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Geology and Au, Ag, Sn, W, Cu, Pb, Zn mineralizations in central Hyogo Prefecture, Southwest Japan

—Study on the mineralization of late Cretaceous to early Tertiary in the inner zone of Southwest Japan (1)—

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Abstract

The Ikuno Group is composed mainly of acidic pyroclastics. It distributes in E-W trend in harmony with the synclinal structure of the late Paleozoic to the Triassic Tamba Group and composes synclinal and anticlinal structures of the E-W trend. Such structures are found clearly in the central part of the district. They seem to have been formed in relation with activities of Kanagase andesite and quartz diorite.

From the stereographic investigation on the fracture systems, it is possible that the quartz diorite mass ascended in a E-W zone with an inclination of 45° toward SE direction and resulted in folding structure of the second stage which has the axes running with NW-SE trend. In accompany with the first folding movement of E-W trend, it yielded large scale of cross, parallel and diagonal fault systems which show N-S, E-W and NE-SW trends; namely the Maruyama, Yamazaki and Nendo faults, respectively. The uplifting movement of the second stage formed a main fracture zone of the trend NW-SE. The block movement bordered by the faults took place and resulted in the third small-scale folds running in N-S trend and its relevant fault system.

The late Cretaceous to early Tertiary mineralization in the district is considered to be related to these movements mentioned above. The first folding and fault structures controlled not only the intension pattern of plutonics but also regional zoning of metallic mineralization. The main metallic mineralized zone including the Ikuno-Akenobe mines was found related to the second structure. The workable veins called such as Kinsei-hi and Senju-hi might have been formed in the third stage of the tectonic movement.

The various types of ore deposits are observed around the district. In the western part, these ore deposits occur showing a zoning distribution from inner to outer side as follows:

Zone I—Ore deposits characterized by magnetite and sulphide skarn, porphyry copper-like stockwork and arsenopyrite bearing polymetalic veins.

Zone II—Ore deposits characterized by tin-wolfram bearing polymetallic veins and gold-silver bearing quartz veins.

Zone III—Ore deposits characterized by pyrrhotite bearing polymetallic veins.

In the eastern part of the district there are plutonics of small scale, and similar mineralization is found, but the zonal arrangement of ore deposits could not be recognized in the surface.

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1. Introduction

Geological investigation of the Ikuno-Akenobe mining district has been carried out by many geologists since the end of the 19th Century. However, the complicated geology of the district has made the identification of the sequence of igneous activities and the related mineralizations so difficult, and it allowed many different interpretations about the origin of the ore were put forward. The representative views on the mineralizations of the district are summarized as follows:

KATO (1917, 1920, 1926, 1927) proposed that the mineralizations might have been related to the late Tertiary volcanic activities. Afterward, SEKINE (1956a, b, 1960), TSUBOYA (1956) and TATSUMI *et al.* (1970) identified the presence of mineralization of late Tertiary age following the MATSUSHITA's conclusion (1953) on the volcanism in the Kinki region. It means KATO's opinion (1927) was followed by them.

The character of mineralization of Akenobe mine was assumed by SEKINE (1956, 1959) from the view point of "rejuvenation theory" established by SCHNEIDERHÖHN (1952): i. e., it can be considered that the metal element of the Akenobe mine was brought from the basement through the regeneration process related with the middle to late Miocene mineralization. The assumption is based on the existence of various kinds of ore deposit in the Paleozoic formations around the Akenobe mine. This view has been quoted by MINATO *et al.* (1965).

On the other hand, IMAI (1967, 1970, 1975) investigated the process of ore formation in this Akenobe district in relation with volcanism and tectonic movement, and he concluded the age of the mineralization should belong to the late Mesozoic-early Tertiary periods. Based on isotopic studies on quartz diorite, basalt, felsites and some other dyke rocks in the Akenobe and Ikuno mines, ISHIHARA & SHIBATA (1972) and YAMAOKA & UEDA (1974) concluded it is possible that the mineralization is settled at the early Paleogene period (57 million years).

The regional geological survey recently carried out for the subsurface ore deposits by Metal Mining Agency of Japan has also yielded many new informations since the reconnaissance of Bantan district started in 1971.

The present authors had the opportunity to restudy geology and ore deposits of the Ikuno-Akenobe district from the geological and mineralogical aspects since 1968. The results obtained are outlined in this paper.

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2. Outline of geology

The mining area, target for this study, is located in the central part of Hyogo Prefec-

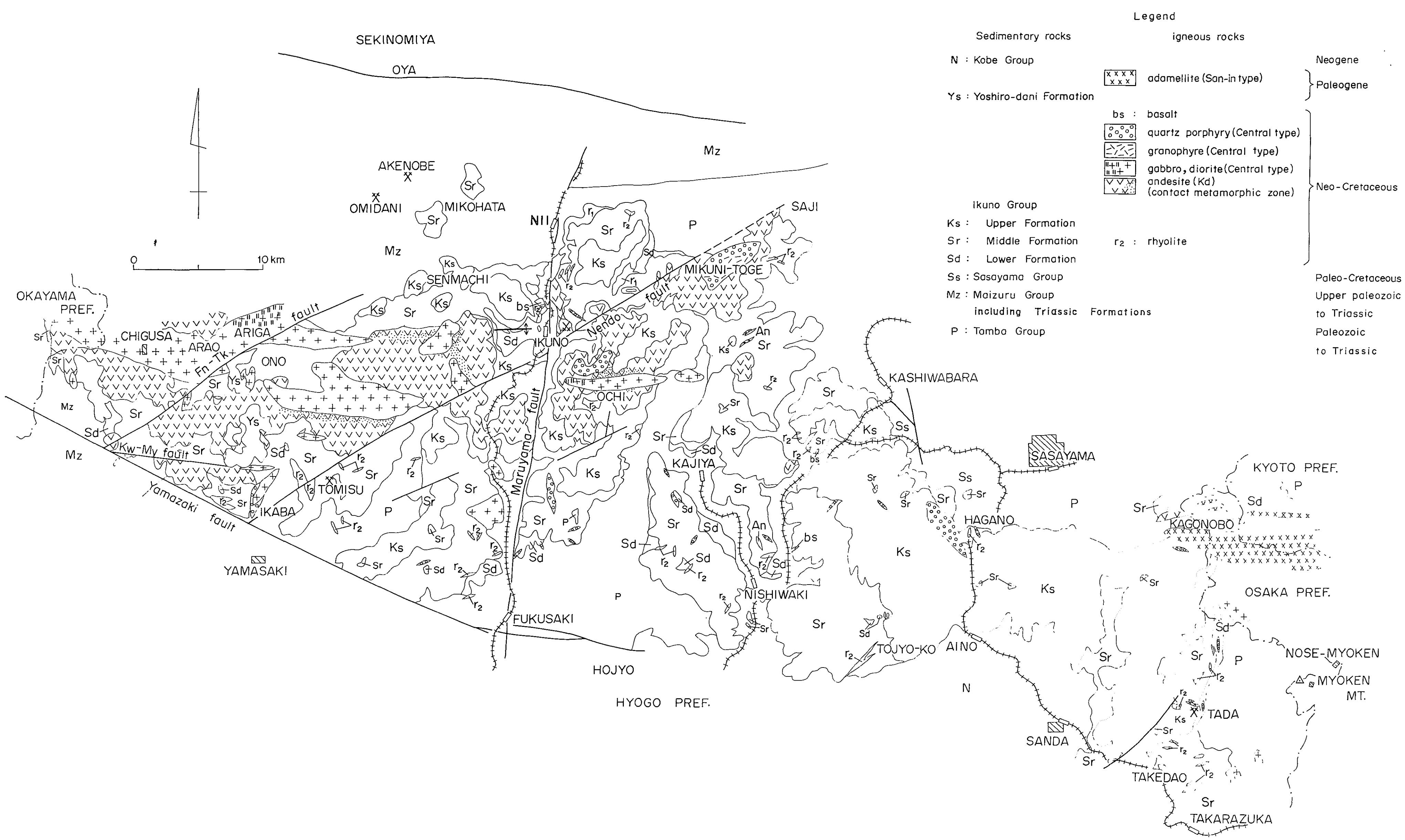


Fig. 1 Geologic map of central Hyogo Prefecture.

ture. Strictly speaking, the area is situated between the southern-end fault of Sekinomiya serpentine zone and the Yamazaki fault (IKEBE *et al.*, 1961).

