Deposits

- Diamonds
- Hydrothermal fields
- Energy metals: U, Th
- Precious metals: Ag, Au, Pd, Pt, Rh
- Special metals: Be, Li, Mo, Nb, REE, Sc, Sn,Ta, W, Zr
- Base metals: Al, Co, Cu, Ni, Pb, Zn
- Ferrous metals: Cr, Fe, Mn, Ti, V

Size and activity

- Active mine
- Imoprtant deposit
- Very large with active mine
- Very large
- Large with active mine
- Large
- Potentially large with active mine
- Potentially large

Scale 1:23 000 000

Stereographic North Pole Projection
Standard Parallel 70°N Coordinate System WGS 1984
Prime Meridian: Greenwich (0.0), Central Meridian 20°W

CHAPTER 9
RUSSIA

Petrov, O.V., Morozov, A.F., Shatov, V.V., Molchanov, A.V., Terekhov, A.V., Lukyanova, L.I., Artem'ev, D.S., Belova, V.N. and Khalenev, V.O.

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OUTLINE OF THE GEOLOGY OF RUSSIA NORTH OF 60°N

This outline has been compiled, on the basis of a number of publications from the last six years, in order to provide a frame of reference for the following sub-chapters which focus on groups of commodities.

The Murmansk and Karelia regions

The north-westernmost part of Russia, consists mainly of Archaean and Proterozoic rocks, divided into three main provinces – the Kola, Belomorian and Karelian provinces (Figure 1): the Rybachy Peninsula, on the north coast of the Kola Peninsula, consists of a sedimentary sequence deformed during the Neoproterozoic Timanide Orogen which has its continuation west of the northern Urals.

The Kola Province

The Kola Province has two sub-provinces, the coastal Murmansk sub-province and the Kola Province, in the specific sense, which occupies most of the Kola Peninsula.

The **Murmansk sub-province** (Hölttä et al., 2008) consists of Neoarchaean granitoids, diorites, enderbites and a lesser component of supracrustal rocks: the effect of Palaeoproterozoic deformation and metamorphism is not extensive.

The **Kola Province** (Hölttä et al., 2008) encompasses four terranes:

- The Kola-Norwegian terrane in which Neoarchaean tonalite-trondhjemite-granodiorite (TTG), diorites, enderbites and peraluminous metasediments are prominent. The terrane contains several volcanic belts including the Pechenga volcanic/intrusive suite, which is host to important nickel-copper ores.
- The Kolmozero-Voron'ya terrane, which is a Mesoarchaean suture zone with components of komatiite, arc-related tholeiitic basalts, andesites and dacites as well as conglomerates. The terrane also includes Neoarchaean monzodioritic and granitic intrusives.
- The Keivy Terrane encompasses Mesoarchaean continental-margin volcanic suites, a suite of alkali granitoids, gabbro-anorthosite intrusives and extensive units of coarse-grained kyanite schist.
- The Sosnovka terrane, close to the south-eastern coast of the peninsula, consists of TTG rocks.

The Devonian alkaline intrusive complexes, Khibiny and Lovozero, are prominent features in the central part of the Province, forming two of the largest alkaline complexes in the world and containing rich and very large resources of special metals.

The Belomorian Province

This province consists (Hölttä et al., 2008) mainly of TTG gneisses, greenstones and paragneisses of Meso- and Neoarchaean age, deformed and metamorphosed in Neoarchaean and Palaeoproterozoic orogenic events. It is also noteworthy in that it contains ophiolites and eclogites.

The Karelian Province

This province consists (Slabunov et al., 2006) of three terranes:

- The Western Karelian Terrane comprises part of Eastern Finland and the western part of Russian Karelia. The most common lithologies (Hölttä et al., 2008) are migmatitic TTG orthogneisses and amphibolites, ranging in age from Palaeo- to Neoarchaean. It also includes Mesoarchaean greenstone belts, including the Kostomuksha belt which hosts important banded iron formations.
- The Central Karelian Terrane contains

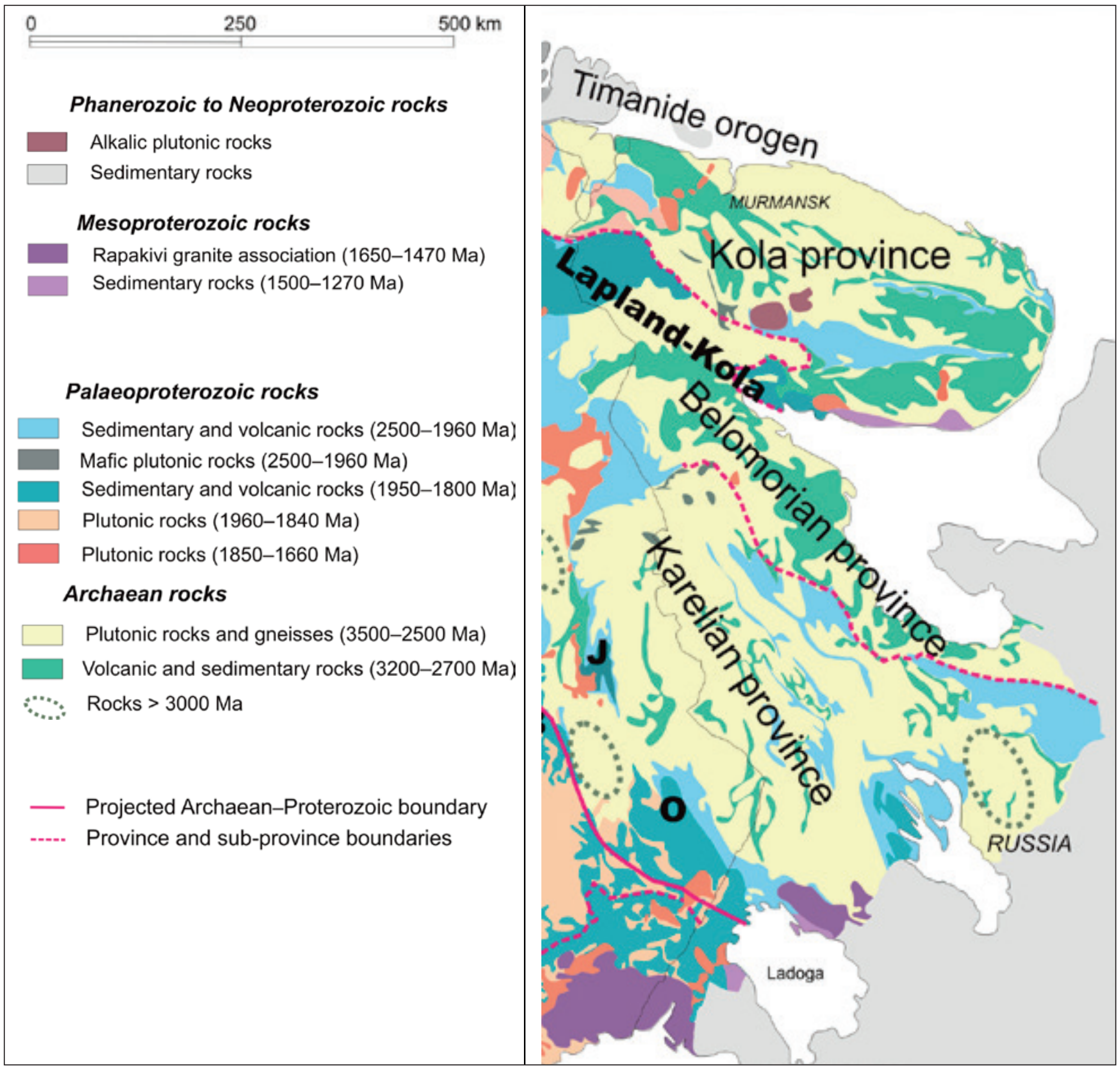

Figure 1: Northwest Russia - the Eastern part of the Fennoscandian Shield (part of Figure 1 in Lahtinen, 2012). International borders are shown in grey.

intrusions varying from granitoids to felsic to ultramafic sanukitoids, as well as several greenstone belts. These are, unlike the lithologies in the neighbouring terranes, exclusively Neoarchaean.

- The Vodlozero Terrane in the southeastern part of the Province has a core of Palaeoarchaean granitoids and gneisses, intruded by Mesoarchaean granites and mafic complexes, and surrounded by three generations of greenstone belts, ranging in age from Meso- to Neoarchaean.

The East European Platform

The whole northern coastline of European Russia, from the Kanin Peninsula, east of the opening of the White Sea to the Ural Foredeep (see next section) consists of the rocks of the Timanide Orogen (see Figure 2, unit 10), which form a wedge-shaped exposure, the southwest margin of which meets the western margin of the Ural Foredeep at ca. 600°N. South of the Timanides the platform cover is represented by two different complexes (www.rusnature.info):

- Riphean to lower Vendian sediments deposited mostly within deep basins (grabens, rifts or aulacogens) and consisting of terrigenous sandy-clayey rocks with a thickness of up to 5 km, locally with units of basaltic rocks.
- Late Vendian to Phanerozoic sediments forming vast synclines and basins with a thickness varying from tens of metres to 20-22 km in the deepest basins.

The Ural Mountain Chain

The Ural mountain chain extends for ca. 2500 km from the Aral Sea in the south to the Barents Sea in the north, with a continuation on Novaya Zemlya north of the Kara Strait. The province is

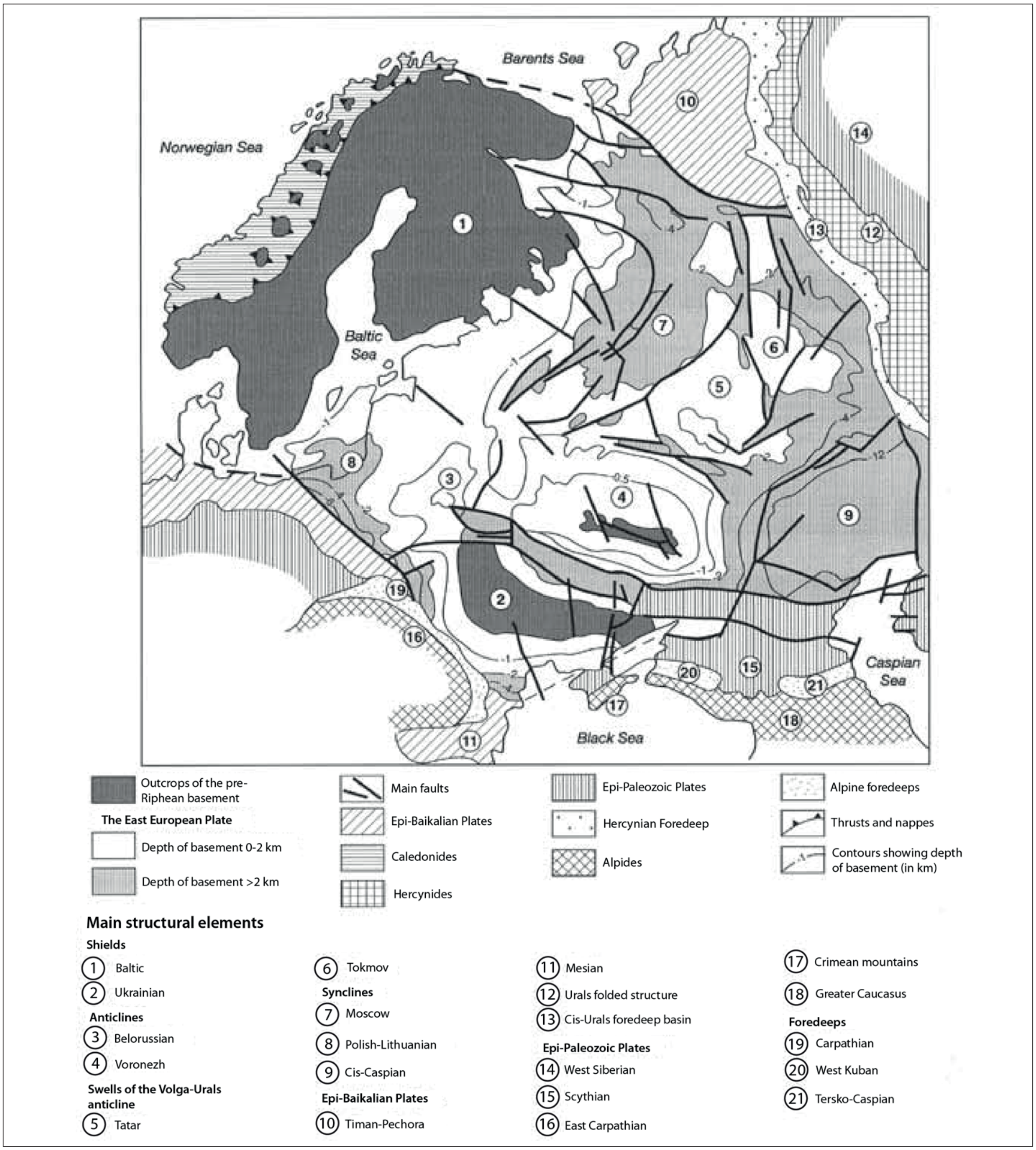

Figure 2: The East European Platform (http://www.rusnature.info/geo/01_3.htm).

a fold-and-thrust belt including the Pre-Uralide sub-province to the west and the main Ural sub-province: the Urals are bounded to the west by the East-European Platform (overlain by the Timan-Pechora Basin) and to the east by the West Siberian Platform and overlying Mesozoic-Cainozoic sediments.

The geological development of the province consists of the following stages:

- Pre-Uralian (Archaean – Early Proterozoic)
- Baikalian or Early Uralian (Riphean – Vendian)
- Uralian – Late Uralian (Ordovician-Permian)
- Development of platform cover (Mesozoic-Cainozoic)

The geotectonic development of the belt includes: subduction-island-arc, collisional, platform and rift-related settings, each with particular, though not equally important metallogenic characteristics. The longitudinal zoning of the province, from west to east is, as shown in Figure 3:

- Uralian Foredeep: Permian molasse
- West Uralian Zone: W-directed nappes of Palaeozoic sedimentary sequences
- Central Uralian Zone: exhumed Precambrian complexes
- Main Uralian Fault Zone
- Magnitogorsk-Tagil Synclinorium (MTS): Palaeozoic ophiolite and island-arc complexes
- East Uralian Upland: as MTS but also includes Precambrian complexes
- Trans Uralian Zone: pre-Carboniferous, probably accretionary complexes, overlain by L. Carboniferous volcanic rocks.

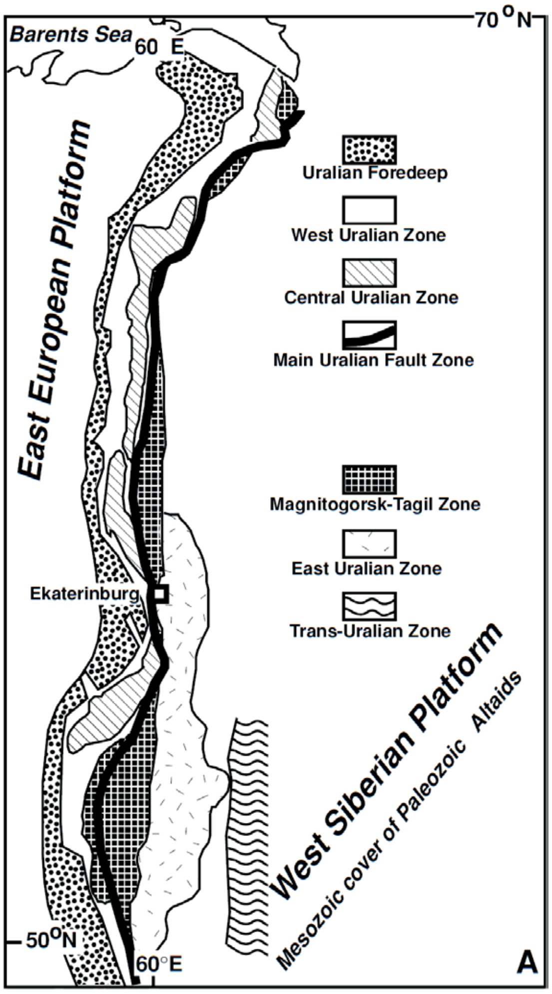

Figure 3: Tectonic zones of the Urals (after Puchkov (1997) in Sazonov et al., 2001.

The longitudinal tectonic zones are cut by NW trending transverse structures which split the belt into four megablocks (Southern, Middle, North and Polar Urals) characterized by specific geological, tectonic and metallogenic features. The presence of multiple structural levels and the complex tectonic zoning of the belt necessitate the definition of a system of longitudinal and transversal metallogenic zones with different ore-geochemical features. The main resource-types found in the metallogenically most important zones (Puchkov, 2016) are:

- West Uralian Zone: barytes, sediment-hosted Cu-Zn.
- Central Uralian Upland: titanomagnetite, iron, chromite, gold, VMS deposits, Mo-W in granite and others.
- Magnitogorsk-Tagil Synclinorium: VMS deposits, Cu and Au-Cu porphyry, platinum metals.

Siberia

Siberia incorporates several large tectonic terranes (Seltmann et al., 2010).

- The Siberian craton
- The Western Siberian Lowland
- Neoproterozoic–Palaeozoic orogenic belts north and south of the craton
- Late Palaeozoic–Mesozoic orogenic belts east of the craton
- The Cretaceous–Tertiary Okhotsk–Chukotka volcanic belt which overprints easterly orogenic belts (Parfenov et al. 2003).

The following description is based on that of Seltmann et al. (2010), focusing on the area north of 60°N.

Siberian craton

The Siberian craton extends from the R. Yenisei in the west to the R. Lena in the east. The Archaean basement of the craton is exposed in the Anabar and Aldan Shields and in smaller uplifted blocks along the margins of the craton. The platform cover on the craton includes sedimentary and volcanic sequences of Mesoproterozoic, Vendian–Cambrian, Palaeozoic, Mesozoic and Cainozoic age. The cover sequences are intruded by several igneous suites, including the voluminous Siberian traps and related mafic/ultramafic intrusives, ultramafic–alkaline rocks, carbonatites and kimberlites.

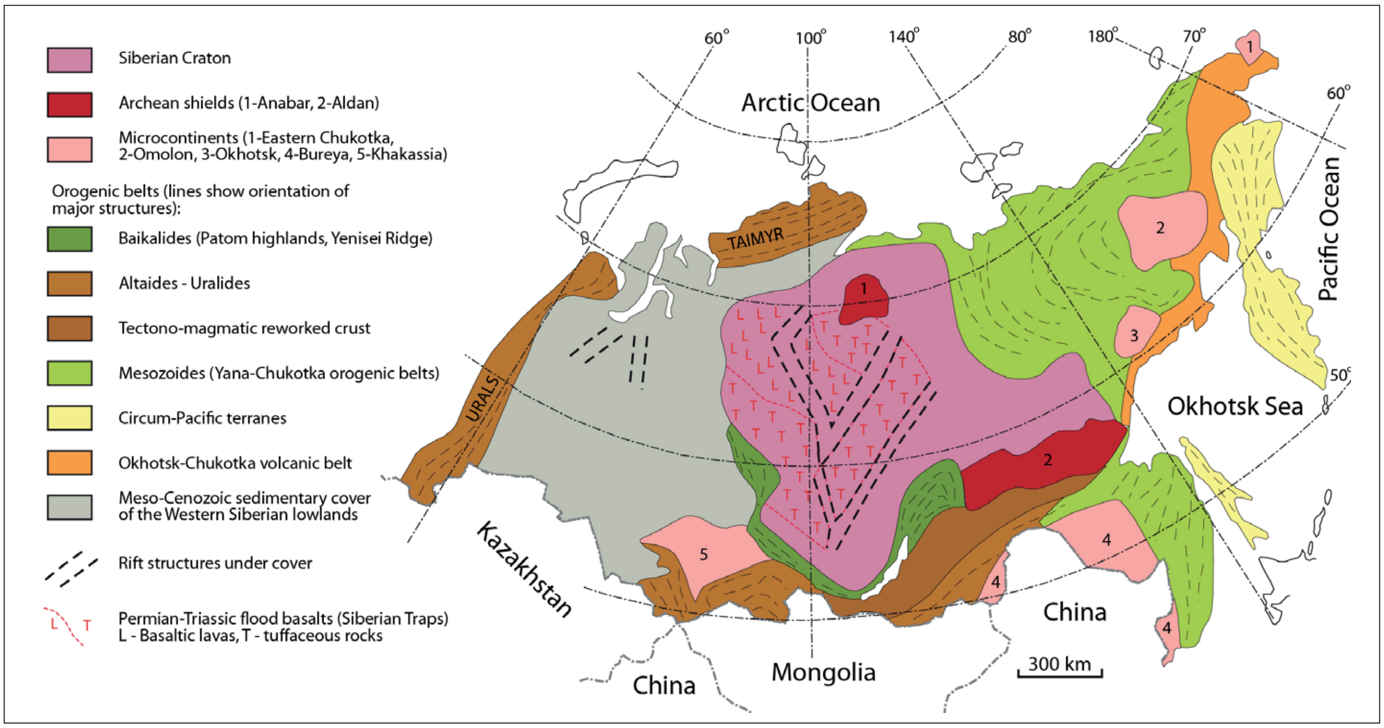

Figure 4: Geology of Siberia (based on Figure 1 in Seltmann et al., 2010).

Anabar and Aldan Shields

The Anabar and Aldan Shields are the largest uplifts of ancient basement within the Siberian craton (Figure 4). The Anabar Shield is composed of Archaean and Proterozoic granulites overthrust by Early Proterozoic granite–greenstone terranes. The Aldan Shield is also composed of Archaean and Proterozoic metamorphic sequences, including major granitoid intrusives, greenstone belts and sedimentary sequences. The Archaean and Proterozoic rocks are discordantly overlain by subhorizontal Mesoproterozoic–Vendian (750–550 Ma) and Cambrian carbonate sequences that represent cratonic cover.

Proterozoic terranes of the Yenisei Ridge and Patom Highlands

These two orogenic belts, adjoin the western (south-western) and southern (south-eastern) edges of Siberian craton, respectively (Baikalides in Figure 4). They include Archaean terranes (crystalline schists, granulites, gneisses) and predominating thick Mesoproterozoic–Neoproterozoic sequences. The latter are composed of metamorphosed shales, sandstones, siltstone, and minor marbles, dolomites and amphibolites that formed on passive continental margins (Obolenskyi et al. 1999). Precambrian granitic and mafic alkaline rocks are locally found. The Precambrian sequences are overlain, locally, by a Lower Cambrian carbonate sequence.

Western Siberian Lowland

The Western Siberian Lowland (Figure 4) is comparable in size to the Siberian craton and underlies most of Siberia west of the craton and is bordered by the R. Yenisei to the east and the Urals to the west. A large orogenic system referred to as the Yenisei Ridge separates southern parts of the Western Siberian Lowland from the Siberian craton. The basement of the Western Siberian Lowland immediately east of the Urals consists of Precambrian and Palaeozoic folded structures of the Altai–Sayan orogenic belts. The basement is overlain, in most of Western Siberia, by 4–6 km of terrigenous Mesozoic-Cainozoic sediments.

Neoproterozoic–Palaeozoic orogenic belts of Northern Siberia

The Taimyr–Novaya Zemlya orogenic belt adjoins the Siberian craton in northwestern Siberia. This terrane is separated from the craton by the Yenisei–Khatanga trough which is composed of Triassic–Oligocene marine–terrigenous sedimentary rocks, and has a Baikalian (Neoproterozoic–Mesoproterozoic) metamorphic basement, which contains blocks of Archaean age (micro-continents). This basement is bordered to the north by Mesoproterozoic–Devonian terrigenous–carbonate rocks and to the south by Ordovician–Triassic terrigenous-carbonate rocks with minor basalts. Orogenic belts in Southern Siberia are part of the Central Asian Orogenic Belt or the Altaid orogenic collage.

Yana–Chukotka orogenic belt

This Mesozoic orogenic belt extends from the northeastern margn of the craton to the Pacific Ocean (Mesozoides in Figure 4). It consists of several terranes/orogenic belts, including:

- The Verkhoyansk foreland and anticlinorium immediately east of the craton,
- The Yana–Kolyma thrust and fold belt,
- The Kolyma and Omolon microcontinents and
- The Oloy and Chukotka terranes.

Formation of this superbelt began on the eastern passive continental margin of the Siberian craton in the Mesoproterozoic and culminated in the Permian–Early Jurassic with deposition of thick sandstone–shale sequences. In the Late Jurassic–Cretaceous, this succession was folded, faulted and intruded by granitic batholiths. These rocks now form the Verkhoyansk and Yana–Kolyma terranes. The Kolyma microcontinent separates the Yana–Kolyma thrust and fold belt from the Oloy and Chukotka terranes: it consists of Archaean and Proterozoic rocks surrounded by Ordovician–Carboniferous sequences, mainly consisting of carbonate rocks. The superbelt incorporates, in addition to the Kolyma microcontinent, several smaller continental blocks, including the Omolon, Okhotsk, Taiganoss and Chukotka microcontinents: these consist of Palaeo-proterozoic schists overlain by Mesoproterozoic, Palaeozoic and Mesozoic sedimentary successions.

Okhotsk–Chukotka volcanic belt

This Mesozoic–Cainozoic volcanic belt overlies the eastern part of the Yana–Chukotka orogenic superbelt and thus separates the latter from the Cainozoic Koryak–Kamchatka orogen to the east (Figure 4). The Okhotsk–Chukotka volcanic belt thus has a Mesozoic basement of Upper Triassic to Lower Cretaceous sedimentary and volcanic sequences and is unconformably overlain by Lower Cretaceous to Palaeocene volcanic sequences, locally 45 km thick. The latter include rhyolite (ignimbrite), andesite and basalt. The Okhotsk–Chukotka volcanic belt evolves, further south along the Pacific coast, into the Sikhote–Alin orogen (Figure 4), which is characterised by volcanic rocks including Late Cretaceous rhyolites, Late Cretaceous–Palaeogene rhyolite–dacite, Late Palaeogene rhyolite–basalt–andesite suites and Neogene andesite and basalt.

Intraplate (or intracontinental) tectonic and magmatic activity

The Siberian terranes have experienced several intense intraplate anorogenic tectono-thermal events. These include the intrusion of igneous suites such as the Siberian traps, alkaline and ultramafic-alkaline complexes, carbonatites, kimberlites and lamproites. The Siberian traps have an extent of ca. 7100 km^2, including continental low-Ti tholeiitic flood-basalts, their possible feeders and comagmatic sill-like intrusions (Ivanov et al. 2008). The giant Noril'sk and Talnakh nickel–copper–PGM deposits are hosted in mafic sills associated with the traps. Intraplate tectonic and magmatic processes also resulted in emplacement of kimberlites in Yakutia, many of them diamondiferous, between the Devonian and the Mesozoic.

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www.rusnature.info

BRIEF HISTORY OF MINING IN RUSSIA

18th – 19th Centuries

Tsar Peter the Great (1672-1725), was responsible for numerous initiatives in Russia, also in relation to the search for and exploitation of mineral resources (http://goldminershq.com/vlad.htm). One of the first important mines was at the Nerchinsk silver deposit, southeast of Lake Baikal, which was discovered in 1702: the mines in the district were in operation from 1704 to 1854, yielding 11,540,000 oz (327,154 kg) of silver. Placer gold was discovered in the area in 1830 and was an important product for the last period of operation. Primary gold mineralizations were discovered on the north coast of the White Sea in 1937 and in the eastern Urals in 1745, the latter leading to a mining operation from 1748: the number of discoveries in the latter area by 1800 reached ca. 140, several of them in production as part of a state monopoly. The state monopoly was disbanded in 1812, leading to a dramatic increase in exploration activity and alluvial gold mining, especially in the Urals, and, in the second half of the 19th Century in eastern Siberia: Russia, has, thereafter, been one of the world's major producers of gold.

Numerous discoveries were made and mines established in Karelia in the first half of the 18th C, among the most important being Voitskoe (Cu) and the Pitkäranta (Cu-Sn-Fe) (Eilu et al., 2012). The mining industry had, by the late 19thC, evolved dramatically, to include major production of Au, Ag, Pt, Cu and Fe in the Urals, Fe and Mn in southern Russia (now the Ukraine), Pb-Zn, Ag and Cu in the Caucasus and Au and Ag in Siberia (https://en.wikipedia.org/wiki/Russian_Empire).

20th Century

The mining industry continued its expansion until the period prior to World War I and the Revolution. The "World War, the civil struggles and foreign invasions" caused a dramatic decline in industrial production in general in the period 1913 – 1921-22 (https://www.marxists.org/history/ussr/government/1928/sufds/ch05.htm). Production of certain metals fell to below 10 % of pre-World War I levels and did not recover until the period of dramatic expansion of the mining industry in the 1930s which continued for decades after World War II. The following sub-chapters indicate implicitly, in the descriptions of numerous major deposits, the efforts made in exploration for and documentation of new deposits of many commodities, several of which are among the largest of their kind in the world. Exact data on the reserves documented, and on production levels, both at the deposit and commodity levels are not publicly available for past discoveries. Current practice, however, allows publication of data on reserves and resources and their grades for deposits of most commodities. Russia was, in 2014, the world's most important producer of diamonds and palladium and one of the three largest producers of antimony, gold, nickel, platinum, tungsten and vanadium (BGS, 2016).

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GOLD, SILVER[1]

Molchanov A.V., Terekhov A.V., Khalenev V.O., Lukyanova L.I., Artem'ev D.S.

Blagodatnoe gold deposit

The Blagodatnoe deposit (not to be confused with the similarly named deposit in Khabarovsk krai) is located in the Proterozoic foldbelt on the northwestern margin of the Siberian Platform. It is located on the SW flank of the Panimbinsky Anticlinorium, which hosts most of the gold deposits of the Yenisei Ridge. The deposit forms a linear (NW strike and NE dip) vein-and-veinlet, sulphide-gold-bearing zone of hydrothermally altered (silicified, sericitized, and carbonatized) Upper Proterozoic quartz-mica schist of the Gorbiloksky Formation (Sovmen et al., 2006) (according to other data, schist of the Kordinsky Formation). Two commercial gold ore bodies have been identified in a 100-400 m thick zone, one in the northern prospect and the other in the southern prospect (Figure 5). The total length of the ore bodies is 3250 m; their thickness varies from 5-148 m, 45.6 m on average. The ores are low-sulphide, veinlet-impregnated and contain no commercial components other than gold. The structure of the ore is spotted, banded – the veinlets are banded and plicated. The host rock is dominated by quartz, feldspar, mica and chlorite: garnet, carbonate, whereas sulphides are subordinate. The main sulphides are arsenopyrite, loellingite, pyrrhotite, marcasite and pyrite: chalcopyrite, galena and sphalerite are less common. Rammelsbergite, nickeline, tellurides (hessite, tellurobismuthite and altaite), sulphosalts, sulphoarsenide and sulphoan-timonide are also recorded. The purity of the gold varies from 67–97 %; 78–90 % on average. The dimensions of the gold grains are typically between 10 and 750 μm, but grains of up to 2-3 mm have been found. Most of the commercial gold is confined to gold-sulphide intergrowths among non-metallic minerals.Most of the fine-grained gold (up to 70 μm) is concentrated in the arsenic-bearing phases.

The Blagodatnoe deposit was discovered in 1968. The inferred resources of the deposit were assessed, in 1975, to contain 40 tons of gold. In 2000-2004, an exploration crew from ZAO Polyus made an assessment of the ore within the framework of a project for exploration and appraisal in the Olimpiadinsky area. As a result, the Blagodatnoe ore showing (northern prospect) was reevaluated and a new, southern prospect that hosts 4/5 of all reserves of the deposit, was discovered. In September 2005 reasonably assured and inferred reserves containing 222.4 tonnes Au (ave. grade: 2.4 ppm Au) were approved within the pit planned in the Blagodatnoe deposit. The gold processing plant was put into operation in 2010. The mine is operated by ZAO Polyus (a subsidiary of OAO Polyus-Zoloto). The gold is extracted by direct leaching, and in 2010 76.73 % of the gold in the ore was recovered. The gold production in 2009 was 1.3 t Au, but increased to 11 to 13 t in the following years (2010-2013). Reserves as of 01.01.2012 were: RAR – 250.5 t Au, with an average gold grade in the ore of 2.4 ppm; inferred resources – 34.7 t Au.

Mayskoye gold mine

The Mayskoye mine is located in the Chaun District of the Chukotka Autonomous Region, 150 km SE of the regional centre, Pevek. The ore field was discovered by S.A. Grigorov during the 1971-1972 geological survey in the Tamnekvun tin ore cluster (Kukeney horst and

1 The deposits described have been selected by the authors from a potentially much larger number. The data on tonnages and grade in the text and in the accompanying database correspond to the figures officially reported by the responsible companies. Data on cumulative production and on certain commodities are not publicly available.

its surroundings). Anomalous gold mineralization was identified over an area of about 2 km² in the "Pakovlad" prospect (now Mayskoye mine). The discoveries were followed up by a detailed survey and assessment in 1973 by the Maysky Production Geological Enterprise of the Chaun Complex Exploration Expedition.

The Mayskoye mine is in the upper reaches of the Keveem River in the eastern Ichuveem-Palyavaam ore district, in which synvolcanic magma-feeding deep faults of NE and near N-S strike occupy an oblique position with respect to the NW striking cofolded faults. The main control on ore location is its confinement to the domeblock structure, located close to the Kukeney intrusion of Early to Late Cretaceous age (Figure 6).

The ore field area of 10 km² has an isometric shape and is confined to a complex horst-like ledge located at the intersection of the NW-, NE- and approximately E-W- and N-S-trending faults. The host rocks are interbedded mudstones, siltstones, and oligomictic sandstones of the Middle Triassic, Karnian, and Lower Norian (Keveem, Vatapvaam, Relkuveem, and Mlelyuveem formations). The host rocks are sandy-silty-shale deposits of the Keveem Formation of the Middle Triassic. Numerous pyrite nodules are observed in shaly silt varieties of the formation. The formation is, in the central part of the mine, at least 600 m thick. The folded structure of the ore field comprises gently dipping fault zones and folds alternating with zones of vertical, steeply-dipping isoclinal folds.

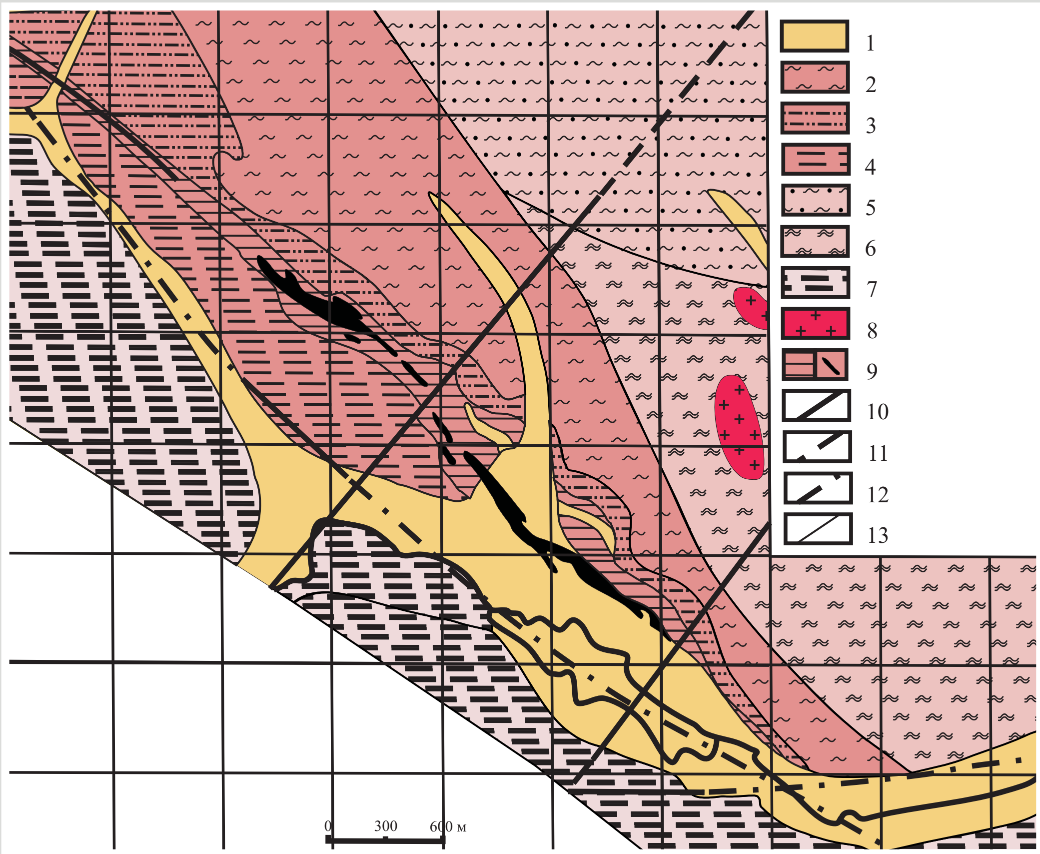


Figure 5: Geological map of Blagodatnoye deposit (Sovmen et al., 2006). 1: Quaternary deposits, Garbilokskaya suite; 2: Third unit. Quartz-muscovite slate, coarse-grained/ flaky with interbedded quartzite-shale; 3: Second unit. Alternation of quartzitic schist, muscovite and quartz-muscovite schists, quartz-biotite-muscovite schists, quartzites interlayers and coarse/flaky shale; 4: First unit. Feldspar-quartz-mica slate, muscovite-biotite-garnet-quartz schist with spotted and patchy structure): gold-sulphide mineralization in the zones of alteration and dynamo-metamorphism; 5: Korda Formation. Main sub-suite: Quartz-sericite-siltstone slate, local garnet; 6: Korda Formation. Lower sub-suite: Quartz-biotite schists, interbedded with quartzites; 7: Karkinskogo ridge. Mica-ceous garnet-staurolite-kyanite-sillimanite slate, bands of quartzite; 8: Granites - Tataro-Ayakhta complex; 9: Ore-bearing Zone (left) ore zone (right); 10 Faults traced; 11: Possible faults; 12: Faults cutting Quaternary formations; 13: Contacts.

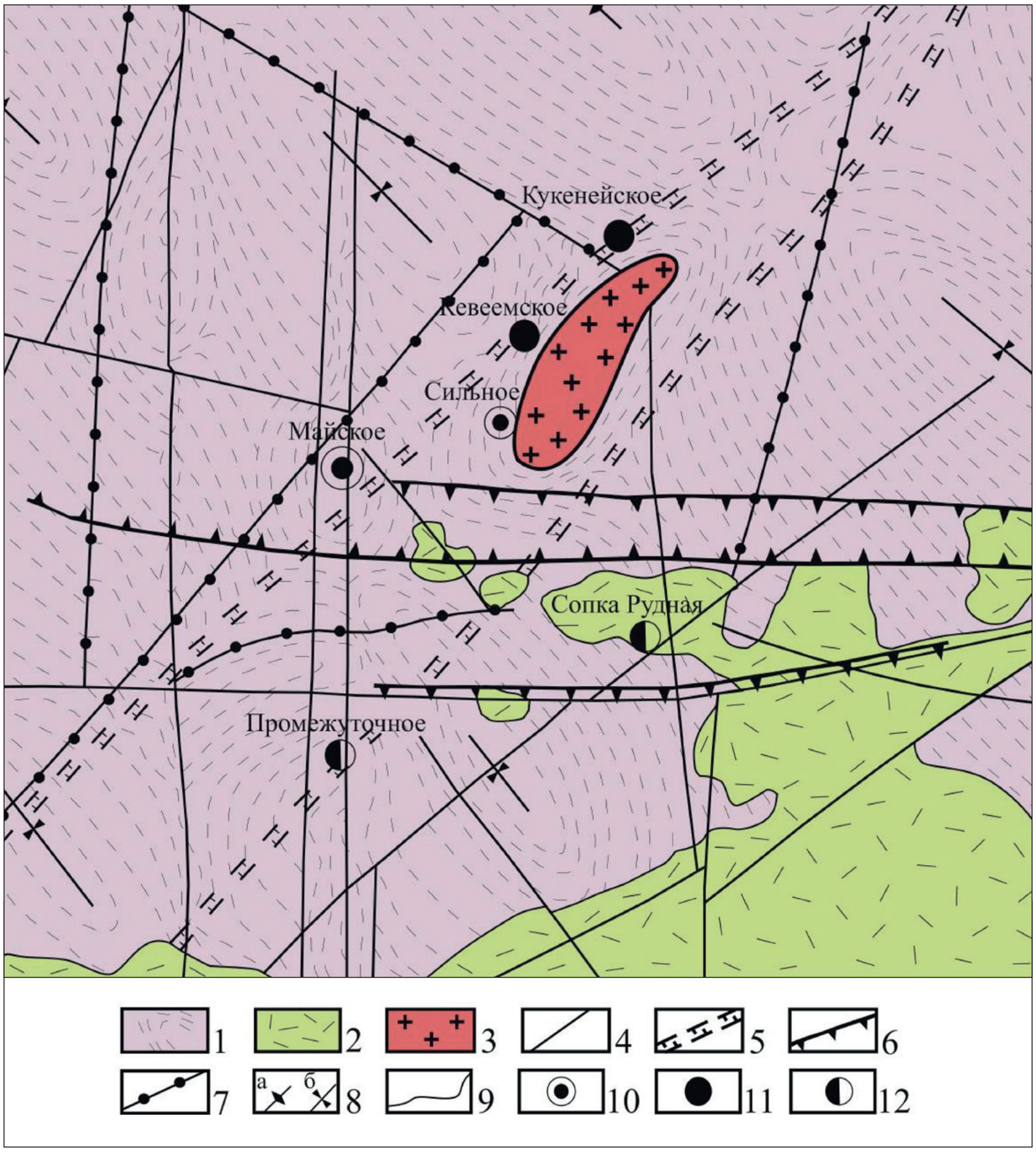


Figure 6: Geology of the Kukeney satellite intrusive-dome structure (Mayskoye ore cluster). 1: Middle-Late Triassic terrigenous flysch sequences; 2: Late Cretaceous effusive rocks; 3: Early-Late Cretaceous granites; 4: Faults; 5: NE-striking synvolcanic faults; 6: Neotectonic faults; 7: Faults deduced from geophysical data; 8: Axes of anticlinal (a), synclinal (b) folds; 9: Geological boundaries; 10-12: Ore deposits: gold-sulphide (10), cassiterite-sulphide (11), gold-silver (12).

Thus, multidirectional folding, combined with numerous intersecting faults, has created the mosaic structure of the ore cluster. Igneous rocks occupy 25 % of the total volume and are represented by the Early-Late Cretaceous dykes. Their outcrops form a belt about 3 km wide and more than 4 km long, spatially associated with mineralized zones. Two dyke groups of different age have been distinguished. (Volkov, 2005). The first group includes granite-granodiorite-porphyry, aplite, and lamprophyre, the second, later sub-volcanic rhyolite porphyry. It is important to note that both the igneous and the sedimentary rocks, have undergone intense epigenetic processes. Quartz is recrystallized and has reaction rims of sericitic composition; feldspar is commonly totally replaced by sericite, chlorite, and clay minerals of the kaolinite-dickite group.

The Mayskoye mine is divided into three tectonic units: the Western, Central, and Eastern units (Figure 7), in which dykes and ore bodies are combined into eight near N-S-oriented ore zones 100 - 300 m wide and 300 - 2,500 m long. Forty-six ore bodies are distinguished in the mine, 28 of them with officially reported ("balance") reserves. The ore bodies are represented by near N-S trending zones of cataclasites 1 - 8 m thick, composed of altered rocks. Up to 85 % of the gold reserves are concentrated in ore body No.1 of the Central unit; 90 % of the ore is refractory, with finely dispersed gold and requires a complex enrichment technology. The Mayskoye mine is among the large ones, with gold reserves of over 200 tons. Ore bodies of the Mayskoye mine are represented by sulphidized linear zones of cataclasites and have an approximately N-S trend. They form a system of near E-W bodies in an E-W-striking zone, 3.5 km long and limited to the north and south by E-W striking faults. Over 30 ore bodies are registered, most of them not exposed at the surface. The ore body boundaries are indistinct due to the development of mineralization on shallow feathering fractures and cleavage zones in host rocks.

The ore bodies are composed of intensely broken and crushed mineralized rocks: silt-stone, shale, fine-grained sandstone, rarely rhyolite porphyry containing 6-10 % of fine-grained, crystalline disseminated sulphides (pyrite, pyrrhotite, arsenopyrite and stibnite). Cataclastic structures, linear breccias including sedimentary and igneous rocks cemented by sulphides and quartz are common. In general, the average thickness of the ore bodies at the mine is 2 m, the average content of gold is 12 g/t, antimony 0.25 %, carbonaceous matter 0.5 %, arsenic 1 % and silver 3 g/t. Over 90 % of the gold is finely dispersed and associated with sulphides, mostly with arsenopyrite, arsenic-bearing pyrite and pyrrhotite (Figure 8). Significant positive correlation is observed between gold and arsenic. There are, in addition, areas with native gold in the fragmented parts of primary quartz veins. The gold is high-grade (920-980 ‰), forming a solid mass cementing quartz fragments (Figure 8). Currently, the license for production of gold and associated components at the Mayskoye gold mine and for geological study of its flanks and deep horizons belongs to LLC "ZK" Mayskoye", a subsidiary of the "Polymetal" holding company. Mining started in December 2012, and in March 2013, the gold processing plant produced its first concentrate. The first metric ton of gold from the mine was produced in October, 2013.

Kubaka gold mine

The Kubaka mine is located in the North Evenk District of the Magadan Region in the Kolyma massif, 1,000 km from Magadan. The ore field

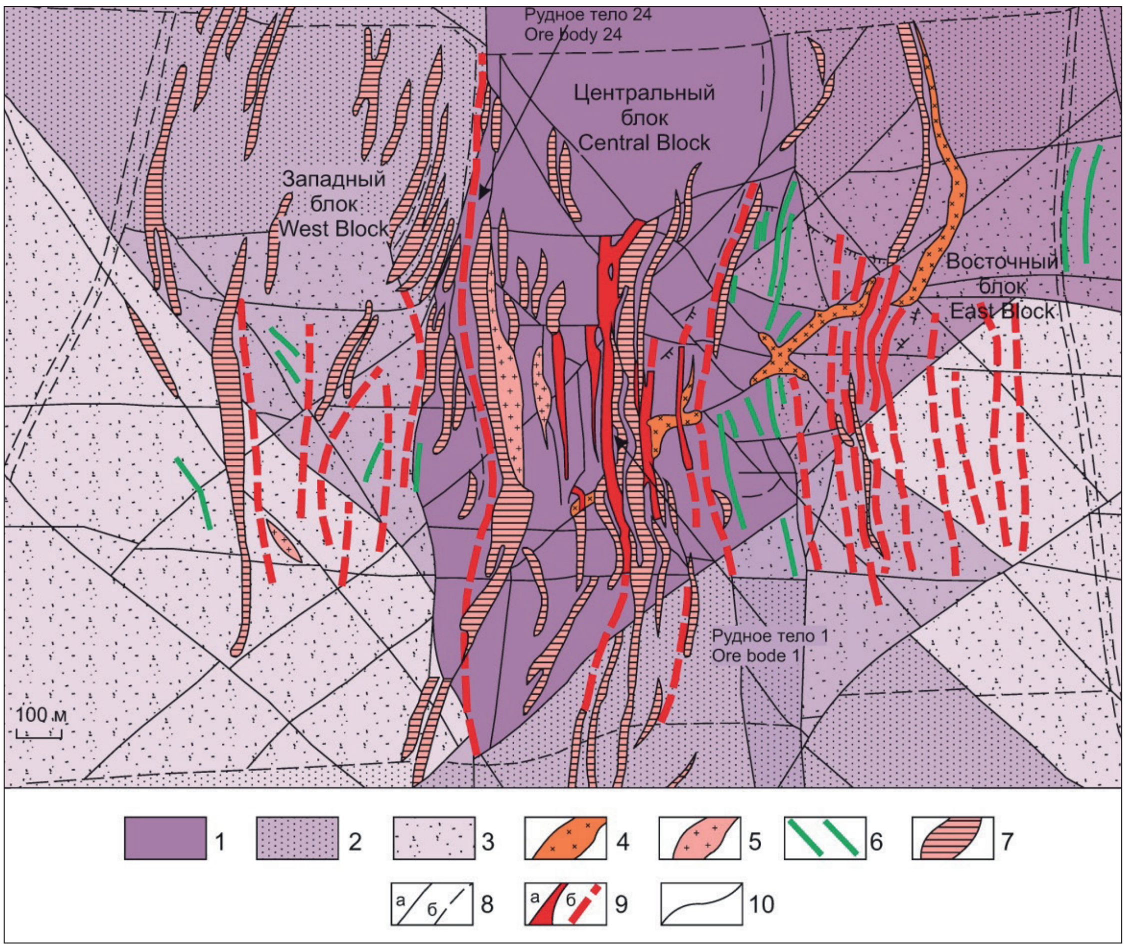


Figure 7: Geology of the Mayskoye ore field (Grigorov 1980).
1) Vatapvaam Formation (Lower); 2) Vatapvaam Formation (Upper);
3) Relkuvem and Mlelyuveem formations;
4) and 5) Quartz-porphyry and rhyolite dykes; 6) Lamprophyre dykes; 7) Quartz-feldspar porphyry dykes;
8) Fault zones (at surface and blind); 9) Ore bodies (at surface and blind); 10) Lithological contacts.

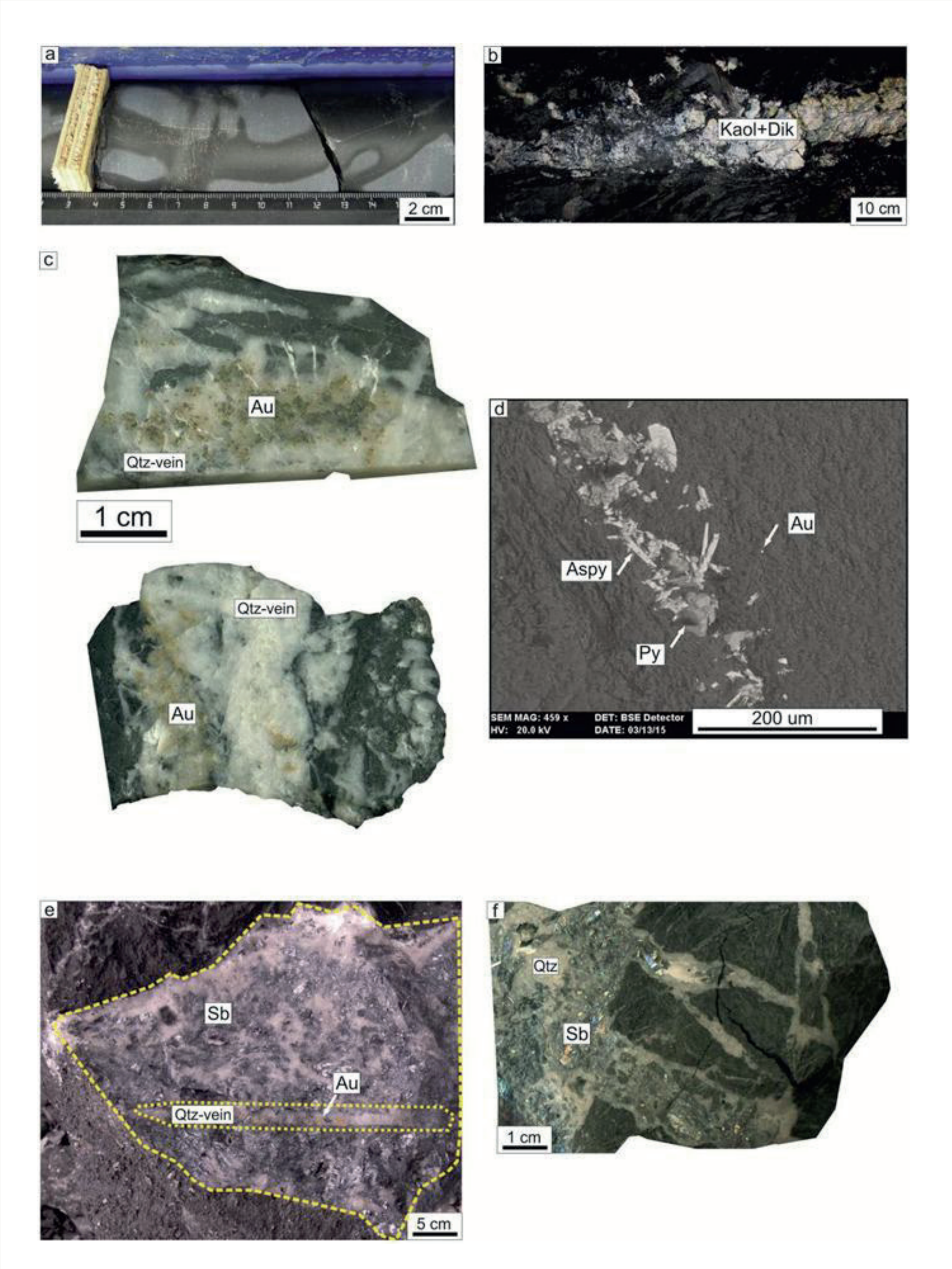


Figure 8: Quartz-antimonite vein with kaolinite and native gold. From the Mayskoye deposit.

was discovered in 1979 by geologists of the Seymchan Prospecting Expedition. Exploration to determine the technological properties of the ores, their position and the morphology of the ore bodies was carried out from 1979 to 1992.

The Avladinsky ore cluster, including the Kubaka mine, is located in the Kedon rise of the Omolon massif. The Precambrian of the Kedon rise is characterized by the presence of both normal leuco- and mesocratic gneiss of

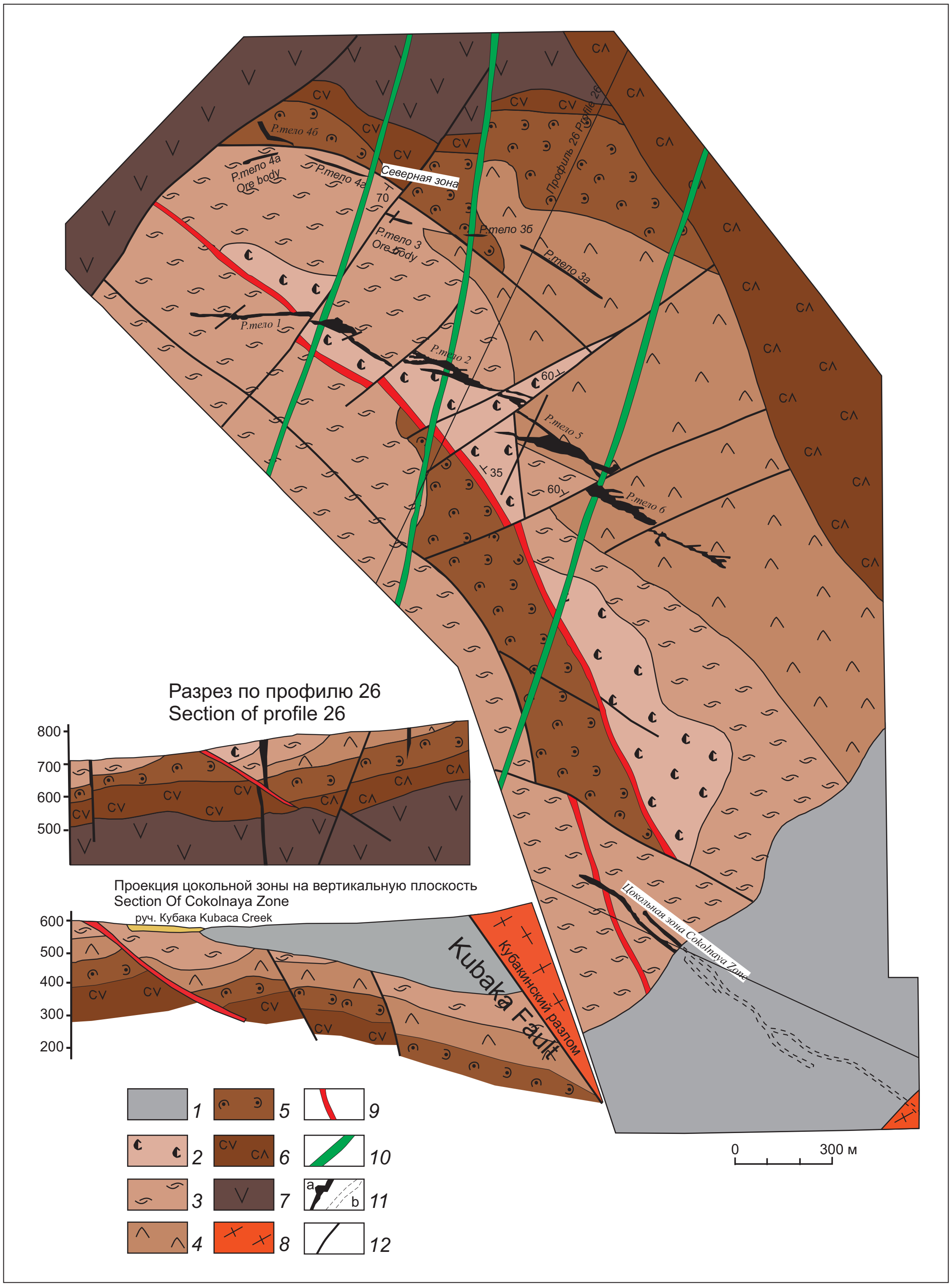


Figure 9: Geology of the Kubaka mine (Konstantinov M.M. et al, 2000). 1: Carbonaceous mudstone and siltstone (Carboniferous); 2: Agglomerate tuff; 3: Rhyodacitic ignimbrites; 4: Rhyodacite; 5: Tuff-sandstone; 6: Ignimbrites, tuffs and dacitic and andesitic lavas; 7: Tuff-siltstone; 8: Archaean granite-gneiss; 9: Middle-Late Devonian rhyolite dykes; 10: Createaceous gabbro-porphyry dykes; 11: Ore bodies: a – exposed at the surface, b – blind; 12: Faults.

amphibolite facies and pyroxene-bearing mafic rocks of granulite facies (including clino- and orthopyroxene). The ore cluster is located in Middle-Late Devonian Kedon Group volcanics and coincides spatially with a palaeovolcanic structure with the same name. The volcanic structure has vent, nearvent, and peripheral parts, separated by concentric fractures. The vent part is composed of ignimbrites and clastic lavas of trachyrhyolitic composition: tephroids with foamy rhyolite lava flows are observed locally. The periphery of the volcanic structure consists mainly of distal facies - tuff-sandstone, tuff-siltstone, acidic and intermediate tuffs including ash and silica tuff, rare ignimbrites and agglomerate tuffs. A number of sub-volcanic bodies of trachyrhyolite and rhyodacite occur, mainly intruded into concentric fractures.

