MEMOIRS OF THE COLLEGE OF SCIENCE, UNIVERSITY OF KYOTO, SERIES B,
Vol. XXXII, No. 2 Geology and Mineralogy, Article 1, 1965

Geochemical Study of the Sambagawa Metamorphic System in the Besshi District, Central Shikoku, Japan

Part III-A

Chemical Characteristics of the Schists in the Conformable Cupriferous Pyritic Ore Deposits

By

Hiroshi TAKUBO

Geological and Mineralogical Institute, University of Kyoto

(Received July 28, 1965)

Abstract

Chemical analyses of the various schists from the conformable cupriferous pyritic ore deposits of the Besshi district supplied several interesting informations, among which the following are most notable:

(1) The sulphide-free part of the basic schists in the deposits is higher in CaO- and CO_2-content and rather lower in SiO_2-, TiO_2-, Al_2O_3- and Na_2O-content, compared to the common basic schists surrounding the deposits. As for Fe_2O_3, FeO, MgO, MnO, K_2O and H_2O, the differences between both schists are not prominent.

(2) As the sulphur-content or the degree of sulphide mineralization increases, the CaO- and CO_2-content of the basic schists comprised in the deposits notably decrease and the H_2O-content increases exceeding that of the common basic schists.

Preface

Several tens conformable cupriferous pyritic deposits of large and small scale occur within the zones of the Sambagawa crystalline schists and of the weakly metamorphosed rocks in the central Shikoku. The Besshi mining district has been most famous for its largest copper production and for the occurrence of the typical "Kieslager" deposits in Japan. Production of copper has come mainly from the Besshi mine—the largest single copper deposit in Japan—, Shirataki deposit and several satellitic deposits clustered around these deposits. The mode of origin of these copper deposits has long been a controversial subject. Before the World War II, epigenetic and synkinematic replacement theory was prevailing, grounded on the microscopic evidences of ores and country rocks and on the syn- to post-kinematic occurrence of ultrabasic rocks as a possible source of mineralization. The intensive prospecting and development of the deposits after the war disclosed the continuous and conformable features of the ore-bodies, and herewith the epigenetic theory has been taken its place by the syngenetic precipitation theory. However, it seems that any of the strong evidences capable of supporting the syngenetic theory, excepting the stratigraphic ones, has not been discovered in the district. Because the primary features of the deposits, if ever presented, must have been obliterated as a result of the Sambagawa metamorphism, it seems very hard to discover such evidences somewhere in the deposits.

The present paper is mainly concerned with the geochemical characteristics of the vein-forming barren schists and of the mineralized basic schists in the several conformable cupriferous pyritic deposits. Chemical analyses of the rocks enclosing the ore were so rare and incomplete that most genetical discussions disregarded a searching examination for the chemical environment during the ore deposition.

The general features of the ore deposits are outlined for convenience in the first half of the paper, as the results of the author's observation in the several deposits, from 1954 to 1962. All analytical data which should be refered to in the present paper will be compiled in Part IV.

General Features of Ore Deposits

Geological setting: The sulphide ore-bodies are closely associated with the metamorphosed basic rocks. In the Hiura formations they are commonly embedded in the thick greenschist member, but in the upper formations of higher grade of metamorphism siliceous and calcareous schists as well as basic schists are commonly found in the ore deposits. There is no workable deposit in the uppermost Ojoin formations almost lacking the basic metamorphic rocks (see Table 1 of Part I). Throughout all deposits, sulphide ores are almost conformable[1] to the country rocks and form the persistent ore horizons along which the weakly disseminated basic schists can be traced over several kilometres away from the workable part on both strike-side and dip-side.

Relationships to local geologic structures: Localization, form and mineralogical

1 Survey at 220 spots in the country rocks near the ore-body limited between 20- and 24-level and between E-3 and E-4 of the Besshi Mine, revealed that the angle of intersection between the ore-bed and the average plane of schistosity of the surrounding rocks is less than six degrees.

composition of the ores are strongly controlled by the geologic structures of regional and local scales. Workable massive sulphide ores on a horizon are generally found in the disturbed part where interformational tight folds are common. An ore-shoot tends to stretch towards the direction parallel to the axis of the tight folds (tectonic B-axis), but occasionally repeats its attenuation and thickening due to the gentle folding having the direction of the tectonic A-axis which is nearly perpendicular to the B-axis in the plane of rock-bed. Large and interrupting lenticular ore-bodies are commonly found with close relation to the quaquaversal or Ω-shaped folds which can be regarded as a result of vertually simultaneous compression along the A- and the B-tectonic axis in a plane of rock-bed. In such cases, the ores show the coarser-grained texture and the style of branching is varied,—the massive ores in a persistent ore-shoot commonly show the fine-grained compact texture and the definite mode of branching[2]. Distribution and grade of the disseminated banded ores are also controlled by the two principal tectonic axes which can be estimated from the various styles of folds, but it is not uncommon that the banded ores show the shooting direction oblique to that of the coexisting massive ore. Obviously post-metamorphic phenomena in the ore deposits such as faults, joints and apophysis-like veins enriched with copper are also controlled their appearance by the A- and the B-tectonic direction.

