

The origin of platinum-group element enrichments in alkalic porphyry systems: evidence from melt inclusions

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Introduction

To elucidate some uncertainties concerning PGE enrichment in alkalic porphyry systems, we have performed a comprehensive study of the mineralogy, bulk rock geochemistry and melt inclusion chemistry of two porphyry systems in British Columbia, Canada.

Results and Discussion

Discrete PGE minerals in these systems are represented by Hg-rich Pd-Pt-As-Sb species (naldrettite-stibiopalladinite-sperrylite) and Pd-Te-Hg species (kotulskite-temagamite). However, these mineral phases are unambiguously late-stage, having formed during either remobilization of the PGE during a stage of carbonate-chlorite alteration, or during an epithermal stage whereby low salinity vapour transported Pd, along with Au, Sb, As, and S and deposited these in quartz carbonate-pyrite veins that cross-cut the porphyry-stage veining.

An indication of the nature of primary enrichment in PGE is supported by LA-ICPMS analyses of primary silicate melt inclusions within leucite-olivine-clinopyroxene-phyric, high-Mg basalt flows that are coeval with the porphyry rocks. The inclusions preserve Pd/Pt ratios, determined by LA-ICPMS, that are very similar to Pd/Pt ratios in bulk ore samples, suggesting that the basalts and porphyry rocks are genetically related (e.g., mixing of mafic and felsic endmembers to produce a hybrid PGE-rich porphyry magma, or contamination of a mafic magma by crustal material during ascent).

Only limited decoupling of Pd from Pt occurred during melt fractionation or mixing, melt ascent, fluid exsolution, and ore precipitation. PGE precipitation in the porphyry stage occurred in pyrite (as a dissolved trace constituent) and was coincident to Co and Ni enrichment in the pyrite, an association that is observed in found in IOCG deposits and Outokompu-type (mantle-peridotite associated) Cu-Co-Ni deposits.

A global Os isotope signal in a narrow seaway – the Late Jurassic from the Barents Sea to S. England

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Late Jurassic organic-rich shales are the dominant source rock for expansive hydrocarbon reserves in the corridor extending from the North Atlantic through the North and Norwegian Seas to the Barents Sea. An enormous accumulation of organic matter is contained in shales deposited over ca. 15 m.y. from the Late Jurassic (Oxfordian) through the earliest Cretaceous (Berriasian). At this time, the region was a drowned continental shelf; a narrow seaway cluttered with small landmasses tenuously linked the Arctic and Tethyan marine systems. Re-Os geochronology is now available from four sites along this seaway, from NE to SW: Nordkapp Basin in the Barents Sea, Troms III on the northern Norwegian Shelf, Staffin Bay on the Isle of Skye (western Scotland) [1], and the Kimmeridge sea cliffs at Dorset (southern England) [2]. Shales from the four sites differ significantly in depositional environment and proximity to shoreline, and in related variations in trace metal chemistry. Despite this complexity, seawater ¹⁸⁷Os/¹⁸⁸Os captured in the shales is remarkably consistent for a given depositional age.

At the two northern locales, Nordkapp Basin and Troms III, Hekkingen Formation shales are divided into a basal Alge Member and overlying Krill Member. At Troms III, the distinction is clear: relative to the rich Alge source rock, the Krill has lower total organic carbon (TOC) and lower gamma radiation. At Nordkapp Basin, this distinction is blurred. TOC is high throughout the Hekkingen section and trace metal concentrations are significantly higher than at Troms III, even when normalized to TOC. Also, biostratigraphy indicates that the units are time-transgressive; Krill deposition ended earlier at Nordkapp Basin than at Troms III.

Our new Re-Os data show a consistent increase in the initial ¹⁸⁷Os/¹⁸⁸Os ratio through the Late Jurassic. Alge shales at Troms III and Nordkapp Basin, with isochron ages of ~152 and ~158 Ma, have relatively low initial ¹⁸⁷Os/¹⁸⁸Os ratios of about 0.51 and 0.45, respectively. Upsection, Krill shales with isochron ages <150 Ma, have ratios >0.6. The correspondence continues to the south, where Staffin Bay shales near the Oxfordian-Kimmeridgian boundary yield an age of 154.1 ± 2.1 Ma with initial ¹⁸⁷Os/¹⁸⁸Os = 0.53 ± 0.02 [1]. The Kimmeridge Clay shales yield an age of 155 ± 4.3 Ma but with higher initial ¹⁸⁷Os/¹⁸⁸Os = 0.59 ± 0.07 [2]. Although the imprecise Kimmeridge isochron age is similar to that of the Staffin Bay and Alge shales, the biostratigraphy (*wheatleyensis* Subzone) indicates an early Tithonian age, more likely correlative with the Krill shales.

The rising initial ¹⁸⁷Os/¹⁸⁸Os shale ratios through the Late Jurassic closely mimic the ⁸⁷Sr/⁸⁶Sr seawater curve. Our study shows that seawater Os is well mixed, even in narrow, confined seaways with relatively shallow water and nearby shorelines. Seawater ¹⁸⁷Os/¹⁸⁸Os is faithfully recorded in organic-rich shales.

NRC Petromaks project 180015/S30. [1] Selby (2007) *Nor. J of Geol.* **87**: 291-299. [2] Cohen et al. (1999) *EPSL* **167**: 159-173.