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Ore Mineralogy and Formation Condition of Epithermal Gold – Silver Deposits in the Southwestern Hokkaido, Japan

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Abstract

The southwestern Hokkaido mining district is well known for the occurrence of many epithermal ore deposits of Neogene Tertiary period. The ore mineral assemblages in the epithermal gold-silver deposits from the southwestern Hokkaido such as Kobetsuzawa, Shin Otoyo, Suttsu, Chitose, Teine, Date, Koryu and Toya mines are examined. The determinations of their minerals assemblages are based on the study of samples collected during field works in the southwestern Hokkaido and from the Hokkaido University Museum collection. Combinations of microscopic, electron-microprobe, and BSE-based image analyses of polished sections were used to evaluate the chemical composition of ore minerals. Most of gold-silver in the magmatic-hydrothermal systems of the southwestern Hokkaido are enriched in tellurides and Te-bearing minerals, suggesting major carriers of precious metal in the ore. Other minerals are sulfides, sulfosalts and oxides group of ores, although each deposit is characterized by the occurrence of some difference ore minerals assemblages. The presences of enargite or famatinite in some deposits suggest the deposition in the higher sulfidation state of epithermal mineralization style. The measurement of homogenization temperature and salinity of fluid inclusions in some gangue minerals such as quartz associated with ores from those deposits suggest that the formation temperature in general are around 170 – 260°C with salinity less than 4 wt.% NaCl eq. Boiling indications in fluid inclusions of some deposits give the possibility this phenomena influence to the ore precipitation.

1. INTRODUCTION

The southwestern Hokkaido mining district has produced of gold, silver, lead and zinc metals. Their production occupies an important portion of the mineral resources in Japan. These resources related with the occurrence of many epithermal ore deposits of Neogen period, such as Teine, Toyoha, Todoroki, Chitose mines etc. in this area. But most of mines in this district have been closed during the past forty years due to the exhausted of ores. The present study attempts to update the association ore minerals and to clarify the formation condition of some deposits in southwestern Hokkaido such as Kobetsuzawa, Shin-Otoyo, Suttsu, Chitose, Teine, Date, Koryu and Toya. The determinations of ores mineral assemblages are based on the study of samples collected during field works in some deposits around southwestern Hokkaido and from the Hokkaido University Museum collection. A combination of microscopic, electron-microprobe data and BSE-based image analyses of polished and doubly polished thin sections were used to evaluate the assemblages of ore minerals. Estimation on the formation temperature of mineral was made by measuring homogenization temperature of fluid inclusions, using a microscope equipped with a heating stage. Their mutual relations are used to make some point of view on ore mineralogy and formation condition of those deposits. They were collaborating with a large number of studies on these ore deposits and geology of this district which have been carried out by previous authors.

2. GEOLOGICAL SETTING OF THE DEPOSITS

The research area is situated at the junction between the ENE-WSW Kuril and the N-S trending northeast Honshu Arcs (Fig. 1). Oblique subduction of the Pacific Plate caused dextral strike-slip movement at the southwest end of the Kuril Arc and westward dislocation of the frontal Kuril arc (Kimura et al., 1983). The movement started at east
and central Hokkaido during the late Miocene. It is inferred that the active point of the movement migrated westward (Watanabe, 1987).

Yamagishi and Watanabe (1986) estimated during the period from Late Miocene to Holocene the NW-SE volcanic chains in the southwestern Hokkaido district are sub-parallel to the maximum principal stress. This indicates that the chains have been formed along tensional fractures caused by NW-SE compressional stress resulted from normal subduction of the Pacific Plate below the northeast Honshu Arc.

The gold-silver deposits in southwestern Hokkaido including major vein-type deposits such as Chitose are located at the intersection between the volcanic chain and the strike-slip shear zone. Thus, the arc-arc junction is one of the most suitable sites for vein type mineralization in this area (Watanabe, 1990). Volcanic and volcaniclastic rocks of Neogen predominate in the district, while granites, rhyolites and sedimentary rocks from Cretaceous and Paleogene ages are scattered in limited areas.