Country rocks: The basic schists adjacent to or intervening between the massive sulphide ores are generally similar in mineral assemblage to the common basic schists in the barren formations. They contain all or some of the minerals albite, quartz, sericite, chlorite, actinolitic hornblende, glaucophane and epidote as the main constituents, (A, B in Fig. 2). Rutil, sphene, magnetite, pyrite, pyrrhotite and apatite are also contained as accessory minerals. Magnetite, hematite, piedmontite, spessartite, rhodonite, rhodochrosite and alkali-rich amphiboles are occasionally concentrated in the quartz schists and calcareous schists adjacent to the ore-bodies, especially at the extremity of ore-body or in the tightly folded part.

Ores: There are some differences in both mineral assemblage and texture of the ores, but they can be classified into two major types, i.e. massive ores and banded ores.

Massive ores—abbreviated as R—are compact aggregate of fine-grained pyrite and interstitial chalcopyrite. Magnetite and sphalerite are common accessory minerals. In general, the grain-size of pyrite in the ores tends to become larger in the deposits belonging to the upper formations of higher grade of metamorphism. Crushed and strongly deformed pyrite-grains are occasionally found on the deeper levels of the Besshi and the Yokei deposit. Neither colloform nor biogenic texture of the ore minerals is found throughout the district. Magnetite- or hematite-rich ores occur in

2 For example, right- or left-handed echelon branching.

Table 1. General features of the deposits from which the samples were obtained.

Deposit	Formations	Country rocks	Mineral assemblage*	
			Basic schists	Acidic schists
Shirataki	Tonaru	spotted basic schists spotted black schists quartz schists amphibolites serpentinite	Hb. Ab. Ep. Mus. Q.C. Zois. Gt. Cc. Ky. ? Di.	Q. Mus. Ab. Ep. G. Zois. Bt. Cc. C. Gt.
Ikadazu	Besshi	spotted basic schists spotted pelitic schists quartz schists calcareous schists	C. Ep. Act. Ab. Q. Cc. Se. Gl. (rare)	Q. Se. Ab. Cc. G.
Besshi	Besshi	spotted & *non*-spotted basic schists and pelitic schists quartz schists massive green rock calcareous schists	C. Ep. Act. Ab. Q. Cc. Se. Gl. (local)	Q. Se. Ab. Cc. C. G.
Yokei	Besshi	spotted & non-spotted basic schists, quartz schists	C. Ep. Ab. Act. Q. Cc. Se. Gl.	Q. Se. Ab. Cc. C. G.
Hiura	Hiura	non-spotted basic schists	C. Ep. Act. Gl. Ab. Q. Cc. Se.	—

Structural situation	Above or below the sea	Scale of workable part		Strike & Dip	Main tectonic axes	Shape of ore-body	Maxim. width	Ores
		lateral	along shoot					
crest of Shirataki fold	+200~ +1300 m	450~ 700 m	4500 m +	variable	(B) E −10°~−20° (A) N5°E −20°~−40°	sheets lenses	6 m	R SK-A SK-B
north-eastern flanks of Nakashichiban dome	−250~ +750 m	300~ 600 m	2500 m +	N55°W 40°±N	(B) S80°E −20° (A) N10°E −40°	sheets	1.5 m	R SK-A SK-B
northern flanks of Nakashichiban dome	−900~ +1250 m	1100~ 1300 m	2500 m +	N60°W 60°±N	(B) S70°E −30° (A) N30° ~55°W −40°~−55°	sheets	10 m	R SK-A SK-C M.G.R.
north-eastern flanks	0~ +750 m	100± m	1000 m +	N60°W 45°±N	(B) S80°E −16° (A) N−40°	sheets	1.5 m	R SK-A SK-B
northern flanks	−600~ +1000 m	not developed	?	N60°W 60°±N	(B) S80°E −20° (A) ?	sheets	0.5 m	SK-A R

* The abbreviated words are explained in Table 1 of Part I (p. 52).

