Black Ore Chimney from the Hanaoka Kuroko Deposits, Japan

Hidehiko Shimazaki* and Ei Horikoshi**

Abstract: Studied are elliptic plates sliced from a columnar black ore mass, collected from the eastern wall of the Tsutsumizawa open pit of the Hanaoka mine in 1960. The plates consist of barite, sphalerite and galena, with small amounts of colloform pyrite and euhedral bipyramidal quartz. Concentric mineral zoning of the plates with fine-grained barite rim and porous center with a hole, suggests that the original columnar mass is a chimney from which Kuroko-forming hydrothermal solution vented. Sulfur isotope ratios of sulfide sulfur and sulfate sulfur are consistent with those reported for typical Kuroko deposits. The specimens confirm the occurrence of chimney structure at least at some parts of Kuroko formation, like those observed at the present active venting sites on the sea floor.

Introduction

Since the discovery of hydrothermal sulfide mounds at 21°N East Pacific Rise by CYANA (Francheteau et al., 1979), and the following observation of active vents jetting out hot waters with sulfide chimneys by ALVIN (RISE Project Group, 1980), a large number of data have been accumulated on hydrothermal activities and associated sulfide deposits along mid-oceanic ridges (e.g. Hekinian et al., 1980; Haymon and Kastner, 1981; Styr et al., 1981; Boulegue et al., 1984; Koski et al., 1984; Zierenberg et al., 1984; Rona et al., 1986; Barrett and Jambor, 1988). Besides, not only at the sites along mid-oceanic ridges, similar hydrothermal activities have been reported at various geologic sites such as back-arc basin and trough (e.g. Both et al., 1986; Craig et al., 1987; Uyeda, 1987; Halback et al., 1989; Kusakabe et al., 1990). Genetical relations between such hydrothermal activities and various types of massive sulfide deposits of volcanic affinity, have also attracted the notice of many economic geologists such as Scott (1982), Goldfarb et al. (1983), Oudin and Constantiou (1984), Von Damm et al. (1985), and Hekinian and Fouquet (1985) among others.

The Kuroko deposits in Japan are famous as one of conspicuous types of massive sulfide deposits. They are associated with submarine felsic volcanisms occurred in the back-arc basin of the Japanese island arc at the time of middle Miocene. Numerous and detailed geological, geochemical and mineralogical studies have been carried out on the deposits, and as comprehensive and easily accessible references could be cited the following three issues edited by Ishihara (1974), Horikoshi (1983), and Ohmoto and Skinner (1983).

Although theoretical calculations on the behavior of hydrothermal systems were repeatedly attempted (Cathles, 1983; Pisutha-Arnold and Ohmoto, 1983) since a classical work by Sato (1972), only few natural evidence has been reported which show the behavior of hydrothermal solutions near the sea floor at the site of Kuroko deposition. In the present paper, a chimney-shaped black ore from the Hanaoka Kuroko deposits will be described. The specimen confirms the presence of vents jetting hot solutions at least at some parts of the deposits during the Kuroko mineralization.

Outline of Geology and Ore Deposits

The Hanaoka mine is situated, as well as other typical Kuroko ore deposits in Japan, in the Miocene submarine volcanic region known
as the "Green Tuff" region, and is located several kilometers north of Ohdate City in the Hokuroku basin, northeastern Japan. The geology of the mine has been studied in detail since old time (e.g. HORIKOSHI, 1951-52; HORIKOSHI, 1966; SUGA and TAKAHASHI, 1970). A brief summary of the outline of the geology is given by TANIMURA et al. (1983).

The mining area consists of lava domes and tuff breccias of rhyolite to dacite in composition, with several thin mudstone beds. Basaltic lava flows are also intercalated. Total thickness of these volcanic sedimentary rocks of middle Miocene age exceeds several hundreds meters. Intrusions of massive rhyolite and dolerite sheets are observed at many places.

More than ten deposits, large and small, have been exploited in the Hanaoka mine. They include black ore (Zn-Pb), yellow ore (Cu-pyrite), pyritic ore and gypsum ore types. The occurrence of large-scale gypsum ore deposits is one of the characteristics of the mine. The Tsutsumizawa deposit, from which the black ore chimney described in the present paper was found, is one of the typical gypsum deposits, and its upper part was exploited by the open pit mining. The size of the Tsutsumizawa deposit reaches about 250 m × 150 m in plan, and 150 m in depth. Although these gypsum deposits in the mine usually contain little amounts of sulfide minerals, the Tsutsumizawa deposit associates considerable copper mineralization in the upper part (Ito, 1963).

