

Characteristics and Formation Process of Tin-Polymetallic Mineralization at the Shinano Vein of Toyoha Mine, Hokkaido, Japan

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The Toyoha mine, producing lead, zinc and silver, is one of the largest polymetallic epithermal vein-type deposits in Japan. It is located 30 km southwest of Sapporo City, Hokkaido, Japan. The deposit is composed of more than fifty veins, and the mining area covers 4,000 m long (NE-SE) and 3,000 m wide (NW-SE). It has produced mainly Pb, Zn, Cu and Ag, and moreover minor amount of Sn, W and In has been produced. A remarkable feature of this deposits is occurrence of rare metals; indium, tin, wolfram, bismuth, cobalt, nickel, gallium, antimony and arsenic. Among them, indium concentration is extraordinary high enough to make the mine a leading indium producer in the world. Trace amounts of molybdenum, vanadium, selenium and tellurium are also detected in and around the mining area.

Host rocks of the deposits are mainly composed of sedimentary rocks, andesite, basalt and rhyolite of Miocene age. All these rocks are affected by pervasive propylitic alteration (quartz-chlorite-calcite-sericite-pyrite \pm apatite \pm epidote), while fracture-controlled phyllic alteration (quartz-sericite-pyrite \pm chlorite) and argillic alteration (kaoline minerals-quartz \pm pyrophyllite \pm sulfate) are dominant around the veins.

The general sequence of mineralization is divided into seven mineralization stages in this deposits based on the individual crosscutting relationships by detailed underground and microscopic observations. The stages I and II are called "Earlier stage mineralization" which are represented by a large amount of pyrite-sphalerite-galena-quartz assemblage with a minor amount of hematite, magnetite and carbonate minerals. The Stages III to VII are called "Later stage mineralizations" which are mainly composed of various kinds of sulfides characterized by rare metal such as Sn, In, Bi, and Co. The Earlier stage and the Later stage mineralizations are estimated to be intimately related to the activities of magnetite-series and ilmenite-series granitoids, respectively.

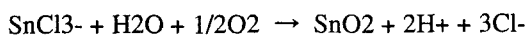
The Shinano vein, hosted within basalt lava, is estimated to be located at the feeder zone of the original ascending hydrothermal water in the mineralized area based on the fluid inclusion study. It was formed in the Later mineralization stage and is characterized by the association of clay minerals such as kaolinite, sericite and/or pyrophyllite in the vein. The stage IV is copper mineralization stage accompanying Sn minerals(cassiterite, stannite, canfieldite), In minerals(In-bearing sphalerite, In-bearing

stannite, roquesite), Bi minerals (native bismuth, cosalite, bismuthinite, gustavite, pavonite, matildite), showing polymetallic feature. Microscopic observations reveal variation of minerals consisting stage IV from -600ML to -300ML in levels. Chalcopyrite, arsenopyrite, cassiterite, Bi minerals, and wolframite are dominant in deep part. Sphalerite and galena are abundant in shallow part, while arsenopyrite and Bi minerals are not recognized. Systematic compositional changes for stannite, arsenopyrite and tetrahedrite are also recognized in ascending levels.

Homogenization temperatures of fluid inclusions of quartz and sphalerite in the stage IV are about 250°C (average) for deeper part and about 200°C for shallow part. The temperatures fall down about 50°C in shallow part with dilution of ore fluid based on salinities of fluid inclusions. Mixing of ore fluid with geothermal fluid could be suggested in here.

Oxygen isotopic ratios of fluid in equilibrium with stage IV quartz are distributed from -0.2 to +1.2 ‰ for deep part, from -4.5 to -3.8 ‰ for middle part, and from -7.1 to -5.8 ‰ for shallow part which is close to the values (-9.0 to -7.6 ‰) for geothermal fluid before boiling in this deposits. Oxygen and hydrogen isotopic studies for clay minerals suggest strong magmatic contribution for ore fluid forming polymetallic mineralization and its mixing phenomena with geothermal fluid. Sulfur isotopic ratios (+3.6 ~ +6.3 ‰) indicate magmatic source of sulfur.

Considering the results of fluid inclusions and stable isotopic studies for ore and geothermal fluid, it may be concluded that ore fluid strongly magmatic contributed might be mixed with geothermal fluid in shallow part in ascending and precipitated large amounts of polymetallic sulfides. Thermodynamic calculations have been done for the estimation of formation environments. Most dominant tin complexes of hydrothermal solution are stannous chloride (SnCl₂) for deep condition, while stannic hydroxide (Sn(OH)₄) for shallow condition. Solubility of cassiterite is about 10 ppm as SnCl₂ in deep part. Precipitation of cassiterite is expressed by following formula;



Solubilities of sphalerite and galena are extremely high at deep part. Precipitation of them could be caused by drop down of temperature, salinity, and activity of H⁺ with the decomposition of their chloride complexes as a consequence of mixing with geothermal fluid.