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Pyroxene–Cr-spinel exsolution in mantle lherzolites of the Syum-Keu ophiolite massif (*Arctic Urals*)

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Abstract

We consider the composition and microstructures of pyroxene–Cr-spinel exsolution products from lherzolites of the deep mantle section of the Syum-Keu ophiolite massif in the Arctic Urals. Enstatite and diopside from the lherzolites contain lamellae and diverse micron segregations of Cr-spinel. We have first determined the composition of Cr-spinel lamellae and the composition trend of pyroxenes undergoing exsolution. The zonal inhomogeneity of their composition is expressed as a decrease in the contents of Cr_2O_3, Al_2O_3, and Na_2O from the core of coarse grains free of exsolution structures to the sites with Cr-spinel segregations. The Cr/(Cr + Al) value in the Cr-spinel lamellae varies from 0.23 to 0.33, and the Mg/(Mg + Fe) value, from 0.61 to 0.67. The degree of iron oxidation in the formed Cr-spinel is low (0.10–0.19) and virtually does not depend on the Cr content in this mineral. We calculated the temperature and pressure of the beginning and completion of pyroxene–Cr-spinel exsolution for the equilibrium enstatite–diopside (of different generations) pairs and established the participation of H_2O fluid in the exsolution. During the exsolution, the temperature decreases from 970 to 650–700 ºC and the pressure grows from 0.9 to 1.3 GPa. The exsolution of pyroxene and migration of elements proceeded under high-temperature solid-plastic flow of mantle material, probably in the local zones where peridotites were subjected to strong shearing strains caused by the above high-velocity flow. The zone with these processes was located in the lithospheric mantle (mantle wedge) above the subduction zone. Migration of ore components from silicates and formation of new Cr-spinel grains contributed to the formation of chromite segregations.

Keywords: exsolution; enstatite; diopside; Cr-spinel; lherzolite; mantle; ophiolites

Introduction

Enstatite–diopside exsolution microstructures are widespread in mantle peridotites of ophiolites. These are commonly clinopyroxene plates in host orthopyroxene, but the reverse is also observed. Exsolution of high-Ca enstatite to two phases usually proceeds in the plane (100) having the lowest energy both in enstatite and in diopside (Hess, 1960). Pyroxene exsolution structures with Cr-spinel lamellae are extremely rare. They were found in xenoliths of mantle peridotites from alkali basalts of the Massif Central (Brown et al., 1980). Cr-spinel needles and plates were discovered in diopside and enstatite from one sample of lherzolite of protogranular structure, which contained high-alumina accessory Cr-spinellid. The composition of lamellae was not examined, but it was noticed that the composition of Cr-spinel varies in the sample containing Cr-spinel lamellae.

Orthopyroxene exsolution with formation of garnet and scarce finest Cr-spinel plates was also detected in high-alumina pyroxenites of the Xugou massif in the Su-Lu metamorphic belt (Spengler et al., 2012). The exsolution product is garnet with excess silica (majorite) and occasional lamellae of magnesian high-Cr spinellid in enstatite. The authors explain the formation of garnet lamellae in pyroxene by pressure growth during subduction, and the formation of pyroxene lamellae in garnet by decompression. Formation of occasional lamellae of high-Cr spinel in enstatite is accounted for by decompression in the presence of fluid at 950–900 ºC.

Cr-spinel exsolution structures were also detected in mantle peridotites, e.g., the podiform chromitites of the Luobusa massif, Tibet, contain lamellae and acicular and rounded microinclusions of clinopyroxene and coesite, resulted from spinel exsolution at ultrahigh pressures (from 12.5 to 3 GPa) (Yamamoto et al., 2009).

