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Conversion of low-pressure chromitites to ultrahigh-pressure chromitites by deep recycling: A good inference

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ABSTRACT

Podiform chromitites have been interpreted as a peridotite/melt reaction product within the upper mantle (= low-P chromitites). Some of them, however, contain ultrahigh-pressure (UHP) minerals such as diamond and coesite (= UHP chromitites). The UHP chromitites can be produced by deep recycling of low-P chromitites via mantle convection. Carbon-rich UHP minerals were changed from fluidal C species (e.g., CO_2) metasomatically entrapped during the travel of chromitites within the mantle. Lamellae of coesite and other silicates observed in UHP chromite were possibly originated from globular inclusions of hydrous minerals and pyroxenes, which are common in low-P chromitites. Platinum-group element (PGE) sulfides, which commonly characterize the low-P chromitites, were converted to PGE metals or alloys by heating on their decompression during mantle convection. Peculiar igneous textures, e.g., nodular textures, characteristic of low-P chromitites can be preserved even after compression and subsequent decompression during recycling because of possible absence of reactions between olivine and chromite or their high-P polymorphs. The UHP chromities can thus be an indicator of mantle convection; UHP minerals in chromitite may support the two-layer convection model.

1. Introduction

There has been a consensus that podiform chromitites are formed through reaction between mantle peridotite (especially harzburgite) and melt, with subsequent magma/melt mixing at an uppermost mantle level (e.g., Arai and Yurimoto, 1994; Zhou et al., 1994; Arai, 1997). The podiform chromitites serve as a good indicator of peridotite–melt reaction in the upper mantle (e.g., Arai, 1997). However, ultrahigh-pressure (UHP) minerals including diamond have been recently found from two Tibetan ophiolites as well as from Ray-Iz massif, the Polar Urals (e.g., Robinson et al., 2004; Yang et al., 2007, 2011; Yamamoto et al., 2009; Xu et al., 2009), and this strongly requires us to revisit the origin(s) of podiform chromitites. Origin of UHP chromitites has been recently proposed but not been discussed in great detail (e.g., Robinson et al., 2004; Ruskov et al., 2010). The important point is that, as far as we know, the UHP podiform chromitites are basically similar in petrography and mineral chemistry to "ordinary" podiform chromitites. The UHP chromitite mainly comprises chromite (chromian spinel) and olivine, and some of them show nodular textures (e.g., Zhou et al., 1996; Yamamoto et al., 2009), which characterize igneous low-P chromitites (e.g., Nicolas, 1989). Arai (2010) proposed a possibility of deep recycling origin for the UHP chromitites. Here I would like to discuss the origin of the UHP podiform chromitites in more detail and more extensively based on mineralogical characteristics, although the discussion below may be speculative at present. This work will promote re-examination and more systematic descriptions of UHP chromitites and related peridotites.

2. Low-pressure magmatic origin of podiform chromitites: some lines of evidence

The podiform chromitites, enveloped by dunite (e.g., Cassard et al., 1981), are commonly found within mantle peridotites, mainly harzburgite (e.g., Arai, 1997) in ophiolites or mantle-derived peridotite complexes (Fig. 1a). They form a kind of cumulates filling melt conduits within the residual mantle peridotite (e.g., Cassard et al., 1981; Lago et al., 1982). Origin of the podiform chromitites with dunite envelope can be explained by harzburgite–melt reaction and subsequent melt mixing (e.g., Noller and Carter, 1986; Arai and Yurimoto, 1994; Zhou et al., 1994): the dunite envelope is essentially similar to a replacive dunite (Quick, 1981; Kelemen et al., 1990; Arai and Yurimoto, 1994). This process includes incongruent decomposition of orthopyroxene, and is effective at low-P conditions (cf. Kushiro, 1969).

