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Neogene Mineralization of the Teine—Chitose District, West Hokkaido, Japan

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Abstract: The zonal distribution of metallic ore deposits around Jozankei quartz porphyry is recognized in the Teine—Chitose district. Toyoha mine is one of the representative lead-zinc deposits in the inner Pb–Zn zone, while Chitose mine is the typical gold-silver deposits in the outer Au–Ag zone.

The temperature and salinity of fluid inclusions from Chitose deposits are 200°–300°C and 0.0–3.6 percent, respectively, and vapor pressure and density of the fluid at the lowest level of deposition are estimated as 84.9 atm and 0.734 g/cc which correspond to the depth of 1050 meters.

At Toyoha deposits, decreasing tendency in temperature and salinity of fluid inclusions as well as mineral zoning are observed from east to west among earlier veins and from southeast to northwest among later ones. Taking account of heat source at southeastern deeper zone, the sequence of mineralization in space and time was deduced for Toyoha deposits.

Introduction

The Teine—Chitose mining district is well known for the occurrence of many epithermal ore deposits of Neogene period, such as Teine, Toyoha, Todoroki and Chitose mines. The district has produced by the end of 1977, a total of 34 tons of gold, 1,684 tons of silver, 345,000 tons of lead and 846,000 tons of zinc metal; this occupies an important portion of the mineral production in Japan. Of this total, however, 79 percent of silver and 99.9 percent of lead and zinc are from Toyoha mine, and the bulk of gold from Chitose mine. Most mines in this district have been closed during the past ten years due to the exhaustion of ores. Toyoha and Chitose are the exceptions.

A large number of studies on these ore deposits and on the geology of this district have been carried out from various view points, such as mineralogy, structural geology and metallogeny. They are introduced in each related chapter of this paper. It should be noted here that NARITA *et al.* (1965a) revealed a clear zonal distribution of metallic ore deposits at Shakotan Peninsula, and in the Teine—Chitose district, AKIBA (1958) pointed out the arrangement of ore deposits in two belts on both sides of the Jozankei quartz porphyry. Also YAJIMA and OKABE (1971) proposed a concentric zoning around quartz porphyry such as inner Pb–Zn zone and outer Au–Ag zone.

The present author attempts to clarify in this work the formation conditions of these zonally arranged deposits also their mutual relation from the view point of geologic structure, mineral paragenesis and fluid inclusion study. Detailed discussion is made with special reference to the results of the detailed study on Chitose and Toyoha deposits.

1. Outline of geology

1.1 General geology

Hokkaido is divided into three geologic units from a geotectonic view point, namely, west,

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central and east Hokkaido which are bounded by the Sapporo—Tomakomai lowland belt and the eastern margin of Tokoro—Toyokoro tectonic belt (MINATO *et al.*, 1965). West Hokkaido is geologically the northern extension of the inner zone of northern Honshu. There occur thick volcanic formations of Miocene period, which constitute the "green tuff region", on the basement rocks of Paleozoic to lower Mesozoic strata. In contrast, the central Hokkaido is characterized by geosynclinal sedimentation of Jurassic to Cretaceous periods and the subsequent Hidaka orogenic movement (MINATO *et al.*, 1956).

The west Hokkaido is divided further into three sub-provinces by the nature of sediments and tectonic features. The first one, characterized by the terrestrial sediments of Fukuyama stage, covers the areas from Matsumae to Kudo and around Shimamaki. The second sub-province is upheaved areas composed of much pyroclastics of Miocene age which appeared in patches at Shakotan Peninsula, Shizukari—Toyoura, Otaru—Muroran and Kameda Peninsula (II in Fig. 1). The third is a sedimentary basin with a thick pile of normal marine formation of Miocene age which is distributed from Kunitomi, Toya to Hakodate and Sapporo to Shikotsu Lake (III is Fig. 1).

The Teine—Chitose district is situated at the northern part of Otaru—Muroran area of the second sub-province. This district is underlain by basement rocks of Paleozoic to Mesozoic age, vast volume of pyroclastic rocks of Miocene and Pliocene age and of Quaternary volcanic rocks. The basement rocks are sporadically distributed along the so-called Shakotan direction at Sangaidaki, Kyogoku and Kunitomi, and are mainly composed of pelitic schist of low grade and quartz diorite. Neogene formations are classified into Jozankei Group, Toyoha Group and Toyama Group of Miocene age and Nishino Formation of Pliocene age in ascending order (SAITO *et al.*, 1972–75) (Table 1).

