Age and Style of Epithermal Gold Mineralization in the Minamikayabe Area, Southwestern Hokkaido

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Abstract: Epithermal gold mineralization in the Minamikayabe area located on the Kameda peninsula, southwestern Hokkaido, includes the Mitsumoriyama high-sulfidation and Hokko-Minami low-sulfidation systems. The Mitsumoriyama high-sulfidation system consists of advanced argillic alteration which is sub-divided into alunite and kaolinite zones. This advanced argillic alteration grades into propylitic alteration laterally, and with a sericite alteration overprint in, and near to the advanced argillic alteration. The Hokko-Minami low-sulfidation system consists of adularia-bearing quartz veins with adularia alteration envelops. K-Ar ages of alunite, sericite and adularia indicate that the Mitsumoriyama high-sulfidation system was formed at approximately 6.5 Ma, and that the sericite alteration followed on from the advanced argillic alteration at 6.0 Ma, possibly due to an evolving hydrothermal system caused by an intrusion of quartz porphyry beneath the advanced argillic alteration zone. The Hokko-Minami low-sulfidation quartz veins formed at 3.9 Ma, which suggests no direct, genetic relation with the Mitsumoriyama high-sulfidation system. The high- and low-sulfidation epithermal systems in the Minamikayabe area occurred during periods of normal and oblique subduction of the Pacific plate beneath the Northeast Japan arc, respectively. Thus, the change in style of the epithermal gold mineralization in the Minamikayabe area from high-sulfidation to low-sulfidation may have been related to a change in the subduction mode of the Pacific plate.

1. Introduction

Epithermal gold deposits are classified into high- and low-sulfidation types, based on the redox state of sulfur in the epithermal environment (HEDENQUIST, 1987). The high- and low-sulfidation epithermal types are formed by acid and neutral pH hydrothermal solutions respectively, and have different mineral assemblages in the ores and alteration haloes (HEALD et al., 1987). The relationship between these two types has been explained as either a space-dependent evolution of a hydrothermal system relative to the intrusive body which is responsible for the mineralization (proximal high-sulfidation and distal low-sulfidation types) (SILLITOE, 1991; HEDENQUIST and LOWENSTERN, 1994), or a time-dependent evolution of a hydrothermal system (early high- and late low-sulfidation types) due to an invasion of meteoric water into the hydrothermal system during the waning stage of the hydrothermal activity (AOKI et al., 1993a, b).

In 1991 and 1992, the Metal Mining Agency of Japan (MMAJ) estimated the regional gold potential in the Minamikayabe area in southwestern Hokkaido (Fig. 1), where epithermal gold prospects of high- and low-sulfidation types are situated close together. The authors joined the field survey in the Minamikayabe area organized by MMAJ. Based on the results of the field survey and laboratory work, this paper presents the geology, alteration, age of the mineralization, and discusses the relationship between the high- and low-sulfidation epithermal systems of the Minamikayabe area.

2. Geology

The Minamikayabe area is situated on the Kameda peninsula, south of the junction of the Northeast Japan arc and the Kuril arc (Fig. 1). Overlying Mesozoic sedimentary rocks, Neogene and Quaternary volcanic rocks are distributed widely on the peninsula, with epithermal precious-metal and base-metal deposits and sedimentary sulfur deposits located along the Neogene NW-SE trending volcanic chain (Fig. 1).

In the Minamikayage area, the Mesozoic sedimentary rocks are not exposed at the surface. The Neogene strata are divided into the Middle Miocene Shiodomarigawa Formation, Late Miocene Togeshita Pyroclastic Rocks, Pliocene Matsukuragawa

Fig. 2 Composite geological map of the Minamikayabe area, based on the maps of SUZUKI et al. (1969), SUGIMOTO (1958) and MITI (1992).
Table 1 Mineral prospects in the Minamikayabe area after SUGIMOTO (1958)

