Title	Study on Wall Rock Alteration Related to Polymetallic Vein-type Deposits, with Special Reference to the Toyoha Mine, Southwest Hokkaido, Japan
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Degree Grantor	北海道大学
Degree Name	博士(理学)
Dissertation Number	乙第3828号
Issue Date	1990-12-25
DOI	https://doi.org/10.11501/3051980
Doc URL	https://hdl.handle.net/2115/49546
Type	doctoral thesis
File Information	000000236665.pdf

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Abstract

The Toyoha mine possessing a number of hopeful ore-veins is situated in the suburbs of Sapporo city. The mine has been exploiting polymetallic ores containing abundant lead, zinc, silver and accessory gold, copper, tin, tungsten and indium.

Geology of the mining area was re-investigated and new stratigraphy has been accomplished by the present author. Country rocks of the deposits are extensively subjected to various grades of alteration, which were divided into two; diagenetic and hydrothermal origins, then the hydrothermal alteration halo enveloping the ore-veins were precisely studied, i.e. mode of occurrence of the halo, petrochemistry of the altered rocks, mineral chemistry of chlorite and other alteration minerals are reported in this paper. Using sericites, K-Ar ages of the altered rocks were also verified.

Results obtained were compared with some typical polymetallic deposits in Japan, and presence of common features in many respects has been confirmed between them. Thus the characterization of the wall rock alteration related to the formation of polymetallic vein-type deposits has been accomplished.

Newly obtained informations regarding above-mentioned subjects led to a conclusion that the Toyoha deposits might have been formed by repeated activities of ascending hydrothermal solutions in the periods of Pliocene to Pleistocene.

1. Introduction

A number of vein- and kuroko- type deposits occur in the Green Tuff Region of Hokkaido and inner belt of northeast Honshu, Japan. Country rocks of these deposits are wholly altered showing various grades of alteration. The alteration is believed to be caused not only by diagenesis but by ascending hydrothermal solutions. Hence, alterations are duplicated nearby the vein- and kuroko- type deposits. Consequently, if a method to discriminate the diagenesis from the hydrothermal alteration were accomplished, it could be contributed to the exploration work for the ore deposits concerned.

Many studies of wall rock alteration have been made at kuroko mining area of northeast Honshu with a purpose of obtaining new method to prospect kuroko deposits. For example, Yoshida and Utada (1968) distinguished the alteration by diagenesis from other alterations based on the mineral assemblage of altered minerals and mode of occurrence of them using many drilling core-samples from the kuroko field in the Odate basin. Otagaki et al. (1969) also discriminated the alterations by burial diagenesis and by hydrothermal solutions in the Shakanai mine. Furthermore, Utada and Ishikawa (1973) disclosed a restricted distribution of alternating hydrothermal alteration zones through investigations of regional alteration, and emphasized that analcime zone was very useful as an indicator of exploration of kuroko deposits in the Nishiaizu district. Afterward, various methods for the kuroko prospecting were proposed, for example, sulfur and magnetic susceptibility haloes method (Hashiguchi and Usui, 1975), altered index method (Ishikawa et al., 1976). Presence of Na_2O poor dacite (Date et al., 1979), zonal distribution of alteration minerals (Date and Watanabe, 1979), low Na_2O anomaly (Hashiguchi et al., 1981), Cu-Pb-Zn haloes (Yamada and Hashiguchi, 1982) were also proposed as valuable indicators to delimit target for prospecting of kuroko deposits and they gained great success. The above-mentioned results led us to a conclusion that wall rock alteration research is very important for the exploration of kuroko deposits.

On the other hand, study on wall rock alteration related to vein-type deposits is not abundant compared with the case of kuroko deposits. Hunahashi and Yoshimura (1966) advanced wall rock alteration research on some vein-type deposits including Toyoha mine. They classified the alteration in the Green Tuff Region into three types; (1) regional alteration, (2) local hydrothermal alteration, and (3) alteration associated with veins. The first type, characterized by extensive propylitization (chlorite+albite+calcite assemblage) was a precursor of the latter two types. The second type is characterized by nearly spheroidal mass in which alteration zones of albite+chlorite+epidote-, chlorite+albite+epidote+quartz-, and sericite+quartz+pyrite assemblage are present in parallel to each other. These alteration minerals were formed by interaction of hydrothermal solution and the propylitic rocks. The third type occurs within the area of local alteration, and is characterized by an extinction of original rock texture due to the formation of chlorite+sericite+quartz+mixed-layer minerals.

The third type represents the latest stage alteration. Okabe and Bamba (1976) reported the mode of occurrence and the rock properties of the propylite mass exposing at the center of the Toyoha mining area, and attempted the alteration zoning in the Toyoha mine. Tsukada and Uno (1980) recognized hydrothermal alteration halo at the Ohe mine. They concluded that sericite-quartz zone was very useful as an indicator for the exploration in the mine. In the Toyoha mine, Sawai (1984) subdivided hydrothermal alteration into several alteration zones, furthermore, Sawai (1986a) discriminated the alterations caused by diagenesis and by hydrothermal solutions.

The Toyoha mine had been long regarded as a typical epithermal Pb-Zn ore deposits in the Green Tuff Region since Akome and Haraguchi (1963)'s work. Recently, however, minerals containing tin, tungsten and indium have been found one after another, and the Toyoha deposits are now regarded as a polymetallic vein-type (Yoshie et al., 1986). It is also verified that the Toyoha deposit is common to polymetallic ore deposits occurred in the Non-Green Tuff Region such as Akenobe (Sawai, 1988), Ikuno (Narita and Sawai, 1988) and Ashio (Sawai, 1984) mines from the view point of wall rock alteration research. The formation age of the Toyoha deposits has been estimated to be middle Miocene mainly based on the age of the host rock (e.g., MITI, 1972). However, Marumo and Sawai (1986) suggested that the mineralization might have continued until Pliocene. As time goes on, exploitation of the deposits advances to deeper level and outer side, and consequently it has been become more clear that the Toyoha mine is not epithermal vein-type deposit related to the Green Tuff activity of Miocene age, but polymetallic vein-type one which is younger than the Green Tuff activity.

Therefore, it is surely profitable for the future exploration of the Toyoha mine to make re-examination of wall rock alteration on the basis of the new concept that the Toyoha deposits belong to polymetallic ore deposit. For that purpose, the alteration intricately duplicated was first divided by the alteration mineral assemblages, then, the distribution and the mode of occurrence of the classified altered rocks were geologically re-investigated in both field and underground. Secondly, characterization of each alteration zone was made through chemical compositions of the altered rocks by means of XRF, and chemistry of major alteration minerals by means of EPMA. Finally, physical properties of major alteration minerals are examined by means of X-ray diffraction. The results were compared with other polymetallic ore deposits.

2. Mineralization in the Shakotan-Toya District

The Toyoha mine is situated in central part of the metallogenic province of Neogene Tertiary period in west Hokkaido (Saito et al., 1967; Bamba, 1977). The metallogenic province in question is divided further into three subprovinces; western edge of Oshima peninsula, central zone of the peninsula and Shakotan-Toya district (Saito et al., 1967)(Fig. 2.1).

In the first subprovince, Au-Ag-Cu-Pb-Zn-Fe vein-type and replacement-type deposits occur around basement blocks. The second subprovince has plenty of exhalative-sedimentary manganese ore deposits in a sedimentary basin with a thick pile of normal marine formation of Miocene age. The third subprovince characterized by violent volcanisms and upheaval movements includes many polymetallic ore deposits of fissure-filling type which are zonally arranged around Shakotan dome (Narita et al., 1965) or Jozankei quartz porphyry (Yajima and Okabe, 1971).

There are many reports regarding the zonal distribution of ore deposits in the Shakotan-Toya district. For example, Akiba (1958) reported the presence of two belts arranged on both

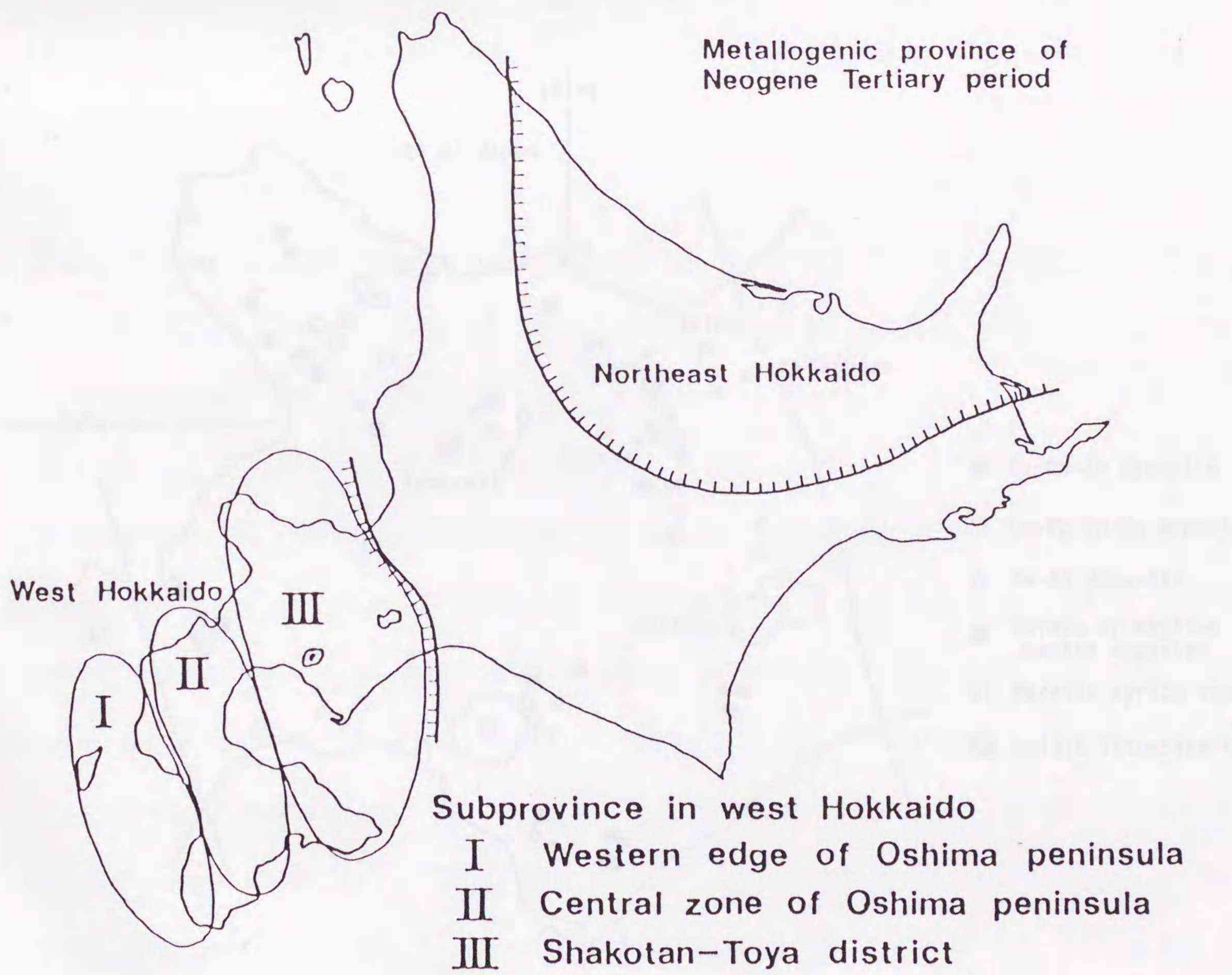


Fig.2.1 Metallogenic province of Neogene Tertiary period in Hokkaido (Saito et al., 1967).

sides of Jozankei quartz porphyry, that is, Au-Ag belt on the east side and Cu-Pb-Zn belt on the west side. Narita et al. (1965) showed a zonal arrangement around Tertiary granitoids, such as Mn-(Cu)-Pb-Zn zone, Cu-Pb-Zn zone, massive iron sulfide and barite zone from inner to outer side (Fig. 2.2). Some of gold and silver ore deposits are dispersed throughout the area independently of this zonation.

Yajima and Okabe (1971) and Yajima (1977, 1979) reported that well arranged zonal distribution around Jozankei quartz porphyry is observed in the Teine-Chitose area, i.e. Pb-Zn

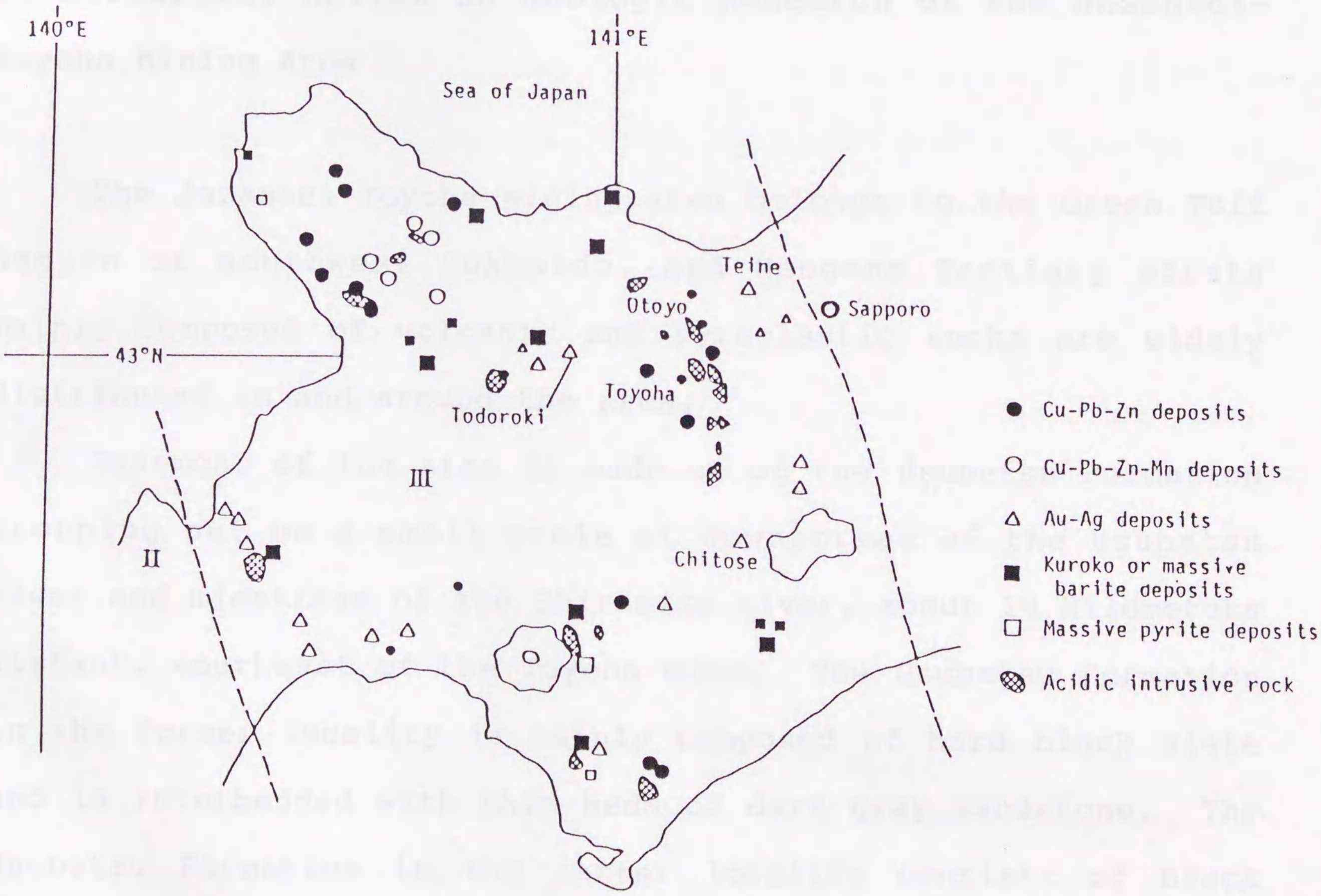


Fig.2.2 Distribution of base metal deposits in the Shakotan-Toya district after Yajima (1979). Metallogenic subprovinces II and III shown in Fig.2.1 are bordered by dashed lines.

vein-type deposits are situated in the central part surrounded by the outer belt of Au-Ag vein-type deposits (Fig. 2.2). Kuroko and massive barite deposits occur at the outer periphery. However, the ages of formation of kuroko and vein-type deposits at southern part of the Shakotan-Toya district are middle Miocene and late Miocene to Pliocene, respectively (Marumo and Sawai, 1986), and it became clear that the age of formation of each deposit is different. Therefore, it may be considered that kuroko deposits are excluded from this zonation.

3. Historical Review on Geologic Research of the Jozankei-Toyoha Mining Area

The Jozankei-Toyoha mining area belongs to the Green Tuff Region of southwest Hokkaido, and Neogene Tertiary strata mainly composed of volcanic and pyroclastic rocks are widely distributed in and around the area.

Basement of the area is made up of the Usubetsu Formation cropping out on a small scale at downstream of the Usubetsu river and midstream of the Shiramizu river, about 10 kilometers distant, southwest of the Toyoha mine. The Usubetsu Formation in the former locality is mainly composed of hard black slate and is interbedded with thin beds of dark gray sandstone. The Usubetsu Formation in the latter locality consists of black slate and light green arkosic sandstone (MITI, 1972). Although age of the Usubetsu Formation is unknown because no fossil is obtained from that strata, the Formation has been estimated to be pre-Cretaceous (Doi, 1953) or pre-Tertiary (MITI, 1972) from the feature of lithofacies. Recently, fission track age of late Oligocene (26.5±2.1 Ma) was obtained from tuff covered by slate of the Usubetsu Formation in the midstream of the Shiramizu river (Koshimizu and Narita, 1987). They asserted from the fact that all of the Usubetsu Formation was not always formed after late Oligocene, thus, reexamination on the dating is necessary.

Outline of stratigraphy of Neogene Tertiary System which unconformably covers the basement in the Jozankei-Toyoha area was given first by Doi (1953). Then, Akome and Haraguchi (1967) reported a revised stratigraphy based on detailed field work and underground survey in the Toyoha mine. Ultimate stratigraphy of the area was almost accomplished by Miyajima et al. (1971) and it has been scarcely corrected until today (Fig. 3.1). However, age of each Formation has been only presumed by comparison with the standard stratigraphy of Neogene Tertiary System in southwest Hokkaido (Nagao and Sasa, 1934), and both of fossil and radiometric ages are very scant. Description of the Formations except for Koyanagizawa, Motoyama and Nagato Formations which are wall rocks of the Toyoha deposits has been made only by Doi (1953) and MITI (1972). Nomenclature and age for each Formation were different according to some investigators, and the stratigraphy in question has been complicated. Stratigraphy of Neogene Tertiary in the Jozankei-Toyoha mining area is indispensable for the consideration of the formation age of the Toyoha deposits.

Recently, Watanabe and Iwata (1986) redefined the Motoyama

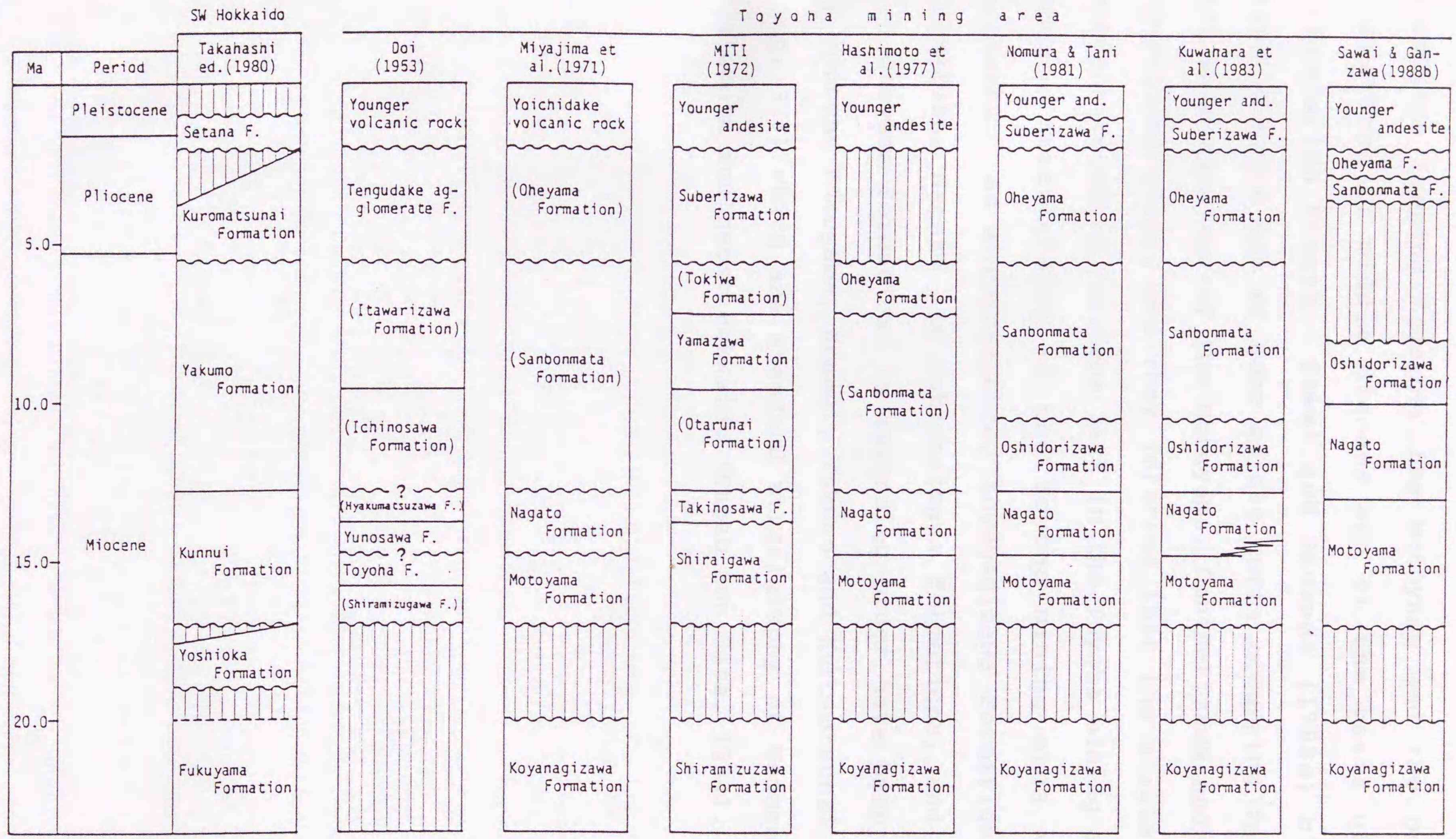


Fig.3.1 Geologic columns for the correlation of the Neogene Tertiary System in the Jozankei-Toyoha area.

Formation lumping together the Motoyama and the Oshidorizawa Formations of middle Miocene age on the basis of study of radiolarian fossil. Sawai and Ganzawa (1988a, b) measured fission track age of some acidic tuffs occurring in the area, and made each age of the Motoyama, Oshidorizawa and Sanbonmata Formations clear, and they inferred that the strata of latest Miocene to early Pliocene lack in the Toyoha mining area. From these, stratigraphy of the Toyoha mining area was fairly arranged. As a consequence, Koyanagizawa Formation, Motoyama Formation, Nagato and Oshidorizawa Formations, and Sanbonmata and Oheyama Formations in ascending order have been correlated to Miocene Fukuyama, Kunnui, Yakumo and Kuromatsunai Formations (Fig. 3.1) which are standard stratigraphy of Neogene Tertiary System in southwest Hokkaido (Nagao and Sasa, 1934).

4. Toyoha Polymetallic Ore Deposits

4.1 Geology of the Toyoha mine

Neogene Tertiary strata around the Toyoha mine consist mainly of andesitic to rhyolitic lavas, dikes and pyroclastic rocks. They are divided into Koyanagizawa, Motoyama, Nagato, Oshidorizawa, Sanbonmata and Oheyama Formations and Younger andesite in ascending order (Fig. 4.1). Above nomenclature of each Formation depends on Kuwahara et al. (1983). These strata show a monoclinic structure which strikes almost N-S and dips 10° to 30° W (Fig. 4.2), and have no distinct fold structure except for slight disorder at the vicinity of faults and dike rocks.

Period		Stratigraphy	Column	Rock facies	F.T. age (Ma)
Neogene Tertiary	Pliocene	Younger andesite		Two pyroxene andesite lava	1.9*
		Oheyama Formation		Two pyroxene andesite lava	
		Sanbonmata Formation		Dacite lava and pyroclastics	3.3±0.2
	Miocene	Oshidorizawa Formation		Alternation of acidic tuff and mudstone	8.8±0.3
		Nagato Formation		Andesite lava and pyroclastics	
		Motoyama Formation		Stratified acidic tuff, tuffaceous sandstone, mudstone and conglomerate	13.3±0.9 14.2±0.4
		Koyanagizawa Formation		Basaltic andesite and pyroclastics	

* after IGARASHI et al.(1978)

Fig.4.1 Stratigraphical sequence of the Toyoha mine.

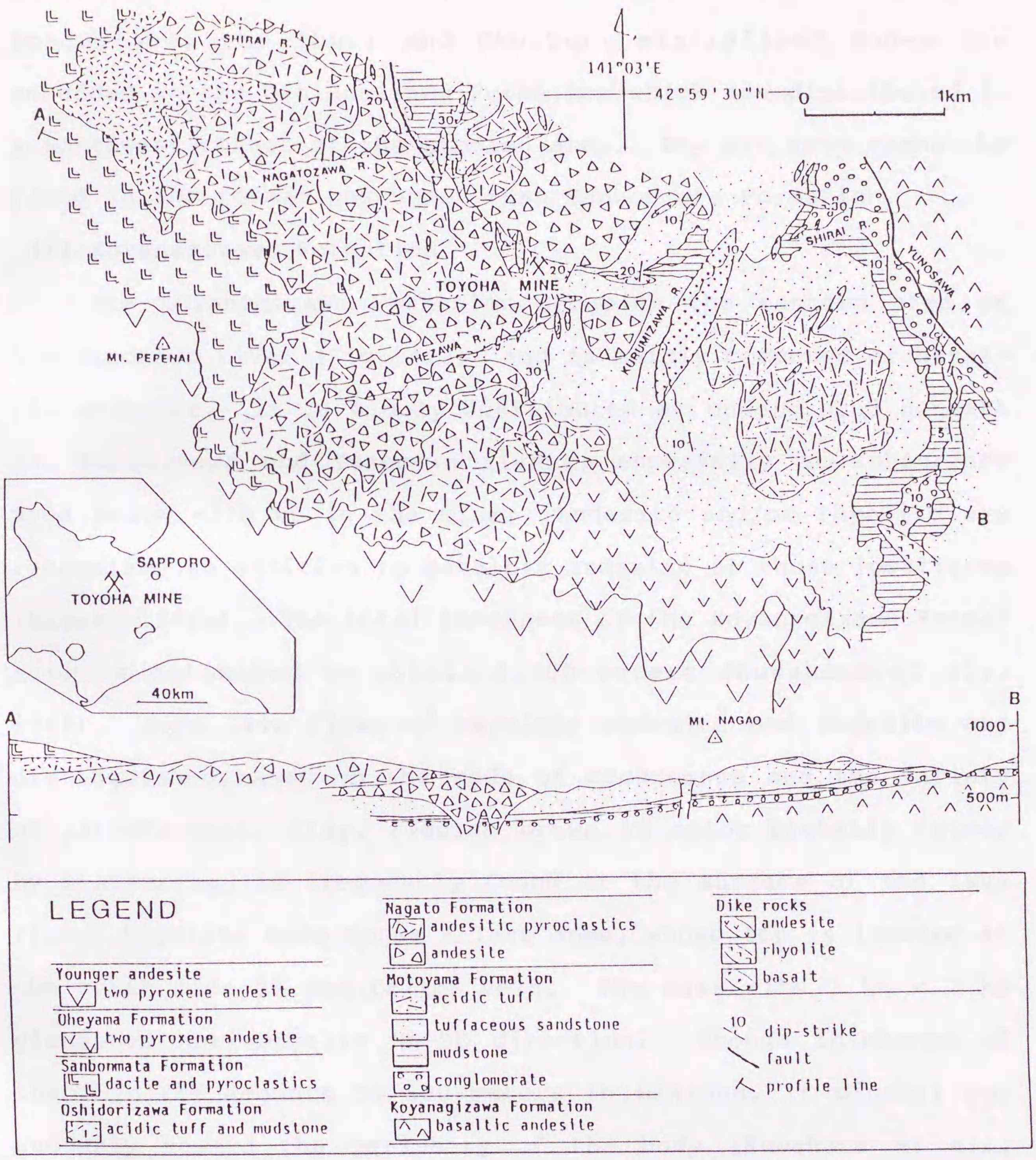


Fig.4.2 Geologic map and profile around the Toyoha mining area.

The country rocks of the Toyoha deposits are Koyanagizawa, Motoyama and Nagato Formations. Besides the preceding three formations, the Iburi and Okuiburi mineralized zones are embedded in the Oshidorizawa Formation which are distributed in a northwest corner of the studied area. Any ore vein cannot be found in the formations upper than Sanbonmata Formation.

(1) Koyanagizawa Formation

The Koyanagizawa Formation occupies the eastern area of the Yunosawa river (Fig. 4.2), and is mainly composed of basaltic andesite. It is widely distributed at underground beneath the Kurumizawa and Yunosawa rivers, especially at subsurface area below -300 mL in the mine. Andesite and/or rhyolite are recognized in addition to basaltic andesite at those localities (Sawai, 1986a). The total thickness of the Koyanagizawa Formation is estimated to attain 1,000 meters (Kuwahara et al., 1983). Some lava flows of basaltic andesite and andesite are distinguished based on the mode of occurrence and the variety of lithofacies. Clay, reddish brown in color probably caused by weathering, is frequently found at the surface of the lava flow. Rhyolite mass forms a lava dome, whose top is located at the north side of the Tajima vein. The mass with 3 km x 2 km elongates horizontally NW-SE direction. Though thickness of the rhyolite amounts to 500 meters in maximum, it pinches out suddenly toward the periphery of the body (Kuwahara et al., 1983).

(2) Motoyama Formation

The Motoyama Formation is widely distributed in the eastern side of the investigated area and in subsurface area between -150 mL and -350 mL. It unconformably covered the Koyanagizawa Formation with a basal conglomerate, though it occurs in fault contact with the Koyanagizawa Formation in the eastern side. It consists of conglomerate, sandstone, mudstone, tuffaceous sandstone and acidic tuff in ascending order (Fig. 4.1). It is presumed that the total thickness is about 400 meters.

Conglomerate is mainly composed of middle-grained pebble of rhyolite, basaltic andesite and andesite which were derived from the Koyanagizawa Formation and the matrix of the conglomerate is made up of green sandstone. Sandstone comprises coarse- and fine- grained materials. The former looks green and is similar to the matrix of the conglomerate. The latter looks gray to dark gray and is more or less tuffaceous and alternates with mudstone. Mudstone is black to dark gray. Tuff dominates over step by step in the upper portion of tuffaceous sandstone and the tuffaceous sandstone changes gradually to acidic tuff toward upper. Acidic tuff is green to white in color and is fine-grained.

Fossils of plant and marine shell are rarely found in mudstone of the Motoyama Formation. It has been pointed out that fossil fauna found in conglomerate of the Motoyama Formation is similar to Vicarya fossil fauna from middle Miocene strata in southwest Hokkaido (MITI, 1972). Watanabe and Iwata (1986) reported that the age of mudstone of the Motoyama Formation is about 12 to 15 Ma on the basis of study of radiolarian fossil from the mudstone. Fission track ages of 14.2±0.4 and 13.3±0.9 Ma were obtained from the acidic tuff by

Sawai and Ganzawa (1988b). All of their ages show that the Motoyama Formation was formed in middle Miocene epoch.

(3) Nagato Formation

The Nagato Formation is widely distributed in western part of the studied area and in subsurface area below -150 mL, and it consists of autobrecciated andesite lava and andesitic pyroclastic rocks such as tuff breccia. It conformably lies on the Motoyama Formation. Total thickness of this formation is over 400 meters. Andesite lava forms several lava domes in the area (Fig. 4.2). Surface and periphery of the lava dome are frequently brecciated. The structure reflects an evidence of volcanic activity in water. Lower part of the lava dome changes to massive andesite dike. Various mode of occurrence of the andesite is observed in the subsurface. Such a peculiar mode of occurrence of rock-body implies that magma ascended within a vent first, then, the vent extended showing funnel-shape controlled the mode of occurrence of the andesite. Such volcanic activity yielded various mode of occurrence of the andesite, i.e. dike-shaped body at lower part, but funnel shaped one at upper part as pointed out by Yoshitani (1970) and Okabe and Bamba (1976).

(4) Oshidorizawa Formation

The Oshidorizawa Formation which conformably overlies the Nagato Formation is distributed in upstream of the Shirai and Nagatozawa rivers (Fig. 4.2). It consists mainly of acidic tuff and tuffaceous mudstone associated with thin bed of conglomerate in the lowermost part. The total thickness measures over 150 meters. Pebbles of the conglomerate are angular or subangular and the size of them is mostly fine to middle. Matrix is made up of acidic tuff. The acidic tuff is light green to grayish white in color and quartz phenocrysts of about 1 millimeter in diameter are scattered. The Oshidorizawa Formation is not country rock of the Toyoha deposits, but is a country rock of the Iburi and Okuiburi mineralized zones. Numerous quartz-pyrite-sphalerite-galena veins are found in the preceding zones. Fission track age of 8.8±0.3 Ma (late Miocene) has been obtained from the acidic tuff (Sawai and Ganzawa, 1988b).

(5) Sanbonmata Formation

The Sanbonmata Formation covering unconformably the Nagato and Oshidorizawa Formations is distributed at the heights along ridge of western part of the mapped area (Fig. 4.2). It comprises dacite and dacitic pyroclastic rocks, over 150 meters thick. Dacite is gray to greenish gray in color and scattering quartz phenocrysts of 1 to 2 millimeters in diameter are observed. Age of the dacite was previously regarded as Miocene (e.g., Kuwahara et al., 1983) (Fig. 3.1), but Sawai and Ganzawa (1988a) have reported fission track age of 3.3±0.2 Ma corresponding to Pliocene.

(6) Oheyama Formation

The Oheyama Formation unconformably overlies the Motoyama and Nagato Formations in the south part of the studied area. It is characterized by the presence of two pyroxene andesite and the thickness measures more than 180 meters. Relationship between the Oheyama Formation and the underlying Sanbonmata Formation is unknown because the boundary of both Formations is unobservable in the investigated area, so that, geologic column concerning the Oheyama and Sanbonmata Formations in Fig. 4.1 is due to Kuwahara et al. (1983).

(7) Younger andesite

The Younger andesite lava occurs along the ridge from Mt. Pepenai to Mt. Nagao. This lava covers unconformably the Nagato, Sanbonmata and Oheyama Formations (Fig. 4.2). It consists mainly of two pyroxene andesite and the thickness is over 250 meters. The lava is called "Flat lava" (Akiba et al., 1966; Hunahashi, 1966) because of the peculiar mode of occurrence that forms flat plateau at the peaks of around 1000 meters above the sea level. Fission track age of the Nagaoyama flat lava measures 1.9 Ma (Igarashi et al., 1978).

4.2 Polymetallic ore deposits of the Toyoha mine

According to Kuwahara et al. (1983), the Toyoha mine has produced refined silver (1,422 t), lead (304,000 t) and zinc (781,000 t) since the beginning of this century until 1982. Toyoha deposit is one of the largest lead-zinc-silver vein-type deposits in Japan. The Toyoha deposits have been regarded as typical epithermal ore veins of fissure-filling type by many authors (e.g., Akome and Haraguchi, 1963; Haraguchi and Tajima, 1969; Hashimoto et al., 1977). However, since the first discovery of tin minerals from the Izumo vein (Yajima, 1977), various minerals containing tin, tungsten, indium, bismuth and molybdenum were found one after another (Narita et al., 1977; Ohta and Yajima, 1977; Kojima et al., 1979; Yajima and Ohta, 1979; Ohta, 1980a, b; Sugaki and Hayashi, 1986; Kase, 1987;

Ohta et al., 1987; Yajima et al., 1987) and the Toyoha deposits are now regarded as polymetallic vein-type (Yoshie et al., 1986).

The exploitation of the Toyoha mine started from the discovery of an ore vein (Harima vein) at the Shirai river around 1900. Now, an area of 6 km^2 extending within 3 km in E-W direction and 2 km in N-S is being mined. The deposits consist of more than fifty veins (Fig. 4.3) and exploration is still progressing with successful results such as discovery of

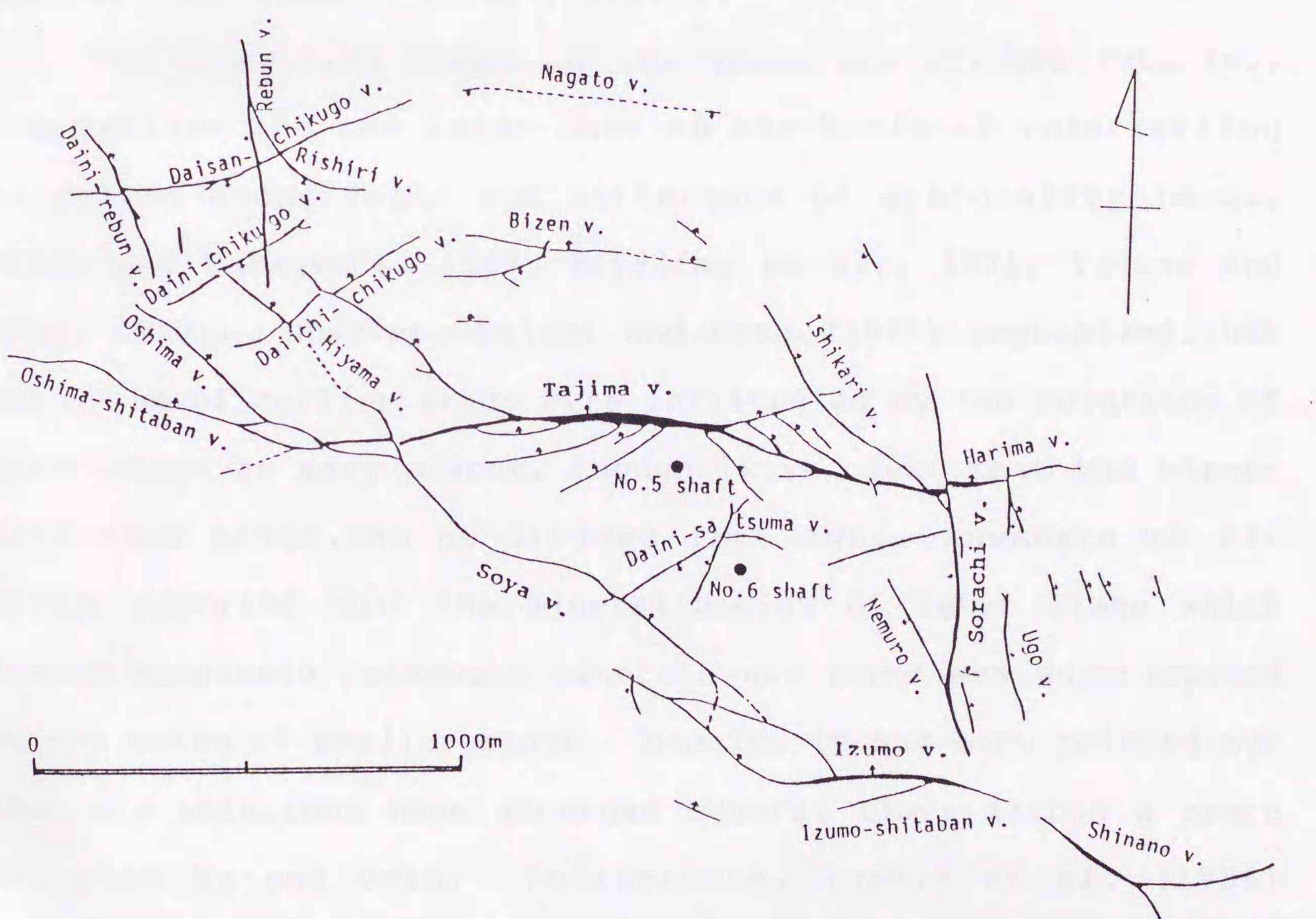


Fig.4.3 Disposition of veins in the Toyoha deposits quoted from Narui et al. (1988).

hopeful Shinano vein (Narui et al., 1988; Kanbara et al., 1989). The veins are now exploited from 0 mL (550 meters above sea level) to -450 mL and are confirmed to extend downward until -600 mL by diamond drilling (Tani et al., 1985).

Among the fissure systems embedding ore veins, four of them are large scale in both lateral and vertical extends (Fig. 4.3), these are Oshimashitaban-Tajima-Harima veins (E-W system), Soya vein (NW-SE), Izumo vein (E-W) and Sorachi vein (N-S) and all fissures are related to normal fault with few lateral slip (Yoshie et al., 1986).

The deposition stages of the veins are divided into two, the earlier and the later ones on the basis of intersecting relations among veins and difference of ore quality (e.g., Akome and Haraguchi, 1963; Miyajima et al., 1971; Yajima and Ohta, 1979). However, Yajima and Ohta (1979) emphasized that the veins of earlier stage were infiltrated by the solutions of later stage at many places, though it is clear that the mineralization stage can be divided into two. Kuwahara et al. (1983) reported that the mineralization of later stage which formed manganese carbonate minerals was sometimes superimposed on the veins of earlier stage. Namely, it has been pointed out that ore solutions have ascended several times within a space occupied by one vein. Furthermore, Yoshie et al. (1986) divided the mineralization stage into seven and asserted the presence of polyascendant solutions related to the formation of the deposits. The I-II and III-VII stages of Yoshie et al. (1986) are correspond to the earlier and later stages, respectively.

Yajima and Ohta (1979) concluded that the ore solutions formed the veins of earlier stage had ascended from the south-eastern lower site of the deposits and moved toward north-western upper site, that is, from the Harima vein to the Tajima vein. On the veins of later stage, the way of ore solutions was considered that the solutions moved from Izumo-Soya-Oshima veins to Sorachi-Nemuro-Ishikari veins (Yajima and Ohta, 1979). On the other hand, the way from lower Izumo-Soya-Soyabunki-Satsuma veins to lower Izumo-Sorachi-Ishikari veins was proposed by Kuwahara et al. (1983). Besides, another way of ore solutions were estimated by Kanbara et al. (1989), i.e. they proposed an opposite direction on a transfer of ore solutions from the lower Izumo to Shinano veins based on zonal distribution of metal elements around eastern part of the lower Izumo vein such as stages III, IV, V, VI and VII from inner to outer side.

Main ore minerals of the Toyoha deposits are galena, sphalerite and pyrite. Chalcopyrite, tetrahedrite, pyrrhotite, arsenopyrite, hematite and magnetite as well as silver, tin, indium, bismuth, tungsten and cobalt minerals are found as accessory minerals. Gangue minerals are quartz, calcite, rhodochrosite, chlorite, sericite and kaolin mineral.

The earlier stage mineralization which formed Tajima and Harima veins is characterized by simple mineral paragenesis of pyrite-sphalerite-galena with abundant quartz and associated silver sulfide minerals (Fig. 4.4). Sorachi and Izumo veins, formed by the later stage mineralization, are located at south-eastern part of the vein swarm. These veins are characterized

vein	general assemblage	characteristic assemblage
Tajima	pyrite-sphalerite-galena-quartz-(chalcopyrite)-(tetrahedrite)-((pyrrhotite))	argentite-((cassiterite-canfieldite)) ((electrum))-galena ((jamesonite)) in a vug
Harima	pyrite-hematite-magnetite argentite-quartz, native silver	pyrite-marcasite-arsenopyrite ((electrum))-sphalerite, -pyrite, -galena sphalerite-(wurztite)-galena-(Pb·sulphosalt-Ag sulphosalt) sphalerite-((wolframite))-quartz (graphite)
Soya	pyrite-sphalerite-galena-carbonates-(chalcopyrite-tetrahedrite) pyrite-(marcasite-pyrrhotite) galena-Ag sulphosalt, ((hematite-magnetite))	sphalerite-((cassiterite)) pyrrhotite-marcasite-arsenopyrite-pyrite-native arsenic-berthierite-Pb sulphosalt* stibnite-berthierite**
Izumo	pyrite-marcasite-arsenopyrite-sphalerite-wurztite-galena-chalcopyrite-tetrahedrite-(pyrrhotite)-quartz	sphalerite-cassiterite-stannite-wolframite pyrite-marcasite-arsenopyrite-pyrrhotite-sphalerite-galena-Pb sulphosalts zinc-star in chalcopyrite (graphite)
Sorachi	((hematite-magnetite)) galena-Ag sulphosalts	sphalerite-cassiterite-stannite sphalerite-galena-Pb sulphosalt (graphite)

* in a veinlet of NW-SE trend. ** in Oshimashitaban vein. ( ): minor amount, (( )): rare

Fig.4.4 Mineral association in the representative veins of the Toyoha mine after Yajima and Ohta (1979).

by massive zinc-sulfide ores containing tin, tungsten and indium minerals as well as silver sulfosalts (Fig. 4.4). Soya and Oshima veins, the later ones, situated at northwestern part of the deposits contain abundant carbonates. Thus the conspicuous zonal distribution of metal elements from southeastern toward northwestern parts of the deposits is recognized (Yajima and Ohta, 1979). On gangue minerals, abundant kaolin mineral and calcium-containing minerals in addition to quartz and chlorite are characteristically present from southeastern and northwestern parts of the deposits, respectively. So that, the zonal arrangement of gangue minerals which is consistent with above-mentioned zonation of ore minerals is recognized (Ohta and Marumo, 1985).

Filling temperatures obtained from liquid inclusions in quartz and sphalerite from several ore veins of the Toyoha deposits are limited within the range from 150°C to 250°C (Tokunaga, 1970; Shikazono, 1975; Enjoji and Takenouchi, 1976; Yajima and Ohta, 1979). Filling temperatures of the Izumo vein are somewhat higher than those of the other veins, ranging from 200°C to 300°C (Yajima and Ohta, 1979). Ore deposition at a slightly higher temperature is regarded as one of the factors for the unique ore-mineral assemblage of the Izumo vein.

5. Alteration Zoning

All rocks of the Koyanagizawa, Motoyama, Nagato and Oshidorizawa Formations embedding ore veins have been hydrothermally altered to various grades. On the other hand, the overlying Sanbonmata and Oheyama Formations have been altered in addition by diagenesis or geothermal activity. Alteration minerals in samples of over one thousand, collected from subsurface area of the Toyoha mine, some drill holes (Fig. 5.11) and outcrops in and around the Toyoha mine were identified by X-ray diffraction method.

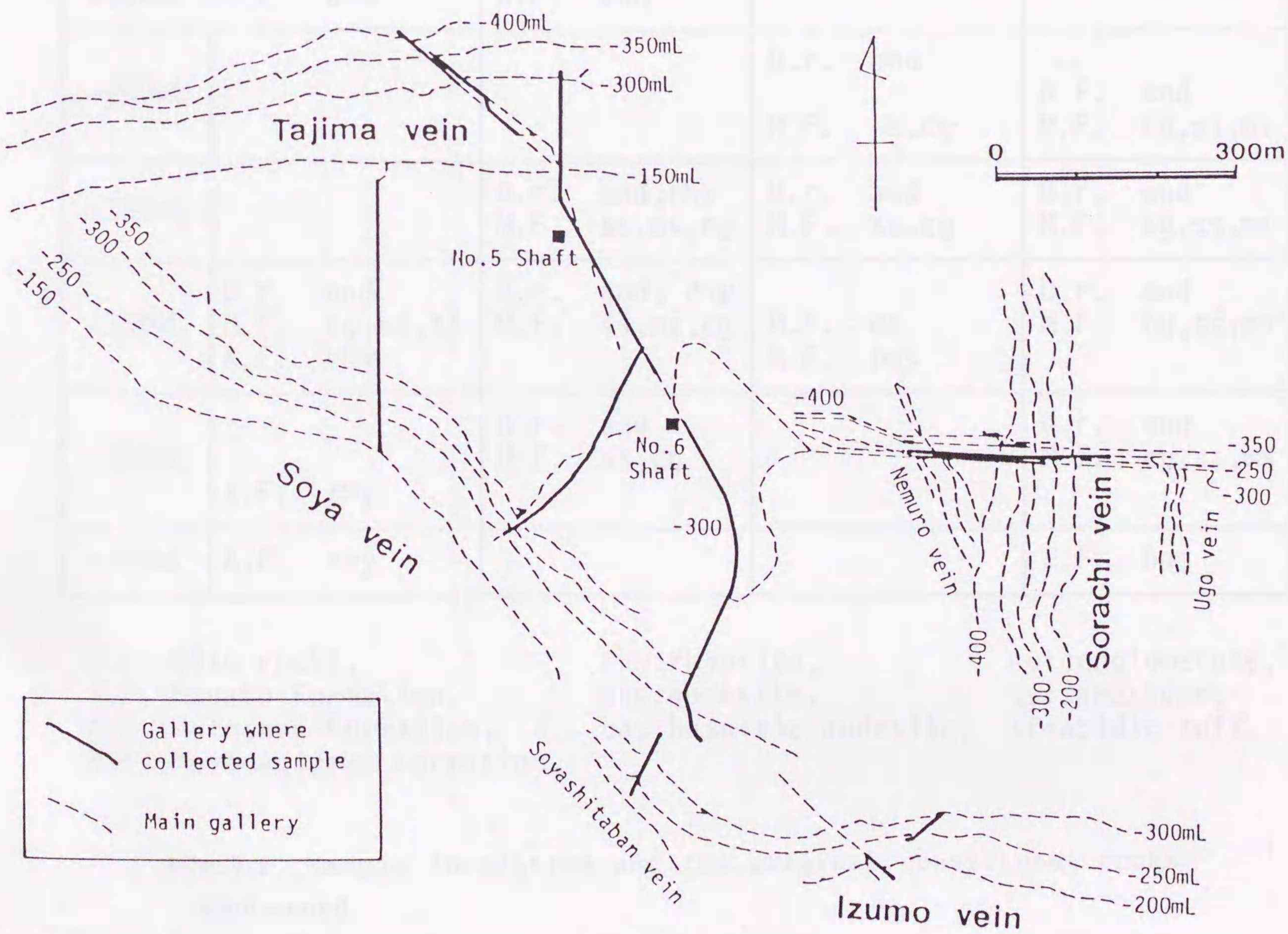


Fig.5.1 Underground route showing the locality of samples for this study at each level of the Toyoha mine.

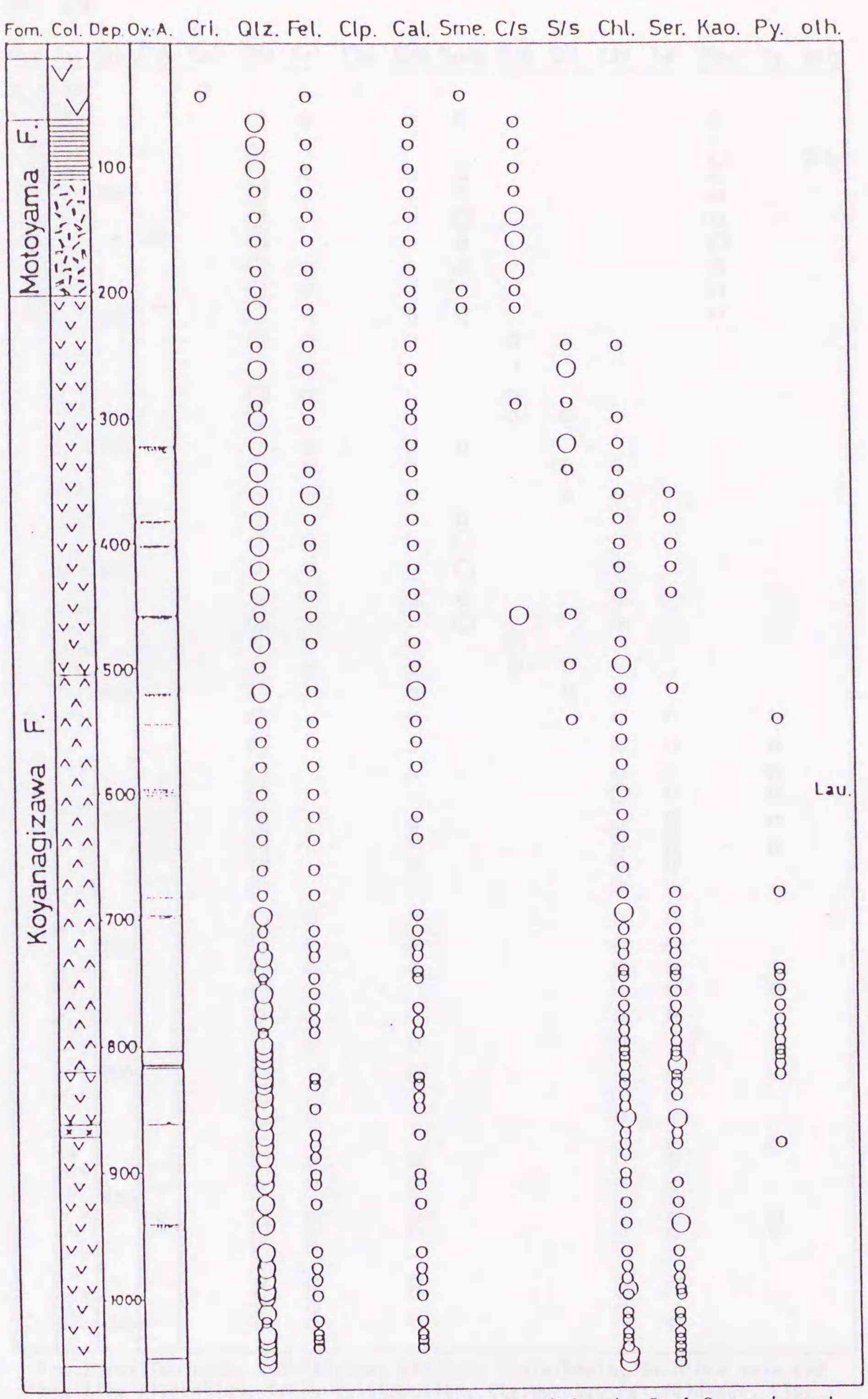
About three hundred wall rocks of both hanging and foot walls were obtained from six main crosscuts at -150, -200, -250, -300, -350 and -400 mL in the Tajima, Soya, Izumo and Sorachi veins (Fig. 5.1). Samples were generally collected at small interval such as several ten centimeters at adjacent to ore vein, then the sampling interval was gradually widened in proportion of the distance from the ore vein. Wall rocks collected show a great variety including volcanic and sedimentary rocks as shown in Fig. 5.2.

	Tajima vein	Soya vein	Izumo vein	Sorachi vein
-150mL	N.F. and	N.F. and		
-200mL			D.r. and M.F. ss,cg	N.F. and M.F. cg,ss,ms
-250mL		D.r. and,rhy M.F. ss,ms,cg	D.r. and M.F. ss,cg	D.r. and M.F. cg,ss,ms
-300mL	D.r. and M.F. cg,ss,tf K.F. rhy	D.r. and, rhy M.F. ss,ms,cg	M.F. ms K.F. bas	D.r. and M.F. cg,ss,ms
-350mL	K.F. rhy	D.r. and M.F. ss,cg		D.r. and M.F. cg,ss,ms
-400mL	K.F. rhy			K.F. bas

D.r.:Dike rocks, rhy:rhyolite, cg:conglomerate,
N.F.:Nagato Formation, and:andesite, ss:sandstone,
M.F.:Motoyama Formation, bas:basaltic andesite, tf:acidic tuff,
K.F.:Koyanagizawa Formation.

Fig.5.2 Sample localities and the original constituent rocks concerned.

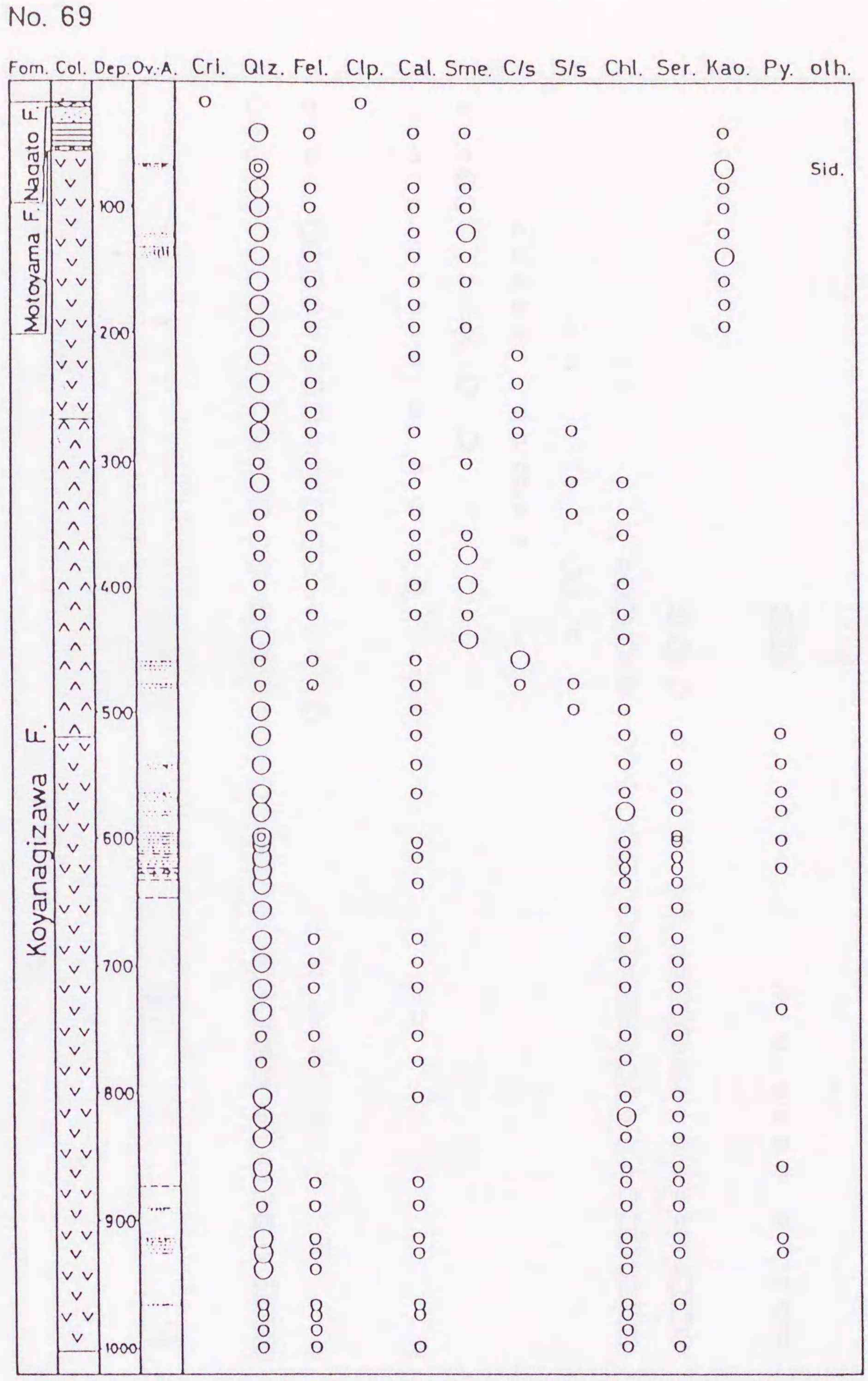
No. 68



Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Cri:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Lau:laumontite.

○common, o rare, argillic alteration, —— ore vein.

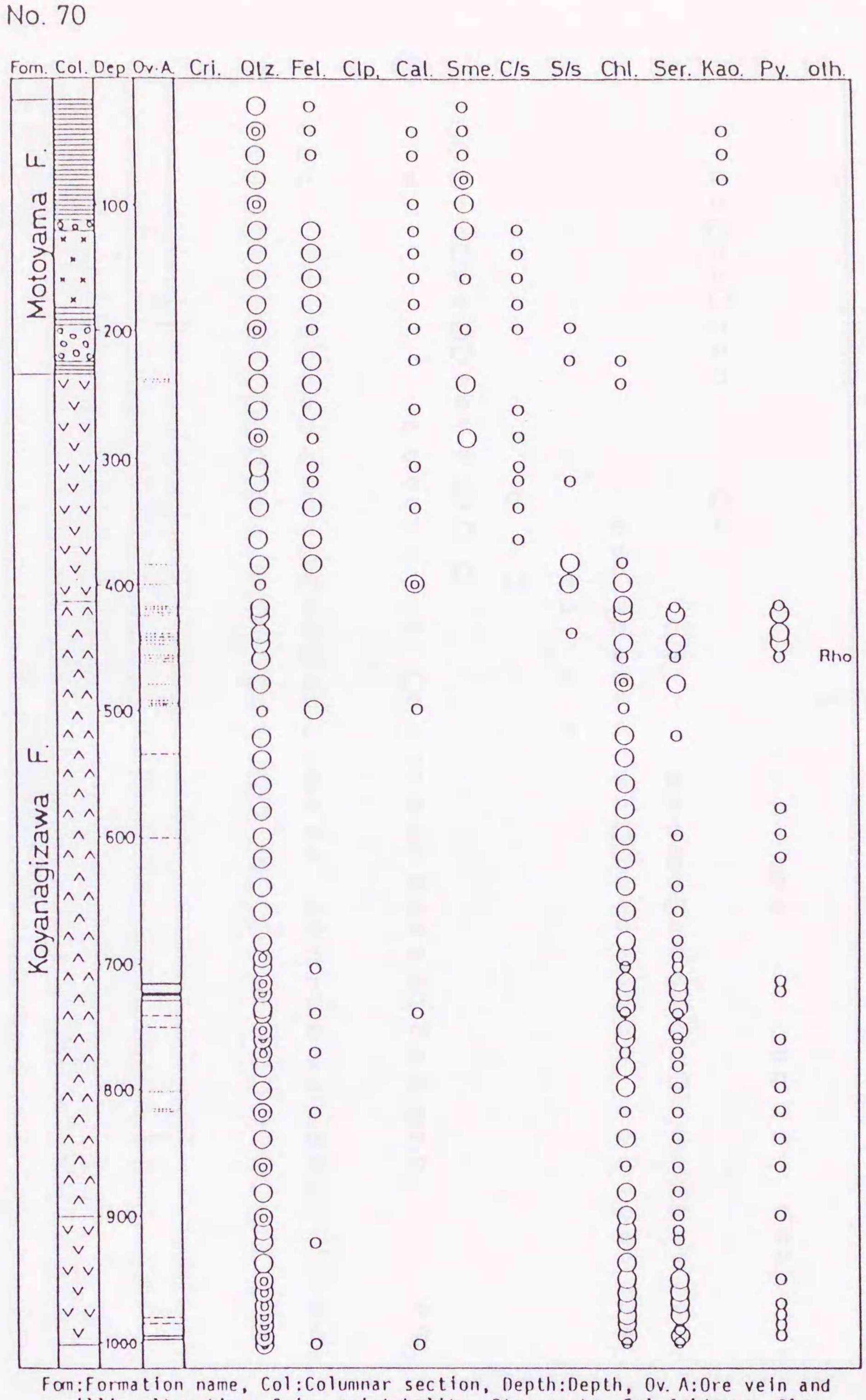
Fig.5.3 Mineral composition of core-sample from drill hole No.68.



Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Cri:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Sid:siderite.

◎large, ◯common, o rare, argillic alteration, ----ore veinlet.

Fig.5.4 Mineral composition of core-sample from drill hole No.69.

