STUDIES ON THE ALTERATION OF HANGING WALL BASALT OF FURUTOBE MINE, AKITA PREFECTURE

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INTRODUCTION

During the recent years, some studies on the wall rock alteration (Hayashi, 1961) and on the distribution of minor elements within the wall rocks (Shiikawa, 1966) have been reported in connection with the geological structure and microscopic observation of ores in order to clarify the genesis of the "Kuroko" deposit and to find out the indication of prospecting for ore-deposits.

Taguchi and Lu (1966) reported on the mineral assemblage and texture of ores from the Furutobe Mine.

In this paper the author describes an experimental study of the clay mineral assemblages in the hanging wall rocks, the distribution of minor elements and the relation between the results of experiments and ore-deposition.

OUTLINE OF GEOLOGY AND ORE-DEPOSITS

The Furutobe Mine is situated near the Aina Mine (Takeuchi, Nanbu, 1949, 1950) in the northern part of the so-called Kazuno-Kita-Akita mineralized zone on the Green Tuff region of the Inner Zone of northeastern Japan.

In the present district, the Miocene formations of Neogene Tertiary period, composed of much volcanics and sediments overlying unconformably the older base rocks belonging to the Paleozoic era are widely distributed. As shown in the simplified geologic map (Fig. 1), these Tertiary formations are divided into 4 groups chiefly on the bases of rock facies and characteristics of volcanic activities, that is, Uppermost, Upper, Middle, and Lower formations with descending order. The Uppermost formation corresponds to the Tobe formation of Northeast Japan.

* Manuscript received, April 18, 1969.
The geological structure of this mine district has NNW trend of the strikes and the dips of $10^\circ\sim15^\circ$W in general; and the structures are monoclinal and simple.

The Quarternary sediments are found locally, laid on the Tertiary formations with remarkable unconformities. The ore-deposits consist of the "Kuroko" deposit and vein-network type deposit; the former with the hanging wall of the Middle formation occurs in the upper of the Lower formation and is massive or bedded in form, the latter occurs chiefly in the Middle and Upper formations.
The "Kuroko" deposits are constituted with 5 ore bodies, namely, Yunosawa, Higashi-Daikokusawa, Nishi-Daikokusawa, Higashi-Magariyasawa and Nishi-Magariyasawa ore-bodies.

THE HANGING WALL BASALT OF THE ORE-DEPOSIT

The hanging wall basalt of the ore-deposit is the member of the Middle formation of the Nishikurosawa Stage in age and is widely distributed from northeast of Ainai Mine to this district. This basalt is called the "Ainai basalt" in general, with 250 m in thickness on the average.

This rock was formed by successive volcanic activities taken place after sedimentation of the Lower formation, and consists of agglomerate, tuff, or lava flow, and intercalates locally thin mudstone beds.

This basalt is considered lava flow formed at the bottom of sea according to the following characteristic evidences: (1) showing complex of massive lava and pillow palagonite and (2) having distinct pillow structure.

MICROSCOPIC OBSERVATION AND CONSIDERATION

The specimens of 129 were selected, from cores of prospecting bore holes drilled at the basalt zone as shown in Fig. 2.

These specimens show pale green, green, brown and blackish brown in colour and range from hard to soft one. The green coloured group changes gradually to the brown colour, or contains partly fragments of brown coloured group. In the brown coloured groups, in general, cavities and many amygdules are developed well. Amygdules are often filled with quartz, chlorite, calcite and epidote and with prehnite rarely. Pumpellyite was found in altered basaltic rock (Shimazu, 1965). Under the microscope, these specimens show, in general, porphyritic and intersertal textures and have many vesicles.

The writer classified the basalt into the following 5 types on the basis of 2 points as follows:

1. Type A: Phenocrysts of plagioclase, fresh.
   Number of specimens: R-1, 2, 3*(Au), 4(Au), 5, 10, 11 (Au), 12(Au), 13, 14, 17, 26, 44, 58, 75(Au), 76, 84(Au, O1**), 87
Fig. 2. Map showing the location of bore holes

(Au), 97, 100, 101, 102, 103, 104, 106, 121, 122
*(Au)—Phenocryst of augite **(Ol)—Phenocryst of olivine

2. Type B: Phenocryst of plagioclase, altered.
   (a): Laths of plagioclase, fresh
       Number of specimens: R-6, 19, 21, 33, 35, 40, 45, 48, 52, 54, 55, 59,
       61, 62, 63, 64, 65, 68, 70, 72, 73(Au), 74(Au), 77, 83, 85(Au),
       90(Au), 93, 95, 98, 110, 111, 113, 115, 128
   (b): Laths of plagioclase, altered
       This type is strongly altered.
4. Type C: Containing both fresh and altered phenocrysts of plagioclase, but laths of plagioclase are comparatively fresh.
Number of specimens: R-7, 20, 22, 24, 32, 34, 38, 39, 42, 50, 51, 66, 69, 75, 79, 80, 81, 82(OI), 89, 96, 112

5. Type D: Phenocryst, indistinct; laths of plagioclase are fresh.
Number of specimens: R-27, 30, 31, 37, 46, 47, 71, 92, 108, 109, 116, 118, 119, 120, 124, 125, 126, 127

As mentioned above, basalt is divided into type A, B(a), B(b), C and D. In this report, the writer calls type A and D as unaltered zone; B(a), B(b) and type C as altered zone.