Geology of the district is shown in Fig. 1 and Table 1. Some informations for the geologic map and colum were quoted from ICHIKAWA *et al.* (1961, 1968), ICHIKAWA (1966) and MINATO *et al.* (1965). Geology of the district has been classified into the following groups in ascending order:

1) Tamba and Maizuru Groups; they are mainly Paleozoic in age and the upper part is believed to be Triassic, in which Yakuno basic rocks are mixed up.

2) Sasayama and Ikuno Group; they belong to Cretaceous system and unconformably overlie the preceding basement rocks, and especially the Ikuno Group predominates in the district. From the lower part to the top of the Groups, volcanics and related pyroclastics of rhyolite and dacite associated with some normal sediments, shale and mudstone, are observed. The chemistry of the pyroclastic rocks is various ranging from intermediate to acidic.

3) Andesite covering the Ikuno Group; it is metamorphosed by intrusion of quartz dioritic rocks. The andesite is confined to appear in the tectonic zone in which quartz dio-

Table 1 Geologic column and paleomagnetism of the central Hyogo Prefecture.

		Sedimentary Rocks	Igneous Rocks	Paleomagne. (I N)
Paleogene	Paleocene	Yoshiro-dani Formation (Ys)	rhyolite (r_3)	
			andesite(An), basalt(bs)	●●●
			×	
Neo-Cretaceous	Hetonian			
	Urakawan		quartz porphyry	
			diorite, granophyre	○
		Ikuno Group	Kanagase andesite (Kd)	○ ○
			basalt (bs)	
	Gyliakian	Upper Formation (Ks)		○
		Middle Formation (Sr)	rhyolite (r_2)	
		Lower Formation (Sd)		
Paleo-Cretaceous	Miyakoan			
	Aritan	Sasayama Group (S_S)		
	Kotian			
Paleozoic		Maizuru Group (Mz)		
		Tamba Group (P)		

× mineralization ● inverse ○ normal magnetism rite masses present.

4) Yoshiro-dani Formation; it encloses rounded pebbles of the above mentioned rocks, especially andesite and quartz dioritic rocks, predominantly in its basal part composed from rhyodacitic tuff breccia or volcanic breccia, suggesting the presence of unconformity between the Ikuno and Yoshiro-dani Formation.

3. Basement rocks

Basement rocks belonging to the Tamba and Maizuru Groups intercalated with the Yakuno basic rocks are distributed surrounding the Cretaceous Ikuno Group consisting mainly of pyroclastic sedimentary rocks, and the Tamba Group forms a basin structure. The boundary between the basement and the Ikuno Group, generally shows the discordant relation, while they are bordered by the Yamazaki fault at the southwestern part of the mapped area.

The Tamba Group is mainly composed of sandstone and shale intercalating with pyroclastic green rocks, limestone and chert. Phyllitic and schistose rocks of the Maizuru Group and the Yakuno basic rocks trending NE are observed at the western area. The main constituent of the Yakuno basic rocks is gabbro which is found at Ariga and other areas. The gabbro shows remarkable facies change represented by gabbro pegmatite, meta-gabbro and amphybolite characterized by the presence of polymetamorphic texture exhibiting plagioclase-blast associated with actinolite-biotite.

Among the basement rocks, the Tamba Group generally shows E-W trend, while the structure of its individual rocks are complicated. However, strikes and dips of the basement rocks are very variable at every locality as shown in Fig. 8.

4. Cretaceous and early Paleogene Systems

4.1 Sasayama Group

The Sasayama Group consisting of andesite and shale forms a basin structure in Sasayama area. It is unconformably covered by the upper and middle Formations of the Ikuno Group.

The Sasayama Group was previously correlated to the Kenseki Group (HASE, 1958) which is distributed in Yamaguchi and Fukuoka Prefectures, southwest Japan, and the Sasayama Group was interpreted to be associated with the sedimentary rocks of early Cretaceous by SAKAGUCHI (1960) and IKEBE *et al.* (1961).

4.2 Ikuno Group

The Ikuno Group is composed mainly of pyroclastic rocks extending for a distance of about 100 km with E-W trend. The width of the Group reaches about 30 km. As given in the geologic columns (Table 2), the Group is divided into three formations as upper, middle and lower. These are lithologically different with each other. The lower formation is composed mainly of andesite, but muddy sediment implying a pause of the volcanic activity is observable, whereas the middle formation consists mainly of dacitic pyroclastic sediment, though the flow sediments are found in the basal part. The upper formation is mostly composed of rhyolitic pyroclastic flow materials. The stratigraphic column of

Table 2 Geologic column of the Ikuno Group.

TAKIMOTO, et al., (1968)	TANAKA, et al., (1971)	NAKAMURA, et al., (1974)	Authors
			An bs Yosiro-dani F.
quartz porphyry	Upper Formation	ID_4	Di QP ×
Kanagase andesite		IS_4 IA_2 IA_3	Kanagase andesite(Kd)
Kanagase rhyolite(Rh_1)	(Rh_1)	IS_2 IS_3 IR_1 IR_2	Upper Formation(Ks)
Kojiikuno Formation(Tf_1)	Middle Formation (Tf_1)	IS_1	r_2 r_2 Middle Formation(Sr) r_2
Uogataki rhyolite(Rh_2) Sakakidani Formation(Tf_2)	(Rh_2) Lower Formation	ID_{CO}	r_1 r_2
Sudareno alternation bed		IS_0	
Naganogawa Formation(Tf_2)	(Tf_2)		Lower Formation(Sd)
pre-Upper Cretaceous	//	//	//

× mineralization

the formation after NAKAMURA *et al.* (1974) and the present authors are shown in Table 2.

The lower formation (Sd): it occurs in some restricted small areas, e. g. in the northern part of Ikuno- and Fukusaki-chos and in the western and eastern parts of the area where the Ikuno Group is distributed. It is generally composed of andesitic volcanic conglomerate, tuff, tuff breccia and shale. The volcanic conglomerate occupies the lowest part of this formation and it unconformably covers the Tamba Group at the western and northern parts of Ikuno mine-Mikuni-toge. The above-noted volcanic conglomerate changes gradually to andesitic tuff breccia intercalating some dacitic pyroclastics. The banded shale bed intercalating with fine sandstone concordantly covers the andesitic tuff and tuff breccia. The preceding pyroclastic rocks undergo chloritization, epidotization and albitization in places. These rocks are characterized by green colour.

Drillings for hot spring at the western area of Ikuno-cho suggest that the formation may be 500 m thick (TAKIMOTO *et al.*, 1968).

Middle formation (Sr): it vastly overspreads in the district, and it consists mostly of pyroclastic sediment intercalating with thin mudstone and rhyolite. In some areas, pyroclastic flow sedimentes observed in the lowest part of the formation. The formation is correlated to Tf_1, Tf_2 and Rh_2 of TANAKA *et al.* (1971), or to the Sakakidani and Kojiikuno formations of TAKIMOTO *et al.* (1968) as shown in Table 2.

The pyroclastic flow sediment (r_1), previousely called rhyolite is distributed in the north-central part of the district. The pyroclastic material is dacitic containing lithic fragments and essential patches which are chloritized and stretched.

The pyroclastic sediments, main components of the middle formation, are composed of well stratified dacitic lapilli tuff. Thin tuffaceous mudstone layers are frequently observed in it. In the Ikuno area, the dacitic lapilli tuff encloses pisolite. Some of the pisolites resembles to the so-called Kikukaseki in the internal structure. And the upper part of the formation is mainly composed of tuff containing a lot of small pumice of 1–3 cm in size. The pumice in this bed is seldom chloritized and does not show stretched texture as found in the pyroclastic flow.

Total thickness of the formation attains to about 1,000 meters at Ikuno area.

Fluidal textured rhyolite (r_2) in the middle formation has been called Mabuchi rhyolite (Rh) by TAKIMOTO *et al.* (1968) and afterwards, it has been called rhyolite (Rhm) by TANAKA *et al.* (1971). The flowage of the rhyolite is very variable. The flowage of N-S, E-W, NE, NW and WNW strikes are dominant. The extent of the rhyolite body is 3 km in maximum along the longitudinal direction of NNW trend. Some bodies are intercalated as lava flow within pyroclastic beds in the middle formation.

