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Vladimir R. Shmelev
Boris V. Perevozchikov
Vasiliy P. Moloshag

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Russian Academy of Sciences, Ural Branch
Zavaritsky Institute of Geology and Geochemistry

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Shmelev V.R., Perevozchikov B.V., Moloshag V.P.

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This guidebook is dedicated to one of the unique objects of the Urals – Rai-Iz peridotite massif. The characteristics of geology, tectonics, mineralogy and geochemistry of ultramafic rocks and associated chromite deposits are briefly outlined. The features of the structure and composition of the post ophiolitic gabbro-diorite-tonalite association are presented. A series of geological intersections for the different rock complexes provides a fairly complete overview of the Rai-Iz massif.

The materials are of a broad interest for geologists that are interested in the problems of the mantle origin and associated rock complexes.

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## INTRODUCTION

The peridotite Rai-Iz massif, located in the Polar Urals became a well-known geological object after the publication of the monograph by Zavaritsky (1932), which gave the first detailed petrographic and petrochemical characteristics of rocks and assumptions about their genesis. This work served as the impetus for further specialized studies of the tectonics, structure, petrology, and metallogeny of ultramafic rocks and associated gabbro and granitoids. As a result of these studies the second monograph dedicated to the Rai-Iz massif was published (Structure.., 1990). It summarized the collected materials and gave an interpretation of structural evolution of rock complexes and chromite mineralization. Now, after nearly a quarter of century, a lot of new data have appeared that changed our understanding of the massif rocks origin, which makes a new interesting work on this subject possible. In the meantime, you are invited to learn more about with this unique massif of the Polar Urals!

## TECTONIC SETTING

The peridotite Rai-Iz massif along with the two other massifs, Voykar and Syum-Keu, form the longest (about 500 km) Polar-Urals ophiolite belt (Fig. 1). The ophiolite belt position is controlled by the trans-regional tectonic structure, known as the Zone of the Main Ural Fault (Thrust). Peridotite massifs are separated from each other by mainly Precambrian metamorphic formations (gneisses, schists, amphibolites) of the Kharbey and Kharamatolou blocks (Dobretsov et al, 1977). It is assumed that the Voykar and Rai-Iz massifs were once a single entity in structural terms (Structure.., 1990).

The Rai-Iz massif is an allochthonous tectonic block (of 400 km$^2$ area), thrusts over the polymictic serpentinite melange zone onto the Paleozoic sedimentary formations of the shelf and continental slope of the East European Platform (Fig. 1). Peridotites in the south of the massif are “superposed” by the

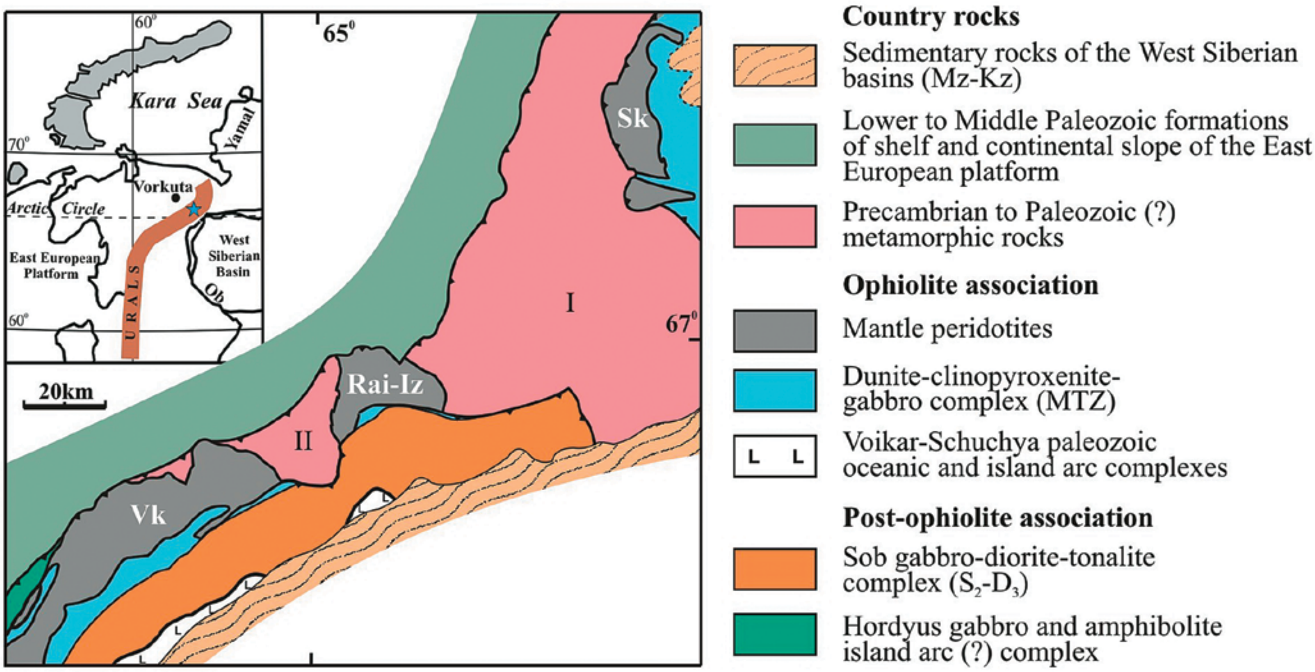


**Fig. 1.** Tectonic settings of the Polar Urals ophiolites. Peridotite massifs: Rai-Iz, Voikar (Vk), Syum-Keu (Sk). I, II – Kharbey and Kharamatolou blocks. The inset shows the geographic location of the Rai-Iz massifs (asterisk).

section of the transition (MTZ) dunite-clinopyroxenite-gabbro complex. In direct contact with them is the Sob intrusive pluton, composed of gabbro-diorite-tonalite rocks of the Late Silurian-Devonian age (Shmelev, Meng, 2013). All these formations, including fragments of the island arc volcanic section of the Voykar-Schuchya megazone are overlapped by sedimentary formations of Mesozoic-Cenozoic cover of the West Siberian basin.

The age of the peridotite formation and that of gabbro ophiolite association of the massif has not been reliably defined yet. Given the results of U-Pb dating of zircons from chromite ores and the results of Re-Os isotopy of the Voykar massif peridotites (Savelieva et al., 2013), we should possibly expect a similar polychronic (0.6-2.0 Ga) age picture of peridotites and chromites formation for the Rai-Iz massif. For gabbroids of the transition complex massif, we can accept the Upper Ordovician (450-460 Ma) age determined by zircon from the eastern ophiolite gabbro of the Voykar massif (Remizov et al, 2010).

## GEOLOGY

Geological features of the Rai-Iz ophiolite massif are described in detail in a series of publications (Zavaritsky, 1932; Dobretsov et al, 1977; Makeev et al, 1985; Shmelev, Puchkov, 1986; Structure.., 1990). The massif structure was found to involve early lherzolite-harzburgite and late dunite-harzburgite rock complexes (Fig. 2). In the process of metamorphism have been formed metaperidotites of different composition.

The rocks of *lherzolite-harzburgite* complex have a fragmented distribution in the northern and south-eastern part of the massif. They are mainly represented by diopside harzburgites and harzburgites of schlieren-like and banded texture, where relic lherzolite sites are recorded (Structure.., 1990). The contact between these types of rocks is apparently gradual; distinct boundaries have not been established. Peridotites are injected by rare thin veins of clino- and orthopyroxenites and dunites.

The rocks of *dunite-harzburgite complex* compose the entire central portion of the massif, taking at least 60-70% of its area. Peridotites are presented by banded alternation of dunites and harzburgites, as well as harzburgite sites containing a stockwork of dunite veins and bodies. In the central part of the massif dominated intensely deformed (often with two orientation systems) harzburgites, enclosing large dunite bodies (central and southwestern). In the southwest pinching of the central dunite body, there is a major “Central” chromite deposit (fig. 2).

*Metaperidotites* are spread in the central part of the massif, where they form a long linear zone of northeastern strike (Fig. 2). They are presented by sagvandites, enstatites and olivine-enstatite-amphibole (with clinochlore) rocks along with secondary porphyroblastic harzburgites and dunites. To the north and south of this central zone, there are mapped areas of late metaperidotites with antigorite, tremolite, and talc.

## TECTONICS

Peridotites have experienced high-temperature plastic deformations, accompanied by the formation of banding, foliation, lineation and multiscale folded structures (Shmelev, Puchkov, 1986; Shmelev, 1990). The formation of large flat-lying syn and antiform mega folds, mapped in the peripheral parts of the massif within the lherzolite-harzburgite complex (Fig. 2) was associated with early deformation stages. In the later stages of deformation a giant mega structure bending of the northeast strike, complicated by the system of conjugated compressed and isoclinal folds was formed.

Along with their folding, peridotites experienced high temperature dynamic metamorphism with the formation of different petrostructural types of rocks (Fig. 3). During the early shield dynamic metamorphism, ultrabasites with coarse-grained, protogranular and mesogranular microstructures

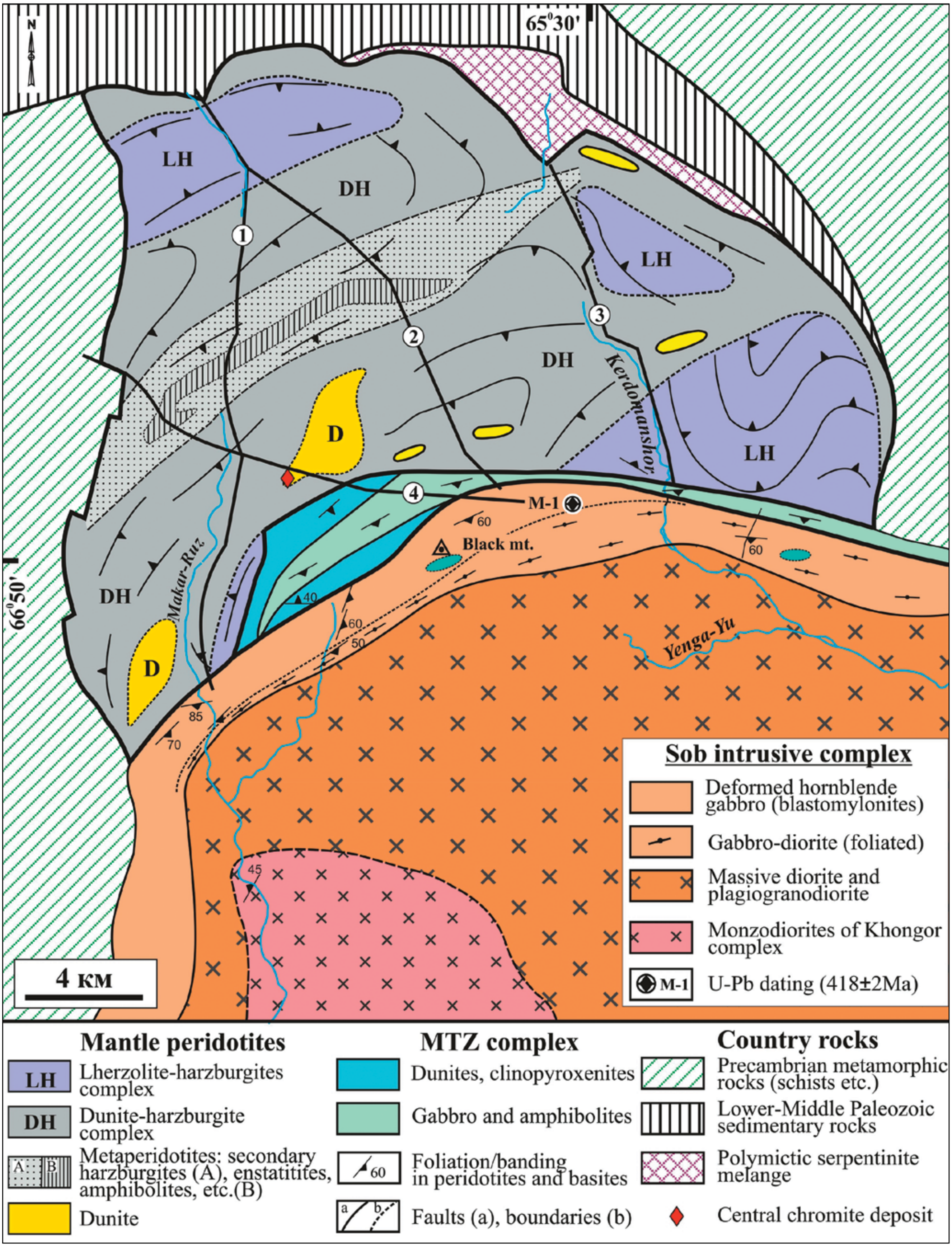


**Fig. 2.** Simplified geological map of the Rai-Iz massif (Polar Urals), modified from (Structure.., 1990; Shmelev, 2011; Shmelev, Meng, 2013). Numbers in the circles mark the main faults: 1 – Kongor, 2 – Yengai, 3 – Kerdomanshor, 4 – Poloyshor

were formed. Subsequently ultrabasites experienced zonal metamorphism controlled by linear zones of brittle and plastic flow. As a result of plastic deformation and syntectonic recrystallization, moderately and highly deformed rock facies with tabular, porphyroclastic and mosaic microstructures were formed. During high temperature hydration of peridotites (in static mode), secondary protogranular and porphyroblastic microstructures have been formed (Structure.., 1990).

The extension of the massif onto the upper crust was associated with the formation of thrust zones, confining the massif from the north and north-east (the Main Thrust zone), and from the south and south-east (the gabbro thrust zone). It involves the emergence of thick shearing zones of sublatitudinal strike and adjoint small folding. In the final stages (Late Devonian-Carboniferous) the massif was split by large meridional faults: the Western, Kongor and Kerdomanshor (in the East) and then dissected by through-faults of the sublatitudinal (Poloyshor) and Northwest (Engayu) strikes (Fig. 2). The Poloyshor fault displaces the West fault (1 km) and cuts the "Central" chromite deposit from the north. The fault falls steeply to the north, traced by the thick (up to 50 m) zone of serpentinites with fresh dolerite dykes, probably related to the Permian-Triassic trappoids (Structure.., 1990).

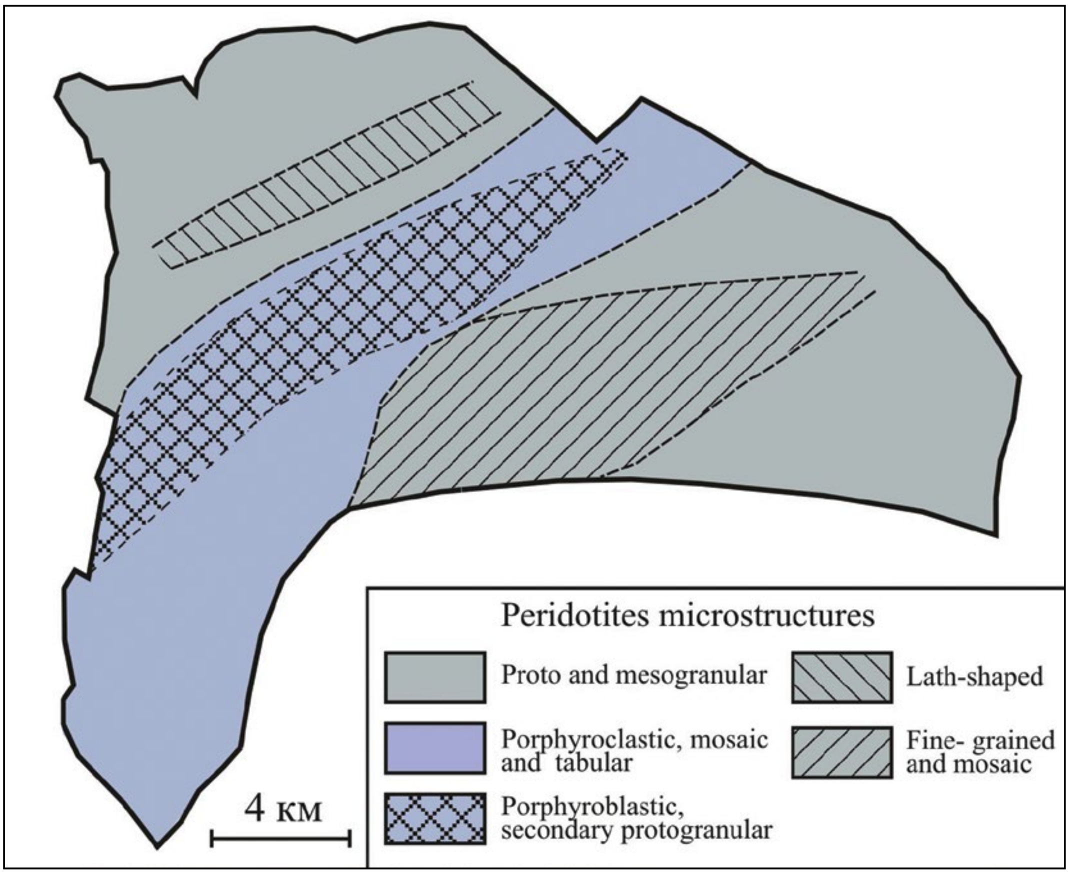


**Fig. 3.** Scheme of dynamometamorphic zonation in peridotites (after Structure.., 1990)

# PERIDOTITES COMPOSITION

The Rai-Iz massif peridotites (lherzolites, harzburgites and dunites) demonstrate regular variations in the composition of rock-forming minerals and chemistry of the rocks, reflecting the specific conditions of their formation in the mantle (Chashchukhin et al, 2007, Shmelev, 2011).

## Mineral chemistry

*Olivine* in peridotites corresponds to forsterite with high Mg-number (0.89-0.96), standard NiO (0.2-0.5 wt%) and very low (less than 0.05 wt%) CaO content (Shmelev, 1990, 2011). In general, Mg-number of olivine increases from lherzolites to harzburgites and dunites, peaking in metaultrabasites with amphibole-clinochlore paragenesis. Olivine in clinopyroxenites is characterized by reduced (to 0.84) Mg# values (Fig. 4a).

*Spinel* in lherzolites is presented by magnesian and aluminous type ($Al_2O_3$ = 48-53 wt%) with extremely low Cr-number values (<0.2). Spinel in harzburgites has a moderate value of chromium (Cr# = 0.3-0.6), while in dunites and some metaperidotites it has highly chromium (Cr# = 0.60-0.84) composition. In olivine-enstatite rocks and secondary harzburgites of the central part of the massif chrome magnetite prevails. In general, from lherzolites to dunites and metaultrabasites an adjoint growth of iron and chrome spinel is recorded, accompanied by a decrease in alumina levels (Fig. 4b).

