Fossil Foraminifera Replaced by Sphalerite in the Shakanai Kuroko Deposits, Hokuroku District, Japan

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Abstract: A fine-grained, compact kuroko ore regarded as one of the most primitive kuroko deposits, occurs in the Shakanai Mine of Hokuroku district, Japan. From this type of ore, fossil foraminifera replaced by sphalerite have been found in an uncovered, doubly-polished thin section. Because of observation only in sectional forms of the foraminifera, it is difficult to decide the species names for most of the specimens, but some well-preserved ones can be identified with regard to the genus level. They include the genera of planktonic and calcareous foraminifera such as Globorotalia, Globobquadrina and Globigerina (or Globigerinoides). Among them an important Miocene index fossil, Globorotalia cf. peripheroronda, has been recognized.

The fossil foraminifera replaced by sphalerite exist in fine-grained matrix of yellow ore mainly composed of chalcopyrite. In the fossils, two types of sphalerite can be recognized under a microscope; one is transparent, colorless sphalerite replacing the test part of the fossils, and another is opaque one filling their chambers. Electron probe X-ray microanalyses have revealed that the opaque nature of the chamber sphalerite can be attributed to small inclusions of chalcopyrite of some six weight percent.

The fossil-bearing kuroko deposit is stratiform and intercalated between altered dacite pyroclastics and mudstones. It shows many features characteristic of slumping and sliding, such as fragmentation of ores and intraformational soft-rock-deformation. It is assumed that the fossil foraminifera which were first replaced by sphalerite after their settling down onto the bottom of the ore-depositing basin, would have been physically mixed with the chalcopyrite-rich ore in an unconsolidated condition by slumping or sliding.

1. Introduction

Mineralized fossils have been reported from many types of sedimentary rocks of various geologic ages throughout the world. The minerals which replaced the solid organic part of the fossils or precipitated in the open space of them are pyrite, chalcopyrite, tetrahedrite, arsenopyrite, hematite and manganese oxides, but pyrite is the most common case (AMSTUTZ, 1964; AMSTUTZ and BUBENICEK, 1967; NUSSMANN, 1975; KUYERS and DENYER, 1979; CLARK II and LUTZ, 1980; HUDSON, 1982). Especially, pyritized ammonite fossils are attractive to collectors for their beauty. Pelecypoda, gastropoda, brachiopoda, corals, foraminifera, radiolarians and plants have been also reported as mineralized ones. In these examples, most of mineralized fossils occur in mudstones, fine tuff, coal, chert, limestones, evaporites and banded iron ores.

From the Hokuroku district of Japan, pyritized arenaceous foraminifera are known in argillaceous mudstones included in the banded fine-grained yellow ores of the Matsuki Mine (KURODA et al., 1977; KURODA, 1978), and foraminifera partly replaced by chalcopyrite were found in ferruginous chert above kuroko ores of the Kosaka Mine (ISHIKAWA, 1964). However, the mineralized fossils directly embedded in the ores have not yet been reported from the district. Kuroko ores of the Shakanai Mine in the district contain fine-grained, compact sulfide ores, which are little affected by diageneric and epigenetic processes, thus, are regarded as one of the most primitive kuroko ores. From these ores, the authors have found foraminifera replaced by sphalerite.

As to the origin of the kuroko deposits, a hydrothermal exhalative concept has been
widely accepted (OHASHI, 1919; HAYASHI, 1960, 1961; HORIKOSHI, 1960, 1969; SATO, 1968, 1972; TATSUMI and WATANABE, 1971; URABE and SATO, 1978; OHMOTO, 1978; BARTON, 1978). But recently, it is being challenged by a new hypothesis of marine, biogenic origin (KAIJWARA, 1983a, 1983b; KAIJWARA and HIRAYAMA, 1983a, 1983b). The presence of organic substance directly embedded in the kuroko ores can be expected to offer an important clue to their origin. In this study, the occurrence of the mineralized fossils and the textural features of the fossil replaced by sphalerite will be described. The general features of the kuroko deposits in the Shakanai Mine will be briefly mentioned in order to discuss an emplacement process of the fossils into the ore.

