GEOCHEMICAL INVESTIGATION OF PRECIOUS AND HEAVY METALS IN THE PLACERS BELONGING TO BOZKIR OPHIOLITIC MELANGE (BOZKIR-KONYA-TURKEY)

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Three different tectonic units (Geyikdağı, Bolkardağı and Bozkır units) showing different structural, metamorphic and stratigrafic features are available in the investigation area that is located in S, E and SE of Bozkır (Konya-Turkey) in the Middle Taurus Mountains. Determining of mineral enrichments characteristics principally consist of platinum group metals (PGM) and Au derived from the rocks belonging to Bozkər ophiolitic melange, and listwanites and current placers was aimed in this study. 62 placer samples that were collected with random sampling method, analysed for major oxides and trace elements. It was determined that precious and heavy metals concentrate around of the parent rocks in the investigation of placers. It was observed that the concentrations of these metals were decrease as getting further from ophiolitic rocks. It was determined that PGM is found not alone but with Co, Ni, Au, Ti and Cu in different mixing forms, in these placers.

DUNITE-WEHRLITE-CLINOPYROXENITE IGNEOUS ASSOCIATIONS IN CRATONS AND MOBILE BELTS: A COMPARATIVE STUDY

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The dunite-wehrlite-clinopyroxenite association (DWCA) comprises two series: (1) dunite–wehrlite–olivine clinopyroxenite–magnetite clinopyroxenite (kosvite) and (2) dunite–plagioclase-bearing wehrlite–plagioclase clinopyroxenite (tylaite). Terms *kosvite* and *tylaite* (after mounts Kosva and Tylai in the northern Urals) were proposed by L. Duparc in the very beginning of the 20th century. The kosvite series consists of restitic material (dunite, often Cpx-bearing), solidified primary and evolved kosvite melts, olivine clinopyroxenite cumulates, and various mixtures of melts, restites, and cumulates (wehrlites, olivinites, etc.). The tylaite series is a combination of restite (dunite, including Pl-bearing variety), solidified tylaite melts, and tylaites enriched in cumulative olivine and clinopyroxene. Kosvite and tylaite series are considered to be derivatives of lithospheric wehrlite mantle; there is sufficient reason for suggesting that wehrlite sources are products of decarbonation of previously carbonated harzburgite (kosvite series) or lherzolite (tylaite series) [7]. The known DWCA vary in age from Paleoproterozoic (~2000 Ma) to Cenozoic (~20Ma ?) and are localized in both continental cratonic domains and mobile belts.

In the light of new geochronological data, the geological systematics of DWCA proposed in [6] requires a revision. In cratonic setting, three types of DWCA (kosvite series only) are recognized: (**1**) pipes, dikes, and sills composed of dunite, olivinite, kosvite, and magnetite rock that cut through the Bushveld layered complex in South Africa dated at 2054 Ma; (**2**) the unique Guli garpolith in the Maimecha (Meimecha)-Kotui province of the Siberian Craton consisting of dunite (the main body), transitional zone of wehrlite, and the uppermost layer of meimechite; dunite is intruded by kosvite dikes and sills, picrite dikes, and ijolite–carbonatite complex; the above rocks dated at 245-248 Ma are somewhat younger than a peak of flood basalt eruptions (251 Ma) in the Siberian Craton; (**3**) multiple central-type intrusions, where the rocks of kosvite series are combined with younger alkaline aluminosilicate rocks, carbonatites, and phoscorites (Gardiner in Greenland, 60-54 Ma; Jacupiranga in Brazil, 151-134 Ma; Bor-Uryakh, Kugda, etc. in the Siberian Craton, 245-248 Ma; Kovdor in the Baltic Shield, 380 Ma; Phalaborwa (Palabora), South Africa, 2062 Ma, and many others) [6 and references therein].

In mobile belts, DWCA are localized in marginal backarc zones, including (1) the rifts subsequently transformed into Alpine-type ophiolitic sutures and allochthons, (2) uplifts combined with backarc rifts and basins devoid of Alpine-type ultramafics, and (3) marginal uplifts. Three generations of DWCA are recognized in marginal backarc zones.

The first generation occurs in ophiolitic sutures and allochtons: the Semail allochthon in Oman; the Jijal Complex in the Indus Suture of Kohistan; ophiolitic belts of western Koryakia, eastern Kamchatka and Olyutor Zone, the Urals, etc. Cumulates of tylaite and kosvite series are predominant. Some gabbroic sheets in the so-called banded complex initially could have been residual melts of tylaite series. Kosvites are extremely rare or absent at all.

The second generation of DWCA is localized in marginal backarc zones devoid of ophiolites. The DWCA belts of southeastern Alaska, Koryak Highland, and the Urals are typical examples. Their analogues are known in the Paleoproterozoic Pechenga–Imandra–Varzuga Belt in the Kola Peninsula and elsewhere. DWCA of this generation is characterized by completely developed and closely associated kosvite and tylaite series. At the moment of DWCA formation, the backarc zones were composed of uplifted continental blocks, rifts and troughs filled with sedimentary and volcanic rocks. DWCA massifs are always localized in tectonic units underlain by continental crust. The Kondyor (Konder), Inagli, Sybakh, and Chad massifs localized in the marginal Aldan–Stanovoi Rise of the Mongolian–Okhotsk Mobile Belt furnish obvious evidence for such setting.