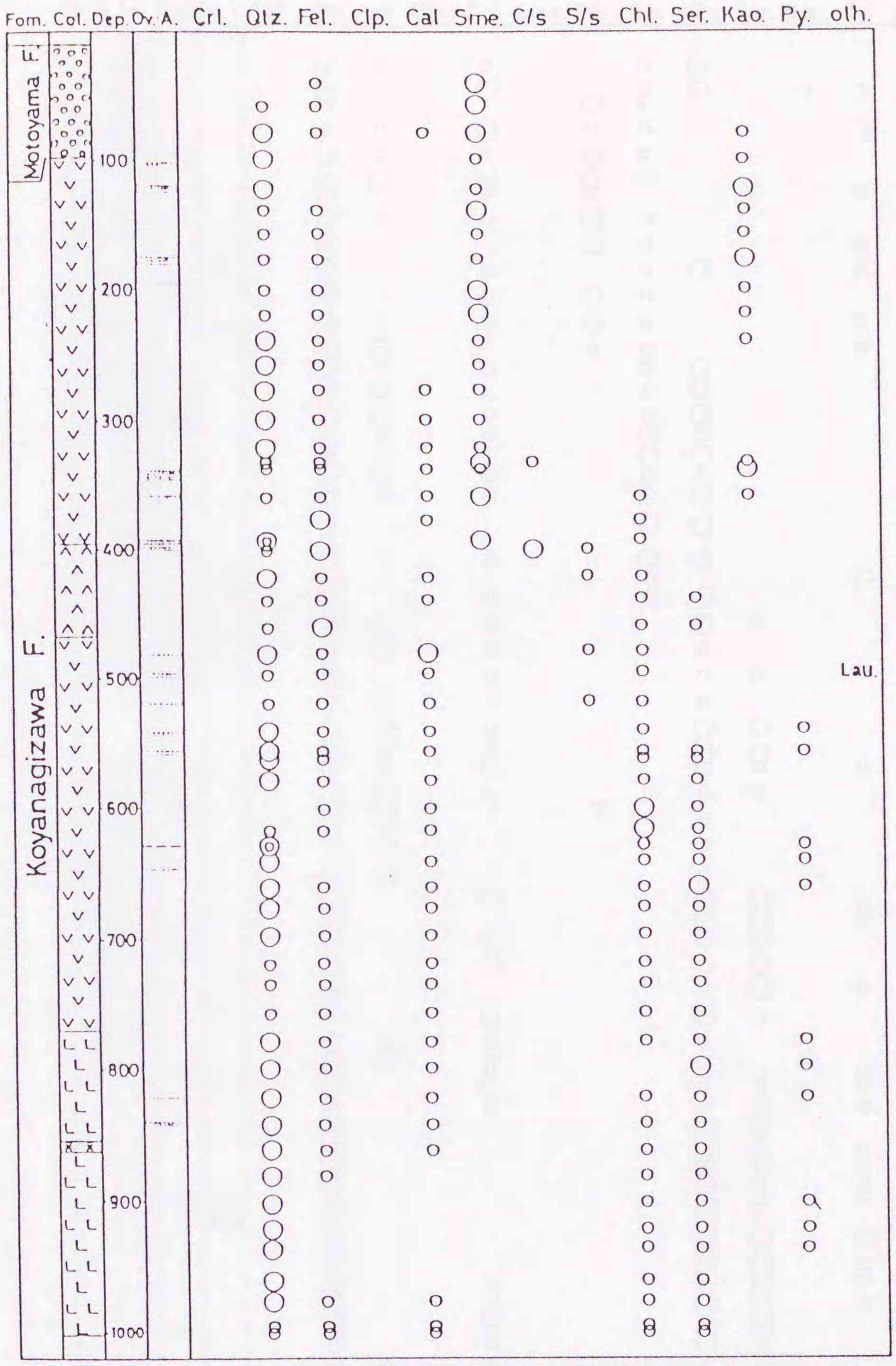


Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Cri:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Rho:rhodochrosite.

◎large, ◯common, o rare, argillic alteration, ---- ore veinlet, —— ore vein.

Fig.5.5 Mineral composition of core-sample from drill hole No.70.

No. 73

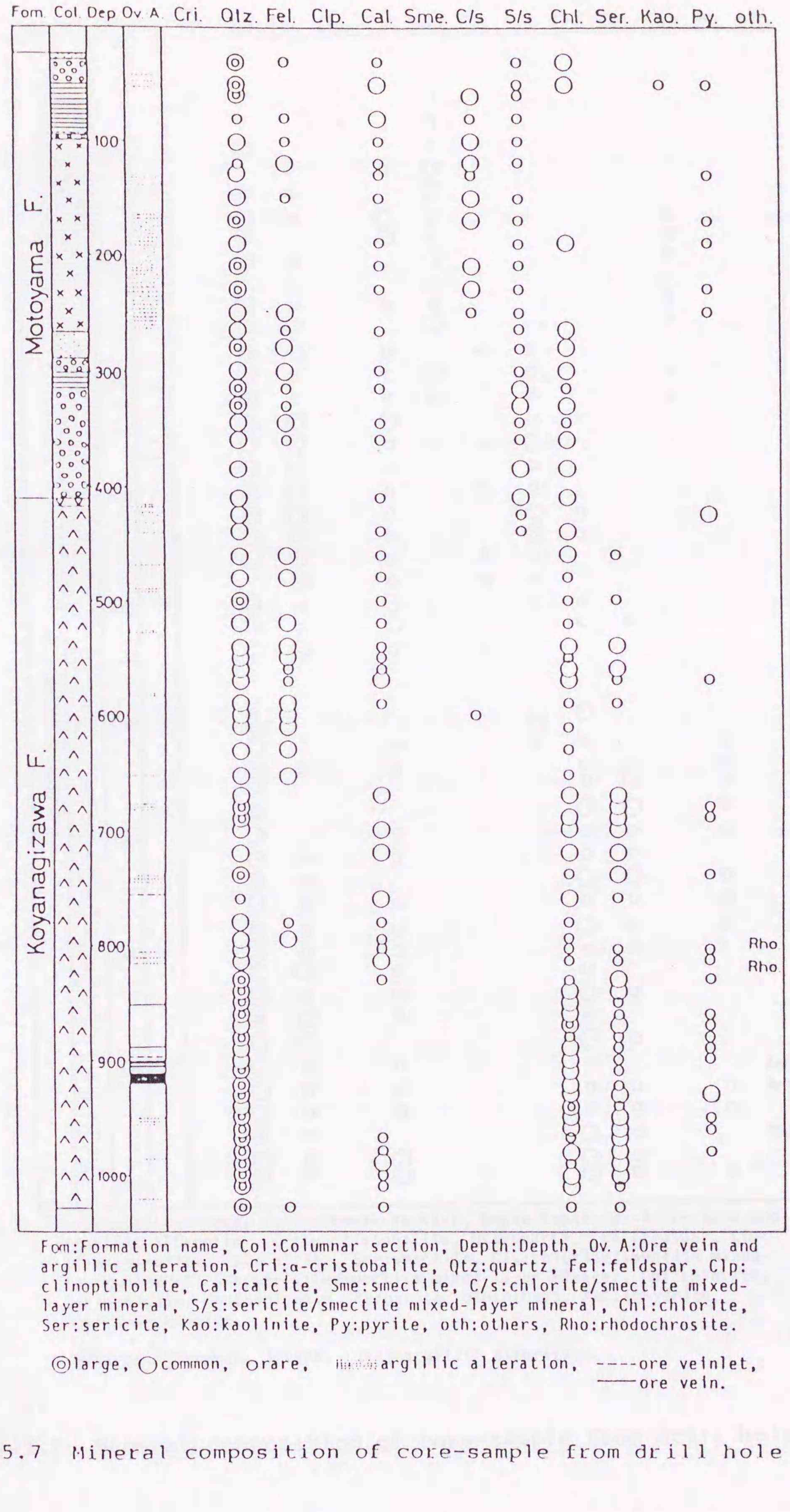


Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Crl:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Lau:laumontite.

◎large, ○common, ○rare, argillic alteration, ---- ore veinlet.

Fig.5.6 Mineral composition of core-sample from drill hole No.73.

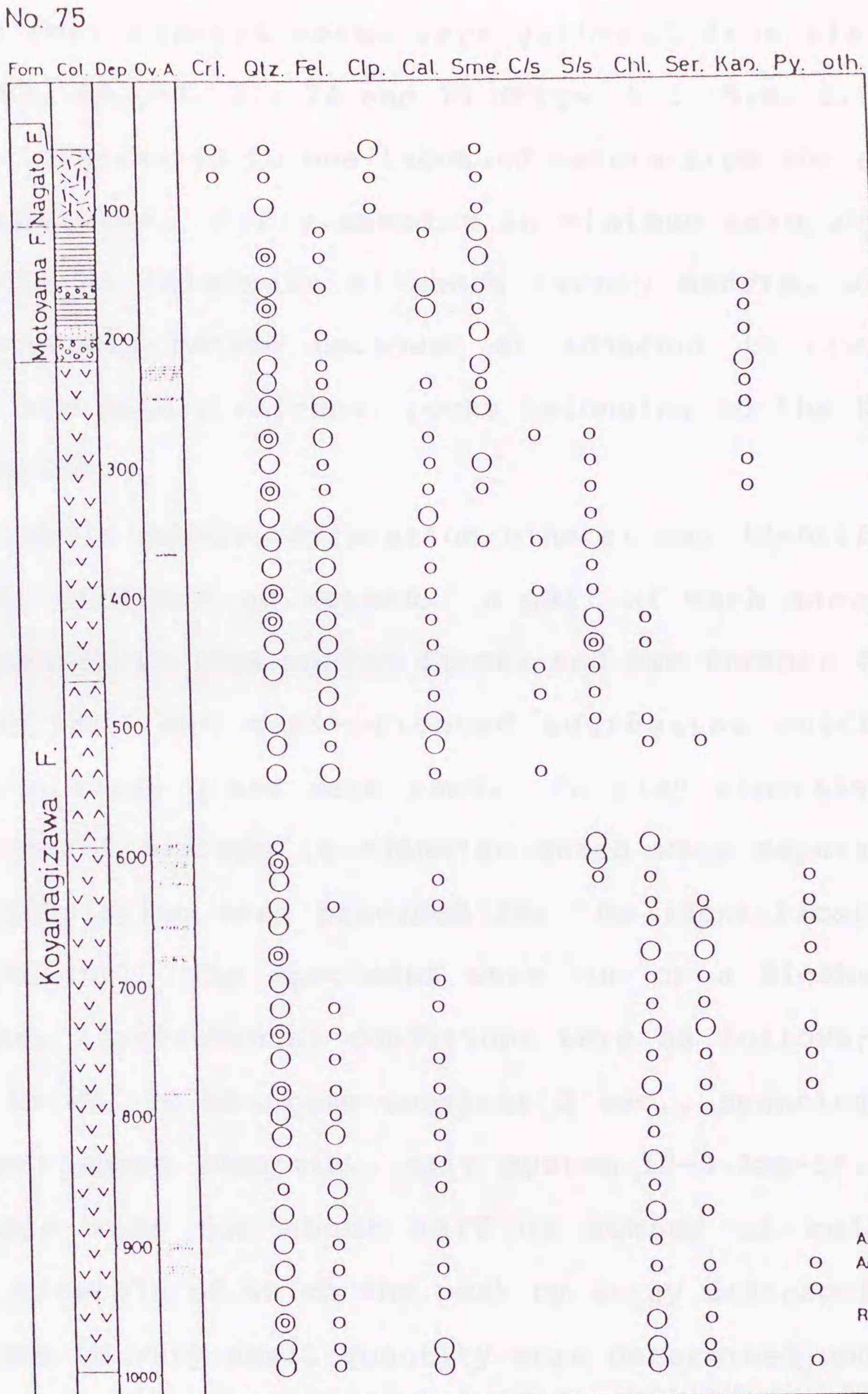
No. 74



Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Cri:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Rho:rhodochrosite.

◎large, ◯common, o rare, argillic alteration, ----ore veinlet, ——ore vein.

Fig.5.7 Mineral composition of core-sample from drill hole No.74.



Fom:Formation name, Col:Columnar section, Depth:Depth, Ov. A:Ore vein and argillic alteration, Crl:α-cristobalite, Qtz:quartz, Fel:feldspar, Clp: clinoptilolite, Cal:calcite, Sme:smectite, C/s:chlorite/smectite mixed-layer mineral, S/s:sericite/smectite mixed-layer mineral, Chl:chlorite, Ser:sericite, Kao:kaolinite, Py:pyrite, oth:others, Anh:anhydrite, Rho:rhodochrosite.

◎large, ◯common, ○rare, argillic alteration.

Fig.5.8 Mineral composition of core-sample from drill hole No.75.

Nearly four hundred cores were gathered from six drill holes, Nos.68, 69, 70, 73, 74 and 75 (Figs. 5.3, 5.4, 5.5, 5.6, 5.7 and 5.8), excavated to one thousand meters from the surface by the Toyoha mine. Fifty samples in minimum were obtained from one hole at intervals of about twenty meters, and the sampling intervals became narrower at adjacent to ore vein. The samples are mainly volcanic rocks belonging to the Koyanagizawa Formation.

On the whole sample, alteration mineral was identified by X-ray powder diffraction method. A part of each sample was crushed to pieces in iron mortar first, and was further crushed by agate mortar, and semi-oriented aggregates which were prepared on a slide glass were used. On clay minerals, clay particles under 2 microns in diameter which were separated by hydraulic elutriation were provided for the identification by X-ray diffraction. The specimens were run on a Rigaku-denki diffractmeter. Instrumental conditions were as follows; CuKα, Ni filter, 35 kV, 20 mA, time constant 2 sec., scanning speed 1°/min., chart speed 20mm/min., slit system 1°-0.3mm-1°. Thin sections were made for about half of number of collected sample, and minerals of which the peak by X-ray diffraction did not appear due to very small quantity were determined under the microscope. Mode of occurrence of alteration minerals was also observed under the microscope.

Through the preceding examinations, wall rock alteration around the Toyoha deposits is divided into six zones, A, B, C, D, E and F, from outer side of the vein in consideration of characteristic alteration minerals and these assemblage as well as the distribution and mode of occurrence (Sawai, 1984, 1986a) (Fig. 5.9). Alteration zone A is widely distributed, while, alteration zones B to E are locally distributed around ore veins being oblique to the formation boundary (Fig. 5.10). Alteration zone F is found at the downstream of the Yunosawa river area, eastward far from the Toyoha mine (Fig. 5.11).

5.1 Zone A

Zone A is widely distributed in an area occupied by the Koyanagizawa, Motoyama and Oheyama Formations at eastern side of the Toyoha mine. Zone A is subdivided into subfacies A-1, A-2 and A-3 on the basis of difference of clay minerals. These subfacies occur showing a zonal distribution. The manner of zonation of subfacies A-1, A-2 and A-3 in descending order is almost parallel to the formation boundary (Sawai, 1986a) (Fig. 5.11).

(1) Subfacies A-1

Subfacies A-1 is characterized by the presence of smectite. It occupies a wide area and the thickness measures over 250 meters vertically (Fig. 5.11). Smectite and α-cristobalite are recognized as alteration mineral in only andesite of the Oheyama Formation. Under the microscope, plagioclase, clinopyroxene and orthopyroxene keep unaltered state and only a part of matrix glass is altered to smectite (Fig. 5.12a). While, smectite, quartz and calcite are recognized as alteration mineral in andesite of the Koyanagizawa Formation. Most of colored minerals are altered to calcite, though unaltered clinopyroxene is rarely observed under the microscope (Fig.

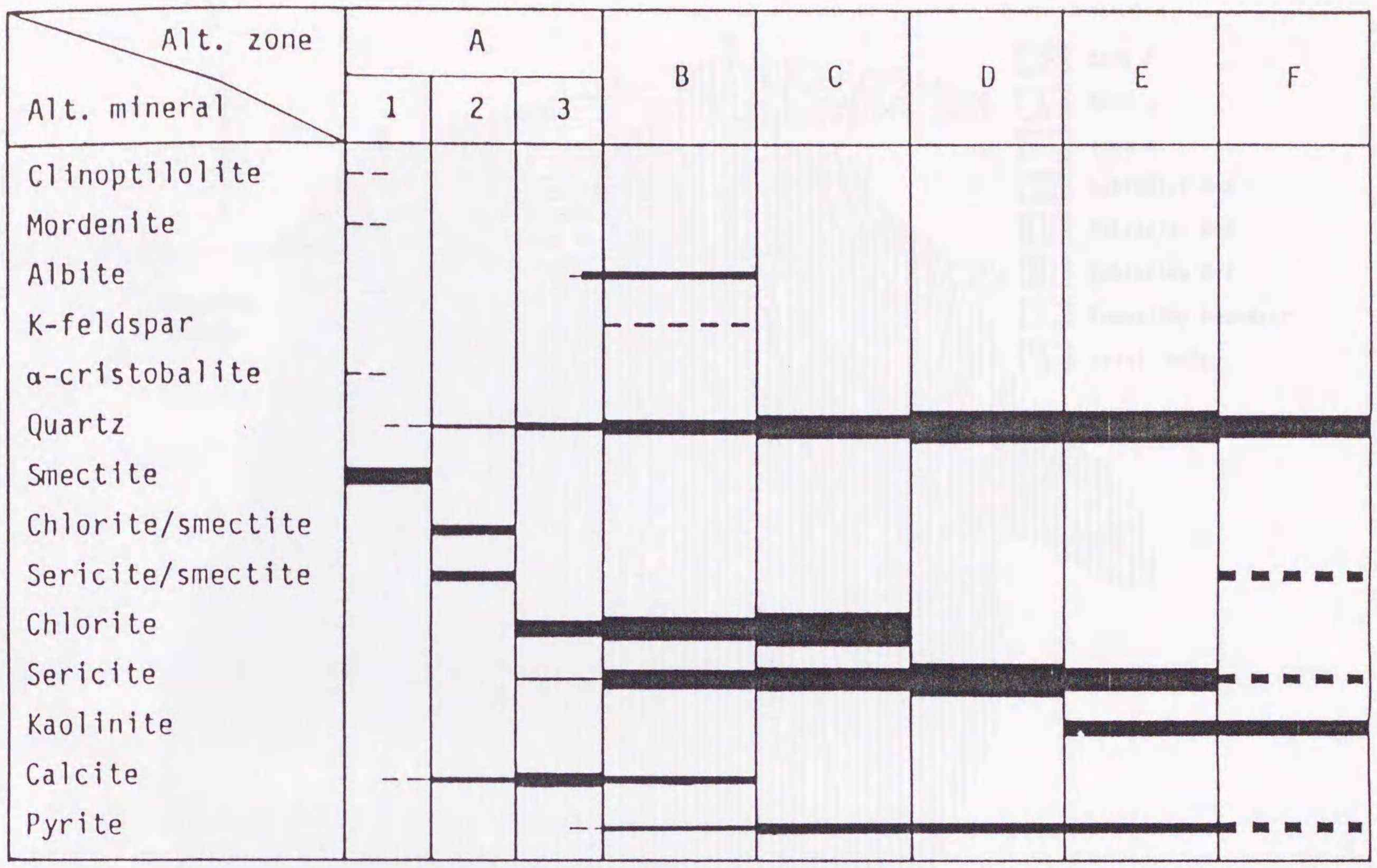


Fig.5.9 Mineral assemblages of the divided alteration zones at the Toyoha mining area.

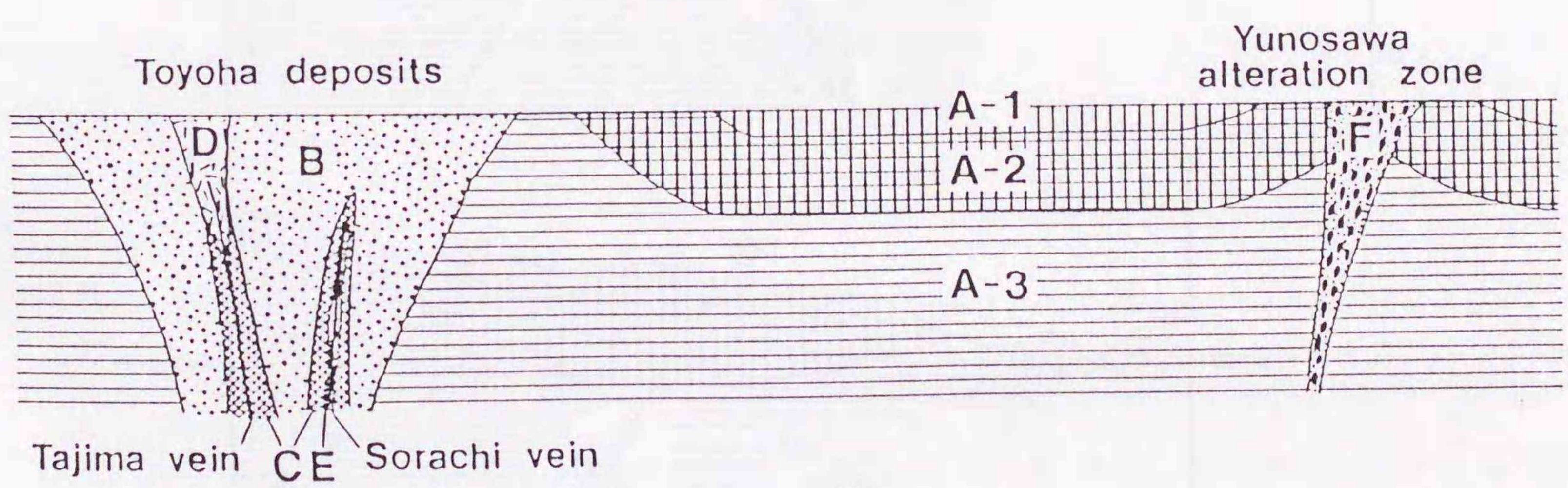


Fig.5.10 Schematic profile illustrating the interrelated positions of eight alteration zones related to the Toyoha deposits. Abbreviations are referred to Fig.5.9.

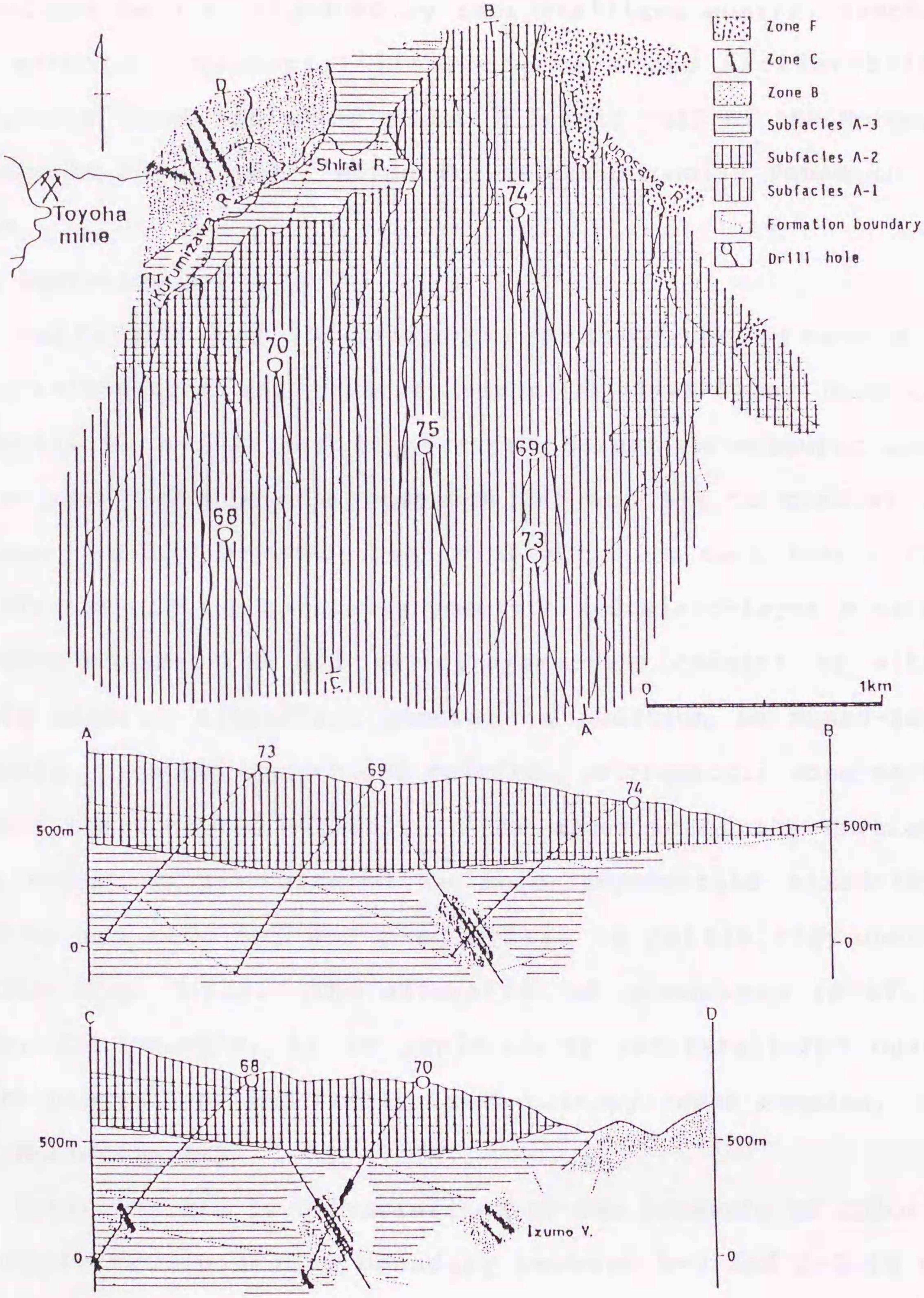


Fig.5.11 Surface and vertical distributions of the divided alteration zones in eastern area of the Toyoha mine.

5.12b). Plagioclase is generally replaced by calcite. Groundmass is also replaced by recrystallized quartz, smectite and calcite. Clinoptilolite, smectite and α-cristobalite frequently occur replacing glass in acidic tuff of the Motoyama and Nagato Formations. Mordenite is occasionally found in the glass.

(2) Subfacies A-2

Subfacies A-2 is characterized by the presence of chlorite/smectite and sericite/smectite mixed-layer minerals. Thickness of A-2 facies in vertical direction measures about 200 meters. The boundary between A-1 and A-2 is gradual and obvious boundary between them is absent. In each sample from the vicinity of the boundary, smectite and mixed-layer minerals of chlorite/smectite and sericite/smectite coexist or alternately occur. Alteration mineral in addition to mixed-layer minerals is mainly quartz and calcite. Microscopic observation reveals that colored minerals in the andesite of the Koyanagi-zawa Formation are altered to chlorite/smectite mixed-layer mineral and calcite, and plagioclase is partly replaced by calcite (Fig. 5.13). The alteration of groundmass is of low grade, for example, it is replaced by recrystallized quartz and/or plagioclase and rarely fresh clinopyroxene remains.

(3) Subfacies A-3

Subfacies A-3 is characterized by the presence of chlorite and sericite. Distinct boundary between A-2 and A-3 is not recognized. Subfacies A-3 is characterized by following mineral assemblage, i.e. quartz+chlorite+sericite+calcite. Though the mineral assemblage is common, mode of occurrence of alteration mineral is different in each sample. It is possible to say that weakly altered sample remains not only pseudomorph of minerals even though plagioclase partly is altered to calcite and pyroxene is altered to chlorite and/or calcite. Occasionally unaltered plagioclase and pyroxene are recognized in the weakly altered rocks (Fig. 5.14). While, plagioclase is altered to albite, sericite and calcite in strongly altered samples, in which pyroxene completely is altered to chlorite and calcite (Fig. 5.15). Moreover, groundmass texture has been frequently destroyed by appearance of alteration minerals such as recrystallized quartz, chlorite and sericite. These features are confirmed under the microscope.

5.2 Zone B

Zone B is extensively found around every ore vein penetrating obliquely the formation boundary. This zone, however, never come in direct contact with ore vein and zone C is generally present between zone B and ore vein (Fig. 5.10). Main alteration minerals of zone B are quartz and chlorite. Sericite, calcite, albite and K-feldspar are usually found as accessory minerals, besides, pyrite is frequently observed.

Microscopic observation discloses that original rock texture has been faintly kept (Fig. 5.16). For instance, though phenocryst pseudomorph remains, groundmass texture disappears in many cases. Namely, phenocrysts of pyroxene and plagioclase are altered to completely chlorite and calcite, albite or K-feldspar and partly to sericite. Glass and colored minerals in groundmass are altered to chlorite and small laths of plagioclase to calcite and albite or K-feldspar. Albite is not coexistent with K-feldspar in a same thin section. Albite is more common than K-feldspar. Fine-grained quartz, about 0.02 mm in diameter, is found in groundmass.

It is difficult to distinguish zone B from strongly altered part of subfacies A-3 only from alteration mineral assemblage. However, it is microscopically revealed that degree of disappearance of groundmass texture, mode of occurrence and quantity of quartz and sericite are different from one another. Groundmass texture in zone B has been more intensively destroyed by the presence of alteration mineral, and quartz and sericite in zone B are generally coarse and are abundant compared with those in subfacies A-3 (Fig. 5.16).

5.3 Zone C

Zone C occurs forming a thin envelope between zone B and ore veins (Fig. 5.10). This zone is symmetrically distributed in both sides of hanging wall and foot wall extending limitedly within 10 to 50 meters from ore vein. Generally speaking, the width of zone C has a tendency to become wide at lower levels and extends the width at upper levels. For example, zone C associated with the Tajima vein is 10 to 15 meters wide at -150 mL, and 30 to 50 meters wide at -400 mL. Alteration minerals of zone C are quartz, chlorite, sericite and pyrite in order of abundance. Albite and K-feldspar which have been present as alteration mineral in zone B are replaced here, and only calcite is rarely found as a relic mineral of zone B.

Under the microscope, original texture of volcanic rock is vanished, and only external form of phenocryst is recognized, but is thoroughly replaced by alteration minerals (Fig. 5.17). Quartz can be divided into two kinds; fine-grained crystal nearly 0.02 mm in diameter and more coarse-grained one, 0.1 to 0.5 mm, and the latter has a tendency to increase nearby ore veins. Two kinds of chlorite can distinguish under the microscope. One of chlorites replacing colored minerals and/or glass is light green in color and generally coarse-grained, and the double refraction is very low. The other one formed everywhere demolishing the original rock texture is brownish green in color and is fine-grained showing acicular-shape. Double refraction of the chlorite is higher than the former. Sericite is always very fine-grained and shows acicular-shape of 2 microns in width.

5.4 Zone D

Zone D is exclusively found at upper levels of the deposits or at outcrops, and it is distributed around the ore vein like zone C. Zone D gradually changes into zone C or B (Fig. 5.10). This zone corresponds to the alteration facies (d) proposed by Okabe and Bamba (1976). They reported that the width of facies (d) is narrow at lower levels of the deposits and is slightly extend the width at the surface. Alteration mineral assemblage of this zone is quartz, sericite and pyrite. Rock of this zone looks grayish white and idiomorphic pyrite, about 0.5 mm, is well recognized in the rock. Under the microscope, original rock texture has been completely destroyed, and constituent minerals are all fine-grained, about 0.1 mm.

Aggregate consisting of quartz and sericite with scattering pyrite is a characteristic feature of zone D (Fig. 5.18).

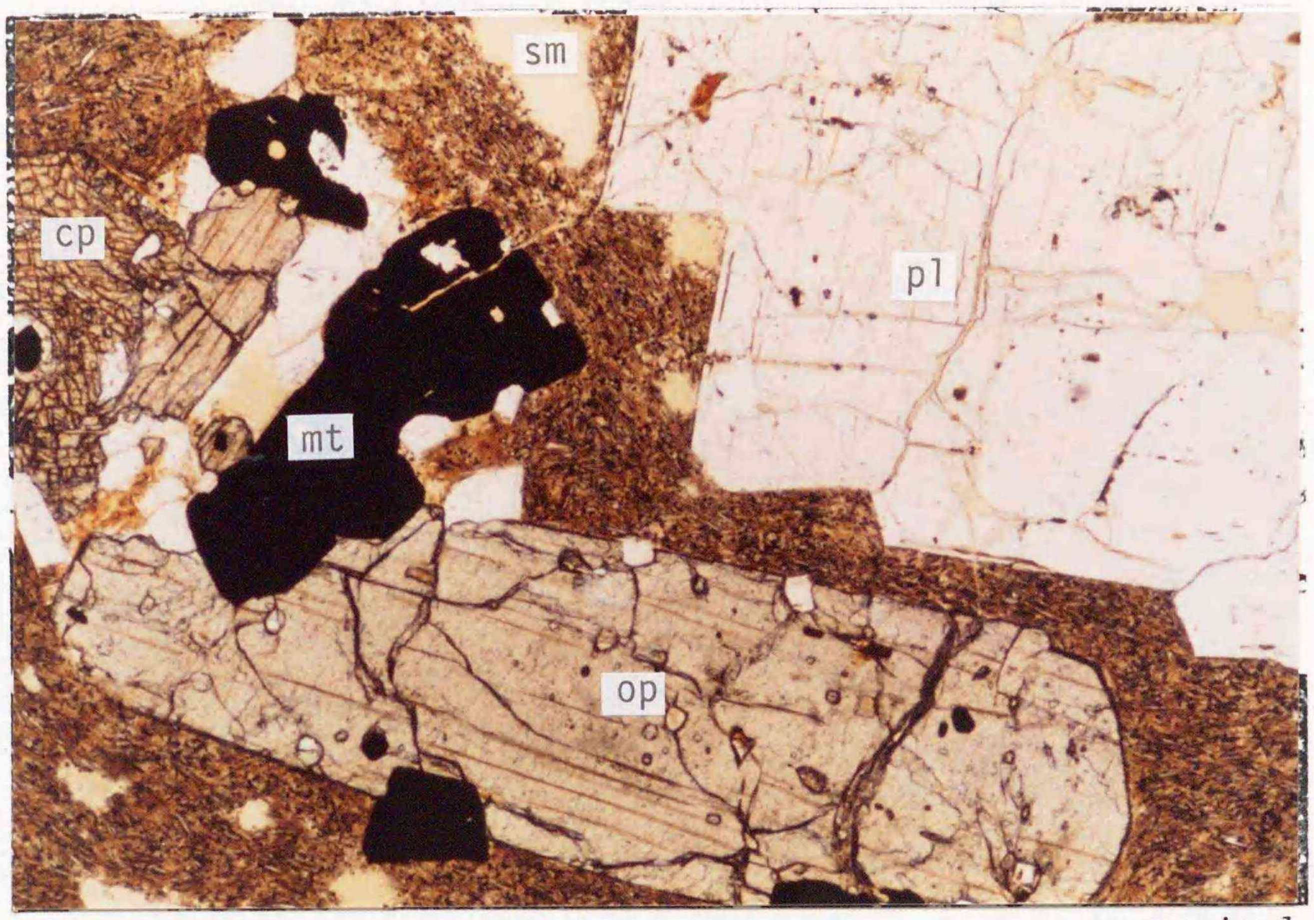
5.5 Zone E

Zone E is exclusively recognized along the Sorachi and Nemuro veins through upper to lower levels (Fig. 5.10). This zone replaces zone C at the boundary between ore vein and zone C (Fig. 5.20), and it occurs showing narrow extent within 0.5 to 5 meters from ore vein. Alteration minerals of this zone are mainly quartz, sericite, kaolinite and pyrite. Gangue mineral assemblage in the Sorachi and Nemuro veins is the same as that of zone E. Clay vein mainly composed of kaolinite, sericite and quartz is frequently recognized in the ore veins concerned. Dickite and sulfate minerals such as alunite, jarosite and gypsum rarely occur in the clay vein (Sawai, 1981).

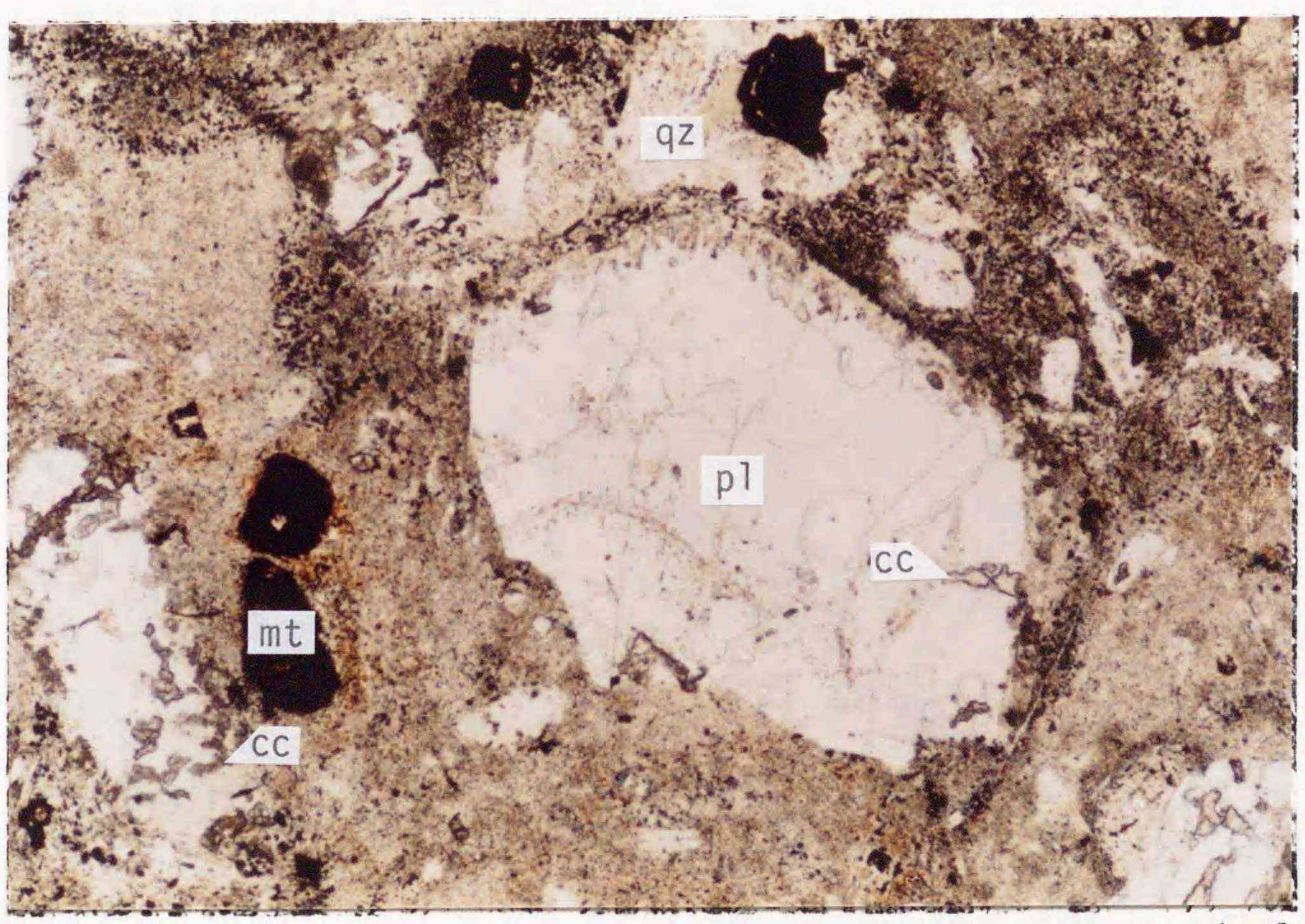
Zone E looks grayish white and idiomorphic pyrite under 0.5 mm is distinctly found in the rock, and it resembles zone D in appearance. Under the microscope, original rock texture has been completely destroyed and is thoroughly replaced by aggregate of quartz, under 0.5 mm, fine-grained sericite, kaolinite and pyrite (Fig. 5.19). Rock of zone E is very similar to that of zone D though kaolinite lacks in zone D.

5.6 Zone F

Zone F is locally distributed at downstream of the Yuno-sawa river. This zone is characterized by local silicification and extensive argillic alteration. Altered rock of this zone



open nicol



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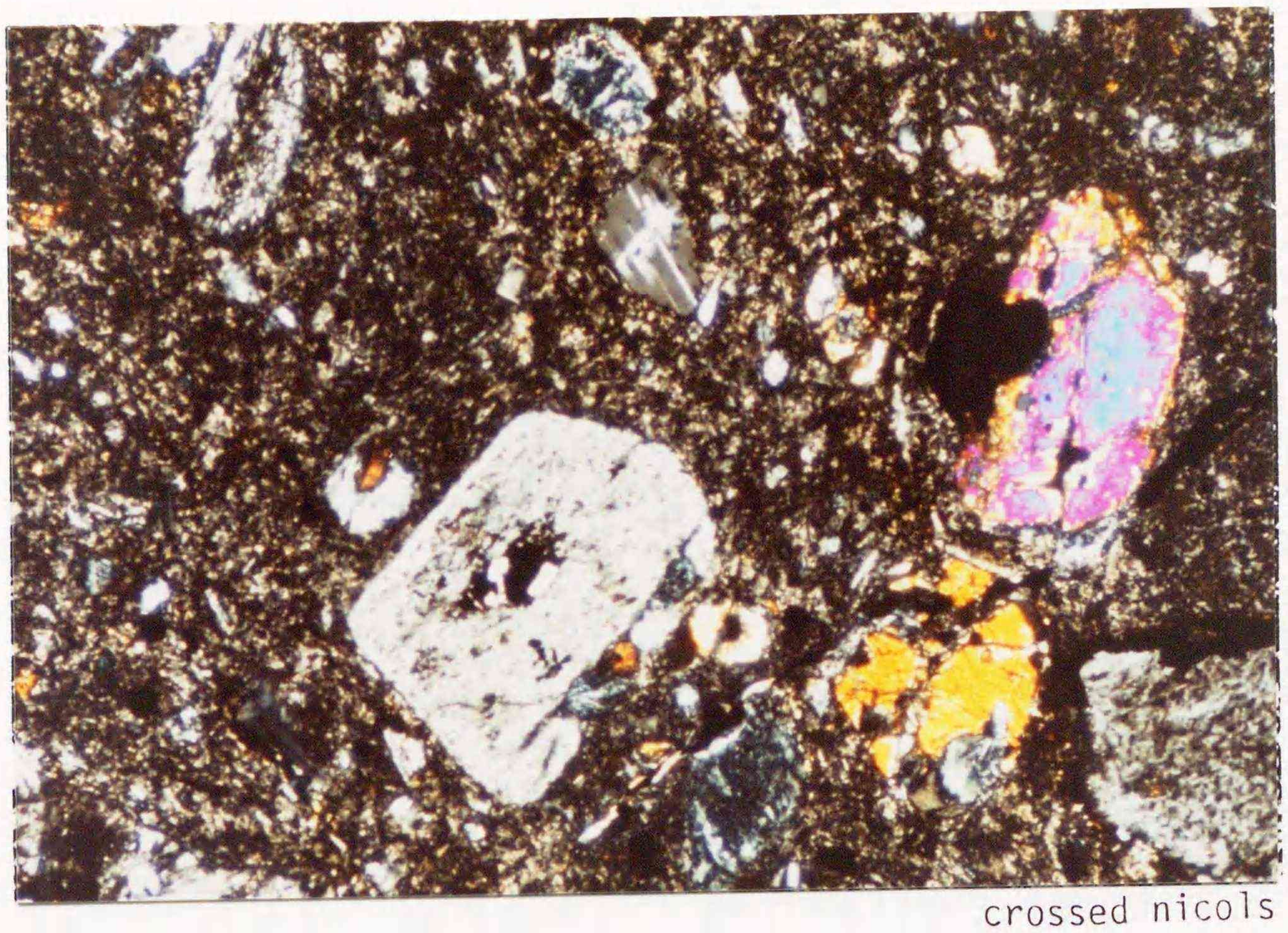
1mm

Fig.5.12 Microphotographs of rocks in subfacies A-1.
a. Andesite of the Oheyama Form., upstream of the Kurumizawa river.
b. Andesite of the Koyanagizawa Form., -84 m of drill hole No.69.
cp:clinopyroxene, op:orthopyroxene, pl:plagioclase, mt:magnetite, qz:quartz, cc:calcite, sm:smectite.



crossed nicols

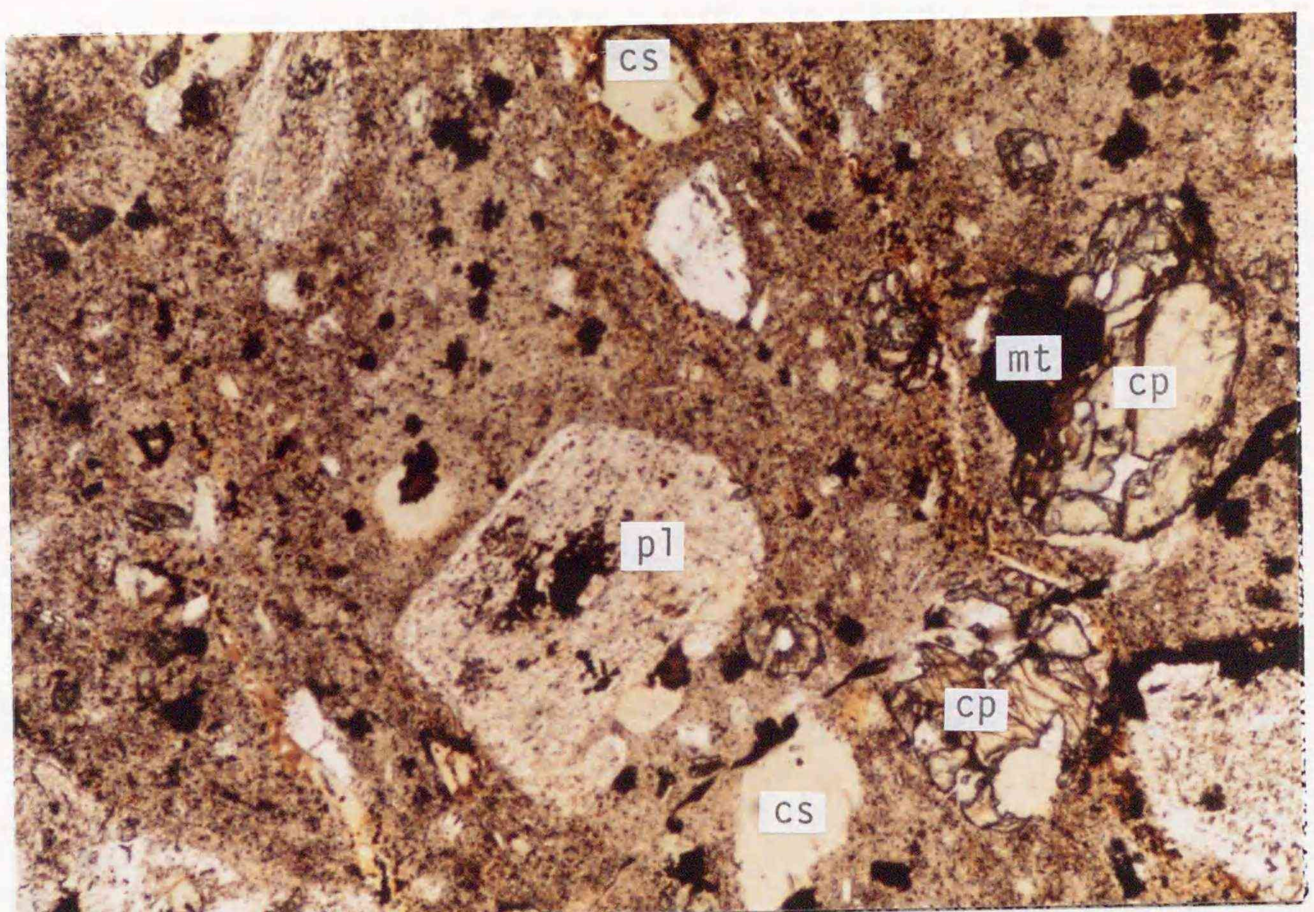


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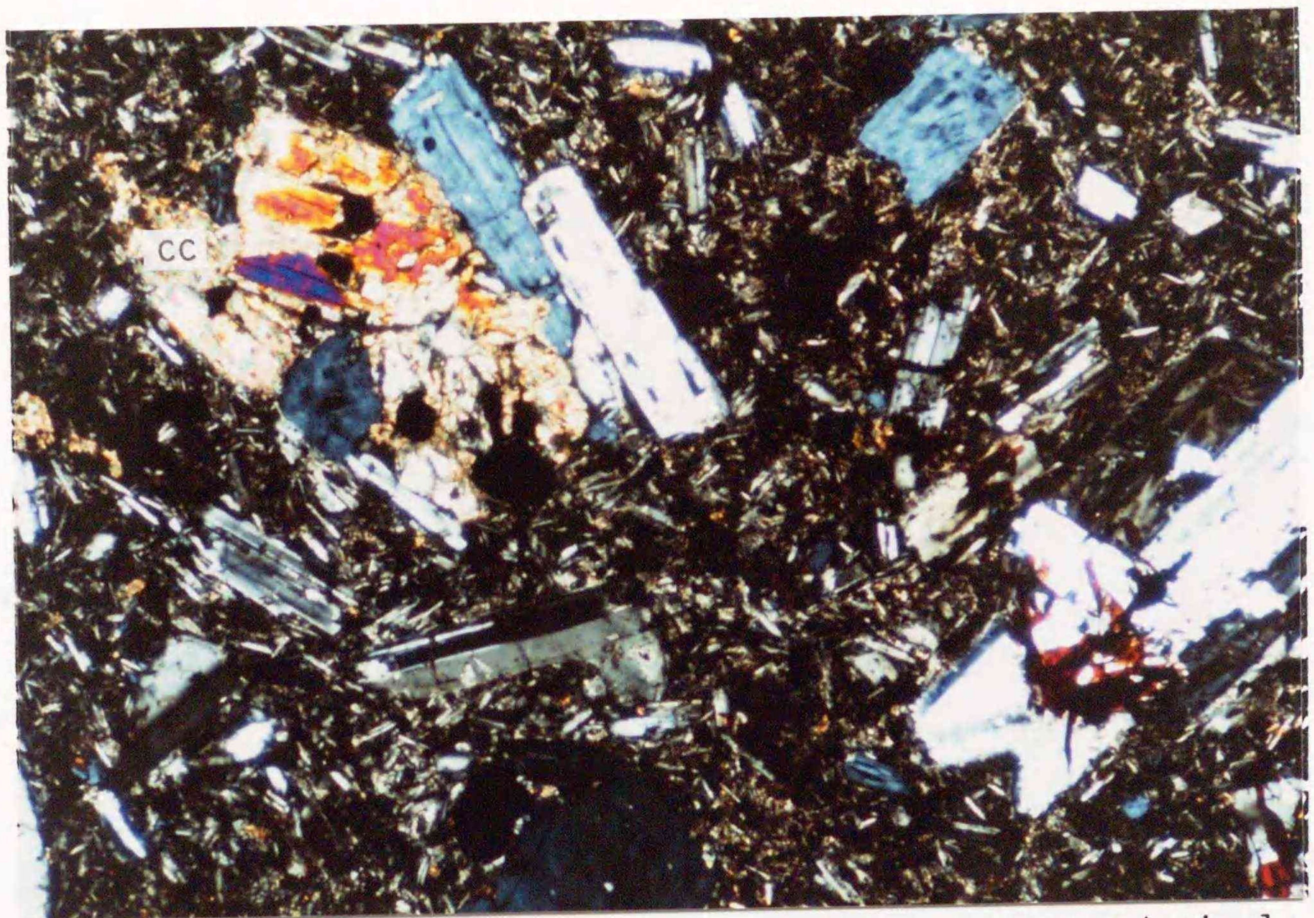
Fig.5.13 Microphotographs of rock in subfacies A-2.
Andesite of the Koyanagizawa Form., -364 m of drill hole No.70.
cp:clinopyroxene, pl:plagioclase, mt:magnetite, cs:chlorite/smectite mixed-layer mineral.



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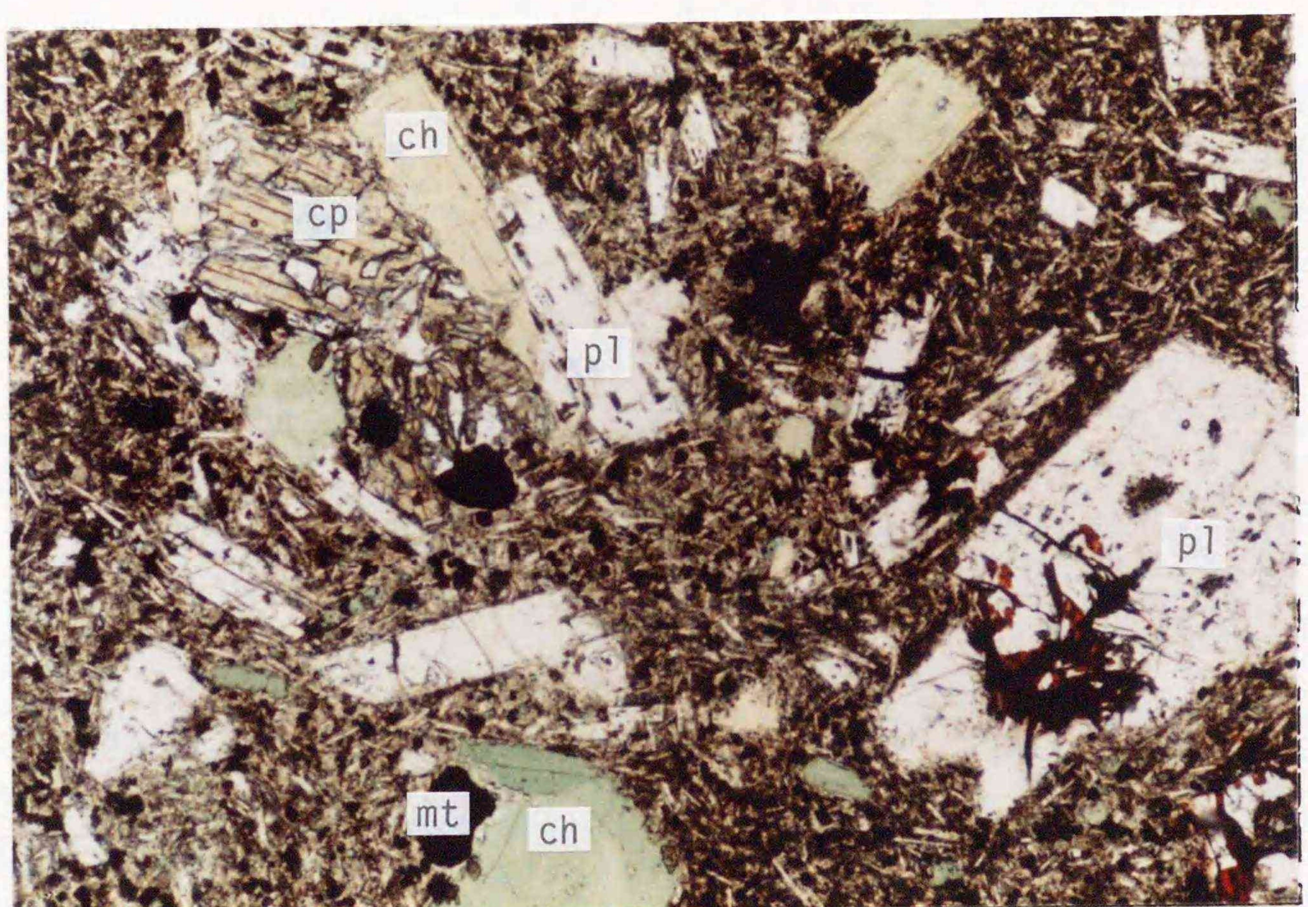

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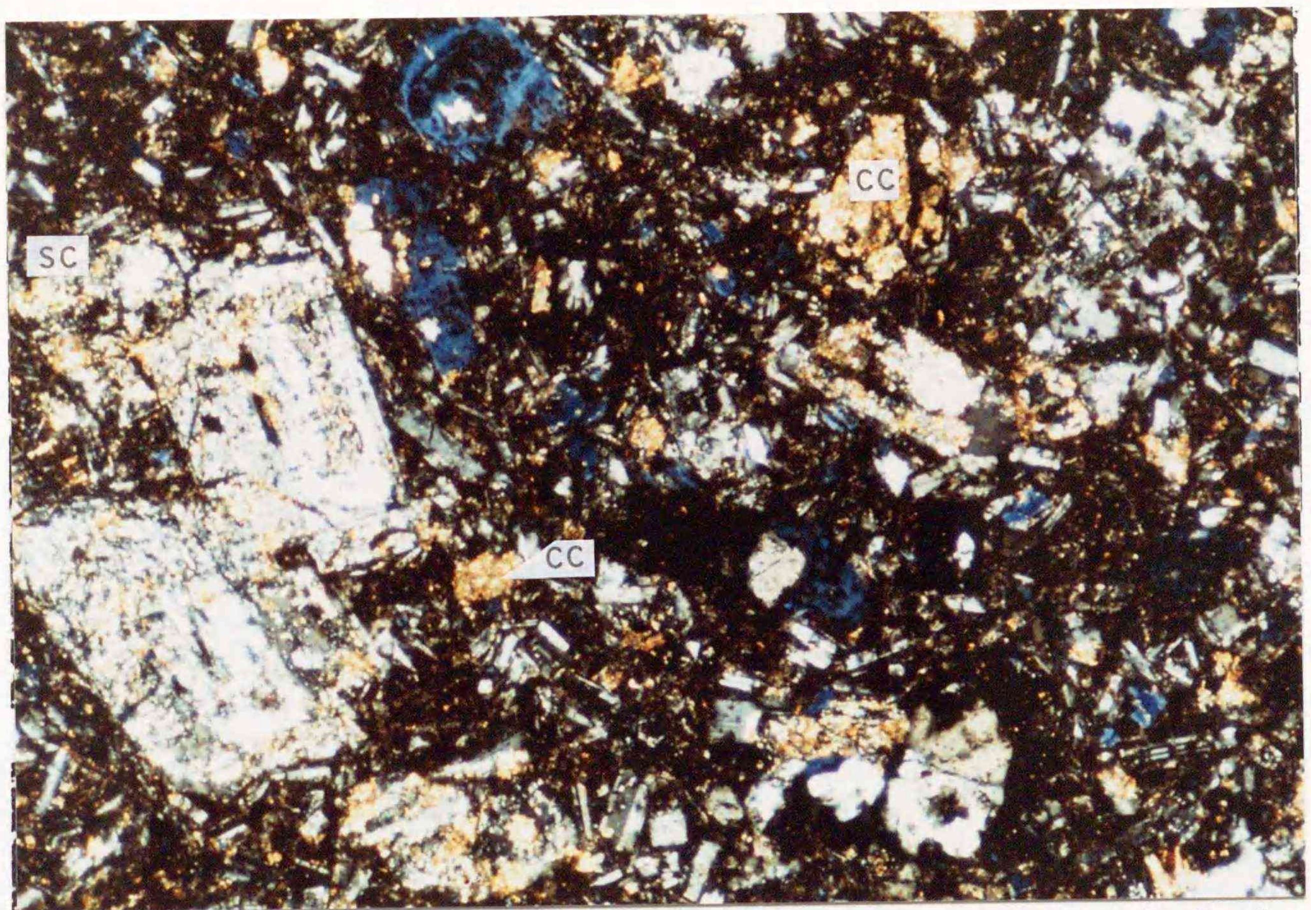
Fig.5.14 Microphotographs of weakly altered rock in subfacies A-3. Basaltic andesite of the Koyañagizawa Form., -550 m of drill hole No.74.
cp:clinopyroxene, pl:plagioclase, mt:magnetite, cc:calcite, ch:chlorite.



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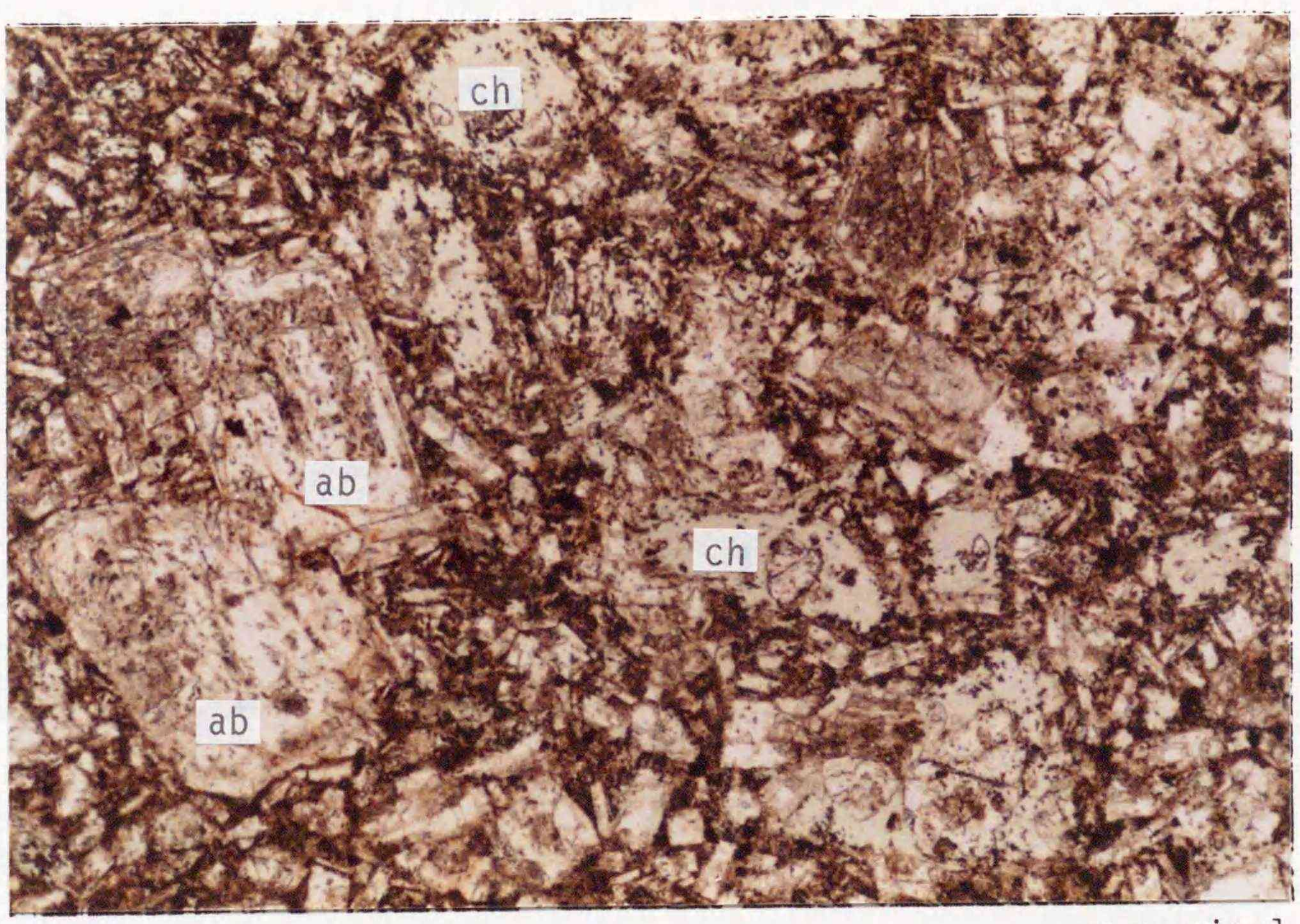

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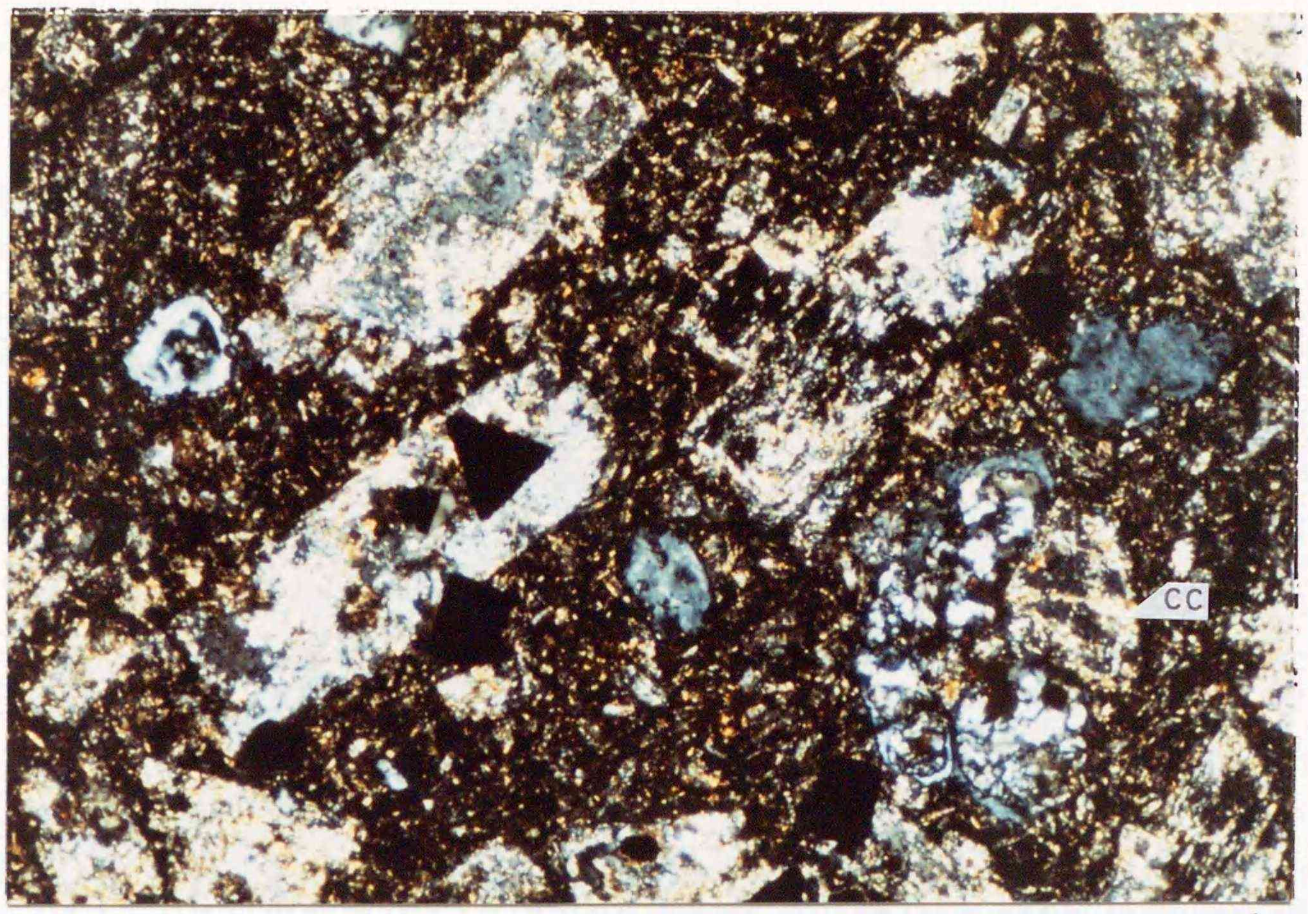
Fig.5.15 Microphotographs of strongly altered rock in subfacies A-3.
Basaltic andesite of the Koyanagizawa Form., -921 m of drill hole No.70.
ab:albite, cc:calcite, ch:chlorite, sc:sericite.



