
Laurite and Osmium from the Guli Massif, Siberian Craton, Russia: New Insights from Osmium Isotopes for the Origin of PGE-Mineralization in Ultramafic Complexes

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Introduction

The Guli clinopyroxenite-dunite massif, like other clinopyroxenite-dunite complexes, e.g. Kondyor and Inagli (Malitch, 1999), is situated at the periphery of the Siberian Craton. The presence of economically important platinum-group element (PGE) placers in spatial association with ultramafites is a specific feature of these massifs. This contrasts with dunite-harzburgite (ophiolite-type) complexes that do not have economic placer deposits. The unique features of the Au-PGE placers at Guli are (1) the dominance of Os-rich alloys over other platinum-group minerals (PGM) and Au, and (2) the considerable predicted resources of noble metals, particularly osmium (Malitch et al., 1998). The morphology of PGM, their physical and chemical properties, textural features, and Os isotope composition, measured by NTI-MS, have been presented elsewhere (Malitch et al., 1995; Malitch and Lopatin, 1997; Malitch, 1999).

In this contribution, we focus on the mineral chemistry of Ru-Os sulfides associated with Os-rich alloys from Guli, for which Os-isotopic composition has been obtained by laser-ablation attached to multiple collector inductively coupled plasma mass spectrometry (LA MC-ICP-MS). *In-situ* osmium isotope study, of intimately intergrown laurite and Os-rich alloys from Guli, further provides Os-isotope constraints on the origin of PGE-mineralization in zoned-type clinopyroxenite-dunite complexes. This study suggests that PGM from zoned- and ophiolite-type complexes are isotopically distinct.

Geological Background and Sample Location

The main geological characteristics of the Guli massif, the world's largest clinopyroxenite-dunite massif located in the Maimecha-Kotui Province, northern part of the Siberian Craton, and associated placer deposits have been summarized by Malitch and Lopatin (1997). Os-rich nuggets including Os-rich alloys and Ru-Os sulfides (nuggets G 1-12, G 2-2, G 23-5 among other PGM nuggets, Fig. 1), were sampled during prospecting

of the Ingaringda River (Line 365) in the southern part of the Guli massif.

Analytical Techniques

After investigation by microprobe analysis, the PGM grains from the Guli massif were investigated by LA MC-ICP-MS at TU Bergakademie Freiberg. LA was performed with a Microprobe II laser ablation device (VG, Nd: YAG laser, 266 nm, pulse duration 3 ns, energy output to sample up to 4 mJ, ablation spot size up to 50 μ m, Fig. 1b-d). Technical details of the method and principal factors that influence the accuracy of LA MC-ICP-MS analyses are presented elsewhere (Becker and Dietze, 2000; Junk, 2001).

Results and Discussion

PGE Mineralogy. The majority of nuggets at Guli, both single crystals (e.g., subhedral, euhedral) and aggregates of euhedral crystals, are Os-rich alloys (osmium, according to the classification by Harris and Cabri, 1991) with considerable inter-nugget variation of Ir and Ru. At Guli Os-rich alloys are frequently intergrown with Ru-Os sulfides, chromite, olivine and clinopyroxene (Fig. 1a, b, e).

Minerals of the laurite-erlichmanite series $\text{RuS}_2\text{-OsS}_2$ are usually documented in association with osmium Os and iridian osmium (Os,Ir), either as interstitial phases between Os-rich alloy grain boundaries, or as a "negative" inclusion in the alloy. Ru-Os sulfides at Guli display large variations in Ru number [$100 \cdot \text{Ru}/(\text{Ru}+\text{Os})$], ranging from 99 to 2 (Fig. 2). Examples of such phenomena are exemplified by several nuggets (Figs. 1a-c, 2) [nugget G 23-5 shows the intimate zoning of at least 3 various laurite compositions (Ru numbers 94, 81 and 71), whereas nuggets GB 2-11 and GBB 5 reveal association of two distinct Ru-Os sulfides (laurite and erlichmanite) assembled with osmium (\pm forsterite)]. The composition of laurite, when plotted on the Os-Ir-Ru ternary diagram (Fig. 2A), shows common Ru substitution for Os. In contrast, erlichmanite compositions are dominated by uncommon Os substitution for Ir, with low Ru contents (Os from 67.61 to 37.95 wt. %, Ir from

