Manganese, Lead, Zinc and Silver Mineralization at the Matahachi Deposit of Jokoku Mine, Southwestern Hokkaido, Japan

Daizo Ishiyama*, Hiroharu Matsueda** and Takeshi Nakamura***

Abstract: Neogene mineralization related to the formation of magnetite skarns and manganese, lead, zinc and silver veins at the Matahachi deposit in the Jokoku-Katsuraoka mining area is summarized on the basis of macrostructures and mineral paragenesis of individual ore bodies, mineralization stages, hypogene zoning and environment of ore formation.

The mineralization sequence, from earlier to later, is divided into five stages as follows; Stage I: formation of magnetite skarns, Stage II: formation of Pb-Zn-(Cu) quartz veins, Stage III: formation of Pb-Zn-(Mn) quartz veins, Stage IV: formation of (Pb)-(Zn) rhodochrosite veins, rhodochrosite veins and massive rhodochrosite deposits and Stage V: formation of ferromanganoan dolomite veins. Mineralization of stages (I) through (V) at the Matahachi deposit is closely related to the mineralization events showing polyascendent zoning.

Three major kinds of vein deposits at the Matahachi deposit include Pb-Zn-(Mn) quartz veins, well-crusted banded rhodochrosite veins and rhodochrosite veins. Ore types such as Pb-Zn, well-crusted banded rhodochrosite and rhodochrosite ores are correlated with ore grade. Based on ore grade, the three zones are arranged from the northwestern to southeastern part of the deposit in the order of Pb-Zn, Intermediate and Rhodochrosite zones. Pb-Zn-(Mn) quartz veins tend to occur in the Pb-Zn zone of the deposit, while rhodochrosite veins are widely distributed in the Rhodochrosite zone. Horizontal and vertical zoning could be formed by polyascendent mineralization related to formation of Pb-Zn-(Mn) quartz, (Pb)-(Zn) rhodochrosite and rhodochrosite veins.

Formation temperatures gradually decrease from earlier to later stages at the Matahachi deposit. Changes of formation temperatures correspond to the progress of mineralization stages associated with multiple mineralization.

1. Introduction

Southwestern Hokkaido is one of important regions of manganese resources in Japan. Most of them genetically related to Neogene volcanism and tectonism. Geotectonically speaking, the Jokoku-Katsuraoka mining area, southwestern end of the Oshima peninsula, is corresponding to the north extension of the outer non-volcanic accretionary belt (North Kitakami belt) and the inner volcanic belt of the “Green Tuff Region”. The recent chemical analysis of the soils and rocks in the area show that the region is characterized by the presence of Mesozoic and Paleozoic bedded manganese deposits and Neogene magnetite skarn deposits and manganese also containing lead, zinc and silver vein deposits (hereafter abbreviated as manganese (Pb, Zn and Ag) vein deposits). The Neogene magnetite skarn deposits and manganese (Pb, Zn and Ag) vein deposits of the Jokoku-Katsuraoka mining area were studied geologically and mineralogically to clarify formation processes of ore deposits and environments of ore deposition (Bamba, 1957; Bamba et al., 1961; Sawa et al., 1965; M.M.A.J., 1981; Ishiyama and Matsueda, 1988).

Recently, Neogene mineralization of magnetite skarn deposits and manganese (Pb, Zn and Ag) vein deposits in the Jokoku-Katsuraoka mining area are considered genetically related to Neogene shallow intrusives rocks, especially of granodiorite porphyry (M.M.A.-J., 1981; Ishiyama et al., 1987). The Neogene mineralization in the area is divided into fol-
The Matahachi deposit of the Jokoku mine, exploiting a large manganese carbonate (rhodochroite) vein deposits is located in the southwestern part of the Jokoku-Katsuraoka mining area (Fig. 1). Various kind of veins with minor skarns occur in the Matahachi deposit. Though there is a few studies with respect to mineralization stages of Neogene mineralization at the Matahachi deposit (MIURA and OMURA, 1961; NISHIO, 1966), mutual relationships between mineralization which formed rhodochroite veins and mineralization of other kind of veins has not been necessarily clarified.