Description of Specimens

Two black ore specimens are included in the collection of Department of Petrology and Mineral Deposits, the University Museum, the University of Tokyo. They are elliptic plates...
Table 1 Characteristics of zones (1) to (4) in the chimney

<table>
<thead>
<tr>
<th>Zone</th>
<th>Color and Texture</th>
<th>Thickness</th>
<th>Grain Size of Barite</th>
<th>Main Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Grey, fine-grained</td>
<td>1 mm</td>
<td>0.0 n-0.1 mm</td>
<td>Barite</td>
</tr>
<tr>
<td>(2)</td>
<td>Black, massive</td>
<td>0-2 cm</td>
<td>0.0 n-0.6 mm</td>
<td>Barite, sphalerite, galena (relatively sulfide-rich)</td>
</tr>
<tr>
<td>(3)</td>
<td>Dark grey, slightly porous</td>
<td>0.5-7 cm</td>
<td>ditto.</td>
<td>ditto. (relatively sulfide-poor)</td>
</tr>
<tr>
<td>(4)</td>
<td>Dark grey, porous with a hole</td>
<td>0-2.5 cm</td>
<td>0.6-1 mm</td>
<td>Barite, galena</td>
</tr>
</tbody>
</table>

about one centimeter thick, sliced from a log-like, columnar black ore mass. The original columnar ore was taken from the eastern wall of the Tsutsumizawa open pit of the Hanaoka mine in 1960. It was found to be lying down in powdery pyritic ore zone of the Tsutsumizawa deposit, as a log of about 40 centimeters length. Several small log-like ores were scattered at the same place. The side surface of the columnar ore is not smooth, and wrinkles are present perpendicular to the direction of the column. Clayey material was observed sticking on the wrinkled surface. Soon after the finding, more than several plates were sliced off perpendicular to the column, and sent to several university laboratories by one of the present authors (E.H.). Two of them have been kept by late Emeritus Professor Takeo Watanabe, and are now included in the collection above mentioned.

A photograph of one of the plates with a sketch of the reverse side is given in Fig. 1. The specimen is registered as TUD 1797. The longer diameter of the elliptic plate reaches about 19.5 cm. As clearly seen in the figure, the original columnar mass consisted of two, large and small, columns with a porous part and a hole at the each center. As described later, concentric zonations are observed from the center to margin in these two ellipses contacting with each other. Marked similarity of such form and structure to those of edifices recently found at the sites of hydrothermal venting on the sea floor (e.g. RISE Project Group, 1980; Haymon and Kastner, 1981; Haymon, 1983; Graham et al., 1988; Kusakabe et al., 1990) indicates without doubt that the original columnar mass was two closely-standing chimneys from which Kuroko-forming hydrothermal solution vented.

During or after such venting activity, the chimney fell down and has been brought by some reasons to the powdery pyritic ore zone. The distance of transportation is probably not far, because several chimneys were found at the same place. As will be mentioned later, some previous papers reported the occurrence of ores with chimney-like structure from Kuroko deposits. As far as the present authors know, however, this is the first report of the study on chimney structure in Kuroko deposits from the viewpoint of hydrothermal venting. Fragments of chimney and mound structure have already been recognized in some massive sulfide deposits, such as Carboniferous Silvermines ore bodies in central Ireland (Boycz et al., 1983) and late Cretaceous Cyprus sulfide deposits (Oudin and Constantinou, 1984).

As shown in Fig. 1, several chips were taken from the plate, and analyzed in the present study. Another plate shows almost same zonal structure, but the knob part representing the small neighboring chimney has been broken and lost. This plate is also elliptic in shape, and slightly larger than the plate described above, probably representing the lower part of the original chimneys. This specimen was used only for comparison.

Mineralogy and Chemistry

The specimen TUD 1797 consists of two ellipses which have almost same structure. As shown in the sketch in Fig. 1, the following four zones (1)-(4) are recognized by the naked eye in each ellipse, from the rim to center; that
is, (1) greyish, fine-grained barite zone of about one millimeter thickness, (2) black, massive zone of about zero to two centimeters thickness, (3) dark greyish, a little porous zone, and (4) central rough, porous zone with a hole. A brief description of each zone will be given as follows, and summarized in Table 1.

