1 Introduction

Metallogenic epoch and mineralization stage are important contents to reveal the genesis of the deposits, especially for magmatism-related deposit. However, the correlative discussion prefers the magmatic hydrothermal deposits rather than the magmatic deposits. The magmatic deposits (traditional orthomagmatic deposits) mainly include Cu-Ni sulfide deposits, V-Ti magnetite deposits and chromite deposits. Based on analyzing and summing a great deal of typical magmatic deposits in China, the metallogenic epoch, mineralization stage and mineralization zoning are discussed in this paper, and aiming for deeply understanding the genesis and prospecting prediction.

2 Types of the Magmatic Deposits

According to the types of ore-forming geological bodies, the magmatic deposits can be divided into several types as follows:

(1) Ophiolite type, mainly chromite deposits which include podiform chromite deposits in the mantle peridotite and the stratiform-stratoid chromite deposits in the cumulate;

(2) Small intrusion type, mainly Cu-Ni sulfide deposits and a few small-sized chromite deposits (e.g., Gaositai, Hebei province);

(3) Layered intrusion type, mainly V-Ti magnetite deposits, followed by Fe-P deposits (e.g., Fanshan, Hebei province), Cu-Ni (PGE) sulfide deposits (e.g., Xinjie, Sichuan province) and chromite deposits (e.g., Xiaosongshan, Ningxia province);

(4) Anorthosite type, mainly V-Ti magnetite deposits (e.g., Damiao, Hebei province).

In addition, there are some other less important types, such as komatite type Cu-Ni deposits, ophiolite type Cu-Ni deposits.

3 Metallogenic Epoch and Mineralization Stage of Main Deposit Types

3.1 Ophiolite type chromite deposits

The metallogenic epoch of the ophiolite type chromite deposits, closely related with the mineralization mechanism, can be classified into three periods:

(1) Partial melting period. Three stages can be divided in this period: initial melting stage (lherzolite as the residues, >2.5GPa, >1470°C, melting degree <35%), mid-term melting stage (harzburgite as the residues, 2.2GPa~2.5GPa, 1450°C~1470°C, melting degree 35%~45%) and late melting stage (dunit e as the residues, 1.2 GPa~2.2GPa, 1380°C~1450°C, melting degree 45%~50%).

(2) Magmatic mineralization period. Early, middle and late stages can be classified. For the chromite deposits in the mantle peridotite, the three stages are mantle plastic deformation stage, chromite reconstitution stage and ore-magma injection stage, respectively.

(3) Post-emplacement reform period. This period mainly damaged the ore bodies with the characteristics of low temperature (<550°C) and brittle shearing deformation and dismemberment of ore bodies.

3.2 Small intrusion type Cu-Ni sulfide deposits

The metallogenic epoch of the small intrusion type Cu-Ni sulfide deposits can be divided into two periods: magmatic and hydrothermal periods. The enrichment of the metallic sulfide can start before the magma emplacement and end in the post magmatic period, but mainly happens during the late magmatic period that can be classified into in situ segregation and ore-magma injection mineralization stages.

(1) During the early magmatic period, the main rock-forming minerals crystallized, such as olivine, pyroxene, basicplagioclase with minor hornblende, biotite and...
picotite, et al.

(2) During the late magmatic period, large amounts of metallic minerals crystallized besides the rock-forming minerals, such as magnetite, pyrrhotine, nicopyrite, chalcopyrite, pyrite and some PGM, et al.

(3) During the hydrothermal period, large amounts of hydrothermal metasomatic minerals occurred, such as tremolite, antigorite, chlorite, talc, calcite, magnesite and minor fuchsite, et al.

3.3 V-Ti magnetite deposits

The V-Ti magnetite deposits may experience magmatic and hydrothermal periods. The deposits mainly formed during magmatic period which included early magmatic differentiation stage and late ore-magma injection stage. The layered intrusion type V-Ti magnetite deposits mainly formed in the early magmatic differentiation stage (minor in ore-magma injection stage), and the anorthosite type V-Ti magnetite deposits mainly formed in the late ore-magma injection stage (minor in magmatic differentiation stage).