Figure 1. Distribution of Neogene volcanic rocks in the northeast Honshu Arc and the Kuril Arc (modified after Watanabe, 1990)

Neogene Tertiary and that of Late Neogene Tertiary to Quaternary mineralization periods are overlapping together in the green tuff regions. The interpretation of metallogeny in this district is not simple. This is because mode occurrences of ore deposits are complicated by repetition and duplication of mineralization. Bamba (1977) defined southwestern Hokkaido on only as one geologic unit but also as a metallogenic province. This metallogenic province is divided further into three sub-provinces which correspond to such geological sub-provinces as:

- The first sub-province is vein type and replacement-type of Au-Ag-Cu-Pb-Zn deposits which occur around basement blocks at the Matsumae-Kudo and Shimamaki area (such as Kudo, Jokoku, Imagane and Sankeimines).

- The second sub-province includes many poly-metallic ore deposits of fissure filling type, where most of deposits investigate here placed such as Koryu, Teine, Chitose etc. (II in Fig.2) which characterized by violent volcanism and upheaval movements.

- The third sub-province is the sedimentary basin with plenty of exhalative-sedimentary manganese ore deposits, as well as bedded iron and dolomite deposits especially at the western side of Suttsu-Hakodate line (III in Fig.2).

Mineralization ages in Hokkaido district (14.4 to 0.3 Ma) tend to getting young southward, resulted from Miocene to Pleistocene terrestrial volcanism, which was initially widespread, but gradually became spatially restricted towards the south (Yahata, 2002). The K-Ar dating of gangue and alteration minerals of the epithermal veins type deposits in southwestern Hokkaido has revealed that they had been placed in the Miocene – Pliocene or younger age.

Most deposits are intimately related to extrusive rocks ranging from andesite to rhyolite and some other deposits are related to acid intrusive. Mineable vein-type deposits in this area are generally hosted by hydrothermally altered Miocene strata overlain by non-altered Pliocene to Pleistocene andesite lavas.
Watanabe (1989) proposed three genetic stages of vein-type deposits in the district based on geologic structures such as latest Middle Miocene, Late Miocene and Pliocene to Pleistocene. Among these, the last is the most productive one. K-Ar ages of the vein-type deposits in the district included Koryu of $1.0\pm0.3$ Ma/Pleistocene age (Sugaki and Isobe, 1985) or in the range of 0.8 to 1.2 Ma (Shimizu et al., 1998), and Chitose of 4.7 Ma and $3.6\pm0.3$ Ma/Pliocene (Sawai et al., 1989). The distribution of vein-type deposits and K-Ar radiometric ages (Ma) of Pliocene to Holocene lavas in the district of west Hokkaido (Watanabe, 1990) is presented in Figure 3.

Middle volcanic chains usually accompany all deposits in this area. Based on K/Ar dating on adularia, it is concluded that mineralization in Koryu deposit is corresponds to the neighboring lave of Soranumadake. These lavas directly overlie the Middle Miocene strata and intrusive rocks around these deposits. Exception is for the Chitose deposit which conclude has similar age with their respective neighboring lavas. The Chitose deposit was formed during Early Pliocene time, whereas no nearby volcanic activity of the same age has been known. The Ninaruyama Lava covered by the Izaridake Lava (2.5 Ma) to the north of the deposit and the Shiraoidake Volcanics (Fujiwara, 1954) to the south might be contemporaneous volcanism.

The Pliocene or younger ages vein in the district mostly strike E-W and are oblique to the NW-SE volcanic chains (Watanabe, 1986). The major veins such as those at Chitose formed by dextral strike-slip movement of E-W trend (Watanabe, 1989 and 1990). These indicate that the dextral strike-slip movement that started at central and east Hokkaido was active in the area during the Pliocene. A small number of NW-SE veins at some deposits are sinistral strike-slip fractures (Shinoda et al., 1974), which are regarded as conjugate parts of E-W veins (Watanabe, 1986).

3. ORE MINERAL ASSEMBLAGES AND GEOCHEMISTRY

It was reported from the previous studies about twenty mines are known in the southwestern Hokkaido district, twelve of which have records of production. The deposits investigated on this study such as Kobetsuzawa, Teine and Date are characterized by its silver-gold tellurides including teineite \([\text{CuTeO}_3\cdot2(\text{H}_2\text{O})]\), Yosimura, 1939 and watanabeite \([\text{Cu}_4(\text{As},\text{Sb})_2\text{S}_5]\), Shimizu et al., 1993 in Teine. Chitose and Koryu are characterized by its silver selenides and tellurides minerals, Suttsu and Shin-Otoyo for its bismuth-bearing minerals. Occurrence of some ore minerals in southwestern Hokkaido deposits are represented in Figure 4.

