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Re–Os isotopic constraints on the genesis of the Limahe Ni–Cu deposit in the Emeishan large igneous province, SW China

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ABSTRACT

There are three types of magmatic sulfide deposits (sulfide-poor PGE deposit, sulfide-rich Ni–Cu deposit and Ni–Cu–PGE deposit) associated with mafic–ultramafic intrusions in the Late-Permian Emeishan large igneous province, SW China. The Limahe deposit represents a sulfide-rich Ni–Cu deposit in the region. Re–Os concentrations and isotopic compositions of the sulfide ores and associated ultramafic rocks in the Limahe intrusion are used to evaluate the relationships between magma evolution and oregenesis. There are two types of sulfide-barren olivine websterites in the Limahe intrusion: one is PGE depleted and the other is PGE undepleted. The PGE undepleted olivine websterites have $\gamma Os_{(260\,Ma)}$ between 5 and 8, whereas a PGE depleted olivine websterite sample has a $\gamma Os_{(260\,Ma)}$ value of ~30. A disseminated sulfide ore sample has a $\gamma Os_{(260\,Ma)}$ value close to 77. Net-textured sulfide ores and sulfide separates from net-textured sulfide ores have the highest $\gamma Os_{(260\,Ma)}$ values, varying between 102 and 124. The results can be explained by successive contamination of a mantle-derived magma with the lower and upper crusts during magma ascent. Mixing calculations indicate that the total amount of crustal contamination is ~15%. The concentrations of Os and Re–Os isotopes in the sulfide ores of the Limahe deposit are consistent with the sulfide liquids that segregated from a PGE depleted magma due to previous sulfide segregation. Higher $\gamma Os_{(260\,Ma)}$ values in the sulfide ores than the sulfide-barren ultramafic rocks in the Limahe intrusion suggest that crustal contamination played a critical role in sulfide saturation. Significant variations in Os concentrations and Re–Os isotopes in the Limahe intrusion suggest that multiple pulses of magma with variable crustal contamination were involved in the development of the intrusion. The different pulses of magma are likely related to each other by variable crustal contamination and sulfide segregation. Our new results support the hypothesis that the Limahe intrusion may represent a dynamic conduit through which magma successively ascended to higher crustal levels or to the surface.

1. Introduction

Magmatic Ni–Cu–PGE deposits associated with mafic–ultramafic intrusions have a wide variation in the composition of the bulk sulfide from PGE-rich to PGE-poor (Barnes et al., 1997; Li et al., 2001), and can be divided into three composition types (Naldrett, 2009): (1) sulfide-poor PGE deposit, the examples include the JM Reef of the Stillwater Complex in Montana, USA and the Merensky Reef of the Bushveld Complex, South Africa (Maier and Barnes, 2009); (2) Ni–Cu–PGE deposit, the examples include the Noril'sk-Talnakh Ni–Cu–PGE deposits, Siberia (Li et al., 2003, 2009; Lightfoot and Keays, 2005; Naldrett and Li, 2009) and the Jinchuan Ni–Cu deposit, western China (Song et al., 2009; Su et al., 2008; Tang et al., 2009); (3) sulfide-rich Ni–Cu deposit, of which the best example is the Voisey's Bay Ni–Cu–Co deposit in Labrador, Canada (Naldrett et al., 2009).

It is widely accepted that high metal contents in the bulk sulfide of PGE-rich deposits (including sulfide-poor PGE deposits and Ni–Cu–PGE deposits) may be due to the fact that the sulfide equilibrated with a large volume of magma, i.e., high *R* value (Barnes et al., 1997; Campbell and Naldrett, 1979). Several hypotheses have been advanced for sulfide-rich, PGE-poor Ni–Cu deposits: either these deposits formed at low *R* values close to *D* values for Ni and Cu but well below *D* values for PGEs (Campbell and Naldrett, 1979); or parent magmas formed at sufficiently low degrees of partial melting to leave sulfides and PGEs in the mantle (Arndt et al., 2005; Barnes and Lightfood, 2005); or magmas underwent a previous episode of sulfide segregation at depth, prior to the episode which formed the orebodies (Barnes, 2004; Lightfoot and Keays, 2005).

There are many magmatic Ni–Cu–PGE deposits in the Late-Permian (260 Ma) Emeishan large igneous province (ELIP), SW China, hosted by small mafic–ultramafic intrusions that are coeval with the Emeishan flood basalts and are considered to have genetic

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relation with the hypothetical Emeishan mantle plume (Zhou et al., 2008). The sulfide deposits show a wide variation in the composition of the bulk sulfide and constitute a series of mineralization from PGE-rich to PGE-poor (Song et al., 2008). The three major types of magmatic Ni–Cu–PGE deposits associated with mafic–ultramafic intrusions in the world (Naldrett, 2009) have their equivalents in the ELIP: the Jinbaoshan deposit represents a sulfide-poor PGE deposit (Tao et al., 2007; Wang et al., 2005); the Yangliuping deposit represents a sulfide-rich Ni–Cu–PGE deposit (Song et al., 2003); and the Limahe and Baimazhai deposits are the best examples of sulfide-rich Ni–Cu deposits in the region (Sun et al., 2008; Tao et al., 2008; Wang et al., 2006, 2007). The coexistence of different types of magmatic sulfide deposits associated with a single event of continental basaltic magmatism in the Emeishan region provides an excellent opportunity to evaluate the relationships between regional basaltic magmatism and metallogeny. To this end we have carried out an integrated study of the Limahe deposit. The mineralogical, petrological, and S and Sm–Nd isotopic data have been reported in our previous paper (Tao et al., 2008). In this paper we report new Re–Os isotopic data that may provide additional constraints on the genesis of the deposit. The Re–Os isotope system is a sensitive tracer of magmatic evolution and ore-forming processes because of the strong fractionation of Re from Os between the crust and mantle, and the consequent sensitivity of Os isotopes to crustal contamination and because they offer a direct measurement of metals involved in magmatic ore genesis (Lambert et al., 1999; Ripley et al., 1999; Ripley et al., 2008, Shirey, 1997).

