A New Window into the Deep Mantle: Podiform Chromitite in the Luobusa Ophiolite, Southern Tibet

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Abstract
Podiform chromitites in Luobusa ophiolite yield a wide variety of unusual minerals, including UHP minerals (micro-diamond, coesite, moissanite), highly reduced minerals (native elements, alloys, carbides, and nitrides), and unusual silicate lamellae of diopside and coesite in chromites. These lines of evidence strongly suggest that podiform chromitites in the Luobusa ophiolite have a deep-mantle origin (probably more than 380 km deep). Podiform chromitite in Luobusa ophiolite might provide crucial clues for studies of the Earth's deep-mantle.

Key words: ophiolite, southern Tibet, podiform chromitite, ultrahigh-pressure minerals

I. Significance: podiform chromitite and recovered UHP minerals in the Luobusa ophiolite
Podiform chromitites, a significant chromium resource orebody, are common in the uppermost sections of ophiolitic peridotites, hosted mainly by harzburgite-type peridotites as pod- or lens-shaped bodies (e.g., Nicolas and Al Azri, 1990). Recently, podiform chromitites in Luobusa ophiolite (Figs. 1, 2 and 3), located about 200 km east-southeast of Lhasa, have received much attention because of the discovery of unusual minerals including ultrahigh-pressure (UHP) minerals (micro-diamond, coesite, and moissanite) and highly reduced minerals (native elements, alloys, carbides, silicides, and nitrides) in heavy mineral separates (Bai et al., 1993; Pearson et al., 1995; Bai et al., 2000a, b; Robinson et al., 2004; Yang et al., 2007; Dobrzhatetskaya et al., 2009; Arai, 2010b). Moreover, a wide variety of mineral species (silicates, oxides, sulfides, arsenides, and platinum-group minerals) have also been found in Luobusa chromitite (see http://www.mindat.org/loc-5457.html), and some silicides and carbides have been approved as new minerals; Luobusaite (Fe₃Si₂) (Jambor and Roberts, 2001; Bai et al., 2006), Linzhiite (FeSi₂) (Li et al., 2010), Naquite (FeSi) (Shi et al., 2010), Zangboite (TiFeSi₂) (Li et al., 2009), Yarlongtite (Cr₂Fe₂NiC) (Shi et al., 2005, 2008), Qusongite (WC) (Fang et al., 2009).

Fig. 1 Locality index of Luobusa ophiolite, southern Tibet. (N29°12′55″, E92°12′18″)
peridotite in Tibet were first reported by Fang and Bai (1981, 1986), and Bai et al. (1993), who discovered them when investigating heavy mineral separates of chromitite, and so far they have recovered more than 1000 grains from three different chromitite orebodies in Luobusa (Figs. 4a and 4b) (Xu et al., 2009). A few diamond grains contain small inclusions, and one grain contains relatively large dark-green inclusions of Mg-Fe silicates with a composition similar to that of clinoenstatite (Bai et al., 2000b). Micro-diamonds recovered from Luobusa chromitite definitely have a natural origin judging from their color, IR spectra, high nitrogen aggregation states, and silicate inclusions (Taylor et al., 1995).

In general, terrestrial diamond occurrences are known only from xenoliths of peridotites and eclogites brought by volcanic eruptions, alpine-type peridotites, and UHP metamorphic rocks. Diamonds and related rocks derived from the deep mantle are important targets to deduce the structure, composition, and history of the Earth’s mantle. Thus, the discovery of micro-diamonds from podiform chromitites in Luobusa ophiolite may provide further crucial clues for studies of the Earth’s mantle.

II. Controversy: shallow magmatic origin vs. deep-mantle origin

Traditional petrology and geochemical studies demonstrate that ophiolitic peridotite massifs originate from depths of less than 60 km (< 2 GPa) (e.g., Coleman, 1977), and podiform chromitites are generally thought to be formed by a harzburgite/magma reaction and related magma mixing at the uppermost mantle (< 30 km) (Arai and Yurimoto, 1994; Arai, 1997; Ballhaus, 1998; Lago et al., 1982; Zhou et al., 1994, 1996, 2005). Therefore, the recovery of UHP minerals from the Luobusa chromitite has been a source of debate.
Here, I briefly mention the geological background and UHP minerals recovered from podiform chromitite in Luobusa ophiolite.

