攀西地区层状辉长岩体及钒钛磁铁矿床的成因

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摘 要: 峨嵋山大岩浆省由大量的溢流玄武岩及其伴生的镁铁和超镁铁侵入岩组成。攀西地区的一些层状辉长岩体形成于 260 Ma, 与早期报道的峨嵋山大岩浆省的年代相同。这些岩体中含有巨大的钒钛磁铁矿床, 矿体呈似层状及透镜状产在层状辉长岩体的下部层位, 不同于典型的层状岩体(如布什维尔德岩体)的磁铁矿床。地球化学资料表明, 攀西地区含磁铁矿的岩体是从高度演化的基性岩浆中结晶而成, 因为富硅的岩浆分离使得母岩浆高度富集铁、钛和钒。相对围岩来说, 磁铁矿石形成较晚, 是从氧化物矿浆中结晶的产物。矿石中有丰富的含水矿物相, 流体的参与对氧化物矿浆的形成有重要的作用。

关键词: Fe_Ti_V 氧化物; 辉长岩; 层状岩体; 峨眉山大岩浆省; 中国西南
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Origin of layered gabbroic intrusions and their giant Fe_Ti_V oxide deposits in the Pan_Xi district, Sichuan Province, SW China

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Abstract: The Emeishan Large Igneous Province comprises voluminous flood basalts and spatially associated mafic_ultramafic intrusions. In the Pan_Xi region, SW China, a number of gabbroic intrusions are dated at ~ 260 Ma, same as the previous reported ages for the ELIP, and host some giant Fe_Ti_V oxide deposits. Unlike the oxide deposits in classic layered intrusions, such as the Bushveld Complex, those in the Pan_Xi region occur as layers and/or lenses within the gabbros and are generally concentrated in the lower parts of the intrusions. Available geochemical evidence suggests that the intrusions were formed from highly evolved Fe_Ti_V_rich ferrogabbroic or ferropicritic magmas. The magmas were further enriched in Fe_Ti_V after separation of Si_rich magmas which formed the syenitic intrusions. Ore textures and associated mineral assemblages indicate that the orebodies were formed by late_stage crystallization of V_rich titanomagnetite from oxide liquids. The abundant accessory hydrous phases suggest that addition of fluids from upper crustal rocks might have induced the separation of the immiscible oxide melts and subsequently gave rise to the oxide orebodies.

Key words: Fe_Ti_V oxide; gabbro; layered intrusion; Emeishan Large Igneous Province; SW China

1 Introduction

In the Pan_Xi (Panzhihua_Xichang) area, SW China, several mafic_ultramafic intrusions host giant Fe_Ti_V oxide deposits. This region is the most important Fe_Ti_V metallogenic district in China (Zhong *et al*., 2002, 2003; Ma *et al*., 2003; Zhou *et al*., 2005a). Some of the oxide deposits are being mined at present time whereas others are under re_evaluation or have not been mined yet. For instance, the Panzhihua Fe_Ti_V oxide deposit has been mined for more than 30 years and have produced large quantities of Fe, Ti and V metal in China. Oxide reserve is abundant in the Pan_Xi area and the estimated tonnage is over 7544 million tonnes, with an average ore grade of 36 wt% Fe, 0.28wt% V_2O_5 and 12.6 wt% TiO_2.

The mafic_ultramafic intrusions exhibit various scales of igneous layering generally similar to those documented in classic layered intrusions such as the Skaergaard intrusion and the

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Bushveld Complex (Cawthorn, 1996). Oxide ore occurs as layers and lenticular bodies in the lower parts of the intrusions as compared to the magnetite layers in the upper part of the Bushveld Complex. This difference in morphology of the orebodies and relative stratigraphic positions seem to reflect the complexity of the formation of these oxide bodies in layered intrusions. Genetic and exploration models of the Pan_Xi oxide deposits are poorly constrained, despite their tremendous economic significance. Likewise, the relationship between the Fe_Ti_V oxide orebodies and their host rocks is not known.