The characteristics under the microscope are as in the following.
1. Type A: Fig. 3 (la, b; 2a, b.)
Phenocryst:
Plagioclase: Fresh, in large or small quantity in specimens, well twinned (in albite), but lack of zonal structure, large euhedral to subhedral, platy or columnar shaped 0.5 ~ 0.3 mm in length, generally 1.0 ~ 1.5 mm.

Augite: 0.5 ~ 1.0 mm in size, subhedral to anhedral shaped, cleavage distinct, no pleochroism, twinned rarely, glomero-porphyritic, associated with plagioclase in general, sometimes ophitic in texture enclosing laths of plagioclase.

Olivine: 0.5 ~ 1.0 mm in size, rounded by corrosion and rimmed by red-brown iddingsite.

Groundmass: Coarse grained in general, intersertal and vesicular texture, and remarkable in brown coloured group, composed of yellow or brown coloured palagonite altered from volcanic glass, chlorite, calcite, epidote and magnetite. The laths of plagioclase are small in general, are often needle like shaped or coarse grained. When laths are coarse grained, the width of them is often 0.2 mm; fresh in general, and sometimes shows fluidal texture.

The writer described as "coarse lath", when laths of plagioclase are larger than 0.2 mm in width and 0.5 mm in length; and as "tiny lath", when smaller than the above.

Interstitial materials are mostly chlorite, palagonite altered from volcanic glass, magnetite and interprecipitated fine quartz.

Vesicle: In many cases rounded, comparatively even-grained, 0.2 ~ 0.5 mm
in general size, 2 mm in maximum size and is filled with minerals. Various minerals are found filling these cavities, which are known as amygdules. The filling minerals are generally chlorite, quartz, calcite, epidote and prehnite. As shown in the figure 3, the cavities are filled with single mineral or sometimes with a few kinds of minerals.

In general, chlorite occurs in outer rim and quartz or calcite in inner part of vesicles, or calcite in outer and chlorite in inner. Comparatively small vesicles belonging to green coloured group consist of palagonite and are rimmed by magnetite.

**Epidote:** This mineral occurs sporadically, forms veinlets within the groundmass and fills vesicles sometimes.

**Prehnite:** This mineral generally associates with epidote, and show special bowtie structure or radial arrangement under the microscope filling vesicles sometimes.

**Chlorite:** This mineral is not only interstitial material, replace the groundmass, but also fills vesicles, or replaces mafic minerals, or occurs as veinlets.

**Calcite:** The mode of occurrence is various: that is, this mineral forms network or impregnates within the groundmass, and replaces partly or perfectly phenocrysts of type B and C rocks.

The characteristics mentioned above are those of type A rock, and chloritization and epidotization are recognized as alteration processes. The kinds of alteration of each type of B(a), B(b) and C are the same as type A, but the degree of alteration is much stronger.

2. **Type B(a):** Fig. 3 (3 a, b, 5 a, b, 4.)

**Phenocryst:**

**Plagioclase:** This mineral is 1.0~1.5 mm in length, generally alter to calcite by carbonatization and then to sericite by sericitization.

Only the external form is preserved as the result of perfect alteration, but some of them remain textures and show distinctly albite twinning.

Albitization is also recognized in some plagioclases, though some of them partly altered to chlorite.

**Augite:** The same as type A rock.

**Groundmass:** Intersertal and vesicular textures, etc. are the same as type A, and carbonatization is especially remarkable. As shown in Fig.3(4) under the reflected light, R-45 specimen shows the "coarse lath" texture, and black-opaque interstitial minerals are magnetite.
Fig. 3 Photomicrographs of specimens

1. a, b (R-3) : Showing glomero-porphyritic texture of plagioclase associated with augite. Intersertal and vesicular texture are remarkable in the groundmass. Chlorite rimming inner side of vesicles and magnetite is attractive as interstitial material.

2. a, b (R-76) : Showing remarkable vesicular texture, and indicating special bow-tie structure. Quartz fills vesicles, and prehnite occurs in them also.

3a, b (R-45) : Laths of plagioclase showing intersertal texture aggregate
as "coarse lath". Phenocrysts of plagioclase preserve the albite twinning and are altered to calcite locally. Interstitial material: chlorite, palagonite and fine grained calcite.

4. (R-45) : Black opaque minerals as interstitial material are magnetite (white) under the reflected light microscope. Rectangular form showing "coarse lath" of plagioclase.