2. Occurrence of Ore Deposits

The Shakanai mine lies on the northwestern part of the Hokuroku district where major kuroko deposits are concentrated. Many papers have been published on the geological setting as well as the mode of occurrence of the ore deposits of the mine (OTAGAKI, 1966; OTAGAKI et al., 1968, 1970; KAIJWARA, 1970; MIYAZAKI et al., 1978; KUMITA et al., 1980, 1982; SUGAWARA et al., 1982). Table 1 shows a generalized stratigraphic column compiled by NAKAJIMA and SASAKI (1985), considering the relationship to the neighboring area. The lowest rock unit confirmed by drillings around the mine is the Middle to Lower Miocene basaltic formation. The middle unit above it contains the ore deposits, and is composed mainly of dacite pyroclastics. The upper unit consists of two formations; an alternation of mudstones and dacite pyroclastic flow deposits, and overlying thick dacite pyroclastic deposits, mostly Upper Miocene in age.

In the Shakanai Mine, eleven individual kuroko deposits are recognized. The specimen involving the mineralized fossils was taken from the No. 11 deposits (Figs. 1 and 2). The deposits is built by two portions; 1) the lower gypsum ores with disseminated sphalerite, chalcopyrite and pyrite, and 2) the upper bedded ores. The host rocks of the lower ores are mainly dacite pyroclastics. The upper bedded ores are overlain by mudstone and fine tuff layers of a few to tens of meters in thickness. In general, the kuroko deposits can be separated into two portions like the Shakanai deposits, but the lower ores are usually composed of silicified stockwork ores.

Another difference in the mode of occurrence is that the No. 11 deposits are exclusively separated into three ore bodies different in horizon, the upper, middle and lower ones, by intervening dacite pyroclastics and mudstones (MIYAZAKI et al., 1978), while the other kuroko deposits occur in one horizon. Figure 1 shows the middle and lower ore bodies which are almost the same in size and internal structures. The upper bedded ores of these ore bodies occur in a lenticular form, 130 m long, 40 m wide and up to 15 m thick in the middle ore body, and 270 m long, 60 m wide and up to 25 m thick in the lower ore body.

The bedded ores of the typical kuroko deposit exhibit characteristic mineral zoning (SATO, 1971, 1972, 1974); the upper black ore mainly composed of sphalerite, galena and barite, and the lower yellow ore built by pyrite and chalcopyrite. However, the No. 11 deposits consist mainly of black ore and siliceous ore with disseminated sulfides. The yellow ore in the bedded ores is less in amount. Besides, the No. 11 deposits show strong intraformational deformation (Figs. 1 and 2). The ores are intensely deformed be-
Fig. 1 Cross-section of No. 11 ore deposits in the Shakanai mine. A = projection of location where the specimen of the mineralized fossils has been taken.

Fig. 2 Plan view of part of the lower ore body at 337.5 m level in the No. 11 deposits. A = location where the fossil-bearing black ore has been found.

The fragmental black ore in the No. 11 deposits is essentially fine-grained and shows compact and uniform aspect in which generally distinct internal structures cannot be observed. It is composed of an aggregate of sphalerite and subordinate amounts of galena, pyrite, chalcopyrite and tetrahedrite. Coarse crystals are usually found as fillings or linings of the vugs and interstitial open spaces between the fine-grained minerals, and as veins and veinlets. They seem to be, more or less, later stage products. Some of the interstitial coarse sphalerites exhibit well-developed growth-banding. Corrosion of the coarse sphalerites is also frequently observed, and in part, sphalerite deposition is repeated on the corroded surface. The sphalerite crystal of the fine-grained black ore is generally dark in color with fine inclusions of other sulfide minerals, whereas the later crystallized bigger sphalerite is transparent or pale-colored.
The fossil-bearing sample was collected from a rounded block of black ore about 13 meters in diameter within the lower ore body (Fig. 2). This block is surrounded by clay materials and other smaller boulders of black ores, and is overlain by mudstone caps. It is fine-grained and compact, but in some part, it is mottled by the fine-grained yellow ore. The sample was taken from this mottled part where the black ore becomes to be small fragments of up to a few centimeters in size in yellow ore matrix. The fragments show various degrees of soft-rock-deformation. They display irregularly deformed and stretched shapes (Fig. 3). Some fragments have distinct outlines but the others exhibit obscure ones, partly mixed with or amalgamated with the matrix yellow ore.

The black ore fragments are mainly composed of sphalerite with galena, tetrahedrite, pyrite and chalcopyrite. Most of sphalerite crystals range from less than 1 to 10 microns in size. Pale-colored sphalerite is principal mode but they are intimately associated with fine dark inclusions. The matrix yellow ore includes mainly chalcopyrite with small amounts of pyrite, galena and sphalerite.