We describe various features of the manganese (Pb, Zn and Ag) veins with minor
skarns at the Matahachi deposit of the Jokoku mine, and interpret the formation processes of these deposits based on macrostructure of ore and mineral assemblages of individual ore bodies. As a consequence, characteristics of mineralization stages, hypogene zoning and environments of ore formation are disclosed in this paper.

2. Geology and Ore Deposits at the Matahachi Deposit of Jokoku Mine

2.1 Geologic setting

The Jokoku-Katsuraoka mining area, including the Matahachi deposit of the Jokoku mine, is composed of late Carboniferous to Jurassic Chisago Formation of the Matsumae Group, Oligocene Matahachizawa Formation, Miocene Fukuyama Formation, and Pliocene Maruyama Formation in ascending order. Besides, dikes and stocks of Neogene age occur (M.M.A.J., 1981; Fig. 1).

The Chisago Formation, the oldest formation in the area, is corresponding to a northern extension of the North Kitakami belt (Yoshii and Yoshida, 1974). The Matahachizawa and Fukuyama Formations belong to the strata of so-called "Green Tuff Region" (Fig. 1). The Chisago Formation occurs in the southwestern, southeastern and northeastern parts of the area and consists of basic tuff and lava, limestone and/or dolomite rock, reddish bedded chert, dark bedded chert, mudstone and sandstone in ascending order (Ishiga and Ishiyama, 1987). Bedded chert is prevalent. Numerous bedded manganese and iron-manganese deposits are embedded within Chisago Formation (Hasegawa et al., 1983). In the Jokoku mining area, the Chisago Formation is composed of thick, alternating, dark bedded chert and mudstone with occasional intercalations of basic tuff and lava, limestone, dolomite rock and sandstone (Fig. 1).

The Matahachizawa Formation occurs locally in the mining area and unconformably overlies the Chisago Formation. The Matahachizawa Formation is about 500 meters thick and consists of rhyolitic and/or dacitic tuff breccia with abundant mudstone and chert fragments. Fission-track ages of Matahachizawa Formation range from 29.5 to 24.5 Ma (late Oligocene; M.M.A.J., 1981).

The Fukuyama Formation is widely distributed in the central part of the area. The Fukuyama Formation (1,400 to 2,300 meters thick) is divided into lower, middle and upper members (M.M.A.J., 1981), and unconformably overlies the Matahachizawa Formation. The lower member of the Fukuyama Formation consists mainly of dacitic pyroclastics occasionally intercalated with mudstone and sandstone. The middle and upper members consist of andesitic lava flows and associated pyroclastic rocks (M.M.A.J., 1981). Fission-track ages of the Fukuyama Formation range from 26.5 to 19.6 Ma (late Oligocene to early Miocene; M.M.A.J., 1981).


The Chisago Formation appears to thrust northwestward over the Matahachizawa Formation near at the Matahachi deposit. Strata of the Chisago Formation trend N-S to NNW-SSE and dip 40° to 70°W and are strongly folded and faulted. Strata of the Fukuyama Formation unconformably overlying the Chisago and the Matahachizawa Formations (Nishio, 1966), trend N-S to NE-SW and dip 20° to 40°E or W and form gently folded structure with a fold axis trending N-S to NNE-SSW.

Numerous andesite dikes and granodiorite-porphry, diorite and diorite-porphryite stocks of Neogene age intrude to Pre-Tertiary and Tertiary formations. Distribution of Neogene stocks is controlled mainly by the Ishizaki and Sumikawa-Katsuraoka tectonic zones (M.M.A.J., 1981).

2.2 Ore deposits

The Jokoku mine consists of the Matahachi*1 and Hikagezawa*1 deposits. In addition, the Shimanosawa*1, Tozawa*1,

*1: Locations of these deposits are referred to Ishiyama et al. (1987).
Fig. 2 (a) Map showing horizontal zoning at the Matahachi deposit on the 50 mL (modified from original plan shown by the Jokoku mine). Arrows show the inclination of the veins. 1: Vein, 2: Rhyolitic to dacitic tuff breccia (Matahachizawa F.), 3: Chert, mudstone and basic tuff and lava (Chisago F.). (b) Map showing vertical zoning at the Matahachi deposit (modified from original cross section shown by the Jokoku mine).