Zone (1) consists mainly of platy crystals of barite (Fig. 2A). This zone rims the chimney almost continuously with relatively constant width of about one millimeter. Zone (2) consists mainly of barite, sphalerite and galena (Fig. 2B). Grain size of barite is slightly larger than that of zone (1). This zone is relatively rich in sulfides. Zone (3) is not much different from zone (2) in mineralogical composition, but is relatively porous and barite-rich. This zone composes the main part of the chimneys.
Table 2 Results of modal, sulfur isotope and electron microprobe analyses.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume Ratio</th>
<th>Weight Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barite</td>
<td>49%</td>
<td>66%</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Galena</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Pyrite</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Quartz</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>(Space)</td>
<td>25</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Sulfur Isotope Analysis

δ³⁴S (CDT)

- Sulfides (Bulk): +2.4‰
- Barite: +20.7‰

Electron Microprobe Analysis of Sphalerites

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Zn</th>
<th>Fe</th>
<th>Mn</th>
<th>Cd</th>
<th>Cu</th>
<th>S</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparent</td>
<td>67.5%</td>
<td>0.1</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
<td>33.0</td>
<td>100.9</td>
</tr>
<tr>
<td>Opaque</td>
<td>67.3</td>
<td>0.4</td>
<td>0.0</td>
<td>0.3</td>
<td>0.0</td>
<td>32.6</td>
<td>100.6</td>
</tr>
</tbody>
</table>

Zone (4) is a rough and brittle part with a hole, and is located nearly at the center of zone (3). In the case of the smaller ellipse, however, the position of zone (4) is much biased from the center. The size of barite crystals reaches to several tenth to one millimeter in this zone (Fig. 2D). Sphalerite is rather rare, and galena is relatively common in this zone (Fig. 2D).

In each zone, small amounts of colloform pyrite and euhedral quartz are recognized. Fig. 2C shows a part relatively rich in colloform pyrite in zone (3). Bipyramidal prisms of quartz euhedral crystal of a few tens microns length (Fig. 2G) are scattered in all zones (Figs. 2A-2D). Barite always occurs as platy, euhedral crystal of various sizes (Figs. 2E and 2F).

An approximate modal analysis was carried out by counting with grids on enlarged photomicrographic prints of polished sections from each zone. The result is given in Table 2. The most abundant mineral in volume and weight is barite. Volume of open space reaches to a quarter of the total volume.

Sulfur isotopic composition of bulk sulfides is determined as +2.4‰ (CDT), and that of barite as +20.7‰ (Table 2), after the method by Yanagisawa and Sakai (1983). Under the microscope with polished thin section, sphalerite is usually transparent and colorless, but some parts are opaque. Analytical results of transparent and opaque sphalerites with electron microprobe are shown in Table 2, and a little higher iron content is recognized in the opaque part. Although typical chalcopyrite desease texture (Barton, 1978) is hardly observed, the presence of very tiny inclusions is inferred for the reason of opacity as discussed by Koski et al. (1984) on the material from the Juan de Fuca Ridge.

Discussion

The occurrence of “ring structure” has been reported from some Kuroko deposits (e.g. “concentric breccia-like ore” by Hayashi, 1961; “tiger eye structure” by Narita et al., 1977). In these papers, however, only little information is given as to whether they had really been chimneys or not. Instead most of them seem to be rounded ball-like ores formed under unconsolidated state as suggested by Sugawara et al. (1982).

“Pipe-like structure” is also reported in some previous works (e.g. Kuromda et al., 1977), but most of them were probably conduits in pre-existing ores, through which later-stage solutions have passed. Kuromda et al. (1977), however, found small pipe-like ores consisting of pyrite or barite in clayey mudstone near the Matsuki A deposit. The photograph (Kuromda et al., 1977; Photo No. 11) and idealized sketch of the occurrence (ibid. Fig. 8-b), indicate that those pipes have presumably been small chimneys discharging solutions in the marginal areas of Kuroko-forming hydrothermal activity. Hirabayashi (1911) and Kinoshtita (1944) once reported the occurrence of rod-shaped ores in mudstone and siliceous ore at the Yamagata-Yoshino and Kano mines. Although both authors thought the ores as pseudomorphs of tree rods, the sketch of the ores given by Hirabayashi (1911; Fig. 25) suggests that the ores are probably parts of small chimneys. Matsukuma (1989) also published photo-
graphs of pipe-shaped black ores from the Motoyama and Uchinotai-West deposits of the Kosaka mine. In addition to such examples in the previous reports, the specimen described in the present paper confirms the occurrence of chimney structure in Kuroko formation.

According to the study of active black and white smokers along the East Pacific Rise at 21°N (e.g. Haymon and Kastner, 1981; Styrt et al., 1981), the chimneys are mainly composed of anhydrite, chalcopyrite, pyrite, sphalerite-wurtzite, marcasite, amorphous silica and sulfur. The chimneys jetting solutions less than 300°C are poor in copper, and instead rich in zinc sulfide. The specimen of the present study is lack in chalcopyrite, and rich in barite as shown above. These features are rather similar to those of chimneys of relatively lower temperatures, like white smokers. As to mineralogical composition, the most similar active vent material ever reported to the present specimen, is taken from the Mariana back-arc basin spreading axis at 18°N (Kusakabe et al., 1990), although the material includes some amounts of chalcopyrite. The temperatures of clear fluids venting at the sampling site of the Mariana basin, are reported as up to 287°C (Craig et al., 1987). Some mineralogical features of the specimen of the present study were presumably obtained during diagenesis. For example, anhydrite is not observed in the present specimen, but it might have been dissolved and removed by pore waters, even if any in the original chimney.