5a, b (R-73) : Plagioclase and augite are recognized as phenocrysts. Plagioclase was altered to sericite partly and preserves twinning.
Chlorite filling smaller vesicles was rimmed by magnetite. Epidote was sporadic in the groundmass.

6a, b (R-43): Showing "coarse lath" of plagioclase. Carbonatization is remarkable and calcite is found everywhere as altered and replaced products. Interstitial materials: chlorite, palagonite, magnetite.

7a, b (R-99): Sericitization is remarkable, and both phenocryst and lath are well replaced by sericite.

Interstitial material: chlorite, magnetite.

8a, b (R-82): Olivine is attractive as phenocryst. Among of the phenocrysts of plagioclase are found both fresh and altered. Interstitial material: chlorite, magnetite.

9a, b (R-47): Laths of plagioclase in the groundmass are generally tiny and acicular. Many vesicles are filled by chlorite and quartz.

Interstitial material: chlorite, palagonite, magnetite.

10a, b (R-36): Showing clay and breccia of basalt. Argillization is recognized remarkably around breccia of basalt. Clay minerals are composed of chlorite and sericite.

F: plagioclase  chl: chlorite  Au: augite  S: sericite
ol: olivine  cal: calcite  Q: quartz  pal: palagonite
Pr: prehnite  Ba: basalt  ep: epidote

3. Type B(b): Fig. 3 (6 a, b, 7 a, b)

Phenocryst: The same as type B (a).

Groundmass: All laths of plagioclase are generally coarse, and are altered to calcite and sericite by carbonatization and sericitization, preserving the external form. As to structure and
others, this type is the same as type A.
The degree of alteration of this type is stronger than the others.

4. Type C: Fig. 3 (8 a, b)
Phenocryst and groundmass have the same characteristics as A and B(b), and contain altered and unaltered phenocrysts of plagioclase. The laths of plagioclase in the groundmass are comparatively fresh.

5. Type D: Fig. 3 (9 a, b)
Phenocryst: indistinct.
Groundmass: The laths of plagioclase are generally tiny, fresh, and acicular.
Interstitial material is composed of chlorite, volcanic glass and magnetite. Vesicles are about 0.2mm in diameter and irregular form, and filled with chlorite and quartz. Sporadic quartz as interstitial grains are remarkable.

The characteristics of “Ainai basalt” are as stated above.

The kinds of alteration are enumerated as chloritization, carbonatization, sercitization, albitization and epidotization. Each type of A, B(a), B(b), C and D is affected with the same alteration, though the degree of alterations varies more or less. As the degree of alteration except A and D is strong, the writer named types of A and D as unaltered zone, and types of B(a), B(b) and C as altered zone. The mineral assemblages in the altered zone are as follows:

albite—chlorite
albite—chlorite—calcite
albite—chlorite—epidote

Sericite is often associated with the above mineral assemblage, and prehnite is also recognized sometimes.

Though the degree of alteration varies more or less, those phenomena are recognized uniformly through all of the rock specimens, and are regarded as general alteration.

6. Crushed clay zone formed along the upper of ore deposit:
Fig. 3, (10 a, b)
Number of specimens: R-25, 36, 57

These specimens are pale green to greyish brown in colour, and fine grained, and compact.

Under the microscope, chloritized and sericitized rock fragments are observed as though phenocrysts in the volcanic rocks, and most of the fragments, 1.0~1.5 mm in size, are composed of altered basalt. The groundmass is pale greyish brown coloured and very fine texture like mudstone
Fig. 4 Gross section showing alteration of basalt (A) under the microscope 
[Echilch type of A, B (a), B(b), C and D] (1)
Fig. 4 (2)

1. basalt (A)
2. rhyolitic-dacitic pyroclastics (A)
3. ditto. (B)
4. dacite
5. ore-body
6. The boundary between altered zone and A, D types
7. epidotization zone
8. The boundary between "coarse lath" and "tiny lath"

(Au) ... phenocryst of augite
(ol) ... olivine
(ep) ... epidote
(CO) ... "coarse lath"
and is strongly argillized (chloritization, sericitization). It seems to be quite all right to consider that altered basalt was crushed and argillized along the upper of ore deposit.

As shown in Fig. 4, this zone is formed along the upper part of the Daikokusawa ore body. The experimental results which were obtained in the way described above are shown in Fig. 4.

Consideration on the above alteration is as follows:

1. Altered zones of each type of B(a), B(b) and C are distributed at the upper part of the Daikokusawa and Magariyasawa ore bodies and very thick in depths. The area far from the ore deposit is weakly altered, or consists of unaltered zone of A and D types.

2. Crushed clay zone was recognized along the upper part of the Daikokusawa ore body.

3. Epidotization was recognized within the altered zone as irregular form at the upper part of the Magariyasawa ore body.