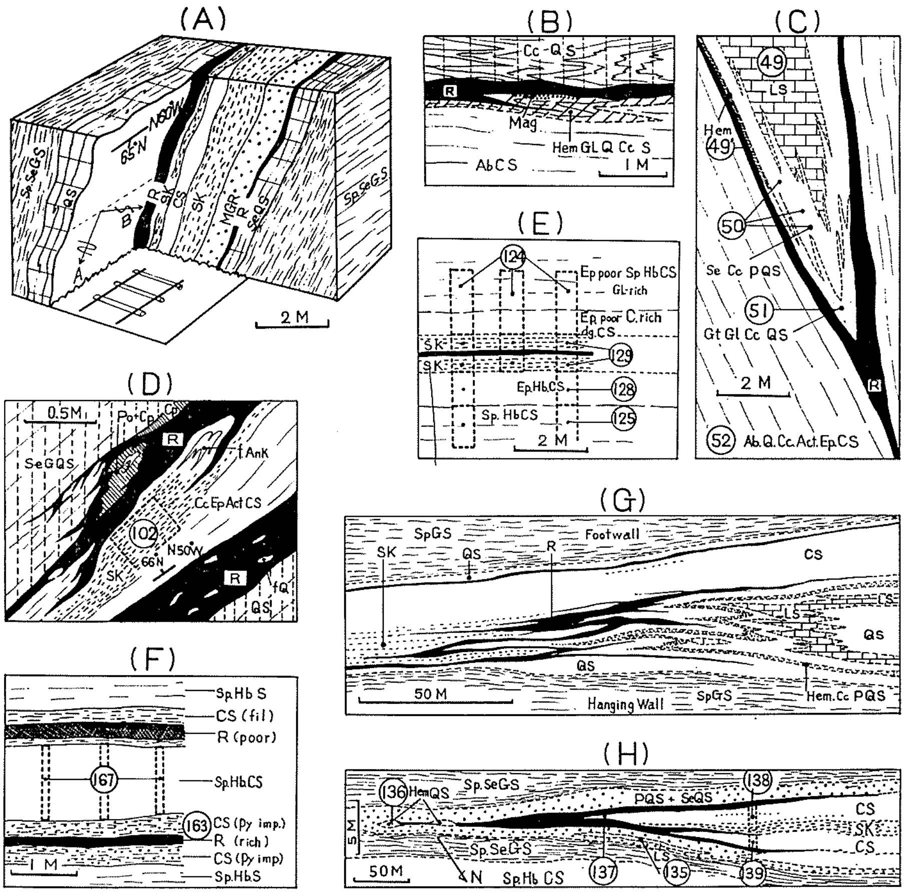


Fig. 1. (A) Block diagram showing the most common mode of occurrence of the ores in the middle part on the levels from 14- to 22-L of the Besshi Mine.

(B) Sketch showing a manner of occurrence of the intermediate calcareous schist, on the side of basic schist, 9-L, W5, western part of the Besshi deposit.

(C) Section, looking NW, showing a manner of occurrence of the intermediate calcareous schist, on the side of highly calcareous schists, 10-L, W5, a part of western bonanza of the Besshi deposit.

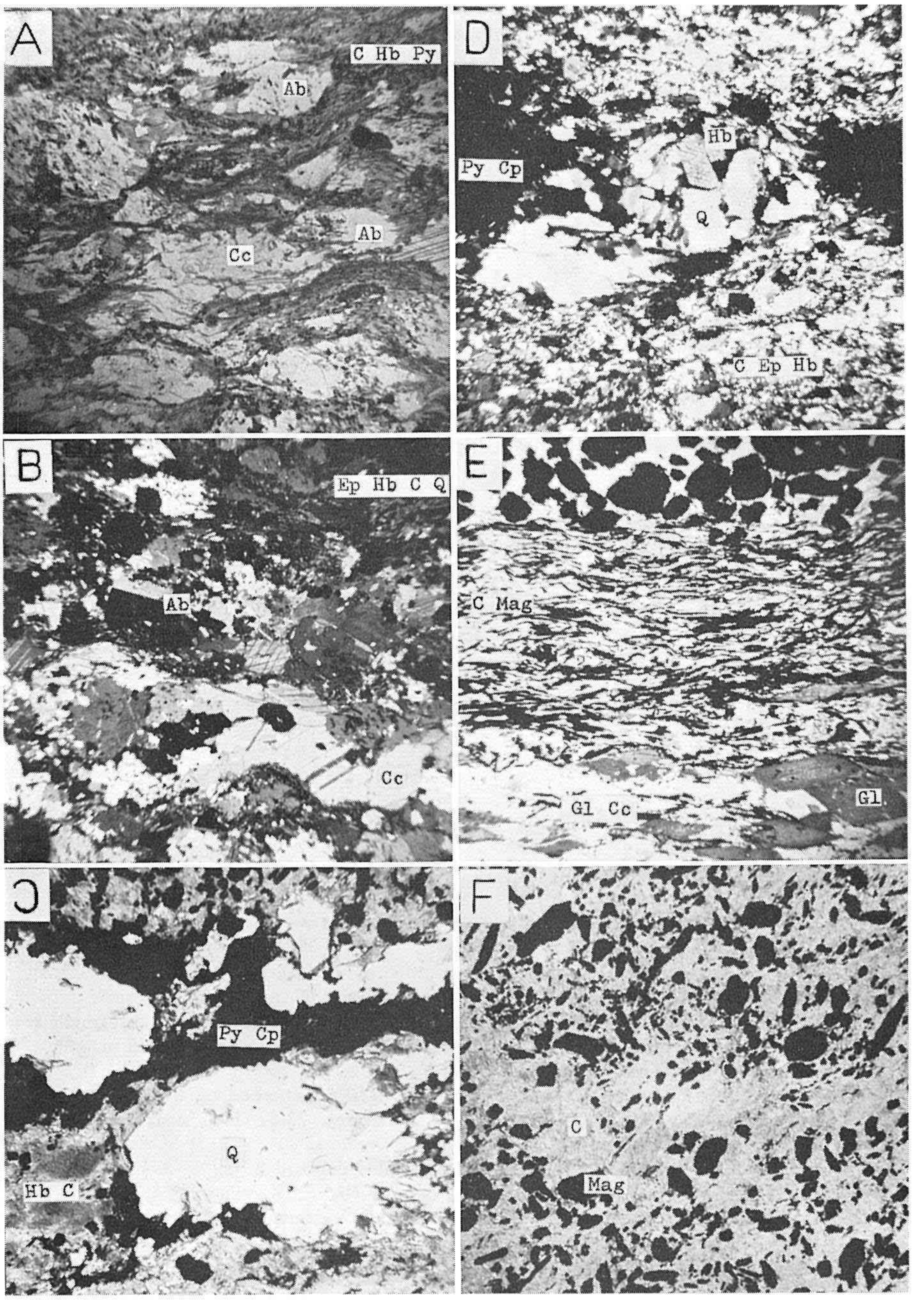
(D) Local occurrence of the banded ore in the disturbed part. Massive ores are affected by the post-metamorphic processes. 23-L, E-8, near the eastern limit of the Besshi deposit.

