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# Mg-Cr-type spinel peridotites in the western part of the Central Asian Orogenic Belt (Zheltau massif, Southern Kazakhstan): the first data on P-T paths and protoliths

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Ultramafic and mafic lithologies, attributed to the orogenic terranes and formed under ultrahigh-pressure (UHP) and high-pressure (HP) conditions, have been intensively studied for the last decades. It is mainly related to a particular significance of these rocks for geodynamics, since they contain an important information on the fluid-rock interactions and element redistribution in the subduction-collision zones and could shed the light on the tectonic evolution of the studied region.

Within the western part of the Central Asian Orogenic Belt ultramafic-mafic (U)HP lithologies are attributed to Kokchetav massif in Northern Kazakhstan [*Katayama et al., 2001*], Makbal complex [*Meyer et al., 2013*], Aktyuz block [*Orozbaev et al., 2010*] in Northern Tien Shan, Atbashi and Chatkal complexes in Southern Tien Shan [*Hegner et al., 2010*] as well within the complexes of the South-Western Tien Shan, China [*Zhang et al., 2013*] and correspond to eclogites. The only case of garnet and spinel peridotites finding in the west CAOB is referred to Kokchetav massif, where UHP garnet peridotites are interpreted to have been formed after shallow metasomatized basalts, imbedded into the upper parts of continental crust prior subduction and correspond to the "crustal" type of UHP ultramafics (e.g. [*Reverdatto et al., 2008*]). Alternatively, in the structure of Precambrian Zheltau massif, located in the SE part of Chu-Ili Mountains (Southern Kazakhstan), spinel peridotites with different geochemical characteristics have been recently revealed for the first time.

Within Zheltau massif metamorphic formations are subdivided into Anrakhai and Koyandy Complexes (after [*Degtyarev et al., 2017*]). The Anrakhai complex rocks are predominant and represented by highly deformed biotite orthogneisses and gneissic granites with bodies of subalkaline garnet amphibolites. The Koyandy complex formations have been overthrust from the SW by the Anrakhai complex and are characterized by considerably less distribution within Zheltau terrane. Metamorphic lithologies of the Koyandy complex include paragneisses and garnet-mica schists, which contain pods of quartzites and marbles, mylonitized acid granulites with relics of alkaline feldspar and kyanite, as well as garnet amphibolites. Besides ortho- and paragneisses of the Anrakhai and Koyandy complexes enclose pods of ultramafic rocks, formed under at least HP metamorphism conditions and represented by eclogites and garnet clinopyroxenites with the estimated age of HP metamorphism 489±9Ma [*Alexeiev et al., 2011*]. These rocks are interpreted to have been derived from the differentiated intraplate tholeiitic melts, introduced into continental crust prior their subduction [*Pilitsyna et al., 2017*]; they correspond to the "crustal" Fe-Ti type of HP ultramafic-mafic rocks [*Carswell et al., 1983; Reverdatto et al., 2008*]. In the southeastern part of Zheltau massif among orthogneisses of the Anrakhai complex tectonic pods of serpentinites were revealed. One of the pods (250×120 m) is characterized by the patchy structure, where ultramafics are represented by homogenous magnetite-bearing serpentinites, enclosing dismembered layers (with thicknesses from the first decimeters up to several meters) of Cr-spinel-bearing serpentinized dunites, Cr-Spl peridotites and intensively amphibolized peridotites with relics of Ol as well as hornblendites. In doing so the rocks were evidently overprinted by late metasomatic changes, since almost all of them contain a number of minerals, normally related to metasomatism (rodingitization processes).