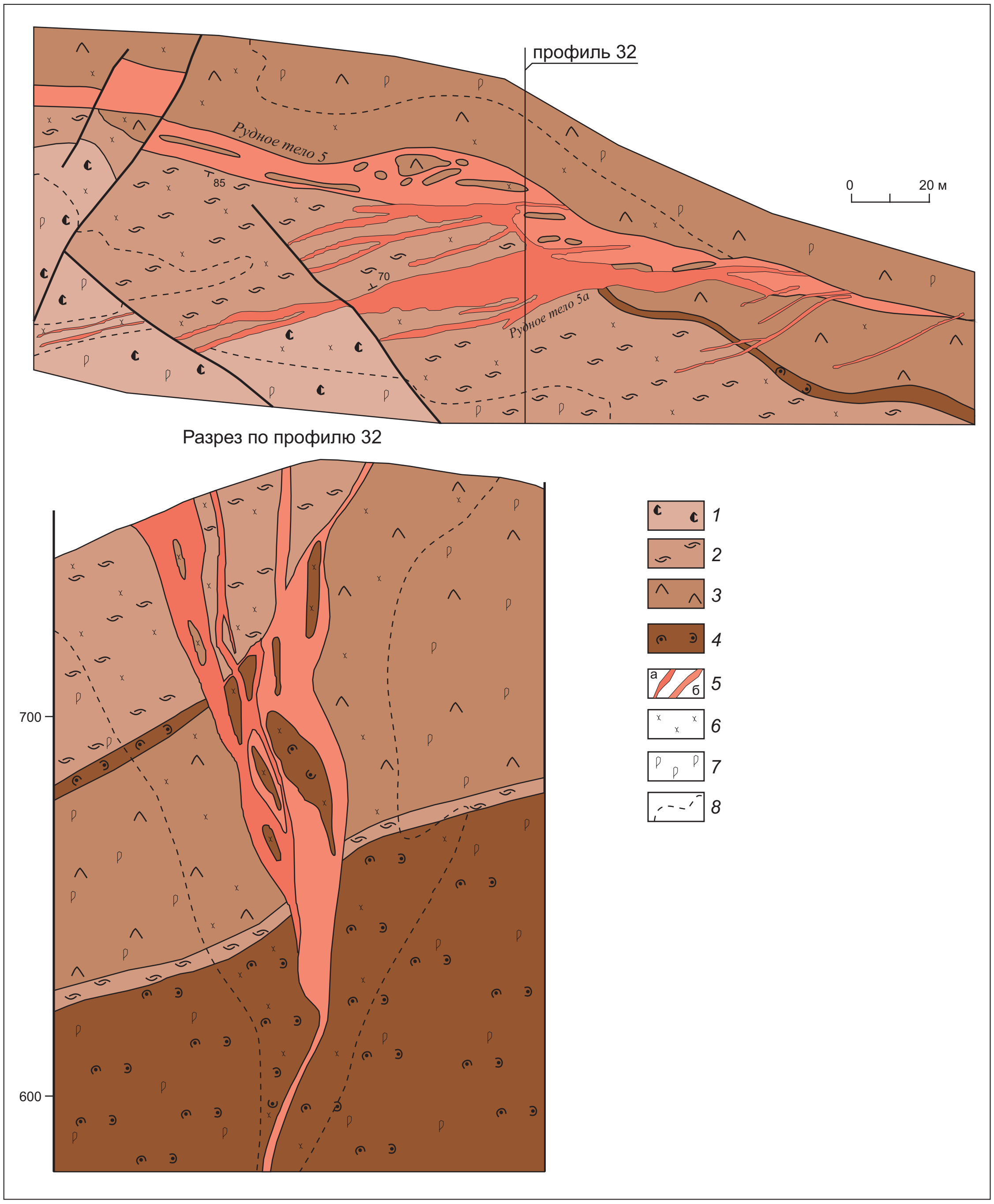


Figure 10: Geology of part of the Central ore zone from the Kubaka mine and section (Konstantinov et al, 2000). 1: Agglomerate tuff; 2: Rhyodacitic ignimbrites; 3: Rhyodacite; 4: Tuff - sandstone; 5: Adularia-quartz veins: a – of the first producing stage, b – of the second producing stage; 6: Wallrock alteration of chlorite-quartz-sericite and quartz-sericite facies; 7: Pre-ore propylite of epidote-chlorite and carbonate-chlorite facies.

Alteration of volcanic rocks includes propylitization, and large fields of altered rocks are developed on the flanks of the volcanic structure. Altered rocks are accompanied by gold-bearing vein-veinlet zones consisting of adularia-quartz, quartz, and carbonate-quartz. Gold mineralization, accompanied by "aureoles" of alluvial gold, occurs unevenly distributed in the outer, peripheral part of the volcanic structure. The mineralization is concentrated in two relatively small mineralized areas, 30-35 km² in size, limited by concentric and radial faults, on the southwestern and northeastern flanks of the volcanic structure. These areas are called, respectively, the Kubaka and Strelinsky-Gruntovsky ore fields.

The known ore bodies in the mine are concentrated in an area of about 8 km² which is elongated in a NW direction (Figure 9). The ore-bearing unit is composed of stratified volcanics of the Kedon Group, forming a monocline dipping gently to the southwest (200-210°) at an angle of 10-15°. Rhytmically alternating effusive rocks of intermediate and felsic compositions are observed. The volcanic rocks are intruded by sills of rhyodacite and andesite-dacite, as well as by trachyrhyolite dykes of the same age and later dolerite dykes. The southern flank of the ore body is covered by unconformably bedded terrigenous sediments of the Early Carboniferous Korbin Formation.

The mineralization is associated with veinlet-vein zones localized within a system of intersecting steep faults oriented to the northwest. Eighty-five percent of the main gold reserves are concentrated in the Central zone, 10 % in the Socle zone, and 5 % in the Northern zone. The veinlet-vein zones are separated into a number of ore bodies by a system of strike-slip faults. The faults are characterized by multiple brecciation and superposition of several stages of mineralization.

A system of E-W-trending composite veins of late-stage mineralization is always present in selvages of the veinlet-vein zones. In cross-section the ore zones form a fan-shaped structure widening upwards. The veinlet-vein zones are accompanied by hydrothermally altered rocks of chlorite-hydromica facies, forming an aureole up to several tens of metres wide. The thickness of the mineralized veinlet-vein zones ranges from a few metres to 20-30 m: the composite veins are 1-3 m wide.

The gold-silver mineralization is mainly localized in the marginal parts of the veins (Figure 10). Vein systems can be traced to depths of 500-700 m. Commercial mineralization is localized in the upper parts of the Kedon Group volcanic rocks; its vertical depth reaches 220 m. The ore is localized in an early stage of carbonate-anorthoclase-quartz mineralization and a late stage of chlorite-adularia-quartz mineralization, separated by the formation of weakly mineralized breccias with chalcedony-quartz cement. Hydromuscovite is also observed in the veins, and ore channel No. 1 contains fluorite and barytes. The ore is dominated by pyrite (50-80 %), Other phases are gold, electrum, custerite, acanthite, hessite, arsenopyrite, galena, sphalerite, hematite, ilmenite, ilmenorutile, rutile, chalcopyrite, freibergite, naumannite, aguilarite, native silver and other, rare minerals. The gold-silver ratio in the ores is high (1:2 - 1:1). Gold fineness is 600-750 ‰. Impurities include mercury (up to 1.48 %), antimony (up to 1.4 %), selenium and tellurium. The gold is mainly hosted in arsenopyrite and pyrite. Hypergene fine gold occurs very rarely in intergrowths with iron hydroxides. Balanced (officially reported) reserves as of 01.01.2013 were: gold: A+B+C1 – 9.031 t, C2 – 5.009 t.

Dvoynoye gold mine

The Dvoynoye mine is located 140 km SE of the town of Bilibino and 330 km SW of the town of Pevek and connected to them by a seasonal winter road. The nearest community is Ilirney village. The commercial ore bodies of the Dvoynoye mine (zone 1) were found by the Anyui State Mining and Geological Enterprise in 1984-1985 during a geological survey at 1:50,000 scale. Further exploration was carried out in 1986-1988. The mineralization of zone 1 was traced along strike and dip, as well as ore zones 8, 37 and 38.

The Dvoynoye mine is located on the south-eastern flank of the Anyui folded zone near its junction with the Okhotsk-Chukotka volcanogenic belt. The ore field has an area of about 20 km² and consists of andesite and andesitic tuff of Aptian-Albian age (Figure 11). Intrusive formations are represented by subvolcanic liparite bodies, granitoids of the Ilirney heterogeneous Early Cretaceous massif and Late Cretaceous dykes of diorite porphyry and andesite-basalt.

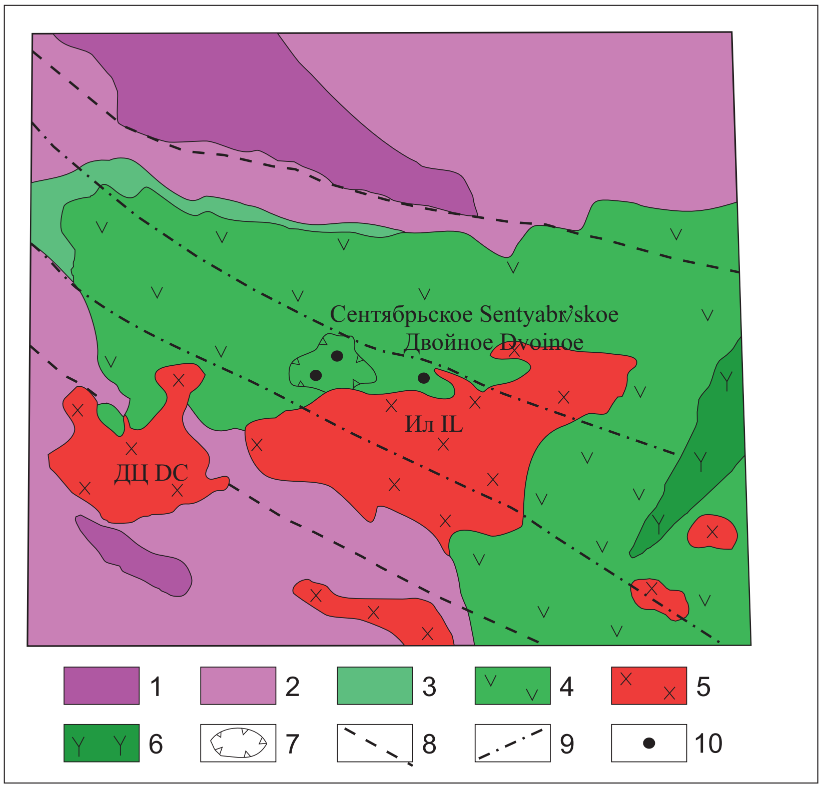


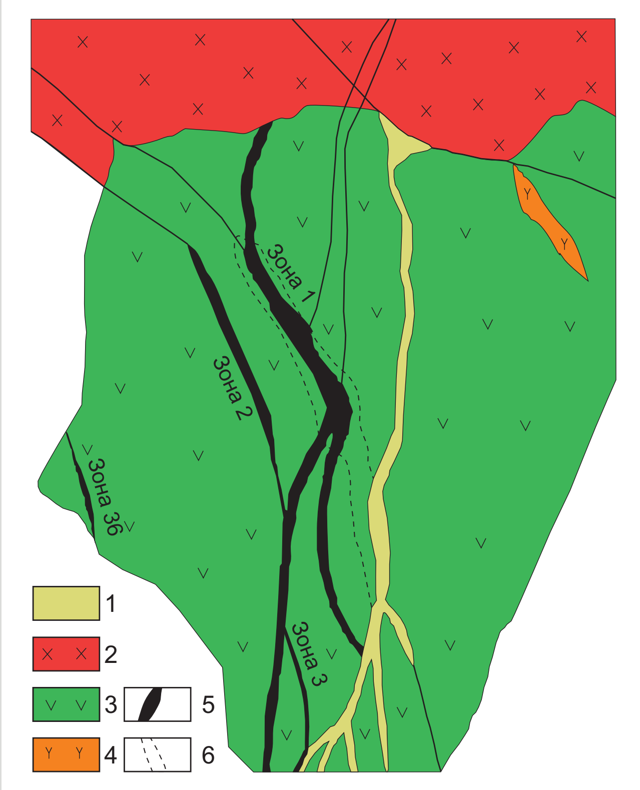
Figure 11: Position of the Dvoynoye mine in regional structures. 1: Keperveem series, schist formation; 2: flysch formation; 3: terrigenous-carbonate formation; 4: rhyolite-dacite formation; 5: Early Cretaceous intrusions; 6: Late Cretaceous subvolcanic bodies; 7: Ilirney volcanic structure; 8: zone of deep Keperveem fault; 9: zone of the Early Cretaceous Tytliutinsky fault; 10: Gold-silver deposits; IL: Ilirney intrusive massif; DT: Dvukh Tsirkov intrusive massif.

Thirteen mineralized vein-veinlet zones have been identified within the ore field, 4 of them being of economic interest and which have been explored in varying detail. Ore zone 1, in which all the officially reported reserves of gold and silver are found, has been exploited by underground mining.

Ore zone 1 is confined to the exocontacts of a granite-porphyry dyke and has a total length of 1,400 m. The length of the productive part is 400 m and its thickness is 25-30 m. The vertical extent of the mineralization is 310 m and has been explored to a depth of 100 m. The zone has a NW strike with a steep (70-80°) dip to the northeast (Figure 12). The major gold and silver mineralization is concentrated in the upper exo-contacts of the porphyry dyke. Morphologically, the exo-contact zone is divided into three segments. The northwestern and southeastern segments are ore shoots. The individual veins within these segments are up to 8 m thick and the total thickness of the segments reaches 23 m. The central part of zone 1 is confined to pinching part of the porphyry dyke and is represented by a zone of veinlets up to 2.5 m in thickness.

Ore zone 37 is up to 100 m thick and consists of closely spaced individual quartz vein bodies, veinlet zones and zones of altered host rocks. The ore zone is exposed on the banks of the Dvoynaya River. The zone is overlain by a post-ore, sill-like, complex intrusive subvolcanic body of syenite, quartz syenite and rhyolite along most of its southern part. In the northern continuation the zone is covered by felsic volcanics. Along strike the zone can be traced for 940 m, down-dip to a depth of 320 m from the surface. The thickness of quartz and quartz-adularia veins varies from 0.1 m to 42 m, over lengths from 45 m to 590 m. Many vein systems are not persistent along strike and down-dip: they have lenticular, en-echelon structures and branch both down-dip and along the strike. Among the numerous quartz vein systems, 13 quartz veins with elevated gold and silver contents have been identified to date. There is a great variety of ore textures: stringer, breccia, framework-tabular, crustified, massive, banded, etc. The quartz vein sytems consist of quartz (80-90 %), adularia (5-7 %), carbonate (up to 5 %), hydromica, chlorite and epidote. The mineralization consists of pyrite, haematite, galena and sphalerite, as well as other minerals in quantities ≤1 %. The main economic mineralization is concentrated in quartz veins. Other formations - stringer zones and metasomatic silicification - have relatively low gold contents, from 0.5 - 2.0 g/t.

Figure 12: Schematic geological map of the Dvoynoye mine. 1: Quaternary alluvial deposits; 2: Ilirney massif granitoid; 3: Andesite, andesite tuffs; 4: Quartz syenite-porphyry dykes; 5: Ore zones; 6: Zone of altered host rocks.



The veins and veinlets consist of quartz, adularia and calcite and lesser amounts of epidote, hydromica, sericite, muscovite and chlorite. Ore minerals constitute less than 1 % and include native gold, electrum, pyrite, sphalerite, galena, chalcopyrite, pyrargyrite, acanthite, fahlores and traces of other minerals. Gold is present as inclusions in quartz, pyrite, sphalerite, galena, and chalcopyrite. Grain size is from tens of microns to 1 mm, rarely larger. The distribution of gold and silver in the ore bodies is extremely uneven; the gold content reaches 3,300 g/t and silver 16,300 g/t; coefficients of variation for individual ore bodies, respectively, reach 376 and 632 %. The Dvoynoye mine belongs to the gold-silver type (the gold:silver ratio is 1:2) of shallow gold formation according to the classification of Petrovskaya (1973). The reserves of the Dvoynoye mine amount to 64 t of gold, 94 t of silver.

The mine has been developed commercially since 1996 as an open pit. Ore zone 1 is currently mined out for the most part. As a result of exploratory work in 1995-2005, economic reserves were approved for zones 8 and 37. In 2009, exploration work was completed at Dvoynoye mine. These investigations showed that ore zones 37 and 38 are a single structure and merge into ore zone 37. Exploration of zone 37 resulted in the following amounts of gold in reserves: in category C1 - 22 t and in C2 - 43 t. The mine was re-opened as an underground mine by Kinross Gold Corporation on October 10, 2013.

Nezhdaninskoye gold mine

The Nezhdaninskoye gold mine is located 160 km from the Tomponsky District centre, near Khandyga village, in the Tyra River valley. It was discovered in 1951 by the Dybinsky Geological Prospecting Party led by G.F. Gurin. The total area of the deposit is 60 km^2; it is one of the largest Russian gold prospects in terms of refractory ore.

The ore field is located within the southern part of the South Verkhoyansk synclinorium and has a two-tier structure. The lower tier is composed of the Verkhoyansk complex of terrigenous rocks (Upper Carboniferous - Middle Jurassic) up to 11 km thick, while the upper tier consists of Upper Jurassic-Cretaceous volcanic strata. The mine is on the northern flank of the Allakh-Yun gold-bearing band at the junction of the Western and Central structural zones of the synclinorium. It is confined to the crest of the Dybinsky anticline at its intersection with major N-S, E-W and NE-striking faults (the Kiderkinsky, Tyrinsky and Suntarsky faults). The mineralization is located in Lower-Upper Permian silt strata (Figure 13), regionally metamorphosed to lowermost greenschist facies. There are two formations: the Dzhuntaginsky Formation which is 600-700 m thick and is overlain by the Dybinsky Formation, 1,400 m thick. The Dzhuntaginsky formation hosts the ore, and is underlain by shale grading into sandy siltstone with sandstone beds. The Dybinsky Formation comprises carbonaceous siltstone and argillaceous sandstone with siltstone beds. Igneous rocks are uncommon: they include the Kurumsky granodiorite massif to the northeast, a dyke complex, diorite porphyry and

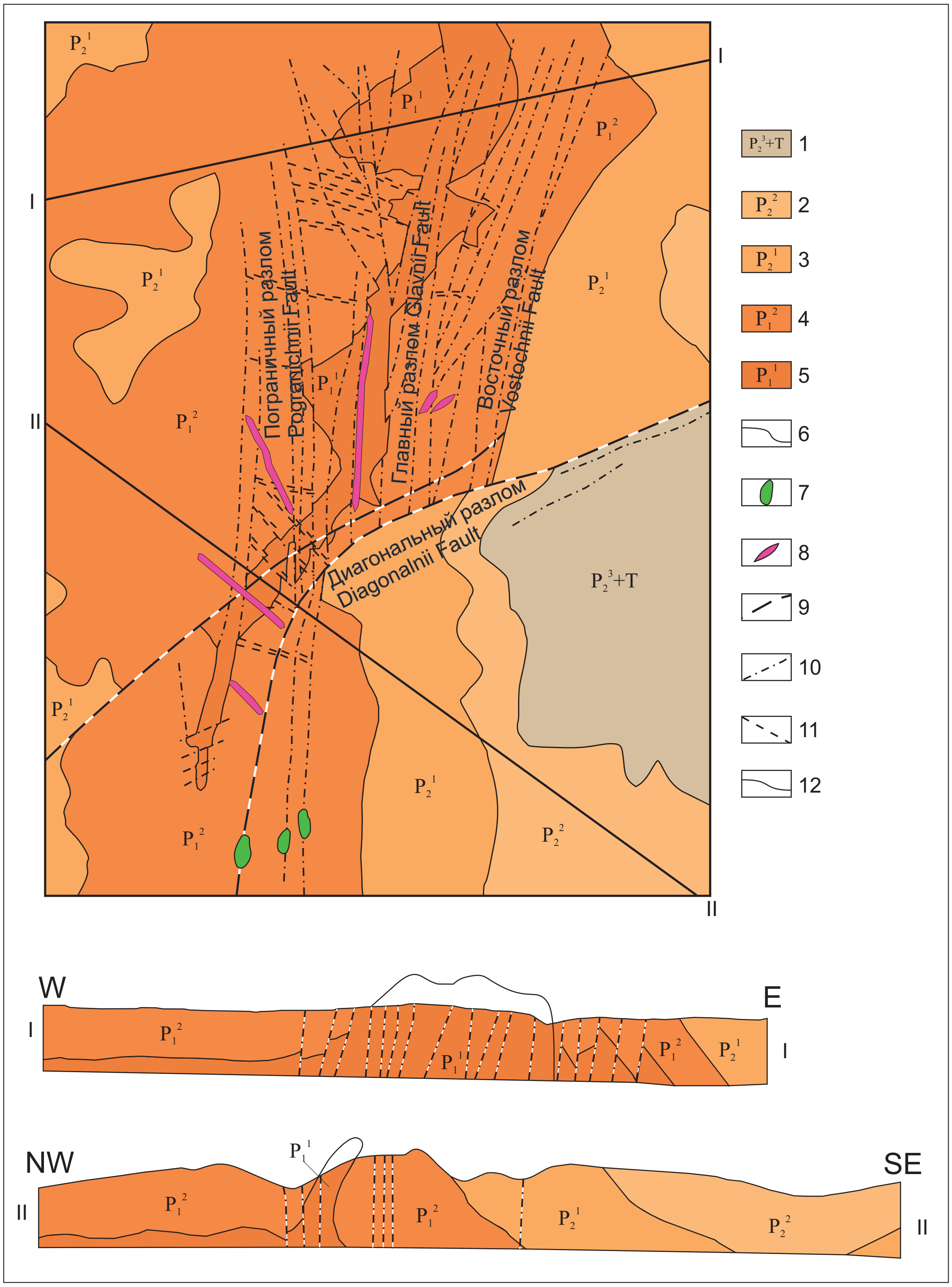


Figure 13: Geological structure and sections of the Nezhdaninsky mine area (Konstantinov M.M. et al., 2000). 1: U. Permian/triassic siltstone-sandstone sediments (P_2^3+T); 2: U. Permian sandstone formation (P_2^2); 3: U. Permian siltstone formation (P_2^1); 4: L. Permian shale formation (P_1^2); 5: L. Permian siltstone formation (P_1^1); 6: Marker sandstone bed; 7: Gabbrodiorite stock; 8: Dykes of intermediate composition; 9: Diagonal fault; 10: Nezhdaninsky system breaks; 11: Poperechnaya system breaks and fracture zones; 12: Geological boundaries.

lamprophyre. The crest of the Dybinsky anticline is strongly deformed and broken up by numerous discontinuous displacements, corresponding to the deep regional faults mentioned above.

The main orebearing structures are splays of the Kiderkinsky (Main) fault which are trending N-S and dipping westwards at 65°. Two main morphological types of ore are distinguished in the mine: 1) extensive mineralized cataclasites composed of altered cataclastic and metamorphic rocks with dissemination and veinsof sulphide mineralization; 2) quartz veins and vein zones with variegated structure. Both types of ore are accompanied by mineralized veinlet zones acquiring a joint-node stockwork appearance. In total, there are about 80 steeply oriented ore bodies, of which ten are major. The richest mineralization is localized in tabular quartz veins formed under tension, in which the ore zones form splays. Some of these can be traced downdip for more than 550 m (vein 14). Along strike, in some cases, they split into two - three veins, which may then be transformed into a system of veinlets. The zones are 270-3,500 m long and 3.9-11 m thick; veins and vein zones are 50-340 m long and 1.3-3.4 m thick respectively. Over 90 % of the mine reserves lie in ore zone No.1 which is 3,500 m long with an average thickness of 11 m. The total vertical extent of the mineralization is 1,330 m.

The ore contains 6 % sulphides with 3 % arsenopyrite, 1 % pyrite, 0.9 % sphalerite, 0.6 % galena, 0.3 % fahlore and 0.1 % chalcopyrite and pyrrhotite. Nonmetallic minerals comprise: 53 % quartz, 29 % clay and feldspar minerals, 6.8 % mica, 3 % carbonates, and 1.7 % graphite. Only the gold and silver are of commercial value. The gold occurs in native state and is associated with sulphides and quartz. The size of the gold grains is 0.002-1.2 mm, fineness 680-840 ‰ and the ratio of gold to silver is 1:3 - 1:10. Silver occurs finely dispersed and scattered in sulphides.

Development of the Nezhdaninskoye mine began in 1974 and it was in production for 25 years. About 25 t of gold were produced over these years (from gold-quartz ore). Gold reserves in the mine as of 01.01.2014 were: proven (categories A+B+C1): 278.7 t, tentatively estimated (C2): 353.3 t, with an average gold content in the ore of 4.89 g/t. The ore is mostly refractory (arsenic). As of 2014, the license for the mine development belonged to OJSC "South-Verkhoyansk Mining Company" (subsidiary of JSC "Polyus Gold"). Further geological exploration and a feasibility study for development of the mine are currently being implemented.

Natalka gold mine

The Natalka gold mine is in the Tenkin District of the Magadan Region, 450 km from the town of Magadan. The ore field has an area of 40 km² and is part of the Omchak ore cluster, the largest in the Kolyma-Chukotka metallogenic province. The field was discovered in 1942 by V.P. Mashko during a detailed survey along the Omchak River, Geologichesky and Pavlik creeks. The Omchak ore cluster is part of the Ayan-Yuryakh anticlinorium and is confined to the margin of an assumed pluton. (Goncharov V.I. et al., 2002). The formation of the ore cluster is related to the collision stage of the Yana-Kolyma fold system. Sedimentary rocks hosting the ore cluster are represented by Permian and Triassic deposits of pelagic mudstone, fine-grained sandstone, and diamictite. In places, the terrigenous sediments are enriched in syngenetic carbonaceous matter (Berger, 1990). Intrusive rocks are present at the periphery of the ore cluster, and include gabbro, leucocratic granite and dykes of various composition. To the north is the large (230 km²) Nerchin granodiorite massif.; The Mirazh and Tengkechan granite massifs as well as small gabbro and diorite bodies and dykes of various composition are located to the south and west of the cluster.

The Natalka mine area comprises Late Permian sedimentary rocks, which is divided into three formations (Figure 14). The lower Pioneer Formation is represented by carbonaceous-argillaceous shale with interbedded calcareous sandstone and gravelstone, the middle Atkan Formation is composed of tuffaceous diamictite and shale (Goncharov, V.I. et al., 2002). The upper Omchak Formation is, in its lower part, represented by siltstone, shale, and gravelstone, in the upper part by sandstone and silty-clayey shale. All the sedimentary rocks of the Natalka ore field, regardless of age, were subject to regional greenschist facies metamorphism; secondary alteration is expressed by newly formed chlorite, sericite, pyrite, rarely stilpnomelane.

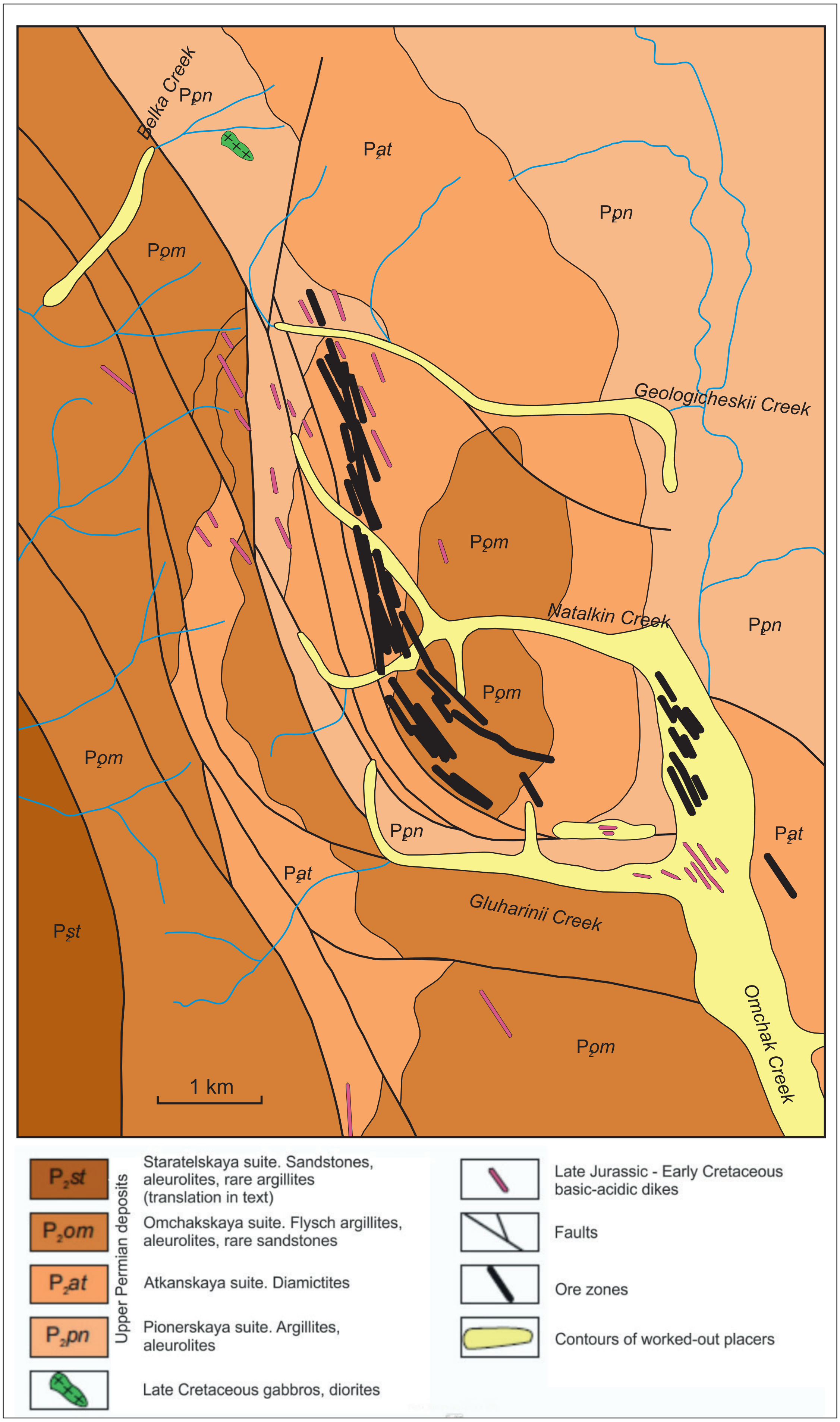


Figure 14: Geology of the Natalka mine (Goncharov V.I. et al., 2002).

Sedimentary rocks of the ore field are folded, the Natalka syncline being the major fold structure. This is a second order fold (with respect to the Tenkin anticline (Goryachev N.A. 1998)), with a simple symmetrical shape; its limbs are dipping 40-50°, the axis is trending NW, extending 4.5 km with a width of 2.5 km. The core is composed of the Omchak Formation rocks which outcrop in the central part of the mine.

The fault tectonics at the Natalka mine largely determine its structural plan. Faults which are longitudinal with respect to the fold structure or transverse to it predominate. The main tectonic unit of the ore field is the Natalka fractured zone, consisting of several faults, the most important being the Glavny and Severo-Vostochny faults, and splays of the Omchak fault accompanied by a large number of smaller joints (Goncharov V.I. et al, 2002).

The gold mineralization is controlled by these faults which affect the southwestern limb of the Natalka syncline. The ore zones are characterized by a predominance of sulphide-disseminated and linear-stockwork mineralization. The linear stockworks are represented by two systems (longitudinal and diagonal) of veinlets up to 3 cm thick, grouped around the tectonic joints in the axial parts of ore zones. The maximum thickness of the veins reaches 10-20 cm; their number/meter ranges from 5-10 to 40-50 (Goncharov V.I. 2002). Along strike and down-dip veinlets commonly grade into short, lenticular or parallel selvage veins, rarely, into zones of silicification. The ore zones are subdivided into two branches forming, in a vertical cross-section, a fan-shaped system with a tendency to converge at depth.

The mineralization is unevenly distributed in four ore elongate bodies (Kalinin et al., 1992) of different shape and size (Figure 15). The richest mineralizations are found in the volcanic-sedimentary rocks of the Atkan Formation and carbonaceous-clay shales (C_{org} up to 2.44 %) of the Omchak Formation. In general, the gold content remains constant with ore body thickness increasing with depth (Kalinin et al., 1992). The main ore type is sulphide-dissemination in a host rock of variably altered terrigenous rocks (Goncharov, 2002). Wallrock aureoles are closely linked to alteration, including silicification, sericitization, carbonatization and chloritization. Gold is consistently found in arsenopyrite and pyrite, in quantities exceeding tens or hundreds of g/t, but it is very rarely observed microscopically. The disseminated sulphides contain, according to calculations by R.A. Eremin and A.P. Osipov, 50-70 % of the total gold content.

The gold is coarser in quartz veins and veinlets; it is represented by cloddy, veinlet-like, tabular,

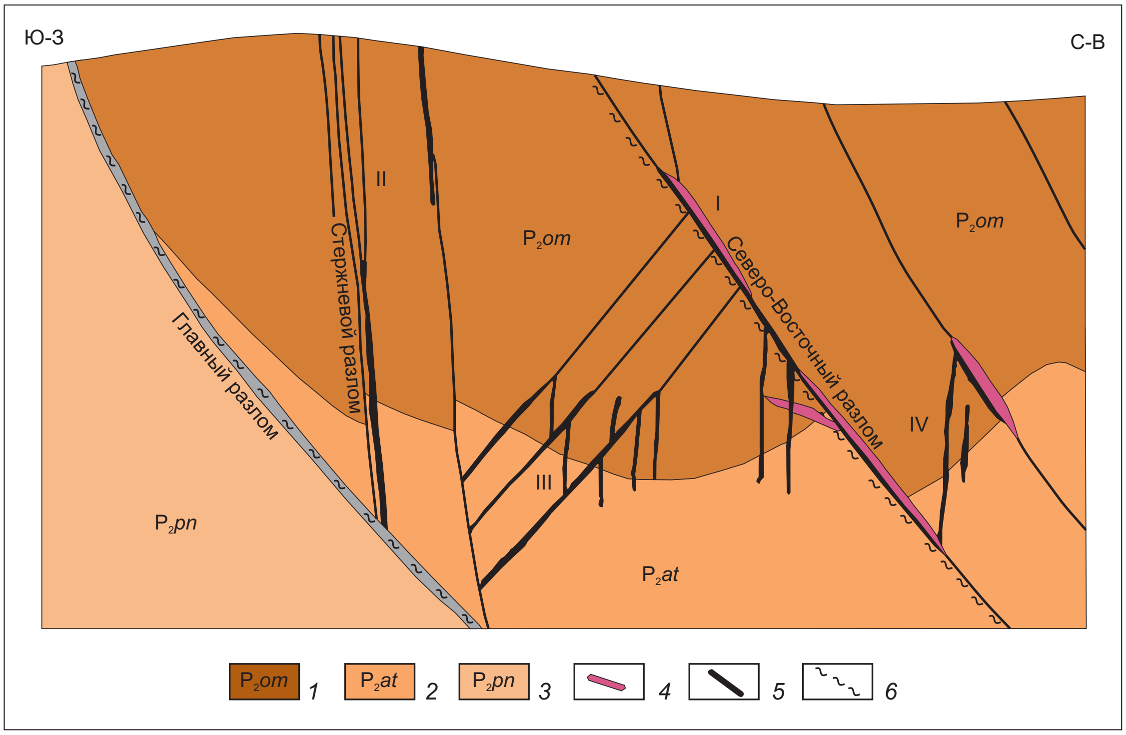


Figure 15: Schematic section of the Natalka mine (Goncharov V.I. et al., 2002). 1-3: Terrigenous sediments of the Omchaksky (1), Atkansky (2), and Pionersky (3) formations; 4: Late Jurassic-Early Cretaceous dykes; 5: Ore zones; 6: Shear zones. I – IV: Ore clusters: I – Northeastern; II – Southwestern; III – Central; IV – Promising.

spongy, dendritic, and crystalline forms up to 2-3 mm in size. Two gold generations are identified: an early generation with a fineness (ppt) of 700-800 units, closely associated with pyrite and arsenopyrite, and a late generation (600-700 units), associated with galena, chalcopyrite, and sphalerite (Goncharov, 2002). Other minerals include pyrrhotite, albite, adularia, ankerite, dolomite, and quartz. Scheelite is observed occasionally. Fahlore (2-12.7 % Ag), bournonite, boulangerite, antimonite, millerite, cobaltite, loellingite are very rare.

Potassium-Argon dating of post-ore and pre-ore dykes (115-55 Ma and 155-130 Ma respectively) limits the age of the mineralization to not younger than the Early Cretaceous (Goncharov V.I,. 2002).

Ore extraction and gold production at the Natalka mine started in 1945; the licensee was the Matrosov Mine. Currently, the license for geological exploration and gold production at the Natalka mine belongs to JSC "Polyus Gold", which is constructing a mine and gold recovery plant. According to investigations in 2006, the reserves within the pit outline for categories B+C1+C2 amount to 1,449.5 t of gold with an average grade of 1.7 g/t in the Natalka mine.

Dukat silver mine

The Dukat mine is located in the Omsukchan district of the Magadan Region, 31 km from the administrative centre of the district and 595 km from Magadan. The prospect was discovered in 1968 by geologists of the Omsukchan Expedition. The silver reserves are the largest in Russia and among the largest in the world. The Dukat ore field is located within the Okhotsk-Chukotka volcanic belt in the Balygychan-Sugoy volcanic depression, the basement of which is composed of intensely dislocated sediments of the Triassic-Jurassic Verkhoyansk complex. The depression is filled by weakly deformed volcanic and sedimentary rocks.

The ore field is situated in a volcanic-intrusive dome complex, 35 km^2 in area, mainly composed of Early Cretaceous felsic volcanic rocks (Konstantinov, 2003). The dome includes a large sub-volcanic body and smaller, sub-volcanic and extrusive bodies (Konstantinov, 2003). The rocks of the Dukat ore field consist of Late Triassic grey marine terrigenous molasse sediments, an Early Cretaceous mineralized rhyolite association and coal-bearing molasse formation, Early-Late Cretaceous andesite and diorite-granodiorite associations, Late Cretaceous rhyolite and leucogranite associations and a Palaeogene basaltic association (Figure 16). The central part of the ore field is composed of ultrapotassic rhyolite, ignimbrite and their tuffs with horizons of black mudstone (Askoldinsky Complex). Along the periphery, there are coal-bearing deposits of the Omsukchan Group, unconformably overlain by a gently dipping andesite cover with conglomerate, tuff and rhyolite horizons. Subvolcanic bodies of various shapes, fissure intrusions and rhyolite dykes, automagmatic breccias of rhyolite, aphyric and nevadite rhyolite, diorite stocks are rather common to the north of the dome structure, forming a semicircle. Semi-circular rhyolite dykes are typical to the east and south. Drill holes in the central part of the ore field penetrated, at a depth of 1200-1500 m, a large intrusion of biotite leucogranite and granodiorite that has a metamorphic imprint on the Askoldinsky volcanic rocks. The uplift is dissected by series (bands) of Palaeogene basalt dykes with a NE strike. They intersect the ore bodies, indicating their post-ore age.

The main mineralized complex is composed of Lower Cretaceous ultrapotassic rhyolite and rhyolite ignimbrite with mudstone horizons. The lower Cretaceous subvolcanic rhyolite hosts chimney deposits and veins with silver and silver-polymetallic mineralization. The latter occur along the periphery of the ore field.

The Dukat ore field is dissected by a series of northeasterly- and, to a lesser extent, northwesterly-trending faults forming step-like breaks, mostly steeply dipping (70°). Ore-controlling faults divide the ore field into several blocks with different ore potential. The blocks can be subdivided into steeply dipping (60-90°) and gently dipping. The latter is less abundant (20 % of the total) and usually formed by splays of faults with larger displacement. Most of the faults have displacements of a few tens of metres, the largest displacement found being 270 m.

The ore bodies are located in pre-ore altered rocks, mainly of chlorite-hydromica-quartz composition. Their emplacement is controlled

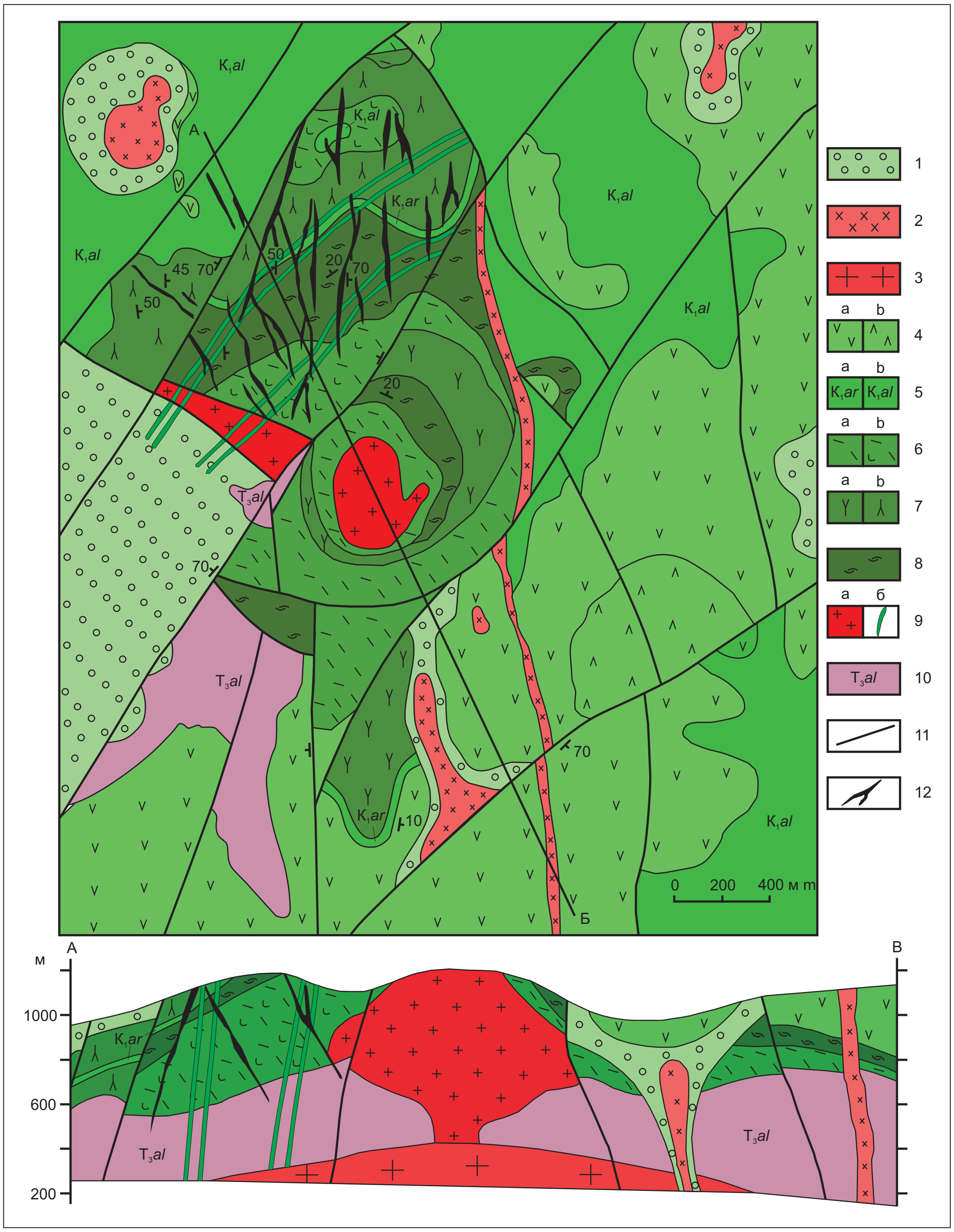


Figure 16: Geology of the Dukat ore field (Konstantinov M.M. et al., 2003). 1-4: Late Cretaceous: 1: Liparite and its tuff, 2: Nevadite, 3: Granite, 4: Andesite of cover facies (a) and subvolcanic facies (b); 5-8: Early Cretaceous: 5: Mudstone (a) and siltstone (b), 6: Fine-grained porphyry rhyolite (a) and its tuff (b), 7: Aphyric rhyolite (a) and its tuff (b), 8: Fluidal aphyric rhyolite; 9: Early Cretaceous nevadite (a) and Palaeogene basaltic dyke belts (b); 10: Triassic siltstone; 11: Faults; 12: Ore zones.

by systems of faults. Two types of ore have been identified: mineralized zones and veins. The mineralized zones are complex formations controlled by the largest faults. They are represented by one or more stem-like veins with a breccia structure, the fragments being of mineralized pre-ore injection breccias and veinlet-disseminated mineralization in the host rocks. The mineralized veins consist of thick (3-5 m) stem-like quartz-rhodonite veins with veinlet-disseminated mineralization in the wall rock (1-3 m). The veins are confined to tectonic zones striking N-S and NE. The contact zones are sharp, curvaceous and 1-2 m thick.

The different ore bodies are characterized by pinches, bulges, cleavage zones, branching and upwards increase in thickness. They may be banded, brecciated, or massive, homogeneous. Zoning has been identified in the emplacement of mineral associations. Stage zoning with mineral assemblages of different ages is confined to different ore-localizing structures. Mineralizations of the quartz-sulphide stage are confined to structures with a northeasterly strike; those of the quartz-chlorite-adularia stage to structures with a near N-S strike, and rocks of the quartz-rhodonite stage to structures with a northwesterly strike. Mineral associations of an earlier gold-silver stage are typical of upper horizons of the prospect: those of the later stages are present in the lower horizons.

There is a clear lithological control on the distribution of the mineralizations. The greatest amount of ore is concentrated in the lower rhyolite, ignimbrite and aphyric rhyolite. The mineralization is rich but uneven. The great heterogeneity with respect to the structures and composition of the rock sequences has caused multi-stage screening of the gold-silver mineralization. The geological and structural position of the ore bodies is determined by various factors including: joints in multidirectional mineralized structures, areas of intersection with large ore-controlling faults, bends in mineralized faults, and intersection of pre-ore fractures filled with basaltic dykes during the post-ore stage.

There are three main ore associations: quartz-sulphide (1 %), quartz-chlorite-adularia (50 %), and quartz-rhodonite (49 %) associations. Almost all the mineral associations are separated by distinct tectonic features. The Au/Ag ratio in the quartz-chlorite-adularia type is 1:340, and in the quartz-rhodonite type, 1:550. More than one hundred minerals of hypogene and supergene origin are known in the deposit. Acanthite, native silver, kustelite, electrum and native gold are of particular economic importance. Galena, silver sulphosalts, sphalerite, chalcopyrite, magnetite and others occur in subordinate amounts.

The most common structures in the ore are banded, rhythmically banded, encrusted, scalloped, colloform and brecciated. So-called "leopard" veins (Konstantinov et al., 2003) are typical of quartz-chlorite-sulphide ore bodies, formed by crushing and later cemented with quartz-chlorite-adularia material.

Rb/Sr geochronology (Konstantinov, 2003, Sidorov, 1985) was carried out on magmatic rocks in the mine and the age of the Askoldinsky rhyolite complex was found to be 123.5 Ma, that of the granites is 80-86 Ma, and the $^{87}Sr/^{86}Sr$ ratio is 0.7119 (+/-) 0.0014, which is typical of granites of crustal origin The radiometric ages of the quartz-chlorite-adularia and quartz-rhodonite types of mineralization are 84 and 74 Ma, respectively.

Development of the Dukat prospect coincided with the commissioning of the Omsukchan gold recovery plant in 1980. In 1995, the work on the field was suspended. 2,500 tonnes of silver were produced from 1980 to 1995. In 2002, the Close Joint-Stock Company "Magadan Serebro" (a subsidiary of "Polymetal") obtained a license for the right to exploit the Dukat deposit and reopened the mine.

Kyuchus gold deposit

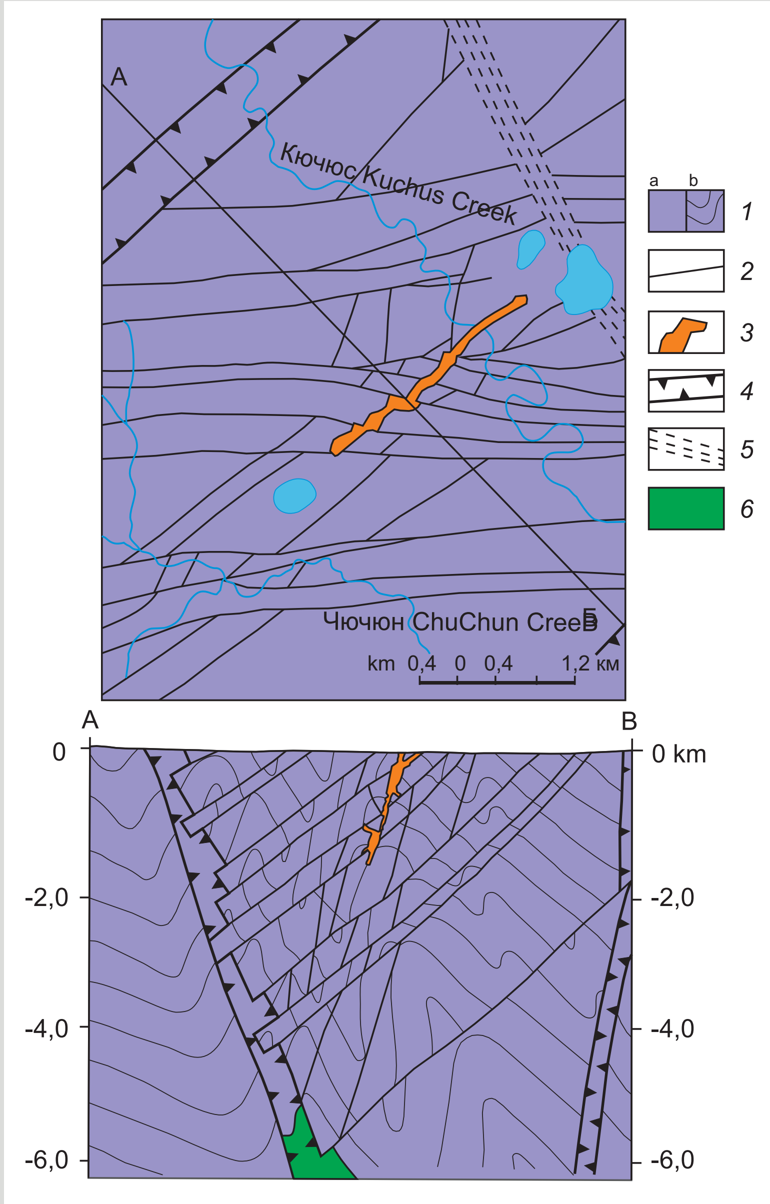
The Kyuchus mine is located in the northern part of the Verkhoyansk Region, in the Republic of Sakha (Yakutia), N of the Arctic Circle, in the lower reaches of the R. Kyuchus, a tributary to the R. Yana. The Kyuchus ore field was discovered in 1963 by the Central Survey Expedition of the Yakut Territorial Geological Department in the course of geological surveying at 1:200,000 scale.

The ore field is located on the eastern limb of the Central Kular anticline cut by the major Yana fault which separates two major tectonic elements of the Verkhoyansk-Chukotka area of folding – the Kular fold-block uplift and the Polousnensky Synclinorium. The ore field is delimited to the northwest by a low-amplitude northeasterly-striking thrust, and to the southeast by a steeply dipping normal fault parallel to the Yana fault zone, and to the southwest by a sub-latitudinal fault that separates it from the block of gentle folding (Figure 17). Two systems of northeasterly-striking faults intersect at an acute angle and dipping towards northwest at an angle of 60-80° are the main elements of the ore field structure (Moskvitin S.G., 2002).

The rocks of the ore field are represented by alternating siltstones and mudstones of Triassic age, characterized by high clay contents and carbonaceous matter. The lower member consists of siltstone interbedded with mudstone and a layer of fine-grained polymictic sandstone. The unit is finely lamellar with inclusions of marcasite and carbonate-siltstone concretions. The upper member consists of siltstone interbedded with numerous layers of light to dark grey sandstone. The sedimentary rocks in the ore field are folded in a north-south trending, anticlinal fold (Konishev V.O., 1995).

The morphology of the ore bodies is compatible with the lithological composition of the sedimentary rocks. Thin, branching shear zones are present in the northeastern part of the field, affecting sandy sediments of the upper member. The ore bodies are dispersed in the sandstone units as thin lens-like deposits. In the middle part of the field, the mineralized zone intersects sediments of the lower member, in which thick persistent shear zones (most favourable for gold-sulphide mineralization) have formed. The morphology of the ore bodies is tabular, commonly lens-like, as is inherent throughout the whole interval of crushed rocks.

Figure 17: Model of the Kyuchus ore field (Konishev V.O., 1995). 1: Ladinian (Upper Middle Triassic) rocks: a: on plan; b: in the cross-section; 2: Faults; 3: Mineralized zones of cleavage, breccia-tion, and boudinage; 4:Tectonic sutures of the transform fault zone; 5: thick cleavage zones transverse to the transform fault; 6: Serpentinized ultrabasic protrusion.



Within the ore field, intrusive rocks are represented by a diorite dyke and porphyric dolerite. The age of the diorite dyke is 137 ± 5 Ma, while the age of the granitoids of the Kular batholith is 156-133 Ma (Moskvitin S.G., 2002).

The ore bodies (a few metres to a few tens of metres thick) with gold-sulphide veinlet-disseminated mineralization partially or completely occupy the shear zones. In some areas, the ore deposits are often disintegrated into series of branching ribbons.

Quartz-stibnite veins are controlled by areas of brecciation and mylonitization of the mineralized zones. They occupy a pivotal part of the shear zones. In plan, the mineralized veins are lenticular and lensoid, with sharp contacts. They are characterized by bulges and twists. The vein thickness ranges from 0.1 to 0.5 m and reaches 1-2 m in the bulges. There are ore shoots (enriched in gold, antimony, and mercury) in gold-sulphide ore bodies. In the longitudinal plane of Ore Body 1, the ore shoots occur as ribbon-like strips inclined northeastwards.

There are three morphogenetic groups of hypogene ores: mineralized shear zones, dilational veins, and breccias. The gold-bearing mineralized shear zones include disseminated and veinlet-disseminated sulphide ores. Disseminated sulphide (1-5 % sulphides) ore is represented by hydrothermally altered sandy siltstone and mudstone with fine, dusty dissemination of needle crystals of arsenopyrite and cubic pyrite. This type of ore makes up the outer zone of the ore-metasomatic system. Veinlet-disseminated sulphide ores fill the inner part of mineralized shear zones and are the main economic ore type in the mine. Newly formed vein minerals are quartz, carbonate, and sericite. A distinctive feature of the ores is the combination of a high frequency of quartz-carbonate veinlets and abundant sulphide dissemination in altered, crushed rocks. Brecciated sulphide-stibnite ores make up selvages of quartz-stibnite veins and areas of intensive brecciation of sulphide mineralization zones. They control the superposition of complex gold-stibnite-cinnabar mineralization on ores of the earlier gold-sulphide stage.

The ore mineralization consists mainly of pyrite, arsenopyrite, stibnite, cinnabar, and rare native gold and mercury. Finely dispersed gold is concentrated in pyrite and arsenopyrite; the economic grade in these ores reaches 100 and 440 ppm respectively. The concentration of dispersed gold in stibnite is never more than 5 ppm (0.5 ppm on the average). From the ratio of gold and silver concentrations in the minerals, the estimated purity of the gold is 800-850 ‰. The inferred gold reserves in the Kyuchus mine are 178 t with an average grade of 8.5 ppm; probable resources are 120 t. By-product grades are: 1.5 ppm Ag, 1.7 % As, 0.5 % Sn, 0.024 % Hg. The prospect can be developed both in open pits and by underground mining. In 2012, the prospect, with a total area of 225.5 km^2, including the Kyuchus mine, was put up to tender, but the tender was not held because of lack of applications for participation. Currently, the ore field belongs to the state.

Prognoz silver deposit

The Prognoz deposit is located north-east of Yakutia, within the Yana-Adycha ore district in the transpolar part of the Verkhoyansk Range on the divide of the Sartang and Nelgese Rivers, tributaries of the R. Adycha. The deposit belongs to the Ulan-Chaidakh ore cluster. It was discovered by Yu. N. Badarkhanov and was first prospected with trenches by V. S. Prokopiev and B. N. Podyachev (1973-1977.)

The deposit is located within the Verkhoyan-Kolyma fold system in the eastern part of the Sartang synclinorium near its junction with the Adycha brachyanticline. Sets of major fractures have near N-S and near E-W strike directions. The former are concordant with the folding, occur in interstratal strips, and separate tectonic blocks with linear folding and blocks with horizontally bedded rocks. The fractures of near E-W and north-easterly strikes, with which the mineralization is related, are later features.

The Prognoz ore field is hosted by Middle and Upper Triassic sandstones and siltstones that are overlain by unconsolidated Quaternary sediments 2-10 m thick (Figure 18). The deposit is confined to the arch of a north-trending anticline. Intrusions within the ore field (Cretaceous quartz porphyry and lamprophyre dikes) are subordinate. The ore bodies show cross-cutting relationships to their host rocks;

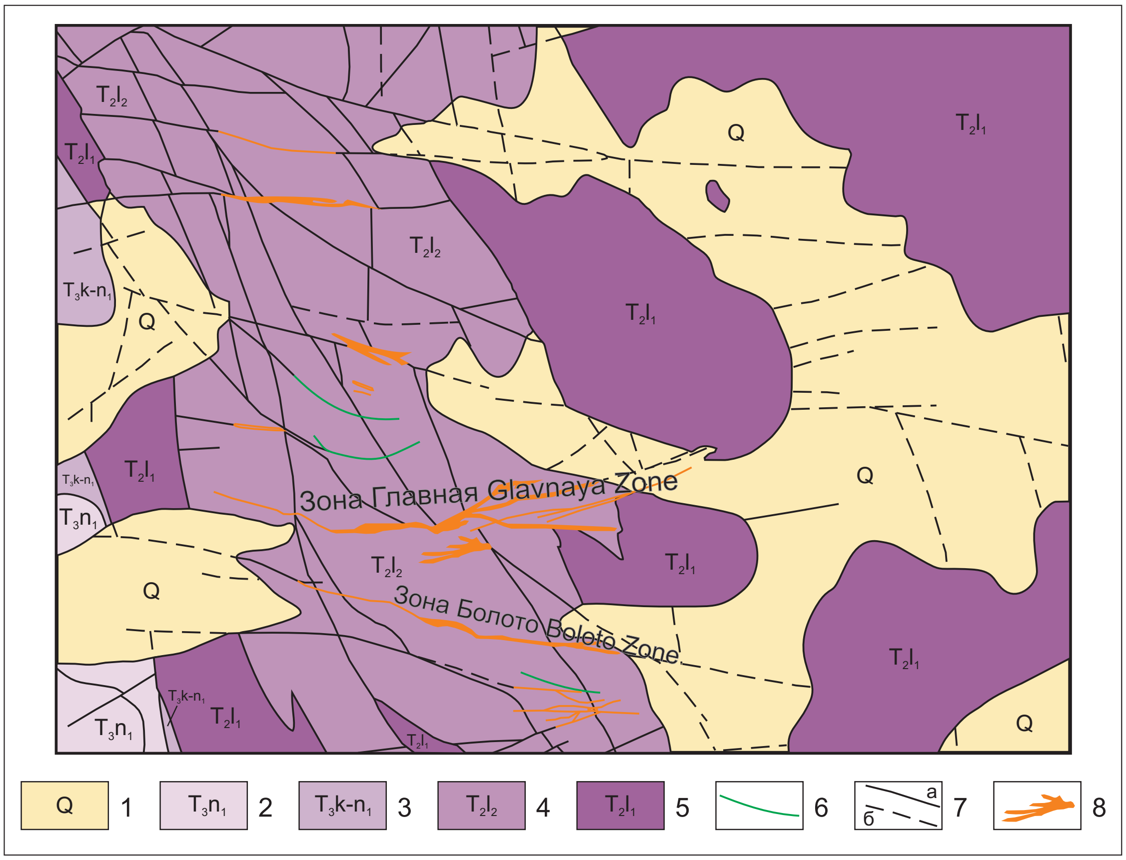


Figure 18: Geological structure of the Prognoz silver deposit (N. P. Zadorozhny, GUGGP Yangeologiya, 2000). 1: Quaternary: Alluvium of flood plain and river bed: pebbles, angular blocks, sandy loam; 2: Norian (Late Triassic): Top substage - Siltstones and sandstones with argillite streaks; 3: Norian: Middle substage - Siltstones and sandstones with benches of interbedded sandstone/siltstone; 4: Carnian (Late Triassic) and basal Norian: Sandstones and benches of interbedded sandstone/ siltstone; 5 Ladinian (Middle Triassic) Top series: Sandstones with rare siltstone strata; 6: Ladinian: Bottom series: Sandstones with siltstone and argillite strata; 7: Anisian (Middle Triassic) Top series: Sandstones with rare siltstone strata; 8: Anisian: Bottom series: Sandstones with siltstone strata and benches of interbedded sandstone/siltstone; 9: Late Cretaceous rhyolite dikes; 10: Late Jurassic lamprophyre (kersantite) dikes; 11: Fractures, mineralized crush zones and their names: 1: verified; 2: supposed.

they are represented by mineralized cataclasite zones with no clear boundaries. The central parts of the ore bodies consist of breccias, brecciated sandstones, quartz-carbonate-sulphide (sulphosalt) veins, and the peripheral parts of cleaved rocks with quartz-carbonate-sulphide veinlets.

The major part of the deposit is represented by the Glavnoye ore body, which contains over 50 % of the reserves and probable resources of silver. Its ascertained length is 4000 m, the maximum commercial mineralization depth is 250-270 m and its thickness is up to 18 m (average: 4 m). It has a near E-W strike (90-120°) and steep southward dip (70-80° up to vertical). Silver is distributed unevenly, with the largest concentrations confined to ore shoots whose positions are controlled by fractures across the body. The content of silver in the ores varies from 10 g/t to 28 kg/t, lead from <10 % to 52 %, and zinc from <10 % to 15 %. The central part of the Glavnoye ore body contains a field of the richest ores, which was given its own name: Izgib.

