

Chromite-PGE mineralization in the Uktus Alaskan-Type Complex (Central Urals, Russia)

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Introduction

It has been proposed that chromitites owe their high Pt (and Pd) content to the segregation of magmatic sulfides during chromite precipitation (Naldrett and Von Gruenewaldt 1989). However, chromitites from Alaskan-type dunites apparently contradict this assumption since they characterize for high Pt contents, although there is no evidence for the attainment of sulfur saturation during their formation. In Alaskan-type chromitites, Pt is usually accompanied by Ir (i.e. St.Louis et al. 1986), thus emphasizing the anomalous behavior of Pt that is forced to precipitate with the refractory Ir, being decoupled from the low-melting allied elements Rh and Pd. The reason for the behavior of Pt in Alaskan-type complexes still remains poorly understood, being in apparent contrast with common mechanisms of PGE fractionation in stratiform and podiform chromitites. This article provides evidence that the PGM assemblage and PGE distribution in the dunite-chromitite association from the Uktus Alaskan-type complex (Central Urals) are strictly related with compositional changes in chromite and coexisting olivine, possibly reflecting variations of oxygen fugacity or silica activity below sulfur saturation.

Geological Setting

The Uktus complex is located close to the southern end of the so-called "Platinum-bearing Belt" of the Urals (Fig. 1). It covers an area of about 50 km² and consists of dunite, clinopyroxenite, wherlite, olivine- and amphibole gabbro arranged in a concentrically-zoned structure. Details of the geology and petrology of the Uktus complex can be found in Pushkarev (2000). Chromitite in the form of tiny vermiculations and wispy aggregates of a few millimetres is common in the dunites. Chromitite also occurs as veins and schlieren of about 0.5-3 x 15-30 cm in size, and at one locality inside the southern dunite body, it forms lenses and layers extended up to some meters along strike.

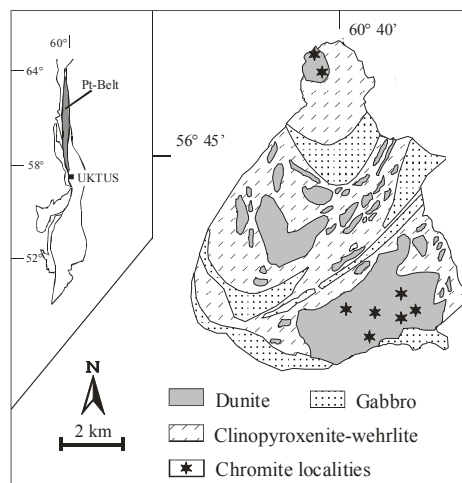


Figure 1. Geological sketch map of the Uktus complex (from Pushkarev 2000).

Composition of chromite

Compositions of disseminated and massive chromite from the Uktus dunite overlap the field of other Alaskan-type chromites of the Urals, and clearly distinguish from ophiolitic chromitites because of a remarkable iron enrichment in both the bivalent and trivalent sites (Fig.2). Some compositions may enter the "spinel gap" (Roeder 1994), thereby the chromite shows unmixing of Fe-spinel lamellae inside Cr-magnetite as a result of equilibration (Pushkarev 2000). The Fe³⁺# increases up to figures of 0.45, and defines a positive covariation trends with Fe²⁺# and TiO₂. The Fe²⁺# of the chromite correlates negatively with the forsterite content of the coexisting olivine (Fig. 3), so that magnesiochromitite (Fe²⁺# = 0.32) is associated with Mg-dunite (Fo = 92-95%) in the southern dunite body, whereas the most Fe-rich chromites (Fe²⁺# = 0.72) are found associated with the Fe-rich dunite (Fo = 80-84%), in the marginal zone of the northern dunite body. The oxygen fugacity (fO₂) calculated according to O'neil and Wall (1987) exceeds the FMQ buffer, and is remarkably in excess compared with values from ophiolites of the Urals (Pushkarev 2000).