It is rather difficult to find the boundary between the rhyolite and pyroclastic rocks, because all of the rhyolites wholly altered into the secondary mineral assemblage as quartz-chlorite. Fluidal texture observed partially is emphasized by the linear arrangement of chlorite.

Upper formation (Ks): it has been correlated to Kanagase rhyolite (Rh_1) by TAKIMOTO *et al.* (1968) and TANAKA *et al.* (1971). This formation is frequently observed from the central to eastern areas of the district and is composed of welded crystal tuff accompanied by coarse phenocrysts of quartz, orthoclase, hornblende and biotite. Slight alteration is observed in the crystal tuff. Altered facies are restricted in loose upper- and lower-part of the formation. Unaltered dark gray and compact facies in the middle part of the formation looks like rhyolite or quartz porphyry at first glance, however, it takes distinct pyroclastic and welded texture. The foliation caused by chloritized and collapsed lenses is observed in the lower and upper parts of the upper formation.

Mineral assemblage of this formation is various, especially the distribution manner of hornblende and biotite is characteristic: i.e. a lot of hornblendes is observed at the Ikuno area and a lot of biotite in the eastern district respectively. Crystal tuff contains lithic fragments in general and fragments of the basement rocks are found at the boundary area between Sanda and Sasayama.

The upper formation conformably covers the middle formation of the Ikuno Group. Sometimes it, however, directly lies on the basement rocks.

The thickness of the formation attains to about 400 meters.

Features of the Ikuno Group is summarized as follows: The Ikuno Group can be classified into the lower (Sd), middle (Sr) and upper (Ks) formations based on the lithologic characters, and these three formations show the characteristic distribution as shown in Fig. 1. The lower formation is composed of pyroclastic sediments of andesitic or dacitic materials. The middle formation consists mostly of pyroclastic sediments of dacitic material intercalated with rhyolitic pyroclastic flow sediments. This implies that the volcanic activity changes from intermediate to acidic in composition in ascending order. The occurrence of shale and mudstone beds in the lower and middle formations implies that there might have been a pause of the volcanic activities. The total thickness of the Ikuno Group is estimated at about 1900 meters.

4.3 Kanagase andesite (Kd)

Kanagase andesite was named by Maruyama (1957) for the andesitic rock distributed around the Kanagase area of Ikuno mine. It covers the upper formation of the Ikuno Group and is overlain by tuff breccia of the Yoshiro-dani Formation. The main part of the andesite is composed of volcanic flow, andesitic tuff and conglomerate. This andesite extends from Mikuni-pass as far as the prefectural boundary with Okayama Prefecture through the Ikuno area. The zonal extent of the preceding andesite is rather parallel to the distribution of quartz diorite (Fig. 1).

Andesite keeping the fresh state is compact and dark gray in colour. Hypersthene and augite are main mafic constituents, which are partially altered to chlorite. Plagioclase phenocrysts are frequently replaced by some secondary minerals such as chlorite, sericite, albite and epidote. The ground mass shows hyalopilitic texture. Characteristic green colour of the rock might have been caused by the presence of chlorite and albite. Thus the andesite can be called as propylite due to its mineral assemblage.

It is notable that the andesite around the quartz diorite intrusion is metamorphosed. A mosaic texture by newly formed quartz and biotite is observed. These andesites of dyke-form intrude into the Ikuno Group and enclose many favorable metallic ore vein at Akenobe, Ikuno and other mines.

4.4 Dyke rocks

Andesite (An) occurs as dyke in the basement rocks and the Ikuno Group. A large number of dykes trending NEE cuts across ore veins at the Ikuno and some other areas.

Basalt (bs) is distributed as sheet or dyke in the upper and middle formations of Ikuno Group at Ikuno and Akenobe areas. At Akenobe and other areas, the basalt dyke cuts across the ore veins. The mode of occurrence of basalt is very similar to that of andesite, and basalt, however, can be distinguished from the andesite by its dark green colour. Though mafic minerals of the basalt are perfectly replaced by secondary minerals such as chlorite and carbonate, typical interstitial basaltic texture is observed in the ground mass.

4.5 Plutonic rocks

Plutonic rocks in the district are classified into two types: and the one is referred to Central type (YOSHIDA, 1961) and the other to San-in plutonic rock type (IKEBE *et al.*, 1961).

The central type shows variety of rock facies ranging from acidic granophyre to basic gabbro. These are gabbro, trondhjemite, diorite, quartz diorite, adamellite, porphyritic adamellite, granophyre and quartz porphyry. The above-stated rock facies appear in one plutonic body and shows gradual change to each other. The predominant facies is quartz diorite, so the plutonic rock mass is called "Quartz diorite" by the gross.

The plutonic rocks of the central type spread over the area where yielded the Kanagase andesite. The E-W trend longitudinal axes of the main masses of the plutonic rocks vary from about 8 to 24 km in length.

Contact metamorphism is observed in the Kanagase andesite and pyroclastic rocks of the Ikuno Group around these intrusive rocks.

Medium-grained gabbroic rock enclosed in the dioritic rock facies are found in a small part of the so-called quartz diorite mass near Ochi and at north of Ariga. The rock is dark gray in colour and includes pyroxene phenocrysts 4–5 mm long. Trondhjemite occupies a part of diorite body at the eastern area of Ochi.

Two main masses of quartz diorite are found in the western part of the district. Besides, there are small bodies of quartz diorite in some other places of the district. Around the intrusive masses, satellitic small intrusive bodies are found.

The quartz diorite is wholly porphyritic. The porphyritic texture is caused by the presence of obvious prismatic plagioclase. Core part of the main masses in Chigusa area, however, shows plutonic rock facies represented by coarse equi-granular leucocratic facies.

Adamellite is found around the small diorite bodies or the main diorite mass. At the margin of the adamellite, porphyritic rock facies is observed.

Aplite, granophyre and quartz porphyry are distributed near the adamellite mass, and quartz porphyry occupies outermost side of the main plutonic masses. The quartz porphyry occurring in small scale seems to be stock or dyke. Along the contact between plutonic mass and the pyroclastic sediment of the Ikuno Group, especially at Ikaba area and at Mikuni-pass, quartz porphyry or aplitic porphyry are found.

Quartz porphyry generally occurs as vertical dyke running in N-S or NE trend at the margine of main plutonic mass. Ground mass of these rocks shows microcrystalline or cryptocrystalline texture.

Plutonic rock of San-in type elongated with E-W trend is locally distributed at northern Nose area. From the rock properties, this rock can be called adamellite. The adamellite has medium- to coarse-grained equigranular texture consisting of quartz, orthoclase and plagioclase. Apatite, sphene, alanite, zircon and fluorite are accessory minerals.

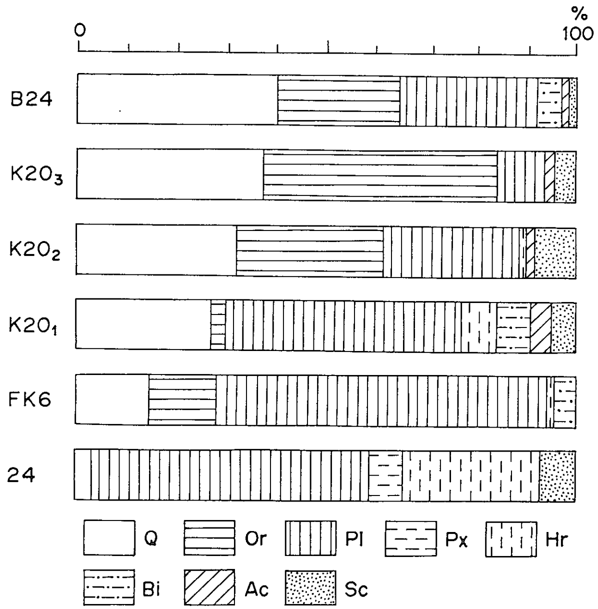
Mineral assemblages of these rocks and the optic characters of each mineral are given in Fig. 2 and Table 3.

4.6 Yoshiro-dani Formation

The pyroclastic sedimentary rocks belonging to the Yoshiro-dani Formation is locally distributed and unconformably covers the Ikuno Group and the Kanagase andesite at the northern area of Ikaba. In these areas, they are rhyodacitic and characterized by dark brown tint and layered texture.

