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Invited review article

Formation and modification of chromitites in the mantle

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ABSTRACT

Podiform chromitites have long supplied us with unrivaled information on various mantle processes, including the peridotite-magma reaction, deep-seated magmatic evolution, and mantle dynamics. The recent discovery of ultrahigh-pressure (UHP) chromitites not only sheds light on a different aspect of podiform chromitites, but also changes our understanding of the whole picture of podiform chromitite genesis. In addition, new evidence was recently presented for hydrothermal modification/formation chromite/chromitite in the mantle, which is a classical but innovative issue. In this context, we present here an urgently needed comprehensive review of podiform chromitites in the upper mantle. Wall-rock control on podiform chromitite genesis demonstrates that the peridotite-magma reaction at the upper mantle condition is an indispensable process. We may need a large system in the mantle, far larger than the size of outcrops or mining areas, to fulfill the Cr budget requirement for podiform chromitite genesis. The peridotite-magma reaction over a large area may form a melt enriched with Na and other incompatible elements, which mixes with a less evolved magma supplied from the depth to create chromite-oversaturated magma. The incompatible-element-rich magma trapped by the chromite mainly precipitates pargasite and aspidolite (Na analogue of phlogopite), which are stable under upper mantle conditions. Moderately depleted harzburgites, which contain chromite with a moderate Cr# (0.4–0.6) and a small amount of clinopyroxene, are the best reactants for the chromitite-forming reaction, and are the best hosts for podiform chromitites. Arc-type chromitites are dominant in ophiolites, but some are of the mid-ocean ridge type; chromitites may be common beneath the ocean floor, although it has not yet been explored for chromitite. The low-pressure (upper mantle) igneous chromitites were conveyed through mantle convection or subduction down to the mantle transition zone to form ultrahigh-pressure chromitites. Some of these reappear at the shallower mantle, and can coexist with newly formed low-pressure igneous chromitites. High-temperature hydrothermal fluids can dissolve and precipitate chromite, and hydrothermal chromitites (chromitites precipitated from aqueous fluids) are possibly formed within the mantle where the circulation of hydrous fluid is available, e.g., at the mantle wedge.

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1. Introduction

Chromitites occur both in the lower crust, as well-layered stratiform chromitites within layered intrusions, and in the mantle as so-called podiform chromitites (cf. Jackson and Thayer, 1972). The former are associated with ultramafic, gabbroic and anorthositic rocks, which filled the crustal magma chamber, and are mostly of Precambrian age (e.g., Mondal and Mathez, 2007). They are interpreted as cumulates from the chrome-oversaturated magma, which was formed when the mantle-derived magma mixed with a silicic melt created by the partial melting of roof crustal rocks (Irvine, 1975). Irvine (1975) ascribed the origin of composite mineral inclusions rich in alkalis, water, and silica in the chromite in chromitites to the entrapment of such a crustal partial melt. Later, Irvine (1977) preferred a relatively silica-rich magma fractionated from the parent magma, instead of the crustal partial melt, in the formation of chromite-oversaturated magmas. Spandler et al. (2005) found a mixing trend for the bulk chemical compositions of homogenized inclusions in chromites from the Stillwater intrusion. Combined with isotopic data, the authors confirmed the importance of the assimilation of the surrounding crustal rocks in the formation of chromitites within the layered intrusions. Mondal and Mathez (2007) discussed the intrusion of batches of chromite-laden magma for the formation of stratiform chromitites in the Bushveld intrusion.

In contrast, the origin of podiform chromitites in peridotites (Fig. 1) is still unclear. One of the most serious problems regarding their origin is the mechanism of chromite concentration and the related Cr budget. Typically, podiform chromitites are surrounded by the dunite envelope within mantle harzburgites (Fig. 1), where the budget of Cr involved in forming the chromitite is not clear. Some chromitites pods cut foliation planes of harzburgite, indicating their younger generation. The origin of the dunites enveloping the podiform chromitites is not easy to understand either: is it crystal accumulation, refractory residue or a magma-harzburgite reaction product?

Poor accessibility to exposures of fresh chromitites and their host peridotites is also serious: the chromitites (especially the silicate part) and surrounding peridotites usually suffer from severe alteration (serpentinization). Due to this selective alteration, the formation of chromitites was easily linked to hydrothermal activity in early chromitite studies (e.g., Fisher, 1929), as stated below. Hydrothermal activities that may affect chromite concentration will be also reviewed and discussed in this paper.

Another problem is that podiform chromitites from a known tectonic setting have been rarely available (e.g., Abe, 2011; Arai and Matsukage, 1998). Chromitite xenoliths in young volcanics, if any, may directly show the tectonic setting of derivation as the location where they occur. But Thayer (1970) already noted that chromitites are as rare as xenoliths in magmas (cf. Arai and Abe, 1994).

Igneous textures in podiform chromitites, especially those indicating a crystal accumulation origin, were recognized in the 1960s (e.g., Thayer, 1964, 1969), but the process of magmatic formation of podiform chromitites was not recognized until later. One of the most important observations related to podiform chromitite genesis may have been recognition of the dunite envelope around the chromitite (e.g., Cassard et al., 1981; Lago et al., 1982) (Fig. 1). Following the hypothesis of stratiform chromitite genesis developed by Irvine (1975, 1977), the podiform

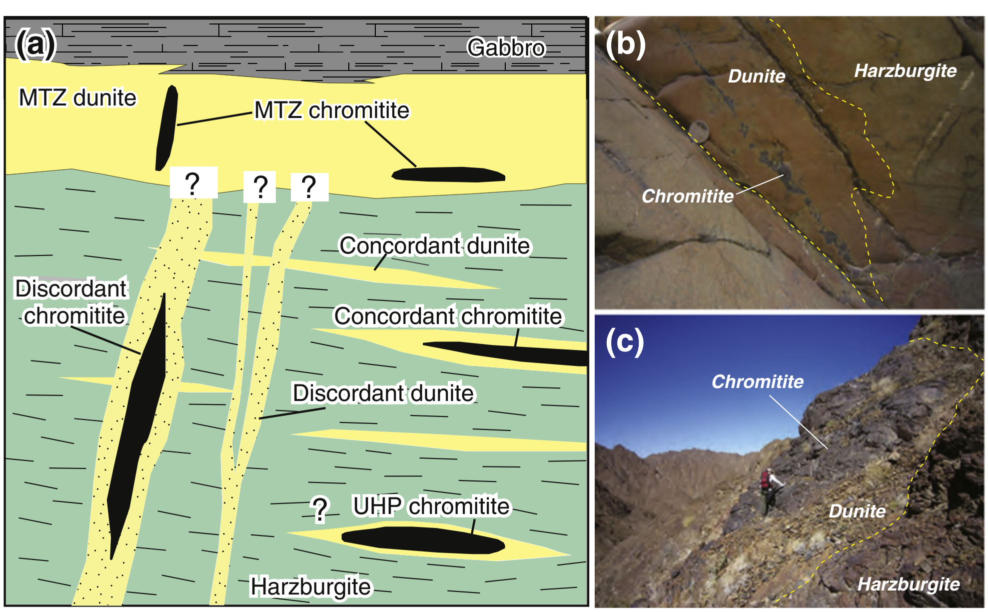

Fig. 1. Podiform chromitites on an outcrop. Note that the chromitites are always enveloped by dunite. Modified from Fig. 1 of Arai and Miura (2015). (a) Schematic illustration for various modes of occurrence. (b) Small-scale chromitite from Wadi Hilti, Oman ophiolite. The coin is 2.5 cm across. (c) Large pod of chromitite from Wadi Hilt, Oman ophiolite.