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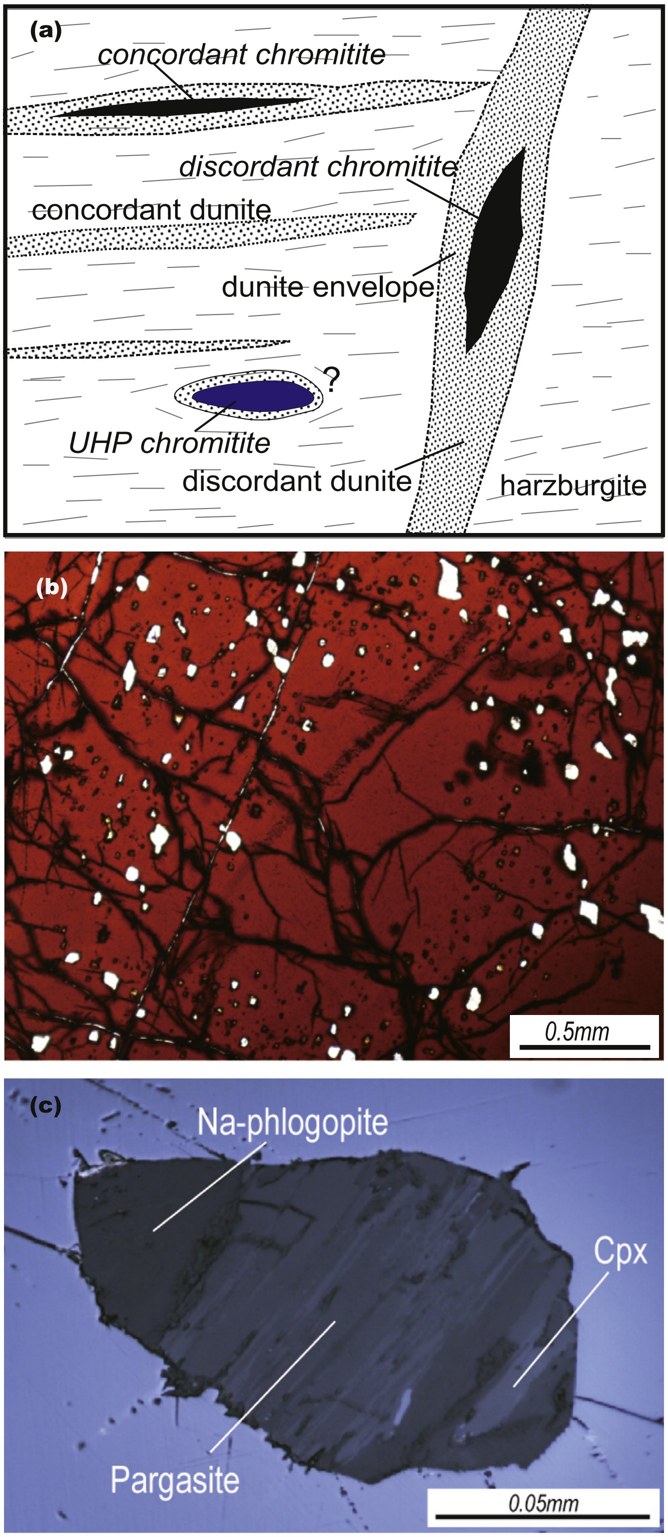

Fig. 1. Geological and petrographical characteristics of podiform chromitites. (a) Idealized modes of occurrence of podiform chromitites on outcrop. Chromitites always, enveloped by dunites, vary in attitude to the surrounding harzburgite, concordant to discordant. UHP chromitites may be concordant to foliation of harzburgite. (b) Photomicrograph of primary inclusions concentrically arranged in chromite of a discordant chromitite from Wadi Hilti, northern Oman ophiolite. Plane-polarized light. (c) Close-up of one of inclusions composed of pargasite, Na-phlogopite and diopsidic clinopyroxene. Note the predominance of pargasite. Reflected light.