(1) Early magmatic differentiation stage. In this stage, the titanic magnetite, ulvite-ilmenite, titanium chromite, picotite and some mafic minerals precipitated and formed low-grade ore bodies. The ore bodies typically occur as conformable layers within layered intrusions.

(2) Late ore-magma injection stage. This stage was the development of the early magmatic differentiation stage and was the main mineralization stage for the anorthosite type Fe (-P) deposit. The ore bodies show characteristics of high-grade and complex morphology.

(3) Hydrothermal period. This period gave priority to the precipitated of metallic sulfide and formed feldspar veins and pegmatitic gabbro veins.

4 Mineralization Zoning

The mineralization zoning of the magmatic deposits mainly expressed the variation of the ore grade, which is closely related with lithofacies. Hence the mineralization zoning mainly points to the lithofacies zonation.

4.1 Ophiolite mélange and chromite deposits

Ophiolite mélange is comprised of the cumulate complex above the Moho surface and the mantle peridotites below the Moho surface. The lithofacies zonation of the cumulate complex from the bottom up is: dunite facies → troctolite facies (dark troctolite, eucocratic troctolite) → pyroxenite facies (diagonal, pyroxenolite, Pl-wehlite) → gabbro facies (cumulate gabbro, homogeneous gabbro). The cumulate complex, ranging in thickness from hundreds meters to 2 km, usually show clear rhythm and can be multiple cycles. The chromite is disseminated throughout the ultramafic facies. According to the partial melting degree, the lithofacies zonation of the mantle peridotites from top to bottom is dunite facies → harzburgite facies (low-degree melting harzburgite → high-degree melting harzburgite) → lherzolite facies. The podiform chromite occurs in hundreds meters of the two sides of dunite-harzburgite interface with the lens or irregular shape.

4.2 Layered intrusive complex and Cu-Ni sulfide, V-Ti magnetite and chromite deposits

The layered intrusion shows preferable rhythmic layers or bands. In general, the rhythm layer can be divided into two lithofacies zonation: the mafic rock facies (mainly layered gabbro with pyroxenite and thin diorite layer) on the top and the ultramafic rock facies (pyroxenite, olivine pyroxenite, peridotite, with some dunite) on the bottom. The vertical subdivisions of the large layered intrusion can consist of the lower zone (dominantly by PGE and Cr), middle-lower zone (Fe, V, Ti and Ni), middle zone (Fe, V, Ti, Cu, Ni and Co), middle-upper zone (Ti, Fe, V, Cu, Co and Ni) and upper zone (P, Ti, Fe and V). In the sub-rhythm layer, this sequence also appears repeatedly as second-order scale.

4.3 Small intrusive complex and Cu-Ni (-PGE) and chromite deposits

The ore-bearing small intrusions of the Cu-Ni sulfide deposits in China usually display an obvious symmetrical lithofacies zonation with acidity increasing from inner to outer. Taking the western block of the Jinchuan deposit for instance, the mafic-ultramafic complex takes on horizontal symmetrical zonation which appears dunite in the core, and lherzolite → olivine pyroxenite → pyroxenite → norite → gabbro → dunitite on the both sides. There are no distinct boundaries in rock fabrics, granularity and mineral composition of each lithofacies. The Cu-Ni sulfides are usually disseminated in the relatively-basic lithofacies of the complex. Annular complex is another important Cr-bearing intrusion except the ophiolite type chrome deposits in China, and shows lithofacies zonation of dunite → clinopyroxene peridotite → olivine pyroxenite → pyroxenite, outwards respectively. The chromite is mainly disseminated in dunitite facies (especially coarse-grained or pegmatitic lithofacies) and minor in augite peridotite facies (e.g. Fangmayu deposit). The ore body is approximately parallel to the boundary of lithofacies zone.

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