Silver Content in Some Common Ore Minerals

Takashi NISHIYAMA* and Yoshihiko KUSAKABE*

Abstract: The silver abundances were determined for common sulfide minerals (374 samples)—pyrite, chalcopyrite, sphalerite, galena, arsenopyrite, pyrrhotite, bornite and tennantite—and manganese ore minerals (162 samples)—rhodochrosite, rhodonite, pyroxmangite, tephroite, spessartine, braunite and hausmannite—from varieties of ore deposits, with the atomic absorption analyzer and the electron microprobe X-ray analyzer. The following conclusions are reached.

(i) Tennantite from the kuroko deposits of the Shakanai mine and the Sangkaropi area, is highly argentiferous. Silver is concentrated in galena in the sedimentary deposits of the Broken Hill district, in the skarn deposits of the Kamioka Mine and in the Toyoha deposits of the vein type. On the other hand, silver is much abundant in chalcopyrite in the porphyry copper deposits of the Mamut Mine and in the Ohe deposits of the vein type. Bornite from the submarine exhalative-sedimentary deposits of the Mount Lyell mine is rich in silver, as compared with coexisting chalcopyrite and pyrite.

(ii) In sulfide ores, silver generally has an affinity for tennantite > galena > chalcopyrite > sphalerite, pyrite > pyrrhotite, arsenopyrite.

(iii) Silver is below the limit of detection in most of the manganese ore minerals, though present in small amounts in some of rhodochrosite from the vein type deposits of Neogene Tertiary. Manganese ore minerals from the bedded manganese ore deposits of Pretertiary are extremely poor in silver.

Introduction

Of the world’s total production of silver, about 75 percent is recovered as a by-product or coproduct of basemetal ores like copper, lead and zinc ores (HEYL et al., 1973). Silver in the most common sulfide minerals—chalcopyrite, sphalerite, galena and pyrite, generally is in the rage of o.n-o.oon percent. The order of decreasing silver content is commonly galena, chalcopyrite and sphalerite or pyrite. However the order varies occasionally due to the types or localities of the ore deposits. For instance, in some lead-zinc deposits of the southeast Missouri lead belt, silver is concentrated in sphalerite rather than galena (HALL and HEYL, 1968).

In this paper silver abundance were determined for the principal sulfide minerals collected from the twelve base metal ore deposits and the manganese ore minerals from vein-type deposits and bedded manganese deposits. Minor element contents in ore minerals have been investigated by the authors over a period of more than 15 years (TAKIMOTO et al., 1968; NISHIYAMA, 1974, 1983; NISHIYAMA et al., 1983a, b; KUSAKABE et al., 1983; KUSUDA et al., 1985). It is the purpose of this paper to assess the variability in the silver content of ore minerals.

Samples

The common sulfide minerals, pyrite, chalcopyrite, sphalerite, galena, arsenopyrite, pyrrhotite, bornite and tennantite were collected from different kinds of ore deposits for intercomparison of silver contents (Fig. 1). The manganese ore minerals, rhodochrosite, rhodonite, pyroxmangite, tephroite, spessartine, braunite and hausmannite were from the 41 bedded manganese deposits and the 6 veins that occur in Japan. Most of the specimens were collected by the authors. The geological
setting of the deposits is described as follows.

(1) **Sulfide minerals**

The Shakanai Mine, Ohdate city, Akita Prefecture.—The mine is one of the leading kuroko mines. The deposits are composed of several metallic orebodies associated with Miocene tuff, tuff-breccia, rhyolite, and mudstone. The metallic orebodies show a characteristic mineral zonation. Stratigraphically highest is the massive sphalerite-galena ores (black ores) which change downwards into the chalcopyrite-pyrite ores (yellow ores) and then into the pyrite ores. Underlying these stratiform metallic ores are the disseminated ores of mainly pyrite with or without chalcopyrite (siliceous ores). Metallic veins of pyrite and chalcopyrite, which are sometimes accompanied with sphalerite and galena, occur in the country rocks. Twenty-three hand specimens of sulfide ores were collected from the deposits as well as from hanging and footwall rocks.

