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Origin of ultrahigh pressure and highly reduced minerals in podiform chromitites and associated mantle peridotites of the Luobusa ophiolite, Tibet

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ABSTRACT

Podiform chromitites and their host peridotites in the Kangjinla mining district of the Luobusa ophiolite contain similar collections of ultrahigh pressure (UHP), highly reduced and crustal-type minerals. Abundant diamonds have been recovered from both lithologies and these are associated with a wide range of base metal alloys, native elements, carbides, oxides, silicates and others. The presence of UHP and highly reduced minerals in these rocks indicates that at least some of the chromite must have crystallized deep within the mantle as well as in a shallow mantle wedge in a suprasubduction zone (SSZ) environment. The unusual minerals were encapsulated in chromite grains and carried upward by mantle convection. The peridotite of Luobusa was trapped in the mantle wedge where it was modified by SSZ fluids and melts. Partial melting and mobilization of the chromite grains allowed them to be carried to shallow levels in melt channels and eventually deposited as chromitites near the crust mantle boundary. The unusual minerals were preserved during this process because they were encapsulated in chromite grains, either during crystallization or by later fluid fluxing.

1. Introduction

Diamonds and other ultrahigh pressure minerals were first reported in chromitites of the Luobusa ophiolite in 1981 (IGCAGS, 1981), but this discovery attracted little attention until a more detailed investigation was undertaken in 1998 (Bai et al., 2000; Yang et al., 2003; Robinson et al., 2004; Yang et al., 2007a). These initial reports were met with considerable skepticism because the diamonds were recovered from heavy mineral separates and it was impossible to rule out natural or anthropogenic contamination of the samples (Taylor et al., 1995). However, in recent years diamonds, as well as other UHP and related minerals, have been found in-situ, providing incontrovertible evidence of their natural origin (Yang et al., 2014). The mineral inclusions (Xu et al., 2011a) and trace element patterns of the diamonds (Griffin et al., 2013) clearly distinguish them from synthetic grains and most cratonic diamonds.

Podiform chromitites occur in the upper mantle sections of ophiolites, near the crust–mantle boundary, and are generally regarded as having formed at very low pressures. However, the discovery of UHP and highly reduced minerals such as diamond and coesite in oceanic chromitites (Bai et al., 1993; Yang et al., 2007a) raises important questions about the origin of ophiolites and their podiform chromitites, as well as the nature of deep mantle processes. Most of the previous work on the Luobusa ophiolite was focused on the podiform chromitites and their unusual minerals (Hu, 1999; Bai et al., 2000; Yang et al., 2003; Robinson et al., 2004; Bai et al., 2006a,b; Yang et al., 2007a; Xu et al., 2008; Yang et al., 2008a,b; Fang et al., 2009; Shi et al., 2009; Xu et al., 2009; Yamamoto et al., 2009; Li et al., 2010; Xu et al., 2013). Understanding the origin of the podiform chromitite is the key in interpreting the UHP and highly reduced minerals that they contain. In order to understand the physical and chemical conditions under which podiform chromitites form, it is necessary to determine their textures and mineralogies, as well as their relationship to the host peridotites. In this study we compared the mineralogy of podiform chromitite 11 in the Kangjinla district of the Luobusa ophiolite in order to determine whether the deep mantle minerals occur only on the chromitites or in both chromitites and peridotites. Same chromite deposit to check whether the similar deep mantle minerals can be always. Thus we report the character and mineralogy of the chromitite and peridotite orebody 11 and present a model for their formation.