Maruyama*1 and Yashinosawa*1 deposits belong to the mine. The Jokoku mine has been exploited for its manganese reserves, and also in recent years, for silver. Total production of crude ores from 1941 to 1974 is 731,126 tons which consists of 723,690 tons containing 23.6% Mn, 5,400 tons containing 1.4% Zn, 2,022 tons containing 0.5% Pb, 14 tons con-
taining 55.0 g/t Ag, and 0.016 tons containing 0.1 g/t Au (GEOLoGICAL SURVEY of JAPAN, 1980). The Matahachi deposit is the most important deposit in the Jokoku mine and consists mainly of Pb–Zn–(Mn) quartz veins, (Pb)–(Zn) rhodochrosite veins, rhodochrosite veins and massive rhodochrosite deposits replacing limestone and dolomite rock (Ôta et al., 1971; HARIYA and HASEGAWA, 1979; ISHIYAMA and MATSUEDA, 1986). Minor magnetite skarns, Pb–Zn–(Cu) quartz veins, ferromanganese dolomite veins and breccia dikes also occur in the Matahachi deposit in addition to the economically exploited Pb–Zn–(Mn) quartz veins, (Pb)–(Zn) rhodochrosite veins, rhodochrosite veins and massive rhodochrosite deposits. Pb–Zn–(Mn) quartz veins (Nos. 6 and 7 veins) and (Pb)–(Zn) rhodochrosite veins (Nos. 4, 6 and 7 veins) contain a larger quantity of silver.

Veins of the Matahachi deposit can be classified into three groups by general trend; the N45°W group, the N75°W group and the N60°W group. Fractures of the first two groups are filled by veins associated with large amounts of clayey materials suggesting that the fractures were caused by shears. Fractures of the N60°W group contain veins accompanied by lesser amounts of clayey materials suggesting the fractures are of tension fractures. Compressional forces trending N60°W–S60°E played an important role in development of the fracture system. This agrees with predicted regional NW–SE or WNW–ESE compressional forces during Neogene in Hokkaido (WATANABE, 1986).

The Honpi that implies main vein with N45°W–S45°E trend of the Matahachi deposit occurs along the reverse fault zone between the Chiisago and Matahachizawa Formations as shown in Fig. 2. The Shitaban veins belong to the N60°W–S60°E group and Nos. 1 to 7 veins of the N75°W–S75°E group occur in the footwall side of the Honpi. The Shitaban veins tend to occur in the Chiisago Formation. On the other hand, the Nos. 1 to 7 veins occur in the Matahachizawa Formation. The No. 1 Shitaban vein and the other Shitaban veins change their dip from NE to SW in the vicinity of the Honpi (Fig. 2b). The Nos. 1 to 7 veins have their dip direction from vertical to NNE.

Two types of wall rock alteration can be distinguished in the Matahachi deposit; a widespread propylitic alteration and hydrothermal alteration associated with vein mineralization. The propylitic altered rocks of the Matahachizawa and the Fukuyama Formations are composed of quartz, plagioclase, chlorite, sericite, epidote, calcite and pyrite (M.M.A.J., 1981). Epidote or calcite and chlorite are the essential minerals of the propylitic alteration assemblage. The mineral assemblage of fine-grained quartz and sericite with minor rhodochrosite and pyrite formed in alteration envelopes adjacent to veins.

3. Sequence of Mineralization Stages at the Matahachi Deposit

This paper distinguished five-Neogene age stages of mineralization at the Matahachi deposit based on mineral paragenesis and tectonic boundary in the sense of definition of macrostructure (KUTINA, 1955, 1957, 1965), as the mineralization stages are separated by tectonic boundary recognized in macrostructures of individual ore bodies at the Matahachi deposit. From earlier to later, they are:

Stage I : formation of magnetite skarns,
Stage II : formation of Pb–Zn–(Cu) quartz veins,
Stage III: formation of Pb–Zn–(Mn) quartz veins,
Stage IV: formation of (Pb)–(Zn) rhodochrosite veins, rhodochrosite veins, and massive rhodochrosite deposits,
Stage V : formation of ferromanganese dolomite veins.