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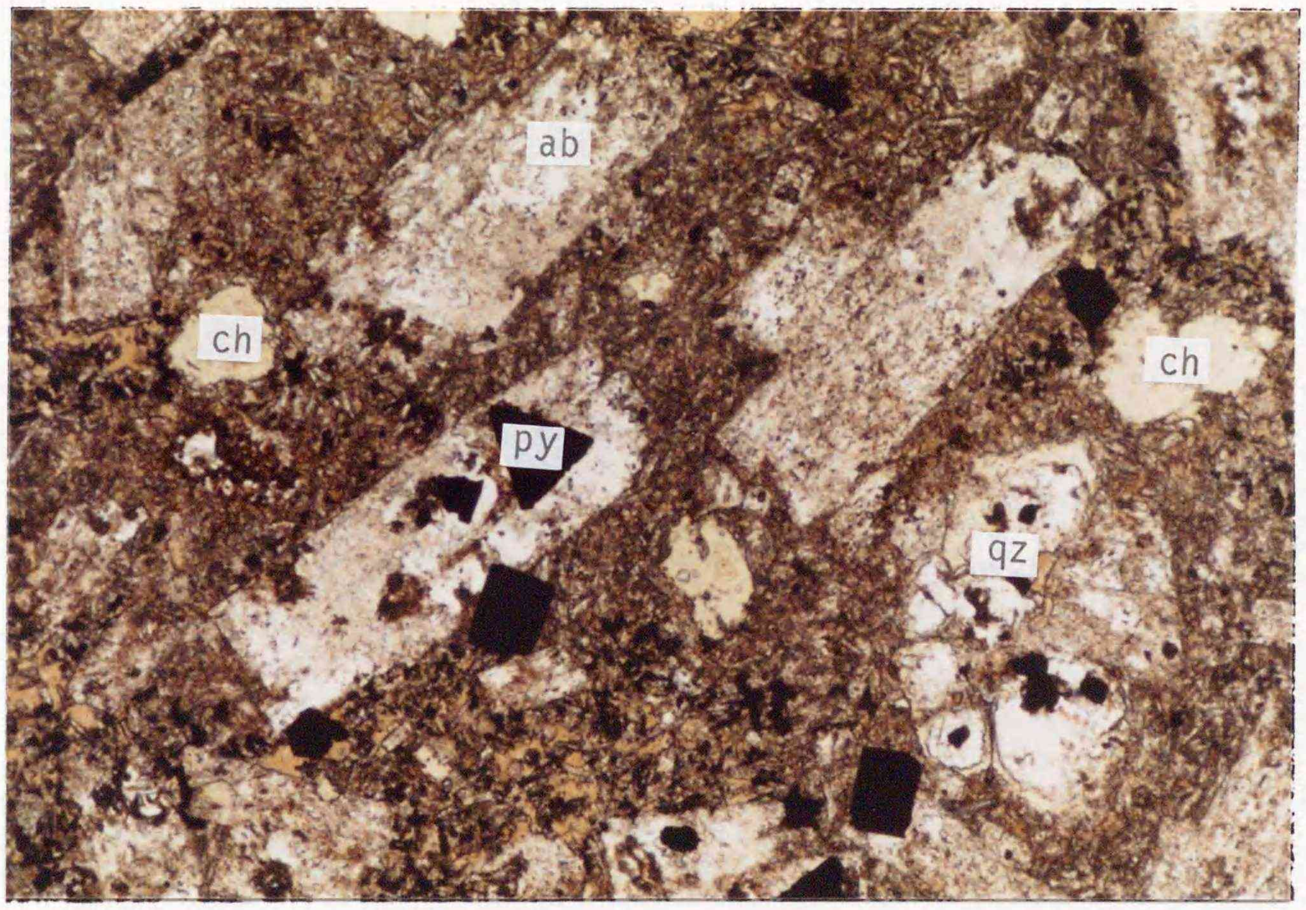

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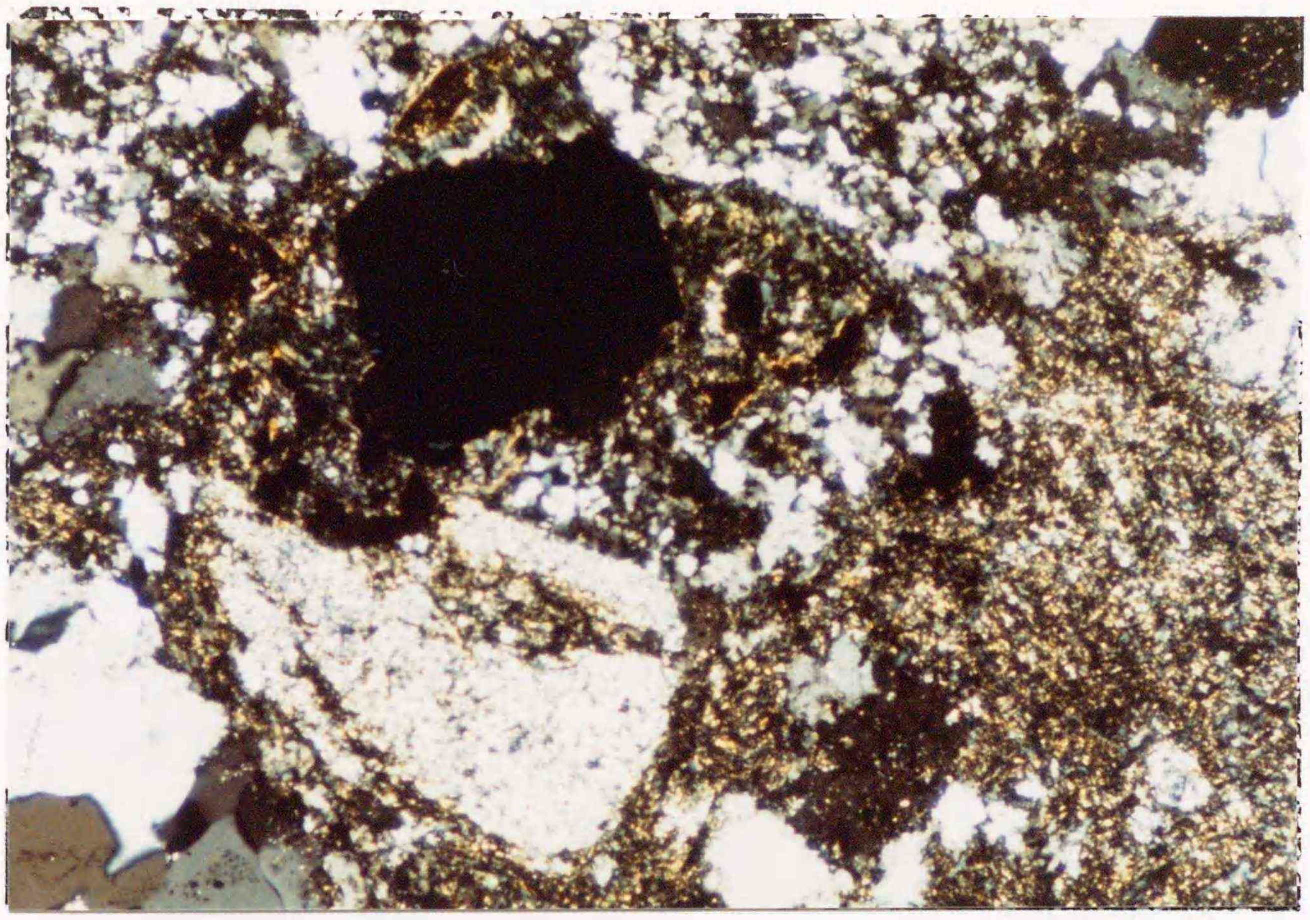
Fig.5.16 Microphotographs of rock in alteration zone B.
Basaltic andesite of the Koyanagizawa Form., -300mL of the Izumo vein.
qz:quartz, ab: albite, cc:calcite, ch:chlorite, py:pyrite.



crossed nicols

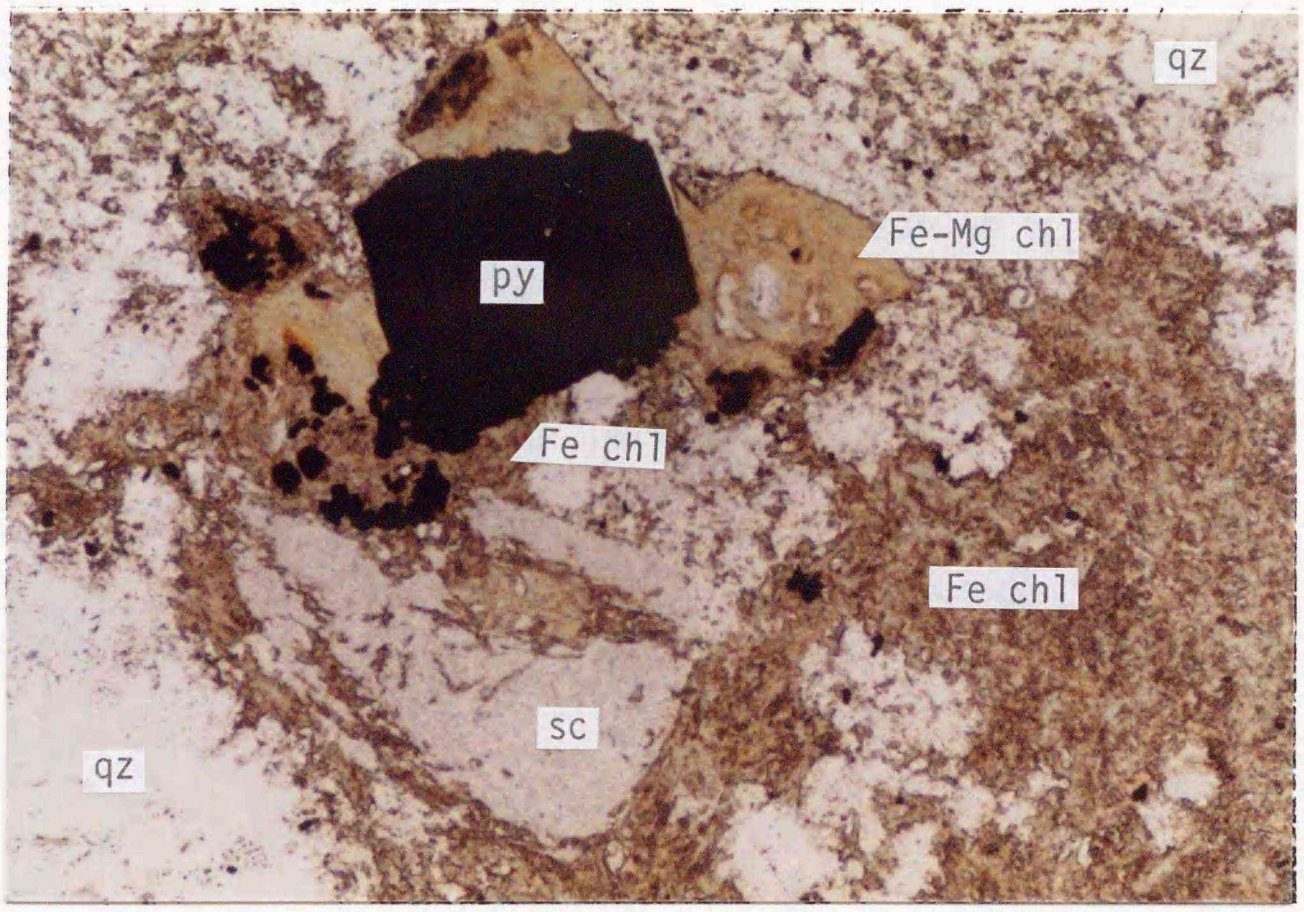


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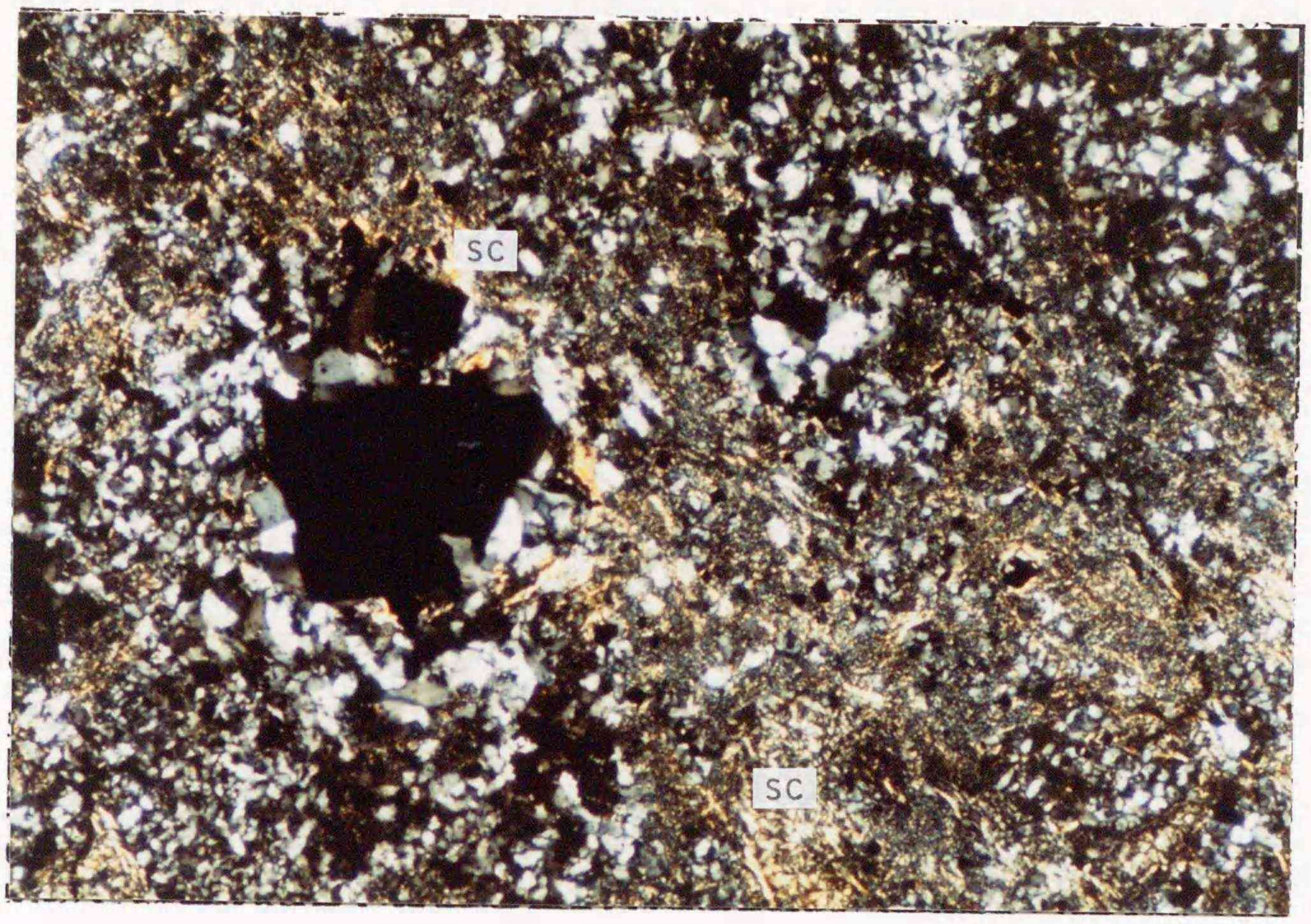
Fig.5.17 Microphotographs of rock in alteration zone C. Andesite of the Nagato Form., -250mL of the Izumo vein. qz:quartz, ch:chlorite, sc:sericite, py:pyrite.



crossed nicols

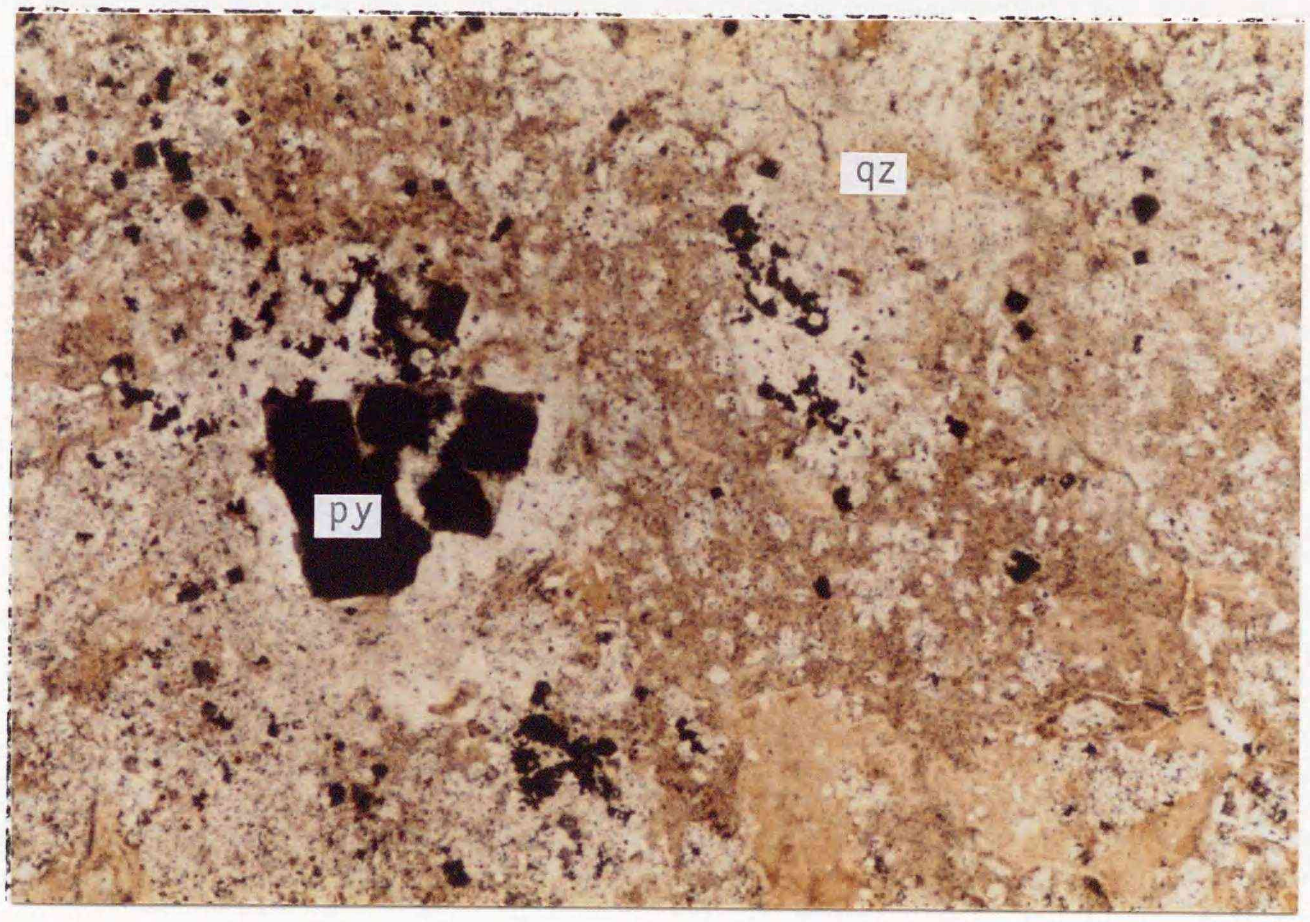


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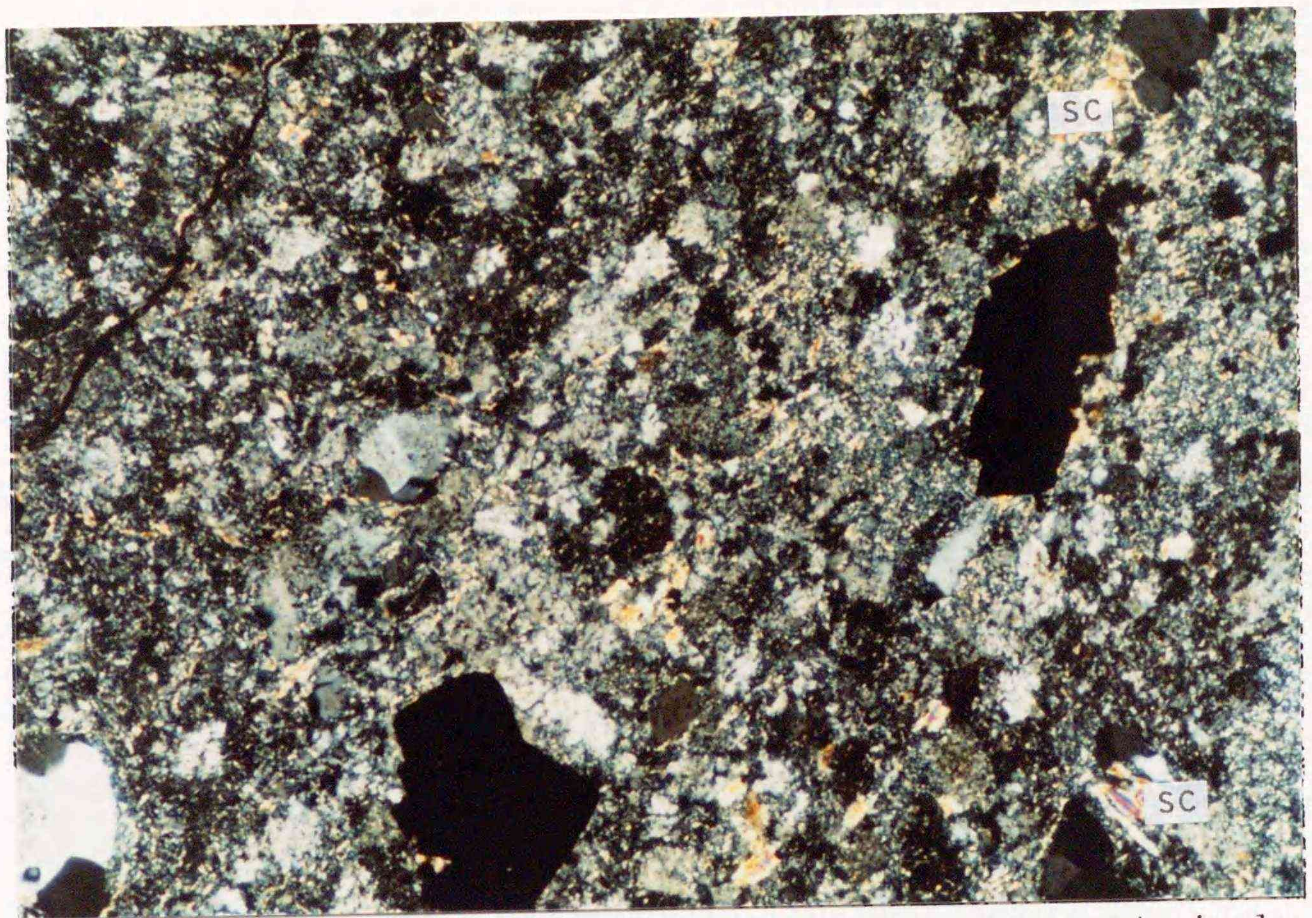
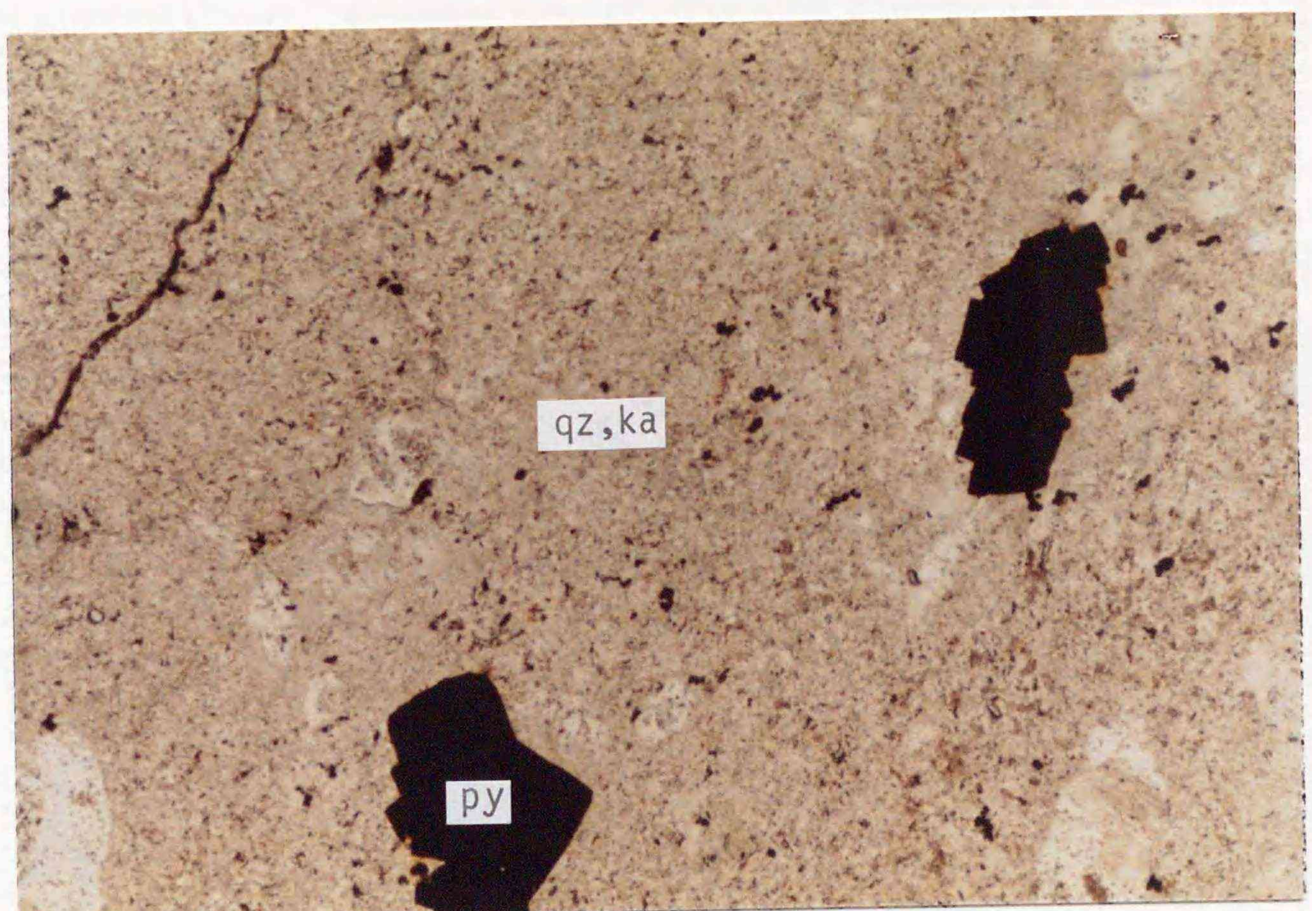
Fig.5.18 Microphotographs of rock in alteration zone D. Andesite of the Nagato Form., midstream of the Shirai river. qz:quartz, sc:sericite, py:pyrite.



crossed nicols



open nicol

1mm

Fig.5.19 Microphotographs of rock in alteration zone E. Andesite dike, -350mL of the Sorachi vein. qz:quartz, sc:sericite, ka:kaolinite, py:pyrite.

is mainly composed of quartz, sericite and kaolinite, with subordinate amounts of pyrite and mica clay mineral. Marcasite and sublimate sulfur are rarely observed. Fumaroles degassing carbon oxide and/or hydrogen sulfide exist in places within zone F. This zone has not exhibited any mineralization.

In addition to the divided alteration zone, argillic alteration which has been obviously altered by hydrothermal solution is frequently recognized in the investigated field and drill holes (Figs. 5.3 to 5.8). Since the alteration mineral assemblage is various, it is assumed that the argillic alteration has been formed by hydrothermal solution having various origins. However, the distribution is very local and the origin of each solution is unknown. Accordingly, various hydrothermal alteration zones except zones B to F are collectively dealt with argillic alteration zone in this paper.

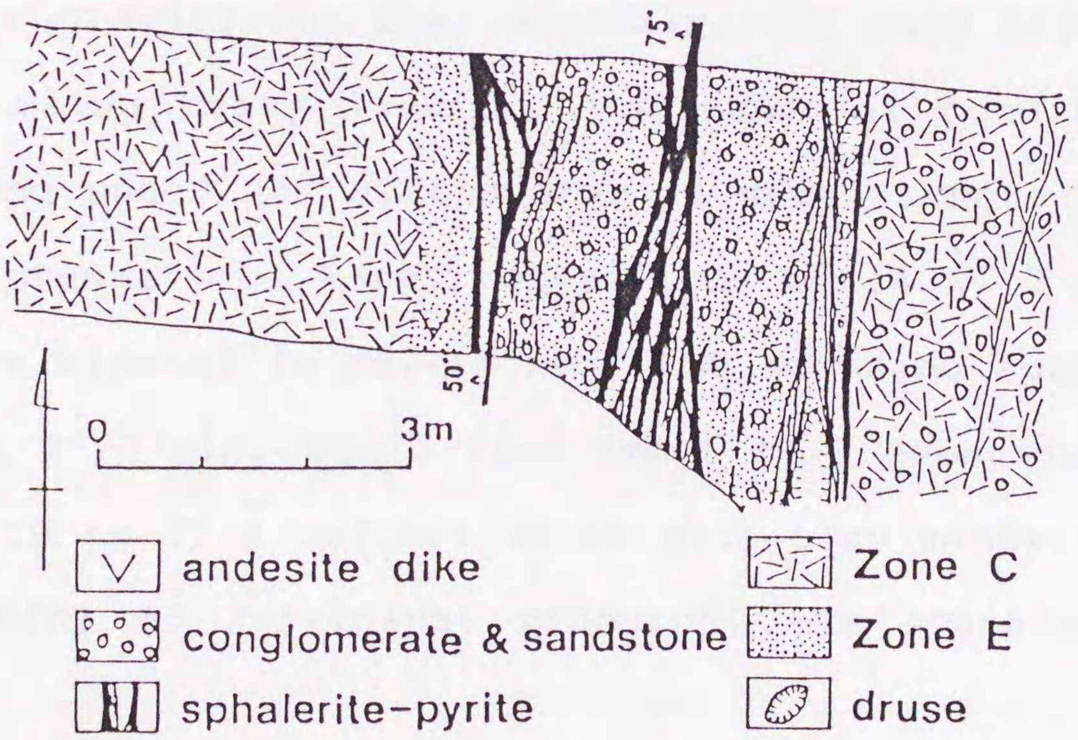


Fig.5.20 Sketch showing the mode of occurrence of zones C and E at -350mL in a branching vein of the Sorachi vein system.

6. Mineralogy of Main Alteration Minerals

Essential alteration minerals in altered rocks around the Toyoha deposits are α-cristobalite, quartz, albite, K-feldspar, clinoptilolite, mordenite, smectite, chlorite/smectite mixed-layer mineral, sericite/smectite mixed-layer mineral, chlorite, sericite, kaolinite, calcite and pyrite. Besides, laumontite, epidote, dickite, rhodochrosite, siderite, anhydrite, alunite, jarosite, marcasite and native sulfur are rarely found. Mode of occurrence, mineral properties disclosed by means of X-ray diffraction and variation of composition of main alteration minerals characterizing each alteration zone are mentioned as follows:

Specimens for X-ray diffraction were prepared by the following procedure. Clay particles under 2 microns in diameter were separated by application of Stokes' law of settling in water under gravity for clay minerals, and pure K-feldspar was separated using heavy liquid. Instrumental condition except for scanning speed and slit system is same as noted in Chapter 5. When intensity of X-ray reflections of 14 Å, 7 Å and 4.7 Å of chlorite mineral is determined, the scanning speed and slit system are 1°/2/min. and 1°/6-0.3mm-1°/6, respectively. When 2θ of the 10 to 12 Å reflection of mica clay mineral and 2θ ($\bar{2}$01, $\bar{2}$04, 060) of K-feldspar measured, the scanning speed is 1°/2/min..

Chemical analyses of clinopyroxene, feldspar, chlorite and sericite were carried out using an EPMA (JXA-50A) of Yamaguchi University. A specimen current was kept at 0.02 microampere with accelerating voltage at 15 kV. A correction was made using Bence and Albee (1968)'s method with α-factor of JEOL calculated by Professor A. L. Albee for JXA-50A. Yusa and Tsuzuki (1976)'s method was also used together for chlorite.

6.1 Chlorite mineral

Chlorite mineral means chlorite and chlorite/smectite mixed-layer mineral in this paper. It occurs in alteration zones A, B and C, and is one of abundant alteration minerals which are extensively found together with quartz and mica clay mineral. Especially, chloritization of zones B and C are so strong that alteration rocks look green generally.

X-ray diffraction patterns of chlorite minerals in alteration zones A, B, C and from ore veins (gangue mineral) are shown in Fig. 6.1. The results of X-ray analysis indicate that the chlorite/smectite mixed-layer mineral in subfacies A-2 can be divided into two types; (1) interstratified chlorite-smectite having long d-spacing reflection of nearly 31 Å (Fig. 6.1) which belongs to the category of regular interstratification and (2) interstratified chlorite-smectite with small amounts of expandable layers belonging to the category of random interstratification. The chlorite minerals have various intensities of each basal reflection of 14 Å, 7 Å and 4.7 Å (Fig. 6.1). From zone A toward zone C, the intensity of the basal reflections of 14 Å and 4.7 Å becomes weaker and 7 Å reflection relatively grows strong. Though the 14 Å reflection is distinctly recognized in zones A and B, it becomes indistinct in zone C.

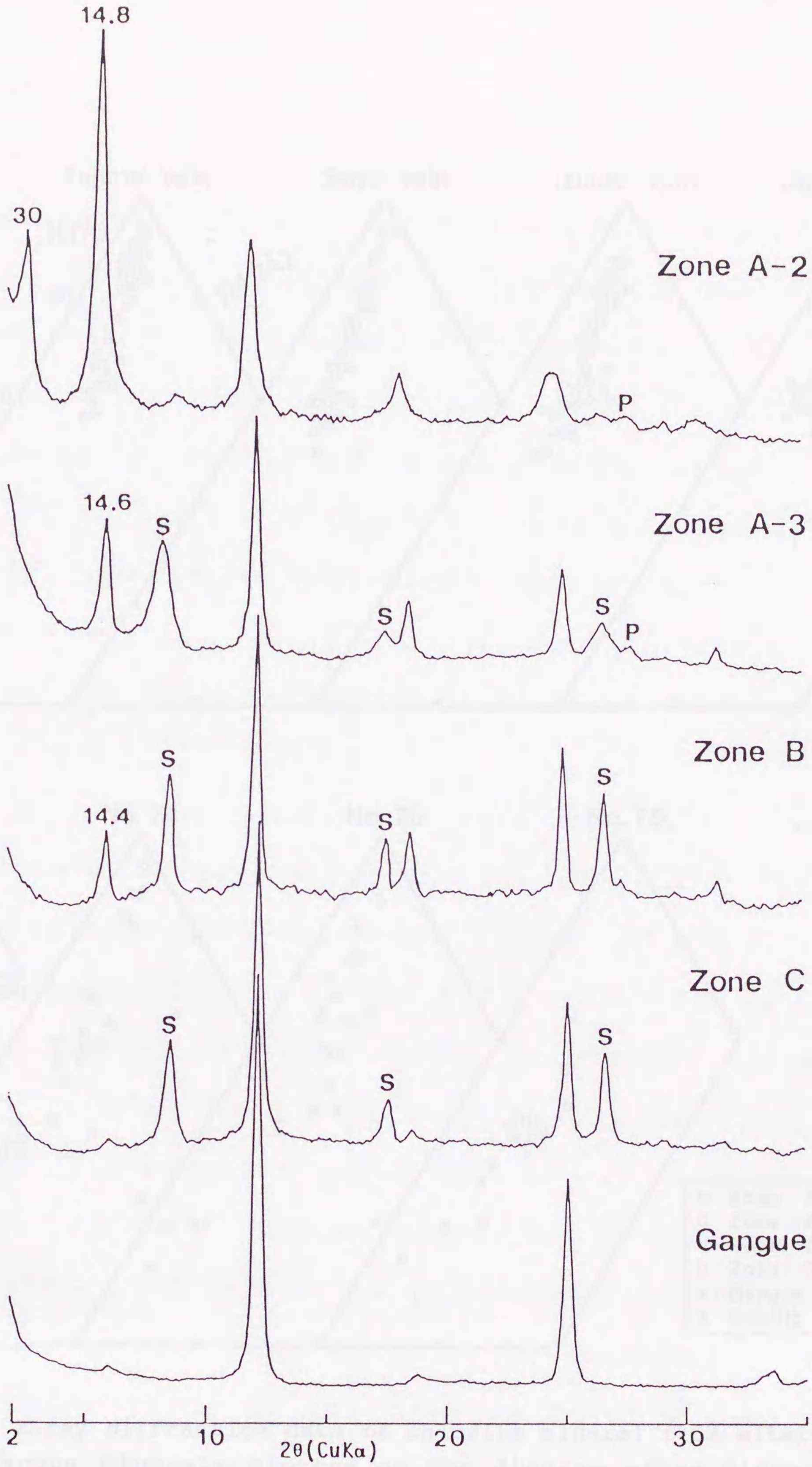


Fig.6.1 X-ray basal reflection patterns of chlorite minerals of under 2 microns fraction. S:Sericite, P:Plagioclase.

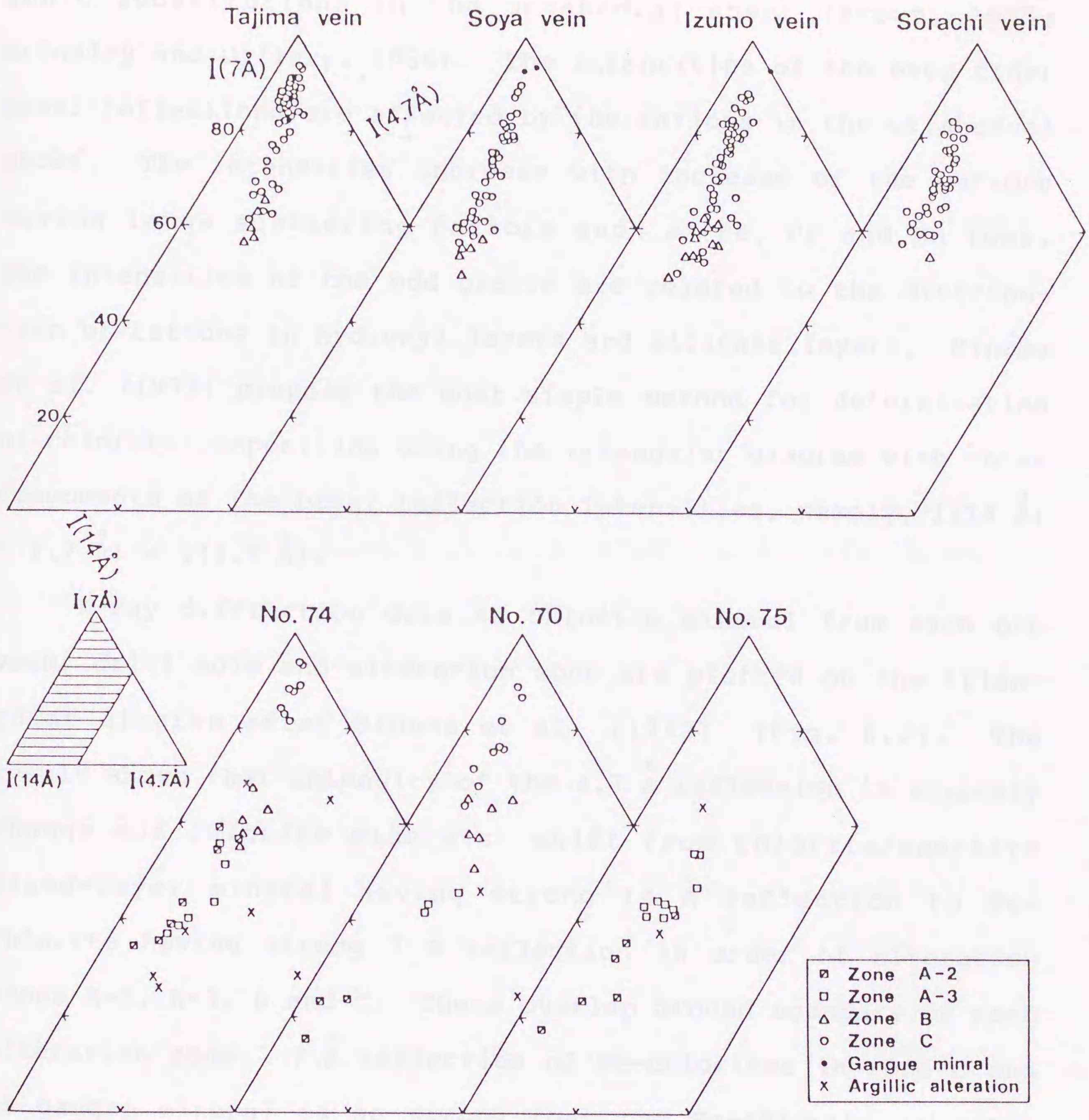


Fig.6.2 X-ray diffraction data of chlorite mineral from altered rocks and gangue minerals plotted on the diagram after Oinuma et al. (1972).

The intensities of the basal reflections of chlorites reflect the variations of chemical composition, especially ionic substitutions in the octahedral sheet (Brown, 1955; Brindley and Gillery, 1956). The intensities of the even order basal reflections are affected by the cations in the octahedral sheet. The intensities increase with increase of the cations having large scattering factors such as Fe, Cr and Mn ions. The intensities of the odd orders are related to the distribution of cations in hydroxyl layers and silicate layers. Oinuma et al. (1972) propose the most simple method for determination of chlorite composition using the triangular diagram with three components of the basal reflection intensities, namely, I(14 Å) - I(7 Å) - I(4.7 Å).

X-ray diffraction data of chlorite mineral from each ore vein, drill hole and alteration zone are plotted on the triangular diagram after Oinuma et al. (1972) (Fig. 6.2). The result shows that intensity of the 4.7 Å reflection is scarcely change and chlorite minerals shift from chlorite/smectite mixed-layer mineral having strong 14 Å reflection to Fe-chlorite having strong 7 Å reflection in order of alteration zones A-2, A-3, B and C. These overlap around boundary of each alteration zone. 7 Å reflection of Fe-chlorites in zone C and as gangue mineral is so strong that the Fe-chlorite is sometimes plotted outside of the diagram after Oinuma et al. (1972). In the Fe-chlorite, a peculiar mineral of which 14 Å reflection is extremely weak is seldom recognized. This may be berthierine (Bailey, 1980) belonging to serpentine mineral. However, the quantity of berthierine in zone C is unmeasured.

Both Fe-chlorite and berthierine exist in zone C. Thus, Fe-chlorite and berthierine are treated together as Fe-chlorite in this study.

Seeing I (7 Å) in Fig. 6.2, those of chlorites in subfacies A-3 and zone B are plotted within a limited range in each alteration zone showing nearly 50 % and 60 % respectively, on the other hand, that in zone C varies almost continuously ranging from 60 % to 95 %. Generally, I (7 Å) of chlorite in zone C at the vicinity of ore vein tends to grow larger than that at the vicinity of zone B.

Looking I (7 Å) of each ore vein, the Tajima, Soya, Izumo and Sorachi veins are common on the tendency of variation. Whereas, chlorite having I (7 Å) of about 90 % lacks in zone C of the Sorachi vein. This implies that zone C at the vicinity of ore vein has been replaced by zone E and the chlorite concerned has disappeared. I (7 Å) of chlorites from drilling core specimens are common to those of chlorites from the Izumo vein on their variation trend.

Regarding chlorites from drilling cores, it is possible to say that I (7 Å) of chlorites is plotted within a certain range in each alteration zone, i.e. those from zones A-2, A-3, B and C are 20 to 60, 40 to 60, 50 to 70 and over 80 %, respectively (Fig. 6.2). It is also characteristic that I (7 Å) of chlorites from zone A-3 are plotted in a limited area of 50 % as given in Fig. 6.3.

EPMA analyses of chlorites are listed in Appendix 1 and the analytical data of each ore vein, drill hole and alteration zone are plotted in Fig. 6.4. Chlorite shows a wide range of

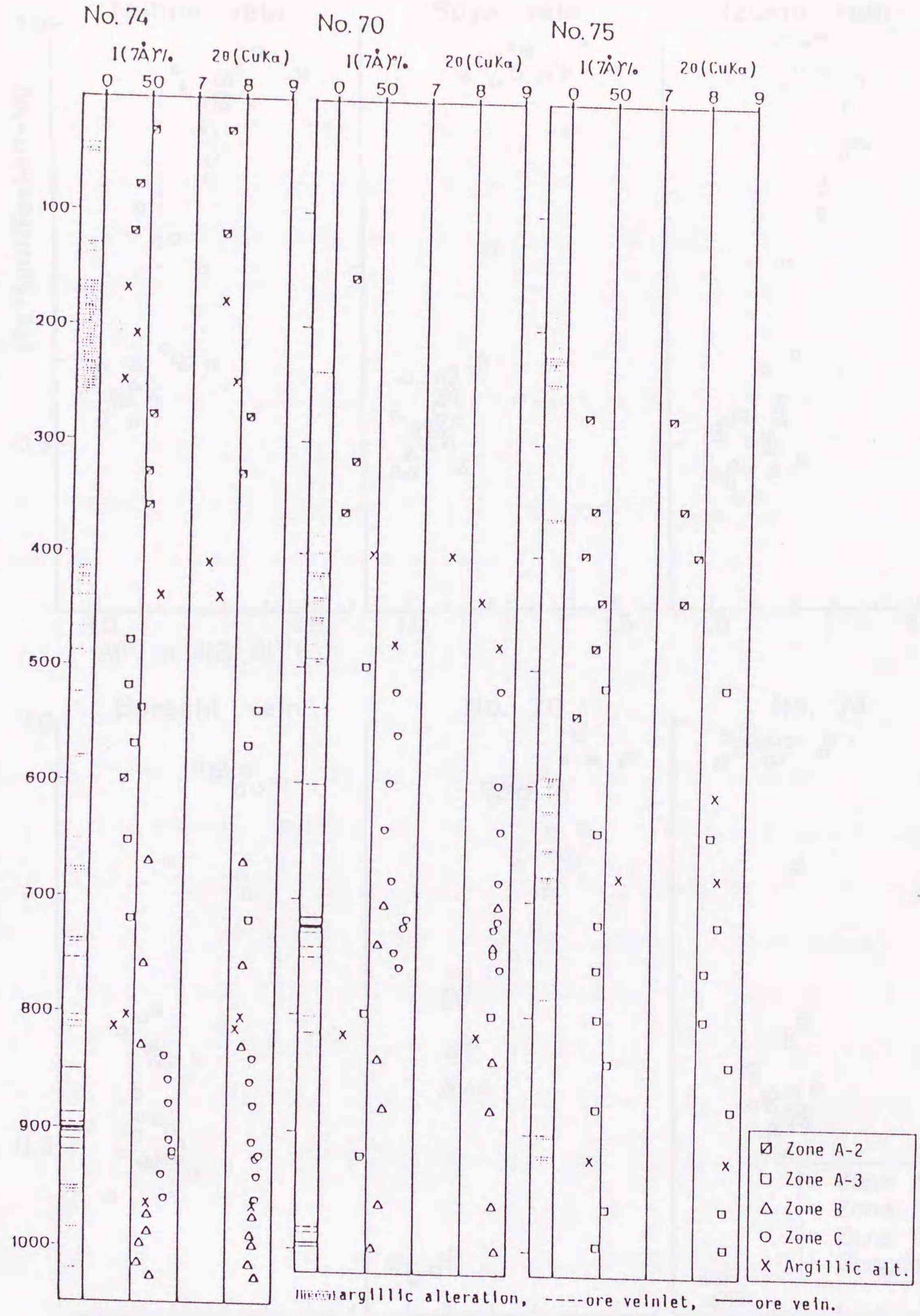


Fig.6.3 Variation of intensity of 7 Å reflection of chlorite mineral and position of the 10-12 Å reflection of mica clay mineral as a function of depth in drill hole Nos.74, 70 and 75.

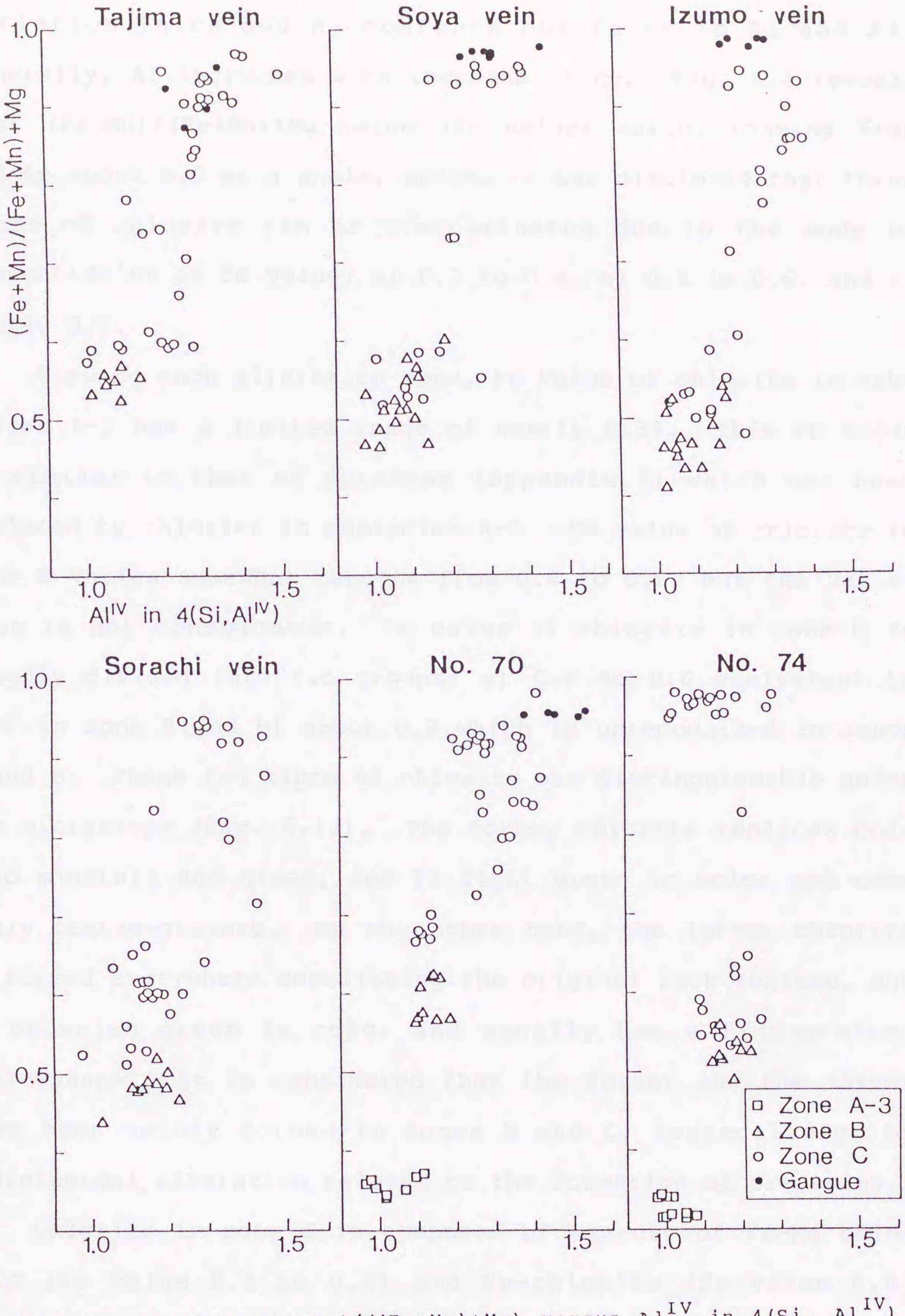


Fig.6.4 Fe value $(Fe+Mn)/((Fe+Mn)+Mg)$ versus Al^{IV} in $4(Si, Al^{IV})$ diagram of chlorite minerals from altered rocks and gangue minerals.

variation in Fe and Mg contents but faint in Si and Al. Generally, Al increases with increase of Fe. Fig. 6.4 reveals that (Fe+Mn)/(Fe+Mn)+Mg value (Fe value) varies ranging from 0.3 to about 0.9 as a whole, while, it was disclosed that three kinds of chlorite can be discriminated due to the mode of concentration of Fe value; a) 0.3 to 0.4, b) 0.4 to 0.6, and c) nearly 0.9.

Viewing each alteration zone, Fe value of chlorite in subfacies A-3 has a limited range of nearly 0.35. This Fe value is similar to that of pyroxene (Appendix 2) which has been replaced by chlorite in subfacies A-3. Fe value of chlorite in zone B varies somewhat ranging from 0.4 to 0.6, but the variation is not conspicuous. Fe value of chlorite in zone C is roughly divided into two groups; a) 0.4 to 0.6 equivalent to that in zone B and b) about 0.9 which is unrecognized in zones A and B. These two kinds of chlorite are distinguishable under the microscope (Fig. 5.17). The former chlorite replaces colored minerals and glass, and is light green in color and commonly coarse-grained. On the other hand, the latter chlorite is formed everywhere demolishing the original rock texture, and is brownish green in color and usually has a fine-grained scale-shape. It is considered that the former and the latter have been mainly formed in zones B and C, respectively, by hydrothermal alteration related to the formation of ore veins.

Chlorite in zone C is composed of mixture of Fe-Mg chlorite (Fe value 0.4 to 0.6) and Fe-chlorite (Fe value 0.9) formed in zones B and C, respectively. This implies that I (7 Å) of chlorite in zone C depends on the quantity of the preceding two kinds of chlorite. The I (7 Å) has nearly 60 % at the vicinity of zone B dominating Fe-Mg chlorite, on the other hand, I (7 Å) becomes over 90 % at the vicinity of ore vein where preponderant in Fe-chlorite.

Fe value of chlorite in gangue mineral is generally far higher than that in zone C, and the chlorite is almost pure Fe-chlorite.

Comparing each ore vein, chlorites from the Tajima, Soya, Izumo and Sorachi veins are similar on compositional variation. Chlorites from Nos.70 and 74 drilling cores show the same manner of change as is observed in the Izumo vein and so on.

6.2 Mica clay mineral

Mica clay mineral in this paper includes both sericite and sericite/smectite mixed-layer mineral. It occurs in almost all alteration zones except for subfacies A-1, and is one of alteration minerals which are extensively found together with quartz and chlorite mineral. Especially, zones D and E are more strongly sericitized, and the alteration rocks concerned look white.

X-ray diffraction patterns of mica clay mineral from alteration zones A, B, C, D, E and from argillic alteration zone are shown in Fig. 6.5. Position of the 10-12 Å reflection tends to shift to high-angle side in following order; argillic alteration zone ⟶ zones A-2 ⟶ A-3 ⟶ D ⟶ B-C-E. Sericite/smectite mixed-layer mineral having obvious long d-spacing reflection is sometimes recognized only in argillic alteration zone (Fig. 6.5).

Positions of the 10-12 Å reflection by X-ray diffraction were measured and the results were shown on Fig. 6.6 in relation to each ore vein and alteration zone. The position of reflections varies ranging from 7.3° to 8.8° (12.1 to 10.0 Å) by 2θ (CuKα) as a whole, but it has a limited range in each alteration zone.

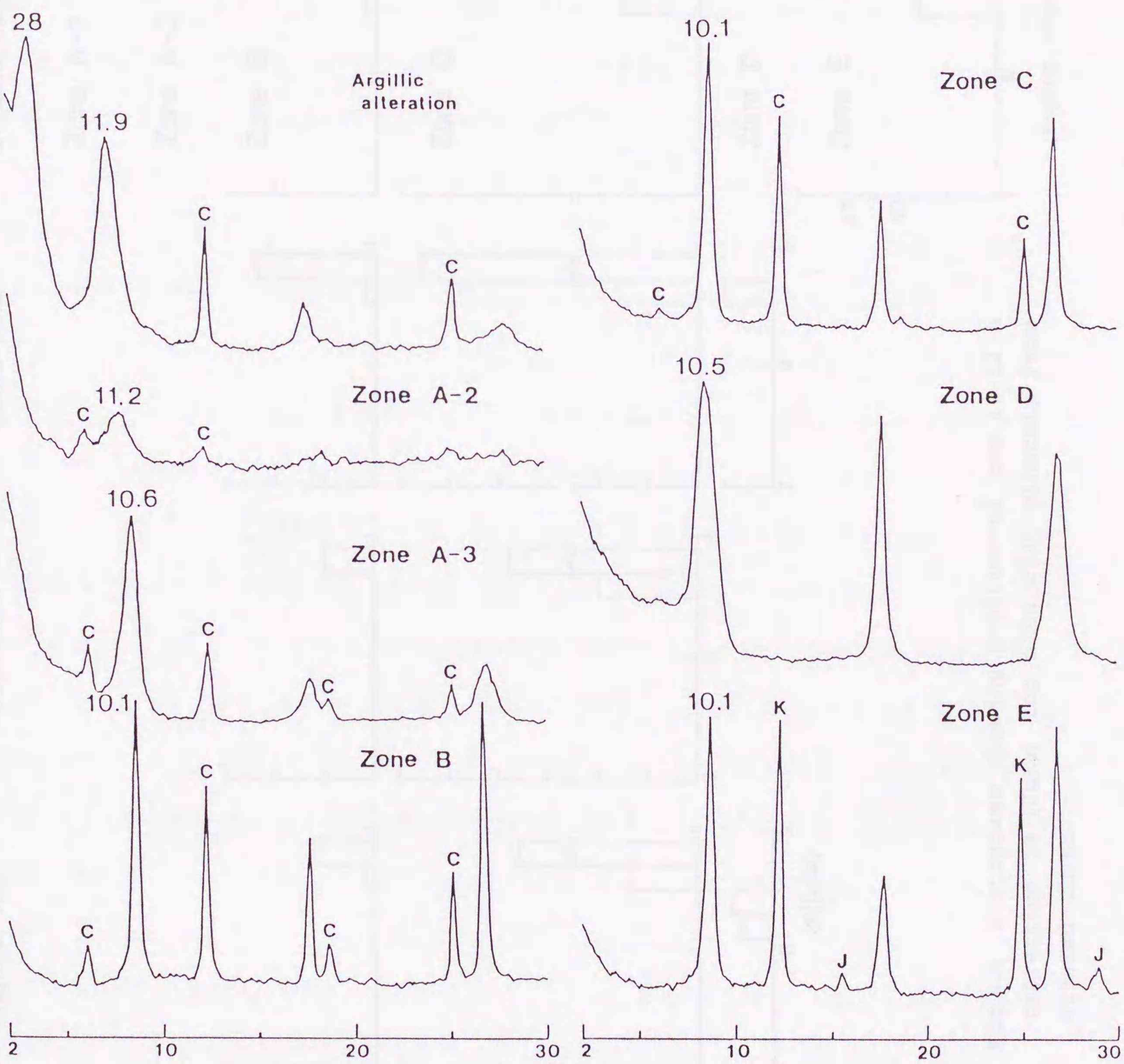


Fig.6.5 X-ray basal reflection patterns of mica clay minerals of under 2 microns fraction. C:Chlorite, K:Kaolinite, J:Jarosite.

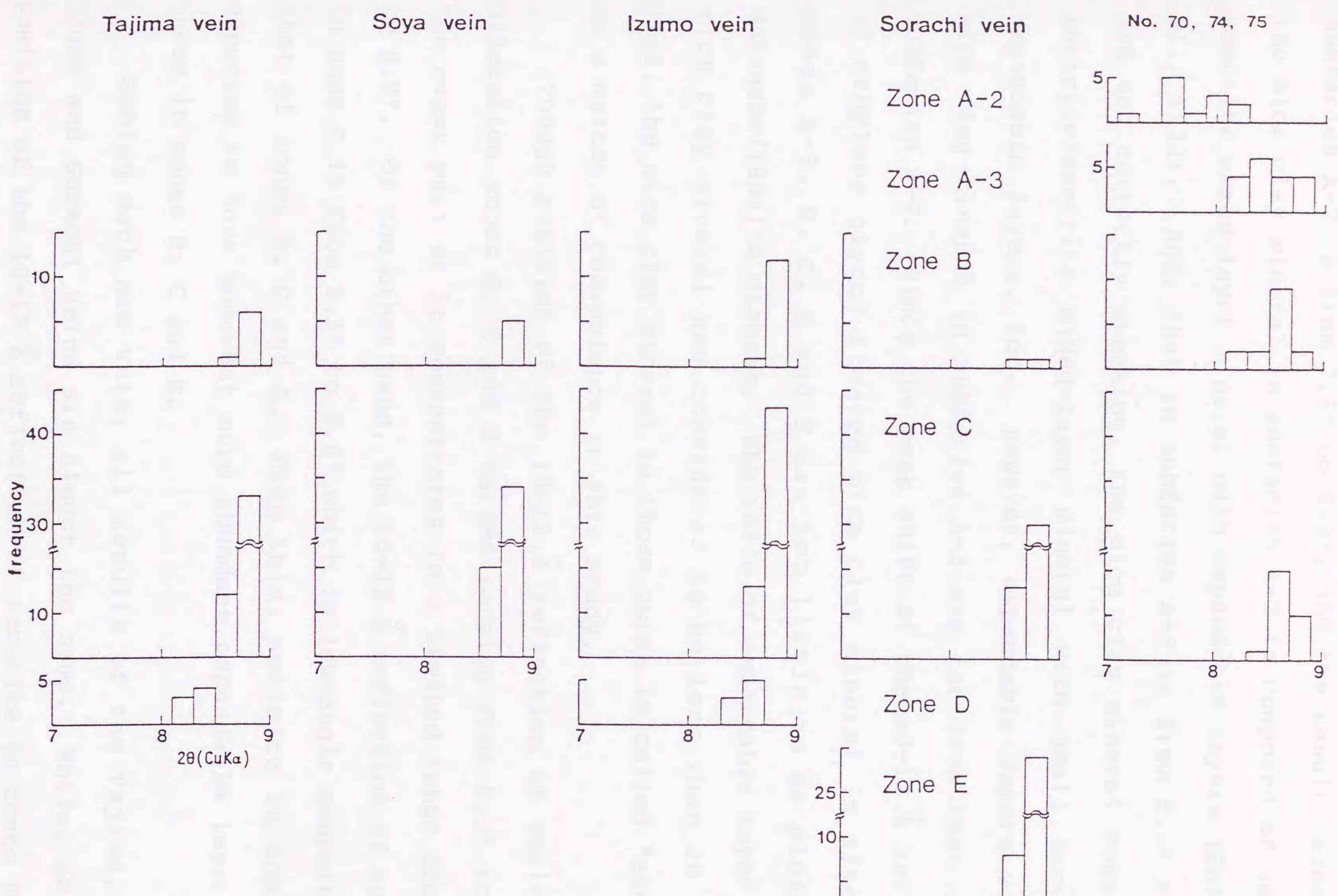


Fig.6.6 Histograms showing position of the 10-12 Å reflection 2θ (CuKα) for mica clay minerals from altered rocks.

Position of the 10-12 Å reflection of mica clay mineral in subfacies A-2 is from 7.3° to 8.2°, and the result reveals that the mica clay mineral in subfacies A-2 is composed of sericite/smectite mixed-layer mineral with expandable layers (Shirozu et al., 1972). And, that in subfacies A-3 is from 8.1° to 8.8°, and so, correctly speaking, the mica clay mineral consists of sericite/smectite mixed-layer mineral with small amounts of expandable layers, too. However, expandable layers with the mica clay mineral in subfacies A-3 are far less than that in subfacies A-2. Since the peak shift of the 10-12 Å reflection of ethylene glycol treated mica clay mineral in alteration zones A-3, B, C, D and E was too little to be plotted on Watanabe(1981)'s diagram. The ratio of expandable layer in the mica clay mineral was considered to be less than 20 %. So that, the mica clay mineral in those zones is called "sericite" as a matter of convenience in this study.

Though position of the 10-12 Å reflection of sericite in alteration zones B, C and E varies ranging from 8.3° to 8.8°, the major part of it concentrates in a limited range from 8.7° to 8.8°. On the other hand, the 10-12 Å reflection of sericite in zone D is from 8.3° to 8.6° which is low-angle compared with that of zones B, C and E. From this, sericite in zone D is expected to have somewhat more abundant expandable layers than those in zones B, C and E.

Seeing each ore vein, all results of the Tajima, Soya, Izumo and Sorachi veins are almost the same. While, owing to position of the 10-12 Å reflection of sericite in zones B and C of drilling cores is lower-angle by about 0.1° than that of these ore veins, the former sericite is considered to have slightly abundant expandable layers compared with the latter one.

Relationship between position of the 10-12 Å reflection of sericite in drilling cores and the depth, vertical distance from the surface, is shown in Fig. 6.3. Position of the 10-12 Å reflection shifts gradually to high-angle side with increasing of the depth, and the mica clay mineral varies from mixed-layer mineral with expandable layers to sericite with increasing of the depth. Especially, such tendency is distinctly recognized in No.75 drill hole (Fig. 6.3).