2. Geological setting

The Luobusa ophiolite lies in the eastern part of the Yarlung Zangbo suture zone, which marks the tectonic boundary between Asia and India. It is located about 200 km ESE of Lhasa where it forms a body −43 km long in an east–west direction and −4 km wide, with an exposed area of −70 km^2. To the south, the ophiolite is separated from Triassic flysch by a steep reverse fault, whereas to the north it is thrust over the Gangdese batholith and clastic sedimentary rocks of the Tertiary Luobusa Formation. The ophiolite is a tectonic slab composed chiefly

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of mantle peridotites and dunites with minor crustal cumulates and mafic dikes (Fig. 1). It hosts the largest chromite deposit in China, containing nearly 5 million tons of ore (Zhang et al., 1996). The chromitite orebodies are grouped into 3 clusters, designated from west to east, the Luobusa, Xiangkashan and Kangjinla districts (Fig. 1). Nearly all of the chromitites are hosted in mantle peridotites, which is typical of Alpine or podiform chromitite deposits (Wang et al., 1983, 1987), however, a few small bodies also occur in the transition-zone dunites. Many of the chromitites have thin envelopes of dunite. The contacts between the chromitites and dunites are typically sharp with no evidence of faulting or shearing (Wang et al., 1983, 1987), however, the dunite grades outward into the host harzburgite with increasing pyroxene (Zhou et al., 1996, 2005, 2014).

The Kangjinla mining district, which lies at an elevation of −5300 m near the eastern end of the ophiolite (Fig. 1), is about 6.5 km long and 2.3 km wide. The ore deposits are mostly vein-like or lenticular bodies of chromitite with dunite envelopes. Orebody Cr-11, the largest deposit being mined in the district, strikes about N75°W and dips 50–72°SW. It ranges from 0.3 to 10.5 m thick, averaging about 3.3 m.

The textures in orebody Cr-11 are highly variable, ranging from compact and massive to disseminated, layered, nodular, anti-nodular, irregular and deformed. Massive ore typically grades into disseminated ore (Fig. 2a), but maintains sharp contacts with the host rocks (Fig. 2b). The disseminated ores are here divided into three types, sparsely, moderately and densely disseminated, depending on the abundance of chromite. Densely disseminated chromitites are commonly coarse-grained, subhedral to anhedral, and typically grade into moderately disseminated ore on the one hand and massive ore on the other (Fig. 2c). Nodular ores are sparse and occur mainly along contacts between disseminated chromitites and mantle peridotites. Individual nodules are spherical to ovoid, range in size from 0.3 to 2.5 cm and are sometimes weakly aligned. Narrow veins of compact ore are also locally present (Fig. 2d). In the Kangjinla district, the chromitite occurs with veins, lenses, and pods associated with blocks of dunite; and its irregular contact with harzburgite (Fig. 2e). Orebody Cr-11 is mainly for open-pit mining (Fig. 2f).

Most of the chromitites are quite fresh and the chromite compositions are remarkably uniform. A total of 136 chromite grains were analyzed in 20 samples and they consist of 54.6–63.1 wt.% Cr_2O_3, 8.9–12.2 wt. % Al_2O_3 and 11.7–15.6 wt. % MgO, and are therefore classified as magnesiochromite. All of the chromite grains within the chromitites have very high Cr#s (75.6–82.7) and moderately high Mg#s (56.4–74.1) (Xu et al., 2011b). These values are consistent with those from orebody 31 of the Luobusa district (Zhou et al., 1996) and with those from the Dongqiao ophiolite in central Tibet. Note that we use the term chromite to describe individual grains and chromitite to designate orebodies formed by accumulations of chromite grains.

Orebody Cr-11 is hosted mainly in clinopyroxene-bearing harzburgite with minor dunite and lherzolite. All of the peridotites are quite fresh with generally less than 5% serpentinization and their original textures and structures are well preserved. The harzburgite is medium- to coarse-grained, greenish-gray in color, and has a thin, buff-colored weathering rind. Large orthopyroxene crystals are prominent on the weathered surface and show a crude foliation, making it easy to distinguish these rocks from dunite. The harzburgite consists chiefly of forsteritic olivine (75–90 modal%), Mg-rich orthopyroxene (7–25%), minor clinopyroxene (2–3%) and accessory minerals such as magnetite and residual chromite (1–2%). Sparse secondary minerals include serpentine, brucite, magnesite and chlorite.