The occurrence of euhedral, bipyramidal quartz crystals has been reported from black ore of the Uwamuki No. 4 deposit by Urabe (1978), and taken with the relations to barite and sulfides as evidence that the black ore was formed near the orifice of the hydrothermal solution by mixing with cold seawater. The occurrence of quartz in the present specimen would give support to his considerations. As far as the present authors know, however, there are no papers reporting the occurrence of euhedral quartz crystals in active or inactive chimneys on the present sea floor. Bipyramidal quartz crystals were possibly formed from amorphous silica during diagenesis.

Compared with isotopic data for Kuroko deposits compiled by Sasaki (1974), isotopic composition of sulfide sulfur, +2.4‰, is normal as the mixture of sphalerite and galena from Kuroko deposits. Sulfur isotopic composition of barite, +20.7‰, is very close to that of seawater sulfate indicating that the source of sulfate was seawater, but is slightly depleted in 34S when compared with those of Kuroko barites (Sasaki, 1974).

All mineralogical and chemical characteristics of the present chimney specimen confirm that the solution having vented from the studied chimney was probably a part of solutions responsible for the formation of usual black ores in Kuroko deposits. Many previous investigators proposed the hypothesis that Kuroko deposits are formed by hydrothermal solutions discharged to the sea floor (e.g. Horikoshi, 1969). Then it is not strange to imagine the occurrence of many chimneys on sulfide mounds at the site of Kuroko formation like those observed by Alvin on the East Pacific Rise at 21°N (RISE Project Group, 1980).

Sato (1972) has once considered the behavior of hydrothermal solutions in seawater when they are welling up onto the sea floor, based on changes in density and temperature by mixing of two different solutions. According to his model, the solution with lower density than that of seawater will float up immediately after reaching at the sea floor, and will be diluted infinitely by seawater. Thus, he concluded that the minerals crystallized out from the solution is dispersed and slowly settled down over a wide area. In nature, however, salinity of hot solutions jetting out from black and white smokers is very close to that of seawater (RISE Project Group, 1980); that is, the density of such solutions making chimney structure is much lower than that of seawater. Then cooling of solutions welling up onto the sea floor and crystallization of minerals from them seem to occur much more rapidly than Sato (1972) considered, although it may partly depend on the rate of outflow.

Fragmental and clastic textures are frequently observed in most Kuroko deposits, and are
believed to represent the brecciation and redeposition of ores, probably caused by slumping or sliding of ores due to some geologic events such as doming of, and steam explosion near, the mineralized area during and after the mineralization. However, if the formation of chimney and mound structures are common at the site of Kuroko mineralization, fragmental and clastic textures are undoubtedly essential features of Kuroko ores just like those observed at the present active venting sites. From this viewpoint, it is necessary in future works to compare the characteristics of fragmental ores in Kuroko deposits with those of present-day hydrothermal sulfide deposits on the sea floor, taking into consideration the effect of diag enesis and ageing.

Acknowledgments: Late Emeritus Professor Takeo WATANABE of the University of Tokyo had noticed long ago the significance of the specimens studied here, and kept them in his ore collection for long time. He encouraged the present writers to study the specimens. This paper is devoted to him to memorialize his excellent intuition as a geoscientist.

References


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花岡黒鉱鉱床からの黒鉱質チムニー

島崎 英彦・堀 聡

要旨：1960年に花岡鉱山焼沢鉱床露天掘りにより採取された黒鉱質で丸太状の形態をもつ鉱石について、これか
ら切り出された二枚の稜円状スライス標本を基に検討し
た。鉱石は重晶石・閃亜鉛鉱・方鉛鉱、および少量のコ
ロフォーム黄鉱・塵鉱自形石英結晶からなっている。
スライス標本の稜円状の形態および同心円状の内部構
造、すなわち細粒重晶石によるリムの存在や中心付近の
多孔質部分と穴の存在、と現世の海底において形成され
ているチムニーを比較検討した結果、この丸太状の鉱
石は黒鉱を沈殿しつつあった鉱液が海底面上に湧出して
形成してチムニーであると判断された。硫黄同位体比
は、硫化物・硫酸塩共に従来黒鉱鉱床から報告されてい
る平均的な値と極めて近い。この標本は、現世の海底に
おける熱水活動の場と同様に、黒鉱鉱床形成の場におい
ても、少なくともその一部にはチムニーの形成があった
ことを示している。