The peak widths in 2θ at the half height of the 10-12 Å and 5 Å reflections were measured and designated as W_1 and W_2 respectively. The values obtained under identical instrumental conditions of each ore vein and alteration zone are plotted in the Shirozu and Higashi (1972)'s diagram (Fig. 6.7). The W_1 and W_2 values of sericites in zones B, C and E of the Tajima, Soya, Izumo and Sorachi veins are 0.3 to 0.6 and 0.3 to 0.5 respectively, and those have somewhat limited range and similar properties to each other, and the sericites have hardly expandable layers. Both of the W_1 and W_2 values of sericite in zone D is larger than those in zones B, C and E, and particularly the W_1 value is very large. So that, sericite in zone D is estimated to have small amounts of expandable layers (Shirozu and Higashi, 1972).

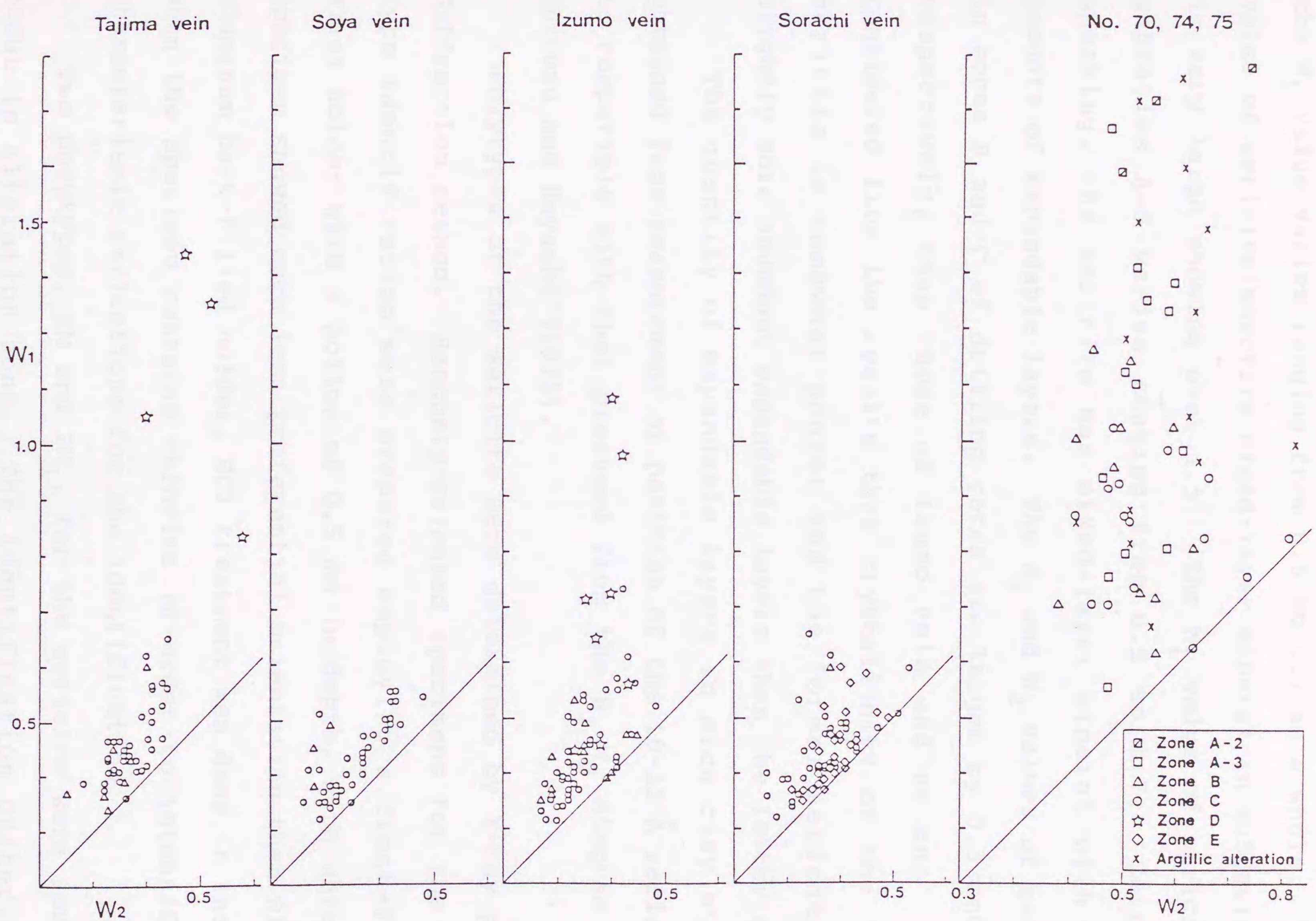


Fig.6.7 X-ray diffraction data of mica clay mineral from altered rocks plotted on the $W_1 - W_2$ diagram after Shirozu and Higashi (1972).

While, on sericites from drilling cores, the W_2 value has a limited range from 0.4 to 0.7 in all alteration zones, but the W_1 value varies ranging from 0.5 to 1.7 as a whole. The W_1 value of sericite/smectite mixed-layer mineral in subfacies A-2 is very large showing over 1.5. The W_1 value of sericite in subfacies A-3 varies ranging from 0.5 to 1.7. Correctly speaking, the sericite has mixed-layer mineral with small amounts of expandable layers. The W_1 and W_2 values of sericite in zones B and C of drilling cores are larger by 0.3 and 0.2, respectively, than those of Izumo vein and so on. It is considered from the results that crystallinity of the former sericite is somewhat poorer and the former sericite has slightly more abundant expandable layers than the latter one.

The quantity of expandable layers in mica clay mineral obtained from measurement of position of the 10-12 Å reflection is compatible with that presumed from the W_1-W_2 diagram after Shirozu and Hayashi (1972).

Polytypes of the sericite were determined by X-ray powder diffraction method. Randomly-oriented specimens for the polytype identification were prepared employing a front-filled glass holder with a hollow of 0.5 mm in depth, with which the specimen showed much less preferential orientation than with as aluminum back-filled holder. HCl treatment was done in the case when the specimen contains chlorite in order to intensify the characteristic reflections for the identification.

Two polytypes, 1M and $2M_1$, for the sericite were found to occur in alteration zone. The identification criteria for polytypes followed the X-ray data by Yoder and Eugster (1955).

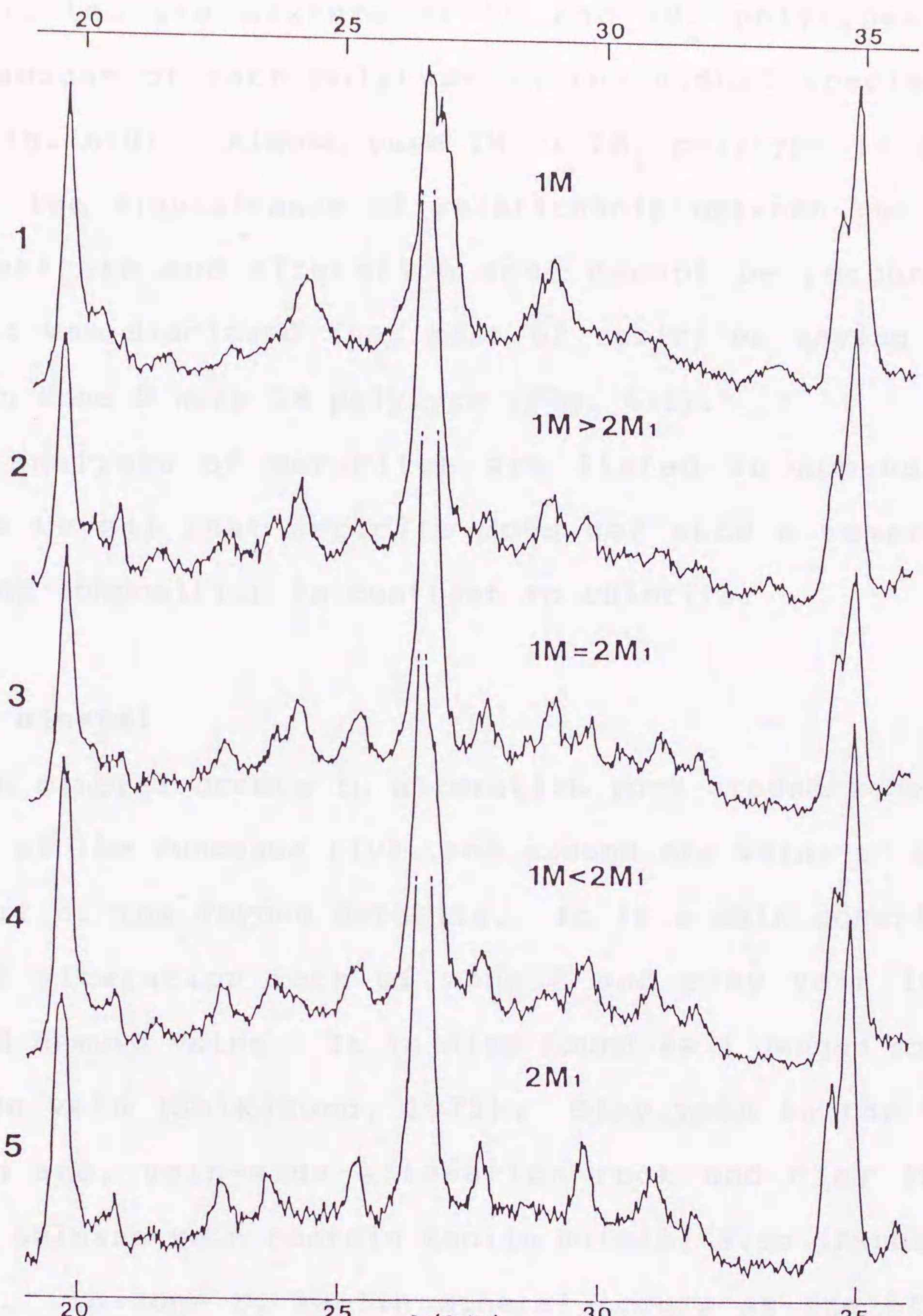


Fig.6.8 X-ray random powder patterns of sericites of under 2 microns fraction.

1. 1M polytype, 51082508 (andesite of the Nagato Form., at a tributary of the Ohezawa river)
2. Mixture of 1M and $2M_1$ polytypes, 52071405 (andesite of the Nagato Form. at -250mL of the Izumo vein)
3. Mixture of 1M and $2M_1$ polytypes, 52070704 (basaltic andesite of the Koyanagizawa Form. at -300mL of the Izumo vein)
4. Mixture of $2M_1$ and 1M polytypes, 52071210 (andesite of the Nagato Form. at -200mL of the Izumo vein)
5. $2M_1$ polytype, Sy-3 (andesite of the Nagato Form. at -150mL of the Soya vein).

Major sericites are mixture of 1M and $2M_1$ polytypes, but relative amount of each polytype in individual specimen is various (Fig. 6.8). Almost pure 1M or $2M_1$ polytype is rarely found, but the significance of relationship between the polytype of sericite and alteration zone cannot be recognized. However, it was disclosed that most of sericites having large W_1 value in zone D were 1M polytype (Fig. 6.8).

EPMA analyses of sericites are listed in Appendix 3. Those data reveal that sericite does not show a remarkable variation of composition in contrast to chlorite.

6.3 Kaolin mineral

Kaolin mineral occurs in alteration rock around zone F at downstream of the Yunosawa river and around ore veins at southeastern part of the Toyoha deposits. It is a main constituent mineral of alteration rock of zone E and clay vein in the Sorachi and Nemuro veins. It is also found as a gangue mineral of the Soya vein (Shikazono, 1975). Clay vein in the lower Izumo vein and, vein-side alteration rock and clay in and around the Shinano vein contain kaolin mineral also (Kanbara et al., 1989). In zone E, kaolin mineral occurs as one of main alteration minerals together with quartz and sericite, and zone E is characterized by the presence of kaolin mineral.

Kaolinite and dickite are recognized as kaolin mineral and kaolinite is more common than dickite. Dickite is rarely confirmed at the Sorachi, Nemuro, lower Izumo and Shinano veins. Each reflection of $1\bar{1}0$, $11\bar{1}$ and $1\bar{1}\bar{1}$ by X-ray diffraction of kaolinites in zone E, of gangue mineral and of clay vein from

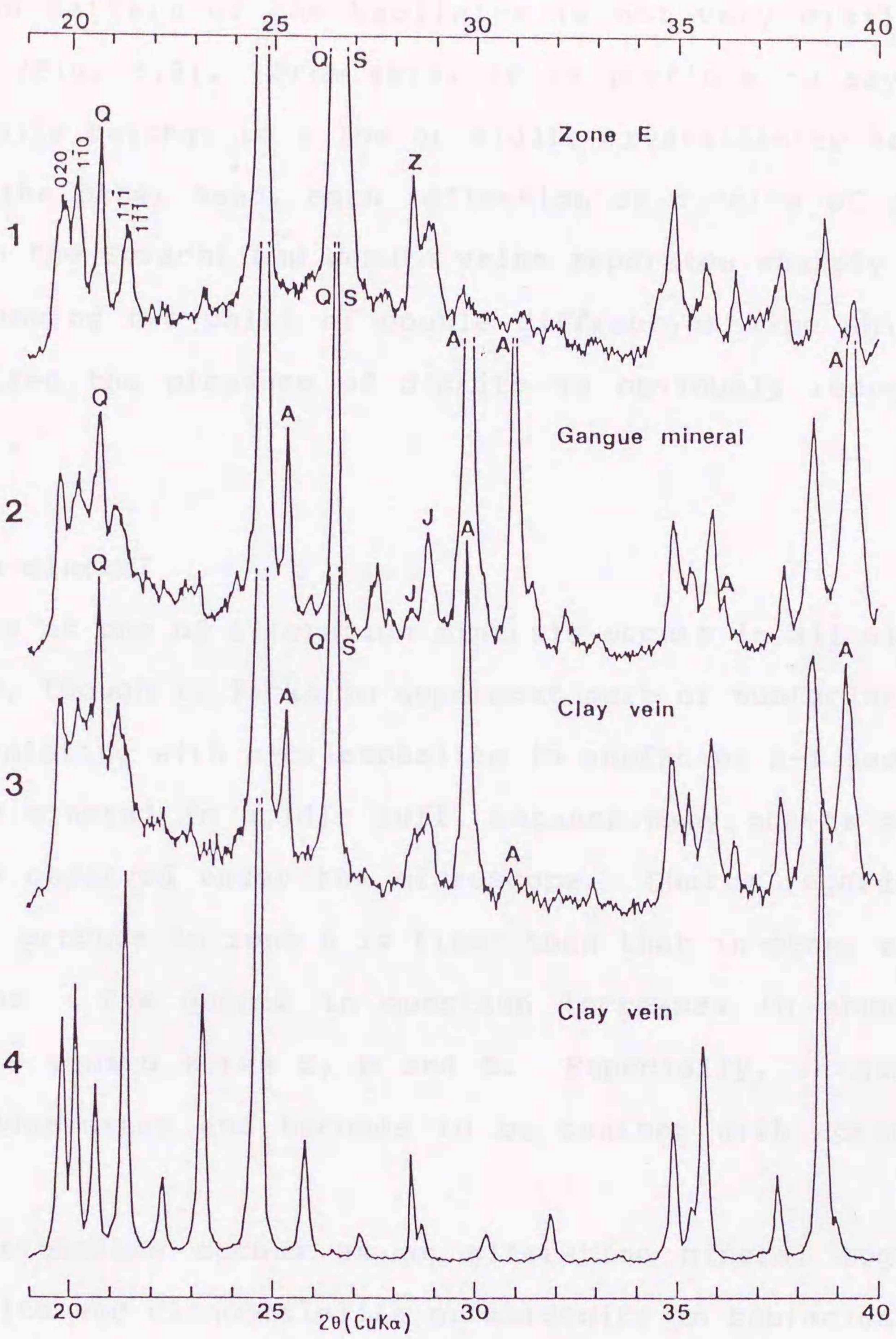


Fig.6.9 X-ray random powder patterns of kaolin minerals of under 2 microns fraction.

1. Kaolinite in zone E, 35Sr01 (sandstone of the Motoyama Form. at -350mL of the Sorachi vein)
2. Kaolinite in gangue mineral, 35Nm06 (at -350mL of the Nemuro vein)
3. Kaolinite in clay vein, 25Sr10 (at -250mL of the Sorachi vein)
4. Dickite in clay vein, 30Sr16 (at -300mL of the Sorachi vein)

the Sorachi and Nemuro veins is obscure. In other words, reflection pattern of the kaolinite is not very distinctly separated (Fig. 6.9). From this, it is possible to say that the kaolinite belongs to a low or middle crystallinity kaolinite. On the other hand, each reflection of dickite of gangue mineral in the Sorachi and Nemuro veins separates sharply at $2\theta=35-39°$ showing two pairs of double diffraction line which is characterized the presence of dickite is obviously recognized (Fig. 6.9).

6.4 Silica mineral

Quartz as one of alteration minerals occurs in all alteration zones, though it lacks in uppermost part of subfacies A-1. Quartz coexisting with α-cristobalite in subfacies A-1 seems to be primary mineral in acidic tuff, because many quartz phenocrysts are observed under the microscope. Quartz regarded as alteration product in zone A is finer than that in other alteration zones. The quartz in question increases in abundance from zone B toward zones C, D and E. Especially, in zone C, quartz predominates and becomes to be coarser with access to ore vein.

α-cristobalite occurs as an alteration mineral together with smectite and clinoptilolite or mordenite in subfacies A-1.

6.5 Feldspars

Though albite and K-feldspar are recognized in alteration zone B, K-feldspar is rarely found. Albite and K-feldspar occur independent of original rock type. However, both above-two minerals never coexist in the same sample.

Albite occurs as an alteration mineral in lower part of subfacies A-3 and zone B. Unaltered plagioclase in subfacies A-3 is labradorite containing roughly 60 % An (Appendix 4 and Fig. 6.10), while, altered plagioclase is microscopically

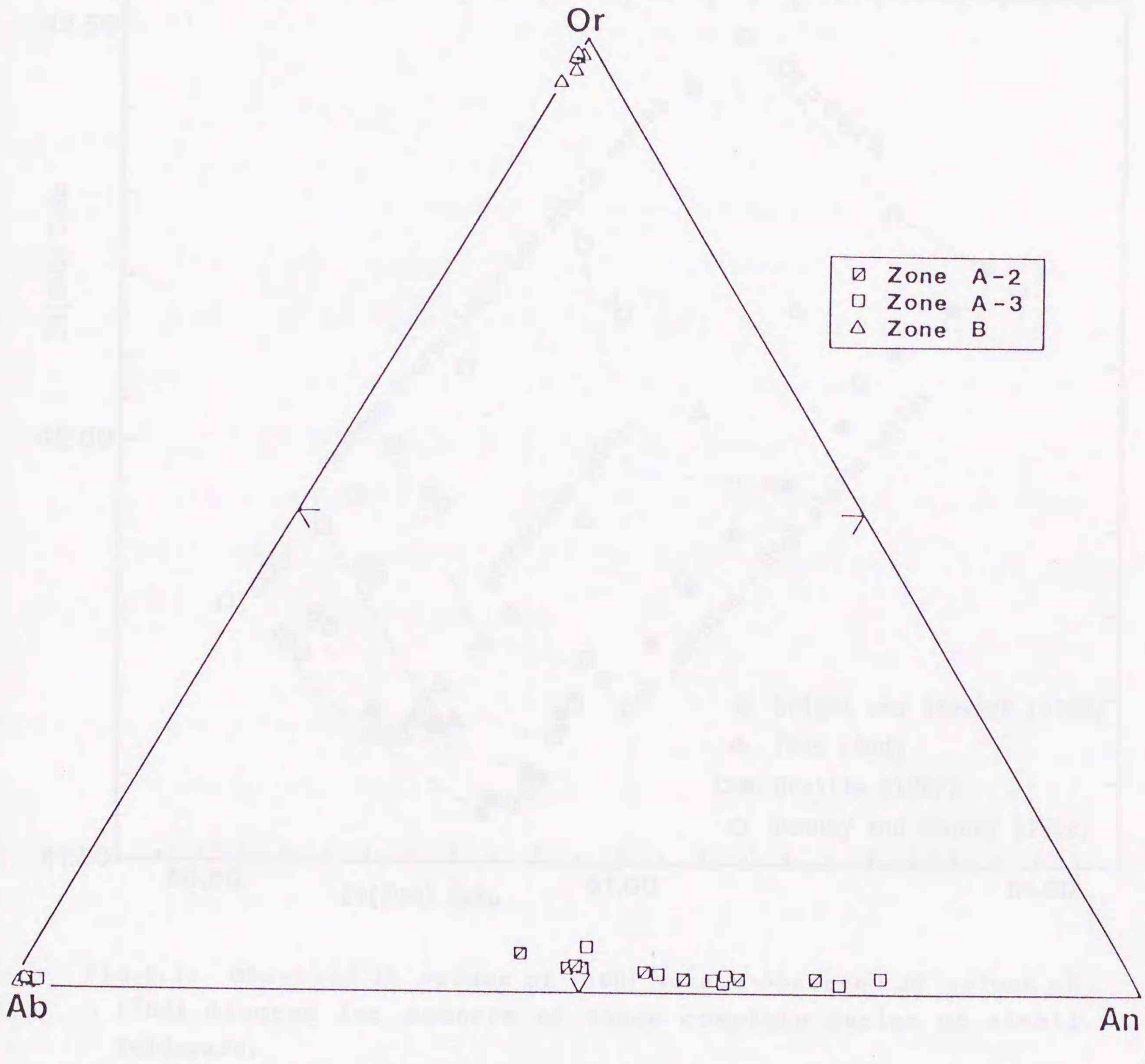


Fig.6.10 Triangular plot of feldspars from alteration zones showing mole percent content of orthoclase (Or), albite (Ab) and anorthite (An).

nearly pure albite wholly replacing the primary plagioclase in a part of subfacies A-3. Albite in zone B is almost pure one (Appendix 4 and Fig. 6.10), and it is associated with calcite in many cases but rarely with sericite which replaces plagioclase phenocryst or plagioclase-lath in groundmass.

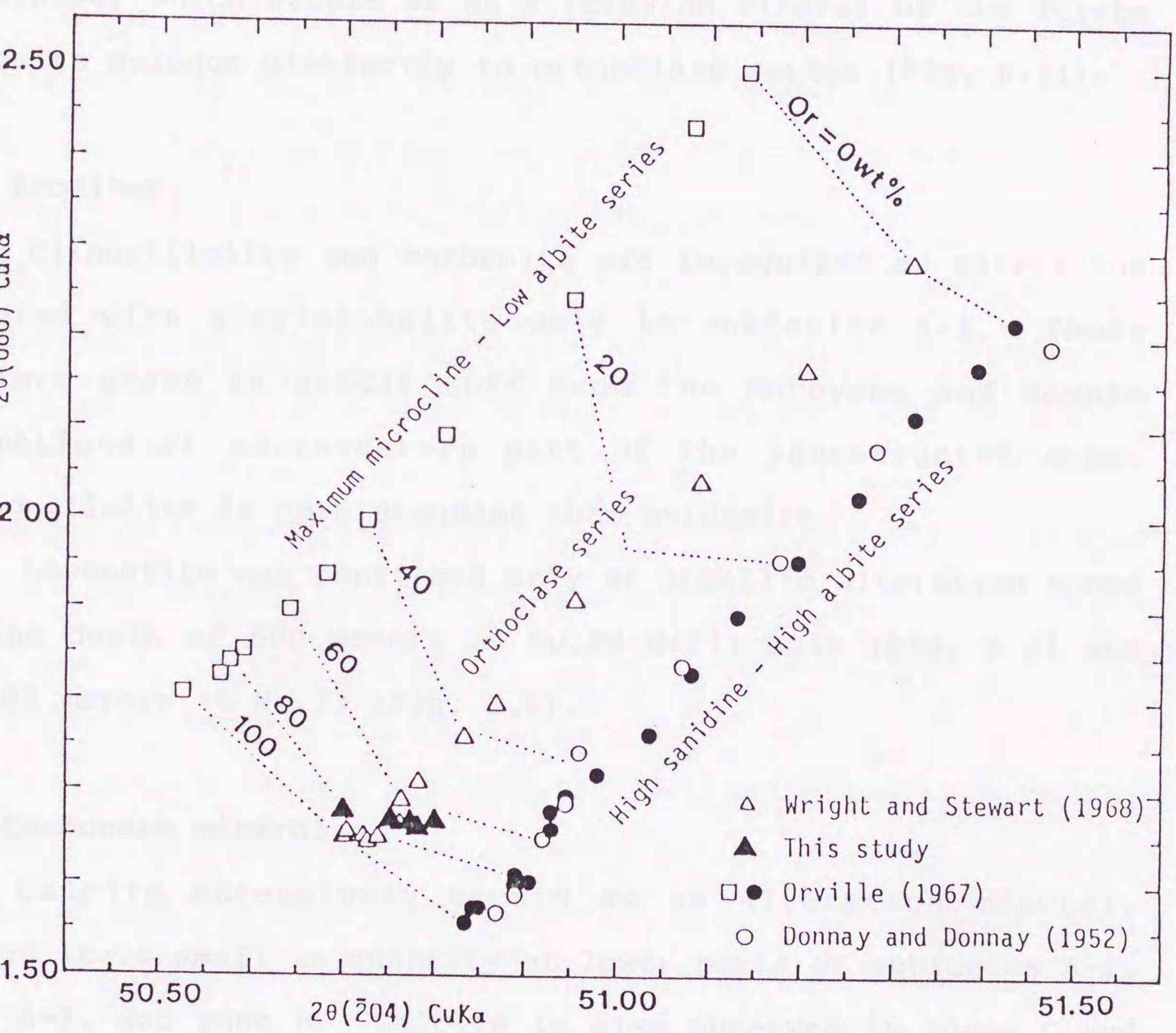


Fig.6.11 Observed 2θ values of (060) versus observed 2θ values of (2̄04) diagram for members of three complete series of alkali feldspars.

K-feldspar is rarely observed as an alteration mineral in zone B. Value of 2θ ($\bar{2}01$) of K-feldspar is 20.98° and the value introduces Or (wt.%) = 94 (Wright, 1968). EPMA analysis of some K-feldspar shows that it is nearly pure K-feldspar (Appendix 4 and Fig. 6.10). 2θ ($\bar{2}04$) and 2θ (060) diagram on alkali feldspar (Wright, 1968; Shoji, 1972) has revealed that K-feldspar which occurs as an alteration mineral of the Toyoha deposits belongs distinctly to orthoclase series (Fig. 6.11).

6.6 Zeolites

Clinoptilolite and mordenite are recognized as alteration mineral with α-cristobalite only in subfacies A-1. Those replace glass in acidic tuff from the Motoyama and Nagato Formations at southeastern part of the investigated area. Clinoptilolite is more abundant than mordenite.

Laumontite was confirmed only at argillic alteration zones at the depth of 600 meters in No.68 drill hole (Fig. 5.3) and of 500 meters in No.73 (Fig. 5.6).

6.7 Carbonate mineral

Calcite extensively occurs as an alteration mineral, though it is small in quantity at lower parts of subfacies A-1, A-2, A-3, and zone B. Calcite is also observed in zones C and D under the microscope. In zone A, calcite associated with chlorite replacing pyroxene is found. Besides, calcite replacing plagioclase and glass is found in places. In zone B, calcite is scanty compared to that in subfacies A-3. In this case, it replaces both plagioclase phenocryst and glass of groundmass.

Rhodochrosite is rarely confirmed in zone B. Siderite presents only in argillic alteration zone at 68 meters from the surface of No.69 drill hole (Fig. 5.4).

6.8 Sulfide mineral

Pyrite occurs extensively in most alteration zones around the Toyoha deposits such as zones B, C, D and E and zone F. It is rarely found in strongly altered part of subfacies A-3. Idiomorphic pyrite showing cubic-shape of about 0.5 mm is often observed in alteration zones C, D and E. These exclusively occur near the contact with ore vein. Pyrite in zone B is fine-grained compared with that in zones C, D and E, and is generally anhedral.

Marcasite was exceedingly rarely confirmed only in zone E and in clay vein of the Sorachi and Nemuro veins.

6.9 Sulfate mineral

Sulfate minerals are alunite, jarosite and anhydrite. Anhydrite was found only at argillic alteration zone appearing in No.75 drill hole at the depth of nearly 900 meters (Fig. 5.8).

Alunite and jarosite are recognized only in alteration zone E, as a gangue mineral or as a constituent mineral of clay vein associated with the Sorachi and Nemuro veins occurring together with kaolin mineral. Occurrence of alunite is exceedingly scant compared with kaolin mineral.

7. Chemical Composition of Altered Rocks

Chemical analyses of 68 samples of altered rocks and 2 samples of unaltered rocks around the Toyoha deposits were carried out by means of XRF and wet methods. 41 samples were collected from subsurface area of the Toyoha mine, 14 samples from drill holes and 15 samples from outcrops. For the analyses, andesite and basaltic andesite in origin have been selected in order to remove chemical influence caused by difference of original rock. However, it was so difficult to obtain the altered andesite in zone E, that sedimentary rocks of the Motoyama Formation as well as andesite were used for this zone. For XRF analysis, a Model JSX-60S7 at Yamaguchi University was used. The results are presented in Appendix 5.

Looking average chemical composition of each alteration zone, SiO_2 and Al_2O_3 as well as TiO_2 and P_2O_5 are not very variable through all zones, but other elements show distinct variation (Table 7.1 and Fig. 7.1), e.g., FeO* (total iron as FeO) varies ranging from 6.41 to 20.63 wt.% in zone C. Although MnO increases to about 1 wt.% in average in zones B and C, it decreases under 0.2 wt.% in other alteration zones (Fig. 7.1). MgO is nearly 3 wt.% in zones A, B and C, but decreases under 1 wt.% in zones D, E and F. CaO and Na_2O are unvaried in unaltered rock and zone A. While, they conspicuously decrease toward vein, especially in zones C, D, E and F. K_2O is distinctly added in alteration zones B, C, D and E around ore vein. H_2O* (total H_2O) increases in order of unaltered rock, zone A and zones B to F. CO_2 augments only in zones A-2, A-3

Table 7.1 Average chemical compositions of each alteration zone

Alt. zone Number*	Unalt. 2	A-1 4	A-2 3	A-3 6	B 8	C 37	D 3	E 5	F 2
SiO_2	58.29	57.65	57.02	55.02	57.39	57.87	65.35	61.33	73.36
TiO_2	0.69	0.81	0.82	0.92	0.82	0.78	0.66	0.81	0.70
Al_2O_3	15.95	15.94	16.87	16.75	16.14	14.40	15.34	14.74	13.69
Fe_2O_3	3.31	4.40	4.22	3.67	2.12	4.63	4.66	8.81	1.95
FeO	5.16	3.90	2.39	3.83	4.60	8.45	0.25	1.02	0.20
MnO	0.16	0.20	0.08	0.19	1.20	1.51	0.06	0.04	0.00
MgO	3.63	3.00	3.55	3.17	2.93	2.46	0.88	0.41	0.48
CaO	7.27	7.16	6.61	7.66	3.20	0.35	0.17	0.13	0.13
Na_2O	2.46	2.34	2.76	2.81	0.52	0.09	0.18	0.06	0.17
K_2O	1.46	1.16	1.67	0.83	4.88	2.79	3.86	2.44	1.83
P_2O_5	0.13	0.16	0.14	0.20	0.20	0.19	0.13	0.12	0.19
$H_2O(+)$	0.81	1.71	2.10	2.67	3.89	4.87	4.41	5.85	4.88
$H_2O(-)$	0.30	0.91	0.46	0.28	0.42	0.42	1.72	0.48	1.11
CO_2	0.02	0.13	0.69	2.10	2.03	0.10	0.00	0.01	0.00
Rest	0.27	0.28	0.02	0.27	0.10	1.09	2.17	3.60	1.26
Total	99.91	99.75	99.40	100.37	100.44	100.00	99.84	99.85	99.95

Number* denotes the total number of analyzed sample

and B, and is hardly contained in other alteration zones.

$CaO+Na_2O$ is 7.34 to 12.85 wt.% in both unaltered rocks and zone A. Whereas, 2.05 to 4.76 in zone B, 0.12 to 1.33 in zone C, 0.23 to 0.41 in zone D, 0.08 to 0.57 in zone E and 0.28 to 0.32 in zone F, respectively. And therefore, based on the $CaO+Na_2O$ content, alteration grade can be chemically divided into three groups; 1) unaltered rocks and zone A (7.34 to 12.85), 2) zone B (2.05 to 4.76) and 3) zones C, D, E and F (0.08 to 1.33). The major element oxides related to each ore

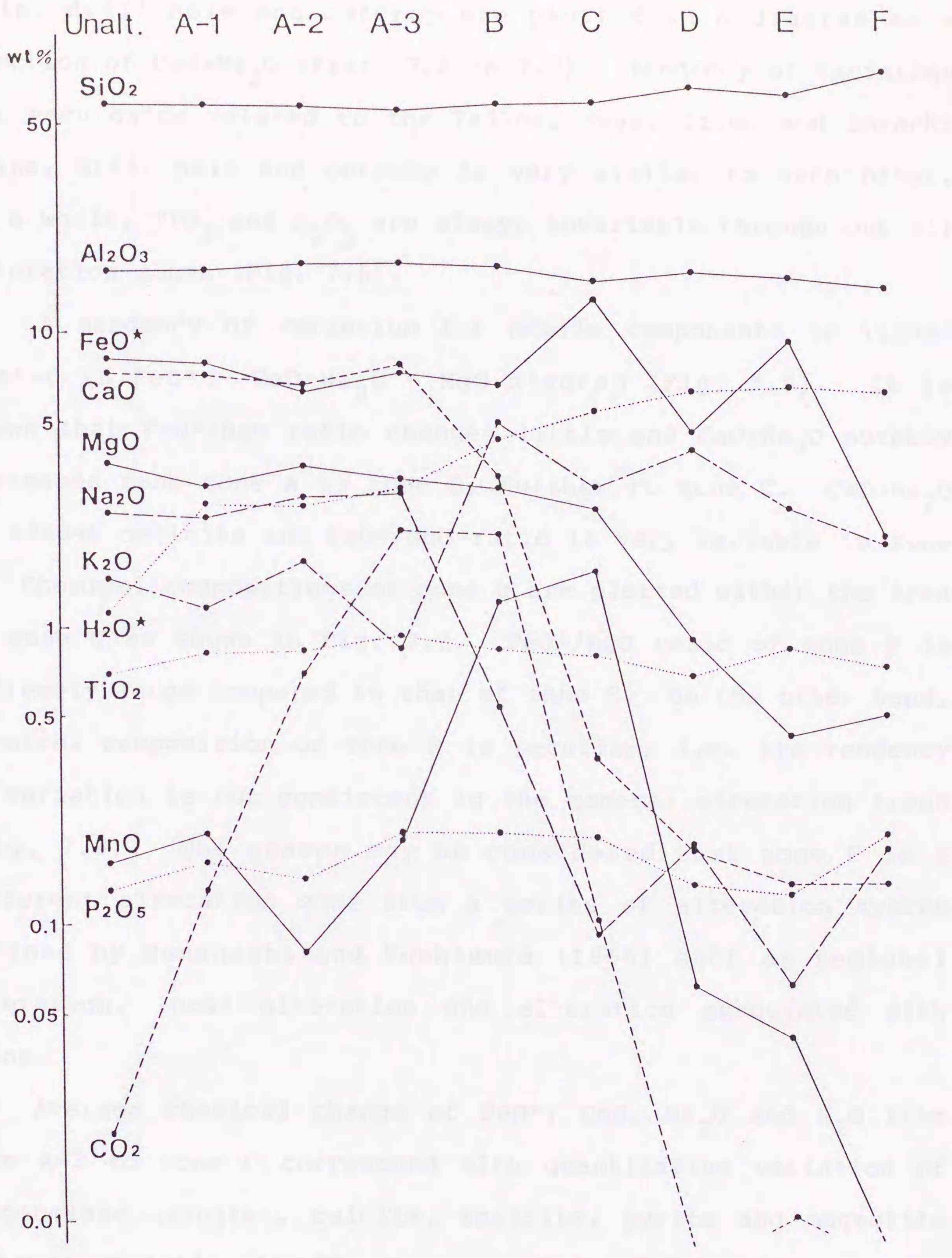


Fig.7.1 Semilogarithmic plot of the average chemical variations between unaltered rock (Unalt.) and altered rocks divided into eight zones in the Toyoha mining area.
FeO* = total iron as FeO. H_2O^* = total H_2O.

vein, drill hole and outcrop are plotted in a diagram as a function of $CaO+Na_2O$ (Figs. 7.2 to 7.7). Tendency of variation for each oxide related to the Tajima, Soya, Izumo and Sorachi veins, drill hole and outcrop is very similar to each other. As a whole, TiO_2 and P_2O_5 are always invariable through out all alteration zones (Fig. 7.8).

A tendency of variation for mobile components is illustrated in FeO* - $CaO+Na_2O$ - MgO diagram (Fig. 7.9). It is shown that FeO*/MgO ratio changes little and $CaO+Na_2O$ notably decreases from zone A to zone B, further to zone C. $CaO+Na_2O$ is almost definite and FeO*/MgO ratio is very variable in zone C. Chemical compositions of zone D are plotted within the area of zone C as shown in Fig. 7.9. FeO*/MgO ratio of zone E is extremely large compared to that of zone C. On the other hand, chemical composition of zone F is peculiar, i.e. its tendency of variation is not consistent in the general alteration trend (Fig. 7.9). The reason may be considered that zone F is a different alteration zone from a series of alteration system defined by Hunahashi and Yoshimura (1966) such as regional alteration, local alteration and alteration associated with veins.

Average chemical change of FeO*, CaO, Na_2O and K_2O from zone A-3 to zone C correspond with quantitative variation of plagioclase (albite), calcite, sericite, pyrite and magnetite and with variation of chlorite composition (Fig. 7.10).

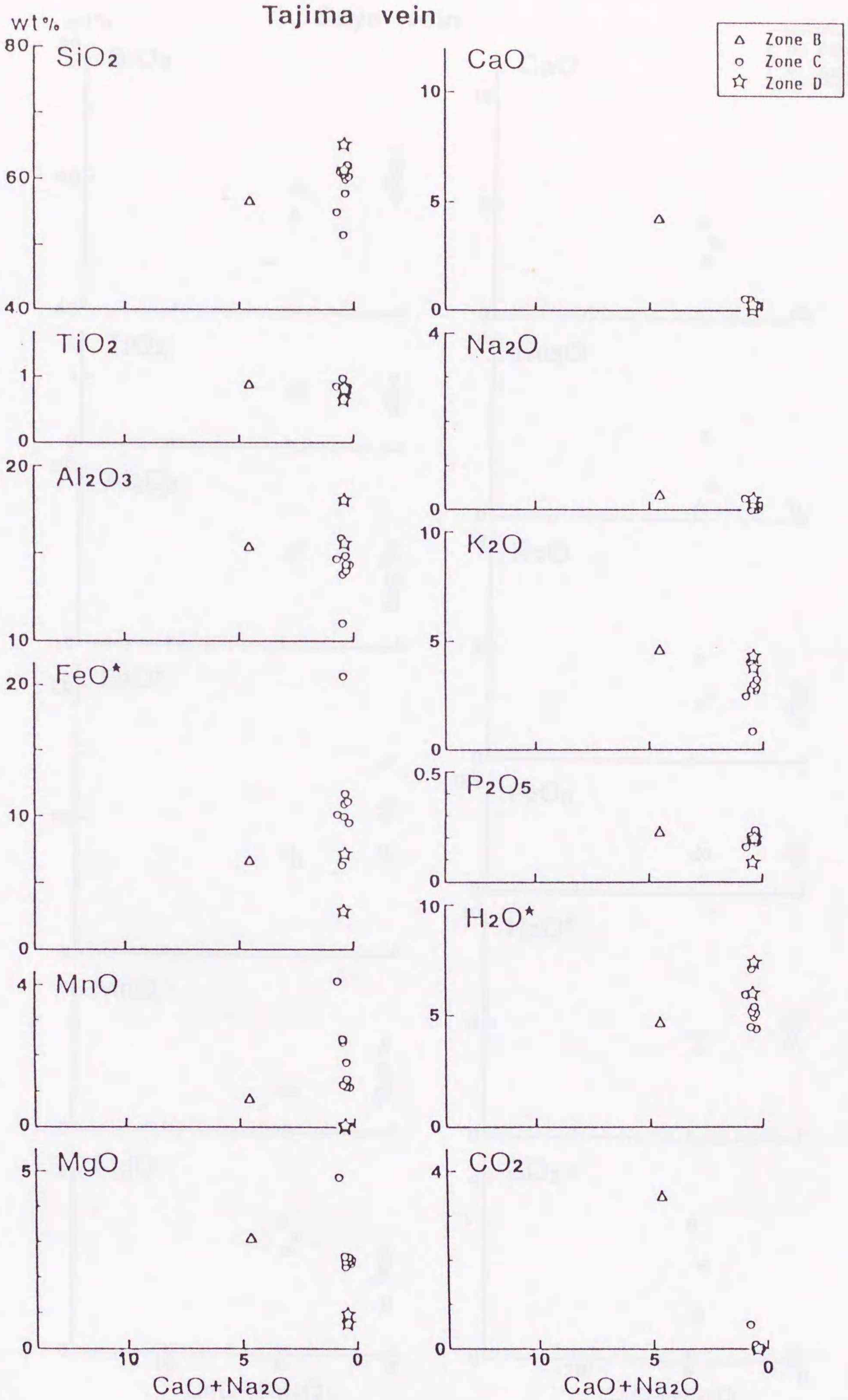


Fig.7.2 $CaO+Na_2O$ - major element oxide diagram of altered rocks in Tajima vein. FeO* = total iron as FeO. H_2O* = total H_2O.

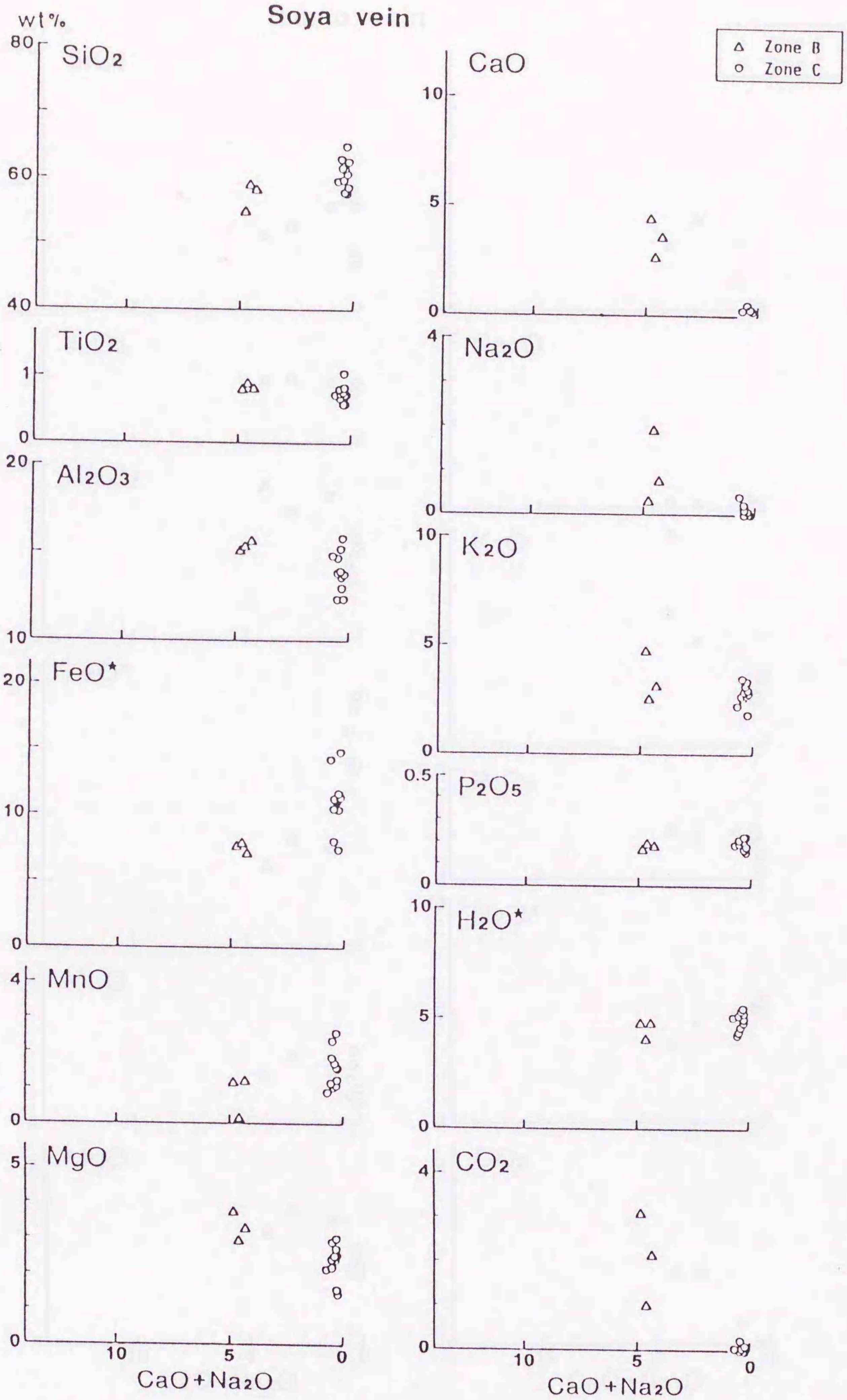


Fig.7.3 $CaO+Na_2O$ - major element oxide diagram of altered rocks in Soya vein. FeO* = total iron as FeO. H_2O* = total H_2O.

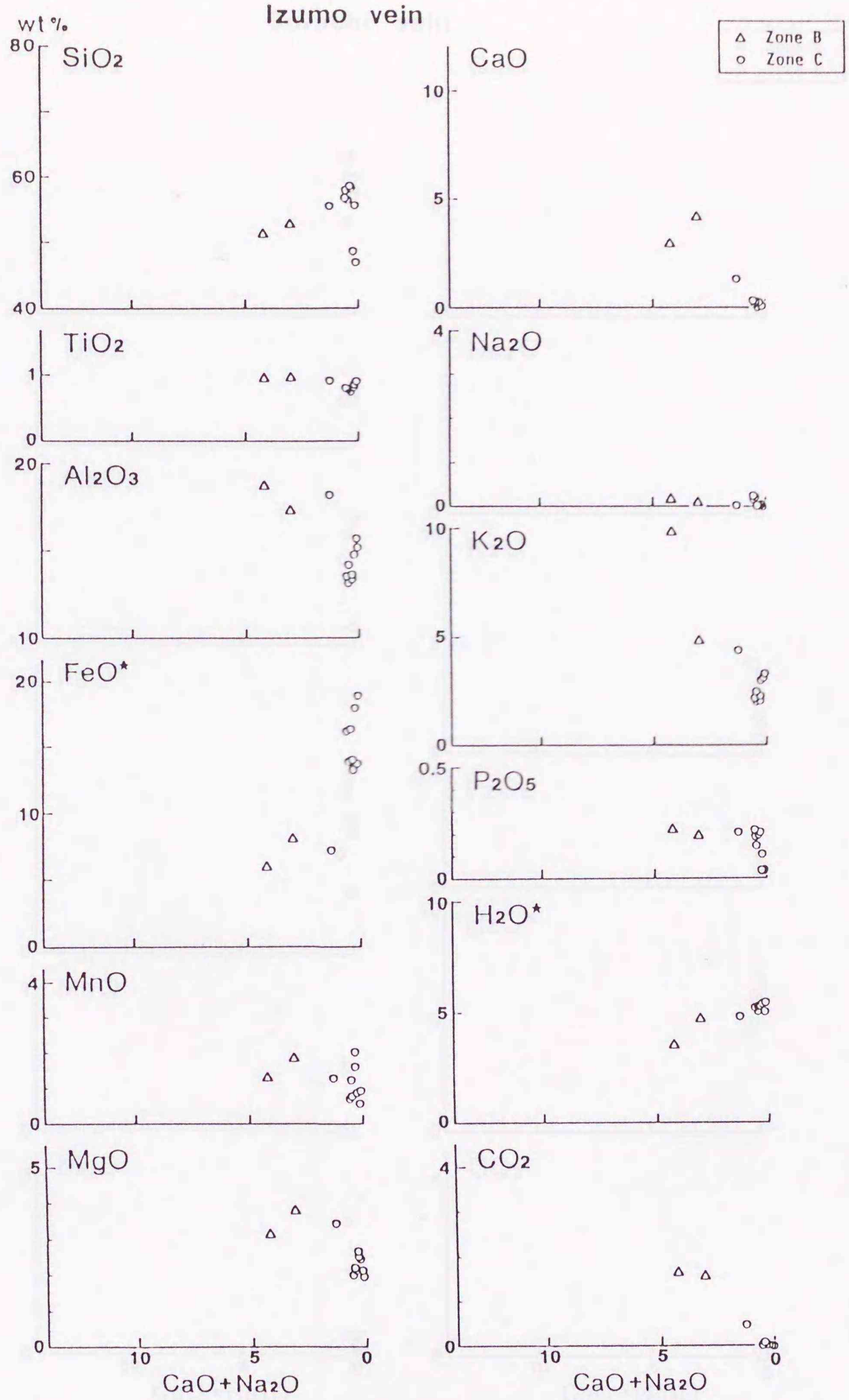


Fig.7.4 CaO+Na_2O - major element oxide diagram of altered rocks in Izumo vein. FeO* = total iron as FeO. H_2O* = total H_2O.

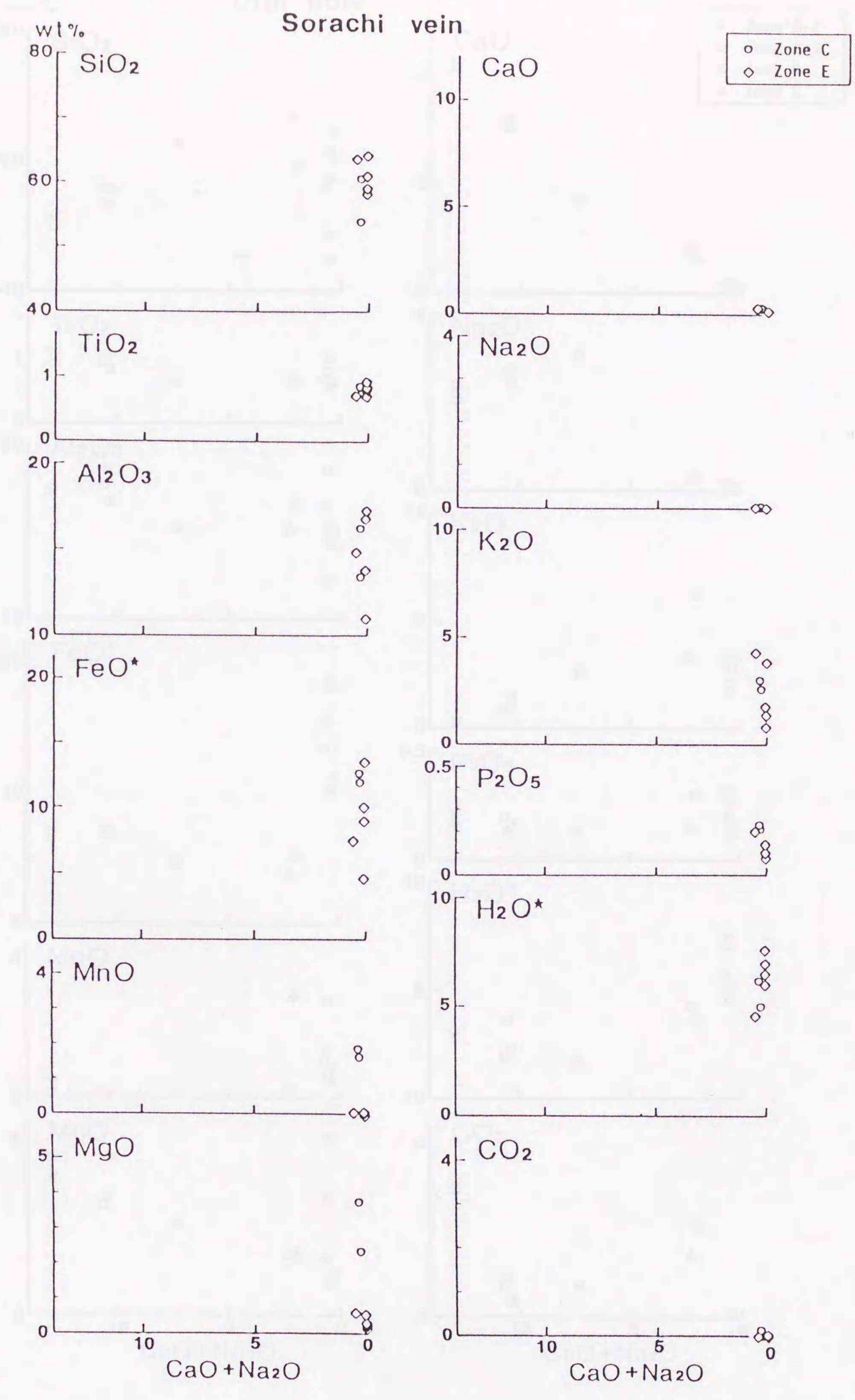


Fig.7.5 $CaO+Na_2O$ - major element oxide diagram of altered rocks in Sorachi vein. FeO* = total iron as FeO. H_2O^* = total H_2O.

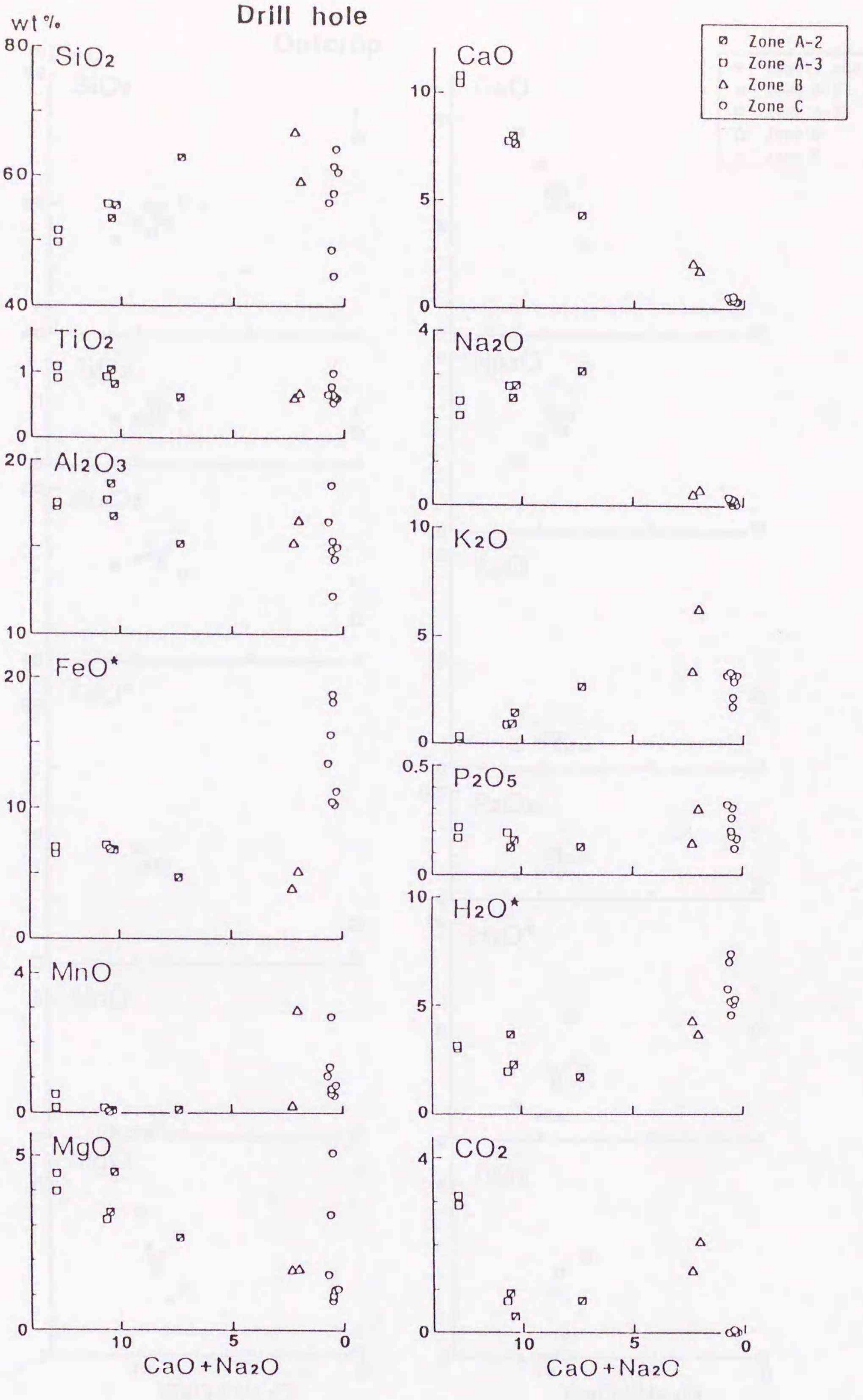


Fig.7.6 $CaO+Na_2O$ - major element oxide diagram of altered rocks in drill holes. FeO* = total iron as FeO. H_2O^* = total H_2O.

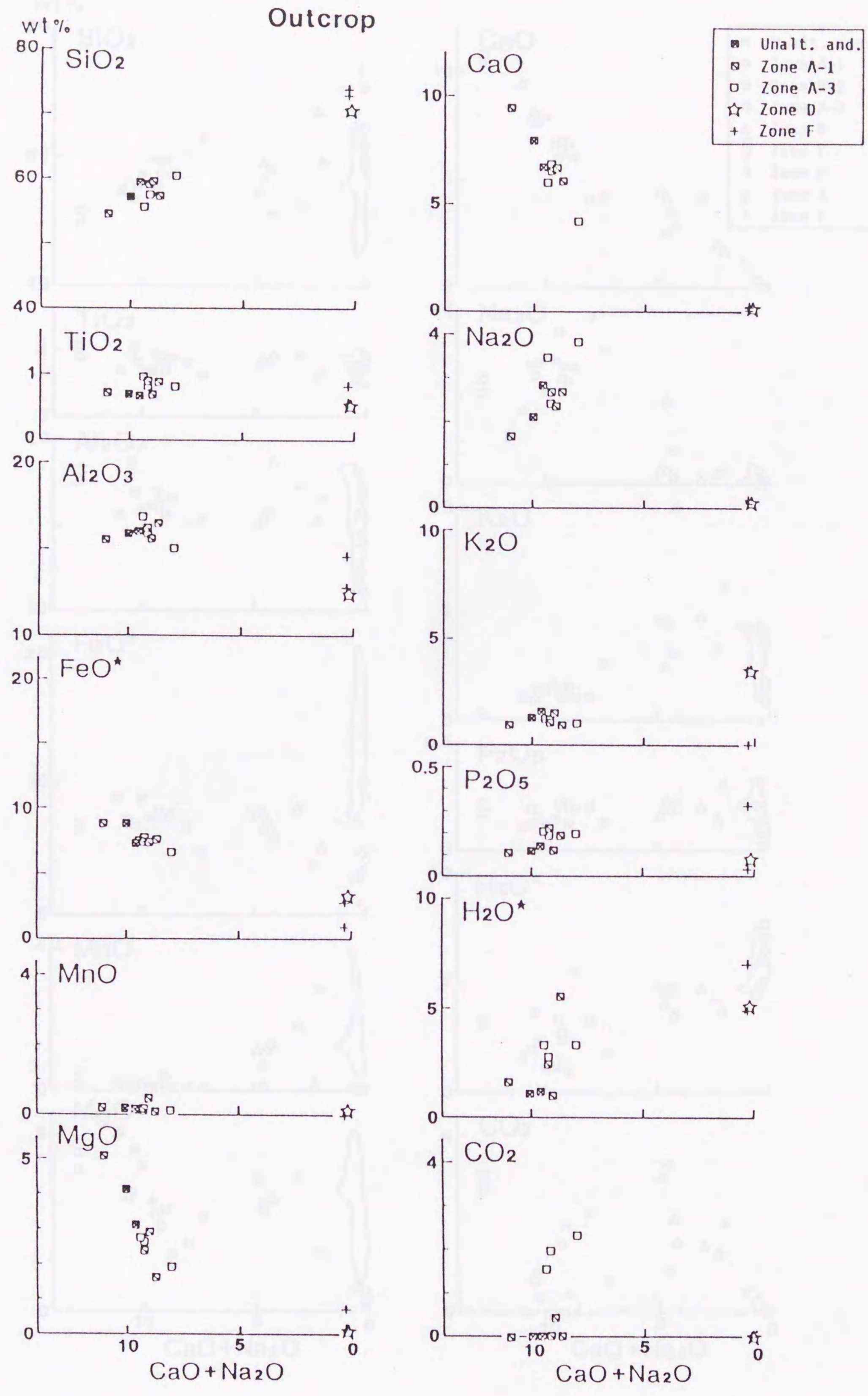


Fig.7.7 $CaO+Na_2O$ - major element oxide diagram of altered rocks in outcrop. FeO* = total iron as FeO. H_2O^* = total H_2O.

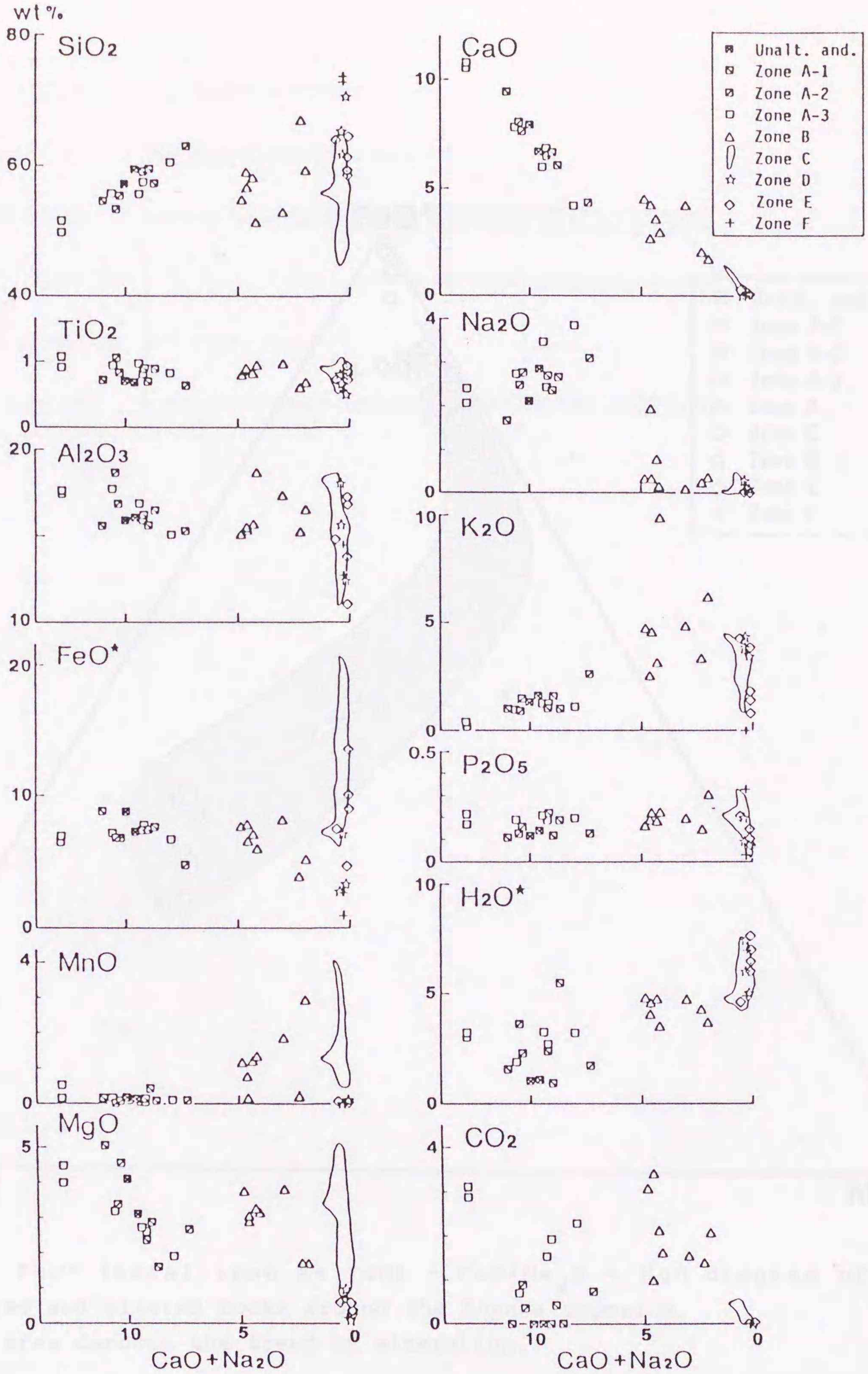


Fig.7.8 CaO+Na_2O - major element oxide diagram as a whole. FeO* = total iron as FeO. H_2O* = total H_2O.