<table>
<thead>
<tr>
<th>Name of prospect</th>
<th>Metal</th>
<th>Strike &amp; dip of vein</th>
<th>Host rock</th>
<th>Ore &amp; gangue minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kamimori</td>
<td>Cu, Pb, Zn</td>
<td>N60°E, 60°SE</td>
<td>andesite (Shiodomarigawa F.)</td>
<td>py, sph, gal, chalc, qtz</td>
</tr>
<tr>
<td>Osatsube</td>
<td>Cu, Pb, Zn</td>
<td>N50°-60°E, 40°-70°SE</td>
<td>quartz porphyry</td>
<td>py, sph, gal, chalc, bar, qtz</td>
</tr>
<tr>
<td>Mitsumori</td>
<td>Cu, Pb, Zn</td>
<td>N45°-75°E, 50°-70°SE</td>
<td>andesite (Togeshita Pyroclastic Rocks)</td>
<td>py, sph, gal, chalc, bar, qtz</td>
</tr>
<tr>
<td>Yamato</td>
<td>Au, Ag</td>
<td>N45°-65°E</td>
<td>andesite (Shiodomarigawa F.)</td>
<td>py, sph, gal, chalc, qz</td>
</tr>
<tr>
<td>Hokko</td>
<td>Au, Ag</td>
<td>NE-SW</td>
<td>andesite (Shiodomarigawa F.)</td>
<td>py, qz, native gold</td>
</tr>
</tbody>
</table>

Formations and Styagawa Pyroclastic Rocks in ascending order (Fig. 2; SUZUKI et al., 1969). Quaternary andesitic volcanic rocks overlie the Neogene strata.

The Shiodomarigawa Formation consists mainly of alternating beds of siliceous mudstone, siltstone, tuff, tuff breccia and andesitic lavas. The siliceous mudstone in the formation contains radiolarians and marine diatoms (NEDO, 1988) from the Denticulopsis hyalina and Denticulopsis nicobarica zones (14.9-13.5 Ma; KOIZUMI, 1985). This formation is intruded by Middle Miocene NNW-SSE trending dolerite sheets and dikes, Late Miocene diorite porphyries and quartz porphyries (Fig. 2). The Late Miocene diorite porphyries occur along a N-S or NNW-SSE trend, and contain phenocrysts of plagioclase and amphibole in a matrix of plagioclase, amphibole and quartz. The thickness of each intrusion is approximately 1 km. The quartz porphyries intrude the Shiodomarigawa Formation, dolerite intrusions and diorite porphyries forming two parallel bodies in this area with a N45°W strike. The quartz porphyry of the western body does not penetrate through the Togeshita Pyroclastic Rocks completely (Fig. 2). The quartz porphyries consist of phenocrysts of quartz and plagioclase with small amounts of amphibole and augite phenocrysts in a matrix of plagioclase, quartz and K-feldspar, and are thicker than 1 km (SUZUKI et al., 1969). A fission track age for the quartz porphyry was determined at 6.15 Ma (NEDO, 1988). Most parts of the diorite and quartz porphyries have suffered propylitic alteration (SUZUKI et al., 1969).

The Togeshita Pyroclastic Rocks overlie the Shiodomarigawa Formation unconformably, and consist of hyaloclastites and lavas of pyroxene andesite and hornblende-bearing pyroxene dacite. K-Ar ages for the pyroxene andesite of the Togeshita Pyroclastic Rocks in the area are 7.24±0.47 Ma and 7.83±0.51 Ma (MITI, 1992). GANZAWA (1992) also reported 6 fission track ages ranging from 12.0 to 7.4 Ma for the Mitsumoriyama Formation, which is the southern extension of the Togeshita Pyroclastic Rocks.

The Matsukuragawa Formation is exposed in limited areas and unconformably overlies the Togeshita Pyroclastic Rocks. The formation consists mainly of thinly laminated, lacustrine mudstone, tuffaceous sandstone, and intercalated pyroclastic flow deposits of amphibole dacite. The mudstone contains plant fossils, which has a similar assemblage to those in the Pliocene (5-2.5 Ma) Tokachi Group and the Takikawa Group in eastern and central Hokkaido (NEDO, 1988). Interfingering with the Matsukuragawa Formation, the Isoyagawa Pyroclastic Rocks are composed of pyroclastic flow deposits of amphibole-bearing dacite, including welded tuff. The pyroclastic flow deposits are dated at 5.10±2.07 Ma and 4.96±1.24 Ma using the fission-track method (NEDO, 1988). Thus, the sedimentary environment in the Minamikayabe area changed from submarine to terrestrial in the period from ca. 7.2 Ma to 5 Ma. Quaternary volcanic rocks composed of pyroxene andesite, erupted from the Yokotsu and Nakitsura volcanoes, and possibly from the Mitsumori volcano, cover the northwestern part of the Minamikayabe area (Fig. 2).