2 Geology of layered gabbroic intrusions in Pan_Xi

The Pan_Xi layered intrusions occur in the western portion of the Permian (~ 260 Ma) Emeishan Large Igneous Province (ELIP), which covers an area of 5×10^5 km^2 in SW China and northern Vietnam and is dominated by voluminous flood basalt with minor intrusive rocks (Fig. 1). Exposure of the intrusive rocks is generally controlled by large_scale N_S trending faults, and the resulting felsic plutons and layered intrusions occur along a mineralized zone about 300 km long and 10- 30 km wide of approximately the same orientation.

The oxide ore_bearing intrusions extend from Taihe on the north to Baima, Panzhihua and Hongge on the south. These intrusions are dated at ~ 260 Ma (Zhou *et al.*, 2002, 2005a; Guo *et al.*, 2004). Rock types comprising these intrusions are mainly gabbros. Spatially there are syenitic intrusions which are also dated at ~ 260 Ma (our un_published SHRIMP age dates)

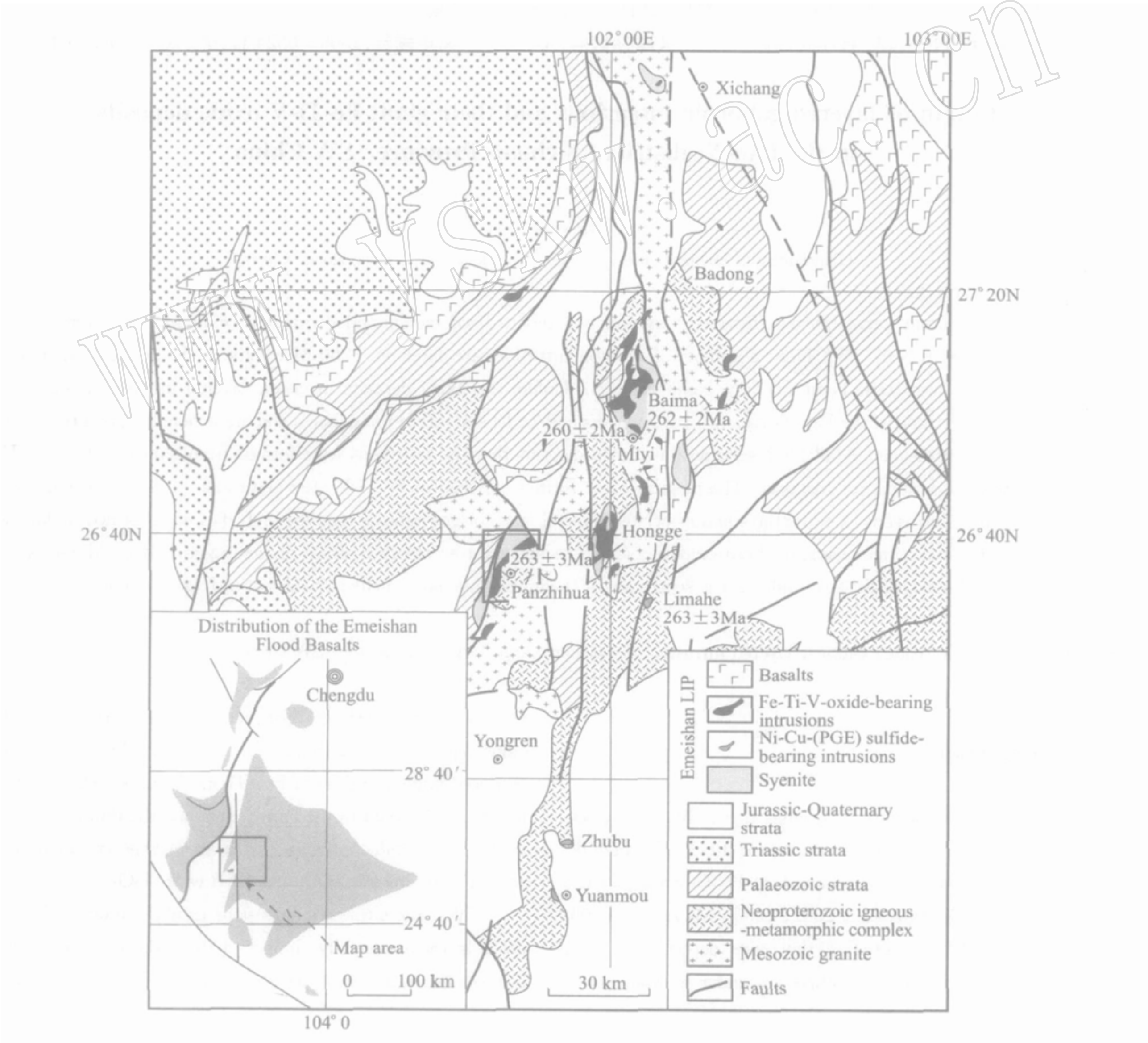

Fig. 1 Fe_Ti_V oxide_bearing intrusions in the Emeishan Large Igneous Province (after Zhou *et al.*, 2005a)

(Fig. 1).

The gabbroic intrusions show enrichment in LREE relative to HREE, enrichment in Ti and depletion in U, Th, Zr, and Hf relative to elements with similar compatibilities. These intrusions are considered to have crystallized from highly evolved, Fe_ and Ti_rich parental magmas (Zhou *et al*., 2005a, 2005b). There must be a loss of a felsic portion in order to obtain excess amounts of Fe_Ti and V in the host mafic intrusions. It is possible that the felsic portion formed the syenitic intrusions.

3 Oxide ore deposits

Three large Fe_Ti_V oxide ore deposits have been explored in the Pan_Xi region: Panzhihua (1333 Mt ore reserves), Baima (1497 Mt ore reserves), and Hongge (4572 Mt ore reserves) (Zhong *et al*., 2002, 2004; Ma *et al*., 2003), but only the Panzhihua Fe_Ti_V oxide mine is currently active.