The Boloto ore body is 500-800 m S of Glavnoye. It is the deposit's second-most productive ore body and includes 21 % of the reserves and probable resources of silver. It has been traced along strike for 2300 m, and for up to 260 m down dip, with thicknesses of up to 7 m (average: 2 m). The content of Ag in the ores is up to 17.7 kg/t, of Pb up to 25 %, and of Zn up to 21.5 %. Apart from Glavnoye and Boloto, nine other ore bodies with NE and near E-W strikes have been discovered in the deposit. Their parameters are: length: 300-650 m, thickness: 1-4 m, average content of silver: 370-1170 g/t, lead: 0.1-5.0 %, and zinc: 0.1-2.0 %.

The ores of the Prognoz deposit are silver-polymetallic and moderately sulphidic. Their principal minerals are carbonates, quartz, galena (in particular, silver-bearing), sphalerite, Pb-sulphosalts (in particular, silver-bearing). Silver minerals include miargyrite, freibergite, ruby silver, owyheeite, diaphorite, schirmerite, zoubekite, argenite, and native silver.

The deposit development license was owned, in 2014, by Prognoz-Serebro LLC. The silver reserves were, as of 01.01.2014: proven (Category A+B+C_1), 4224.5 t, with an average silver content in ores of 906.3 g/t; inferred (C_2), 4966.0 t. Prognoz was, as of 01.01.2014, Russia's largest true silver deposit in terms of silver reserves (larger than Dukat). In Russia, more silver is concentrated only in the silver-bearing Udokan giant copper deposit (No. 1 in in-situ reserves). The average silver grade in the Udokan ores however is only just over 1 % of that in the Prognoz ores, and silver can be mined at Udokan only as a by-product from copper mining.

Blagodatnoye gold deposit

The Blagodatnoye deposit[2] is located in the Central Sikhote-Alin (Khabarovsk Krai). The ore field is confined to a cryptobatholithic zone of the early phase of the Priiskovsky granitoid massif consisting of monzogranodiorite and granodiorite with a high magnetic response, mostly of a sodic type, with high iron oxidation factors (0.33–0.6), and intruded into a series of Lower Cretaceous sandy/clayey rocks. These rocks are, in addition, intruded by dioritic stocks and by many diorite porphyry dikes. The rare-metal mineralization (Sn, W, Mo, Be) is closely related to granites of the second phase (non-magnetic, potassium) which is of late Cretaceous age. The deposit consists of multiple mineralized cataclasite zones containing rare thin quartz veinlets, and veins of quartz, quartz-carbonate, and quartz-sulphide. The mineralized zones' thickness is 0.1-0.9 to 3.6 m. Fragments of sandy/clayey rocks in the zones are cemented by quartz, carbonate and limonite; siderite, and pyrite and arsenopyrite impregnation are observed. The ore veins are complex, branching bodies with many apophyses and pinches. The vein thickness is 0.1-0.3 m (up to 0.5-0.6 m). They are dominated, near the surface, by quartz; apart from quartz, carbonate occurs in the underground mines. Sulphides, including pyrite, arsenopyrite, sphalerite, galena and, less commonly chalcopyrite and molybdenite make up 3-5 %. Impregnation (up to 0.5-1 mm across) of straw-yellow gold is observed. The length of the main mass of veins is a few tens of metres, locally up to 100-200 m and rarely up to 500 m. Their strike may be north-easterly or near north-south, less frequently north-westerly and their dip 50-90°. The average gold contents in the deposit are 1.5-2 g/t. Ore shoots stand out at vein intersections with mineralized zones of north-easterly and north-westerly strikes. The deposit has been partially mined.

The license for prospecting and mining in the Blagodatnoye deposit is owned by Highland Gold Mining Limited (Russdragmet). A multifaceted exploration program is intended to verify the proven reserves. The deposit's forecast resources are 5 tons of gold.

Kupol gold-silver deposit

The Kupol deposit is at the border of the Bilibino and Anadyr Districts of Chukotka Autonomous Okrug (AO) in the north-west of the Anadyr Highlands, near the R. Keyemraveem (tributary of the R. Mechkereva), 300 km from Bilibino. The deposit was discovered by V. V. Zagoskin in 1995 during a 1:200,000 scale geochemical survey. Supplementary exploration was carried out in 1996 and detailed prospecting from 2003.

The deposit is in the northern part of the Mechkereva depression of the Okhotsk-Chukotka volcanic belt deformed by younger tectonic subsidence. It is confined to the the Middle Kayemraveem N-S striking fault zone. The deposit occurs in an area of Upper Cretaceous andesites, andesite-basalts, and their tuffs. Intrusive bodies in the district include diorite-porphyry plutons and felsic to mafic dikes, including rhyolites, microgranites, andesites, andesite-basalts, and micro-gabbros (Figure 19). The thickness of the penetrative Middle Kayemraveem fault zone in the ore field is about 150 m, and it dips 75°E.

2 This deposit should not be confused with the Blagodatnoe deposit in Krasnoyarsk Krai.

The enclosing diorite-porphyry, andesites and granodiorite porphyries in the western footwall of the fault are intensely altered by hydrothermal and metasomatic processes. The rocks are well-developed quartz-sericite metasomatites and contain epithermal ore-bearing veins of quartz and, less frequently, of carbonate-quartz, with weak sulphide impregnation (less than 0.5 %). The ore-bearing vein zone is over 3.1 km long, its thickness is 10-30 m, and the length of the area with ascertained economic mineralization is about 1000 m. The mineralization has a vertical extent of over 430 m.

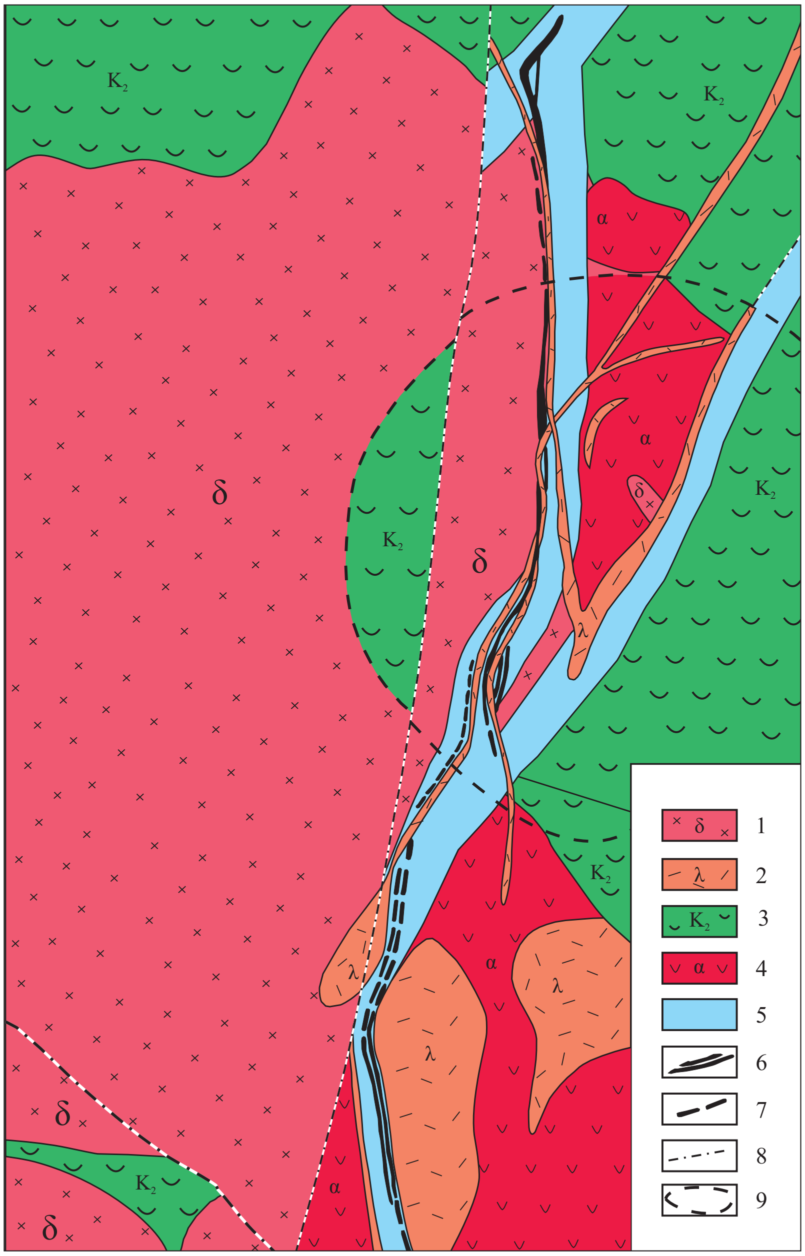


Figure 19: Geology of the Kupol deposit (M. M. Konstantinov, 2006). 1: Diorite porphyrites; 2: Rhyolites, rhyodacites; 3: Intermediate tuffs; 4: Andesites; 5: Crush/argillization zones; 6: Quartz veins; 7: Veinlet silicification zones; 8: Tectonic faults; 9: Ring volcanic structure boundary.

Sixteen ore bodies have been identified in the deposit. They are represented by quartz veins and, to a much lesser extent, by breccias with quartz cement. The veins are not persistent in strike and dip, and are partly replaced by breccias or veinlet silicification zones. The strike of the veins is N-S, concordant with the regional tectonic strike; the dip is 75-85°. The ore bodies are 2-32 m thick and 50-2300 m long. The gold and silver distribution in the ore bodies is extremely uneven. The gold content in the ores varies from 0.01 to 100.0 g/t (up to 2622.1 g/t), the average being 21.5 g/t. The silver content is 0.5-10.0 to 500 g/t (up to 32417.3 g/t), the average is 266.6 g/t. The highest gold and silver contents are confined to quartz and carbonate-quartz breccias. The gold occurs in the ores as nuggets. The gold-silver ratio in the deposit varies from 1:1.6 to 1:50, with 1:10 - 1:11 on average.

The gold-silver mineralization of the Kupol deposit occurs in hydromica-adularia-quartz veins and vein-veinlet zones. The vein minerals are mainly quartz (up to 75 %), sericite, white agate, chlorite, kaolinite, montmorillonite, and zeolites. Ore textures include colloform-banded, concentrically banded, scallop-banded, and sheaf-banded breccia combined with framework-platy, cockade, crested and drusoid textures. The latter is typical for amethyst and crystal quartz. The ore aggregates are mainly thin/fine-grained, less frequently medium-grained. The alternation of bands and ore mineralization distribution in them is determined by the varying textural/structural features of ore aggregate structures, with ovoid, globular, and columnar-crested unevenly recrystallized texture. A feature of the ores is their low content of ore minerals, 1 % or less, though in certain vein sections their content reaches 3 %. Apart from native gold, various sulphides occur in the ores: pyrite, pyrrhotite, chalcopyrite, sphalerite, arsenic and antimony sulphosalts of silver and copper, less frequently gold- and silver selenides. The main economic ore minerals are native gold (mainly 610-700 fineness), ruby ore, stephanite, tennantite, freibergite, acanthite and pearceite. Naumannite and aguilarite occur, but are rare.

The gold occurs as nuggets, varying in size from <0.01 mm to 2.2 mm; the main bulk of the gold in the ore (75 %) is found in fine (less than 0.074 mm) fractions. Native gold occurs in aggregates with vein- and the ore minerals as listed above. The reserves at Kupol, after a geological survey by ChGGP JSC in 2004-2005, were found to be: gold: 154.8 t, with an average content of 18-20 g/t, and silver: 1875 t, with average contents of 220-260 g/t, which make it a large deposit. The mining and gold recovery plant were opened in 2008. The plant's daily capacity is 3,000 t of ore. As of 2011, 45 % of the deposit's active reserves had been mined.

Pavlik gold deposit

The Pavlik gold deposit is located in the Tenkinsky District of Magadan Oblast, by the Omchak stream where it joins the R. Tenka, 20 km S of the Natalkino gold field. The site was discovered by geologist Ye. P. Mashko in 1942: detailed exploration began in 1944, continuing until 1954. The deposit is part of the Omchak placer ore cluster (Figure 20), located in the Ayan-Uryakh anticlinorium, within the contact zone of a granitoid pluton cut by the major Tenka fault (Goncharov et al., 2002) and related to the collisional stage of the Yana-Kolyma fold system.

The rocks enclosing the Pavlik ore field are Late Permian sediments, mostly tuffaceous, silty/pelitic and clayey schists, as well as polymict and arkosic sandstones and fine-pebble conglomerates. The ore occurrences dip steeply or very steeply, complicated by minor folds and fractures. Two minor intrusions are localized on the flanks of the Pavlik ore field: the Vilkin diorite stock at the Vilkin creek, and the Vanin stock of quartz diorite, granodiorite, quartz porphyry, and rhyolite breccias between the Vanin and Lyotchik creeks. Several dykes of intermediate composition (spessartites, porphyrites) are found, and more rarely acidic rhyolites and granite porphyries. The dykes strike NW and dip SE and NE at angles of 50-80°, and are 0.5-1.5 m thick.

The fracture tectonics in the deposit area are very intense, with faults varying in extent, strike, intensity and mode. Contiguous fault systems build up cataclasite zones; their thickness varies from fractions of a metre to scores of metres. The internal ore tectonics are defined by the wide development of local shear zones which typically, in the postore stage, show reactivation with amplitudes of 0.1-20 m.

About 30 ore zones are known within the Pavlik ore field, of which two represent the bulk of the ore. The mineralized zones have a north-westerly strike and a thickness of 5-10 m to 30-40 m. The ore zones are consistent in strike and dip, but their thicknesses vary; the average thickness is 1.5 - 7.0 m and the average gold content varies from 3.4 to 6.6 g/t. The ore zones are a combination of veins, veinlets, and metasomatic- to breccia-silicification zones; the mineralizations commonly form stockworks. Selvages of the ore zones are unclear and can only be identified by analytical data. The deposit has blind ore zones, some of them outcropping as veinlet systems with weak mineralization, which develop into thick ore bodies with depth. In terms of morphology, the ore bodies in the Pavlik deposit occur as:

- Veins and lenses of open-cavity filling with clear, sharp contacts.
- Systems of near-parallel branching quartz veinlets.
- Silicified intensely crushed zones.
- Belts of hydrothermally altered wallrock enclosing rocks.

The mineralogy and genetic attributes of the Pavlik deposit mineralization indicate that it belongs to the low-sulphide (pyrite-arsenopyrite) type of gold-quartz deposits. The veins are mostly of quartz, commonly quartz-carbonate and rarely only carbonate. Apart from native gold, the ore minerals observed in bulk are arsenopyrite and pyrite. The former is more frequently found in vein quartz, but is also widespread in the enclosing rocks as small scattered disseminations, and less frequently as nodular accumulations. Pyrite is more typical for the host rocks, the total sulphide content not exceeding 1 %. Gold is observed consistently with arsenopyrite; its distribution is uneven or very uneven; it occurs as irregular grains, lamellae and flakes. The particle size varies from <0.1-0.5 mm and, rarely, from 1.5-4.0 mm.

Currently, the license for geological surveying and mining of the Pavlik deposit is held by Arlan

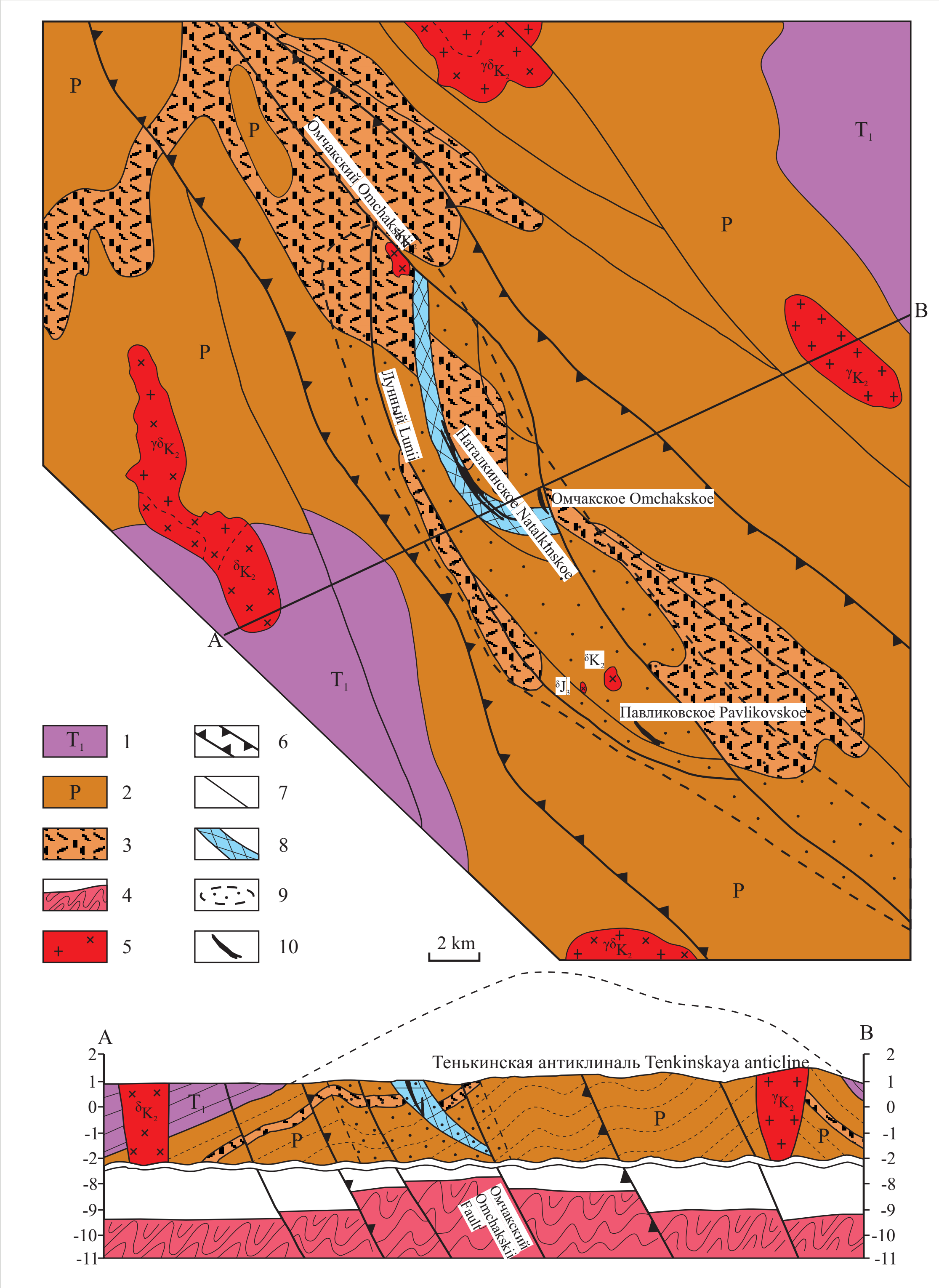


Figure 20: Geological structure of the Omchak ore cluster (Goncharov et al., 2002). 1: Triassic silt-clayey sediments; 2: Permian sediments; 3: Atkan suite diamictite; 4: Meso-zoic basement; 5: L. Cretaceous granitoid massifs; 6: Boundaries of the Tenkino Deep Fault; 7: Faults; 8: Natalkino fault zone; 9: Stilpnomelane sub-facies of greenschist-facies of regional metamorphism; 10: Gold fields.

Investment Co. An open pit and concentrating mill are being built, for a capacity of 3 Mt of ore per year. The deposit reserves in Category C_1+C_2, based on company data, are estimated at 154 t of gold, with probable reserves of over 200 t.

Ametistovoye gold deposit

The Ametistovoye deposit is located in the northern part of the Kamchatka Peninsula, 100 km NW of Korf. The deposit was discovered in 1968 during a 1:200,000 scale geological survey. The Ametistovoye deposit is located in the Tklavayam ore field, in the western part of the Ichigin-Unneivayam volcanogenic district, a fragment of the Palaeogene West Kamchatka volcanic belt.

The district's magmatic formations are grouped into two complexes (Khvorostov & Zaitsev, 1983): Unnei, of acidic composition and crustal origin, and Ichigin, intermediate and of deep-seated origin. The base of the section (150–200 m) is represented by rocks of the Unnei complex: ignimbrite-like liparites, liparite dacites, acidic tuffs overlain by tuffites, and tuff sandstones with carbon streaks. The top of the section, represented by the Ichigin complex, comprises lavas and tuffs of dacites, andesitic dacites, andesites and andesite basalts (200-400 m), and by subvolcanic bodies of diorite porphyrites, andesites, and dacites forming the central and peripheral orifices of the original volcano.

The Tklavayam ore field (Figure 21) is confined to a volcanic structure (of the same name) of a central type, intruded at the intersection of the near N-S trending Uchigin and north-westerly-trending Tklavayam regional faults. The ore field has a complex structure; it is split into several sectors by fractures of northwesterly and near N-S strike and blocks sunk stepwise into the central part of the structure. These fractures, together with the extrusive and subvolcanic bodies, are the basic structural elements of the ore field.

The mineralization is localized in the centre of a palaeo-volcano in subvolcanic intrusions of diorite porphyrites, dacites, andesites, trachydacites, which are propylitized and adularized. The ore bodies are parts of vein bodies and vein zones containing economic grades of gold and silver, primarily by cavity filling, with subordinate metasomatic replacement. The ore zones' thicknesses are up to 100 m, and their length up to 1.5 km. The ore bodies' length varies from <100-800 m, their thickness being 0.5-2 m, and 3-6 m in swells. The ore bodies' strikes are diverse: E-W, N-S, NW and NE. The veins dip steeply, and consist predominantly of quartz with or without sulphides. The veins are grouped in zones, 4-6 veins in each. The largest veins are Champion, Izyumin-ka and Ichiginskaya. In all, about 300 veins are known, with economic ones located in an area of 5 km^2, which constitutes only one-seventh of the area of the ore field. The structures and composition of the vein fillings are diverse, but banded and rhythmically banded textures predominate. Four ore deposition stages have been identified: early silicification, sulphide-quartz, gold-kaolinite-sulphide-quartz (main productive stage), and carbonate-quartz. High selenium contents (30-40 g/t) are observed in the ores, and up to 1 % of total lead, zinc, and copper.

The veins consist of quartz with lesser quantities of kaolinite and chlorite; less common minerals include illite, calcite, montmorillonite, dickite, and adularia; fluorite and zeolite are present, but rare. The sulphide content is up to 3-5 %, but up to 20-30 % at depth. The ore minerals are electrum, acanthite, and more rarely, ruby, silver, polybasite, stibiopearceite, stephanite, miargyrite, proustite, plagionite, naumannite, aguilarite, kustelite, native silver etc. Pyrite, galena, sphalerite, and chalcopyrite are also quite abundant in the ores. The Au:Ag ratio is commonly 1.5-2.1, and up to 1:10-20 in sulphide ores.

Native gold is found in quartz, in aggregates with acanthite; gold grains abut locally on silver-bearing minerals. The size of the gold particles is 0.001-0.01 mm. Isometric cloddy and flattened cementation-honeycomb forms predominate; the smallest, cub-octahedral and dendroid crystals up to 0.05 mm in size, are typical. Gold assays (fineness) vary from 200 to 680, with 550-600 predominating; at deeper horizons assays increase to 730-875, and 830-960 in oxidized ores. Impurities in the gold include: Sb, Pb, As, Sn, Cu, Mn. Gold is positively correlated with Ag, Se, and Sb, and show negative correlations with Pb, Zn, Cu, and As.

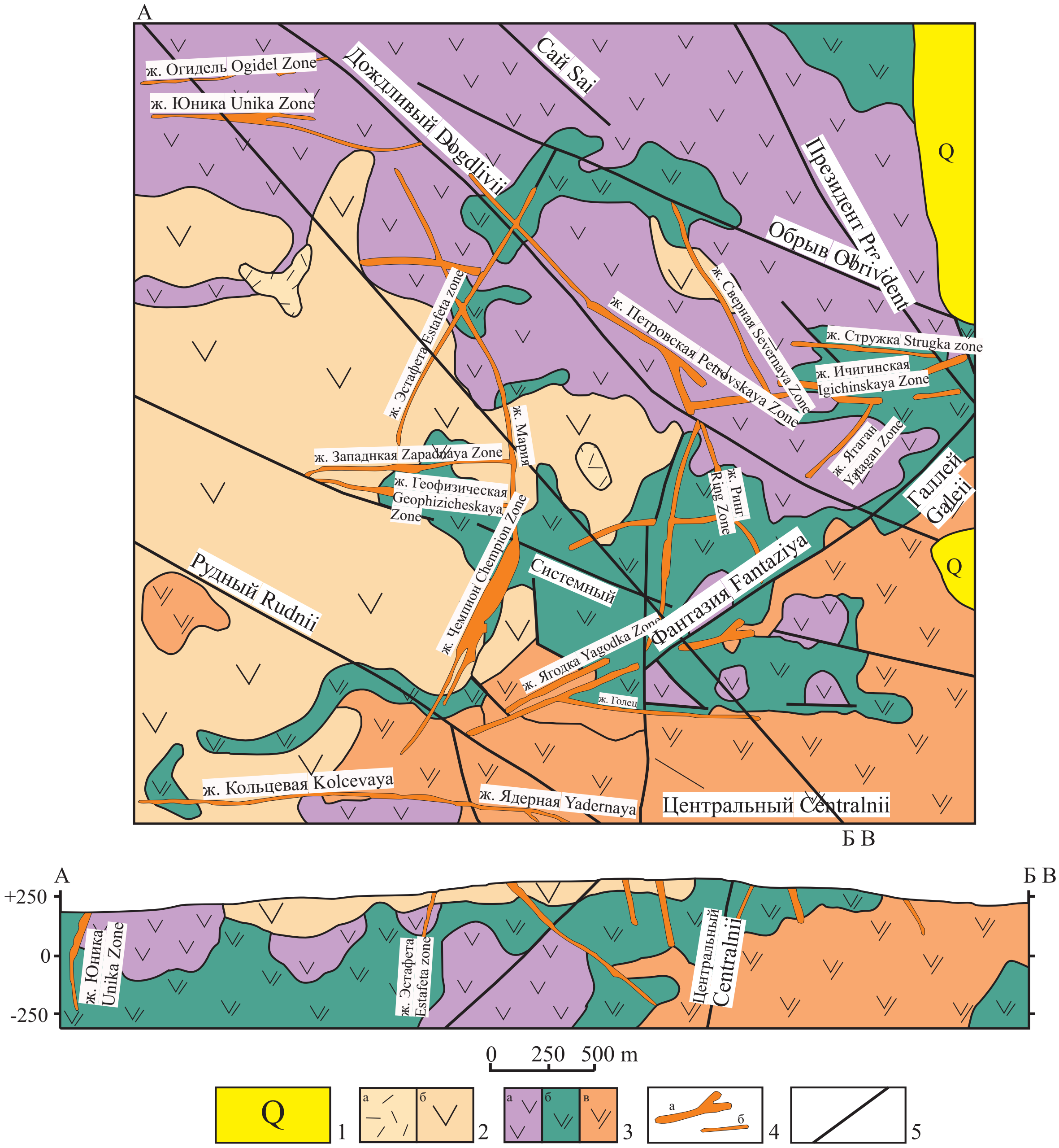


Figure 21: Geological structure of the Ametistovoye deposit (acc. to L. A. Bezrukov). 1: Quaternary sediments; 2: Oligocene volcanites: rhyolites (a), andesites (b); 3: sub-volcanic Oligocene intrusions: diorite porphyrites and spessartites (a), andesites (b), trachytes and trachydacite porphyries (c); 4: Productive (a) and non-productive (b) quartz veins; 5: Fractures.

The deposit's reserves were approved by the RF State Commission for Reserves on May 24, 1995; for Category C1+C2, they are 52.5 tons of gold with an average content of 13.62 g/t, the cut-off being 3 g/t. The deposit mining license is owned by Zoloto Kamchatki JSC. Development of the deposit began in 2014 and a gold recovery plant, with a capacity of 600,000 t/a, is being built. A test using a direct-leaching method gave a gold recovery level of 97.5 %. The ore will be mined by both open-pit and un-derground methods, which will reduce mining costs and lead to more efficient attain-ment of the facility’s design capacity.

Elgi River Placer (Au)

The Elgi River placer is located in the Yana-Kolyma gold-bearing belt, in the Upper Indigirka District. The R. Elgi is a tributary of the R. Indigirka and flows across the Elgi Plateau. The placer is part of the Taryn-Elgi gold-bearing zone, 100 km away from the river head, in a 4.5—5 km wide valley. The highest water flow rate is 191

m^3/s. The valley extends along a fracture zone and along the axis of a synclinal structure. The placer extends for 2.6 km, is tens of metres wide, has a lens-like structure, and comprises several channels 100-600 m long. The direction of the enriched channels corresponds to the strike of the parent rocks. The thickness of the productive strata is generally 1-2 m, seldom 3.2-4.8 m; gold is found in the parent rocks to a depth of 2 m. The linear distribution of the gold reserves changes noticeably through the placer, with the highest values recorded in the middle.

The gold is relatively uniform in the distribution of its forms. Plates and grains predominate; tablets, dendritic crystals, dendroid forms, and rods are less frequent. Plates make up 30-95 % and have varying thickness, their numbers increasing both down the placer and laterally. In the most enriched channels the content of plates and rounding of gold grains decrease. The grain sizes are distributed as follows: fine (< 2 mm), 47.1 %; medium (2-6 mm), 38.7 %; large (over 6 mm), 14.2 %. The average gold grain size is 3.99 mm; within the placer's commercial sector, grain size variations are small. The highest contents of the 4-6 mm fraction are observed on Lines 482, 486, and 490. Large-fraction gold and nuggets are found in the middle of the placer because of local mother lodes on Line 482. The gold fineness varies from 850 to 986 ‰. The average fineness for 35 analyses is 887 ‰.

Bolshoi Taryn River Placers (Au)

The Bolshoi Taryn is a tributary of the R. Indigirka located in the Taryn-Pilsky ore cluster. The placer deposit extends along ore-bearing fractures that emerge due to destruction of quartz veins and silicification zones located directly in the placer bedrock and related to gold-arsenopyrite-pyrite and partially to the gold-sulfo-antimonite mineral types. The flood plain placer has been traced for several kilometres. Its commercial channel starts from Line 552 where a quartz vein with a certain gold grade is located. The accessory minerals are pyrite and arsenopyrite, which are also found in alluvial sands. Plate, tablet, dendroid, and irregular gold grains have been found both in the placer and in the quartz vein. Silicification zones (0.12-0.5 m thick) have also served as sources for the placer; they are found not only in its upper but also in its middle part. An important feature of the Bolshoi Taryn placer is alteration of the mineral composition of parent gold sources across the valley profile.

Berelekh River Placer (Au)

The deposit is located in the central part of the Inyali-Debin synclinorium. Its basement consists predominantly of Middle Jurassic sandy/clayey schists, cut by multiple dikes of acidic and intermediate composition and by granitoid intrusions. Quaternary sediments form a ubiquitous cover. Middle Jurassic sediments are represented by the Meredui suite, the base of which has a rhythmic alternation of grey fine-grained quartz-feldspar sandstones, lamellar siltstones and dark-grey clayey schists. The upper part of the suite consists of thick strata of grey fine-grained sandstones with streaks of clayey schists and siltstones. Sparse streaks and lenses of gravelstone and conglomerate are typical. Quaternary sediments fill the wide (up to 3 km) valley of the Berelekh and the valleys of its tributaries, and form a cover on valley slopes and divides. The sediments are of various genetic types and facies including alluvium, deluvium, eluvium and proluvium.

The district is located in the central part of the Inyali-Debin synclinorium of the Yana-Kolyma orogen. The entire sedimentary complex is deformed by linear folds with a north-westerly strike and a subsequent fracture system. The largest folds are the Solkalyakh syncline and Berelekh and Yutichna anticlines which have wavelengths of 5-10 km and lengths of tens of kilometres. They consist of linear folds of higher orders, whose axes are oriented in the same direction as those of the larger folds. The strata on the fold limbs have steep to vertical dips; inverted folds are also found. In terms of spatial orientation relative to folding and displacement amplitude, three groups of faults corresponding to three deformation stages are identified in the district: pre-intrusive, post-intrusive, and neo-tectonic.

Geomorphologically the district is located in the piedmont of the Burganda massif and occupies the northwestern part of the Talon trough, which, in addition to various exogenetic and endogenetic factors, predetermined the nature of its geomorphic structure. The Berelekh River has an approximately north-south direction and valley width of 4–5 km. The cross section is asymmetric, with a steep east side and flat west side. In all, seven terrace levels have been identified, 3-5 to 200-210 m high. In addition to those seen in today's relief, buried ancient valleys are also found.

The gold-bearing stratum occurs in the lower horizon of alluvial sediments, in the eluvium and the upper part of the parent rocks, penetrating them to depths of up to 1 m. The gold distribution is pocket-and-channel; against the background of vertical reserves of 0,1-1 g/m^2, 1-2 g/m^2, and 2-4 g/m^2, there are channels and pockets with vertical reserves of 4-8 g/m^2, rarely 8-16 g/m^2. The gold occurs as flattened plates, flakes, tablets, or lumps, in individual rods or grains, sometimes ore-like (in fine and very fine fractions), nuggets of up to 1.5 g occur. The gold grain surface is smooth, pitted, pitted and granular, cavernous; the shapes are well-rounded oval, extended, elongated, or irregular. Gold of large and very large fractions often occurs in aggregates with milk-white quartz. The gold color is yellow with a slight reddish tint. The grains are generally well-rounded. Apart from gold, the placer contains cassiterite, scheelite, wolframite, ilmenite, arsenopyrite, pyrite, pyrrhotite, garnet, zircon, hematite, galena, and monazite.

As of 01.01.2012, in the summary balance report for Magadan Oblast, commercial and non-commercial gold reserves within the allotted mineral area were registered for the Berelekh River valley proper and for its tributaries' valleys. In all, within the licensed area, the economic reserves of placer gold, Category C1, were registered at 9,384 kg gold with an average gold content of 2.93 g/m^3, and non-commercial reserves of Category C1 at 205 kg with an average gold content of 7.59 g/m^3.

Allakh-Yun River Placer (Au)

The placer gold deposit of the Allakh-Yun River (Vidny field) is a part of the Allakh-Yun ore-bearing district in the south-east of the Republic of Sakha (Yakutia), in Ust-Maya Ulus municipality and 286 km from the central town of Ust-Maya. Exploration for gold in the River Allakh-Yun began in 1932. Commercial placers were discovered in the north-bank tributaries of the Allakh-Yun at an early stage – in the Baatylo, Yevkandja, and Segine creeks. In 1934-1940 new placers were discovered in the valleys of the Minor, Ynykchan, Koro, and Zaderzhnaya creeks. Prospecting and exploration by the Yudom crew of the Allakh-Yun Expedition in 1961-66 resulted in an appraisal of the Ust-Ynykchan field, a large placer deposit, as suitable for dredge mining. In 1988, the Djugdjurzoloto mill carried out further exploration work.

As of 01.01.2011 the National Register included, for the Allakh-Yun River deposit (Vidny field): Category C_1 commercial reserves of 5,089,000 m^3 of sand and 3,960 kg of gold, and non-commercial reserves of 349,000 m^3 of sand and 146 kg of gold.

Bolotny Creek Placer (Au)

The Bolotny creek is a tributary of the At-Uryakh creek; the placer is within the At-Uryakh ore cluster. Geologically, the deposit is related to the Inyali-Debin megasynclinorium which folds Jurassic terrigenous sediments.

The Bolotny creek placer has an alluvial genesis; the creek valley is asymmetric, with depositional terraces 2-3 m or 4-6 m high. The deposits consist of variably sized pebbles with silt-clay-sand fill, of gravel and rocky inclusions, and individual smaller boulders; the section's top is formed by peat and silt with lenses of ice. The sands consist of variably sized pebbles, moderately to well rounded, with gravel, sand, and silty clay, and of a few boulders near the bedrock. The bedrock is formed by clayey and sandy/clayey schists, siltstones and less commonly by sandstones; the bedrock surface is wavy.

The placer is 1170 m long, 10-80 m wide and has an average gold content of 2.2 g/m^3; and a fineness of 931 ‰. The gold distribution is pocket-and-channel; the vertical reserves are represented by the classes 0.1-1 g/m^2 and 1-2 g/m^2. The gold consists mainly of tablets and plates of irregular shapes with rugged edges, less common lumpy grains; medium rounding; gold grains with a spongy surface and quartz growths can be found; the colour is yellow or reddish-yellow. Apart from native gold, the placer contains ilmenite, magnetite, scheelite, rutile, zircon, and arsenopyrite.

Rakovsky Creek Placer (Au)

The Rakovsky creek is a tributary of the River Sluchainy; the placer is part of the Orotukan ore cluster. Geologically, the deposit is related to the Inyali-Debin megasynclinorium built up by Middle Jurassic terrigenous sediments. The relief consists of a dissected low-hill terrain with absolute elevations of 600-900 m and relative elevations above the valley bottoms of 250-400 m; the creek valley is asymmetric, with remnants of buried terraces 5-10 m high.

The Rakovsky creek placer is a valley and banded placer, with channel distribution of ore; the gold-bearing stratum is confined to the near-bedrock part of alluvial sediments and to weathered parent rocks, down to to 0.2 m. Surficial sediments consist of gravel-pebble sediment with sandy/clayey fill and silty clay with lenses of ice. The bedrock consists of fractured sandy/clayey schists with a wavy surface.

The placer is 1200 m long, 20-90 m wide and has an average gold content of 1.47 g/m^3 and a fineness of 957 ‰. The gold distribution is pocket-and-channel, against a background of vertical reserves of 0.2-1.0 g/m^2; channels with extremely unstable strikes, with a vertical reserve of 1-2 g/m^2 and >2 g/m^2 are observed. The gold is mainly medium-rounded, the grain shape is tablet or plate, less frequently lumpy: gold and quartz aggregates occur; the grain colour is yellow or golden yellow.

Kongo River Placer (Au)

The Kongo River flows into the R. Kolyma from the east; the placer is located within the Sibik-Tyellah ore cluster. Geologically, the deposit is related to the Inyali-Debin megasynclinorium formed by Middle and Upper Triassic terrigenous sediments. The relief of the area is dissected low-hill terrain with moraine in the upper part of the valley: summit elevations are 800-1250 m and the relative elevations above the valley bottoms are 200-500 m. The southern tributaries of the Kongo originate from the Pravo-Obninsky granite massif where summits reach 1840 m; the valley is asymmetric, and has terraces 0.5-4 m, 5-10 m, and 20-40 m high.

The Kongo River placer is a valley and banded placer, with channel ore distribution and of alluvial genesis. Commercial reserves for open-pit mining have been explored at the outwash of the Ozerny, Sukhoi, and Agach creeks with branching to the Ozerny creek valley and on the right terrace of the 10th level; on the lower flank, the placer has been partially mined (at shallow depths); the gold-bearing stratum occurs in the bottom horizon of alluvial sediments and in the decayed top part of parent rocks, to a depth of up to 1.8 m.

The placer is 6625 m long, 20-520 m wide and has an average gold content of 7.48 g/m^3 and a fineness of 859 ‰. The gold distribution is pocket-and-channel; grades in successive layers are 0.1-1 g/m^2, 1-2 g/m^2, 2-4 g/m^2 and 4-8 g/m^2, there are channels and pockets with vertical reserves of 8-16 g/m^2, 16-32 g/m^2, but rarely higher.

The gold is represented by plates, tablets, tiny lumps, dendrites, flakes, or dust with wavy, smoothed, or embayed edges, with an even, tuberous, or coarse surface; the grains are well-rounded, with poorly-rounded gold occurring in fine fractions; the colour is pinkish-yellow or reddish-yellow, locally greenish-yellow, brown or black due to an iron oxide film. Apart from native gold, the placer contains pyrite, arsenopyrite, galena and chalcopyrite.

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BASE METAL DEPOSITS AND ASSOCIATED PGE ORES

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Sardana Lead-Zinc Deposit

The Sardana stratiform lead-zinc deposit was discovered during a 1:200,000 scale geological survey carried out by A. I. Gorbunov in 1971. The deposit is a part of the Kurung-Dyukat ore cluster. It is located near the middle reaches of the R. Aldan, in the spurs of the Gornostakh ridge extending N-S from the Tompo River to the R. Allakh-Yun River parallel to the Sette-Daban ridge. 1:50,000 scale geological mapping was carried out in 1972-1974, and detailed prospecting at 1:10,000 scale in 1972–1977. The deposit area was covered by an aerial magnetic survey for the 1:200,000 scale, partially for 1:50,000 scale mapping, and also by a 1:200,000 scale gravity survey.

The deposit is located in the Yudomian-Mai structural/formational zone at the interface between the Siberian platform and Verkhoyansk fold system. Regionally, the Sardana deposit is confined to the Kyllakh foldblock rise of the Sette-Daban horst anticlinorium. The deposit is located in the Sardana syncline, extends 9 km N-S, and has a markedly variable crosssection shape. Its width is 3.5–4 km but contracts southwards to 1.5–2 km. Second- and third-order

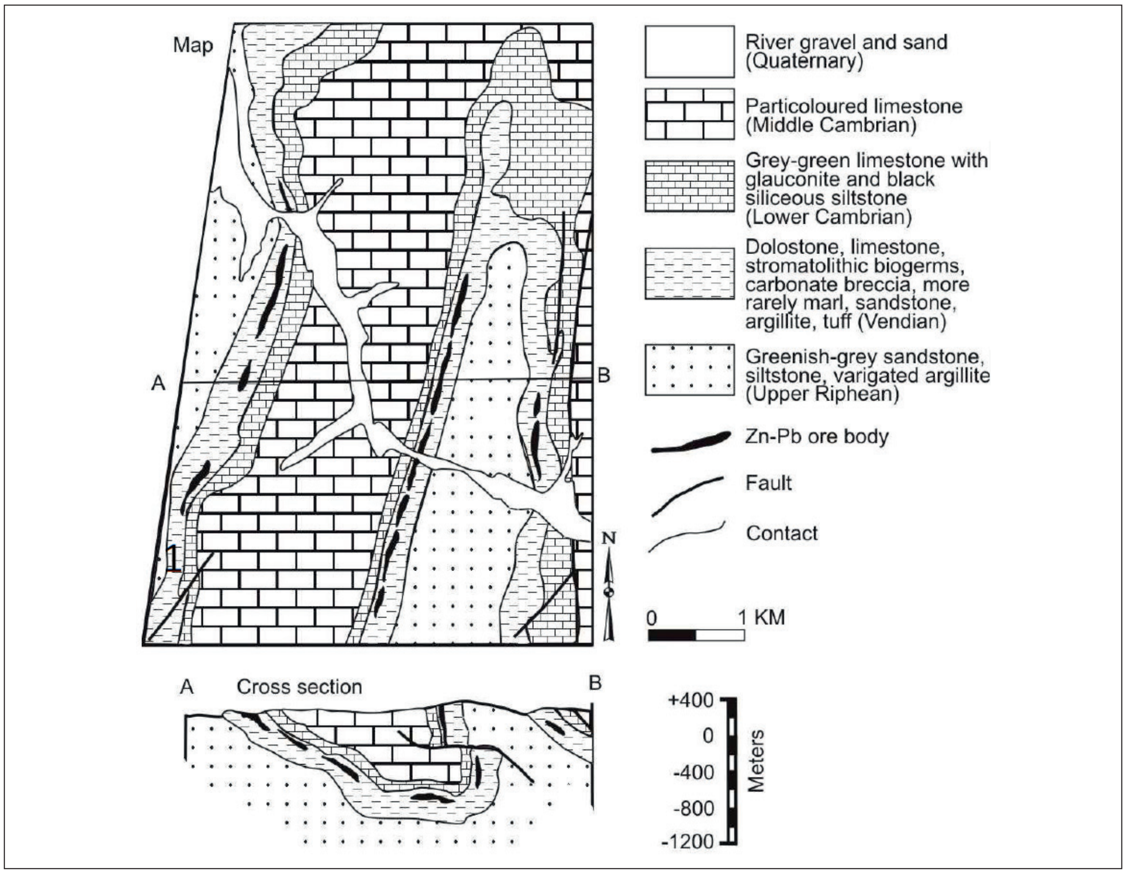


Figure 22: Schematic geological map and cross section of the Sardana lead-zinc deposit (Nokleberg et al., 2005).

folds, commonly accompanied by fractures are widely developed in the core of the Sardana syncline. Magmatic rocks are represented by rare sills and dikes of dolerite and microgabbro of Late Proterozoic age, and very rare alkaline rocks.

Three structural stages are identifiable in the district: Middle-Upper Riphean folded basement and Vendian to Palaeozoic, and Mesozoic, forming the fold nappe of an epi-Baikal platform. Within the deposit, the stratigraphic base is represented by Upper Riphean sediments (argillites, siltstones and sandstones). Terrigenous carbonate and carbonate sediments of the Vendian Yudomian suite (silica dolomites, dolomites, sandstones with siltstone streaks, dolomites with argillite streaks, limestones) overlie these. The uppermost sequence in the section consists of Lower and Middle Cambrian carbonate and terrigenous carbonate formations (dolomites, limestones, bituminous dolomites, argillites, carbonate breccias, marls). The orefield rocks are deformed into a series of linear folds with an approximately E-W strike and a marked asymmetric structure. The anticlines mostly have flat eastern limbs and steep, in some cases west-vergent limbs.

Most of the ore bodies are confined to steep or vergent fold limbs. The ore zones are both concordant and occasionally flat and with cross-cutting relationships to the lithological bedding. They have a N-S elongation and are closely associated with epigenetic dolomites. The ores are localized in hydrothermally/metasomatically altered carbonate rocks and dolomites (Figure 22). They consist of strips of impregnated and nested-impregnated sulphide mineralization with alternating poor and rich impregnation zones. Mineralization is widespread in the rocks of the upper subsuite of the Sardana suite. The ore-enclosing host unit is 80-120 m thick. There are three main groups of ore bodies in the host rock: one near the base, one in the central part and one in the upper horizons.

Figure 23: Galena-sphalerite ore, Sardana deposit.

The lower ore level is confined to the bottom of the ore-bearing unit, and locally enters the bituminous horizon. The metal accumulation at this ore level is the largest, and is represented by galena-sphalerite and pyrite-galena-sphalerite (pyrite-polymetallic) ores. The ribbon-like banks are up to 3 m thick and up to 1500 m long. The middle ore level comprises ore bodies consisting of galena-sphalerite ores, locally with pyrite. Most of the ore bodies are confined to this level. The ore bodies form “tabular” banks about 5 m thick and 150 to 200 m long. The uppermost ore level is localized under variegated limestones, though the mineralization occasionally extends even higher. The ore bodies consist of galena and sphalerite and are usually confined to a productive horizon of dolomites, and have a limited lateral extent. The ore bodies consist of ore shoots with an average thickness of 10 m and length of 75-100 m, and are rich lead-zinc ore.

The main economic type of ore in the deposit is galena-sphalerite ore with sphalerite predominant (Figure 23). Locally there are monomineralic sphalerite and sphalerite-galena-pyrite ores. Textural features observed in the ores include massive, banded, veinlet, veinlet-nested-impregnated, veinlet-impregnated, and impregnated ores; breccia-like ores also occur, but are rare. Massive sphalerite-galena ores do not form separate ore bodies and have limited, local development. The ores are generally banded, locally breccia-textured and impregnated types occur.

The deposit’s main minerals are sphalerite, galena, dolomite, and calcite; subordinate minerals are pyrite, marcasite, sulphosalts of antimony and arsenic, arsenopyrite, and chalcopyrite. The lead:zinc ratio is 1:4 - 1:5. Cleiophane (a pale-coloured variety of sphalerite), rare jordanite, geocronite, guadalcazarite, electrum and other minerals have also been observed. Secondary minerals developed in the oxidation zone (in small amounts) include cerussite, smithsonite, hemimorphite, scorodite, crocoite, anglesite (lead sulphate), goethite, and hydrogoethite. The deposit is characterized by rich galena-sphalerite ores with high, contents of accessory components, including germanium (20-1150 g/t), of cadmium (10 - 2900 g/t), of silver (1-234 g/t), and mercury (0.001-100 g/t). The host minerals are sphalerite for germanium, cadmium and mercury, and galena for silver. The deposit's reserves (Category C2) were, as of 01.01.14: lead: 592,000 t, with an average grade of 3.23 %; zinc: 1,926,400 t (10.50 %). The deposit development license was in 2014 held by Siberian Nonferrous Metals LLC (a member of the Summa Group). Under the terms of the license, the target date for beginning the development of the Sardana deposit is October 2017.

Pavlov Lead-Zinc Deposit

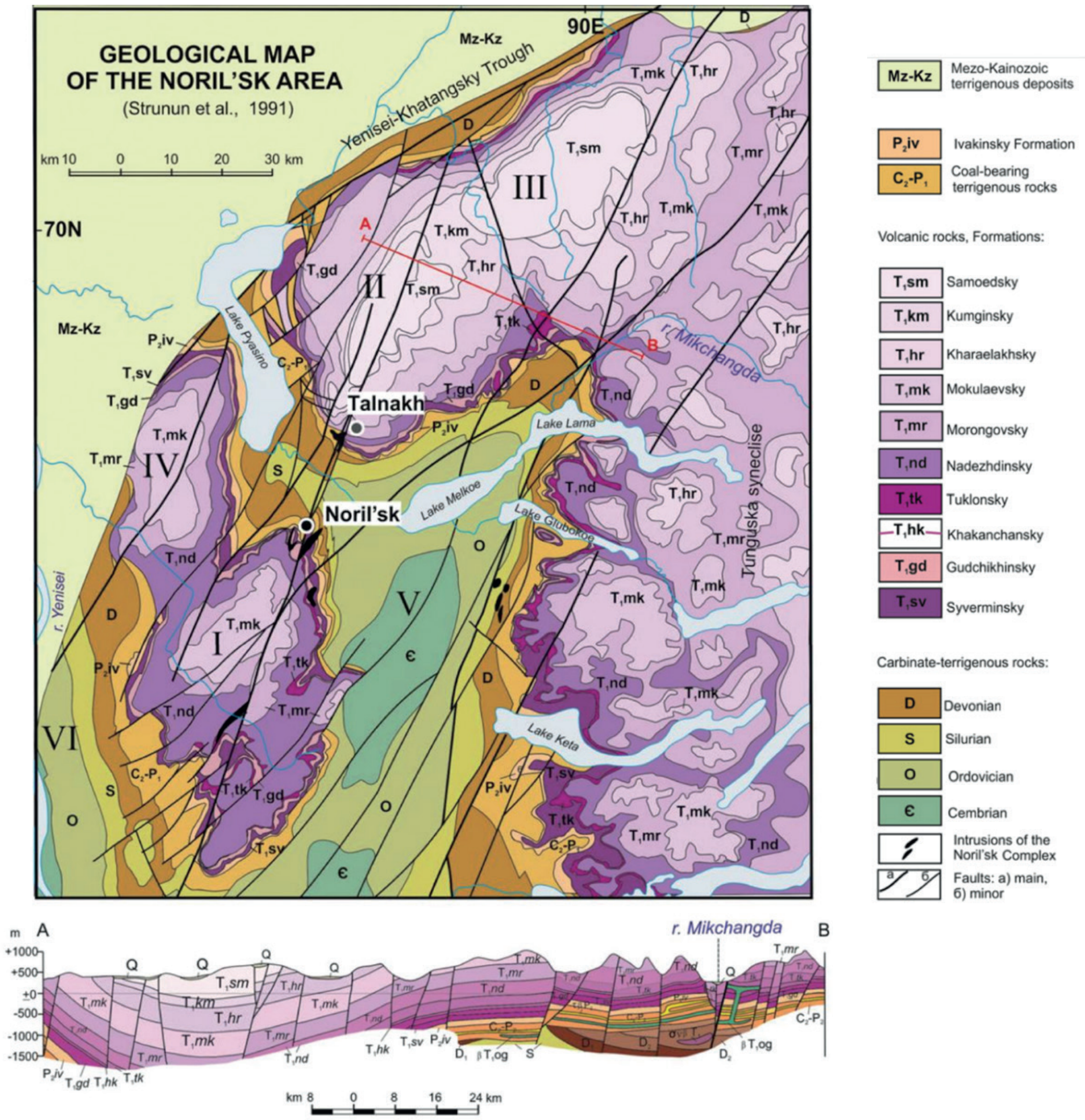
The Pavlov deposit is located on the NW coast of South Island, Novaya Zemlya. The deposit was discovered in 1990-1995 during 1:50,000 scale geological mapping by the West Arctic crew of the Polar Marine Geosurvey Expedition. The Pavlov ore field is within the Pai-Khoi-Novaya Zemlya fold system formed in the early phases (late Triassic) of Cimmerian tectogenesis. The host rocks are marine sediments of varying composition, with subordinate igneous and igneous-sedimentary formations. Silurian and Devonian terrigenous sediments and carbonates are found in the area of the deposit, which covers >12 km^2. These units are folded into the large Bezymyanskaya anticline the amplitude of which is 3-4 km; the fold limbs plunge at 25°-45° S/SE. A few occurrences of magmatic rocks are found in the region of the Pavlov deposit. Sills of dolerite and gabbro-dolerite of the late Devonian Kostin Shar complex are located on the SE flank of the Bezymyanskaya anticline, outside the ore field. Mesozoic sub-alkaline picrite-dolerite dikes are also found. Both sills and steeply-dipping dikes intersect the ore body.

The Pavlov deposit is located in the area of the periclinal closure of a brachyform anticlinal fold, complicated by longlived fracture zones, primarily local thrusts with significant (a few tens of metres) displacement. The eastern limb of the Bezymyanskaya anticline is complicated by a horst structure, with a north-westerly strike, forming the deposit's eastern block. Systems of arcuate thrusts and thrusts with north-westerly strikes are present in the south-eastern part of the ore body. Three ore-bearing blocks, the Central, Western, and Eastern blocks, are identifiable within the Pavlov ore field. The ores are confined to carbonate formations of the early Devonian Gribov suite, which outcrops on the anticlinal fold limbs. The fold limbs, on the south-eastern flank of the anticline, are cut by a series of faults (of oblique-slip and up-throw/thrust nature) which forms the "keyboard" structure of the cross-section of the area in question.

The deposit comprises five extensive (>600 m), banded, sheet-like layers of ore from 3-5 to 50 m thick, which are confined by lithology. The ore bodies have a monoclinal form, with small-scale folds dipping at angles of 30°-45°. The distribution of the main commodities (zinc, lead, and silver) within the ore bodies is relatively uniform. The ore body boundaries have been defined by various geophysical methods and by drilling. In plan and in axial section, the ore bodies plunge from the outcrop to the south-east, to depths of 200-350 m. Within the sheet-like ore bodies there are later, multiple ore veins and nested-veinlet segregations of ore formed by influx of later hydrothermal fluids during tectonic activity. Syn- and post-mineralization tectonic breccias do not disturb the continuity of the ore. The mineralization processes are accompanied by penetrative metasomatism in the form of silicification and dolomitization.

The main ore minerals are pyrite, sphalerite, and galena. Dolomite, calcite, and quartz are widespread as vein minerals. Chlorite, albite, micas, ruby silver, boulangerite, jordanite, arsenopyrite, cinnabar, and millerite are found in small amounts. The ores are massive (solid, nested-veinlet, breccia), vein-veinlet, veinlet-impregnated and mostly pyritic in their composition (40-90 %), the rest being sphalerite and galena of various generations. The contents of lead vary from 1.0-2.9 %, and of zinc from 1.6-20.8 %. The ores belong to the carbonate-hosted stratiform (lead-zinc) deposit type. The reserves of the Pavlov deposit, estimated by the National Reserves Committee for Categories C_1 + C_2 are > 2.4 million tons; the probable Category P_1 resources are 7 million t, and P_2, 12 million t total for lead and zinc. The silver reserves are estimated as accessory. The deposit can be developed by open-pit mining.

Figure 24: Geological map of the Norilsk District (from Strunun, 1991, see Krivolutskaya, 2016).



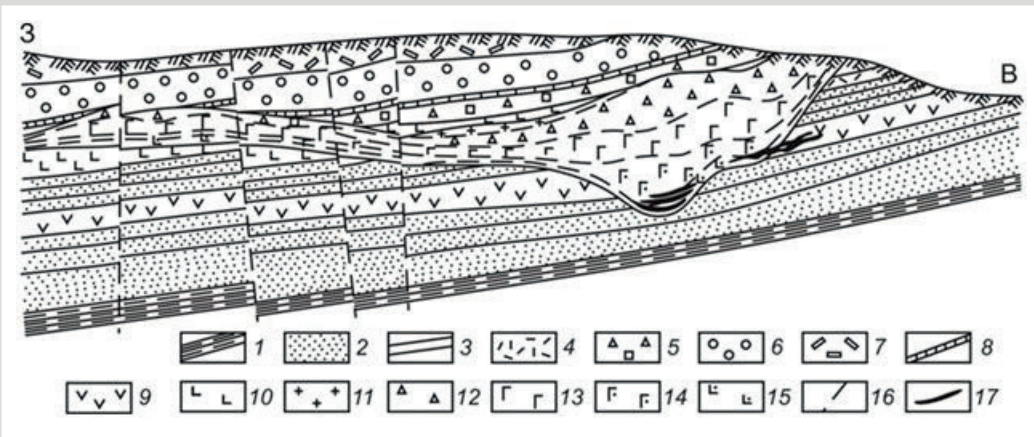


Figure 25: Schematic section of the Norilsk I intrusion (M. Godlevsky, 1959). 1–1 Host rocks: 1: Devonian sedimentary rocks; 2: Tungusian series rocks; 3: coals; 4: Alkali diabases; 5: Two-feldspar basalts; 6: Tholeiitic diabases; 7: Plagiophyric basalts; 8: Tuffites; 9: Titanium-augite diabase porphyrites; 10: Labradorite porphyrites; 11–17: Differentiated intrusive rocks: 11: Hybrid rocks and diabase pegmatites; 12: Gabbro-diorites/gabbros; 13: Ophitic/poikiloophitic olivine gabbro dolerites; 14: Picrite gabbro dolerites; 15: Taxite and contact gabbro dolerites; 16: Faults; 17: Sulphide veins.

Deposits in the Norilsk District

Intense prospecting in the Norilsk district, related to the search for coal for the Northern Sea Route, began in 1919–1920. Norilsk was first ranked as a unique ore district in the early 1960s when the Talnakh and Oktyabrskoye deposits were discovered as a result of exploration by the Norilsk Integrated Survey Expedition. The Norilsk ore district is, in a tectonic context, an independent block with a reduced thickness of continental crust consisting of a crystalline basement and an igneous-sedimentary platform mantle. The structure of the district shows a flat to wavy distribution of an effusive-sedimentary rock series, from Cambrian to Anthropocene over 6000 m thick, and with swell-like structures, brachy-synclines and deep-seated faults, through which melts penetrated the upper levels of the section, resulting in the generation of extensive magmatic units (traps). All the rocks are intruded by dolerites and gabbro dolerites of various ages and compositions. The district is at the junction of the Khantai-Rybninsky ridge and the Norilsk-Kharaelakh depression. Smaller structures have been identified within the latter: the Norilsk and Kharaelakh troughs, the Kayerkan-Pyasino and Oganer brachyanticlines and the Valkov saddle. The largest commercial deposits are located along the Norilsk-Khatanga deep-seated fault. The Norilsk and Talnakh ore clusters are located along this structure. Two types of ore are known in the deposits of the Norilsk ore district: PGE-copper-nickel-sulphide ores and low-sulphide PGE ores (Figure 24).

Norilsk 1 (PGE-Ni-Cu-Co)

The first data on the deposit is related to merchant K. P. Sotnikov who, in 1865-1868, melted 7222 pounds of crude copper out of chalcopyrite-rich argillites of the Tungusian series and sulphide veins cross-cutting them at the base of the northern slope of Mount Rudnaya. In 1920, geologist N. N. Urvantsev found primary sulphide ores. In 1922, N. K. Vysotsky who worked there by order of SibGeolCom found platinum in copper-nickel ores.

The deposit is confined to a differentiated sheet-like intrusion of the same name extending north-eastwards, with a length of ca. 12 km

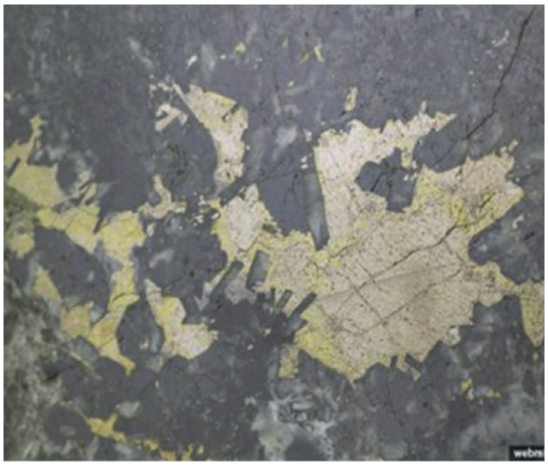


Figure 26: Interstitial sulphide ore in gabbro dolerite from Norilsk.