The observed ultramafic rocks are characterized by MgO contents in the range of 27.93–37.88 wt. % with Cr and Ni concentrations of 402–3114 ppm and 1085–2240 ppm, respectively. In doing so the rocks are strongly depleted by $TiO_2$ (151–373 ppm) and all REE (∑REE=0.24–0.98 ppm). These features are close to those ones, described in peridotites derived from the mantle source [*Bodinier, Godard, 2003; Godard et al., 2009; Janák et al., 2006*] rather than formed from mafic melts, imbedded into continental crust [*Reverdatto et al., 2008*], possessing considerably more enriched geochemical characteristics. On the other hand, the ultramafics of Zheltau massif tend to have high contents of fertile components (e.g. 1.06–9.15 wt. % of $Al_2O_3$; 0.12–7.07 wt. % of CaO); amphibole-bearing lithologies are also characterized by perceptible ∑ ($Na_2O$+$K_2O$) (0.21–1.06 wt. %). The contents of some elements in the ultramafics show representative covariations. Thus, Cr to Ni and CaO to $Al_2O_3$ display positive correlations, whereas MgO to $Al_2O_3$ and Ca/(Ca+Al) to Cr show clear negative correlations. These features are normally considered to have been attributed to either fractional crystallization (for example, crystallization succession of Ol -> Opx -> Cpx -> Pl reflects gradual decrease of MgO and $Al_2O_3$ with CaO increase) or variable degrees of partial melting. In comparison to chondrite composition the ultramafic rocks show moderately depleted REE contents (Yb=0.15–0.47 * C1-chondrite; Ce=0.14–0.58 * C1-chondrite) with prominent Eu anomalies (0.36–1.43 * C1-chondrite). Besides the patterns are characterized by smoothly U-shaped (or spoon-shaped) forms with Eu peaks, with slight MREE depletion relatively to LREE and HREE ((La/Sm)n – 0.85–2.48; (Dy/Lu)n – 0.31–0.68). On the primitive mantle (PM)-normalized plot the samples display clear Sr anomalies, which are complementary to Eu; furthermore, compared to depleted MORB mantle (DMM) the rocks are considerably enriched by LILE (Rb=6.46–566.75 * DMM; Pb=31.75–114.48 * DMM), whereas the right side of the plot is characterized by MREE and HREE depletion (generally up to 0.25 * DMM). It should be added that normative plagioclase, recalculated to vol. %, has positive correlations with Eu and Sr, implying the possible link of the observed Eu and Sr anomalies with Pl crystallization.

Concerning the petrography, Cr-Spl-bearing peridotites are characterized by two principal microtextural features, namely extensive Px-Spl and Amp-Spl symplectites development and Opx (Coarse Opx Rims or the CORs) as well as later Cr-bearing Cpx rims around olivine growth. These features are well documented in a number of metamorphosed ultramafic-mafic rocks of the different massifs throughout the world (e.g. Ulten zone, Italian Alps [*Godard et al., 1996*]; Moldanubian zone, Bohemian massif [*Obata et al., 2012*]). Regardless of the protolith origins, P-T paths of these complexes are determined by two general scenarios; the first one (counterclockwise) includes igneous stage with Ol+Pl assemblage crystallization, followed by cooling at granulite and then amphibolite facies re-equilibration (with formation of Opx coronas as well as Cpx-Spl and Amp-Spl symplectites, respectively) [*Cruciani et al., 2008*]. These rocks are normally attributed to metatroctolites, formed at pressures, that do not exceed 8 kbar. Alternatively, the second P-T path (clockwise) is related to Grt+Ol assemblage formation at high pressures (the spans vary considerably), followed by decompression with the CORs and Px-Spl (and later Amp-Spl) symplectites after garnet breakdown development [*Godard et al., 1996*]. The conducted investigations of petrography and mineral chemistry displayed, that the ultramafics apparently achieved garnet-stability field during their evolution and then were drastically re-equilibrated with Cpx-Opx-Spl symplectites and Coarse Opx Rims development. The main P-T assessments were obtained with using of Gibb's energy minimization method by means of pseudosections construction in Perple_X software [*Connolly, 2005*] for calculated effective bulk compositions (EBC) of the symplectitic and coronitic domains; the obtained intervals are overlapped in the P-T range of 11.5–14.5 kbar; 580–800 °C. Later amphibole from the symplectites was formed at P=8.5–10.5 kbar.

Metamorphic alterations of the ultramafics have obliterated their initial mineral compositions, however the manifested spoon-shaped (or smoothly U-shaped) form of the REE patterns could be resulted from the progressive fractionation of the certain minerals from a parental melt [*Janák et al., 2006; Godard et al., 2009*] (e.g. positive Eu anomaly reflects plagioclase fractionation). Besides plotted patterns of Zheltau massif ultramafics generally follow the patterns of the cumulative sequence rocks from the Middle Atlantic Ridge and are strongly differed from the mantle refractory harzburgites. An additional feature of the studied rocks is presence of vuagnatite, which has been solely found within rodingitic zones of ophiolites and is interpreted to have been formed after primary plagioclase [*Sarp et al., 1976*]. Summarizing, the ultramafic lithologies of Zheltau massif could possibly represent a part of an oceanic cumulative sequence, represented by Pl harzburgites and troctolites, derived from a partial melting of suboceanic mantle substance, that were subsequently subducted to garnet-stability field and then exhumed.

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