4. Epidotized zone was remarkably recognized at the unaltered area, that ranges from middle part to upper part in depth and from No. 160 bore hole to No. 74. This zone is accordingly not in relation to ore-deposit.

5. Altered zone in No. 179 bore hole at Hinokagesawa was recognized from middle to lower part, but each hole of No. 184, 175 and 172 is not altered.

6. Scrutinizingly investigate the inner part of the altered zone, each type of B(a), B(b) and C has not fixed regularity in the arrangements and has sporadically narrow unaltered zone within them.

7. The "coarse laths" of plagioclase are characteristically found at the lower part of altered basalt, that is, the hanging wall side of ore deposit.

8. As mentioned above, the altered zones at the hanging wall of ore deposits are composed, in general descending order, of clay zone, "coarse lath" zone of each type of B(a), B(b) and C, "tiny lath" zone of them and the unaltered zone of each type of A and D.

9. The above distribution of the altered zone shows, in general, that it originates from the zonal structure within the thick rocks. Judging from the altered condition above, this alteration is recognized as general alteration resulting from autometamorphism of basalt.

10. Clay zone formed along the hanging wall side of ore body and strongly argillized zone have, relation to the genesis of ores.

CLAY MINERALOGICAL STUDY AND CONSIDERATION

Specimens were powdered by an agate mortar and were examined by means of X-ray and thermal analysis for qualitative analysis. Tests by X-ray after heating and chemical treatments were not examined.
Table 1 (a) X-ray powder data of monoclinic type.

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*1 Data from Shirozu (1958)
The X-ray Identification and Crystal structures of Clay Minerals.
G. Brown (1961) P. 288
*2 Bore hole No. 179, depth 95.70m~102.70m
*3 Bore hole No. 170, depth 23.60m~27.70m
*4 Q: quartz    F: feldspar

(1) X-ray analysis
In this examination 15Å, 14Å and 10Å reflections were detected remarkably, and the existence of montmorillonite, chlorite and sericite were recognized.

Scrutinizing X-ray powder pattern on chlorite on the basis of A.S.T.M. card and data reported by Shirozu (1959, 1960, 1961, 1962) and Nakamura (1960),
Table 1 (b) X-ray powder date of ortho-hexagonal type

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*1 Data from Shirozu (1958)
*2 Bore hole No. 53. depth 108.30m~110.30m
*3 Py : Pyrite

Both monoclinic and ortho-hexagonal types were detected. Many specimens, taken from basalt and alteration products of mafic minerals generally belong to Fe-Mg-chlorite and to monoclinic type by X-ray analysis (Table 1). However, chlorite of ortho-hexagonal type were also detected in this district. Specimens are classified as in the followings by the characteristics of powder pattern.

1) Monoclinic type
   1) (020) reflection distinct—Mg-type in general (containing Mg-Fe-type)
   2) (020) reflection indistinct—Fe-Mg type (ditto)
Fig. 5 D. T. A. curves of specimens studied (a~d)
(a) Specimens showing distinct reflection of (020), monoclinic type

[II] Ortho-hexagonal type—Fe-type
Chlorite belonging to monoclinic type contains from Mg-type to Mg-Fe-type in chemical component, but the writer expressed those of remarkable (020) reflection as Mg-type on the basis of reports of many experiments. (Hayakawa, Takasawa, 1966)
These data are summerized as follows:
[I] monoclinic (1), (020) reflection distinct.
Studies on the alteration of hanging wall basalt of Furutobe Mine

Fig. 5. (b) Specimens showing distinct reflection of (020), monoclinic type

Number of specimen: R-6, 7, 9, 11, 12, 19, 22, 24, 27, 30, 31, 32, 34, 37, 38, 40, 41, 42, 44, 46, 47, 48, 49, 51, 52, 53, 54, 55, 58, 61, 63, 66, 67, 68, 71, 73, 77, 80, 83, 84, 85, 86, 87, 89, 92, 93, 95, 96, 98, 99, 100, 101, 102, 103, 104, 105, 106, 109, 110, 111, 112, 113, 114, 115, 116, 118, 119, 120, 121, 122, 124, 126, 127, 128

[T] monoclinic (2), (020) reflection, indistinct.

Number of specimen: R-1, 2, 3, 4, 5, 10, 13, 14, 18, 20, 21, 23, 26, 28,
Chlorite has characteristics controlled by chemical components in powder pattern and thermal curve. The writer examined its relation to chemical components by the D.T.A. Mixed layered minerals in the specimens are not detected, but mixed layered minerals of sericite-montmorillonite are found at the underground.

(2) Differential thermal analysis

The D.T.A. curves were taken by automatic thermal analysis at the heating
rate of 10°C per minute for the specimens classified by the powder pattern in order to clarify the relation of thermal curves, chemical components and X-ray powder patterns. Results obtained are shown in Fig. 5.