(Figure 25). The intrusion's thickness varies from 30-350 m, the average being ca. 130 m. The copper-nickel sulphide mineralization is related to the lower ultrabasic horizons of the intrusion (picrites, olivine gabbros, and gabbro troctolites), near the contact, and is represented by veinlet-impregnation and massive ore types. The sulphide mineralization forms a persistent ore horizon, matching the outline of the intrusion. Veinlet-impregnated ores of the exocontact zone form an intermittent "aureole" around the intrusion. In the north, the intrusion splits into two branches, the western (“Coal Creek”) and eastern (“Bear Creek.”) Contact metasomatic alteration in the deposit is negligible; calcsilicate skarn occurs locally in fissures. Biotitization and chloritization are widespread processes, but discordant to the structures.

The copper-nickel sulphide mineralization is represented by disseminated ores and nest-like accumulations of pyrrhotite, pentlandite, and chalcopyrite, occurring mainly in the lower, olivine-rich picrite and taxite, and in contact dolerites (Figure 25 and 26). Schlieren ore bodies have limited occurrence among the taxitic dolerites in the intrusion’s basal part. The schlieren ores contain large quantities of basic plagioclase, olivine, and pyroxene, and show a gradual transition to weak impregnation. Veins of massive sulphides occur locally at the base of the intrusion and in sedimentary country rocks: veinlet-impregnated mineralization is locally developed in the country rocks. The sulphide mineralization forms, in general, a persistent ore horizon, which matches the intrusion's outline in plan.

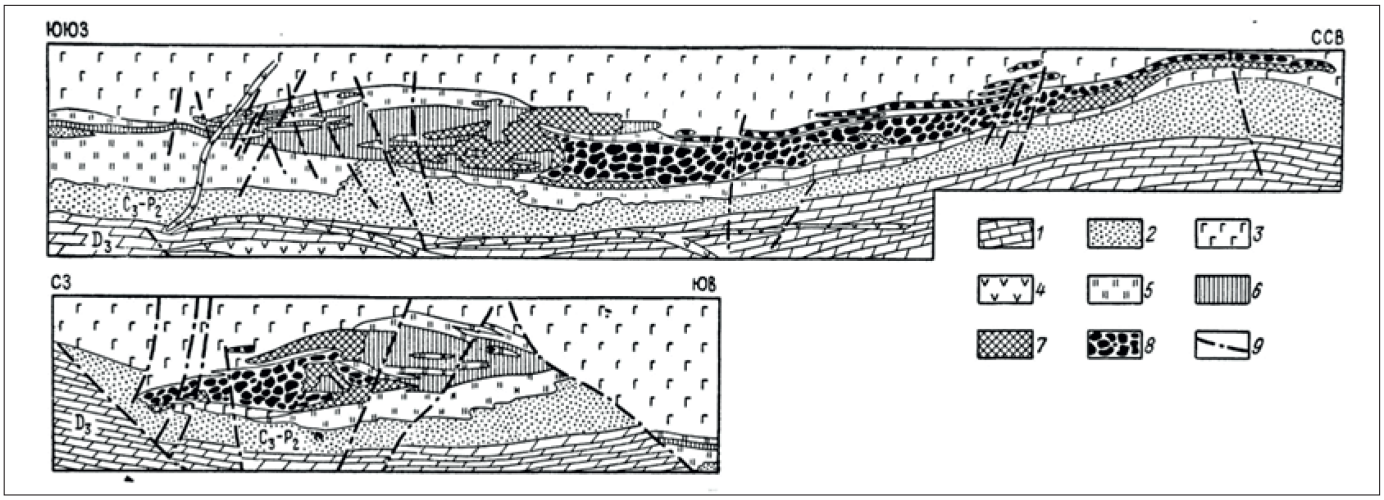


Figure 27: Geological structure of massive ores in the SW part of the Talnakh deposit (Sukhov & Izoitko, 1971). 1: Dolomite, marl; 2: Sandstones, siltstones, argillites; 3: Gabbro dolerite (Talnakh intrusion); 4: Dolerites of undifferentiated sills; 5: Contact-altered rocks; 6: Pentlandite-chalcopyrite-pyrrhotite ores; 7: Pentlandite-chalcopyrite-pyrrhotite-cubanite ores; 8: Pentlandite-cubanite-chalcopyrite ores; 9: Tectonic faults.

The massive sulphides exploited in the first years on the northern ridge of Mount Rudnaya are no longer mined. They were originally rather large (up to 200×100×20 m) lenslike bodies. A 2 m aureole of rich impregnation ores crosscutting the contact of the intrusion was observed in taxite dolerites surrounding the massive ore. The massive ore veins are mainly developed in the intrusion's northern part. They have a complex form and sharp boundaries. They contain pyrrhotite, chalcopyrite, pyrrhotite with pentlandite exsolution lamellae, cubanite-pentlandite-chalcopyrite, rich chalcopyrite or cubanite and bornite-chalcocite. Some millerite-pyrite ores are found among the massive ores.

The reserves of the deposit's southern part are 273,000 t of nickel, 378,000 t of copper, 12,700 t of cobalt, and about 518 kg of platinoids. Norilsk 1 was, for 27 years, the only raw mineral source for the Norilsk Mill.

Talnakh (PGE-Ni-Cu)

The Talnakh deposit is located in the Kharaelakh trough, 25 km NE of Norilsk, near the town of Talnakh. The deposit was discovered in 1960 by G. D. Maslov, V. F. Kravtsov, Yu. D. Kuznetsov, V. S. Nesterov, and Ye. N. Sukhanova, researchers of the Norilsk Survey Expedition, during prospecting work. The first mine, Mayak, started operation on April 22, 1965. Currently, the deposit is operated by underground mining at the Komsomolsky mine comprising the Mayak, Komsomolskaya and Skalistaya shafts. The deposit development license is owned by MMC Norilsk Nickel.

The copper-nickel ores of the Talnakh ore cluster, comprising the Oktyabrskoye and Talnakh deposits, are related to a large gabbro-dolerite intrusion located in the southern part of the Kharaelakh trap trough (Figure 27). The trough is intersected along its long axis by the NNE-SSW-trending Norilsk-Kharaelakh ore-controlling fault, which determines the positions of the intrusions hosting these deposits.

The deposit is connected to the interstratal, differentiated Talnakh basic-ultrabasic intrusion. The ore-bearing intrusion consists of

Figure 28: Sulphide veins among graphite. Talnakh deposit.

several separate branches diverging from the assumed feeder. The Talnakh deposit is confined to the intrusive branches of the so-called "top" ore level located in Carboniferous-Permian terrigenous-carbonate rocks (Tungusian series), comprising the north-eastern, central, and south-western branches. The stratified magmatic bodies are divided into the following units (from the top): 1) eruptive breccias, leucocratic gabbros; 2) gabbro dolerites and quartz dolerites; 3) olivine-free dolerites; 4) olivine dolerites; 5) picritic dolerites, olivinites; 6) taxitic and contact dolerites. The intrusions are surrounded by aureoles of contact hornfels about 20 m thick on average, among which are found skarn, albite-microcline metasomatites and serpentinites.

Figure 29: The Bear Creek open pit, Talnakh deposit.

The main bulk of the copper-nickel sulphide ores is localized in the area of the lower endo- and exocontacts of the nickel-bearing massifs; some bodies of impregnated and massive ores are also located in the roof of the intrusion. The main bulk of the ores is in picrite, taxite and in contact dolerites. Impregnation has, in some cases, been recorded in rocks of gabbroic composition. Veinlet-impregnated ores are localized in the exocontact zone and are confined to altered sedimentary rocks (Figure 28). The ore bodies are sheet- and lens-like, and their outlines are similar to that of the intrusion in plan. Three types of ore are found: 1) impregnation in parent rocks, 2) massive sulphides near the base of the intrusion and 3) veinlet-impregnation in exocontact rocks. The primary ore minerals are pyrrhotite, pentlandite and chalcopyrite. Cubanite, magnetite, titanomagnetite, and ilmenite are also common. Talnakhite, mooihoekite and troilite commonly form significant aggregates in massive ores. The subordinate ore minerals include pyrite, millerite, bornite, valleriite, heazlewoodite, covellite and several PGE-bearing minerals.

The most common ore textures are massive, veinlet-impregnation, breccia, and disseminated. The most common structures are porphyritic, hypidiomorphic granular, subgraphic, drop-shaped and sideronitic. Apart from copper and nickel, the ores contain cobalt, platinum metals, gold, silver, tellurium, and selenium.

The metal reserves of the Talnakh deposit, as of 01.01.2012, were:

- Proven copper reserves: Category A+B+C1, 7,858,500 t Cu: the average content in the ores is 1.11 % Cu; inferred reserves, as Category C2, 2,761,900 t Cu;
- Platinum group metal reserves (palladium and platinum): for Category ABC1, 3,275 t Pd+Pt (4.6 g/t), for Category C2, 1,224.9 t Pd+Pt.
- Nickel reserves remain confidential, but the average Ni-content in explored ores is 0.69 %.

The Talnakh deposit is Russia's second largest in terms of nickel and platinum group metal reserves (after Oktyabrskoye which is located NE of Talnakh). Its proportion in Russia's explored nickel reserves for Category A+B+C1 was 23.6 % as of 01.01.2012. For copper reserves, the Talnakh deposit is Russia's third largest, after Oktyabrskoye and Udokan. Its proportion in Russia's commercial copper reserves for Category A+B+C1+C2 was 11.4 % as of 01.01.2012. Geological surveys are currently progressing on the northern flanks of the Taimyrsky mine, the eastern flanks of the Skalisty mine, around the Mayak mine, and on the southern flank of the Talnakh deposit. Copper-nickel sulphide ore bodies have been intersected by several drillholes. The expected growth in reserves in 2014–2016 is >500,000 tons of nickel. A geological survey is being conducted on the south-eastern flank of the Bear Creek open pit (Figure 29). The expected growth in ore available for open pit mining will (according to Norilsk Nickel) be about 40,000,000 t.

Figure 30: Geographical position of the Maslov Deposit (blue shading) (Norilsk Nickel Annual Report, 2014).

Maslov (Pd-Pt-Ni-Cu)

The Maslov deposit of platinum-palladium-copper-nickel ores is located 12 km S of Norilsk in the northern part of Krasnoyarsk Krai (Figure 30). The deposit is located in the eastern branch of the Norilsk-1 intrusion, and adjoins the southern boundary of the deposit of the same name.

The Maslov deposit was discovered in 2009 during a geological survey by MMC Norilsk Nickel. The deposit was given its name after the famous Norilsk geologist, G. D. Maslov, who indicated, the prospects of the area along the Norilsk-Kharaelakh fault S of the Norilsk-1 deposit in the 1960s. The deposit contains copper-nickel sulphide ores with exploitable grades of nickel, cobalt, copper, PGEs, gold, etc. The main reserves of the Maslov deposit are concentrated in a large sheet-like layer 27-45 m thick. The layer extends along the intrusion's central axis and has a configuration near-concordant to it in plan. The ore body lies at depths of 800-1100 m. Mineral reserves data are given in Table 1.

	Reserves, Category C1+C2	Metal content in ore
Ore (Mt)	215	
Palladium (koz)	32262	4.56 g/t
Platinum (koz)	12479	1.78 g/t
Nickel (kt)	728	0.33 %
Copper (kt)	1122	0.51 %
Cobalt (kt)	34	0.02 %
Gold (koz)	1305	0.19 g/t

Table 1: Mineral reserves of the Maslov deposit and metal content in ore (www.nornik.ru/).

Norilsk 2 (Pd-Pt-Ni-Cu)

The Norilsk 2 low-sulphide platinum group metal deposit (Figure 31) is located 7 km from Norilsk, also within Krasnoyarsk Krai. The deposit was discovered during a geological survey conducted by Norilskstroy under the supervision of N. N. Urvantsev in 1926.

The low-sulphide mineralization in the Norilsk 2 intrusion is confined to upper heterogeneous gabbro series rocks, which include taxite, gabbro dolerites with chromite, leucogabbros, olivine-bearing and olivine gabbro dolerites and eruptive breccias of carbonaceous argillites. The thickness of the low-sulphide mineralization is highest in the northern part of the intrusion and average in the central part. Three types of palladium-platinum-copper-nickel sulphide ores are identified in the deposit:

- Massive ores in the intrusions and their exocontacts
- Impregnation and veinlet-impregnation ores in the intrusions
- Impregnated, veinlet-impregnated and breccia-like ores in the exo- and endocontacts of ore-bearing intrusions ("cupriferous.")

The platinum-group metal mineralization is present as palladium arsenides but also as tellurides, and platinum arsenides. The total platinum-group metal content seldom reaches 1.67 g/t, and in unique cases, 3.3 g/t, which is at the level of average values in similar intrusion horizons in Norilsk I. The sulphide associations typical for this low-sulphide mineralization is

Figure 31: The Norilsk 2 deposit.

Figure 32: The Chernogorskoye deposit. (Source: Russian Platinum).

pentlandite-chalcopyrite-pyrrhotite and pyrite-chalcopyrite, both of which have variable proportions of the main sulphides. Currently, Norilsk 2 is considered a non-economic deposit.

Chernogorskoye (PGE-Ni-Cu-Au)

The Chernogorskoye deposit is 15 km SE of Norilsk, also within Krasnoyarsk Krai (Figure 32). The first ore discoveries on the site were made in 1943-1944 during a detailed survey and prospecting effort. The deposit forms a sheet-like layer extending approximately E-W and with a trough-like cross section. The ore-bearing differentiated intrusion (which is up to 200 m thick) typically has a significant thickness of acid hybrid ores in the roof and a wide (up to 40 m) aureole of contact alteration (of hornblendites, magnesian and calcic skarns). The sequence of differentiated units is very persistent. The impregnated ore horizon is confined to picrite, taxite, and contact dolerites. Their composition is similar to that of the Norilsk 1 deposit. The license for prospecting, extraction, and production of sulphides and precious metals of the Chernogorskoye deposit is owned by the Chernogorskaya Mining Company.

The Chernogorskaya Mining Company was acquired by Russian Platinum in April 2011. Mining (open pit) was expected to commence in 2015. Future development of the deposit by underground mining is also probable. It is intended to build a dressing mill in the vicinity of the deposit, and a smelter at which concentrate will be processed to produce copper-nickel matte. Construction of a plant for hydrometallurgical processing of matte and production of marketable metals is being considered. The approved commercial ore reserves are 143 million tons, the average content of nickel being 0.22 %, of copper 0.29 %, and of platinum group metals and gold 3.9 g/t. Platinum group metals occur at a depth of 20 m in the western part, and at 245 m in the eastern part of the ore body.

Copper and Nickel Deposits of the Pechenga Ore District

The Sputnik, Verkhneye, Zhdanov, Tundra and other deposits are part of the Pechenga group of deposits, located in the Eastern ore cluster of the Pechenga ore district. Administratively, this group of deposits is located in Murmansk Oblast, on the Kola Peninsula close to the Norwegian border. The deposits occur in two near-parallel levels extending for ca. 9 km in an east-south-easterly direction within the Pilgujarvi Suite of tuffaceous sedimentary rocks.

The ore-bearing differentiated intrusions and copper-nickel deposits within them are located both at the bottom and top of the suite; they are accompanied by relatively small bodies of altered peridotite and gabbro, and by gabbro-dolerite sills. The differentiated Kierdjipori massif and the related Sputnik deposit are on the western flank of the ore cluster, at the very bottom of the Pilgujarvi Suite. The ore-bearing intrusions of the Verkhneye deposit are found to the south, at the top of the Suite (Figure 33); these link to the east with the Tundra deposit, which in turn is the western extremity of the Zhdanov deposit. The Zapolarnoye deposit is located in the footwall of the important Pilgujarvi nickel-bearing intrusion along the contact with dolerites. The Onki deposit forms the extreme south-eastern flank of the Eastern cluster.

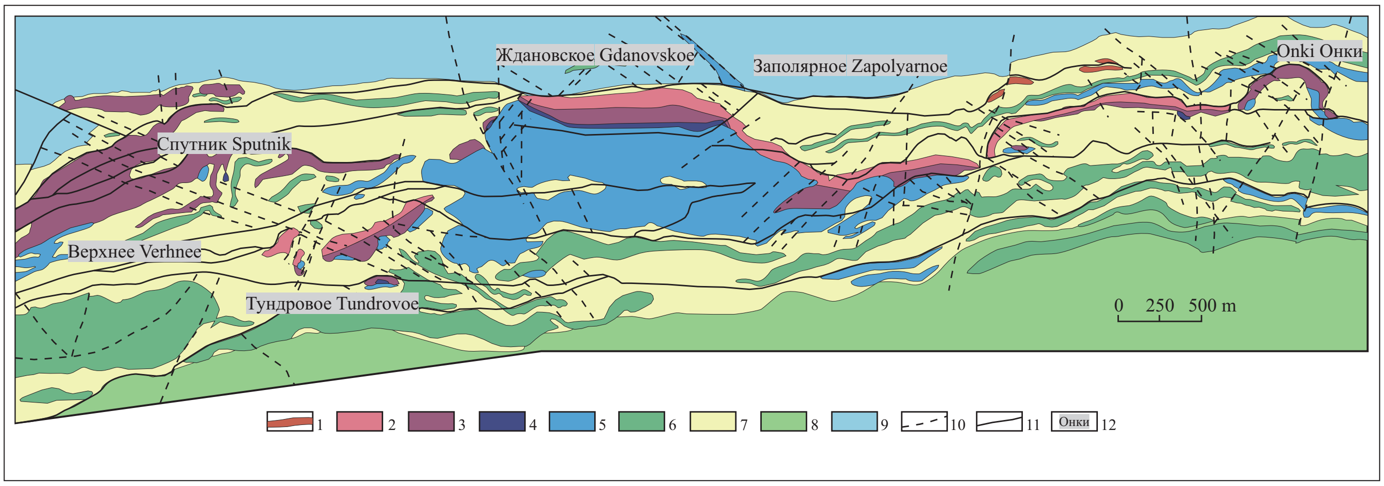


Figure 33: Geological map of the Eastern Ore cluster, Pechenga (Kazansky & Lobanov, 2005). 1 – epigenetic breccia-like, solid and rich impregnated sulphide copper-nickel ores; 2 – impregnated ore in serpentinized peridotites; 3 - peridotites; 4 – pyroxenites; 5 - gabbros; 6 – gabbro diabases; 7 – rocks of productive tuff sedimentary series; 8 – igneous rocks of Pilgujarvi suite; 9 - igneous rocks of Kolosjoki suite; 10-11 - fractures: 10 – diagonal faults, 11 – interstratum tectonic zones (I–IV); 12 – oriented sampling spots and sites of detailed structural/petrophysical surveys.

Sputnik Nikkel-Copper Deposit

The Sputnik deposit, 2.5 km W of the Zhdanov deposit, was first explored and described as the Kierdjipor deposit. An additional survey in 19731974 (by A. M. Dudkin, V. G. Kukharukh, V. V. Trushik) revealed a new "blind" ore body confined to a thin interstratal intrusion in the footwall of the Kierdjipori nickel-bearing massif, and later named "Main". Since then, the associated group of ore bodies has been given the collective name, "Sputnik deposit" (Figure 34). The deposit is confined to two sheet-like differentiated massifs occurring in parallel near the surface. The two massifs are in contact along a steep thrust zone in the middle of the site below the +20 m level. The main branch of the mineralized tectonic zone extends along the base of the lower massif. Both zones link to the mineralized tectonic zones of the Zhdanov deposit to the east, and to the occurrences in Mirona and Raisoaivi to the west.

The copper-nickel sulphide mineralization is mainly concentrated in the near-basal parts of both massifs, and partially along the marked tectonic faults. Ore bodies 1 and 2 are confined to the lower part of the northern Kierdjipori massif and to the upper part of the southern Kierdjipori massif, respectively. Ore body 3 is located on the western flank, ore body 4 on the eastern flank,

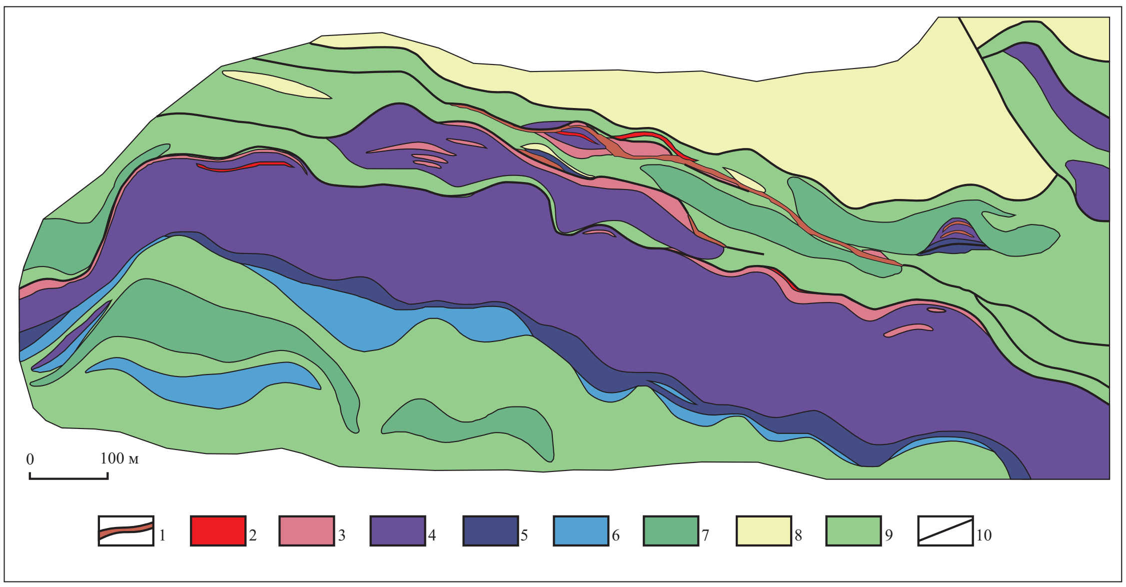


Figure 34: Geological map of the Sputnik deposit. 1 - breccia ores; 2 – densely impregnated ores in serpentinites; 3 – run-of-mine scattered impregnated ores in serpentinites; 4 - serpentinites; 5 - metapyroxenites; 6 - metagabbros; 7 - gabbro diabases; 8 - effusive diabases of nappe III; 9 - tuffaceous sedimentary rocks; 10 – tectonic faults.

and ore body 5 occurs in deep horizons. The ore bodies have a sheet-like, slightly curved shape, and strike ESE and dip 40-60° SSW. Their thickness varies from 1 to 45 m. Ore bodies 1, 2, 3, 4, and 5 contain about 80 % of the deposit's ore reserves. They all consist of impregnated serpentinites. Grades in the ore bodies have the following ranges: 0.82-1 % nickel; 0.46-0.77 % copper; 0.02-0.023 % cobalt.

The main ore body is tabular in shape and has been traced along strike in a near E-W direction for 700 m, with a dip of 50-60° S; the body tapers at about 120 m from the surface. It has been traced down-dip for >1500 m. The ore body is confined to a thin intrusion of intensely mineralized ultramafic rock occurring along the interstratum tectonic zone 50-60 m away from the base of the Kierdjipori massif. Its thickness varies from 0.5 to 25 m. Unlike the other ore bodies, it consists of rich breccia, less commonly massive ore (nearly 60 % sulphide), rich, densely impregnated and less impregnated ores in serpentinites in about equal proportions. Mineralized xenoliths have limited occurrence. Mineralization in serpentinites predominates in the central part of the ore body where the parent intrusion is dragged into blocks along the interstratal zone. The mineralized tectonic zone is ubiquitously filled with breccia ores forming the base and flanks of the ore body. Alternation of breccia ores and densely impregnated ores in serpentinites is observed in the central part of the orebody. Breccia ores occur moreover, not only on both sides of the mineralized intrusion but also within it. The main ore body is the only one in the deposit in which ores in serpentinites are of secondary importance. They are most widespread in the top part of the layer where they form lenses among breccia ores. The contents of economic components in the ore body are: 1.0-4.5 % nickel; 0.5-2.0 % copper; 0.020-0.080 % cobalt.

Verkhneye Nikkel-Copper Deposit

The Verkhneye deposit is at the very top of the ore-bearing series, 700-800 m up-section from the Sputnik deposit. The ore bodies of the deposit were first intersected in 1970 by the Kola super-deep borehole SG-3 and were traced up section by the Pechenga survey crew with two drillholes at a distance of up to 1000 m from the SG-3 hole. Further exploration was suspended due to the great depth of the ore body. In 1980-1990, the same concealed ore bodies, then grouped under the name Verkhneye deposit, were explored simultaneously with prospecting of the deep horizons of the Sputnik deposit (Figure 35).

The Verkhneye deposit comprises three ore bodies confined to the near-basal parts of two superimposed, slightly curved interstratum intrusions of altered gabbro-peridotites 20-130 m thick and 600-200 m long traced to a depth of over 1700-1800 m. Nickel-bearing intrusions and

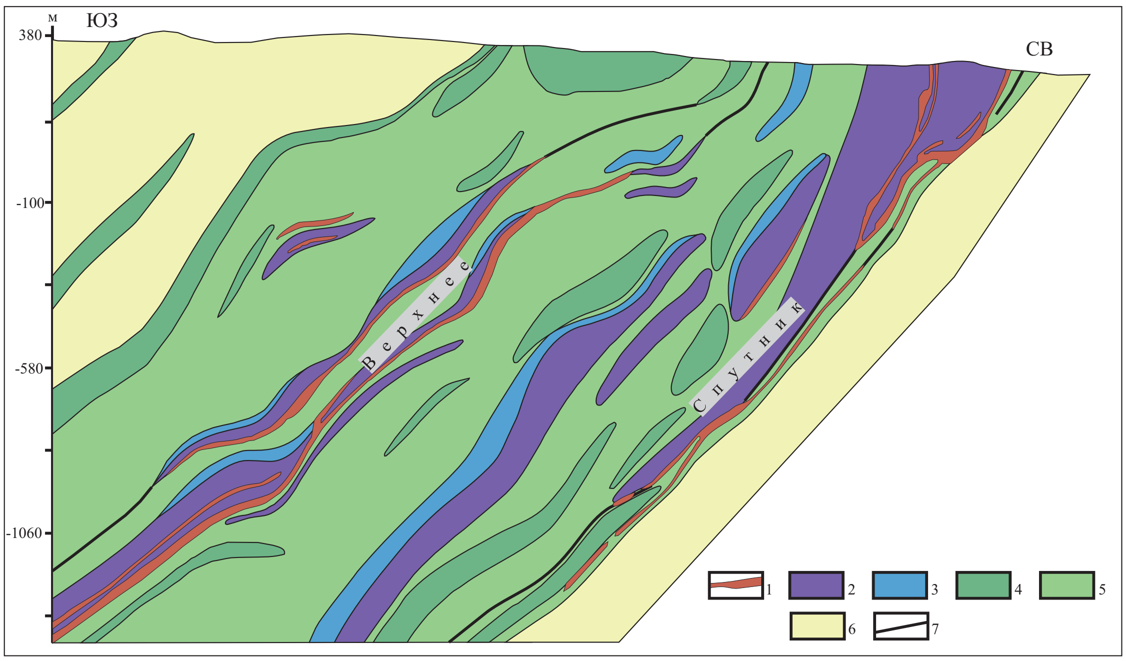


Figure 35: Cross section of the Sputnik and Verkhneye deposits. 1: Breccia ores; 2: Serpentinites; 3: Metagabbros; 4: Gabbro diabases; 5: Tuffaceous sedimentary rocks; 6: Effusive diabases of nappe III; 7: Tectonic faults.

ore bodies occur concordant with the bedding of enclosing tuffaceous sedimentary rocks, and have a strike and dip, on average, at ca. 40° SW. Two sheet-like series of typical impregnated ores in altered peridotites, the Western and Eastern ore bodies, have been explored in the upper intrusion. The so-called Main ore body, also formed mostly by impregnated ore in talcose serpentinites, is confined to the lower, and longest intrusion. The strike lengths of the ore bodies are: Main, 200 m; Western, 1000 m; Eastern, 400-600 m. Their thickness is irregular, varying from 0.8 to 60 m (in swells). The Main ore body is not completely delineated, and continues even deeper than the level of its intersection with the Kola super-deep borehole, the absolute depth below the surface being 1315-1325 m. Typical impregnated ores in talcose serpentinites are predominant in the composition of all the ore bodies: ca. 2 % is rich impregnated, breccia-like and massive sulphide ore. The mineralogical composition of these ores is similar to that of the Sputnik deposit.

Zhdanov (Pilgujarvi) Ni-Cu Deposit

The Zhdanov deposit has a central position in the Eastern ore cluster. It was studied by Finnish geologists in 1929-1934, but was found then to be unviable due to the low metal content of the ore. In 1945-1946, an expedition from the Leningrad Geology Agency gave the deposit the first positive estimate. Between 1947 and 1959, the deposit was explored in detail to depths of 600-800 m by the Pechenga survey crew. Six interconnected ore bodies have been identified: the Central, Eastern, South-Eastern, Southern, Western, and South-Western ore bodies. In 1959, the deposit was transferred to the Pechenga Nickel mill for development, and open-pit mining started the same year.

The formation and localization of the Zhdanov ore bodies are closely related to the inner structure and tectonics of the main differentiated gabbro-peridotite massif, although the deposit area contains about ten more nickel-bearing intrusive bodies of similar composition but smaller size. The main massif is shaped as a curved interstratum intrusion with a total length of up to 6 km, dipping at 45-60° SW. Its greatest thickness (up to 600 m) is confined to a trough-shaped depression in the centre of the deposit (Figure 36 A). The massif is surrounded by intensely folded tuffaceous sedimentary rocks, and occurs in general concordantly with these rocks, reflecting the area's folded structure in its morphology. Relatively flat-lying, exposed cross-folds, with their axes oriented south-westwards, in the direction of the common dip of the ores, control the shape and inner structure of the massif, and that of all the ore bodies. Transverse folding appears most intensely on the western limb of the deposit, where the Western, Seventh and other insufficiently studied ore lenses and small massifs are confined to the axes of synclinal folds. The massif's inner structure is marked by layered rocks and ores consisting of (from base to roof): 1) mineralized serpentinized olivinites and serpentinized, primary impregnated sulphide ores; 2) serpentinized peridotites (without ore); 3) pyroxenites; 4) gabbros. The latter makes up about 65 % of the massif's volume, whereas the proportion of serpentinized peridotites make up about 30 %, and that of pyroxenites, 5 %.

The layer of mineralized serpentinized olivinites and peridotites is in general concordant with the multiply-folded basal contact of the massif. The Zhdanov ore bodies are thus simply mineralized lowermost layers of the initially layered intrusion. The thickness of the primary impregnated ores with economic concentrations of nickel and copper sulphides reaches its maximum values in the central depression of the massif. The Central ore body is confined to this part of the intrusion. In anticlinal hinges on both its flanks the content of mineralization decreases to complete absence. The same ore layers continue north-westwards and south-eastwards in other synclinal depressions, but structurally slightly above the base of the central depression, forming the Western, Eastern, South-Eastern and Southern ore bodies respectively. Unlike these, the South-Western and Seventh ore bodies, and the Tundra deposit, which form the deposit's western limb, are most probably related to tectonically separate parts of the Main massif.

The primary magmatic features of the deposit were noticeably affected by tectonic faults in the epigenetic stage. Among them, steep interstratal tectonic zones play an important role in structuring the deposit. The main tectonic zone extends along the parent intrusion's lower contact and controls the occurrence of rich breccia and massive sulphide ores in the Central, Western and Eastern ore bodies. It extends on

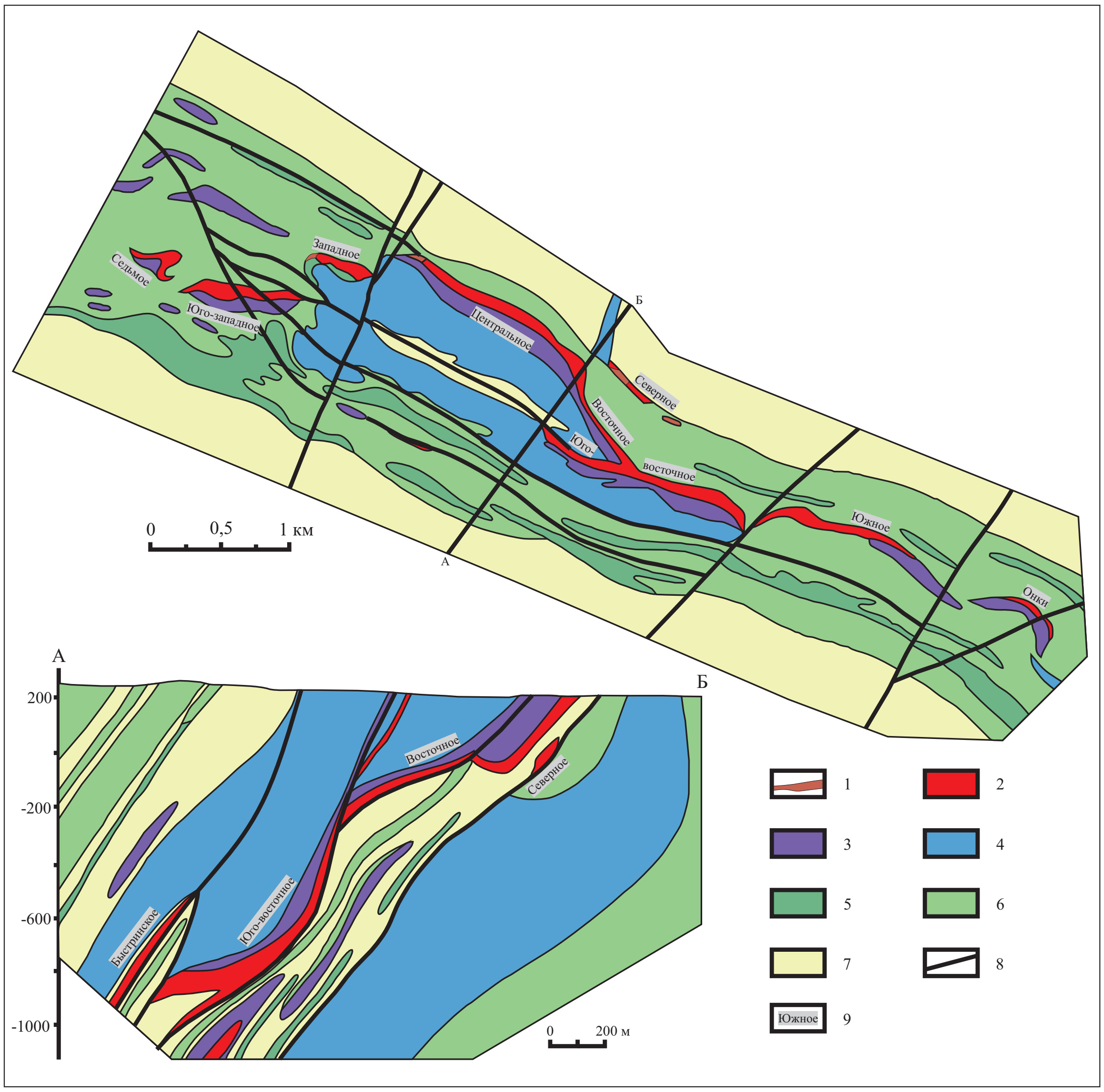


Figure 36: A (top): Geological map of the Zhdanov deposit (acc. to G. I. Gorbunov, 1999]. B (bottom): Schematic cross section along Line 0-0' (based on the Pechenga survey data): 1: Mineralized tectonic breccias, breccia and solid sulphide ores; 2: Impregnated ores in serpentinites; 3: Serpentinite; 4: Gabbro; 5: Gabbro diabases; 6: Effusive diabases; 7: Tuffaceous sedimentary rocks of productive sequence; 8: Tectonic faults.

the deposit's western flank, with the same strike, to the Sputnik-Kierdjipor-Mirona and Raisoaivi deposits. Eastwards from the main zone, a straight tectonic fault extends at a low angle, controlling the occurrence of the massive sulphide ores of the Zapolarnoye deposit. Morphologically, the Main zone is defined by brecciation and foliation of mineralized serpentinized peridotites, and in places by mineralized tectonic breccia and massive sulphide ores.

The second (Upper) interstratal tectonic zone extends parallel to the Main zone, 200-500 m up section, and dips at 70-80° SW. It splits the Pilgujarvi parent massif into two large blocks: the Main block, with the Western, Central and Eastern ore bodies located at its base, and the Upper block, which controls the positions of the South-Eastern and Southern ore bodies. A third tectonic thrust zone extends parallel to the first two, 300-400 m to the S or higher in the section, above the South-Eastern and Southern ore bodies, and controls the localization of the Third Bystrinskoye ore bodies (Figure 36 B). A fourth interstratal tectonic zone intersects the very top of the Pilgujarvi suite, 300-400 m from overlying dolerites in the nappes. Only thin lens-like, stratified bodies of ultrabasic rocks are found within this zone, with mineralization occurring locally. The vertical displacement of the blocks differs for the various areas. The maximum displacement (300-500 m) is observed in the centre of the ore cluster, decreasing somewhat on both flanks.

The general outline and relative positions of the ore bodies of the Zhdanov and other deposits of the Eastern ore cluster may be seen in Figure 36 A. Their shapes are mostly sheet-like, tabular, and lens-like, and they are equally extensive in strike and dip. The ore bodies have a strike length of 200 to 1800 m (Central ore body), the dip is on average 50-60°S to SE and their thicknesses vary from a few metres to 100 m..

Fedorov Tundra Deposit (PGE)

The Fedorov Tundra deposit is 80 km E of the city of Apatity, and 58 km SE of the district centre Lovozero. It is localized within a stratified intrusion of the same name, in taxitic norites and gabbro norites of the marginal zone, and in overlying stratified norite and gabbro norite zones, in which sulphide mineralization occurs both disseminated and as sulphide-enriched lenses. The Fedorov-Pana stratified intrusive massif forms an elongate range of hills in the central part of the Kola Peninsula. From structural and tectonic aspects, this district is a part of the northern contact betweeen igneous-sedimentary rocks of the early Proterozoic Imandra-Varzuga paleorift structure and formations of the Archean basement.

The Fedorov-Pana massif has a sheet-/lopolith-like shape, and is exposed at the present erosional level by fragments of the northern part of the lopolith. It extends in a NW direction for nearly 80 km, with outcrop widths of 600 m to 5-7 km and thicknesses of ca. 3.8-5.0 km (Figure 37). It dips 30-50°SW in the west and up to 50-80° SW in the centre: in the south-east, the dip decreases with depth. The Fedorov-Pana massif can, according to gravimetric and magnetic data, be traced for a considerable distance under the sedimentary-igneous rocks of the Imandra-Varzuga rift-induced structure, to a depth of 4-5 km, retaining its south-westerly dip.

The Fedorov-Pana intrusion is a peridotite-pyroxenite-gabbronorite complex. The following age data have been determined for the intrusive rocks: gabbronorites, 2501+1.7 Ma and 2491+1.5 Ma; gabbro pegmatites, 2470+9 Ma; anorthosites, 2447+12 Ma. The massif has a limited differentiation sequence as it has no lower ultramafic and "critical" zones. It consists of a poorly differentiated series of mafic rocks represented by gabbronorites. This type of structure is, however, quite typical for layered intrusions in the Baltic Shield.

The intrusion is divided into large blocks by transverse fault zones. From west to east, the following have been identified: The Fedorov block, mostly consisting of gabbroid rocks, and separated from the West Pana block by the thick Tsaga fault zone; the Lastyavr block, adjacent to the fault zone, and intensely deformed; the West Pana block, the thickest, most well-exposed and well-studied part of the intrusion, consisting mainly of gabbronorites, within which two

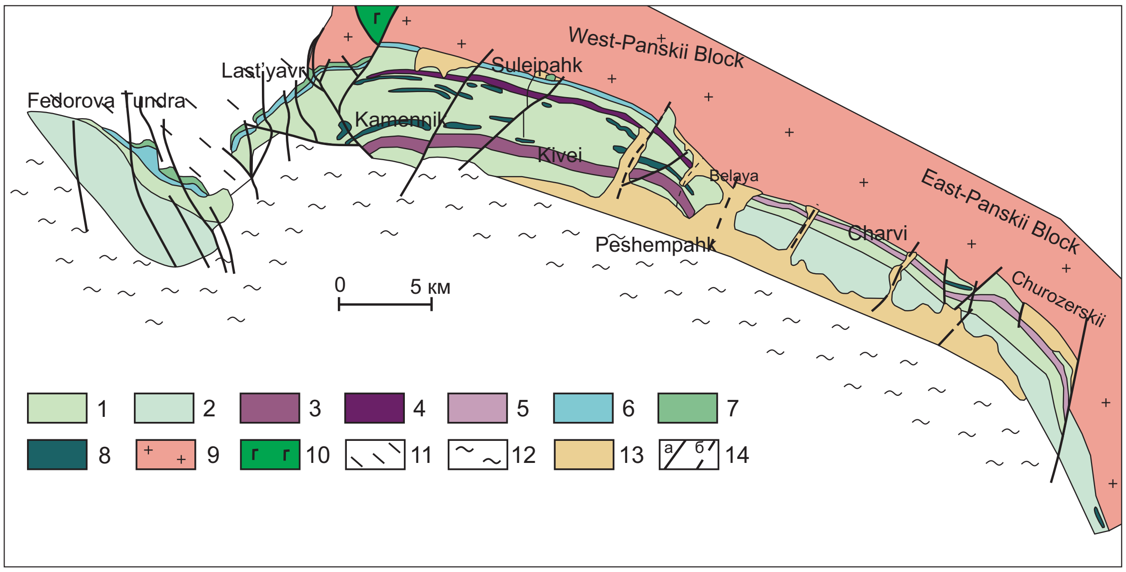


Figure 37: Geology of the Fedorov-Pana intrusion (Karpov, 2004, Pana JSC). 1) Gabbro zone (GZ); 2) Gabbro norite zones (GNZ 1, 2, 3); 3) Upper stratified horizon (USH); 4) Lower stratified horizon (LSH); 5) Stratified horizon of Eastern Pana block Norite zone (NZ); 6) Lower marginal zone (LMZ); 7) Bodies of magnetite gabbros; 8) Gabbronorites. 9) Belaya Tundra complex of alkali granites; 10) Plagioclase gneisses and schists; 11) Amphibolite; 12) Igneous and sedimentary formations of the Imandra-Varzuga series; 13) Tsaga massif of gabbro labradorites; 14) Quaternary sediments, moraine.

stratified horizons stand out: the "upper" (USH) and "lower" (LSH) Stratified Horizons. The East Pana block has a heterogeneous lateral structure, with a predominance of gabbros in the section, and a stratified horizon in the section's basal part which resembles the structure of the stratified horizons in the West Pana block. The main PGE-enriched levels in the Fedorov-Pana massif are related to the stratified horizons. Known PGE ores in the intrusion are of two types: A near-basal layer of low-sulphide copper/nickel/PGE ores in the Fedorov tundras massif; and low-sulphide PGE reefs in the western and eastern part of the Pana massif.

The Fedorov tundra massif shows the sequence: Marginal norite (taxite gabbronorite) and plagio-pyroxenites, gabbronorite and gabbro zones. The marginal-zone, so-called taxite gabbronorites extend to near the base of the body. The norite-plagiopyroxenite zone, occurring higher in the section, reaches a thickness of 200 m. The largest part of the Fedorov block section is formed by equally thick units of gabbronorite and massive gabbro. The gabbros contain rare, thin streaks of leucocratic gabbro and anorthosite. The platinum metal mineralization is inclined to the marginal and norite zone for a total width of up to 1 km in plan, traceable for 10 km. A feature of this massif's platinum metal occurrences is levels with almost equal contents of platinum and palladium (up to 3.53 and 3.91 g/t respectively), but with platinum predominating in some parts. The main platinum-group element minerals found are: kotulskite, braggite, and merenskyite. Less common precious metalbearing minerals include moncheite, vysotskyite, sobolevskite, stillwaterite, sperrylite, and gold.

The approved reserves are: A+B+C1: 173 Mt of ore (238 t of PGE); C2: 87 Mt of ore (109.9 t of PGE); non-economic reserves are approved at 15,823,000 t of ore (18.5 t of PGE). It is intended to develop the deposit in two open pits with a total annual capacity of at least 12 million tons of ore. The ore will be processed by flotation. The mill's finished product will be a concentrate containing copper, nickel, gold, platinum and palladium for further metallurgical processing and refinement.

The Kievei PGE deposit

The Kievei PGE deposit is situated 120 km E of Apatity, and was discovered in the period 1991-1999. It is related to a mafic-ultramafic complex in the central part of the West Pana massif, a layered intrusion of the Fedorov-Pana tundras (see Figure 37). The massif is divided into the upper and lower stratified horizons: the Kievei deposit is confined to the lower horizon (LSH for short). The PGE mineralized level is called the North Platinum Reef. The LSH is found 600–800 m above the base of the massif. It is marked by thin layers of norite, pyroxenite, spotty leucocratic gabbro and anorthosite among alternating gabbronorites and gabbros with consertal (extensively intergrowing) texture. The average thickness of the LSH is 46 m, with a dip of 30°S.

Sulphide and platinum-group metal mineralization is observed in the bottom and middle parts of the LSH section. The ore body thickness is 3–15 m. The ore mineralization occupies interstices between grains in all the rocks of the lower stratified horizon. The thickness of the sulphide-bearing rock varies from a few centimetres to 2–3 m. Two layers of ore have been identified; the Main and, less persistently, the Upper layer. The layers consist of impregnation which has no distinct boundaries: the outlines of the ore are therefore based on sampling results. The ore is heterogeneous: PGE-bearing mineralization is confined to the boundaries of the spotty leucocratic gabbros and anorthosites with norites and gabbronorites, with plagio-pyroxenites and rarely with plagio-websterites. The main ore-bearing zone comprises several contiguous sheet- and lenslike sulphide-bearing layers occurring en echelon and with lengths of up to 100-400 metres. The distribution of sulphides in the mineralized layers is irregular: the sulphide content varies from <1% to 3-5 %. The thickness of the main ore body varies from 0.1-6.5 m, averaging 1.7 m. The approved reserves (1.01.2009) were: A+B+C1: 1.8 Mt of ore giving 6.5 t of PGE.

The main economic elements are palladium, nickel, platinum and copper. The average content of platinum is 0.479 g/t, and of palladium 3.172 g/t (Pd/Pt-ratio 6.7). In low-sulphide ores, the primary minerals are chalcopyrite, pentlandite and pyrrhotite. Apart from pentlandite, palladium is present in kotulskite, vysotskite,

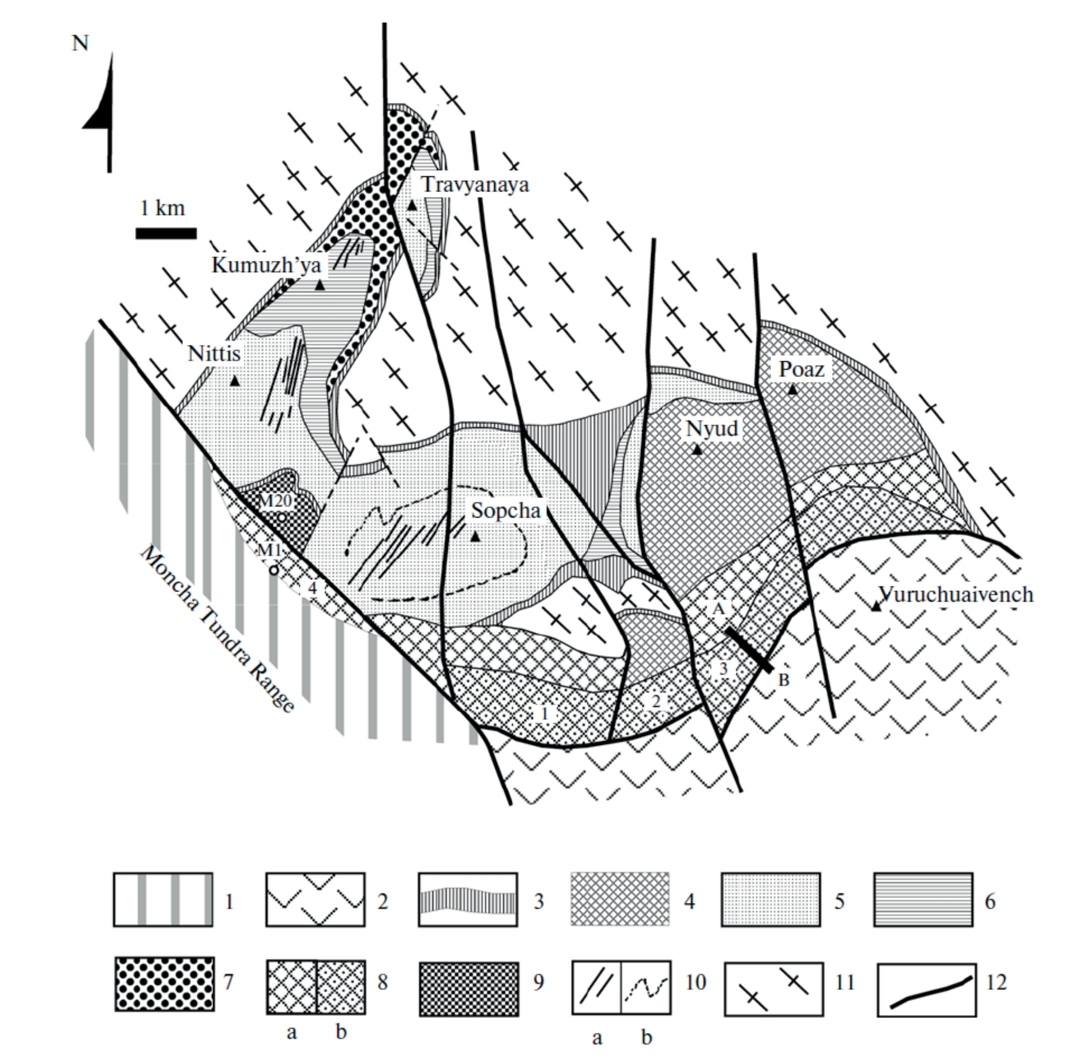


Figure 38: Geological structure of the junction of the Monchegorsk and MoncheTundra plutons and position of the studied massifs (V. V. Knauf, N. S. Guseva, 2009 ; E. V. Sharkov, A.V. Chistyakov, 2012). Massifs: 1: South Sopchi, 2: Lake Moroshkovoye, 3: Vuruchuaivench, 4: Mount NKT. Symbols: 1: Gabbronorite/ gabbronorite-anorthosites, Monche-Tundra massif; 2: Igneous-sedimentary complexes of the Imandra-Varzuga series; 3-9: Formations of the Monchegorsk Pluton; 3: Marginal series with Cu-Ni sulphide mineralization ("bottom bank"); 4: Alternation of Ol+Opx ±Chr, Opx-Ol and Opx+Ol(+Pl) cumulates (a: fresh, b: altered); 5: Opx cumulates; 6: Pl+Opx±Cpx cumulates; 7: Cumulates and formations of dunite; 8: Cu-Ni sulphide mineralization (a: massive sulphide veins, b: Impregnated ores of "Sopchi ore stratum – Horizon 330"); 9-10: Archean formations: granulites; 9: Dioritic gneiss, Kola block; 10: Rhyodacite/dacites; 11: Tectonic faults; 12: Dip/ strike.

merenskyite and braggite, and platinum in moncheite, braggite, merenskyite and vysotskite. Some gold is present as electrum. The platinum minerals are generally associated with the sulphides. The morphology of the platinum mineral grains is diverse. Both automorphic crystals of PGE minerals and xenomorphic grains and limbate (zoned) segregations are observed. The internal structure of grains is blocky and zoned. PGE arsenides occur locally, leading, because of alteration, to an increasing proportion of sperrylite.

Vuruchuaivench (PGE)

The Vuruchuaivench platinum-group metal deposit is located in the central part of the Kola Peninsula, 10 km from Monchegorsk and 5 km from the operating Severonickel mill of Kola MMC (Norilsk Nickel). The Vuruchuaivench site was discovered by KOLA MMC surveys in Monchegorsk District in 2004-2008, and is now being prospected for precious metals. The Vuruchuaivench mineralization (Figure 38) is a reef layer with a horizon of disseminated sulphide enrichment in albitized anorthosites in the western and central blocks of the ore body, and in leucocratic metagabbronorites in the eastern block. According to prospecting data from 2004, the Vuruchuaivench reef extends in a SW-NE direction for 1.0–1.2 km as a layer with individual attenuating lenses. The Vuruchuaivench massif adjoins the norite-gabbronorite part of the Monche-Pluton section (Mount Nyud-Poaz) in the south. It is a wedge-like body, dipping gently south-eastwards, resting on Archaean granite gneisses and overlain by Imandra-Varzuga series rocks, under which the massif is traceable southward in drillholes. The massif's rocks crop out SW and SE of the Nyud-Poaz massif, and are traceable for 7-8 km in a north-easterly direction, before disappearing under the Lake Imandra basin. The deposit is broken up into blocks by a series of thrusts and faults. The ore bodies are represented by sheet-like beds and flattened lenses without clear outlines. The main reserves are concentrated in Ore Body No. 1, and confined to a layer 0.5 to 10–20 m thick with sulphide impregnation.

The Vuruchuaivench massif consists of two main rock types:

- Melanonorites, norites and gabbronorites, the upper part of which underwent post-crystallization alteration, form the lower part of the section

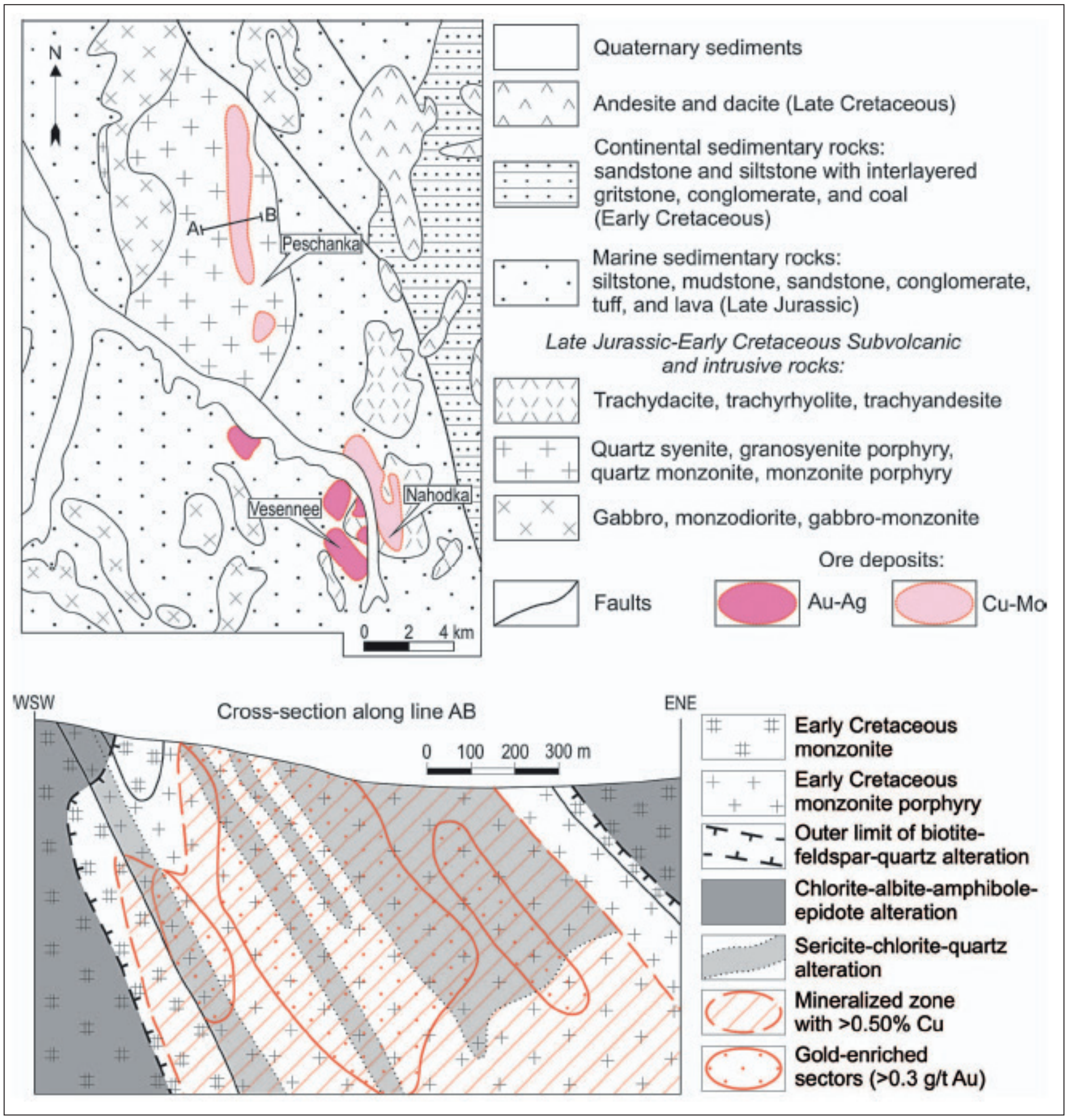


Figure 39: Cross section of the Peschanka porphyry deposit (after Migachev et al, 1995, in Seltmann et al, 2010).

- Talc-chlorite (zoisite-vuagnatite)-plagioclase rocks, previously described as meta-leuco-gabbros, meta-anorthosites or plagioclasites – form the upper part of the section.

Data on the commercial reserves of the Vuruchu-aivench deposit are presented in Table 2.

Reserves, Vuruchuaivench deposit, Category C1+C2	
Ore (Mt)	83.6
Nickel (kt)	248.2
Copper (kt)	164.9
Cobalt (kt)	10.9
Platinum (t)	569.0
Palladium (t)	2781.0
Gold (t)	144.0

Table 2: Reserves of the Vuruchuaivench deposit. (Norilsk Nickel Annual Report 2014. p 65.)

Peschanka (Cu-Au-Mo)[1]

The Peschanka (Baimskoe) Cu–Au–Mo porphyry deposit (Figure 39) (Migachev et al. 1995) contains resources of 1350 Mt of ore grading 0.61% Cu, 0.015% Mo, 0.32 g/t Au and 3.7 g/t Ag corresponding to 8.3 Mt Cu, 200 kt Mo, 425 t Au and 5 kt Ag. The deposit is situated in the Circum-Pacific orogen (Chukotka Peninsula), close to the western margin of the Okhotsk–Chukotka volcanic–plutonic belt, where this belt is su-perimposed on the Omolon microcontinent. The belt contains multiphase diorite–monzonite–syenite–granite intrusions, located within the Baym metallogenic zone. This metallogenic zone forms a linear structure traceable for over 200 km, with a width of 20–25 km, and hosts a number of porphyry deposits. Monzodiorite and quartz monzo-diorite intruded by younger granodiorite porphyry stocks are present in the deposit area. Hydrothermal alteration has created an innermost zone of quartz–sericite–carbonate assemblage, an intermediate zone composed of K-feldspar and biotite, and an outer zone composed of propylitic (hydrosilicate) assemblages (Figure 39). The Cu porphyry mineralisation is coincident with the zone of quartz–sericite–carbonate altera-tion replacing the entire granodiorite porphyry body, whereas the Mo mineralisation is confined to a narrow area inside the Cu halo, generally associated with a dense quartz stockwork. The mineralization formed during four stages (from earlier to later): (I) molybdenite; (II) chalcopyrite–pyrite; (III) bornite–chalcopyrite–tennantite; and (IV) chalcopyrite–sphalerite–galena stages. The chalcopyrite–pyrite mineralisation is most widespread, but the higher-grade ores are associated with the bornite–chalcopyrite–tennantite assemblage.

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FERROUS METALS

Molchanov A.V., Terekhov A.V., Artem'ev D.S., Shatov V.V., Belova V.N.

Aganozero chromium deposit

The Aganozero chromium deposit is located in Pudozh District, Republic of Karelia, 30 km E of Lake Onega and 40 km N of the city of Pudozh, near Lake Aganozero. The first data on the chromium ores in this area were obtained by the Karelian integrated Geological Survey Expedition in 1956.

