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Geological Features and Ore Genesis of the Ag-Pb-Zn Deposits Occurring in Tsav-Jiawula Region along the Sino-Mongolian Border

NIE Fengjun, LIU Chunhua and LIU Yifei

Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China

1 Geological Setting

The Tsav-Jiawula region lies along the southeastern part of the central Mongolia-Argon Pre-Meso zoic metamorphic massif, which is located at northeastern part of the northern China-Mongolia block (NCMB) (Hu et al., 1998; Nie et al., 2011). Ag and Ag-Pb-Zn deposits are widely distributed both in Pre-Mesozoic metamorphic rocks and Mesozoic volcano-sedimentary rocks, but all of them are spatially and temporally associated with Mesozoic felsic intrusive dykes and stocks. At present, twenty-three deposits have been identified. Amongst them, the Tsav, Erentaoregai Tsagenbulagen and Jiawula deposits are well known for their large-tonnage, high ore grade and unique geological features (Hu et al., 1998; Nie et al., 2011).

Three geological units were recognized in the region. (1) The Argon Group is the oldest units in the region, and constitutes a major part of the Mongolia-Argon massif (MIT, 2002). (2) The Cambrian-Ordovician strata mainly crop out in the Erentaoregai district. Permian basalt, andesite, rhyolite, tuff, slate and sandstone are distributed in the Jiawula and Tsagenbulagen districts. (3) Jurassic volcano-sedimentary rocks occur as a widely spread “blanket” covering the whole Tsav-Jiawula region. The region has experienced multiple phases of deformations since the Early Paleozoic (Nie et al., 2011). The Argon-Hulun deep-seated fault and the subsidiary Muhaer fault zone transect the region. Faults and fractures strike nearly NE, NNE, SN and NNW. Of the fracture zones, the NNE-trending faults and associated fractures are the most spectacular features (Hu et al., 1998). During the Yanshanian orogeny, the large-scale fault zones were reactivated, accompanied by the emplacement of the granitoid magma that resulted in the formation of these Ag and Ag-Pb-Zn deposits and prospects. It has been noted that some of the Yanshanian granitoid dykes and stocks have intimate spatial and temporal relations with the Ag and Ag-Pb-Zn mineralization (Hu et al., 1998; Nie et al.,2011).

* Corresponding author. E-mail: nfjj@mx.cei.gov.cn

2 Description of the Selected Ag and Ag-Pb-Zn Deposits

2.1 Tsav Ag-Pb-Zn deposit

Located about 135 km northeast of the Chobaisan city, Dornod province, eastern Mongolia, the Tsav is one of the largest Ag-Pb-Zn deposits occurring in northeast Asia (Nie et al., 2011; MIT, 2002). Two types of Ag-Pb-Zn mineralization were identified in the Mesozoic intrusive dykes and Jurassic wall rocks: quartz veins and carbonate veins. The total metal (Ag+Pb-Zn) reserve of the deposit is more than 0.8Mt (MIT, 2002). Dating of biotite from the granitoid dykes gave ^{40}Ar-^{39}Ar isotopic ages of 135±2Ma (Nie et al., 2011). The two types of the ore-bearing veins comprise thin veins, veinlets, sulfide-rich pockets, lenses and breccias. For the quartz-vein type ore, its average grades are 7.21 wt% Pb, 3.42 wt % Zn, 0.23 wt % Cu and 141 g/t Ag. For the carbonate-vein type ore, its average metal grades are 3.61 wt % Pb, 2.66 wt % Zn, 0.08 wt % Cu and 372 g/t Ag (MIT, 2002; Nie et al., 2011). The metal minerals include pyrite, chalcopyrite, galena, arsenopyrite and sphalerite, with small amount of sulfoantimonite, polybasite, tetrahedrite, hessite and pyrargyrite. Gangue minerals are quartz, chlorite, rhodochrosite oligonite and calcite, Mn-siderite. Hydrothermal minerals include quartz, illite, sericite, calcite, montmorillonite, epidote, chlorite, smectite, kaolinite. In general, the silicification and carbonatization are closely associated with the mineralization.

2.2 Jiawula Ag-Pb-Zn deposit

Located abour 40 km east of the Tsav deposit in northeastern Inner Mongolia, the Jiawula is one of the largest Ag-Pb-Zn deposits occurring in northeast Asia, and has the similar geological setting with that of Tsav deposit. The Ag-Pb-Zn mineralization at Jiawula is exclusively confined to quartz veins occurring in the Permian strata, but it is closely associated with a number of granite porphyry stocks or dykes that has been dated at 143±3 Ma and 131±6 Ma by zircon U-Pb method (Nie et al., 2011). Metal minerals of the ores include pyrite, galena, sphalerite, marcasite, pyrrhotite and chalcopyrite, with a small amount of magnetite, hematite and bornite. Ag-bearing minerals are polybasite, native silver, pyrargyrite, tetrahedrite, hessite, senandorite, ourayite and gustavite. Quartz is the dominant gangue mineral, with subordinate fluorite, sericite, chlorite, illite, muscovite, and calcite. The average ore grades are 2.25 wt% Pb, 3.2 wt % Zn and 30g/t Ag (Nie et al., 2011). Alteration around the ore-bearing quartz veins consists of mainly silicification, sericitization, chloritization and carbonatization. Among them, the silicification shows an intimate spatially relations to the Ag-Pb-Zn mineralization.