(E) Sampling sketch, western part of the Yokei deposit, 20-L.

(F) Sampling sketch, 23-L, Shirataki deposit (by F. KAYUKAWA).

(G) Plan showing generallized feature of the western bonanza, on the levels from 9- to 20-L of the Besshi Mine.

(H) Plan showing general feature of the Ikadazu deposit, on the levels from 10- to 16-L, (by Y. HAYASHI, geologist of the Besshi Mine.)


A
C Hb Py
Ab
Ab
Cc
B
Ep Hb C Q
Ab
Cc
C
Py Cp
Q
Hb C
D
Hb
Py Cp
Q
C Ep Hb
E
C Mag
Gl Cc
Gl
F
C
Mag

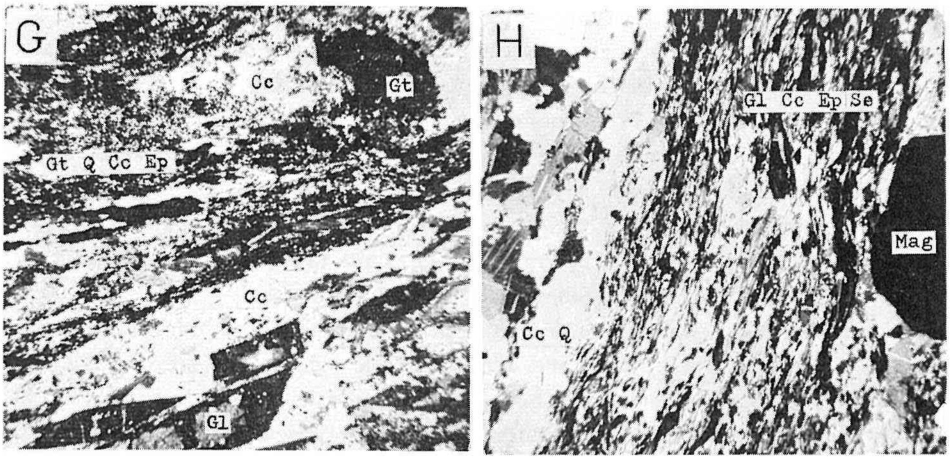


Fig. 2. Thin sections of the rocks comprised in the Besshi ore deposit.

(A) Inter-orebody spotted basic schist, almost barren. Main constituents are albite and calcite as porphyroblasts and chlorite, epidote and actinolitic hornblende in fibrous part. Minute grains of quartz and epidote are included in albite porphyroblasts. 17-L, W2; ordinary light, ×20.

(B) Inter-orebody calcareous basic schist, almost barren, having the prominent banded structure. Upper half: melanocratic band of the intermingled mass of epidote, hornblende and chlorite. Lower half: leucocratic band of albite and calcite with small amount of quartz. 17-L W2; crossed nicols, ×20.

(C) Sulphide disseminated basic schist (SK) banded ore of Type-A, of 1.5% Cu and 7%S. Quartz occurs as the aggregates of minute grains showing irregular orientation and wave extinction. Greyish part is mainly of chlorite and actinolite. Dark part is aggreagte of rounded grains of pyrite and interstitial chalcopyrite. Albite and calcite are very scarce, probably having been corroded by sulphides and quartz. 20-L, E3; ordinary light, ×40.

(D) Sulphide disseminated basic schist (SK), poor in sulphides, Cu: 0.3% S: 2%. Main constituents are chlorite, epidote, hornblendes and quartz, with very small amount of albite and carbonates. Aggregates of sulphides probably replace the porphyroblastic albite and calcite. Two kinds of chlorite and of hornblende are present. 17-L, W2; ordinary light, ×22.

(E) Hanging wall boundary between the massive sulphide ore (upper) and the calcareous schist (lower). Massive ore: pyrite and quartz with little amounts of chalocpyrite and carbonate, intermediate part: chlorite and strongly deformed magnetite—not specularlite, lower part: glaucophane and calcite; such a large crystal of glaucophane is rather rare in the common glaucophane schists. 15-L, W1; ordinary light, ×20.

(F) Massive green rock (MGR), chlorite magnetite schist. Carbonates and quartz occur as secondary veinlets only. 22-L, E4; ordinary light, ×40.

(G) Intermediate calcareous schist comprising calcite, glaucophane and garnet as main constituents and quartz, epidote and specularite as accessories; tightly folded part bordering the western bonanza of the Besshi deposit, 15-L, W2, Besshi Mine; crossed nicols, ×20.

(H) Intermediate calcareous schist comprising carbonates, glaucophane, quartz, sericite and magnetite, with small amount of epidote and albite; on right-side magnetite layer contact with the massive suphide ore; 9-L, W5, Besshi Mine; crossed nicols, ×20, (see sketch B of Fig. 1).

places at the extremities of the sulphide ore-bodies[3].

Grade of the massive ore varies to greater extent depending on its structural state, but the most normal ore contains several per cent of copper and 40 to 50 per cent of sulphur. Gangue-minerals of the massive ore, though their amount is very small, are mainly quartz, carbonates and chlorite, and rarely actinolite, epidote and albite[4]. Margin of the massive ore-body is generally well-defined (E in Fig. 2).