Stage I: Magnetite skarns of this stage are of the earliest mineralization during Neogene age at the Matahachi deposit and are associated with quartz diorite of Neogene regarded as shallow intrusive rock. The magnetite skarns are characterized by the presence of garnet, wollastonite, actinolite, epidote, magnetite and hematite assemblage (HARIYA and HASEGAWA, 1979). The magnetite skarns are cut by rhodochrosite and calcite veinlets(Fig. 3).
This evidence leads us to a conclusion that the tectonic boundary between magnetite skarns and veins formed through Neogene mineralization events at the Matahachi deposit.

**Stage II:** Constituent minerals of Pb-Zn-(Cu) quartz veins of stage II are represented by large amounts of sphalerite, galena and quartz and small amounts of chalcopyrite, marcasite, tennantite, hessite and Ag-Ni-(As)-S minerals. The mineral assemblage of the Pb-Zn-(Cu) quartz veins at the Matahachi deposit is similar to that of Pb-Zn-(Cu) quartz veins in the Maruyama deposit (ISHIYAMA et al., 1987), and amounts of sphalerite and galena of Pb-Zn-(Cu) quartz veins are more than those of Cu-Pb-Zn quartz veins at the Hayakawa, Gamanosawa and Ishizaki deposits and are less than those of Pb-Zn-(Mn) quartz veins at the Matahachi deposit. Pb-Zn-(Cu) quartz veins (N63°W, 40°NE) of stage II are cut by (Pb)-(Zn) rhodochrosite veins (N65°W, 45°NE) of stage IV-a.

**Stage III:** Pb-Zn-(Mn) quartz veins of stage III consist of coarse-grained brownish sphalerite, coarse-grained anhedral galena, pyrite and small amounts of marcasite, chalcopyrite, famatinite, freibergite, pyrargyrite, antimony millingsleyite, polybasite, arsenopolybasite, argyrodite, argentite, electrum, very pale pinkish rhodochrosite, barite and quartz (ISHIYAMA and MATSUEDA, 1988). Both rhodochrosite, often showing reniform structure, and fine-grained quartz after barite are adjacent to wall rock. Sphalerite and galena occur as compact masses overlying reniform rhodochrosite (Fig. 4). Stage III veins are sometimes transected by rhodochrosite veins of stage IV-b (Fig. 5).

**Stage IV-a:** Ore of (Pb)-(Zn) rhodochrosite veins in stage IV-a is characterized by well-crustified growth banding consisting of very fine alternating bands of rhodochrosite and sphalerite and galena (Fig. 4). (Pb)-(Zn) rhodochrosite veins include a large amount of rhodochrosite with lesser amounts of sphalerite, galena, pyrite, freibergite, pyrargyrite, poly-
Manganese, lead, zinc and silver mineralization

Stage IV-a: Rhodochrosite veins contain a large amount of loosely crustified, pale pinkish rhodochrosite (Fig. 4) and lesser amounts of coarse-grained greenish sphalerite, coarse-grained euhedral galena, fine-grained pyrite and marcasite, fine-grained anhedral chalcopyrite, freibergite, pyrrygyrite, polybasite, arsenopybasite, acanthite, electrum, barite and quartz (ISHIIYAMA and MATSUEDA, 1988).

Massive rhodochrosite deposits replacing basite and small amounts of marcasite, chalcopyrite, proustite, argyrodite, argentite, electrum, Pb-Mo-Sb-S minerals, quartz and barite (ISHIIYAMA and MATSUEDA, 1988). Rhodochrosite varies from yellowish white to pink in color, and changes from reniform and/or oolitic to rhombohedral in structure. Sphalerite occurs as fine-grained brownish crystals and galena occurs as fine-grained euhedral crystals. Barite, which occurs near the margin of the veins, is sometimes corroded. Fine-grained quartz is pseudomorphous after barite. The (Pb)-(Zn) rhodochrosite veins are partly transected by the later rhodochrosite veins (Fig. 6).