(I) monoclinic (1), (020) reflection distinct. Fig. 5 (a), (b)

This type belongs to Mg-type in chemical components on the basis of the results of the investigations already reported. The general feature of the D.T.A. curves of these specimens shows the type of chlorite. Three principal peaks were revealed:

(a) a strong and sharp endothermic peak (C₁)
(b) a clear endothermic peak (C₂)
(c) a strong and sharp exothermic peak (C₃)

and the curve from C₂ to C₃ shows characteristically very long and steep vertical S-shaped curve.

This thermal curve explains that chlorite of this type belongs to Mg-type in chemical components.

The above investigation shows distinctly that powder pattern with remarkable reflection of (020) belongs to Mg-type by the D.T.A.

[1] monoclinic (2), (020) reflection indistinct. Fig. 5 (c).
S-shaped thermal curves from C₂ to C₃ of this type are shorter than that of the above type, and temperature of C₁ is slightly lower than that of the above.

Accordingly, this type shows decrease of Mg and increase of Fe in chemical components as compared with the above and belongs probably to Mg-Fe type or Fe-Mg type. The exothermic peaks of C₃ of each R-60, 70, and 81 are not revealed by the appearance of the sharp endothermic peak of calcite at the same temperature.

[II] ortho-hexagonal type. Fig. 5 (d)

The D.T.A. curves of this type revealed distinctly endothermic peak of C₁, but peaks of C₂ and C₃ are indistinct owing to thermal reaction. The curve from C₂ to C₃ forms such a gently S-shaped curve as R-50 specimen. Thermal curves of this type show that chlorite of this type belongs to Fe-type in chemical components. For the peaks of calcite [Fig. 5 (c) (d)], two peaks are recognized. According to the reports of Gruber and Faust, this phenomenon is attributed to the presence of two types of calcite—one is a secondary calcite resulting from the transition of aragonite and the other a primary calcite.

(Mackenzie, 1957)

Summarizing the results of above examination are as follows:

Table 2. The results of DTA examination

<table>
<thead>
<tr>
<th>Classification by X-ray</th>
<th>Mg</th>
<th>Fe</th>
<th>C₁</th>
<th>C₂</th>
<th>C₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoclinic (020) distinct</td>
<td></td>
<td></td>
<td>620°~650°C</td>
<td>840°C</td>
<td>860°C sharp</td>
</tr>
<tr>
<td>Monoclinic (020) indistinct</td>
<td></td>
<td></td>
<td>615°~630°C</td>
<td>830°C</td>
<td>860°C medium</td>
</tr>
<tr>
<td>Ortho-hexagonal</td>
<td>decrease</td>
<td>increase</td>
<td>600°C</td>
<td>830°C</td>
<td>860°C gentle</td>
</tr>
</tbody>
</table>

The above results indicate distinctly that the temperature of endothermic peak of C₁ moves to lower temperature with increasing of Fe and the figure of S-shaped curve from C₂ to C₃ is controlled by a quantity of Mg and specimens classified by X-ray powder pattern shows the same characteristics as by the differential thermal analysis curve.

Scrutinizing on the relation between kinds of chlorite identified by the X-ray and the D.T.A., distribution of clay minerals and ore deposits (Fig. 6) are as follows:

(1) Mg-chlorite is widespread within rock body and then Fe-Mg-chlorite is attractive. On the other hand Fe-chlorite, sericite and montmorillonite are locally.
Fig. 6. Distribution of clay minerals (1)
Fig. 6 (2) Legend.

Mg : Mg-chlorite
Fe-Mg : Fe-Mg-chlorite
Fe : Fe-chloelite
S : sericite

M : montmorillonite
The boundary between Mg-chlorite zone and Fe-Mg-chlorite zone
(2) The clay minerals of the clay zone at the hanging wall of the Daikokusawa ore body are composed of Fe-chlorite and sericite.
(3) Fe-Mg-chlorite is distributed at part of the clay zone.
(4) Fe-Mg chlorite zone is recognized at upper part of the Magariyasawa ore body.
(5) Mg-chlorite zone is mainly distributed at upper part of the above zone and containing Fe-chlorite and Fe-Mg-chlorite locally.
(6) Mg-chlorite zone is widespread at the northern part far from the No. 184 bore hole.
(7) As mentioned above, the zonal distribution of chlorite is recognized at the upper part of the ore deposit. That is, in descending order, Fe-chlorite zone associated with sericite at the upper part of the ore deposit, and Fe-Mg-chlorite zone at the outer part of the above. These zones vary in thickness and might have probably been related to the genesis of ore deposit. At the marginal part of these zones Mg-chlorite zone is distributed thickly and has no relation to the genesis of ore deposit in spite of containing Fe-chlorite and Fe-Mg-chlorite locally.