Banded ores—abbreviated as SK—have various textures and mineralogical compositions. In individual deposit, several different names are given to them, but they fall into three major types as the following:

Type A, —SK-A— the most common in the district, show the prominent banded structure. Hypidiomorphic pyrite and allotriomorphic chalcopyrite are disseminated along leucocratic bands in the basic schists. Albite and calcite, though they are not so common as quartz and chlorite, frequently show the irregular texture suggesting replacement or corrosion by sulphides or quartz. Average grades of 1 to 2 per cent of copper and of 5 to 15 per cent of sulphur are normal (C and D in Fig. 2).

Type B, —SK-B— lacks the banded structure. Coarse-grained, rather idiomorphic pyrite is sporadically disseminated in phyllitic chlorite schists or actinolite-chlorite schists in the deposits. Other ore- and gangue-minerals are very rare. An average grade is less than 0.5 per cent copper. The ore of this type is, in general, dominant in the places where poly-axial folds, parallel shear zones or lenticular ore-bodies are commonly found.

Type C, —SK-C— shows sub-banded to mesh structures. Network veinlets of chalcopyrite with subordinate bornite and quartz pierce chlorite-schists or magnetite chlorite-schists. On rare occasion, a corroded pebble of the massive sulphide ore is included in the veinlet. The copper content is higher and ranges from several to thirties per cent. The upper portion of the Besshi deposit are enriched with the ore of this type. Many evidences on this ore are favourable for the interpretation that the chalcopyrite was secondarilly introduced from the pre-existing ore-bodies into the host rocks during post-metamorphic disturbance.

Massive green rock: Massive green rock—ab reviated as M.G.R.—occurs in the intermediate to lower portion of the Besshi deposit. Their occurence is schematically illustrated in Fig. 6 of Part I and in the diagram A of Figure 1 of this part. They are dark-green coloured, compact and rather massive in appearance, and generally lack the marked banded structure. Constituent minerals are mainly chlorite and magnetite.

---

3 In places, besides these mineral there is local enrichment of pyrrhotite, tetrahedrite, cubanite or other ore minerals, but most of these minerals are genetically related to the hydrothermal process or to the shearing process of the later stage.

4 In most cases, the carbonates in the massive sulphide ores of the Besshi deposit occur as the most common material which forms the secondary network of veinlets piercing the aggregate of sulphides and other gangue minerals.

The magnetites in the massive green rock scatter in the chlorite mass of lepidoblastic structure and are peculiar for their minute spindle-shaped appearance which is uncommon to the magnetites in other rocks and ores (F in Fig. 2). Sulphide minerals are generally absent or very scarce. YAMAOKA (1962) pointed out the chemical and mineralogical peculiarities of the massive green rock of the Besshi deposit.

Chemical Characteristics of the Schists in the Ore Deposits

Five deposits were selected to study the chemical characteristics of the barren schists and sulphide disseminated basic schists which are the important members constituting the conformable pyritic deposits. The general features of these deposits are summarized in Table 1.

Analyzed rock- and ore-samples are all from the underground. The sketches of sampling spots are collectively shown in Fig. 1. Sampling method for each sample will be expressed together with the numerical data compiled in Part IV. Microscopic study on the mineral paragenesis was made as to the typical samples. Subsidiary study by X-ray diffractometer, using powder samples, for determining the relative abundances of the constituent minerals, was made as to all analyzed samples[5]. For most minerals comprised in the basic schist, except epidote, the relative abundances determined by the above method are well correlated with the analytical results and with the apparent mineral abundance determined by the microscopy[6]. Variations both in the chemical composition and in the relative abundance of main constituent minerals, except epidote, are illustrated for each deposit in the diagrams of Fig. 3.

(A) Sulphide-free schists in and around the deposits

1) *Basic schists*: In many tables and figures in the papers on these serial studies, the following remarkable differences in chemical composition are recognized between the barren schists constituting the deposits and the common basic schists distant from the deposits.

Compared to the common basic schists distant from the deposits, the deposit-forming and sulphide-free basic schists are higher in CaO- and CO_2-content (Fig. 11, Part I; CaO-CO_2 diagram of Fig. 1, Part II; Fig. 3, Part II; etc.), and are rather lower in SiO_2-, Al_2O_3-, Na_2O- and TiO_2-content (Figs. 1 and 3, Part II). As for Fe_2O_3-,

5 For this purpose, the conditions of operating the diffractometer were fixed as shown in Table 2. The available representative diffractions of the main constituent minerals of the basic schists under these conditions are shown in Table 3.

6 For pelitic schists having sericite, albite, quartz, graphite, chlorite, calcite and epidote association, especially for sericite-rich schists, the X-ray method to determine the relative abundance of minerals was not successful, because of the overlapping of diffraction pattern and of the inevitable orientation due to sample packing.

Table 2. Conditions for operating X-ray diffractometer, for determining the relative abundances of minerals in rocks.

Target	Radiation	Filter	Divergence slit	Scattering slit	Receiving slit
Cu	30 KV, 10 mA	Ni	1°	1°	0.4 mm

Scanning speed	Chart speed	Scale factor	Multiplier	Time constant	2θ
4°/min.	20 mm/min.	16	1	4 sec.	3°—40°

Table 3. Representative diffractions of the minerals investigated.