Rhyolitic dome lavas, a couple of hundred meters wide, were extruded on top of the Shiodomarigawa Formation to the south of the Minamikayabe area (SUZUKI et al., 1969). A quartz porphyry, intruding in the Shiodomarigawa Formation, with a fission track age of 2.5±0.2 Ma has also been reported to the north of the Minamikayabe area (NEDO, 1988).

Three base-metal (Kamimori, Osatsube and Mitsumori) and two precious metal (Yamato and Hokko) prospects are known in the Minamikayabe area (Fig. 2; Table 1). All of these are hydrothermal vein-type and hosted by the andesites of the Shiodomarigawa Formation, the Togeshita Pyroclastic Rocks, or quartz porphyry. These base-metal and
precious-metal deposits have alteration envelopes of quartz, chlorite and sericite (SUGIMOTO, 1958). Sericite situated in an alteration halo associated with a quartz vein of the Yamato prospect is dated at 4.6 Ma and 5.2 Ma by the K-Ar method (Dowa Mining Co., unpublished data). Geochemical prospecting by MMAJ revealed another two gold anomalies in addition to the Hokko and Yamato prospects in the Minamikayabe area, which are named Mitsumoriyama and Hokko-Minami in this paper (Fig. 2).

3. Regional Alteration

The regional alteration pattern is examined within an area 2.5 km by 6.5 km at the center of the Minamikayabe area, which includes the Mitsumoriyama and Hokko-Minami gold-anomalies (Fig. 2). In general, the Miocene rocks in the area are hydrothermally altered, whereas the Quaternary and Pliocene rocks have suffered little alteration. Alteration in the area is divided into alunite, kaolinite, sericite, propylite and smectite zones, based on the mineral assemblages detected by an X-ray diffractometer (XRD) (Fig. 3). The alunite zone is defined by the mineral assemblage of quartz, alunite, pyrophyllite, diaspore, dickite and kaolinite. Rare zunyite and topaz are also sometimes included in the rocks of this zone. These minerals occur in vugs of residual silica, formed from the andesite lavas and hyaloclastites. The alunite zones occur in two separate areas, each being approximately 1 km in diameter and about 4 km apart (Fig. 4). The kaolinite zone contains quartz, dickite and kaolinite ± pyrophyllite, and lacks alunite. The zone fringes the alunite zones, which form the two separate advanced argillic alteration areas (Mitsumoriyama and Nukeishi), and also occurs sporadically in other small areas (Fig. 4). The propylite zone, characterized by an assemblage of sericite, pyrite, chlorite, calcite and K-feldspar. This zone is recognized in two main areas; one is to the south of the Mitsumoriyama advanced argillic area (equivalent to the location of the Mitsumoriyama gold anomaly), and the other is located between the Mitsumoriyama and Nukeishi advanced argillic alteration areas. The propylite zone, characterized by an assemblage of sericite, pyrite, chlorite, calcite and K-feldspar (Fig. 3), has the widest distribution in the area (Fig. 4). The smectite zone is characterized by the presence of pyrite and smectite. This zone is situated in the west of the survey area (Fig. 4). K-feldspar is detected mainly in the propylite and sericite zones where quartz veins are distrib-
4. Epithermal Gold Mineralization

An outline of the Mitsumoriyama and Hokko-Minami gold anomalies is presented in this section. The Mitsumoriyama area is characterized by advanced argillic alteration (high-sulfidation type; Hedenquist, 1987), and the Hokko-Minami area includes adularia-quartz veins in the propylite zone (low-sulfidation type; Hedenquist, 1987) between the advanced argillic alteration areas.

4.1 Mitsumoriyama gold anomaly

The area of the Mitsumoriyama advanced argillic alteration is elongated in a N60°E orientation (Fig. 4). The host rock is composed of the andesitic lavas and hyaloclastites of the Togeshita Formation. A dike-like body of hydrothermal breccia, approximately 10 m thick, is found at the center of the zone. The drill hole (4MAOS-2; Figs. 2 and 4), penetrating the advanced argillic area, revealed that the alunite zone is mushroom-shaped as a whole in cross section, and approximately 300 m thick (Fig. 5). The lower part of the alunite zone consists of residual silica, of which pores are filled with alunite and other alteration minerals. Zunyite and topaz are detected near to the center of the alunite zone. Barite and pyrite are both common near to the margins of the zone. The sericitic alteration overprints the alunite zone with kaolinite haloes (Fig. 5). The quartz veinlets are between 0.1 and 6 cm thick (most < 2 cm) and are distributed in the residual silica-alunite zone. Between 1 ppm and 2 ppm of gold was detected in the quartz veinlets within the alunite zone. Homogenization temperatures of fluid inclusions in quartz from a quartz veinlet exposed at the surface vary from 240°C to 290°C with a mode of 250°C (Aoki and Watanabe, 1995).