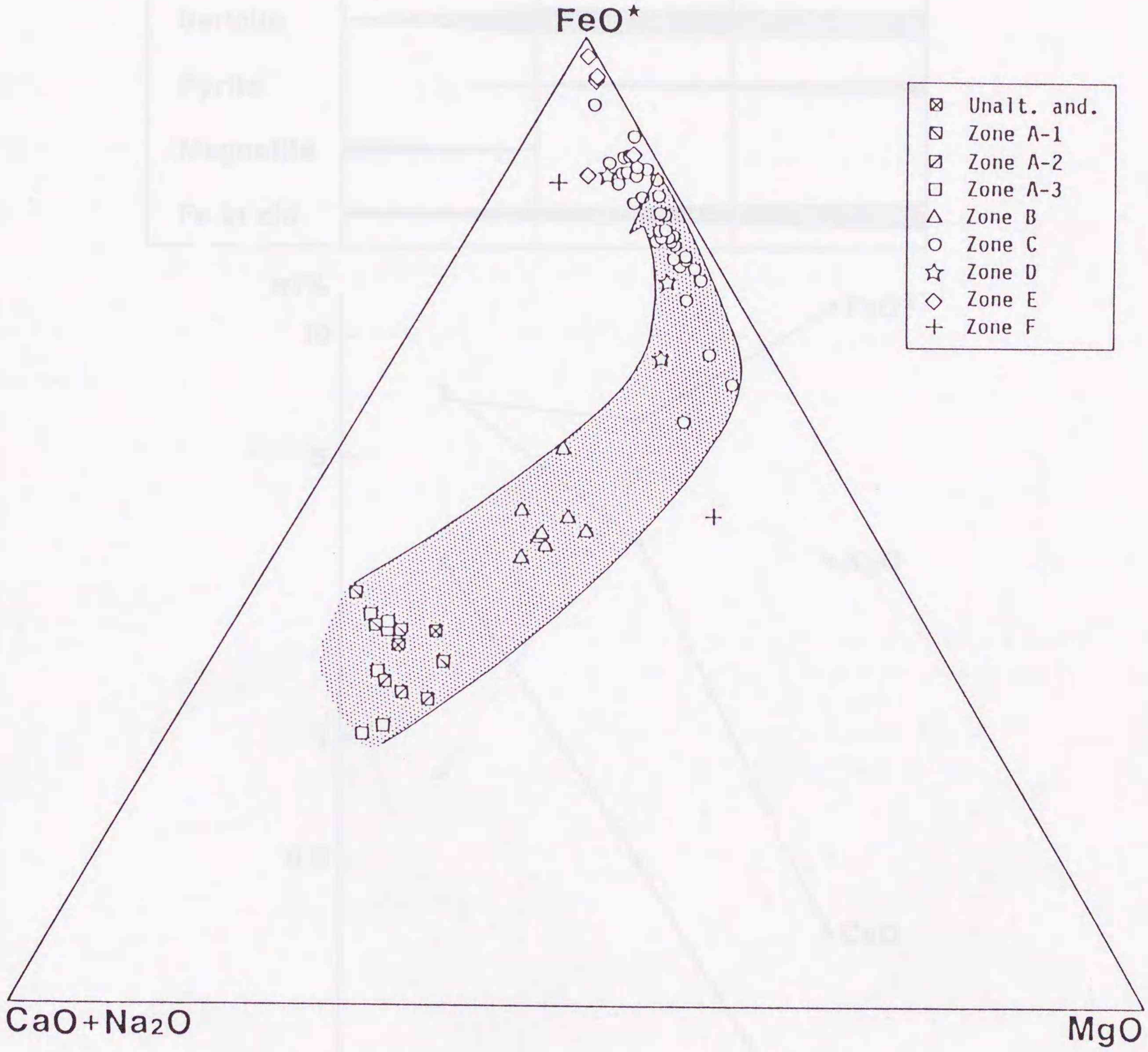


Fig.7.9 FeO* (total iron as FeO) - CaO+Na_2O - MgO diagram of unaltered and altered rocks around the Toyoha deposits. Shaded area denotes the trend of alteration.

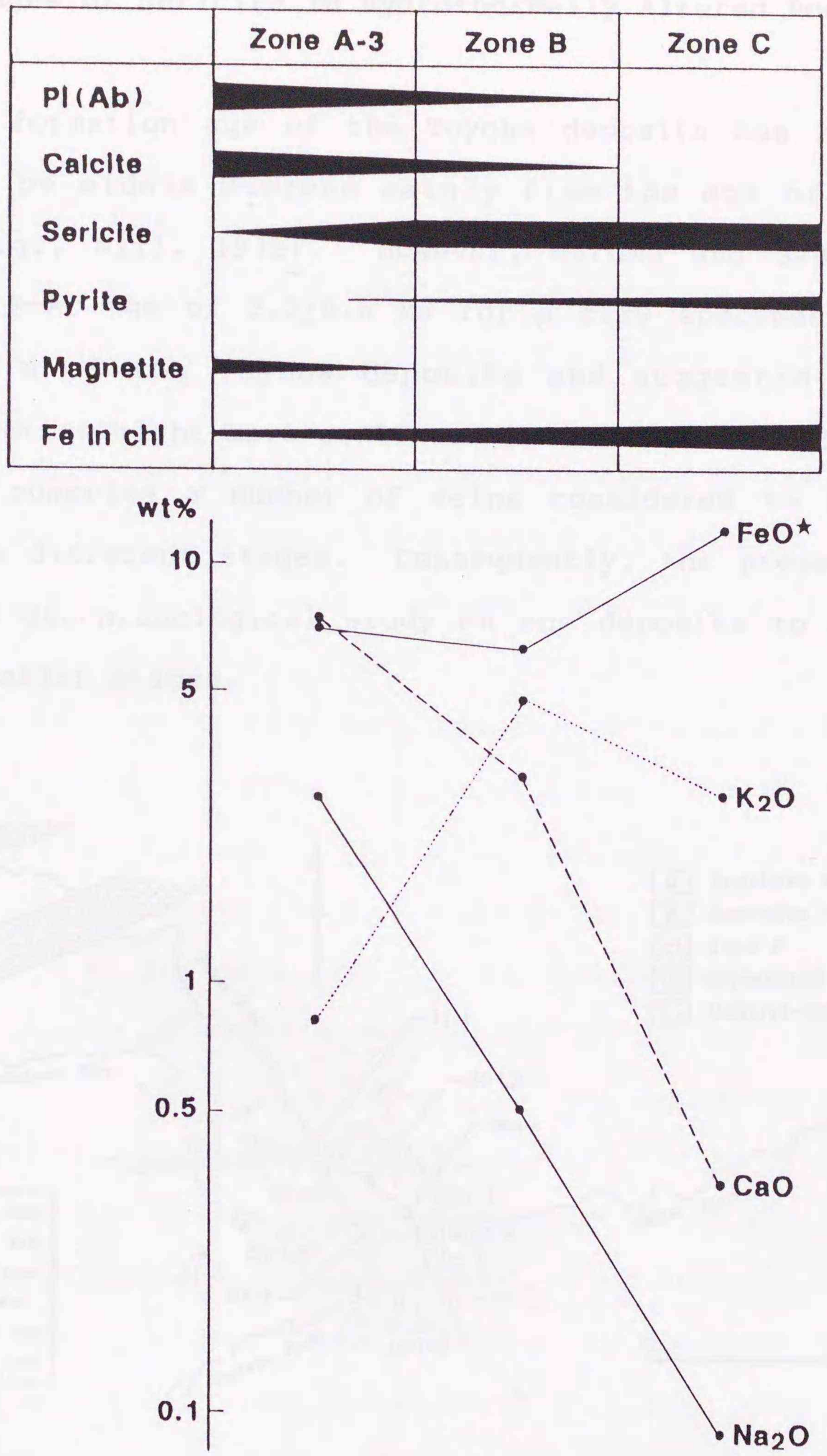


Fig.7.10 Quantitative variation of main mineral composition and semilogarithmic plot of the average variations of major chemical component.
Pl:Plagioclase, Ab:Albite, Fe in chl:Fe content in chlorite, FeO* = total iron as FeO.

8. K-Ar Ages of Sericite in Hydrothermally Altered Rocks

The formation age of the Toyoha deposits has been estimated to be middle Miocene mainly from the age of the host rocks (e.g., MITI, 1972). However, Marumo and Sawai (1986) reported K-Ar age of 2.2±0.6 Ma for a clay specimen from the Izumo vein of the Toyoha deposits and suggested that the mineralization might have continued until Pliocene. The Toyoha deposits comprise a number of veins considered to have been formed in different stages. Consequently, the present author performed geochronological study on the deposits to grasp the mineralization stages.

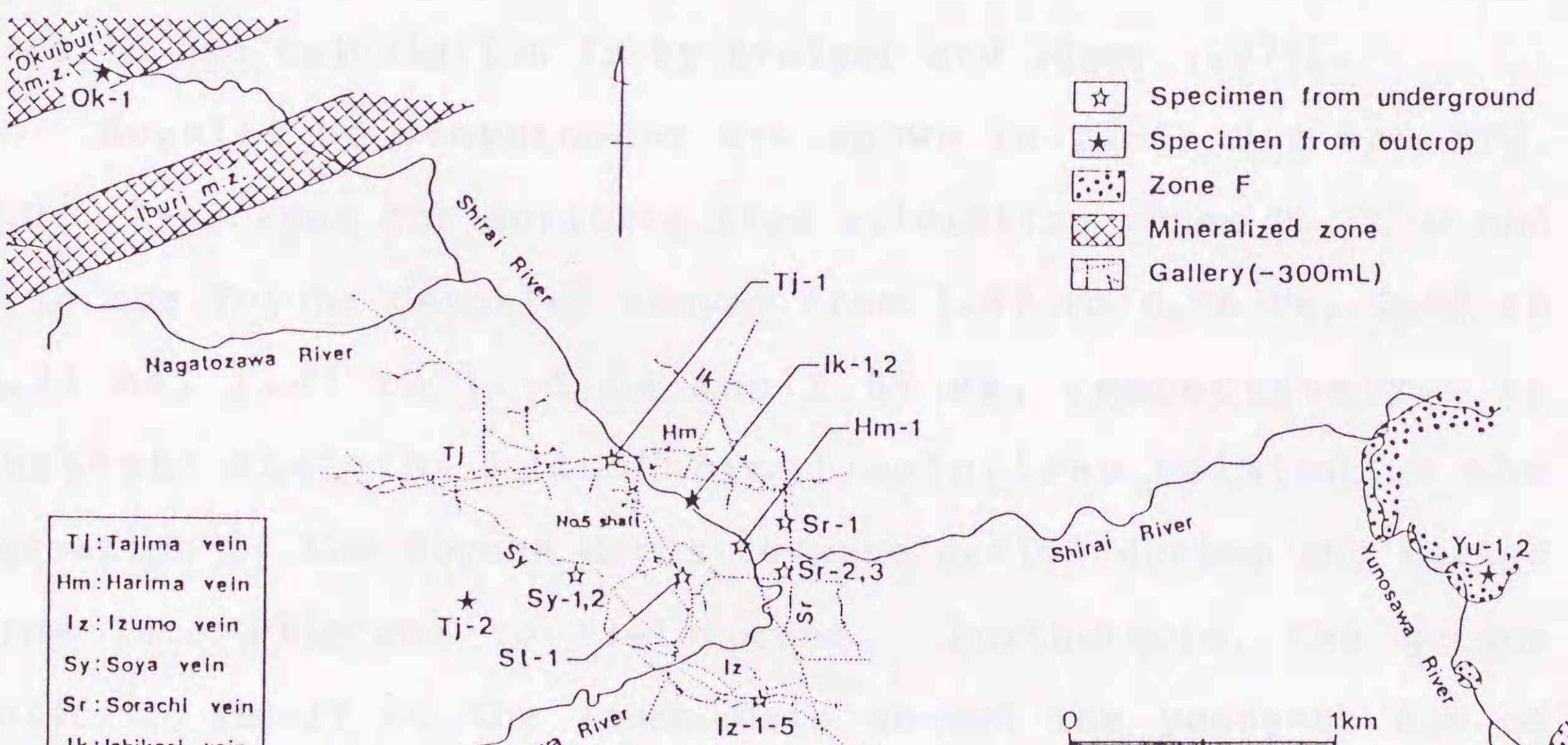


Fig.8.1 Map showing the locality of specimens used for K-Ar dating. The mineralized zone around the Toyoha deposits is not hatched to refrain from complication.

K-Ar ages were determined on hydrothermally altered rocks, clay veins and gangue mineral collected from the Toyoha deposits. Besides, the Okuiburi mineralized zone and the Yunosawa geothermal alteration zone were also examined (Fig. 8.1). Pure sericite under 2 microns in diameter, separated from the sample by application of Stokes' law of settling in water under gravity and HCl treatment, was used for measurement (Sawai et al., 1989).

Mica K-Ar age determination clock starts at the time when the rocks cool below this temperature, approximately 350°C (Jäger, 1979). As the estimated maximum formation temperature of the Toyoha deposits is 300°C (Yajima and Ohta, 1979) which is lower than the closure temperature, the age obtained shows formation age of sericite in altered rock. The decay content used in age calculation is by Staiger and Jäger (1977).

Results of measurement are shown in Table 8.1 and Fig. 8.2. K-Ar ages for sericite from alteration zones B, C, D and E in the Toyoha deposits showed from 1.87 to 0.96 Ma, 2.93 to 1.41 Ma, 1.97 to 1.55 Ma and 2.61 Ma, respectively. It suggests that the hydrothermal solutions related to the formation of the Toyoha deposits were active during the period from late Pliocene to Pleistocene. Furthermore, the gangue sericite (Iz-1) of the Izumo vein showed the youngest age of 0.49 ± 0.04 Ma, and it was ascertained that the formation stage of the Izumo vein was conceivable to be Pleistocene.

K-Ar age data for sericite from the Tajima and Izumo veins (Fig. 8.2) roughly support the two-stage mineralization model proposed by Yoshie et al. (1986). However, a number of data of

Table 8.1 K-Ar ages for sericite in hydrothermally altered rocks from the Toyoha mining area

Specimen number	Locality of specimen	Alteration zone	Mineral assemblage	Original rock	K (wt.%)	Rad. Ar (10^{-8} STP/g)	Non Rad. Ar (%)	K-Ar age (Ma)
Tj-1	-300mL	C	Qz,Ch,1M,Py	dac(K.F)	6.00±0.12	68.2±1.1	58.8	2.93±0.08
Tj-2	Ohezawa R.	D	Qz,1M,Py	and(N.F)	6.42±0.13	49.1±0.7	54.7	1.97±0.05
Hm-1	0mL	C	Qz,Ch,1M,Py	and(N.F)	6.32±0.13	39.2±0.8	65.5	1.60±0.05
Iz-1	-300mL	gangue	1M,Py		6.68±0.13	12.7±1.1	90.3	0.49±0.04
Iz-2	ditto	clay	$2M_1$,1M,Py		8.04±0.16	37.2±0.6	57.1	1.19±0.03
Iz-3	ditto	C	Qz,Ch,$2M_1$,1M,Py	b.and(K.F)	6.91±0.14	48.4±0.9	62.4	1.80±0.05
Iz-4	ditto	C	Qz,Ch,$2M_1$,Py	ditto	6.36±0.13	34.7±1.9	76.3	1.41±0.08
Iz-5	ditto	B	Qz,Ch,$2M_1$,1M,Kf,Ca,Py	ditto	6.73±0.14	25.1±0.7	75.3	0.96±0.03
Sr-1	-300mL	clay	Qz,Ka,$2M_1$,1M,Py		4.38±0.09	45.6±1.7	67.2	2.68±0.11
Sr-2	-350mL	E	Qz,Ka,$2M_1$,1M,Py	cg(M.F)	5.10±0.10	51.6±1.3	70.3	2.61±0.08
Sr-3	ditto	C	Qz,Ch,$2M_1$,1M,Ka,Py	and dike	6.42±0.13	45.2±0.9	62.4	1.81±0.05
Sy-1	-150mL	C	Qz,Ch,1M,Py	and(N.F)	6.69±0.13	55.9±0.9	39.4	2.15±0.06
Sy-2	ditto	B	Qz,Ch,$2M_1$,Ab,Ca,Py	ditto	5.40±0.10	35.0±1.2	64.7	1.67±0.07
St-1	-300mL	B	Qz,Ch,$2M_1$,Ab.Ca,Py	and dike	5.31±0.11	38.5±0.6	56.8	1.87±0.05
Ik-1	Shirai R.	D	Qz,1M,Py	and(N.F)	6.85±0.14	41.1±1.0	70.1	1.55±0.05
Ik-2	ditto	B	Qz,Ch,$2M_1$,1M,Ab,Ca,Py	ditto	6.74±0.14	37.3±0.5	50.7	1.42±0.03
Ok-1	Shirai R.	D	Qz,$2M_1$,Py	and(N.F)	6.60±0.13	74.4±1.1	55.5	2.90±0.07
Yu-1	Yunosawa R.	clay	Qz,Ka,1M,Py		6.05±1.12	56.3±2.0	78.6	2.40±0.10
Yu-2	ditto	F	Qz,1M,Py	b.and(K.F)	6.17±0.12	57.3±1.9	77.0	2.39±0.09

Qz:Quartz, Ch:Chlorite, 1M:1M polytype sericite, $2M_1$:$2M_1$ polytype sericite, Ka:Kaolinite, Py:Pyrite, Kf:K-feldspar, Ab:Albite, Ca:Calcite, dac:dacite, and:andesite, b.and:basaltic andesite, cg:conglomerate, K.F:Koyanagizawa Formation, M.F.:Motoyama Formation, N.F.:Nagato Formation.

K-Ar ages suggest that the mineralization took place continuously during the period from 3 Ma to 1 Ma (Fig. 8.2). Temporal gap between the oldest and the youngest values was 0.96 Ma for the Tajima, 0.48 Ma for the Sorachi and 0.13 Ma for the Ishikari veins. It is considered from the result for the Izumo vein (Fig. 8.3) that hydrothermal solutions ascended repeatedly from 1.80 to 0.49 Ma.

It is generally accepted that veins of the Toyoha deposits are classified into two; those of earlier formation and those of later one (Yajima and Ohta, 1979; Yoshie et al., 1986). However, it is summarized from K-Ar dating that activities of hydrothermal solutions repeated for more than two million years. Ore deposition might have also taken place at many stages as proposed by Yoshie et al. (1986), but the result of dating does not correspond directly to the stages of ore-formation because the alteration stage does not necessarily correspond to them. Namely, when activity of hydrothermal solution of primary stage was replaced by that of younger stages, the obtained age shows only the youngest stage of ore-formation at the place.

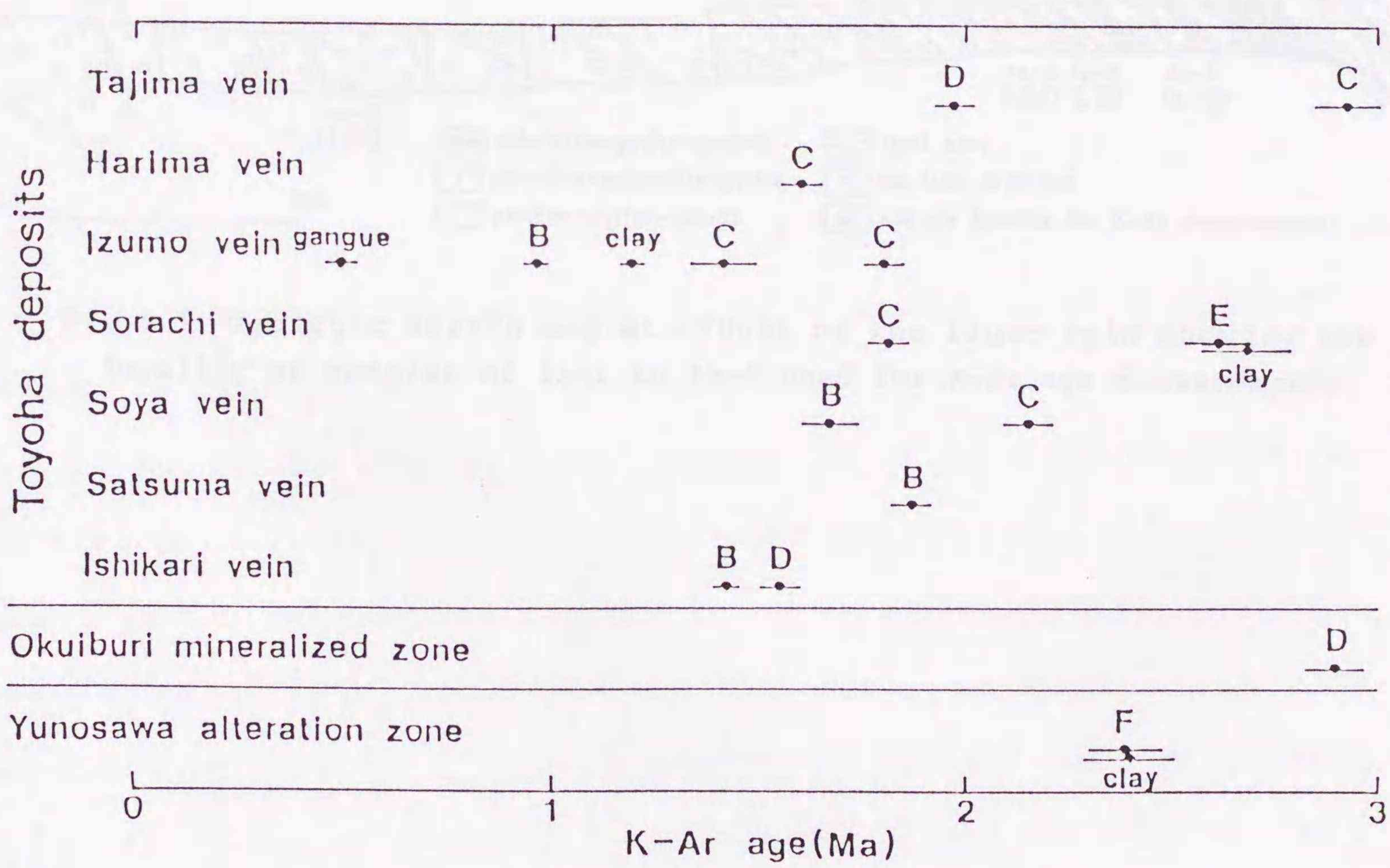


Fig.8.2 Diagram illustrating the K-Ar ages of veins and alteration zones in and around the Toyoha mine.
B, C, D, E and F denote the divided alteration zones.

Sericites from the Okuiburi mineralized zone and the Yunosawa geothermal alteration zone showed the K-Ar ages of 2.90$\pm$0.07 Ma and 2.40$\pm$0.10, 2.39$\pm$0.09 Ma, respectively. The result suggests that hydrothermal solutions related to the formations of the Toyoha deposits, the Okuiburi mineralized zone and the Yunosawa geothermal alteration zone ascended nearly at the same time.

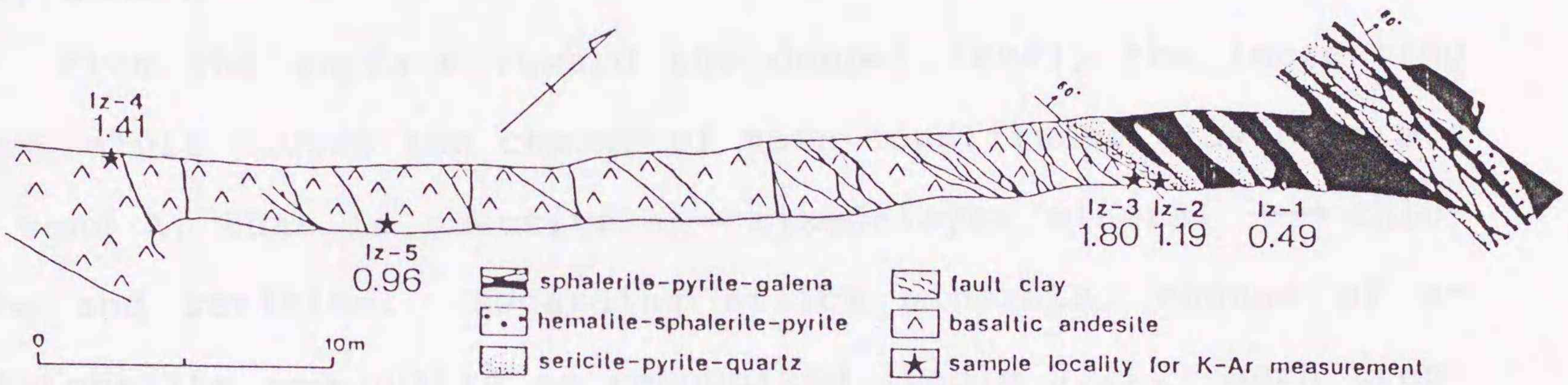


Fig.8.3 Geologic sketch map at -300mL of the Izumo vein showing the locality of samples of Iz-1 to Iz-5 used for K-Ar age measurements.

9. Discussions

9.1 Genesis of alteration zones

Formation process of six alteration zones in and around the Toyoha mine is discussed based on the mode of occurrence of alteration zones, alteration mineral assemblage, and X-ray analytical, microscopic and chemical data of alteration minerals (Table 9.1).

(1) Zone A

From the surface toward the deeper level, the increasing temperature causes the change of main constituent clay minerals in zone A, that is smectite ⟶ mixed-layer mineral ⟶ chlorite and sericite. Regarding silica minerals, change of α-cristobalite ⟶ quartz is recognized (Table 9.1). Such transitional change of alteration minerals is a characteristic feature in the alteration by diagenesis (Utada, 1980). The alteration of zone A in the Toyoha mine is also common to hydrothermal alteration of geothermal area (e.g., Kimbara and Ohkubo, 1978; Seki et al., 1980). Especially, the alteration minerals and their characters in the Satsunan geothermal area (Kimbara and Ohkubo, 1978), Kagoshima Prefecture, are quite similar to those of zone A of the Toyoha mine in question.

The vicinity of the Toyoha mine is a prominent geothermal area and there are many reports on the geothermal activity (e.g., Ishikawa, 1969; Nomura, 1973). Heat flow around the Toyoha mine amounts to 25.7 HFU (heat flow unit), about ten times higher than general HFU in the Green Tuff Region of Japan (Nomura, 1973). The source of the high heat flow concerned is

Table 9.1 Mode of occurrence and characteristic minerals of alteration zones around the Toyoha mining area

Genesis of alteration	Mode of occurrence	Alteration zone	Characteristic minerals	Other main minerals	Fe value of chlorite	Position of the 10-12 Å reflection 2θ° (CuKα) for mica clay minerals	Sericite Polytype
Diagenesis	Zonal distribution on almost parallel to formation boundary	A-1	Smectite	α-cristobalite			
		A-2	Chlorite/smectite Sericite/smectite	Quartz,Calcite		7.3 - 8.2	
		A-3	Chlorite,Sericite	Quartz,Calcite	0.3	8.1 - 8.8	
Hydrothermal alteration associated with ore vein	Around ore vein	B	Quartz,Chlorite,Sericite	Albite,Calcite Pyrite	0.6	8.7 - 8.8	$2M_1$ + 1M
	Contact with ore vein	C	Quartz,Chlorite,Sericite	Pyrite	0.9	8.7 - 8.8	$2M_1$ + 1M
		D	Quartz,Sericite	Pyrite		8.3 - 8.6	1M
		E	Quartz,Sericite,Kaolinite	Pyrite		8.7 - 8.8	$2M_1$ + 1M
Hydrothermal alteration by geothermal activity	Oblique to formation boundary with some fumaroles	F	Quartz,Kaolinite	Sericite Sericite/smectite Pyrite			

presumed to be derived from a kind of hot dry rock. Vertically temperature gradient at the southeast part of the Toyoha deposits is 20°C to 30°C/100m, partially 50°C/100m, and rock temperature at -600 mL (-50 meters above sea level) attains at 180°C (Nomura and Tani, 1981). Abnormally high rock temperature is recognized within a limited area with radius of several kilometers. It is estimated that the center is located near the Yunosawa river (Nomura, 1973). According to Kanbara et al. (1989), the center of active geothermal system is estimated to be surely situated at southeastern side of the Shinano vein. Therefore, it is possible to say that alteration in the investigated area is strongly affected by the geothermal activity.

Alteration zone A which is divided into A-1, A-2 and A-3 subfacies occurs showing zonal distribution vertically, i.e. the manner of zonation of subfacies A-1, A-2 and A-3 in descending order is almost parallel to the formation boundary (Fig. 5.11). However, subfacies A-2 and A-3 are heaved up to the level of the Toyoha deposits and/or the Yunosawa river areas, where hydrothermally altered rocks such as zones B, C, E, and F are observed. Hereby the boundary of each subfacies obliquely crosses the formation boundary (Figs. 5.10 and 5.11). This implies that these subfacies have heaved up by the activity of hydrothermal solutions related to the formation of the Toyoha deposits and zone F. Generally, subfacies A-2 and A-3 at the Toyoha deposits area occupy upper part compared with those at the Yunosawa river area (Fig. 5.10). This fact verifies that the activity of hydrothermal solutions related to the formation of the Toyoha deposits might have been preponderant compared with the case of zone F.

From these, it is concluded that zone A has been principally formed through a process of burial diagenesis. During the process, it has been also subjected to high geothermal activity related to a concealed hot dry rock-body. In addition, zone A is considered to be affected by hydrothermal solutions related to the formation of the Toyoha deposits and zone F.

In general, zeolite mineral, together with clay mineral, occurs widely in the alteration zone of diagenetic or geothermal origin, and this mineral plays an important role to divide alteration zones. For example, alteration zone of diagenetic origin occupying eastern area of Lake Toya is characterized by the presence of abundant zeolite mineral as reported by Marumo (1985). Although geologic constitution, embedded ore deposits and geothermal indications of the preceding vicinity is very similar to those in the Toyoha mining area, clinoptilolite and mordenite are only recognized within acidic tuff of the upper subfacies A-1 in the Toyoha mine. The reason why such difference is caused can be explained as follows; carbonate mineral such as calcite which is widely found in zone A at the Toyoha mining area is unobserved at the eastern area of Lake Toya (Marumo, 1985). Therefore, it is presumed that carbonate mineral has been formed instead of zeolite mineral at the Toyoha mining area due to high CO_2 fugacity.

(2) Zones B, C, D and E

Alteration zone B is extensively found among subfacies A-3 and zone C around every ore vein, and occupies the whole area including the deposits except zones C, D and E associated with vein (Fig. 5.10). In zone B, colored mineral and glass are altered to chlorite, and plagioclase is altered to calcite and albite. Calcite and albite are regarded as a relic mineral of subfacies A-3. Quartz, sericite and pyrite are generally found in this zone. Fe value of chlorite in zone B is about 0.6 and is different from the value (0.3) in zone A of diagenetic origin. From this, it is considered that zone B characterized by high Fe value of chlorite is not of diagenetic origin but of hydrothermal origin. From subfacies A-3 to zone C, chemical change of major chemical component, quantitative variation of main alteration mineral and variation of chlorite composition are gradual (Fig. 7.10). Therefore, the zone B is inferred to be a transitional zone from subfacies A-3 to zone C.

Zone C occurs around every ore vein through upper to lower levels, but is restrictedly distributed showing narrow extent between zone B and ore veins (Fig. 5.10). Alteration grade of zone C is so high that original texture and minerals of original rock are vanished in this zone. Fe value of the chlorite from zone C is nearly 0.9 and is higher than the Fe value (0.6) in zone B (Table 9.1). Vestige of zone B remains partly in zone C near the contact with zone B; e.g., chlorite possessing Fe value of 0.6 formed in zone B is dominant and calcite is rarely observed. However, the chlorite and calcite are thoroughly unrecognized in zone C at the vicinity of ore vein. From these, it is inferred that zone C has been formed by hydrothermal solutions related to the formation of the

Toyoha deposits.

Alteration zone D is exclusively found at upper levels of the ore veins, and the alteration degree is almost the same as that of zone C. Sericite from zone D has a different character compared with those from zones B, C and E. The W_1 value of the sericite from zone D is large and position of the 10-12Å reflection is low-angle compared with those from zones B, C and E (Table 9.1), and the sericite from zone D is regarded to have small amounts of expandable layer. This fact suggests that the sericite in zone D might have been formed under lower temperature compared with the cases in zones B, C and E. And, sericites from zone D, and from zones B, C and E are 1M polytype and mixture of 1M and $2M_1$ polytypes, respectively (Table 9.1). It is well known that the polytype of sericite of $2M_1$ - 1M - 1Md is formed reflecting the formation temperature from high to low (Yoder and Eugster, 1955; Velde, 1965). Polytype data also suggest that sericite in zone D has been formed under low temperature compared with those in zones B, C and E. From this, zone D is assumed to be an alteration represented the latest stage of mineralization. Namely, zone D might have been formed by the rest solutions possessing low temperature generated after precipitation of main ore minerals.

Alteration zone E is exclusively recognized along the Sorachi and Nemuro veins continuously from upper to lower levels, and occurs showing narrow extent around ore veins without any interruption (Fig. 5.10). Microscopic observation led a conclusion that alteration degree of zone D is comparable to that of zone C. Zone E is distributed replacing zone C at the boundary between ore vein and zone C (Fig. 5.20). This zone is characterized by the presence of kaolin mineral, alunite and jarosite which are absent in zones B, C and D, and this suggests that this zone has been formed by an acidic solutions.

From the above-mentioned fact, zones C, D and E are equivalent to "alteration associated with veins" (Hunahashi and Yoshimura, 1966) or to "veins and wall rock alteration zone" (Izawa, 1986). It is possible to say that zones C to E are envelope of the vein.

Zone E corresponds to kaolinite zone in silicate series acidic zone of hydrothermal alteration by Utada (1980) from the alteration mineral assemblage.

(3) Zone F

Alteration zone F is characterized by the presence of kaolinite, and is regarded as a product of acidic solutions. It resembles zone E on these aspects. However, zone F at the Yunosawa river area has not exhibited any mineralization. Consequently, the origin of zones E and F is different from one another, i.e. zone E is closely related to some mineralizing solutions but zone F is unrelated to mineralization. Alteration mineral assemblage and mode of occurrence of zone F are similar to those of the acidic alteration zone at the Matsukawa geothermal area (Sumi, 1968).

It is revealed from the above consideration that alteration in the studied area is formed by intricate duplication of the composite alteration of various origins such as diagenetic process, geothermal activity (high geothermal gradient), and lively activities of hydrothermal solutions connected with the mineralization and acidic solutions. Alteration zone of diagenetic origin in the studied area may be generated by the VH-type diagenetic process at the highest geothermal gradient as Utada (1980) pointed out.

9.2 Relationship between alteration mineral assemblage and chemical composition of altered rocks

Mineral assemblage in each alteration zone generally well reflects the variation of composition of altered rocks concerned. H_2O* increases to 3 wt.% on an average in zone A containing clay minerals such as montmorillonite, mixed-layer minerals, chlorite and sericite, and furthermore, up to nearly 5 wt.% on an average in zones B to F in which abundant clay minerals of hydrothermal origin have been added (Table 7.1). CO_2 augments in zones A-2, A-3 and B in which calcite is universally recognized, especially amounts to 2 wt.% on an average in zones A-3 and B, but is almost absent in unaltered rock and zones D, E and F, those are devoid of calcite (Fig. 7.1). CaO measures 7 wt.% in zone A, while, it reduces to 3 wt.% in zone B. Such variation is considered to be caused by chloritization of clinopyroxene, and furthermore, CaO decreases to less than 0.2 wt.% in zones C to F, those are characterized by disappearance of calcite (Fig. 7.1). Na_2O shows similar variation trend with CaO. Namely, Na_2O decreases from 2.5 wt.% in zone A to 0.5 wt.% toward zone B. This change may caused by sericitization and calcitization of plagioclase in zone B. Na_2O decreases to 0.1 wt.% in zones C to F. This is a reflection of disappearance of albite in those zones. K_2O increases up to 4.88 wt.% in zone B, in which sericite and rarely K-feldspar have been formed. Zones C to E contain 2.4 to 3.8 wt.% K_2O. It may be due to abundant sericite.

On the other hand, SiO_2 and Al_2O_3 contents are uniform through out most alteration zones. Though a large quantity of quartz is observed in zones C, D and E, SiO_2 content in those altered rocks does not increase conspicuously in those zones (Fig. 7.8). This is considered that surplus SiO_2 is consumed for the formation of recrystalline quartz when plagioclase and clinopyroxene containing 50 to 60 wt.% SiO_2 are altered to chlorite and/or sericite those contain 25 to 50 wt.% SiO_2. Because analyzing sample from zone F is weakly silicified rock, that is rich in SiO_2 compared with the samples from the other zones. Although Al_2O_3 content of zones C, D and E varies ranging from 10 wt.% to 20 wt.% (Fig. 7.8). This value is almost equal or slightly low compared with Al_2O_3 of zone A on an average (Fig. 7.1). Accordingly, it is concluded that SiO_2 and Al_2O_3 contents show little variation through the all alteration zones, in other words, regarding SiO_2 and Al_2O_3, both of addition and subtraction are hardly recognized as a whole.

Compositional variation of FeO*, MnO and MgO is related to both alteration mineral assemblage and chlorite composition. Bulk rock chemical analyses disclosed that MgO decreases in order of zones A-3 (3.17 wt.%), B (2.93 wt.%) and C (2.46 wt.%), and variation trend of MgO of chlorites from above-mentioned three zones is consistent to the bulk rock chemistry through the variation range is as given in Appendix 1. In zone

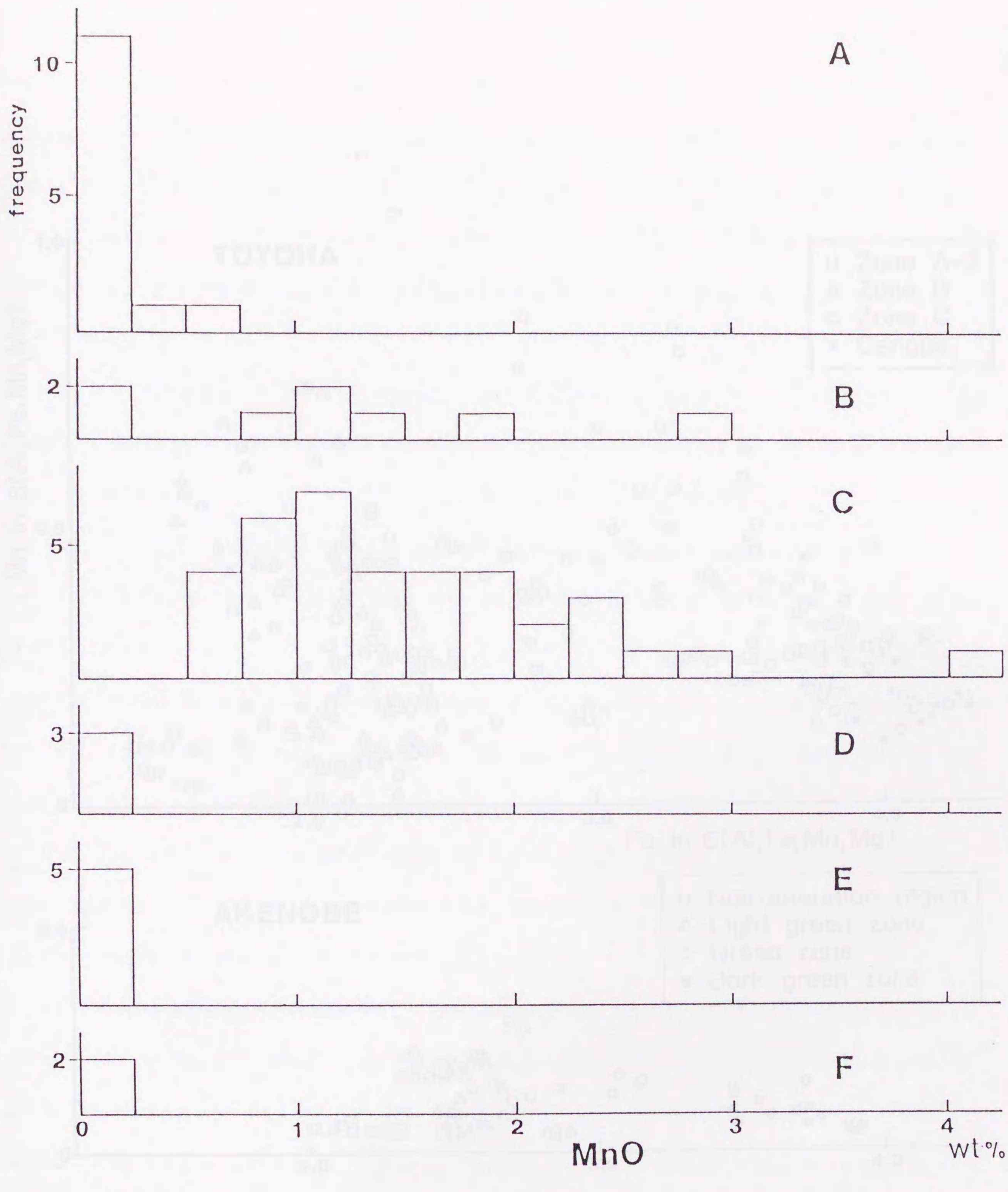


Fig.9.1 Histogram showing range in MnO contents of altered rocks.

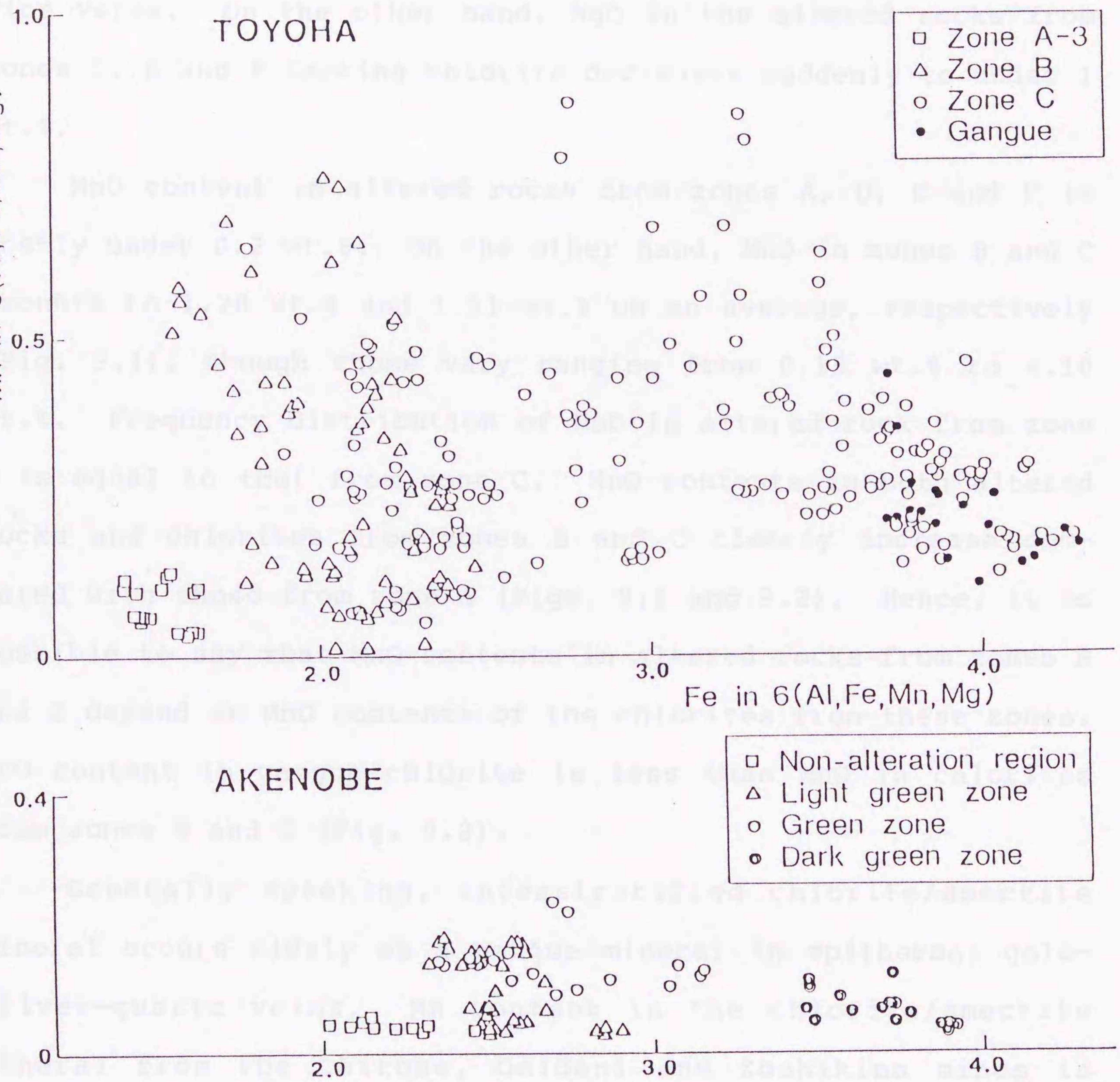


Fig.9.2 Plot of Mn versus Fe in 6(Al, Fe, Mn, Mg) of chlorites from Toyoha and Akenobe mines.

C, the intensity ratio of 7 Å reflection to 14 Å and 4.7 Å reflections (I(7 Å)) of chlorite is related to MgO content of the rock concerned. MgO content in a rock having chlorite of large I(7 Å) is scanty, i.e. an altered rock including abundant Fe-chlorite is characterized by the small content of MgO and vice versa. On the other hand, MgO in the altered rocks from zones D, E and F lacking chlorite decreases suddenly to under 1 wt.%.

MnO content in altered rocks from zones A, D, E and F is mostly under 0.2 wt.%. On the other hand, MnO in zones B and C amounts to 1.20 wt.% and 1.51 wt.% on an average, respectively (Fig. 9.1), though those vary ranging from 0.15 wt.% to 4.10 wt.%. Frequency distribution of MnO in altered rock from zone B is equal to that from zone C. MnO contents in both altered rocks and chlorites from zones B and C clearly increase compared with those from zone A (Figs. 9.1 and 9.2). Hence, it is possible to say that MnO contents in altered rocks from zones B and C depend on MnO contents of the chlorites from these zones. MnO content in gangue chlorite is less than MnO in chlorites from zones B and C (Fig. 9.2).

Generally speaking, interstratified chlorite/smectite mineral occurs widely as a gangue mineral in epithermal gold-silver-quartz veins. Mn content in the chlorite/smectite mineral from the Chitose, Omidani and Kushikino mines is comparatively low. It may be related that manganese mineral is absent in the ore of these mines. Whereas, Mn content in the mineral from the Todoroki mine where manganese mineral is commonly recognized in the ore is relatively high (Yoneda and

Watanabe, 1989). Namely, the chemical composition of the chlorite/smectite mineral reflects the presence or absence of manganese minerals in the ores. At the Toyoha mine, manganese mineralization yielded manganese carbonate and silicate minerals belongs to stages II and VII after Narui et al., (1988). While, Mn content in chlorite from altered rock of the Akenobe mine lacking manganese mineralization is far low compared with that of the Toyoha mine (Fig. 9.2). Therefore, Mn-rich chlorite in the Toyoha deposits is considered to have been formed in relation to the manganese mineralization.

MnO in altered rocks from zones D, E and F containing no chlorite decreases sharply to under 0.1 wt.% (Fig. 7.8).

FeO* in chlorite increases in order of zones A, B and C (Appendix 1). FeO* in altered rock increases obviously in zone C, and this is comparable with variation of chlorite composition. While, FeO* in zone B is almost equal to that in zone A, and this is inconsistent with variation of chlorite composition (Fig. 9.3). Fe value of chlorite in zone A is similar to that of clinopyroxene which has been replaced by chlorite in zone A (Appendix 3). Mineral containing FeO* in zone A is mainly magnetite. Hence, it is considered that FeO* in the magnetite was added to chlorite during the formation process of zone B, and consequently, chlorite in zone B becomes to be rich in Fe compared with the chlorite in zone A. Magnetite is unobserved in zone B under the microscope. This is the reason why Fe_2O_3 in altered rock of zone B is far less than that of zone A (Appendix 5). These facts also support above-considerations. Although FeO* in zone E is more scant than FeO* in zone C.

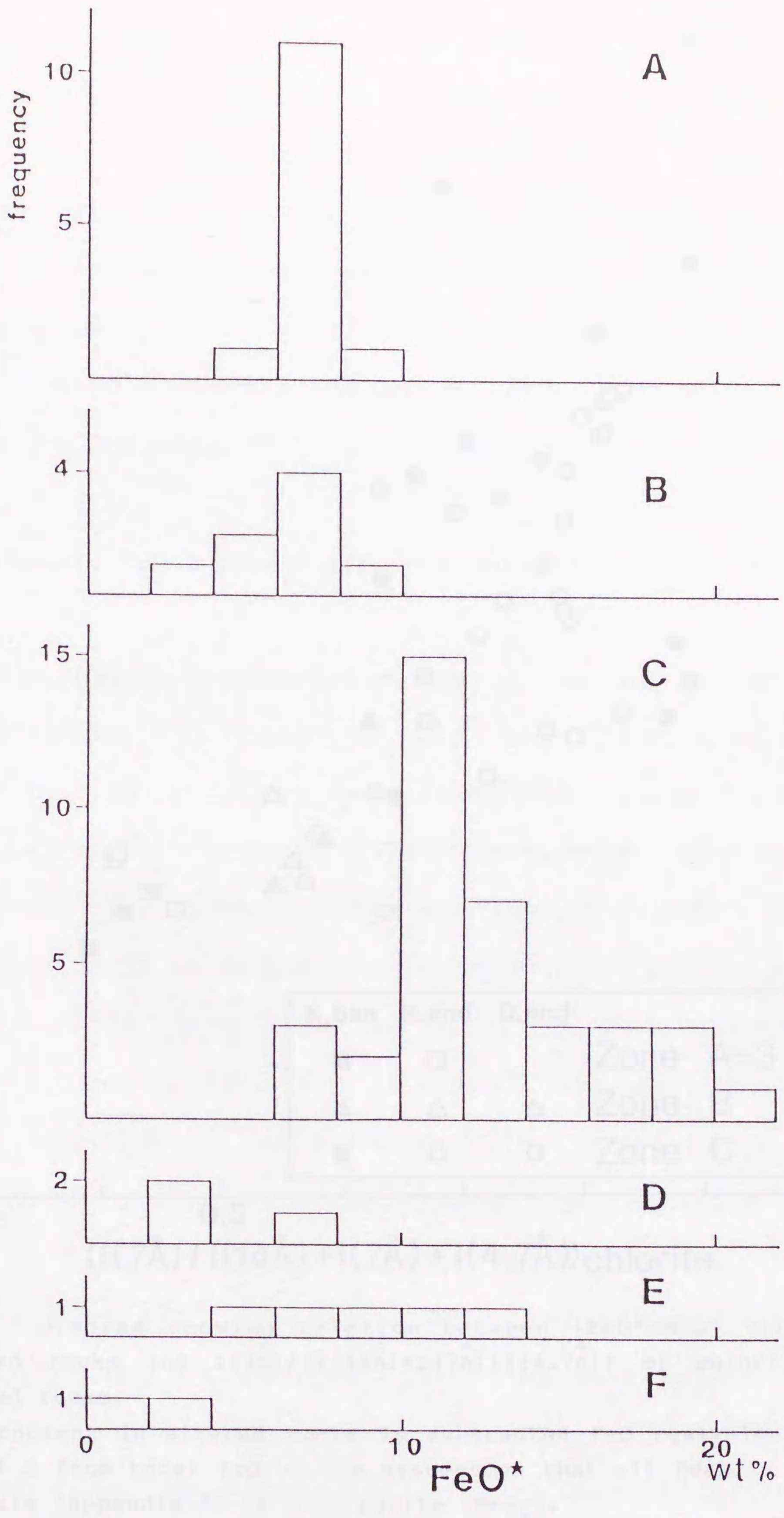


Fig.9.3 Histogram showing range in FeO*(total Fe as FeO) content of altered rocks.

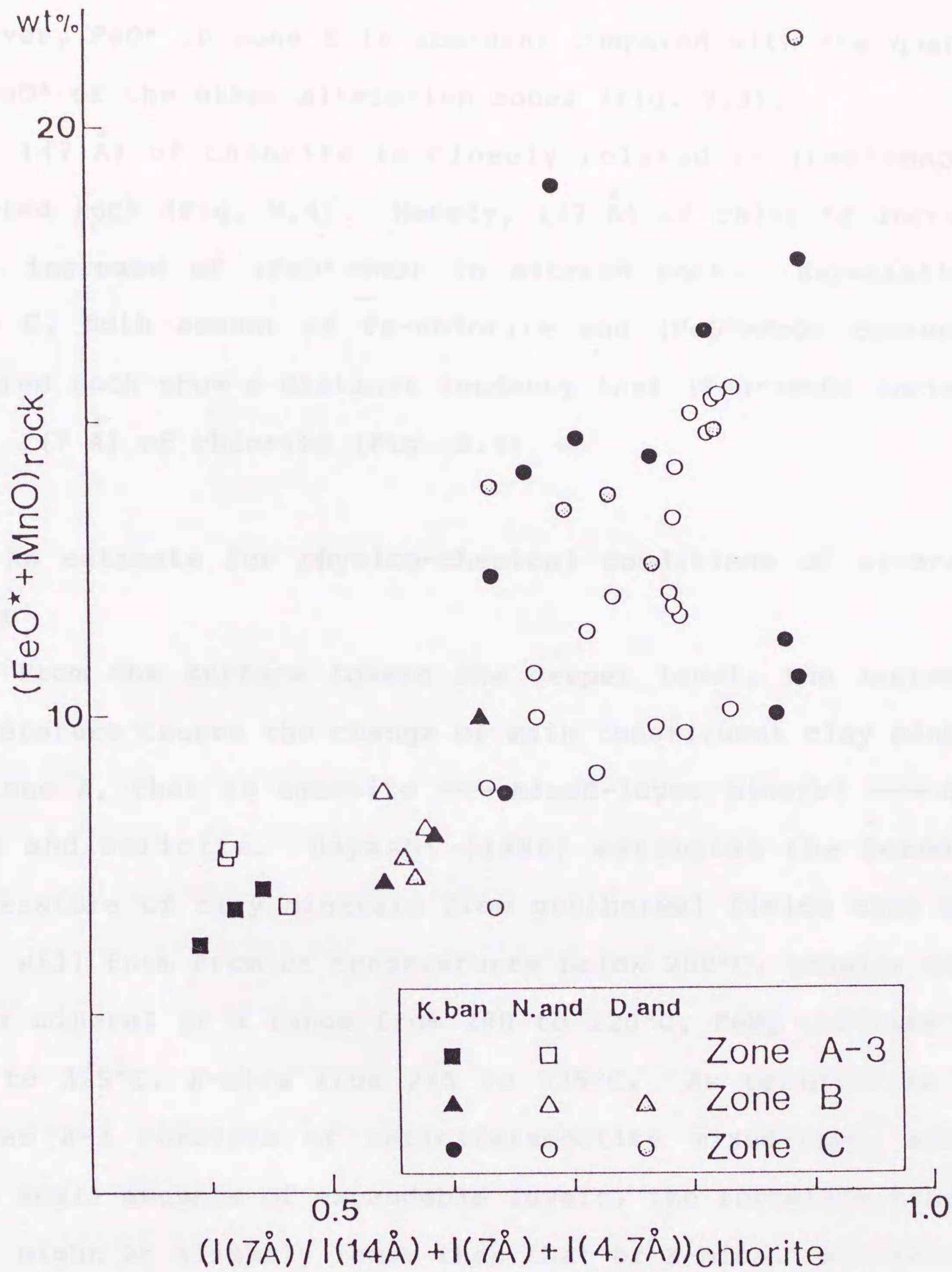


Fig.9.4 Diagram showing relation between (FeO*+MnO) content in altered rocks and I(7Å)/(I(14Å)+I(7Å)+I(4.7Å)) of chorites from altered rocks.
FeO* content in altered rocks is subtracted FeO equivalent to 1/2 mol of S from total FeO on the assumption that all Rest in chemical analysis (Appendix 5) is S in pyrite (FeS_2).
K.ban:basaltic andesite of Koyanagizawa Formation, N.and:andesite of Nagato Form., D.and:andesite dike.

However, FeO* in zone E is abundant compared with the quantity of FeO* of the other alteration zones (Fig. 9.3).

I(7 Å) of chlorite is closely related to (FeO*+MnO) of altered rock (Fig. 9.4). Namely, I(7 Å) of chlorite increases with increase of (FeO*+MnO) in altered rock. Especially in zone C, both amount of Fe-chlorite and (FeO*+MnO) content in altered rock show a distinct tendency that (FeO*+MnO) increases with I(7 Å) of chlorite (Fig. 9.4).

9.3 An estimate for physico-chemical conditions of alteration zones

From the surface toward the deeper level, the increasing temperature causes the change of main constituent clay minerals in zone A, that is smectite ⟶ mixed-layer mineral ⟶ chlorite and sericite. Hayashi (1986) estimates the formation temperature of clay minerals from geothermal fields that smectite will form from at temperatures below 200°C, regular mixed-layer mineral at a range from 200 to 220°C, FeMg chlorite from 220 to 325°C, K-mica from 245 to 325°C. As sericite in subfacies A-3 consists of sericite/smectite mixed-layer mineral with small amounts of expandable layers, the formation temperature might be slightly lower than that of K-mica. Accordingly, it is considered that subfacies A-1, A-2 and A-3 have been formed at temperature below 200°C, at a range from 200 to 220°C and above 220°C, respectively (Table 9.2).

Judging from the alteration mineral assemblage, zones B and C might have been formed by a neutral hydrothermal solution, and those correspond approximately to propylite zone in

Table 9.2 Summary of estimated conditions for alteration zones around the Toyoha mining area

Alteration zone	Characteristic clay mineral	Acting hydrothermal solution	Estimated temperature
A-1	Smectite		below 200°C
A-2	Mixed-layer min.		200 to 220°C
A-3	Chlorite,Sericite		above 220°C
B	Chlorite,Sericite	neutral	220 to 300°C
C	Chlorite,Sericite	neutral	about 300°C
D	Sericite	neutral	lower than zones B,C,E
E	Kaolinite,Dickite	weakly acidic to acidic	150 to 250°C
F	Kaolinite	weakly acidic to acidic	100 to 200°C

Ca-Mg series intermediate zone of hydrothermal alteration by Utada (1980). As calcite and albite are absent in zone C, zone C has been formed at higher temperature than zone B. Formation temperature of chlorite and sericite are estimated to be over about 220°C (Hayashi, 1973, 1986; Izawa, 1985; Ibaraki and Suzuki, 1990). The estimated maximum formation temperature of the Toyoha deposits from filling temperature is 300°C (Yajima and Ohta, 1979).

Both of Fe value of chlorite and (FeO*+MnO) in altered rock increase in order of zones A-3, B and C (Appendix 1 and Fig. 9.5). I (7 Å) of chlorite increases also with increase of (FeO*+MnO) in altered rock in order of zones A-3, B and C (Fig. 9.4). These variations are common to in analyzed three rocks, basaltic andesite of Koyanagizawa Formation, andesite of Nagato Form. and andesite dike. Namely, variation of chlorite compo-

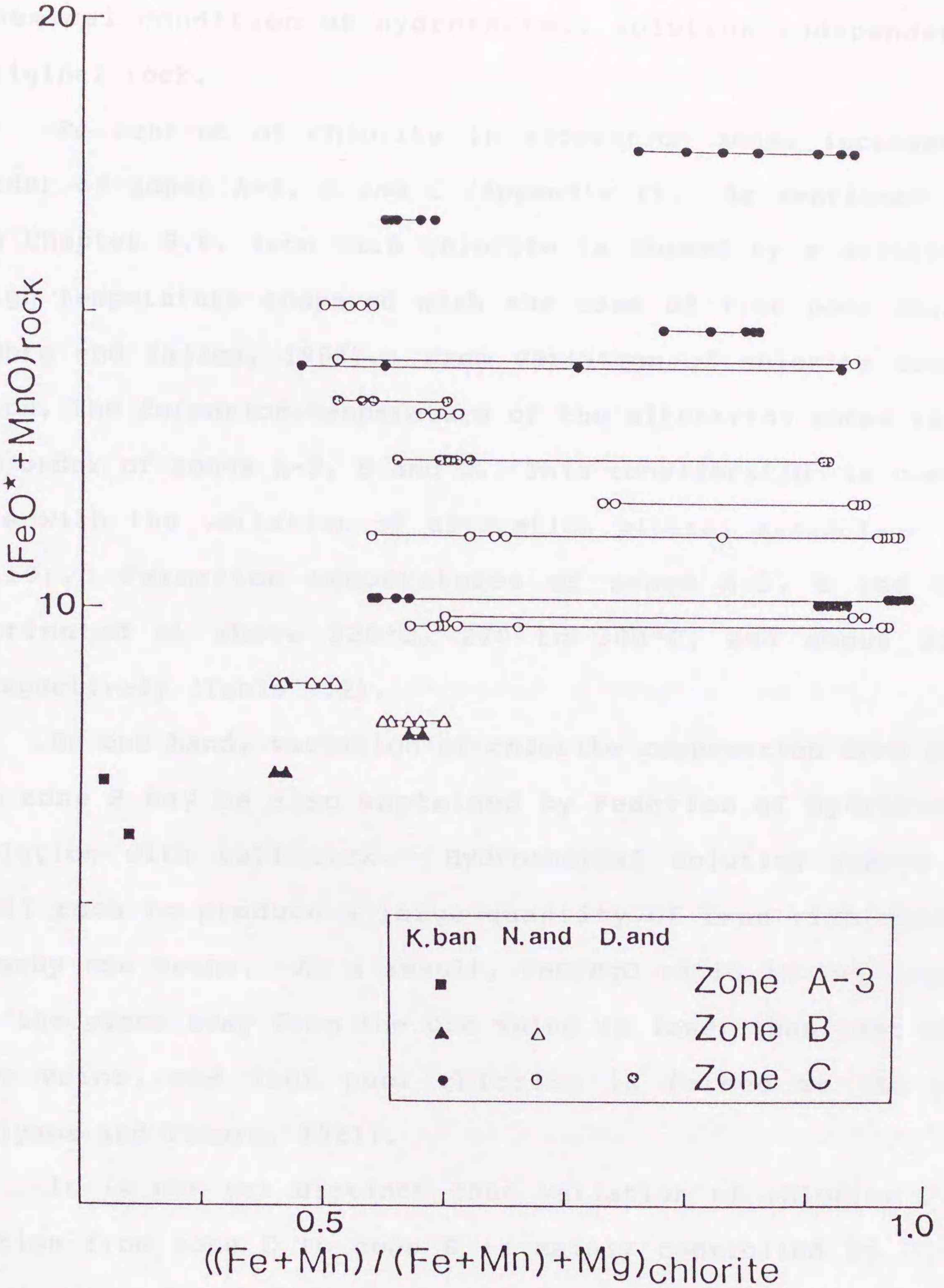


Fig.9.5 Diagram showing relation between (FeO*+MnO) content in altered rocks and Fe value of chlorites from altered rocks. See Fig. 9.4 for FeO* content in altered rocks, K.ban, N.and and D.and.

sition from zone A-3 to zone C might be caused by physicochemical condition of hydrothermal solution independent of original rock.

Fe content of chlorite in alteration zones increases in order of zones A-3, B and C (Appendix 1). As mentioned later in Chapter 9.4, iron rich chlorite is formed by a solution of high temperature compared with the case of iron poor chlorite (Ohta and Yajima, 1988). From variation of chlorite composition, the formation temperature of the alteration zones is high in order of zones A-3, B and C. This consideration is compatible with the variation of alteration mineral assemblage (Fig. 7.10). Formation temperatures of zones A-3, B and C are estimated at above 220°C, 220 to 300°C, and about 300°C, respectively (Table 9.2).

On one hand, variation of chlorite composition from zone C to zone B may be also explained by reaction of hydrothermal solution with wall rock. Hydrothermal solution reacts with wall rock to produce a large quantity of iron rich chlorite nearby ore veins. As a result, FeO/MgO ratio in the solution at the place away from the ore veins is lower than that nearby ore veins, and iron poor chlorite is formed at the place (Iiyama and Tamura, 1981).

It is not yet distinct that variation of chlorite composition from zone C to zone B is mainly controlled by whether temperature or FeO/MgO ratio of hydrothermal solution. Because formation process of the Toyoha deposits, for example, hydrothermal solutions ascended many times repeatedly during the whole stage of mineralization, and alteration nearby ore veins is formed by intricate duplication of each alteration related to many stage mineralization.

Sericite from zone D is regarded to have small amounts of expandable layer, and this fact suggests that the sericite in zone D might have been formed under lower temperature compared with the cases in zones B, C and E. Moreover, polytype data also suggest that sericite in zone D has been formed under low temperature compared with those in zones B, C and E. So that, zone D might have been formed by the rest solutions possessing low temperature generated after precipitation of main ore minerals.

Zone E is characterized by the presence of kaolinite and dickite formed by weakly acidic to acidic solutions related to formation of ore veins. Estimated temperature of zone E is 150 to 250°C (Hayashi, 1973) from the alteration mineral assemblage.

Zone F is characterized by the presence of kaolinite which is regarded as a product of weakly asidic to acidic solutions unrelated to mineralization. Alteration mineral assemblage and mode of occurrence of zone F are similar to those of the acidic alteration zone at the geothermal area. The estimated temperature is 100 to 200°C (Hayashi, 1973), and is somewhat low compared with that of zone E because dickite lacks in zone F.

9.4 Common characters compared with other polymetallic vein-type deposits in Japan

Similar or common alteration zoning is recognized in some other polymetallic ore veins in Japan. These are of the

Akenobe, Ikuno and Ashio mines in the Non-Green Tuff Regions (Fig. 9.6). The mode of occurrence of the alteration haloes, the divided alteration zones of these mines are given in Table 9.3 for the correlation to the Toyoha mine in question.