Stage IV-b: Rhodochrosite veins contain a large amount of loosely crustified, pale pinkish rhodochrosite (Fig. 4) and lesser amounts of coarse-grained greenish sphalerite, coarse-grained euhedral galena, fine-grained pyrite and marcasite, fine-grained anhedral chalcopyrite, freibergite, pyrrygyrite, polybasite, arsenopybasite, acanthite, electrum, barite and quartz (ISHIIYAMA and MATSUEDA, 1988).

Massive rhodochrosite deposits replacing...
limestone and dolomite rock is regarded to be concurrently formed with the rhodochrosite veins of stage IV–b (ISHIYAMA and MATSUEDA, 1986). Massive rhodochrosite deposits include a large amount of massive pale pinkish rhodochrosite with small amounts of fine-grained sphalerite and galena.

**Stage V:** Ferromanganan dolomite veins of stage V occur as network veinlets (Fig. 7). In addition, the ferromanganan dolomite occurs as euhedral crystals within druses in rhodochrosite veins of stage IV–b (ISHIYAMA and MATSUEDA, 1986). The ferromanganan dolomite veins are mainly composed of a great quantity of ferromanganan dolomite and are associated with minor amounts of sphalerite, galena, pyrite and quartz.

Veins of stage IV–b, rhodochrosite veins cut and are cut by breccia dikes which are widely distributed in the Matahachi deposit. Some breccia dikes may be formed concurrently with rhodochrosite veins of stage IV–b. Many fragments of rhodochrosite ore are found in the breccia dikes. Original features of brecciated rhodochrosite ore resemble ore of rhodochrosite veins. Representative ore minerals in the breccia dikes are loosely crustified pale pinkish rhodochrosite, coarse-grained euhedral greenish sphalerite, coarse-grained eu-
hedral galena and small amounts of chalcopyrite and pyrrargyrite.

Stages II, III, IV and V are discriminated by distinct tectonic boundaries at the Matahachi deposit. The earlier fractures are filled with Pb-Zn-(Mn) quartz, (Pb)-(Zn) rhodochrosite and rhodochrosite veins. On the other hand, later fractures developed during deposition of rhodochrosite veins of stage IV are lacking Pb-Zn-(Mn) quartz vein and (Pb)-(Zn) rhodochrosite vein materials. Neogene hydrothermal mineralization of stages II through V at the Matahachi deposit is recognized as the mineralization events showing "polyascendent zoning" (KUTINA, 1957) which is defined by multiple re-opening and filling of an individual fissure during evolution of vein.

4. Hypogene Zoning of the Matahachi Deposit

Three major kinds of vein deposits of the preceding seven types of Neogene mineralization are present at the Matahachi deposit: They are Pb-Zn-(Mn) quartz veins (Type 3), well-crustified banded (Pb)-(Zn) rhodochrosite veins (Type 4A) and rhodochrosite veins (Type 4B). The first type is made up of Pb-Zn ore, the second type consists of well-crustified banded rhodochrosite ore, and the third one is composed of rhodochrosite ore (Fig. 4). These three ore types of vein deposits are distinguished on the basis of macrostructures observed in each ore body and in ore-textures.

The three different types of veins correspond to their ore grade. Type 3 is distinguished from Types 4A and 4B on the basis of [Mn]/T ratio (%), where T is the summation of [Au], [Ag], [Pb], [Zn] and [Mn]; [Au], [Ag], [Pb], [Zn] and [Mn] are weight percentages of each element in the ore. Veins having [Mn]/T less than 0.4 belong to Type 3, while those having [Mn]/T greater than 0.4 are typical of Types 4A and/or 4B.

Type 4A is distinguished from Type 4B by AKIYAMA et al's (1980) method. Average ore grades of Pb, Zn and Mn are 0.5, 1.35 and 23.6 wt%, respectively. Conversion factors are calculated so as to make a weight percent ratio of average grade Pb:Zn:Mn=1:1:1. Conversion factors of Pb, Zn, and Mn are 2.70, 1.00 and 0.06, respectively. Converted ore grades of Pb, Zn and Mn are calculated using the formula:

