Introduction

Cobalt is an important strategic material and used in aerospace, electrical appliance, machine manufacturing, chemistry and ceramic industries. It occurs in higher concentrations as companion metals in seven major deposit types (Mudd et al., 2013). A known example of magnetite deposit comprising cobalt mineralization hosted in diabase and skarn is Cornwall and Morgantown in Pennsylvania, USA. Although several studies have been conducted on the Cornwall-type deposit, there has been no consensus on a common genetic model (Hans et al., 1979).

The Cihai cobalt-rich magnetite deposit, located at the Beishan region of the eastern Tianshan, is hosted in diabase and skarn associated with the Permian mafic-ultramafic magmatism. Compared with several economic and sub-economic iron deposits in the eastern Tianshan (such as Tianhu, Yamansu and Weiya, etc.), it differs significantly in its hosted rocks and accompanying a certain amount of Co in the ore. It is probably the first-reported magnetite deposits hosted in diabase in China, and is similar in some respects to the Cornwall-type deposit. Consequently, Cihai deposit provides an opportunity to investigate the origin of Cornwall-type Fe-(Co) deposit. Cobalt is detected and achieves industrial grade with tenor about 1.9% to 2.53%. However, difficulties and technology to comprehensively utilize cobalt in Cihai deposit is unclear. Cobalt is a sulphophile and siderophile element and widely occurs in a variety of forms in many deposits. Co recovery is intrinsically linked with deposit mineralogy (Mudd et al., 2013).

In this paper, research on the occurrence and distribution of cobalt in Cihai deposit was performed to provide clues on the deposit metallogenesis and cobalt recovery technologies.

Geology of the Cihai Fe (-Co) Deposit

The Cihai Fe (-Co) deposit was discovered in 1968. It is located about 180km southwest of Hami city, east of Xinjiang, NW China. In the mining area, the exposed strata belong to Low-Middle Permian Hongluhe Formation and Sinian Baitoushan Formation. The EW and NS striking faults control the distribution of the iron ore bodies. The main intrusive rocks are diabase dated at 284Ma, gabbros dated at 294.8±1.6Ma.

The Cihai deposit is dominated by Fe mineralization hosted by diabase and skarn. This deposit is composed of three major ore districts: the Cihai ore district, the Cinan ore district and the Cixi ore district. The Cihai ore district is the biggest open pit and contain a reserve of 100 million tons with an average Fe₂O₃ grades of 45.7 wt.%. About 100 ore bodies have been recognized and are being mined. These ore bodies occur as structurally controlled lenses and veins. The Cixi and Cinan ore districts have small scale and low Fe grade ranging from 25% to 68% and from 25% to 48%, respectively, with Pyrite Re-Os weighted average ages of 261.8±6.4Ma.

Four ore types are identified based on their structure: massive, brecciated, disseminated and banded. Ore minerals are dominated by magnetite, hematite, pyrrhotite, pyrite and chalcopyrite. Gangue minerals are dominantly pyroxene, garnet, hornblende, biotite, chlorite, epidote, plagioclase and minor quartz. Wall rock alteration is intensely developed and is characterized by garnet, diopside, chlorite, epidote, albite, amphibole and calcite.

Occurrence States of Cobalt

Cobalt occurred mainly as independent minerals and isomorphism state in the sulphides and oxides of the Cihai Fe-(Co) deposit (Fig. 1).

Distribution of cobalt has been determined in 5
independent minerals, 23 pyrite, 6 pyrrhotite, 10 magnetite and 15 chalcopyrite samples from the various ore-types by electron microprobe (EMP) at the Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing, China.

Independent minerals of cobalt were cobaltite and safflorite. Cobalt is enriched greatly in pyrite and pyrrhotite from Cihai deposit (average 2330 ppm and 2090 ppm) relative to chalcopyrite (470 ppm Co) and magnetite (300 ppm Co). Cobalt contents in magnetite and chalcopyrite in all styles of mineralization are very consistent and Cobalt concentration has a considerable variation in two categories Pyrite. One is euhedral crystal associated with euhedral magnetite in skarns and another is veinlet cut euhedral crystal. The former shows maximum tenors of cobalt (1140- 2134ppm) and relative high Co/Ni ratio (1.72), and the latter has cobalt concentration ranging from 630-940ppm with low Co/Ni ratio (0.44).

4 Discussion and Conclusions

As described above, there is a distinct difference in the Co/Ni ratio of pyrite in Cihai deposit. Previous studies have demonstrated that Co/Ni ratio in pyrite has been acclaimed as a sensitive indicator of the environment of formation. Pyrite derived from magmatic melts would have higher nickel content and a lower Co/Ni ratio, than pyrite formed from late fluids (Wilson, 1953). This variability can be attributed to variations in the activities of the ions at the time of mineral phase’s crystallization (Bajwah et al., 1987). The contents of Co and Co/Ni ratio in pyrite in Cihai deposit resemble those from magmatic hydrothermal deposits. Thus, we suggest that the Cihai deposit is of magmatic-hydrothermal origin and the cobalt intensely enriched at the fluids and the higher Co values in the euhedral pyrites may be a result of high Co$^{2+}$ in the hydrothermal fluids and/or higher temperature. In addition, cobalt is beneficiated and can be extracted for it occurs as isomorphism state in pyrite and pyrrhotite.

To sum up, cobalt in Cihai deposit occurs mainly as independent minerals and preferentially concentrates in cobalt-bearing pyrite and pyrrhotite. The Cihai Fe-(Co) deposit is a large scale deposit related to the magmatic hydrothermal process.

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