Polished samples of ore minerals from these deposits were studied with an electron microprobe to determine the distribution of selected elements in the minerals. The data show some variations that are inherent in the procedures and materials to be analyzed. The elements content were analyzed quantitatively by EPMA. Operating conditions were 20kV, integrated beam current, 200 x 10^{-7} amperes referenced to all minerals.

Gangue minerals are composed of invariably quartz with varying amount of carbonates (calcite and Mn-calcite/rhodocrosite), anatase, barite, chlorite, rare kaolinite, zeolite and gypsum. Adularia is characterized in Chitose and Koryu. There are also reported the occurrence of melanite in Kobetsuzawa and other is johannsenite in Koryu (Shimizu et al., 1998). Ration of gangues to ore minerals is highly variable.

Veins with typical fissure-filling show crustified banded structure composed of several nearly monomineralic layers such as in Koryu and Chitozmines. Major ore minerals in Suttsu, Chitose, Koryu, Date andToya are predominantly byszulfide minerals such asshapelerite, galena, chalcopyrite and pyrite. The exception is for Shin-Otoyo where sulfide minerals are rare except for pyrite. Those are associated with telluride and Te-bearing minerals, sulfosalts, and sulfide. Bismuth minerals identified at Teine, Suttsu and Shin-Otoyo, as bismuthinite, aikinite, emplectite, friedrichite, gustavite, lillianite, pavonite, and as telluride minerals of tellurobismuthite and tetradymite.

Beside electrum, the gold-silver also dominated in Te minerals of calaverite (Date), petzite (Teine, Date, Kobetsuzawa, Chitose), hessite (Kobetsuzawa, Teine, Chitose, Koryu), silvanite (Teine, Kobetsuzawa), stutzite (Teine, Kobetsuzawa), agularite (Koryu, Chitose), gustavite (Suttsu), pavonite (suttsu), proustite-pyargyrite (Chitose, Koryu, Date), pearceite-polybasite (Toya, Koryu, Chitose), acanthite (Koryu, Date, Chitose). Shimizu et al. (1998) also reported the occurrence silver minerals of mckinstryite \([\text{Ag,Cu}_2\text{S}]\) and jalpaite \([\text{Ag}_3\text{Cu}_2\text{S}_2]\) in Koryu mine.

Aggregations of fine-grained sulfide minerals form banded black streaks (“ginguro” = silver black) in the quartz veins also characterized some deposit such as in Shin-Otoyo, Suttsu, Chitose, Koryu, Date and Kobetsuzawa. In the ore shoot such as in Chitose and Koryu mines, electrum in the vein is observed from hand specimen samples and displaying tabular, scaly or form dendritic texture. It contains 19.3 to 51.8 wt.% of silver in Chitose and 32.5 to 41.8 wt.% in Koryu mines. The silver content in electrum from other deposits are vary (Fig. 5) such as in Teine (16.64 – 17.70 wt.%), Date (18.84 – 20.94 wt.%), and Toya (19.38 – 20.68 wt.%).

Figure 5. Silver contents (wt.%) in electrum from some deposits in southwestern Hokkaido.

The deposits are rich in telluride and Te-bearing minerals (except for Shin-Otoyo and Toya and rare in Suttsu). Native tellurium is found at Teine, Kobetsuzawa and Date. Various kinds of sulfosalt minerals, as partly mention previously, are also identified in various proportion. Some tellurantimony in Kobetsuzawa also contain silver (up to 1.9 wt.%) and gold (up to 0.7 wt.%); in altaite, silver up to 2.4 wt.% and gold up to 0.5 wt.%; in sulfide minerals of sphalerite, pyrite and chalcopyrite silver up to 2.6 and gold up to 0.9 wt.%.

In Suttsu mine, sample of kawazulite contain silver up to 2.4 wt.%, and in stannite gold content up to 0.6 wt.%. In Chitose mine, pyrite and sphalerite also contain gold up to 0.4 wt.%. In Teine mine, tetrahedrite contain silver up to 5.5 wt.% and gold up to 0.5 wt.%.

Tennantite from Toya mine is characterized by silver content up to 1.3 wt.% and gold up to 0.7 wt.%, otherwise in tetrahedrite silver up to 5.11 wt.%.
The measurements of iron contents in sphalerite from those deposits also show wide range values (Fig. 6). Iron content in sphalerite is characterized by low FeS content in Chitose (0.6–3.0 mol.%), Teine (0.0–3.0 mol.%), Date (1.2–1.9 mol.%), Koryu (0.8–2.5 mol.%) and Toya (0.3–1.2 mol.%). High content of FeS shows by sphalerite samples from Kobetsuzawa (15.9–22.1 mol.%) and Suttsu (4.9–16.7 mol.%) deposits.