Structurally, the deposit is confined to the northern (Aganozero) block of the Burakovo-Aganozero layered mafic/ultramafic intrusion (Fig. 40). The intrusion has been traced for 7100 m along strike: its thickness is 110-150 m. Titanium-magnetite mineralization is present as sheet-like ores at the base of the intrusion and is traceable to depths of 330.7 m. The vertical thickness of the layer varies between 7.4 and 32.2 m. Individual ore lenses occur higher in the section. The chromite mineralization is confined to the top of the peridotite subzone in thin streaks and lenses, and to the contact between the ultramafic and pyroxenite zones, the main chromite horizon in the massif's layered series. In all, eight chromite horizons, 0.1 - 9.0 m thick, are known in the section, but of these, only the main chromite horizon is of commercial importance. The ore occurs in pyroxenites and poikilitic peridotites of varying composition. Olivine clinopyroxenites or wehrlites occur at the top of the main chromite horizon, and poikilitic wehrlites, or, less commonly, lherzolites and harzburgites, occur at its base. The chromium ores typically have an olivine-pyroxene-chrome-spinel composition with a fine-grained texture and two generations of chrome-spinel. The main chromite horizon forms a synform extending 8.5 km in an approximately N-S direction and up to 3.6 km wide, with the stratum dipping towards the structure's centre at 11-33° in the southern, northern, and western parts of the deposit, and at 30-53°, in the eastern and south-eastern parts. The synform is divided by thrust faults into several tectonic blocks with vertical displacements of 20 - 170 m relative to each other. The main chromite horizon is a layer, the internal structure of which is locally complicated by thin (0.2-1.2 m) streaks and lenses of unmineralized rock – wehrlite and, less commonly, clinopyroxenites, with lengths from a few metres to hundreds of metres. On the whole, the main chromite horizon shows a persistent dip and strike. Its true thickness varies from 0.7 to 6.3 m, with average thicknesses of 3.2, 2.6 and 2.3 m for cut-off grades of 10, 15 and 20 % Cr_2O_3, respectively. The thickness of the ore increases along strike and at depth in the N-S direction. The host rocks are pyroxenites and poikilite peridotites with differing structures.

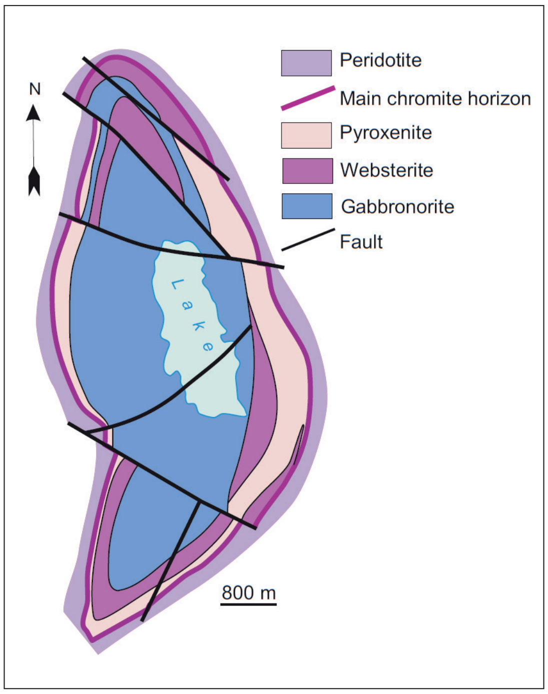


Figure 40: Geology of the Aganozero chromite deposit (Korsakova, 2012, based on Raw Mineral Base of the Republic of Karelia, 2005).

The reserves and inferred resources of the Aganozero deposit are, in total, 205 Mt with an average of 21.78 % Cr_2O_3, which is considered

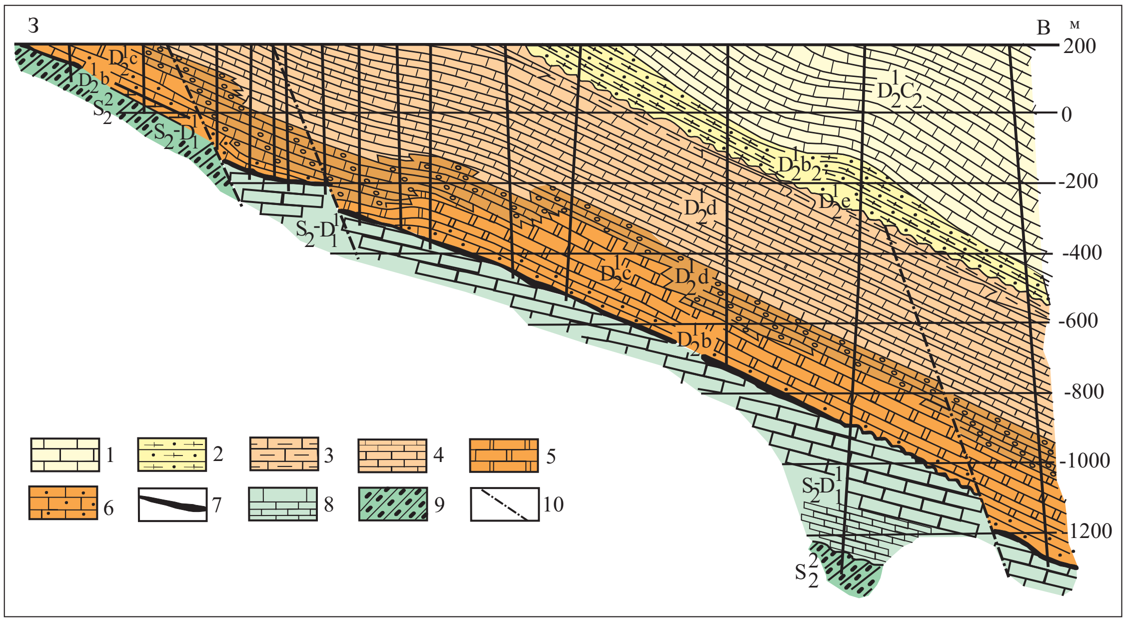


Figure 41: Geological section of the Kalyinskoye deposit at Mount Bolshun: (Gutkin, 1978) 1: U. Eifelien limestones, massive, often reef D2c2; 2: U. Eifelian limestone, dark-grey, bituminous, amphibolic D2'b2; 3: L. Eifelian limestone, light-grey, reef D2'l; 4: L. Eifelian limestone, grey, tabular, silicified in lower part D2'd; 5: L. Eifelian limestone, light-grey, reef D2'c; 6: L. Eifelian limestone, dark-grey, bituminous, amphibole-bearing D2'b; 7: Bauxite horizon; 8: Limestones of the Petropavlovskaya Suite, light-grey, reef, laminated in lower part , 9: Tuff breccias of the Sosva suite ; 10: Tectonic faults.

to be a large deposit. The size of the deposit is comparable to that of the Kemi deposit in Finland, and exceeds those of the Sopcheozero and Bolshaya Varaka deposits in Murmansk Oblast. Open pit mining is possible to depths of 40-60 m, according to a feasibility study, on a relatively small part of the deposit (in the marginal parts of the synform). Underground mining is economic in the remaining part. Sparsely impregnated, medium-impregnated and densely impregnated ores are distinguished on the basis of their chrome spinel content, which reaches 75-85 %. The chromium ores contain accessory platinum metal and gold mineralization. The weighted average concentrations are: for platinum, 0.087 g/t, for palladium, 0.12 g/t, for rhodium, 0.001 g/t, and for gold, 0.25 g/t. The commercial chromium reserves to a depth of 220 m are, for Category C1+C2, 26.5 Mt, of which 7.8 Mt for open pit mining (to a depth of 50 m) and 18.7 Mt for underground mining.

North Urals Bauxite Deposits (Kalyinsky, Novo-Kalyinsky)

The North Urals bauxite district is located in the western part of the Nizhny Tagil synclinorium. The bauxite ores are confined to the monoclinal zone of the western end of the Shegultan syncline comprising Silurian and Devonian limestones. The whole complex of rocks strikes N-S and dips 18 – 40° E. The bauxite deposits are of the karst sheet-like type. The bauxite basin is divided by faults, trending approximately E-W, and by sterile intervals into several large areas that were conventionally called deposits: Krasnaya Shapochka 7.7 km long (with the Zavagransky, Main Ore Field, First, Second, and Third Northern, and Eastern Shoot sections); Kalyinskoye deposit 5.5 km long (South Kalyinsky, Central Kalyinsky, and North Kalyinsky sections); Novo-Kalyinskoye deposit 2 km long; Cheremukhovskoye deposit 7.9 km long (with the South Cheremukhovsky and Kedrovsky sections); Sosvinskoye deposit, and Vsevolodo-Blagodatskoye deposit.

The geology of the North Urals deposit area comprises Upper Silurian and Devonian formations (Fig.41). The Wenlock (Silurian) is represented by andesite-basalt porphyries (Pokrovskoye Suite). Higher in the section there are formations of Ludlow age, which in their lower part are made up of massive pink limestones (Voskresenskoye Suite) and bedded, dark-grey limestones (Kolonga Suite), and in the upper part, by dolerite porphyries, conglomerates, tuff breccias, and tuff shales with streaks of grey limestone (Sosva Suite).

The Subrovsky horizon of bauxites is directly underlain by poorly defined sediments of Ludlow and Pridolian age. In the lower part, there are conglomerates, sandstones, shales, and dark-grey bituminous limestones (pink and light-grey) of the Petropavlovskaya Suite.

Bauxite ores of the SUBR horizon (held by North Ural Bauxite Mine) occur on the uneven karst surface of the reef limestones of the Petropavlovskaya Suite. The bauxites are overlain by limestones of Eifelian age, which are divided into three units (from the base upwards): dark grey, bituminous, amphibole-bearing, bedded; light grey, massive, reef ; dark grey flag-like and thin flag-like, with streaks of clayey and clayey siliceous shales. Limestones of Givetian and Frasnian ages occur higher in the section.

The ore horizons have a complex, sheet-like shape determined by the relief of the underlying limestones, post-mineralization tectonics and karstification processes. Bauxites develop in relation to erosion, and occur locally, unconformably, on pink karstic limestones of the Petropavlovskaya Suite, where they are abundant in large, irregularly shaped pits and sinks, 1 - 25 m deep, so that the ore thicknesses vary correspondingly. The strata vary in thickness from 0.1 - 9 m, with an average of 2 - 5 m. The strike length commonly exceeds 3 – 3.5 km, and the ores have been traced to depths of more than 1600 – 2000 m.

The bauxite horizon consists lithologically of three subhorizons, from the base upwards: red stained ores, red unstained, jasper-like ores and green-grey variegated ores. The bauxites fill the irregularities of the karst paleorelief surface. The middle sub-horizon ores are commonly found on an uneven surface of red-stained bauxites, and thinner ore bodies may consist only by them. Coarse pisolitic bauxites and bauxite conglomerates belonging to that subhorizon are widespread in all the deposits in the basin. The total thickness of red ores of the basal and middle subhorizons varies from 2 to 7 m; swells 30-40 metres thick are found, but are not common. Red jasper-like bauxites also occur as streaks and lenses in the upper subhorizon of grey bauxites. The upper subhorizon of greenish-grey variegated ores is represented by bedded bauxites, with a granular, less frequently dense, jasper-like structure. Bauxites in this horizon have a spotty ochre and brown colour. Below this level, their colour is greyish-green. Variegated bauxites occur, overlying red bauxites, with rather even and commonly abrupt contacts. The subhorizon's thickness is 0.2 – 0.4 m, less frequently 2-3 m. Breccias of a sedimentary-metasomatic nature consisting of underlying limestone fragments cemented by bauxite are commonly found at the base of an ore body.

Red-stained and non-stained bauxites form about 80 % of the whole ore horizon. These bauxites are of the highest grade. Diaspore is the main mineral in the ore, whereas boehmite and chlorite are subordinate. Minerals containing impurities, including silica, carbon dioxide and sulphur, occur in small quantities and are mainly confined to shear fractures as pyrite and calcite. Red jasper-like bauxites are slightly inferior in quality to the other varieties due to their high silica content. Boehmite is the main mineral in this ore type; diaspore and kaolinite are subordinate. Variegated bauxites are very heterogeneous. Diaspore and boehmite are the major phases, whereas pyrite, siderite, haematite, chlorite, and kaolinite are subordinate.

The high-quality red bauxites have the following chemistry: Al_2O_3 53-55 wt.%, SiO_2 6 wt.%, Fe_2O_3 23-25 wt.%, CaO 1.6-2.5 wt.%, S02.12-0.4 wt.% (up to 1.1 %), CO_2 1.9 – 3.6 wt.%, TiO_2 2.0-2.5 wt.%. High-sulphur pyrite and variegated bauxites containing 1 - 15 wt.% of sulphur make up 5 % of the overall reserves. The North Urals bauxites are enriched in REE and contain 19 - 57 g/t scandium, 4.8 g/t yttrium, and 1.55 g/t ytterbium. The deposits are being mined by Sevuralboksitruda JSC: shafts in the underground mines reach 1000 – 1500 m.

Keiv Deposits of High-Alumina Raw Materials

High-alumina kyanite deposits are located in the eastern part of the Kola Peninsula, within the 200 km long, northwesterly striking Keiv ridge. The geology of the ridge comprises deeply metamorphosed sedimentary rocks of the Lower Proterozoic Keiv series, which have been partly metamorphosed to kyanite-rich schists. The kyanite deposits were discovered in 1928 during expeditions of the USSR Academy of Sciences.

The eastern deposits of the Keiv suite were discovered by A. A. Grigoriev, and those in the west, by A. A. Vorobyova. Exploration activities in this district have revealed 29 kyanite deposits (Fig. 42), of which the largest are Shuururta, Bezymyannoye, Tyapysh-Manyuk, Vorgelurta, Novaya Shuururta, Chervurta and Bolshoi Rov. The proven reserves of these deposits exceed 3 billion tons. The use of kyanite and other aluminosilicate minerals as a potential source of alumina was developed in the Soviet Union, due to the low grade of known domestic bauxite resources (Shabad, 1976; Voytekhovsky & Neradovsky, 2012). The Keiv series of rocks forms a large synclinorium with a general westerly / north-westerly strike complicated by multiple smaller folds, structures which are found even on a micro-scale. The synclinorium's northern limb is overturned southwards, so that a reverse stratigraphic sequence is observed. The rocks dip at 60-80° N. The synclinorium's southern limb shows a normal stratigraphy; the dip is also northwards but at lower angles (20 - 40° N). The Keiv series rocks are subdivided into two main parts, a lower gneiss part and an upper schist part. The latter is divided in six identifiable units (Nosikov, 1960).

All known kyanite deposits are confined to unit б in which three main kyanite schist types are identified: 1) Radiate/fibrous, 2) paramorphic and 3) concretion ore (Fig. 43).

Paramorphic kyanite schists (Manyuk type) are characterised by white kyanite, mostly as pseudomorphs of andalusite: a cross typical for chiastolite can be seen in their cross-section. The most interesting deposits of the Manyuk type are Vorgelurta, Manyuk, and Bezymyannoye.

Vorgelurta, Manyuk and Bezymyannoye kyanite deposits

The Vorgelurta deposit is located on the north-eastern slope of a tundra of the same name, 20 km NW of the Sukhoi River and 180 km E of Apatity Station on the Kirov Railroad. Gneisses, garnet-mica-, kyanite-, paramorphic kyanite- and staurolite-kyanite schists belonging to the Proterozoic Keiv series are the main rock types in the area of the deposit. Structurally, the deposit is confined to the northern limb of a synclinorium which is overturned southwards, and which is complicated by secondary and tertiary folds.

Morphologically, the deposit is represented by two sheet-like bodies of paramorphic kyanite schists, 35 and 50 m thick, separated by mica-quartz and mica-staurolite-garnet schists.

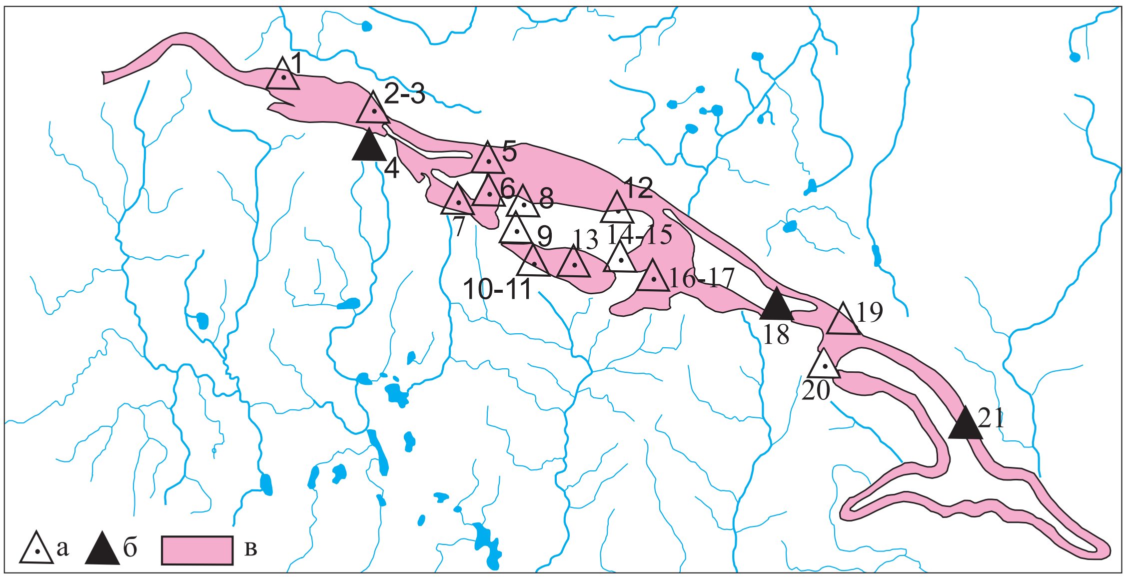
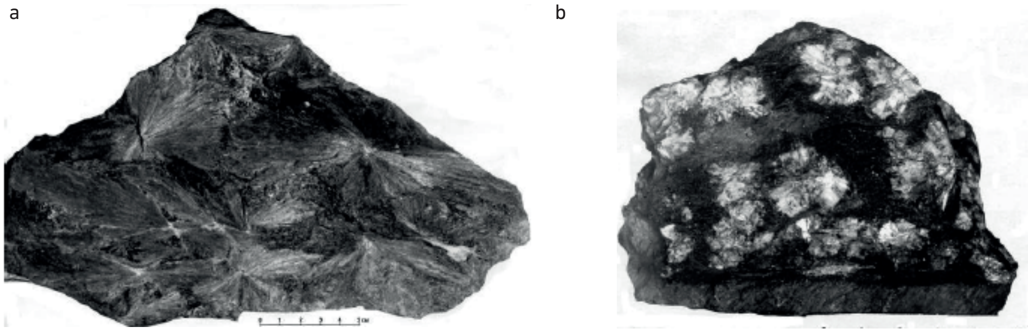


Figure 42: Kyanite deposits within the Keiv productive suite (acc. to V. V. Nosikov, 1960).
а: Commercially viable deposits; б: Non-commercial deposits; в: productive suite.
Deposit names: 1: Vorgelurta; 2: Tyapysh-Manyuk; 3: Tavurta; 4: West Valurta; 5: Bezymyannaya tundra; 6: Lysturta tundra; 7: Chervurta; 8: East Chervurta; 9: Bolshoi Rov II; 10: Bolshoi Rov I; 11: West Kyrpurta; 12: Novaya Shuururta; 13: Yagelurta; 14: East Kyrpurta; 15: Kyrpurta; 16: Shuururta; 17: South-East Shuururta; 18: Acha River; 19: Yevlecherrui (Kaipurta); 20: Nussa tundra; 21: Manyuk.

a b



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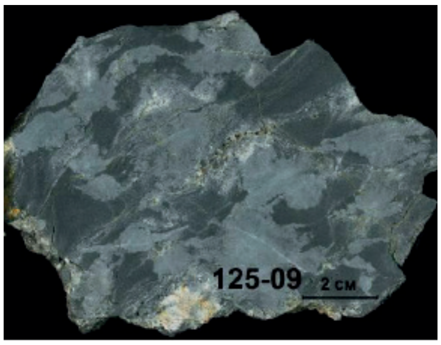


Figure 43: Main types of kyanite ore
(from: Voytekhovsky & Neradovsky, 2012)
a:. Fibrous/acicular ore
b: Paramorphic ore
c: Concretion ore

Kyanite pseudomorphs in the schists reach a length of 20 cm along the major axis, with cross-sections of up to 5-6 cm. The bodies have been traced for 5 km along strike. The kyanite content in individual samples varies from 32.75 to 45.5 %, with an average of 37.93 % for the deposit as a whole. Two other deposits of paramorphic kyanite ores, Manyuk, and Bezymyannoye, are located respectively 275 km and 200 km E of Apatity Station on the Kirov Railroad: these differ from the Vorgelurta deposit by the smaller grain size of the kyanite pseudomorphs (for chiastolite), with lengths up to 5-7 cm, and cross sections of 2-3 cm.

Tyapysh-Manyuk, Tavurta and Novaya Shuururta kyanite deposits

Concretion kyanite schist deposits are characterised by spherical and, less frequently, spindle-shaped aggregates, consisting of black, fibrous or acicular kyanite crystals, tightly clustered and resembling a concretion. The size of the concretions varies from several millimetres to 5-7 cm across; spindle-shaped concretions reach 10-12 cm along the major axis. Concretion schists commonly grade into pseudomorphic varieties along strike (Bezymyannoye and Vorgelurta deposits). Transitions from concretionary kyanite schists into divergent and fibrous types were observed in two cases (the Novaya Shuururta and Tyapysh-Manyuk-Tavurta kyanite deposits). Currently, three deposits of concretion-type ores are known: Tyapysh-Manyuk, Tavurta, and Novaya Shuururta.

The Tyapysh-Manyuk and Tavurta deposits are located 12 km W of the Bezymyannaya tundra deposit and 200 km E of the Apatity Station on the Kirov Railroad. The deposits were explored by the North-Western Geological Agency in 1950-1953. The deposits are confined to the northern limb of the Keiv synclinorium which is overturned southwards. The rocks dip northwards at up to 80°. These kyanite schists contain large- and small-concretion varieties with average kyanite contents of 30-32 %. Small-concretion kyanite schists are difficult to process, therefore only large-concretion varieties can be regarded as ores in the deposits. The latter occur as sheet-like bodies traceable within the Tyapysh-Manyuk deposit for almost 4 km, and within the Tavurta deposit for 1.4 km.

The thickness of the ore bodies is variable, partly due to replacement of large concretion kyanite ores by other types of kyanite schist. Small-concretion schists are primarily developed on the footwall side of large-concretion ores; less frequently, they occur as lenses inside a main ore body formed by large-concretion schists.

The Novaya Shuururta deposit (Fig. 44) is located on the Shuururta tundra summit, 3 km NW of the top of the Tsitsnykury-Nollourty tundra, 2.5 km N of Lake Semuzhye, and 225 km E of Apatity Station on the Kirov Railroad. The deposit lies 95-100 m above Lake Semuzhye. The ore is large-concretion kyanite schist (as found in the Tyapysh-Manyuk deposit) and was discovered in 1952 and explored in single trenches. The average thickness of the deposit is 148 m and its kyanite content is 42.44 %. East of the deposit, large-concretion kyanite ores grade via flattened (squeezed) varieties into fibrous, variably sheaf-textured kyanite schists. To the west, large concretions are replaced by smaller ones and are gradually displaced by this texture.

Deposits of divergent and fibrous kyanite schists feature kyanite as elongate needles or fibres, commonly forming diverse fibrous aggregates resembling a sheaf, a starlet or other shapes. Divergent kyanite schists are widely developed in the southern wing of the Keiv synclinorium and in the southern fold structures, both secondary and tertiary. Features of this schist type are their wavy structure and small folding. In the northern wing of the main synclinorium, divergent and fibrous kyanite schists are absent or subordinate to other kyanite ore types.

Many deposits of divergent kyanite schists have been discovered in the Keiv ridge, notably Chervurta, Bolshoi Rov I, Bolshoi Rov II, Kyrpurta, Lysturta as well as other deposits,

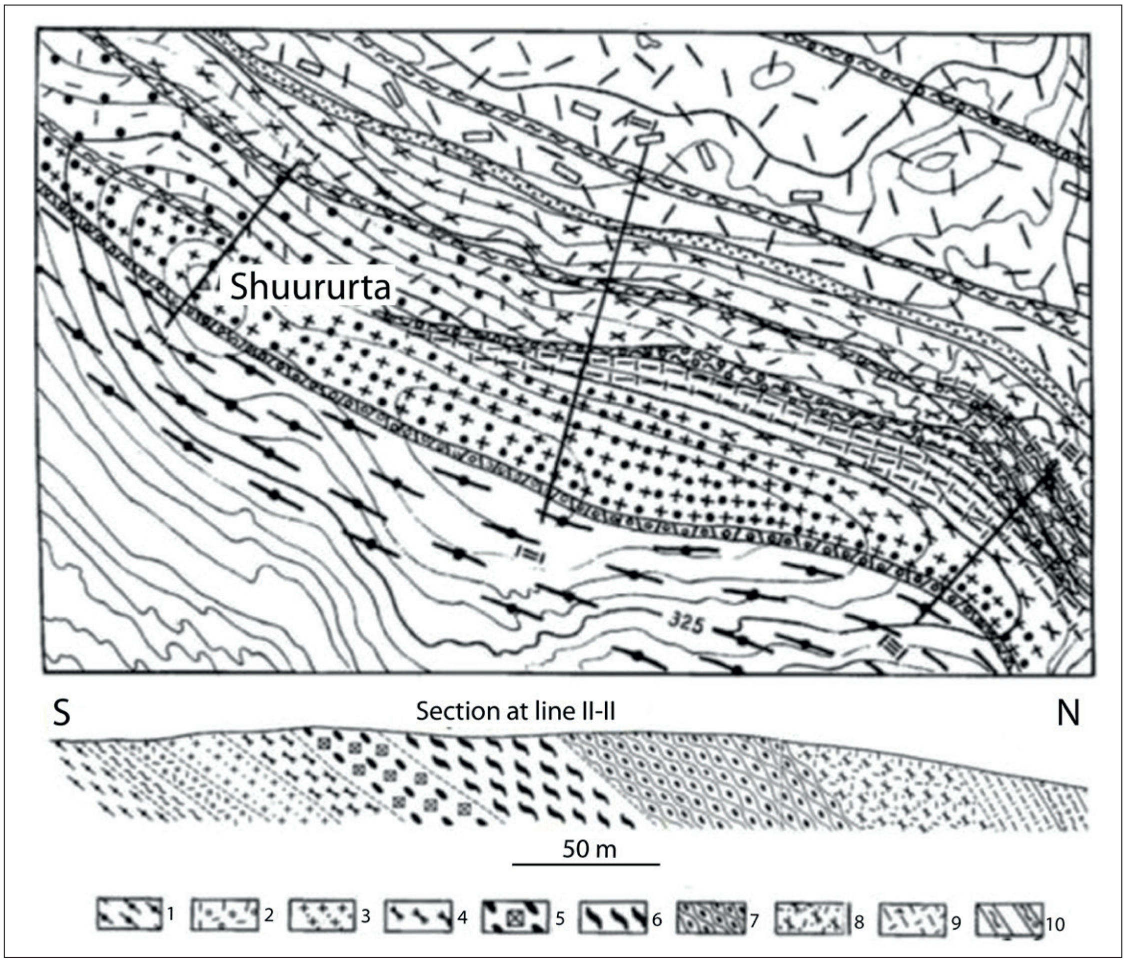


Figure 44: Geology of the N. Shuururta deposit (I. V. Belkov,1963, see also Voytekhovsky & Neradovsky (2012).
1: Garnet-biotite gneisses; 3: Schists of bench A; **3-7: Kyanite schists:** 3: Small concretion-paramorphic; 4: Aggregate-fibrous; 5: Concretion-paramorphic; 6: Large-concretion kyanite schist; 7: Small-concretion kyanite schist; 8: Staurolite porphyroblastic schists; 9: Staurolite-kyanite porphyroblastic schists, 10: Amphibolites: a – feldspar, b – garnet-feldspar.

mostly confined to the lower productive horizon of Mass Ъ and located mainly on the southern wing of the main Keiv synclinorium or on the smaller southern folds.

Chervurta kyanite deposit

The Chervurta deposit, 26 km SE of the former Semiostrovsky Pogost village and 200 km E of Apatity Station of the Kirov Railroad, is located on the Chervurta tundra which rises 60 – 80 m above the surrounding valley. The deposit is confined to the main synclinorium's southern wing, within which the rocks dip at 40-45° NE. The ores are kyanite schists in the basal horizon of the productive level, with a kyanite content of 38 - 40 %. The kyanite grains are grey and black in colour, and have a fibrous habit; the grains commonly form radiating and sheaf-like aggregates. The fibre length is 3.5—5.0 mm, locally more. The deposit has been explored in an area located near the highest part of the Chervurta tundra and covering part of the stratum for a length of 1.5 km. The thickness of the stratum is 38-45 m.

Iksa (North Onega bauxite district)

The Iksa bauxite deposit was discovered in 1949, and explored in 1950-1963, in particular the western parts of the Belovodskaya and Yevsyukovskaya beds which have the most favourable mining conditions. In 1965, the deposit was allocated to the North Onega bauxite mine and mining began in 1974. The deposit is located in Plesetsk District, Arkhangelsk Oblast near Navolok village, 5-6 km SW of Navolok Station. The ores are located on both banks of the R. Onega in the estuarine part of its tributary, the R. Iksa.

The deposit is confined to the Iksa basin, a secondary structure of the ancient, buried North Onega trough. The basin is 18 km long, trending in a north-westerly direction and about 7.5 km wide in the centre; its deeper part and margins have depressions carrying the main bauxite layers of the deposit. The bauxites occur, stratigraphically, at the base of the Visean section. The deposit is made up by six bauxite beds: Belovodskaya, Yevsyukovskaya, Chirkovskaya, Kudryavtsevskaya, Tarasovskaya and Kazakovskaya. The total area of the bauxite is 120 km^2, of which ore-quality bauxite covers 35 km^2, with a thickness of 0.8 - 16 m (the average thickness of the beds is 2.5-8 m). The depths of the beds are, on average, 45-75 m. The bauxite quality within the beds and in the deposit in general, is marked by a high degree of continuity.

The western parts of the Belovodskaya and Yevsyukovskaya ore beds are classified as commercial, while the eastern part of the deposit which is overlain by limestones is non-commercial. The Belovodskaya bed is the largest (over 81 % of proven reserves, of which 95 % is commercial): Yevsyukovskaya is the second largest (11 % of proven reserves, of which 70 % is commercial). The total reserves of the other four beds are about 8 %, and they are all considered non-commercial. The Belovodskaya bed is, on the basis of mining and hydrogeological conditions, subdivided into the Western, Eastern, and Zaluzhemsky fields. The Western field is somewhat elongated in an E-W direction (3.5 × 2-2.5 km) and has an area of 12,912,000 m^2, a thickness 1.0 - 16.0 m (average: 8.0 m) and depth 40-55 m (average: 48 m). The overburden consists of loose sandy/clayey fluvioglacial sediments.

The Belovodskaya ore body has a convex shape and thickness of 5 m or more in the central part, decreasing to a minimum economic thickness on the sides. The highest-quality bauxites form the core of the ore bed, being replaced towards the base and roof and towards the periphery by low-quality ores and by clays. The western part of the Yevsyukovskaya bed covers an area of 5,565,000 m2, the average thickness of the bed is 2.8 m and it is found at a depth of 45 m. The bauxite deposit consists of kaolinite-boehmite and locally, kaolinite-gibbsite-boehmite. The deposit contains, on average, 30-40 % kaolinite, 25-35 % boehmite and 10-15 % gibbsite. In addition the deposit contains goethite or haematite as iron-bearing phases and leucoxene, rutile and anatase as titanium phases. Small quantities of calcium and magnesium oxides are related to epigenetic siderite and zeolite formation, and sulphur is bound in gypsum. On average the Cr_2O_3 content is 0.60 % but reaches 7.3 % in some areas. According to VAMI (the Russian National Aluminum-Magnesium Institute), chromium occurs as a free hydroxide adsorbed to clayey minerals, and in chrome spinel.

Compared to other deposits, the Iksa ores have high concentrations of gallium (62 g/t), V_2O_5 (1200 g/t), Cr_2O_3 (0.58-0.60 %), Sc (90-100 g/t), Li (160-450 g/t), yttrium (200 300 g/t) and REE (up to 1000 g/t): precious metals are also found.

Vezhayu-Vorykva bauxite deposit (Middle Timan bauxite district)

The first bauxite stratum was found in the Vychegda River in the Middle Timan in 1949. This initiated detailed prospecting and in 1970, high quality bauxites were found in the Vorykva River, leading to discovery of the economically viable Vezhayu-Vorykva bauxite deposit (Fig. 45). Later prospecting revealed new deposits and occurrences (Upper Schugor, Eastern, Zaostrovskoye, Volodinskoye and Sventlinskoye), which made Middle Timan the leading bauxite district in Russia.

The Vezhayu-Vorykva bauxite deposit is the largest in the whole Timan district. It contains 56.4 % of the bauxite reserves of the Vorykva ore cluster, and nearly 12 % of Russia's commercial reserves. The deposit includes three beds: Central, Western, and Upper Vorykva beds whose parameters are presented in Table 3.

The ore bodies have a bed to lens-like shape with a relatively even, slightly convex roof and a wavy base complicated by pockets and pit-like cavities. The average chemistry on a dry basis is (%): SiO_2, 8.01; TiO_2, 2.73; Al_2O_3, 48.69; Fe_2O_3, 27.87; CaO, 0.36; S_{total} = 0.02. Silicon module (Al_2O_3/ SiO_2): 6.08 (The silicon module is a measure of the quality of the bauxite, the higher the value the better the quality, Nikolaeva et al., 2015). In the Central bed, three blocks of stained, low-iron bauxites which are suitable for production of abrasives, high-quality refractories and ceramics for electrical applications have been exposed. The commercial reserves exceed 43 Mt.

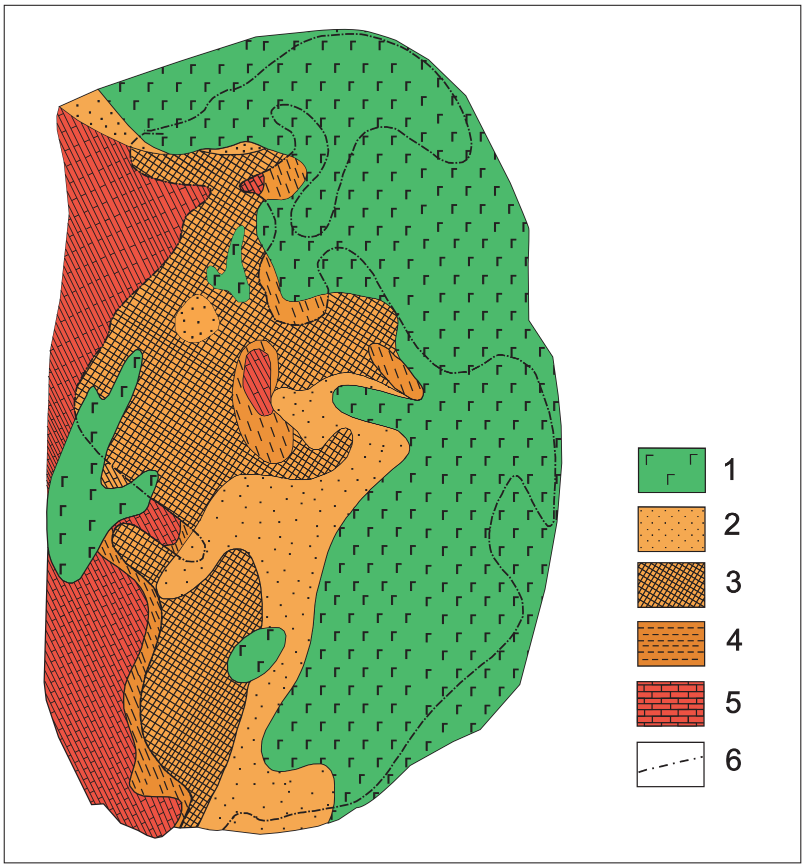


Figure 45: Schematic geological/lithological map of the central part of the Vezhayu-Vorykva deposit. Off scale (A. M. Plyakin, 2005) 1: Basalt; 2: Lower Frasnian sediments; 3: Bauxite; 4: Kaolinite-hydromica weathering profile; 5: Dolomite PR2; 6: Contour of bauxite bodies.

Diversity and a variable nature are typical for the ores, which is also manifested in variable concentrations of the main elements and of the silicon module value: Al_2O_3 - 34-76 %, SiO_2 – 1.5-21 %, Fe_2O_3 - 2-40 %, TiO_2 - 2-4.6 % and silicon module: 2.1-50 %. Accordingly, the mineral contents are also very variable. The main ore types are: haematite-boehmite, haematite-chamosite-boehmite, chamosite-boehmite, haematite-kaolinite-boehmite, kaolinite-boehmite and boehmite, of which the first two are most common; In the Central bed kaolinite-boehmite

Ore bed or field	Length, m.	Width, m.	Ore body thickness, m.	Depth of occurrence, m.	
				limits	average
Western	2200	200-1300	1.5-24.4	0.6-66.7	33.2
Upper Vorykva	2200	100-600	1.5-21.0	0.2-57.0	18.6
Central, ore body 1	2100	2200	1.5-27.5	0.6-50.0	24.4
Low-iron bauxite area	460	180-350	0.6-3.6	18.4-41.9	30.7

Table 3: Parameters of the Vezhayu-Vorykva deposit bauxite ores (Plyakin, 2005).

and boehmite types with a broad range of intermediate varieties are also important, many of which are suitable for abrasive production. The contents of trace elements in the ores of the Vezhayu-Vorykva deposit are normal for laterite-type bauxite, being (in g/t): Ga; 35-110; Sc, 40-140; V, 120-630; Nb, 30-90; REE, 600-1350. Since 1993, the deposit mining license has been owned by Boksit Timana JSC. The conditions allow open-pit mining; overburden rocks (mainly basalts) may be utilized as construction materials. Commercial development of the deposit began in February 1998; about 2 Mt of bauxite had been produced by 2002.

Upper Schugor bauxite deposit

The Upper Schugor deposit is located NW of the Vezhayu-Vorykva deposit. It consists of a South and North group of ore beds, which main difference is the different compositions of their decayed substrate. The North bauxite group was formed on feldspar-carbonate metasomatites; the ore bodies are heterogeneous, and are commonly split into a series of strata of various thicknesses, by alumina-rich laterites (allites) and clayey rocks (Fig. 46). The thickest ore strata (10 m and more) are confined to the top half of the ore body. The South bauxite group, formed on shale-carbonate rocks and meta-marls includes ore bodies usually consisting of one stratum occurring in the central part of the ore. The bauxites of the South group do not basically differ from the bauxite ores of the Vezhayu-Vorykva deposit in their chemistry and mineral composition, except for slightly higher contents of diaspore and aluminophosphate. A large part of the bauxites is usable for production of abrasives (5.7 Mt).

The North bauxite group contains more high-quality (high-module) grades, with haematite-boehmite, boehmite and kaolinite-boehmite mineralogy predominating. Very high silicon-module varieties (silicon module >28) varieties are frequent. Of special interest is a large unit of stained self-discoloured, iron-free high-module boehmite type bauxites. The average composition is (%): SiO_2 - 1.48; TiO_2 - 4.35; Al_2O_3 - 76.97; Fe_2O_3 - 0.78; FeO - 0.06; MgO - 0.13; FeO - 0.06; Al_2O_3/SiO_2, 91.65. In kaolinite-boehmite bauxites, the average silica content increases to 10.66 %, and the silicon-module value drops to 9.77. High-module haematite-boehmite bauxites are also quite widespread in the North ore group, containing, on average, 0,88 % SiO_2, 61,26 % Al_2O_3 and 20,09 % Fe_2O_3 (silicon module: 69.6). Low contents of chamosite are a feature of all the bauxites in the Northern ore group. The main parameters of several of the bauxite beds of the Upper Schugor deposit are shown in Table 4.

The average composition of the Upper Schugor deposit is (%, dry basis): SiO_2: 6.61, TiO_2: 2.87, Al_2O_3: 49.76, CaO: 0.39, S: 0.04, Ga: 0.0071, V_2O_5: 0.049; silicon-module value, 7.53.

The bauxites of the North ore group are characterised by extremely high concentrations of niobium and REE, which is due to REE mineralization in the parent metasomatic rocks. The average Nb contents are 200-700 g/t, in some samples up to 2000 g/t, present in pyrochlore, columbite, and niobotitanates. The bauxite sections show thin ore streaks with 2-5 % of Nb. Brown high-module bauxites contain 0.1 to 5.4 % of REE and up to 4.5 % Sr, present in monazite, apatite, or pyrochlore. These elements are not produced at the present.

Timsher (South Timan Bauxite District)

The Carboniferous bauxites in this district form the southern part of the Timan bauxite ore

Field	Length, m	Width, m	Ore body thickness, m		Depth of occurrence, m.	
			limits	ave.	limits	ave.
1st South	4500	400-1050	2.0-24.0	5.26	6.8-90.8	49.1
2nd North	4000	75-600	0.4-50.8	12.70	31.3-158.5	68.0
3rd North	2900	24-500	0.6-47.6	12.64	76.0-184.0	115.6

Table 4: Parameters of the Upper Schugor deposit ore fields (Plyakin, 2005)

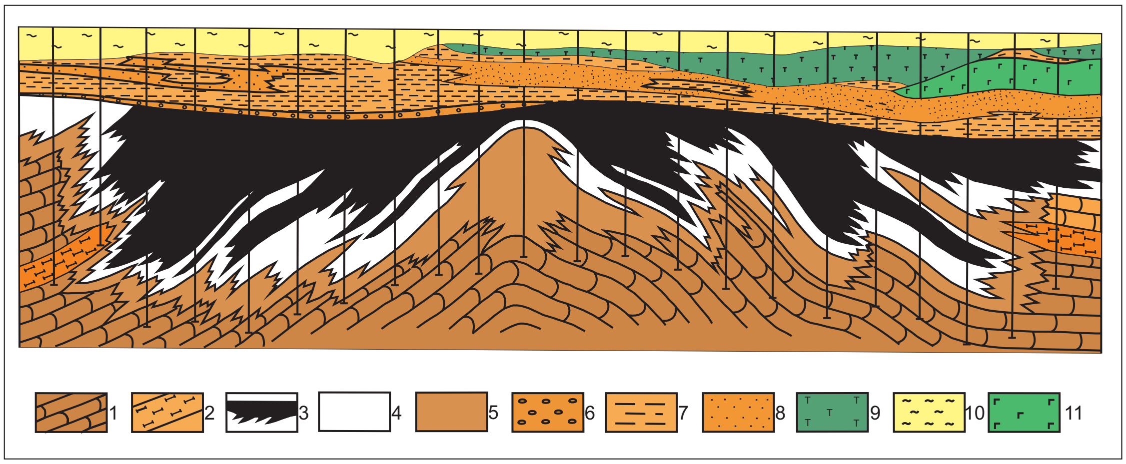


Figure 46: Geological section for one of the shoots of the Upper Schugor deposit (A. M. Plyakin, 2005) 1: Feldspar-carbonate schists; 2: Marls and calcareous schists; 3: Bauxites; 4: Allites; 5: Kaolinized metasomatite decay products; 6: Diluvial/proluvial bauxites; 7: Clays and siltstones; 8: Sandstones; 9: Tuffs and tuffites; 10: Quaternary sediments; 11: Main intrusions.

province. Stratigraphically, they are confined to the Visean stage, occurring on top of Devonian clayey carbonate sediments, and overlain most commonly by coal, and less frequently by Quaternary sediments. The South Timan bauxite district is mainly located 30-40 km, but up to 150 km, SSE of Ukhta. Two groups of deposits are identified within the district, Timsher-Puzla and Kedva-Volskaya.

The Timsher-Puzla deposits contain high-alumina, high-silicon, low-module, mostly pyritized (sulphurous) bauxites, characterised by a low iron content and white / light grey colour. The average depth of the bauxites is about 60 m; their thickness normally varies from 1.0 to 3.0-3.5 m, and, rarely, reaches 10 m. The bauxites of the Kedva-Volskaya group differ from those of the Timsher-Puzla group due to their low sulphur content. The Timsher deposit is located on the Vychegda-Izhma divide, along the R. Vychegda, furthest from Ukhta (120-150 km) compared to the other South Timan deposits. Structurally, it is confined to the south-western slope of the Timsher rise. Several beds are present in the deposit, the largest ones being the Western, Ezhvador, and Timsher beds. They are all near each other, forming one ore field. The First Timsher, Western, and Ezhvador beds have a sheet-like isometric shape with a wavy outline. The roofs and bases of the ore bodies are relatively uniform. White and grey kaolinite-boehmite bauxites predominate; red haematite-kaolinite-boehmite bauxites are less frequent. The following average contents of basic components are found in the bauxites (%): Al_2O_3 – 51.6; SiO_2 – 20.2; Fe_2O_3 – 5.44; S_{total} – 1.84.

Gremyakha-Vyrmes Fe-Ti deposit

The Gremyakha-Vyrmes Fe-Ti deposit is located in the Kola District, Murmansk Oblast and is hosted by a layered ultramafic-mafic complex within a mainly alkaline-gabbro massif of Proterozoic age (1973 Ma, U-Pb age on monzodiorite, Vursii et al. (2000)). The massif is located in Mesoarchaean gneisses and granite gneisses. Its surface dimensions are 19 km N-S and 4-6 km E-W. The massif comprises four major complexes (from oldest to youngest): 1: ultramafic-- mafic (marginal, gabbro wehrlite, and monzodiorite series and anorthosites); 2: alkaline complex (ijolites, melteigites, and foyaites); 3: complex of alkali granites and granosyenites; 4: complex of alkali metasomatites.

The complex Gremyakha-Vyrmes apatite-titanomagnetite-ilmenite deposit is related to a layered series of gabbro-anorthosite-peridotite rocks (Fig. 47). The ore deposit is hosted by the alkaline gabbro part of the layered intrusion. The most promising resources are titanomagnetite-ilmenite ores found in the south-eastern part of the complex (Southern field), containing, on average, 10-20 % TiO_2. The overall calculated ore reserves in this part of the ore body are estimated to be 330 Mt (Category C1+C2), with an average content of 10.7 % TiO_2 and 23.17 % Fe_{total}. An additional 150 Mt of richer ores with 12.5 % TiO_2 and 25.94 % of Fe_{total} have been identified in the central part of the ore body.

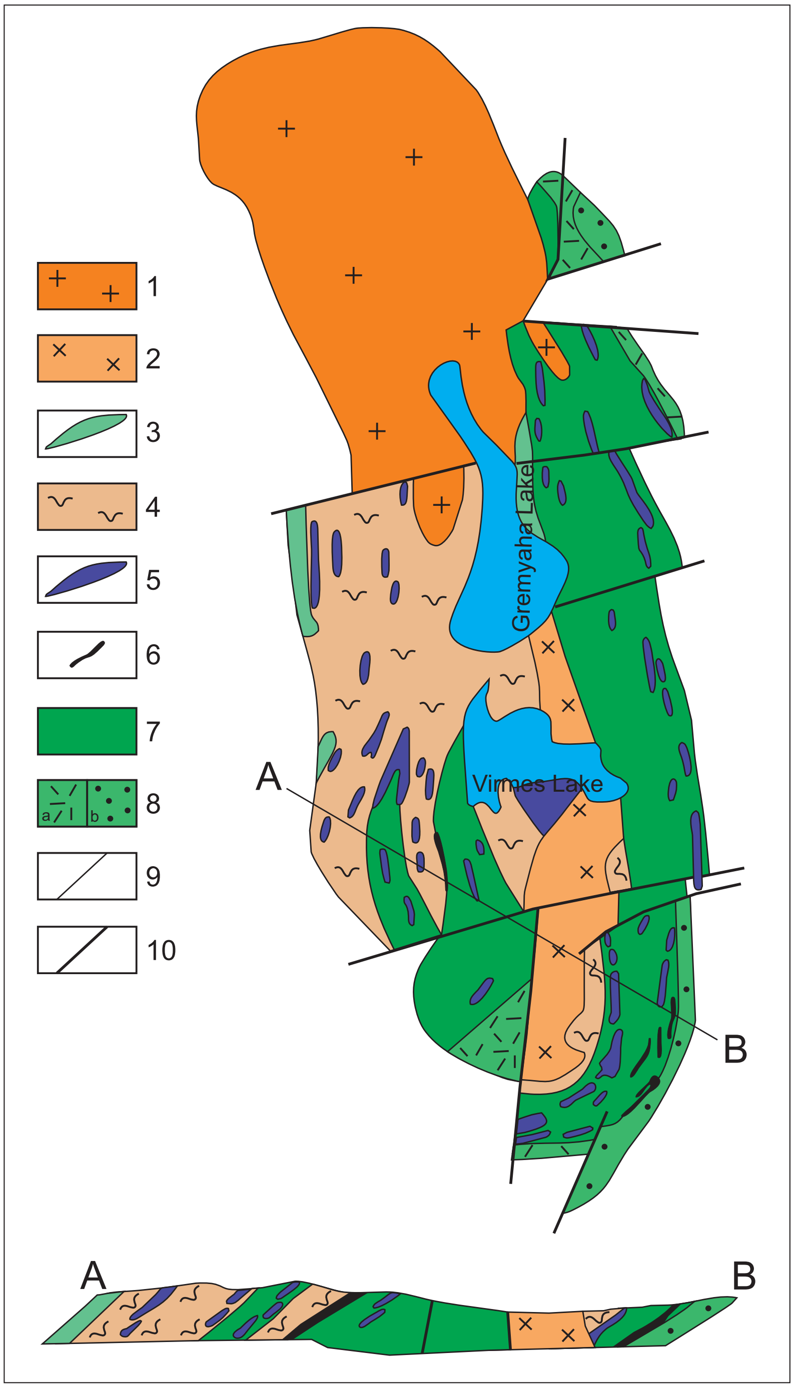


Figure 47: Geological map of the Gremyakha-Vyrmes massif (Gorbunov et al.,1981]:
1: Alkali granites and alkali syenite; 2: Nepheline syenite, ijolite, urtite, melteigite, jacupirangite, juvite, malignite, foyaite, aegirinite; 3: Ilmenite-apatite gabbro; 4: Alkali gabbro, pulaskite, akerite; 5: Peridotite, pyroxenite, olivinite with ilmenite titanomagnetite mineralization; 6: Rich ilmenite-titanomagnetite ores; 7: Gabbro, gabbro-anorthosites, anorthosite;8: Gabbro and gabbro norites (a: ore-free, б: bearing segregated titanomagnetite ores); 9: Boundaries between individual complexes (a) and enclosing rocks (б); 10: Tectonic faults.

The average TiO_2 content in the ilmenite concentrate is 47 %, while the TiO_2 content in the titano-magnetite concentrate is 9 %, and the content of Fe(total) ~58.4 %.. Based on its composition and physical properties, the ilmenite in the Gremyakha-Vyrmes deposit (i.e. the Southern field) gives a virtually pure mineral concentrate, and s easily decomposed in sulphuric acid, and a good raw material for the sulphuric acid process for production of titanium dioxide pigment.

A feasibility study by the company Giredmet has shown the viability of mining of the titanium ores of the Southern Gremyakha-Vyrmes deposit and their processing, using available capacities in the Olenegorsk and Monchegorsk mills. Based on prospecting and evaluation efforts, the overall reserves of titanium and phosphorus ores were estimated to 1.7 billion tons, with average contents of 2.84 % P_2O_5 and 5.53 % TiO_2. Concentrates of both apatite, with 39 % P_2O_5, and of ilmenite, with 49 % TiO_2, have been produced.

The Kovdor massif

The Kovdor massif of alkali/ultrabasic rocks and carbonatites is located on the Kola Peninsula, about 30 km from the Finnish border, in the basin of the R. Kovdora, a tributary of the R. Yona. The massif is a large intrusion, dated at 380-420 Ma, and emplaced into biotite-plagioclase- and granite gneisses (Fig. 48). The massif covers an area of about 41 km² and is pear-shaped in plan, with a zonal structure easily identified in the terrain. The ring structure is determined by long-lived injection of olivinite, ijolite-melteigite, and nepheline syenite, accompanied by silicate metasomatite and carbonatite.

The oldest intrusive rocks in the massif are olivinites forming its core of about 8 km² in horizontal section. The marginal zone of the massif is formed by alkaline rocks: melteigite, ijolite and turjaite. Their injection along the contact of olivinites with the surrounding gneisses was accompanied by active alteration of both lithologies. Fenites are developed on the contact between the alkaline rocks and the enclosing gneisses of the White Sea series. The thickness of the fenite aureole varies from 0.5-1 km in the north to 2-3 km in the south of the massif. Mica-clinopyroxene rocks occur between the olivinites in the core and the ijolites and turjaites replacing them.

The olivinites were enriched in mica and pyroxene during the ijolite stage, and partially replaced by monticellite, melilite and melilite-pyroxene metasomatites during the turjaite stage. Melilite-bearing rocks are commonly replaced by garnet-monticellite-phlogopite, garnet-monticellite-amphibole and garnet-diopside-amphibole (apomelilite) rocks.

A zone enriched in phlogopite forms a semi-circle 8 km long and 1.5-2 km thick along the periphery of the central olivinite core in the north. It consists of medium- to fine-grained phlogopite-diopside-forsterite rocks with lenses of large- to giant-grainsize phlogopite-diopside-forsterite metasomatites. Mining of phlogopite from the deposit, the largest in the world, started in 1965. The phlogopite rocks are cross-cut by feldspar ijolites. Forsterite, forsterite-apatite and calcite-tetraferriphlogopite lenses and veinlets are commonly developed in the diopside-phlogopite rocks. Baddeleyite and zirkelite occur in these lenses. Melilite rocks in contact with rocks of the phlogopite complex were intensely transformed and replaced by hastingsite-calcite-diopside rocks. A monticellite-garnet association, called skarn-like by Kovdor massif researchers, is common in the melilite and hastingsite-calcite-diopside rocks.

In the south-west of the massif, there is an ore body of forsterite-apatite-magnetite rocks (foscorites) and apatite-calcite-magnetite rocks. The ore body is located among ijolite, nepheline-clinopyroxene and olivine-mica-pyroxene rocks. The ore body is crosscut by bodies of calcite carbonatites with green phlogopite, apatite, and magnetite, mainly on the south-west side, among fenites. Veins (up to a few metres thick) of carbonatite are also developed in the north of the massif cross-cutting ijolites, olivinites, melilite rocks, mica-pyroxene rocks, and phlogopite rocks. Aegirine-calcite carbonatites with brown phlogopite and sphene occur in the south-eastern part of the massif. Dolomite carbonatites are developed exclusively within or in the immediate vicinity of the main ore body.

Formation of multiple carbonatite stockworks was one of the final stages in the evolution of the Kovdor massif. These rocks are highly diversified and of great commercial interest, because of the associated deposits of baddeleyite-apatite-magnetite, rare metals, carbonate and apatite-carbonate ores. Four stages of carbonatite formation have been identified:

1: Calcite carbonatites with forsterite, magnetite, phlogopite, baddeleyite.
2: Calcite carbonatites with forsterite (or clinohumite), magnetite, tetraferriphlogopite, baddeleyite, and uranium pyrochlore.
3: Dolomite and calcite-dolomite carbonatites in ijolites with ancylite-(Ce), strontianite, catapleite, Nb-anatase and labuntsovite.
4: Dolomite carbonatites with tetraferriphlogopite, richterite, strontian whitlockite, strontian collinsite, girvasite, rimkorolgite, bobierrite, krasnovite, and kovdorskite.

The youngest intrusive rocks of the Kovdor massif are nepheline- and cancrinite syenites, thin veins of which cut across all the above rocks, including the carbonatites. They are massive, grey, coarse-grained rocks, consisting mainly of feldspar, aegirine, diopside and nepheline. The nepheline is usually variably replaced by cancrinite, zeolites and other minerals. The ring-shaped bodies of alkaline rocks and melilite-, mica-pyroxene- and other rocks situated between them and the olivinites dip at 70-80° towards the centre of the massif. The form of each type of alkaline rock and carbonatite is related to its own fault system inside the Kovdor massif (Krasnova & Sokolova, 1978).

A weathering crust is developed on top of the massif, covering ca. 60 % of its area. It is most widespread on the olivinites and phlogopite metasomatites of the central part, locally reaching a depth of 150 m. The formation of two commercial deposits is related to the weathering crust: vermiculite, by alteration of phlogopite metasomatites, and francolite by oxidation of the iron-ore complex rocks. The Kovdor massif contains five commercial deposits: a) Active mining of integrated baddeleyite-apatite-magnetite ore, phlogopite-vermiculite ore and rare earth elements b) Not in production: apatite-bearing carbonatites, olivinites, and francolite deposits. In addition, the kaolinite-lizardite ores confined to the weathering crust are also promising.

Figure 48A: Geology of the Kovdor massif (д, plotted by B. V. Afanasiev, I. P. Panshin and B. B. Sulimov) and its 1: Apatite-francolite complex; 2: Trachytoid ijolites and nepheline syenites of Minor Kovdor massif. Complex of carbonatites and camaphorites; 3: Undifferentiated carbonatites, 4: Calcite-forsterite-magnetite and dolomite-magnetite, 5: Apatite-forsterite-magnetite ores, 6: Forsterite and apatite-forsterite rocks; 7: Feldspar ijolite (dyke complex); 8: Diopside-phlogopite-forsterite ores of phlogopite complex (и – fine- and medium-grained, б – pegmatoid and coarse-grained); 9: Ijolite, 10: Micas with titanium magnetite, olivine and pyroxene; 11: Pyroxenites {a - with nepheline – melteigites and jacupirangites, б - without nepheline, commonly with phlogopite and olivine); 12: Garnet-amphibole-monticellite rocks with diopside and calcite ("skarnoids"); 13: Melilite rocks (a - melilitoliths, б - turjaites); 14: Olivinites (a - normal, б - ore); 15: Fenites 16: Middle Proterozoic (?) ultrabasites, mica-rich in fenitization zone. 17: Knyazh-Guba suite, 18: Undifferentiated Chupa suite; 19, 20: Lower and upper undifferentiated Chupa subsuites; 21: Undifferentiated Louhi suite; 22: Contacts (a - defined, б - assumed). Deposits of: I: Ore olivinites, II: phlogopite, III: Complex iron, phosphoric and rare metal ores (camaphorites), IV: Calcite carbonatites, V: Apatite-francolite ores, VI: Vermiculite (a – north-western pit, б – northeastern pit).