*Clinopyroxene and orthopyroxene* in peridotites are characterized by comparable levels of $Al_2O_3$ (1.5-3.5 wt%), despite the fact that enstatite has a lower Mg-number compared with diopside (0.90-0.93 vs 0.94-0.95). From lherzolites to harzburgites in pyroxenes, alumina, titanium and chromium content decreases (Fig. 4c). In metaperidotites prevails magnesian enstatite with extremely low $Al_2O_3$ (0.1-0.5 wt%) and CaO levels (<0.02 wt%). Diopside in pyroxenite is characterized by consistently low and moderate alumina contents (0.9-2.0 wt%).

Pyroxenes (especially enstatite) show two fundamental chemistry features (Shmelev, 2011). First, from lherzolites to harzburgites in pyroxenes, chromium content growth and alumina reduction is recorded, reflecting their evolution during depletion. Secondly, for each type of rocks in pyroxenes an overall level decrease of these components is observed, which is probably due to subsolidus reequilibration and fluid influence (Fig. 4d).

*Amphibole* in peridotites belongs to the group of calcium hornblendes. In lherzolites and diopside harzburgites, prevail aluminous ($Al_2O_3$ = 11.9-13.2 wt%) pargasite and edenite. In harzburgites, along with edenite and even Cr-edenite (2.3wt % $Cr_2O_3$) there is later magnesian hornblende with low $Al_2O_3$ level (4.5-9 wt%). Low aluminous (<3wt % $Al_2O_3$) tremolite prevails in metaultrabazites (Fig. 4e).

## Bulk geochemistry of peridotites

The ICP-MS data on the geochemistry of rare earth elements in different types of the Polar Urals peridotites (Shmelev, 2011) provides substantial complementary information on the composition of these formations.

*Lherzolites* are characterized by the highest REE levels and show linear trends of distribution of spoon-shaped morphology, sometimes complicated by a small negative Eu anomaly (Fig. 5a). They have almost the same composition as the lherzolite of Syum-Keu massif. *Diopside harzburgites* are comparable to lherzolites in distribution and general level of trace elements. However, they demonstrate more pronounced LREE enrichment, although have a more depleted composition in mineralogy. Both groups have geochemical similarities with spinel and plagioclase lherzolites of the Southern Urals (Nurali, Mindyak) ophiolite massifs (Shmelev, 2011).

*Harzburgite*s compared with diopside harzburgites and lherzolites are characterized by distinctly lower level of medium and heavy REE at comparable concentrations of LREE (Fig. 5a). In LH-complex

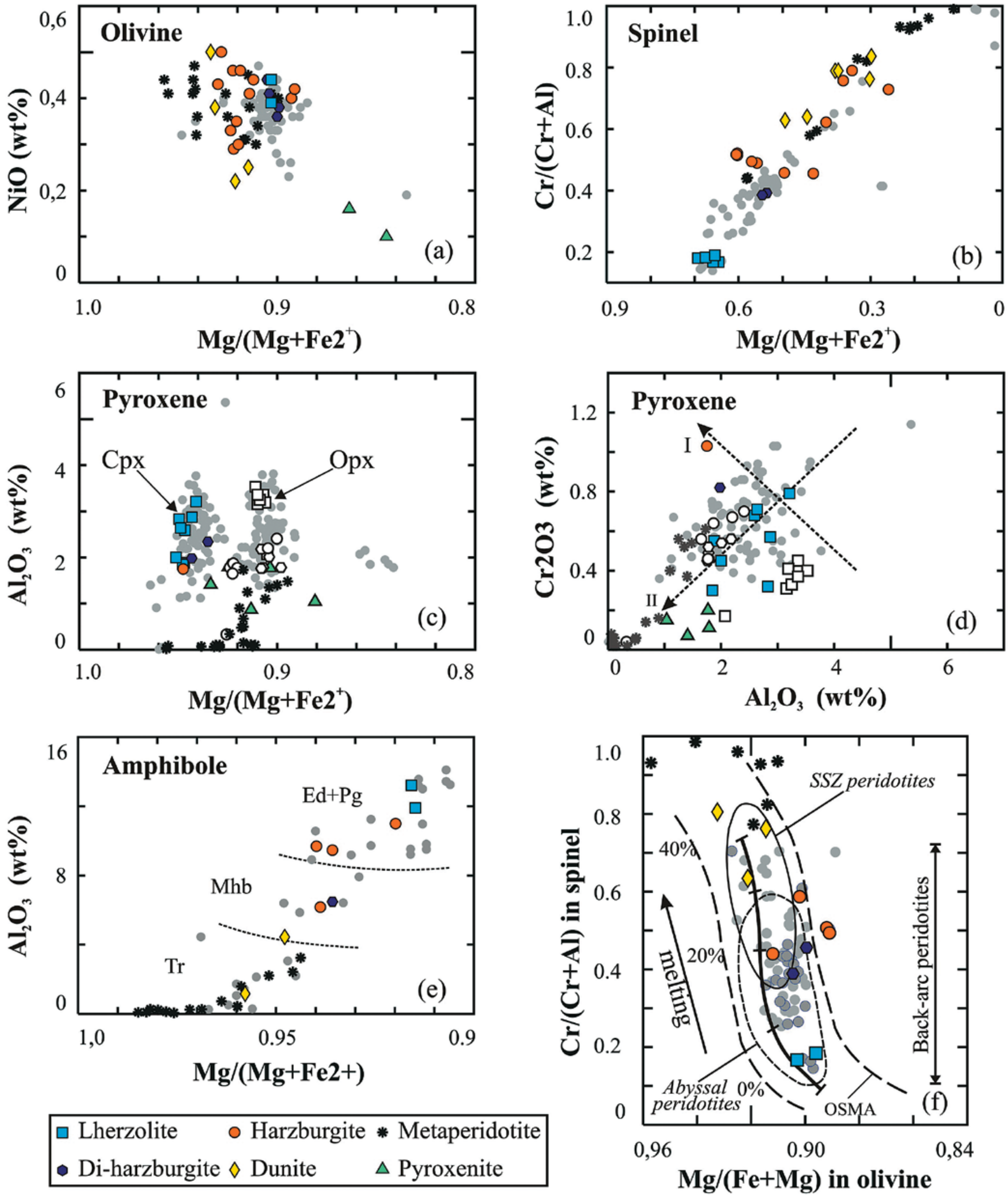


**Fig. 4.** Variations of mineral compositions (a-f) in the peridotite massif (modified from Shmelev, 2011). Cpx, Opx – clinopyroxene and orthopyroxene respectively (colored and white), Ed + Pg – edenite and pargasite, Mhb – magnesian hornblende, Tr – tremolite. I, II – evolutionary trends of compositions. In the diagram (f) is shown the OSMA – Olivine-spinel mantle array; solid line with marks – the trend of partial melting (% degree of melting) of the original FMM mantle (Arai, 1994). Gray circles in the diagrams show the composition of minerals in the Syum-keu and Voykar peridotite massifs

they have low REE contents and slightly concave U-shaped pattern of REE distribution, which is typical of peridotites in ophiolite complexes. In the late DH-complex harzburgites have a similar distribution, but exhibit higher REE levels and a distinct negative Eu anomaly (Fig. 5b). Such “abnormal”rocks are definitely the result of fluid-magmatic transformation of early complex peridotites.

*Metaperidotites* from the high-temperature metamorphism zone is characterized by flat U-shaped ($La_N/Yb_N$ = 1.1-1.3) distribution trends with negative Eu-anomaly (Fig. 5c). A similar distribution is established in the varieties with tremolite-talc paragenesis from the southern part of the massif. Secondary enstatite-olivine (containing carbonate) rocks have maximum contents of lanthanides (sample 176). Dolomite from segregations in metaultrabasites is characterized by extremely high levels of contents, while maintaining the similarity in the REE distribution (Shmelev, 2011). In general, geochemistry of metaperidotites and harzburgites of dunite-harzburgite complex has an obvious similarity, which indicates the isochemical nature of metamorphism.

*Dunites,* forming large bodies in the massif, are characterized by flat (slightly concave) distribution trends ($La_N/Yb_N$ = 1.1-2.3) with pronounced negative Eu-anomaly (Fig. 5d). In the vein-shaped bodies of the LH-complex (sample 401A) they differ by high REE contents and LREE richness that determines the distribution of the negative slope of the trend. Dunites from the dunite-clinopyroxenite-gabbro complex (sample 325a) do not differ from dunites of the mantle section part. In general, the REE dunites show obvious similarity with harzburgites in geochemistry.

Rare incompatible elements are characterized by regular behavior in all types of ultrabasites expressed in distinct rock enrichment with “mobile” elements (Cs, Rb, Ba), and U, Nb, Ta, relative to content levels of lanthanides (Shmelev, 2011). Stable positive anomalies of lead and strontium and weak anomalies of zirconium and hafnium are observed in multielement spectra. Variations of rare elements levels in metaperidotites correspond to those in harzburgites. The distribution of incompatible trace elements corresponds to that in oceanic abyssal peridotites.

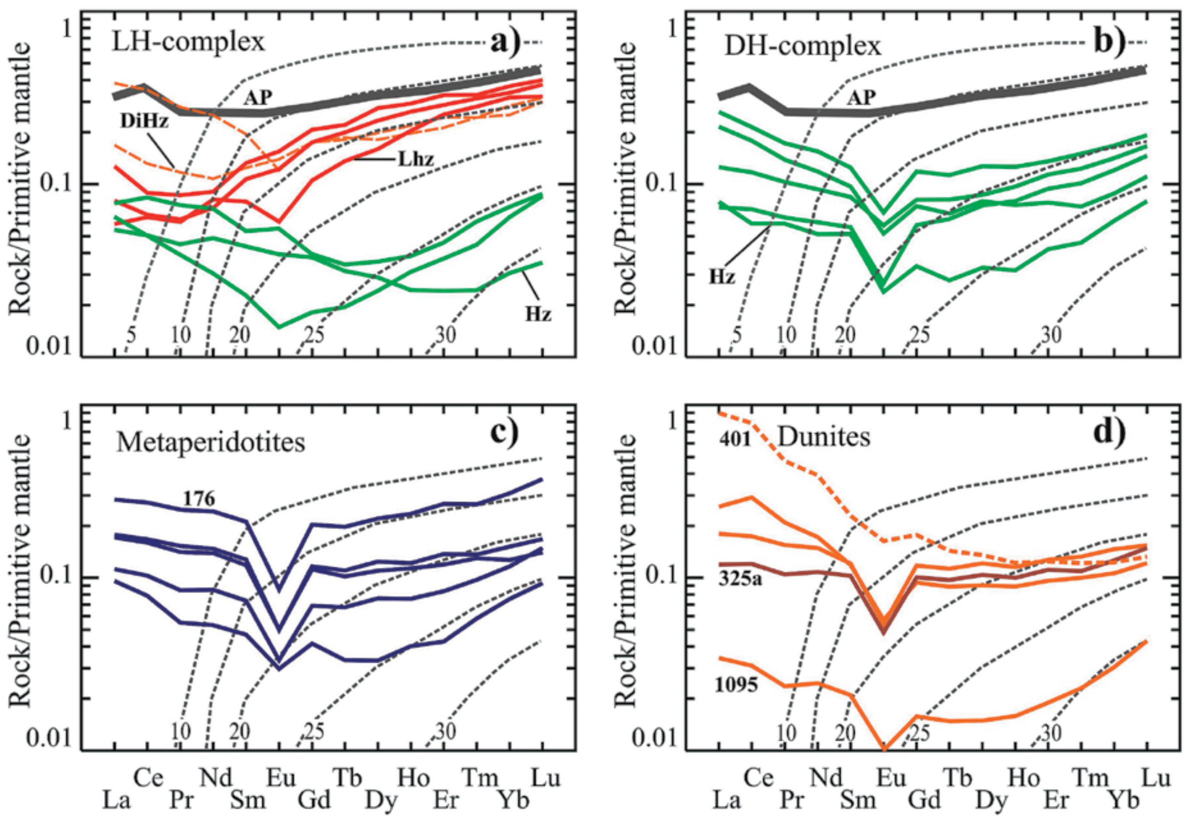


**Fig. 5.** Normalized to primitive mantle REE pattern for the rocks of LH and DH-complexes (a, b), metaperidotites (c) and dunites (d) in the Rai-Iz massif (modified from Shmelev, 2011). Lhz – lherzolites, DiHz – diopside harzburgites, Hz – harzburgites. Dashed lines show the model compositions of the residue at various degrees of fractional melting (F = 5–30%) of the depleted mantle (Niu, 2004). AP – average composition of abyssal peridotite

# PETROGENESIS OF PERIDOTITES

Structural, mineralogical and geochemical diversity of the Polar Urals peridotites is the result of multiple scale processes – partial melting and depleting of mantle, fluid-magmatic and subsequent metamorphic transformation, that occurred in different geodynamic settings (Shmelev, 2011).

**Depletion** is the root cause of the main peridotite types formation. Taking into account the existing range of olivine and spinel compositions, peridotite can be regarded as a series of rocks with varying degrees of melting. Therefore lherzolite will have the minimum (10%), harzburgites – moderate (10-25%), and dunites – moderate or high (over 30%) degree of partial melting (Fig. 4f). However, the comparison of REE compositions of ultrabasites with model trends of restites in partial melting of the mantle indicates a more complex picture of their formation.

According to the distribution trends of MHREE, partial melting products (12-16%) in spinel facies closely correspond to lherzolites and diopside harzburgites, which differ from the model compounds only by increased LREE levels (Fig. 5a). The remaining peridotites, presented by harzburgites and dunites of the LH and DH complexes, show a significant difference from the model compositions. They can be attributed to restites (at 20-30% degree of "dry" melting) only in HREE composition and distribution (Fig. 5 b-d). The existence of a clear "La/Yb" trend in peridotites, perpendicular to the evolutionary trend of compositions in dynamic melting in a closed system (Fig. 6), gives a reason to believe that specific geochemistry of harzburgites is mainly the result of fluid-induced partial melting of lherzolites and diopside harzburgites.

Mineralogical and geochemical characteristics of rocks and their redox state (Chashchukhin et al., 2007, Shmelev, 2011) indicate that the depletion during partial melting occurred under changing geodynamic conditions. Lherzolites and diopside harzburgites were apparently formed in oceanic (back-arc?) spreading environments, while harzburgites were formed under suprasubduction (forearc) conditions.

**Fluid-magmatic transformation** of peridotites under the influence of percolating melts and fluids was accompanied by their widespread refertilization and *depyroxenization* (dunitization) (Shmelev, 2011). During the *refertilization*, obviously associated with partial melting, ultrabasites underwent enrichment by light and medium REE (Fig. 5, 6), as well as by incompatible rare elements (Cs, Ba, Sr, Pb, Zr, Nb, etc.). Presumably this process was also related to the emergence of common negative Eu anomaly in rocks.

*Depyroxenization* was controlled by tectonic permeability zones (axial part of the folded structures, shear zones) and took place in the oxidized (1.2-2.7 units above QFM buffer) redox conditions in the suprasubduction setting. It was associated with the formation of veined stockwork and large dunite bodies, as well as chromite manifestations including the «Central» deposit. The detection of diamond paragenesis in chromitites (Yang et al, 2014) opens new perspectives in understanding the nature of ophiolites.

**Metamorphism** of the peridotites associated with advancing the massif to the upper horizons of the crust under the influence of fluids, led to the

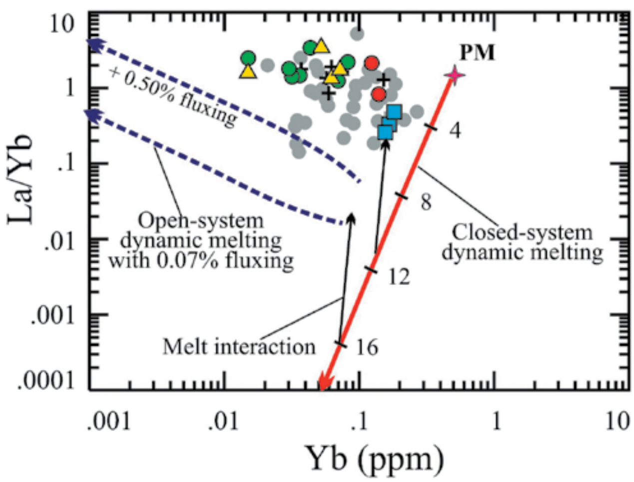


**Fig. 6.** La/Yb – Yb (ppm) diagram for peridotites of the Rai-Iz massif, showing trends of compositions of the primitive mantle (PM) for dynamic melting in a closed system (red line) and subsequent melting in an open system with the addition of fluid (Uysal et al., 2012). Symbols are the same as in Fig. 4

formation of high-temperature olivine-enstatite-tremolite, later olivine-antigorite and other metaperidotites. Metamorphic transformations were essentially of isochemical character, i.e. without changing specific geochemistry of initial ultrabasites. The metamorphites formation was obviously associated with tectonic stratification of oceanic lithosphere in the final subduction stages. During the subsequent obduction and the massif moving to the current position, ultrabasites experienced antigoritization and talc formation along tectonic zones, and then looped serpentinization.

## CHROMITE MINERALIZATION

Three deposits, 36 ore occurrences and about 200 mineralization points were revealed in the Rai-Iz massif (Structure.., 1990; Perevozchikov et al, 2000, 2005). The main quantity of chromite occurrences are located in the western and southern parts of the massif and are grouped into three ore fields: North, South and West (Fig. 7). The inferred resources of the chromite ores were estimated at 190 mln. tons, of which 120 million tons with $Cr_2O_3$ above 25 wt % (Makeyev et al, 1985). Later potential resources were adjusted to 163 million tons, including categories: $P_1$ – 31 million tons, $P_2$ – 97 million tons, $P_3$ – 35 million tons.

### Types of chromite mineralization

With the lherzolite-harzburgite complex in the Rai-Iz massif are genetically and spatially associated aluminous chromite ores, while the dunite-harzburgite complex is related to industrial high-chromium mineralization (Perevozchikov et al, 2005).

*Aluminous* type is presented by the Upper Sob I ore occurrence in the northwestern part of the massif and single mineralization points (Fig. 7). This type includes: poorly interspersed schlieren ores (less than 50% Cr-spinels) in small dunite bodies (segregation class) and thickly interspersed ores in thin-veined and flattened lenticular bodies of harzburgites (injection class). The Upper Sob I ore occurrence refers to injection class.

*High-chromium type* is located in the dunite-harzburgite complex and is divided into three mineralization classes: (I) segregation ores in dunite bodies, (II) injection thickly interspersed ores in zones of shear-plastic deformations of harzburgites with schlieren-banded dunite segregations, (III) mixed thickly and poorly interspersed ores.

Class I is presented by poorly or rarely interspersed ores occurring in dunite bodies in the form of stocks-shaped, irregular lenticular, schlieren bodies with blurred boundaries. The ores are syngenetic to dunites. The Poloishor II ore occurrence, occurring in the Central dunite body and the Southwest III ore occurrence located in the Southern circuit dunite body are referred to class I (Fig. 7). Cr-spinel ores of this class are of high-chromium type (54-57 wt % $Cr_2O_3$, 9-10 wt % $A1_20_3$). In medium and small dunite bodies mineralization occurs more frequently and is presented by Engai, Engai II, Lekvozh III, IV, V, and Upper Sob II ore occurrences.