Strictly speaking, the Formation is composed of rhyodacitic tuff breccia or volcanic breccia, dacitic tuff enclosing big andesite bolder, vitric tuff and medium to fine-grained tuff from the bottom to the top. The total thickness of the Formations is calculated at about 400 meters. Upper vitric tuff has lithic fragments and shows welded texture. Rhyodacitic tuff breccia in the Formation encloses sub-angular pebbles of quartz diorite, porphyritic adamellite, quartz porphyry and andesite. This may be a kind of "breccia dyke" implying the presence of channel way through the above-described pyroclastic rocks.

Rhyolite occurs restrictedly in the northern area of Ikaba. The rhyolite in the Yoshiro-dani Formation is in general situated on the andesite of Kanagase type. It shows dark gray colour and fluidal texture made up by lineated phenocrysts of small-grained feldsper.



Q: quartz, Or: orthoclase, Pl: plagioclase, Px: pyroxene, Hr: hornblende, Bi: biotite, Ac: accessary minerals, S: secondary minerals. Plutonic rock of the Sanin type-B24: adamellite. Plutonic rocks of the Central type-K2O$_3$: granophyre, K2O$_2$: adamellite, K2O$_1$: trondhjemite, Fk6: q. diorite, 24: gabbro.

Fig. 2 Volume percent of rock forming minerals in plutonic rocks.

Table 3 Optical Properties of the Rock Forming Minerals in the Plutonic Rocks.

		or	Pl	Biotite			Hornblende			Zircon
				x	y	z	x	y	z	
24	Gabbro		An_{70}				pale brown	brown	greenish brown	pale brown
Fk6	Q. dio.	microperthitic	An_{56}	pale yellow	brown	dark brown	pale yellow		pale brown	
K20$_1$	Trondhj.		An_{52}	pale brown	brown	dark brown	pale yellow	pale greenish brown	pale greenish brown	
K20$_2$	Adam.	microperthitic	An_{37}		chloritized		pale yellow	pale yellowish brown	pale greenish brown	
K20$_3$	Aplite	graphic	An_{10}							
B24	Adam.	perthitic	An_{17}	yellowish brown	brown	dark brown	pale yellowish brown	dark brown	greenish brown	pale yellow

5. Tectonic features of Ikuno Group

The Ikuno Group running with E-W trend is clearly controlled by the synclinal structure of basements. The lower and middle Formations of the Ikuno Group consist mainly of pyroclastic materials but thin layers of shale and mudstone are intercalated. From the bedding plane formed by the layers of above-noted clastic rocks, geologic structure is understood. From these features, three fold systems as to the Ikuno Group are distinguished as A, B and C Types. The whole sequence is folded with a dip of 20–30°. Deeply developed fractures perhaps caused by the intrusion of plutonic mass are observed in the sequence.

5.1 Fold system

Three types of fold can be distinguished in the field. These are called A, B and C. Type A is parallel to the syncline axis of basement. It runs with nearly E-W trend at the north-western area of Ikuno and at the southern area of Ochi. The slaty rock of the Tamba Group occurs at the eastern side of the synclinal axes. One of the synclinal structures trending E-W coincides with that of basement, and the distribution of the Ikuno Group is controlled by this structure.

Type B running with NW-NE trend is found in the area where the Ikuno Group occurs. The structure of Type B is somewhat perpendicular with the Type A. At the western side of the district, a synclinorium of 3–4 km width is recognized. At the northern areas of Fukusaki, the anticlinal and synclinal axes run along N-S, and at the westernmost area and the northern and southern areas of Kojiya, folding axes run with NE trend. Besides, at the area of Ikuno mine, semibasin structure elongated along the N-S direction is observable.

The synclinorium belonging to Type B is observed in some places of the area. The direction of the synclinorium is various, e.g. NW, NE and N-S. This is one of the characteristic features as to the geologic structure of the Ikuno Group. The structure is interpreted by the contour map of the basal plane of the middle Formation (Fig. 3).

Type C, as to the folding, has an axis trending N-S in the Kanagase gallery of the Ikuno mine. The width of the folding is about 200 m at biggest. In the Kanagase gallery, the Ikuno Group is composed of pyroclastic rocks of tuff breccia (Tb), andesitic tuff (Tf II_2), lapilli tuff (LaT II_1), medium tuff (Tf II_1), (Tf I_2) and lapilli tuff (LaT I_2) in ascending order as shown in Fig. 4. The folding at the Kanagase gallery is different in scale from the type B, because the latter has a folding width of about 3–4 km whereas that of the former is about 200 meters. Thus the folding of small scale can be distinguished as Type C. Although the N-S fold in the Kanagase gallery appears in a local area, it plays an important role to control the arrangement of the workable ore veins.

5.2 Fracture and fault system

There are faults running for a distance of 20–50 km, with N-S trend at Maruyama and Akenobe. The NWW fault recognized by IKEBE *et al.* (1961) at YAMAZAKI runs for a distance of 50 km. The Nendo fault trending with NE also runs for a distance of 50 km.

The Yamazaki fault appears at the boundary between the Tamba Group and the

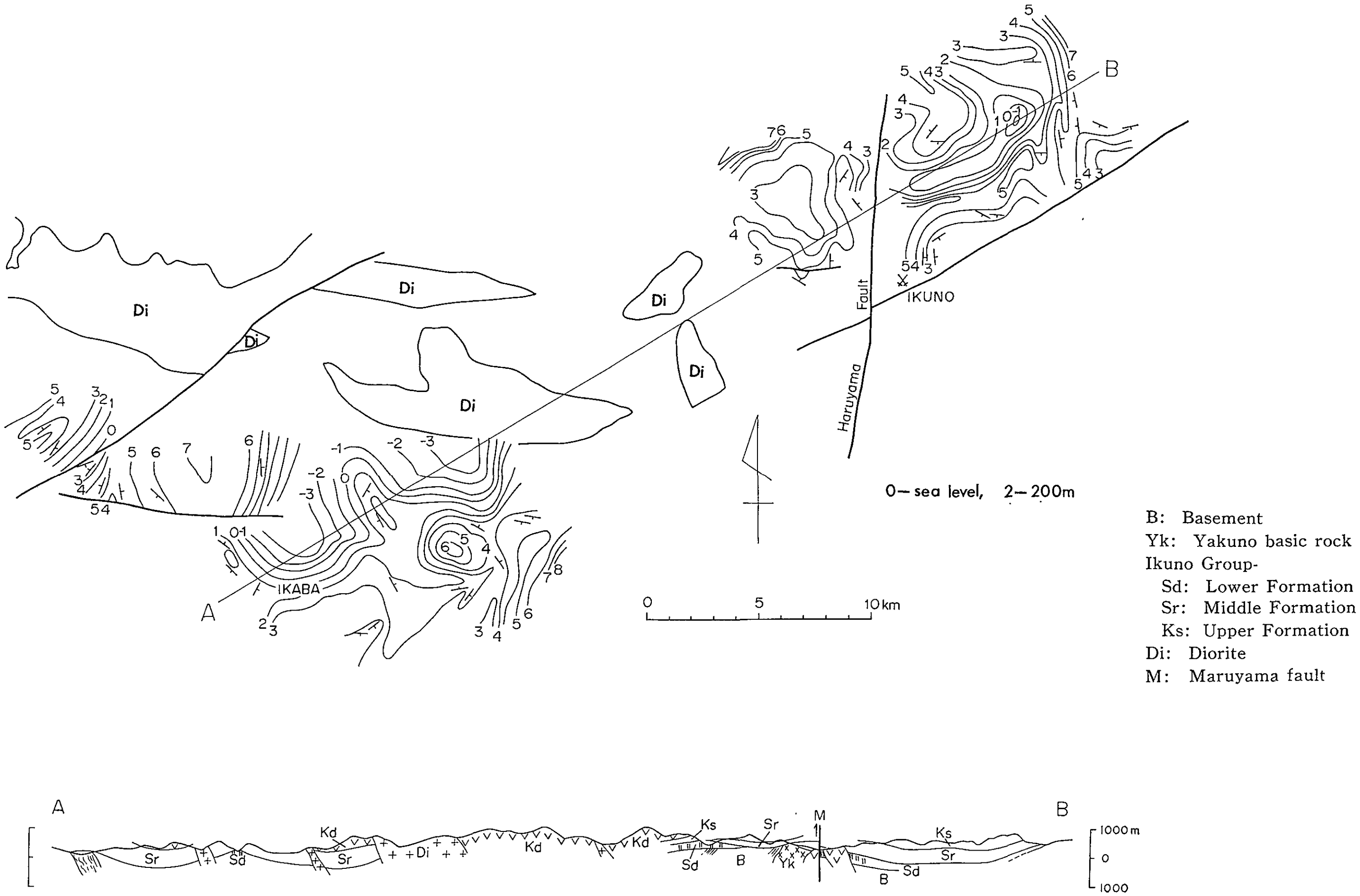


Fig. 3 Contered map showing base plane of the middle formation of the Ikuno Group.