2. Geological background

In the western part of the Yangtze block, there are large volumes of flood basalts which erupted during the Late-Permian (Fig. 1). The flood basalts constitute a major part of the ELIP. They cover over an area of 5×10^5 km^2, with thickness ranging from several hundred meters up to 5 km (Chung and Jahn, 1995; Fan et al., 2008; Song et al., 2001; Xiao et al., 2004; Xu et al, 2001; Zhang et al., 2008a; Zhou et al, 2006). The ELIP is considered to be a good example of mantle plume magmatism in continental setting by many researchers (Ali et al.,

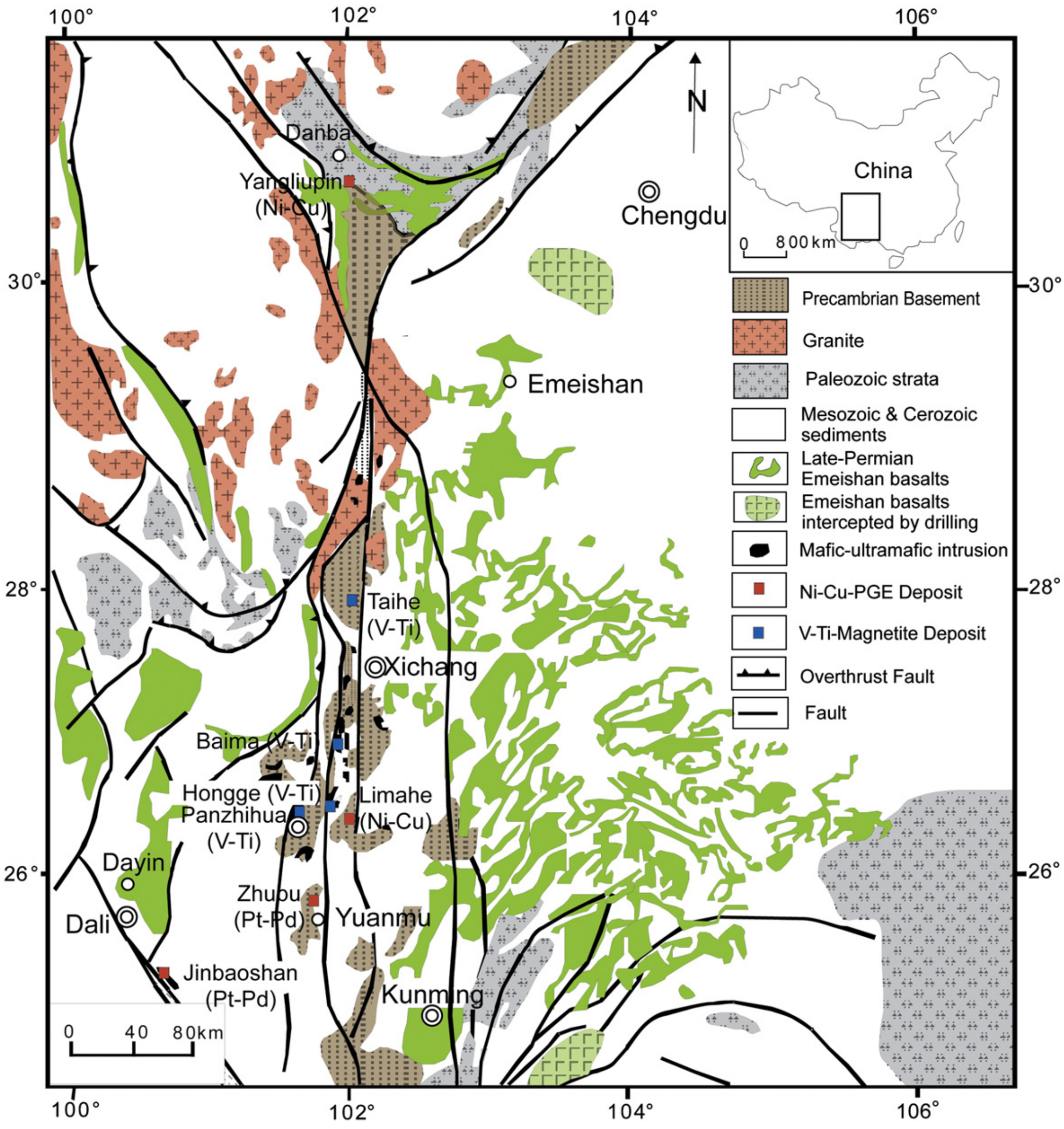

Fig. 1. Distribution of the Emeishan continental flood basalts and some coeval mafic–ultramafic intrusions that host different types of magmatic ore deposits. Modified from Wang et al. (2005).