Mineral		d (Å)
albite	Ab	3.20±
ankerite	Ank	2.90±
biotites	Bt	(A) 10.1± (B) 3.37
calcite	Cc	3.03
chlorites	C	(A) 7.08± (B) 3.50±
glaucophane	Gl	(A) 8.3± (B) 3.06±
hornblendes*	Hb	(A) 8.5± (B) 3.13±
muscovites	Mus	(A) 9.9± (B) 3.3±
quartz	Q	3.34
sericite	Se	(A) 9.9± (B) 3.3±

* Including the common and the actinolitic hornblendes.

FeO-, MgO-, MnO- and K_2O-content, remarkable and general differences are not recognized. The difference in H_2O-content is also indistinct, except in the Shirataki deposit in and around which H_2O-content of the spotted basic schists (mainly the spotted common hornblende schists) abruptly increases.[7]

2) *Siliceous or calcareous schists*: Several analyses were tentatively made on the quartz schists and calcareous schists accompanying the massive sulphide ore-bodies of the Besshi and the Ikadazu deposit (see Part IV). They involve hematite quartz schist (analysis No. 136), piedmontite quartz schists (analysis Nos. 69, 134), sericite albite graphite quartz schist (analysis No. 85) and highly calcareous schists or limestone-schists (analysis Nos. 49, 117, 135). These analyses yielded the results that the chemical components constituting the characteristic mineral of each schist in question are not so large in their amounts as expected from their apparent features, for examples, MnO for piedmontite quartz schist and total Fe for hematite quartz schist, and that CaO

7 Local higher concentration of water in the country rocks of the Shirataki deposit seems to be exceptional. Probably this would be attributed to the retrogressive metamorphism either due to re-folding of the country rocks or due to the sulphide mineralization.

is more or less contained in the quartz schists poor in opaque minerals.[8]

3) *Intermediate calcareous schists*: A special type of calcareous schist is found in the places where the highly calcareous schist contacts with the inter-orebody basic schist, being accompanied by intervention of the massive sulphide ore and frequently by tight folding of the neighbouring rocks. In such cases, layered concentration of iron-oxide minerals such as magnetite and hematite is commonly found in several centimetres zones bordering the massive ore-bodies (sketches B and C in Fig. 1). This calcareous schist is in general composed of all or some of the minerals such as glaucophane, riebeckite, spessartite, rhodonite, rhodochrosite, magnetite, hematite, epidote, calcite and quartz (G, H in Fig. 2). This rock may be conveniently termed the "intermediate calcareous schist".

Chemical and mineralogical compositions of the intermediate calcareous schist and of other kinds of the schists neighbouring it are compared diagramatically in (F) of Fig 3. From this diagram, it is quite evident that the bulk chemical compositions of the intermediate calcareous schists lie between those of the basic schists and of the highly calcareous schist.

It can be said as a general result that the barren basic schists and some quartz schists, constituting the deposits embedded in the Hiura and the Besshi formations are more or less calcareous and are not always higher in Fe-content, compared to those distant from the deposits. Moreover, such a transitional chemical composition as recognized in the intermediate calcareous schist seems as a rule rather rare for the ordinary sedimentary or igneous rocks, except for skarn rock in the pyrometasomatic deposits.[9]

(B) Mineralized basic schists in the deposits

Differences in chemical and mineralogical compositions between the sulphide disseminated part (SK) and the barren part of the basic schists in the deposits are shown for each deposit in Fig. 3. Tendencies of the variation in chemical and mineralogical compositions, due to sulphide mineralization, are summarized in Table 4. On the chemical characteristics of the sulphide disseminated basic schists, the data of No. 17 in Table 1 and Fig. 4 of Part II should also be refered to. From these figures and tables, the following noticeable results are obtained:

---

8 All siliceous schists, except the magnetite-bearing one, of the Besshi deposit contain at least so much amounts of calcite as can be detected by the X-ray powder method which is defined above.

9 As already mentioned in Part 1 (page 64), in the Besshi district, it is hard to find out the schists having the bulk chemical composition which is transitional or intermediate between those of the ordinary metamorphic rocks having the contrasted chemical compositions, except in the case of the intermediate calcareous schist localized in the ore deposit.