31.94 to 5.50 wt. %, and Ru from 9.78 to 0.35 wt. %). Two solid solution series are, therefore, present in erlichmanite: (1) usual Os for Ru substitution in continuous solid solution between erlichmanite OsS_2 and laurite RuS_2 (Ru number 2 to 43); and (2) uncommon Os for Ir substitution between erlichmanite OsS_2 and unnamed IrS_2 (Fig. 2A).

Equilibrium phase relationships of Os-rich alloys at Guli, based on the binary system Os-Ir (Massalski, 1993), the presence of numerous silicate and oxide inclusions (Malitch and Auge, 1998), and exsolution lamellae of polycomponent Ru-Os-rich alloys in detrital Pt-Fe alloy at Guli (Malitch and Badanina, 1998) are indicative of high-temperature origin of PGM.

Osmium Isotope Systematics. The $^{187}\text{Os}/^{188}\text{Os}$ ratios in Os-rich alloys (osmium and iridian osmium) vary from 0.12433 ± 0.00010 to 0.12472 ± 0.00034 , whereas those of laurite range from 0.12432 ± 0.00029 to 0.12463 ± 0.00009 . Consequently, isotopic fractionation among these

Os-rich minerals is insignificant. The average $^{187}\text{Os}/^{188}\text{Os}$ value of Os-rich alloys and laurite are 0.12446 ± 0.00020 ($n=7$) and 0.12446 ± 0.00015 ($n=5$), respectively. Thus, based on the average Os-isotope composition, different PGM (e.g. Os-rich alloys and laurite) from the Guli massif yield the same model $^{187}\text{Os}/^{188}\text{Os}$ ages of 423 Ma, assuming a chondritic mantle reservoir.

The early formation of Os-rich minerals at high temperatures implies that the Os-isotopic composition of Os-rich alloys and laurite should reflect that of the source region. Therefore, the low $^{187}\text{Os}/^{188}\text{Os}$ values obtained and the constant Os-isotope ratios of different PGM at Guli, clearly indicate a common chondritic or subchondritic mantle source for the PGE. We, therefore, propose that the PGE were derived from the mantle without any significant crustal contribution of Os, and that the $^{187}\text{Os}/^{188}\text{Os}$ values have not been changed by subsequent processes (e.g. transport, sedimentation and weathering during placer formation).