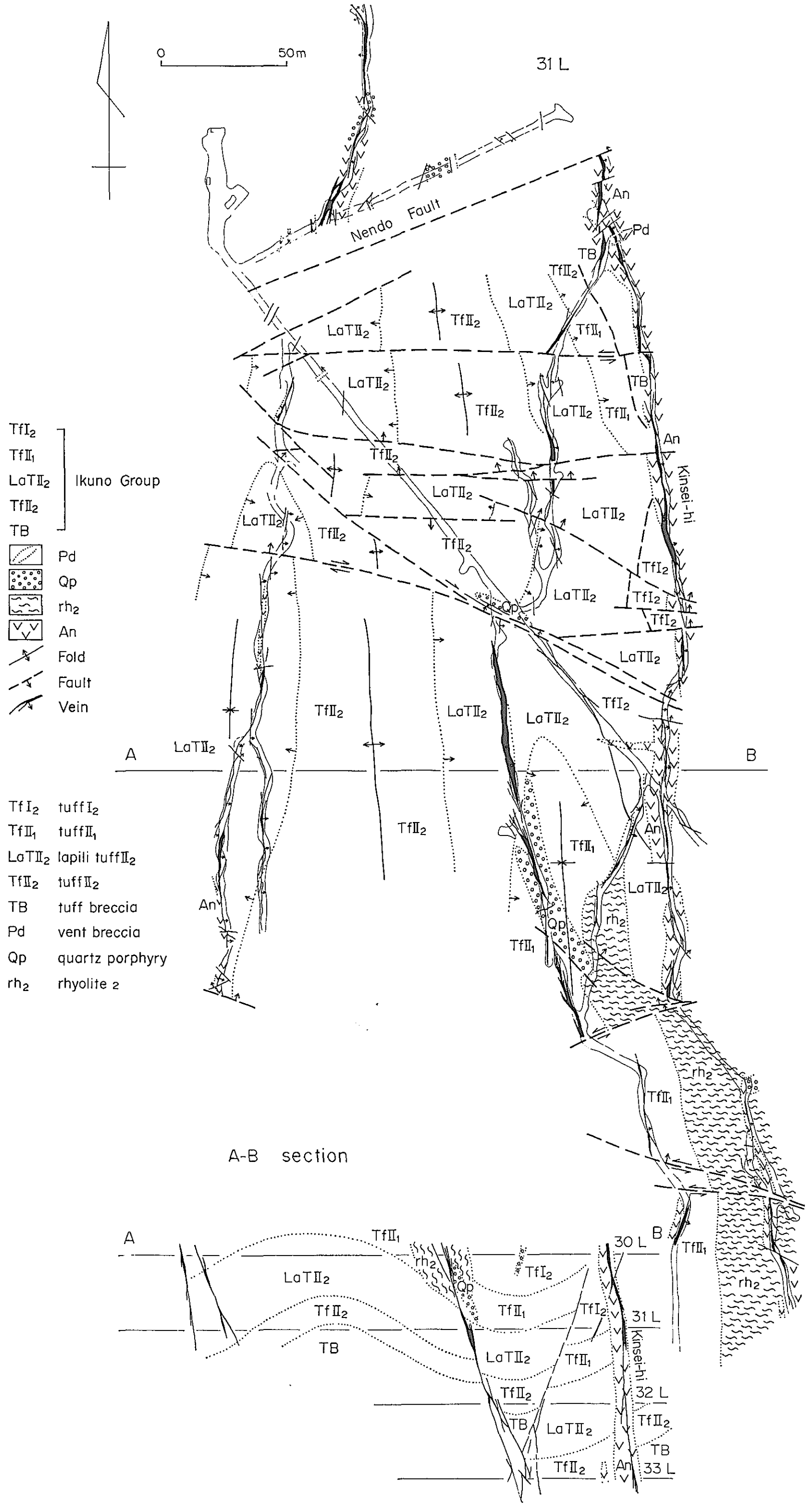


Fig. 4 Map showing the distribution pattern of type C fold and fault system in Kanagase area, Ikuno mine.

southern end of the Ikuno Group. From the distribution of the Ikuno Group, it is estimated that the western block of the Maruyama fault was horizontally dislocated about 3 km to the left side along the fault. It is a hinge fault which is characterized by sinking at the northeastern side of the fault and uplifting at the northwestern side. Its characteristic appearance is shown by the folding axis of the basement which trends E-W at the Sasayama area and swings towards NW at the northeastern side of Maruyama fault.

The dislocation of the Ikuno Group affected by Nendo fault is so slight that is estimated to have moved about 100 m downward and westward along the fault plane dipping 70–80° to the north at Kanagase. Funakoshi-Takano (Fn-Tk) fault, which is parallel

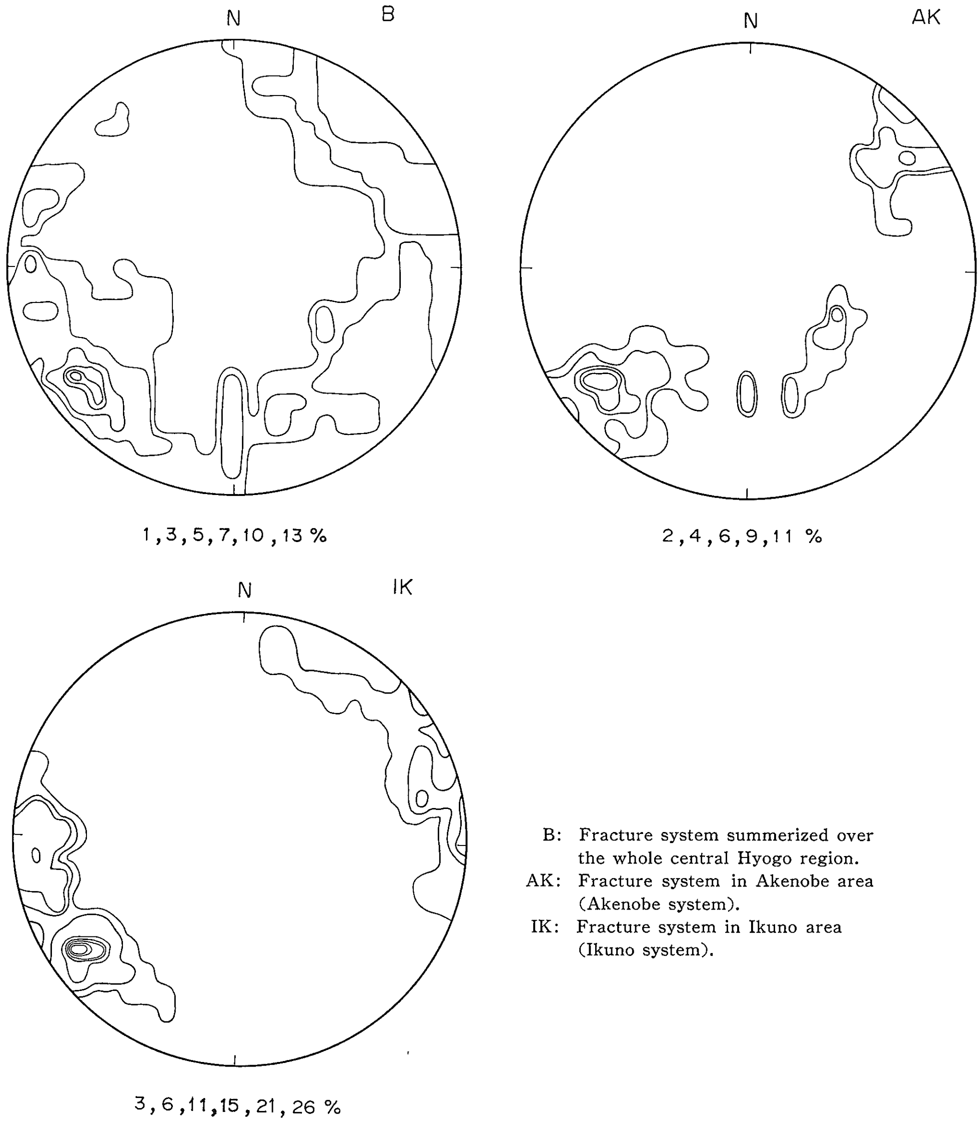


Fig. 5 Stereographic projection of the fracture system in central Hyogo Prefecture.

to the Nendo fault, is remarkable. According to the geologic map (Fig. 1), Kawasaki-Miyamoto (Kw-My) fault, running along E-W, sink at the southern block of the area.