Highly enriched tellurides in mostly magmatic-hydrothermal systems of southwestern Hokkaido are probably representing major carrier of precious metals in the ore. The presence of enargite or famatinite in some deposits (such as in Shin-Otoyo and Teine deposits) suggests deposition at a higher sulfidation state.

Figure 6. Frequency (number of analyses) of FeS content (mole fraction of FeS) of sphalerite from some ore deposits of southwestern Hokkaido.

Hedenquist et al. (2000), and Sillitoe and Hedenquist (2003) defined that tellurides may be present in all types of epithermal deposits (e.g. high-, intermediate- and low sulfidation), but the most common variety is the low-sulfidation type that is spatially associated with alkaline igneous rocks (e.g. Emperor-Fiji, Ahmad et al., 1987; Pals and Spry, 2003) However, other important deposits are genetically related to calc-alkaline rocks and include intermediate sulfidation deposits in the Baguio District, Philippines (Cooke and McPhail, 2001), high-sulfidation deposits at El Indio, Chile (Jannas et al., 1990) and the mixed high-intermediate sulfidation deposit at Kochbulak, Uzbekistan (Kovalenker et al., 1997).

4. FORMATION CONDITION OF ORE

Though sphalerite is one of the main constituent ore mineral in most of these deposits, fluid inclusions in these kind ore minerals are rather hard to observe. In this study, inclusions in quartz and barite were used for the measurements, because these minerals are the most abundant gangue minerals with main sulfide minerals according to the mode of occurrence. Some quartz and barite samples are prepared from some deposits for measurement of their filling temperature and salinity. The filling temperature of inclusions in samples are presented here as their average values.

The fluid inclusion filling temperature measured was assumed as formation temperature of the minerals in the system. The lower temperatures are usually obtained from barite. In this case temperatures might not be considered to represent the whole range of formation temperature. But in a few samples from Teine and Koryu mines, the measurements were carried out on both co-existing quartz-barite with sphalerite and the filling temperature were shows almost similar values. Then it can be assumed that the filling temperature of inclusion in quartz is generally almost same as that of association barite and sphalerite, and generally this temperature may represents the temperature of ore deposition of those deposits.

Based on the results of filling temperature measurements, the range of the formation temperature for the main mineralization from those Kobetsuzawa, Suttsu, Chitose and Teine are as followed: 213–275°C with salinity 3.4–6.2 wt.%NaCl equiv. (average 4.5 wt.% NaCl equiv.) for Kobetsuzawa; 208–254°C with salinity 1.2–6.2 wt.% NaCl equiv. (average 2–3 wt.% NaCl equiv.) for Suttsu; 235–260°C with salinity 1.6–6.2 wt.% NaCl equiv. (average 2 wt.% NaCl equiv.) for Chitose; 208–255°C with salinity 1.9–2.1 wt.% NaCl equiv. for Teine; 197–264°C with salinity 0.5–5.2 wt.% NaCl equiv. (average 2 wt.% NaCl equiv.) for Koryu; 170–230°C with salinity 2.6–4.5 wt.% NaCl equiv. for Shin-Otoyo, respectively.

Compilation with some data reported on the formation temperature of related ore deposits in this area, in general show the formation temperature are range from 170°C to 260°C. Homogenization temperatures of fluid inclusions in sphalerite were also determined from several samples. But the result of measurement was not good enough since it was too difficult to observe during measurement.
Evident of boiling was identified in fluid inclusions from Chitose, Koryu and Teine samples. Drummond and Ohmoto (1985) cited that boiling is a more efficient mechanism for precipitation gold and silver from an epithermal fluid than simple cooling. Thus, it is conclude that boiling probably occurred during gold and silver mineralization in those deposits (such as in Koryu, Shimizu et al., 1998, and in Chitose, Yajima, 1979).

Umehara (1996) reported the measurements of fluid inclusion in veinlet quartz of Shin-Ot oyo samples are range between 200 to 300°C without systematic vertical variation, while the salinity increases with increasing depth. This indicates that the ascending saline fluid was probably mixed with a dilute fluid of similar temperatures. Therefore fluid mixing seems to be a probable cause for the polymetallic mineralization at the Shin-Ot oyo deposit (Imai et al., 1999).

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**References**

