IOP Conf. Series: Earth and Environmental Science **319** (2019) 012004 doi:10.1088/1755-1315/319/1/012004

The Barkhatny ultramafic-mafic massif (Kuznetsk Alatau Ridge, SW Siberia): structural and compositional evolutions of rocks

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Abstract. A complex of petrographic and petrofabric analyses that was carried out for rocks from an ultramafic-mafic massif of the Barkhatnaya Mountain in the Northern part of the Kuznetsk Alatau allowed us to prove that internal anisotropy of mineral aggregates had deformation-type evolution, which indicates possible plastic exhumation of lithosphere mantle fragments into upper crust levels. Additional mineralogical and geochemical researches of the basic component point out high possibility of multistage model for obduction of ophiolite association segments proposed for this region.

1. Introduction

Fragments of lithosphere mantle like dunite-harzburgite tectonic complexes are an essential part of structural zones of modern mountain-folded formations. Their relation to country-rock structural assemblages has tectonic nature. They are often assumed to have a complicated exhumation evolution into upper crust levels. Hyperbasite massifs of the Severnaya, Zelenaya, Zayachya, and Barkhatnaya mountains located on the northern slope of the Kuznetsk Alatau Ridge are typical representatives of such formations within Altay-Sayan Folded Area (ASFA). They form an arch-shaped chain, which points out block-type style of geological composition of this certain region and ASFA in general [1]. The main tectonic elements of the northern part of the Kuznetsk Alatau are faults, grabens, linear intrusions, and dike belts spreading in two directions: North – North East (to submeridian strike) and North-West (to sublatitude one). Oceanic crust fragments are drawn towards axial part of the ridge and form isolated horse shoe-shaped structures, where margins are composed by mantle hyperbasites, and the core is composed by basites (starting with cumulative ultramafic rocks and gabbroids, and to their hypabyssal and volcanic analogues) (figure 1).