Small amounts of lherzolite are also locally present, being characterized by 5–10 modal% clinopyroxene. The clinopyroxene grains are small (<1 mm) and interstitial to the granular olivine. Orthopyroxene in these rocks typically forms short, prismatic grains with many clinopyroxene exsolution lamellae and undulatory extinction.

Dunite occurs chiefly as envelopes around the orebodies or as patches and zones interspersed with the chromite ore. Some small lenses of dunite also occur locally in the peridotites. These dunite lenses are distinct from the thick, transition-zone dunite at the base of the ophiolite, and show very complicated relationships with the chromitite

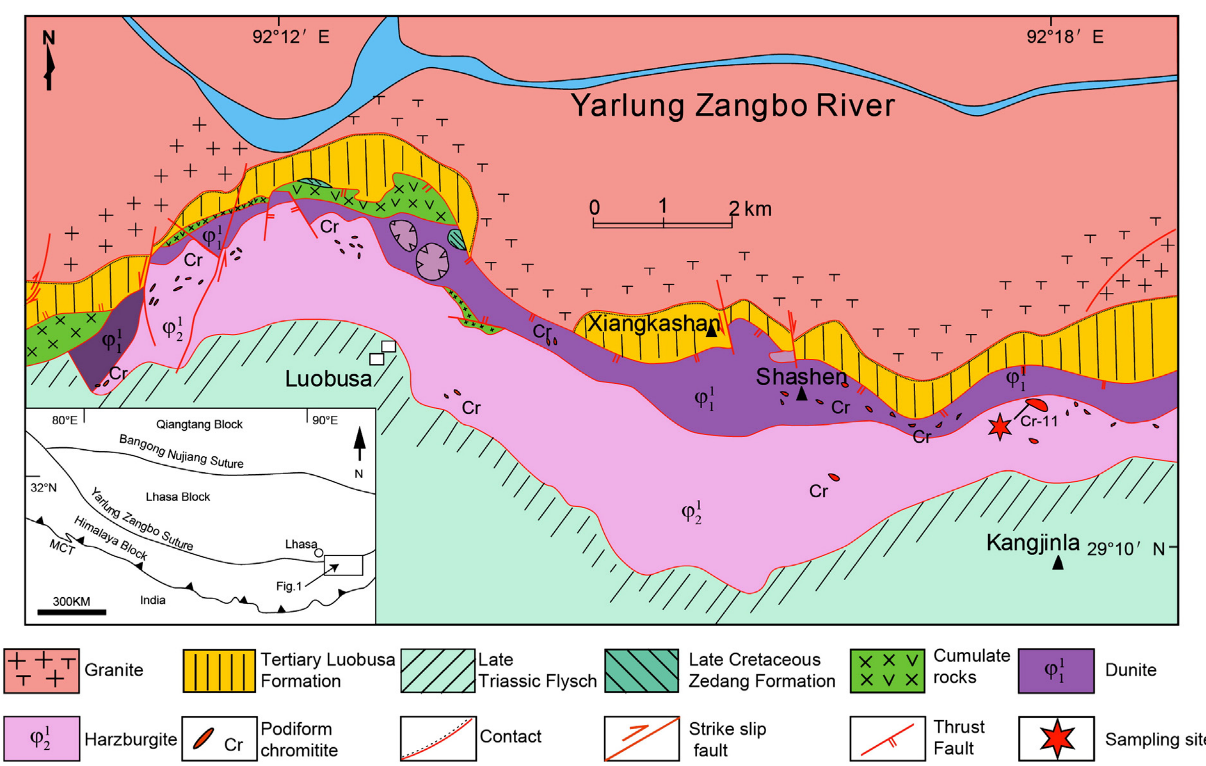

Fig. 1. Simplified geological map of the Luobusa ophiolite, Tibet. Revised after Zhou et al. (1996).

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