Class II is represented by thickly interspersed chromite ores localized along the zones of shear-plastic deformations in harzburgites. The ores are divided into two groups: those occurring in thick extended zones associated with large dunite bodies (1) and those in thin areas associated with medium and small dunite bodies (2).

The first group includes the West and 214 deposits localized in a large area stretching over 12 km, deviating to the southwest from the Central dunite body (Fig. 7). The deposits contain numerous flattened lenticular, rarely irregular ore bodies lying in echelon along the chromite-bearing zone. The dimensions of individual bodies range from 300 to 520 meters in length, and 6-14 m in thickness. The contacts of the ore bodies are distinct; they are usually surrounded by dunite rim. Chromite ores are thickly interspersed

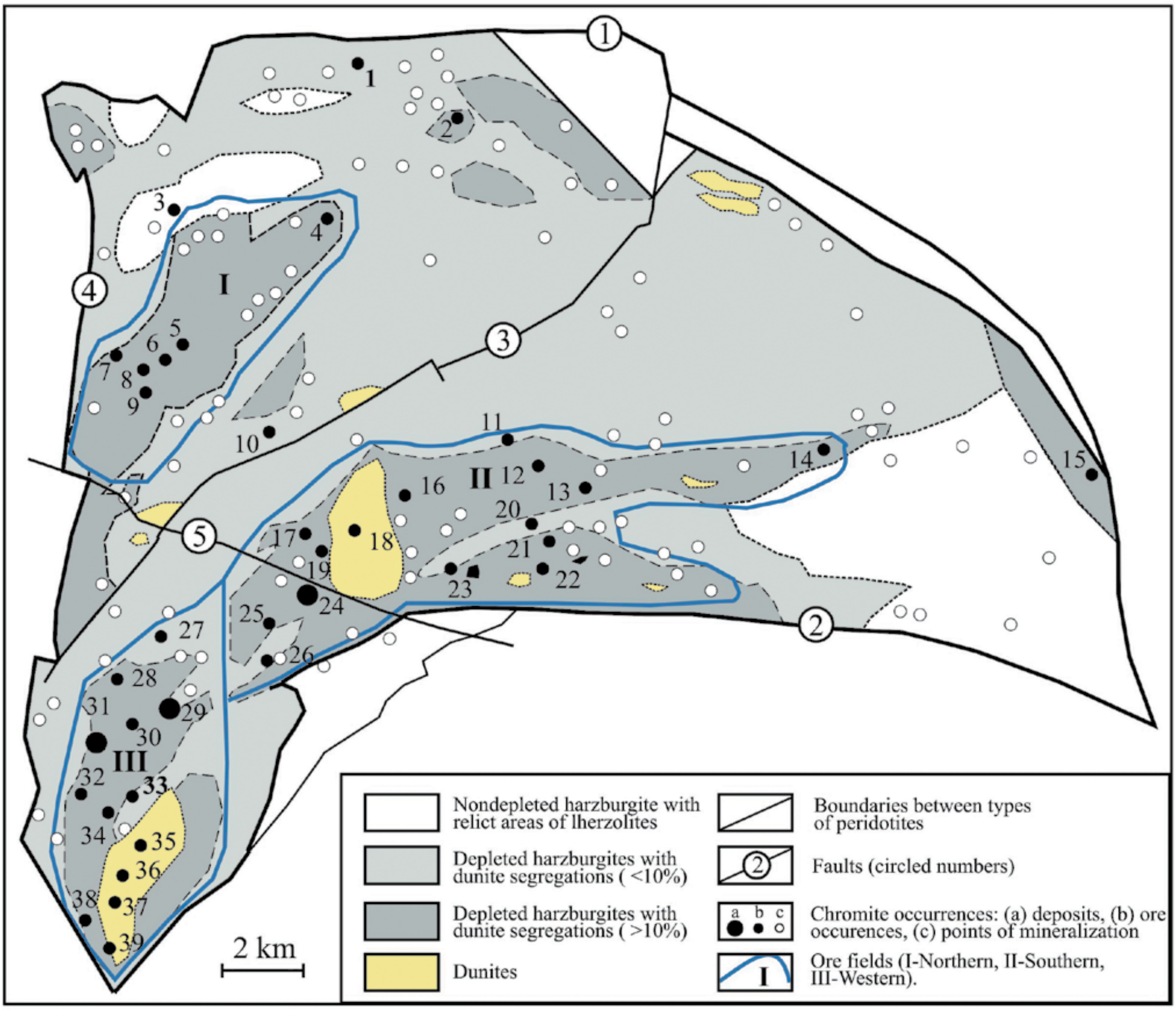


**Fig. 7.** Location of chromite deposits and occurrences in the Rai-Iz massif (modified from Perevozchikov et al., 2005). *Fault* (numbers into circles): 1 – Main Uralian, 2 – Gabbro, 3 – Axial, 4 – Western, 5 – Poloishor. *Deposits*: 24 – Central, 29 – Western, 31 – 214. *Ore occurrences*: 1 – Neighboring, 2 – 2038, 3 – Upper Sob I, 4 – Upper Sob II, 5 – Lekvozh V, 6 – Lekvozh IV, 7 – Lekvozh III, 8 – Lekvozh I, 9 – Lekvozh II, 10 – Upper Makar-Ruz, 11 – Upper Engai, 12 – Engai IV, 13 – Ridee, 14 – Canyon, 15 – Eastern, 16 – Fish Tail, 17 – Central II, 18 – Poloishor II, 19 – Poloishor I, 20 – 3e, 21 – Engai III, 22 – Engai II, 23 – Engai, 25 – Hillside, 26 – 1135, 27 – 272, 28 – 257, 30 – 282, 32 – 229, 33 – 237, 34 – Southwestern V, 35 – Southwestern IV, 36 – 1030, 37 – Southwestern III, 38 – Southwestern II, 39 – Southwestern I

and massive; in the marginal and apical parts of the ore bodies there are medium and rarely interspersed types. Ore spinels are the most high chromium (57-62 wt % $Cr_2O_3$, 8.5-11.0 wt % $A1_20_3$).

The second group includes the following ore occurrences: Southwest I and V, Ridge, Hillside and others. This group is characterized by typomorphic signs similar to the first group, and differing in smaller scale of mineralization. The ore occurrences contain a small number of ore bodies (1-3) having a simple veined, flattened lenticular morphology. Ore spinelides contain 50-56 wt % $Cr_20_3$ and 10-15 wt % $A1_20_3$.

Class III of mixed rich and poor high-chromium ores is characterized by signs of superimposition on the above mentioned ore classes. In large dunite bodies it is usually developed in marginal parts and apophyses (the first mineralization group). In smaller dunite bodies mixed mineralization type may be localized in different parts of the dunite bodies (the second mineralization group).

The reference representative of the first group is the Central deposit, which is confined to the dunite "apophysis", separated from the southern part of the Central dunite body by the Poloyshor fault. The dunite apophysis is surrounded by harzburgites with schlieren-banded dunite effusions, the amount of which decreases towards the periphery. In the southwestern part the dunite apophysis "is replaced by" a wide (up to 850 m) zone of shear-plastic deformations. This zone is characterized by alternating harzburgite bands with different content of dunite segregations, some of which are elongated dunite bodies 150-250 m long and 20-80 m wide. This group includes the Southwestern IV ore occurrence, confined to the northern closure of the South dunite body.

## Structure and composition of chromitites

Chromite ores are very diverse in structure; one can differentiate spotted, banded, striate-banded, schlieren-banded, and schlieren textures (Perevozchikov et al, 2005). Thickly interspersed and solid ores usually have a uniform composition with massive, nodular and rarely spotted and banded textures.

Ore structures vary from fine-grained to coarse-grained depending on the density of dispersion. Ores with uneven granular structures are very common. The bulk of the ore chrome spinels is presented by grains of irregular or isometric-rounded shape. Ore crystals brecciation for microblocks of 0.1-0.6 mm in size, 0.4 mm on average is regularly observed. Chrome spinels grains tend to form clusters, i.e. segregations measuring 3-10 mm, 5-10 mm and 100-300 mm in poorly interspersed, thickly interspersed and massive ores, respectively. $Cr_20_3$ content in chromite segregations exceeds 48 wt %, which is of great importance for the enrichment of chromite ores.

Chromite ore Central deposits have more than 50 minerals, whose contents vary widely, from 99% for chrome spinels up to 1x $0^{-5}$% for native metals and platinum group minerals. The main minerals of chromite ores are spinel and olivine, which experienced transformations during metamorphism. Secondary minerals are serpentine, chromic clinochlore – kemmererit as well as talc, clinochlore, brucite, etc. in small quantities. Accessory minerals are magnetite, PGE minerals, sulfides and native metals (Volchenko, 1990; Anikina, 1995; Moloşhag et al, 1999).

**Spinel** is referred to high chromium type where a modal content of $Cr_20_3$ is 59-60 wt %. Primary phases are presented by magnesian chromite and alumochromite, while metamorphosed ones by ferrous subferrichromite and subferrialumochromite.

In primary ores with increasing dissemination density in chrome spinel, $Cr_20_3$ and $Al_2O_3$ content increases and magnesium content decreases (Table 1). Metamorphic processes do not lead to a significant reduction in the quality of chromite ores, on the opposite, their quality is improved due to the removal of "bad" (CaO, etc.) components.

***Olivine*** together with serpentine and chlorite (kemmererit) forms a cement of chromite ores. In the process of medium-temperature metamorphism it undergoes recrystallization and acquires non-homogeneous grain structure with grain sizes from 1-2 to 10-15 mm. The largest (5-10 cm) olivine grains are found in the ore-bearing dunites. With increasing of dissemination density the size of olivine grains decreases. During a low-temperature transformation olivine is replaced by serpentine. The degree of olivine serpentinization ranges from 0-10% at the depth greater than 160-340 m up to 80-100% in the fault zones.

Olivine corresponds to forsterite in its composition. In a series of ore-bearing dunite – poorly interspersed ores – richly interspersed ores in olivine the content of Fe, Mn, Ti decreases and the content of Si, Mg, Ni proportionally increases; with this the iron content of olivine decreases significantly (Table 2).

A recent study of mineral composition of chromite ores and host dunites of the southwestern part of the Central deposit (Vakhrusheva, 2012), generally confirms the existence of previously established patterns. It is noted that in the host dunites in the range 4.45-5.11 of Fe-number olivine (contact with the ore) up to 7.7, variations of NiO contents in olivine remain stable at 0.35-0.47 wt %. Along with this, in the medium and thickly interspersed chromite ores, as olivine iron content reduces (from 3.77 to 1.88 wt %) its NiO content increases sharply from 0.46 to 0.81 wt % (Fig. 8).

Table 1

**Average chemical composition of chromite ore from Central deposits, wt %**
(after Perevozchikov et al., 2005)

| *Ore types on dissemination density* | *Cz2O3* | *SiO2* | *A2O3* | *Fe2O3* | *FeO* | *CaO* | *MgO* | *P.p.p.* | *Cz2O3/FeO'* |
|---|---|---|---|---|---|---|---|---|---|
| Eastern subzone of the Northen part of the deposit | | | | | | | | | |
| Massive | 52,26 | 4,32 | 9,42 | 6,45 | 8,96 | 0,42 | 17,41 | 0,76 | 3,54 |
| Thickly interspersed | 43,01 | 9,1 | 9,13 | 5,12 | 8,39 | 0,31 | 22,48 | 2,46 | 3,3 |
| Medium interspersed | 32,81 | 14,99 | 7,4 | 3,84 | 8,41 | 0,3 | 27,28 | 4,97 | 2,76 |
| Rarely interspersed | 16,59 | 23,52 | 5,56 | 3,74 | 7,7 | 0,34 | 35,64 | 6,91 | 1,5 |
| Poorly interspersed | 7,98 | 30,12 | 3,34 | 2,38 | 6,03 | 0,2 | 41,24 | 8,71 | 0,98 |
| Western subzone of the Northen part of the deposit | | | | | | | | | |
| Massive | 51,88 | 2,49 | 13,59 | 3,82 | 8,45 | 0,32 | 18,81 | 0,63 | 4,36 |
| Thickly interspersed | 43,39 | 7,79 | 10,19 | 4,53 | 11,1 | 0,26 | 21,04 | 1,70 | 2,86 |
| Medium interspersed | 32,2 | 15,28 | 7,56 | 3,8 | 9,37 | 0,3 | 28,15 | 3,34 | 2,52 |
| Rarely interspersed | 16,21 | 23,37 | 6,5 | 3,76 | 9,28 | 034 | 35,76 | 4,78 | 1,28 |
| Poorly interspersed | 7,56 | 31,61 | 1,99 | 1,58 | 7,77 | 0,45 | 45,23 | 5,81 | 0,82 |
| The southern part of the deposit | | | | | | | | | |
| Massive | 52,46 | 3,8 | 8,32 | 7,42 | 7,19 | 0,3 | 17,86 | 2,12 | 3,78 |
| Thickly interspersed | 45,03 | 6,78 | 9,07 | 6,78 | 7,59 | 0,45 | 19,97 | 2,89 | 3,09 |
| Medium interspersed | 32,6 | 12,56 | 8,97 | 7,18 | 7,23 | 0,84 | 25,39 | 5,26 | 2,38 |
| Poorly interspersed | 8,26 | 31,49 | 3,46 | 4,98 | 5,64 | 0,57 | 38,35 | 7,25 | 0,82 |

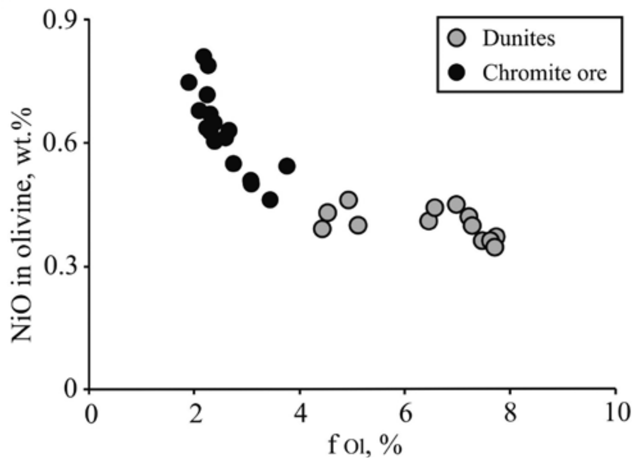


Fig. 8. NiO content vs. f value in olivine from dunites and chromite ores (after Vakhrusheva, 2012).

Table. 2

**Chemical composition of olivine**, wt %
(after Perevozchikov et al., 2005)

| *Components* | *Dunites* | *Medium interspersed ores* | *Thickly interspersed ores* |
|---|---|---|---|
| SiO2 | 41,1 | 41,31 | 42,39 |
| TiO2 | 0,04 | 0 | 0 |
| Al2O3 | 0 | 0,00 | 0 |
| Cr2O3 | 0 | 0 | 0 |
| FeO | 7,59 | 4,29 | 2,36 |
| MnO | 0,14 | 0,07 | 0 |
| MgO | 50,13 | 53,28 | 53,8 |
| CaO | 0,01 | 0 | 0 |
| V2O5 | 0,00 | 0 | 0 |
| NiO | 0,4 | 0,51 | 1,26 |
| Total | 99,41 | 99,46 | 99,81 |
| f | 7,8 | 4,3 | 2,4 |

High Ni contents in olivine chromitites are linked with high pressures, presumably arising in the deformation stresses (Vakhrusheva, 2012). A more reasonable explanation for this "phenomenon" is nickel growth in olivine chromitites due to diffusion redistribution from Ni-containing sulfide phases, which are widespread in the ores (Structure.., 1990, Moloshag et al, 1999).

## PGE, SULPHIDE AND NATIVE MINERALIZATION

Accessory mineralization of chromitites from peridotites of the Rai-Iz massif is presented by sulfides, oxides, carbides and intermetallic compounds. Of particular interest are the sulfides and intermetallic compounds of platinum group elements (PGE) as well as nickel, iron and copper, as they are synchronous to chromite forming processes and their subsequent transformation.

**PGE mineralization** of the Rai-Iz massif chromitites has been studied since the 90s of the last century (Anikina et al., 1995, Volchenko, 1990, Garuri et al., 1999). In the last work presents the results of a detailed study of platinoids and gives data on their composition. The authors highlighted early mineralization, syngenetic to chromites, and late mineralization related to chloritization. The leading PGE minerals of early associations are laurite, erlichmanite, and Os-Ir alloys, accompanied by cuproiridsite (Ir2CuS4), kashinite ($Ir_2S_3$), rhodian pentlandite, unknown sulfides with stoichiometries varying from

$(Ni{>}Fe{>}Cu)_2(Ir{>}Rh)S_3$

to $(Ni{>}Fe{>}Cu)_2(Ir{>}Rh)S_4$,

irarsite, cherepanovite (RhAs), and unknown $(Rh, Ni)_2As$ (Table 3). Later the list of PGE minerals was clarified and supplemented with a new iridium-nickel sulfide composition $Ir_2Ni_4S_7$ (Gurskaya et al, 2004).

The temperature of formation of the PGE minerals early generation in the Rai-Iz massif , according to the sulfur crystallization parameters (Garuri et al., 1999), ranged from 1100 to 900°C with increasing volatility from -3 to +1 log $f\,S_2$. Comparable temperatures are obtained using syngenetic accessory sulfides and especially iron-nickel monosulfide solid solution (MSS).

The assessment of the platinoids content in the Rai-Iz massif ores is based on bulk analysis of PGE in chromitites (Gursky et al, 2004; Pasava et al., 2011). Virtually all studies note the predominance of refractory Os, Ru, and Ir concentrations over other PGE. This trend is observed for the majority of the known chromite ore deposits, genetically related to Alpine-type peridotites.