4.2 Hokko-Minami gold anomaly

Quartz veins and veinlets, hosted in the andesitic lavas and hyaloclastites of the Togeshita Pyroclastic Rocks are distributed in the propylite zone between the Mitsumoriyama and Nukeishi advanced argillic areas. These quartz veins and veinlets have a NE-SW strike (Fig. 4) and range between 1 and 30 cm in width. The veins include disseminated pyrite and adularia bands, with haloes of smectite, sericite-smectite mixed layer clay and adularia, overprinted...
on the propylitic alteration. Electrum and sphalerite rarely occur in these veins. The drill hole (4MAOS-1) revealed that gold-bearing quartz veins are concentrated and occur within an adularia-overprinted propylitic alteration zone, whereas no quartz veins thicker than 10 cm exist within calcite-dominant propylitic andesites (Fig. 6). Gold grades in the veins exposed at the surface and in the drilled core attain up to 17 ppm (MITI, 1992). Homogenization temperatures of fluid inclusions in quartz in veins range from 150°C to 340°C with a mode of 210°C (MITI, 1992; WATANABE and SCOTT, 1996). Salinity of the fluids within these inclusions is generally lower than 2 wt.% (NaCl equivalent), although relatively saline fluids (3 to 12 wt.%) are included in the inclusions of which homogenization temperatures are between 160°C and 200°C (WATANABE and SCOTT, 1996). WATANABE and SCOTT (1996) explained that the saline fluids were formed by boiling and condensation of the source fluids whose salinity is approximately 1 wt. %.

5. Age of Alteration and Gangue Minerals

5.1 Samples analyzed

Two alunite-bearing samples (YW-400, YW-401) from the alunite zone of the Mitsumoriyama area, a sericite-bearing sample (YW-63) from the sericite zone to the south of the Mitsumoriyama area, and an adularia-bearing sample (YW-402) from a quartz vein from the Hokko-Minami area (Fig. 4) were dated using the K-Ar technique in order to determine the age of alteration and mineralization.

Both of the alunite-bearing samples were taken from different surface outcrops, close to each other (approximately 30 m apart). The samples are composed of alunite-rich residual silica, and YW-400 and YW-401 contain euhedral coarse-grained alunite (0.1-0.3 mm in size) and fine-grained alunite.
(\(<0.1\) mm), respectively. The alunite was separated using a dental drill and the composition was checked by XRD analysis. The alunite in sample YW-400 has clear growth bands within individual crystals that are composed of a natroalunite (100 mol \%) and alunite (50 mol \%)-natroalunite (50 mol \%) solid solution. The alunite in sample YW-401 consists of a homogeneous alunite (60 mol \%)-natroalunite (40 mol \%) solid solution (Fig. 7).

The sericite-bearing sample (YW-63) is a white-colored andesitic hyaloclastite from the Togeshita Pyroclastic Rocks exposed at the surface, and has undergone severe alteration with only quartz, sericite and pyrite being detected by XRD. The sericite was separated by hydraulic elutriation.

The adularia-bearing sample (YW-402) is a fragment taken from the surface exposure of a well-banded quartz vein (approximately 30 cm-thick), which contains 8.4 ppm of gold and 51.8 ppm of silver. Adularia was separated from a band composed of a fine-grained adularia-quartz mixture using a dental drill.

All of the separated samples contained small amounts of quartz as well as the minerals required for the dating.