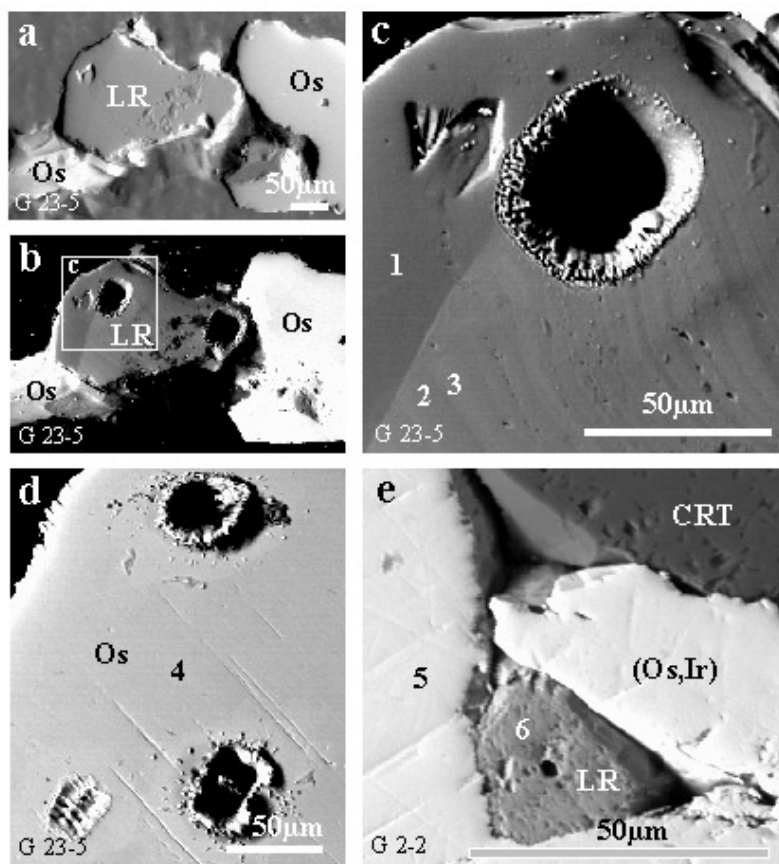


Figure 1. Back-scattered electron images of Os-rich nuggets (G 23-5 and G 2-2) from the Guli massif before (a, e) and after (b-d) laser ablation MC-ICP-MS. (Os, Ir) - iridian osmium, Os – osmium, LR – laurite, CRT – chromite; details of nugget G 23-5 show laurites of different composition (c) and osmium (d). Numbers 1-6 denote areas of electron microprobe analyses corresponding to the same numbers in Figure 2B. Black holes refer to areas of laser ablation MC-ICP-MS analyses.

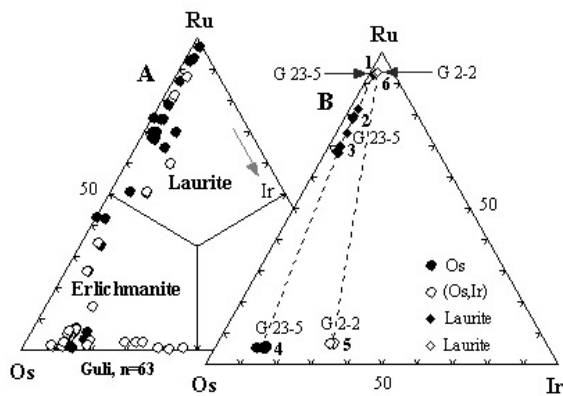


Figure 2. Composition of Ru-Os sulfides at Guli (A) and intimately intergrown PGM from nuggets G 23-5 and G 2-2 (B) in the ternary diagram Ru-Os-Ir, at.%. Open and filled circles in Fig. 1A refer to Ru-Os sulfides documented as (1) inclusions and (2) intergrown phases with Os-rich alloy, respectively.

The $^{187}\text{Os}/^{188}\text{Os}$ values for the PGM nuggets at Guli are close to those from a former NTI-MS study, which showed mean value of 0.1248 ± 0.0003 (Malitch, 1999). The very narrow range of $^{187}\text{Os}/^{188}\text{Os}$ values of PGM at Guli, exemplified by both LA MC-ICP-MS and NTI-MS (0.12446 ± 0.00020 and 0.1248 ± 0.0003

respectively, the expanding uncertainties correspond to the 95%-confidence interval), is consistent with similar results for PGM from Kondyor and Inagli (Fig. 3), and likely indicates a highly productive single-stage PGM formation in clinopyroxenite-dunite complexes. Os-isotope model ages of distinct PGM at Guli indicate that this event took place in the Middle Paleozoic, prior to the Devonian-Carboniferous boundary, which corresponds to a stage of active tectonism in the development of the Siberian Craton.

The range of $^{187}\text{Os}/^{188}\text{Os}$ and the $\gamma_{\text{Os}(T=0)}$ values in PGM derived from clinopyroxenite-dunite complexes are distinctly different from those observed for ophiolite-type ultramafic complexes (Fig. 3). For instance, PGM derived from the Guli, Kondyor and Inagli complexes, Siberian Craton, Russia show a narrow range of $^{187}\text{Os}/^{188}\text{Os}$ and γ_{Os} values (e.g., 0.12432-0.12520 and from -2.39 to -1.70, respectively, n=32, Malitch, 1999, this study), whereas those from the Kunar Complex, Taimyr, Russia, the Ust'-Bel'sky Complex, Far East, Russia and the bedrock PGM from podiform chromitites of the Speik Complex, Eastern Alps, Austria (Fig. 3), have a wide range of $^{187}\text{Os}/^{188}\text{Os}$ (e.g. 0.1094-0.1252, n=55) and $\gamma_{\text{Os}(T=0)}$ values (e.g. from -14.10 to -1.70, n=55).