The third generation of DWCA follows the second one, being localized in the same marginal backarc zones. Kosvites and tylaites are enriched in Fe, Ti, P, K, Ba, Sr, and other lithophile elements. Apatite- and phlogopite-bearing kosvites, as well as pseudoleucite tylaite with abundant mica are typical. These rocks are known in central Kamchatka (Levoandrianovsky massif), marginal Aldan-Stanovoi Rise (late kosvites in the Kondyor massif), Platinum Belt of the Urals (late kosvite and tylaite in the Kytlym and Tagil massifs), the late generation of DWCA in the Pechenga–Imandra–Varzuga Belt, etc.

In polycyclic mobile belts, DWCA were formed during the early tectonomagmatic cycles transitional from the preceding cycles of rifting under cratonic conditions to the late cycles characterized by widespread island-arc and orogenic magmatism. In the Uralian Foldbelt, DWCA developed largely during the Cadomian cycle (Late Riphean–Late Ordovician): the first generation is dated at 760-580 Ma, the second generation, at 550-500 Ma, and the third generation, at 441-444 Ma. In the southern Urals, DWCA dated at 415-410 Ma was formed at the end of the Caledonian cycle. No DWCA pertaining to the younger Acadian (D) and Hercynian (D_3–P) cycles are known in the Urals. In Alaska, Koryak Highland, northern and central Kamchatka, DWCA of the first and second generations were formed during the Paleozoic, Late Paleozoic–Middle Jurassic, Late Jurassic–Early Cretaceous (Barremian), and Aptian–early Albian cycles. In Alaska, the oldest generation of DWCA is dated at 440-400 Ma and the youngest (the most abundant) generation, at 118-100 Ma. Tentative Sm-Nd age estimates of DWCA from the Koryak Highland yielded 158±110 (Epilchik), 181±10 Ma (Seinav), and 110±31 (Galmoenan). The third generation (Levoandrianovsky massif in central Kamchatka and its analogues in northern Kamchatka) pertain to the late Albian–Paleocene cycle (97-66 Ma ?); no DWKA massifs were formed during Eocene–Miocene and Pliocene–Quaternary cycles.

The age of DWKA from the marginal Aldan-Stanovoi Rise remains ambiguous. According to scanty and controversial evidence, several DWCA generations cover a wide chronological range from Neoproterozoic to Early Cretaceous. At least two generations are recognized in the Kondyor massif: (1) dunite core and related outer clinopyroxenite rim and (2) stockwork of phlogopite–apatite kosvite dikes cutting through the dunite core.

The DWCA massifs formed in cratonic setting, in stable marginal rises, and large ophiolitic allochthons (Semail, Jijal) retain their primary morphological features that bear direct evidence for the formation of partially melted wehrlitic bodies accumulated immediately beneath the mantle–crust interface and then extruded into the crust as separating dunitic restite (early cumulate) and primary melts. Moving upward, the melts entrained restite fragments and fractionated into high-Mg cumulates and evolved melts enriched in Fe (kosvite series) or Al (tylaite series). The process was accompanied by interaction of residual melts with restites and cumulates. Under appropriate physical conditions, a heavy (!) high-Fe silicate–oxide melt could have percolated downward, interacting with olivine and other solid phases to form olivinite and ore wehrlite [7].

The DWCA massifs localized in marginal backarc zones of mobile belts at early stages of their evolution were subsequently involved in multiple deformations and polymetamorphism related to these deformations, thermal effects of younger intrusions, and hydration during the closure of backarc marine basins. In many cases, DWCA is exposed now as allochthonous blocks and sheets that contact along faults with younger volcanic and sedimentary rocks (Platinum belt of Koryakia) or make up tectonic melange together with younger gabbroic bodies (Platinum belt of the Urals).

The DWCA localized in the Uralian ophiolitic belts are coeval with chromite-bearing dunite superimposed on harzburgite allochthons and with lherzolite closely related to harzburgite [8]. In the ophiolitic belt that extends along the Main Uralian Fault (Mindyak, Nurali, etc.) all these rocks are the Late Vendian, whereas in the Sakmara Zone (Khabarny and Kempirsay allochthons), they are dated at the Late Silurian–Early Devonian. Dunite veins and larger bodies are regarded as products of interaction of harzburgite with mantle-derived melts undersaturated with orthopyroxene at a low pressure. Kosvite melt is a suitable candidate for a magmatic solvent of orthopyroxene contained in harzburgite. As in the Lherz massif in the Pyrenees [4] and the Ronda massif in the Betic Cordillera [1], the lherzolites in ophiolitic belts of the Urals likely are products of refertilization of much older harzburgites percolated by basaltic melt; tylaite melt could have been such a refertilizer.