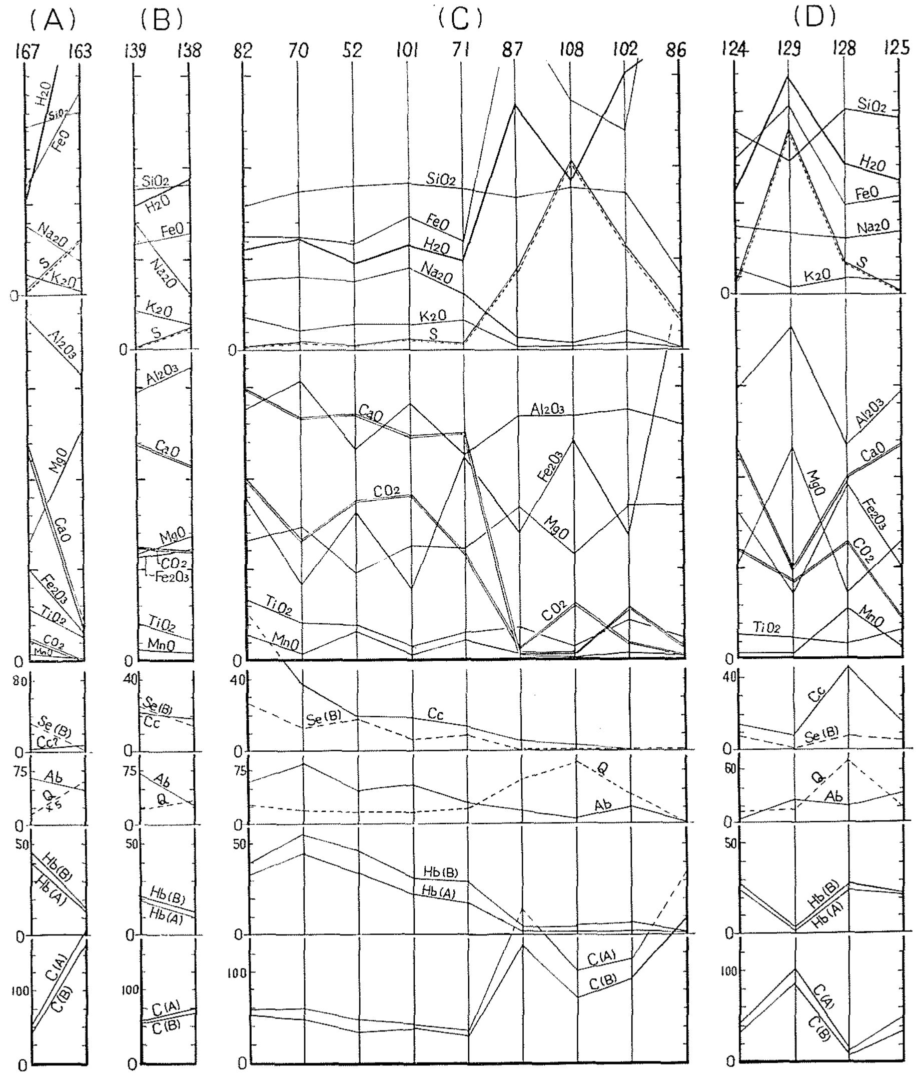


Fig. 3. Diagrams showing the variation in chemical composition (upper) and in relative abundance of minerals, represented by the height of peaks in X-ray powder pattern (lower), for the schists coexisting with the ores. An interval corresponds to 5% for SiO_2, to 1% for FeO, Al_2O_3, CaO, Fe_2O_3, MgO, and to 0.5% for H_2O, Na_2O, K_2O, S, CO_2, TiO_2, MnO; *height of peaks for minerals is shown in millimetre.*
(A) Shirataki deposit, 23-L, (see sketch F in Fig. 1); (B) Ikadazu deposit, 16-L, (see diagram H in Fig. 1); (C) Besshi deposit, samples from various places; Nos. 82, 70, 52, 101, 71 are the barren basic schists in the deposit, Nos. 87, 108, 102 are SK., and No. 86 is MGR., (see Figs. 5, 6, 11 of Part I, and diagram A in Fig. 1); (D) Yokei deposit, 20-L, (see sketch E in Fig. 1);