The Jozankei Group which is composed of altered andesite and pyroclastics is distributed along Shirai, Migimata, Shiramizu and Pepenai Rivers, and it is correlated to Fukuyama Formation (NAGAO and SASA, 1934) or Kayanuma Formation (TANAI, 1961). The Toyoha Group is sub-

Table 1 Correlation of Neogene Tertiary formations in west Hokkaido.

West Hokkaido (NAGAO and SASA 1934)	Jōzankei (SAITO et al. 1972–75)		Toyoha Mine (HASHIMOTO et al. 1977)	Chitose Mine (FUJIWARA 1954)
Setana F.	Nishino F.			
Kuromatsunai F.	Toyama G.		Oeyama F.	
Yakumo F.	Toyoha G.	Otarunaigawa F.	Sanbonmata F.	Naruo F. / Bifue F. / ?
Kunnui F.	Toyoha G.	Takinosawa F.	Nagato F.	
Yoshioka F.	Toyoha G.	Shiraigawa F.	Motoyama F.	
Fukuyama F.	Jozankei G.	Shiramizugawa F.	Koyanagizawa F. / ?	
Pre-Tertiary	Usubetsu F.			

divided into Shiraigawa, Takinosawa and Otarunaigawa Formations. Shiraigawa Formation, which covers the Jozankei Group discordantly with basal conglomerate, is located at Shirai River, a neighbouring area of the Chitose mine and upper streams of Shiribetsu and Yoichi Rivers. Takinosawa Formation consists of dacitic to rhyolitic pyroclastics, and Otarunaigawa Formation of shale, altered andesite, rhyolite and their pyroclastics. The Takinosawa Formation shows a wide distribution at western to southern parts of this district and narrower occurrence at eastern side. Otarunaigawa Formation occurs almost throughout the district. Toyama Group is a rather thick unit consisting mainly of sandstone and mudstone at Yunosawa River and northern or southern areas of Shikotsu Lake. At the central and northern parts of this district, the same formation, though being intercalated with normal sediments in its upper part, changes into andesitic volcanic breccia which occupies a vast area around Otarunaigawa Formation. Nishino Formation is composed of sandstone, mudstone and dacitic pyroclastics and distributed not only at Zenibako—Yoichi sea-coast but also at the basal part of Quaternary volcanoes, such as Mts. Asari and Izari with an altitude of about 800 meters above sea level.

Quaternary period is characterized by violent volcanism. It forms flat lava plateau (1.9 m.y., Sumi *et al.*, 1978) at Mt. Muine. The eruptive activity continues to recent at Mts. Tarumae, Eniwa and Usu.

