, one of the few remaining land regions with extensive areas of "prospective" geology in which knowledge of the mineral potential is limited.

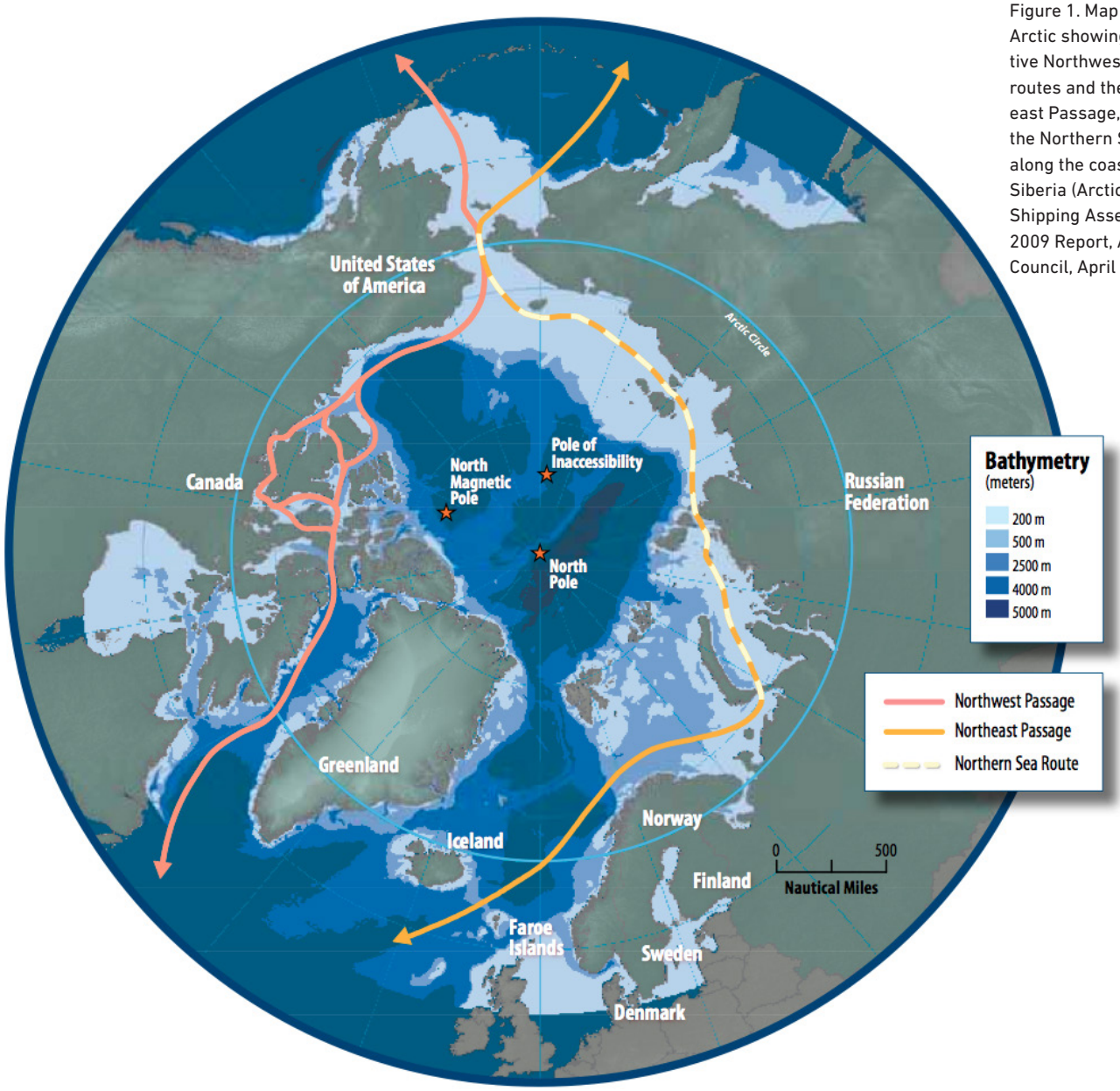

Figure 1. Map of the Arctic showing alternative Northwest Passage routes and the Northeast Passage, including the Northern Sea Route along the coast of Siberia (Arctic Marine Shipping Assessment 2009 Report, Arctic Council, April 2009)

Figure 2. The Arctic, according to the four definitions indicated below. (Map courtesy of the The Perry-Castañeda Library Map Collection, University of Texas Libraries, The University of Texas at Austin)

Definition of the Arctic

The following are among several definitions of the Arctic (see Fig. 2):

- The area north of the Arctic Circle, currently (February 2015) defined, using the method developed by Laskar (1986), as 66° 33min 46s north of the Equator. The Arctic Circle is the southernmost latitude in the Northern Hemisphere at which the sun can remain continuously above or below the horizon for 24 hours. Because of changes in the Earth's axial tilt due to tidal forces, the Arctic Circle at the present moves northwards by about 15 m/year.
- The region in which the average temperature for July is below 10°C.
- The northernmost tree line.
- 60°N. This definition includes:
  Most of Alaska,
  The Yukon, Northwest Territories, Nunavut and the northernmost parts of Québec and Labrador in Canada.
  The whole of Greenland, given a slight infringement of the southern limit in order to reach Cape Farewell at 59° 46min 23s N.
  Iceland
  The Faroe Islands
  The Shetland Islands, except for the southernmost 12 km of Mainland.
  Most of Fennoscandia, approximately the area north of the capitals Oslo, Stockholm and Helsinki.
  Northern Russia, including almost all areas north of the 10°C summer isotherm.

  The last of these four definitions is geographically convenient and was adopted in the first of the geoscientific projects implemented in the region.

