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Metal-saturated peridotite in the mantle wedge inferred from metal-bearing peridotite xenoliths from Avacha volcano, Kamchatka

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ABSTRACT

Lithospheric mantle is inferred to be more oxidized than the asthenosphere, and mantle-wedge peridotites are characterized by high oxidation state relative to abyssal and continental peridotites due to addition of slab-derived fluids or melts. We found metals (native Ni, Fe silicides, native Fe and possible native Ti) from otherwise oxidized sub-arc mantle peridotite xenoliths from Avacha volcano, Kamchatka. This is contrary to the consensus and experimental results that the metals are stable only in deeper parts of the mantle (>250 km). The metals from Avacha are different in chemistry and petrography from those in serpentinized peridotites. The Avacha metals are characteristically out of chemical equilibrium between individual grains as well as with surrounding peridotite minerals. This indicates their independent formation from different fluids. Some of the Avacha metals form inclusion trails with fluids and pyroxenes, leading to the inference that very local metal saturation resulted from rapid supply ('flashing') of reducing fluids from deeper levels. The fluids, possibly rich in H_2, are formed by serpentinization at the cold base of the mantle wedge just above the slab, and they reduce overlying peridotites. We propose a metal-saturated peridotite layer, underlying the main oxidized portion, within the mantle wedge beneath the volcanic front to fore-arc region.

1. Introduction

A whole picture of the redox state of the upper mantle is difficult to understand due to limited and uneven coverage of mantle-derived materials for the earth's mantle. Distribution of metal phases within the mantle has been poorly known due to the scarcity of mantle materials with "in-situ" metal phases. Metals can exist at high pressures, i.e., in deeper parts of the upper mantle (>250 km) (Rohrbach et al., 2007) and/or at extremely reduced conditions, such as the iron–wüstite (IW) buffer, although native Ni is stable in more oxidized condition near the Ni–NiO (NNO) buffer, 0.8 log units above from fayalite–magnetite–quartz buffer (FMQ) (Carmichael, 1991). The presence of metal phases also means low sulfur fugacities because the base metal elements, e.g., Fe, Ni, Cu and Zn, prefer to bond to sulfur to form sulfides under high sulfur activities.

Metals formed at crustal conditions have been commonly reported from serpentinized peridotite or serpentinites (e.g., Nickel, 1959; Chamberlain et al., 1965; Dick, 1974), but rarely found in fresh peridotite xenoliths (Ryabchikov et al., 1995), altered peridotite xenoliths (Lorand and Grégoire, 2006), and diamondiferous mineral assemblages within kimberlites (e.g., Jacob et al., 2004; Tikov et al., 2006). Some of those metals have been interpreted as a product of reduction of magnetite in serpentinites (e.g., Dick, 1974) or desulfurization of Fe–Ni sulfides in peridotite xenoliths (Ryabchikov et al., 1995; Lorand and Grégoire, 2006) at low pressures. Podiform chromitite of Luobusa ophiolite is well known for occurrence of various types of alloys, e.g., PGE and base metal alloys, and native metals, e.g., Si, Fe, Ni and Cr (e.g., Bai et al., 2000; Robinson et al., 2004), together with high-pressure minerals such as coesite (Yang et al., 2007; Yamamoto et al., 2008) and diamond (Yang et al., 2007). Most of podiform chromitites have been interpreted, however, to form at the shallowest mantle condition (e.g., Arai, 1997; Matveev and Ballhaus, 2002). These metals are frequently enclosed by chromian spinel, an essential mineral of chromitites, indicating that the derivation and condition of precipitation of the metals are not so clear for the Luobusa ophiolite (Robinson et al., 2004).

In general, the lithospheric mantle is more oxidized than the asthenospheric mantle, and the sub-arc mantle is also more oxidized than the continental mantle and the sub-oceanic mantle (Frost and McCammon, 2008). We found, however, several metal phases of metasomatic origin, being in disequilibrium with each other as well as with ambient peridotite minerals, in sub-arc mantle peridotite xenoliths from Avacha volcano, Kamchatka. This means an extremely reduced condition is available somewhere within the mantle wedge, and can give us new constraints on the redox state of the upper mantle.