$$CG_i = CE_i \cdot OG_i$$

where $CG_i$ is the converted ore grade of the $i$th element and $CF_i$ and $OG_i$ are the conversion factor and ore grade of $i$th element, respectively. An efficacious classification of ores is defined using a $CG_{Mn}-CG_{Pb}-CG_{Zn}$ ternary diagram (Fig. 8). The 0.4 [Mn]/T ratio corresponds to the boundary line between Pb-Zn and Pb-Zn-Mn and/or Zn-Pb-Mn fields in the diagram. Mineralization which falls within the Pb-Zn field corresponds to Pb-Zn-(Mn) quartz (Type 3) veins (Fig. 8). Mineralization which falls within the Pb-Zn-Mn field corresponds to (Pb)-(Zn) rhodochrosite (Type 4A) veins, and mineralization which falls within the Zn-Pb-Mn, Mn-Pb-Zn and Mn fields corresponds to rhodochrosite (Type 4B) veins.

Plots of converted ore grades of the No. 6 Shitaban vein and the No. 7 vein (at 80mL) in a $CG_{Mn}-CG_{Pb}-CG_{Zn}$ ternary diagram are plotted chiefly within the Pb-Zn and Pb-Zn-Mn fields, respectively (Fig. 8). The No. 6 Shitaban vein (at 80mL) is classified as Pb-Zn-(Mn) quartz vein (Type 3), while the No. 7 vein (at 80mL) is placed in the (Pb)-(Zn) rhodochrosite vein (Type 4A). Nos. 3 and 4 veins (at 80mL) belong to the rhodochrosite vein (Type 4B) because ternary plots of converted ore grades for both veins fall mainly within the fields for Zn-Pb-Mn, Mn-Pb-Zn and Mn (Fig. 8).

Zonal distribution of ore types on the basis of metal production at the Matahachi deposit is shown in Fig. 2. Three zones are: (1) Pb-Zn zone, (2) Intermediate zone and (3) Rhodochrosite zone. At plan view of the 50mL (Fig. 2a), the Pb-Zn zone appears in the northwestern part of the deposit, the Rhodochrosite zone lies in the southeastern part of the deposit and the Intermediate zone occupies between the former two zones as a transitional zone. Earlier Pb-Zn-(Mn) quartz veins (Type 3) occur in the northwestern part of the
Later rhodochrosite veins (Type 4B) tend to be widely distributed in the southeastern part of the deposit. In cross section (Fig. 2b), the zones are distributed with the Pb–Zn zone on the northwest lower levels and the Rhodochrosite zone on the southeast upper levels. The Intermediate zone lies as a transitional zone between the Pb–Zn and the Rhodochrosite zones. Besides Pb–Zn–(Mn) quartz veins (Type 3), minor (Pb)–(Zn) rhodochrosite (Type 4A) and rhodochrosite veins (Type 4B) occur within the Pb–Zn zone. Minor Pb–Zn–(Mn) quartz (Type 3) and (Pb)–(Zn) rhodochrosite veins (Type 4A) occur in the Rhodochrosite zone. Horizontal and vertical zoning could be formed by polyascendent mineralization of Pb–Zn–(Mn) quartz, (Pb)–(Zn) rhodochrosite and rhodochrosite veins.

5. Sequence of Mineralization and Environments of Ore Formations

Liquid-rich two-phase fluid inclusions are common in quartz, sphalerite, rhodochrosite and dolomite from Pb–Zn–(Mn) quartz (stage III), (Pb)–(Zn) rhodochrosite (stage IV–a), rhodochrosite (stage IV–b) and ferromanganooan dolomite (stage V) veins of the Matahachi deposits. Homogenization temperature measurements were made on primary fluid inclusions in quartz, sphalerite, rhodochrosite and dolomite of various modes of occurrences.

Fluid inclusion study on those minerals has been already described in detail (ISHIYAMA et
Homogenization temperature data for sphalerite and quartz in stage III ranges from 196°C to 275°C. The highest frequency is around 250°C. Homogenization temperature data for sphalerite and rhodochrosite in stages IV-a and IV-b range from 129°C to 293°C and from 167°C to 280°C, respectively. Although the homogenization temperature data of vein minerals in stage IV-a and IV-b show a rather wide range, the highest frequencies in stages IV-a and IV-b are around 200°C and 190°C, respectively. The homogenization temperature data of ferromanganese dolomite veins in stage V range from 178°C to 216°C. The homogenization temperatures of mineralization of the Matahachi deposit decrease from around 250°C in stage III to around 190°C in stage IV-b.