As is evident from the reports of Shirozu (1959) and Nakamura (1960) on Fe-chlorite, chlorite occurring in veins is rich in Fe and chlorite in the altered zone of veins is generally rich in Fe-Mg. Fe-chlorite is, accordingly, formed by hydrothermal alteration at comparatively low temperature. It seems clear that Fe-chlorite associated with sericite occurred in the clay zone is formed by hydrothermal alteration and is considered to be genetically related to the ore deposits.

CHEMICAL COMPOSITION

The chemical composition of rock types classified by the microscopic observation is shown in the table 3 and 4. From the table, Na₂O, K₂O and CaO are especially quite smaller as compared with those of general basalt, but the amount of MgO is generally larger. The ratio of CaO to MgO varies remarkably owing to the kinds of rock and nature of chlorite. The amounts of MgO in the specimens containing monoclinic chlorite with distinct reflection of (020) are more than 10% and CaO are less than 1%.

The amount of MgO is slightly larger than that of CaO in the specimens containing monoclinic chlorite with indistinct reflection of (020).

Accordingly, it seems true that larger amounts of MgO are derived from chlorite in the specimens containing chlorite with distinct reflection of (020).

DISTRIBUTION OF MINOR ELEMENTS

During the recent years, Ishikawa and Sudo (1957), Ishikawa and Kuroda
Table 3. Chemical composition of each rock type.

<table>
<thead>
<tr>
<th></th>
<th>A (R-76)</th>
<th>A (R-122)</th>
<th>B (a) (R-111)</th>
<th>B (a) (R-70)</th>
<th>B (b) (R-60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>58.52%</td>
<td>49.07%</td>
<td>46.88%</td>
<td>48.57%</td>
<td>46.11%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.90%</td>
<td>1.08%</td>
<td>1.04%</td>
<td>0.77%</td>
<td>0.77%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.87%</td>
<td>16.38%</td>
<td>15.15%</td>
<td>16.77%</td>
<td>16.19%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>4.08%</td>
<td>4.08%</td>
<td>4.25%</td>
<td>4.08%</td>
<td>6.72%</td>
</tr>
<tr>
<td>FeO</td>
<td>4.04%</td>
<td>6.31%</td>
<td>7.70%</td>
<td>4.57%</td>
<td>2.12%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.14%</td>
<td>0.17%</td>
<td>0.62%</td>
<td>0.17%</td>
<td>0.18%</td>
</tr>
<tr>
<td>CaO</td>
<td>5.39%</td>
<td>0.57%</td>
<td>0.13%</td>
<td>6.84%</td>
<td>5.82%</td>
</tr>
<tr>
<td>MgO</td>
<td>6.39%</td>
<td>12.97%</td>
<td>13.51%</td>
<td>7.31%</td>
<td>8.35%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.63%</td>
<td>0.89%</td>
<td>0.81%</td>
<td>1.75%</td>
<td>0.69%</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.38%</td>
<td>0.35%</td>
<td>1.36%</td>
</tr>
<tr>
<td>Ig. loss</td>
<td>3.12%</td>
<td>7.55%</td>
<td>8.80%</td>
<td>8.33%</td>
<td>10.70%</td>
</tr>
<tr>
<td>S</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.65%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total</td>
<td>99.09%</td>
<td>99.07%</td>
<td>99.92%</td>
<td>99.51%</td>
<td>99.01%</td>
</tr>
<tr>
<td>Fe/Mg</td>
<td>1.56%</td>
<td>1.00%</td>
<td>1.11%</td>
<td>1.46%</td>
<td>1.27%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>C (R-51)</th>
<th>C (R-81)</th>
<th>C (R-50)</th>
<th>D (R-12)</th>
<th>D (R-125)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>53.08%</td>
<td>47.13%</td>
<td>62.25%</td>
<td>48.41%</td>
<td>59.82%</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.12%</td>
<td>0.78%</td>
<td>0.88%</td>
<td>1.27%</td>
<td>1.15%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.55%</td>
<td>18.42%</td>
<td>14.47%</td>
<td>16.23%</td>
<td>12.77%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.81%</td>
<td>3.78%</td>
<td>7.76%</td>
<td>4.42%</td>
<td>4.82%</td>
</tr>
<tr>
<td>FeO</td>
<td>3.57%</td>
<td>5.04%</td>
<td>1.26%</td>
<td>6.41%</td>
<td>4.64%</td>
</tr>
<tr>
<td>MnO</td>
<td>0.13%</td>
<td>0.13%</td>
<td>0.06%</td>
<td>0.17%</td>
<td>0.12%</td>
</tr>
<tr>
<td>CaO</td>
<td>0.33%</td>
<td>7.59%</td>
<td>0.98%</td>
<td>0.26%</td>
<td>0.27%</td>
</tr>
<tr>
<td>MgO</td>
<td>12.12%</td>
<td>5.63%</td>
<td>4.94%</td>
<td>12.88%</td>
<td>8.55%</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.96%</td>
<td>1.55%</td>
<td>1.86%</td>
<td>0.47%</td>
<td>0.3%</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.27%</td>
<td>0.01%</td>
<td>0.01%</td>
<td>0.19%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Ig. loss</td>
<td>7.34%</td>
<td>8.52%</td>
<td>4.63%</td>
<td>9.13%</td>
<td>7.04%</td>
</tr>
<tr>
<td>S</td>
<td>0.00%</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Total</td>
<td>99.30%</td>
<td>98.59%</td>
<td>99.10%</td>
<td>99.84%</td>
<td>99.72%</td>
</tr>
<tr>
<td>Fe/Mg</td>
<td>0.75%</td>
<td>1.95%</td>
<td>2.17%</td>
<td>1.04%</td>
<td>1.36%</td>
</tr>
</tbody>
</table>
(1958, 1960) and Ishikawa (1959a, 1959b) reported on minor elements in the altered zone of "Kuroko" deposits.