The land area of the Faroe Islands is not known to contain mineral resources of significance (USGS, 2012) and the metallic mineral deposits known on the northernmost of the Shetland Islands – ophiolite-hosted chromite and platinum group metal deposits are of very limited tonnage (Brough et al., 2015). The deposits on Shetland will not be given further attention in this volume.

The Circum-Arctic Mineral Resource Project

The Fennoscandian Ore-Deposit Database (FODD) project implemented by the Norwegian, Swedish and Finnish geological surveys and authorities in Murmansk and Karelia regions in NW Russia for the area underlain by the Fennoscandian Shield has had great importance for the Circum-Arctic project (http://en.gtk.fi/informationservices/databases/fodd/index.html). The database developed in the FODD project, which is available at the above site, has functioned as a template for the Circum-Arctic project, though the Circum-Arctic project includes, for numerous practical reasons, only the deposits in the three largest size categories of the FODD system. The method for calculation of the size category of the deposits is described by Eilu et al. (2007). It is based on the calculation of the "in situ" value of each deposit according to ten-year averages of metal prices on the London Metal Exchange (LME) (for the period 1995-2005 in the original version of the database). The values for each deposit are then converted to a tonnage of copper corresponding to the value, so-called copper-equivalent, in order to provide a basis for the comparison of values of widely differing deposits. The FODD database is up-dated every year, most recently in May 2015, using metal prices for the period 2003 – 2012.

This volume is one of the four main products to emerge from the above project. It contains descriptions of the most important metallogenic provinces in the Arctic, the largest individual metal deposits and the most important deposits of diamonds. Metal and diamond deposits were prioritised in the project as being the mineral resources with the highest unit values, as opposed to industrial minerals (in general), construction materials and fertiliser minerals. Information on the individual deposits is entered into a database, which is accessible at the project web site: www.ngu.no/camet. The folder at the back of the volume contains a geological map at a scale of 1:10 million, based on the 1:5 million map (Harrison et al., 2008) on which the largest deposits are plotted.

Inevitably, the authors of the following chapters have faced greatly differing challenges – reflecting the differences in the scale and geological diversity of their countries. The numbers

Figure 3. The Black Angel zinc-lead mine on the W coast of Greenland (photo courtesy of Bjørn Thomassen, GEUS).

Figure 4. Drilling operations at the St. Jonsfjorden gold prospect, Svalbard (photo courtesy of Birger Amundsen, Svalbardposten)

of deposits in the FODD categories Large and Very large is very much larger in certain countries than in others – leading to differences in approach, including greater emphasis on the metallogenic-province level in the former. Independent of such variations the authors have strived to provide the most up-to-date information on the origin and resources of the deposits.

Abbreviated versions of this volume, aimed at general-interest readers, will be published in three languages – English, French and Russian.

REFERENCES

Arctic Council, 2009: Arctic Marine Shipping Assessment 2009 Report (http://library.arcticportal.org/1400/1/AMSA_2009_Report_2nd_print.pdf

Brough, C.P., Prichard,H.M., Neary, C.R, Fisher,P.C. & McDonald, I, 2015: Geochemical Variations within podiform chromitite deposits in the Shetland Ophiolite: Implications for Petrogenesis and PGE Concentration, Economic Geology, v. 110, pp. 187–208

Dallmann, W.K., 2015: (Ed.): Geoscience Atlas of Svalbard. Norwegian Polar Institute, Report 148, 292 pp.

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, 17p.

European Commission, 2014: Report on Critical Raw Materials for the EU

Fennoscandian Ore-Deposit Database project: http://en.-gtk.fi/informationservices/databases/fodd/index.html

Gaina, C., S. Werner, R. Saltus, S. Maus, S. Aaro, D. Damaske, R. Forsberg, V. Glebovsky, K. Johnson, J. Jonberger, T. Koren, J. Korhonen, T. Litvinova, G. Oakey, O. Olesen, O. Petrov, M. Pilkington, T. Rasmussen, B. Schreckenberger and M. Smelror. 2011. Circum-Arctic mapping project: new magnetic and gravity anomaly maps of the Arctic. In: Spencer, A.M., A.F. Embry, D.L. Gautier, A.V. Stoupakova and K. Sørensen (editors). Arctic petroleum geology. London: Geological Society of London (Memoirs 35): 39–48.

Harrison, J.C., M.R. St-Onge, O. Petrov, S. Strelnikov, B. Lopatin, F. Wilson, S. Tella, D. Paul, T. Lynds, S. Shokalsky, C. Hults, S. Bergman, H.F. Jepsen and A. Solli. 2008. Geological map of the Arctic. Ottawa: Geological Survey of Canada (Open File 5816, scale 1:5 000 000).

Lasker, J., 1986: Secular Terms of Classical Planetary Theories Using the Results of General Theory, Astronomy and Astrophysics 157, 59-70.

Petrov, O.V., M. Smelror, S. Shokalsky, A. Morozov, S. Kashubin, G. Gurikurov, N. Sobolev and E. Petrov. 2013. A new international tectonic map of the Arctic (TeMAr) 1:5 M scale and geodynamic evolution in the Arctic region. Geophysical Research Abstracts 15: EGU2013-13481 (EGU General Assembly 2013).

Petrov, O. V., & Smelror, M., 2014: Uniting the Arctic frontiers – International cooperation on circum-Arctic geological and geophysical maps, Polar Record 09, 1-6.

US Department of Energy, 2011: Critical Materials Strategy, 2011

US Geological Survey, 2012: 2012 Minerals Yearbook; Denmark, The Faroe Islands, and Greenland