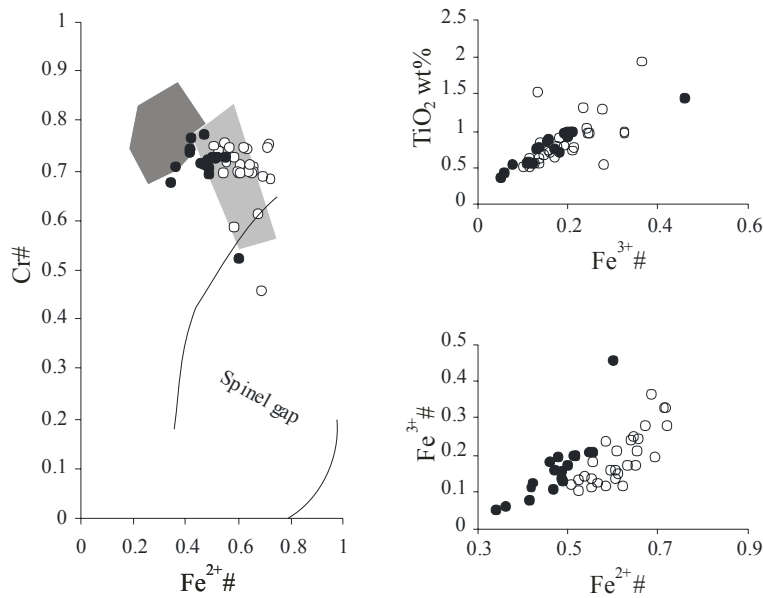


Figure 2. Chemical composition of chromite from chromitite (dots) and dunite (circles) of the Uktus complex. $Cr\# = Cr/(Cr+Al)$, $Fe^{2+\#} = Fe^{2+}/(Fe^{2+}+Mg)$, $Fe^{3+\#} = Fe^{3+}/(Fe^{3+}+Al+Cr)$. Fields of chromitites from the Urals, dark grey: ophiolites, light grey: Alaskan type.

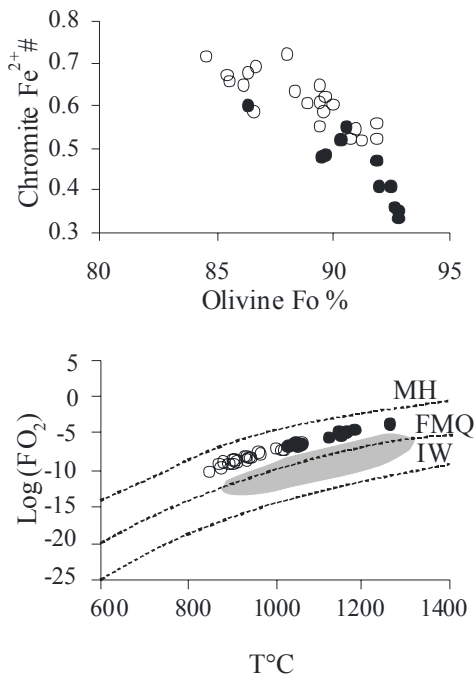


Figure 3. Chromite-olivine compositional relationships and variation of the oxygen fugacity (fO_2) as a function of temperature ($T^\circ C$), according to the equation of O'Neill, H. and Wall, V. (1987). Chromitite: dots, dunite: circles, grey field: ophiolitic chromitites of the Urals (Pushkarev 2000). MH: magnetite-hematite, FMQ: fayalite-magnetite-quartz, IW: iron-wustite.

Relationships between chromite composition and PGE mineralization

Chondrite-normalized PGE patterns of the Uktus dunites (Fig. 4) are characterized by a sharp positive anomaly of Pt, as it is typical of Alaskan-type dunites of the Urals (Garuti et al. 1997). The PGE profiles of chromitites vary from negative, with the Os, Ir, and Ru predominating over Pt, Rh, and Pd (Type Ia, b), to saw-like, with variable anomalies of Pt and Ir (Types II and III). These PGE profiles correspond to three different types of PGM assemblage, and conspicuously are correlated with changes in chromite composition and oxygen fugacity (Fig. 4):

Type Ia, b profile corresponds to PGM assemblages consisting of laurite (Ia), or kashinite and cuproiridsite (Ib) with accessory irarsite and tolovkite. These assemblages do not contain Pt minerals, and occur associated with magnesiocromite having oxidation ratio lower than 0.35.

Type II profile refers to PGM assemblages dominated by Pt-Fe alloys with isoferroplatinum-type composition (Pt_3Fe) and Ir-PGM (iridium, cuproiridsite, cuprorhodsite), along with accessory tulameenite, erlichmanite, malanite, cooperite, and very accessory geversite, potarite and prassoite. Type II assemblage is associated with magnesiocromite having the highest oxidation ratios (0.40-0.44).