The Sangkcaropi deposits, Sulawesi, Indonesia.—The ore deposits occur as massive, fissure and stockwork types in the rhyolitic rocks of Tertiary. The common sulfide minerals of the deposits are sphalerite, galena, pyrite, and chalcopyrite with lesser amounts of bornite, minerals of the tennantite-tetrahedrite series, arsenopyrite, chalcocite, and covellite. Geology and mineralogy of the deposits show resemblances to the kuroko ore deposits of Japan. Three orebodies, the Batu Marupa, the Rumanga and the Bilolo have been discovered in the area. Seven hand-specimens of sulfide ore were collected from the outcrops of the three orebodies.

The Shimokawa Mine, Shimokawa, Kamikawa county, Hokkaido.—The Shimokawa mine is one of the Besshi-type deposits (Kieslager-type deposits). The ore deposits occur in the Kamui group, which is composed mainly of claystone and sandstone with subordinate amount of basic lava and pyroclastics, quartzite and limestone of Mesozoic age whose total thickness reaches over 6,000 m (KANEHIRA and TATSUMI, 1970). Both footwall and hanging wall rocks of the ore deposits are basic lavas and clay slates, respectively. The ores are classified into two types, massive ore and banded ore. The massive ore is compact, and chiefly composed of chalcopyrite, pyrrhotite, and pyrite with minor sphalerite and magnetite, and quartz and chlorite as gangue minerals. The banded ore consists of pyrrhotite and pyrite with minor chalcopyrite and sphalerite in a gangue of quartz, feldspar, and sericite. Lesser amount of sulfide minerals such as pyrrhotite, is impregnated in host rocks. Forty handspecimens were collected from various representative parts of the deposits and host rocks.

The Mount Lyell Deposits, western Tasmania, Australia.—The Mount Lyell deposits and associated host rock alteration are genetically connected with the Cambrian Mount Read Volcanism. The mineralization shows features indicating hydrothermal emplacement as well as those suggesting a volcanic exhalative-syngenetic origin. The ores composed of the main ore minerals— notably pyrite, chalcopyrite and bornite, and some of the accessory minerals including galena, sphalerite, tennantite, molybdenite,
chalcopyrite, with the massive and banded pyritic ores towards the top of the sequence (Reid, 1975). Eight samples were collected from the Prince Lyell orebody, the Cape Horn orebody, the Crown Lyell orebody, the Lyell Tharsis orebody and the West Lyell (Blow) orebody.

The Mount Isa Mine, northwest Queensland, Australia. —The Mount Isa deposits lie within the Urquhart Shale of the Mount Isa Group of middle Proterozoic age which consist of mainly very fine grained dolomitic sediments. The copper orebodies are restricted within a zone, called “silica dolomite” which is recrystallized and deformed part of the Urquhart Shale. This silica dolomite is terminated at depth by a volcanic basement. The large number of copper orebodies are known at Mount Isa. The 1100 orebody, one of the leading copper orebodies, occurs in the central and southern portions of the mine over a known strike length of 2400 m and a maximum horizontal width of 370 m. Ten hand-specimens of sulfide ore were collected from various parts of the 1100 orebody between 18 and 19 level.

The Broken Hill Deposits, western New South Wales, Australia.—The Proterozoic ore deposit of the Broken Hill which has a continuous strike length of 7.3 km, vertical extent of 850 m, and horizontal width of 250 m was initially deposited at about 1,800 Ma and underwent a number of episodes of coeval deformation and high grade metamorphism at about 1,700 Ma (Johnson and Klingner, 1975; Plimer, 1984). The deposit consists of six separate ore bodies called from the stratigraphic base: B Lode, A Lode, Upper No. 1 Lens, Lower No. 1 Lens, No. 2 Lens, and No. 3 Lens. The major economic minerals at the Broken Hill are galena and sphalerite. Other common sulfides are pyrrhotite, chalcopyrite, arsenopyrite, tetrahedrite, dyscrasite and loellingite. Pyrite is rare. The ore deposit have been grouped into sediment-host stratiform deposit (Johnson and Klingner, 1975). Four samples were obtained from B Lode, 1 sample from A Lode, 3 samples from No. 3 Lens, and 2 samples from a store of ore specimens at the mine’s laboratory.