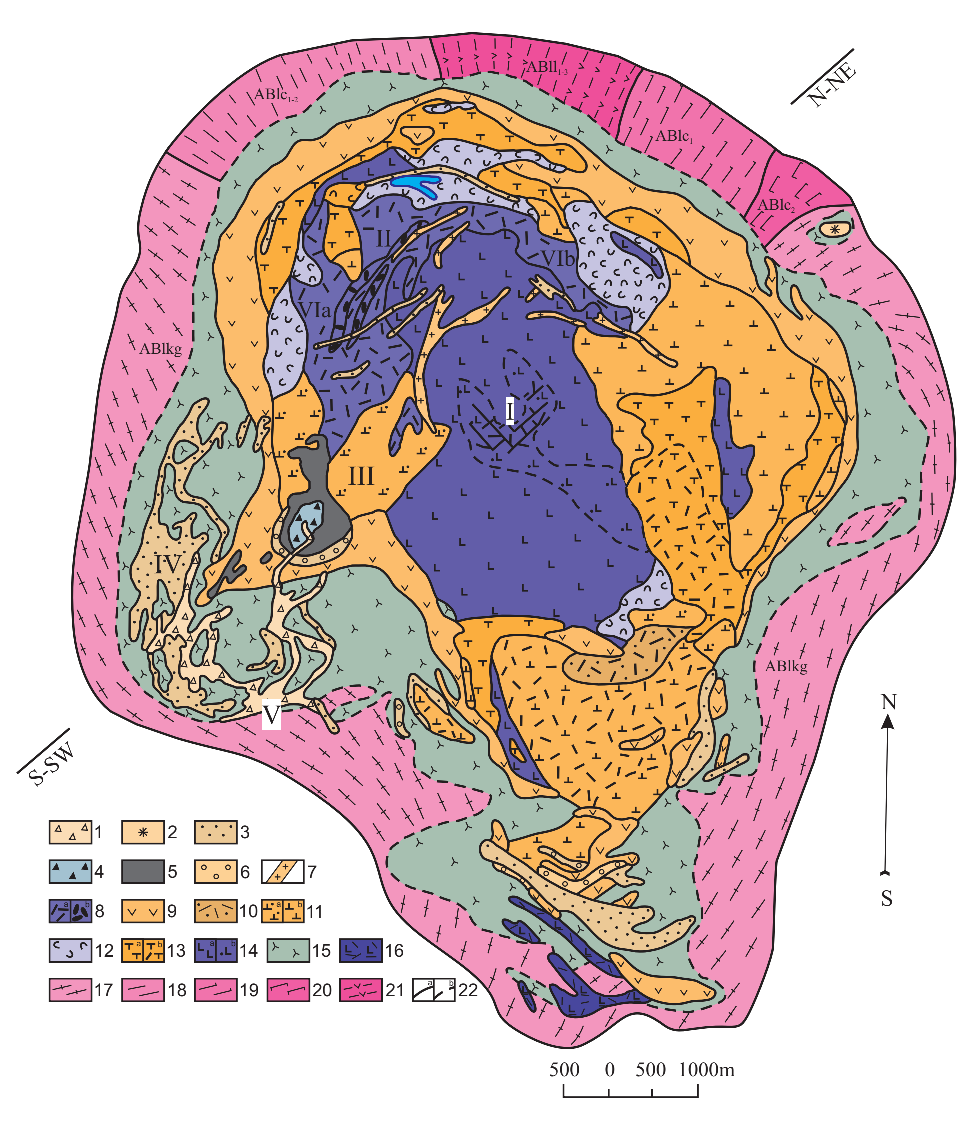
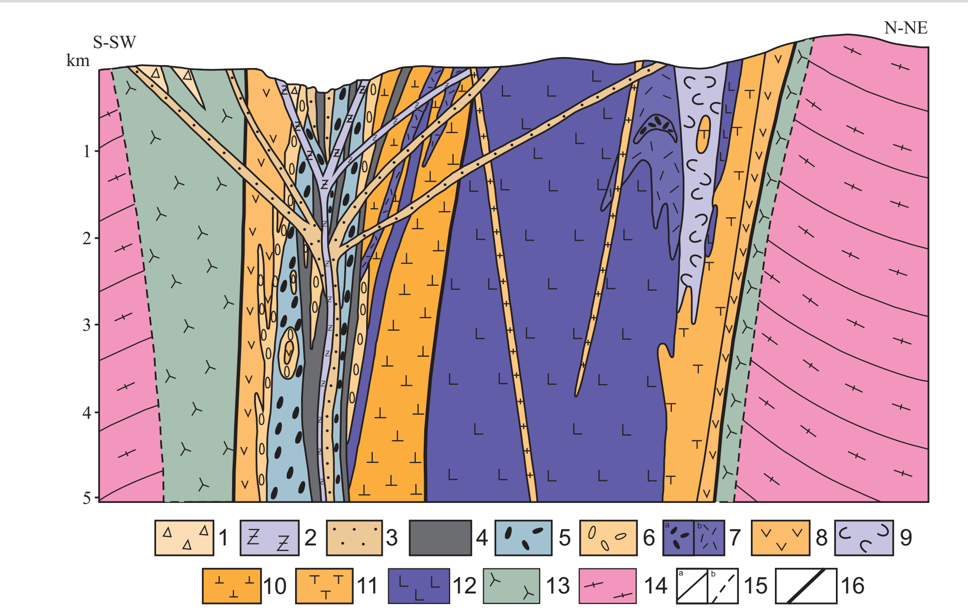


Figure 48B: Schematic section of the Kovdor Massif at Line S—SW—N—NE (б, plotted by N. I. Krasnova). Symbols: 1: Apatite-francolite complex; 2: Dolomite carbonatites and dolomite-magnetite ores; 3: Calcite carbonatites; 4: Calcite-forsterite-magnetite ores; 5: Apatite-forsterite-magnetite ores; 6: Apatite-forsterite rocks, olivinites; 7: Phlogopite complex (a – coarse-grained, б – medium-grained); 8: Ijolites; 9: Apomelilite skarn-like rocks; 10: Turjaites, melilitolith; 11: Pyroxenites; 12: Olivinites; 13: Fenites; 14: Granite gneisses; 15: Contacts (a - defined, б -assumed); 16: Faults; arrows show directions of uplift or subsidence.



The Kovdor Iron Deposit

The Kovdor baddeleyite-apatite-magnetite deposit was discovered in 1933 simultaneously with the massif itself: the Kovdor mine and concentrating mill came into production in 1962. The iron-ore deposit is confined to the south-western part of the massif where it forms a vertically dipping tubular "Main body" with a cross-section of 800×1300 m and, in addition, some more linearly elongated bodies. There is clear evidence that the iron-ore complex was formed through magmatic replacement by carbonatites.

The deposit is divided into several ore types according to the content of characteristic minerals: apatite-forsterite, apatite-forsterite-phlogopite, apatite-forsterite-magnetite, apatite-calcite-magnetite, calcite-forsterite-magnetite, and apatite-calcite rocks. A less common ore type consists of magnetite, tetraferriphlogopite, calcite, and apatite. The ores vary in structure and may be banded, impregnated, spotty, and massive, but are generally characterised by a granular allomorphic texture. The grain size of the magnetite is from < 1 mm to several centimetres, with grains larger than 1 mm predominating. Common accessory minerals in all the different ore types include pyrrhotite, chalcopyrite, pyrite, marcasite, baddeleyite and pyrochlore (or uranium pyrochlore in rare cases). Sulphides are unevenly distributed. The magnetite has high contents of MgO (4.7-7.9 %) and Al_2O_3 (2-4.4 %). All parent rock species and carbonatites contain non-uniform weak, variable dissemination of baddeleyite. The ores contain: FeO 20-55 wt.% (average: 28.8 wt.%); MgO 15-17 wt.%; CaO 11-12 wt.%; P 2.9 wt.%; S 1.19 wt.%; MnO and TiO_2, < 1 wt.%.

The magnetite-apatite-baddeleyite deposit is being mined by Kovdor Mining and Concentrating Mill Co. using open-cast methods. The Kovdor Mill produces a magnetite concentrate with 64.0-64.2 % iron, a baddeleyite concentrate with 98.1-98.3 % ZrO_2 and an apatite concentrate with a minimum of 38 % P_2O_5. The ore reserves of the Kovdor deposit are 650 Mt.

The Kostomuksha Iron Deposit

The Kostumuksha deposit was discovered in 1946 as a result of a 1:200,000 scale airborne magnetic survey. It is located 12 km N of the city of Kostomuksha which was built to support the mining. The Kostomuksha mining and concentrating mill (now Karelsky Okatysh JSC) started full-scale ore extraction and pellet production in July 1982.

Conventionally, the deposit is subdivided into three units, the Northern, Central, and Southern units, differing in ore body shape and relationship with cross-cutting bodies of hälleflinta (microcrystalline to glassy felsic rock). Currently, all of the sites are being mined. The deposit is confined to horizons of iron quartzite which are part of the Kostomuksha Suite of the upper Lopian rhyodacite-iron-quartzite formation (Fig. 49). Up to 70 % of the reserves are in the main layer, which is situated in the western limb of a synclinal fold. The main layer consists of three steeply dipping, sheet-like ore bodies of iron quartzites. The bodies are 10 - 330 m thick and have been traced for 3.3 - 14 km in an approximately N-S direction. The ore bodies are separated by thin layers of schist, including quartz-biotite-sericite- and graphitic-schist. In the central part of the deposit, the Main layer is folded in such a way that it becomes sub-horizontal. The maximum width of the layer in the folded area reaches 1750 m while on the fold flanks, the width is from 13 m to 70-100 m. In the central part of the deposit, at a depth of 400 m, the thickness of the Main ore layer is 250-350 m, which decreases to 120 m at greater depths. The Main ore layer is 600 m long at its northern flank, 800 m at the southern flank, and 2100 m in the central part. Close to its extremities the ore quality drops because of increasing contents of grunerite.

The interbedded layers are situated 100-600 m E of the Main ore: they are characterised by rhythmic alternation of multiple (> 40) strata of iron quartzites and mica schists containing little or no iron. An ore reserve calculation considered 23 of the interbedded layers. These have strike lengths of 0.5 - 6.2 km, down-dip lengths of 100 - 500 m, and thicknesses of 5 - 130 m. With depth, some of the layers tend to increase in thickness, also having an improvement in ore quality. The ore zone has been traced for 16 km. It is intersected by drillholes at depths of up to 500-600 m on the flanks and up to 1000-1200 m in the central part of the deposit.

Three ore types are identifiable in the deposit: 1) Alkali-amphibole-magnetite quartzites containing 40-60 % magnetite, 30-50 % quartz, and <10 % alkali amphiboles (riebeckite, crossite, and aegirine). The ore has coarse-grained magnetite aggregates and is thus easier to process, 2) Biotite-magnetite quartzites with 30-50 % magnetite, <15 % biotite and locally up to 30 % carbonate (brown spar or magnesian dolomite), 3) Grunerite-hornblende-magnetite and grunerite-magnetite quartzites containing 35-50 % quartz, 20-35 % magnetite, up to 10 % pyrrhotite and up to 3% apatite. Sulphur and phosphorus are unwanted impurities. The average contents of magnetite iron (Fe_{magn}) decrease from the first to the third ore type. The predominant type in the Main ore layer is the first ore type, while the second (57 %) and third (22 %) types are most common in the interbedded layers. The third type is more common in smaller ore bodies and in the rims of large bodies.

	Main Layer	Interbedded layer
Fe_{magn}	27.15 %	23.48 %
SiO_2	48.01	50.88
TiO_2	0.09	0.11
Al_2O_3	2.71	3.34
Fe_2O_3	25.96	21.37
FeO	15.96	16.60
MnO	1.93	2.09
K_2O	1.11	1.24
Na_2O	0.52	0.48

Table 5: Chemistry of the two ore layers:

The average contents for the whole deposit are: Fe_{total}, 32.2 %; Fe_{magn}, 26.45 %; S, 0.21 %, P, 0.07 %. The ores are free-milling. Their dressing is a three-stage process of wet magnetic separation, producing a magnetite concentrate with an iron content of 65.7-70 %, while providing a recovery of Fe_{total} of 73.6-78.5 %, Fe_{magn} recovery of 94.6-95.4 %, and concentrate yield of 33.8-37.3 %. The sulphur content in the concentrate is from trace levels to 1 %.

The commercial iron ore reserves were approved by the USSR State Committee for Reserves (Resolution No. 8668 of 19.12.1980) as prepared for mining. The quantity was 1,107,655,000 tons for Category B+C1 and 261,931,000 tons for Category C2. In addition, 1,023,025,000 of non-commercial iron ores were calculated, including ores that are too low-grade in terms of Fe_{magn} content and ores beyond the open pit outline. With the mill's design capacity of 24 Mt of raw ore per year, the reserves were estimated to last for 45 years. The iron ore resources are currently calculated to be 300 Mt (Category P1).

Olenegorsk iron deposit

The Olenegorsk iron ore deposit was discovered by D. V. Shifrin in 1932. It is 7.5 km NW of the Olenya railway station in Murmansk Oblast. Open-pit mining started in 1954. The sheet-like ore layer extends 4 km NW, and dips 55-70° SW (Fig. 50). The ores have been explored to a depth of 800 m. The ore thickness varies from 20-30 metres at the flanks to 250-300 metres in the centre of the deposit. The ore body consists of magnetite and haematite quartzites with an average magnetite/haematite ratio of 3:1. The accessory minerals of the iron quartzite ore are tremolite, actinolite, cummingtonite, pyroxenes, alkali amphiboles, calcite, and siderite. Sulphides - pyrite, pyrrhotite and chalcopyrite are found but are rare. The ore is generally banded and "corrugated". The deposit is characterised by extremely low contents of sulphur and phosphorus, (of the order of 10-100 ppm). Processing yields a very high ore mineral recovery to concentrate: 91 %. The ore is free-milling.

The iron quartzites of the Olenegorsk deposit are up to 150 m thick and extend for 2.8 km: they are hosted by amphibole-bearing gneisses and amphibolites of the Archaean Kola series. Gradual transitions between the iron quartzites and gneisses have been observed. In plan view, the iron quartzite layer has the shape of a large lens pinched by transverse flexures. The quartzite is deformed into a synclinal fold overturned south-westwards and complicated by anticlinal and synclinal folds of lower orders. The synclinal structure has a north-westerly strike, with the limbs dipping at 50-80° SW. The structure is intersected by low-angle, south-west- directed thrusts with amplitudes of up to 50-55 m. Flow cleavage, linear parallel textures and fracturing are pronounced features of the rocks in the

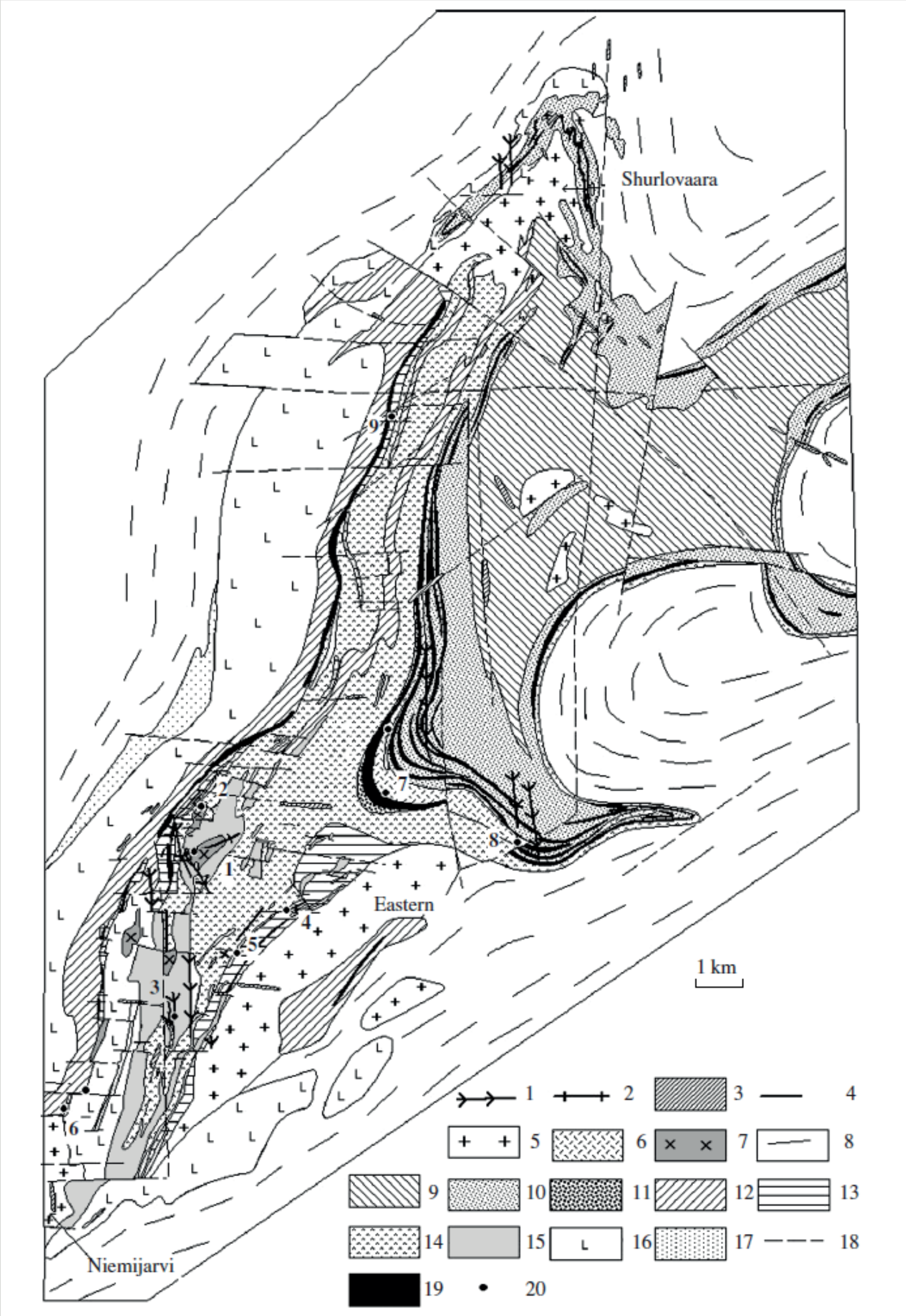


Figure 49: Schematic geological map of the Kostomuksha greenstone belt. (after V.Ya. Gor'kovets and V.N. Furman. **(1, 2) Dyke complex**: (1) Riphean lamproite, (2) alkali picrite; (3) Late Archean–Early Proterozoic gabbro, unspecified; (4) Late Archean andesite and dacite dykes; **(5–7) Late Archean late orogenic intrusive rocks**: (5) potassium granite, (6) rhyodacite (helleflinta, plagiophyre), (7) Taloveis Complex of diorite, quartz diorite, and granite porphyry; (8) tonalite and granite gneiss; **(9–11) Upper Archean Gimol Group**: (9) schists of the Surlampi Formation, (10) quartz–biotite and amphibole–biotite schists and BIFs, (11) conglomerate; **(12–16) Upper Archean Kontok Group**: (12, 13) Shurlovaara Formation: (12) rhyodacitic lava and tuff, (13) carbonaceous quartz–biotite and amphibole–biotite schists, BIFs, and banded amphibolite; **(14, 15) Ruvinvaara Formation**: (14) basalt and variolitic basalt, (15) komatiite, basaltic komatiite; (16) Niemijarvi Formation: metabasalt (amphibolite); (17) Nyukozero Sequence: two-mica schist; (18) fault; (19) iron ore; **(20) gold deposits and occurrences (numerals in map)**: 1, Taloveis; 2, Faktorny; 3, Berendei; 4, Kurgelampi; 5, Eastern; 6, Niemijarvi; 7, Kostomuksha open pit; 8, South Kostomuksha; 9, West Ruvinvaara.

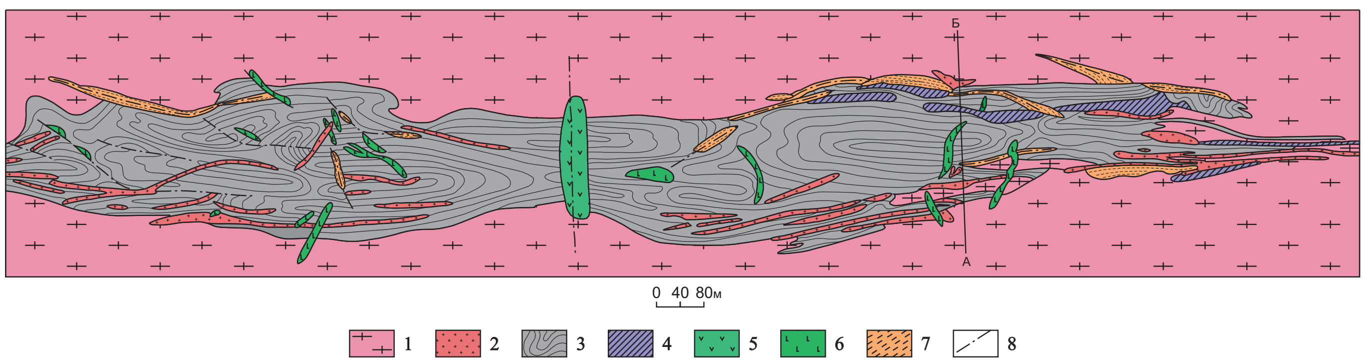
deposit. The magnetite quartzite reserves in Categories A + B + C1 are 440 Mt, with an average iron content of 32.3 %.

Yarega titanium-oil deposit

The Yarega titanium-heavy oil deposit is located in the Republic of Komi, 25 km SW of Ukhta in the Timan-Pechora oil and gas province. The deposit was discovered by the Ukhta Integrated Prospecting Expedition in 1932 and has been explored for titanium since 1958. The deposit is hosted by Middle Devonian sandstones and is confined to a wide, flat asymmetric anticlinal fold northwest of the Ukhta-Izhma ridge, on the north-eastern slope of the Timan anteclise. The form of the crest of the anteclise is influenced by the Yarega, South Yarega, Lyael and Vezhavozh local rises. The Upper and Middle Devonian sediments in the area are commercially oil-bearing, with reservoirs in quartz sandstones.

The unique feature of the deposit is that, apart from the large oil resources, it also contains high concentrations of leucoxene. The lower part of the titanium-bearing sandstone is of Eifelian/ Early Givetian age, and the upper part is of Pashian age. The deposit is interpreted as a buried placer. The productive stratum is 30-100 m thick and discordantly overlies Riphean slates. It is divided into two lithological layers which contain three placer deposits: 1) A lower, sheet-like placer with an average thickness of 14.5-21.4 m which contains 11.2 % TiO_2 on average; 2) A middle placer 0.4-13 m thick containing 3.0–10.4 % of TiO_2; 3) An upper placer with an average thickness of about 3 m and a TiO_2 content ranging from a few percent up to, locally, 21.9 %. The lower lithological horizon consists of coarse-grained quartz sandstones with siltstone and argillite layers, while the upper horizon, contains polymict conglomerates and consertal quartz sandstones containing up to 30 % leucoxene (TiO_2: 58.5-71.9 %; SiO_2: 20-37.8 %). The deposit emerged as a result of erosion of the weathering crust of the Riphean slates. Later study of the titanium mineralization has revealed high contents of niobium and tantalum.

Yarega is the largest titanium deposit in Russia. The calculated reserves are about 640 Mt of titanium ore. The oil in the reservoir has been produced since 1939 by a unique shaft technique. In 2004, engineers of LUKOIL-Komi made some



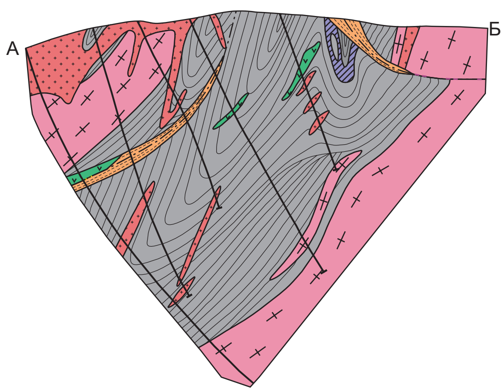


Figure 50: Geological structure of the Olenegorsk deposit (L. Goryainov,1976)
1: Amphibolitic-, biotite-amphibolitic- and epidote-biotite-amphibolitic gneisses, mica-amphibole- and two-mica augen schists, banded and schistose amphibolites;
2: Pegmatites and pegmatoid granites;
3: Iron quartzites;
4: Zone of low-ore metasomatic quartzites with garnet, alkali amphiboles and sulphides;
5: Diabase, gabbro diabase;
6: Gabbronorite;
7: Mylonites/ blastomylonites on basic rocks in thrust zone;
8: Tectonic faults

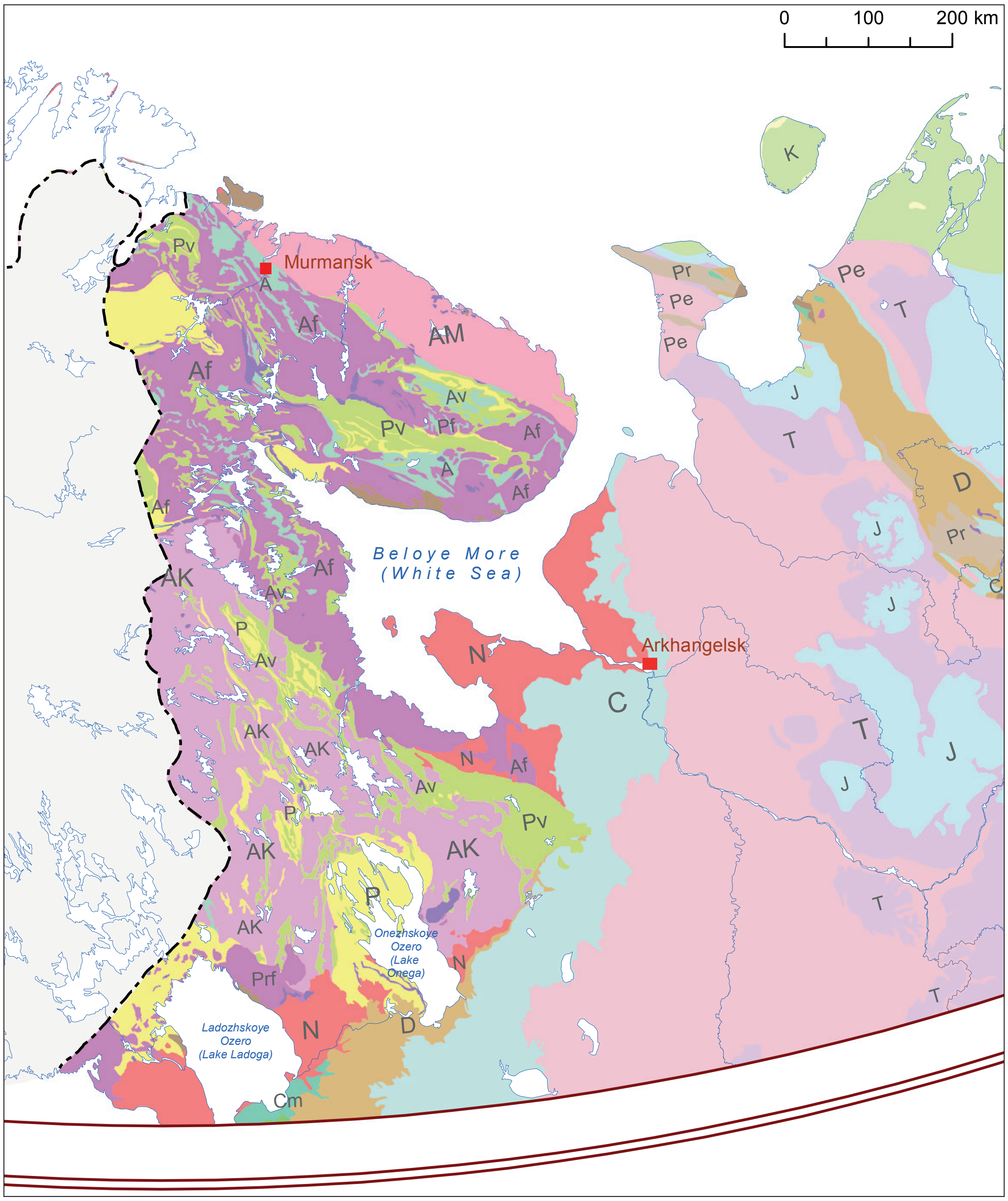


Figure 51. Geological location map of NW Russia (from 1: 5 000 000 map, Nordahl et al., 2016). Lithological codes: A: Archean, Af: Archean felsic intrusives, AK: Karelian Craton, felsic intrusives, AM: Murmansk Craton, felsic intrusive, Av: Archean extrusives, P: Paleoproterozoic, Pr: Proterozoic, N: Neoproterozoic, Cm: Cambrian, D: Devonian, C: Carboniferous, Pe: Permian, , T: Triassic J: Jurassic K: Cretacaeous.

experiments to recover titanium dioxide and titanium coagulant from the Yarega ores. Work is currently underway to set up a pilot titanium coagulant production facility, to be managed by SITTEC JSC. The start-up of the first stage of a titanium coagulant mill for an annual output of 25,000 tons of finished product took place in the last quarter of 2015.

Srednaya Padma vanadium deposit

The Srednaya Padma vanadium deposit is located in the Medvezhegorsk District, Republic of Karelia, 17 km SW of Tolvui. The deposit is located on the Zaonezhsky Peninsula, which is a part of the Onega Trough, within the Karelian megablock (Fig. 51 and 52).

Exploration of the deposit area started with studies of shungites in the late 18th C. The vanadium deposit was discovered in 1985 as a result of prospecting by PGO Nevskgeologiya. In addition to Srednaya Padma, five other deposits and over ten promising occurrences of vanadium (with associated uranium, PGE, gold, silver, and other valuable components) were found – ores with unique mineralogical, geochemical, and technological properties. The Verkhnaya Padma

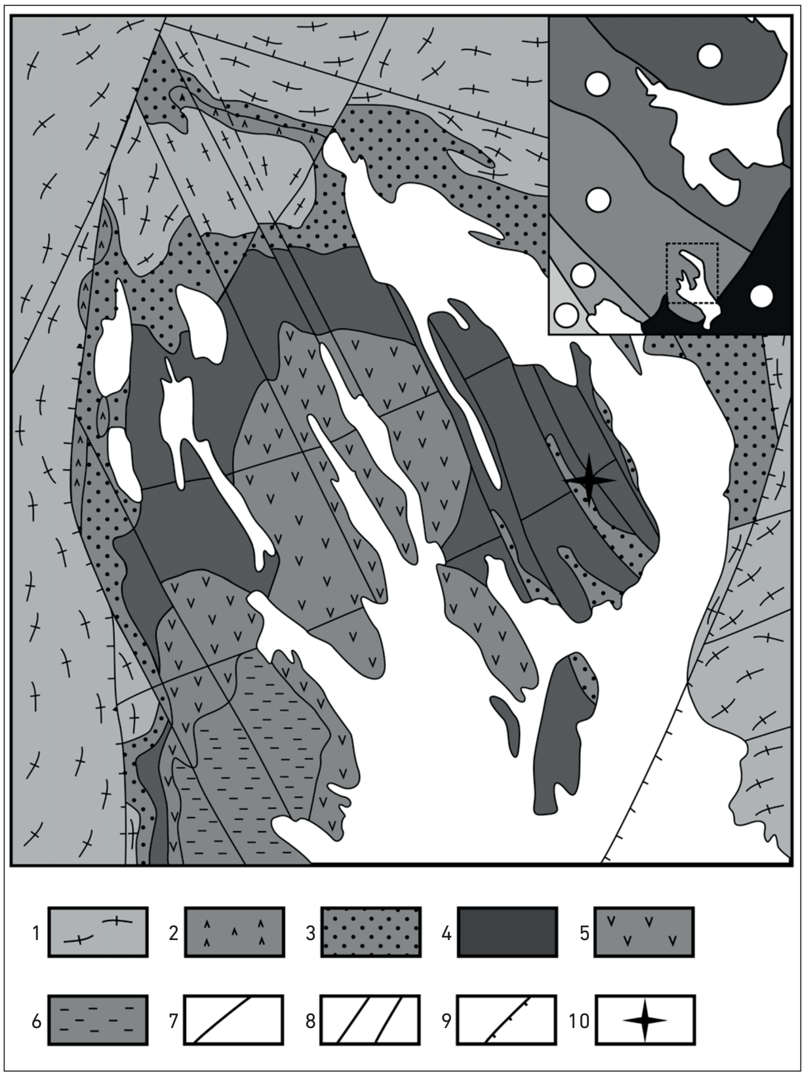


Figure 52: Schematic geological structure of the Onega trough (Borozdin et al., 2014): (1) Archean basement; (2–5) Lower Proterozoic rocks of the Onega trough: (2) Sumian–Sariolian, (3) Yatulian terrigenous–carbonate and volcanogenic rocks, (4) Lower Lyudikovian carbonaceous metasediments and metavolcanics, (5) Upper Lyudikovian and Kalevian, undivided; (6) Vepsian; (7) faults; (8) boundaries of fold–fault dislocation: (UP) Unitsa–Pigmozero, (SK) SvyatukhaKosmozero, (T) Tambitsa, (K) Kuzaranda; (9) interblock deep-seated faults; (10) Srednyaya Padma deposit. Inset: schematic block structure of the eastern Baltic Shield: (1) Kola megablock, (2) Belomorian megablock, (3) Karelian megablock, (4) Ladoga–Bothnia megablock, (4a) Raakhe–Ladoga zone, (5) sedimentary cover of the East European Platform.

and Kosmozerskoye deposits are unique, with no known direct analogues in Russia or anywhere else.

The deposit is structurally confined to the south-western flank of the Padma anticline having, a symmetrical form and limbs dipping at >75°.

The richest mineralization is observed on the southwestern flanks of the axial anticlines, in areas of intense multi-stage, tectonic processes of bulk brecciation and cataclasis. The ore bodies have a complex but generally cigar- or vein-like shape and a wedge-shaped cross-section. Less frequently, the ores occur in stockwork/veins traceable to a depth of 500-600 m. All the ore deposits have a polymineralic multi-element composition. The main recoverable elements are vanadium, uranium, palladium and gold, but a number of other elements may also be extracted, including rhenium, rhodium and others.

Vanadium is the main ore-forming element. The most common ore mineral assemblage is pitchblende-roscoelite-sulphide, which may contain precious metals. The ores consist of albite and carbonates (60 %) and mica (25 %). The bulk of the vanadium (90 %) is held in micas (mainly roscoelite, some in vanadium phlogopite), in vanadium-bearing haematite (10 %), and a lesser part in other oxides, e.g. uranium vanadates. The ores occur as impregnations (38 % of the explored reserves), massive mineralization (50 %) and in vein in stockwork (12 %). The ores are characterised by high contents of vanadium pentoxide, on average 2-5 %, but locally up to 15-17 %. The precious metal mineralization occurs in stockwork/veins and is usually developed within bodies of mica. The content of palladium reaches 140-440 g/t, of gold up to 120 g/t, of platinum up to 30 g/t and of silver up to 1500 g/t. Uranium occurs in all the ore deposits, usually as pitchblende and coffinite, less frequently as broggerite.

The average V_2O_5 content in the deposit is 2.78 % for Reserve Category C1, and 1.97 % for Category C2. The reserves of uranium-vanadium ores have been calculated to a depth of 350 m: Category C1 reserves of V_2O_5 are 58,770 t, and Category C2 reserves are 48,880 t.

Porozhinskoe manganese deposit

The Porozhinskoe manganese deposit was discovered in 1974, 650 km N of Krasnoyarsk, in the north-western part of the Yenisei Range, 12 km E of the R. Yenisei. It is located in the Mikheevskaya depression in the eastern part of the Vorogovka trough. The depression formed in Upper Riphean-Cambrian sediments deformed by a complex system of linear-brachyform folds, later disrupted by NW- to NE-trending faults.

The sediments in the Vorogovka trough are divided into two series; the lower part is the Vorogovka series and the upper part the Chap series. The Vorogovka sediments form narrow bands on the western and eastern sides of the trough: they comprise conglomerates, gravelstones, sandstones, siltstones, limestones and dolomites. The total thickness of the series is 2.2-4.3 km. The series is subdivided into three suites which, from the bottom, are the Severnaya River, Mutnaya River and the Sukhaya River suites.

The Chap sediments overlie the Vorogovka series concordantly. The Chap sediments are subdivided into two parts. The lowermost, the Podyom Suite, contains dolomites, pyroclastic and terrigeneous formations. The upper part consists of terrigeneous rocks of the lower Nemchany Suite, consisting of red arkosic sandstones. The main manganese ores occur in the Podyom Suite, in persistent layers on weathered dolomites. The lower part, about 2 m thick, is represented by variegated manganiferous clays, in which fragments of dolomites or siltstones (aleurolites), and rarely of manganese ores occur in variable quantities. On top of this clay-rich layer there is a 4.3 m layer of grey brecciated silica rocks, followed by terrigeneous formations consisting of siltstones, argillites and thin layers of tuff, overlain by a sandstone unit. The siltstone and tuff rocks contain accumulations of manganese minerals. The productive layers are 22 - 85 m thick and occur at several stratigraphic levels, but mainly in the lower part of the Podyom Suite. Both primary and secondary ores are found in the deposit. The following types have been identified, based on their mineral composition: carbonate or manganocalcite ores, semi-oxidized or todorokite-manganocalcite ores, and oxidized or pyrolusite ores. The secondary ores, mainly pyrolusite ores, predominate. The main ore minerals are psilomelane, pyrolusite, manganite, dialogite, goethite, cryptomelane, bog ore, vernadite, manganocalcite, hydrogoethite, and todorokite. The ore textures are clayey-earthy-lumpy (nodular), lumpy-clayey-earthy and clayey. As of 2012, the ore reserves of the Porozhinskoe deposit were 15,696,000 t for Categories A+B+C1, and 13,767,000 t for Category C2, with an average manganese content of 18.85 %. The deposit development license is owned by Turukhansky Meridian LLC, now preparing for exploitation of the deposit.

Porozhinskoe bauxite deposit

The Porozhinskoe bauxite deposit is located in the Irkineevo culmination of the Yenisei Range, confined to the Irkashevo anticlinal rise as part of the sequence of Upper Proterozoic carbonate and shale rocks (Fig. 53). It contains several bauxite ore fields, such as Porozhinskoe, Artyugino and others. In each field, several ore deposits of the contact-karst type are known (over thirty in all): they are confined to karst depressions at the contact of shale rocks of the Krasnogorsk terrigenous Suite with carbonate rocks of the Potoskui series of the Upper Proterozoic Djura Suite. Some karst ore deposits are identified in karst depressions of the polje (interior valley) type and in individual small karst depressions confined to carbonate sediments of the Upper Proterozoic Aladnino Suite. The bauxite beds and ore bodies are located among variegated, brick-red kaolinite and hydrargillite-kaolinite clays. Their shape is complex, pocket-like in sink holes and lens-like in erosional karst depressions. The lateral extent of the ore bodies is 130—2000 m, and the depth of their occurrence, 0.1—94 m. Ore bodies with high-quality bauxites are confined directly to the zones of contact to the Krasnogorsk clayey shales with carbonate rocks. The bauxite quality deteriorates with distance from the possible sources of alumina for weathering. The average contents of the main components in the bauxites are 43.6 wt.% Al_2O_3, 13.1 wt.% SiO_2, 17.6 wt.% Fe_2O_3, 2.6 wt.% TiO_2 , and silicon module (Al/Si) = 3.4. Basically, three types of bauxite ore are present: stony (11 %), loose (42.8 %) and clayey (38.4 %). The bauxites are of the gibbsite type. The primary ore-forming minerals are generally gibbsite, kaolinite, corundum, magnetite, haematite and goethite. Other minerals found are quartz, sphene and rutile. The mineralogy of the bauxite species is constant, but the quantity of the different minerals varies.

Pudozhgora Fe-Ti deposit

The Pudozhgora iron-titanium deposit is situated in the Pudozh District of the Republic of Karelia, on the east coast of Lake Onega, 6 km from Rimskoye settlement. The deposit was

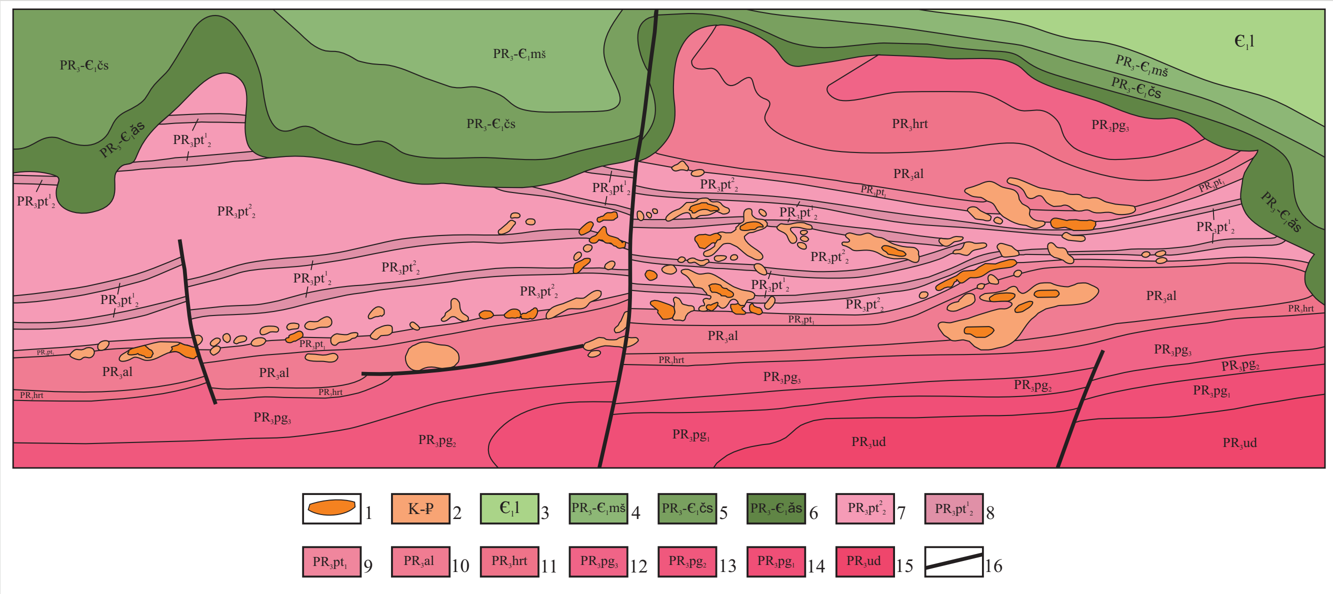


Figure 53A: Schematic geological map of the Palaeozoic basement and bauxite-bearing sediments of the Porozhinskoe deposit. Based on Angara Expedition data. **1: Bauxite ores**; 2: Cretaceous-Paleogenic kaolinite-, bauxite-bearing sediments, kaolinite-gibbsite variegated clays with bauxite ores Cr—Pq; **3 – 15: Paleozoic basement rocks**: 3: Bituminous dolomite, dolomitic limestone, dolomite and argillite of L. Cambrian Lena age, Cm1l, 4: Sandstones with lenses of dolomites and argillites of Mashakovo suite Pt_3 — Cm_1mš, 5: Sandstone, argillite, dolomite of the Chistyakovo suite Pt_3 — Cm_1čs, 6: Sandstone, aleurolite, argillite of the Aleshkino suite Pt_3 — Cm_1ăs; **7 – 9: Sediments of the Potoskui suite Pt_3pt**: 7: Clayey shales, argillites of the Jura series Pt_3pt_2, 8: Carbonate rocks of the Jura series,9: Clayey shales, argillites, sandstones of red series Pt_3pt1; 10: Dolomites, limestones of the Aladnino suite Pt_3al; 11: Clayey limestones, dolomitic limestones of suite of Card Pt_3hrt; **12 – 14: Sediments of the Pogoryui suite**: 12: Aleurolite-clayey and clayey shales, sandstones, quartzites Pt_3 pg_3, 13: Sandstones, quartzites, aleurolites Pt_3 pg_2, 14: Aleurolites, sandstones, aleurolite-clayey shales Pt_3 pg_1; 15: Clayey shales of the Udergei suite Pt_3ud; 16: Tectonic faults.

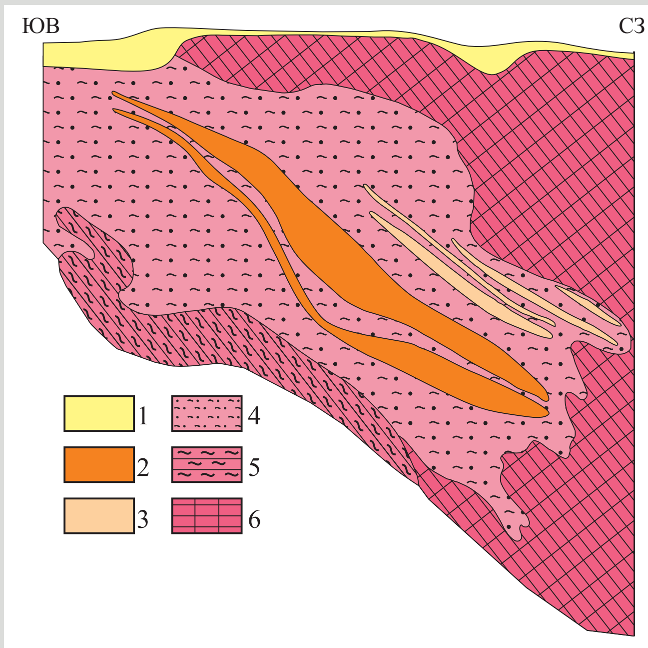


Figure 53B: Geological section of the Porozhinskoe deposit. Based on the Angara Expedition data. 1: Quaternary formations; 2: Clayey, loose and stony bauxites; 3: Bauxite clays, allites; 4: Vvariegated clays; 5: Clayey shale; 6: Limestones, dolomites, dolomitic limestones.

discovered in 1859 by Captain Anossov of the Mining Engineers Corps. The Pudozhgora Mining Company was established in 1898, but the deposit has not been mined to this day.

The main economic mineralization is titanium magnetite (Ti-V-Fe) ore: a Pd-Pt-Au mineralization, mainly associated with copper sulphides, is less important. The deposit is confined to an early Proterozoic poorly differentiated gabbro dolerite intrusion filling a near-horizontal fissure in Archean granitoids of the Vodlozero block (Fig. 54). The strike of the ore-bearing massif is north-westerly, and its dip is 30 - 48° SW. The intrusion has been traced for 7.1 km along strike and is 130-180 m thick in its central part, decreasing to 40-50 m towards its limits. The intrusion has a sheet-like, irregular shape with wavy contacts matching the fissure planes in the enclosing granites.

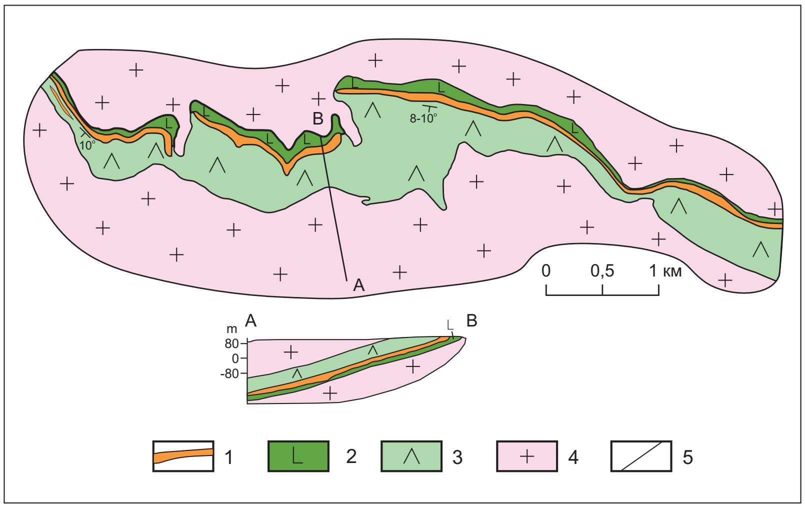


Figure 54: Geological structure of the Pudozhgora deposit based on data by Ya. Kh. Yeselev, 1952, as extended by M. M. Lavrov, N. N. Trofimov, A. I. Golubev, 1999. **Lower Proterozoic, Pudozhgora sill-dyke complex, gabbro zone**: 1 – aphanitic gabbro diabase (sub-ore horizon), 2 – titanium magnetite ore (ore horizon; 3 – fine-grained gabbro diabase, 4 – uralite medium-grained gabbro diabase, 5 – pegmatoid leucocratic gabbro diabase; upper Archean: 6 – plagiomicrocline granites; 7 – geological section lines.

The titanium magnetite mineralization is a uniformly rich impregnation, occurring in three layers with strike lengths of 1000-3000 m, and 7.2 - 23.2 m thick (average: 14-17 m), occurring parallel to the footwall contact of the intrusion, on average 30 m above its base (in the upper, gabbro part of the section). The mineralization has been traced to a depth of 380 m. Two ore categories have been identified based on their contents of titaniferous magnetite, ores with 45 -75 % and 25 -45 % magnetite, respectively. Most of the ore layer falls into the richest category. The ores are persistent in strike and dip throughout the ore-bearing intrusion. Their thickness varies from 5.95 - 23.5 m, averaging 11-13 m. The economic components of the ore are iron, titanium, vanadium. Copper, gold, and platinum group metals are locally enriched in a sulphide-rich upper part of the Fe-Ti ore layer (3-8.5 m thick). The average contents of the ore are: Fe 28.91 %; Ti 8.13 %; V 0.43 %. The sulphide-rich layer contains on average: 0.13 % Cu, 0.21 g/t Au and up to 0.51 g/t Pt and 1.11 g/t Pd. The titaniferous magnetite ore reserves are 316.69 Mt but are currently classified as non-commercial. Development of the deposit is considered to be unprofitable due to the high energy costs of processing the titaniferous magnetite ore and to the complexity of the required metallurgical process.

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REE AND SPECIAL METALS

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Deputatsky tin deposit

The Deputatsky tin deposit is located in Ust-Yana District, Republic of Saha-Yakutia, not far from the settlement of Deputatsky. The deposit was discovered by G. I. Kolmakov, member of the Irgichansk field crew of Dalstroy. The deposit was opened for production in 1951. The Western mine of the deposit was closed in 1999 and the operation was finally closed in 2009. The deposit is located in the western part of the Polousny megasynclinorium marked by widespread flat dislocation blocks, which are delimited by discontinuous tectonic fractures of a fault-heave and thrust-heave nature, and by linear fold zones. The area consists of Jurassic terrigeneous strata with an overall thickness of ca. 5 km, resting conformably on Upper Triassic sediments in the south (Fig. 55). The known tin ore deposits and occurrences are mainly located in flat dislocation blocks, where they are limited to the exocontact zones of small stocks of granite porphyry or granites, or to hornfels zones above hidden intrusions.

Only one small block of granitoid crops out on the surface in the ore district; another intrusion bulge was intersected at a depth of 377 m by a structural drillhole under the central part of the Deputatsky deposit. The area of the subsurface granite bulge within the Deputatsky ore cluster has been assessed by geophysical data to be ca. 50 km^2. Its depth is from 300 to 800-1200 m. Multiple indirect data indicate the presence of a large granite block, in an area of hundreds of km^2 at depth (Smirnov, 1978). K/Ar dating of biotite yielded ages for the granites of 143 million and 138 million years (Yablokov and Ivanov), which corresponds to Upper Jurassic (bulk sample tests yielded slightly lower and probably underestimated values, corresponding to Lower Cretaceous).

Apart from granites, the sedimentary block is intruded by multiple mafic, intermediate, and silicic dykes. These include dolerites, doleritic and diorite porphyrites, andesitic dacites, liparites, felsitic liparites, and lamprophyres. The dykes of the more mafic rocks form E-W striking suites, up to 15 km long. Felsic rocks are less common and typically strike in near E-W or north-easterly directions. Assessments of the dykes' absolute ages have given a broad scatter, from 128 million to 70 million years, but mostly indicate Upper Cretaceous ages. Many of the dykes of dolerite, porphyrite, and especially of lamprophyre contain xenoliths of granite porphyry, quartzite, and metamorphic rocks carried up from the deep.

The Deputatsky deposit is located on the flat-lying limb of a large fold, dipping towards a hidden bulge of a granite body. The Upper Jurassic stratum of sandstones with subordinate siltstones form the ore field, dipping at angles of 4—20°S (rarely up to 30° or more) where the folded structure is cut by an E-W striking fault. In the central part of the deposit, the sedimentary rocks underwent intense contact metamorphism, generating mainly two-mica and andalusite-bearing biotite-quartz hornfelses. Quartz-muscovite, quartz-topaz and quartz-tourmaline greisens with tin ore, arsenopyrite and fluorite formed over offshoot dykes of granite and in hornfelses in zones of jointing. The intensely metamorphosed area is surrounded by a zone of less modified rocks, which are nevertheless noticeably silicified, chloritized and sericitized, and locally have a nodular texture with new formation of andalusite, cordierite, and axinite. Such rocks cover up to 65 % of the entire ore field and are most abundant at the western edge of the deposit. The ore field's peripheral part is marked by weak silicification, sericitization, and local pyritization.

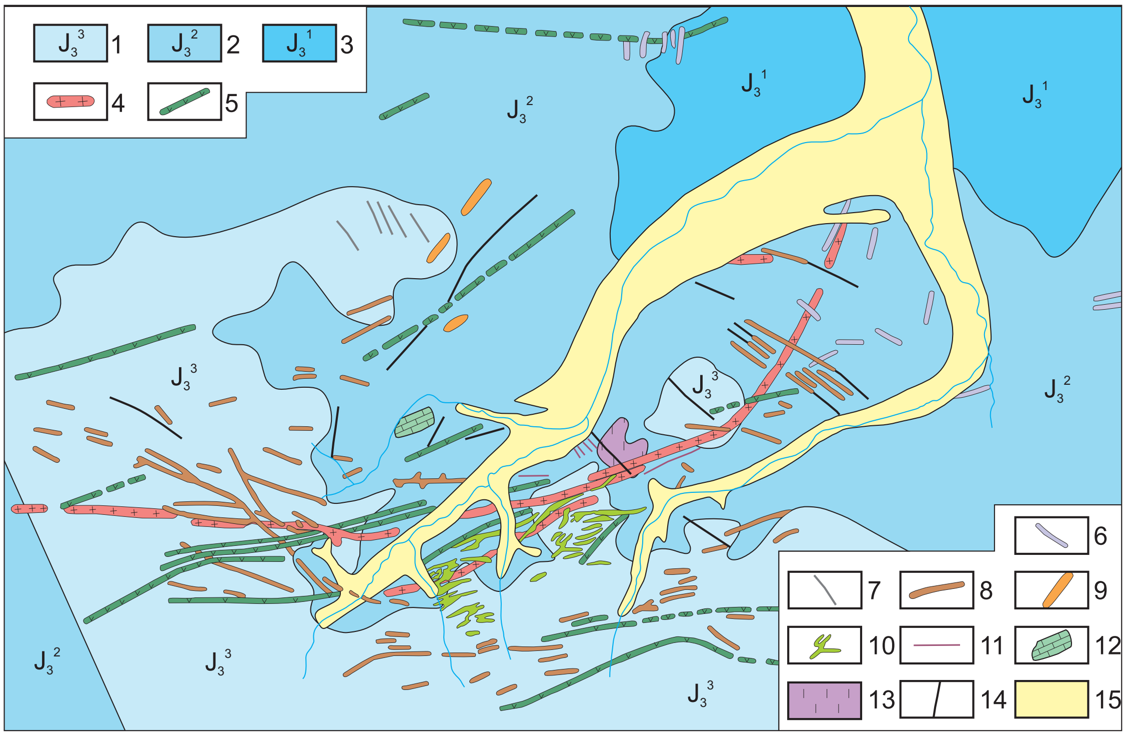


Figure 55: Structure of the Deputatsky Deposit. (Smirnov, 1978) **1-3: U. Jurassic sediments**: 1: Upper suite - interbedded sandstones, siltstones, and argillites, 2: Middle suite - predominantly polymict and calcareous sandstones, 3: Lower suite - alternating sandstones, siltstones, and argillites; **4-12: Vein rocks and ore formations**: 4: Quartz porphyries, 5: Diorite porphyries, andesites, diabases, and lamprophyres, 6: Quartz-carbonate veins with sphalerite and galena, 7: Calcite veins with weak sulphide impregnation, 8: Cassiterite-chlorite-sulphide veins, 9: Cassiterite-chlorite-quartz veins, 10: Cassiterite-tourmaline-sulphide-quartz veins with fluorite, and stockwork zones, 11: Quartz tourmaline greisens veins with cassiterite, 12: Axinite skarns; 13:Greisen-bearing area; 14: Fractures; 15 Tin-bearing placers.

The ore field boundaries approximately coincide with the boundaries of weakly metamorphosed rocks. They extend in near E-W direction concordantly with the strike of sedimentary rocks, main dyke suites and principal ore faults.

In all, there are about 150 ore bodies in the deposit. They are classified, according to their morphological features, into three types: veins, linear elongated stockwork-like zones, and mineralized cataclastic zones traceable for many hundreds of meters, with thicknesses of up to 10 m and more; combinations of two or all three types are common. Most of the ore bodies are related to thick, extended mineralized shear zones, within which a central fissure vein generally shows up as the most persistent one laterally and down-plunge, accompanied by a series of parallel apophyses, zones of crushed and mineralized rocks, en echelon fractures of tear and shear, also consisting of ore material.

The mineralized cataclastic zones are marked by a complex morphology, diversified mineral composition, and rather uniform, high content of tin; their strike is from north-westerly to north-easterly, plunging 75-85° S. Vein-type ore bodies, with a similar steep southward plunge, with east-west and north-east strike, are much thinner and have relatively limited lateral extent on the order of a few hundreds of meters; forking of veins and their transition from one fracture set to another is observed. Stockwork-like zones typical for the deposit's eastern parts also are not extensive, but their width is measured in tens of metres.

Primary minerals predominant in the ores are quartz, pyrrhotite and, locally, tourmaline, chlorite and pyrite, typical mainly for altered wall-rock. Ubiquitous secondary minerals include cassiterite, chalcopyrite, sphalerite, manganosiderite, siderite, and ankerite. Marcasite, fluorite, and calcite occur locally in large quantities. Rare minerals include arsenopyrite, galena, sericite, topaz, wolframite, albite, boulangerite, jamesonite, frankeite, proustite, pyrargite, fahlores and bismuthinite. The most widespread hypergene minerals are limonite, jarosite, fibroferrite, melanterite, scorodite, pisanite, melnikovite, kaolinite, and gypsum. The host rocks have been hydrotermally altered, most commonly silicification, tourmalinization and chloritization and less intensely sericitization, sulphidization, and carbonatization. The ore textures include brecciated, massive, and ribbon textures.

Four main types of ore, in terms of mineralogy, are found: 1) quartz-tourmaline veins with cassiterite; 2) cassiterite-sulphide-quartz veins with tourmaline and fluorite; 3) cassiterite-chlorite-sulphide mineralized cataclastic zones and veins; 4) quartz-carbonate veins with sphalerite and galena; weakly tin-bearing greisen formations are also found. Ores of the second and third types formed in several stages have the largest economic importance.

The predominant part of the Deputatsky deposit's resources is in oxidized ores containing relics of primary ores. The total depth of the oxidization zone in the deposit is 400 m and more. The upper part of the oxidization zone consists of jarosite-limonite ores. The deposit's tin reserves, as of 01.01.2014, were: Proven (Categories A+B+C_1), 198,300 tons; Inferred (C_2), 57,500 tons, with an average tin content in the ores of 1.15 %. The reserves show that it is the largest tin deposit in Russia. As of 2014, the license for its development was held by Deputatsky Mining & Concentration Works JSC. There has been no ore production at the deposit in recent years.

Odinokoye tin deposit

The Odinokoye tin deposit was discovered by M. I. Ipatov in 1945. It is located in the southern part of the Polous synclinorium, on the eastern flank of the Deputatsky brachysynclinal zone. The deposit is located in a granite porphyry stock penetrating the northern limb of the Odinokoye E-W trending brachysynclinal fold structure refolded in an anticlinal structure. The structure consists of Upper Jurassic, predominantly sandstones with lesser shale, locally metamorphosed by the Omchikandya intrusion.

The granite stock is confined by the intersection of NE- and NW-striking faults, the faulting separating the brachysynclinal system from the district of near E-W trending linear folds of the Bakyn anticline to the north. The outcrop of the stock has an ellipsoidal outline, extending in a northeasterly direction and complicated by many short apophyses in a northwesterly direction, as well as elongate apophyses in a northeasterly direction. At the northern contact, the intrusion consists of eruptive breccias with fragments of both country rocks and the granite porphyries.

The porphyry rocks are intensely greisenized, except for the central part of the outcrop where the granite porphyries are only weakly modified by autometamorphism. Their chemical composition indicates that the intrusion is a highly siliceous granite with excess aluminum, potassium predominating over sodium, and a high content of alkalies, and trace elements as follows (in g/t): lithium, 190; boron, 11; and tin, 273. Together with a series of dykes crosscutting the biotite granites, these rocks belong to a late phase of the granodiorite-granite complex.

The deposit forms an ore shoot in a typical roof position with an apophysis/ inclusion nature of the ore body. The ore shoot was formed in the greisen zone, which preceded the ore productive phase. The extent of greisenization correlates with the position of the southern contact of the intrusion and faults which strike ENE and NW. Topaz-quartz greisens were formed along the stock's granite porphyries, its apophyses and along the exocontact hornfels. A second facies is represented by topaz-mica-quartz, and a third by kaolinite-mica-quartz greisens, the latter being found only in the granite porphyry stock. The ore body is marked by a south-western pitch on the eastern flank: it flattens out in the central dome and takes an opposite westerly pitch in accordance with the form of the contact on the western flank. The tin content in the topaz-quartz and topaz-mica-quartz greisens increases by one order of magnitude as compared to the weakly auto-metamorphosed granite porphyries.

The Odinokoye deposit belongs to the greisen type of tin ore-quartz formation, with extensive development of micaceous iron ores. The ores are strongly enriched in fluorine-bearing minerals, including fluorite or topaz, and high iron contents in mica and other minerals. The major minerals in the ores are quartz, topaz and siderophyllite. Muscovite, kaolinite, fluorite, haematite, goethite, and cassiterite are less common and accessories include native bismuth, sphalerite, pyrrhotite, chalcopyrite, molybdenite, lollingite, pyrite, marcasite, arsenopyrite, siderite, wolframite, apatite, chlorite. Galena, stannite, bornite, valleriite, cubanite, bismuthite, rutile, magnetite, columbite, tapiolite, samarskite, pyrochlore, gypsum, scheelite, monazite, xenotime, zircon, cordierite, tourmaline, and epidote occur locally. Hypergene minerals are represented by hydrogoethite, kaolinite, scorodite, psilomelane, azurite, malachite, and pharmacosiderite. Reserves of Category A+B+C_1: 125,800 tons, C_2 – 1,800 t. The deposit was developed from 1987 to 1993, but the operation was stopped and the deposit abandoned in 1994.