Shiiikawa (1966) has reported that Ag, As, Ba, Bi, Cd, Co, Cu, Mn, Mo, Ni, Pb, Sb, Sr, Ti, V and Zn are enumerated as minor elements distributing within the hanging and foot wall of ore deposits except main rock forming elements.

All specimens examined to determine the kinds and amounts of minor elements by spectroscopic analysis.

The results are as follows:

1) general common elements ——Cr, Cu, Ga, Mg, Mn, Ni, V.

2) slightly common elements —---Pb, Zn.

3) sporadic elements ————Ag, B, Ba, Mo.

4) undetected elements ———As, Bi, Co, Sb, Sn, Sr.

It is reported that Co, Cr, Ni and V are generally distributed densely in the altered basalt (Shiiikawa, 1966). However, in the Furutobe district, Co is not detected, but Cr, Ni and V are detected densely.

Fig. 7 shows the distribution of minor elements except common elements.

1) Pb and Zn as slightly common elements.

Pb and Zn are widely distributed unrelated to geological formation and rock facies, and resemble to the general common elements. On the point of distribution,
Fig. 7. Distribution of minor elements (excepting general common elements) (1)
Fig. 7. Distribution of minor elements (excepting general common elements) (2)

Legend:
- Cu...Cu very weak
- Cu...Cu very very weak
- Cu...Cu weak
- Cu...Cu very strong
- Cu...Cu medium
- Cu...Cu strong
- Cu...Cu medium
- Cu...Cu very weak

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Pb does not show characteristic variation of strength for the altered zone and ore deposit. Zn is detected strongly near the Daikokusawa ore body, but slightly at the Magariyasawa ore body. In each specimen of bore hole No. 179, Zn is generally detected strongly, and in the lower part of No. 184, 175 and 172 bore holes the same facts are obtained. These bore holes are located at far from the Daikokusawa ore body and along basalt zone and the cores obtained from these holes do not grasp ores.

Therefore, it is very doubtful that strong detection of Pb and Zn is due to the presence of ore body, and especially Pb has not intimate relation to ore deposit.

2) Sporadic elements: Ag, B, Ba, Mo.

Ag is detected irregularly at the A type rock far from the ore deposit. B is detected not only at the caly zone (R-25) at the hanging wall of ore deposit but also at the D type rock near the surface. Ba is detected at the clay zone as B, but at the dacite far from the ore deposit. Mo is detected at the boundary between rhyolitic tuff, dacite and the altered basalt far from the ore deposit. Chlorite does not occur in those specimens. Accordingly, these four elements might have probably no relation to the ore deposit and the altered zone.

The above results are the characteristic distribution of minor elements detected within the altered basalt at the hanging wall of the ore deposit.

Such minor elements as indicating definitely a trend related to altered zone or ore deposits, are not detected, but Zn seems to be effective for the prospecting of mineralized zone, though its occurrence is slightly common.

**SUMMARIZED CONSIDERATION**

Various kinds of alteration are recognized among the altered basalts forming the hanging wall of the Furutobe “Kuroko” deposit as the result of microscopic observation, clay mineralogical study, and chemical and spectroscopic analyses.

Thick rocks were produced by volcanic activities with large amount of magma and caused various rock facies by the degree of cooling owing to its condition of accumulation. The structure of the groundmass of the basalt is almost holocrystalline at the deeper part near the ore body, and porphyritic textures are found gradually at nearer surface and show the texture without phenocrysts formed by rapid cooling near surface.

Concerning the alteration of phenocrysts and the groundmass, the latter is generally altered, but the former is altered or not. Such a phenomenon as this is not attractive.

The main altered minerals of these rocks are chlorite, and chemical components of chlorite determined by X-ray and the D.T.A. are Mg-type and Fe-Mg-type, and there is no difference between the alteration products above-stated
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and the products formed by autometamorphism in basalt or basic rocks. As the altered zone are widely distributed in general, the origin of this alteration is attributed to autometamorphism of basalt.