The Kamioka Mine, Kamioka, Yoshiki county, Gifu Prefecture.—The mine is the largest zinc and lead producer in Japan. The mining region consists of the Hida gneiss, granite, the Tetoji Group (Jurassic system) and later acid igneous rocks (including quartz porphyry). The Hida gneiss is intercalated with a large number of limestone beds, which were intruded by the Funatsu granitic rocks, and both are covered by the Tetoji Group (Imai, 1978). Three major skarn deposits which replaced folded crystalline limestone beds in the gneiss formation, are situated in the eastern side of the Takahara gorge, namely Tochibora, Maruyama and Mozumi from south to north. The ore deposits are composed of four types of kinds of Ag-Pb-Zn ores, called “mokuji ores”, “shiroji ores”, dissemination ores, and gold-silver ores. Samples of ore minerals were collected from the surface to −280 m level in the Tochibora ore deposits. Eleven hand-specimens were collected from “mokuji ores”, 3 hand-specimens from “shiroji ores”, 5 hand-specimens from dissemination ores, and 1 handspecimen from mineralized calcite veins.

The Chichibu Mine, Ohtaki, Chichibu county, Saitma Prefecture.—The ore deposits of the Chichibu mine occur in the Palaeozoic sediments which were intruded by the quartz diorite intrusives probably of late Miocene age and are genetically related to the intrusives. Several types of ore deposits, skarn-type to fissure-filling were worked in this mine. Nine handspecimens of sulfide ores were collected from the Daikoku orebody, one of the skarn-type orebodies.

The Toyoha Mine, Jozankei, Sapporo city, Hokkaido.—The mining region consists of pyroclastic formations of Miocene age with marine and epiclastic rocks including andesite, propylite, basalt dikes, rhyolite and quartz porphyry (El Shatoury, et al., 1975). The deposits of the mine are more than 40
hydrothermal lead-zinc veins which is supposed to be genetically related to the intrusion of quartz porphyry. Common sulfide minerals are galena, sphalerite, pyrite, and some silver minerals. Besides quartz, the ore carries considerable amount of manganese carbonates as gangue mineral. Eight samples were collected from the Daini-rebun vein, 9 samples from the Tajima vein, 6 samples from the Izumo vein, 4 samples from the Soyashitaban vein, and 10 samples from the Sorachi vein.

The Ohe Mine, Niki, Yoichi county, southwestern Hokkaido.—The ore deposits of the mine are epithermal polymetallic veins. The region consists of the Miocene pyroclastics and quartz diorite. Main ore minerals are rhodochrosite, galena, and sphalerite. Twenty-two specimens of sulfide minerals and manganese minerals were collected from the Yachio-Senzai vein.

The Ohtani Mine, Kameoka city, Kyoto Prefecture.—The ore deposits of the mine are the hypothermal tungsten veins. The region consists of the Permo-Carboniferous Tamba formation which is composed of sandstone, claystone, schist, and chert. The vein-forming minerals are quartz, scheelite, pyrite, cassiterite, pyrrhotite, chalcopyrite, sphalerite, arsenopyrite, cubanite, calcite, etc. Three handspecimens were collected from the Tsuudou vein and 1 handspecimen from the Zinzen vein.

The Mamut Mine, northwestern Saba, Malaysia.—The porphyry copper deposits of the mine is related to upper Miocene adamellite intrusion which has invaded sedimentary rocks and serpentinites. Copper mineralization is localized in the intrusion as well as in the host rocks. The main minerals is chalcopyrite and other sulfide minerals found in significant amount are pyrite and pyrrhotite. Minor concentration of sphalerite, galena, and molybdenite are present. Twenty-eight handspecimens of sulfide ores were collected from various representative parts of the deposits.

(2) Manganese minerals

Rhodochrosite is frequently found in the hydrothermal vein deposits which produce silver as main or by-product. Among these vein deposits, such ore deposits rich in rhodochrosite as Ohe, Inakuraishi, Jokoku etc. are regarded as vein type manganese ore deposit.