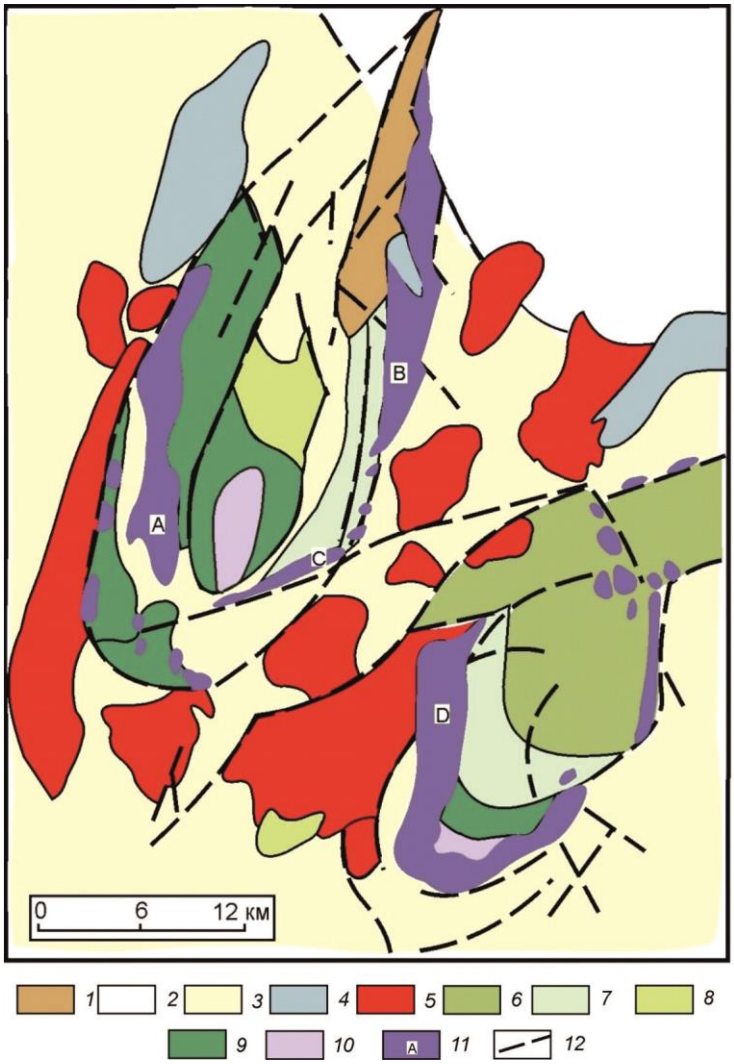

Figure 1. Scheme of the internal structure of ophiolite parageneses from the NE slope of the Kuznetsk Alatau ridge (based on materials [2], as amended [3])
Structural-compositional complexes of framing:
1 – subcontinental volcanic-terrigenous formation (D);
2 – carbonate-volcanic formation of island arc units ($Є_{1-2}$);
3 – carbonate and terrigene formations of suboceanic units (R –$Є_1$).
Intrusive massifs:
4 - subalkaline gabbroic intrusions;
5 - granitic intrusions.
Ophiolitic units:
6 - basaltic;
7 – gabbro-diabasic;
8 - gabbro-dioritic;
9 - gabbroic;
10 – gabbro-pyroxenites;
11 – ultramafic massifs
(**A** -Severnaya-Zelenaya, **B** - Barkhatnaya, **C** – Zaichaya, **D** – Srednetersinsky);
12 - faults.

2. Structural evolution

The Barkhatny massif forms the Eastern side of ophiolite paragenesis and is a linear body (20×2-3 km^2) with submeridian orientation with a well-defined deformation zoning. Its central zone is composed by eutaxitic/banded harzburgite, dunite, and chromitite complex, which is supposed to have following evolution sequence of deformation petrofabrics: “protogranular → protogranular- parquet-like → leystic → mosaic-leystic” (figure 2, row I) that corresponds to axial compression mode. Outer zones of the massif are composed by rocks with mesagranular and porphyroclastic structures (figure 2, row II), including serpentinites, which form more often during recrystallization under shear deformations or significant gradient of static pressure and temperature. Specifics of the deformation zoning observed in couple with data on other ultrabasite massifs of ophiolite paragenesis let us developed a multistage model of obduction for lithosphere mantle fragments [3]. It is assumed that there are at least three stages of exhumation, which indicate main steps of tectonic evolution of the Kuznetsk Alatau folded assemblage structure.

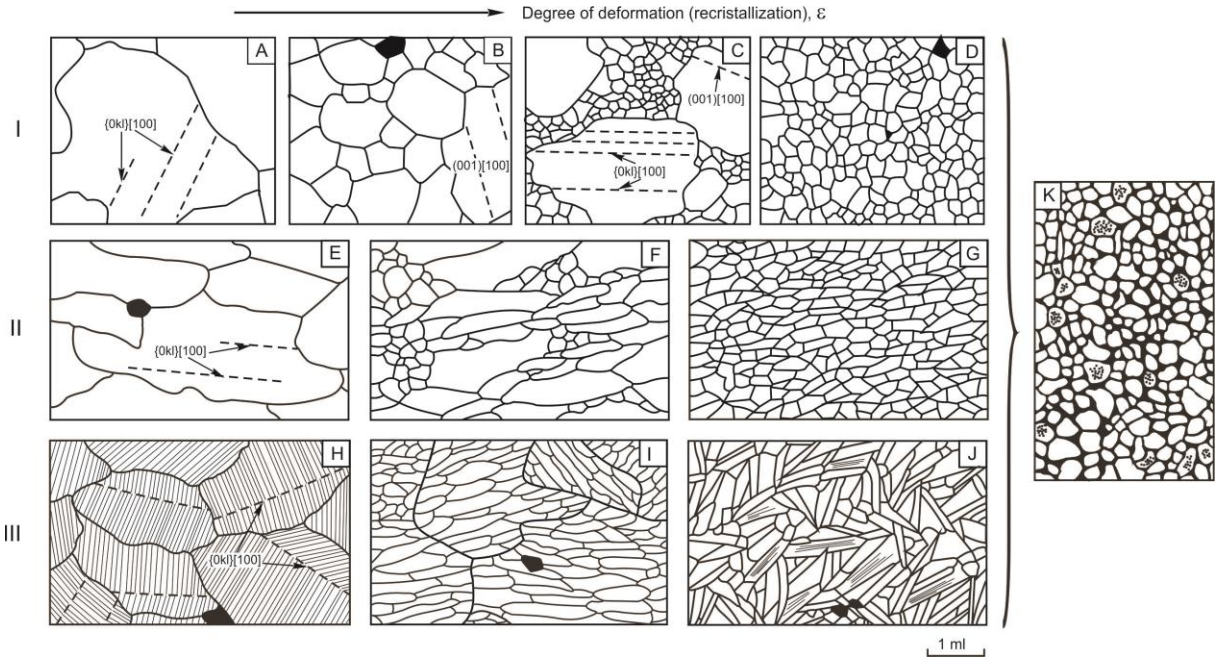

Figure 2. Deformation types of olivine microfabrics according to [3]: A – protogranular; B – mesogranular; C – porphyroclastic; D – mosaic; E – leystic; F – porphyroleystic; G – mosaic-leystic; H – protogranular-cleavaged; I – parquet-like; J – pseudospinifex; K – regenerated.