5.2 Results

The result of the K-Ar measurements are shown in Table 2. The constants used for the age calculations are \(\lambda_B=4.962\times10^{-10}/y\), \(\lambda_e=0.581\times10^{-10}/y\) and \(^{40}\text{K}/K=0.01167\) atom.\% (Steiger and Jäger, 1977). The calculation for the measurement error (1\(\sigma\)) was followed according to Nagao et al. (1984). The K-Ar measurements were performed twice on each sample, and we have used the age with the least air contamination for each sample. The ages obtained are interpreted to be the age of mineral precipitation due to the reaction between the hydrothermal solutions and host rocks. The ages of the alunite (6.59±0.38 Ma and 6.53±0.19 Ma) correspond to each other within the limits of error, in spite of the different occurrence of the alunites. The age of the sericite (5.97±0.17 Ma) from the sericite zone is slightly younger than those obtained for the alunites. The adularia age (3.91±0.11 Ma) is clearly younger than those of the alunites and sericite. All the obtained ages for the alteration are younger than the ages of the host rocks (7.24±0.47 Ma and 7.83±0.51 Ma).

![Fig. 7 X-ray diffraction patterns of the alunite samples (YW-400 and YW-401) used for the K-Ar dating. The composition of alunite can be calculated, based on the diffraction angle of (006). The line profiles in the figure indicate (006) of the alunite samples.](image)

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Locality (Latitude, longitude)</th>
<th>Analyzed material</th>
<th>K wt%</th>
<th>Rad. (^{40}\text{Ar}) (10(^4)cc/g)</th>
<th>K-Ar age (Ma)</th>
<th>Air Contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>YW-400</td>
<td>Mitsumoriyama ((N41°53′50″,E140°52′33″))</td>
<td>Alunite</td>
<td>1.80±0.05</td>
<td>46.0±2.26</td>
<td>6.59±0.38</td>
<td>73.7%</td>
</tr>
<tr>
<td>YW-401</td>
<td>Mitsumoriyama ((N41°53′49″,E140°52′32″))</td>
<td>Alunite</td>
<td>3.52±0.07</td>
<td>90.4±4.46</td>
<td>6.61±0.35</td>
<td>73.6%</td>
</tr>
<tr>
<td>YW-63</td>
<td>South of Mitsumoriyama ((N41°53′44″,E140°53′14″))</td>
<td>Sericite</td>
<td>7.48±0.15</td>
<td>172±3.56</td>
<td>5.97±0.17</td>
<td>43.9%</td>
</tr>
<tr>
<td>YW-402</td>
<td>Hokko-Minami ((N41°53′50″,E140°53′47″))</td>
<td>Adularia-quartz mixture</td>
<td>3.48±0.07</td>
<td>52.7±1.08</td>
<td>3.90±0.11</td>
<td>42.9%</td>
</tr>
</tbody>
</table>
The ages suggest that the advanced argillic and sericitic alteration occurred at ca. 6.5 and 6.0 Ma, respectively, and that the gold-bearing quartz vein formed at 3.9 Ma.

6. Discussion

6.1 Relation of the high- and low-sulfidation types

The geology and alteration in the Minamikayabe area indicate that the eastern part of the area has been eroded more deeply than the western part, where the Pliocene and Quaternary rocks remain and the smectite alteration is preserved. The homogenization temperatures in the quartz and the assemblages of the alteration minerals show that the gold mineralization both of the high- and low-sulfidation types occurred within an epithermal environment (<320°C) (WHITE and HEDENQUIST, 1990).

Recently, HEDENQUIST et al. (1995) revealed that a single hydrothermal system which evolved over space and time was responsible for forming the porphyry and high-sulfidation ore bodies at the FSE-Lepanto hydrothermal system in the Philippines. During the early stages of the porphyry intrusion, a gas-rich vapor separated from the magmatic fluid that had exsolved from the melt. The vapor ascended and was absorbed by the shallow meteoric water overlying the porphyry, resulting in the generation of a hot, acidic solution, due to disproportionation of SO$_2$ to form H$_2$SO$_4$ and H$_2$S at temperatures below approximately 400°C (ARRIBAS, 1995). This acidic solution altered the upper portions of the volcanic edifice, forming a cap of advanced argillic alteration. The hypersaline magmatic liquid and its associated mineralization was subsequently overprinted by a hydrothermal system with an increased component of meteoric water, forming a later stage of quartz-sulfide veins and sericite alteration (HEDENQUIST et al., 1995). In the FSE-Lepanto hydrothermal system, the time difference between the Mitsumoriyama and Hokko-Minami hydrothermal systems is at least 2.1 million years, which cannot be explained as being due to the evolution of a single hydrothermal system. Therefore, the high- and low-sulfidation types, represented by the Mitsumoriyama and Hokko-Minami hydrothermal systems, respectively, do not have a direct genetic relation as proposed in the model of HEDENQUIST and LOWENSTERN (1994).