The authors have analyzed the concentration and distribution of the minor elements in rhodochrosite and other manganese minerals collected from the following hydrothermal vein, vein type and bedded type manganese ore deposits (KUSAKABE et al. 1983). In this paper, the concentration of silver in these manganese minerals is stated alone.

The Kuratani Mine, Kuratani, Kanazawa city, Ishikawa Prefecture.—The Kuratani ore deposit is hydrothermal vein in the rhyolite and rhyolitic tuff of the Tertiary. The principal ore minerals are sphalerite, galena, pyrite, chalcopyrite and rhodochrosite. The average tenor of ores has been estimated Au 8 g/t, Ag 120 g/t, Pb 2.5%, Zn 5%, but the mining operations have been ceased on and after 1942.

The Inakuraishi Mine, Shakotan Peninsula, Southwestern Hokkaido.—The Inakuraishi mine which is located at about 5 km northwest of the Ohe ore deposits, is epithermal vein deposits in the propylitized andesite and is the same type deposits as the Ohe mentioned before. The principal ore minerals are rhodochrosite, chalcopyrite, galena, sphalerite, tetrahedrite, pyrite and alabandite. The base metal sulfide minerals mentioned above, are less abundant than in the Ohe.

The Daikoku Manganese Ore Deposit in the Chichibu mine.—The Daikoku manganese ore deposit which is found in the upper part of the Daikoku skarn ore deposit, is vein type deposit in the crystalline limestone of the Palaeozoic strata. The principal ore mineral is rhodochrosite with small amount of sphalerite, galena and pyrite.

The Ryujima Mine, Nagano Prefecture.—The Ryujima ore deposits which are located at 15 km WSW of Matsumoto city, are rhodochrosite veins found in the Paleozoic strata and the porphyrite dyke which intruded into this Paleozoic formation. Rhodochrosite and katonahorite are principal ore mineral and vey
small amount of galena, sphalerite, tetra-
hedrite, pyrite and arsenopyrite coexist with these manganese carbonates.

The Futatsuya Mine, Kawai, Yoshiki county, Gifu Prefecture.—The Futatsuya ore deposits also are rhodochrosite veins found in the Hida gneiss and are accompanied by small amount of galena, sphalerite, chalcopyrite and pyrite.

Bedded Manganese Ore deposits: Many bedded manganese ore deposits which are considered to belong to the category of the volcanogenic-sedimentary manganese deposits, are present in the Paleozoic-Mesozoic formations and metamorphic rocks. Principal ore minerals in these manganese ore deposits are originally rhodochrosite, hausmannite and/or braunite. However, principal ore minerals have been converted into manganese silicates such as rhodonite, pyroxmangite, tephroite and spessartine in the ore deposits which have undergone the alteration owing to contact metamorphism or regional metamorphism.

Among the many kinds of mineral samples collected from the bedded manganese ore deposits which distribute in the areas extending from Ashio mountainland to Kyushu, 98 samples have been analyzed.

Microanalysis

Sample separation — Ore minerals were carefully separated using techniques applicable for the physical and chemical properties of the mineral. Mineral separation techniques included heavy liquids, isodynamic separator and elutriating tube, selecting leaching and hand picking. The separated specimens were checked for their impurities by X-ray diffraction method. Judging from the sensitivity of X-ray diffraction analysis, the maximum amount of opaque mineral impurities is estimated to be 1 percent. Based on the detection limit of measurement by atomic absorption analysis, main ore mineral contamination like pyrite, chalcopyrite, sphalerite, and pyrrhotite contamination except galena contamination, is not important source of silver. In the case of a much low abundance of silver, galena contamination may influence analytical values.

Atomic absorption analysis—Each separated specimen was treated with aqua regia. The dissolved specimen was once evaporated to dryness and then regulated to a concentration of 0.02 g of specimen per milliliter with 1N HCl. Atomic absorption analyses were performed on these solution for silver, employing a Jarrel-Ash AA-8500 atomic absorption spectroscopy.