Luobusa ophiolite, at the east-end of the Indus-Yarlung Zangbo suture zone, is believed to have originally been formed at a mid-ocean ridge setting and was subsequently affected by supra-subduction zone magmatism (Dupuis et al., 2005; Girardeau et al., 1985a, b; Malpas et al., 2003; Nicolas et al., 1981; Shi et al., 2007; Zhou et al., 2002; Ziabrev et al., 2003; Zhou et al., 2005). Spinel peridotite in the Luobusa exhibits an equilibrium pressure of around 15 kb GPa (Hébert et al., 2003), and there is no evidence that the ophiolites experienced UHP metamorphism (Huot et al., 2002). Luobusa podiform chromitites have generally been mined and exposed in open pits (Fig. 3), thus most chromitites and harzburgite are extremely fresh without intense serpentinization. They are typically surrounded by dunite envelopes several centimeters to several meters thick, and have also been interpreted to be a product of magma/harzburgite reactions at shallow depths (< 30 km) (e.g., Zhou et al., 1994, 1996, 2005).

Thus, the above-mentioned UHP minerals were initially thought to be xenocryst captured by chromites crystallized from boninitic magma at shallow mantle depths (Bai et al., 1993, 2000b; Robinson et al., 2004). However, Yamamoto et al. (2009) report unusual coesite and clinopyroxene exsolution lamellae within chromites of Luobusa podiform chromitite (Figs. 4c and 4d). The existence of coesite exsolution lamellae within chromite directly indicates UHP evidence of Luobusa chromitite having a deep-mantle origin. Based on petrological evidence preserved in chromite, Yamamoto et al. (2009) conclude that chromites with unusual silicate lamellae are a former CaFe2O4-structured chromite, a high-pressure polymorph that is stable at pressures above 12.5
GPa (> 380 km deep). This implies that mantle peridotite with podiform chromities under the Tibetan mid-ocean ridge has a much deeper origin than was previously believed, although the origins of the podiform chromite are still not clear. Conversely, Arai (2010a) proposes a deep recycling origin; they were originally formed as cumulates under low-pressure conditions, and then were subducted into the deep-mantle, finally upwelling again to the shallowest mantle due to mantle convection. This scenario is a combination of traditional low-pressure magma and deep-mantle derived origins. More detailed petrological and geochemical studies are, however, needed to decipher the genesis and history of deep-origin podiform chromitite because most UHP minerals were obtained only from mineral separates.

### III. Potential target for studies of the deep mantle

Podiform chromitites in Luobusa ophiolite yield a wide variety of unusual minerals, including UHP minerals (micro-diamond, coesite, moissanite), highly reduced minerals (native elements, alloys), and such unusual minerals have been identified from chromitites of the Dongqiao ophiolite of Tibet (Bai et al., 1993), Semail ophiolite of Oman, and Ray-Iz ophiolite of Polar Urals (Trumbull et al., 2009). Thus, it is reasonable to assume that podiform chromitites in ophiolites have a common deep-mantle origin. Although rare and small, chromite pods have been recovered from the Mid-Atlantic Ridge (Abe, 2003) and equatorial Pacific (Arai and Matsukage, 1998), thus podiform
chromitite in the abyssal peridotite could be an important target for a deep-sea drilling project.

References


深部マントルへの新しい扉
—南チベット、ルオブサオフィオライトにおける
ボディフォームクロミタイト—

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ルオブサオフィオライトに産するボディフォームクロミタイトからは、これまで数多くの“異常な”鉱物が見いだされている。それらは、マイクロダイヤモンドを含む種々の超高圧鉱物や、金属相などの還元的鉱物、そしてクロマイト中におけるディオプサイドやコース石などの異常な珪酸塩離溶相などである。これらの鉱物学的証拠は、本ボディフォームクロミタイト岩体が超深部マントル（おそらく380 km以深）由来であることを強く示唆する。したがって、ルオブサオフィオライトにおけるボディフォームクロミタイトは、これまで手の届かなかった深部マントルに関する重要な知見をもたらすであろう。

キーワード：オフィオライト，南チベット，ボディフォームクロミタイト，超高圧鉱物

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