Table 3

**Mineralogy of the PGM from Ray-Iz chromitites**

(after Garuti et al, 1999)

| *Sample* | *Deposits* | *PGM assemblages* |
|---|---|---|
| 1398 | Central | laurite |
| 1399 | " | laurite, unknown Ir-Rh-Ni sulfide |
| 1400 | " | laurite, irarsite, unknown Ir-Rh-Ni sulfide, |
| | | rhodian pentlandite |
| 1401 a | " | laurite |
| 1401 b | " | laurite, cuproiridsite, kashinite, unknown |
| | | Ir-Rh-Ni sulfide |
| 2243 a | " | laurite, Os-Ir alloy |
| 2243 b | " | laurite, unknown Rh-Ni arsenide (*) |
| 2246 | " | laurite, irarsite |
| 2344 | " | laurite, unknown Ir-Rh-Ni sulfide |
| 2356 | " | laurite, unknown Ir-Rh-Ni sulfide |
| 2375 | " | laurite, Os-Ir alloy, unknown Ir-Rh-Ni sulfide |
| 2399 a | " | laurite, unknown Ir-Rh-Ni sulfide |
| 2399 b | Central | laurite |
| 2076 | West | laurite, Os-Ir alloy |
| 2077 | " | laurite |
| 2078 | " | laurite, irarsite, cherepanovite |
| 2079 | " | laurite |
| 2081 a | " | laurite |
| 2081 b | " | laurite, irarsite |
| 2083 | West | laurite |
| 4078 | Poloishor | Ru-Os-Fe oxides (*) |
| 5081 | " | laurite (*), irarsite (*) |
| 5825 | Poloishor | laurite, Os-Ir alloy |

Petrological and structural analogies indicate that the fluid-induced metasomatism occured in the residual oceanic mantle of the Polar Urals, was probably responsible for the formation and reequilibration of the chromite-PGM system at the Ray-Iz massif (Garuti et al., 1999).

**Sulfide mineralization** of the chromite ores is presented by heaslewoodite, pentlandite, bornite, pyrrhotite, cubanite, chalcopytite, monosulfide solid solution (MSS),digenite, godlevskite, millerite and violarite (in the order of their relative spreading). With the enumerated sulfides are being associated native metals and nickel arsenides (orselite, maucherite).

The most interesting among the studied sulfides is the monosulfide solid solution (MSS). At the Voykar-Syn'insk and Rai-Iz massifs as distinct from the Nurali MSS it is widely spread in the form of early inclusions with drop-like, seldom – framed contours in the unalterated grains of olivine and pyroxene from ore-enclosing dunites and harzburgites. Composition of the MSS grains correlates with a continuous series of solid solutions Fe-S and Ni-S with small quantities of copper and cobalt impurities. Points composition of the investigated MSS are arranged on lines in the system stability Fe – Ni – S, corresponding to temperatures of 900 to 1150°C (Moloshag et al, 1999).

The compound part of paragenesis of the sulfide syngenetic inclusions of the infusible platinoids of monosulfide copper-iron-nickel solid solutions, as well as of high-temperature heazlewoodite are the detected by us escolaite, corundum and moissanite (Moloshag et al., 1999). Moissanite has been detected in the Centralnoye deposit, Rai-Iz massif and different mineral occurrences of the Voykar massif. It is presented in the form of isometric, seldom – faceted inclusions in chromite of sizes to 15 mk. The major part of the moissanite inclusions in chromite is surrounded by amorphous graphite-chlorite (?) rim.

**Ultra-high pressure (UHP)** minerals, including diamond, first discovered in chromite ores of the Rai-Iz massif (Yang et al., 2007). Diamonds from chromitites (discovered more than 1000 grains) are clear, colorless, well-developed crystals with octahedral morphology, generally 0.2-0.4 mm in size. In association with diamond are found native Si and Ta, corundum, zircon, feldspar, garnet, moissanite. Other mineral group includes: carbides SiC and WC; alloys such as Cr-Fe, Si-Al-Fe, Ni-Cu, Ag-Au, Ag-Sn, Fe-Si, Fe-P, and Ag-Zn-Sn; oxides Ni-Cr-Fe, Pb-Sn, REE, rutile and Si- bearing rutile, ilmenite, corundum, chromite, MgO, and $SnO_2$; silicates as kyanite, pseudomorphs of octahedral olivine and quartz; sulfides of Fe, Ni, Cu, Mo, Pb, Ab, AsFe, FeNi, CuZn, and CoFeNi; and iron groups: native Fe, FeO, and $Fe_2O_3$.

It is important to note that diamond was also found as inclusions in chromite (Yang et al., 2014). The diamonds occur in situ as subhedral to euhedral crystals ~0.2–0.5 mm in diameter, contained in small patches of carbon hosted in magnesiochromite. These patches consist mainly of amorphous carbon, as deduced from the absence of any Raman pattern and from element mapping by electron microprobe. The amorphous carbon is a solid glass and very hard, and commonly contains small fragments of chromite (Fig. 9).

The discovery of UHP minerals in chromitites of the Urals ophiolites and other regions does not yet have universal explanation, because it is not clear where the diamonds were formed and how they were integrated into the shallow mantle peridotite (Arai et al., 2013, Yang et al., 2014).

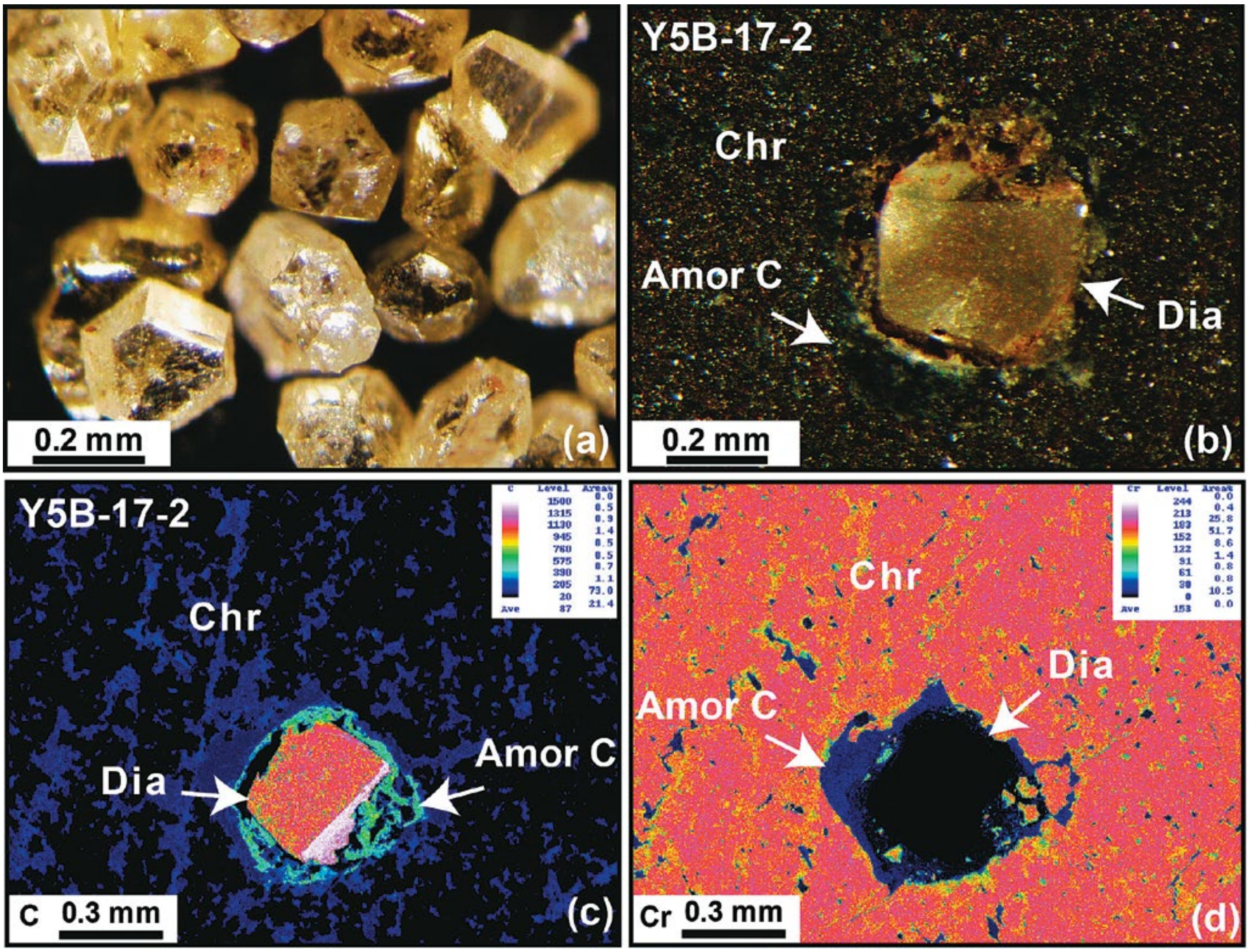


**Fig. 9**. Diamonds are discovered in chromitites of the Rai-Iz massif (after Yang et al., 2014). (a) Diamond grains separated from chromitite of the Ray-Iz ophiolite. (a) In situ diamond occurring as an inclusion in chromite (sample Y5B-17-2). (a) Carbon element map showing a diamond grain (reddish orange) in a subcircular patch of amorphous carbon (light green) hosted in chromite (dark blue). (d) Chromium element map indicating small chromite grains in the amorphous carbon patch is shown in (C). Chr = chromite, Amor C = amorphous carbon, Dia = diamond

# SCHEDULE OF EXCURSIONS

## Day 1 (August 1, 2014): Arrival Day

Arrival of the trip participants at Salekhard Airport.
Visit to the Shemanovsky museum complex and other attractions.
Ferry transfer to the town of Labytnangy across the Ob River.
The participants get-together in the scientific station of the Institute of Plant and Animal Ecology UB RAS (Zelenaya Gorka Street, 21).
Visit to the Geological Museum of the YaNAO Territorial core storage.
Departure of the participants to Kharp township (35 km), accommodation at the "Sob" hotel.

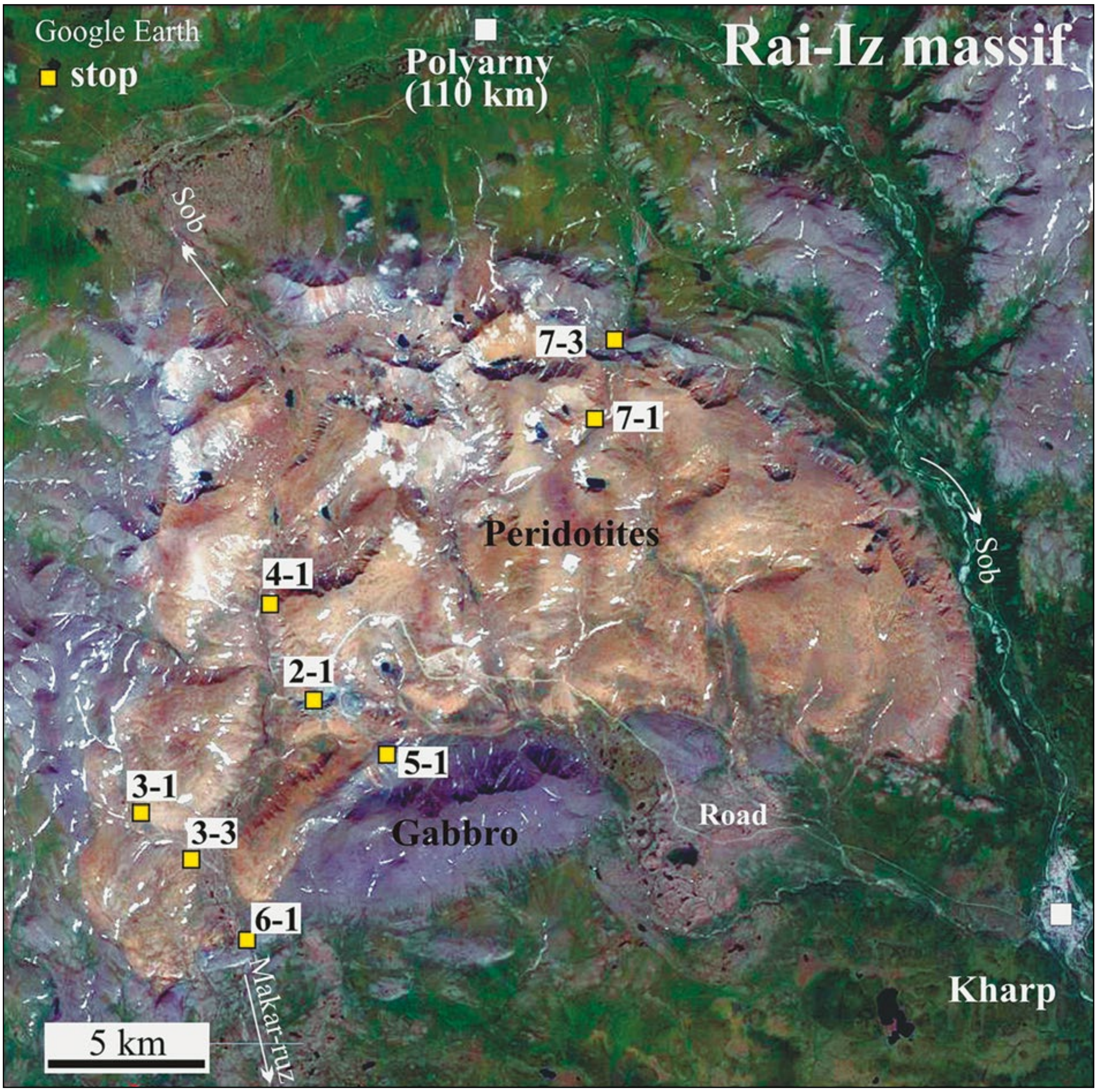


**Fig. 10.** Position of the main objects and stop excursions of the Rai-Iz massif

## Day 2 (August 2, 2014) THE "CENTRAL" CHROMITE DEPOSIT

## Brief Description

**The Northern area** of the deposit is controlled by the apophysis of a large dunite body about 540 m wide. Within the dunite block, 39 chromite ore bodies with an average thickness of about 4.8 m have been identified. The length of the ore bodies is from 9 to 313 m. Mineralization is represented by the Eastern and Western subzone separated by a dunite band, whose width decreases in the northeastern direction from 230 to 80-100 m (Perevozchikov et al., 2005).

*The Eastern subzone* has a length of about 600 m. Its thickness increases in the northeastern direction from a few meters to 120 m. Within the subzone, 19 ore bodies have been identified, the largest of which (numbers 6, 8, 17, and 83) are accompanied by smaller bodies and can be regarded as a reservoir. The ore bodies strike to the northeast (25°-60°) with smooth curves and dip steeply (75°-85°) to the north-west, almost subvertically (Fig. 11). For the majority of ore deposits and bodies the northeast inclination angle of 25° to 80° has been established. The form of ore bodies varies from lenticular to tabular and irregular. The length of ore bodies along strike varies from a few tens to 300 m. The ore body thickness varies from 0.5m to 39.5 m (average 5.7 m). Most bodies are characterized by smooth change of thickness along strike and dip; the contacts of the ore bodies are mostly sharp. Prevailing among chromite ores are medium- or thick- interspersed varieties with modal content of 40-45 wt.% of $Cr_20_3$. Balance reserves chromite orec of the Eastern subzone amount to 4,010,000 tons at an average $Cr_20_3$ content of 33.38 wt.%.

*The Western subzone* has a length of about 500 m, its thickness increases from south to north from 120-150 m to 170-200 m, and then decreases sharply to 70 m. Within the Western subzone, 20 chromite ore bodies have been identified. The ore bodies strike to the northeast (from 20° to 70°) with smooth curves and dip steeply to the northwest, almost subvertically. The ore body length varies from 11 m to 93 m (average – 39 m). The thickness of ore bodies varies from 0.2 m to 9.1 m. A distinctive feature of the Western subzone is an increased impregnation halo around chromite bodies. The zone is characterized by frequent alternation of different types of chromite ores and dunite layers. Poorly interspersed ores dominate here. Balance reserves of chromite ores in the Western subzone is 1,400,000 tons, with an average $Cr_20_3$ amount of 30.95 wt. %. Balance reserves of chromite ores for the Northern portion is 5,410,000 tons with an average amount of $Cr_20_3$ of 32.98 wt% (Perevozchikov et al. 2005).

**The Southern area** of the deposit is a continuation of the Northern area with a possible shift along the large cross fault. The geological structure of the Southern area includes dunites and harzburgites with different content of the dunite component.

Within the Southern area of the deposit, 27 chromite bodies have been identified. The distance between the ore bodies vary from 5 m to 200-250 m, averaging 55 m. The ore bodies strike to the northeast (30°-80°) and dip steeply (70°-85°) to the northwest. For individual ore bodies the northeastern inclination (30°-70°) has been established. The ore body thickness varies from 0.4 m to 20.3 m (4.1 m on average). The largest ore body is number 9, which was uncovered by the South quarry. The deposit is composed of ore bodies 9, 35, 48, 50, and several others, which often merge with each other. The shape of ore bodies is flattened lenticular, irregular or tabular (rarely). Dominating are rich-impregnated (medium-, thick- and solid- interspersed) chromite ores with $Cr_2O_3$ content of more than 35-40 wt. %. Balance reserves of chromite ores for the Southern area are 606,000 tons at an average $Cr_2O_3$ content of 41.26 wt.%, including 213,000 tons for open-pit mining.

Total balance reserves (C1 + C2) of the Central chromite ore deposit, calculated to the depth of 100-200 m, are 6.0 million tons (Ovechkin, 2003, 2010). The total potential reserves of chromite ores of the Central deposit, estimated to the horizon +240 m is 20.5 million tons. Currently the Central deposit has been largely worked out from the surface. Further extraction of chromites is planned from deep horizons by underground mining in prepared exploration galleries (G-420, 480).

