On the formation of peridotite-derived Os-rich PGE alloys

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ABSTRACT

Osmium-rich Pt group element (PGE) alloys occur worldwide in association with chromite in ultramafic (peridotite) complexes. It has been suggested that these Os-rich alloys formed under extreme P-T conditions in the lowermost mantle, before the metallic core of the Earth formed, or later, in the outer core, and have been transported to the upper mantle as xenoliths in deep-rooted mantle plumes.

Our investigation of syn- and pregenetic inclusions (including silicate and chromite) found in Os-rich alloys from peridotites in northern California and southwest Oregon yield no evidence that these alloys formed under extreme P-T conditions. Instead these inclusions point to a hydrous magmatic origin in the shallow upper mantle, most likely in an arc-environment. Indeed, the common occurrence of Os-rich PGE alloys as primary inclusions in massive (commonly podiform), chromite deposits and, conversely, the occurrence of chromite, olivine, pyroxene, laurite, and siliceous (boninitic) melt inclusions in Os-rich PGE alloys suggest a common origin for all these minerals.

Integrating our observations with recent experimental work and with observed field relations, we find support for a model in which massive chromite deposits, olivine, laurite, and Os-rich PGE alloys form in a single magmatic process. In an arc-environment, H2O-rich fluids and siliceous melts (e.g., boninites) are produced in the mantle wedge above the descending and dehydrating plate. Large differences in interfacial energy between the precipitated chromite and PGE alloys, and the hydrous fluid(s) and siliceous melt(s), cause a strong concentration of chromite and PGE alloys in the hydrous fluid(s). This general scenario is capable of simultaneously explaining all key observations, including: (1) the formation of massive chromite deposits; (2) nodular chromite textures; (3) Os-rich PGE alloys, laurite, olivine, and pyroxene as common inclusions in massive chromite; (4) inclusions of chromite, olivine, pyroxene, and hydrated siliceous inclusions (the current study) in the Os-rich PGE alloys; and (5) a similar range of variation in 187Os/188Os ratios among Os-rich PGE alloys and massive chromite deposits from individual ultramafic bodies world-wide.

INTRODUCTION

Material from the deep regions of the Earth’s mantle is extremely scarce. This scarcity limits our efforts to explore in detail the chemistry and mineralogy of mantle phases below the transition zone. It has been argued that certain inclusions in diamonds (e.g., Harte and Harris 1994; Stachel et al. 2000a, 2000b; Brenker et al. 2002) and probably also a suite of small xenoliths from Malaita (Collerson et al. 2001) may indeed originate in the transition zone or from the lower mantle. These two occurrences might be the only known examples of minerals that have preserved their chemical (and perhaps structural) information during ascent from the deep mantle. However, already decades ago it was proposed that rocks called “josephinite” from the Josephine ophiolite in southwest Oregon and northern California, which contain a high proportion of Ni-rich FeNi metal (awaurite), might have originated from the outer core of the Earth or the core-mantle boundary region and was transported up to the surface of the Earth as xenoliths in deep-rooted mantle plumes (Bird and Weathers 1975, 1979; Bird et al. 1979). This idea was abandoned by the vast majority of researchers as it became clear that Ni-rich FeNi metal is easily formed under the reducing conditions prevailing during serpentinitization of ophiolites (e.g., Chamberlain et al. 1965; Dick 1974; Eckstrand 1975; Dick and Gillette 1976; Sleep et al. 2003). A case also was made that mantle-derived Os- and Ir-rich PGE alloys (osmiridium and iridosmine), occurring in chromite-rich placers in southwest Oregon and northern California, but not otherwise related to josephinite, either are primordial materials that have survived since the formation of the Earth, or formed as the result of melting in one of three alternative scenarios: (1) in the lower mantle in the early Earth when mantle temperatures were higher than at present; (2) in the mantle at depths greater than 2900 km before that region was occupied by the core; or (3) in the outer core (Bird and Bassett 1980). These inferences were based on petrologic observations of complex PGE alloy intergrowths suggesting that these alloys crystallized from a melt, a hypothesized phase change argued to reflect pressure release as the alloys were transported to the upper mantle, and extremely high estimated melting temperatures (>3000 °C at deep mantle pressures) inferred by ex-