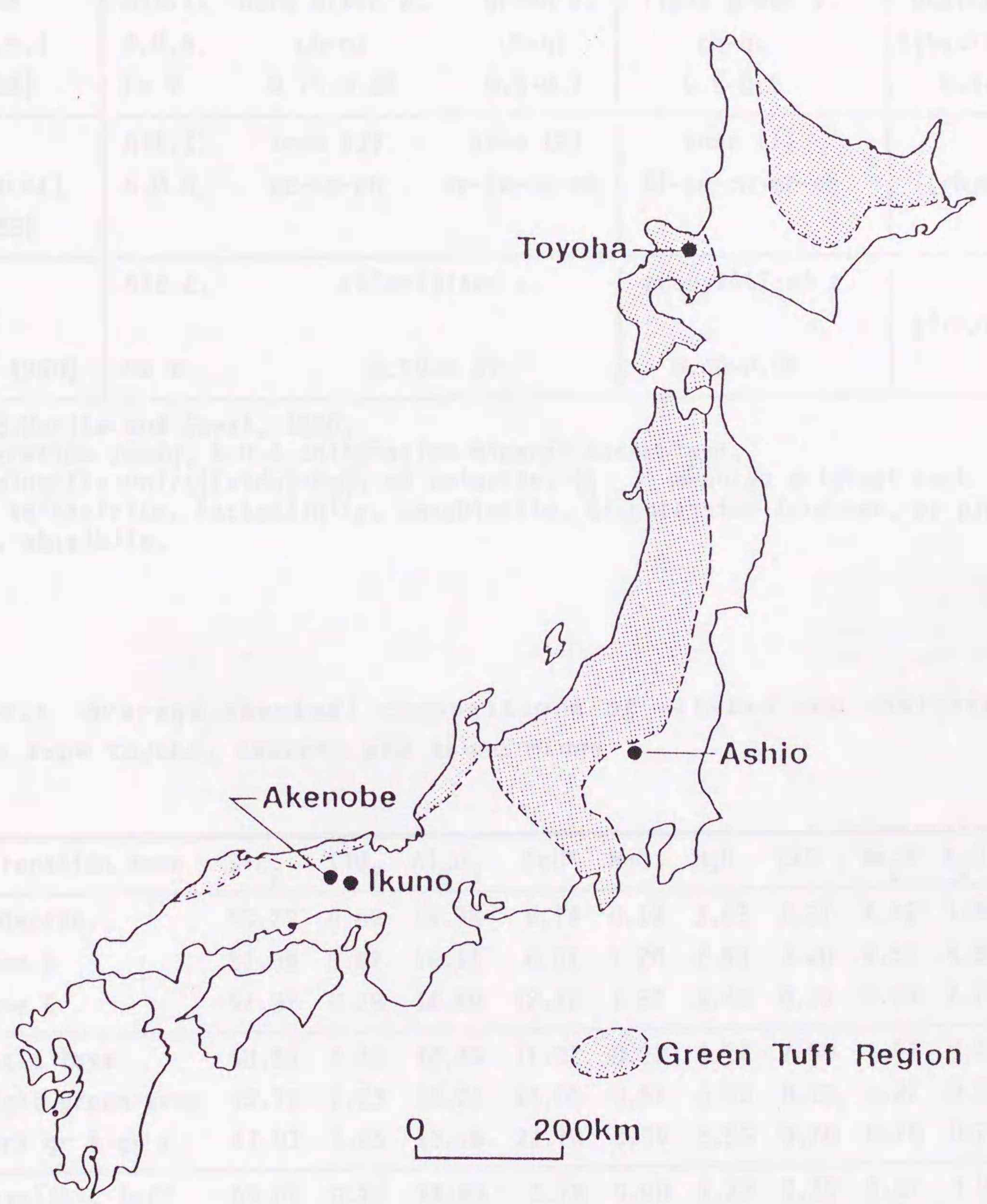


Fig.9.6 Map showing the extent of Green Tuff Region and major polymetallic ore deposits in Japan.

Table 9.3 Correlation of alteration zones of Toyoha, Akenobe, Ikuno and Ashio deposits

Toyoha mine (Toyoha dep.) (This study)	Alt.Z.	zone C		zone B	zone A
	A.M.A.	ch-qz-se-py		ch-qz-se-ca-ab-py	((andesite))
	Fe V.	0.5-0.6 and 0.9		0.5-0.6	0.3-0.4
Akenobe mine (Chiemon v.s.) (Sawai, 1988)	Alt.Z.	dark green z.	green z.	light green z.	unaltered z.
	A.M.A.	ch-qz	ch-qz	ch-qz	((basic lava))
	Fe V.	0.75-0.85	0.5-0.7	0.5-0.6	0.4-0.5
Ikuno mine (Kanagase area) (N & S, 1988)	Alt.Z.	zone (3)	zone (2)	zone (1)	
	A.M.A.	qz-se-ch	se-ka-qz-ch	Kf-se-ch-qz-ab	((rhyolitic tuff))
Ashio mine (Nakamura, 1960)	Alt.Z.	chloritized z.		propylitized z.	((rhyolite))
	Fe V.	0.69-0.89		0.40-0.66	

N & S, 1988:Narita and Sawai, 1988,
Alt.Z.:Alteration zonig, A.M.A.:Alteration mineral assemblage,
Fe V.:Fe value((Fe+Mn)/((Fe+Mn)+Mg)) of chlorite, (( )) denotes original rock.
qz:quartz, se:sericite, ka:kaolinite, ch:chlorite, Kf:potassium feldspar, py:pyrite, ca:calcite, ab:albite.

Table 9.4 Average chemical compositions of altered and unaltered rocks from Toyoha, Akenobe and Ikuno mines

	Alteration zone	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	H_2O*
TOYOHA MINE	andesite	58.29	0.69	15.95	8.14	0.16	3.63	7.27	2.46	1.46	1.11
	zone B	57.39	0.82	16.14	6.51	1.20	2.93	3.20	0.52	4.88	4.31
	zone C	57.87	0.78	14.40	12.62	1.51	2.46	0.35	0.09	2.79	5.29
AKENOBE MINE	basic lava	50.86	2.16	12.48	11.02	0.22	6.17	7.90	3.53	0.82	3.70
	light green zone	45.72	2.23	13.21	14.05	0.51	6.43	8.25	2.37	0.34	5.40
	dark gr & gr z.	43.03	1.65	13.18	23.78	0.99	5.55	0.78	0.14	0.20	8.48
IKUNO MINE	rhyolitic tuff	69.01	0.27	14.83	3.78	0.00	1.22	2.25	2.67	3.07	2.12
	zone (1)	71.81	0.19	12.55	3.92	0.27	0.53	0.53	0.08	6.16	2.81
	zone (2), (3)	74.90	0.12	10.32	5.49	0.14	0.38	0.12	0.08	2.54	3.31

FeO*:total Fe as FeO, H_2O*:$H_2O(+)+H_2O(-)$, dark gr & gr z.:dark green and green zones.
References are indicated in Fig. 9.7.

The main host rocks of the Toyoha, Akenobe and Ikuno mines are andesite, basic lava and rhyolitic tuff, respectively. The remarkable difference of sericite to chlorite ratio among these three deposits is surely attributed to the chemical compositions of their original host rocks. Average chemical compositions of altered rocks for each zone of the three deposits are shown in Table 9.4, and variation trend of mobile elements is illustrated in Fig. 9.7. Decrease of CaO and Na_2O, and

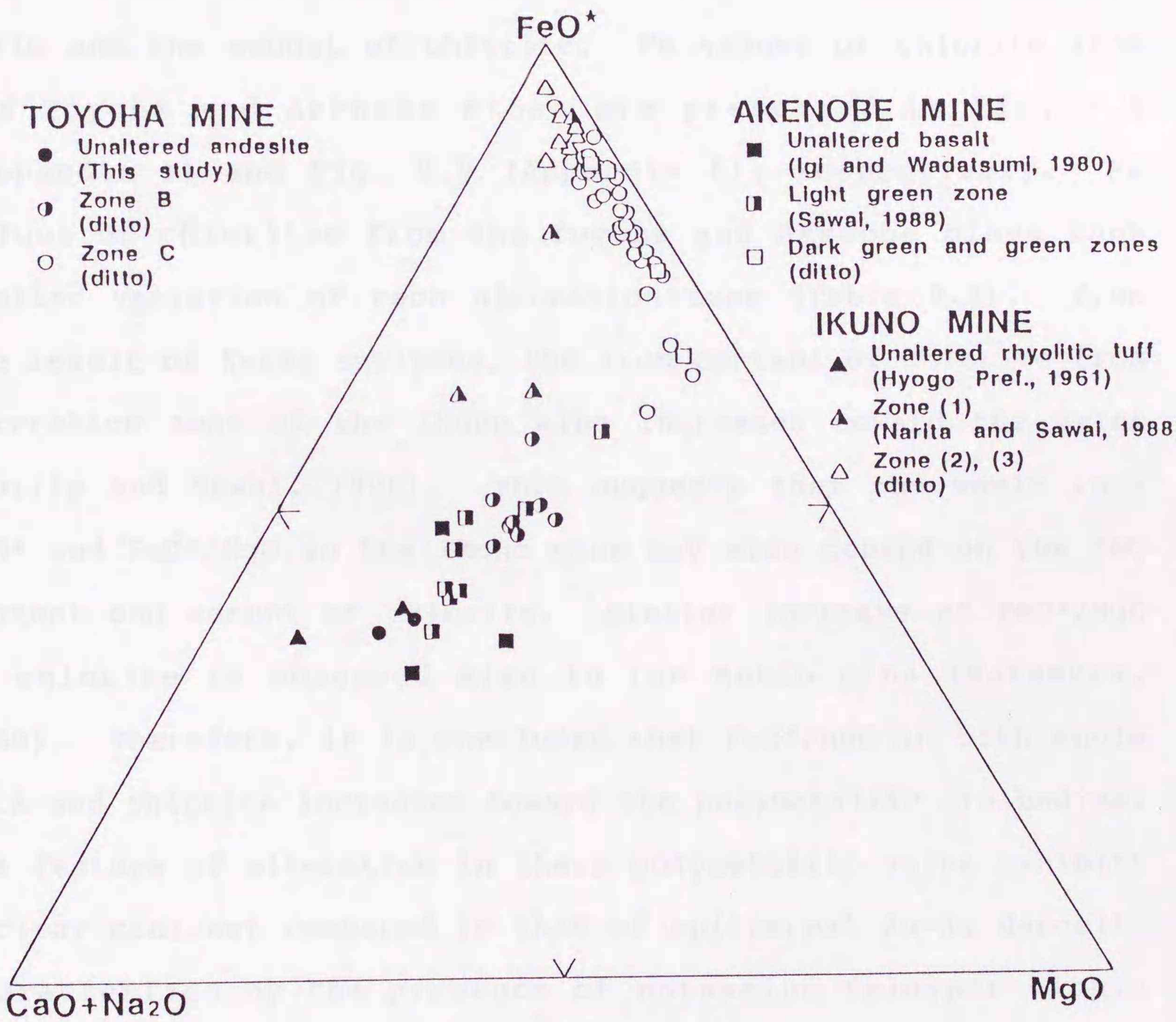


Fig.9.7 FeO*(Total Fe as FeO)-($CaO+Na_2O$)-MgO diagram showing the variation in unaltered and altered rocks from Toyoha, Akenobe and Ikuno mines.

increase of FeO* (total Fe as FeO), FeO*/MgO and H_2O toward the veins are common characteristics among these three deposits. The increase of H_2O is due to the increasing of clay minerals. The decrease of CaO and Na_2O is caused by the disappearance of calcium- and/or sodium- containing minerals such as calcite, albite (Toyoha), clinopyroxene, albite (Akenobe) and hornblende, albite (Ikuno).

The increase of FeO* and FeO*/MgO in the Toyoha and Akenobe mines is mostly due to the increase of both the FeO/MgO ratio and the amount of chlorite. Fe values of chlorite from the Toyoha and Akenobe mines are presented in Fig. 9.8 (Appendix 1) and Fig. 9.9 (Appendix 6), respectively. Fe values of chlorites from the Toyoha and Akenobe mines show similar variation of each alteration zone (Table 9.3). From the result of X-ray analyses, the iron content of chlorite from alteration zone of the Ikuno mine increases toward the veins (Narita and Sawai, 1988). This suggests that the whole rock FeO* and FeO*/MgO in the Ikuno mine may also depend on the FeO content and amount of chlorite. Similar increase of FeO*/MgO in chlorite is observed also in the Ashio mine (Nakamura, 1960). Therefore, it is concluded that FeO*/MgO in both whole rock and chlorite increases toward the polymetallic ore bodies. The feature of alteration in these polymetallic veins exhibits a clear contrast compared to that of epithermal Au-Ag deposits characterized by the presence of potassium feldspar within veins or at the vicinity of veins, and by decrease of FeO/MgO in chlorite toward the deposits (e.g., Yoneda and Watanabe, 1981; Takeuchi, 1984; Imai, 1986).

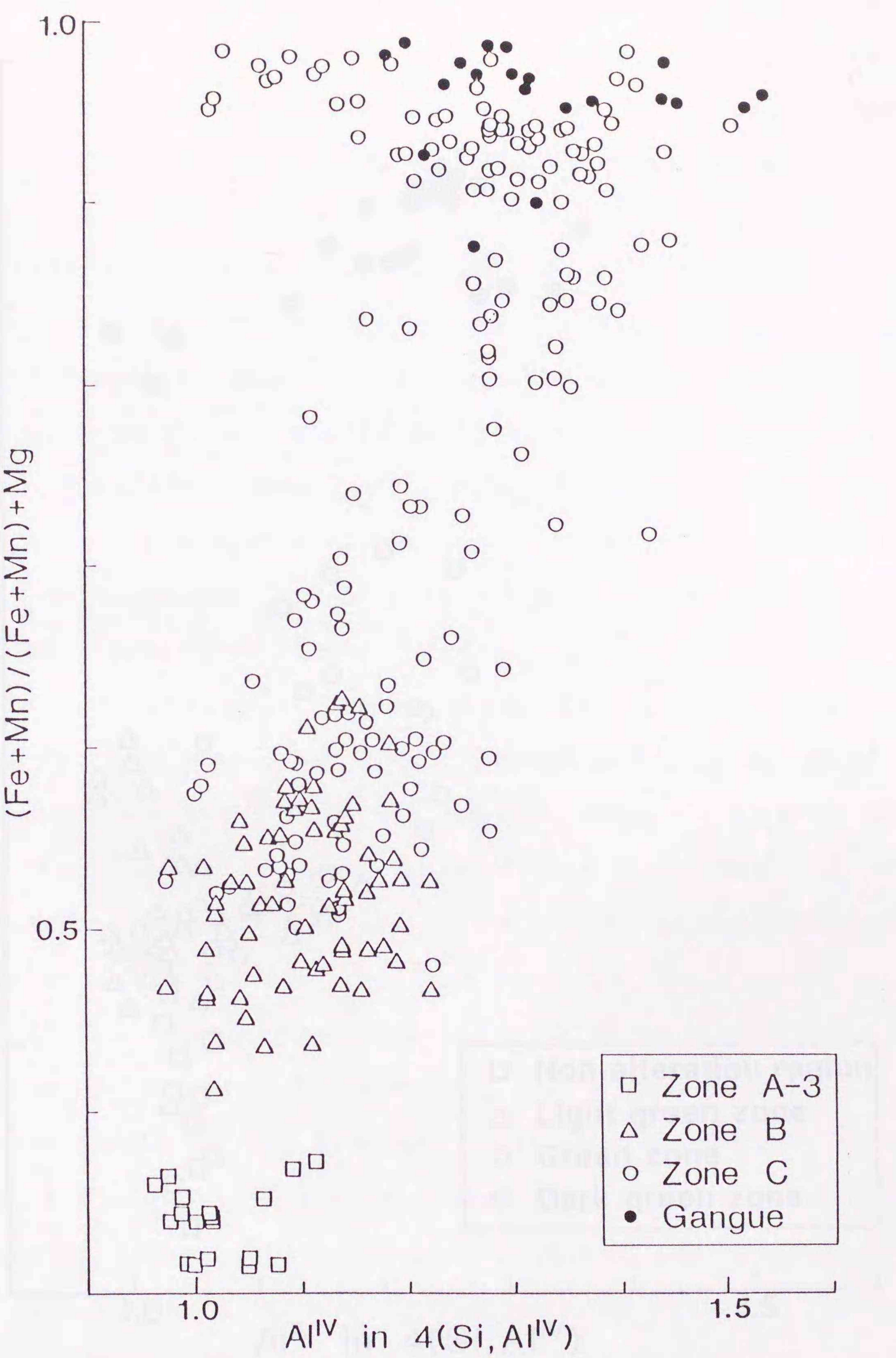


Fig.9.8 Fe value (Fe+Mn)/((Fe+Mn)+Mg) versus Al^{IV} in 4(Si, Al^{IV}) diagram of chlorites from altered rocks and gangue mineral around the Toyoha mining area.

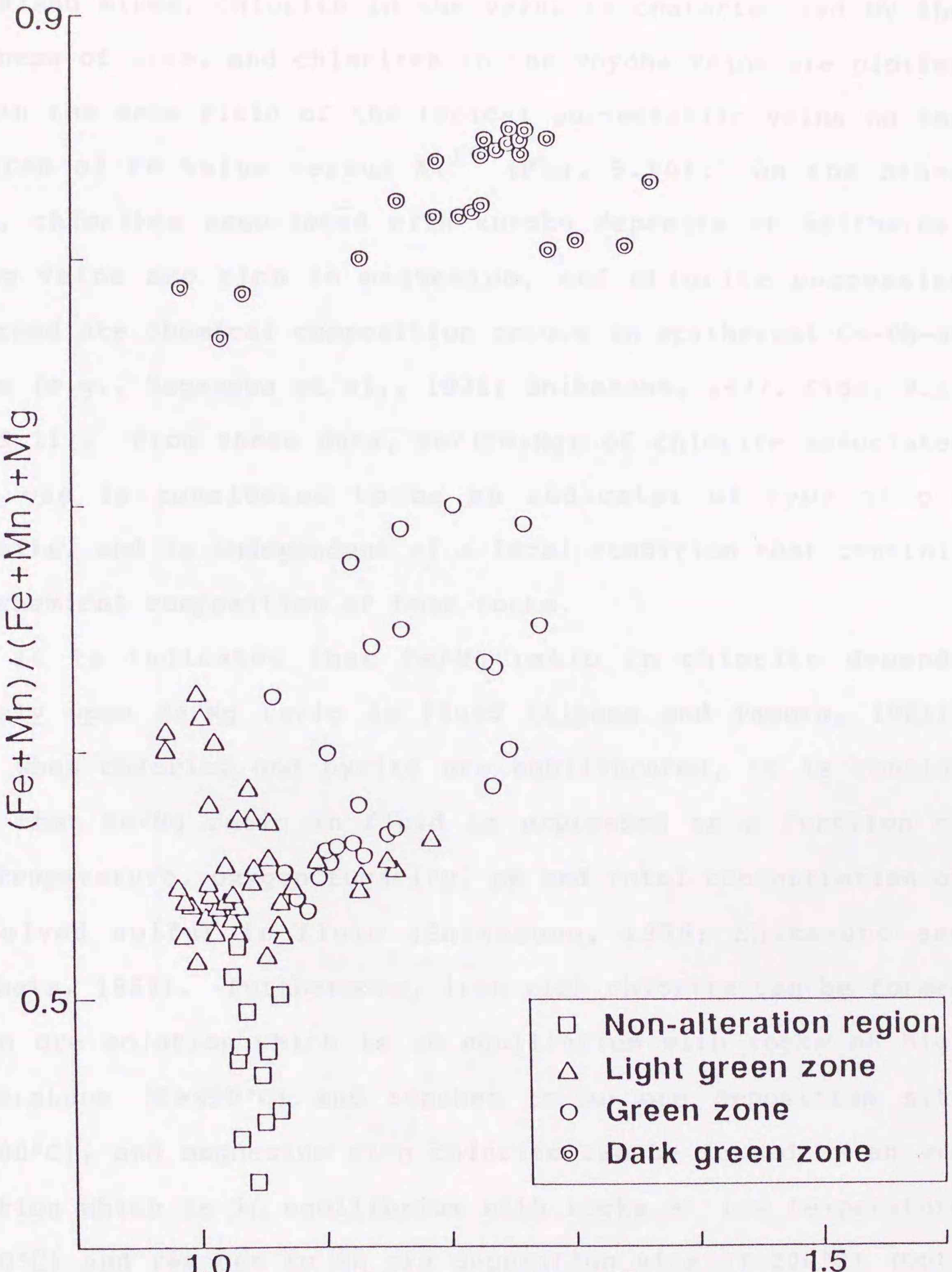


Fig.9.9 Plot of Fe value (Fe+Mn)/((Fe+Mn)+Mg) versus Al^{IV} in 4(Si, Al^{IV}) of chlorites from altered rocks around the Chiemon vein swarm, Akenobe mine after Sawai (1988).

Generally, in the polymetallic veins of the Ashio, Ikuno and Kishu mines, chlorite in the veins is characterized by the richness of iron, and chlorites in the Toyoha veins are plotted within the same field of the typical polymetallic veins on the diagram of Fe value versus Al^{IV} (Fig. 9.10). On the other hand, chlorites associated with kuroko deposits or epithermal Au-Ag veins are rich in magnesium, and chlorite possessing intermediate chemical composition occurs in epithermal Cu-Pb-Zn veins (e.g., Nagasawa et al., 1976; Shikazono, 1977. Figs. 9.10 and 9.11). From these data, Fe/(Fe+Mg) of chlorite associated with ore is considered to be an indicator of type of ore deposits, and is independent of a local condition that controls the chemical composition of host rocks.

It is indicated that Fe/Mg ratio in chlorite depends largely upon Fe/Mg ratio in fluid (Iiyama and Tamura, 1981). And, when chlorite and pyrite are equilibrated, it is considered that Fe/Mg ratio in fluid is expressed as a function of the temperature, oxygen fugacity, pH and total concentration of dissolved sulfur in fluid (Shikazono, 1976; Shikazono and Kawahata, 1987). Furthermore, iron rich chlorite can be formed by an ore solution which is in equilibrium with rocks at high temperature ($T > 450°C$) and reaches to an ore deposition site ($T=200°C$), and magnesium rich chlorite can be formed by an ore solution which is in equilibrium with rocks at low temperature ($T < 80°C$) and reaches to an ore deposition site ($T=200°C$) (Ohta and Yajima, 1988). And, compositions of chlorite suggest that the ore solutions of the polymetallic veins, epithermal Cu-Pb-Zn veins and epithermal Au-Ag veins are of high, intermediate

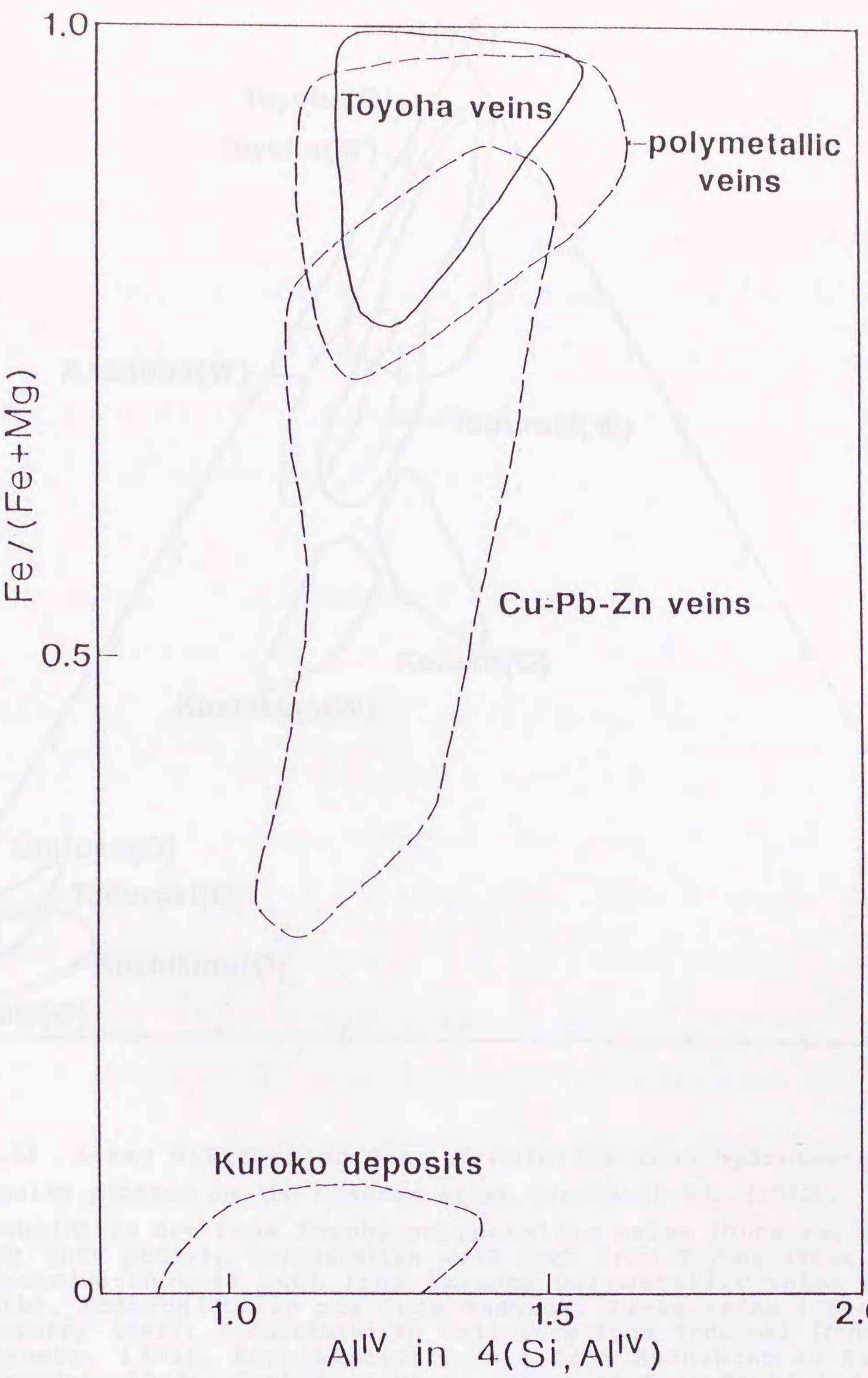


Fig.9.10 Chemical composition of chlorite associated with ore from vein-type and Kuroko-type deposits in Japan.
Toyoha veins (Ohta and Yajima, 1988; This study), polymetallic veins (Nakamura, 1960, 1963; Shirozu, 1958; Nagasawa et al., 1976), Cu-Pb-Zn veins (Shirozu, 1958; Sudo, 1941; Nagasawa, 1961; Nagasawa et al.,1976), Kuroko deposits (Hayashi, 1961; Hayashi and Oinuma, 1965; Tsuzuki and Honda, 1977; Shirozu et al., 1975; Sakamoto and Sudo, 1956; Katsumoto and Shirozu, 1973).

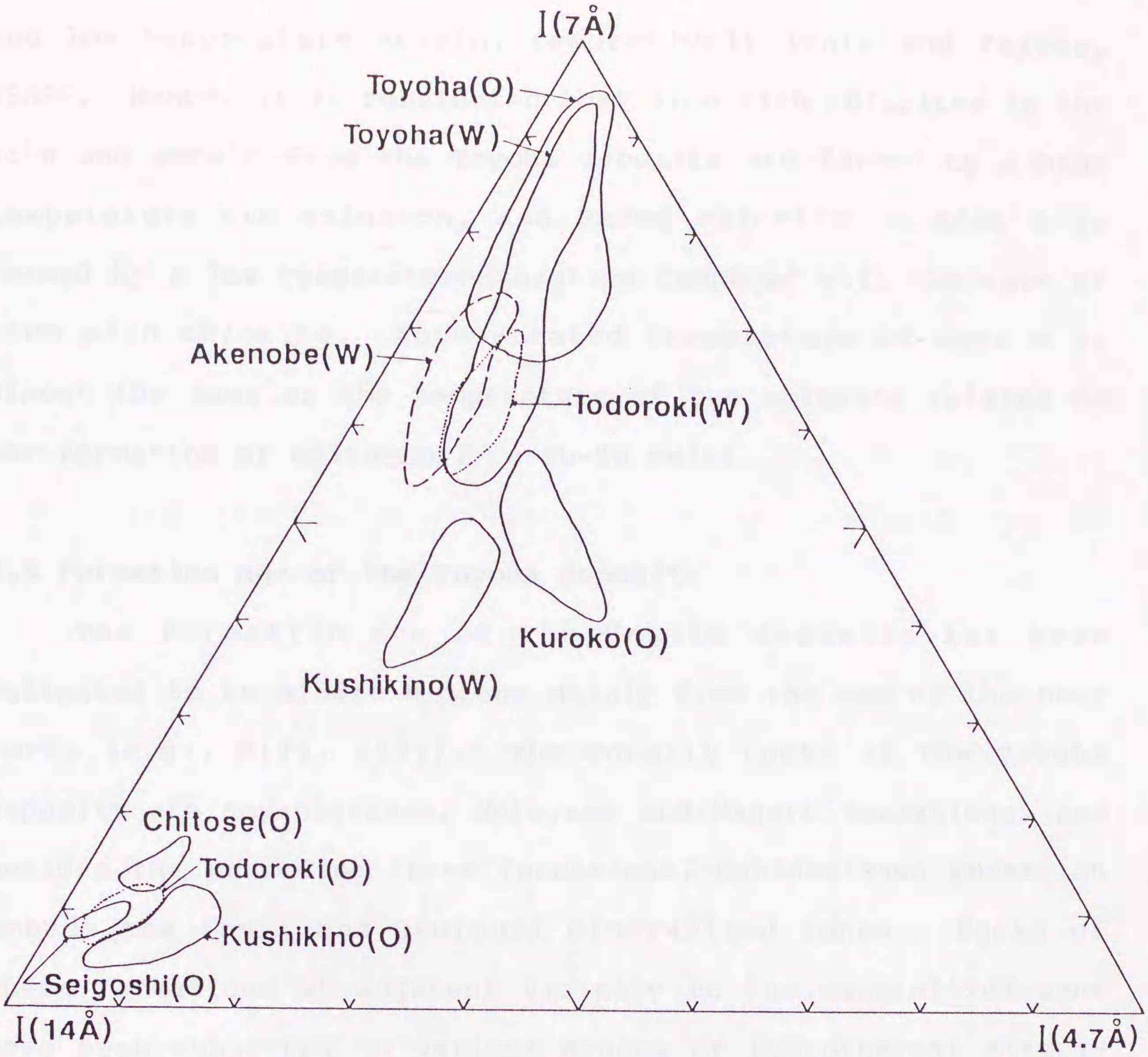


Fig.9.11 X-ray diffraction data of chlorite from hydrothermal ore deposits plotted on the diagram after Oinuma et al. (1972).

Toyoha(O):in ore from Toyoha polymetallic veins (Ohta and Yajima, 1988; This study), Toyoha(W):in wall rock from Toyoha (This study), Akenobe(W):in wall rock from Akenobe polymetallic veins (Sawai, 1986b), Todoroki(O):in ore from Todoroki Au-Ag veins (Yoneda and Watanabe, 1981), Todoroki(W):in wall rock from Todoroki (Yoneda and Watanabe, 1981), Kushikino(O):in ore from Kushikino Au-Ag veins (Takeuchi, 1984), Kushikino(W):in wall rock from Kushikino (Takeuchi, 1984), Chitose(O):in ore from Chitose Au-Ag veins (Yoneda and Watanabe, 1989), Seigoshi(O): in ore from Seigoshi Au-Ag veins (Yoneda and Watanabe, 1989), Kuroko(O):in yellow ore and siliceous ore from Kuroko deposits, Hokuroku district (Shirozu, 1974). Note that Todoroki(O), Kushikino(O), Chitose(O) and Seigoshi(O) are chlorite/smectite interstratification.

and low temperature origin, respectively (Ohta and Yajima, 1988). Hence, it is considered that iron rich chlorites in the vein and zone C from the Toyoha deposits are formed by a high temperature ore solution, and Fe-Mg chlorite in zone B is formed by a low temperature solution compared with the case of iron rich chlorite. Above-stated temperature of zone B is almost the same as the temperature of ore solution related to the formation of epithermal Cu-Pb-Zn veins.

9.5 Formation age of the Toyoha deposits

The formation age of the Toyoha deposits has been estimated to be middle Miocene mainly from the age of the host rocks (e.g., MITI, 1972). The country rocks of the Toyoha deposits are Koyanagizawa, Motoyama and Nagato Formations, and besides the preceding three formations, Oshidorizawa Formation embeds the Iburi and Okuiburi mineralized zones. Rocks of these formations at adjacent vicinity to the mineralized zone have been subjected to various grades of hydrothermal alterations (Fig. 9.12). Main alteration minerals are chlorite and sericite. Fission track age of 8.8 ± 0.3 Ma (late Miocene) has been obtained from acidic tuff of the Oshidorizawa Formation (Sawai and Ganzawa, 1988b). From this, the deposits might have been formed after late Miocene. Mineralized zone and hydrothermal alteration zone mainly composed of chlorite and sericite are unrecognized in the Sanbonmata Formation from which the fission track age of 3.3 ± 0.2 Ma has been obtained (Sawai and Ganzawa, 1988a). However, chlorite/smectite mixed-layer mineral occurs in the Sanbonmata Formation only nearby the mineralized zone in the Motoyama and Nagato Formations (Sawai and Ganzawa, 1988a). In other words, this mixed-layer mineral is absent in the Sanbonmata Formation occurring at long distance away from the mineralized zone. From this, mixed-layer mineral in question may be formed by hydrothermal solutions related to the formation of the ore deposits. From the field survey and fission track age of the Sanbonmata Formation, it is possible to say that the deposits have been formed also after 3.3 Ma (middle Pliocene) corresponding to the age of the Sanbonmata Formation.

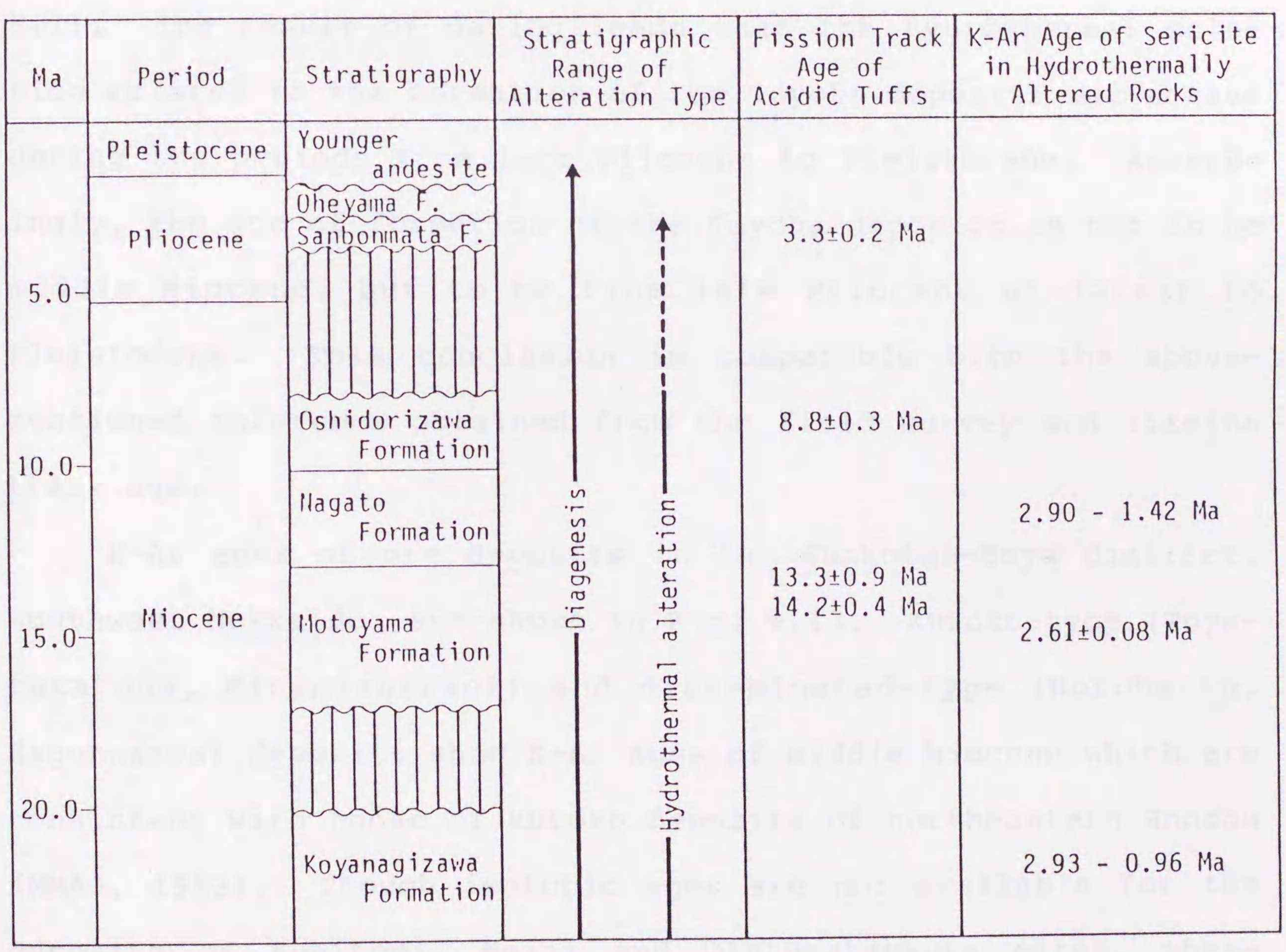


Fig.9.12 Stratigraphic range of diagenesis and hydrothermal alterations based on fission track age and K-Ar age data.

On the other hand, Marumo and Sawai (1986) reported K-Ar age of 2.2 Ma for a clay vein from the Izumo vein of the Toyoha deposits and suggested that the mineralization might have continued until Pliocene. K-Ar ages for sericite in hydrothermally altered rocks of the Koyanagizawa, Motoyama and Nagato Formations are 2.93 to 0.96 Ma, 2.61 Ma and 2.90 to 1.42 Ma, respectively (Fig. 9.12). There is a very long time gap between the ages of country rock and of hydrothermal alteration related to the formation of the deposits. K-Ar ages for sericite in hydrothermally altered rocks, clay veins and gangue sericite are limited within a range from 2.93 to 0.49 Ma (Table 8.1). The result of dating leads that the hydrothermal solution related to the formation of the Toyoha deposits was active during the periods from late Pliocene to Pleistocene. Accordingly, the age of formation of the Toyoha deposits is not to be middle Miocene, but to be from late Pliocene at latest to Pleistocene. This conclusion is compatible with the above-mentioned inference obtained from the field survey and fission track age.

K-Ar ages of ore deposits in the Shakotan-Toya district, southwest Hokkaido, are shown in Fig. 9.13. Kuroko-type (Toya-takarada, Minamishiraoi) and disseminated-type (Horobetsu, Kagenosawa) deposits show K-Ar ages of middle Miocene which are consistent with those of kuroko deposits of northeastern Honshu (MMAJ, 1982). Though isotopic ages are not available for the deposits of Kunitomi, Meiji and Otarumatsukura mines, these kuroko-type deposits might have also been formed in the same period judging from their embedded horizon (MMAJ, 1973). On

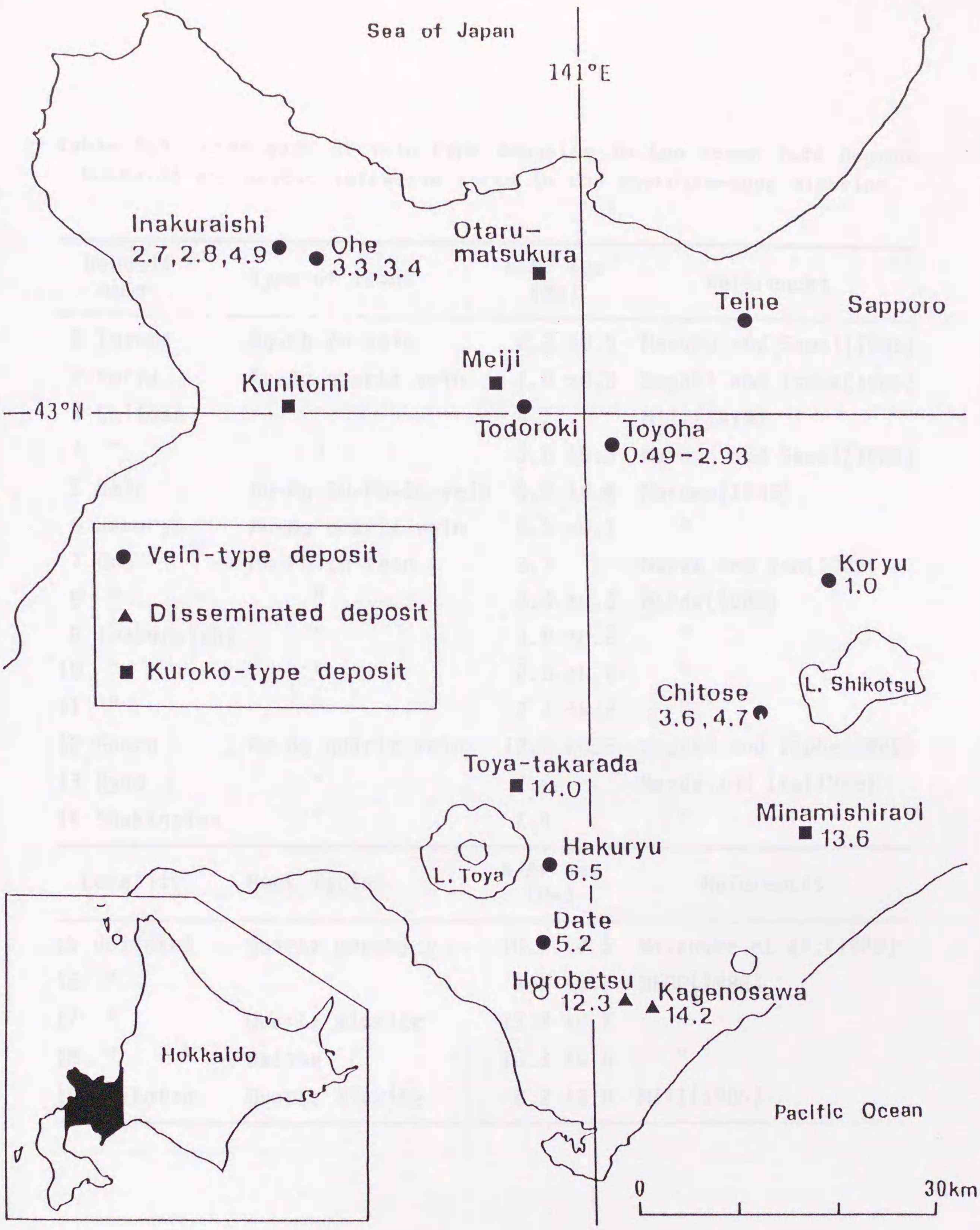


Fig.9.13 Map showing the localities and K-Ar ages of ore deposits in the Shakotan-Toya district.

Inakuraishi (Maeda, 1988), Ohe (Maeda and Ito, 1985; Maeda, 1988), Toyoha (Marumo and Sawai, 1986; This study), Koryu (Sugaki and Isobe, 1985), Chitose (MITI, 1979; Marumo and Sawai, 1986), Hakuryu and Date (Marumo, 1985), Toya-takarada, Minamishiraoi, Horobetsu and Kagenosawa (Marumo and Sawai, 1986).

Table 9.5 K-Ar ages of vein-type deposits in the Green Tuff Region, Hokkaido and acidic intrusive rocks in the Shakotan-Toya district

	Deposit name	Type of veins	K-Ar age (Ma)	References
1	Toyoha	Ag-Pb-Zn vein	2.2 ±0.6	Marumo and Sawai(1986)
2	Koryu	Au-Ag quartz vein	1.0 ±0.3	Sugaki and Isobe(1985)
3	Chitose	"	4.7	MITI(1979)
4	"	"	3.6 ±0.3	Marumo and Sawai(1986)
5	Date	Au-Ag-Cu-Pb-Zn vein	5.2 ±0.4	Marumo(1985)
6	Hakuryu	Au-Ag quartz vein	6.5 ±0.3	"
7	Ohe	Mn-Pb-Zn vein	3.3	Maeda and Ito(1985)
8	"	"	3.4 ±0.3	Maeda(1988)
9	Inakuraishi	"	4.9 ±0.2	"
10	"	"	2.8 ±0.2	"
11	"	"	2.7 ±0.2	"
12	Sanru	Au-Ag quartz vein	12.4 ±0.6	Sugaki and Isobe(1985)
13	Ryuo	"	7.7	Maeda and Ito(1986)
14	Shakinzawa	"	7.4	"
	Locality	**Rock facies**	**K-Ar age (Ma)**	**References**
15	Jozankei	Quartz porphyry	10.9 ±0.5	Watanabe et al.(1989)
16	"	"	9.5 ±0.7	NEDO(1988)
17	"	Quartz diorite	13.9 ±0.7	"
18	"	Dacite	10.3 ±0.5	"
19	Shakotan	Quartz diorite	8.2 ±3.8	MITI(1985)

the other hand, vein-type deposits in the Shakotan-Toya district are formed in a period from the latest Miocene to Pleistocene. Especially, the Toyoha mine together with the Koryu mine belongs to the youngest group.

K-Ar ages of the Jozankei quartz porphyry which is situated in center of the zonal arrangement of ore deposits in the Teine-Chitose district (Yajima, 1979) are 13.9 to 9.5 Ma (NEDO, 1988; Watanabe et al., 1989. Table 9.5). K-Ar age of quartz

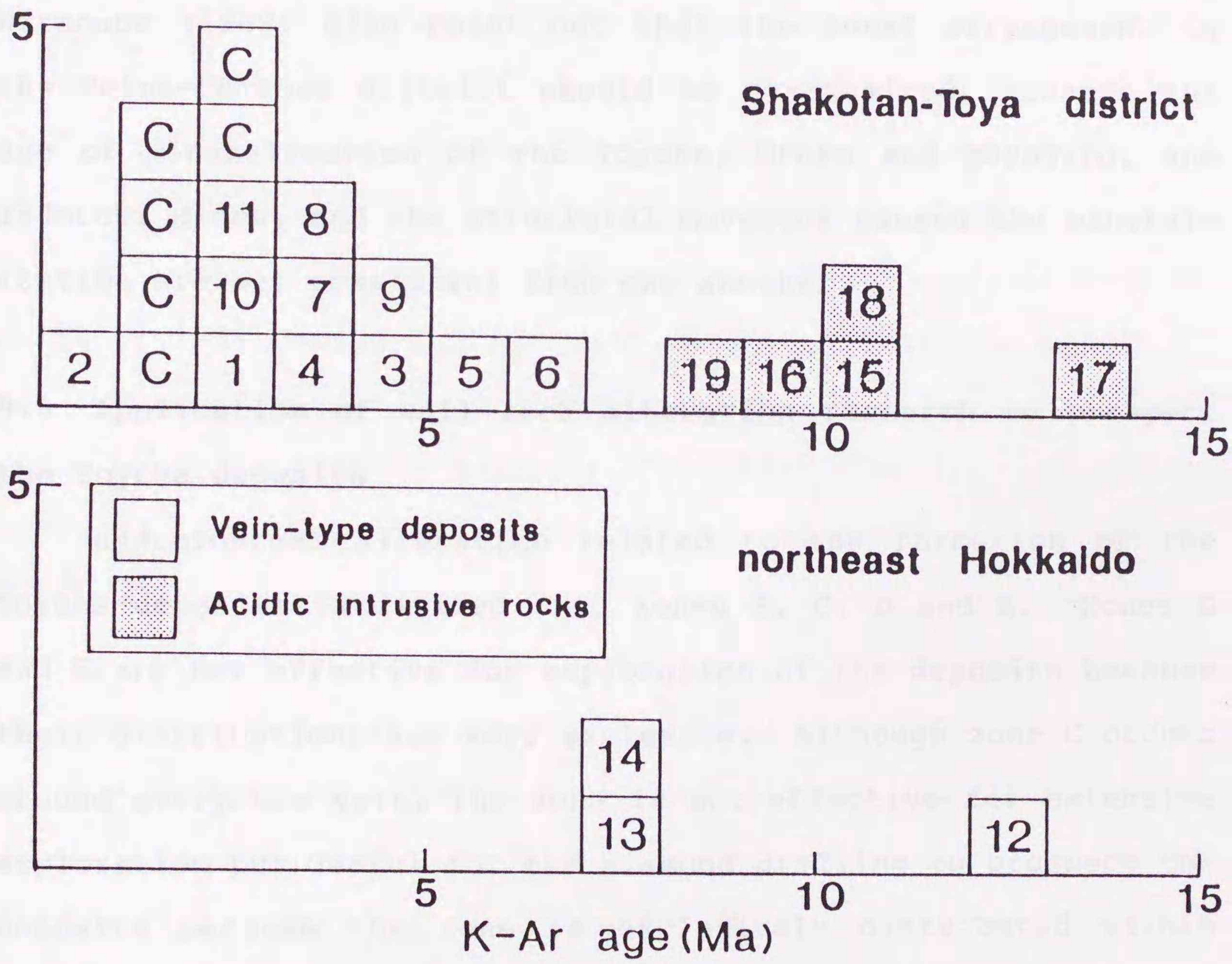


Fig.9.14 Histogram showing range in K-Ar ages of vein-type deposits in the Green Tuff Region, Hokkaido and acidic intrusive rocks in the Shakotan-Toya district. Number in diagram is referred to Table 9.5. C denotes the K-Ar ages of zone C in this study.

diorite which is situated in center of the zonal arrangement of ore deposits in the Shakotan district (Narita et al., 1965) is 8.3 Ma (Table 9.5), but the age may be rejuvenated because the dated sample is affected to a certain alteration related to the mineralization of the Ohe mine (MITI, 1985). These ages are much older than those of vein-type deposits showing the zonal arrangement (Fig. 9.14). Hence, the previous theory on zonal arrangement of ore deposits around acidic intrusions in the Teine-Chitose and Shakotan districts should be re-examined. Watanabe (1989) also point out that the zonal arrangement in the Teine-Chitose district should be re-examined, because the age of mineralization of the Toyoha, Otoyo and Toyohiro, and Todoroki mines, and the structural movement caused the mineralization are not consistent from one another.

9.6 Application of wall rock alteration research to prospect the Toyoha deposits

Hydrothermal alteration related to the formation of the Toyoha deposits is divided into zones B, C, D and E. Zones D and E are not effective for exploration of the deposits because their distributions are very exclusive. Although zone C occurs around every ore vein, the zone is not effective for extensive exploration but useful for the diamond drilling to prospect the deposits because the zone is exclusively distributed within nearly ten meters from ore veins. Zone B is the best target for the extensive exploration, because the zone occupies the whole area including the deposits.

Histograms of mobile elements in alteration zones A, B and

C are shown in Fig. 9.15. These histograms reveal that K_2O and Na_2O are the most useful components for the exploration. K_2O contents in zone A and zones B, C are under and over 1.8 wt.%, respectively. Na_2O contents in zone A and zones B, C are over 1.5 wt.% and under 0.9 wt.%, respectively. Na_2O content in altered rocks has been widely used for the exploration in kuroko deposits of the Hokuroku district, e.g., Na_2O poor dacite (Date et al., 1979) and low Na_2O anomaly (Hashiguchi et al., 1981).

$CaO+Na_2O$ is divided into following three groups; 1) over 7 wt.% in zone A, 2) 3 to 5 wt.% in zone B and 3) under 1 wt.% in zone C (Fig. 9.16). Hence, $CaO+Na_2O$ is more effective for the exploration than the case using Na_2O only. Furthermore, altered index $(100x(MgO+K_2O)/(Na_2O+K_2O+CaO+MgO))$ after Ishikawa et al., (1976) using for the exploration of kuroko deposits in the Hokuroku district is also useful. MgO and K_2O, added components have been used as altered index in the kuroko deposits, but FeO* has been used in the Toyoha deposits in stead of MgO , because MgO is constant but FeO* increases toward ore veins. Namely, altered index in the Toyoha deposits is calculated by $100x(FeO^*+K_2O)/(Na_2O+K_2O+CaO+FeO^*)$. The altered indices in zones A, B and C are 40 to 60, 70 to 90 and over 90, respectively (Fig. 9.16). However, $CaO+Na_2O$ can be used more easily than the altered index being obliged to do four elements analyses.

CaO, Na_2O and K_2O in zone F which is a hydrothermal alteration zone unrelated to the formation of the deposits show the same variation trends as those in zones B and C (Fig. 7.1). On

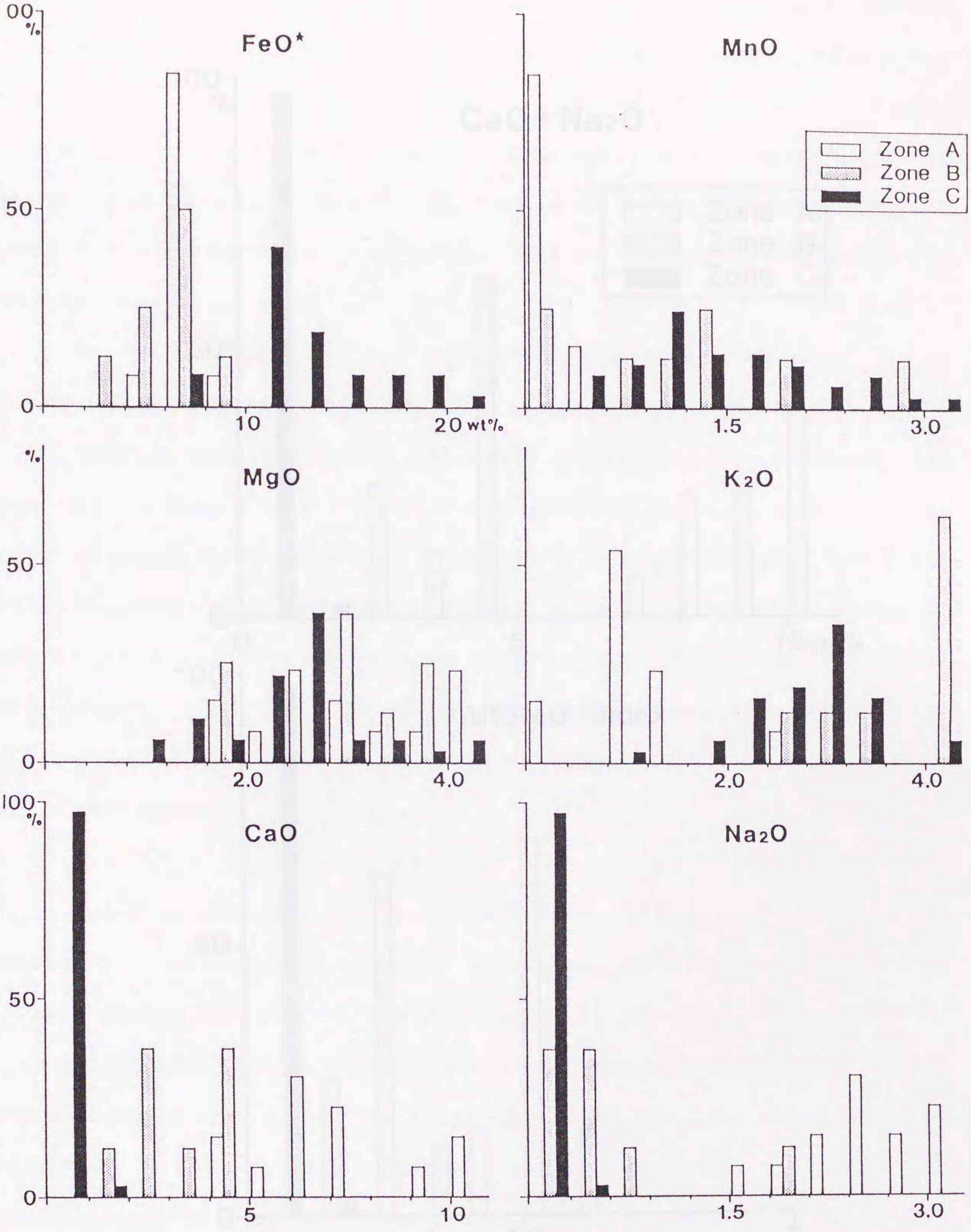


Fig.9.15 Histograms showing range in content of mobile components in altered rocks from alteration zones A, B and C.

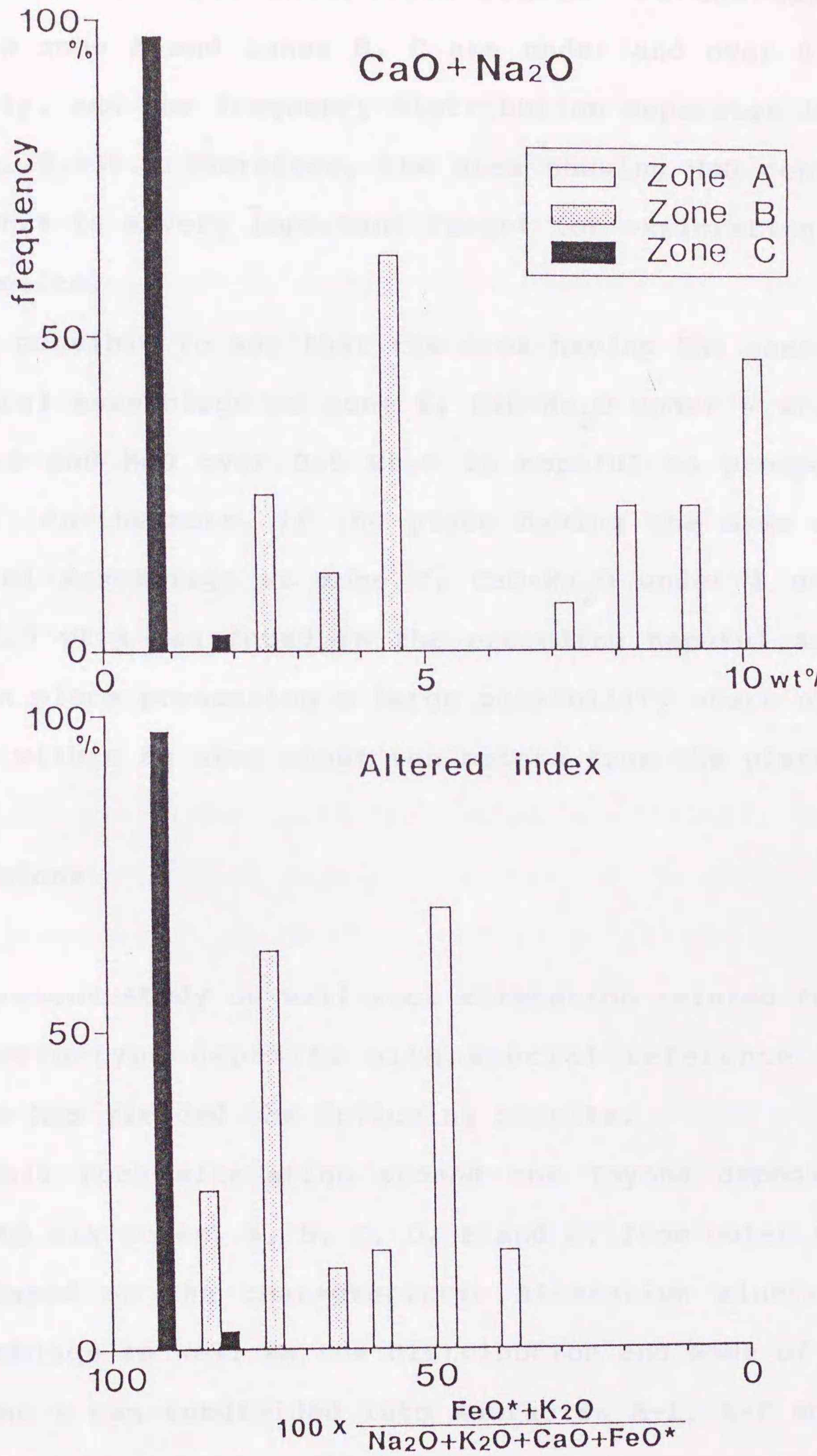


Fig.9.16 Histograms showing range in $(CaO+Na_2O)$ content and altered index of altered rocks from alteration zones A, B and C.

the other hand, MnO content in zones B and C is clearly larger than that in the other alteration zones. Furthermore, MnO contents in zone A and zones B, C are under and over 0.5 wt.% respectively, and the frequency distribution separates into two areas (Fig. 9.15). Therefore, the area showing MnO content of over 0.5 wt.% is a very important target for exploration of the Toyoha deposits.

It is possible to say that the area having the same alteration mineral assemblage as zone B, CaO+Na_2O under 5 wt.%, K_2O over 2 wt.% and MnO over 0.5 wt.% is hopeful to prospect new ore veins. Furthermore, if the place having the same alteration mineral assemblage as zone C, CaO+Na_2O under 1 wt.% and MnO over 0.5 wt.% was found in the preceding hopeful area, it should be a place possessing a large possibility where ore vein is present within an area about ten meters from the place.

10. Conclusions

The present study on wall rock alteration related to polymetallic vein-type deposits with special reference to the Toyoha mine has yielded the following results.

(1) Wall rock alteration around the Toyoha deposits was divided into six zones, A, B, C, D, E and F, from outer side of the vein based on the characteristic alteration minerals and their assemblage as well as the distribution and mode of occurrence. Zone A was subdivided into subfacies A-1, A-2 and A-3. Alteration zone A is widely distributed and shows zonal distribution of subfacies A-1, A-2 and A-3 in descending order.

Alteration zones B, C, D and E are locally distributed around ore veins. Alteration zone F is recognized at the downstream of the Yunosawa river.

(2) Formation process of alteration zones in and around the Toyoha mine was considered as follows. Zone A has been principally formed through a process of burial diagenesis. During the process, it has been also subjected to a geothermal activity derived from a concealed hot dry rock-body. In addition, zone A was considered to be affected by hydrothermal solutions related to the formation of the Toyoha deposits and zone F. Zone B is a transitional zone from subfacies A-3 to zone C. Zones C, D and E are alteration associated with ore veins which distribute exclusively nearby ore veins. Zone F was regarded as a product of acidic solutions related to geothermal activity. It was revealed from the above considerations that alteration in the studied area was formed by intricate duplication of the composite alterations of various origins such as diagenetic process, geothermal activity (high geothermal gradient), and lively activities of hydrothermal solutions caused ore deposition and acidic solutions.

(3) Formation temperatures of alteration zones estimated from the alteration mineral assemblage are as follows. Those of subfacies A-1, A-2 and A-3 are below 200°C, 200 to 220°C and above 220°C, respectively. Those of zone B 220 to 300°C, of zone C about 300°C, of zone E 150 to 250°C. Temperature of zone D is lower than those of zones B, C and E. Temperature of zone F is 100 to 200°C. Judging from the alteration mineral assemblage, zones B, C and D were considered to have been

formed by neutral hydrothermal solutions and zones E and F by weakly acidic to acidic ones.

(4) Three kinds of chlorite could be discriminated from Fe value ((Fe+Mn)/(Fe+Mn)+Mg) of chlorites. The value concentrates forming three groups; these are (0.3 to 0.4), (0.4 to 0.6) and (nearly 0.9). Fe value of chlorite in subfacies A-3 has a limited range of nearly 0.35. Fe value of chlorite in zone B varies ranging from 0.4 to 0.6. Fe value of chlorite in zone C is roughly divided into two groups; (a) 0.4 to 0.6 equivalent to that in zone B and (b) about 0.9 which is unrecognized in zones A and B. It was inferred that the former (a) and the latter (b) have been mainly formed in zone B and zone C, respectively, by hydrothermal alteration related to the formation of ore veins. Accordingly, chlorite in zone C is composed of mixture of Mg-Fe chlorite (Fe value 0.4 to 0.6) formed in zone B and Fe one (Fe value = 0.9) formed in zone C, respectively.

(5) Mineral assemblage in each alteration zone generally well reflects the chemical composition of altered rocks concerned. While, variation of composition of FeO*, MnO and MgO is related to both alteration mineral assemblage and chemistry of chlorite. Although CaO and Na_2O are unvaried in unaltered rock and zone A, they conspicuously decrease toward vein, especially in zones B, C, D and E around ore vein. Based on the CaO+Na_2O content, alteration grade can be chemically divided into three groups; 1) unaltered rocks and zone A (7.34 to 12.85), 2) zone B (2.05 to 4.76) and 3) zones C, D, E and F (0.08 to 1.33).

(6) Fe values of chlorite and FeO* contents of altered rocks from the alteration halo in the Toyoha, Akenobe, Ikuno and Ashio mines were compared, and it was disclosed that Fe value of chlorite and FeO* content of altered rocks increase toward the ore veins in any case. Such a trend of Fe value of chlorite is one of the most characteristic features in the alteration halo related to the formation of polymetallic ore deposits in Japan.

(7) K-Ar ages from 2.93 to 0.49 Ma were obtained from sericites in hydrothermal alteration zones, in clay veins, and of gangue mineral, and the Toyoha deposits are inferred to have been formed in the periods from Pliocene to Pleistocene. The Toyoha deposits are roughly believed to have been formed through two-stage mineralizations. However, it has been disclosed from K-Ar dating that hydrothermal solutions ascended many times repeatedly during the whole stage of mineralization.