Electron microprobe X-ray analysis—The minerals of the tennantite-tetrahedrite series were analyzed by means of the electron microprobe X-ray analyzer using polished sections. The pure metal of silver was used as a standard. Measured intensities were corrected for atomic number effect, absorption effect, and for the fluorescence effect due to characteristic X-ray by using the correction scheme of Shimazu Seisakusho Ltd.

The Silver Content in Individual Mineral Species

The analytical data of silver in 8 species of sulfide minerals and 7 species of manganese minerals, have been summarized in Table 1 and Table 2, or Fig. 2 and Fig. 3. The tables given indicate the number of specimens, the range of silver content, the mean value of silver content, and the name of ore deposits. The analytical results in each mineral are as follows.

(1) Sulfide mineral

Pyrite: Silver contents of 139 pyrite separates collected from the 11 ore deposits except for the Broken Hill ore deposits range from below the limit of detection to 530 ppm. The amounts of silver are very variable and in general, the silver level of pyrite is low. The atomic absorption detection limit in an ordinary state is a few parts per million. In the most stable conditions it is available to detect 2 ppm of silver. With respect to average of silver content in the mineral, pyrites from the Kamioka mine, the Sangkaropi deposits, the Toyoha mine and the Ohe mine are relatively rich in silver, while those from the Shimokawa mine, the Mamut mine, the Mount Isa mine are poor. The averages of silver content in pyrite from the Kamioka mine and the
Sangkaropi mine are more ten times abundant than those from the Shimokawa mine.

Chalcopyrite: Silver contents in 43 chalcopyrite separates from the 10 ore deposits are in the range of 13-640 ppm. Some chalcopyrites from the Ohe mine and the Kamioka mine show comparatively high concentrations of silver, though in most cases the values less than 100 ppm are observed. It is remarkable that there is much the difference in silver analyses of the mineral among the 10 ore deposits. The number of analyses in some ore deposits however is too small to discuss details on silver concentrates in the mineral.

Sphalerite: The amounts of silver in 88 sphalerite separates collected from 7 ore deposits are very variable, ranging from 5 ppm to 750 ppm, but silver averages in the mineral from each ore deposits lie in short range of 180-53 ppm.

Galena: Silver contents in 59 galena separates from 6 ore deposits were detected. Galenas, which contain 65 ppm to 1.1 percent of silver is highly argentiferous. Silver in galenas from the Kamioka deposits, the Toyohashi deposits and the Broken Hill deposits is much abundant. Because the galenas from the Kamioka mine with the highest silver average show high bismuth, silver is estimated to be present as matildite (AgBiS₂) in solid solution in the galena.

Arsenopyrite: Six specimens of arsenopyrite
<table>
<thead>
<tr>
<th>Pyrite</th>
<th>Chalcopyrite</th>
<th>Sphalerite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shakakai</td>
<td>Hangkeapi</td>
<td>Shimokawa</td>
</tr>
<tr>
<td>Mt. Lyell</td>
<td>Mt. Isa</td>
<td>Broken hill</td>
</tr>
<tr>
<td>Kamioka</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chichibu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyoha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ohtani</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mamut</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2 Diagram showing ranges and averages of silver content in some sulfide minerals.
Fig. 2 Continued
Silver Content in Some Common Ore Minerals

**Fig. 2 Continued**

**Bornite**

Shakanai  
Sangkaropi  
Shimokawa  
Mt. Lyell  
Mt. Isa  
Broken Hill  
Kamioka  
Chichibu  
Toyoha  
Ohe  
Ohtani  
Mamut

**Tennantite**

Shakanai  
Sangkaropi  
Shimokawa  
Mt. Lyell  
Mt. Isa  
Broken Hill  
Kamioka  
Chichibu  
Toyoha  
Ohe  
Ohtani  
Mamut

○: one analytical value, ▲: 2-4 analytical values, ◆: 5-7 analytical values, □: 8-10 analytical values, ♦: more than 11 analytical values, ▲: average

Separated from the Kamioka mine was available for silver analysis. Silver is present in the range of 280-110 ppm and the average is 110 ppm. The silver content of arsenopyrite is about the same as that for pyrite in the Kamioka mine.