Pervonachalnoye tin deposit

The Pervonachalnoye tin deposit belongs to the Pyrkakai tin ore cluster located in the Chaun District of the Chukotka Autonomous Okrug on the east coast of the Chaun Bay 85 km from the town of Pevek, which is located on the Arctic coast at 170°E. The deposit was discovered by B. N. Yerofeev in 1938 during a geological survey by the Mleluveem crew of the All-Union Arctic Institute. The deposit was explored in the period 1964-1980 (trenches, drillholes and adits) and since then has been included in the State Reserve.

The Pyrkakai tin-bearing cluster is a part of the Kuiviveemo-Pyrkakai tin-bearing district covering an area of 4,000-5,000 km^2 on the east coast of the Chaun Bay, in a zone affected by the deep-seated, arc-shaped Palyavaam-Yanranai fracture. The district is marked by the widespread occurrence of early Cretaceous stanniferous granitoid intrusions. The known ore fields and occurrences are related to intrusive roof bulges, and in some cases are located directly within the bodies of eruptive massifs. The Pyrkakai cluster is located in the above-dome part of the “blind” East Chaun granite batholith which has been localized by geophysical surveys. The explored stockwork zones are related to local rises in that block, and are controlled by nodes of intersection of pre-mineral N-S-trending fracture zones with discontinuous northwesterly and near-E-W-trending faults.

The ore bodies of the Pervonachalnoye deposit are typical representatives of the stockwork morphological type (Fig. 56). The Krutoi, and Central stockworks are spaced 750-800 m apart, and several smaller ones - Feathering, Southern, and Eastern stocks, have been studied in detail. Other stock-work type occurrences are also known, as well as linear veined zones, mineralized cataclasite zones, and mineralized lamprophyre dykes. The surrounding rocks, mainly clayey shales with siltstone and sandstone lenses are subdivided into four layers 50 - 250 m thick (upward): siltstone-shale, shale, sandstone, and sandstone-shale. The first two layers are classified, on the basis of their fauna as being of Carnian (Late Triassic) age, and the others, of the younger Norian stage. Intrusives are represented by lamprophyre dykes, mostly with a N-S strike and less common granodiorite porphyry dykes. All the dykes are affected, to some extent, by metasomatic processes. According to the results of gravity and magnetic surveys, the ore field is located above the roof of the granitoid block at its transition from a horizontal to steeply dipping attitude, at a depth of 1.6-2 km to the granitoid block.

The sedimentary rocks hosting the deposit were hydrothermally modified as a result of tourmalinization, silicification, sericitization, sulphidization, and chloritization. Scattered occurrences of biotitized rocks have been recorded. Evidently, the hydrothermal alteration occurred mainly in a pre-mineralization phase. More local fields of hydrothermally altered rocks are related to wall-rock metasomatism. The fields of hydrothermally altered rocks have no clear boundaries and are usually spatially linked, forming quartz-sericite, tourmaline-sericite, and tourmaline-quartz rocks with transitional varieties between them. Sulphides are inherent to all the rock varieties.

A NW-trending anticlinal fold is present within the deposit, complicated by high-order anticlines and synclines. Carnian sediments crop out in the fold core. The main role in forming the structural framework of the deposit and stockwork shoots is related to N-S, NW, and E-W-trending faults. All of the deposit’s stockworks are localized in the joint nodes of northwesterly-trending and E-W fractures in the Olenyino fault zone with concentration of small shear fissures, forming part of the N-S-trending Pervonachanlnaya-Nagornaya fracture zone. The intensity of the mineralization in each stockwork decreases with distance from the Olenyino zone. The stockworks, i.e. the main ore-bearing structures, are linear vein systems. Apophyses are spaced at 20-25 cm across the stockwork and strike N-S with a deviation of ± 15° and a steep plunge. Two minor N-S-trending

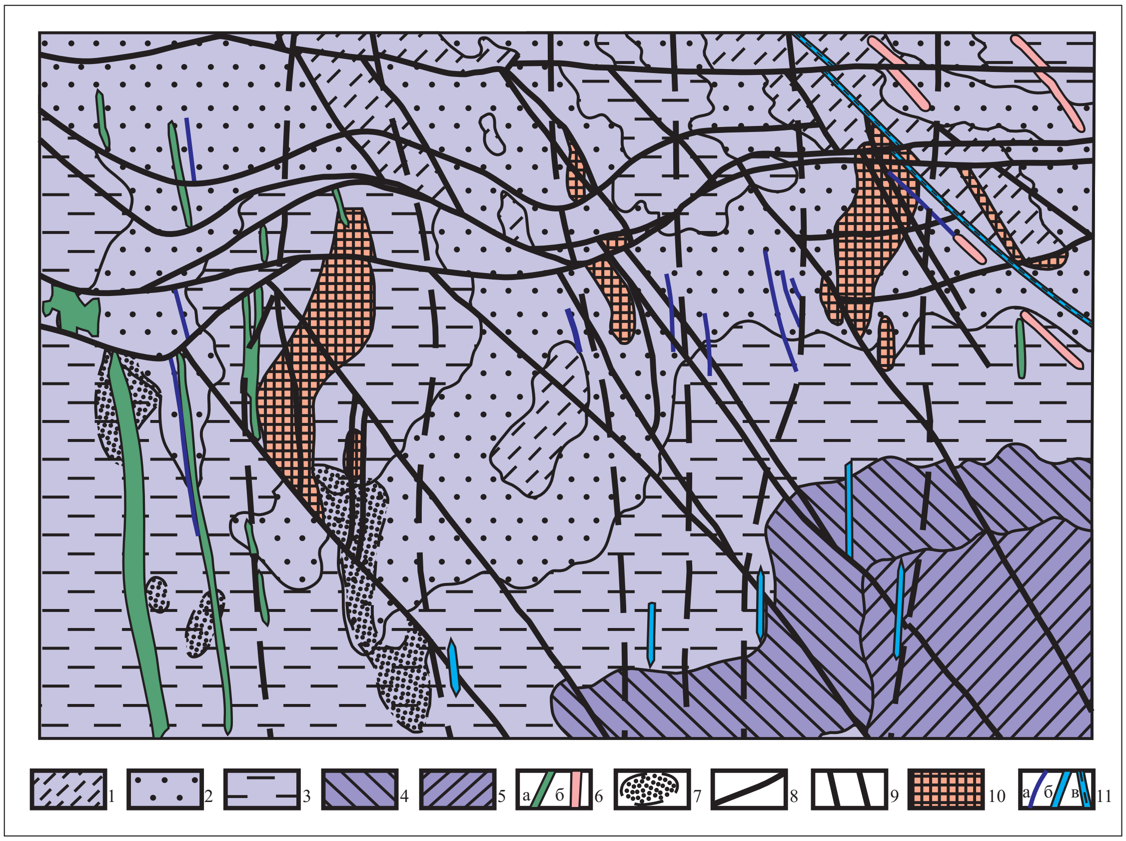


Figure 56. Schematic geological map of the Pervonachalnoye deposit: **1-3: Middle-Upper Norian benches of the Kuveemkai suite**: 1: Sandstone-shale, 2: Sandstone, 3: Shale; **4-5: Carnian benches**: 4: Shale, 5: Siltstone-shale; **6: Dykes**: a: Lamprophyre, б: Quartz porphyry (?) and granodiorite porphyries; 7: Hornfels; 8: Tectonic fractures; 9: Minor N-S fracture zones; **10-12: Morphological types of ore body**: 10: Stockworks, 11: Veins (a), linear veining zones (б) and mineralized crush zones (в).

fracture systems are commonly developed in each stockwork, with opposite plunges - westwards and eastwards at angles of 70-85°. The second system is generally represented by thin joints without mineralization, and locally consisting of pre-mineral quartz or small inclusions of early sulphides.

The apophyses, which make up the productive ore, contain over 60 hypogene and hypergene minerals. Quartz (> 20 %) is the main mineral: muscovite, fluorite, topaz, pyrrhotite, arsenopyrite, pyrite, sphalerite, albite and chlorite are less common (1 - 20 %); rutile, apatite, tourmaline, siderite, calcite, wolframite, galena and cassiterite are rare (< 1 %). Inclusions of cassiterite reach a size of 15-20 mm, with an average of 5-6 mm. The large size of the cassiterite segregations, the absence of intergrowths with other minerals, and the negligible content of tin sulphide compounds permit categorization of the Pyrkakai stockwork ores as free-milling. The average tin content in the ore is 0.23 %. The reserves of the Pervonachalnoye deposit in Category A+B+C_1 are 243,000 t, and in Category C_2, 7,000 t.

Svetloye tin-tungsten deposit

The Svetloye tin-tungsten deposit is located in the north of Central Chukotka, in the Amguema tungsten ore district, at the SE end of the Kuekvun anticlinorium. The mineralization is related to granites of the Cretaceous Iultin type. The Svetloye deposit is located in the Northern tin-tungsten cluster. The rocks forming the ore field are Triassic sediments, primarily silt- and sandstone. The host rocks are contact metamorphosed by a granite intrusion outcropping at Mount Veshkap. The resulting hornfelses contain pyroxene-hornblende, mica-andalusite and tourmaline-mica but also include spotty and nodular schists and hornfelsed sandstones. The area is cut by faults with a north-easterly strike which control the distribution of the tungsten mineralization and of ore-free quartz veins. Post-mineralization tectonic faults are evident in the ore field. The displacement on these is up to 8.5 m. Various dykes occur widely within the ore field, confined to a north-westerly-striking deformation zone, the thickness of which is ca. 400 m and the length >1 km. Dykes of coarse-grained granite porphyry occur in the north-west, micro-granites in the central part, and aplites in the south-east. The dykes have a north-westerly strike (290 - 330°) and dip at 60° SW; their thickness reaches 50 m.

Two morphological types of ore bodies are identifiable within the deposit: 1) vein-type, developed mostly in hornfelsed rocks where ore bodies occur without any important alteration of the wall rocks, and 2) mineralized ore zones generated mainly in granitoid dykes subjected to intense alteration. The ore bodies of the vein type have higher contents of cassiterite and wolframite. The veins occur in sedimentary rocks and are persistent in strike but not in thickness and dip; locally they cross-cut dyke formations. The vein thicknesses vary within a broad range. Ore body thicknesses decrease sharply when the veins extend from sedimentary rocks into dykes. The veins have a north-westerly strike (300—310°) and dip 70-85°SW. The contacts with enclosing sandy shales are markedly linear; but in dykes, they are diffuse. At the contact with veins, a marginal zone of 3-5 mm of mica appears in the sedimentary rocks: intense greisenization is recorded in dykes (in zones up to 2 m wide).

The mineralized zones are not persistent in strike and dip. Thickened mineralized portions are replaced by thread-like veinlets within a few tens of metres. Sampling data indicate that large accumulations of ore minerals in such zones are confined to quartz veinlets and vein accumulation areas. At the contact with these zones, the granitoids are more intensely greisenized and contain a higher grade of tin mineralization.

The following mineralogically defined ore types containing wolframite and cassiterite are found: quartz, quartz-topaz, and occasionally quartz-arsenopyrite. The quartz type is predominant. The ore bodies have a varied mineralogical composition. Quartz is the basic mineral of the ore veins together with topaz, arsenopyrite, and wolframite. Muscovite, feldspar, cassiterite and pyrite are subordinate and fluorite, biotite, chalcopyrite, pyrrhotite, and löllingite are accessory: carbonates, scheelite, bismuthite, molybdenite, apatite, anatase, and sphalerite are very rare.

Wolframite occasionally forms large pockets up to 0.4 cm in size, associated with cassiterite ore. In some ore bodies, a noticeable increase in the concentration of wolframite with depth has been observed. The ratio of wolframite and cassiterite in the ore bodies varies from 2.7:1 in the vein type to 1:1-1:1.5 in mineralized zones. Wolframite is rather irregularly distributed throughout the ore body and occurs both in the fringes and central parts of veins. Cassiterite is found in greisens, quartz and arsenopyrite-quartz veins, and in the micaceous margins of quartz veins occurring in sandy shales. The highest tin contents occur in mineralized zones. Cassiterite is mainly associated with quartz, occasionally with topaz. It is mostly coarse-grained, and its distribution throughout the ore body is rather erratic.

Tomtor REE deposit

The Tomtor REE deposit is located in the north-west of the Republic of Sakha (Yakutia), within Olenek Ulus, on the divide of the Udja and Chimara rivers, 400 km S of the Laptev Sea coast. The alkali-ultramafic-hosted ore was discovered by E. N. Erlikh in 1959 during a 1:200,000 scale prospecting survey. Several areas with radioactive REE mineralization were discovered within the region in 1960. In the 1970s and 1980s, significant accumulations of iron, phosphorus and rare earth elements were found in the carbonatites and their weathered zone in the core of the Tomtor massif. The remote location of the deposit, despite its large resources, has delayed its development for several decades.

The Tomtor deposit is located on the western slope of the Udja rise, and confined to an alkaline, ultramafic and carbonatite massif of the same name (Fig. 57). The surrounding rocks are dolomites, shales, and argillites of the Riphean Ulakhan-Kurung suite and terrigenous metamorphosed rocks of the Vendian Tomtor suite. In plan, the massif has a round, nearly isometric shape ca. 20 km in diameter, and a total area of ca. 250 km^2. The structure is concentrically zoned. The central part, 4 - 5 km in diameter, consists of carbonatite complex rocks, which are a substrate for an ore-bearing, weathered mantle. The carbonatite core is flanked by ultramafic and foiditic rocks on its eastern and western sides.

The ore body is confined to a kaolinite-crandallite horizon of a re-deposited weathering mantle, occurs on siderite horizon ores in most cases,

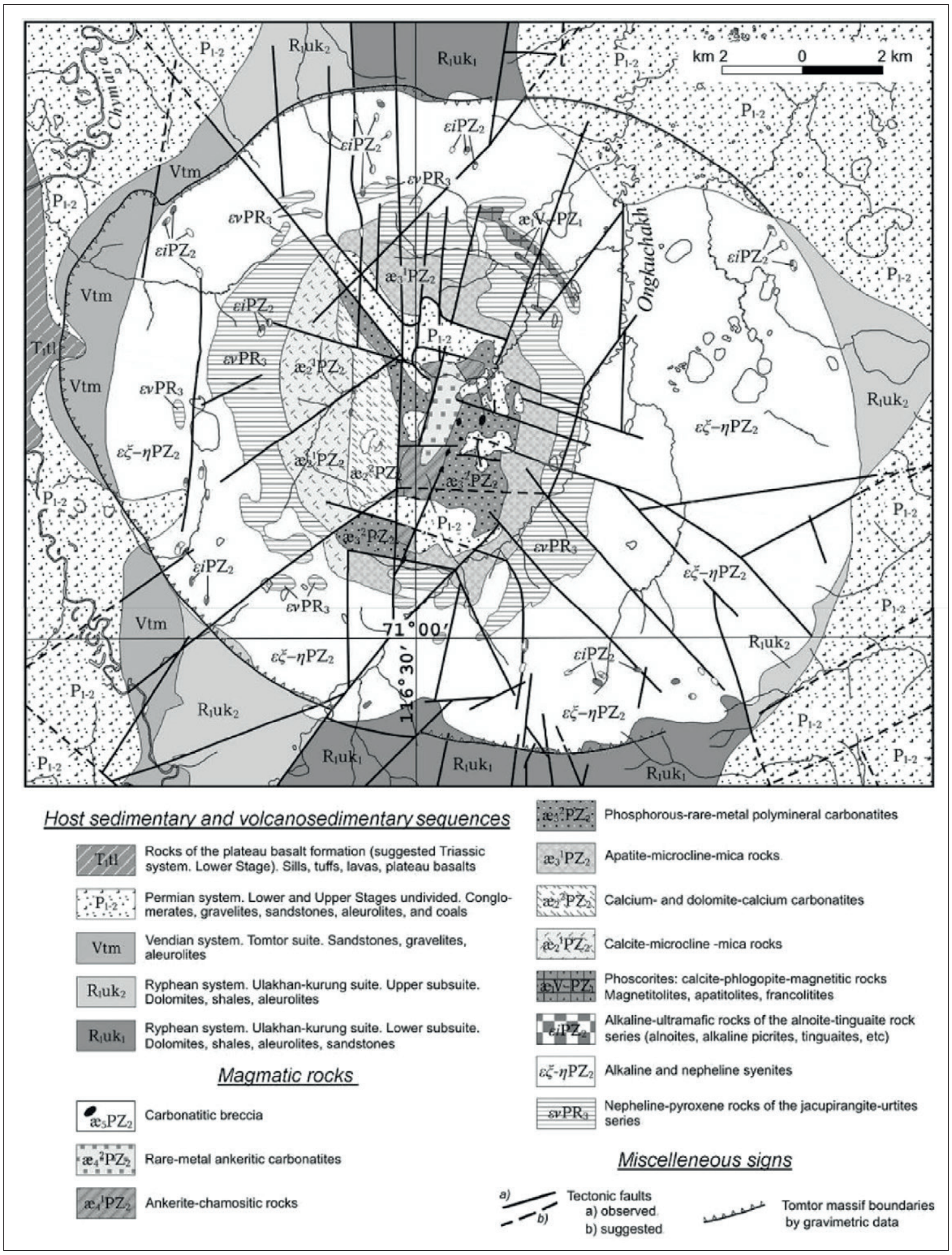


Figure 57. Geological map of the Tomtor mass (Erlich & Tolstov, 2011). (https://docs.google.com/viewer?a=v&pid=sites&srcid=ZGVmYXVsdGRvbWFpbnx2dWxrYW5pY2Vza2FhZ2VvbG9naW-F8Z3g6NDcyZjgwMDA-zYzEyZmI5MQ).

and is overlaid by sedimentary formations of the Permian, Jurassic, and Quaternary age. The total thickness is 7.5 m - 160 m. The ore stratum is an alternation of layers variably enriched in pyrochlore and monazite with lean crandallite (Ba phosphate) and kaolinite-crandallite layers containing 1-2 % of niobium oxides and up to 3-5 % of rare earth oxides. No zoning has been found in the distribution of layers, but pyrochlore streaks are restricted to the core and base of the section.

The ores within the Tomtor ore deposit are subdivided into the following types according to their mineral and chemical composition and geological/genetic features:

- Ores in the re-deposited (epigenetically altered) weathering mantle (main economic type);
- Ores in bedrock carbonatites;
- Ores in sedimentary Permian deposits.

The economic ore reserves of niobium ore calculated for the Buranny ore field are 42.7 Mt. The contents in the ores are: Nb_2O_5, 6.71 %; Y_2O_3, 0.595 %; Sc_2O_3, 0.048 %; REE_2O_3, 9.53 %. Tomtor is also one of the world's largest REE deposits. The niobium content per ton of rock varies from 23 to 63 kg, and for REE, up to 93 kg. The rights for exploration and mining of ores of niobium, REE, scandium, and associated components of the Buranny field of the Tomtor deposit were granted to Vostok Engineering LLC (subsidiary of TriArc Mining) in May 2014.

Lovozero Nb-Ta-REE-rich Massif

The Lovozero alkali massif was first described by W. Ramsay in 1887. The massif's surface area is 650 km² and it is the world's largest agpaite intrusion. The massif is located in the central part of the Kola Peninsula, between Lovozero and Umbozero. It is of Paleozoic age and intruded into Archaean granitic gneisses and, to a lesser extent, Proterozoic sillimanite schists and jaspilites, and weakly metamorphosed Lower and Middle Devonian sedimentary and igneous rocks (Fig. 58). The massif's rocks were formed in several intrusive phases. Rocks of the earlier phases and relics of the Lovozero stage have only survived in xenoliths inside the massif and in the preserved part of its roof and margins.

The Lovozero massif is related to a late Devonian province of alkali- and nepheline syenites with carbonatite. It was formed by three successive phases (Kalinkin, 1974). The first phase is represented by a stratified series of loparite-bearing lujavrite/foyaite/urtite, nepheline and cancrinite-nepheline syenites, with alkali syenites in the marginal zone. The second phase forms the largest, central part of the massif, consisting of lujavrite and murmanite. Both of these phases are accompanied by veins of alkali pegmatites and rare-metal metasomatites. The third phase is represented solely by dykes, veins and volcanic pipes of alkali lamprophyre. The massif's rare-metal deposits are related to the rocks of the first two phases. Apatite-nepheline ores, agglomerations of which are found in the juvite and urtite zones of the first phase and in the lujavrite zones of the second phase may become objects for exploration. Eudialyte-bearing lujavrite predominates in the massif (eudialyte-feldspar-nepheline-aegirine). About 310 mineral species, of which over 70 contain rare elements (zirconium, niobium, REE, rubidium, gallium, tantalum etc.) are currently known in the massif.

The massif is located within a ring-fault system, and resembles a laccolith in its shape. The overall dip of the rocks is centre-oriented, with a vertical feeder at depth. The widest (uppermost) part (24×29 km) is 1.52 km thick and confined to the gneiss and Lovozero Suite contact zone. Under this there is a ring intrusion with a horizontal section of 320 km² and a depth of at least 8 km. The section's reconstructable overall thickness is 650 m. The south-eastern, southern, and western contacts of the massif are close to vertical down to a depth of 4 km; at a depth of 8-10 km they are seen to flatten. The northern and north-western contacts are flatter, but at 9-10 km they become near-vertical.

The Lovozero alkali massif in the Kola Peninsula is one of the largest known stratified intrusions, related to which there are immense deposits of loparite ($(Ce,Na,Ca)(Ti,Nb)O_3$). The massif consists (Fig. 58) of a complex of eudialyte-bearing lujavrite building up the top part of the massif with alternating horizons of leucocratic, mesocratic and melanocratic varieties, as well as eudialyte-bearing lujavrite, foyaite and urtite. Underneath this there is a thick differentiated complex, formed by recurrent three-fold layers of foyaite-urtite-lujavrites. A complex of nephelinite, nepheline-hydrosodalite and poikilite syenites is concentrated mainly in the massif's marginal parts and probably underlying the differentiated complex rocks, and a complex of veined alkali rocks (Bussen, Sakharov, 1967; Vlasov et al., 1959; Gerasimovsky et al., 1966). Loparite mineralization is mainly confined to the horizons of urtite, malignite, and less commonly lujavrite of the differentiated complex. A consistent change in the composition of the loparite has been identified throughout the massif (Vlasov et al., 1959; Ifantopulo, Osokin, 1979; Kogarko et al., 1996, and others). In a vertical section of the intrusion, the SrO, Nb_2O_5, Ta_2O_5, ThO_2, Na_2O contents increase upwards, but the contents of CaO, FeO, TiO_2, Ce_2O_3, La_2O_3, Nd_2O_3, and total REE decrease. The loparite of eudialyte-bearing lujavrites and some pegmatites show an increase in lueshite ($NaNbO_3$) and tausonite ($SrTiO_3$) components compared to the loparites of the differentiated complex (Kogarko et al., 1996).

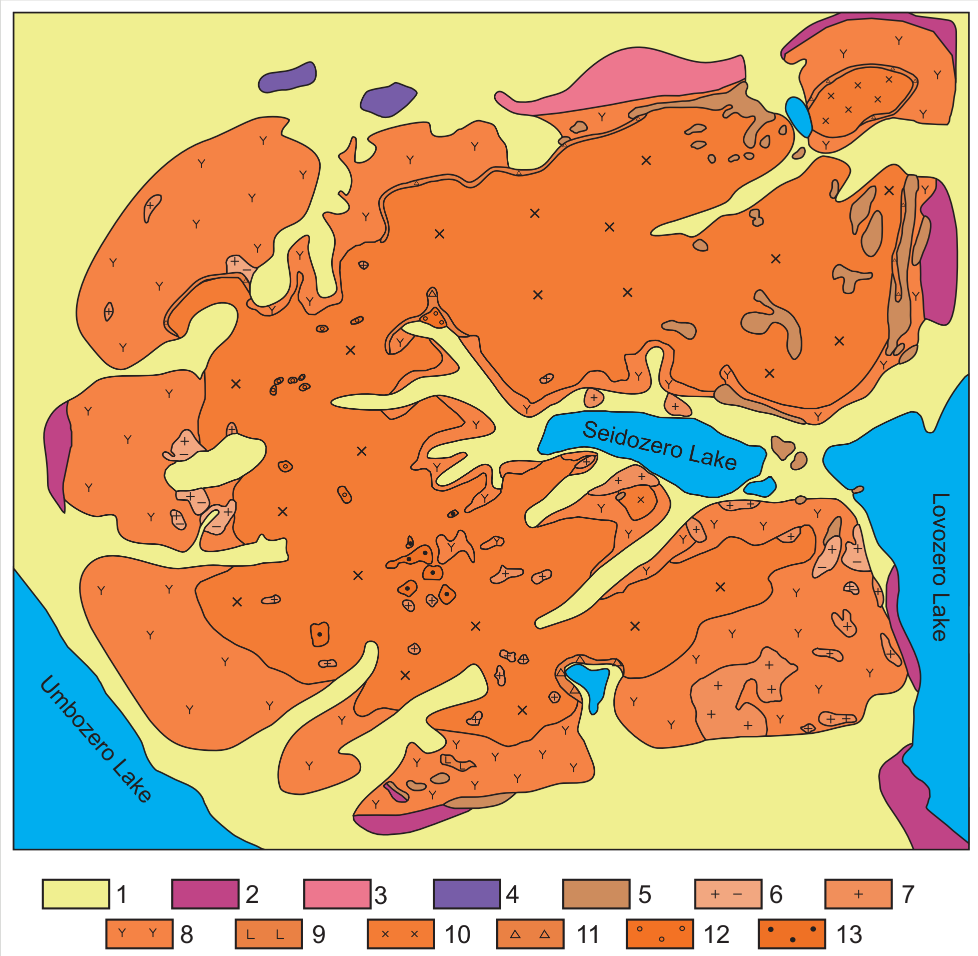


Figure 58. Geological structure of the Lovozero alkali massif (after materials of Ya. M. Feigin, N. A. Yeliseev et al.) (Gerasimovsky et al., 1966). Lower Archaean: 1: granite gneisses. Proterozoic: 2: sillimanite-andalusite shales; 3: ultrabasic rocks. Paleozoic igneous complex: 4: effusive sedimentary rocks of the Lovozero suite. Intrusive rocks of the Lovozero Massif: 5: metamorphosed nepheline syenite; 6: poikilite hydrosodalite syenite, nepheline-hydrosodalite syenite and equigranular nepheline syenites; 7: urtite, foyaite, lujavrite; 8: poikilite sodalite syenites; 9: eudialyte lujavrites; 10: porphyric lujavrites; 11: porphyric lovozerite-murmanite lujavrites; 12: poikilite sodalite syenites and tawites.

The Lovozero deposit comprises 12 ore fields, of which those currently developed (Karnasurt, Kedykvyrpakhk and Umbozero) account for 75 % of the reserves. Other fields are earmarked for development in the foreseeable future. The operating underground mines have reserves for at least 55-100 years. The reserve base consists of eudialyte-loparite ore with the advantages of high contents of tantalum (up to 1 %) and niobium (up to 10-12 %). Additional reserves with other elements include deposits of eudialyte-loparite and eudialyte ore containing zirconium and yttrium in the Alluaiv field, which can be developed underground. The metal oxide content in loparite exceeds 80-85 % (Ta_2O_5, 0.6 %; Nb_2O_5, 7-8 %; SrO, 0.7 %; TiO_2, 40 %; REE (oxide), 36 %). The Lovozero mining and concentration mill comprises an ore dressing mill with an annual capacity of up to 1.5 Mt of ore. The dressing mills use a gravity pattern to produce 95 % loparite concentrate, which is processed in the Solikamsk Magnesium Mill using chlorine technology to produce niobium, tantalum, and rare earths.

“Karnasurt” was opened in 1951 and “Umbozero,” in 1984. However, the Umbozero mine suffered a heavy man-made earthquake in 1999, as a result of which, the mine was closed (Kozyrev et al., 2002; Lovchikov, Savchenko, 2013). The Karnasurt mine, about 10 km away from the Umbozero mine, continues to be operated.

Kolmozero Li-Be-Ta-Nb deposit

The Kolmozero (A. E. Fersman) deposit of rare metal pegmatites was discovered by A. A. Chumakov and I. V. Ginzburg, researchers of the Kola branch, USSR Academy of Sciences, in 1947. The deposit is located in the Lovozero District, Murmansk Oblast, 80 km E of Lovozero settlement, in an unpopulated and undeveloped area. The Kolmozero deposit is located in the SE part of the Uraguba-Kolmozero ore belt, being part of the Kolmozero-Voronya ore district, Iokanga ore field.

The deposit consists of 12 veins of albite-spodumene pegmatites localized in metagabbro-anorthosites of the Potchemvarek massif which is at the junction of the Kolmozero-Voronya greenstone belt and the Murmansk block. In plan, the metagabbro-anorthosite massif has a lens-like shape with a northwesterly strike (300–310°). Its length is ca. 7 km, and its maximum width, 2 km. The massif consists of metagabbro, meta-anorthosite and amphibolites, dipping steeply to the NE. The age of the metagabbro-anorthosite is 2925 ± 7 Ma (U-Pb zircon dating). The massif is cut by faults striking NW, approximately N-S and NE.

The metagabbro-anorthosite massif is, to the south, in contact with the Kolmozero-Voronya greenstone complex (dated at 2.92–2.65 Ga) and to the north with Murmansk block rocks, sanukitoids of the Kolmozero massif dated to 2736 ± 11 Ma (U-Pb zircon). The TDM model Sm-Nd age of the rocks is 2.9 Ga. A new Sm-Nd (TDM) model age obtained for migmatized granite gneisses of the Murmansk block is 3.1 Ga. In the contact zone, the rocks have been strongly shearedto form banded mylonites and ultramylonites, and later folded into asymmetric S-shaped folds. The contact of the metagabbro-anorthosite massif with migmatized granite gneisses of the Murmansk block is complicated by a zone of quartz-chlorite schists alternating with holmquistite schists, which result from hydrothermal alteration of the metagabbro-anorthosites during pegmatite formation. Alteration products are confined to a NW-striking tectonic zone favourable for circulation of post-magmatic solutions.

Early pegmatite bodies, located near a granite source, are of limited length and thickness, and do not contain rare-element bearing minerals. Later, less viscous pegmatite melts were enriched in volatile components (H, F, Cl, P, S, B) and lithophile rare elements (Li, Cs, Sn, Rb, Ta). The pegmatite veins dip steeply to the SW, have a length of up to 1400 m and a thickness of up to 25 m; the strike is northwesterly with a slight deviation to the SW. Large veins are complicated by apophyses, swells, and pinches. The main structural elements controlling the locations of rare metal pegmatite veins are NW striking fractures with a dip of 50–70°. The rare metal pegmatites contain xenoliths of metamorphosed, foliated host rocks, which indicates injection of pegmatite melt into deformed and metamorphosed gabbro-anorthosites. The contacts of the pegmatites with the metagabbro-anorthosite wallrock are well-defined, and, in some cases, tectonized. Fine-grained acicular holmquistite ($Li_2Mg_3Al_2Si_8O_{22}(OH)_2$) and biotite has been observed in the endocontact zone. The rare metal pegmatites are deformed and disrupted by fractures. The age of the pegmatites is 1994 ± 5 Ma (U-Pb zircon dating, L. N. Morozova, 2014).

Quartz-feldspar (ore-free), quartz-muscovite-feldspar (ore-free with beryllium) and albite-spodumene (ore) pegmatites are found within and around the Kolmozero deposit. Feldspar pegmatites are developed in all the above-mentioned rocks, but albite-spodumene pegmatites occur only in the amphibolites and metagabbro-anorthosites, and muscovite-feldspar pegmatites among the rocks of the Kolmozero-Voronya greenstone complex.

The deposit's economic reserves in Categories B+C_1+C_2 are 844,200 t of lithium oxide with an average content of 1.14 %. The average contents of tantalum, niobium, and beryllium (0.009 % Ta_2O_5, 0.011 % Nb_2O_5 and 0.037 % BeO) permit considering these components merely as accessory to spodumene production and their reserves are included in the register.

Polmostundra Li-Ta-Nb deposit

The Polmostundra rare metal deposit is located in the Lovozero District, 48 km NE of Lovozero settlement, in an undeveloped area. The deposit was investigated in detail in 1957-1960. Rare metal pegmatites were intersected by trenches at 50 m intervals and were explored in depth by densely spaced drilling.

The deposit comprises 12 en-echelon arranged veins of rare metal pegmatite with a northwesterly strike and a dip of 50°NE within an area of 3000 × 200 m. The host rocks are schistose amphibolites. The veins are 1000-1300 m long, 3 to 15-30 m thick, and have been traced down-dip for 200-300 m without signs of thinning. The pegmatites consist of quartz (30-40 %), albite (10-70 %), spodumene (20-50 %) and microcline (up to 20 %). The average content of Li_2O is 1.25 %, and of its accessory components: Ta_2O_5, 0.004 %; Nb_2O_5, 0.007 % and BeO, 0.027 %. A block of rich spodumene ores with 2 % Li_2O (4.5 Mt) has been identified in the deposit. Dressing technology has been studied at a pilot production level, leading to concentrates of: spodumene with 5.1 % Li_2O (90 % recovery), tantalite-columbite of 8.7 % Ta_2O_5 and 30.4 % Nb_2O_5 with 28 and 59 % recovery, respectively; a beryllium concentrate has not been obtained.

Odinokoye placer tin deposit

The Odinokoye placer tin deposit is located on the border between the Ust-Yana Ulus District and Allaikha Ulus District, in the Republic of Sakha (Yakutia), along the boundary between the Kuranakh and Berelekh river systems. The deposit has no permanent communication routes, except for the Odinokaya – Omchikandya – Deputatsky – Ust-Kuiga winter motor road. The first information on the geological aspects of the deposit area dates from the late 1930s. In 1945, a geological reconnaissance revealed an ore body (Polyarnoye), a placer tin deposit (Omchikandya) and the tin occurrences of Mount Odinokaya. The Odinokoye tin ore deposit was, in the period 1970-83, the object of prospecting. The deposit was mined from 1987 to 1993. The operation was suspended in 1994 and the deposit was put under care and maintenance.

The Odinokoye tin placer deposit is a heterogeneous formation and includes the placer tins of the Odinoky, Mokry and Yasny streams and the slope placer of Mount Odinokaya. The deposit was formed by a stock-work of cassiterite and quartz with topaz (greisen deposit). Due to the high hardness of the greisens, about 50 % of the tin ore of the placer is in aggregates, which must be crushed.

The placers are (except for the Yasny deposit) economic and have the following average parameters: Odinoky stream: extension 5,900 m and average width 640 m. The peat thickness above the placer averages 4.28 m. The average thickness of the productive stratum is 12.62 m. Mokry stream: extension 1950 m and average width 230 m. The peat thickness above the placer averages 4.52 m. The average thickness of the productive stratum is 12.50 m. Slope placer: the area is 907,000 m². The peat thickness above the placer averages 0.12 m. The average thickness of the productive stratum is 5.45 m. The placer's commercial reserves are 50,900 tons, with an average tin content of 0.83 kg/m³.

Valkumei placer tin deposit

The Valkumei placer tin deposit (Fig. 59) is located at Chaun Bay (Pevek ore placer) on the shore of the East Siberian Sea. It is confined to the offshore flank of the Valkumei tin ore deposit. All the placer bodies are within the tectonic zone separating the arch-dome rise of the Pevek granitoid block and the Chaun neotectonic depression. The placer material sources are mineralized veins and scattered mineralized parts of tin ore/silicate formation confined to the Valkumei block. Outcrops of ore bodies are observed both directly in an abraded cliff and in the area adjacent to the shore belt. The diluvial-alluvial formations deposited at the beach zone also are tin-bearing. The direct tin source for today's littoral placer is the zone adjacent to the beach in the end of a beach drift N of Cape Valkumei.

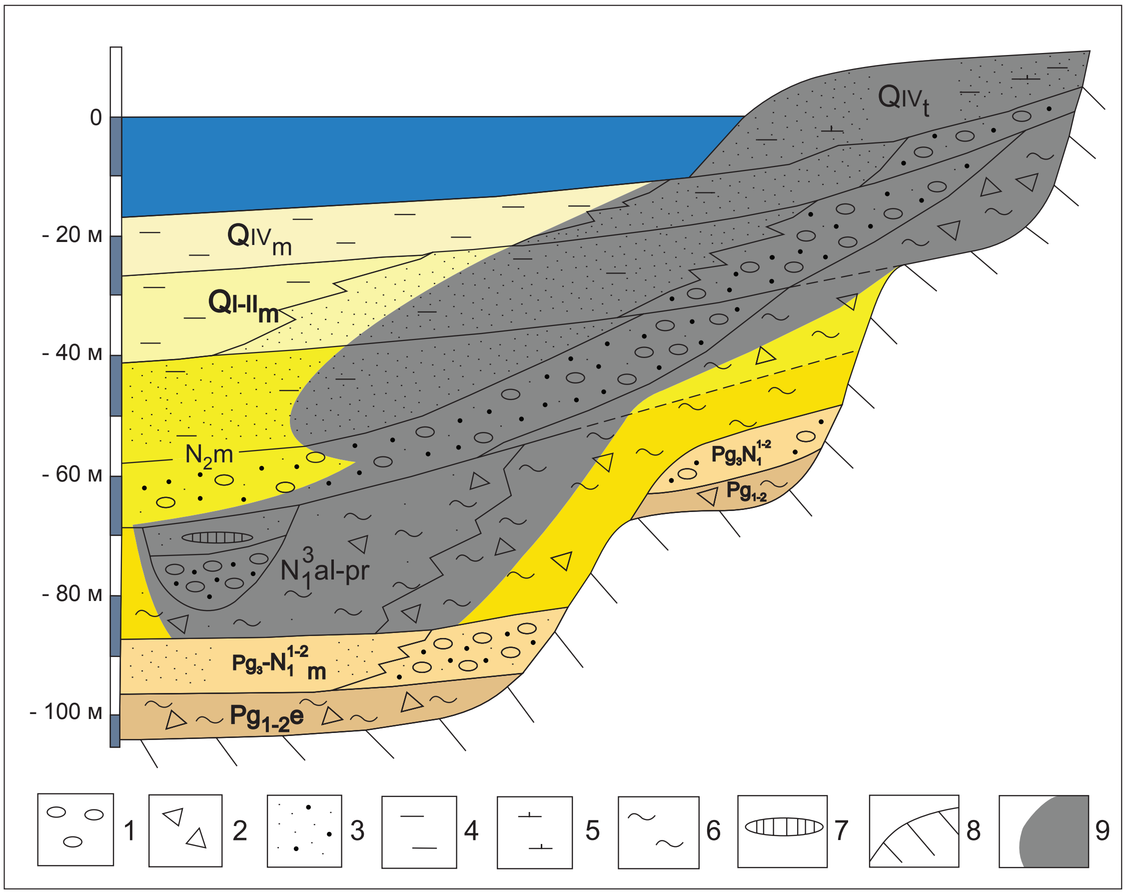
Genetically, diluvial, alluvial, littoral and man-made formations are present. The reserves were assessed for a mineable thickness varying from 2 - 50 m (8.8 m on average) with an average tin content of 0.68 kg/m³. The commercial reserves of Category C_1 together with the adjacent man-made placer are 12,500 tons. The, currently, uneconomic reserves (for mining/geological operating conditions > 50 m from the shoreline) are 9,500 t. The inferred resources are estimated to be 35,000 t with an average tin content of 0.7 kg/m³.

Tin and tungsten mining from placer and hard rock ore deposits in the district continued from 1941 till 1992. In 1992 the tin and tungsten mining in the region was stopped due to general economic factors: now the mines and concentration mills are beyond repair, and the mine camps have been abandoned.

Chokurdakh placer tin deposit

The Chokurdakh placer tin deposit is part of the Chokurdakh-Svyatoy Nos placer district located in the offshore Van'kina Bay, south-eastern part of the Laptev Sea, 200 km E of Nizhneyansk settlement. The deposit is confined to the central part

Figure 59:. Generalized section of the Valkumei placer (acc. to A. V. Lalomov, 2009). 1: Pebbles; 2: Gravel; 3: Variably grain-sized sands; 4: Silt; 5: Ice; 6: Clay; 7: Organic matter, 8: Primary metamorphosed sedimentary rocks; 9: Tin placer. Designations: Pg1-2e: Eluvial sediments, Paleocene-Eocene, 1-2 Pg –N m 3 1: Shallow littoral sediments, Oligocene-Lower & Middle Miocene, 3 N al-pr 1: Set of proluvial sediments of Upper Miocene with nested alluvial sediments, N2m: Littoral sediments, Pliocene, QI-IIm: Littoral sediments, Lower & Middle Pleistocene, QIVm: Littoral sediments, Holocene, QIVt: Man-made sediments, Holocene.



of the Chokurdakh-Lyakhovsky tin-bearing zone and is the first prospected offshore placer tin deposit in Russia. The placer is located at a tectonic zone developed during the Miocene – Holocene on a bed of lacustrine-alluvial loams of Eocene-Oligocene age to an elevation of -60 m, and is represented by tin-bearing, mostly coastal, sediments overlain by Holocene placers, a beach and diluvial sediments. The thickness of the offshore tin-bearing stratum varies from 4 m (littoral) - 58 m (with distance from the shoreline). The placer is 2.4 km long and 520-800 m wide in the centre and 240 m at the flanks. The maximum tin contents (up to 6.9 kg/m³) have been found in the Pliocene-Early Pleistocene layers of the placer's central part. The average tin content in the deposit is 0.74 kg/m³. The deposit's reserves are estimated in Category C_1 (with all process surveys of sands associated with this estimation level) to be 19,000 tons.

Tirekhtyakh placer tin deposit

The Tirekhtyakh placer tin deposit is also located in Ust-Yana Ulus, 60 km SW of Deputatsky settlement, or 130 km along the winter road via the Mamont deposit. Tirekhtyakh is a unique deposit in Russia, both with respect to reserves and the quality of its sands. The ores and sands of the Tirekhtyakh deposit are free-milling; the concentrates obtained are of a high quality (60 % and higher) and free of harmful impurities, which ensures a high price both in and outside Russia.

As of 01.01.2014 the RF State Register recorded for the Tirekhtyakh tin placer deposit Commercial reserves for open mining, Category B+C_1 – 84,682,000 m³ of sands and 68,942 t of tin; for Category C_2, 6,638,000 m³ of sands and 5,326 t of tin; non-commercial reserves of Category C_1+ C_2 – 49,044,000 m³ of sands and 14,302 t of tin. Associated component reserves in marketable tin concentrates included the following quantities for Category C_2: Commercial: 84,682,000 m³ of sands and 738 t of tungsten trioxide with a grade of 1.34 %, 1.2 t of indium with an average grade of 0.0021 %; the average grade for scandium is 0.223 % and for niobium pentoxide 0.0047 %. Non-commercial resources are 48,336,000 m³ of sands, 219 t of tungsten trioxide and 0.3 t of indium.

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Tirekhtyakh Placer

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KIMBERLITE-HOSTED, PLACER AND IMPACT DIAMOND DEPOSITS

Molchanov, A.V., Terekhov, A.V., Khalenev, V.O., Lukyanova, L.I., Artem'ev, D.S.

Large diamond deposits are found in kimberlite pipes in the East Siberian minerogenic province, within which several kimberlite fields are distinguished. The main deposits are: Daldyn-Alakit, Lesser Botuoba, and Middle Markha, in which kimberlite bodies of different ages form extensive fields (Fig. 60). The oldest, small dykes and pipes of Precambrian age, are in the southwestern part of the province and contain few diamonds. All primary deposits of economic interest in the province were formed during the period of the Palaeozoic tectonic and magmatic activity; Mesozoic kimberlites have low contents of diamond.

The first kimberlite pipe to be discovered in the USSR (Russia) was the "Zarnitsa" pipe in the East Siberian diamondiferous province (Fig. 60). It was found in bedrock in 1954 as a result of a panning survey focussing on pyrope, led by VSEGEI employees L.A. Popugaeva and N.N. Sarsadskikh, who were the pioneers in this field. In subsequent years, a large number of diamondiferous kimberlite pipes, containing rich diamond deposits were discovered (in several parts of the world) using this method.

"Udachnaya" pipe deposit

The "Udachnaya" deposit is located within the East Siberian minerogenic province in the northern part of the Daldyn-Alakit diamondiferous area in the Daldyn kimberlite field in the junction zone of the Anabar anticline and the Tunguska syncline, to the north of the town of Udachny. The deposit is unique due to its size and average diamond grade. The kimberlite pipe was discovered in 1955, also as

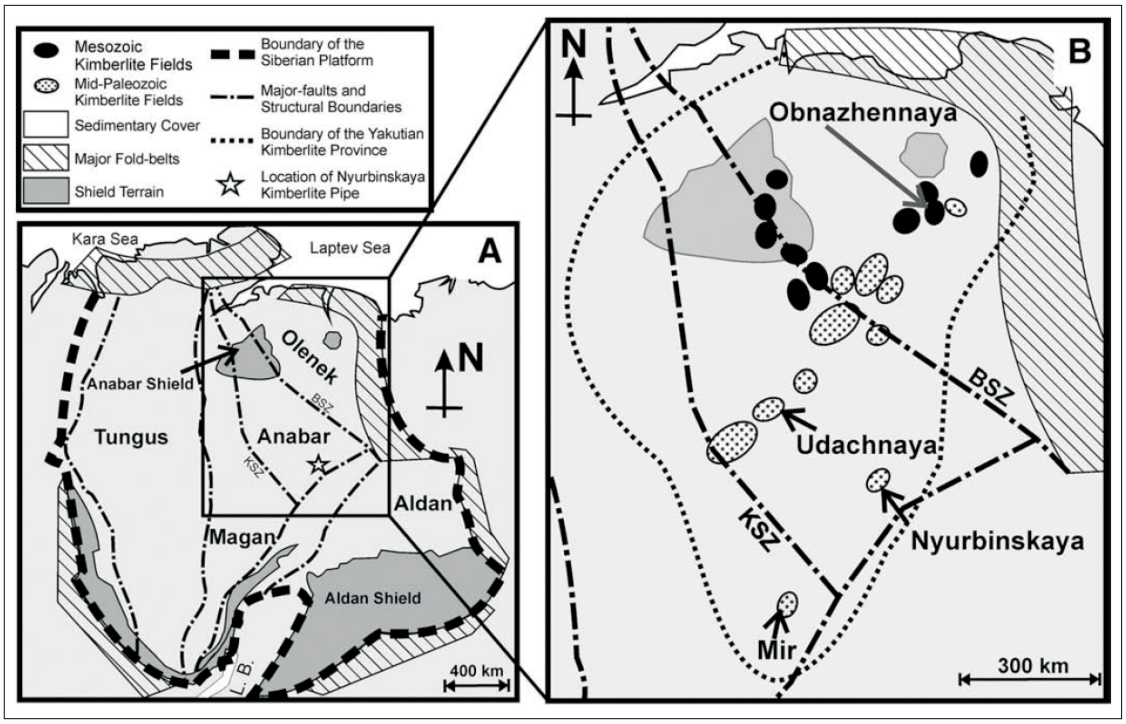

Figure 60: Diagram of the East Siberian (Yakutian) kimberlite province (Riches et al., 2010) with the sites of the Obazhennaya, Udachnaya, Mir and Nyurbinskaya kimberlite pipes. KSZ=Kotuykan Shear Zone. BSZ=Bilyakh Shear Zone. L.B. =Lake Baikal.

a result of panning prospecting by .N. Zdota and V.N. Shchukin of the Amakinsky Expedition and by L.A. Popugaeva and N.N. Sarsadskikh (VSEGEI).

The geology of the area includes a basement of crystalline schists and Archaean granite-gneisses, covered by sedimentary rocks consisting of Ordovician and Silurian terrigenous-carbonate and carbonate rocks, Upper Palaeozoic terrigenous rocks, Upper Permian and Lower Triassic igneous and igneous-sedimentary rocks, and Quaternary sediments. The "Udachnaya" pipe is one of the largest pipes explored in the Republic of Sakha (Yakutia). Since 1971, the deposit has been mined in the "Udachny" open pit. The current surface dimensions are 2.0 × 1.5 km and the deposit has been exploited to a depth of more than 600 m (Fig. 61). The deposit is currently mined from the "Udachny" underground mine. The mine is predicted to reach a maximum production capacity of 4 Mt/a by 2019. The "Udachnaya" pipe intersects the Vendian-Palaeozoic terrigenous-carbonate rocks of the sedimentary cover. It is confined to the intersection of a near-E-W trending fault system with a NW-trending fault (Kharkiv, Zinchuk, Kryuchkov, 1998), and can be traced as a consistent ore body from the surface to a depth of 250 m (Fig. 62). Below this level the pipe splits into two independent ore bodies, Eastern and Western bodies, separated by Upper Cambrian sediments. The distance between the ore bodies increases significantly with depth, from about 100 m at the level of the bottom of the existing open pit (-320 m) to 325 m at -1,080 m elevation.

Figure 61. Udachnaya pipe open pit.

The Western body is elliptical in shape and elongated in a northwesterly direction. Contacts between the ore body and its host rock are distinct, only rarely becoming so-called "floating" due to host rock brecciation in the proximal exocontact zone (Fig. 62). Dip angles in the western part are 80-85°; at the eastern edge, above - 789 m elevation, the dip is 60°, and down to -1080 m elevation, the dip steepens to vertical. The Western body contains karst cavities filled with breccias, brine, and gas.

The Western body is, to a depth of 450-530 m, composed of grey and green kimberlite breccias (the first phase of the intrusion). The breccia structure is crystal-lithoclastic, in areas autolithic. The rock is intensely altered by secondary processes. Pseudomorphs of first-generation olivine (xeno- or phenocrysts) amount to 20-25 %; epigenetic material is represented by fragments of sedimentary rocks, crystalline schists and, rarely, ultramafic rocks including garnet (Fig. 4a). Autoliths amount to 26 % of the rock volume; various xenoliths act as autolith cores or centres. The breccia cement consists of carbonate-serpentine aggregate and contains small segregations of ore minerals and numerous pseudomorphs on second-generation olivine.

Kimberlite breccias of the second phase of the intrusion fill the main volume of the deep pipe levels. They are characterized by increased content of pseudomorphs on olivine (up to 30 %), autoliths (up to 25 %), sedimentary rock xenoliths (up to 25 %). The bulk of the rock is replaced by serpentine-carbonate aggregate (Fig. 63). Porphyritic kimberlites with a low content of sedimentary rock xenoliths (3-5 %) were formed at the final stage of pipe development and are present at depths of 294-409 m. They are characterized by the presence of autoliths with increased content of phlogopite in the matrix.

The Eastern body is ellipsoid in plan, elongated in a northeasterly direction and dips at 80-90°. It consists of autolithic kimberlite breccia. Porphyry kimberlite relics occur within the diatreme selvage. Five kimberlite varieties are distinguished in the Eastern body, formed as a

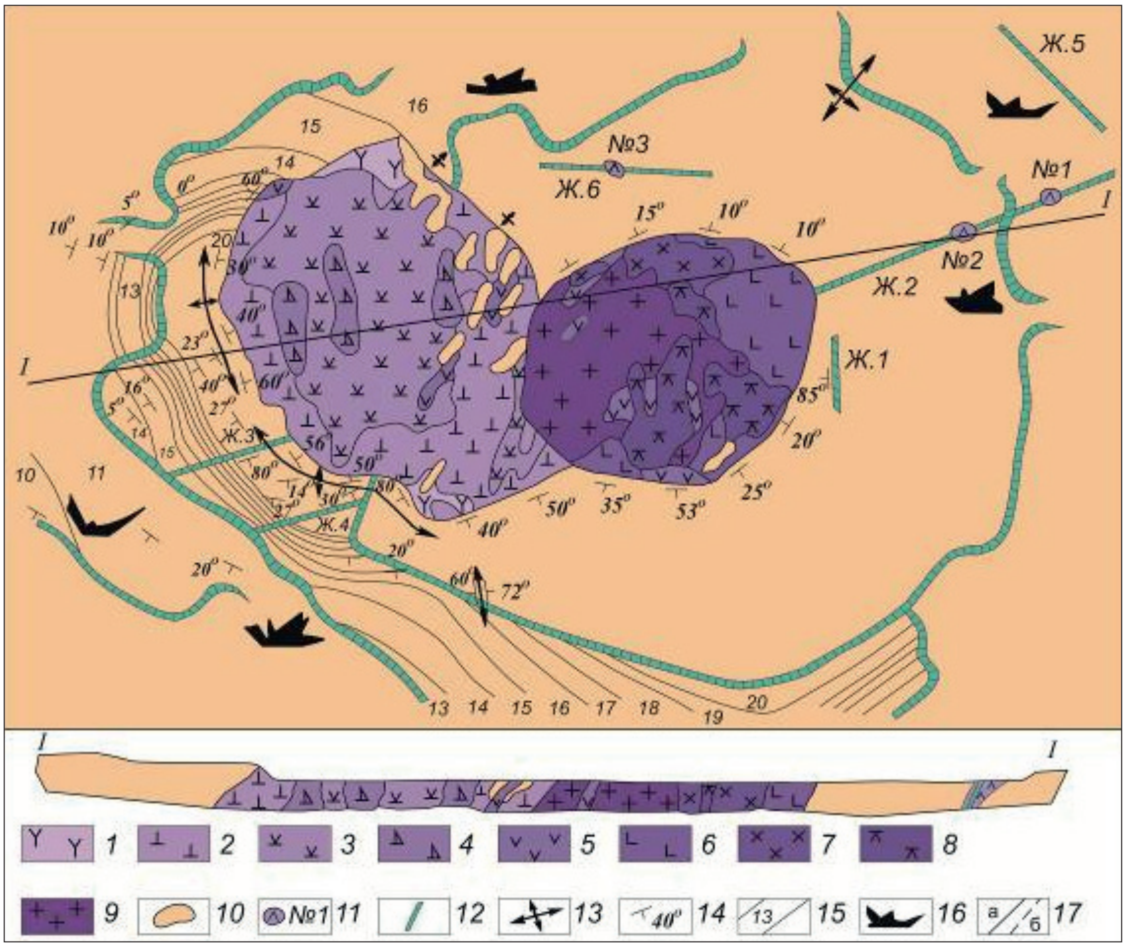

Figure 62: Schematic geological map and section of the Udachnaya kimberlite pipe (Gotovtsev, 1985). 1-9: Different kimberlite types of the Western (1-4) and Eastern (5-9) bodies; 10: Xenoliths of sedimentary rocks ("floating reefs"); 11: "Blind" kimberlite bodies; 12: Kimberlite dykes; 13: Fold axes and undulation directions; 14: Layer bedding; 15: Host rock layers and their numbers; 16: Fracture rose diagrams; 17: Layer boundaries: a) identified, b) estimated.

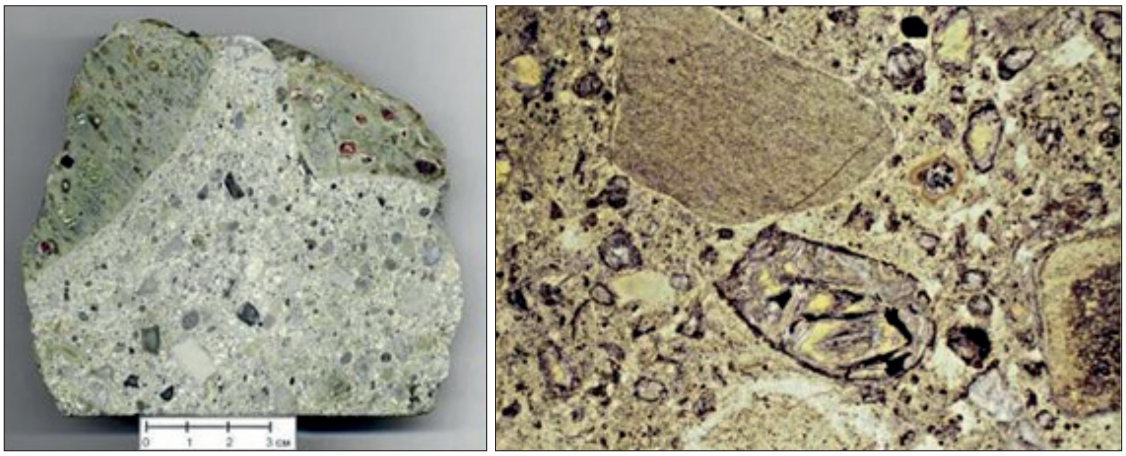

Figure 63: Photo of sample (a) and thin section (b) from the Western body of kimberlite breccia of "Udachnaya" pipe (without analyzer; viewing field 6.5 × 4.5 mm).

result of four injection phases: 1) Breccia with massive cement texture forming the upper pipe horizons to a depth of 400 m; 2) Autolithic breccia developed in marginal areas of the body below a depth of 350 m; 3) A subvertical stock-shaped breccia body in the central part of the pipe; 4) Breccia in near-contact areas, stretching for almost the entire explored depth of the pipe as a series of small, parallel subvertical injections; 5) A porphyry kimberlite dyke (Kharkiv, Zinchuk, Kryuchkov, 1998).

The content of deep-sourced xenoliths is higher in both bodies of the "Udachnaya" pipe, compared to kimberlites from other fields. In the Western body their average content is 0.1-0.3 %. The most common group (57.1%) of xenoliths are cataclastic garnet serpentinites (apolherzolite variety): Equigranular garnet serpentinites (apodunites, apoharzburgites, apolherzolites) amount to 31.1 %, while garnet-free (spinel apolherzolites) are present in a subordinate amount. Eclogite and pyroxenite are rare, not exceeding 6 %. Kyanitic, coesitic, chromium-pyropic and picroilmenitic varieties of eclogite xenoliths are found. Single grospydite xenoliths, including diamondiferous ones, alkremites (rocks of spinel - pyrope composition), pyroxenites with primary mica and other rare rocks are found. A large number of deep rocks with diamond-paragenesis minerals are discovered. The only primary minerals preserved in the deep-sourced xenoliths are garnet, picroilmenite, and chromite: the other minerals are replaced by aggregates of serpentine and chlorite.

The composition of the kimberlites, the grain size and the grade of the "Udachnaya" pipe diamonds have been studied in detail, based on data from the mined horizons in the upper part of the deposit. The price of 1 carat diamond of +0.5 mm class from the "Udachnaya" pipe deposit amounted in 2012 to US $ 65.5/carat. The largest diamonds found in the deposit are "Alexander Pushkin" – 320 carats, "The Power of the Soviets" –196.6 carats, "60 years of the Yakut ASSR" – 173.7 carats, "Academician Sakharov" – 172.5 carats.

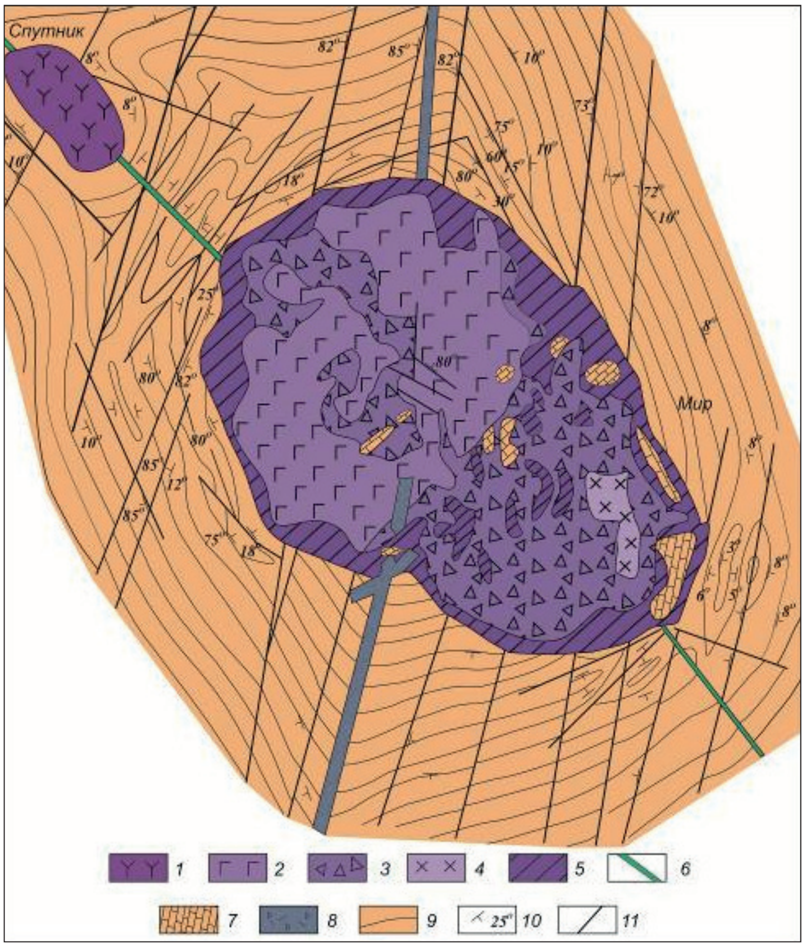

Figure 64. Geological structural diagram of the Mir and Sputnik pipes (Kharkiv, Zinchuk, Kryuchkov, 1998).
1: Sputnik pipe; 2–4: Mir pipe, kimberlites of the first - third injection phases, respectively; 5: Endocontact zone; 6: Kimberlite dyke; 7: Sedimentary rock xenoliths; 8: Crush zone with galena and sphalerite mineralization; 9: Carbonate country-rock layers uncovered by the open pit; 10:Attitude of sedimentary rocks and faults; 11: Faults.