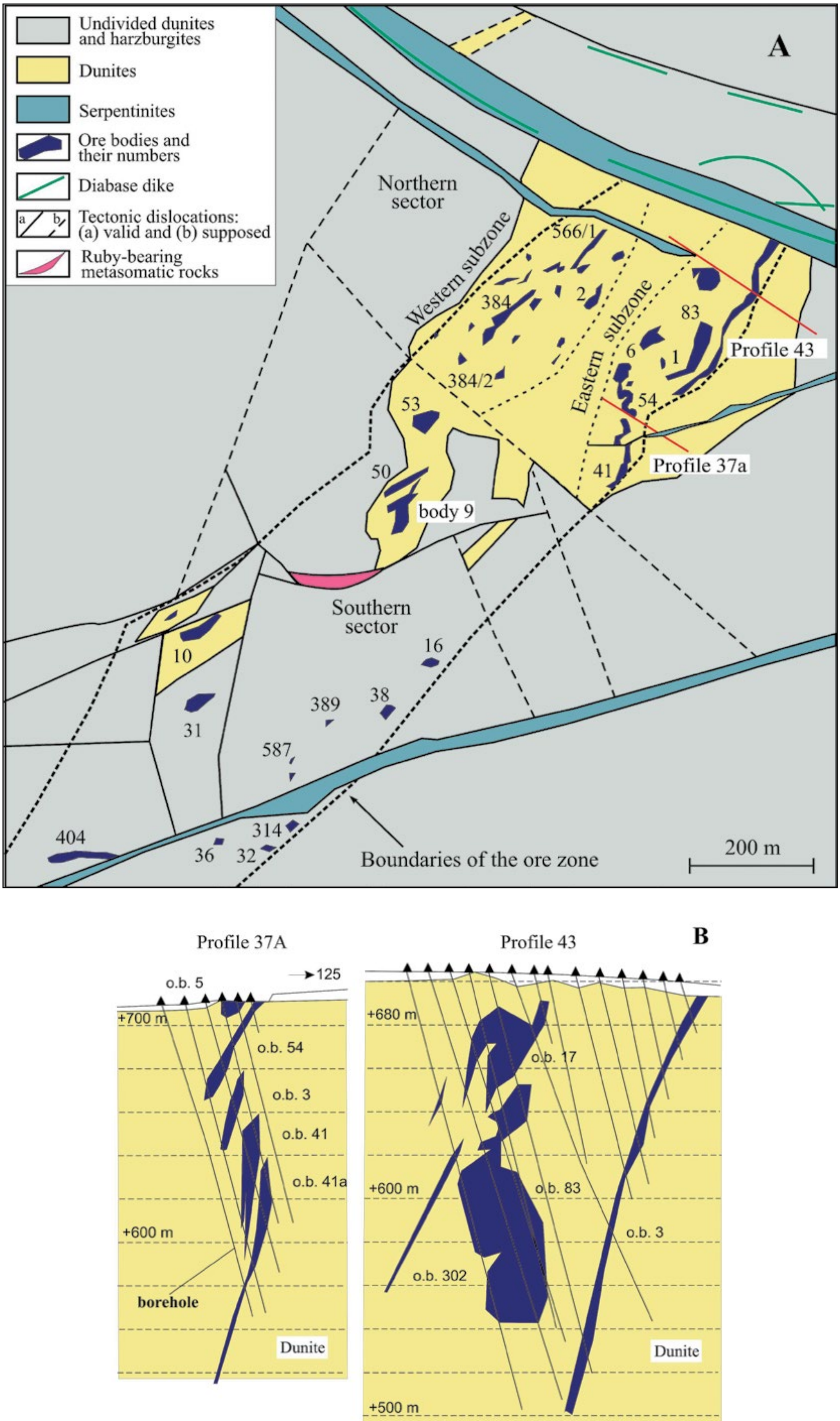


**Fig. 11**. (a) Geological plan of the Central deposits, (b) sections for the Eastern subzone (Profile 37A and Profile 43) (after Perevozchikov et al., 2005)

An interesting feature of the Rai-Iz massif is the presence of **corundum (ruby)-bearing metasomatites** in peridotites. There are several point manifestations and one small deposit of corundum (rubies), located in the western part of the Central chromite deposit (Scherbakova, 1975).

The ruby deposit is presented by an only body with the thickness of 20-22 m, north-west strike (300°) and subvertical dip. There are three zones in this body: plagioclase (central), mica and amphibole (marginal). The central zone, up to 3 m thick, has a lenticular shape and is composed of plagioclase (andesine-oligoclase) rock. The mica area has variable thickness (0.3-1.0 m) and consists of inner phlogopite and alternating phlogopite-ruby with acid (oligoclase-albite) plagioclase. Rubies are mostly small, but we came across large crystals of cherry-red color and up to 12 cm in size (Fig. 12a). The outer zone of 7-8 m thickness is mostly actinolitic, and it contacts with dunites through a thin (20-30 cm) rim of talc-chlorite-serpentine rocks. Ruby-containing rocks are considered a product of diffusion (Al, K, Na) metasomatism of gabbro-pegmatites, at temperatures of about 400-420° (Shcherbakova, 1975).

According to isotopic Rb/Sr data, metasomatites are of Late Devonian (373.1 ± 5.4 Ma) age, and were formed under the influence of fluids of suprasubduction nature (Glogny et al., 2003). Their formation was possibly associated with the intrusion of the Sobsky complex plagiogranitoids, also having similar (Devonian) age marks.

Another manifestation of corundum (Sapphire) in the Rai-Iz massif is located more to the south, among the rocks of the MTZ transition complex. It is characterized by large (up to 20 cm) grayish-blue crystals of corundum in plagioclasite veins (photo 12b).

**Stop 2-1. The eastern subzone chromites** (Fig. 10)

Position: 66°51’39.03”N 65°15’34.81”E.

The Southern side of the North quarry. From this site participants have a good view of the largest (more than 80 m deep) deposit, where chromites were mined from ore bodies numbers 8, 17, 54, 83, etc. In the northern background one can be trace a serpentinite zone of Poloyshorsky fault with dolerite dykes (Fig. 13). The walls of the roadway excavation and mine dumps shed light on structural features of the host dunites and chromitites. Currently, mining operations are not conducted in the quarry.

**Stop 2-2. The western subzone chromites**

Position: 66°51’49.9”N 65°15’21.5”E

The southwestern part of the North open-pit. Several large bodies have been uncovered here, including ore body 384/1 of the northeastern orientation, traced over a distance of 200 m (Fig. 14). The contacts

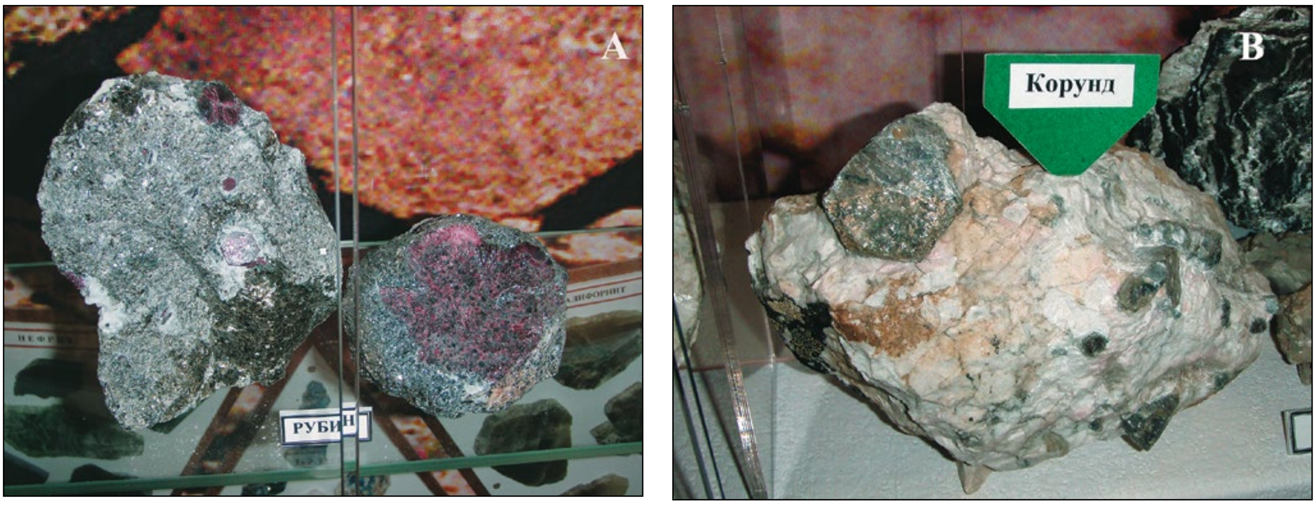


**Fig. 12.** (a) Ruby crystals in mica metasomatic rocks of the Central chromite deposits; (b) blue-gray crystals of corundum in plagioclasites of the contact zone peridotite with gabbro (from the collection of I. Popov, Territorial core storage Museum, Labytnangy)

**Fig. 13.** Panorama of Central chromite deposits (eastern subzone). The arrow shows the position of the Poloyshor fault. View from the south wall of the quarry (2011)

**Fig. 14.** Chromite sampling from the ore body «384/1» and host dunites. In the picture researchers from Japan, Prof. Arai S., Dr. Ishimaru S. and Miura M. (2013)

between chromitites and dunites are usually sharp, the ores belong to densely impregnated type and are located in dunites with increased chromite impregnation.

**Stop 2-3. The southern part chromites**

Position: 66°51'43.1"N 65°15'06.0"E

The South quarry/ open-pit uncovers the ore reservoir/pool/deposit No. 9 (Fig. 12). In its northern part it is represented by ore body No. 48/1 (up to 1.5 m thick) of northeastern strike, composed of thickly interspersed chromite ores. Fifty meters to the south there is ore body No.9 (worked out from the surface) of massive ores, surrounded by a halo of densely and moderately interspersed ores of complex morphology.

**Stop 2-4. Chromitites and ruby-bearing metasomatites**

Position: 66°51'35.40"N 65°14'44.93"E

Area near the road close to the former Ruby quarry offers a majestic view of the Makar-Ruz river valley and down-streaming serpentine roads (Fig. 15). In the quarry wall and blocky rock debris one can observe various in texture chromite ores and their relationship with dunites, showing a complex mechanism of their formation (Fig. 16).

Nearby, among the mine dumps there are scattered debris of fine and medium-grained plagioclase-phlogopite rocks with small (up to 5 mm) ruby, albitite and actinolite crystals. Ruby metasomatite outcrops unfortunately not available for inspection (they are backfilled). Below, in the Makar-Ruz river valley, there is a series of trenches, with which miners tried to uncover an alleged ruby placer.

**Fig. 15**. Panorama of the Makar-Ruz river valley. At the bottom before the turn of the road is an exploratory adit in chromitites. Over the mouth of the Kuztyvis creek is located metaperidotite and amphibolite area. In the background the Lekvozh mountain is hidden by clouds

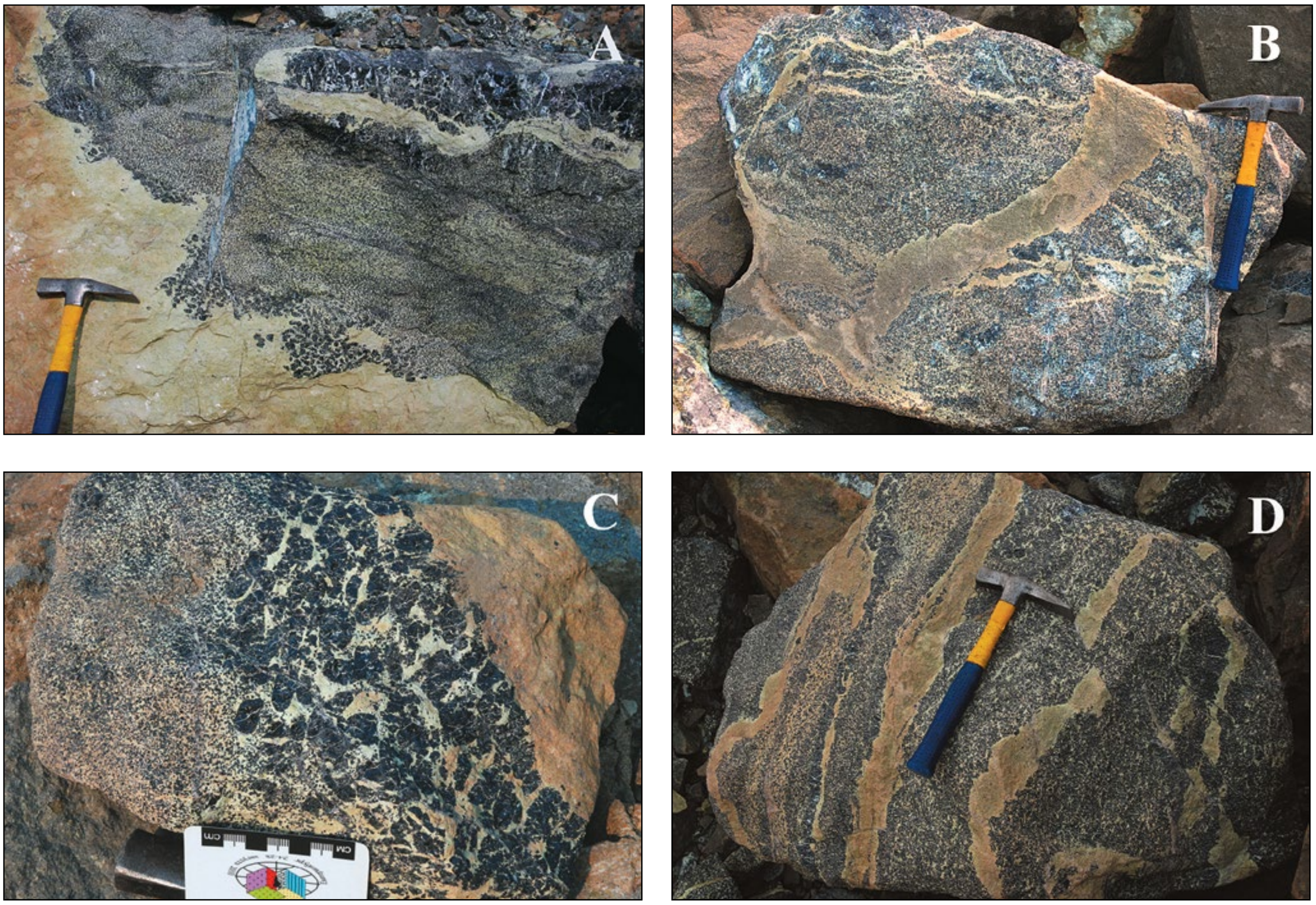


**Fig. 16.** Textural features of rocks and chromite ores, Central deposit: (a) nodular chromite at the contact of pegmatoid dunite, (b) chromite ore with stockwork of dunite veinlets, (c) relationships of different type chromite ores and dunite, (d) schlieren-banded texture formed by dunite veins. Photos presented E. Pushkarev

**Stop 2-5. Host peridotites and dunites of the southeastern flank**

Position: 66° 51’ 21.4”N 65°16’ 35.6”E

A series of outcrops on the plateau (near the village), traced along the edge of “Moldavantsev” kar in the southeastern direction from the chromite-bearing zone to the border of the MTZ transition complex. Outcrops are presented by schlieren-like and banded harzburgites with concordant bands (veins) of yellow dunite (up to 10 cm or more) (Fig. 17a,b). Among dunites one can identify pegmatoid dunites of medium- and coarse-grained variety. Banding has subvertical bedding and northeast (50-60°) strike. In harzburgites (near the kar edge) a small concordant body of densely interspersed chromite ore (about 0.7 m thick) with sharp contacts is exposed (Fig. 17c).

The role of dunite component in harzburgites increases (up to 50%) toward the chromite-bearing zone, and a well-defined deformation mineral foliation (dip azimuth 130-150°) and the lineation of the steep northeastern pitch appear. In the southeastern direction the rocks of the dunite-harzburgite complex are replaced by a wide band of sand-yellow dunites, located on the border with the transition complex. Peridotites of this complex have experienced metamorphism; clinochlore and tremolite prevail in harzburgites along with olivine and enstatite.



**Fig. 17**. The host peridotites of the Central deposit: (a) schlieren-like harzburgite, (b) dunite and (c) small concordant chromitite body in harzburgite

## Day 3 (August 3, 2014) THE SOUTHWESTERN CHROMITES ORE FIELD

### Brief description

**Deposit «214»** is located in the western part of the ore field in the left side of the Vizuv-Shor River valley (Fig. 7). It is located within the dunite-harzburgite rock complex with low (10-30%) content of the dunite component; the rocks have experienced metamorphism. It is composed of three lenticular and one flattened lenticular body, forming an ore-bearing zone stretching over 450 meters. Ore bodies are from 70-160 m to 450 m in length, with thickness of 0.1-8.7 m. The bodies strike northeast (0-40°), and dip steeply, almost subvertically, the inclination of lenticular bodies is to the northeast at an angle of 50-60°. The bodies have sharp contacts and a dunite rim around them (Perevozchikov et al, 2000).

The ores are usually thickly interspersed and massive; in their marginal parts the bodies are rarely and medium interspersed. The ore metamorphism in rarely interspersed varieties is weak or moderate. Chrome spinel ore has the composition of magnesian subferrichromite with the following component composition (wt%): $Cr_2O_5$ – 64.3, $A1_2O_3$ – 7.84, $Fe_2O_3$ – 7.76, FeO – 9.13, MgO – 15.11. The predicted reserves are (kt) cat. $C_2$ – 577, cat. $P_1$ – 618, cat. $P_2$ – 800. According to the results of technological tests, the ores are characterized by good enrichment ability with a high percentage of chromium extraction (obtained from the ore concentrate with 52.51 wt % of $Cr_2O_3$).

**Southwestern Ore Occurrence IV** is on the right bank of the Makar-Ruz and Vizuvshor River, in the northeastern circuit of the Southern dunite body. Host rocks are large- or giant-grained dunites (Perevozchikov et al, 2000). The ore occurrence is located within a zone up to 2 km long and 1 km

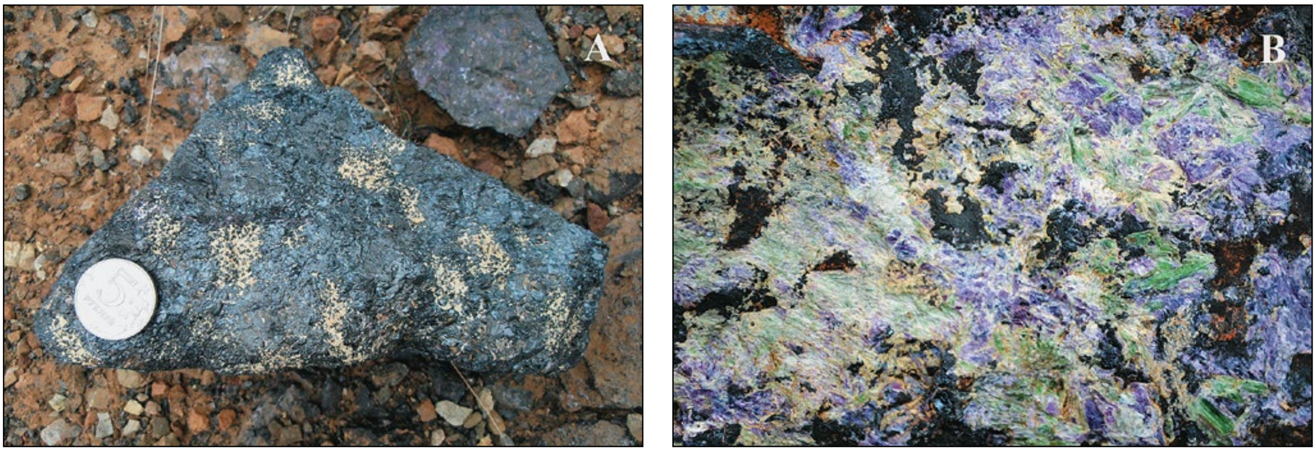


**Fig. 18**. Chromite deposit "214": (a) ore with antinodular texture formed by subisometric "spots" olivine aggregate with grains of chromite; (b) kemmererite and fuchsite aggregates developing over planes in chromite

wide. Its structure has more than two tens chromite ore bodies of lenticular flattened shape with primarily submeridian strike and steep dip. The bodies are large, such as 237, 1052, 1053, 1054, etc. The ore bodies have a length of 20-200 m and thickness within 0.2 m to 9.0 m. The ores vary from poorly interspersed to massive and nodular. The content of $Cr_2O_3$ in the ore is 15.68-53.30. Chrome spinel ore has the following average composition (wt%): $Cr_2O_5$ – 54.3, $A1_2O_3$ – 12.72, $Fe_2O_3$ – 5.87, FeO – 13.51, MgO – 13.34, $TiO_2$ – 0.2. The ore occurrence refers to a highly promising type.