From the relations among the distribution of clay minerals, characteristics under the microscope and the ore deposit, the following facts are pointed out, though the thickness of the altered zone are variable:

( altered condition observed under the microscope ) ( kinds of clay minerals ) ( alteration )

Unaltered zone as A and D type
"Tiny lath" zone of B(a) ........ Mg-chlorite (Mg-Fe chloride) .... autometamorphism
B(b) and C type
"Coarse lath" zone of B(a), ...... Fe-Mg chlorite
B(b) and C type
Clay zone ..................................Fe-chlorite, Sericite...... hydrothermal alteration
Ore deposit ..................................Fe-chlorite, hydrothermal alteration ore deposit

The above distribution constitutes a kind of zonal distribution, though each zone changes gradually to each other.

The above altered zone are not recognized at the district far from the ore deposit, and are irregular in general.

As mentioned above, chlorite found in ore deposit is all Fe-type and in country rocks is Fe-Mg type. Accordingly it is no doubt that Fe-chlorite associated with sericite in the clay zone is a product formed by hydrothermal alteration.

The above phenomena recognized only at the hanging wall of ore deposit are the alteration by autometamorphism and hydrothermal influence, and have relation to the genesis of ore deposit.

The clay zone consists of breccia of crushed basalt and clay filling up the space of breccia. It is a question that the above crushing movement took place by any kinds of stress, but ore deposits are actually formed under the clay zone.

Judging from the phenomena that clay minerals found generally both in "Kuroko" deposit and in the clay zone are sericite, the ore genesis is due to volcanic activities, subsequent brecciation and the mineralization with hydrothermal solution in later stage.

Thus the same clay minerals occurred in ore body and in wall rocks around the ore deposit.

CONCLUSION

The zonal distributions of chlorite, occurred remarkably in thick basalt at the hanging wall of the Furutobe "Kuroko" deposit by autometamorphism and hydrothermal influence, are enumerated as follows: from surface to the deeper
ore body, Mg-chlorite, Fe-Mg-chlorite and Fe-chlorite respectively. The alteration at the district far from ore deposit is irregular and formed only by the autometamorphism.

The clay minerals of the clay zone along the hanging wall of ore body are composed of Fe-chlorite and sericite. The above phenomena are recognized as alteration having the relation to the genesis of ore.

**ACKNOWLEDGEMENT**

The writer expresses his sincere thanks to Prof. Dr. Tsunehiko Takeuchi and Prof. Dr. Norihisa Hayakawa of the Tohoku University for their helpful instruction in the study.

Many thanks are due to Dr. Takaaki Watanabe, the director of the Central Research Laboratory, who permitted him to publish this work. The writer is indebted to Mr. Eiichi Saito, Manager of Exploration Department and Dr. Masao Abe, Sub-Manager of Tohoku Exploration Office, Mitsubishi Metal Mining Co., Ltd., who gave him hearty assistance in the course of the work.

**REFERENCE**


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(V) Distribution of copper in the altered zone of the Yamabuki deposit, Hanawa Mine. Mining Geol., 10, 29~31 (in Japanese).


古遠部釧山における鉱床上盤玄武岩の変質

高　沢　松　逸

摘　要

古遠部釧山黒鉱鉱床上盤は厚層の玄武岩によって構成されている。この玄武岩は相内釧山より当地域にかけて広い分布を示して発達し、「相内玄武岩」と称され、第三紀中新世の海底噴出岩流である。

本岩につき顕微鏡観察、X線及び示差熱分析試験等により、粘土鉱物の解析を行い、且つ分光分析により微量元素の特性を検討したものでその結果次の様な構成粘土鉱物及び変質状況が判明した。
<table>
<thead>
<tr>
<th>(鏡下の特徴)</th>
<th>(粘土鉱物)</th>
<th>(変質作用)</th>
</tr>
</thead>
<tbody>
<tr>
<td>上 A, D 型無変質帯</td>
<td>Mg-緑泥石</td>
<td>自己変質</td>
</tr>
<tr>
<td>部 B (a). B (b). C 各型細 lath 帯</td>
<td>(Mg・Fe 緑泥石を含む)</td>
<td></td>
</tr>
<tr>
<td>B(a). B(b). C 各型粗 lath 帯</td>
<td>Fe・Mg 緑泥石</td>
<td></td>
</tr>
<tr>
<td>粘土 蕃</td>
<td>Fe・緑泥石・橿雲母…</td>
<td>熱水変質</td>
</tr>
</tbody>
</table>

鉱床上盤に緑泥石の帯状分布が、玄武岩の自己変質及び熱水変質作用により形成され、鉱床に沿う玄武岩の破碎粘土化帯があり、この帯は Fe-緑泥石橿雲母の生成から熱水溶液の影響を受けて居ることが明らかで、鉱床の成因と関連を有する現象と考えられる。