2. Geological background

Avacha, one of the volcanoes that erupt magmas with peridotite xenoliths in Kamchatka arc (Kepezhinskas et al., 1996; Widom et al.,

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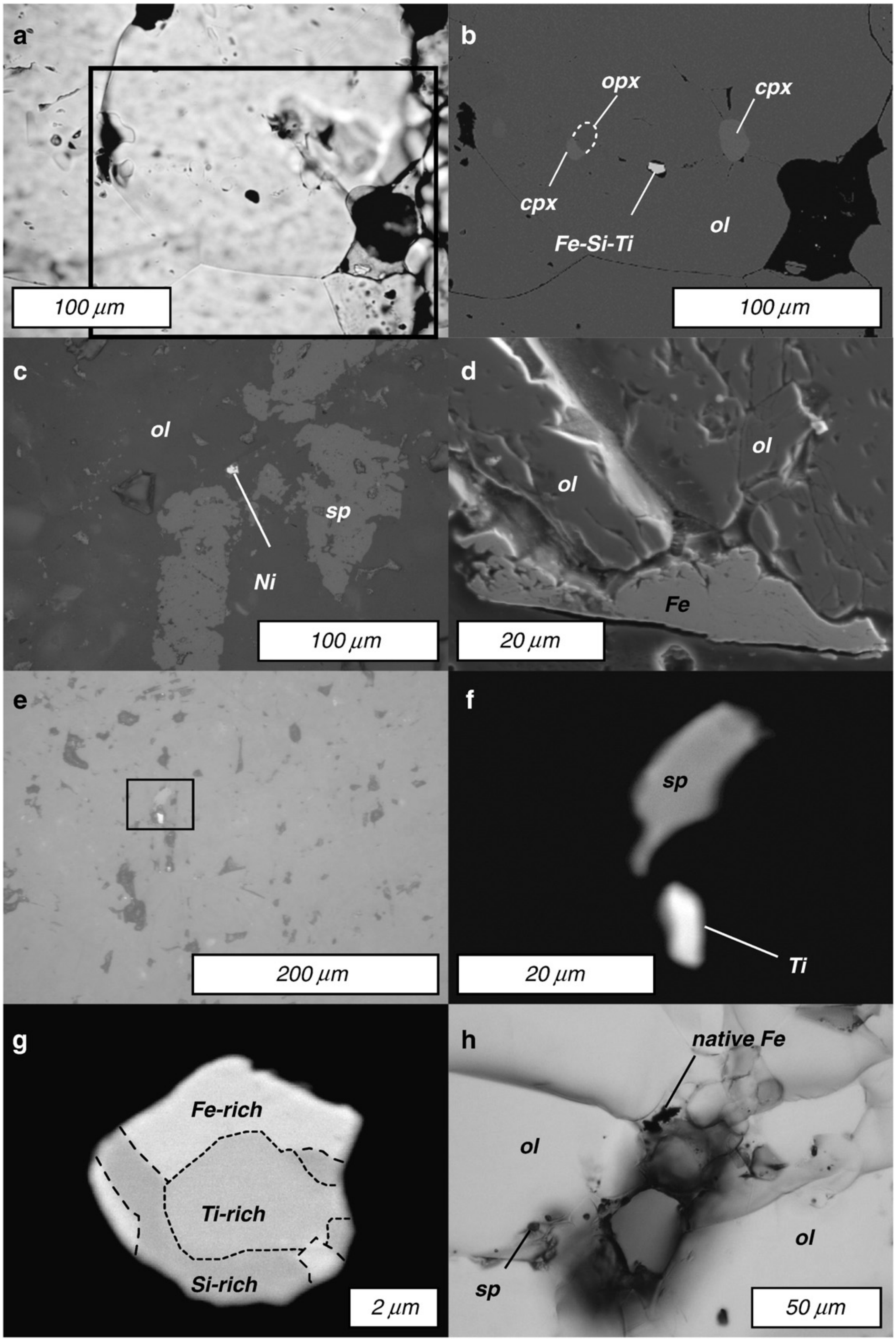

Fig. 1. Photomicrographs and microprobe SE (= secondary electron) or COMP (= compositional) images of metallic minerals in Avacha peridotite samples. (a) Plane-polarized light image of Fe silicide (Fe–Si) in sample #159 taking part in inclusion trail formation in olivine. (b) Microprobe COMPO image of the rectangle area in panel (a). The inclusion trail is composed of clinopyroxene (cpx), orthopyroxene (opx), Fe silicide, and fluids (not shown). (c) Reflected-light image of native Ni (Ni) inclusion in olivine in sample #159. (d) SE image of native Fe (Fe) located at the edge of sample #159. (e) Reflected-light image of native Ti (Ti) close to chromian spinel (sp). (f) Microprobe X-ray image of the rectangle area in panel (e). (g) COMPO image of Fe silicide in sample #166. (h) Plane-polarized light image of native Fe in sample #679 observed along the olivine–olivine grain boundary.