**Stop 3-1. Chromite of ore body 214** (Fig. 10)
Position: 66°49' 37.6"N 65°07'27.3"E
The left bank of the Vizuvshor river (1.5 km from the western contact of the massif). In clearings and trenches, massive and densely interspersed chromite ores, surrounded by dunite rim, are exposed. There are unusual varieties among them with "antinodular" texture formed by subisometric olivine-chromite clusters in massive chromite (Fig. 18a). The development of brightly colored aggregates of kemmererite and fuchsite is observed in the ores (Fig. 18b). In close vicinity of the ore bodies there are harzburgite outcrops. The structure of the harzburgites and dunites can be seen in the abandoned borehole core.

**Stop 3-2. Host harzburgites and dunites**
Position: 66°49'18.98"N 65°7'39.47"E
To the south of ore body 214 (within 500 m) on the left bank of the Vizuvshor River, multi-deformed (of cellular appearance) banded harzburgites with concordant or discordant dunite veins are exposed. Their distinctive feature is the presence of two systems of planar orientations. The basic system is presented gneissic harzburgites and concordant parallel dunite veins of northeastern (130°) strike. The second system is recorded by cutting submeridional (strike 350-10°) orientation of enstatite schlierens, which penetrate into the dunite in the form of aggregates by shear cracks (Fig. 19). Harzburgite microstructure analysis shows the existence of clear double maxima of [010] axis of olivine that control planar orientation systems. These relationships reflect a two-stage plastic deformation and recrystallization of rocks (Structure.., 1990). Similar to the Central deposit peridotites, they have undergone to metamorphism.

**Stop 3-3. Chromites of ore body 237** (Fig. 10)
Position: 66°48'51.63"N 65°9'23.38"E
The right bank of the Vizuvshor River, near the north-western end of the large South dunite body. A large lenticular flattened ore body 237 of submeridional strike and subvertical dip crops out in a trench. Host rocks are medium-grained dunites. The body is up to 6 m thick and more than 80 m long. The ores are medium and densely interspersed or massive, fresh or slightly metamorphosed..

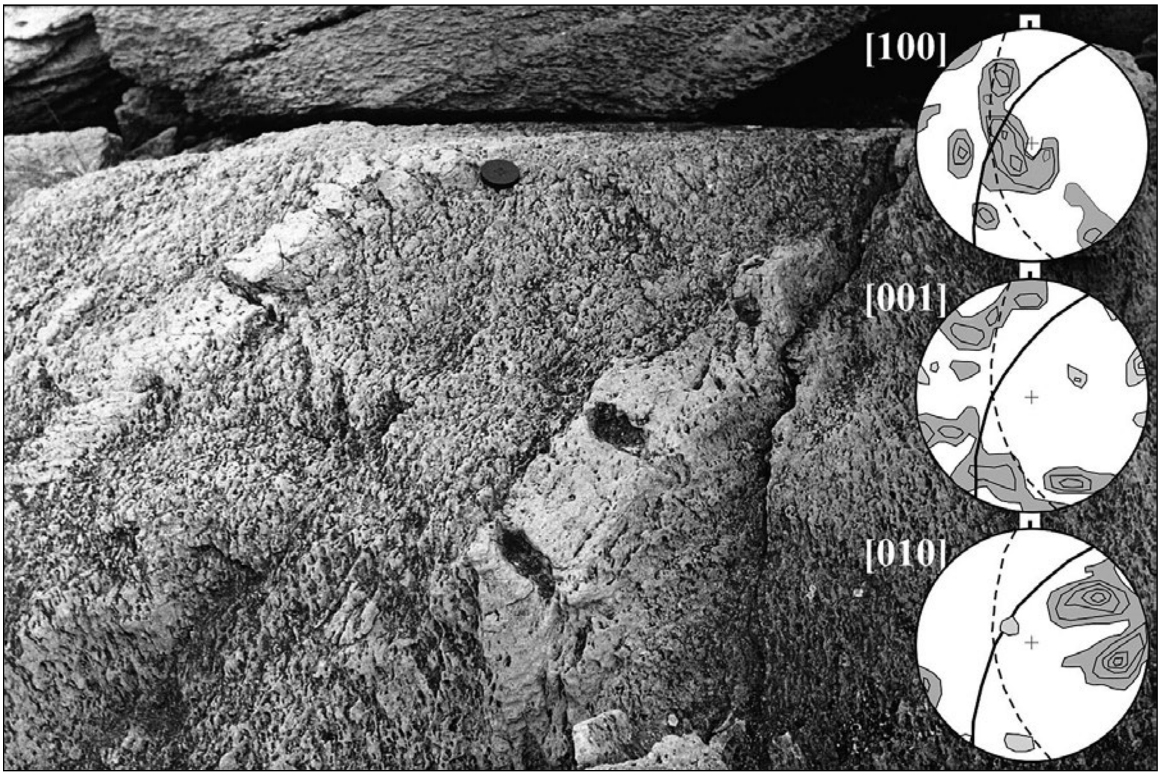


**Fig. 19.** Harzburgite with dunite veins and bands exhibiting second (crosscutting) planar orientation of enstatite. The inset shows the orientation of the olivine axes relative of the mineral foliations system in harzburgites (Vizuvshor river)

The ore levels of $Cr_2O_3$ are 39.2-44.2 wt.%. Chrome spinel ore has the following average composition (wt.%): $Cr_2O_5$ – 57.7, $A1_2O_3$ – 10.91, $Fe_2O_3$ – 6.31, FeO – 10.47, MgO – 14.61. The ore occurrence refers to low and medium potential type (Perevozchikov et al, 2000).

**Stop 3-4. Chromites of ore body 1053-1054**

Position: 66°48'46.16"N 65°9'42.49"E

The western slope of the Makar-Ruz River, 300 m to the south of Stop 3-2. Two contiguous ore bodies 1053 and 1054 of submeridional orientation located in dunites, have been uncovered in the trenches. Ore body1053 has a length of about 100 m and an apparent thickness of about 6 m. The ores are densely and moderately impregnated, the contacts with the host dunites are sharp. The ore has thin (up to 2 cm) straight crosscutting submeridional bands of dunite composition. The orientation in the host dunites is emphasized by chromite schlieren and bands. The second body No.1054 is presented by medium and poorly disseminated ores, among which there are boudinaged areas of thickly disseminated and nodular ores (Fig. 20). The ore body is deformed

**Fig. 20**. Nodular chromite from the marginal parts of the body «1053», the manifestation of southwestern IV (right slope of the Makar-ruz river)

by folding, whereby the orientation of chromite layers and chromite banding becomes predominantly sublatitudinal (105-120°) with a steep (80-90°) dip in the northern direction. Chromite banding is deformed into small flow folds of isoclinal type. The folds have steeply dipping joints and submeridional orientation of axial planes (Fig. 21). Parallel to these planes are band thin dunite veins, similar to the noted above.

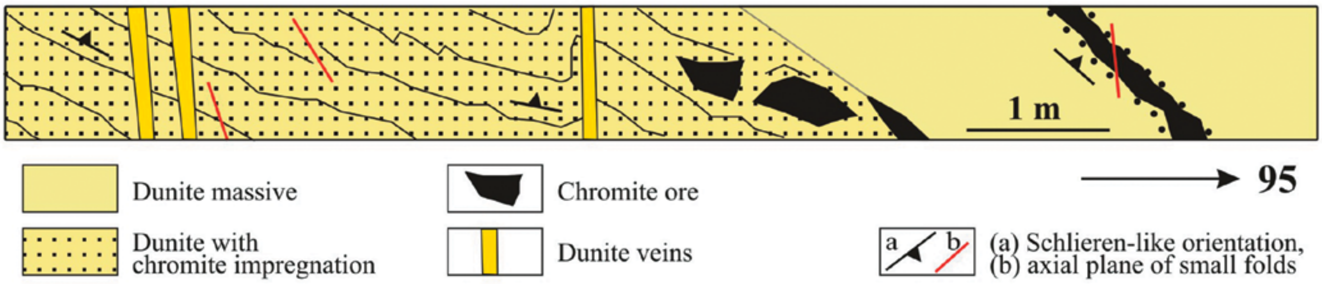


**Fig. 21**. Fragment of the ore body «1054» structure is located at the periphery Southern dunite body (after Structure.., 1990)

## Day 4 (August 4, 2014) METAMORPHIC ROCKS OF THE CENTRAL PART MASSIF

### Brief description

The Rai-Iz Massif is the only object of the Urals ophiolites, where the products of high-temperature metamorphism of amphibolite facies are presented most comprehensively. They are concentrated within a wide zone of northeast strike, dissecting the massif into two parts. The zone is confined to the massif contours and shows signs of a symmetric structure (Dobretsov et al., 1977, Structures.., 1990).

The axis of the zone of about 500-800 m wide has coarse-grained and pegmatoid olivine-enstatite rocks, enstatitites and sagvandites. Enstatite forms typical porphyroblasts and grain aggregates of radial fibrous structure, reflecting the conditions of static rock crystallization. Unlike enstatite of "primary" peridotites, it is practically sterile regarding calcium and alumina impurities.

Metaperidotites are associated with dyke-like and more complex morphology (with thickness up to a few tens of meters) bodies of banded amphibolites and hornblendites. Among them zoisite-epidote and garnet (almandine) amphibolites are observed. The rocks often have isoclinal and more complex flow folds. The orientation of structural elements in amphibolites and host metaperidotites is usually concordant. No other "exotic" rocks, e.g. shales (from the surrounding formations massif) are observed in the zone of metamorphism.

Amphibolites belong to moderately- or high-titanium (1.0-2.6wt% $TiO_2$), ferrous formations with low strontium content (less than 200 ppm). The distribution, characteristic for most rocks, is similar to that of N-MORB basalts, but with a relatively high REE and low Zr content. The rock varieties with usual titanium content tend to have lower REE and especially LREE content. In general, these structures can be identified as dolerites and gabbro-dolerites, differing significantly from depleted REE of the layered gabbro ophiolite association of the Polar Urals (Fig. 22).

Enstatite-olivine rocks, enstatitites and amphibolites are surrounded by a wide (up to 3 km) area composed of secondary porphyroblastic harzburgites and dunites (enstatite dunite). Harzburgites contain not only olivine and secondary enstatite, but also amphibole (tremolite), clinochlore and chrome magnetite. The rocks demonstrate a significant degree of deformation; they exhibit a distinct mineral foliation, frequent presence of two planar orientations and flowage features. Toward the zone periphery, the level of metamorphism is reduced, and normal harzburgites with chrome spinel gradually appear in the section.

Ultramafic and mafic rocks metamorphism occurred in the process of the massif advancement into the upper crust horizons, under the influence of significantly hydrous (possibly silica-containing)

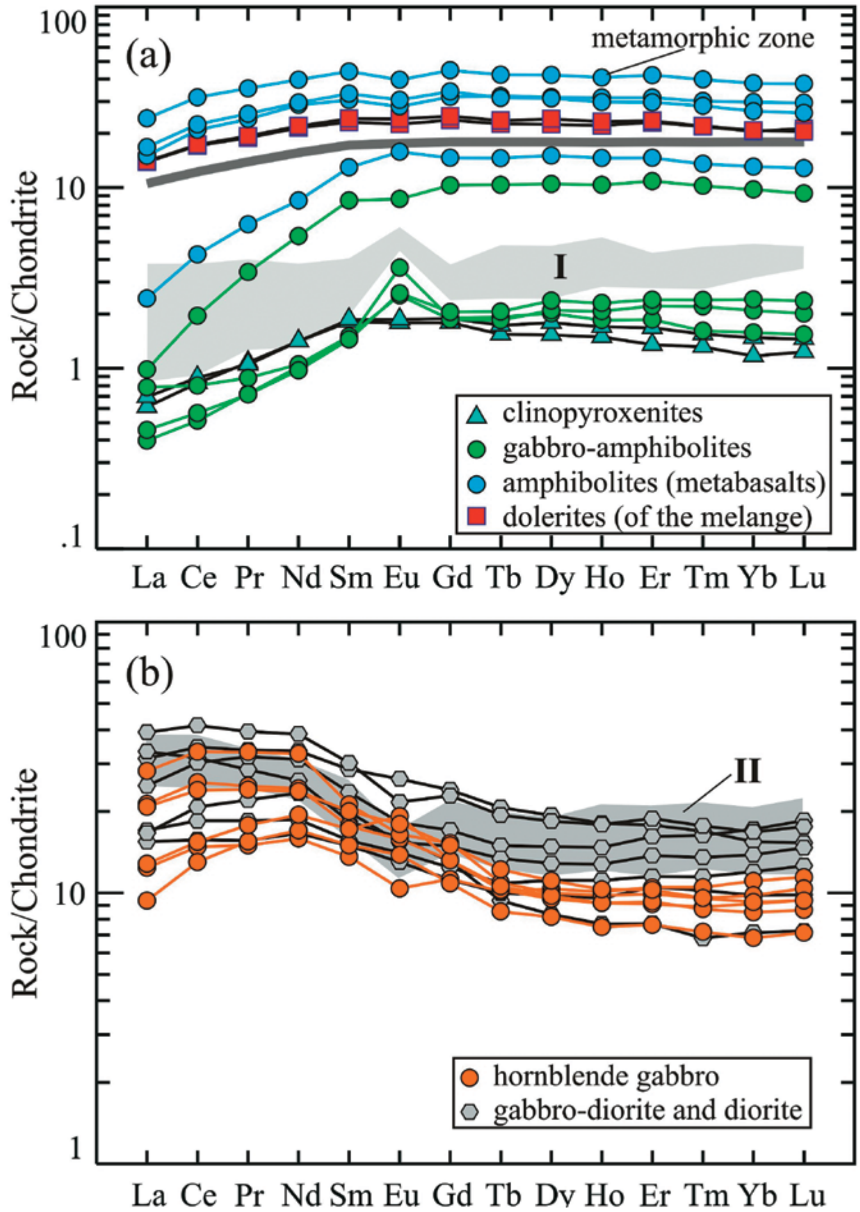


**Fig. 22**. REE distribution in the basites: (a) ophiolite and (b) postophiolite association of the Rai-Iz massif (modified from Shmelev, Meng, 2013). Numerals designate: I – gabbro kershor complex compositions of the Voykar massif (Remizov et al, 2010), II –plagiogranitoides compositions of the Upper Tagil complex of the Horasyur massif (Shmelev, 2005)

fluids before the low-temperature looped serpentinization (Stroenie.., 1990). According to an alternative view, the metamorphism was progressive in nature and was accompanied by ultramafic rock deserpentinization (Chashchukhin, 1985, 2007).

**Stop 4-1. Sagvandites, olivine-enstatite rocks (secondary harzburgites)** (Fig. 10)
66°53'31.45"N 65°12'49.83"E

A small hill with outcrops on the left bank of the Makar-Ruz River (near the mouth of the Makar-Ruz left brook). These exposures are represented by massive coarse-grained, structureless, essentially enstatite and olivine-enstatite rocks. Enstatite forms aggregates of radial structure, reaching more than 10 cm in cross-section (Fig. 23a). The rock contains small plates of light green clinochlore, tremolite


**Fig. 23**. (a) pegmatoid enstatitite of axial zone metamorphism (green mineral – actinolite, clinochlore). (b) secondary harzburgite with large enstatite porphyroblasts. In rock are observed bands (interlayers) of olivine composition. Left bank of the Makar-Ruz river

(actinolite), and carbonate; the presence of the latter allows us to call these rocks sagvandites. There are some areas of development of talc and intense serpentinization..

To the north and east, these rocks are surrounded by secondary harzburgites with characteristic large (up to 2 cm) accumulations of porphyroblastic enstatite (Fig. 23b) with a gneissic-banded structure. They have stable northeastern (40-60°) strike and predominantly southeastern dip at an angle of 45-60°. Somewhere secondary harzburgites are crumpled into compressed subisoclinal folds with steep plunge (Stroenie.., 1990).

**Stop 4-2. Garnet amphibolites and metasomatites**

66 °53’12.38”N 65°11’17.24”E

The area of an unnamed right tributary of the Makar-Ruz River, about 1 km south-west of point 4-1 (Fig. 24). On the banks of the creek exposed outcrops of brown antigoritised and brecciated secondary olivn-enstatite rocks. Among them there are segregations of chlorite-magnetite (with sphene) metasomatic rocks, and a little higher up the slope there are body of light quartz-plagioclase rocks with biotite. The latter are surrounded by an actinolite rim containing a hard blue-gray mineral (corundum?).

Higher in the left side of the creek, gneissic serpentinized peridotites are in direct contact with banded garnet amphibolites. The gneissic and banding have the same orientation with the southwest (105°) dip at an angle of 60-70°. Banding reversals are observed within outcrops. Among amphibolites there are both garnet and garnet-free variations. Higher along the creek, they are replaced by outcrops of variously tectonized peridotites and serpentinites.

After rising to the pass with views of the Kuzty-vis River valley, the participants will find several bodies of amphibolite and associating enstatitites and olivine-enstatite rocks (Fig. 25). Further to the west, they can see the massif peridotite contact with the surrounding Riphean schists of the Kharamatolow block.

**Fig. 24**. Outcrops of amphibolites (including garnet amphibolite) among the metaperidotite central part massif. View of the right bank of the Makar-Ruz River

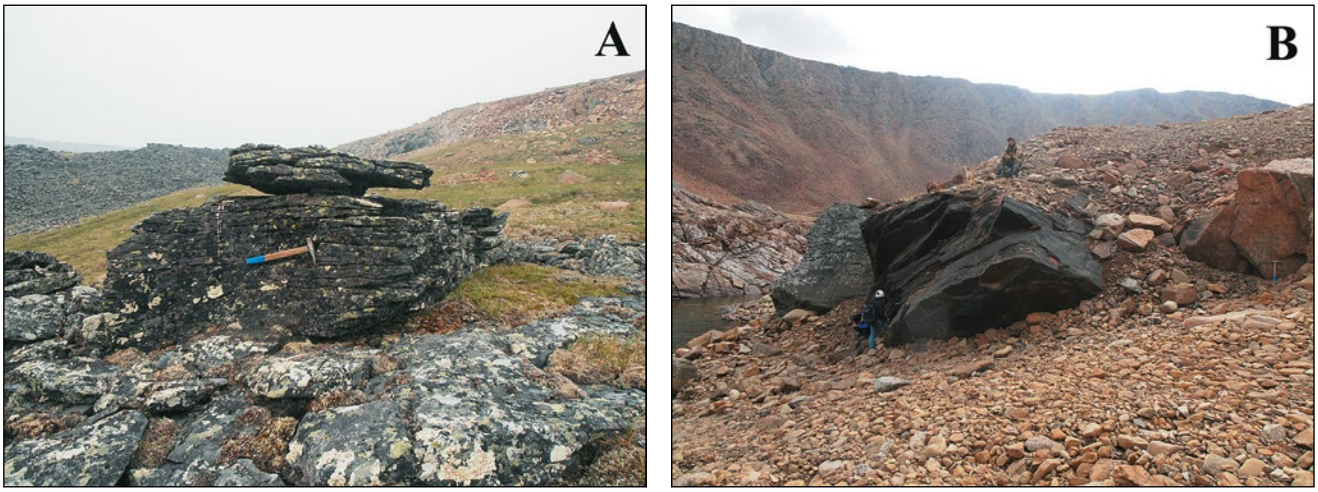


**Fig. 25.** (A) a large body of massive amphibolites with subhorizontal cleavage, among the olivine-enstatite rocks (pass of Makar-Ruz – Kuztyvis River); (b) banded garnet amphibolites occurring in accordance with the host secondary harzburgites (Left Makar-Ruz River)

## Day 5 (August 5, 2014) DUNITE-CLINOPYROXENITE-GABBRO COMPLEX

### Brief description

Dunite-clinopyroxenite-gabbro MTZ complex is located directly along the southern contact of the massif (Fig. 1), revealing elements of "symmetric" structure, which is largely a result of its tectonic transformation (Structure.., 1990).