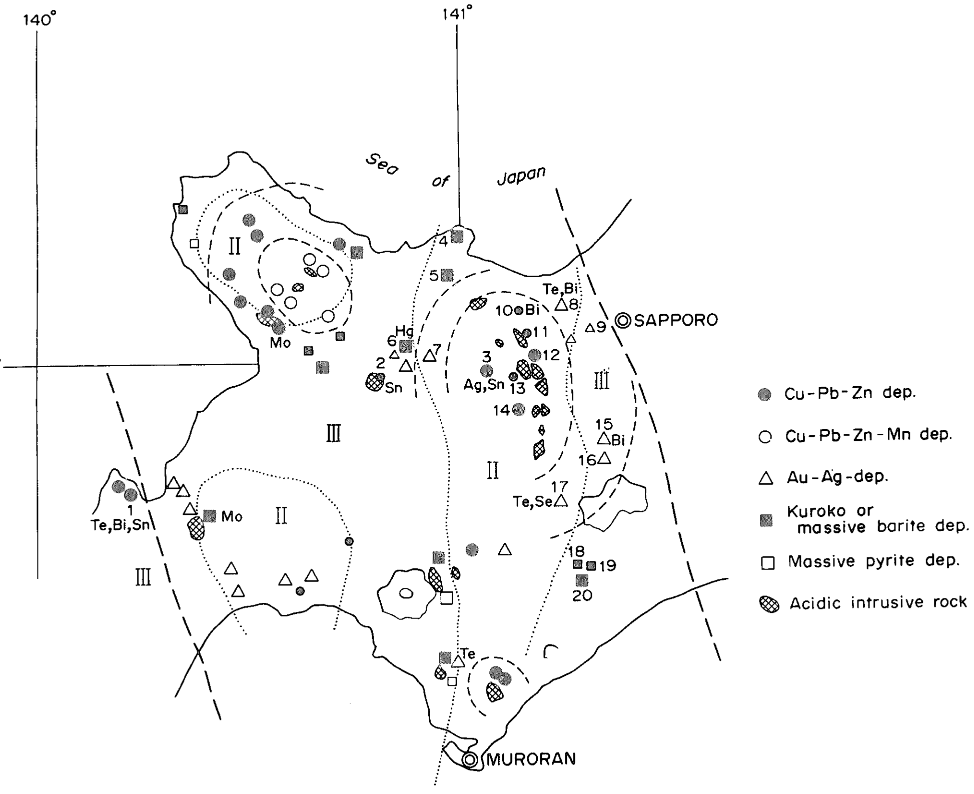


Fig. 1 Zonal distribution of base metal deposits in west Hokkaido.
Zonal distribution of deposits is indicated by smaller dashed lines. Geological sub-province is bordered by dotted lines. II: the second sub-province, III: the third sub-province. Names of mines are as follows; 1: Suttsu, 2: Kutosan, 3: Toyoha, 4: Akaiwa, 5: Matsukura, 6: Meiji, 7: Todoroki, 8: Teine, 9: Kobetsuzawa, 10: Otoyo, 11: Inatoyo, 12: Toyohiro, 13: Jozankei, 14: Toyotomi, 15: Koryu, 16: Eniwa, 17: Chitose, 18: Shiraoi, 19: Morino, 20: Minami-Shiraoi.

1.2 Igneous activity

The characteristics of the igneous activity in this district are summarized as follows. At the stage of the Jozankei Group, terrestrial volcanism which often includes alkalic rocks (IKEBE *et al.*, 1971; HASEGAWA and OSANAI, 1978) occurred accompanied by block movements. In the following earlier stage of transgression, basic volcanic rocks of tholeiitic series appeared at the Shiraigawa stage. Bimodal volcanic activity belonging to calc-alkali rock series developed at the marginal part of the sedimentary basins of the Takinosawa stage. At the Otarunaigawa and Toyama stages, violent volcanic activities of calc-alkali rock series occurred around volcanogenic collapsed basins to form the somma structures at Jozankei, Mt. Amemasu and Akaigawa. The biggest intrusive body in this district, the so-called "Jozankei quartz porphyry", intruded at the latest stage of Otarunaigawa Formation (8.5 m.y., SUMI *et al.*, 1978), cutting above-mentioned collapsed structure in NNW direction.

1.3 Tectonic movement and age of mineralization

The Otaru—Muroran area, the second of the three sub-provinces within west Hokkaido, is situated between normal sedimentary basins, and it is an elevated unit accompanied by violent volcanisms and structural movements of early to later Miocene periods. The composite fold structure of N–S trend is developed in the third sub-province and this structure is also maintained in volcanogenic sediments of the uplifted sub-province. On the other hand, the volcanogenic collapsed basin structure is observed in this area and three basins are arranged in the so-called Shakotan direction from Jozankei to Amemasu and Akaigawa. The collapse is recognized from middle Miocene, and the distribution of volcanic rocks of Otarunaigawa stage represents a collapsed caldera and surrounding somma lava structure. The age of collapsed basins become younger from southeast to northwest. In the youngest Akaigawa caldera, Kunitomi Formation (SAITO *et al.*, 1969–1971, corresponding to Takinosawa Formation) forms a deep volcano-sedimentary basin and its topographical features together with the distribution of Quaternary volcanic rocks retains distinct features of a caldera.

Nishino Formation covers the Miocene system with an unconformity and shows a fold structure of E–W trend in clear constrast with that of underlying formations.