3. Description of Mineralized Fossils

Scattered sphalerite grains of 0.01 to 0.1 millimeters in diameter can be observed in chalcopyrite matrix of the specimen (Fig. 3). Mostly, they are very small and fragmental, but some sphalerite grains show ellipsoidal and rounded shapes characteristic of microfossils. By the observation in a doubly polished thin section, many of internal structures become to be visible in the grains. Among them, some of bigger sphalerite grains exhibit internal structures typical of foraminifera (Fig. 4 and 5). Because most of them are still fragmental and incomplete in section, only four specimens can be identified with regard to the genus name as follows.

1. *Globorotalia* cf. *peripheroronda* BLOW and BANNER
2. *Globorotalia* sp.
3. *Globigerina* or *Globigerinoides* sp.
4. *Globoquadrina* cf. *obesa* AKERS

These are all planktonic and calcareous foraminifera. Any benthonic foraminifera could not be found in the thin section. The specimen no. 1 can be identified with *Globorotalia* cf. *peripheroronda* by its characteristic form. *Globorotalia peripheroronda* is known from the middle part of Lower Miocene to lower part of Middle Miocene (BLOW’s Zone No. 6–No. 9). The specimen no. 2 includes two fragmental foraminifera of genus *Globorotalia*. The specimen no. 3 has a relatively complete shape, which belongs to
Fig. 4 Mineralized fossil foraminifera. Sphalerite grains in chalcopyrite matrix are shown in reflected light (1 and 3), and in transmitted light (2, 4, 5 and 6). Note the difference of sphalerite between test and chamber parts. (1) and (2) Globorotalia cf. peripheroronda. (3) and (4) Globigerina or Globigerinoides sp. Chamber sphalerite of this specimen shows densely dotted fine dark inclusions. (5) At least two fragmental fossils are included near center. Right-hand one is Globorotalia sp. (6) Three micro-fossils can be found in the photo. Left-hand one is Globobadrina cf. obesa. Scale bars equal 0.05 mm.

genus Globigerina or Globigerinoides. In the specimen no. 4, at least three individual foraminifera can be recognized, among which the left-hand one in Figure 4-(6) is similar to Globobadrina obesa, whose geologic age is from the upper part of Lower Miocene to the middle part of Middle Miocene (Blow's Zone N.7-N.12).
Fig. 5 Sketch showing the details of the foraminifera, *Globorotalia cf. peripheroronda*, replaced by sphalerite, which is the same specimen as in Figure 4-(1) and -(2); a = sphalerite in the test part and b = sphalerite in the chamber part.

In the mineralized foraminifera, two kinds of sphalerite can be observed in the thin section; one is transparent, colorless sphalerite replacing the test parts of the foraminifera, and another dark, opaque sphalerite filling the chamber parts (Figs. 4 and 5). The foraminiferal fossils in the specimen no. 4 are mineralized by the same sphalerites, but one chamber is completely replaced by chalcopyrite.

Under a high-power microscope, most of the chamber sphalerite is uniformly dark. But in part, very small and dense dark inclusions can be observed. The interstitial part between inclusions consists of transparent sphalerite, so that the inclusions probably make the chamber sphalerite to be opaque. In order to confirm the presence of the opaque minerals and to determine those kinds, the sphalerites have been analysed by the electron microprobe. Table 2 shows the result of the analyses. The transparent sphalerite in the test part contains mainly zinc and sulfur. The amount of other elements is negligible in it. On the other hand, the opaque sphalerite in the chambers contains about four weight percent of iron and copper in addition to major elements of zinc and sulfur. Thus, the result of the analyses indicates that the inclusions might be fine chalcopyrite grains.

### 4. Discussion and Summary

The features of the mineralized fossils found in the kuroko deposits of the Shakanai Mine, and their mode of occurrence are summarized as follows.

1. Foraminiferal fossils replaced by sphalerite occur in a black ore block of some 13 m in diameter within the No. 11 ore deposits.
2. The fossils can be identified with planktonic foraminifera including the genera of *Globorotalia*, *Globigerina* or *Globigerinoides* and *Globoquadra*.
3. Textural difference of the sphalerite replacing the fossils can be recognized between the chamber and test parts. The sphalerite forming the chamber part is opaque partly with very-fine-grained solid inclusions, whereas the test part sphalerite is transparent without inclusions. The opaque nature of the chamber sphalerite is mainly due to small amounts of chalcopyrite inclusions.