According to EPMA analyses, atomic fractions of silver in electrum from Pb-Zn-(Mn) quartz veins (No. 6 Shitaban vein, 80 mL and No. 7 vein, −10 mL) at the Matahachi deposit (stage III) range from 0.54 to 0.58. And FeS contents of sphalerite from the deposit range from 2.6 to 6.8 FeS mole percent. Considering the mineral assemblage electrum-argentite-pyrite-sphalerite and chemical composition of coexisting electrum and sphalerite in the assemblage, estimated temperatures and sulfur fugacities of Pb-Zn-(Mn) quartz vein (stage III) mineralization at the Matahachi deposit range from 252°C to 293°C and 10^{-11.5} to 10^{-10.3} atm, respectively (ISHIYAMA et al., 1987).

Electrum-pyrargyrite-pyrite-sphalerite assemblage occurs in the (Pb)-(Zn) rhodochro-site vein (stage IV-a; No. 6 Shitaban vein, 50 mL) at the Matahachi deposit. Because many silver-bearing minerals such as pyrargyrite and polybasite occur around the electrum in the veins, it is assumed that the electrum was
precipitated from a solution which was nearly saturated with silver. Ag contents in electrum and FeS contents in sphalerite of (Pb)-(Zn) rhodochrosite vein (No. 6 Shitaban vein, 50 mL) in stage IV-a vary from 52.3 to 54.2 atomic percent and from 3.7 to 3.1 FeS mole percent, respectively. The estimated maximum values of sulfur fugacity and temperature in stage IV-a at the Matahachi deposit are 10⁻¹² atm at 258°C.

Electrum-acanthite-pyrite-sphalerite assemblage also occurs in the rhodochrosite vein (stage IV-b; No. 1 Shitaban vein, 50 mL) at the deposit. The Ag contents in electrum and FeS contents in sphalerite of rhodochrosite vein (No. 1 Shitaban vein, 50 mL) in stage IV-b are 68.2 atomic percent and 0.96 FeS mole percent, respectively. Estimated sulfur fugacities and temperatures in stages IV-b at the Matahachi deposit are 10⁻¹⁵ atm at 178°C (ISHIYAMA et al., 1987). The estimated sulfur fugacities and sulfur fugacities of stages IV-a and b show good agreement with the estimated temperature shown by MOTOMURA (1981) and MAEDA and ITO (1984).

These estimated temperatures based on the mineral assemblages and chemical compositions of sphalerite and electrum coincide with homogenization temperatures obtained from fluid inclusions. Temperature and sulfur fugacity decrease from stage III (Pb-Zn-(Mn) quartz vein) to stage IV-a (rhodochrosite vein) of the Matahachi deposit (Fig. 9). Change of formation temperatures corresponds to changing mineralization stages associated with multiple mineralization. Estimated formation temperatures ranging from 293°C to 178°C indicate that the Matahachi deposit was formed through multiple mineralization stages.

6. Summary

This paper presents mainly geological, mineralogical and fluid inclusion data showing characteristic features of manganese, lead, zinc and silver mineralization at the Matahachi deposit. The characteristic features of mineralization at the Matahachi deposit are summarized as follows:

1. Seven kinds of skarn and/or vein deposits, formed during Neogene manganese carbonate mineralization, are recognized in the Matahachi deposit; magnetite skarns, Pb-Zn-(Cu) quartz veins, Pb-Zn-(Mn) quartz veins, (Pb)-(Zn) rhodochrosite veins, rhodochrosite veins, massive rhodochrosite deposits and ferromanganese dolomite veins.

2. The sequence of Neogene mineralization at the Matahachi deposit is summarized as follows:
   - Stage I: formation of magnetite skarns,
   - Stage II: formation of Pb-Zn-(Cu) quartz veins,
   - Stage III: formation of Pb-Zn-(Mn) quartz veins,
   - Stage IV: formation of (Pb)-(Zn) rhodochrosite veins, rhodochrosite veins and massive rhodochrosite deposits,
   - Stage V: formation of ferromanganese dolomite veins.