As for mineralization, two epochs are discriminated in the Teine—Chitose district with reference to the above-mentioned stages of volcanic activities and tectonic movements. The first epoch corresponds to the upper Takinosawa stage when stratabound type kuroko and massive barite deposits were formed in intimate association with the basin structure of Takinosawa or Kunitomi Formation and with bimodal volcanic activities. The second is the latest stage of Otarunaigawa Formation when many polymetallic vein-type ore deposits were generated in a clear zonal distribution around quartz porphyry intrusive bodies.

2. Mineralization in the Teine—Chitose district

2.1 Metallogenic province in west Hokkaido

West Hokkaido is defined not only as one geologic unit but also as one metallogenic province (SAITO *et al.*, 1967; BAMBA, 1977). This metallogenic province is divided further into three sub-provinces which approximately correspond to such geological sub-provinces as mentioned in the preceding chapter.

In the first sub-province at Matsumae—Kudo and Shimamaki areas, Au–Ag–Cu–Pb–Zn–Fe vein-type and replacement-type deposits occur around basement blocks. The examples are Kudo, Jokoku, Imagane and Sankei mines. The second sub-province (II in Fig. 1) characterized by violent volcanisms and upheaval movements includes many polymetallic ore deposits of fissurefilling type which are zonally arranged around Shakotan dome (NARITA *et al.*, 1965a) or Jozankei quartz porphyry (YAJIMA and OKABE, 1971). The sedimentary basin of the third sub-province (III in Fig. 1) has plenty of exhalative–sedimentary manganese ore deposits, as well as bedded iron and dolomite deposits especially at the western side of Suttsu—Hakodate line. At the eastern side of the same tectonic line, kuroko and massive barite deposits occur and they are distributed sporadically at the marginal parts of the basins. Thus, the mineralization of Neogene period is affected by a subsiding movement of basement rocks, formation of basin structure and igneous activity, and yield characteristic ore deposits in each sub-province. The mineralization continued to Quaternary period and formed sulphur and iron sulphide ore deposits (IGARASHI, 1976).

The Teine—Chitose district includes, among these groups of deposits, several famous mines; Toyoha mine for its large amount of ore reserves, Teine mine for the occurrence of gold-silver tellurides or teineite and Todoroki mine for todorokite. About twenty mines are known in this district, twelve of which have records of production (Table 2). Only two, Chitose and Toyoha, are working at present.

Table 2 Metal production in the Teine—Chitose mining district.

	Minami-Shiraoi	Chitose	Eniwa	Koryu	Toyotomi	Toyoha	Toyohiro	Teine	Todoroki	Meiji	Matsukura	Akaiwa
Period	1957 – 77	1935 – 77	1931 – 42	1937-56	1933 – 37	1937 – 77	1943 – 52	1931 – 72	1906 – 77	1913 – 43	1936 – 72	1935 – 40
Au(kg)		16803	726	83	1	3186	0.18	10404	2571	0.33		0.3
Ag(t)		73	5.1	1.5	0.12	1337	0.73	163	104	0.22		0.7
Cu(t)		40			0.8			75608		99728		4.5
Pb(t)					1.5	345108	133			—		2.0
Zn(t)					7	844917	150			—	1069	3.4
$BaSO_4$(t)	167193										323173	