The above-described faults are considered to have been formed in relation to the formation of the sedimentary basin, of E-W trend, in which the Ikuno Group accumlated. Maruyama fault running with N-S might have been formed as a crevice crossing the axis of the preceding basin. Nendo and Yamazaki faults trending NE and NW, are diagonal to the axis and Kawasaki-Miyamoto fault of E-W trend is parallel to the axis. It is considered that the origin of these faults should be related to the tectonic movement of the basement, perhaps caused by the late Cretaceous plutonism.

All these fault, which yielded some compressive fracture swarms associated with tensional cracks are observed at the area from Akenobe-Omidani to Ikuno and are composed of numerous small cracks or fractures. Ascent of the andesite dykes, and the mineralization found in the Ikuno-Akenobe mining area is controlled by the above-mentioned structures.

These fractures in the district were divided on the basis of their distribution pattern into two systems; Ikuno system (Ik) and Akenobe system (Ak). In addition, in order to clarify their geologic significance, fracture system (B) developing over the whole central Hyogo region were summarized, and these fracture systems, Ik, Ak and B, were plotted on Schmidt's stereographic nets (Fig. 5) respectively.

At the Ikuno area, fractures running with N38°W trend prevail and are accompanied by subordinate fractures trending N10–15°W as given in Fig. 5-Ik. As for the Akenobe area (Fig. 5-Ak), the main fracture takes N40°W direction, and the subordinate ones showing N25°E, N38°W and E-W trend are observable. In the other districts the main fractures take N55°E direction, while associated minor fractures run with N25°W and N70°W direction. Veins and fractures of the whole district are projected in Fig. 5-B. The figure shows that the system showing N38°W concentrated as far as 12%, while subordinate ones characterized by N15°W, N25°W, N-S and E-W trends are not so much concentrated.

5.3 Consideration

The distribution pattern of the fracture systems in the district is similar to that of Sitter's (1956) joint system associated with anticlinal fold (Fig. 6). It seems to suggest that the main peaks of stereographically plotted fractures of this district might have been caused by diapiric movement with an inclination of 45° to SE along the scared weak zone running to E-W. Trend of above-mentioned compression is perhaps controlled by Type A fold system. The faults running along N-S, NE and E-W trends might have been formed by the compressive tectonic movement of N-S trend during the formation of the basin accumulation of the Ikuno Group. The Type B fold may have been formed by the intrusion of igneous rocks of late Cretaceous along a scared weak zone of the Type A fold movement. The tensional cracks of NW trend which played a role for the formation of the main mineralized zone at the Ikuno-Akenobe area are small in scale and are more locally developed. The structure in this area, however, might have been formed in relation to the movement of the Type B fold and the diapiric movement of the block surrounded by the scared weak zone of Type A. Type C fold is observed in the block surrounded by a lot of faults, Nendo and the other faults are shown in Fig. 4.

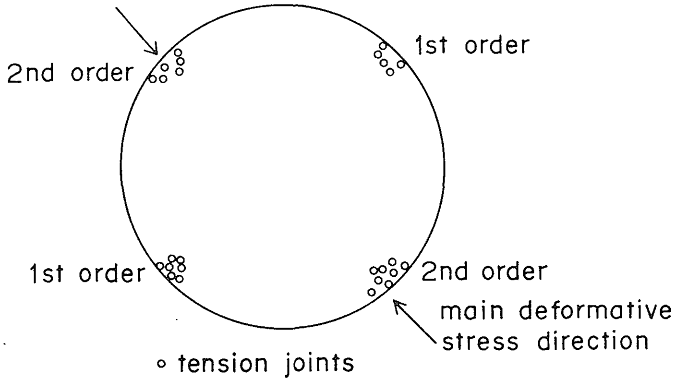


Fig. 6 Stereographic representation of main joint in anticlinal structure (SITTER, L.U.DE, 1956).

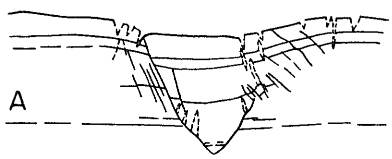


Fig. 7 Normal fault by clay cake mounted on two board (CLOOS, H., 1930).

The above-noted fractures and the related tensional cracks were also favorable for ore lodes. The faults and fractures at the Kanagase area seemingly have been formed during the folding movement of Type C. This manner is very similar to the CLOOS's (1930) model as given in Fig. 7. As discribed above, the fractures at the Kanagase area show that they have repeatedly removed by the triple movements: those are Type A, B, and C.

As above-stated, it is clear that the igneous activities related to subordinate volcanic intrusion were controlled by the tectonic pattern trending N-S, NE and E-W, whereas main volcanic and plutonic emplacements were realized along the E-W weak zone. Some dykes of andesite (An) and rhyolitic breccia cutting ore vein are controlled by the NE fracture. So, the above-stated volcano-plutonic igneous activities seem to be a harbinger of the formation of ores, because the fractures are closely related to the folds of Types A, B, C. The felsite (SAIGUSA, 1958) and rhyolitic breccia dyke (MARUYAMA, 1957, ISHIHARA & SHIBATA, 1972), slightly mineralized, might have been formed in the latest phase of the mineralizations.

6. Geomagnetism of the Ikuno Group

Several samples of volcanic rock and ore from the Ikuno area, e. g., rhyolitic crystal tuff of the upper formation of the Ikuno Group, Kanagase andesite, sheet-formed basalt, meta-andesite, Kojo andesite, were obtained for geomagnetic examination. Hand-specimens of magnetite ore from Ryusei vein and basalt cutting the vein of the Akenobe mine were also provided for the same purpose.

The results of the examination showed that all the samples from the upper formation of the Ikuno Group were normally magnetized, whereas all the Kojo andesite of the northern side of the Ikuno area, basalt cutting the ore vein and magnetite ore from Ryusei vein of the Akenobe mine showed inverse magnetism. It was also found from the examined result that the samples showing inverse magnetism were equivalent to the magnetism of upper Tenkadaiyama Group, early paleogene system of the inner zone of southwest Japan reported by SASAJIMA *et al.* (1966). According to ISHIHARA *et al.* (1972), stratigraphic position of the rock sample indicating inverse magnetism shows an age of 57 million years, and the emplacement of the rock took place during the epoch of the early Paleogene. Those were shown at the right side of Table 2.

7. Relation between igneous activities and mineralization

Outline of the mineralization observed in the central Hyogo region is roughly reported in this paper. Two mineralized zones, west zone and east zone, can be distinguished. One of them, west zone, is a mineralized zone developing around the plutonic massif of Chigusa-Ochi, and is characterized by zonal mineralization. The other, east zone, is restrictedly found around the plutonic massif of the Kasai-Nose area eastwards far from the Ikuno-Akenobe area (Fig. 8).

On the other hand, peculiar mineralized zone characterized by the presence of clay deposits is known. This zone mainly occupies the space between above-mentioned two mineralized zones. In addition some clay deposits are distributed within a gold-silver mineralized subzone as shown in Fig. 8.

7.1 West zone

The western mineralized zone is divided into three zones (I, II and III), and they are distinguished by the distance from the pluton. They display a kind of zonal arrangements around the Chigusa plutonic massif.

Zone I: This mineralized zone apears in the plutonic main mass and at the contact of the pluton. Zone I can be divided into following subzones based on the presence of different ores.

I_1 Ore deposits of magnetite and sulphide skarn type.

I_2 Ore deposits of stockwork-like porphyry copper and arsenopyrite bearing polymetallic vein type.

I_3 Ore deposits consisting of both above two type.