Pyrrhotite: Thirty-two pyrrhotite separates from the Shimokawa deposits, the Broken Hill deposits, and the Ohtani deposits range in silver content from below the limit of detection to 40 ppm. Pyrrhotite has much lesser abundance of silver than galena, chalcopyrite, and sphalerite.

Bornite: Bornite is one of the minor constituents. Concentrations of silver in 3 bornites are in the range of 80-360 ppm. Two bornites from the Mount Lyell deposits show relatively high silver contents.

Tennantite: The silver abundances were determined for 3 tennantites from the Shakanai mine and the Sangkaropi deposits. The silver contents (1.4-2.2%) obtained for the specimens are found to be the highest in all the sulfide specimens studied in the present work.
(2) Manganese ore mineral
Rhodochrosite: The silver contents in 90 rhodochrosites were determined. The silver contents of rhodochrosite is very low, ranging from below the limit of detection to 360 ppm. Silver was not detected in all samples collected from the bedded manganese deposits. In the case of the Ohe mine the values less than 360 ppm.

Fig. 3 Diagram showing ranges and averages of silver content in some manganese minerals.
Table 3 Comparison of the silver contents in some sulfide minerals.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Pyrite</th>
<th>Chalcopyrite</th>
<th>Sphalerite</th>
<th>Galena</th>
<th>Arsenopyrite</th>
<th>Pyrrhotite</th>
<th>Bornite</th>
<th>Tennantite</th>
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<tr>
<td></td>
<td>ppm</td>
<td>ppm</td>
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<td>(1.1)</td>
<td>13</td>
<td>(2.2)</td>
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<td>23</td>
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<td>Mamut</td>
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</table>

Table 3: Comparison of the silver contents in some sulfide minerals.

ppm are observed and the average is 41 ppm. Silver is present in small amounts in the mineral from the Ryujiama deposits and the Futatsuya deposits.

Silver is at or below the detection limit in other manganese ore minerals including rhodonite, pyroxmangite, tephroite, spessartine, braunite and hausmannite separated from the ores of the bedded manganese deposits.

Discussion

(1) The modes of occurrence of silver in individual ore deposits

Argentiferous minerals in each ore deposits are as follows. Tennantite from the kuroko deposits of the Shakanai mine and the Sangkaropi area, is highly argentiferous. Silver is concentrated in galena in the sedimentary deposits of Broken Hill district, in the skarn deposits of Kamioka mine and in the Toyoha deposits of the vein type. On the other hand, silver is much abundant in chalcopyrite in the porphyry copper deposits of the Mamut mine and in the Ohe deposits of the vein type. Bornite from the submarine exhalative-sedimentary deposits of the Mount Lyell mine is rich in silver, as compared with coexisting chalcopyrite and pyrite. It however is remarkable that all of mineral species separated from argentiferous ore deposits never show high concentrations of silver. For instance, galena, chalcopyrite and pyrite from the argentiferous Kamioka ore deposits have much higher abundance of silver than those from the other ore deposits, but the silver contents in sphalerites from the ore deposits are very low. Moreover in the case of the Broken Hill ore deposits, galena is argentiferous, while sphalerite and chalcopyrite don’t show high concentrations of silver.

With respect to the difference in silver distribution between galena and sphalerite, all of galenas are enriched in silver compared with coexisting sphalerites in the present work. The ores of the Kamioka deposits and the Broken Hill deposits are characterized by strong fractionation of silver between galena and sphalerite. That in the kuroko deposits is not strong. It has been described by Hall and Heyl (1968) that silver is more abundant in sphalerite than in galena in the Upper Mississippi Valley district. The Broken Hill deposits is originally one of sedimentary deposits, and after precipitation, underwent high grade metamorphism. Studies of isotopic temperature in coexisting sphalerite and galena from the Kamioka deposits by Kiyosu and Nakai (1977) indicate a temperature range from 350°C to 400°C. Kajiwara (1971) found that the kuroko ores had precipitated at around 250°C based on the measurement of isotope temperature for different mineral pairs. The Upper Mississippi Valley district contains epigenetic, low-temperature, hydrothermal deposits of galena, sphalerite, pyrite, etc. It appears that the silver distribution between galena and sphalerite may reflect the temperature of formation. The ore deposits of the Illinois-Kentucky fluorite district, however, is characterized by strong fractionation of silver between galena and sphalerite, though the temperature of formation of the ore deposits is estimated to be about 150°C.
(Hall and Heyl, 1968). The further investigation in more detail is necessary.

