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Ore-Forming Mechanism for the Hongshan Deposit in Yunnan Province, China

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The Hongshan deposit is a porphyry-skarn Cu-Mo deposit formed in post-collisional setting with hotly debated on genetic model and ore-forming mechanism. S and Pb isotopic compositions and fluid inclusions are presented here for us to better understand the ore-forming mechanism of the Hongshan deposit.

1 Regional and Deposit Geology

The Hongshan deposit is located in the Zhongdian arc, which gets its attention for the host of numerous giant porphyry deposits, and forms a key metallogenic district of Sanjiang Tethys metallogenic domain in Southwestern China (Hou et al., 2007). Extensive research has been done on the Triassic subduction orogeny and its associated porphyry-skarn hydrothermal metallogenic systems. But the research on the Yanshannian collisional metallogeny didn't arouse attention until the Late Cretaceous porphyry-skarn Cu-Mo mineralization systems (e.g., Hongshan and Tongchanggou) had been identified in recent years.

Lithologies in the Hongshan deposit are mainly Triassic volcanoclastic rocks, slate, meta-siltstone and limestone. The ore-bearing strata are restricted dominantly to the phase transition zones from slate to lenticular marbles. Two epochs of intrusions related to the regional Triassic and Cretaceous magmatic activities were emplaced in the field. The Cu-Mo orebodies are hosted mainly by skarn in the contacting zones between marble and hornfels with lenticular, podiform or stratoid forms. Two main types of mineralization were identified in the deposit, including the major layered skarn Cu-Pb-Zn orebodies, and later vein-type ores which crosscut the skarn-type orebodies. Previous research ascribed the skarn mineralization to the subduction system in Triassic with later overprinting by vein-type Mo mineralization in Cretaceous (Xu et al., 2006). The latest dating work has been done to the mineralization age of the Hongshan deposit, and reveals

that the metallogeny occurred in the Late Cretaceous post-collisional setting.

2 Fluid Inclusions Study

The quartz-sulfide veins with widely disseminated pyrite, chalcopyrite, pyrrhotite and molybdenite, weather densely or sparsely development crosscutting the skarns, which account for the bulk of Cu and Mo mineralization at Hongshan, are used for fluid inclusions studies. Different types of inclusions generally have similar homogenization temperature (T_h), ranging from 180 to 380 °C. However, they have contrasting salinities. For aqueous two phase fluid inclusions (Type A) and vapor-rich fluid inclusions (Type C) inclusions, salinities are relatively low peaking at 6 to 16 wt% NaCl equiv. The existence of daughter mineral is response for the higher salinity of halite-bearing fluid inclusions (Type B) that ranges from 27.80 to 34.12 wt%. Considering the coexistence of type A and type C inclusions, the FIs have widely variable proportions of CO₂ phases in volume, and are divergently homogenized to liquid or vapor. This suggests that the fluids were immiscible or boiling, and characterized by CO₂ escape, in other words, the fluid-system is somewhat heterogeneous. Fluid-boiling was evidenced by coexistence of type A, type B and type C FIs that are divergently homogenized at similar temperatures and yielded contrasting salinities.

3 S and Pb Isotopic Composition

Samples for analyzing of sulfur and lead isotopes were performed on pyrite, chalcopyrite and pyrrhotite in the bulk skarn ores collected from adits of the Hongshan deposit. A total of 38 sulfide minerals were analyzed, and they yielded $\delta^{34}\text{S}_{\text{V-CDT}}$ values from 3.81‰ to 5.80‰ (averaged on 4.61‰). $\delta^{34}\text{S}$ data for the 38 samples are normally distributed.

Pb isotope data from sulfides and whole rocks (calibrated common Pb compositions of andesite in host Tumugouzu

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formation, Triassic porphyry intrusions (Leng et al., 2008) and Cretaceous intrusions) are presented in plots of $^{208}\text{Pb}/^{204}\text{Pb}$ against $^{206}\text{Pb}/^{204}\text{Pb}$ and $^{207}\text{Pb}/^{204}\text{Pb}$ against $^{206}\text{Pb}/^{204}\text{Pb}$ with references to the average growth curves.

Pb isotope data of the Tumugou formation and Triassic diorite porphyries fall within an overlapped and relatively restricted field, representing a subduction-related lead source dominated with mantle reservoir and little crustal assimilation (Leng et al., 2008). Lead isotopes on Late Cretaceous quartz monzonite porphyry from the Hongshan deposit are relatively radiogenic, falling on the average upper crustal growth curve, and representing a remelting of thickened lower crust source. Pb isotope of sulfides all yield compositions that are significantly more radiogenic than data from the Triassic volcanic formations but fall within the broad field of composition between the Triassic volcanic and the Cretaceous intrusions. It indicates that the lead in the hydrothermal fluids was derived from a mixture source of mantle and crust.

4 Ore-Forming Mechanism

The mixture Pb isotope compositions indicate that the metal sources have originated from the quartz monzonite and subduction-related sources. The former was formed in post-collisional setting, and may generated from partial melting of thickened lower crust (Wang et al., 2014), and may be responsible for the Mo mineralization. The later could be explained as derivation from the cumulated sulfide in the MASH zone or assimilation from the Triassic volcanic wall rock during its ascending.

The $\delta^{34}\text{S}_{\text{V-CDT}}$ values of sulfides from the deposit range from 3.81 ‰ to 5.80‰ with an average of 4.61‰, hinting a magmatic origin. Considering the spatial and temporal association of the Hongshan copper deposit with the quartz monzonite porphyry, this observation suggests that the ore-forming fluids were mainly derived locally from the quartz monzonite porphyry.

The formation of an immiscible low salinity vapor (Type A and C) and high salinity brine (Type B) are usually

exsolved from shallowly emplaced magmas, which is consistent with the calculated formation depth between 1.44 and 3.00 km with an average of 2.22 km for lithostatic conditions. This depth is consistent with the Cu and Cl released from shallowly emplaced magmas during late stages crystallization. The solubility of Cu^{2+} would decrease dramatically as fluid cool through the temperature interval ~400 to 300 °C. The homogenization temperatures of the type A inclusions (153 to 434 °C, with a frequency peak of 200 to 340 °C) are consistent with copper deposition. Under this similar temperature, permeability would increase due to the transition in silicate rocks from ductile to brittle. Also this transition represents the boundary between lithostatic and hydrostatic fluid pressures (Richards, 2011). As fluid entered the faults across this boundary, boiling and depressurization caused rapid precipitation of ore minerals, and formed various fluids with the variation of temperature and pressure.

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