Zone II: This mineralized zone appears outside of Zone I. In this zone, polymetallic or gold-silver deposits are found;

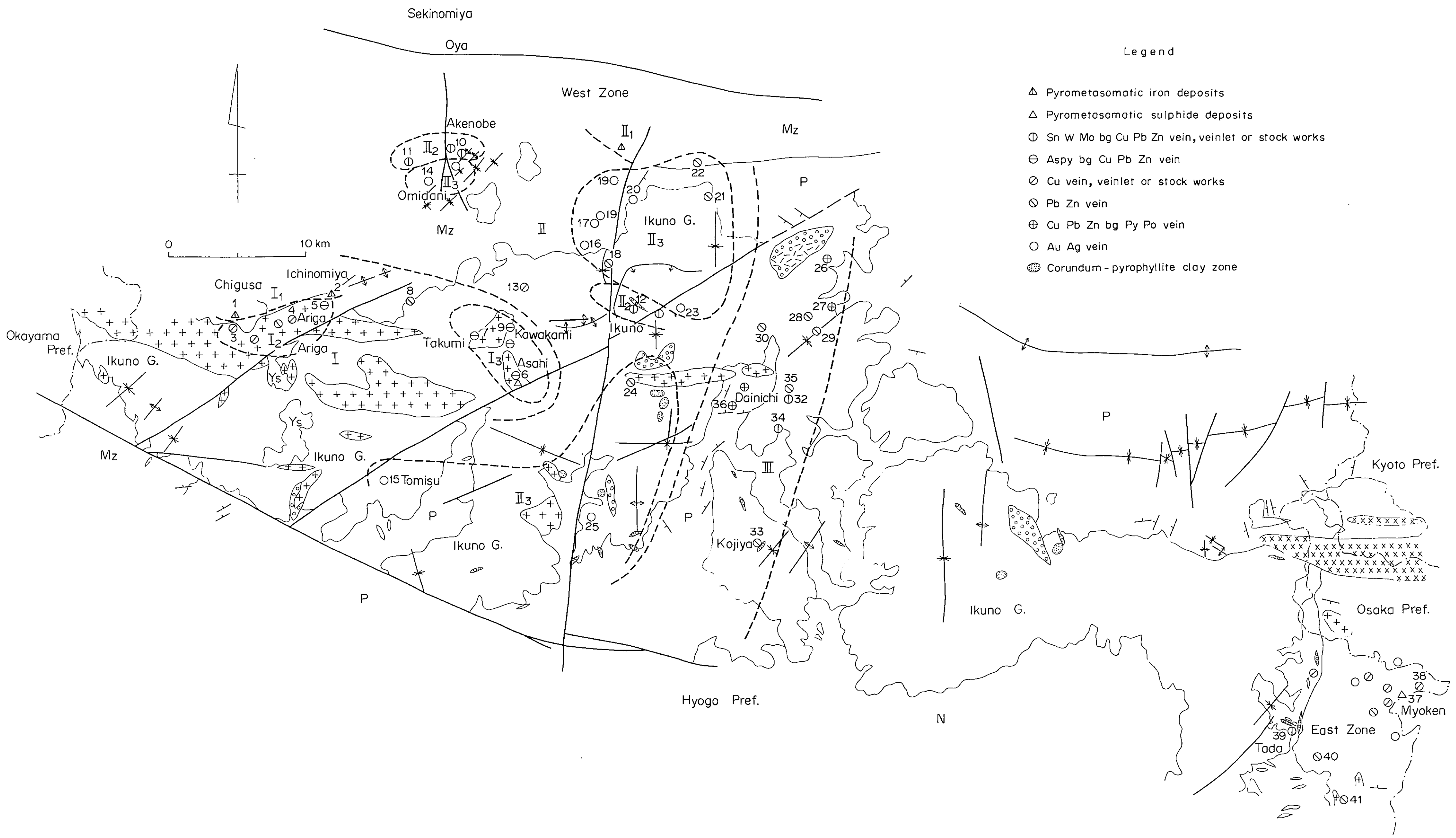
II_1 Ore deposits of magnetite skarn type.

II_2 Ore deposits of tin-wolfram bearing polymetallic vein type.

II_3 Ore deposits of gold-silver bearing aduralia-quartz vein type.

Zone III: This mineralized zone occupies the outermost from the pluton; this is characterized by the presence of pyrrhotite bearing polymetallic vein type.

Although the ore deposits distributed around the central pluton do not always coincide with the model of zonal arrangement proposed by EMMONS (1940), i.e. (15) Sn, (14) W, (13) Bi, (12) As, (11) Au, (10) Cu, (8) Zn, (7) Pb and (6) Ag from central part to



Ore deposits and mines. West zone I_1-1 Chigusa, 2 Ichinomiya, I_2-3 Arao, 4 Ariga, 5 Hideshige, I_3-6 Asashi, 7 Takumi, 8 Sankata, 9 Kawakami, II_2-10 Akenobe, 11 Akagane, 12 Ikuno, II_3-13 Senmachi, 14 Omidani, 15 Tomisu, 16 Daijyo, 17 Omiya, 18 Asako, 19 Nii, 20 Tatara, 21 Aokura, 22 Yobuto, 23 Sudareno, 24 Omiya, 25 Sanyo, III-26 Sankata, 27 Kuromi, 28 Kyu-Kuromi, 29 Sin-Kuromi (Ueda), 30 Shimizu, 31 Toba, 32 Omisaka, 33 Kojiya, 34 Nyukaku, 35 Kabasaka, 36 Dainichi. East zone-37 Myoken, 38 Katsuhoshi, 39 Tada, 40 Akamatsu, 41 Mizuho.

Fig. 8 Distribution of ore deposits and geologic structure of central Hyogo Prefecture.

margin of a mineralized zone, they have characteristic properties as preceding notes.

I_1 type is mainly composed of massive magnetite ore replacing quartz diorite and paleozoic limestone, and is associated with skarn minerals such as garnet, salite, amphibole and epidote. Iron ore deposits of Chigusa mine replacing quartz diorite of Arao area and of Ichinomiya mine replacing limestone of the Tamba Group, are representatives.

The above-stated ore deposits are so small in size that these mines have been closed already.

I_2 type occurs in the northern margin of the Chigusa plutonic mass. Low grade copper ore deposits are present in Arao and Ariga mines. The ore body of the Ariga mine shows a pipe-form, consisting of network vein swarm in which chalcopyrite and molybdenite are observable. The ore deposit of Hideshige mine at the west side of Ichinomiya mine is polymetallic chlorite vein type. The deposit is characterized by the presence of a lot of arsenopyrite.

I_3 type ore deposits are found in diorite or andesite on the west side of Ikuno-cho.

This type is composed of skarn type deposits and chlorite copper vein type deposits, the former consists of pyrite, hematite and sphalerite belonging to skarn type, and the latter arsenopyrite bearing chlorite vein.

Ore deposit of Asahi mine is a kind of skarn type, in which garnet, epidote, quartz, chlorite, pyrite, sphalerite, galena and hematite are present. The ore deposits of Takumi and Kawakami mines are polymetallic chlorite vein type accompanying a lot of arsenopyrite, and are similar to that of the Hideshige mine. The manner of alteration around the ore vein in diorite is similar to that of Ariga and Arao mines, and in the alteration halo, lower grade ores consisting of scattering chalcopyrite and other copper minerals occur in sericitized quartz diorite.

II_1 type ore deposits (magnetite ore deposits of skarn type), are found at northern-end of the district. These II_1 type ore deposits should be excluded from the group of the western zone, because these are closely related to the magmatism belonging to the San-in type granite, although those are similar to the magnetite skarn ore deposits at Chigusa and Ichinomiya mines.

II_2 type ore deposits are known in Akenobe, Fudono, Akagane and Ikuno mines. These ore deposits belong to polymetallic vein type, in which tin, wolfram and molybdenum are present. The main ore minerals of the vein are lead, zinc and copper sulphides. Cassiterite, scheelite, wolframite, tin sulphosalts, native gold and silver are important accessory minerals. Besides, sulphide and sulphosalt minerals of silver, arsenium, antimonium, bismuth and tellurium are obserbed.

II_3 is gold and silver bearing quartz vein type, found at Omidani, Tomisu, Daijo and some other mines. Besides, there are a lot of polymetallic veins consisting of lead, zinc and copper sulphide minerals. These are observed at Omiya, Asako, Arai, Tatara, Yobuto, Aokura, Sudareno, Sanyo and some other mines. In these veins, aduralia and flourite are found as gangue minerals.

The ore deposits belonging to II_3 type are found outer side of II_2 type ore deposits. The II_3 type deposits, Sudareno, Mikohata and Omidani vein swarms are distributed outside the Ikuno and Akenobe mines.