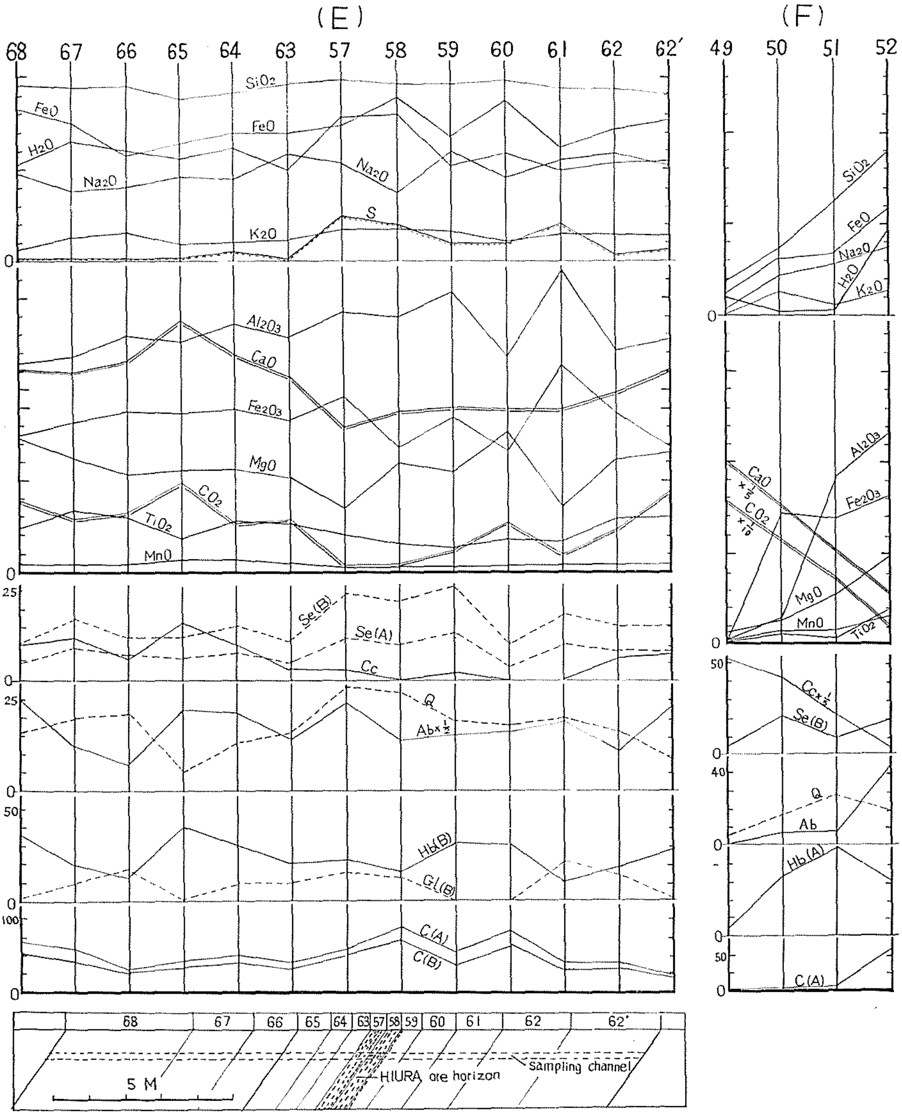


Fig. 3-continued. (E) Profile across the Hiura ore-horizon, showing the variation of chemical composition and the sampling localities; footwall crosscut, 14-L, W5, Besshi Mine. (F) Relationships in the chemical and the mineralogical composition among the intermediate calcareous schist, inter-orebody basic schist and highly calcareous schists, 10-L, W5, Besshi deposit (see diagram C in Fig. 1).

Table 4. Tendencies of variations in the chemical and the mineralogical composition of the basic schists, relatd to the sulphide mineralization in the conformable pyritic deposits. +: increase with and −: decrease with the sulphur-content. *: common hornblende. M.G.R.: massive green rock.

	Shirataki	Ikadazu	Besshi	Yokei	Hiura	Average	M.G.R.
SiO_2	+	+	?	−	?	?	−
Al_2O_3	−	+	?	?	?	?	?
Fe_2O_3	−	+	?	?	?	?	+
FeO	+	+	+	+	?	+	+
MgO	+	+	?	+	?	?	+
CaO	−	−	−	−	−	−	−
Na_2O	−	−	−	?	?	?	−
K_2O	−	−	−	−	+	±	−
H_2O	+	+	+	+	+	+	+
CO_2	−	−	−	−	−	−	−
TiO_2	−	−	?	−	−	−	−
MnO	?	?	?	?	?	?	?
actinolite	−*	−	−	−	?	−	−
albite	−	−	−	?	?	?	−
calcite	−	−	−	−	−	−	−
chlorite	+	+	+	+	+	+	+
glaucophane	...	...	...	...	?	?	...
quartz	+	+	+	−	+	±	−
sericite	−	−	−	−	+	±	−
From diagram in Fig. 1	(A)	(B)	(C)	(D)	(E)		(B)

(i) With increase of sulphur-content or of the grade of mineralization, CaO- and CO_2-content notably decrease and H_2O-content increases exceeding that of common basic schists. Behaviours of chlorite and calcite most clearly reflect these chemical tendencies.
(ii) Na_2O-content and correspondingly albite-content decrease with increase of sulphide-content, except in cases of the Yokei and the Hiura deposit which occur in thick formation of the basic schists poor in porphyroblastic albite.
(iii) K_2O-content and correspondingly the amount of sericite decrease in the sulphide-bearing basic schists, except in case of the Hiura deposit which is characterized by higher concentration of glaucophane in the country rocks.[10]
(iv) The Fe-content estimated from the total amount of Fe_2O_3 and FeO does not always increase as the amount of sulphur increases. Between Fe_2O_3 and MgO-content there is

10 Concentration or presence of the glaucophanitic amphiboles in the basic schists is largely dependent on the K_2O-content, as described in Part II (page 269).

such an inverse proportional relation as recognized in cases of the common greenschists (see page 262 of Part II).

(v) Massive green rock of the Besshi deposit has unique chemical and mineralogical compositions. Three analyses of the massive green rock are plotted near the area for ultrabasic rocks as shown in the $H_2O \cdot CO_2$-$FeO \cdot CaO$-Al_2O_3 triangle (see Fig. 4 of Part II).

Summary

The forgoing is an attempt only to present the chemical data regarding the ore genesis on the conformable cupriferous pyritic ore deposits of the Besshi district. Chemical analyses of the metamorphic rocks occurring in and around the deposits revealed that tendencies in the compositional variation related to the suphide mineralization in the basic schists are, for most chemical components, similar to those recognized as to the ordinary hydrothermal replacement mineralization, and that there is in places a special mineral assemblage having the bulk chemical composition intermediate between that of the basic schists and of the highly calcareous schists in the deposits.

"to be continued to Part III-B"

Literature

TAKUBO, H. 1964, 1965, Geochemical study of the Sambagawa Metamorphic System in the Besshi District, central Shikoku, Japan.

Part I. Variation of chemical compositions of the Schists, Related to the local Tectonic Phenome-a: Mem. Coll. Sci. Univ. Kyoto, Ser. B, 31, pp. 43-70.

Part II. General Tendencies in the Variation of the Bulk Chemical Composition of the Metamorphic Rocks: Mem. Coll. Sci. Univ. Kyoto, Ser. B, 31, pp. 255-277.

YAMAOKA, K. 1960, On the magnetite, hematite and magnesioferrite in some chlorite rocks at the Kieslager deposits, (in Japanese): Jour. Japanese Assoc. of Mineralogists, Petrologsits and Economic Geologists. Vol. 44, pp. 162-170.