6.2 Tectonic setting and the epithermal gold mineralization

Subduction mode is regarded as one of the major factors that controls the stress field in an overriding plate (CROSS and PILGER, 1982), and there is a close relation between the style of epithermal gold mineralization, stress field and subduction mode recognized in the circum-Pacific volcanic arcs: For example, high-sulfidation mineralization tends to occur in an intermediate or weakly compressive stress field under normal subduction, and low-sulfidation mineralization in an extensional or intermediate stress field under oblique subduction (WATANABE, 1995). If we assume that the Hawaiian volcanic chain, which is the trajectory of the Hawaiian hot spot (JACKSON et al., 1975) has been the subduction direction of the Pacific plate beneath the Northeast Japan arc, then the subduction direction rotated clockwise from N90°W at 10.6 Ma to N66°W at 6.3 Ma, followed by a rapid rotation from N66°W.
at 6.3 Ma to N55°W at 6.1 Ma. Subsequently, the rotation direction changed counterclockwise from N51°W at 5.8 Ma to N65°W at 2.6 Ma (Fig. 8). Due to these changes in the subduction direction, the subduction mode of the Pacific plate beneath the Northeast Japan arc changed from normal (10.6 Ma-6.2 Ma) to oblique (6.2 Ma-3.6 Ma) (Fig. 8). The change of the subduction mode should have decreased the convergent rate normal to the Northeast Japan arc, because the absolute subduction velocity is estimated to have been constant during this period (JACKSON et al., 1975). This change in convergent rate might have been responsible for a change in the stress field of the upper crust of the Northeast Japan arc; a more compressive regional stress field is expected during the periods of normal-subduction from 10.6 Ma to 6.2 Ma and from 3.6 Ma to 1.5 Ma, than the periods of oblique-subduction from 6.2 Ma to 3.6 Ma and from 1.5 Ma to the present (Fig. 8).

The Mitsumoriyama high-sulfidation hydrothermal system in the Minamikayabe area and the other high-sulfidation systems in the Kameda peninsula (Kobui and Tokiwamatsu; Fig. 1; WATANABE and AOKI, 1996) were formed during the periods of normal subduction, whereas the low-sulfidation systems (Hokko-Minami and Yamato) occurred during the period of the oblique subduction (6.2-3.6 Ma) (Fig. 8). Thus, in the Kameda peninsula, there may be a relation between the style of the epithermal mineralization and the subduction mode of the Pacific plate. It is concluded that the high- and low-sulfidation epithermal systems in the Minamikayabe area are not genetically related to each other, but that the Pliocene low-sulfidation system was overprinted onto the Late Miocene high-sulfidation system. This change in style of the epithermal gold mineralization might be ascribed to the different regional stress fields related to the change in subduction mode of the Pacific plate beneath the Northeast Japan arc.

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References


**資源学：**

西北北海道南藻部地域の浅熱水性金鉱化作用の年代と様式

渡辺 宽・青木正博・中島信久

要旨：西北北海道，亀田半島に位置する南藻部地域の浅熱水性金鉱化作用には三盛山高硫化水系を北光南低硫化水系が含まれる。三盛山高硫化系は明礬石帯とカオリニット帯に細分される酸性変質帯からなる。この酸性変質帯は側方にプロピライト帯に続移し、総雲母変質の重複が変質帯の内部および周辺部に認められる。北光南低硫化系は氷長石変質を伴う氷水石含有石灰脈からなる。明礬石・総雲母・氷長石のK-Ar年代は三盛山高硫化系が約6.5Maに形成され、総雲母変質帯の形成は、酸性変質帯の下部に石英塩岩が貫入することにより形成された一つの熱水系の進化により説明される。北光南低硫化系の石英脈は3.9Maに形成されており、三盛山高硫化系との直接の成因関係を示さない。南藻部地域の高硫化水系と低硫化水系はそれぞれ東北日本弧への太平洋プレートの直交沈込みと斜め沈込みの時期に形成されている。このことは、南藻部地域の高硫化水系から低硫化水系への浅熱水性金鉱化作用の様式の変化が、沈込み様式に関係していることを示唆する。