(8) From mode of occurrence of alteration halo in the Toyoha mine and chemistry of altered rocks and minerals concerned, the present author concluded that an area having the same alteration mineral assemblage as represented by zone B, under 5 wt.% $CaO+Na_2O$, over 2 wt.% K_2O and over 0.5 wt.% MnO is hopeful target to prospect new ore veins. Furthermore, if the place having the same alteration mineral assemblage as presented in zone C, under 1 wt.% $CaO+Na_2O$ and over 0.5 wt.% MnO were found within the preceding hopeful area, it should be a place possessing a large possibility where ore vein is present within an area about ten meters from the place.

(9) From field geological survey and fission track age

determination from some acidic tuffs, it was concluded that Motoyama Formation , and Nagato and Oshidorizawa Formations are correlated to Miocene Kunnui and Yakumo Formations of the standard stratigraphy of southwestern Hokkaido of Neogene Tertiary System. Sanbonmata and Oheyama Formations are correlated to Pliocene Kuromatsunai Formation respectively, and the strata of latest Miocene to early Pliocene are considered to be absent in the Toyoha mining area.

Acknowledgments: The author wishes to express sincere gratitude to Professor Shunzo Yui, Prof. Yu Hariya, Prof. Juichi Sato and Assistant Prof. Hiroharu Matsueda of Hokkaido University for their guidances and encouragements throughout the course of this study, as well as for careful review of the manuscript. Many thanks are due to Professor Takeo Bamba for valuable suggestions and discussions from early stage of this study and critical reading of the primary manuscript. The author is also deeply grateful to Dr. Junkichi Yajima of the Geological Survey of Japan for his invaluable comments. He is also indebted to Professor Yujiro Nishimura and Assistant Professor Takashi Nagao for their discussions and supports in experimental work. The author is very grateful to many geologists of the Toyoha mine for their generous cooperation during the field work. This study could not have been accomplished without their supports.

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The languages used in each paper are indicated as follows. **:written in Japanese. *:written in Japanese with English abstract. The papers without such indications are written in English.

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Appendixes

Appendix 1 Electron microprobe analyses of chlorite

Appendix 2 Electron microprobe analyses of clinopyroxene

Appendix 3 Electron microprobe analyses of sericite

Appendix 4 Electron microprobe analyses of feldspar

Appendix 5 Chemical compositions of andesitic rocks from the alteration zones around the Toyoha deposits

Appendix 6 Electron microprobe analyses of chlorite in altered rocks from the Akenobe mine

Appendix 1 Electron microprobe analyses of chlorite

Tajima vein

Sample Locality Alt. zone	15Sy08(N.and) -150mL B							15Sy13(N.and) -150mL C			15Sy14(N.and) -150mL C							
SiO_2	27.67	27.95	27.69	27.51	26.66	27.64	27.87	25.98	20.91	23.41	27.33	21.75	27.72	22.21	26.62	27.17	26.35	25.11
TiO_2	0.03	0.03	0.05	0.06	0.05	0.06	0.02	0.03	0.07	0.07	0.04	0.06	0.02	0.09	0.06	0.05	0.06	0.02
Al_2O_3	18.72	18.31	18.47	18.57	19.79	18.62	17.21	21.26	21.76	22.06	18.78	21.94	17.97	21.04	18.01	19.09	20.08	20.43
FeO*	25.99	26.30	25.37	25.13	25.18	24.65	25.39	25.32	38.56	37.18	26.84	39.33	26.76	41.14	27.57	27.38	27.81	27.40
MnO	1.36	2.10	3.61	4.35	3.09	3.30	2.34	2.94	3.22	3.75	2.72	1.65	2.26	2.32	2.90	2.77	2.70	4.93
MgO	14.10	13.23	13.31	12.72	12.70	12.63	13.36	10.76	1.35	1.54	11.50	0.76	12.07	0.72	11.79	11.41	10.76	9.31
CaO	0.11	0.04	0.08	0.14	0.04	0.04	0.06	0.04	0.04	0.02	0.04	0.06	0.04	0.04	0.04	0.04	0.11	0.11
Na_2O	0.02	0.01	0.02	0.00	0.01	0.02	0.01	0.03	0.01	0.04	0.02	0.03	0.02	0.03	0.02	0.01	0.02	0.02
K_2O	0.02	0.02	0.01	0.03	0.04	0.04	0.03	0.04	0.05	0.02	0.04	0.02	0.01	0.04	0.03	0.04	0.03	0.03
Total	88.52	88.49	88.61	89.01	87.26	87.50	87.29	86.90	85.97	88.09	87.91	85.50	86.37	88.13	87.04	87.96	87.92	87.36
O=14																		
Si	2.913	2.950	2.929	2.913	2.861	2.955	2.988	2.804	2.492	2.674	2.985	2.582	2.997	2.599	2.906	2.917	2.837	2.757
Al^{IV}	1.087	1.050	1.071	1.087	1.139	1.045	1.012	1.196	1.508	1.326	1.015	1.418	1.003	1.401	1.094	1.083	1.163	1.243
Al^{VI}	1.235	1.287	1.232	1.231	1.324	1.299	1.162	1.506	1.548	1.643	1.348	1.653	1.284	1.498	1.221	1.330	1.384	1.400
Ti	0.002	0.002	0.003	0.004	0.004	0.005	0.001	0.002	0.006	0.005	0.003	0.005	0.002	0.008	0.005	0.004	0.004	0.001
Fe	2.288	2.318	2.244	2.225	2.257	2.201	2.276	2.327	3.843	3.551	2.396	3.906	2.416	4.021	2.514	2.455	2.504	2.515
Mn	0.165	0.187	0.323	0.434	0.281	0.344	0.258	0.268	0.324	0.363	0.246	0.165	0.207	0.279	0.268	0.252	0.246	0.458
Mg	2.213	2.078	2.099	2.007	2.029	2.010	2.214	1.728	0.240	0.262	1.829	0.133	1.942	0.125	1.916	1.823	1.725	1.524
Ca	0.012	0.005	0.008	0.015	0.005	0.005	0.006	0.005	0.004	0.002	0.005	0.006	0.005	0.005	0.005	0.005	0.012	0.012
Na	0.003	0.002	0.003	0.000	0.002	0.004	0.001	0.006	0.002	0.009	0.004	0.006	0.004	0.007	0.004	0.002	0.005	0.005
K	0.002	0.003	0.001	0.004	0.005	0.005	0.004	0.006	0.007	0.003	0.005	0.002	0.001	0.006	0.004	0.005	0.004	0.003
Total	9.920	9.882	9.913	9.920	9.907	9.873	9.922	9.848	9.974	9.838	9.836	9.876	9.861	9.949	9.937	9.876	9.885	9.918
Fe value	0.53	0.55	0.55	0.57	0.56	0.56	0.53	0.60	0.95	0.94	0.59	0.97	0.57	0.97	0.59	0.60	0.61	0.66

FeO* = total iron as FeO, K.:Koyanagizawa Formation, M.:Motoyama Formation, N.:Nagato Formation, D.:Dike rocks,
rhy:rhyolite, and:andesite, ban:basaltic andesite, bas:basalt, ms:mudstone, ss:sandstone, cg:conglomerate.

Appendix 1 Continued

Tajima vein

Sample	T-7(M.cg)											35Tj01(K.rny)				
Locality	-300mL											-350mL				
Alt. zone	C											C				
SiO_2	23.05	24.05	23.82	25.47	24.08	23.66	23.33	25.89	23.94	26.24	23.45	25.78	25.10	23.81	23.54	24.22
TiO_2	0.07	0.00	0.00	0.00	0.03	0.04	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.08	0.03	0.03
Al_2O_3	20.27	20.83	20.81	20.32	20.47	20.19	20.51	19.99	21.21	20.74	21.34	21.64	21.35	20.50	21.83	21.35
FeO*	38.45	33.01	35.86	31.72	37.42	35.43	38.26	31.07	33.89	30.85	39.20	27.32	29.30	38.67	37.52	37.45
MnO	3.62	4.71	4.04	4.07	4.70	4.22	3.44	4.62	4.01	4.24	3.25	3.03	4.80	4.00	3.39	2.51
MgO	2.25	4.77	3.36	6.87	2.39	4.01	2.19	5.55	4.09	6.90	1.47	11.60	7.89	2.57	1.61	1.20
CaO	0.07	0.07	0.06	0.07	0.05	0.07	0.07	0.09	0.08	0.13	0.08	0.05	0.09	0.05	0.09	0.05
Na_2O	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.02	0.03	0.03	0.02
K_2O	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.03	0.04	0.03	0.04	0.04
Total	87.80	87.46	87.97	88.55	89.17	87.65	87.90	87.25	87.25	89.13	88.81	89.45	88.63	89.74	88.08	86.87
O=14																
Si	2.673	2.721	2.713	2.804	2.732	2.707	2.692.	2.889	2.717	2.848	2.681	2.722	2.737	2.698	2.692	2.791
Al^{IV}	1.327	1.279	1.287	1.196	1.268	1.293	1.308	1.111	1.283	1.152	1.319	1.278	1.263	1.302	1.308	1.209
Al^{VI}	1.443	1.498	1.506	1.440	1.472	1.429	1.481	1.518	1.554	1.501	1.556	1.415	1.478	1.433	1.631	1.688
Ti	0.006	0.000	0.000	0.000	0.002	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.003	0.007	0.003	0.003
Fe	3.728	3.124	3.415	2.919	3.552	3.390	3.693	2.900	3.217	2.799	3.748	2.412	2.669	3.660	3.583	3.605
Mn	0.355	0.451	0.389	0.379	0.451	0.408	0.336	0.437	0.385	0.390	0.314	0.270	0.443	0.383	0.328	0.245
Mg	0.389	0.805	0.570	1.127	0.404	0.684	0.376	0.923	0.692	1.115	0.249	1.825	1.281	0.433	0.274	0.206
Ca	0.008	0.008	0.007	0.008	0.006	0.008	0.008	0.010	0.009	0.014	0.009	0.005	0.011	0.006	0.011	0.006
Na	0.000	0.001	0.001	0.001	0.003	0.001	0.003	0.001	0.002	0.005	0.000	0.000	0.004	0.007	0.007	0.004
K	0.003	0.001	0.002	0.003	0.003	0.003	0.002	0.004	0.003	0.001	0.002	0.004	0.006	0.004	0.006	0.006
Total	9.932	9.888	9.890	9.877	9.893	9.926	9.904	9.793	9.862	9.825	9.878	9.931	9.895	9.933	9.843	9.763
Fe value	0.91	0.82	0.87	0.75	0.91	0.85	0.92	0.78	0.84	0.74	0.94	0.60	0.71	0.90	0.94	0.95

FeO* = total iron as FeO

Appendix 1 Continued

Tajima vein

Sample	30Tj18(K.rhy)				40Tj15			
Locality	-350mL				-400mL			
Alt. zone	C				Gangue			
SiO_2	25.82	25.77	23.17	22.79	23.84	23.22	23.60	22.37
TiO_2	0.04	0.04	0.03	0.10	0.00	0.01	0.00	0.00
Al_2O_3	23.12	22.17	21.11	20.85	19.46	19.76	19.03	20.13
FeO*	19.91	21.59	34.66	34.23	38.42	38.69	39.16	40.85
MnO	7.03	5.79	8.49	8.74	3.57	4.48	2.70	2.44
MgO	10.19	10.57	2.18	2.41	1.86	2.67	3.32	1.16
CaO	0.04	0.02	0.09	0.09	0.03	0.04	0.04	0.05
Na_2O	0.01	0.02	0.00	0.02	0.02	0.01	0.05	0.02
K_2O	0.04	0.02	0.04	0.05	0.04	0.04	0.04	0.03
Total	86.20	85.99	89.77	89.28	87.24	88.92	87.94	87.05
O=14								
Si	2.773	2.787	2.634	2.610	2.781	2.675	2.734	2.648
Al^{IV}	1.227	1.213	1.366	1.390	1.219	1.325	1.266	1.352
Al^{VI}	1.697	1.609	1.459	1.420	1.454	1.356	1.329	1.453
Ti	0.003	0.003	0.003	0.009	0.000	0.001	0.000	0.000
Fe	1.786	1.950	3.291	3.274	3.744	3.723	3.789	4.038
Mn	0.639	0.530	0.816	0.847	0.352	0.437	0.265	0.244
Mg	1.629	1.701	0.369	0.411	0.323	0.458	0.572	0.204
Ca	0.005	0.002	0.011	0.011	0.004	0.005	0.005	0.006
Na	0.002	0.004	0.000	0.004	0.005	0.002	0.011	0.005
K	0.005	0.003	0.006	0.007	0.006	0.006	0.006	0.005
Total	9.766	9.802	9.955	9.983	9.888	9.988	9.977	9.955
Fe value	0.60	0.59	0.92	0.91	0.93	0.90	0.88	0.96

FeO* = total iron as FeO

Appendix 1 Continued

Soya vein

Sample	15Sy04(N.and)						15Sy05(N.and)					52907(N.and)				
Locality	-150mL						-150mL					-250mL				
Alt. zone	B						B					B				
SiO_2	28.72	28.71	27.38	28.06	28.01	28.49	26.94	26.40	27.86	27.37	27.32	27.74	27.57	27.54	27.12	27.62
TiO_2	0.06	0.06	0.08	0.05	0.04	0.08	0.04	0.04	0.07	0.06	0.10	0.00	0.00	0.00	0.00	0.00
Al_2O_3	17.54	18.07	19.65	19.42	18.91	18.25	19.09	19.92	19.47	19.48	19.45	17.64	18.71	15.74	17.28	16.75
FeO*	23.33	23.59	23.26	24.53	23.85	23.86	24.05	25.14	24.38	24.68	24.35	26.87	25.99	26.90	26.00	26.20
MnO	1.49	1.47	1.61	2.32	2.07	1.90	4.32	5.86	4.13	4.60	4.73	1.26	0.99	1.47	1.23	1.30
MgO	15.87	16.24	15.82	14.29	14.72	15.21	12.32	11.52	13.05	12.61	11.93	14.29	15.08	13.98	14.49	14.64
CaO	0.04	0.04	0.04	0.04	0.04	0.04	0.09	0.04	0.06	0.05	0.04	0.12	0.09	0.12	0.11	0.11
Na_2O	0.00	0.01	0.02	0.02	0.01	0.02	0.02	0.00	0.01	0.02	0.01	0.00	0.00	0.01	0.02	0.03
K_2O	0.01	0.01	0.04	0.04	0.03	0.02	0.03	0.02	0.02	0.03	0.04	0.04	0.02	0.03	0.04	0.06
Total	87.06	88.20	87.90	88.77	87.68	87.87	87.40	88.94	89.05	88.90	87.97	87.96	88.45	85.79	86.29	86.71
O=14																
Si	3.025	2.986	2.861	2.925	2.946	2.986	2.885	2.815	2.917	2.888	2.913	2.949	2.894	3.020	2.935	2.977
Al^{IV}	0.975	1.014	1.139	1.075	1.054	1.014	1.115	1.185	1.083	1.112	1.087	1.051	1.106	0.980	1.065	1.023
Al^{VI}	1.200	1.199	1.278	1.309	1.287	1.238	1.294	1.318	1.320	1.310	1.354	1.159	1.208	1.054	1.139	1.105
Ti	0.005	0.005	0.006	0.004	0.003	0.006	0.002	0.002	0.005	0.004	0.008	0.000	0.000	0.000	0.000	0.000
Fe	2.052	2.049	2.030	2.136	2.095	2.089	2.154	2.241	2.135	2.177	2.168	2.389	2.281	2.467	2.353	2.361
Mn	0.133	0.129	0.142	0.205	0.184	0.168	0.392	0.529	0.366	0.410	0.427	0.113	0.088	0.136	0.112	0.118
Mg	2.488	2.514	2.460	2.217	2.304	2.373	2.047	1.830	2.037	1.982	1.893	2.264	2.358	2.285	2.337	2.352
Ca	0.005	0.004	0.004	0.004	0.005	0.004	0.010	0.004	0.006	0.005	0.005	0.013	0.010	0.014	0.012	0.012
Na	0.000	0.002	0.004	0.004	0.002	0.004	0.004	0.000	0.002	0.003	0.002	0.000	0.000	0.001	0.003	0.006
K	0.001	0.001	0.005	0.005	0.004	0.003	0.003	0.002	0.002	0.003	0.005	0.005	0.002	0.004	0.006	0.008
Total	9.884	9.903	9.929	9.884	9.884	9.885	9.906	9.926	9.873	9.894	9.862	9.943	9.947	9.961	9.962	9.962
Fe value	0.47	0.46	0.47	0.51	0.50	0.49	0.55	0.60	0.55	0.57	0.58	0.53	0.50	0.53	0.51	0.51

FeO* = total iron as FeO

Appendix 1 Continued

Soya vein

Sample Locality Alt. zone	15Sy01(N.and) -150mL C				15Sy03(N.and) -150mL C					52902(N.and) -250mL C							
SiO_2	22.96	22.80	22.84	23.61	24.77	25.09	23.05	23.57	22.21	28.06	27.26	26.98	27.14	26.20	26.64	22.21	22.40
TiO_2	0.08	0.08	0.00	0.05	0.07	0.04	0.00	0.00	0.05	0.03	0.00	0.08	0.04	0.00	0.00	0.05	0.00
Al_2O_3	20.79	21.91	19.79	20.28	20.72	21.16	21.51	20.37	20.38	17.54	18.01	17.84	19.18	18.88	17.54	20.38	20.22
FeO*	36.42	35.82	37.88	36.26	29.28	29.65	37.57	38.02	39.38	26.74	27.44	26.78	26.58	26.87	28.07	38.38	42.50
MnO	3.95	2.58	3.34	5.92	3.85	3.99	2.60	3.36	3.09	1.05	1.11	1.07	1.09	1.11	1.33	3.09	2.47
MgO	1.32	1.56	1.13	1.48	6.75	6.79	1.43	1.33	1.43	14.41	13.63	13.89	13.93	13.30	13.06	1.43	1.21
CaO	0.04	0.02	0.04	0.04	0.04	0.11	0.03	0.09	0.04	0.05	0.09	0.07	0.08	0.07	0.05	0.04	0.05
Na_2O	0.01	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.02
K_2O	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.03	0.03
Total	85.61	84.83	85.56	87.69	85.53	86.88	86.24	86.77	86.61	87.93	87.56	86.73	88.07	86.46	86.71	85.61	88.90
O=14																	
Si	2.711	2.682	2.724	2.739	2.795	2.788	2.692	2.754	2.631	2.976	2.920	2.912	2.872	2.843	2.906	2.650	2.612
Al^{IV}	1.289	1.318	1.276	1.261	1.205	1.212	1.308	1.246	1.369	1.024	1.080	1.088	1.128	1.157	1.094	1.350	1.388
Al^{VI}	1.602	1.721	1.506	1.509	1.548	1.556	1.650	1.557	1.473	1.168	1.194	1.181	1.264	1.255	1.159	1.512	1.389
Ti	0.007	0.006	0.000	0.004	0.006	0.003	0.000	0.000	0.004	0.002	0.000	0.006	0.003	0.000	0.000	0.004	0.000
Fe	3.592	3.525	3.778	3.513	2.759	2.751	3.665	3.711	3.896	2.371	2.458	2.417	2.352	2.435	2.558	3.824	4.143
Mn	0.395	0.257	0.387	0.581	0.367	0.375	0.257	0.332	0.310	0.094	0.100	0.098	0.097	0.102	0.123	0.312	0.244
Mg	0.232	0.274	0.200	0.256	1.134	1.123	0.249	0.231	0.252	2.278	2.176	2.234	2.197	2.148	2.120	0.254	0.210
Ca	0.005	0.001	0.005	0.005	0.005	0.013	0.004	0.011	0.005	0.005	0.009	0.008	0.008	0.008	0.006	0.005	0.006
Na	0.002	0.004	0.000	0.002	0.002	0.002	0.002	0.000	0.000	0.003	0.000	0.000	0.000	0.002	0.002	0.000	0.004
K	0.006	0.005	0.005	0.006	0.006	0.006	0.006	0.004	0.005	0.004	0.003	0.002	0.004	0.003	0.001	0.005	0.003
Total	9.841	9.793	9.881	9.876	9.827	9.829	9.833	9.846	9.945	9.925	9.940	9.946	9.925	9.953	9.969	9.916	9.999
Fe value	0.95	0.93	0.95	0.94	0.73	0.74	0.94	0.95	0.94	0.52	0.54	0.53	0.53	0.54	0.56	0.94	0.95

FeO* = total iron as FeO

Appendix 1 Continued

Soya vein

Sample	60301(D.and)				35Sy01					
Locality	-300mL				-350mL					
Alt. zone	C				Gangue					
SiO_2	25.99	27.85	26.08	26.46	21.70	23.14	23.33	23.76	22.64	23.92
TiO_2	0.01	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Al_2O_3	18.36	19.12	19.59	18.84	21.90	21.62	21.09	22.31	20.43	20.58
FeO*	25.86	24.89	24.90	25.03	40.88	40.14	39.86	40.48	39.86	40.02
MnO	3.31	3.26	4.71	5.17	1.97	1.07	1.44	2.27	2.26	2.56
MgO	11.55	11.51	11.69	10.68	0.49	0.63	0.64	0.72	0.86	0.82
CaO	0.07	0.05	0.07	0.05	0.11	0.07	0.08	0.14	0.10	0.11
Na_2O	0.01	0.02	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.02
K_2O	0.05	0.04	0.04	0.02	0.03	0.03	0.02	0.03	0.02	0.03
Total	85.21	86.78	87.10	86.28	87.10	86.72	86.48	89.73	86.19	88.07
O=14										
Si	2.883	2.992	2.829	2.906	2.556	2.698	2.731	2.682	2.685	2.762
Al^{IV}	1.117	1.008	1.171	1.094	1.444	1.302	1.269	1.318	1.315	1.238
Al^{VI}	1.283	1.411	1.331	1.343	1.596	1.670	1.641	1.651	1.539	1.562
Ti	0.001	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe	2.398	2.234	2.256	2.296	4.025	3.915	3.902	3.822	3.952	3.864
Mn	0.311	0.296	0.432	0.480	0.196	0.105	0.143	0.217	0.226	0.249
Mg	1.909	1.841	1.887	1.746	0.085	0.109	0.111	0.120	0.151	0.141
Ca	0.008	0.006	0.008	0.006	0.014	0.008	0.010	0.016	0.012	0.013
Na	0.002	0.004	0.002	0.006	0.004	0.003	0.005	0.003	0.003	0.003
K	0.007	0.005	0.006	0.003	0.004	0.004	0.002	0.004	0.003	0.004
Total	9.919	9.800	9.923	9.880	9.924	9.814	9.814	9.833	9.886	9.836
Fe value	0.59	0.58	0.59	0.61	0.98	0.97	0.97	0.97	0.97	0.97

FeO* = total iron as FeO

Appendix 1 Continued

Izumo vein

Sample	71417(N.and)				Sam.4(K.ban)					70705(K.ban)		70714(K.ban)		
Locality	-250mL				-300mL					-300mL		-300mL		
Alt. zone	B				B					B		B		
SiO_2	26.49	28.49	28.61	26.37	27.39	26.40	29.03	28.46	27.59	28.53	27.41	27.36	27.79	27.63
TiO_2	0.09	0.04	0.05	0.06	0.03	0.04	0.14	0.03	0.06	0.04	0.04	0.06	0.04	0.01
Al_2O_3	20.40	21.19	20.46	19.90	17.58	18.57	18.78	19.03	19.56	18.74	18.90	20.02	18.60	19.03
FeO*	19.37	19.00	18.20	20.15	21.93	24.47	20.77	22.54	21.23	20.12	19.64	19.51	17.60	17.79
MnO	7.49	6.09	6.56	6.62	1.39	1.21	1.31	1.84	1.65	3.91	4.60	5.20	5.64	6.14
MgO	12.87	12.78	13.53	13.57	16.96	14.82	17.74	15.99	16.60	15.69	15.49	15.92	15.90	14.93
CaO	0.04	0.09	0.08	0.11	0.10	0.04	0.04	0.04	0.04	0.11	0.04	0.10	0.10	0.11
Na_2O	0.00	0.01	0.01	0.00	0.02	0.07	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01
K_2O	0.02	0.04	0.04	0.04	0.04	0.03	0.05	0.02	0.04	0.04	0.04	0.02	0.05	0.05
Total	86.77	87.73	87.54	86.82	85.44	85.65	87.88	87.97	86.78	87.19	86.16	88.20	85.73	85.70
O=14														
Si	2.834	2.963	2.979	2.824	2.933	2.860	2.980	2.955	2.888	2.985	2.914	2.842	2.950	2.943
Al^{IV}	1.166	1.037	1.021	1.176	1.067	1.140	1.020	1.045	1.112	1.015	1.086	1.158	1.050	1.057
Al^{VI}	1.403	1.557	1.488	1.333	1.149	1.230	1.250	1.282	1.299	1.293	1.280	1.292	1.277	1.332
Ti	0.007	0.003	0.004	0.005	0.002	0.003	0.011	0.002	0.005	0.003	0.003	0.004	0.003	0.000
Fe	1.731	1.650	1.583	1.802	1.961	2.198	1.781	1.955	1.856	1.758	1.744	1.694	1.562	1.584
Mn	0.678	0.536	0.578	0.600	0.126	0.111	0.114	0.162	0.146	0.346	0.414	0.457	0.507	0.554
Mg	2.049	1.978	2.097	2.163	2.703	2.393	2.710	2.471	2.587	2.443	2.451	2.464	2.516	2.370
Ca	0.005	0.010	0.009	0.013	0.011	0.004	0.004	0.004	0.004	0.012	0.005	0.011	0.011	0.012
Na	0.000	0.002	0.002	0.000	0.004	0.014	0.004	0.004	0.002	0.002	0.000	0.002	0.002	0.002
K	0.003	0.005	0.005	0.005	0.005	0.004	0.005	0.003	0.005	0.005	0.005	0.002	0.006	0.006
Total	9.876	9.741	9.766	9.921	9.961	9.957	9.879	9.883	9.904	9.862	9.902	9.926	9.884	9.860
Fe value	0.54	0.53	0.51	0.53	0.44	0.49	0.41	0.46	0.44	0.46	0.47	0.47	0.45	0.47

FeO* = total iron as FeO

Appendix 1 Continued

Izumo vein

Sample	71117(K.ban)		71402(N.and)				71405(N.and)				71422(N.and)		70704(K.ban)			
Locality	-250mL		-250mL				-250mL				-250mL		-300mL			
Alt. zone	C		C				C				C		C			
SiO_2	26.81	23.62	24.63	22.59	23.96	23.11	28.34	28.46	28.01	27.44	26.86	23.68	26.84	22.91	25.44	26.39
TiO_2	0.09	0.04	0.06	0.07	0.07	0.08	0.04	0.03	0.05	0.05	0.05	0.03	0.06	0.08	0.03	0.04
Al_2O_3	20.65	21.40	20.67	20.73	21.32	22.23	20.16	19.29	20.11	19.69	20.78	22.49	20.88	22.38	20.81	21.17
FeO*	21.22	36.19	29.89	33.30	35.59	35.06	24.41	24.28	24.23	23.90	23.09	35.55	25.30	38.28	30.16	22.67
MnO	3.51	2.66	9.26	6.87	2.33	4.12	2.94	2.84	1.80	2.81	1.86	4.17	2.55	2.75	3.10	1.93
MgO	13.42	1.19	5.37	3.67	1.64	2.40	13.46	13.87	14.43	13.06	13.38	1.38	12.71	1.63	7.48	14.93
CaO	0.07	0.08	0.02	0.02	0.04	0.02	0.08	0.04	0.05	0.12	0.06	0.03	0.14	0.05	0.12	0.09
Na_2O	0.01	0.00	0.01	0.01	0.01	0.00	0.03	0.01	0.00	0.01	0.00	0.01	0.01	0.02	0.02	0.02
K_2O	0.04	0.02	0.02	0.01	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.14	0.04
Total	85.82	85.20	89.93	87.27	85.00	87.06	89.50	88.86	88.72	87.12	86.12	87.37	88.52	88.14	87.30	87.28
O=14																
Si	2.863	2.769	2.719	2.611	2.798	2.652	2.931	2.964	2.901	2.918	2.863	2.707	2.822	2.621	2.805	2.775
Al^{IV}	1.137	1.231	1.281	1.389	1.202	1.348	1.069	1.036	1.099	1.082	1.137	1.293	1.178	1.379	1.195	1.225
Al^{VI}	1.462	1.722	1.409	1.435	1.729	1.656	1.385	1.329	1.355	1.383	1.470	1.734	1.409	1.638	1.509	1.395
Ti	0.007	0.004	0.004	0.006	0.006	0.007	0.003	0.002	0.003	0.004	0.004	0.003	0.004	0.006	0.002	0.003
Fe	1.895	3.543	2.760	3.219	3.471	3.361	2.108	2.112	2.098	2.122	2.055	3.395	2.224	3.662	2.781	1.991
Mn	0.317	0.264	0.866	0.672	0.230	0.400	0.257	0.250	0.157	0.253	0.168	0.403	0.227	0.266	0.289	0.172
Mg	2.136	0.208	0.883	0.632	0.285	0.410	2.071	2.150	2.243	2.067	2.122	0.235	1.992	0.277	1.229	2.336
Ca	0.008	0.010	0.002	0.002	0.005	0.002	0.009	0.004	0.005	0.014	0.007	0.004	0.015	0.006	0.014	0.001
Na	0.002	0.000	0.002	0.002	0.002	0.000	0.006	0.002	0.000	0.002	0.000	0.002	0.002	0.004	0.004	0.004
K	0.005	0.003	0.002	0.001	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.005	0.019	0.005
Total	9.832	9.754	9.928	9.969	9.734	9.842	9.844	9.854	9.866	9.850	9.831	9.780	9.877	9.864	9.847	9.907
Fe value	0.51	0.95	0.80	0.86	0.93	0.90	0.53	0.52	0.50	0.54	0.51	0.94	0.55	0.93	0.71	0.48

FeO* = total iron as FeO

Appendix 1 Continued

Izumo vein

Sample Locality Alt. zone	30Iz02(M.ms) -300mL C		30Iz04(K.ban) -300mL C					71407 -250mL Gangue				
SiO_2	25.06	26.56	23.79	23.54	23.39	23.09	23.15	23.53	22.36	22.63	22.89	23.59
TiO_2	0.03	0.03	0.01	0.00	0.04	0.01	0.05	0.04	0.04	0.00	0.00	0.00
Al_2O_3	19.25	21.16	20.04	19.80	21.24	21.09	21.52	18.99	19.10	19.02	19.13	19.29
FeO*	28.54	25.76	31.46	28.47	33.16	34.20	34.08	41.19	42.00	42.62	41.60	41.89
MnO	1.53	1.85	6.94	7.98	5.81	5.82	5.05	1.35	1.82	1.63	1.64	1.45
MgO	10.99	10.85	4.77	5.90	4.01	3.63	3.53	0.42	0.30	0.28	0.52	0.26
CaO	0.02	0.03	0.07	0.00	0.04	0.05	0.04	0.02	0.05	0.05	0.09	0.03
Na_2O	0.02	0.03	0.01	0.00	0.01	0.01	0.03	0.01	0.02	0.00	0.03	0.01
K_2O	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.02	0.03	0.02	0.02
Total	85.48	86.31	87.13	85.73	87.74	87.93	87.49	85.58	85.71	86.26	85.92	86.54
O=14												
Si	2.791	2.864	2.720	2.715	2.662	2.641	2.646	2.817	2.704	2.721	2.746	2.799
Al^{IV}	1.209	1.136	1.280	1.285	1.338	1.359	1.354	1.183	1.296	1.279	1.254	1.201
Al^{VI}	1.315	1.550	1.420	1.404	1.508	1.481	1.543	1.495	1.427	1.417	1.451	1.496
Ti	0.003	0.002	0.001	0.000	0.003	0.001	0.004	0.003	0.003	0.000	0.000	0.000
Fe	2.655	2.320	3.008	2.743	3.152	3.267	3.254	4.123	4.248	4.286	4.172	4.157
Mn	0.144	0.169	0.672	0.779	0.559	0.563	0.488	0.136	0.186	0.166	0.166	0.146
Mg	1.822	1.741	0.812	1.013	0.679	0.618	0.601	0.074	0.053	0.050	0.093	0.045
Ca	0.002	0.003	0.008	0.000	0.005	0.006	0.005	0.002	0.006	0.006	0.011	0.004
Na	0.004	0.006	0.002	0.000	0.002	0.002	0.007	0.001	0.004	0.000	0.006	0.001
K	0.006	0.005	0.005	0.006	0.006	0.004	0.006	0.004	0.002	0.004	0.002	0.002
Total	9.951	9.796	9.928	9.945	9.914	9.942	9.908	9.838	9.929	9.929	9.901	9.851
Fe value	0.61	0.59	0.82	0.78	0.85	0.86	0.86	0.98	0.99	0.99	0.98	0.99

FeO* = total iron as FeO

Appendix 1 Continued

Sorachi vein

Sample Locality Alt. zone	20NS14(M.cg) -200mL B						20NS17(M.ss) -200mL B			20NS16(M.ms) -200mL C					
SiO_2	27.13	26.44	26.35	27.46	27.01	26.60	26.17	26.41	28.34	22.82	22.76	23.30	22.82	22.73	26.73
TiO_2	0.03	0.03	0.07	0.03	0.01	0.09	0.05	0.09	0.00	0.06	0.00	0.04	0.04	0.02	0.03
Al_2O_3	18.19	19.92	18.74	18.03	20.07	19.99	19.12	19.16	18.95	19.68	19.53	18.41	20.00	19.34	19.50
FeO*	21.79	21.88	23.56	21.53	20.47	20.37	20.36	21.54	20.53	38.70	39.98	39.86	39.05	39.43	25.06
MnO	4.37	4.40	3.85	4.78	3.32	3.93	4.66	4.24	1.99	2.81	2.76	2.34	2.73	2.69	4.63
MgO	15.90	14.65	14.23	15.90	14.60	14.26	14.76	15.61	16.24	1.52	1.26	1.26	1.43	1.38	9.52
CaO	0.05	0.05	0.03	0.04	0.04	0.07	0.04	0.04	0.04	0.04	0.07	0.01	0.05	0.04	0.07
Na_2O	0.03	0.01	0.00	0.03	0.02	0.02	0.02	0.03	0.07	0.02	0.02	0.03	0.02	0.05	0.04
K_2O	0.02	0.03	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.03	0.02	0.04	0.03	0.05	0.04
Total	87.51	87.41	86.86	87.84	85.58	85.37	85.22	87.15	86.20	85.68	86.40	85.29	86.17	85.73	85.62
O=14															
Si	2.876	2.805	2.836	2.899	2.882	2.858	2.836	2.808	2.977	2.718	2.707	2.761	2.704	2.719	2.944
Al^{IV}	1.124	1.195	1.164	1.101	1.118	1.142	1.164	1.192	1.023	1.282	1.293	1.239	1.296	1.281	1.056
Al^{VI}	1.146	1.292	1.211	1.141	1.404	1.386	1.276	1.206	1.320	1.478	1.441	1.469	1.493	1.443	1.473
Ti	0.002	0.002	0.006	0.002	0.001	0.007	0.004	0.007	0.000	0.005	0.000	0.004	0.004	0.002	0.002
Fe	1.929	1.938	2.118	1.899	1.824	1.828	1.843	1.913	1.801	3.850	3.971	3.945	3.864	3.940	2.305
Mn	0.392	0.395	0.351	0.427	0.300	0.357	0.427	0.381	0.177	0.283	0.278	0.235	0.274	0.272	0.431
Mg	2.508	2.313	2.280	2.499	2.319	2.280	2.381	2.470	2.539	0.269	0.223	0.222	0.252	0.246	1.561
Ca	0.006	0.006	0.003	0.005	0.005	0.008	0.005	0.005	0.004	0.005	0.009	0.001	0.006	0.005	0.008
Na	0.006	0.002	0.000	0.006	0.004	0.004	0.004	0.006	0.014	0.005	0.005	0.007	0.005	0.012	0.009
K	0.003	0.004	0.004	0.005	0.005	0.005	0.006	0.004	0.005	0.005	0.003	0.006	0.005	0.008	0.006
Total	9.992	9.952	9.973	9.984	9.862	9.875	9.946	9.992	9.860	9.900	9.930	9.889	9.903	9.928	9.795
Fe value	0.48	0.50	0.52	0.48	0.48	0.49	0.49	0.48	0.44	0.94	0.95	0.95	0.94	0.95	0.64

FeO* = total iron as FeO

Sorachi vein

Sample	30NS10(M.cg)					30Sr07(M.ms)				30Sr08(K.rhy)		35Sr08(D.and)			
Locality	-300mL					-300mL				-300mL		-350mL			
Alt. zone	C					C				C		C			
SiO_2	26.58	21.53	22.03	28.09	26.05	26.83	26.53	26.98	26.35	23.49	25.30	27.39	27.52	27.39	27.07
TiO_2	0.02	0.00	0.00	0.04	0.04	0.12	0.06	0.06	0.06	0.05	0.09	0.07	0.04	0.03	0.04
Al_2O_3	21.19	21.04	20.48	17.08	21.18	20.69	21.41	21.50	21.62	21.74	24.58	22.16	21.47	18.99	19.65
FeO*	23.90	35.42	36.83	24.48	25.37	26.76	28.17	26.45	26.28	32.36	29.15	23.46	22.72	23.48	23.86
MnO	5.05	6.24	3.89	2.95	2.86	2.97	2.73	3.69	2.01	5.06	4.45	4.96	2.74	3.13	3.67
MgO	10.02	1.74	1.37	13.87	11.58	10.90	8.72	8.95	9.77	4.55	3.58	10.68	12.42	14.14	13.67
CaO	0.04	0.08	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.08	0.07	0.07	0.08	0.10
Na_2O	0.01	0.01	0.01	0.01	0.03	0.00	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.02	0.00
K_2O	0.04	0.06	0.06	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.05
Total	86.85	86.12	84.71	86.60	87.19	88.35	87.73	87.72	86.19	87.36	88.40	88.84	87.03	87.31	88.11
O=14															
Si	2.866	2.556	2.647	3.024	2.795	2.856	2.860	2.892	2.854	2.657	2.335	2.866	2.899	2.911	2.860
Al^{IV}	1.134	1.444	1.353	0.976	1.205	1.144	1.140	1.108	1.146	1.343	1.165	1.134	1.101	1.089	1.140
Al^{VI}	1.556	1.500	1.547	1.188	1.470	1.448	1.577	1.604	1.611	1.556	1.955	1.595	1.562	1.276	1.307
Ti	0.002	0.000	0.000	0.003	0.003	0.010	0.005	0.005	0.005	0.003	0.007	0.006	0.003	0.002	0.003
Fe	2.152	3.517	3.701	2.201	2.273	2.379	2.536	2.368	2.377	3.061	2.624	2.050	1.999	2.086	2.107
Mn	0.461	0.627	0.396	0.269	0.260	0.267	0.249	0.335	0.184	0.486	0.406	0.439	0.244	0.281	0.328
Mg	1.608	0.308	0.246	2.222	1.849	1.727	1.399	1.428	1.575	0.767	0.590	1.663	1.947	2.240	2.151
Ca	0.005	0.010	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.007	0.009	0.008	0.008	0.009	0.011
Na	0.002	0.001	0.001	0.002	0.006	0.000	0.006	0.002	0.002	0.002	0.006	0.002	0.002	0.004	0.000
K	0.005	0.008	0.008	0.005	0.005	0.005	0.005	0.005	0.006	0.005	0.005	0.005	0.005	0.007	0.006
Total	9.791	9.971	9.904	9.895	9.871	9.841	9.782	9.752	9.766	9.887	9.502	9.768	9.770	9.905	9.913
Fe value	0.62	0.93	0.94	0.53	0.58	0.61	0.67	0.65	0.62	0.82	0.84	0.60	0.54	0.51	0.53

FeO* = total iron as FeO

Appendix 1 Continued

Sorachi vein

Sample Locality Alt. zone	35Sr11(D.and) -350mL C								40Sr05(D.and) -400mL C		
SiO_2	22.43	27.37	22.69	26.42	26.70	26.64	25.66	27.11	21.68	22.86	24.85
TiO_2	0.00	0.00	0.04	0.05	0.03	0.00	0.00	0.03	0.00	0.01	0.08
Al_2O_3	21.44	19.34	20.58	21.01	20.91	21.14	20.54	21.39	21.93	22.28	20.62
FeO*	36.22	23.90	36.28	24.31	27.13	24.25	24.80	24.33	36.00	29.78	27.24
MnO	4.79	4.67	5.01	5.36	1.98	5.41	5.69	5.17	2.82	3.84	5.04
MgO	1.91	12.52	1.97	11.01	10.13	10.89	11.25	11.17	2.94	7.41	10.06
CaO	0.04	0.06	0.04	0.07	0.04	0.05	0.06	0.07	0.04	0.09	0.06
Na_2O	0.02	0.01	0.01	0.04	0.04	0.03	0.01	0.04	0.00	0.02	0.03
K_2O	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.06	0.02
Total	86.90	87.92	86.66	88.31	87.00	88.45	88.05	89.35	85.46	86.35	88.00
O=14											
Si	2.618	2.911	2.662	2.815	2.878	2.831	2.764	2.843	2.551	2.571	2.708
Al^{IV}	1.382	1.089	1.338	1.185	1.122	1.169	1.236	1.157	1.449	1.429	1.292
Al^{VI}	1.563	1.334	1.505	1.451	1.531	1.475	1.369	1.484	1.589	1.524	1.357
Ti	0.000	0.000	0.004	0.004	0.002	0.000	0.000	0.002	0.000	0.001	0.006
Fe	3.530	2.125	3.555	2.164	2.442	2.152	2.231	2.131	3.538	2.800	2.483
Mn	0.473	0.420	0.497	0.483	0.181	0.486	0.518	0.459	0.281	0.365	0.465
Mg	0.332	1.984	0.344	1.746	1.625	1.722	1.804	1.743	0.515	1.242	1.635
Ca	0.005	0.007	0.005	0.008	0.005	0.006	0.007	0.008	0.005	0.010	0.007
Na	0.005	0.001	0.002	0.008	0.008	0.006	0.002	0.008	0.000	0.004	0.005
K	0.007	0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.007	0.007	0.002
Total	9.915	9.877	9.918	9.869	9.799	9.852	9.936	9.840	9.935	9.953	9.960
Fe value	0.92	0.56	0.92	0.60	0.62	0.61	0.60	0.60	0.88	0.72	0.64

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.70

Sample Locality Alt. zone	70-24(D.bas) -500m A-3				70-55(K.ban) -839m A-3				70-40(K.ban) -705m B				70-47(K.ban) -740m B				
SiO_2	29.94	30.05	29.32	29.23	27.69	29.34	29.19	29.46	26.43	26.71	26.39	26.41	27.00	27.62	26.48	26.35	26.91
TiO_2	0.04	0.01	0.00	0.00	0.02	0.03	0.01	0.08	0.04	0.05	0.03	0.03	0.01	0.02	0.01	0.00	0.00
Al_2O_3	17.81	18.01	16.36	17.54	20.72	19.35	20.82	22.87	19.87	20.03	20.20	20.20	19.33	19.36	19.30	19.77	18.85
FeO*	19.25	18.50	18.33	18.06	17.46	16.60	17.19	17.12	22.36	23.09	22.73	23.56	26.71	26.80	26.33	26.55	26.61
MnO	1.21	1.56	1.21	1.46	1.21	1.21	1.19	1.46	8.19	8.13	6.79	7.12	2.79	2.63	2.84	2.96	2.58
MgO	20.08	20.66	20.04	20.88	17.65	19.23	19.03	17.92	10.36	10.48	10.59	10.48	12.10	12.72	12.44	12.49	12.31
CaO	0.12	0.16	0.11	0.16	0.12	0.16	0.13	0.14	0.13	0.11	0.12	0.15	0.12	0.09	0.07	0.10	0.10
Na_2O	0.04	0.04	0.05	0.05	0.06	0.16	0.09	0.03	0.04	0.02	0.02	0.03	0.00	0.01	0.02	0.07	0.01
K_2O	0.02	0.01	0.01	0.01	0.11	0.05	0.06	0.04	0.04	0.03	0.04	0.04	0.02	0.02	0.03	0.04	0.03
Total	88.51	89.00	86.43	87.39	85.04	86.63	87.71	89.12	87.46	88.65	87.41	88.02	88.08	89.27	87.52	88.33	87.40
O=14																	
Si	3.025	3.012	3.037	2.986	2.887	2.984	2.935	2.908	2.863	2.859	2.892	2.843	2.886	2.905	2.850	2.814	2.899
Al^{IV}	0.975	0.988	0.963	1.014	1.113	1.016	1.065	1.092	1.137	1.141	1.108	1.157	1.114	1.095	1.150	1.186	1.101
Al^{VI}	1.144	1.138	1.093	1.095	1.434	1.361	1.402	1.566	1.397	1.384	1.450	1.403	1.319	1.302	1.295	1.300	1.289
Ti	0.003	0.001	0.000	0.000	0.001	0.002	0.001	0.006	0.003	0.004	0.002	0.002	0.001	0.002	0.001	0.000	0.000
Fe	1.625	1.549	1.629	1.541	1.524	1.410	1.447	1.411	2.023	2.064	2.042	2.118	2.385	2.354	2.367	2.368	2.394
Mn	0.104	0.132	0.106	0.127	0.107	0.104	0.102	0.122	0.751	0.736	0.618	0.648	0.252	0.234	0.259	0.268	0.235
Mg	3.020	3.082	3.089	3.175	2.745	2.911	2.854	2.633	1.670	1.670	1.695	1.679	1.925	1.991	1.993	1.986	1.973
Ca	0.013	0.017	0.013	0.018	0.013	0.017	0.014	0.015	0.015	0.013	0.014	0.017	0.014	0.010	0.008	0.011	0.012
Na	0.008	0.008	0.009	0.010	0.012	0.032	0.017	0.006	0.008	0.004	0.004	0.006	0.000	0.002	0.004	0.015	0.002
K	0.002	0.002	0.001	0.001	0.015	0.006	0.007	0.005	0.006	0.004	0.005	0.005	0.003	0.003	0.004	0.005	0.004
Total	9.919	9.929	9.940	9.967	9.851	9.843	9.844	9.764	9.873	9.879	9.830	9.878	9.899	9.898	9.931	9.953	9.909
Fe value	0.36	0.35	0.36	0.34	0.37	0.34	0.35	0.37	0.62	0.63	0.61	0.62	0.58	0.57	0.57	0.57	0.57

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.70

Sample Locality Alt. zone	70-31(K.ban) -560m C									70-42(K.ban) -717m C						
SiO_2	23.57	23.88	23.87	23.46	23.10	25.29	23.18	22.92	22.80	24.47	24.53	23.80	24.52	24.42	24.23	23.14
TiO_2	0.03	0.04	0.03	0.05	0.03	0.03	0.02	0.00	0.04	0.04	0.03	0.01	0.01	0.00	0.02	0.02
Al_2O_3	21.10	21.48	22.97	23.34	23.13	22.55	21.53	23.11	21.31	21.16	22.04	20.84	21.13	21.21	21.33	21.86
FeO*	34.24	31.24	35.64	35.00	34.92	30.83	37.25	36.99	39.25	36.46	32.30	35.60	37.79	40.57	40.13	40.79
MnO	3.80	3.24	2.73	2.72	2.68	2.61	2.33	2.62	2.53	2.64	3.83	2.79	2.28	1.68	1.62	1.52
MgO	5.20	7.40	3.88	3.83	3.95	6.99	3.18	3.08	2.14	4.36	6.33	5.30	3.77	1.64	2.36	1.82
CaO	0.13	0.16	0.08	0.08	0.07	0.12	0.15	0.07	0.08	0.05	0.06	0.09	0.06	0.05	0.05	0.06
Na_2O	0.01	0.01	0.03	0.02	0.02	0.03	0.00	0.03	0.03	0.00	0.01	0.03	0.00	0.00	0.00	0.01
K_2O	0.02	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.04	0.01	0.01	0.04	0.03	0.05	0.01
Total	88.10	87.46	89.23	88.50	87.91	88.47	87.65	88.83	88.18	89.22	89.14	88.47	89.60	89.60	89.79	89.23
O=14																
Si	2.658	2.658	2.646	2.616	2.598	2.746	2.652	2.578	2.627	2.727	2.689	2.676	2.734	2.755	2.722	2.633
Al^{IV}	1.342	1.342	1.354	1.384	1.402	1.254	1.348	1.422	1.373	1.273	1.311	1.324	1.266	1.245	1.278	1.367
Al^{VI}	1.459	1.472	1.643	1.680	1.660	1.627	1.551	1.639	1.517	1.503	1.532	1.434	1.508	1.571	1.542	1.561
Ti	0.002	0.004	0.002	0.004	0.002	0.002	0.002	0.000	0.003	0.003	0.002	0.001	0.001	0.000	0.002	0.002
Fe	3.225	2.904	3.299	3.259	3.280	2.795	3.559	3.475	3.777	3.394	2.957	3.343	3.519	3.822	3.765	3.876
Mn	0.363	0.305	0.256	0.257	0.255	0.239	0.225	0.249	0.247	0.249	0.355	0.265	0.215	0.160	0.154	0.146
Mg	0.873	1.226	0.640	0.636	0.661	1.130	0.541	0.515	0.367	0.723	1.032	0.887	0.626	0.275	0.395	0.308
Ca	0.016	0.019	0.010	0.010	0.008	0.014	0.018	0.009	0.010	0.006	0.007	0.011	0.007	0.006	0.006	0.007
Na	0.002	0.002	0.007	0.005	0.005	0.006	0.000	0.007	0.007	0.000	0.002	0.007	0.000	0.000	0.000	0.002
K	0.002	0.002	0.001	0.000	0.001	0.002	0.001	0.002	0.000	0.006	0.002	0.001	0.006	0.004	0.007	0.001
Total	9.942	9.934	9.858	9.851	9.872	9.815	9.897	9.896	9.928	9.884	9.889	9.949	9.882	9.838	9.871	9.903
Fe value	0.80	0.72	0.85	0.85	0.84	0.73	0.88	0.88	0.92	0.83	0.76	0.80	0.86	0.94	0.91	0.93

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.70

Sample Locality Alt. zone	70-44(K.ban) -725m C							70-50(K.ban) -760m C									
SiO_2	24.07	24.31	24.10	23.84	24.36	23.21	23.57	25.84	25.72	23.63	22.91	22.23	22.50	25.88	25.79	26.34	25.78
TiO_2	0.06	0.06	0.06	0.04	0.03	0.02	0.03	0.01	0.01	0.03	0.04	0.04	0.04	0.01	0.02	0.01	0.01
Al_2O_3	20.99	19.86	20.22	20.73	20.32	20.05	20.86	17.95	18.78	20.92	20.75	22.25	20.95	19.14	17.89	18.90	19.47
FeO*	39.76	39.57	39.52	40.19	38.90	38.54	38.63	32.23	31.51	38.09	38.97	41.64	37.93	32.23	31.25	32.16	32.04
MnO	1.93	2.10	2.15	2.02	2.01	2.78	2.78	1.68	1.58	2.68	3.19	1.27	3.50	1.59	1.65	1.66	1.78
MgO	1.86	2.23	2.04	2.07	1.79	2.04	2.00	8.79	8.99	1.66	1.40	0.34	1.73	8.60	9.10	8.91	7.94
CaO	0.04	0.03	0.04	0.03	0.05	0.03	0.04	0.05	0.04	0.06	0.03	0.01	0.04	0.06	0.04	0.06	0.06
Na_2O	0.00	0.00	0.02	0.01	0.01	0.03	0.01	0.02	0.00	0.02	0.00	0.00	0.00	0.03	0.02	0.00	0.01
K_2O	0.03	0.02	0.03	0.03	0.04	0.00	0.01	0.06	0.04	0.06	0.02	0.02	0.02	0.04	0.04	0.04	0.04
Total	88.74	88.18	88.18	88.96	87.51	86.70	87.93	86.63	86.67	87.15	87.31	87.80	86.71	87.58	85.30	88.08	87.13
O=14																	
Si	2.740	2.790	2.767	2.719	2.805	2.719	2.712	2.896	2.864	2.735	2.675	2.590	2.640	2.858	2.904	2.888	2.861
Al^{IV}	1.260	1.210	1.233	1.281	1.195	1.281	1.288	1.104	1.136	1.265	1.325	1.410	1.360	1.142	1.096	1.112	1.139
Al^{VI}	1.554	1.474	1.500	1.502	1.559	1.485	1.538	1.264	1.326	1.588	1.528	1.641	1.533	1.347	1.276	1.328	1.405
Ti	0.005	0.005	0.005	0.003	0.003	0.002	0.003	0.001	0.001	0.002	0.004	0.003	0.004	0.001	0.002	0.001	0.001
Fe	3.781	3.793	3.789	3.828	3.741	3.771	3.712	3.017	2.931	3.683	3.800	4.051	3.717	2.973	2.939	2.945	2.970
Mn	0.186	0.204	0.209	0.195	0.196	0.276	0.271	0.159	0.149	0.263	0.315	0.125	0.347	0.148	0.157	0.154	0.167
Mg	0.315	0.381	0.349	0.351	0.307	0.356	0.342	1.466	1.491	0.287	0.242	0.058	0.302	1.414	1.525	1.453	1.312
Ca	0.005	0.004	0.005	0.004	0.006	0.004	0.005	0.006	0.004	0.007	0.003	0.001	0.005	0.008	0.005	0.007	0.007
Na	0.000	0.000	0.004	0.002	0.002	0.007	0.002	0.004	0.000	0.003	0.000	0.000	0.000	0.006	0.004	0.000	0.003
K	0.004	0.003	0.004	0.004	0.006	0.000	0.001	0.009	0.006	0.009	0.003	0.004	0.002	0.005	0.006	0.006	0.006
Total	9.850	9.864	9.865	9.889	9.820	9.901	9.874	9.926	9.908	9.842	9.895	9.883	9.910	9.902	9.914	9.894	9.871
Fe value	0.93	0.91	0.92	0.92	0.93	0.92	0.92	0.68	0.68	0.93	0.95	0.99	0.93	0.69	0.67	0.68	0.71

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.70

Sample Locality Alt. zone			70-45 -728m Gangue		
SiO_2	21.13	22.24	22.13	21.21	22.52
TiO_2	0.02	0.00	0.02	0.00	0.01
Al_2O_3	23.84	23.67	22.75	22.90	22.62
FeO*	38.87	39.15	39.94	39.55	38.17
MnO	2.23	2.15	2.02	2.50	2.09
MgO	0.90	1.03	0.97	1.10	0.99
CaO	0.06	0.07	0.12	0.06	0.10
Na_2O	0.00	0.02	0.01	0.03	0.03
K_2O	0.00	0.00	0.01	0.02	0.02
Total	87.05	88.33	87.97	87.37	86.55
O=14					
Si	2.462	2.544	2.558	2.480	2.622
Al^{IV}	1.538	1.456	1.442	1.520	1.378
Al^{VI}	1.733	1.730	1.654	1.631	1.722
Ti	0.002	0.000	0.001	0.000	0.001
Fe	3.783	3.739	3.856	3.862	3.711
Mn	0.220	0.208	0.197	0.247	0.206
Mg	0.156	0.175	0.168	0.191	0.171
Ca	0.007	0.008	0.014	0.008	0.012
Na	0.000	0.004	0.003	0.008	0.007
K	0.000	0.000	0.002	0.003	0.003
Total	9.901	9.864	9.895	9.950	9.833
Fe value	0.96	0.96	0.96	0.96	0.96

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.74

Sample	74-48(K.ban)				74-55(K.ban)						74-121(K.and)					
Locality	-480m				-550m						-1000m					
Alt. zone	A-3				A-3						B					
SiO_2	29.10	28.81	29.17	28.56	29.12	28.72	28.25	29.27	29.79	30.26	26.43	26.63	26.94	27.05	26.84	26.78
TiO_2	0.00	0.05	0.03	0.00	0.00	0.05	0.04	0.05	0.01	0.00	0.01	0.04	0.05	0.04	0.03	0.02
Al_2O_3	17.44	16.86	17.38	17.14	17.90	17.68	17.92	17.62	17.90	18.20	22.96	22.55	22.98	22.06	22.30	22.35
FeO*	18.55	18.56	18.13	18.43	17.32	17.32	16.93	17.22	17.09	17.38	24.23	24.54	24.41	24.83	23.10	22.71
MnO	0.40	0.44	0.42	0.43	0.74	0.74	0.73	0.68	0.74	0.75	0.68	0.77	0.74	0.94	0.72	0.86
MgO	20.67	20.36	20.28	20.54	22.05	21.55	21.48	21.49	21.64	22.11	12.60	12.19	12.65	11.68	12.29	12.39
CaO	0.10	0.15	0.18	0.17	0.28	0.24	0.24	0.29	0.25	0.30	0.08	0.11	0.09	0.08	0.11	0.10
Na_2O	0.00	0.01	0.01	0.01	0.02	0.04	0.03	0.03	0.02	0.04	0.03	0.04	0.04	0.04	0.06	0.01
K_2O	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.01	0.03	0.02	0.07	0.04	0.04	0.05	0.03	0.04
Total	86.26	85.24	85.60	85.28	87.46	86.37	85.65	86.66	87.47	89.06	87.09	86.91	87.94	86.77	85.48	85.26
O=14																
Si	2.999	3.012	3.023	2.983	2.950	2.949	2.922	2.988	3.006	3.000	2.776	2.811	2.803	2.865	2.858	2.855
Al^{IV}	1.001	0.988	0.977	1.017	1.050	1.051	1.078	1.012	0.994	1.000	1.224	1.189	1.197	1.135	1.142	1.145
Al^{VI}	1.118	1.088	1.146	1.093	1.086	1.088	1.106	1.108	1.135	1.127	1.619	1.614	1.619	1.615	1.653	1.660
Ti	0.000	0.004	0.002	0.000	0.000	0.004	0.003	0.004	0.001	0.000	0.001	0.003	0.004	0.003	0.002	0.002
Fe	1.600	1.623	1.572	1.612	1.467	1.487	1.464	1.469	1.442	1.440	2.130	2.164	2.121	2.196	2.054	2.022
Mn	0.035	0.039	0.037	0.038	0.063	0.063	0.063	0.059	0.063	0.063	0.061	0.069	0.065	0.084	0.065	0.078
Mg	3.177	3.173	3.135	3.199	3.329	3.299	3.312	3.269	3.254	3.267	1.973	1.915	1.959	1.841	1.947	1.966
Ca	0.011	0.017	0.020	0.018	0.030	0.025	0.026	0.031	0.027	0.032	0.009	0.012	0.010	0.009	0.013	0.011
Na	0.000	0.002	0.002	0.002	0.003	0.007	0.006	0.006	0.004	0.007	0.006	0.008	0.008	0.008	0.012	0.002
K	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.001	0.003	0.002	0.009	0.005	0.005	0.007	0.004	0.005
Total	9.941	9.946	9.914	9.962	9.981	9.976	9.983	9.947	9.929	9.938	9.808	9.790	9.791	9.763	9.750	9.746
Fe value	0.34	0.34	0.34	0.34	0.32	0.32	0.32	0.32	0.32	0.32	0.54	0.54	0.53	0.55	0.52	0.52

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.74

Sample	74-128(K.and)			74-92(K.ban)											
Locality															
Alt. zone	B			C											
SiO_2	27.56	26.88	26.81	24.22	24.88	24.77	24.53	23.37	23.48	24.85	24.51	26.25	25.55	25.93	26.46
TiO_2	0.03	0.01	0.05	0.05	0.04	0.06	0.04	0.06	0.04	0.04	0.03	0.04	0.04	0.05	0.02
Al_2O_3	21.91	22.35	21.78	18.98	19.26	21.33	19.84	19.10	20.69	17.87	18.66	21.97	22.85	22.73	23.74
FeO*	24.65	23.30	26.02	39.56	41.88	31.88	41.62	40.51	42.01	40.63	39.52	27.21	26.56	26.06	23.95
MnO	0.15	0.15	0.22	3.00	3.02	4.53	2.71	4.61	1.87	2.72	3.65	1.85	2.14	1.82	0.81
MgO	13.24	13.70	11.53	1.06	0.49	4.13	0.54	0.91	0.45	0.79	1.11	9.87	8.70	9.00	11.65
CaO	0.09	0.10	0.10	0.10	0.11	0.12	0.11	0.11	0.03	0.09	0.08	0.07	0.09	0.08	0.07
Na_2O	0.01	0.04	0.03	0.00	0.01	0.02	0.00	0.02	0.01	0.01	0.00	0.00	0.02	0.02	0.03
K_2O	0.03	0.04	0.05	0.01	0.03	0.03	0.02	0.02	0.02	0.01	0.03	0.04	0.03	0.04	0.04
Total	87.67	86.57	86.59	86.98	89.72	86.87	89.41	88.71	88.60	87.01	87.59	87.30	85.98	85.73	86.77
O=14															
Si	2.871	2.821	2.856	2.843	2.849	2.795	2.811	2.731	2.717	2.928	2.863	2.817	2.782	2.316	2.785
Al^{IV}	1.129	1.179	1.144	1.157	1.151	1.205	1.189	1.269	1.283	1.072	1.137	1.183	1.218	1.184	1.215
Al^{VI}	1.558	1.583	1.588	1.465	1.447	1.628	1.488	1.359	1.537	1.406	1.429	1.594	1.711	1.723	1.726
Ti	0.002	0.001	0.004	0.004	0.003	0.005	0.004	0.005	0.004	0.003	0.002	0.003	0.003	0.004	0.002
Fe	2.144	2.042	2.315	3.878	4.006	3.005	3.984	3.954	4.061	3.998	3.854	2.439	2.415	2.364	2.105
Mn	0.013	0.013	0.020	0.297	0.292	0.432	0.263	0.455	0.183	0.271	0.360	0.168	0.197	0.167	0.072
Mg	2.053	2.140	1.828	0.184	0.084	0.694	0.092	0.159	0.078	0.138	0.193	1.577	1.410	1.455	1.825
Ca	0.010	0.011	0.011	0.013	0.013	0.015	0.014	0.014	0.004	0.012	0.010	0.008	0.010	0.009	0.008
Na	0.002	0.008	0.006	0.000	0.002	0.004	0.000	0.005	0.003	0.002	0.000	0.000	0.004	0.004	0.006
K	0.004	0.005	0.007	0.001	0.004	0.004	0.003	0.003	0.003	0.001	0.004	0.005	0.004	0.006	0.005
Total	9.786	9.803	9.779	9.842	9.851	9.787	9.848	9.954	9.873	9.831	9.852	9.794	9.754	9.732	9.749
Fe value	0.51	0.49	0.56	0.96	0.98	0.83	0.98	0.97	0.98	0.97	0.96	0.62	0.65	0.64	0.54

FeO* = total iron as FeO

Appendix 1 Continued

Drill hole No.74

Sample Locality Alt. zone	74-104(K.ban) -911m C										74-106(K.ban) -925m C		74-109(K.ban) -940m C				
SiO_2	24.82	24.96	25.16	24.64	24.87	24.79	26.46	26.73	26.05	26.79	25.06	25.33	27.17	27.56	27.19	27.71	27.33
TiO_2	0.01	0.00	0.01	0.00	0.00	0.00	0.02	0.02	0.03	0.01	0.00	0.02	0.04	0.03	0.03	0.01	0.03
Al_2O_3	18.05	16.75	17.80	18.57	18.97	17.92	23.74	23.16	23.12	21.58	16.31	16.19	20.82	20.85	21.01	20.88	21.23
FeO*	41.51	43.07	42.90	41.79	42.40	43.05	23.95	25.53	26.33	25.27	41.59	42.06	25.77	26.16	25.87	25.07	25.44
MnO	1.80	1.82	1.65	1.75	1.67	1.71	0.81	0.80	0.61	0.88	2.88	2.95	1.97	2.13	1.96	1.91	1.69
MgO	0.74	0.39	0.59	0.69	0.58	0.46	11.65	11.47	11.49	12.74	1.09	1.27	12.26	11.52	10.73	12.47	12.62
CaO	0.08	0.06	0.07	0.07	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.05	0.14	0.18	0.08	0.16	0.17
Na_2O	0.03	0.02	0.01	0.02	0.03	0.01	0.03	0.00	0.05	0.05	0.01	0.02	0.01	0.01	0.01	0.00	0.00
K_2O	0.02	0.01	0.05	0.03	0.02	0.02	0.04	0.03	0.03	0.04	0.04	0.01	0.05	0.05	0.05	0.04	0.01
Total	87.06	87.08	88.24	87.56	88.60	88.02	86.77	87.80	87.78	87.43	87.04	87.90	88.23	88.49	86.93	88.25	88.52
O=14																	
Si	2.921	2.969	2.936	2.884	2.877	2.907	2.785	2.802	2.748	2.827	2.978	2.938	2.865	2.901	2.908	2.903	2.859
Al^{IV}	1.079	1.031	1.064	1.116	1.123	1.093	1.215	1.198	1.252	1.173	1.022	1.062	1.135	1.099	1.092	1.097	1.141
Al^{VI}	1.422	1.315	1.381	1.444	1.460	1.381	1.726	1.661	1.619	1.508	1.260	1.228	1.449	1.484	1.554	1.479	1.473
Ti	0.001	0.000	0.001	0.000	0.000	0.000	0.002	0.002	0.002	0.001	0.000	0.002	0.003	0.002	0.002	0.001	0.002
Fe	4.080	4.279	4.181	4.086	4.096	4.216	2.105	2.235	2.320	2.227	4.128	4.137	2.269	2.300	2.311	2.194	2.223
Mn	0.179	0.183	0.163	0.173	0.163	0.170	0.072	0.071	0.054	0.079	0.289	0.294	0.175	0.190	0.177	0.169	0.149
Mg	0.130	0.069	0.102	0.120	0.100	0.080	1.825	1.790	1.804	2.001	0.193	0.223	1.923	1.805	1.708	1.945	1.965
Ca	0.010	0.008	0.009	0.009	0.007	0.008	0.008	0.007	0.008	0.008	0.008	0.006	0.015	0.020	0.009	0.018	0.019
Na	0.007	0.005	0.002	0.005	0.007	0.002	0.006	0.000	0.010	0.010	0.002	0.005	0.003	0.002	0.002	0.000	0.000
K	0.003	0.002	0.007	0.004	0.003	0.003	0.005	0.004	0.004	0.005	0.006	0.002	0.007	0.007	0.007	0.005	0.001
Total	9.832	9.861	9.846	9.841	9.836	9.860	9.749	9.770	9.821	9.839	9.886	9.897	9.844	9.810	9.770	9.811	9.832
Fe value	0.97	0.99	0.98	0.97	0.98	0.98	0.54	0.56	0.57	0.54	0.96	0.95	0.56	0.58	0.59	0.55	0.55

FeO* = total iron as FeO

Appendix 2 Electron microprobe analyses of clinopyroxene

Sample Locality Alt. zone	70-18(K.and) Drill hole No.70, -364m A-2					74-60(K.ban) Drill hole No.74, -600m A-2						74-55(K.ban) Drill hole No.74, -550m A-3			
SiO_2	53.04	52.23	52.99	52.99	52.90	51.87	52.10	51.50	51.75	52.56	52.37	50.88	50.70	51.88	51.85
TiO_2	0.19	0.19	0.19	0.19	0.20	0.39	0.48	0.47	0.49	0.30	0.45	0.64	0.57	0.55	0.39
Al_2O_3	0.93	0.83	0.86	0.90	0.92	2.49	2.99	3.09	2.63	2.00	2.88	2.44	2.39	1.69	1.33
FeO*	8.65	8.54	8.32	8.75	8.57	7.29	7.77	7.50	8.51	6.47	8.12	9.94	10.09	9.70	10.31
MnO	0.44	0.45	0.38	0.43	0.34	0.22	0.21	0.20	0.26	0.18	0.23	0.29	0.30	0.40	0.34
MgO	14.49	14.26	14.69	14.34	14.53	16.78	16.56	16.37	15.85	17.47	15.96	15.18	14.86	15.49	14.72
CaO	22.23	22.06	22.16	21.89	22.41	19.88	20.22	20.04	20.06	19.68	20.30	20.21	20.42	20.00	20.96
Na_2O	0.32	0.31	0.31	0.27	0.30	0.23	0.25	0.27	0.30	0.22	0.26	0.35	0.34	0.34	0.31
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.01	0.02
Total	100.29	98.87	99.90	99.76	100.17	99.15	100.58	99.44	99.85	98.88	100.57	99.96	99.69	100.06	100.23
O=6															
Si	1.972	1.972	1.975	1.979	1.970	1.926	1.912	1.910	1.921	1.946	1.924	1.905	1.906	1.934	1.941
Al^{IV}	0.028	0.028	0.025	0.021	0.030	0.074	0.088	0.090	0.079	0.054	0.076	0.095	0.094	0.066	0.058
Al^{VI}	0.013	0.009	0.012	0.019	0.010	0.035	0.041	0.046	0.036	0.034	0.049	0.012	0.011	0.008	0.000
Ti	0.005	0.005	0.005	0.005	0.006	0.011	0.013	0.013	0.014	0.008	0.012	0.018	0.016	0.015	0.011
Fe	0.269	0.270	0.260	0.273	0.267	0.226	0.239	0.233	0.264	0.201	0.250	0.311	0.317	0.302	0.322
Mn	0.014	0.014	0.012	0.013	0.011	0.007	0.006	0.006	0.008	0.006	0.007	0.009	0.009	0.012	0.010
Mg	0.804	0.803	0.816	0.799	0.807	0.930	0.906	0.906	0.877	0.965	0.875	0.847	0.832	0.861	0.821
Ca	0.885	0.892	0.885	0.876	0.894	0.791	0.795	0.796	0.798	0.781	0.799	0.810	0.822	0.799	0.840
Na	0.023	0.023	0.022	0.019	0.022	0.016	0.018	0.019	0.022	0.016	0.018	0.025	0.024	0.024	0.022
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Total	4.013	4.016	4.012	4.004	4.017	4.016	4.018	4.019	4.019	4.011	4.010	4.033	4.031	4.021	4.025
$CaSiO_3$	45.21	45.42	45.12	44.97	45.43	40.62	40.98	41.15	41.13	40.11	41.55	41.16	41.71	40.72	42.36
$MgSiO_3$	41.04	40.85	41.63	41.00	41.00	47.75	46.71	46.81	45.24	49.58	45.47	43.04	42.21	43.88	41.40
$FeSiO_3$	13.75	13.74	13.24	14.04	13.57	11.63	12.30	12.04	13.63	10.31	12.99	15.80	16.08	15.40	16.24
Fe value	0.26	0.26	0.25	0.26	0.26	0.20	0.21	0.21	0.24	0.18	0.23	0.27	0.28	0.27	0.29

FeO* = total iron as FeO, K.:Koyanagizawa Formation, and:andesite, bas:basaltic andesite.