Chromite in chromitites sometimes contains minute inclusions of Na-rich pargasite, Na-phlogopite and pyroxenes (e.g., Augé, 1987; Lorand and Ceuleneer, 1989; Borisova et al., 2012) (Fig. 1b, c). Their globular shape (Fig. 1b, c) indicates their initial entrapment as melt by spinel (e.g., Borisova et al., 2012). They sometimes show concentric distribution within spinel grains, indicating their primary nature (Roedder, 1984) (Fig. 1b). Pargasite, one of the main constituents of the inclusions (Fig. 1c), shows a low-P ($<$ ca. 3 GPa) stability field (e.g., Niida and Green, 1999; Frost, 2006). The presence of low-P hydrous minerals in the primary inclusions in spinel (Fig. 1b, c) indicates a shallow upper mantle origin for concerned chromitites (e.g., Borisova et al., 2012), which is consistent with the above inference.

Typical low-P chromitites may be represented by so-called discordant chromitites, which are relatively young and, if flattened, can become so-called concordant chromitites together with surrounding peridotites via mantle flow beneath a spreading center (Cassard et al., 1981; Lago et al., 1982). Cassard et al. (1981) concluded that peculiar igneous textures, e.g., nodular, anti-nodular and orbicular, were only found in the discordant chromitites, but got unclear via deformation (cf. Nicolas, 1989). The minute mineral inclusions possibly disappeared with the progress of deformation too (Cassard et al., 1981). The situation is, however, not so simple with concordant and discordant chromitites (Ahmed and Arai, 2002) from the northern Oman ophiolite; the two types are essentially different in terms of chemical and petrographical characteristics (Miura et al., 2012). That is, the concordant chromitite is not simply a deformed equivalent to the discordant one (Ahmed and Arai, 2002; Miura et al., 2012).

3. Characteristic of UHP chromitites

The geological context of UHP chromitites has not been described in great detail and is not clearly known, but, as far as we know from the literature, they show features on the outcrop similar to those of ordinary low-P chromitites. The chromitites from Luobusa, Tibet (e.g., Zhou et al., 1996; Xu et al., 2011), some of which show UHP features (e.g., Robinson et al., 2004; Yang et al., 2007; Yamamoto et al., 2009; Xu et al., 2009), seem to share the same geological features to those of low-P origin, e.g., those from Oman ophiolite (e.g., Miura et al., 2012) (Fig. 1a). UHP chromitites are enveloped by dunite, within harzburgitic mantle peridotite (e.g., Zhou et al., 1996, 2005; Yamamoto et al., 2009). A concordant attitude to surround harzburgite is expected for UHP chromitites but not clearly shown (cf. Zhou et al., 1996) (Fig. 1a).

Diamond and other UHP minerals have been found as inclusions in chromite in podiform chromitites from Tibetan ophiolites (e.g., Robinson et al., 2004; Yang et al., 2007, 2011; Yamamoto et al., 2009; Dobrzhinetskaya et al., 2009; Xu et al., 2009) (Table 1). They include native elements (e.g., diamond), alloys (e.g., PGE and Ni–Fe–Cr–C), Fe-silicides, carbide (moissanite), oxides (e.g., Si-rich rutile) and nitrides (TiN and c-BN) (Table 1). In addition, even the former presence of much higher-P minerals was suggested, although they had been broken down. Yamamoto et al. (2009) suggested a precursor UHP CF(calcium ferrite)-type chromite that is decomposed to low-P chromite containing silicate exsolutions. Yang et al. (2007) considered the precursor stishovite for the blade-shaped coesite. Robinson et al. (2004) suggested the presence of ringwoodite as a precursor of now altered Mg–Fe silicate with an octahedral shape.

Robinson et al. (2004) referred to a possibility of a xenocrystal origin for UHP minerals; they were accidentally trapped as xenocrysts by chromite in magmatic formation of podiform chromitites in the upper mantle. Yamamoto et al. (2009), however, found exsolution of coesite and pyroxenes in chromite from