During the first stage an accretionary prism of an active island arc forms, where oceanic lithosphere fragments obduct preserving NW-trends in central blocks of the ultramafic bodies from Severnaya and Barkhatnaya Mountains. This stage corresponds to the highest-temperature processes of plastic deformations of olivine and development of isoclinal folding in ultrabasites. These events last from the Late Riphean to the Middle Cambrian. The second stage is controlled mainly by vertical movements along submeridional tectonic fissures with extensive development of recrystallization on the flanks of ultrabasic units at relatively moderate temperatures and pressures. It is accompanied by linear type intrusions of large basites, syenitoids and granitoids; geodynamic setting for their formations correspond to the stage of Altai-Sayan superterrane's collisional accretion in the Late Cambrian - Ordovician. The third stage correlates to the Devonian rifting and is accompanied by formation of some depressions and grabens composed by high-alkaline volcanics and "red-colored" terrigene sediments. In the studied ophiolite paragenesis, actual tectonic events of this stage were shown in turning a core block of basic rocks southward with respect to hyperbasite sides. Other tectonic events were a formation of a serpentinite melange on Zayachia Mountain and in zones of intensive gabbro schistosity on the eastern slope of Severnaya Mountain, and activation of crosscutting faults in massifs of Severnaya and Barkhatnaya Mountains with NE and NW trends respectively. These deformations mostly corresponded to dynamic metamorphic alterations of rocks in upper crust levels, and were characterized by low temperatures and locally raised pressures. Another indicator of late events is formation of Barkhatnyi-Kiysk intrusive of subalkali gabbroids and pulaskites, whose rocks "break" through ultrabasites of Barkhatnaya Mountain and Early Devonian effusive rocks of the Rastaysk graben.

3. Mineralogy and geochemistry

Additional research in mineralogy and geochemistry of basites from Barkhatnaya and Zelenaya Mountains confirm multistage metamorphic transformations at different P-T conditions and different stages of obduction of oceanic fragments. On the western slope of Barkhatny Massif, prevailing rocks are homogeneous fine- and medium-grained gabbro and gabbro-diabases pierced through by numerous

dyke and vein bodies of microgabbro, microgabbrodiorits and rarely dacite porphyries. By petro- and geochemical characteristics, these rocks correspond to moderate and high-Ti and low-Mg mafites, which are widely spread in upper parts of the gabbroid section and in a parallel dike complex. On the eastern slope of Severnaya and Zelenaya Mountains, basites are represented by gabbroids with various melanocraticity and with signs of differentiation and banded structures, which belongs to upper series of the plutonic complex [4]. All basites have signs of superimposed metamorphic changes (up to the epidote-amphibolite facies).

During studying of mineral composition of metabasites, we found that feldspars are represented by a wide range of minerals from albite to bytownite (figure 3). Basic plagioclases form prismatic elongated grains, which are replaced by secondary minerals (sericite, zoisite and calcite) to some extent. Andesines are found in diabases from the Barkhatny Massif; they have elongated rectangular shape and irrational orientation. Acid plagioclases are seen in all samples and are characterized by replacement structure, where albite develops in medium and basic plagioclases forming irregularly shaped grains. This type of plagioclase demonstrates metamorphogenic, quite low-temperature transformations of parental rocks.

Other widely spread minerals are amphiboles, whose composition ranges a lot (ferro-edenit, ferropargasite, magnesiohastingsite, actinolite, magnesio- and ferrohornblende) (figure 3). They form slightly elongated or very elongated grains, sometimes with hexagonal section. We can often see irregularly shaped aggregates. In some crystals, zonal structure of a mineral is clear optically and compositionally. Central parts are usually composed by ferropargasite, whereas external zones consist of actinolite and ferrohornblende [6].