The oxide orebodies have a variety of geometry as lenses, layers or dyke_like bodies. They may or may not be intimately associated with rocks which show igneous layering. The majority of oxide orebodies are situated at the lower parts of the intrusions, although those smaller in scales sometimes occur at higher stratigraphy. Due to limited exposure, whether the oxide ore is part of the layered sequence is poorly understood. However, several field observations suggest that the deposits are invariably magmatic in origin: (1) the orebodies are integral parts of the intrusions regardless of whether layering is conspicuous; (2) both oxide ore and its host rocks are characterized by a fresh igneous assemblage; (3) geometry of the orebodies, e. g. lenses, dyke, points to a magmatic origin; and (4) sharp contacts of certain well exposed orebodies characteristic of igneous contacts.

The textures of oxide ores range from massive, through net_textured to disseminated. Massive ore is virtually monomineralic consisting of titanomagnetite with minor ilmenite. Accessory minerals are typically less than 10%. The oxide grains are medium to coarse and have polygonal shape outlined by straight to slightly curved boundaries. This subsolidus texture is also documented in the Bushveld magnetite layers. Net_textured ore has a larger modal amount of silicate minerals, e. g. olivine, plagioclase and/or clinopyroxene. The ratios between oxide to silicate and that between different silicates are highly variable, i. e. certain net_textured ore contains magnetite and olivine without other silicate phases at all. Silicate minerals in net_textured ore are usually sub_rounded and surrounded by oxides. They are often outlined by embayed grain boundaries. Disseminated ores are oxide gabbro or oxide peridotite, both of which have generally less than 20% oxides. The oxides are invariably interstitial to the silicate minerals.

Hydrous minerals are important accessory mineral for almost all oxide ore types. They are represented by hornblende and lesser biotite. These hydrous phases are usually associated with oxides. Hornblende occurs as small grains with irregular boundaries and as reaction rim in certain oxide_silicate interface, particularly those involving plagioclase.