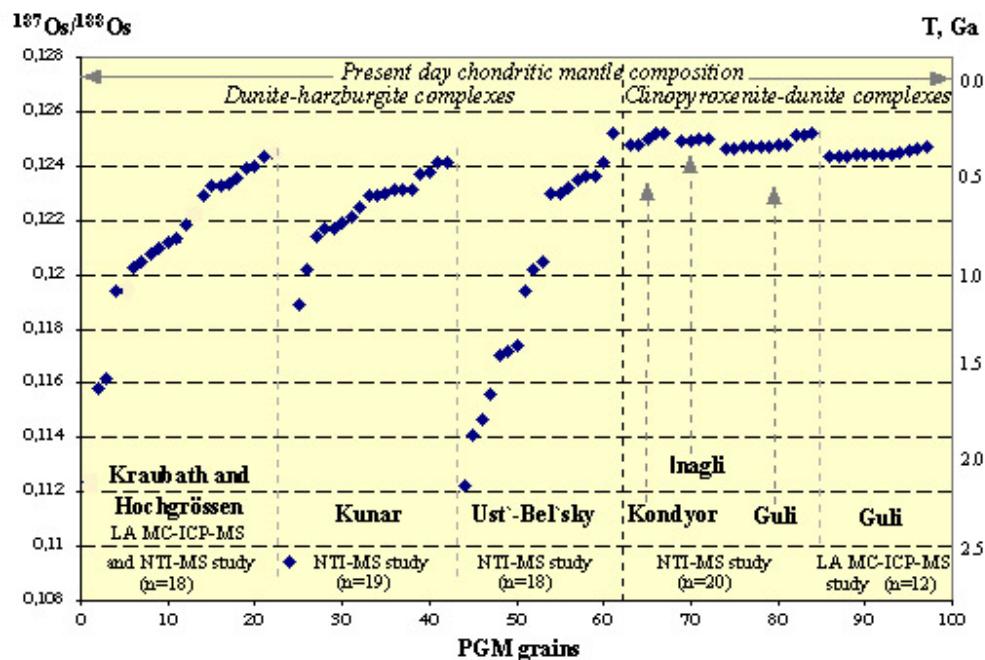


Figure 3. Os-isotope composition of PGM from dunite-harzburgite and clinopyroxenite-dunite complexes, Russia. Os-isotope data are from Malitch (a,b, this volume) for Kraubath, Hochgrössen and Kunar PGM, from Rudashevsky et al. (1999) for Ust'-Bel'sky PGM, from Malitch (1999) for Guli, Kondyor and Inagli PGM.

These results are consistent with a high and low metallogenic potential of clinopyroxenite-dunite and dunite-harzburgite complexes, respectively. Indeed, considerable scatter of chondritic Os isotope values of PGM from the residual mantle in ophiolites exemplifies prolonged melting-event history of parent ultramafic protoliths, which did not result in a significant concentration of PGE. In contrast, a highly productive single stage process of PGE-concentration in clinopyroxenite-dunite complexes [deduced from almost identical Os-isotopic composition of PGM (Fig. 3)], is in accordance with a significant metallogenic potential of their parent ultramafic protoliths.

On the basis of the Os-isotopic data obtained, we conclude that the Os-isotopic composition for PGM nuggets derived from placer deposits, with an unknown provenance, could be employed as a useful tool in deciphering their parent bedrock sources (e.g., clinopyroxenite-dunite and dunite-harzburgite ultramafic complexes). Further work, combined with previously unpublished data, will explore this application in depth.

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