The most primitive chemical compositions are characteristic of the first DWCA generation localized in ophiolitic belts and allochthons. The scarce or completely lacking kosvites indicate that the Fe content in primary melt was too low for producing a significant amount of evolved Fe-rich liquid. The extremely low content of incompatible lithophile trace elements is close to that in peridotite protolith of wehrlitic source. Thus, these elements were not supplied to the source along with carbonate melt. It cannot be ruled out that beneath the initial rifts subsequently transformed into ophiolite sutures the carbonation of peridotites proceeded at a relatively shallow depth due to the influx of carbon dioxide into a peridotite swell.

The chemical compositions of the second and third generations of DWCA in mobile belts demonstrate progressive enrichment in Fe, Ti, P, K, Rb, Sr, Ba, and LREE, owing to the supply of the above-mentioned elements (except Fe and Ti) along with carbonatite melt. The same is valid for the DWCA of continental cratons.

In contrast to cratonic domains, where spatial association of DWCA with carbonatites is a common phenomenon, DWCA in mobile belts are not spatially associated with carbonatites. It may be suggested that mantle-derived carbonatites were not able to reach the upper crust because of extensive melting in the lower crust and the uppermost mantle with formation of partly molten plastic zones impermeable for the melts generated below.

The cause of enrichment of kosvite series in Fe and Ti is an issue, which has not been settled until now. The primary kosvites are comparable in chemistry with ferropicrites, the origin of which also remains a matter of debate. All lines of evidence lead to the conclusion that primary high-Fe rocks are derivatives of a mantle source having anomalously high Fe/Mg ratio and olivine composition of ~Fo_{85}. Suggestions on the nature of such a source did not overstep the limits of speculations. In contrast to kosvites and related rocks, which are as ancient as ~2000 Ma, ferropicrites are known from Archean terranes in association with komatiites. The model assuming that the Archean ferropicrites originated at a depth of 150 km (P = 5 GPa) and at a temperature of ~1600°C [3] is hardly applicable to kosvites. It seems reasonable to look for more appropriate interpretation. First, a certain compositional similarity of olivinites and kosvites with forsterite–apatite–magnetite phoscorites attracts attention [2]. The genetic links between phoscorites and carbonatites are evident, and it cannot be ruled out that phoscorites made a certain contribution to the genesis of Fe-rich magma sources. The second point concerns the fact that fractionation of kosvite melt leads to the segregation of residual Ti–Fe oxide liquid, which is appreciably heavier than high-Mg cumulates and restites and enables to sink, interacting with mantle material. Ferropicritic magma with a density higher than 3.33 g/cm^3 is unable to float because of negative buoyancy [3]. This idea, which was attracted to the explanation of zonal DWCA pipes in the Bushveld layered complex, might be spread over the mantle sources of kosvite series. Finally, the apatite-bearing magnetite ores at the deposits of iron oxide-copper-gold (IOCG) group and the Kiruna-type iron deposits is another noteworthy topic. The inferred magmatic origin of these ores has sufficient grounds to be a subject of reasoning. The Plio-Pleistocene El Laco apatite-magnetite deposit formed 2.1 Ma ago in the High Andes of Chile is the most remarkable in this respect. The deposit contains 500 Mt of almost pure magnetite ore (>98% iron oxide) in form of pyroclastic material, lava flows, and related dikes [5].

All these topics seemingly unrelated to DWCA, taken together, might drop a hint at the origin of Fe- and Ti-enriched rocks of kosvite series.

The DWCA varieties localized in cratonic domains and mobile belts make up a genetically coherent series related to wehrlitic mantle sources as products of decarbonation of previously carbonated peridotites [7]. The geochemical difference between DWCA formed in cratons and mobile belts is determined by nature, depth of origin, and thus variable LILE and HFSE contents in carbonate material reacted with peridotite protolith and by so far poorly understood enrichment of sources and melts in Fe and Ti. All diversity of rocks pertaining to DWCA was formed in partially molten wehrlite diapirs that originated at a depth of no greater than_80 km probably by merging of veins and then extruded into the crust under loading of overlying rocks or/and tectonic compression.

The metallogenic specialization of DWCA in mobile belts and continental cratons is the same (Fe-Ti and Fe-Cr oxides and PGE intermetallic compounds). The pristine magmatic matter of DWCA is depleted in sulfur, chlorine, and water. Exotic economic sulfide deposits presumably related to DWCA, e.g., Pechenga, were fed by sulfur from external sources. Mobile belts are more appropriate than cratons for the formation of economic titanomagnetite deposits and PGM-bearing chromite mineralization as a source of PGM placers. The redistribution and local concentration of ore components and recrystallization of ore minerals in the course of superimposed thermal and hydrous metamorphism create favorable conditions for increasing scope of primary ore and for enlargement of PGM mineral grains to the size sufficient for their accumulation in placers.

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THE PETROGENETIC SIGNIFICANCE OF THE RARE SULFIDE DJERFISHERITE: AN EXAMPLE FROM THE GULI DUNITE MASSIF (POLAR SIBERIA)

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INTRODUCTION

After its discovery in a meteorite [1] the uncommon sulfide djerfisherite, ideally $K_6(Fe,Cu,Ni)_{25}S_{26}Cl$, has been reported from different terrestrial localities [2,3,4 and references therein]. The data available