Appendix 3 Electron microprobe analyses of sericite

Sample	15Sy11	15Sy04	15Sy06		71103		70714	74-31	15Sy13		15Sy14	35Tj18	15Sy01	15Sy03	52902	60304
Locality	Tj.v. -150mL	Sy.v. -150mL	Sy.v. -150mL		Iz.v. -250mL		Iz.v. -300mL	No.74 -305m	Tj.v. -150mL		Tj.v. -150mL	Tj.v. -350mL	Sy.v. -150mL	Sy.v. -150mL	Sy.v. -250mL	Sy.v. -300mL
Alt. zone	B	B	B		B		B	B	C		C	C	C	C	C	C
SiO_2	50.39	50.32	50.48	49.99	51.64	52.08	51.93	51.35	50.92	50.37	50.79	50.26	49.12	49.00	51.48	49.30
TiO_2	0.11	0.09	0.04	0.06	0.17	0.17	0.08	0.03	0.11	0.05	0.06	0.14	0.07	0.12	0.15	0.07
Al_2O_3	31.45	30.38	32.56	32.11	31.04	30.21	31.54	33.31	29.09	33.74	32.92	31.08	31.94	31.79	29.78	31.47
FeO*	2.80	3.05	2.31	2.17	1.93	2.10	2.16	0.74	3.21	1.50	2.06	1.88	3.02	2.38	2.36	2.51
MnO	0.26	0.06	0.09	0.39	0.09	0.17	0.66	0.03	0.17	0.04	0.04	0.09	0.34	0.03	0.11	0.18
MgO	0.99	1.15	0.65	1.21	1.31	1.93	2.16	1.50	2.01	1.12	0.35	1.61	1.59	0.96	1.06	1.31
CaO	0.05	0.13	0.07	0.11	0.18	0.24	0.14	0.38	0.10	0.05	0.06	0.13	0.14	0.04	0.04	0.08
Na_2O	0.07	0.07	0.10	0.06	0.07	0.07	0.05	0.23	0.02	0.05	0.08	0.07	0.05	0.09	0.04	0.07
K_2O	9.09	9.50	9.37	9.74	8.33	8.60	6.30	7.52	9.00	8.99	9.08	10.06	8.70	9.30	9.66	9.37
Total	95.21	95.25	95.67	95.84	95.76	95.57	95.52	95.09	94.63	95.91	95.94	95.32	94.97	94.21	95.18	95.36
O=11																
Si	3.330	3.368	3.312	3.291	3.369	3.403	3.364	3.325	3.394	3.275	3.311	3.325	3.261	3.282	3.410	3.302
Al^{IV}	0.670	0.632	0.688	0.709	0.631	0.597	0.636	0.675	0.606	0.725	0.689	0.675	0.739	0.718	0.590	0.698
Al^{VI}	1.778	1.738	1.828	1.779	1.753	1.727	1.770	1.865	1.676	1.858	1.837	1.746	1.758	1.789	1.732	1.758
Ti	0.005	0.004	0.002	0.003	0.008	0.008	0.004	0.001	0.006	0.002	0.003	0.007	0.003	0.006	0.007	0.003
Fe	0.155	0.169	0.127	0.119	0.105	0.115	0.117	0.040	0.179	0.081	0.112	0.104	0.167	0.161	0.158	0.139
Mn	0.015	0.003	0.005	0.022	0.005	0.009	0.036	0.002	0.010	0.002	0.002	0.005	0.019	0.002	0.006	0.010
Mg	0.097	0.113	0.063	0.119	0.176	0.188	0.208	0.145	0.199	0.108	0.082	0.159	0.157	0.096	0.104	0.129
Ca	0.004	0.009	0.005	0.008	0.013	0.017	0.010	0.026	0.007	0.003	0.004	0.009	0.010	0.003	0.003	0.006
Na	0.009	0.009	0.013	0.008	0.009	0.009	0.006	0.029	0.003	0.006	0.010	0.009	0.006	0.012	0.005	0.009
K	0.765	0.802	0.783	0.817	0.734	0.716	0.561	0.620	0.764	0.745	0.754	0.848	0.736	0.794	0.815	0.834
Total	6.828	6.847	6.826	6.875	6.803	6.789	6.712	6.728	6.844	6.805	6.804	6.887	6.856	6.863	6.830	6.888
Fe value	0.64	0.60	0.68	0.54	0.39	0.40	0.42	0.23	0.49	0.44	0.58	0.41	0.54	0.63	0.61	0.54

FeO* = total iron as FeO, Tj.v.:Tajima vein, Sy.v.:Soya vein, Iz.v.:Izumo vein, Sr.v.:Sorachi vein, No.70:Drill hole No.70, No.74:Drill hole No.74.

Appendix 3 Continued

Sample	71117		71402	30Sr03			30Sr04			20NS16	70-55	20NS15			
Locality	Iz.v. -250mL		Iz.v. -250mL	Sr.v. -300mL			Sr.v. -300mL			Sr.v. -200mL	No.70 -839m	Sr.v. -200mL			
Alt. zone	C		C	C			C			C	C	E			
SiO_2	50.51	50.92	50.85	47.68	50.72	50.07	50.93	51.68	50.21	50.61	48.89	50.09	50.56	50.44	50.57
TiO_2	0.11	0.08	0.07	0.15	0.05	0.08	0.06	0.13	0.08	0.03	0.06	0.12	0.06	0.06	0.05
Al_2O_3	31.47	31.86	31.67	33.42	31.27	31.93	30.45	28.79	31.38	31.67	34.11	31.88	32.08	31.23	31.45
FeO*	3.47	2.98	1.61	1.61	2.22	2.41	3.04	3.06	2.08	1.52	1.12	0.94	0.79	1.49	1.80
MnO	0.12	0.48	0.26	0.10	0.02	0.01	0.02	0.03	0.09	0.15	0.58	0.03	0.04	0.10	0.03
MgO	1.57	1.88	1.55	1.83	1.62	1.56	1.52	1.65	1.69	1.37	1.36	2.34	1.84	2.48	2.57
CaO	0.06	0.08	0.10	0.10	0.17	0.16	0.11	0.13	0.19	0.07	0.31	0.07	0.07	0.07	0.07
Na_2O	0.03	0.04	0.05	0.05	0.04	0.04	0.04	0.05	0.03	0.08	0.38	0.20	0.07	0.05	0.07
K_2O	6.76	6.22	8.46	9.88	9.51	9.52	8.72	9.40	9.71	9.80	8.22	9.21	8.90	8.65	8.44
Total	94.10	94.54	94.62	94.82	95.62	95.78	94.89	94.92	95.46	95.30	95.03	94.88	94.41	94.57	95.05
O=11															
Si	3.337	3.334	3.346	3.175	3.335	3.293	3.370	3.433	3.313	3.333	3.211	3.298	3.328	3.327	3.318
Al^{IV}	0.663	0.666	0.654	0.825	0.665	0.707	0.630	0.567	0.687	0.667	0.789	0.702	0.672	0.673	0.682
Al^{VI}	1.785	1.790	1.800	1.794	1.755	1.765	1.742	1.684	1.751	1.789	1.848	1.769	1.814	1.752	1.748
Ti	0.005	0.004	0.003	0.008	0.002	0.004	0.003	0.006	0.004	0.001	0.003	0.006	0.003	0.003	0.002
Fe	0.191	0.163	0.088	0.090	0.122	0.132	0.168	0.170	0.115	0.084	0.061	0.052	0.043	0.082	0.099
Mn	0.007	0.027	0.014	0.006	0.001	0.001	0.001	0.002	0.005	0.008	0.032	0.002	0.002	0.006	0.002
Mg	0.154	0.183	0.152	0.181	0.159	0.153	0.150	0.163	0.166	0.134	0.133	0.229	0.180	0.243	0.251
Ca	0.004	0.006	0.007	0.007	0.012	0.011	0.008	0.009	0.013	0.005	0.022	0.005	0.005	0.005	0.005
Na	0.004	0.005	0.006	0.006	0.005	0.005	0.005	0.006	0.004	0.010	0.048	0.025	0.009	0.006	0.009
K	0.569	0.519	0.709	0.838	0.797	0.798	0.735	0.795	0.816	0.822	0.688	0.773	0.746	0.727	0.706
Total	6.719	6.697	6.779	6.930	6.853	6.869	6.812	6.835	6.874	6.853	6.835	6.861	6.802	6.824	6.822
Fe valu	0.56	0.51	0.40	0.35	0.44	0.47	0.53	0.51	0.42	0.41	0.41	0.19	0.20	0.27	0.29

FeO* = total iron as FeO

Appendix 4 Electron microprobe analyses of feldspar

Sample	70-18(K.and)				74-60(K.ban)			69-54(K.and)		74-48(K.ban)			
Locality	Drill hole No.70, -364m				No.74, -600m			No.69, -999m		No.74, -480m			
Alt. zone	A-2				A-2			A-3		A-3			
SiO_2	55.80	55.55	50.24	57.57	51.46	55.44	55.54	68.99	69.83	55.91	50.86	53.51	54.02
TiO_2	0.00	0.01	0.00	0.00	0.07	0.03	0.04	0.00	0.00	0.04	0.05	0.04	0.05
Al_2O_3	27.80	27.87	31.31	26.97	29.84	27.74	27.61	18.11	18.12	26.99	32.10	28.53	28.04
Fe_2O_3*	0.10	0.07	0.10	0.14	0.05	0.12	0.15	0.10	0.09	0.20	0.13	0.16	0.20
MnO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.02	0.01	0.03
MgO	0.01	0.02	0.01	0.01	0.08	0.07	0.10	0.08	0.00	0.08	0.07	0.08	0.11
CaO	9.67	9.88	14.61	8.30	13.35	10.94	9.89	0.42	0.22	9.77	13.61	11.93	12.48
Na_2O	5.54	5.53	3.27	5.68	4.11	4.79	5.41	11.28	11.16	5.25	2.24	4.54	4.26
K_2O	0.42	0.47	0.26	0.65	0.27	0.36	0.47	0.14	0.05	0.81	0.24	0.24	0.21
Total	99.34	99.40	99.80	99.32	99.24	99.49	99.21	99.16	99.47	99.05	99.32	99.04	99.40
Or	2.47	2.72	1.47	3.98	1.50	2.14	2.78	0.78	0.31	4.77	1.60	1.38	1.22
Ab	49.66	48.97	28.40	53.14	35.22	43.25	48.37	97.23	98.60	46.96	22.57	40.20	37.68
An	47.87	48.31	70.13	42.88	63.28	54.61	48.85	2.00	1.09	48.27	75.83	58.42	61.10

Sample	74-55(K.ban)				52907(N.and)				71417(N.and)		70705(K.ban)		
Locality	Drill hole No.74, -550m				Soya vein, -250mL				Izumo, -250mL		Izumo, -300mL		
Alt. zone	A-3				B				B		B		
SiO_2	52.75	53.45	49.76	52.36	69.30	68.94	69.09	68.87	66.05	66.67	64.97	67.29	66.87
TiO_2	0.03	0.06	0.06	0.10	0.00	0.00	0.00	0.00	0.08	0.03	0.02	0.11	0.02
Al_2O_3	29.27	28.39	31.02	29.20	18.59	18.77	18.42	18.92	18.41	18.23	20.51	18.43	18.61
Fe_2O_3*	0.12	0.18	0.15	0.16	0.18	0.03	0.12	0.15	0.13	0.03	0.12	0.17	0.10
MnO	0.00	0.01	0.06	0.03	0.00	0.03	0.00	0.00	0.03	0.02	0.05	0.04	0.02
MgO	0.09	0.08	0.00	0.08	0.02	0.00	0.00	0.00	0.10	0.03	0.11	0.04	0.03
CaO	12.66	11.69	15.23	12.91	0.18	0.32	0.36	0.11	0.02	0.00	0.07	0.12	0.00
Na_2O	4.13	4.86	3.08	4.18	11.16	11.33	11.64	11.80	0.18	0.19	0.12	0.27	0.47
K_2O	0.28	0.35	0.18	0.27	0.14	0.06	0.08	0.14	14.19	15.29	14.07	14.48	14.65
Total	99.33	99.07	99.54	99.29	99.57	99.48	99.71	99.99	99.19	100.49	100.04	100.95	100.77
Or	1.63	1.98	0.99	1.54	0.78	0.34	0.45	0.76	97.99	98.15	98.31	96.59	95.35
Ab	36.51	42.08	26.51	36.37	98.36	98.11	97.86	98.72	1.89	1.85	1.27	2.74	4.65
An	61.86	55.94	72.50	62.09	0.86	1.55	1.69	0.52	0.12	0.00	0.41	0.67	0.00

K.:Koyanagizawa Formation, N.Nagato Formation, and:andesite, ban:basaltic andesite,
Fe_2O_3* = total iron as Fe_2O_3.

Appendix 5 Chemical compositions of andesitic rocks from the alteration zones around the Toyoha deposits

Sample No.	71701	72101	72501	72201	80801	81302	70-18	74-60	72003	70-27	74-48	74-55
Locality	Mt. Muine	Mt. Nagao	Mt. Nagao	Mt. Nagao	Kurum River	Yunos River	No.70 -364m	No.74 -600m	Yunos River	No.70 -500m	No.74 -480m	No.74 -550m
Rock facies	Y.and	Y.and	Y.and	Y.and	O.and	O.and	K.and	K.ban	K.ban	K.ban	K.ban	K.ban
Alt. zone	Unalt	Unalt	A-1	A-1	A-1	A-1	A-2	A-2	A-2	A-3	A-3	A-3
SiO_2	59.45	57.13	54.53	59.45	59.28	57.33	62.68	55.20	53.19	49.76	51.35	55.77
TiO_2	0.67	0.70	0.72	0.69	0.89	0.95	0.61	0.82	1.03	1.07	0.90	0.93
Al_2O_3	16.01	15.89	15.52	15.58	16.21	16.43	15.22	16.75	18.64	17.53	17.40	17.71
Fe_2O_3	3.17	3.46	2.87	3.04	4.84	6.85	3.69	3.21	5.77	1.11	2.95	4.54
FeO	4.57	5.74	6.25	4.75	3.12	1.48	1.47	3.98	1.72	6.03	3.90	3.07
MnO	0.15	0.16	0.17	0.42	0.13	0.07	0.09	0.11	0.03	0.52	0.15	0.13
MgO	3.12	4.13	5.06	2.90	2.39	1.64	2.72	4.55	3.39	4.51	3.98	3.19
CaO	6.65	7.89	9.40	6.63	6.55	6.04	4.26	7.59	7.98	10.78	10.46	7.75
Na_2O	2.82	2.09	1.65	2.35	2.68	2.67	3.08	2.75	2.46	2.07	2.39	2.73
K_2O	1.62	1.29	0.98	1.57	1.11	0.98	2.64	1.46	0.90	0.24	0.35	0.89
P_2O_5	0.14	0.12	0.11	0.12	0.22	0.19	0.13	0.16	0.13	0.22	0.17	0.19
$H_2O(+)$	0.85	0.77	1.09	0.70	1.57	3.47	1.29	2.12	2.89	2.91	2.90	1.85
$H_2O(-)$	0.30	0.30	0.50	0.28	0.84	2.03	0.41	0.20	0.76	0.32	0.26	0.10
CO_2	0.02	0.01	0.00	0.45	0.03	0.02	0.75	0.40	0.92	2.89	3.14	0.74
Rest	0.26	0.28	0.50	0.55	0.08	0.00	0.00	0.07	0.00	0.69	0.49	0.19
Total	99.80	99.96	99.35	99.48	99.94	100.15	99.04	99.37	99.81	100.65	100.79	99.78

Sample No.	81307	81506	81508	T-2	15Sy04	15Sy05	60320	70705	70706	70-47	74-121	15Sy09
Locality	Yamad Path	Yamad Path	Yamad Path	Tj.v. -300mL	Sy.v. -150mL	Sy.v. -150mL	Sy.v. -300mL	Iz.v. -300mL	Iz.v. -300mL	No.70 -740m	No.74 -1000m	Tj.v. -150mL
Rock facies	N.and	N.and	N.and	D.and	N.and	N.and	D.and	K.ban	K.ban	K.ban	K.and	N.and
Alt. zone	A-3	A-3	A-3	B	B	B	B	B	B	B	B	C
SiO_2	55.47	60.29	57.47	56.56	54.65	58.04	58.90	51.18	52.67	59.25	67.85	60.20
TiO_2	0.96	0.81	0.82	0.88	0.79	0.81	0.89	0.93	0.95	0.67	0.60	0.79
Al_2O_3	16.89	15.04	15.95	15.31	15.09	15.68	15.34	18.67	17.28	16.51	15.20	14.02
Fe_2O_3	3.98	3.87	5.59	1.33	1.60	1.89	3.70	1.76	3.22	2.71	0.73	3.04
FeO	4.04	3.22	2.72	5.32	6.21	5.38	4.50	4.32	5.21	2.70	3.14	8.26
MnO	0.11	0.11	0.11	0.75	1.16	1.20	0.15	1.30	1.85	2.95	0.22	1.84
MgO	2.75	1.95	2.65	3.06	3.75	3.27	2.94	3.15	3.81	1.75	1.74	2.60
CaO	5.95	4.18	6.85	4.23	4.44	3.56	2.65	2.89	4.13	1.68	2.04	0.32
Na_2O	3.45	3.82	2.41	0.32	0.32	0.75	1.90	0.16	0.06	0.37	0.24	0.04
K_2O	1.26	1.06	1.19	4.58	4.72	3.07	2.50	9.85	4.79	6.20	3.32	2.78
P_2O_5	0.21	0.20	0.19	0.22	0.16	0.18	0.19	0.22	0.19	0.30	0.14	0.22
$H_2O(+)$	2.89	2.94	2.51	4.13	4.33	4.25	3.68	3.37	4.48	3.22	3.67	4.56
$H_2O(-)$	0.42	0.32	0.26	0.50	0.46	0.54	0.38	0.16	0.20	0.45	0.64	0.40
CO_2	1.54	2.31	1.95	3.42	3.07	2.12	0.99	1.63	1.54	2.08	1.41	0.02
Rest	0.12	0.01	0.12	0.01	0.10	0.22	0.35	0.02	0.00	0.11	0.01	0.69
Total	100.04	100.13	100.79	100.63	100.86	100.97	99.07	99.62	100.37	100.95	100.96	99.78

Kurum:Kurumizawa, Yunos:Yunosawa, Oheza:Ohezawa, Yamad:Yamadori, Tj.v.:Tajima vein, Sy.v.:Soya vein, Iz.v.:Izumo vein, Sr.v.:Sorachi vein, No.70:Drill hole No.70, No.74:Drill hole No.74, K.:Koyanagizawa Formation, M.:Motoyama Form., N.:Nagato Form., O.:Oheyama Form., D:Dike rocks, Y.:Younger andesite, and:andesite, ban:basaltic andesite, ss:sandstone, cg:conglomerate.
Rest = ignition loss - (total H_2O + CO_2)

Appendix 5 Continued

Sample No.	15Sy10	15Sy11	15Sy12	15Sy13	15Sy14	T-4	T-8	15Sy02	15Sy03	15Sy06	15Sy07	60301
Locality	Tj.v. -150mL	Tj.v. -150mL	Tj.v. -150mL	Tj.v. -150mL	Tj.v. -150mL	Tj.v. -300mL	Tj.v. -300mL	Sy.v. -150mL	Sy.v. -150mL	Sy.v. -150mL	Sy.v. -150mL	Sy.v. -300mL
Rock facies	N.and	N.and	N.and	N.and	N.and	D.and	D.and	N.and	N.and	N.and	N.and	N.and
Alt. zone	C	C	C	C	C	C	C	C	C	C	C	C
SiO_2	60.29	61.01	61.10	62.10	57.89	54.97	51.53	64.95	62.54	61.70	57.89	59.80
TiO_2	0.82	0.75	0.73	0.74	0.84	0.87	0.98	0.58	0.58	0.82	0.83	0.76
Al_2O_3	14.40	15.86	13.83	14.35	14.89	14.70	11.01	13.69	13.73	14.74	15.26	13.90
Fe_2O_3	3.20	2.46	2.83	3.26	2.84	2.91	14.47	4.87	2.36	3.04	3.56	2.99
FeO	8.20	4.20	7.49	6.60	9.16	7.48	7.61	3.07	9.24	5.29	7.89	8.54
MnO	1.35	2.46	1.18	1.15	1.15	4.10	2.41	1.13	1.31	1.91	1.75	2.38
MgO	2.49	2.61	2.49	2.50	2.48	4.85	2.32	1.59	1.47	2.46	2.46	2.97
CaO	0.33	0.50	0.28	0.27	0.31	0.52	0.32	0.32	0.23	0.49	0.36	0.34
Na_2O	0.00	0.00	0.17	0.01	0.08	0.24	0.16	0.00	0.03	0.00	0.00	0.13
K_2O	2.87	4.08	2.85	3.23	2.99	2.51	0.91	3.37	2.84	3.48	3.17	2.57
P_2O_5	0.23	0.20	0.19	0.18	0.21	0.16	0.19	0.17	0.16	0.21	0.22	0.21
$H_2O(+)$	4.68	4.03	4.51	4.10	5.04	5.55	6.34	3.96	4.42	4.04	4.73	4.95
$H_2O(-)$	0.44	0.46	0.68	0.30	0.34	0.42	0.78	0.89	0.56	0.26	0.62	0.24
CO_2	0.05	0.92	0.10	0.16	0.00	0.55	0.02	0.00	0.05	0.24	0.06	0.05
Rest	0.40	0.11	1.01	0.64	2.76	0.27	1.32	1.65	0.78	0.83	1.30	0.23
Total	99.75	99.65	99.45	99.59	100.98	100.10	100.37	100.24	100.30	99.51	100.10	100.07

Sample No.	60304	60305	60306	60309	60310	60319	71111	71115	71405	71409	71422	301z04
Locality	Sy.v. -300mL	Sy.v. -300mL	Sy.v. -300mL	Sy.v. -300mL	Sy.v. -300mL	Sy.v. -300mL	Iz.v. -250mL	Iz.v. -250mL	Iz.v. -250mL	Iz.v. -250mL	Iz.v. -250mL	Iz.v. -300mL
Rock facies	N.and	N.and	N.and	N.and	D.and	D.and	N.and	N.and	N.and	N.and	N.and	K.ban
Alt. zone	C	C	C	C	C	C	C	C	C	C	C	C
SiO_2	62.98	60.80	58.71	61.58	59.67	57.69	56.54	56.87	58.65	58.31	58.42	47.02
TiO_2	0.69	0.73	0.73	0.78	0.73	1.05	0.73	0.79	0.80	0.76	0.76	0.90
Al_2O_3	12.38	13.03	12.41	13.97	13.62	14.60	13.17	13.59	13.43	13.68	14.16	15.18
Fe_2O_3	5.69	4.29	3.51	3.22	2.97	3.96	5.58	5.78	3.47	2.97	4.24	11.94
FeO	5.33	6.55	11.66	8.33	11.61	8.14	11.23	11.02	10.86	10.56	10.05	8.15
MnO	1.22	1.67	1.65	1.06	0.95	2.60	0.80	0.76	1.65	2.07	1.28	0.96
MgO	2.22	2.74	2.57	2.55	2.20	3.05	2.19	2.00	2.69	2.58	2.21	1.98
CaO	0.29	0.32	0.27	0.31	0.27	0.31	0.25	0.34	0.32	0.32	0.32	0.12
Na_2O	0.24	0.00	0.00	0.08	0.43	0.03	0.21	0.23	0.05	0.02	0.18	0.00
K_2O	2.66	2.72	1.81	2.90	2.22	2.85	2.05	2.18	2.10	2.28	2.50	3.30
P_2O_5	0.20	0.22	0.18	0.21	0.19	0.22	0.15	0.22	0.20	0.21	0.19	0.04
$H_2O(+)$	4.10	4.50	4.99	4.45	4.89	5.04	5.00	4.84	5.11	5.04	4.77	5.18
$H_2O(-)$	0.26	0.22	0.32	0.20	0.22	0.42	0.28	0.40	0.22	0.26	0.26	0.28
CO_2	0.05	0.00	0.01	0.07	0.07	0.09	0.09	0.03	0.00	0.00	0.02	0.03
Rest	1.78	1.25	0.77	0.56	0.31	0.47	1.47	1.38	0.42	0.42	0.82	4.57
Total	100.09	99.04	99.58	100.27	100.34	100.51	99.73	100.43	99.97	99.47	100.18	99.64

Appendix 5 Continued

Sample No.	301z05	70704	70712	35Sr08	35Sr11	70-34	70-42	70-44	70-48	74-92	74-104	74-109
Locality	Iz.v. -300mL	Iz.v. -300mL	Iz.v. -300mL	Sr.v. -350mL	Sr.v. -350mL	No.70 -600m	No.70 -717m	No.70 -725m	No.70 -747m	No.74 -860m	No.74 -911m	No.74 -940m
Rock facies	K.ban	K.ban	K.ban	D.and	D.and	K.ban	K.ban	K.ban	K.ban	K.ban	K.ban	K.ban
Alt. zone	C	C	C	C	C	C	C	C	C	C	C	C
SiO_2	55.81	48.63	55.60	53.91	60.63	44.71	57.49	61.59	55.95	60.65	64.32	48.69
TiO_2	0.86	0.81	0.90	0.85	0.75	0.99	0.56	0.67	0.68	0.64	0.63	0.80
Al_2O_3	15.69	14.77	18.19	16.22	13.40	14.85	12.20	15.39	16.49	15.04	14.33	18.55
Fe_2O_3	5.50	10.68	2.93	4.52	5.13	8.37	6.33	3.99	3.94	4.62	2.87	3.02
FeO	8.79	8.35	4.65	8.58	7.39	10.64	13.01	6.88	10.00	7.16	7.71	12.93
MnO	0.57	0.91	2.13	1.88	1.63	2.79	0.73	0.55	1.07	0.82	0.54	1.30
MgO	2.18	2.52	3.47	3.82	2.38	5.13	0.87	1.03	1.65	1.23	1.22	3.25
CaO	0.11	0.21	1.33	0.31	0.29	0.36	0.41	0.50	0.53	0.33	0.29	0.39
Na_2O	0.04	0.04	0.00	0.05	0.00	0.14	0.09	0.00	0.19	0.00	0.13	0.20
K_2O	3.14	3.04	4.42	3.04	2.59	2.16	1.69	3.24	3.15	3.16	2.88	3.33
P_2O_5	0.04	0.11	0.21	0.23	0.21	0.18	0.26	0.31	0.32	0.17	0.12	0.20
$H_2O(+)$	4.71	5.18	4.57	5.72	4.68	6.90	4.89	4.04	5.15	4.60	4.44	6.38
$H_2O(-)$	0.34	0.20	0.22	0.48	0.36	0.53	0.34	0.58	0.65	0.72	0.73	0.65
CO_2	0.03	0.03	0.49	0.17	0.00	0.06	0.04	0.06	0.03	0.02	0.01	0.04
Rest	1.76	4.19	0.67	0.90	0.97	1.72	1.47	0.90	0.17	0.79	0.20	0.34
Total	99.57	99.66	99.78	100.68	100.42	99.53	100.38	99.73	99.97	99.95	100.42	100.06

Sample No.	81504	71611	71613	35Sr02	35Sr04	35Sr05	35Sr06	35Sr09	73008	73017
Locality	Shira River	Oheza River	Oheza River	Sr.v. -350mL	Sr.v. -350mL	Sr.v. -350mL	Sr.v. -350mL	Sr.v. -350mL	Yunos River	Yunos River
Rock facies	N.and	N.and	N.and	M.ss	M.cg	M.cg	M.cg	D.and	K.ban	K.ban
Alt. zone	D	D	D	E	E	E	E	E	F	F
SiO_2	70.52	64.52	61.01	64.37	58.94	61.02	58.49	63.83	73.85	72.87
TiO_2	0.53	0.81	0.64	0.92	0.72	0.88	0.82	0.72	0.82	0.58
Al_2O_3	12.36	18.05	15.62	17.23	10.99	13.82	16.82	14.82	14.58	12.80
Fe_2O_3	3.45	2.91	7.63	4.28	12.47	10.27	9.28	7.76	0.92	2.99
FeO	0.25	0.25	0.24	0.87	2.28	0.79	0.63	0.50	0.25	0.15
MnO	0.12	0.01	0.06	0.06	0.02	0.02	0.03	0.06	0.00	0.00
MgO	0.89	1.00	0.75	0.56	0.19	0.34	0.32	0.66	0.78	0.18
CaO	0.09	0.15	0.26	0.08	0.08	0.08	0.10	0.29	0.07	0.19
Na_2O	0.14	0.26	0.15	0.00	0.00	0.00	0.00	0.28	0.21	0.13
K_2O	3.45	4.30	3.82	3.85	0.84	1.78	1.42	4.31	3.60	0.06
P_2O_5	0.08	0.09	0.21	0.08	0.10	0.10	0.14	0.20	0.04	0.33
$H_2O(+)$	3.37	4.09	5.77	5.15	6.66	6.20	7.13	4.12	3.35	6.40
$H_2O(-)$	1.65	1.90	1.61	0.88	0.32	0.28	0.46	0.46	1.61	0.60
CO_2	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.02	0.00	0.00
Rest	2.26	2.08	2.17	2.23	6.02	3.74	3.45	2.57	0.74	1.79
Total	99.16	100.41	99.94	100.56	99.67	99.33	99.09	100.59	100.82	99.06

Appendix 6 Electron microprobe analyses of chlorite in altered rocks from the Akenobe mine

Non alteration region

Sample No. Locality	E-4 Sakuto-cho											
SiO_2	28.08	27.97	27.52	28.08	27.89	28.75	28.21	28.06	28.13	27.50	27.90	27.71
TiO_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Al_2O_3	18.39	18.19	16.49	17.78	17.58	18.30	17.47	17.49	18.05	16.82	17.24	17.55
FeO*	26.77	26.92	27.18	24.18	25.11	24.91	23.13	23.60	26.17	25.79	25.54	24.22
MnO	0.40	0.35	0.39	0.53	0.42	0.43	0.49	0.46	0.40	0.47	0.43	0.61
MgO	15.17	14.00	14.90	16.91	16.28	16.51	17.89	16.95	15.21	16.11	15.86	16.72
CaO	0.11	0.20	0.15	0.05	0.07	0.05	0.05	0.07	0.05	0.07	0.11	0.10
Na_2O	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.01
K_2O	0.02	0.06	0.02	0.01	0.01	0.02	0.04	0.01	0.01	0.02	0.01	0.02
Total	88.94	87.71	86.65	87.54	87.36	88.97	87.28	86.66	88.05	86.80	87.11	86.94
O=14												
Si	2.933	2.968	2.974	2.946	2.948	2.968	2.954	2.966	2.960	2.945	2.966	2.935
Al^{IV}	1.067	1.032	1.026	1.054	1.052	1.032	1.046	1.034	1.040	1.055	1.034	1.065
Al^{VI}	1.194	1.240	1.072	1.143	1.136	1.191	1.107	1.143	1.196	1.066	1.124	1.123
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Fe	2.335	2.385	2.454	2.119	2.216	2.148	2.022	2.083	2.300	2.307	2.267	2.143
Mn	0.035	0.031	0.035	0.047	0.038	0.038	0.044	0.041	0.035	0.042	0.039	0.055
Mg	2.358	2.211	2.396	2.640	2.560	2.537	2.787	2.667	2.382	2.567	2.509	2.636
Ca	0.013	0.022	0.017	0.005	0.008	0.006	0.006	0.008	0.005	0.008	0.013	0.012
Na	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.004	0.003	0.004	0.003	0.002
K	0.002	0.008	0.002	0.001	0.001	0.002	0.005	0.002	0.002	0.003	0.001	0.002
Total	9.937	9.900	9.976	9.955	9.959	9.922	9.971	9.948	9.924	9.997	9.956	9.973
Fe value	0.50	0.52	0.51	0.45	0.47	0.46	0.43	0.44	0.50	0.48	0.48	0.46

FeO* = total iron as FeO

Appendix 6 Continued

Light green zone

Sample No. Locality	14Ch07 No.3 vein, 14L									14Ch15 No.3 vein, 14L					14Ch17 No.8 vein, 14L		
SiO_2	27.17	27.01	27.51	27.28	28.11	27.39	27.10	28.08	27.48	27.42	27.69	27.49	27.86	27.68	27.62	27.74	27.53
TiO_2	0.01	0.03	0.04	0.04	0.04	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
Al_2O_3	17.06	16.73	16.90	16.91	16.77	17.38	17.19	16.57	17.03	18.08	17.79	17.37	17.04	17.08	17.64	15.86	17.15
FeO*	28.70	28.36	28.32	28.90	27.09	29.56	27.66	27.39	27.28	26.42	26.13	26.43	26.31	27.04	27.60	28.10	27.62
MnO	1.82	1.82	1.85	1.68	1.72	1.18	1.66	1.65	1.65	1.91	1.54	1.77	1.90	1.52	0.38	0.34	0.36
MgO	12.84	12.63	12.35	12.71	13.79	12.23	13.09	13.64	13.12	13.58	14.48	13.65	13.86	14.03	13.51	14.39	13.63
CaO	0.12	0.16	0.26	0.21	0.24	0.14	0.12	0.13	0.13	0.18	0.07	0.11	0.21	0.07	0.10	0.17	0.09
Na_2O	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.02	0.01	0.03	0.02	0.02	0.01	0.00	0.00	0.00
K_2O	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.03	0.02	0.00
Total	87.74	86.74	87.25	87.73	87.76	87.91	86.85	87.50	86.74	87.61	87.75	86.84	87.22	87.45	86.88	86.62	86.38
O=14																	
Si	2.943	2.959	2.990	2.957	3.010	2.960	2.943	3.015	2.979	2.933	2.946	2.968	2.994	2.972	2.974	3.011	2.986
Al^{IV}	1.057	1.041	1.010	1.043	0.990	1.040	1.057	0.985	1.021	1.067	1.054	1.032	1.006	1.028	1.026	0.989	1.014
Al^{VI}	1.119	1.116	1.152	1.114	1.124	1.171	1.140	1.109	1.153	1.210	1.175	1.176	1.150	1.131	1.211	1.038	1.175
Ti	0.000	0.003	0.003	0.003	0.003	0.001	0.001	0.002	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000
Fe	2.597	2.595	2.571	2.616	2.423	2.668	2.508	2.456	2.470	2.360	2.322	2.383	2.362	2.425	2.483	2.548	2.501
Mn	0.167	0.169	0.170	0.154	0.155	0.108	0.152	0.150	0.151	0.173	0.138	0.162	0.172	0.138	0.035	0.031	0.033
Mg	2.070	2.059	1.998	2.050	2.198	1.966	2.116	2.180	2.116	2.162	2.293	2.193	2.216	2.243	2.166	2.325	2.199
Ca	0.014	0.018	0.030	0.024	0.027	0.017	0.014	0.015	0.016	0.021	0.007	0.013	0.024	0.008	0.012	0.020	0.010
Na	0.000	0.000	0.003	0.000	0.000	0.004	0.003	0.000	0.003	0.003	0.006	0.004	0.004	0.001	0.000	0.000	0.000
K	0.003	0.000	0.002	0.000	0.000	0.000	0.001	0.002	0.002	0.001	0.002	0.000	0.001	0.000	0.003	0.003	0.000
Total	9.970	9.960	9.929	9.961	9.930	9.935	9.935	9.914	9.912	9.930	9.943	9.931	9.930	9.948	9.910	9.965	9.918
Fe value	0.57	0.57	0.58	0.57	0.54	0.59	0.56	0.54	0.55	0.54	0.52	0.54	0.53	0.53	0.54	0.53	0.54

FeO* = total iron as FeO

Appendix 6 Continued

Light green zone

Sample No. Locality	14Ch23 No.8 vein, 14L								14Ch32 No.17 vein, 14L				140806 No.8 vein, 14L					
SiO_2	27.66	26.52	27.64	27.42	25.82	27.72	27.41	26.98	27.51	27.90	27.54	27.20	27.32	27.19	26.59	27.05	28.15	26.56
TiO_2	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.02	0.02	0.02	0.02	0.03	0.03	0.06	0.05	0.02	0.04
Al_2O_3	16.68	18.94	16.81	17.01	18.81	18.03	17.08	17.79	16.85	16.35	16.44	16.78	17.31	17.23	18.10	17.92	17.86	18.06
FeO*	27.87	28.10	27.06	27.49	27.94	27.90	29.55	27.54	31.86	31.40	30.93	30.81	28.49	27.62	28.71	29.07	27.87	28.49
MnO	0.79	1.06	0.75	0.76	1.47	0.76	0.70	0.74	0.38	0.36	0.36	0.38	0.57	0.62	0.52	0.53	0.46	0.49
MgO	14.45	13.13	14.03	13.55	12.74	13.29	12.68	13.29	10.95	11.85	11.34	11.55	13.19	14.08	13.39	13.20	13.43	13.56
CaO	0.24	0.11	0.25	0.32	0.11	0.21	0.18	0.23	0.24	0.17	0.21	0.15	0.26	0.18	0.18	0.24	0.15	0.10
Na_2O	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.03	0.01	0.02	0.03	0.04	0.04	0.06	0.02
K_2O	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.00	0.00	0.02	0.02	0.02
Total	87.70	87.88	86.60	86.56	86.91	87.93	87.62	86.58	87.83	88.09	86.88	86.92	87.21	86.98	87.59	88.12	88.02	87.34
O=14																		
Si	2.968	2.845	2.985	2.976	2.812	2.956	2.967	2.924	3.002	3.026	3.026	2.987	2.954	2.937	2.868	2.902	2.991	2.869
Al^{IV}	1.032	1.155	1.015	1.024	1.188	1.044	1.033	1.076	0.998	0.974	0.974	1.013	1.046	1.063	1.132	1.098	1.009	1.131
Al^{VI}	1.074	1.237	1.122	1.149	1.224	1.220	1.144	1.195	1.167	1.114	1.153	1.157	1.158	1.128	1.166	1.165	1.226	1.166
Ti	0.000	0.000	0.003	0.000	0.000	0.001	0.000	0.000	0.002	0.001	0.002	0.002	0.002	0.002	0.005	0.004	0.002	0.003
Fe	2.497	2.517	2.441	2.492	2.542	2.486	2.672	2.494	2.904	2.844	2.838	2.826	2.574	2.491	2.587	2.605	2.474	2.571
Mn	0.072	0.096	0.068	0.069	0.135	0.069	0.064	0.068	0.035	0.033	0.034	0.035	0.052	0.057	0.047	0.048	0.041	0.045
Mg	2.307	2.096	2.255	2.188	2.065	2.110	2.042	2.145	1.778	1.913	1.854	1.887	2.122	2.264	2.149	2.108	2.123	2.181
Ca	0.028	0.012	0.029	0.037	0.013	0.024	0.021	0.025	0.027	0.019	0.025	0.017	0.030	0.020	0.021	0.028	0.017	0.011
Na	0.000	0.003	0.003	0.000	0.000	0.001	0.001	0.000	0.000	0.004	0.005	0.002	0.004	0.006	0.008	0.007	0.012	0.003
K	0.001	0.001	0.001	0.001	0.003	0.001	0.002	0.001	0.002	0.002	0.001	0.003	0.002	0.000	0.001	0.002	0.003	0.003
Total	9.979	9.962	9.922	9.936	9.982	9.912	9.946	9.928	9.915	9.930	9.912	9.929	9.944	9.968	9.984	9.967	9.898	9.983
Fe value	0.53	0.55	0.53	0.54	0.56	0.55	0.57	0.54	0.62	0.60	0.61	0.60	0.55	0.53	0.55	0.56	0.54	0.55

FeO* = total iron as FeO

Appendix 6 Continued

Green zone

Sample No.	140805												
Locality	No.8 vein, 14L												
SiO_2	26.63	26.47	25.68	26.34	27.25	27.11	27.20	26.96	25.60	26.83	27.11	26.29	26.63
TiO_2	0.02	0.02	0.04	0.07	0.04	0.07	0.05	0.11	0.04	0.10	0.14	0.13	0.05
Al_2O_3	18.32	17.63	20.67	18.76	17.84	18.50	19.14	18.85	21.02	18.95	18.32	19.24	19.07
FeO*	29.24	27.14	28.01	26.98	27.51	26.15	27.08	27.13	28.49	27.13	26.38	27.26	27.09
MnO	1.35	1.50	1.61	1.48	1.48	1.54	1.81	1.45	1.69	1.57	1.49	1.57	1.53
MgO	12.47	13.13	11.70	12.62	13.26	13.20	12.66	12.79	11.21	12.54	13.53	12.24	12.44
CaO	0.07	0.09	0.04	0.12	0.11	0.12	0.12	0.13	0.06	0.06	0.12	0.14	0.15
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
K_2O	0.00	0.01	0.01	0.03	0.02	0.02	0.03	0.03	0.01	0.02	0.01	0.01	0.04
Total	88.10	85.99	87.76	86.40	87.51	86.71	88.09	87.45	88.12	87.21	87.10	86.88	87.00
O=14													
Si	2.871	2.903	2.763	2.867	2.931	2.921	2.898	2.894	2.750	2.889	2.912	2.848	2.876
Al^{IV}	1.129	1.097	1.237	1.133	1.069	1.079	1.102	1.106	1.250	1.111	1.088	1.152	1.124
Al^{VI}	1.197	1.179	1.380	1.271	1.191	1.269	1.298	1.276	1.407	1.291	1.228	1.302	1.301
Ti	0.002	0.002	0.003	0.006	0.003	0.006	0.004	0.008	0.003	0.008	0.011	0.010	0.004
Fe	2.634	2.485	2.516	2.452	2.472	2.353	2.409	2.432	2.556	2.440	2.367	2.466	2.443
Mn	0.123	0.139	0.146	0.136	0.134	0.141	0.163	0.132	0.154	0.143	0.135	0.144	0.139
Mg	2.001	2.142	1.874	2.044	2.123	2.116	2.008	2.042	1.792	2.010	2.163	1.974	1.999
Ca	0.008	0.010	0.004	0.014	0.013	0.014	0.013	0.014	0.007	0.007	0.014	0.016	0.017
Na	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
K	0.000	0.001	0.002	0.004	0.002	0.002	0.004	0.004	0.002	0.003	0.001	0.002	0.006
Total	9.965	9.958	9.925	9.927	9.938	9.901	9.899	9.908	9.921	9.904	9.919	9.914	9.909
Fe value	0.58	0.55	0.59	0.56	0.55	0.54	0.56	0.56	0.60	0.56	0.54	0.57	0.56

FeO* = total iron as FeO

Appendix 6 Continued

Green zone

Sample No. Locality	140804 No.8 vein, 14L										
SiO_2	24.43	25.11	26.59	25.87	25.18	26.71	25.46	25.86	24.47	25.26	24.64
TiO_2	0.02	0.01	0.04	0.02	0.03	0.03	0.06	0.01	0.04	0.02	0.01
Al_2O_3	20.29	19.74	17.95	18.43	19.49	18.52	18.91	18.22	19.74	18.20	18.70
FeO*	29.46	29.31	29.98	27.99	28.79	29.80	30.78	32.78	32.86	33.47	33.23
MnO	2.31	2.53	1.04	1.21	3.69	0.97	1.20	1.11	1.42	1.23	1.29
MgO	9.56	10.20	10.55	12.40	10.47	11.49	9.64	9.05	8.52	8.69	8.27
CaO	0.06	0.09	0.11	0.10	0.05	0.11	0.13	0.10	0.02	0.01	0.04
Na_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
Total	86.14	86.99	86.26	86.03	87.70	87.64	86.19	87.13	87.07	86.88	86.18
O=14											
Si	2.724	2.768	2.939	2.845	2.762	2.896	2.837	2.877	2.736	2.838	2.793
Al^{IV}	1.276	1.232	1.061	1.155	1.238	1.104	1.163	1.123	1.264	1.162	1.207
Al^{VI}	1.387	1.331	1.275	1.232	1.279	1.261	1.319	1.265	1.334	1.244	1.288
Ti	0.002	0.001	0.003	0.002	0.003	0.003	0.005	0.001	0.003	0.002	0.001
Fe	2.743	2.699	2.767	2.571	2.638	2.699	2.866	3.046	3.069	3.140	3.146
Mn	0.218	0.236	0.097	0.113	0.342	0.089	0.113	0.104	0.134	0.117	0.124
Mg	1.586	1.674	1.735	2.029	1.710	1.855	1.599	1.499	1.418	1.453	1.395
Ca	0.007	0.010	0.012	0.011	0.006	0.013	0.016	0.012	0.003	0.001	0.005
Na	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
K	0.001	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000
Total	9.944	9.951	9.889	9.959	9.978	9.922	9.919	9.927	9.961	9.957	9.959
Fe value	0.65	0.64	0.62	0.57	0.64	0.60	0.65	0.68	0.69	0.69	0.70

FeO* = total iron as FeO

Dark green zone

Sample No. Locality	14Ch10 No.3 vein, 14L												
SiO_2	23.02	24.00	23.93	24.28	24.03	23.71	23.75	24.00	24.43	23.97	24.16	24.36	23.87
TiO_2	0.04	0.04	0.03	0.03	0.14	0.08	0.07	0.03	0.04	0.09	0.03	0.07	0.04
Al_2O_3	20.65	19.10	19.30	18.78	19.24	21.72	19.20	18.92	18.26	18.92	18.98	18.89	19.01
FeO*	39.07	40.93	40.91	39.62	40.76	37.24	40.92	40.84	40.46	40.32	40.54	40.79	40.63
MnO	0.49	0.41	0.38	0.61	0.39	0.47	0.40	0.38	0.40	0.40	0.40	0.37	0.36
MgO	4.44	3.94	3.95	4.86	4.07	5.07	4.06	4.11	4.32	4.15	4.02	4.25	4.22
CaO	0.11	0.15	0.17	0.09	0.11	0.09	0.12	0.19	0.12	0.09	0.14	0.17	0.13
Na_2O	0.02	0.03	0.02	0.02	0.02	0.02	0.01	0.02	0.03	0.01	0.03	0.04	0.03
K_2O	0.00	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.02	0.00	0.02	0.02	0.01
Total	87.84	88.62	88.71	88.30	88.77	88.40	88.54	88.50	88.08	87.95	88.32	88.96	88.30
O=14													
Si	2.634	2.746	2.734	2.770	2.739	2.654	2.717	2.749	2.806	2.756	2.767	2.770	2.738
Al^{IV}	1.366	1.254	1.266	1.230	1.261	1.346	1.283	1.251	1.194	1.244	1.233	1.230	1.262
Al^{VI}	1.416	1.318	1.328	1.293	1.320	1.516	1.304	1.300	1.275	1.316	1.326	1.298	1.305
Ti	0.003	0.003	0.002	0.002	0.012	0.007	0.006	0.003	0.003	0.008	0.003	0.006	0.003
Fe	3.734	3.910	3.903	3.775	3.880	3.481	3.911	3.908	3.881	3.871	3.877	3.874	3.892
Mn	0.047	0.040	0.037	0.058	0.038	0.045	0.038	0.037	0.038	0.039	0.038	0.036	0.035
Mg	0.756	0.670	0.672	0.825	0.691	0.845	0.692	0.700	0.738	0.711	0.685	0.720	0.720
Ca	0.013	0.019	0.021	0.011	0.013	0.010	0.014	0.023	0.015	0.011	0.017	0.021	0.016
Na	0.004	0.007	0.005	0.004	0.005	0.005	0.002	0.005	0.007	0.002	0.006	0.008	0.007
K	0.000	0.002	0.002	0.001	0.001	0.000	0.001	0.001	0.003	0.000	0.002	0.003	0.001
Total	9.973	9.969	9.970	9.969	9.960	9.909	9.968	9.977	9.960	9.958	9.954	9.966	9.979
Fe value	0.83	0.86	0.85	0.82	0.85	0.81	0.85	0.85	0.84	0.85	0.85	0.84	0.85

FeO* = total iron as FeO

Appendix 6 Continued

Dark green zone

Sample No. Locality	140803 No.8 vein, 14L									
SiO_2	24.03	24.77	25.57	26.20	24.47	24.03	24.67	26.08	24.53	24.99
TiO_2	0.05	0.07	0.06	0.05	0.07	0.08	0.04	0.01	0.04	0.01
Al_2O_3	20.67	20.75	18.61	16.20	18.42	21.29	18.73	16.14	19.70	18.49
FeO*	36.64	37.22	38.04	37.92	39.16	36.59	38.87	39.28	37.99	39.18
MnO	0.71	1.15	0.91	0.65	1.23	1.09	0.71	0.75	0.83	0.75
MgO	5.08	4.69	5.41	6.51	5.03	5.00	4.92	6.08	4.76	4.76
CaO	0.17	0.04	0.08	0.06	0.06	0.11	0.11	0.08	0.13	0.15
Na_2O	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.02
K_2O	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.02
Total	87.37	88.71	88.70	87.61	88.46	88.21	88.08	88.44	88.01	88.37
O=14										
Si	2.716	2.766	2.869	2.980	2.787	2.695	2.808	2.962	2.779	2.838
Al^{IV}	1.284	1.234	1.131	1.020	1.213	1.305	1.192	1.038	1.221	1.162
Al^{VI}	1.465	1.494	1.327	1.150	1.258	1.506	1.318	1.120	1.407	1.310
Ti	0.005	0.006	0.005	0.005	0.006	0.007	0.003	0.001	0.004	0.001
Fe	3.458	3.471	3.565	3.602	3.726	3.427	3.695	3.726	3.594	3.716
Mn	0.067	0.108	0.086	0.062	0.119	0.104	0.068	0.072	0.079	0.072
Mg	0.854	0.780	0.903	1.103	0.853	0.834	0.833	1.027	0.802	0.804
Ca	0.021	0.005	0.009	0.008	0.008	0.013	0.014	0.010	0.016	0.018
Na	0.000	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.003	0.005
K	0.003	0.002	0.003	0.001	0.002	0.002	0.003	0.003	0.002	0.002
Total	9.873	9.866	9.898	9.933	9.972	9.893	9.936	9.959	9.907	9.928
Fe value	0.81	0.82	0.80	0.77	0.82	0.81	0.82	0.79	0.82	0.82

FeO* = total iron as FeO

Studie zur Nebengesteinsveränderung bei polymetallischen Erzgang-Lagerstätten unter besonderer Berücksichtigung der Toyoha-Grube in Südwesthokkaido, Japan

Osao SAWAI

Zusammenfassung: Die Toyoha-Grube war lange bekannt als eine typische epithermale Silber-Blei-Zink-Erzlagerstätte in der Grüntuff-Region. Seit neuem jedoch wurden nacheinander Mineralien gefunden, die Zinn, Wolfram und Indium enthalten und die Toyoha-Lagerstätte wird nun als polymetallisches Erzlager betrachtet. Es wurde ebenso festgestellt, daß die Toyoha Lagerstätte die gleichen Charakteristika aufweist wie polymetallische Erzlagerstätte außerhalb der Grüntuff-Regionen. Zum Beispiel weisen die Lagerstätten in Akenobe, Ikuno und Ashio hinsichtlich der Nebengesteinsveränderung die gleichen Eigenschaften auf, wie die Toyoha-Lagerstätte.

Felsen in der Umgebung der Toyoha-Grube, die sich aus vulkanischem und Sedimentgestein des Miozäns und Pliozäns zusammensetzen, haben sich aufgeteilt in verschiedene Typen unterschiedlichen Gesteins. Die Komplizierte Vielfalt der Veränderungen mag verschiedenen Ursachen zugeschrieben werden. Es ist bekannt, daß die Erforschung der Nebengesteinsveränderungen eine wichtige Rolle bei der Erkundung von schwarzen Erzgang-Lagerstätten spielt. Eine erneute Untersuchung der Nebengesteinsveränderung auf der Basis des neuen Konzepts, daß die Toyoha-Lagerstätte eine polymetallisches Erzlager ist, wäre für die zukünftige Erschließung der Toyoha-Grube von großen

Nutzen.

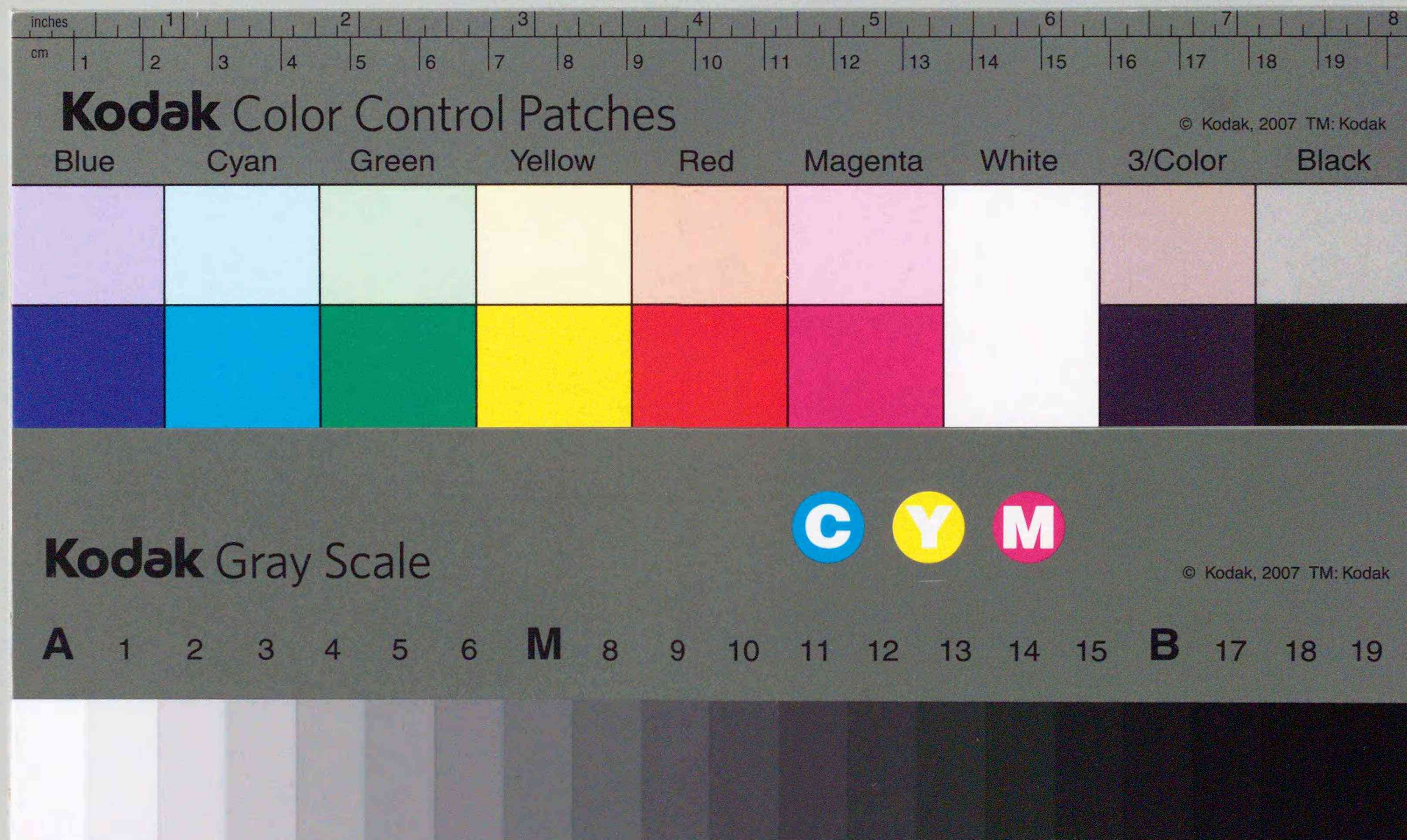
Die Nebengesteinsveränderung um die Toyoha-Lagerstätten teilt sich in 6 Veränderungszonen (A, F, B, C, D und E) auf. Diese erstrecken sich von außen her bis zum Erzgang und unterscheiden sich in ihrem charakteristischen Veränderung-Mineral, ihrer Zusammensetzung und der Verteilung, sowie der Art ihrer Erscheinung. Die Veränderungszone A erstreckt sich weit und zeigt eine zonale Verteilung auf die Unterzonen A-1, A-2 und A-3 in absteigender Reihe. Die Veränderungszonen B bis E sind örtlich um die Erzgänge verteilt, während die Zone F vereinzelt am Unterlauf des Yunosawa-Flusses auftritt. Man geht davon aus, daß die Zone A in erster Linie in einem Prozeß der Diagenese gebildet wurde. Die Zone B ist eine Übergangszone von der Unterzone A-3 zur Zone C. Die Zonen C, D und E sind Veränderungen in Verbindung mit Erzgangformationen, die sich ausschließlich um die Erzadern verteilen. Man geht davon aus, daß die Zone F aus einer Reaktion zwischen Fels und saueren Lösungen in Verbindung mit geothermischen Aktivitäten entstanden ist. Daraus geht hervor, daß die Veränderungen im untersuchten Gebiet durch eine komplizierte Vielfalt zusammengesetzter Veränderungen unterschiedlicher Ursachen hervorgerufen wurden, etwa diagenetische Prozesse, geothermische Aktivitäten und starke Aktivitäten hydrothermale Lösungen, die zu Erzablagerungen und saueren Lösungen führten.

Die Mineralzusammensetzung einer Veränderungszone zeigt im allgemeinen sehr genau die chemische Komposition des betreffenden Felsen. Aber die unterschiedliche Zusammensetzung von FeO*, MnO und MgO wird ebenso von der Chloriten-Zusammensetzung wie von der Mineralien-Zusammensetzung bestimmt. Aufgrund des Eisengehaltes können drei Arten von Chloriten unterschieden werden ((Fe+Mn)/(Fe+Mn)+Mg); 0.3 bis 0.4, 0.4 bis 0.6 und bis zu 0.9. Der Eisengehalt des Chlorits in der Unterzone A-3 hat einen begrenzten Bereich von etwa 0.35. Der Eisengehalt im Chlorit der Zone B variiert zwischen 0.4 und 0.6. Der Eisengehalt des Chlorits der Zone C läßt sich vereinfacht in zwei Gruppen aufteilen: a) 0.4 bis 0.6 wie in Zone B und b) etwa 0.9, was in den Zonen A und B nicht vorkommt. Man nimmt an, daß die Gruppe a) hauptsächlich in der Zone B und die Gruppe b) vornehmlich in der Zone C gebildet wurde. Folglich ist das Chlorit in der Zone C eine Mischung von MgFe-Chlorit, das in der Zone B gebildet wurde und Fe-Chlorit, das in der Zone C gebildet wurde.

Der Eisengehalt von Chloriten und der FeO*-Menge von verändertem Gestein der Veränderungszonen in den Gruben von Toyoha, Akenobe, Ikuno und Ashio wurde verglichen. Es wurde festgestellt, daß der Eisengehalt von Chloriten und der FeO*-Menge von verändertem Gestein in Richtung Erzgang ausnahmslos zunimmt. Diese Art des Vorkommens vom Eisengehalt der Chloriten ist einer der charakteristischsten Merkmale der Veränderungshalo in den Formationen der polymetallischen Erzlagerstätten in Japan.

Aufgrund geologischer Feldforschung und Fissiontrack-Altersbestimmung wurde gefolgert, daß die Motoyama-, Nagato- und Oshidorizawa-Formation mit dem Miozän, die Formationen Kunnui und Yakumo mit dem Neogen-Tertiär-System der Standardstratigraphie von Südwesthokkaido in Zusammenhang stehen.

Sanbonmata-Formation und Oheyama-Formation stehen in Verbindung mit der Kuromatsunai-Formation des Pliozäns. Es wurde ebenso festgestellt, daß die Schichte des letzten Miozäns und des frühen Pliozäns im Gebiet der Toyoha-Grube fehlen. K-Ar-Alter vom 2.93 bis 0.49 Ma werden nachgewiesen im Sericit von hydrothermisch verändertem Gestein, Tongängen und Gangmineral. Daraus schließt man, daß die Toyoha-Lagerstätte in der Periode zwischen Pliozän und Pleistozän gebildet wurde. Darüber hinaus hat man aus der K-Ar-Alter-Datierung geschlossen, daß hydrothermale Lösungen durch das ganze Stadium der Mineralisierung hindurch wiederholt aufgestiegen waren.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