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Table 2 Comparison of chemical composition (in wt%) of sphalerites between test and chamber. Sphalerites 4 to 8 are uniformly dark, and sphalerites 9 and 10 with densely dotted inclusions.
(4) The fossil-bearing black ore block contains in part fragmental fine-grained black ore with a matrix of fine-grained yellow ore. The fossils are embedded in the yellow ore matrix together with other small fragments of black ore.

(5) The No. 11 ore deposits include a fine-grained, compact black ore. The sphalerite which constitutes the major part, is usually dark or opaque, and heterogenous, containing fine inclusions such as pyrite, chalcopyrite, galena and tetrahedrite. On the other hand, later sphalerite which occurs as veinlets and infillings of vugs in the fine-grained black ore, is coarse and transparent.

The fine-grained, compact black ore in the No. 11 deposits is similar to those described as the initial kuroko ore by Barton (1978) from the Furutobe Mine. The presence of the mineralized fossils in this ore indicates that it is primary ore hardly affected by diagenetic alteration after its deposition. The fact also supports a view that the black ore has been deposited on the sea bottom.

The difference of sphalerite texture between the chamber and the test parts of the foraminifera is probably attributed to the difference in time of replacement by sphalerite. The fact that opaque and heterogenous sphalerite in the chamber part resembles that of fine-grained, compact black ore, suggests that cavities caused after decomposition of the organic materials in the foraminiferal chamber have been filled by sphalerite precipitated from the same solution as that from which the fine-grained black ore was deposited. On the other hand, the test part sphalerite might have formed as a result of replacement by transparent one at rather later stage when the coarse transparent sphalerite crystallized as veinlets or vug fillings in the black ore.

The growth-banding sphalerite, and its partial corrosion and subsequent deposition of sphalerite on the corroded surface have been observed in the No. 11 deposits of the Shakanai Mine as in the Furutobe Mine. This means that the chemistry of the interstitial fluid has repeatedly changed during ore formation. Therefore, the resolution of the calcareous test of the foraminifera and subsequent replacement by the transparent sphalerite might have been caused by this changeable fluid.

The manner of the fragmentation of the fossil-bearing black ore suggests that the soft-rock-deformation and mechanical mixing of unconsolidated ores took place after deposition of black and yellow ores. Thus, it is assumed that first, the fossils were replaced by sphalerite in the black ore, and then they were moved into the chalcopyrite-rich ore together with other black ore fragments by a synsedimentary deformation, probably by slumping or sliding.

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References


北鹿・釈迦内鉱山の黒鉱中より発見された
関亜鉱鉱で交代された有孔虫化石

中嶋輝允・平山晴彦・名取博夫

要旨：北鹿地域・釈迦内鉱山のもっとも初生的とみなされる細粒、緻密な黒鉱から関亜鉱鉱によって交代された浮遊性有孔虫化石が発見された。有孔虫化石の観察は両面研磨薄片においてなされたので、有孔虫の断面形から種を判定しなければならない。そのため、多くの種を決めることは困難で、保存状態のよいものについてのみ属名を求めることができた。同定された有孔虫は浮遊性、石灰質有孔虫で、Globorotalia, Globosquadrina, Globigerina（またはGlobigerinoides）の各属である。その中に、中新世の示準化石として有名なGloborotalia cf. peripherorondaが見出された。

関亜鉱鉱で交代された有孔虫化石は、主に黄銅鉱からなる細粒黄鉱の基質中に存在する。有孔虫化石中には、殻の部分を交代する無色透明な関亜鉱鉱と浮遊を充填する不透明な関亜鉱鉱の2種が認められる。電子プローブX線マイクロアナライザによるこれら2種の関亜鉱鉱の分析の結果から、浮遊の関亜鉱鉱の不透明な原因は、ごく細粒な黄銅鉱の包有物が約6%関亜鉱鉱中に含まれていることによると判断した。

有孔虫化石を含む黒鉱鉱床は層状で、変質石英安山岩、火成岩質岩類と泥岩の間に挟まれている。しかし、その内部には、鉱石の未固結変形を観察したりスランピングやスライディングの特徴が多くみられる。したがって、浮遊性有孔虫の遺骸が黒鉱の形成されつつある海底面に最初沈降し、次いで関亜鉱鉱によって交代され、その後鉱床がまだ未固結の間にスランピングやスライディングが生じ、関亜鉱鉱で交代された有孔虫が黄鉱中に物理的に埋込まれたものと考えられる。