(2) The behavior of silver in some sulfide minerals

When silver averages in pyrite of individual ore deposits are substituted for 1 to disclose the silver distribution among sulfide minerals, silver averages in the other sulfide minerals are given in Table 3. In the case of the Broken Hill deposits, the silver average in chalcopyrite are substituted for 2 because of a shortage of the silver contents in pyrite. The fractionation of silver between chalcopyrite and pyrite is in the range of 1.2-6.0 except for that of the Sangkaropi deposits in which number of analysis is only one and the silver content is extremely low. The fractionations in the Mamut deposits and the Ohe deposits are higher than those in other ore deposits. The ratios of sphalerite to pyrite range from 0.4 to 1.7. The silver content in sphalerite is almost the same as that in pyrite. The ratios of galena and pyrite are very variable, ranging from 1.6 to 26.6. Silver commonly is greatly enriched in galena. The ratios of pyrrhotite and pyrite 0.3-1.3. Pyrrhotite is slightly lower in silver than pyrite. The ratios of tennantite and pyrite range from 142 to 437. High ratios are characteristic of tennantite.

As a result of the data mentioned above, in sulfide ores, silver generally has an affinity for tennantite > galena > chalcopyrite > sphalerite, pyrite > pyrrhotite, arsenopyrite.

(3) Silver abundances in manganese ore minerals

Silver were at or below the limit of detection in most of the manganese ore minerals, though small amounts of silver were present in some of the rhodochoresite from the vein type deposits of Neogene Tertiary. Manganese ore minerals from the bedded manganese ore deposits of Pretertiary were extremely poor in silver.

References


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主要鉱石鉱物中の銀の含有量について

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要旨：銀の世界生産量の多くは鉱，亜鉱あるいは銅鉱床からの副産物として生産され，銅鉱床からの産額よりも多い。副産物としての銀は銅鉱物の形で産出するが，鉛鉱物，亜鉱鉱物，銅鉱物などに散在元素として含まれるものがある。そこで，主要鉱石鉱物の黄鉄鉱（139個），黄銅鉱（43個），方鉛鉱（88個），方鉛鉱（59個），硫化鉄鉱（6個），硫化鉄鉱（32個），黒鉱鉱（3個），四面錫鉱（4個）およびマンガン鉱物の菱マンガン鉱（90個），バハード鉱（27個），バイロクサマンジャイト（20個），テフロ石（6個），マンガンザクロ鉱（3個），ブラウン鉱（10個），ハウスマン鉱（6個）について原子吸光分光分析法ならびにEPMA法により銀を分析し，各鉱石鉱物中の銀の分布状況を検討した。その結果，次のようことが明らかになった。

(i) 鉱床によって銀を多く含む鉱物は異なっており，分析した8種の硫化鉱物に限ると，釧蝦内鉱床，Sangkaropi鉱床では四面錫鉱に，Broken Hill鉱床，神岡鉱床，豊羽鉱床では方鉛鉱，Mount Lyell鉱床では硫銅鉱に，Mamut鉱床，大江鉱床では黄銅鉱に多くの銀が含まれている。

(ii) 一般に，四面錫鉱＞方鉛鉱＞黒鉱鉱＞亜鉛鉱，黄銅鉱＞硫化鉱鉱，硫化鉱鉱の順に含銀量は少なくななる。しかし鉱床による含銀量の変動は大きく，一義的に決めることはできない。とくに上記の四面錫鉱および方鉛鉱を除く，黄銅鉱以下の鉱物では鉱床により含銀量比はさまざまなパターンをとる。

(iii) マンガン鉱物中の銀の量は極めて少なく，第三紀の銅鉱型鉱床からの菱マンガン鉱の一部に銀が検出される程度である。層状マンガン鉱床からのマンガン鉱物には銀はほとんど含まれていない。