3. Three kinds of vein deposits at the Matahachi deposit are Pb-Zn-(Mn) quartz veins, well-crustified banding (Pb)-(Zn) rhodochrosite veins and rhodochrosite veins. The first type consists of Pb-Zn ore (Type 3). The second one is made up of well-crustified banded rhodochrosite ore (Type 4A). And the last type is mainly composed of rhodochrosite ore (Type 4B).

4. These ore types can be also identified by ore grade. Three zones, the Pb-Zn, Intermediate and Rhodochrosite zones are distinguished from the northwestern part to southeastern part of the deposit. Pb-Zn-(Mn) quartz veins occur in the Pb-Zn zone of the deposit, while rhodochrosite veins tend to occur widely in the Rhodochrosite zone. Horizontal and vertical zonings could be formed by polyascendent mineralization of Pb-Zn-(Mn) quartz, (Pb)-(Zn) rhodochrosite and rhodochrosite veins.

5. Estimated temperatures of ore formation at the Matahachi deposit tend to decrease from earlier to later stages. Change of formation temperatures corresponds to changing mineralization stages associated with multiple mineralization.

Acknowledgments: The authors wish to ex-
press their sincere thanks and gratitude to Mrs. N. Hoashi and E. Kato of the Chugai Mining Co., LTD. and Mr. K. Adachi of the Mitsui Mineral Development Engineering Co., LTD. for rendering support during the course of field work and providing pertinent data. They also would like to acknowledge the continuing guidance and encouragement of Prof. S. Yui of Hokkaido University, K. Kurosawa of the Geological Survey of Hokkaido, Prof. Y. Ishikawa of Akita University and Prof. Emeritus, T. Matsukuma of Akita University. Dr. R. E. Derkey of the Washington State Department of Natural Resources is also gratefully acknowledged for critical reviewing the primary English manuscript.

References


南部北緑道上国鉱山又八鉱床のマンガン・鉛・亜鉛・銀鉱化作用

石山大三・松枝大治・中村 威

要旨：上国一帯鉱床地域の又八鉱床の磁鉱鉱スカルクとマンガン・鉛・亜鉛・銀鉱脈鉱床の形成に関連する中新世の鉱化作用が、個々の鉱体の性質共通と鉱脈の構造・鉱化ステージ・初生的帯状分布および生成環境に基づいてまとめられている。

鉱化作用の順序は、初期から末期にかけて、以下の 5つの鉱化ステージに区分される。Ⅰ期：磁鉱鉱スカルクの形成、Ⅱ期：Pb-Zn-(Cu)石英脈の形成、Ⅲ期：Pb-Zn-(Mn)石英脈の形成、Ⅳ期：(Pb)-(Zn)・H短鉱脈、V期：又八鉱床の鉱化薬封状からV期までの鉱化作用は、polyascendent zoning を示す鉱化作用と密接に関連している。

又八鉱床の3種類の主要鉱脈鉱床は、Pb-Zn-(Mn)石英脈・繊状(Pb)-(Zn)・亜鉛脈・綱状(Pb)・マンガン鉱脈・亜鉛脈・亜鉛マンガン鉱脈における Pb-Zn 鉱鉱石・繊状亜鉛マンガン鉱鉱石・亜鉛マンガン鉱鉱石の3種類の鉱石タイプは、鉱石品位に関連している。鉱石品位に基づけば、又八鉱床の北西から南東にかけてPb-Zn 帯・中間帯・亜鉛マンガン鉱帯の順に配列する。Pb-Zn-(Mn)石英脈は、又八鉱床の Pb-Zn 帯中に認められる傾向があり、一方、亜鉛マンガン鉱脈は、亜鉛マンガン鉱脈に広く分布する。水平および垂直的帯状分布は、Pb-Zn-(Mn)石英脈・(Pb)-(Zn)亜鉛マンガン鉱脈および亜鉛マンガン鉱脈の形成と関連する鉱液の繰り返し上昇によって起こる鉱化作用により形成された。

又八鉱床での鉱床生成温度は初期から末期にかけて徐々に低下する。鉱床生成温度の変化は、複数の鉱化作用に伴う鉱化ステージの進行と対応している。