According to some informations on the mines the ore reserves of the Ikuno and

Akenobe mines are estimated at about 20 million tons (Cu 2%) respectively. Ikuno mine produced about 15 million tons of ores and closed in 1973, whereas Akenobe, Omidani and Tomisu mines are successively working.

Zone III is polymetallic chlorite-quartz vein type consisting of pyrrhotite, arsenopyrite, chalcopyrite, galena and sphalerite. Ore deposits of this type are found at the outer-most side of the western mineralized zone. Many mines, Sankata, Kyu-kuromi, Shin-kuromi, Kuromi, Shimizu, Kabasaka, Nyukaku, Dainichi, Kojiya and Omisaka, within the mineralized zone of type III are noted.

Cassiterite is found in Nyukaku mine, and molybdenite in Omisaka and Shin-kuromi (Ueda) mines respectively. This mineralized zone is characterized by the presence of metal elements such as tin and molybdenum, although those elements are not workable.

7.2 East zone

The area is occupied by the central pluton at the east zone restrictedly. The pluton is found in a narrow area in the district (Fig. 8).

Myoken, Katsuboshi, Tada, Akamatsu and Mizuho mines, are known in this mineralized zone. Zonal arrangement of ore deposits around the pluton of the area is not observable on the ground surface. Ore from the Myoken mine, rich in pyrrhotite, shows the mineral assemblage of skarn type, and gold-silver ore from the Tada mine contains tin minerals as cassiterite, stannite and mawsonite. These ore deposits are usually accompanied by pyrrhotite and tin minerals. It is thus considered that this zone is a peculiar mineralized zone showing composite character of three mineralized zones, I, II and III. The pecularity is perhaps due to the lack of big plutonic mass in the eastern district.

7.3 Summary

The mineralized west zone can be divided into three zones due to the zonal arrangement of different types of ore deposits: I-skarn and porphyry copper, II-tin tungsten bearing polymetallic vein and gold-silver bearing quartz vein, and III-pyrrhotite bearing polymetallic vein. On the other hand, mineralization in the east zone is distinguished from that of preceding zone, due to the lacking of zonal arrangement of ore deposits though the telescoping ore consisting of tin, tungsten, copper, zinc, lead, gold and silver is present.

The radiometric age of the plutonic rocks related to the mineralization and the volcanic rocks which cut the ore vein of the Ikuno and Akenobe mines was examined by ISHIHARA (1972), IMAI (1970), YAMAOKA & UEDA (1974) and IMAI *et al.* (1975). Those age determinations suggest that the duration of mineralization relating to the tectonism and the volucano-plutonism is between late Cretaceous and early Paleogene time.

8. Conclusion

The authors reported the igneous activities, geologic structure of the Ikuno Group and related mineralization in the central district of the Hyogo Prefecture. Results obtained are concluded as follows:

1) There are three different structural patterns in the pyroclastic sediments of the Ikuno Group.

2) The first structural pattern might have been caused by tectonic movement related to the formation of the Type A fold in the Ikuno Group.

The fault systems such as Maruyama and Nendo faults which cut the Type A fold were formed during the above structural movement.

3) It is clear that the tectonic movements of the Ikuno Group is closely related to the igneous activities forming various rocks of basic to acidic facies, i.e., the shear zone trending E-W has provided a space for the plutonism and andesitic volcanism.

4) The upward movement of the plutonic rocks ascending probably with an inclination of 45° to SE in a E-W zone caused the formation of Type B fold of NE to N-S.

5) The above described faults and fractures might have been moved repeatedly, and main fracture swarms were formed in the zone of NW trend tensional cracks extending as far as the Ikuno-Akenobe mining area, and then main mineralization was emplaced in these fracture swarms.

6) The formation of fracture swarms should be caused as the results of local block movement related to the Type C fold. The small scale faults of the Ikuno mine might have been formed in relation to the movement, and tension crack were newly formed in the fractures trending N-S.

7) It is considered that in the second stage of the intrusion of plutonics, polymetallic mineralization took place along those tension cracks around pluton.

In the western district, three mineralized zones were formed around the Chigusa plutonic mass.

The zone I is found in the plutonic mass and at the contact of the pluton, and the zone is characterized by the presence of magnetite ore of skarn type, stockwork ore deposits of porphyry copper type and arsenic bearing polymetallic vein. Among these, Takumi mine extracted only arsen mineral.

The zone II which is farther from plutonic mass is characterized by the presence of ores such as tin- and wolfram-bearing polymetallic veins in the fracture zone trending NW. Gold- and silver-bearing quartz and lead-zinc veins are found outside the above-stated Sn-W bg. polymetallic veins.

The zone III is found farthermost position from the plutonic mass, in which polymetallic veins including a lot of pyrrhotite appear.

8) In the mineralized zones of I, II and III, a composite ore made up of tin- wolfram-molybdenium, associating with bismuth, tellurium, arsenium, indium and antimonium, is observable. These elements characteristically migrate together with base metals like copper, lead and zinc in each main vein of the Akenobe and Ikuno mines.

9) Zonal arrangements of ores can not be observed in the swarm of ore deposits in the east zone of the district, whereas the typical ore zoning is observable in the west zone. It is notable that the ore veins in the east zone is characterized by the presence of composite mineralization of I, II and III types.

The ores containing various elements, Sn, Mo, W, Bi, As, Sb and Te, indicate that the ores were formed under various conditions of high to low temperatures, so these should be called "xenothermal mineralization". These mineralization were related to the central plutonic activities, because no metallic ore deposit is found in the areas without the central pluton.

10) Based on the examinations of radiometric ages and the geomagnetic investiga-

tions on various rocks and ores, it is concluded that the ores were formed during late Cretaceous to early Paleogene periods.

The origin of the lateral distribution of ores in the Ikuno-Akenobe district is scheduled to be reported by another paper.

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兵庫県中央部地方の地質と金銀錫タングステン銅鉛亜鉛鉱床

——西南日本内帯白亜紀末—第三紀初期の鉱化作用 (I)——

成田英吉・三村弘二・小村良二

要　旨

兵庫県中央部の広域地質調査を行い，生野・明延を中心とする白亜紀末—第三紀初期の鉱化作用の検討を行った．この調査で，生野層群中に3つの異なった褶曲構造が明らかとなり，これらの構造と火成作用，鉱化作用との関連を第1報として報告した．

生野層群は主として酸性火砕岩で構成され，古生層に顕著に認められる東西方向の向斜構造に規制され東西に延長して分布する．生野層群中には，この構造に調和した東西系の向斜，背斜構造が栃原，栗賀地区にみられる．安山岩，深成岩の活動は，この構造に規制され，同一方向に伸びる安山岩貫入帯，深成岩底盤迸入帯をつくっている．

この深成活動は関係する断裂系から，SW 方向にほぼ 45° の傾斜で上昇したことが推測され，新しい第2次の NE, NS 方向の軸をもつ褶曲構造を作っている．第1次の EW 系褶曲運動は，丸山，明延断層その他の大規模な NS, EW, NE 系の直交，平行，斜交断層を作ったが，第2次の上昇運動は生野・

明延につながるNW系を主とする裂ヵ群の帯を形成する．第1次の断裂系は，この運動でくりかえし動かされ，断層間でブロック運動を行い，ブロック内で生野鉱山金香瀬地区のような小規模な第3次のNS系褶曲，断裂系を形成する．

鉱化作用は，これらの運動と深く関係し，生野—明延を結ぶNW裂ヵ帯は，この地域の主要な鉱化帯域となった．

この鉱化作用は，この地域的で小規模な断裂系のみに関係して行われただけでなく，東部と西部の2地域に深成岩を中心として様々な型の鉱床を形成している．

西部の大規模な深成岩地帯では，深成岩底盤を中心として特徴ある帯状の鉱化作用が認められ

Ⅰ 磁鉄鉱，硫化物スカルン型鉱床，斑岩銅鉱床型鉱床，含砒雑鉱型鉱脈鉱床

Ⅱ 含錫-タングステン雑鉱型鉱脈鉱床，含金銀石英脈鉱床

Ⅲ 含磁硫鉄鉱雑鉱型鉱脈鉱床

が形成されている．小規模な深成岩の分布する東部地域では，類似した鉱化作用は存在するが，地域的な帯状配列は認められない．

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