The frontal part of the complex is composed of alternating dunites, wehrlites, clinopyroxenites, websterites and gabbro with the general northeast strike and steep south-east dip of the banding. Wehrlites and clinopyroxenites are in direct contact with peridotites or "separate" from them by bands (up to 600-800 m) of sand-yellow dunites. Besides, there are structural signs that dunites not only overlap clinopyroxenites, but are intruded by the latter. In dunites there are small bodies of gabbro-amphibolites and boudinaged layers of olivine clinopyroxenites. The role of gabbro-amphibolites (blastomylonites) alternating with clinopyroxenites increases on approximation to the central part of the complex. The orientation of planar elements is subordinated to the sublatitudinal strike of the southern contact of the massif.

The back part of the complex, located to the south of amphibolite band, is represented massive olivine clinopyroxenites and clinopyroxenite with rare interlayers dunites. The orientation of their banding has sublatitudinal strike with the dip (40-70°) to the south. In general, it is discordant to the contact with Sob gabbro complex. To the east of the Black mountain, along the contact with peridotites, there is just a narrow band of gabbro-amphibolites, while wehrlites and clinopyroxenites are virtually absent here (tectonically disrupted).

As regards their petrology and geochemistry, gabbro-amphibolites correspond to iron-poor (Fe number = 0.23-0.32) gabbro with low titanium (0.1-0.5 wt% $TiO_2$), zirconium and strontium (less than 200 ppm) content. They have a low REE level with a distinct deficit of LREE and a positive Eu anomaly, which is typical for basic cumulates; in less differentiated rocks a higher REE level is observed (Fig. 22). Clinopyroxenites are characterized by a REE distribution pattern comparable to metagabbroids. In general, the massif amphibolites and pyroxenites are close to the rocks of the transition complex of the Voykar massif ophiolite association that appeared in the Late Ordovician (Remizov et al., 2010).

**Stop 5-1. Dunites and clinopyroxenites contact zone with peridotites** (Fig. 10)
66°51'1.94"N 65°16'57.21"E

The southeastern part of the Moldavantsev cirque edge (behind turn). Here the peridotite of dunite-harzburgite complex are in contact with the rocks of the transitional dunite-clinopyroxenite-gabbro complex (Fig. 26a). From the observation point one can see the outputs of coarse grained sand-yellow dunite forming a band width up to 400m. The dunites have schlieren and bands of wehrlite-clinopyroxenite composition with a gentle (30°) dip in the northeast (50°) direction (Fig. 26b). To the south-west in the cirque outcrops (spots) of similar brownish wehrlite- clinopyroxenites are observed, where banding has a steep (60-85°) dip in the same direction. Besides, in dunites there is a subvertical cross-cutting body of medium-grained gneissose gabbro-amphibolites of the north-east orientation.

**Stop 5-2. Clinopyroxenite and gabbro of the layered series**
66°50'59.81"N 65°18'14.65"E

The right side of the Poloyshor River valley. At the observation point a band of yellow dunites is replaced by a cross section of the layered series presented by banded alternation of clinopyroxenites, olivine clinopyroxenites, wehrlites and thin layers of plagioclase websterites (Fig. 27). Contacts between rock types are both sharp and gradual, caused by variations in mineral content. The rocks demonstrate sustainable northeastern (45°) strike with a steep dip to the Northwest. Further on, in the southern direction in section beginning to dominate blastomylonites by gabbro. On the opposite side of the Poloyshor River, clinopyroxenites and gabbro have formed a tectonic "blotch" that is thrust upon the massif peridotites (Fig.28).

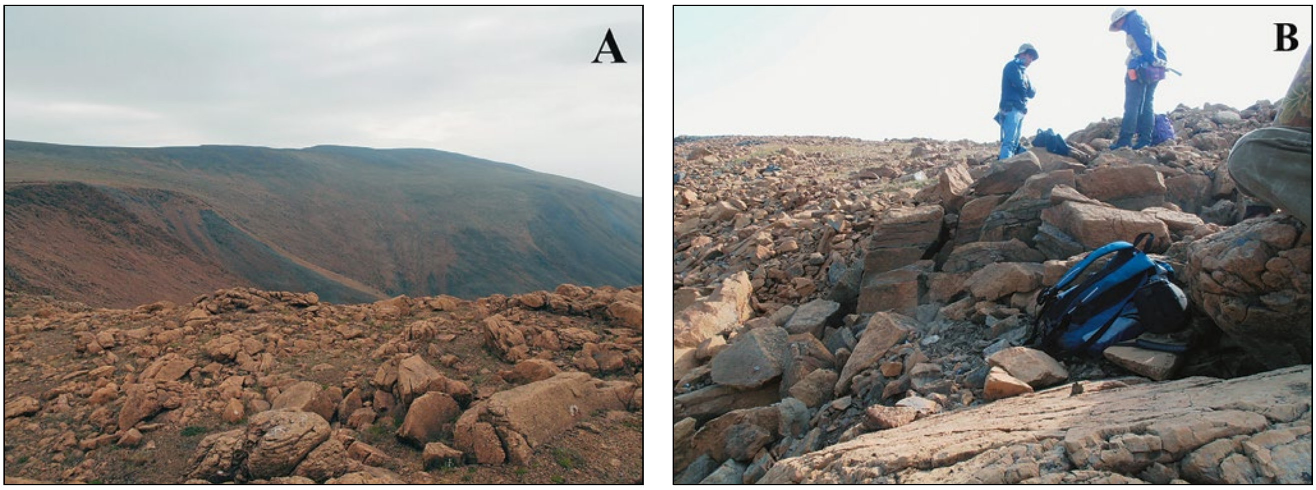


**Fig. 26.** (A) The view on front part of the transition complex (MTZ) from the edge of the cirque "Moldavantsev". In foreground outcrops of dunite-harzburgite complex on the other side of the cirque – pyroxenite "spots" (dark) are surrounded by dunite (wehrlites). (b) gently dipping of banding in the transition complex rocks (southern wall of cirque)

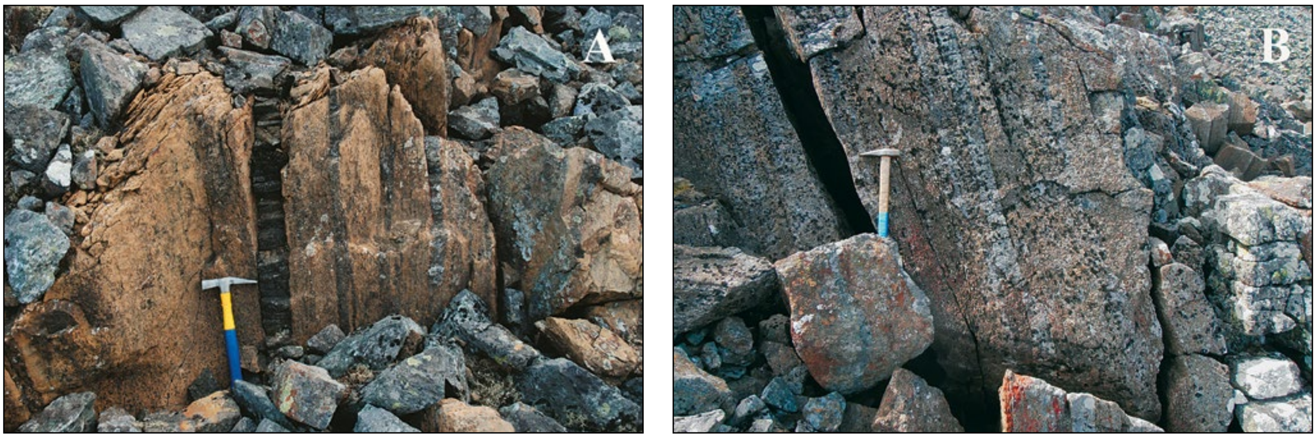


**Fig. 27**. (A) layered wehrlite-clinopyroxenite series with subvertical orientation banding; (b) outcrops of the clinopyroxenite (websterite) – gabbro series. Mountain slope facing the Poloyshor River valley

**Fig. 28**. The view of the southern part of the Rai-Iz massif (valley of the Yenga-Yu River). In the middle part of panorama (on the left side of the Poloyshor River) stands out "blotch" of the MTZ complex lying on the peridotites

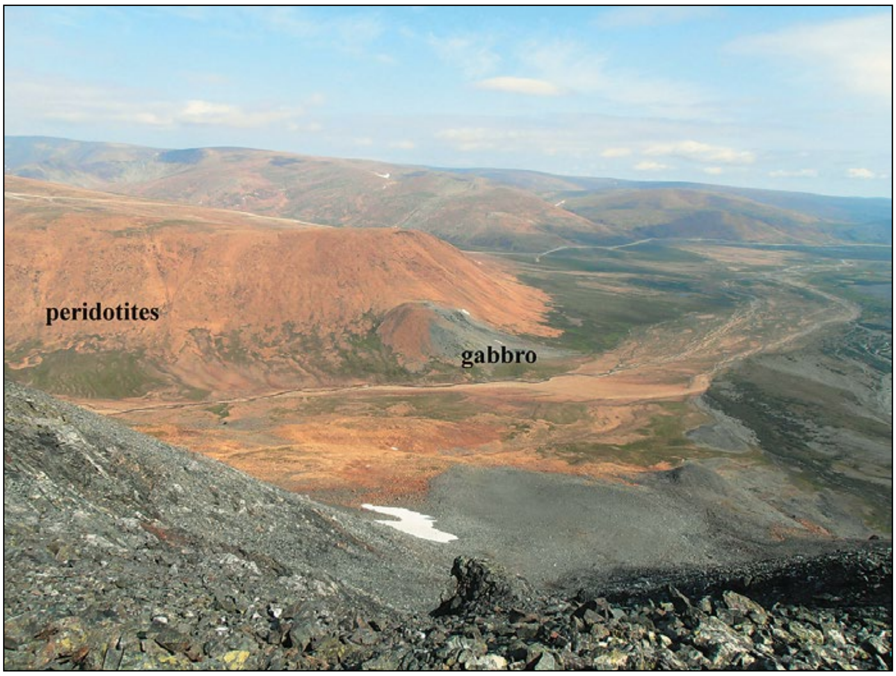


**Fig. 29**. South contact of the peridotite massif (brown) with gabbro-amphibolite (dark) of the Sob complex. View from the right bank of the Makar-Ruz River.

**Stop 5-3. Clinopyroxenites rear parts of the complex**

66°49’37.39”N 65°16’49.88”E

The edge of the cirque (springhead of the Sedzyshor River). From here on to the east-southeast, the section (of about 1.5 km in length) has prevailing homogeneous weakly differentiated clinopyroxenites and wehrlites with sublatitudinal orientation of planar elements. Thin (up to 5 mm) subparallel clinopyroxenite veinlets are observed in dunites. Upon ascending to the pass (mark 836.0 m), one can observe how rocks of the rear part are replaced by coarse-grained amphibole gabbro (with bluish quartz grains) of postophiolite type. Near the contact with the latter, clinopyroxenites experienced recrystallization to form pegmatoid structures and local gabbroization.

## Day 6 (August 6, 2014)
### POSTOPHIOLITE GABBRO AND GRANITOIDS OF THE SOUTHERN MARGIN

## Brief description

Peridotites of the Rai-Iz massif contact directly or through rocks of the transitional MTZ-complex with gabbroids and gabbro-diorites. Initially, these formations were allocated under the name of "plagiomigmatite complex" and were referred by researchers to ophiolite association of the Polar Urals (Yazeva, Bochkarev, 1984, Shishkin et al., 2007). During the subsequent detailed study of the contact area of the southern massif, these structures were referred to a later postophiolite association (Shmelev, Meng, 2013), which composes a wide (1-3 km) area, surrounded by plagiogranitoids of the Sob complex. The structure of this area outlines the zoning due to the existence of two section types (Fig. 2).

*The gabbroid type* is represented by banded, taxitic and blastomilonite hornblende gabbro (gabbro-amphibolites) with veins and segregations of plagioclasites, plagiogranites, fine-grained amphibole-plagioclase rocks, pegmatoids, and hornblendites. Small bodies (xenoliths) of clinopyroxenites and wehrlites are observed in gabbroids. The banding orientation is concordant with the sublatitudinal strike of the southern contact of the massif.

*The gabbro-diorite type* is composed of gneissic, sometimes banded gabbro-diorites and diorites, which replace gabbro in the southern direction. The linear-planar orientation to the south gradually disappears, and diorites acquire homogeneous massive structure.

Hornblende gabbro, gabbro-diorites and diorites differ from gabbro-amphibolites of the ophiolite association by high (50-60%) ferruginosity, and higher titanium (0.5-1.5 wt% $TiO_2$) and strontium (400-850 ppm) content. All rock varieties, including fine-grained amphibole gabbro, crosscutting the massif harzburgites, have high REE content and a negative distribution trend (Fig. 22b).

Gabbro-diorites and diorites as compared to gabbroids, demonstrate the enrichment by medium and heavy lanthanides, which makes them similar to plagiogranitoids of the Sob complex. The rocks of postophiolite association are comparable by geochemical characteristics with island-arc amphibole gabbro and plagiogranitoids of the Khorasyur massif of the Ural Platinum Belt (Fig. 22b).

Thus, southern surroundings of the massif are structurally and substantially heterogeneous. The current understanding of the ophiolite nature of the basites substrate of "plagiomigmatite" complex is not supported by the findings. The regular position in the section and similar geochemical specialization of postophiolite gabbroids, gabbro-diorites, diorite and plagiogranitoids of the Sob complex gives reason to consider them structurally and genetically related magmatic formations, creating a single multiphase gabbro-diorite plagiogranitoid pluton.

The U-Pb dating (LA-MC-ICPMS) of zircons from the rocks of postophiolite association shows that their formation occurred in the period from the Late Silurian (418 ± 2 Ma) through the Devonian, and it apparently occurred in suprasubduction geodynamic conditions (Shmelev, Meng, 2013).

**Stop 6-1. Marginal gabbros and plagiomigmatites** (Fig. 10)

66°47'29.86"N 65°12'14.43"E – 1741 (2317)

The beginning of a series of exposures (about 500 m long) in the Makar-Ruz River canyon. The right bank of the river reveals a distinct contact of the massif peridotites and gabbro (Fig. 29). In the riverbed there are outcrops schlieren-like banded amphibole gabbro with sublatitudinal (70-90°) strike and subvertical dip; subhorizontal mineral lineation can be noted. These gabbros belong to the bytownite ($An_{70-80}$) type, in which amphibole is represented by alumina (9.8-12.4 wt% $Al_2O_3$) magnesian hornblende. In gabbros there are veins, schlieren and irregular effusions of hornblendites, plagioclasites, fine-grained amphibole-plagioclase rocks, pegmatoids and plagiogranites forming a typical injection-migmatite complex (Fig. 30a-c). One kilometer to the west, near the contact with peridotites, gabbroids experienced a strong shear flow and were transformed into blastomylonites (Fig. 30d).

**Stop 6-2. Gabbros and diorites of the back area**

66°46’54.54”N 65°12’33.78”E – 1738 // 66°46’35.34”N 65°12’3.24”E – 1742

1.5 km south of point 6-1 on the bank of the Makar-Ruz River (near the mouth of the Kush-vozh brook). Outcrops of gneissose amphibole gabbro of the labrador type with concordant and discordant plagiogranite veins. Gneissose rocks have northeastern strike with a steep (60-80°) dip in the southeastern direction. Deformed melanocratic dyke-like bands are observed in gabbro. Downstream (1 km), this type of rock is replaced by massive diorites with biotites without a pronounced orientation (Fig. 30e-f).

## Day 7 (August 7, 2014) SERPENTINITE POLYMICTIC MELANGE

## Brief description

The tectonic allochthonous nature of the Rai-Iz massif is confirmed by the existence in its frontal northern part of the polymictic serpentinite melange n the sole of the thrust, which is characterized in many publications (Kazak et al., 1976; Structure.., 1990)). In the most representative form, the mélange is observed in the submeridian intersection along the Nyrdvomenshor River and its tributaries. The following structure has been established for it.

At the base of the mélange zone there is a strata of carbonaceous-siliceous, carbonaceous clayey, quartz-sericite, phyllitic shales interbedded with chert, sandstones and sometimes limestones of predominantly Late Devonian-Lower Carboniferous age. Shales near the mélange zone are intensively cleavaged and bent into isoclinal folds, the axial planes of which dip at steep angles (50-80°) in the southern and south-eastern direction (under the massif). There are serpentinite interbeds and wedges in shales.

The melange zone (300-600 m thick) has a scaly mosaic structure. Its matrix is formed by schistosity crumpled antigoritic serpentinites (with slickensides) with “floating” boulders and larger blocks of rocks of different composition and of different size and shape. The main part (> 80%) of inclusions is presented by serpentinized harzburgites, dunites and sometimes chromite ores. The remaining inclusions in serpentinites are presented by dolerites, their tuffs and tuff breccias. There are also carbonaceous-siliceous schists and green (metabasaltic) shales, cherts, jasperoids and rodingites.

The presence of nephritis and single white jadeit occurrence has been established in the melange serpentinites. A large deposit of nephrite boulders (over 4 km long and up to 50 m wide) with reserves of about 50 tons of conditioned raw material was found here by prospecting. The nephritis occurrence was worked out at the end of the last century.

Above and to the south of the mélange zone one can trace a wide (1 km) band, predominantly presented by green and amphibole (including glaucophane) schist with jasperoids bodies. At the top of the section there are weakly metamorphosed lumpy and brecciated basaltoids and riolites.