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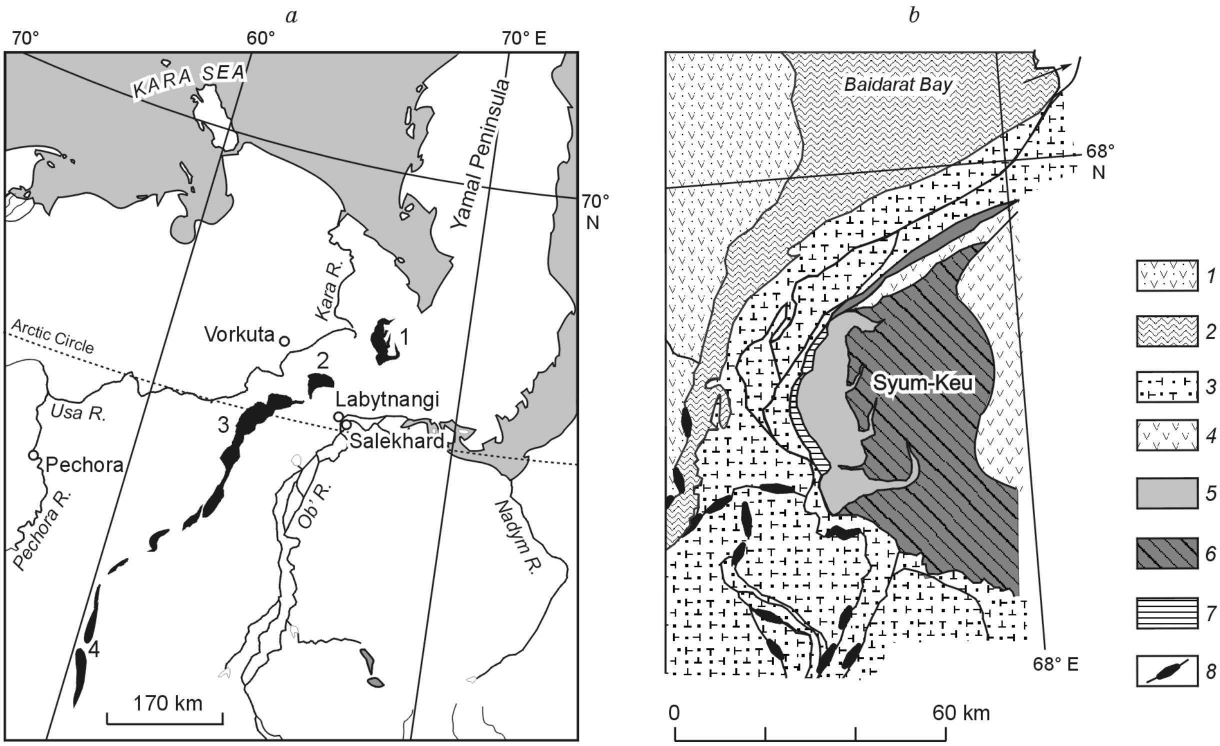

Fig. 1. Map of the Syum-Keu massif: *a*, position of the massif in the ophiolite belt of the Arctic Urals: 1, Syum-Keu, 2, Raiiz, 3, Voikar–Syn'ya, 4, Khorasyur; *b*, geological map of the Syum-Keu massif area: *1–3*, deposits of the basement and continental slope of the East European Platform: *1*, Early–Middle Paleozoic limestones, phyllites, sandstones, conglomerates, basalts, and tuffs; *2*, Early Paleozoic basalts, dacites, and silico-argillaceous shales; *3*, united Vendian–Early Paleozoic and Early Proterozoic deposits of the Kharbei complex; *4*, oceanic and island-arc complexes of the Shchuch'e structure: Early Paleozoic basalts, dacites, rhyolites, silico-argillaceous shales, limestones, basalts, andesites, rhyolites, and tuffs; *5*, harzburgites, lherzolites, dunites, and rocks of the banded complex of the Syum-Keu massif; *6*, gabbroids and diabases (dike complex); *7*, metamorphites in the base of the Syum-Keu allochthone; *8*, tectonic boundaries, including thrusts with serpentine melange.

All these examples show that the transition of peridotites from deep mantle to crust is accompanied by the evolution of the multicomponent composition of mantle minerals and the formation of new mineral phases of simpler composition. Traces of this process are seldom preserved in mantle peridotites because of the tectonic disintegration, metamorphism, and serpentinization of the latter.

In this paper we consider pyroxene–Cr-spinel exsolution microstructures from peridotites of the Syum-Keu ophiolite massif in the Arctic Urals. Exsolution of silicates (pyroxenes) with the formation of oxides (Cr-spinel) and subsequent migration of ore components with the formation of chromite segregations are also of interest because of the earlier revealed empirical relationship between the composition of pyroxenes from peridotites of different ophiolite massifs and the presence of Cr-ore deposits in the latter (Savelieva et al., 2015).

Brief geological outlines

The Syum-Keu massif is located on the northern margin of the ophiolite belt in the Arctic Urals, on the western edge of the Shchuch'e structure lying at the center of the area of junction of the Hercynian structures of the Urals and northern West Siberia and the Kimmeridgian Pai-Khoi structures (Fig. 1). The tectonic position and composition of the ophiolites were considered by many researchers, who described them as giant tectonic allochthones in the crust and oceanic lithosphere formed in marginal basins above subduction zone in the Early and Middle Paleozoic (Afanas'ev, 1986; Batanova et al., 2011; Koronovskii, 2001; Puchkov, 2005; Saveliev, 1997). In the late Middle Paleozoic and Late Paleozoic, the ophiolites, together with the overlying and intruding island-arc rock complexes, were thrust over the continental margin of the East European Plate. Structural analysis of the rocks of this massif and petrological studies were first carried out by Shmelev (1991), who showed that the peridotite microstructures with regular crystallo-optical orientation of olivine and pyroxenes resulted from subsolidus plastic deformations over a wide range of deformation rates (degrees of stress). Subsequent studies refined the geologic structure and structural pattern of the subsolidus peridotite flow in the massif and showed its difference from the Raiiz and Voikar–Syn'ya massifs of the Arctic Urals (Gurskaya et al., 2004; Kostyukhin and Remizov, 1995; Savelyeva and Suslov, 2014). For example, the Syum-Keu massif is the only one where intense solid-plastic rock deformations are developed in the zone of transition from mantle to crustal complexes and where garnet pyroxenes, wehrlites, and garnet gabbronorites are present in dunite–wehrlite–pyroxenite complex changing mantle peridotites upsection.