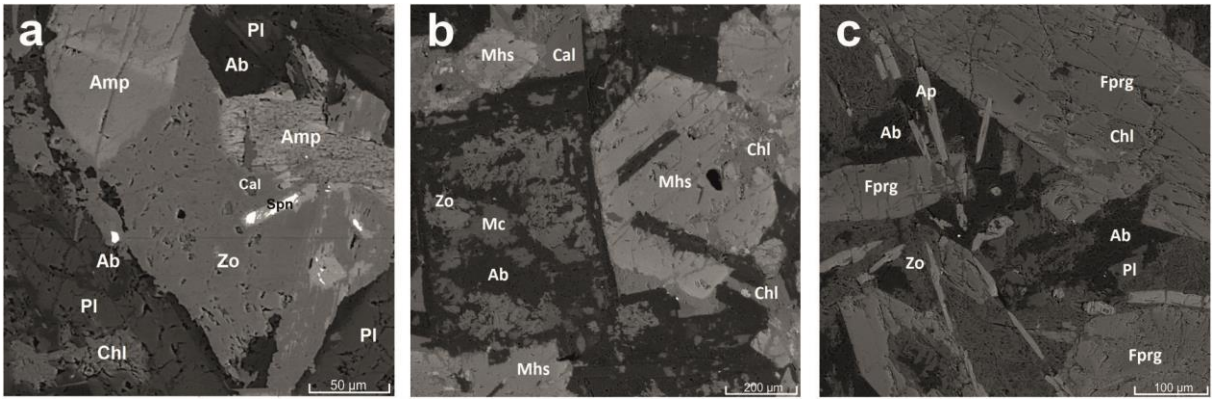

Figure 3. Paragenetic associations. Image BSE (back-scattered electrons): a – sample Bkh-22/1; b – sample Bkh-22/3; c – sample Bkh-96/3. Symbols of minerals are taken upon [5].

The data obtained by the phase relationships and changes in chemical composition of the mineral pair "plagioclase - amphibole" suggest several stages of transformations for studied rocks with signs of progressive and retrograde metamorphism. Using bimineral geothermobarometers we established two stages: progressive metamorphism peak occurs at T = 500-700 °C and P = 2-6 kbar, and regressive stage occurs at T = 350-510 °C and P = 2-9 kbar. This is also confirmed by the results of amphibole geothermobarometer, where minerals of marginal parts formed at T = 340-440 °C and P = 1kbar, being superimposed over higher-temperature amphiboles from central parts, which were generated at T = 550-650 °C and P = 2-7 kbar [7]. The obtained data on the formation temperatures of these minerals confirm three probable stages of deformations and metamorphic transformations of ophiolites.

Another proof of multi-stage exhumation of ancient oceanic crust fragments into upper crust levels is isotope-geochemical analyses on these rocks and their composing minerals performed by us within last few years. The earliest stage of obduction of restitic ultrabasites, which occurred during formation

of "Riphean" [8] oceanic island arc, may be associated with episodes of regional metamorphism at epidote-amphibolite facies. This process was registered based on the results of Sm-Nd isotope analyses of amphibolites from the Tomsk Salient, which yield an isochronous age of 703 ± 63 Ma [9], and 676 ± 16 Ma for metabasalt dike (microgabbro-amphibolite)"breaking" through the southern end of the Barkhatny ultramafic massif. As of now, we have a wide range of ages for different magmatic complexes, which reflects different stages of tectonic evolution in the Kuznetsk Alatau. However, the most recent fragment of magmatic activity in this region is still activation at the age of 265 Ma, which was noted in alkaline rocks from the Goryachegorsk massif [10-11]. For magmatic peridotite from the western slope of Barkhatnaya Mountain, Sm-Nd mineral isochrones yield the age of 244 ± 37 Ma, which reflects the most recent tectonic movements along the boundary of the Rastayskii graben. A wide range of minerals (albite, analcime, labrador, K-Na feldspar, calcite, etc.) was established as part of the leucocratic component of this rock in microprobe studies which reflects the likely alkaline metasomatism in the later stages of the transformation of the parental igneous rocks.

4. Conclusion

Thus, structural and compositional evolution of the basic component of ophiolite association from Barkhatnaya, Severnaya and Zelenaya Mountains correlates to the stages of plastic deformation of restitic ultramafic rocks, and in some cases fulfills it.

5. Acknowledgements

This work was conducted as a government task of the Ministry of Science and Higher Education of the Russian Federation, Project Number 5.9342.2017/P220. Analytical researches were conducted at the center of collective use Analytic Center of Natural Systems Geochemistry of Tomsk State University.

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