Importantly, the structure and composition of metabasalts is comparable to that of dolerites located in peridotites of the Main Uralian Fault melange zone in the PrePolar Urals, which are considered diamondiferous and having features of fluidized-explosive formations (Shmelev, 2005). Metabasalts of the Nyrdvomenshor River contain elevated (2.6-3.9 wt %) content of potassium oxide, but are almost identical in their geochemistry to N-MORB basalts. They are also close in REE to amphibolites zone metamorphism of the Rai-Iz massif (Fig.22a ).

In the upper section, the mélange zone rocks are replaced by an area of antigorite serpentinites and then by usual harzburgites and dunites.

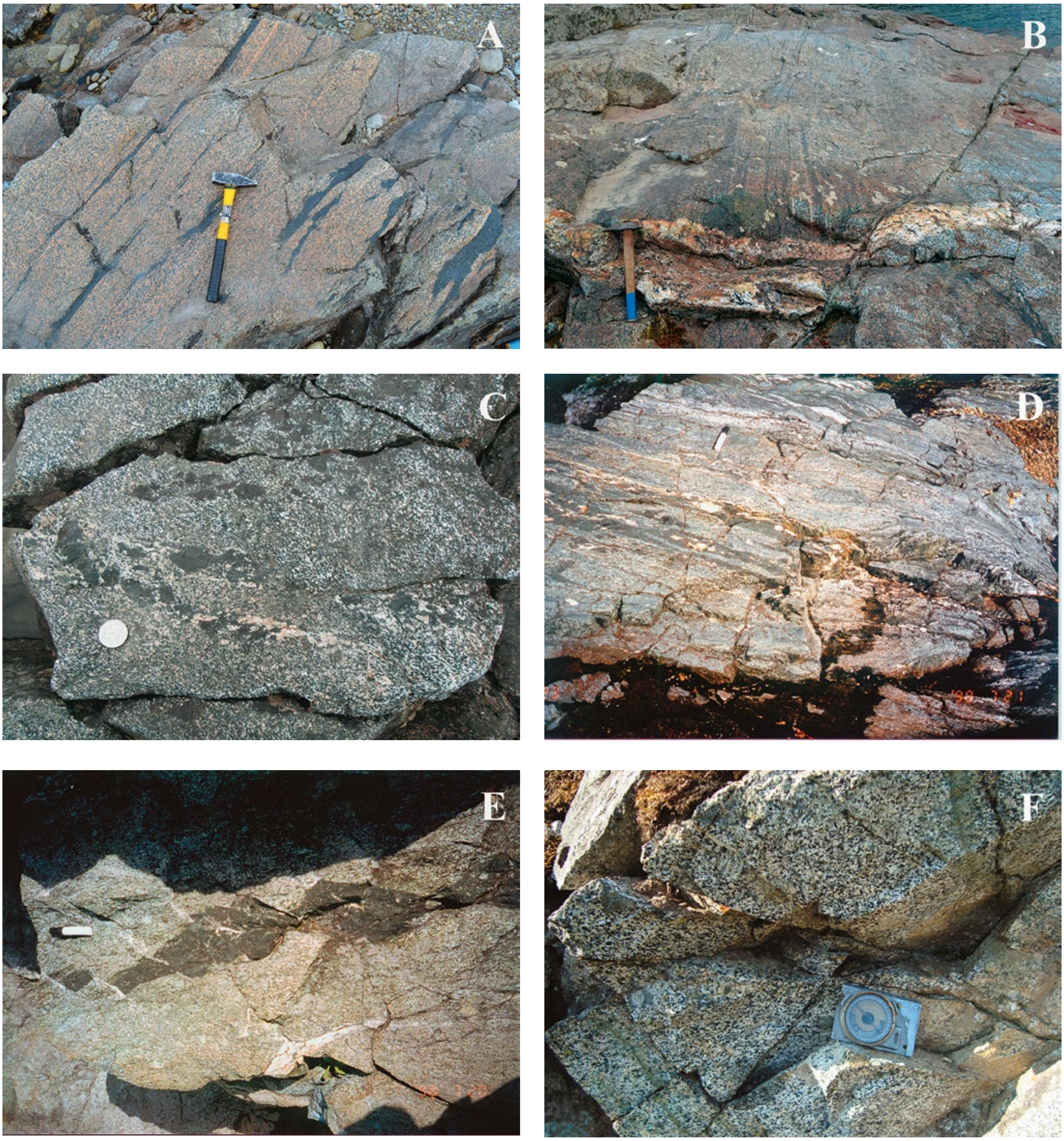


**Fig. 30**. Features of the Sob complex rocks structure: (a) banded amphibole gabbro of marginal part with schlieren-like segregations hornblendite (black) (the Makar-Ruz River); (b) vein injection leucocratic rock in gabbro; (c) spotted texture gabbro with segregations of amphibole and plagioclase; (d) gabbro-amphibolites (blastomylonites) from zone direct contact with the peridotites (nameless creek west of the Makar-Ruz River); (e) deformed leucogabbro internal area with diabase dyke (near the mouth of the Kushvozh creek); (f) undeformed massive diorite of the rear part complex (Kerdomanshor River).

**Stop 7-1. Peridotites marginal area of the massif** (Fig. 10)

66°56’40.50”N 65°27’19.73”E

The left bank of the Nyrdvomenshor River headwaters (for a big turn) (Fig. 31) shows outcrops of schlieren-like banded peridotites (dunites) that underwent antigoritization. The rocks have subparallel bands (up to 5 cm) of enstatitites that are concordant with chromite schlieren. There are large grains of cleavage olivine (up to 3 cm). Planar elements have a shallow (25-40°) dip in the northern direction. On the opposite river bank, there are similar antigoritized dunites and harzburgites with chromite banding, which is dipping gently (5-10°) in the opposite (south) direction. In the outcrop one can see small isoclinal folds.

**Stop 7-2. Metavolcanites of the mélange zone**

66°57’17.48”N 65°27’36.57”E

The left bank of the Nyrdvomenshor River (1.2 km south of 7-1) before the S-turn. The outcrops present talc-containing antigorite-tremolite schists with the southern dip at the angle of 50°. Relict areas of massive harzburgites are present in schists. About 200 m lower (at the latitudinal part of the River) there are outcrops of metavolcanites (Fig. 31) separated by crumpled serpentinite zones. They are mostly presented by green metavolcanic schists of the northeastern strike (60°) with a dip in the southeastern direction. Among them there are not only dolerite rocks, but also varieties of more acidic (rhyolite) composition. Quite often of the rocks have lumpy and brecciated texture (Fig. 32).

Green schists can be traced further to the south, forming a band of about 800 m wide. At the level of “Nephrite” waterfall there are relics of amphibole (epidote-glaucophane?) schists and interbeds (lenses) of cherry jasperoids.


**Fig. 31.** The contact area of the peridotite (brown background) with metabasalts of the mélange zone. Headwater Nyrdvomenshor (above the “Jade” waterfall)

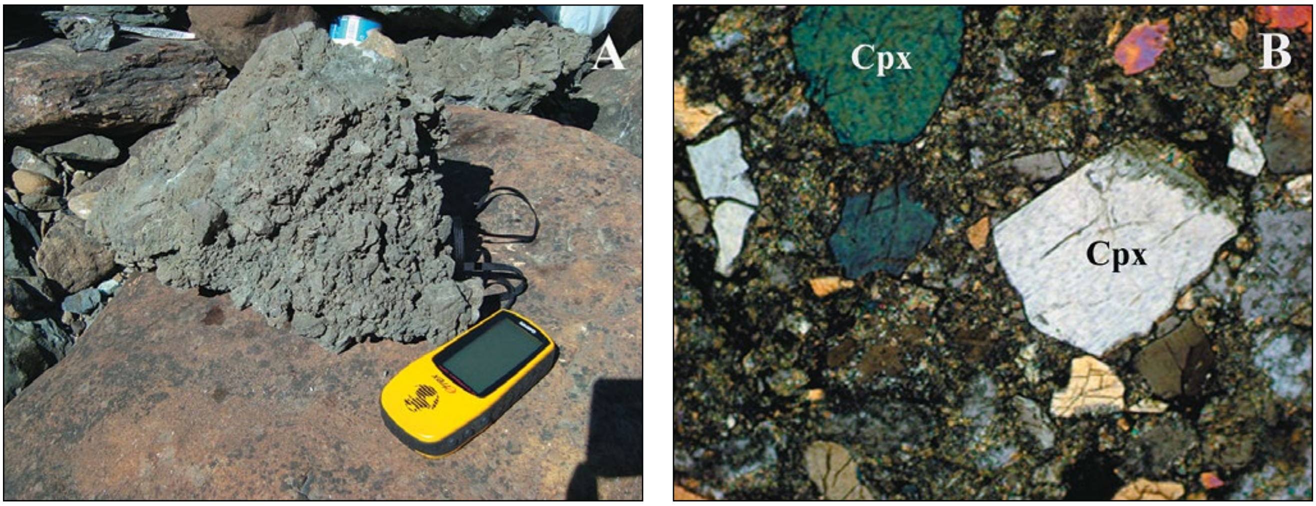


**Fig. 32**. Details of the metabasalts structure from mélange zone: (a) a sample with a typical lumpy (brecciated) rock texture (b) clastic microstructure of metabasalts with large crystals of clinopyroxene in mica aggregate (the Nyrdvomenshor River)


**Fig. 33**. Features of the structure polymictic melange zone: (a) schists ridge in the foreground, above which rises massif of peridotites (view from the Nyrdvomenshor River); (b) chaotic structure of the melange in the middle part of section; (c) outcrops of crumpled serpentinite with blocks of peridotites and shales in a riverbed (in the background); (d) the general view of the melange. In the foreground (left side of the Nyrdvomenshor River) are located outcrops of the host metaterrigenous rocks, plunging under the massif

**Stop 7-3. Serpentinite polymictic mélange** (Fig. 10)
66°58’8.49”N 65°27’42.64”B

The confluence of three streams constituting the Nyrdvomenshor River. The observation point is in the serpentinite melange, which has a width of about 700 m here. The most representative outcrops are along the left and right tributaries, standing out against the background by a bright color (Fig. 33a-b). In the outcrops, in the crumpled serpentinite matrix there are inclusions of massive serpentinized dunites and harzburgites, metabasaltoids, green shales and greenish-white rodingites. There are a few boulders of nephrite.

**Stop 7-4. Schists with lenses of serpentinites**
66°58’39.24”N 65°28’15.78”E

The right side of the Nyrdvomenshor River (260 m below the mouth of the right tributary). Here in the middle of a wide (1.5 km) band, underlying the zone of polymictic mélange, prevailing in the section are various shales (quartz-chlorite-sericite, silica- carbonaceous) and massive chert rocks. Less frequently green metavolcanic and phyllitic shales are observed. Isoclinal and more complex folding is manifested in the rocks, resulting in schistosity changing from southeast to southwest at the angles of 40-75°. In the shale strata section there are numerous serpentinite bodies (Fig. 33c).

**Stop 7-5. Surrounding rocks**
66°59’22.02”N 65°28’37.60”E

The left bank of lower reaches of the Nyrdvomenshor River. The outcrops of quartz-chlorite-sericite schists, plunging at an angle of up to 50° in a southern direction under the massif. On the opposite bank of the river there is a mosaic picture of the structure mélange zone (Fig. 33d)

## Day 8 (August 8, 2014) Departure day

Departure from Kharp to Labytnangy and Salekhard. Flight to Ekaterinburg.

# REFERENCES


1. Anikina, E.V. (1995). Platinoids in chromite ores of the Polar Urals. IG Komi Science Center. Syktyvkar, 27 (in Russian).
2. Anikina,. Ye.V., Moloshag, V.P., Alimov, V.Yu. (1995). Typomorphism of laurite from the Polar Urals alpine ultrabasites. Reports of RAS, 344, 789-790.
3. Chashchukhin, I.S., Perevozchikov, B.V., Tsaritsyn, E.P. (1986). Metamorphism of the Rai-Iz peridotite massif (Polar Urals). Research on petrology and metallogeny of the Urals. Sverdlovsk USC USSR Academy of Sciences, 49-75 (in Russian).
4. Chashchukhin, I.S., Votyakov, S.L., and Shchapova, Yu.V. (2007). Crystal chemistry of spinel and oxythermobarometry of ultramafic rocks from fold areas. Yekaterinburg: IGG UrO RAN, 310 (in Russian).
5. Garuti, G., Zaccarini, F., Moloshag, V., Alimov, V. (1999). Platinum-group minerals as indicators of sulfur fugacity in ophiolitic upper mantle: an example from chromitites of the Ray-Iz ultramafic complex, Polar Urals, Russia. Canadian Mineralogist, 37, 1099 – 1116.
6. Glodny, J., Austrheim, H., Molina, J.F., Rusin, A., Seward, D. (2003). Rb/Sr record of
7. fluid-rock interaction in eclogites: The Marun-Keu complex, Polar Urals, Russia.
8. Geochimica et Cosmochimica Acta, 67, 4353–4371.
9. Gurskaya, L.I., Smelova, L.V., Kolbantsev, L.R. etc. (2004). Platinum metals of chromite-bearing massifs of the Polar Urals. St. Petersburg: Publishing House of St. Petersburg VSEGEI printing works, 306 (in Russian).
10. Dobretsov, N.L., Moldavantsev, J.E., Kazak, A.P. etc. (1977). Petrology and Metamorphism of Ancient Ophiolites: Evidence from the Polar Urals and Western Sayan, Novosibirsk: Nauka, 217 (in Russian).
11. Kazak, A.P., Dobretsov, N.L., Moldavantsev, J.E. (1976). Glaucophane schists, zhadeitites, vezuvianites and nephrites of the Rai-Iz ultramafic massif. Geology and Geophysics, 2, 60-66 (in Russian).
12. Makeev, A.B., Perevozchikov, B.V., Afanasyev, A.K. (1985). Chromite potential of the Polar Urals. Siktivkar: Komi fi. AN USSR, 152 (in Russian).
13. Moloshag, V.P., Alimov, V.Y., Anikina, E.V. etc. (1999). Accessory mineralization in chromitites of alpine type ultrabasites of the Urals. Zap. WMO, CXXVIII, 2, 71 – 83 (in Russian).
14. Pasava, J., Knésl, I., Vymazalová, A., Vavrin, I., Gurskaya, L.I., Kolbantsev, L.R. (2011). Geochemistry and mineralogy of platinum-group (PGE) in chromitites from Centralnoye I, Polar Urals, Russia. Geoscience Frontiers, 2, 81 – 85.
15. Perevozchikov, B.V., Bulykin, L.D., Popov, I.I. etc. (2000). List of chromite occurrences in alpine type ultramafic rocks of the Urals. Perm: KamNIIKIGS, 274 (in Russian).
16. Perevozchikov, B.V., Kenig, V.V., Lukin, A.A., Ovechkin, A.M. (2005). Chromites of the Rai-Iz massif in the Polar Urals (Russia). Geology of Ore Deposits, 47, 206-222.
17. Remizov, D.N., Grigoriev, S.I., Petrov, S.Yu. etc. (2010). New data on the age of gabbroides kershor complex in the Polar Urals. Doklady, 434, 238-242.
18. Savelyeva, G.N. (1987). Gabbro-ultrabasic complexes of the Urals ophiolites and their analogues in modern oceanic crust. M.: Nauka, 245 (in Russian).
19. Savelieva, G.N., Batanova, V.G, Berezhnaya, N.A. etc. (2013). Polychronous Formation of Mantle Complexes in Ophiolites. Geotectonics, 47, 167–179.
20. Shishkin, M.A, Astapov, A.P, Kabatov N.V, Kazak, A.P etc. (2007). State Geological Map of the Russian Federation. Scale 1: 1 000 000 (third generation). Series Ural. Sheet Q-41 Vorkuta. Explanatory note. St. Petersburg.: Cartographic Factory VSEGEI, 541 (in Russian).
21. Shmelev, V.R., Puchkov, V.N. (1986). Features of tectonics Rai-Iz ultramafic massif (Polar Urals). Geotectonics, 4, 88-105.
22. Shmelev, V.R. (2005) Magmatic complexes of the Main Uralian deep fault zone (PrePolar segment) in the light of new geochemical data. Lithosphere, 2, 41-59 (in Russian).
23. Shmelev, V.R. (2011). Mantle Ultrabasites of Ophiolite Complexes in the Polar Urals: Petrogenesis and Geodynamic Environments. Petrology, 19, 618–640.
24. Shmelev, V.R., Meng, F-C. (2013). The nature and age of basic rocks of the Rai-Iz ophiolite massif (Polar Urals). Doklady Earth Sciences, 451, 758–761.
25. Shcherbakova, S.V. (1975). Mineralogy of ruby-bearing metasomatites of the Polar Urals. Author's abstract of thesis. Candidate. geol.-min. sciences. L., 28 (in Russian).
26. Sobolev, S.F. (1965). Gabbro-tonalite complex of the Polar Urals. M.: Nauka, 163 (in Russian).
27. Structure, evolution, and metallogeny of the Rai-Iz ultramafic massif. (1990). Eds. Puchkov V.N and Shteinberg D.S. Sverdlovsk: UrO AN SSSR, 228 (in Russian).
28. Udoratina, O.V., Kuznetsov, N.B. (2007). Sob plagiogranitoid complex of the Polar Urals. Bull.MOIP. Dep. Geologic, 82, 49-59 (in Russian).
29. Vakhrusheva, N.V. (2012).The traces of ultrahigh pressures in chrome ores from the ultrabasites of the Polar Urals. Geodynamics, ore deposits and deep structure of the lithosphere. XV Reading memory A.N. Zavaritsky. Yekaterinburg, 36-38 (in Russian).
30. Volchenko, Y.A. (1990).Geochemistry and mineralogy PGM and gold in ultramafic rocks and chromite ores Rai-Iz massif. In: Structure, evolution and metallogeny ultramafic massif Rai-Iz. Sverdlovsk, Ural Branch of the USSR, 195-206 (in Russian).
31. Yang, J., Bai, W., Fang, Q., Meng, F., Chen, S., Zhang, Z., Rong, He. (2007). Discovery of diamond and an unusual miner al group from the podiform chromite ore, Polar Ural. Geology in China, 34(5), 950-953 (in Chinese).
32. Yang, J., Robinson, P.T., Dilek, Y. (2014). Diamonds in Ophiolites. Elements, 10, 127–130.
33. Yazeva, R.G., Bochkarev, V.V. Voykar volcano-plutonic belt (Polar Urals). (1984). Sverdlovsk USC USSR Academy of Sciences, 158 (in Russian).
34. Zavaritskiy, A.N. (1932). Rai-Iz peridotite massif in the Polar Urals. M. ONTI, 221 (in Russian).

**Shmelev V.R., Perevozchikov B.V., Moloshag V.P.**

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