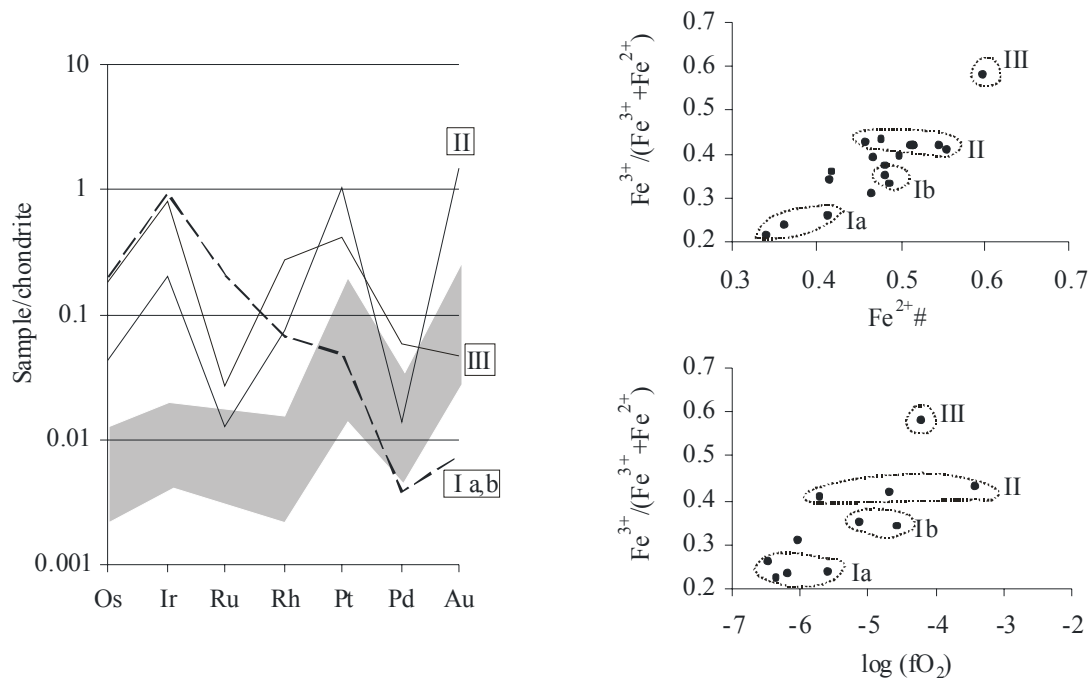


Figure 4. (Left) chondrite-normalized PGE patterns for chromitites and dunites (grey field) from Uktus. The PGE were determined by ICPMS after Ni-sulfide assay at the Modena University. Chondrite values from Naldrett and Von Gruenewaldt (1989). (Right) variation of the chromite oxidation ratio $\text{Fe}^{3+}/(\text{Fe}^{3+}+\text{Fe}^{2+})$ as a function of $\text{Fe}^{2+}\# = \text{Fe}^{2+}/(\text{Fe}^{2+}+\text{Mg})$ and oxygen fugacity ($f\text{O}_2$). Labels I (a,b), II, and III indicate type of PGE profile and the corresponding PGM assemblage (see text for explanation).

Type III profile corresponds to a PGM assemblage consisting of irarsite, tulameenite, Rh-Sb-S compound, Pt-Pd-Cu and Pd-Cu alloys and Pd-rich copper. It is associated with chromian magnetite characterized by oxidation ratio of 0.59. The mineralogical data consistently indicate a slight increase of Rh- and Pd- with respect to Pt-phases, that causes attenuation of the Pt anomaly in Type III PGE profile.

Most of the PGM occur as euhedral grains included in the chromite, the texture indicating that they are early magmatic phases mechanically entrapped in growing chromite crystals. However, there is textural evidence that part of the PGM assemblage (i.e. geversite, tulameenite, irarsite, potarite, prassoite) formed at some late stage as a result of PGE re-mobilization by the action of hydrothermal fluids.

Concluding remarks

1) The Uktus occurrence supports the contention that high concentrations of Pt in the Alaskan-type chromitites are originally due to extensive stabilization of Pt-Fe alloys during chromite precipitation. The close co-precipitation of

isoferroplatinum with magnesiochromite at the maximum state of oxidation would suggest that a sharp drop of the Pt solubility in the silicate melt was triggered by an increase in $f\text{O}_2$, while $f\text{S}_2$ was keeping well below the sulfur saturation threshold (Amossé et al. 1990). The fact that Pt minerals are absent in the magnesiochromite with low oxidation ratio, and the PGM assemblage is dominated by laurite and Ir-sulfides, would support this conclusion.

2) An alternative explanation is based on the assumption that the low silica activity in Alaskan-type magmas favors crystallization of olivine instead of orthopyroxene and produces an increase of the Fe_2O_3 activity, so that the coexisting chromite has relatively higher oxidation ratios compared with chromites derived from tholeiitic and high-alumina basalts (Irvine, 1967). The high iron activity has also a very strong effect in enhancing stabilization of Pt-Fe alloys (Borisov and Palme 2000), thereby considerable drop of the Pt solubility is to be expected in the magma. This process would be independent from variations in $f\text{O}_2$.

3) The positive Pt anomaly observed in

chromitites and dunites of the Alaskan-type complexes may reflect a distinctive feature of their parent melts, possibly inherited from a mantle source that had been previously enriched in Pt. This Pt enrichment in the source region of the Alaskan-type magmas might have been produced in the course of second-stage melting of a depleted and metasomatised mantle below the subduction zone (Garuti et al. 1997).

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