"Mir" pipe deposit

The "Mir" kimberlite pipe is located within the Lesser Botuoba diamondiferous district of the East Siberian minerogenic province (Fig. 60). It was discovered on June 13, 1955 by geologists of the Amakinsky Expedition - Yu.I. Khabardin, E.N. Elagina, and V.P. Avdeenko. The rocks that host the "Mir" pipe are sub-horizontally bedded and of Cambrian age. The "Mir" pipe is confined to the approximately N-S-trending zone of the Parallel fault of the Vilyui-Markha group of regional tectonic faults. The pipe-shaped kimberlite is steeply plunging, and has a conical shape to a depth of 300 m (elevation +30 m), and becomes cylindrical in the depth interval of 300-900 m (elevation range of +30 m/-600 m). The body becomes markedly narrower in the depth range of 900-1,000 m and evolves into a subvertical kimberlite feeder dyke, about 300 m long and 25-30 m thick. The "Mir" pipe is composed of kimberlitic rocks formed as a result of a three-phase kimberlite magma intrusion.

Rocks of the different phases do not show significant variation in composition, physical and mechanical properties, or diamond grade. They include kimberlite breccias containing variable amounts of carbonate host rock and dolerite fragments. Their distribution in the pipe is uneven (Fig. 64).

Upper mantle xenoliths are widespread in the "Mir" pipe. Pyrope lherzolite prevails (Fig. 65); diamond-bearing ultramafite and eclogite are found and also relatively low-pressure pyroxenite, spinel and spinel-free ultramafite, mica pyroxenite and cataclastic varieties of these. Their distribution pattern in the pipe has not been determined. Inclusions of other minerals in the diamonds belong to ultramafic (99.45 %) and eclogitic parageneses.

Diamond recovery in the field began in 1957 by open-pit mining and continued for 44 years. The

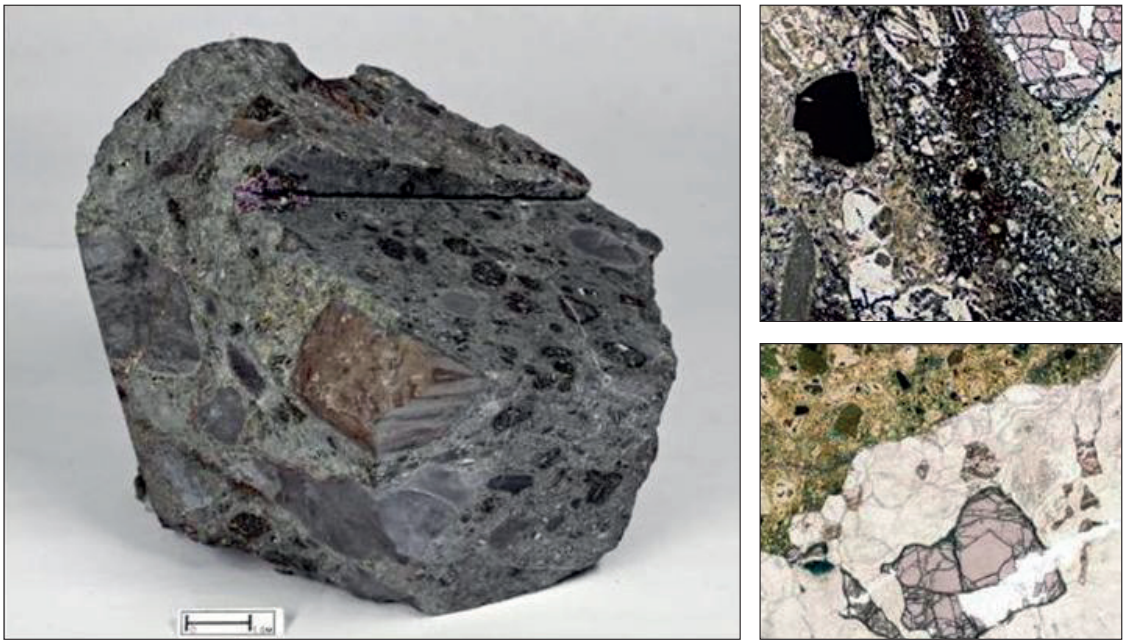

Figure 65: Photo of sample (a) and thin sections (b) of kimberlite breccia of the "Mir" pipe (without analyzer; viewing area of 12 × 15 mm).

open pit in the "Mir" pipe field is 525 m deep and 1.2 km in diameter. Open-pit mining of the diamondiferous kimberlite ceased in June 2001. According to exploration results, the depth of diamondiferous kimberlites in the field is more than a kilometre. "Alrosa" started underground diamond recovery in 2009. The diamond content of the "Mir" pipe is high, averaging above 3 ct/t. The diamonds are noted for their fairly high quality; the average price for diamonds from the deposit amounted in 2012 to US $ 94.96/ct. The diamonds include octahedra (61 %), rhombic dodecahedra (10 %), combinational forms (30 %), and cubes. Colourless stones are most common but brownish, bluish-green, smoky gray, and purple varieties also occur.

Studies of the diamond content in the pipe area and to a depth of 1,000 m have not shown any regular variations in their distribution in kimberlite ore. The largest diamond, "XXIV Congress of the CPSU" recovered at the "Mir" mine in 1980 weighed 342.5 carats. The reserves of the "Mir" pipe deposit in A+B+C1 grade are 139,558.9 Kct, in C_2 grade, 3,338.5 Kct.

"Internationalnaya" pipe deposit

The "Internationalnaya" kimberlite pipe lies within the East Siberian minerogenic province in the Lesser Botuoba diamondiferous district, 16 km SW of the "Mir" pipe (Fig. 60). The pipe was discovered in 1969 by A.G. Ivanov, V.F. Romanov, A.A. Gorbunov, I.N. Ivanov, V.N. Shchukin, A.A. Vasiliev, V.S. Mokeev, I.A. Pogudin, and M.I. Popov.

The kimberlite pipe is accompanied by a system of dykes and is overlain by a thin (up to 9.2 m thick) stratum of Lower Mesozoic sediments. The host rocks are Cambrian and Lower Ordovician sediments forming a monocline. The pipe is 0.4-0.5 km W of the axis of the ore-controlling Kyuellyakh fault. The pipe dimensions do not change significantly to a depth of 1,000 m. It is a funnel-shaped body to a depth of 125 m which evolves into a near-cylindrical body plunging steeply southeastwards. At the surface the pipe has an irregularly oval cross-section, elongated in northwesterly direction, with dimensions of 152 × 112 m. At the -560 m level, the dimensions of the pipe are 104 × 70 m, at the -690 m elevation, 99 × 68 m, and at the -820 m elevation, 92 × 62 m.

The upper horizons of the pipe comprise kimberlite breccias cutting massive porphyritic kimberlites. The kimberlite breccias contain, to a depth of 370 m, considerable amounts of wall rock (sediments). In general, the ore body is represented by autolithic kimberlite breccia (80 %) composed of round, oval kimberlite segregations of early-generation (lapilli) and porphyritic kimberlite varieties. The kimberlite rocks of the pipe are characterized by low contents of heavy minerals. Pyrope prevails over picro-ilmenite;

unaltered olivine, chrome diopside, and zircon are rare. In its content and the composition of deep-sourced minerals, the kimberlites of the pipe differ from the vast majority of the bodies in Yakutia.

The autolithic and porphyritic kimberlites are generally similar in terms of diamond grade, but the average grade is slightly higher in the porphyritic kimberlites. The average diamond grade decreases with depth.The diamonds that dominate in this deposit have an octahedral habit, with a low content of twinning, splices, and naturally stained crystals. The crystals have high clarity and the number of coloured crystals and stones with solid inclusions is low. As a result, the diamonds in the deposit are of high quality and value. In combination with the high diamond grade (average ca. 8 ct/t of ore) this makes the "Internationalnaya" pipe deposit globally unique in terms of diamond material value. The average price for diamonds from the deposit in 2012 amounted to US $ 145.72/ct. Balance deposit reserves in A+B+C_1 grade are 37,020.9 Kct, in C_2 grade, 12,303.7 Kct.

"Botuobinskaya" and "Nyurbinskaya" pipe deposits

The "Botuobinskaya" and "Nyurbinskaya" pipe deposits and related placers of the same names occur within the Middle Markha diamondiferous district and are confined to the Nakyn kimberlite field in the southern part of the East Siberian province (Fig. 60). The geology of the area is determined by its location in the central part of the Siberian Platform at the junction of the southeastern slope of the Anabar anticline and the Vilyui syncline. The "Botuobinskaya" kimberlite pipe was discovered in 1994. It is 3.3 km southwest of the "Nyurbinskaya" pipe. Open pit mining started in 2012. Ore and sand extraction should be launched in 2015. The "Nyurbinskaya" pipe was discovered in 1996. The "Nyurbinsky" open pit was commissioned in 2000 and as of 01.07.2013 its depth was 255 m.

The stratigraphic succession of the host rocks includes Upper Cambrian and Lower Ordovician strata, into which the kimberlites were emplaced. Some 60-70 m of Triassic and Lower and Middle Jurassic strata overlay the kimberlites. The kimberlites are confined to the intersection of the Vilyui-Markha and Middle Markha major fault zones. Palaeo-depressions and sink holes, mostly filled with unconsolidated sediments of Dyakhtar (Triassic-Lower Jurassic), age are common in the area of the primary deposits and the diamond content in the basal layers of the Ukugutian Formation of the Lower Jurassic is such that they are of commercial interest as placer diamond deposits.

The "Nyurbinskaya" pipe has a northeasterly strike and is confined to the axial line of the Dyakhtar fault. In plan view it has a rounded-ellipsoid shape. The dimensions of the upper part of the pipe (+190 m elevation) are 358 × 177 m, with an area of 41,700 m^2. The pipe width decreases significantly with depth and at -55 m elevation its horizontal intersection is 24,220 m^2, and at -200 m elevation, only 1200 - 1800 m^2. At a depth of 280-320 m below the surface, the pipe is divided into two ore bodies separated by a dyke-shaped mafic intrusion. The contacts of the pipe with its wall rock have a general dip of ca. 80° towards the central part of the pipe. Kimberlite injections up to 0.5 - 3 m thick occur along the contact of the pipe and into the wall rock. Residual weathering crust represented by altered breccias and clayey greenish-gray formations is observed in the upper horizons of the pipe.

The "Nyurbinskaya" pipe is the largest pipe within the Nakyn kimberlite field. It hosts three types of kimberlite: autolithic kimberlite breccias, kimberlite breccias comprising the main pipe volume, and porphyry kimberlites that have limited distribution in the deeper levels. Fine- to medium-grained clastic breccias in the central part of the ore body and carbonate kimberlite breccia in the near-contact zone of the northeastern and southwestern flanks of the pipe are distinguished among autolithic kimberlites. Autolithic breccias of the central part of the pipe consist of fine- to medium-grained porphyry rocks with an autolithic structure in the kimberlite cement. They are characterized by the presence of small amounts of wall rock debris, giving it the breccia texture. The content of xenoliths of metamorphic rock reaches 10 %. Xenoliths of mantle rocks are extremely rare (0.1 %) and are represented by fragments of garnet serpentinite and glimmerite. The heavy fraction of the kimberlite pipe, is dominated

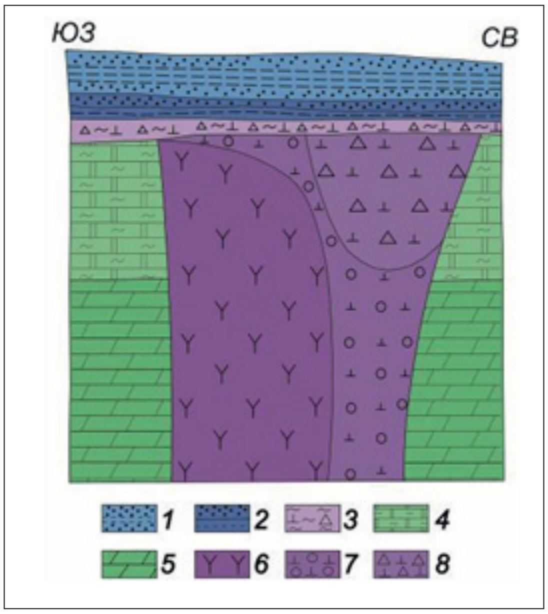

Figure 66: Schematic section of the Botuobinskaya" kimberlite pipe (Kharkiv, Zinchuk, Kryuchkov, 1998)
1: Overlapping Mesozoic rocks; 1: Mudstone, siltstone, sandstone of the Suntarian Formation; 2: Sandstone, siltstone of the Tyungsky and Ukukitsky formations, 3: Carbonate clay with debris of dolomite, kimberlite, Upper-Middle Triassic siltstone; 4-5: Host rocks: 4: Dolomite interbedded with conglomerate, limestone, and siltstone of the Olondonsky Formation, 5: Limestone, marl, dolomite with interbedded sandstone and mudstone of the Markha Formation; 6: Porphyry kimberlite of the first injection phase; 7: Autolithic kimberlite breccia (second phase); 8: Kimberlite tuff breccia (crater facies).

by pyrope and chrome-spinel, while picro-ilmenite, olivine, and clinopyroxene are rarer. These minerals are generally fine-grained, with a maximum dimension of 5 mm. The pipe has a high diamond grade; the average content in the reported reserves of the field exceeds 4 c/t. The diamonds predominantly show octahedral and transitional octahedral-rhombic dodecahedral crystals (up to 87 % of the total amount). 5-10 % of the diamonds are yellow-green crystals, rarely gray. The composition of the kimberlites, their grain size and diamond grade have been studied in full, based on data from mining of the upper horizon. According to the price list of the Ministry of Finance of the Russian Federation, the average price for 1 carat diamond in +3 nominal sieve class from the "Nyurbinskaya" pipe mine in 2012 was US $ 56.2/ct.

The "Botuobinskaya" pipe is a complex, paired kimberlite body. The field hosts two kimberlite phases: porphyritic, composing the dyke part of the pipe, and explosive autolithic kimberlite breccias of the second phase developed mainly in the vertical channel. Crater facies rocks are preserved in the upper part of the pipe (Fig. 66).

The diamond grade of the "Botuobinskaya" pipe is very high, averaging about 5 ct/t. The pipe contains many gem and near-gem quality crystals with a high transparency and low proportion of coloured stones. Fragmented crystals prevail but the quality of the stones is still high. The average price for diamonds from the deposit is US $ 72/ct.

Lomonosov diamond field

The Lomonosov diamond field lies within the East European minerogenic province, in the Arkhangelsk diamond subprovince, Zimny Bereg diamondiferous area. The discovery in the early 1980s of a new diamondiferous kimberlite subprovince in the north of the European part of Russia (100 km NE of Arkhangelsk) was the result of a systematic study of the geological structure of the region, started by Arkhangelsk geologists in the early 1960s. In 1978, an airborne magnetic survey was conducted, promising anomalies were distinguished and test drilling intersected a large number of diamond-bearing pipes, including commercial ones, forming individual fields (Fig. 67). The pioneers in exploration of the Lomonosov diamond field, which comprises six high diamondiferous kimberlite pipes, were A.F. Stankovsky, E.M. Verichev, K.N. Sobolev, A.V. Efimov, V.P. Grib, V.A. Medvedev, V.A. Larchenko, Yu.G. Konstantinov, L.P. Dobeyko, S.P. Aleksandrov, V.S. Fortygin, G.Z. Grinevitsky, V.A. Lyutikov, R.S. Kontorovich, and G.M. Levin.

The kimberlite magmatism of the Arkhangelsk sub-province is associated with the Middle Palaeozoic tectonomagmatic activation of the East European province. The reserves of the district, which hosts the kimberlite pipes "Arkhangelskaya", "Karpinsky-1", "Karpinsky-2 ", "Lomonosov", and "Pionerskaya", were estimated in 1987.

Structurally, the field is within the Tovsky block of the crystalline basement (Arkhangelsk diamond province, 1999) and is characterized by a linear-chain arrangement of pipes in the area of a N-S trending deep fault. The total length of the pipe chain is 14 km and the distance between the individual pipes varies from 100 m to 2.5 km. The pipes give weak magnetic anomalies with

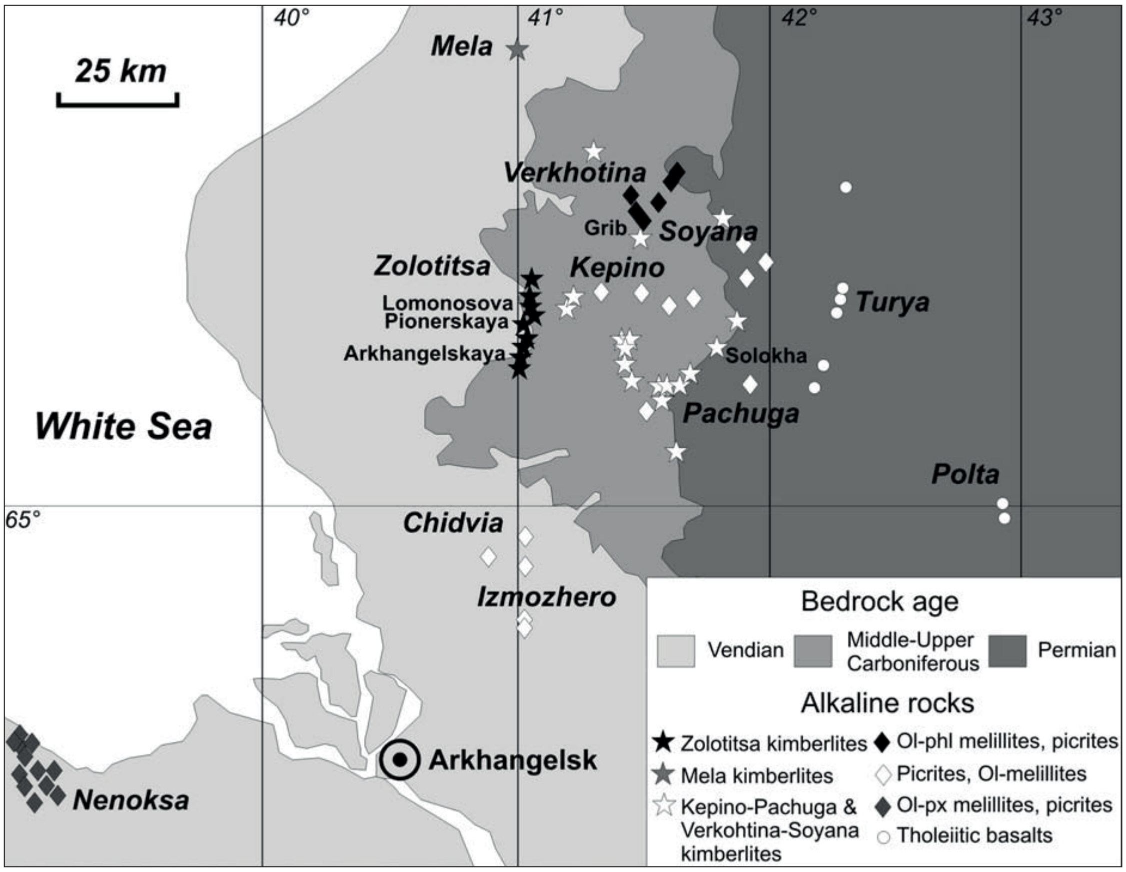

Figure 67. Distribution of kimberlites and other alkaline complexes in the Arkhangelsk diamond province (Lehtonen et al., 2009).

intensities from 15 to 50 nT. They intrude into Upper Vendian terrigenous sedimentary rocks. Isometric subsidence troughs exceeding the pipe area by 6-8 times are observed around the pipes in the top Vendian strata (Erinchek et al. 1997). The average thickness of the overburden layer varies from 28.3 m ("Arkhangelskaya" pipe) to 54.5 m ("Lomonosov" pipe).

Each pipe consists of a feeder channel, which, in the case of the "Arkhangelskaya", "Karpinsky-1", and "Pionerskaya" pipes is overlapped by crater facies. The "Arkhangelskaya", "Karpinsky-1", and "Lomonosov" pipes are almost circular in plan view, while the "Karpinsky-2" and "Pionerskaya" pipes are elliptical (Fig. 68). The thicknesses of the crater facies range from 72 m ("Karpinsky" pipe) to 123 m ("Arkhangelskaya" pipe) (Verichev, Garanin, Grib et al., 1991).

The age of the kimberlite, determined both from geological data and from the age of carbonized wood from xenoliths in the kimberlite breccia, corresponds to the Middle Palaeozoic. The diatremes are composed of rocks of crater, vent, and hypabyssal facies. Rocks of the crater facies are represented by tuff, tuffite, tuff sandstone and tuff siltstone, and sedimentary breccia in the near-contact parts. The rocks are composed of saponite pseudomorphs on olivine and autolithic lapilli (10-20 %), but mostly of wall rock and individual quartz grain fragments.

Vent facies formations are represented by xeno- and tuff breccias. Rock textures are brecciated; lapilli proportions vary from 10 to 60 % and are unevenly distributed in the rock. Wall rock fragments are up to 20 cm in size (Fig. 69). Lapilli are represented by crystal-clasts of altered olivine and spherical autoliths and xenoliths of the enclosing rocks. Porphyritic impregnations are represented by megacrysts and phenocrysts of altered olivine and rare phlogopite. The matrix consists of fine aggregate of the same components, with an abundance of xenogenic quartz grains cemented by cryptocrystalline aggregates, which include saponite, illite, carbonate, chlorite and iron hydroxides (Lukyanov, Lobkova, Mikhailov et al., 1994).

Mantle rock xenoliths are rare and intensely altered (Sobolev, Pokhilenko, Grib et al., 1997). Autolithic breccias of the vent facies consists of a variable content of lapilli with megacrysts

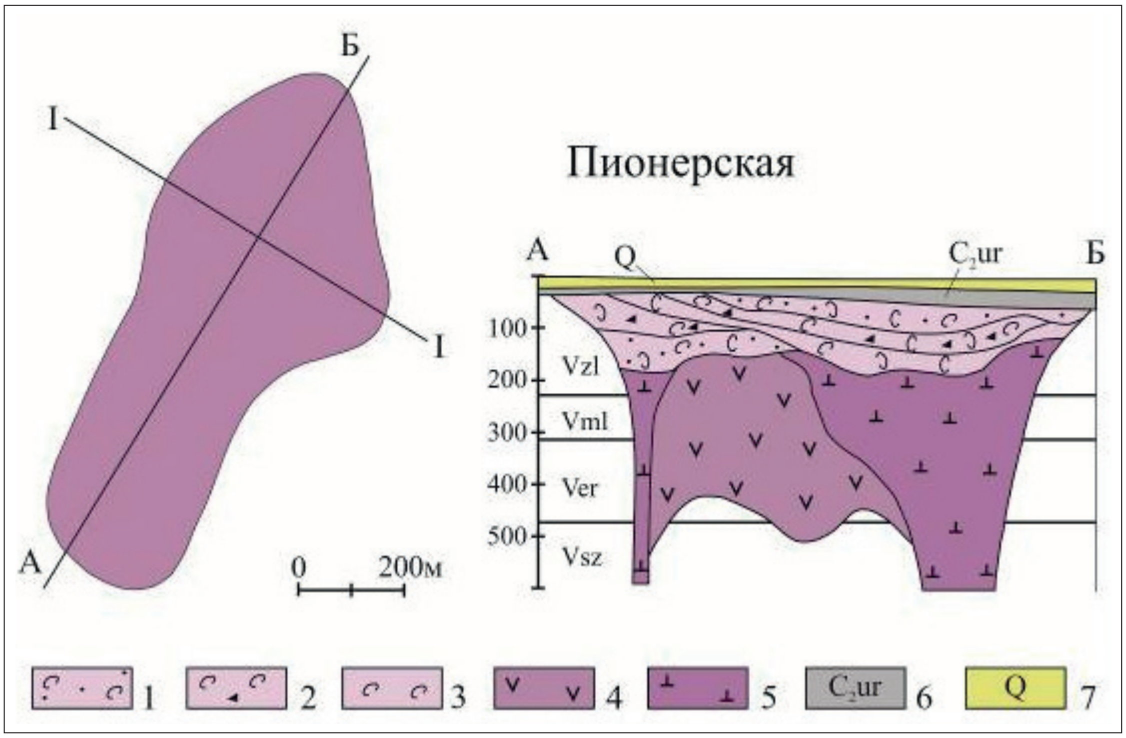

Figure 68. The geological structure of the "Pionerskaya" pipe (Verzhak, Garanin, 2005) **1-3: Crater facies**: 1: Tuffaceous sedimentary strata composed mainly of tuff sandstone with interbedded tuff siltstone; 2: Tuff breccia of enclosing rocks; 3: Tuffaceous strata. Sandy tuff. **L4-5: vent facies**: 4: lithocrystalline tuffisite breccia (tuff- and xenotuff breccia) of the I-st injection phase; 5: Autolithic tuffisite breccia of the II-nd injection phase; 6: Carboniferous deposits; 7: Quaternary deposits.

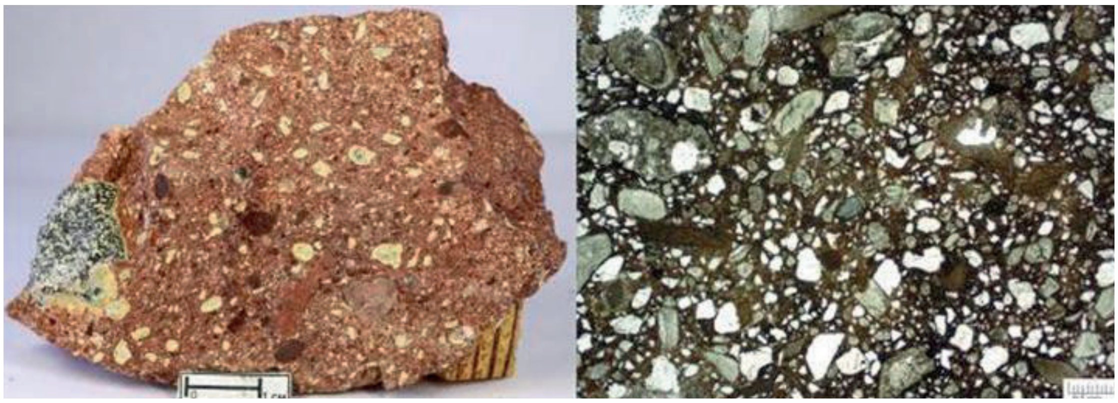

Figure 69. Photo of sample (a) and thin section (b) of kimberlite xenotuff breccia from the "Pionerskaya" pipes (without analyzer; viewing area of 5 × 4.5).

of altered olivine and spherical autoliths. Mantle xenoliths and rocks from the basement and sedimentary cover are rare. All of these components vary greatly in abundance in different parts of the pipes and in the various pipes. In some cases (e.g. at a depth of 800 m in the Pionerskaya pipe) autolithic breccias grade into massive porphyry kimberlite. The pipe's roots consist of rocks of the hypabyssal facies composition, represented by porphyritic and aphanitic kimberlites. Typical porphyry kimberlite consists of elliptical megacrysts (size up to 10 mm, over 30 %) and olivine impregnations (grain-size <1.5 mm, up to 30 %) embedded in a groundmass composed of olivine microlites, phlogopite laths, fine-grained oxide, calcite microlites, and a matrix of crypto-crystalline serpentine-chlorite aggregate.

The diamond crystals are usually gray or with a gray flash (42 %). The proportion of colourless diamonds is 39 %. Coloured (black, yellow, green-gray, brown) crystals and those with different shades account for 19 %. More than 50 % of the crystals are transparent. The proportion of opaque diamonds is 15 %, that of splices 21.5 %, of crystal fragments 11.8 % and twinned crystals 10 %. Forty percent of the crystals are fractured. The proportion of isometric crystals is 35 %, while 25 % are deformed.

Lomonosov GOK, the production enterprise of the Open Joint Stock Company "Severalmaz", is currently developing the "Arkhangelskaya" and "Karpinsky-1" pipes. Open pit mining was initiated on the "Arkhangelskaya" pipe in 2005. The surface dimensions of the quarry are 1.16

Kimberlite pipe	JORC Code Category	Ore weight (Kt)	Diamond Grade +3 nominal sieve class (ct/t)	Contained Diamonds +3 nominal sieve class (Kct)
Arkhangelskaya	Probable	57, 087	0.76	43,189
Karpinsky -1	Probable	18,438	1.13	20,918
Total probable reserves		75,525	0.85	64,107

Table 6: Ore reserves of the Lomonosov field (Report: "Micon International Co Limited", 2013).

km × 1.12 km, and its depth is currently 110 m. Stripping operations began at the "Karpinsky-1" pipe field in 2010. Currently, the quarry depth is 90 m; its surface dimensions are 830 m × 500 m. The "Karpinsky-1" quarry is scheduled for full production capacity (2 Mt/a) in 2015.

V. Grib diamond field

The V. Grib diamond field consists of a single kimberlite pipe located within the Arkhangelsk diamond subprovince. It was discovered in 1996. It is located in the centre of the Zimny Bereg diamondiferous area, 30 km from the Lomonosov diamond field (Fig. 67). Diamondiferous kimberlites were uncovered by drilling in the area of a magnetic anomaly with an intensity of 15 nT. 150 diamond microcrystals were found in the kimberlite core after thermochemical digestion. The pioneers in this field are A.N. Buyun, E.M. Verichev, N.N. Golovin, A.A. Zaostrovtsev, V.F. Kurushin, and V.I. Sotnikov.

The kimberlite pipe intrudes weakly lithified Vendian terrigenous sediments; it is covered by Early Carboniferous rocks and Quaternary deposits with a total thickness up to 70 m. The pipe show features typical for weakly eroded pipes, with a clearly manifested crater and vent components. Its diameter is 1.6 km (Fig. 70).

The petrographic composition of the crater facies is defined by the ratios of magma, silty-sandy material and xenoliths of the enclosing terrigenous rocks. The magmatic material in it, unlike the vent, is significantly altered. The cement is iron-clayey, carbonate, or saponite. The vent part of the pipe is composed of rocks of two injection phases – tuff- and xenotuff breccias gravitating towards the southern part of the pipe and massive kimberlites of a later injection phase. The kimberlites are characterised by a lithoclastic, psammitic to fine-psephitic structure and massive texture. The crystalloclasts are of olivine or olivine pseudomorphs. Olivine of the first generation (38-46 %) is generally 1-4 mm in size (up to 2.5 cm) and has a rounded shape. Olivine of the second generation (2 %) is represented by idiomorphic crystals 0.1-0.8 mm in size.

Cystalloclasts of pyrope, pyrope-almandine, ilmenite, phlogopite, and clinopyroxene do not

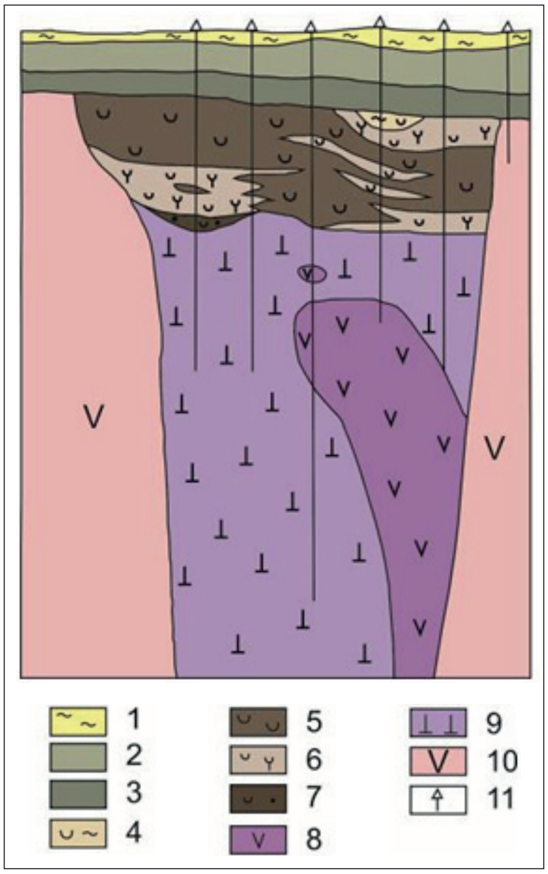

Figure 70: Schematic section of the Grib kimberlite pipe (Arkhangelsk diamond province, 2000). 1: Quaternary deposits (loam, sand); 2: Carboniferous limestone, dolomite; 3: Urzugian Formation sandstone; 4-7: Crater facies rocks: 4: Clayey sand; 5: Tuff sandstone; 6: Tuff and tuffite; 7: Host-rock breccias, conglomerates with tuff and tuffite inclusions; 8-9: Vent facies rocks: 8: Tuff-xenotuff breccias; 9: Kimberlite; 10: Vendian host rocks; 11: Drillholes.

Object	Compo-nent	Units of ore measure	Units of comp. measure	Ave. grade	Units of ave.grade measure	ABC1 (ore)	ABC1 (com)	C2 (ore)	C2 (com)	Off-balance (ore)	Off-balance (com)
V. Grib pipe	Diamond	Kt	Kct	1.245	ct/t	56,677	70,581	19,395	14,614	33,379	12,473

Table 7: Reserves at V Grib pipe as of 01.01.2014.

exceed a total of 4 %. Lithoclasts (10 %) are represented by nucleated, zoned autoliths of oval shape and 1-30 mm in size. The autolith structure is porphyritic: second generation olivine impregnations make up 25-30 % of the autolith volume; phlogopite, not exceeding 5 %, is represented by fused laths. Oxides in the autolith matrix are perovskite, titanomagnetite, chrome spinel, and ilmenite. Xenogenic material (3.1 %) includes fragments of mudstone, siltstone, and plutonic rocks. The dimensions of the latter sometimes reach 20 cm. Granulite and eclogite-like rocks are most common, while pyrope and ilmenite, as well as various altered phlogopite rocks are rare. Mantle rocks are dominated by pyrope-bearing dunite and lherzolite; less common rocks are olivinite, pyrope-bearing clinopyroxenites and websterites. The rock cement (30-40 %) is composed of serpentine with a small carbonate admixture. The kimberlites in the V. Grib pipe differ from the Zolotitsa field kimberlites in their high content of kimberlite indicator minerals and in the predominance among them of picroilmenite, garnet, and clinopyroxene and lesser amounts of chrome spinel.

Diamonds from the V. Grib pipe are characterised by a large proportion of high clarity stones (80% of the total). The diamond crystals are predominantly octahedral (37 %); dodecahedral crystals (26 %), and crystals of transition type O - D (26-20 %). Assessment and approval of the reserves was carried out in 2005 and additional exploration was completed in 2010. Currently the diamonds are being mined by open pit methods; the depth of the pipe revealed by the pit is 136 m.

PLACER DIAMOND DEPOSITS

"Solur-Vostochnaya" placer diamond deposits

The"Solur-Vostochnaya" placer deposit is located in the East Siberian minerogenic province. It consists of two ancient, spatially separate, buried deposits "Solur" and "Vostochnaya" located in the area between the Irelyakh and Chuonalyr rivers, 25 km NW of the town of Mirny. The deposit area is 15.18 km². The deposits were discovered during prospecting work undertaken by the Botuoba Expedition in 1979 and 1989, respectively. In 1981-2005, exploration and reserve estimation work was completed on the deposits.

The sedimentary formations which host the diamond-bearing primary deposits in the area are terrigenous-carbonate rocks of the Vendian-Upper Cambrian periods. The overlying terrigenous deposits of the Upper Palaeozoic, Mesozoic, and Cenozoic host the diamond placers. Rocks of the Middle Palaeozoic kimberlite formation, belonging to the Mirny field, are situated to the southeast (12 km) and east (20 km) of the "Solur - Vostochnaya" placer deposit. They form a series of kimberlite pipes and bodies, including the "Internationalnaya" and "Mir" pipes (described above). The pipes are characterized by a high diamond grades and are the main sources for the Upper Palaeozoic and Mesozoic alluvial deposits within the area.

The "Solur-Vostochnaya" field consists of two spatially separate but contiguous buried strata; the Middle Carboniferous "Vostochnaya" strata and the Mesozoic "Solur" strata. "Vostochnaya" strata are localized within the Ottursky valley-like palaeodepression with a northwesterly strike, 5 km in length and 1-2 km wide. The "Solur" Early Jurassic strata are controlled by the smaller Solur palaeodepression with a southeasterly strike.

The "Vostochnaya" deposit, with its alluvial genesis, is located within the coarse clastic basal horizon of the Middle Carboniferous Lapchanskian Formation. The economic circumference is 4.6 km. The productive mantle-like horizon varies in thickness, from 0.1-1.9 m, averaging 0.68 m. The lithological composition of the layer includes conglomerate, pebbles, sand and sandstone with admixed gravel and pebble material, clayey sand, sandy siltstone with gravel and clayey siltstone. The thickness of sediments overlying the productive layer in the "Vostochnaya" deposit varies from 12-58 m, averaging 47.7 m.

The "Solur" deposit, with its alluvial genesis is confined to the basal level of the Lower Jurassic Yulegir Formation. Upper Cambrian terrigenous-carbonate rocks commonly form the placer basement. The thickness of the productive layer varies from 0.5 to 5.1 m, with an average of 2.35 m. The productive layer is mainly confined to the basal alluvial pebble-rich bed with interbeds and lenses of gravelite, clayey sand and sandstone, siltstone and silty clay. The rocks of the productive layer are poorly lithified. The thickness of the sediments overlying the "Solur" deposit is 5- 54 m, averaging 41.7 m.

In the "Vostochnaya" placer the content of diamonds in individual samples varies from 0.0 - 99.29 ct/m^3, with an average of 3.01 ct/m^3 for the deposit as a whole. The diamond distribution is irregular; enriched areas are found mainly associated with the conglomerates in the central part of the deposit. The diamond content of the "Solur" placer is considerably lower, with samples varying from 0.0-10.12 ct/m^3, with an average of 1.0 ct/m^3. Diamonds from the two areas are similar. The dimensions of the diamonds in both placer deposits vary widely, but diamonds of -4 +2 mm and -2 +1 mm classes predominate: their total amount, in general over the field, is 94.7 %. -4 +2 mm class is dominant by weight; its content in general over the placer field is 66.4 %. The average weight of 1 crystal in +1 mm class over the Vostochnaya deposit is 17.1 mg, in the "Solur" deposit as a whole, 20.3 mg (Fig. 71).

The habit and morphological character of the diamonds from the "Solur-Vostochnaya" deposit are identical to those of the "Mir" pipe and the "Vodorazdelnye Galechniki" placer. 34 % of the "Solur-Vostochnaya" field diamonds have

Figure 71. "Solur" placer diamonds (Grakhanov, Shatalov, Shtyrov, 2007).

gem quality. The price of 1 carat diamond of +1 mm class from the "Solur-Vostochnaya" placer amounted to US $ 96.18/carat. The Balance reserves in $A+B+C_1$ grade are 15 903.2 Kct and in C_2 grade 864.7 Kct.

Ebelyakh River and Gusiny Stream placer diamond deposits

The Ebelyakh diamond area, covering the Gusiny Stream placer deposit is located in the Anabar-Olenek diamondiferous region, in the East Siberian minerogenic province, in the northeastern margin of the Siberian Platform, at the junction of the Anabar anticline and the Lena-Anabar deflection. The area was discovered in 1965. The pioneers in finding these placer deposits were the geologists of the Amakinsky Expedition, Yu.P. Belik, S.A. Grakhanov, L.M. Zaretsky, V.M. Kunitsky, Y.A. Lomakin, V.M. Podchasov, and M.A. Chumak.

The area is represented by terrigenous-carbonate and volcanic rocks of the Middle Cambrian, Carboniferous, Permian, Triassic, Jurassic and Cretaceous, as well as polygenetic unconsolidated sediments of Cenozoic age. Diamonds are found within terrigenous rocks from the Permian, Jurassic and Lower Cretaceous periods in the weathering crusts and in all unconsolidated formations of Neogene to Quaternary age. (Grakhanov, Shatalov V.I., Shtyrov V.A., et al., 2007).

The Ebelyakh River placer covers the river valley section stretching for 83 km from its mouth. The valley cuts through Middle Cambrian carbonate rocks, which are represented by dolomite of the Anabar Formation and limestone of the Dzhakhtar series. The depth of the valley with respect to the watershed averages 100 m, varying from 110 m near the mouth to 80-90 m in the upper reaches of the river. The valley slopes are terraced in the lower and upper reaches of the river; but are virtually absent in the central section.

The diamond field is a large alluvial placer; its economic circumference includes the sediments of the river bed, lower and upper plains, four flood-plain terraces, and redeposited weathering crusts. The commercial placer has a length of 82 km. Its width averages 78.6 m, varying from 50 to 345 m. According to the conditions, occurrence, size and degree of continuity of the stratum, and the distribution of the commercially valuable sections, the deposit can be divided into two areas: the valley and the terraces. The valley areas of the deposit have relatively continuous widths and thicknesses with relatively flat-lying sediments with a shallow dip. The distribution of diamonds is highly variable. Terrace placer areas have been formed from fragments of previously large, partially eroded placer deposits. These are characterized by relatively continuous widths and thicknesses, within which relatively broad zones can be distinguished as having low diamond grades. The main lithologies forming the river bed and upper and lower plains are pebble-gravel-sandy sediments, silts with pebbles and rock debris. The diamond-bearing layer in the terraces consists of pebble-gravel-sandstone sediments, boulder-pebble-gravel formations and alluvium underlain with redeposited weathering crusts. The bedrock of the alluvial complex in the Ebelyakh River valley is composed of either carbonate rocks from the Middle Cambrian or of weathering crusts.

Based on the occurrence of the diamond-bearing horizon, size, discontinuity, granulometric composition of diamond-bearing layers, regularity of diamond distribution, the following three sections of the Ebelyakh River placer deposit can be distinguished: "Priustyevoy" (Confluence area), "Nizhny" (Lower area) and "Verkhny" (Upper area). The average diamond grade within the Ebelyakh River placer deposit varies along the exploration lines from 0.28 to 7.82 ct/m^3, while along the selected estimated blocks the variation is from 0.22 to 5.91 ct/m^3. The average value across the deposit is 1.34 ct/m^3.

Gusiny Stream

The Gusiny Stream placer deposit is genetically related to the alluvial sediments. The economically mineable portion of the placer extends for 8.7 km. Its width along the trend of the deposit varies from 42 - 262 m, with an average of 128 m. The thickness of the diamond-bearing layer is quite uniform, on average 2.20 m. It is covered by a 2.2 m thick peat layer. Two sites are distinguished within the alluvial deposit, the "Verkhny" (Upper) site and the "Nizhny" (Lower) site. These are characterized

Grade	Balance reserves			Off-balance reserves		
	Sands (k m^3)	Grade +2 mm (ct/m^3)	Contained Diamonds +2 mm (Kct)	Sands (km^3)	Grade +2 mm (ct/m^3)	Contained Diamonds +2 mm (Kct)
Ebelyakh River placer						
B	2,436	1.55	3 784	-	-	-
C_1	13,396	1.46	19 494	585	0.37	218
B + C_1	15,832	1.47	23 278	585	0.37	218
C_2	3,800	0.76	2 885	1,416	0.34	485.1
Gusiny Stream placer						
B	804	1.35	1 088	-	-	-
C_1	1,743	1.37	2 383	90	0.37	33.3
B + C_1	2,547	1.36	3 471	90	0.37	33
C_2	1	4.53	2.9	86	0.45	38.4

Table 8: The balance reserves of the Ebelyakh River and Gusiny Stream deposits as of 1.01.2013 ("Micon International Co Limited". 2013).

by different diamond contents, thickness of the diamond-bearing layer, width of the commercial circumference and the stripping ratio. The average diamond grade within the Gusiny Stream placer deposit varies along the exploration lines from 0.38 to 2.40 ct/m^3: block grades vary from 0.74 to 1.87 ct/m^3 and the average value for the whole deposit is 1.364 ct/m^3.

About 170,000 diamond crystals with a total weight of 17.74 Kct were extracted in the process of geological and exploration work within the Ebelyakh River, Gusiny Stream, and Yraas-Yuryakh Stream (another tributary of the Ebelyakh River) area. Studies of the crystals revealed that the size of diamonds from the Ebelyakh River placer deposit varies from fine crystals to large stones in excess of 20 ct. The "Priustyevoy" site (Confluence area) is characterized by larger diamonds. Generally the size of the diamonds in the deposit gradually decreases upstream relative to the Ebelyakh River. Study of the typomorphic properties of the diamonds within the Ebelyakh River placer deposit have shown that they are different from the diamonds of the Daldyn-Alakit and Lesser Botuoba kimberlite areas.

Industrial-quality diamonds are predominant. The content of gemstone diamonds (category I) comprises only 6.55 % of the total. The deposit is characterized by low-integrity diamonds; their average value is US $ 49.88/ct.

IMPACT DIAMOND DEPOSITS

Impact diamond deposits of the Popigai area

Primary and placer impact diamond deposits are found in the Popigai diamondiferous area, within the East Siberian minerogenic province, on the northeastern margin of the Anabar Shield of the Siberian Platform. The source of the diamonds is rocks within the large, ancient Popigai meteorite crater (Fig. 72)

In 1971-1987 and later, a comprehensive study of the Popigai structure was undertaken by VSEGEI experts, geologists of the Kotui Party and Polar Exploration Expedition PGO "Yakutskgeologiya". The discoverer of the

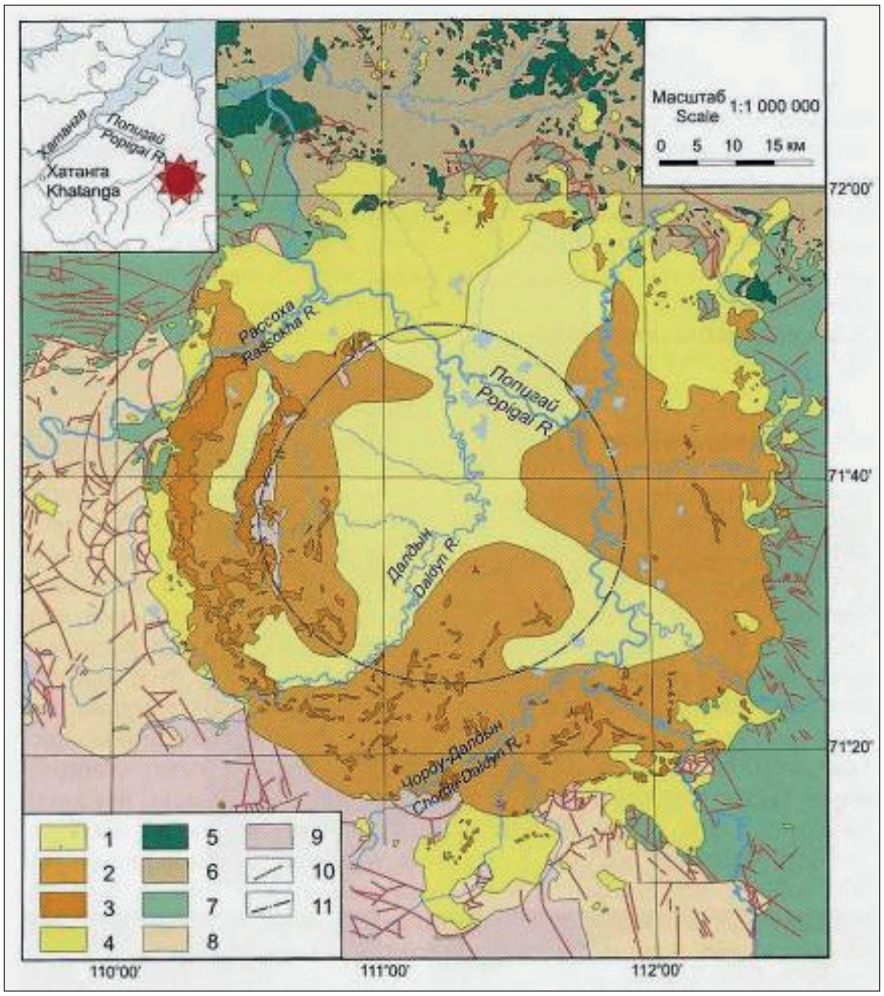

Figure 72. Schematic geological map of the Popigai impact crater (V.L. Masaitis et al., 2004). Legend: 1- 4: Coptogenic (impact) complex; 1: coptoclastites, 2: suevites, 3: tagamites (impact melt rocks), 4: polymictic allogenic megabreccias, 5: Early Triassic dolerites, 6: Permian sedimentary rocks, 7: Cambrian sedimentary rocks, 8: Late Proterozoic sedimentary rocks, 9: Archaean metamorphic rocks, 10: Faults, 11: Axis of circular high.

deposit was V.L. Masaitis (VSEGEI). Prospecting with bedrock sampling for diamonds, a geological survey at 1: 100,000 scale with detailing mapping at 1:50 000 scale in certain areas and test drilling were carried out. The exploration included drilling to depths generally of 200-500 m, with a maximum of 1.5 km, accompanied by core and process sampling (Masaitis, Kirichenko, Mashchak et al., 2013).

The Popigai impact structure (diameter 100 km) resulted from an asteroid impact approximately 35.7 million years ago. Rocks of the basement (various gneisses and schists) and the cover of Late Proterozoic – Mesozoic sediments with total thickness of about 1 km, including graphite-bearing horizons, became the target for the asteroid. The internal astrobleme structure is characterized by the presence of a central depression, a circular elevation of the crystalline basement, and a ringshaped trench surrounded by a zone of deformed rocks. The depression and trench are filled with different impact breccias and impactites. Impact breccias and impactites are also developed in small areas outside the crater.

Impactites were formed by impact metamorphism and gneiss melting, as well as by intrusion of the melt. Graphite underwent polymorphic transition to diamond due to quasi-hydrostatic compression above 35 GPa. Diamondiferous impactites are represented by two varieties – tagamites and suevites. Impactites are exposed on the surface within an area of approximately 1,140 km^2; the total area of their development is approximately 3,500 km^2 : diamonds are ubiquitous in this area. Diamond-bearing impactites occur as thick (up to 600 m), extensive (up to 10-15 km) sub-horizontal and lenticular bodies; smaller irregular bodies tens of metres thick are also present.

Unconsolidated Pliocene - Quaternary sediments are widespread, serving as intermediate accumulators for placer deposits. Primary deposits of the Popigai structure are represented by the Udarnoe and Skalnoe fields. The Udarnoe deposit is located in the NW sector of the Popigai structure; covering an area of 8.3 km². Tagamites form tabular bodies from a few tens to >100 m thick and rarely also small lenticular bodies of irregular shape in allogenic monomictic breccia of crystalline rocks. Massive tagamites are widespread. Ataxite (iron meteorite) and porous impact melt are less frequent. Suevite forms a single thick tabular body covered by tagamites: its average thickness is 63 m (up to 264 m), increasing from south to north.

The proven area of productive impactite strata is 7.66 km², its thickness varying from 368.9 to 97.7 m, increasing from the southeast to the northwest. The strata comprise three ore horizons differing in material composition and diamond content: upper tagamite, suevite, and lower tagamite. The vast majority of the tagamite horizon is composed of massive rocks 110.9 m thick; suevites occupy only an insignificant volume (4 %). The diamond content in the productive series is from 2.20 - 21.64 ct/t in individual drillholes and, relative to reserve estimation blocks, from 2.63 - 13.64 ct/t. The average content of the deposit in reserve estimates is 7.6 ct/t, of which in tagamites - 9.5, and in suevites - 6.6 ct/t. The cover of eluvial-deluvial deposits with an average thickness of 3.8 m is rich in diamonds - 8.43 ct/t. 90 % of the diamonds are light-coloured varieties (Fig. 73).

The Skalnoe deposit in the southwestern sector of the crater has dimensions of 13×6.5 km and covers an area of about 85 km². It covers the SW slope of a circular high within a ring trench. Impact metamorphosed and cataclastic gneisses of authigenic breccia traced by drillholes to a depth of 900 m are exposed in the axial part of the high. In the SW part of the deposit gneisses are covered by thick lenses of different allogenic breccias cemented by suevites and tagamites: their thickness exceeds 1 km. A flat-lying tabular tagamite body, associated with the highest diamond contents, is traced in the northeastern part of the deposit. The diamond content in the field varies laterally and with depth. Tagamites contain an average of 17.3, and suevites 11.5 ct/t. Marginal (near-roof) parts of tagamite beds are usually enriched in diamonds, the content reaching 24.5 ct/t; rich ore is available for open-pit mining. Light-coloured diamonds amount to approximately 85 %.

Impact diamond placers

Impact diamonds in unconsolidated Pliocene-Quaternary sediments are identified as different genetic types in the entire area of the Popigai impact structure and in close proximity to it. The advantage of placers over primary deposits is their higher content of coarse diamond fractions, their greater hardness, as well as cheaper technology for extraction. The diamond content of alluvial deposits in the Popigai basin has been determined for the alluvium in all the river systems. The highest concentrations of impact diamonds in eluvial-deluvial sediments (in some samples up to 166 c/m³) are found in the Skalnoe and Udarnoe deposits. The diamond reserves in the Udarnoe deposit are estimated in $B+C_1+C_2$ grades and amount in total to more than 12 Gct (Giga carat) with a ratio of grades, respectively, of 1:2:3. In the Skalnoe deposit area, commercial high-grade reserves amount to approximately 150 Gct. Inferred resources in P1 grade for the Syuryunge, Vstrechny and Tongulakh sites, etc. amount to 50 Gct.

Proven reserves and inferred resources of impact diamonds in bedrock in the total area of approximately 120 km² in Popigai area amount to 212 Gct. The total number of diamonds in an impactite layer 50 m thick in the rest of the area (about 1,020 km²), in addition to the deposit areas and prospects, are assessed to be about 150 Gct. Reserves and resources of placer impact diamonds are very significant: The diamond reserves of the Popigai astrobleme exceed the diamond reserves of all other diamondiferous provinces in the world.

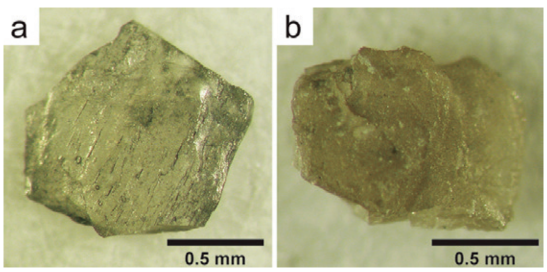

Figure 73. Impact diamonds collected from the Popigai impact structure (Ohfuji et al. 2015).

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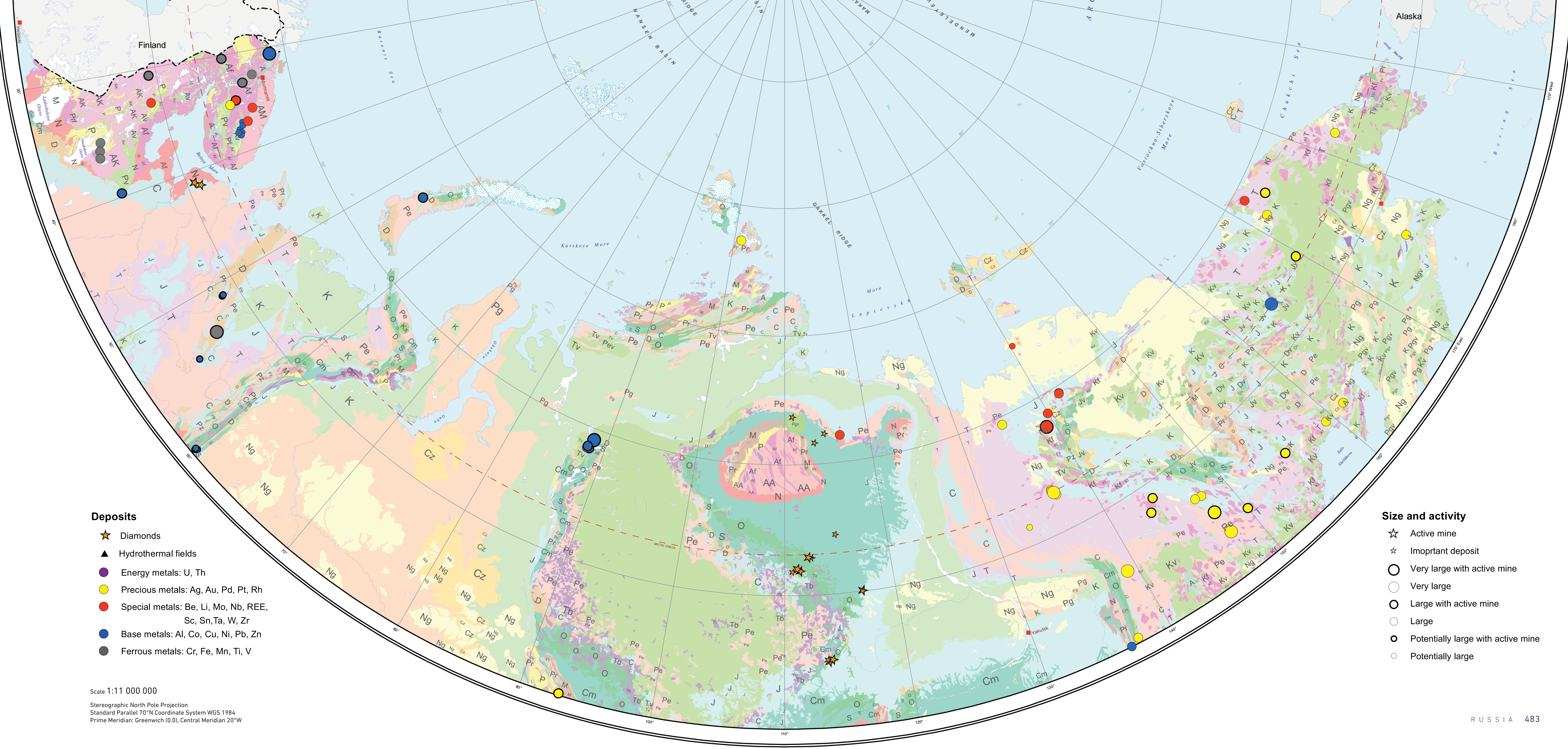
Finland
Alaska
Karskoye More
ARCTIC CIRCLE
Yakutsk
Deposits
Diamonds
Hydrothermal fields
Energy metals: U, Th
Precious metals: Ag, Au, Pd, Pt, Rh
Special metals: Be, Li, Mo, Nb, REE, Sc, Sn,Ta, W, Zr
Base metals: Al, Co, Cu, Ni, Pb, Zn
Ferrous metals: Cr, Fe, Mn, Ti, V
Size and activity
Active mine
Imoprtant deposit
Very large with active mine
Very large
Large with active mine
Large
Potentially large with active mine
Potentially large
Scale 1:11 000 000
Stereographic North Pole Projection
Standard Parallel 70°N Coordinate System WGS 1984
Prime Meridian: Greenwich (0.0), Central Meridian 20°W

LEGEND FOR THE INSET MAPS

Sedimentary and or metamorphic, undivided: lighter shades of each are offshore

Cz	Cenozoic
Ng	Neogene and Quaternary
Pg	Paleogene
K	Cretaceous (often includes Paleogene)
J	Jurassic (often includes Cretaceous)
T	Triassic (often includes Jurassic)
Pz	Paleozoic (mostly Cambrian to Devonian)
Pe	Permian (often includes Triassic)
C	Carboniferous (often includes Permian)
D	Devonian (often includes Carboniferous)
S	Silurian (often includes Devonian)
O	Ordovician (often includes Silurian)
Cm	Cambrian (often includes Ordovician)
Pr	Proterozoic (up to Devonian in Yukon and Alaska)
N	Neoproterozoic (often includes Cambrian)
M	Mesoproterozoic
P	Paleoproterozoic
A, AP	Archean, Archean and Paleoproterozoic

Distinct lithologic suites (with age label prefix): lighter shades of each are offshore

v	Extrusive; igneous, undivided
f	Felsic intrusive suites (granite, tonalite)
b	Gabbro suite (also anorthosite)
p	Peridotite suite
x	Impact breccia

Cratons, shield areas

ASl	Slave Craton: felsic intrusive suites
AR	Rae Craton: intrusive undivided
AH	Hearne Craton: felsic intrusive suites
AM	Murmansk craton: felsic intrusive suites
AK	Karelian Craton: felsic intrusive suites
AN	North Atlantic Craton: intrusive undivided
AA	Anabar shield: sedimentary undivided