2.3 Tsagenbulagen Ag-Pb-Zn deposit

Located about 6km southeast of the Jiawula deposit, northeast Inner Mongolia, China, the Tsagenbulagen is one of the largest Ag-Pb-Zn deposits occurring in northeast Asia, with the metal reserve over 0.5 Mt. Most of the ore-bearing quartz vein groups and associated altered-fractured rocks occur along the contact of the Permian sandy slate and Mesozoic intrusive dykes. Dating of potassium-bearing minerals (K-feldspar and biotite) and whole rock samples from the felsic porphyry dykes gave K-Ar isotopic ages of 157.5-136.6Ma (Nie et al., 2011). The Metal mineral assemblage of ore-bearing quartz veins consists of asenopyrite, pyrrhotite, sphalerite, pyrite, galena and chalcopyrite. Silver-bearing minerals are native silver, electrum, hessite, tetrahedrite,argentite, pyrargyrite, gustavite, ramdohrite, ourayite and polybasite. Quartz and muscovite are the dominant gangue minerals, with subordinate fluorite, chlorite, epidote, calcite and kaolinite. The average ore grades are 3.6 wt% Pb, 4.5wt % Zn, and 40g/t Ag. Alteration around the quartz vein consists of mainly sericitization, silicification and carbonatization. Among all these alterations, the silicification and carbonatization are intimately associated with Ag-Pb-Zn mineralization.

2.4 Erentaoregai Ag deposit

Located about 90 km southeast of the Tasv deposit, the Erentaoregai is the largest Ag-only deposit occurring in northeast Asia, with the Ag metal reserve over 3000 tons. Ag mineralization is exclusively confined to quartz veins and associated alteration zones occurring within the Jurassic strata, but it shows an intimate spatial relation to the granite porphyry dykes. The whole rock samples from the quartz porphyry dyke have been previously dated at 120±6Ma by Rb-Sr methods (Nie et al., 2011). Sulfides commonly comprise less than 15 of the ore materials. Pyrite is the dominant metal mineral, and is accompanied by galena, sphalerite, chalcopyrire and tetrahedrire. Ag minerals are native silver, electrum, argentite ramdohrite pyrargyrite, hessite, ramdohrite ourayite, gustavite and polybasite. Gangue mineral assemblage includes quartz, sericite, K-feldpsar, adularia, calcite, chlorite, epidote, fluorite, barite, siderite montmorillonite, illite, and rhodochrosite. The ore grade varies from 30 to 1250g/t Ag, with an average value of 30g/t. Alteration mineral assemblage consists of quartz, adularia, sericite, chlorite and calcite. Among the alterations, the sericirizarion and adularization are closely associated with Ag mineralization.

3 Discussions and Conclusions

Previous studies indicate that the collision of the amalgamated the northern China-Mongolia block (NCMB) and the Siberian plate is likely to have occurred during the time span of late Middle to early Late Jurassic. Subsequent, post-collision lithospheric and crustal extension may lead to a large-scale magmatic activity and a great volume of fluid ascent (Hu et al., 1998). For the ore-bearing felsic dykes and stocks occurring within the studied region, isotopic age data brackets them between late Jurassic and Early Cretaceous (155-120Ma). $\varepsilon_{Nd}(t)$ value of the ore-bearing felsic intrusions in the studied mineralized districts varies from -3 to +2, with average values of -1.5 (Nie et al., 2011). Nd isotopic data indicate that all the Mesozoic felsic intrusions were formed by partial melting of the Pre-Mesozoic strata and various intrusions. Some mantle- related rock-forming material may be also involved during the re-melting processes or emplacement of the magma. Comparative studies indicate that all the four deposits belong to the epithermal Ag-Pb-Zn deposit with low to intermediate sulfidation states (Nie et al., 2007; Nie et al., 2011). Sulfur isotope data for pyrite separates is similar for all the four the Ag and Ag-Pb-Zn deposits, ranging between +0.5‰- +4.5‰, of which most data cluster in the range of +2.5‰ to +5.5‰ ,that correspond to values of magmatic sulfur. Field observation and sulfur isotopic data indicate that all the four deposits are of probable magmatic hydrothermal origin. Some of the ore-forming materials of the deposits were derived from the felsic intrusions. The role of the Pre -Mesozoic strata in the ore-forming process is still problematic, but intimate spatial relations between the strata and all the four deposits have been observed. The Pre-Mesozoic strata may have contributed some metallic components (Ag, S and Pb) via the interaction of circulating mixed fluids and the strata. It seems unlikely that the nature of the strata is critical for the localization of the deposits, but the association of the Pre-Mesozoic, Mesozoic felsic intrusions and intensive silicification, sericirizarion, adularization and carbonatization zones will be one of the useful indicators for Ag and Ag-Pb-Zn deposit exploration in the Tsav-Jiawula region.

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