4 Origin of the host intrusions and their oxide ores

The Fe_enrichment may be a primary feature of the parental magma attributable either to the mantle source composition or conditions of partial melting. In the Funing region of the eastern part of the ELIP, Zhou *et al*. (2005b) identified two types of magmas that formed oxide_rich gabbroic intrusions and sulfide_rich mafic_ultramafic sills. The former magmas were rich in Ti and Fe and were produced by low degrees of melting of an enriched, OIB_type mantle source with EM2 characteristics. The latter magmas were low_Ti type that formed at a shallower depth with crustal contamination. However, no large oxide deposits and syenitic intrusions were found in Funing.

It is possible that the oxide_bearing intrusions in the Pan_Xi region formed from high_Ti magma type as documented in Funing. The eruptive equivalents are believed to be the high_Ti flood basalts. However, the host intrusions and their giant oxide deposits must have crystallized from magmas even higher in Fe and Ti than those in Funing. It is difficult to envision how such dense, high_Fe magmas could migrate from the mantle into shallow magma chambers. A more likely mechanism is that the primary high_Fe liquids after emplacement have experienced immiscible separation of Si_poor and Si_rich magmas (Fig. 2). The Si_poor magmas formed the host gabbroic intrusions, whereas the Si_rich magmas formed the syenitic intrusions spatially associated with the oxide_bearing intrusions.

On the other hand, ore textures suggest that the oxide orebodies are formed from oxide melts. The interstitial character of the oxides and the hornblende reaction rim indicate that such melt might have invaded a silicate crystal mush and reacted with the silicate minerals. The dense, viscous oxide melt is presumably developed in the magma chamber rather than transported from elsewhere. It is usually linked to immiscible separation because fractional crystallization alone could only produce a Fe_rich silicate liquid, not an oxide liquid (Duchesne, 1999).

The formation of an immiscible oxide melt from the silicate magma may have resulted from mineral fractionation, magma mixing, an abrupt change in oxygen fugacity, and/or an intro_

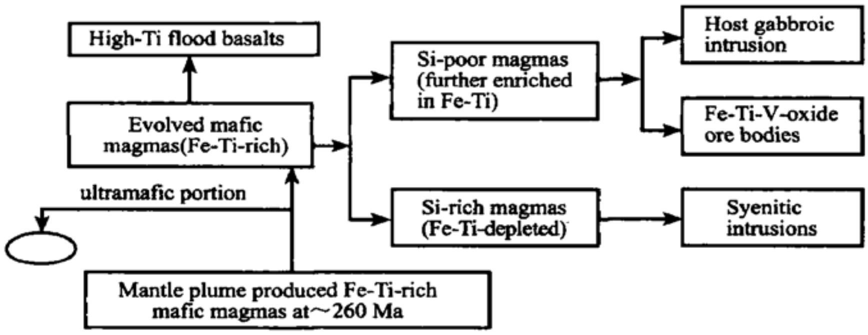

Fig. 2 A possible model for the formation of the giant oxide deposits within the ELIP, SW China

duction of fluids. The presence of minor disseminated sulfides and apatite suggest that S and P may have acted as fluxing agents that facilitated development of the immiscible liquids. The association of amphibole and magnetite suggests that water and other fluids also played a part in this process. Water and CO_2_rich fluids may have been introduced through magma/wall rock interaction during or after the emplacement of the high_Fe gabbroic magmas. The abundance of hydrous minerals in the oxide gabbros in the Panzhihua intrusion suggests that fluids were introduced into the system during crystallization.

5 Conclusions

The oxide_bearing intrusive bodies in Pan_Xi are all part of the ELIP, formed at ~ 260 Ma, by a mantle plume. They represent products of Fe_Ti_rich mafic magmas derived from an enriched OIB_type mantle source. These magmas were further enriched in Fe_Ti_V by separation of Si_rich magmas that formed the spatially associated syenites. Immiscible separation of oxide melts from such Fe_Ti_V_rich magmas resulted in the formation of the giant oxide deposits in the Pan_Xi region.

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