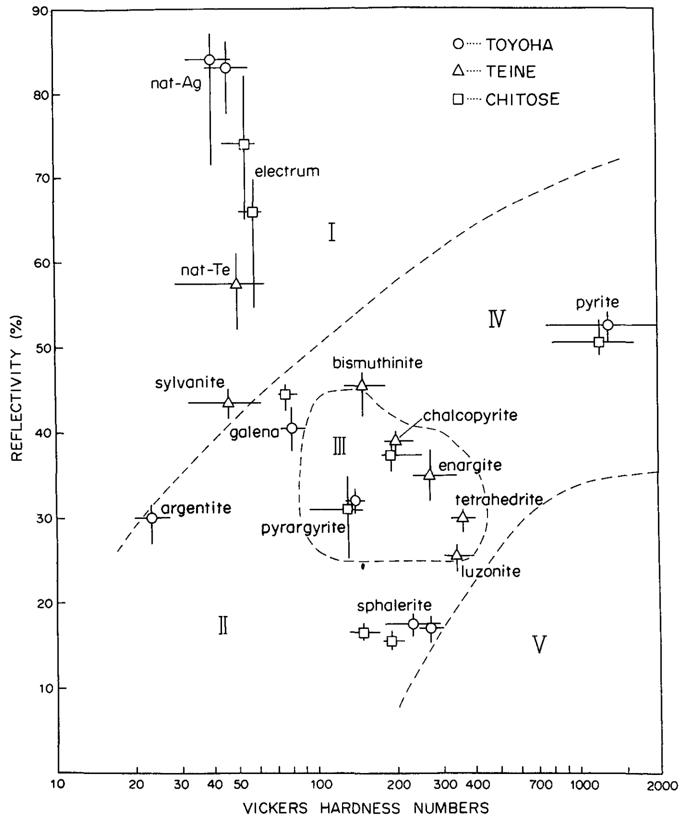
2.2 Classification of metallic ore deposits

Many investigations have been carried out since 1932 on the minerals and ore deposits in this district, including the classic works by WATANABE, M. (1932, 1933, 1934), WATANABE, T. (1936a, b, 1943) and by YOSHIMURA (1934, 1936) which marked the beginning of the microscopic studies of ore minerals in Hokkaido. All mineral species described in the district until today are summarized in Table 3 from many papers which are indicated by a notation (*) in references.

Since BOWIE and TAYLOR (1958) established the new method of ore mineral identification by reflectivity and hardness, it has been adopted widely in the field of ore microscopy (UYTENBOGAARDT and BURKE, 1971). YAJIMA (1976) examined some minerals from this district by the method, the result of which is shown in Fig. 2.

As it is shown in Table 3, all deposits have very similar paragenesis, namely monoparagenetic association. Consequently the classification in this paper is established considering the form of ore body and the major components expressed in mineral paragenesis or in quantity of metal production. The metal production is shown in Table 2. Ore deposits in this district are classified into the following three types:

1. Kuroko type.........Akaiwa, Matsukura ,Meiji, Shiraoi, Minami-Shiraoi, Morino.



I: metals, II: sulphides, III: sulphosalts, IV: Ni–Co–Fe sulphides, V: oxides. (Bowie and Taylor, 1958)

Fig. 2 Distribution of ore minerals from the Teine—Chitose district on the basis of their reflectivity and hardness.

2. Au–Ag vein type ....Teine, Todoroki, Koryu, Eniwa, Chitose, Kobetsuzawa.
3. Pb–Zn vein type ....Otoyo, Toyohiro, Inatoyo, Toyoha, Jozankei, Toyotomi.

Type 1 includes massive or network barite deposits of Matsukura, Minami—Shiraoi, Akaiwa, Shiraoi and Morino mines which are accompanied by very little sulphide minerals. Occurrence of these workable barite deposits is one of characteristic features in west Hokkaido as compared with the sulphide-predominant kuroko deposits of Hokuroku district (Igarashi *et al.*, 1974). The major components of this type are Pb, Zn, Cu and Ba. As for the minor element, Meiji mine has an isolated small mercury deposit of dissemination type (Hasegawa *et al.*, 1976). The ore minerals are cinnabar and marcasite which are excluded in Table 3. No other indicative minor constituent is observed in this type. In Table 3, a small amount of Au and Ag are indicated in Akaiwa mine which are listed not from a mineralogical description but from a production record.

Type 2 represents vein-type deposits of gold and silver with abundant quartz as a gangue mineral, which is usually called as "gold-bearing quartz vein". Todoroki, Koryu, Eniwa and Chitose mines comprise the typical deposits of this group. The ores of Teine mine are different from typical gold-quartz vein. The deposits consist of three groups of vein swarm which are called Bannosawa, Mitsuyama and Koganesawa. The latter two vein groups contain, in addition to the

Table 3 Mineral association of ore deposits in the Teine—Chitose district.

minerals	chemical composition	Kuroko-type						gold—silver							lead—zinc								
												Teine						Toyoha					
		Akaiwa	Meiji	Shiraoi	Morino	Matsukura	Minami-Shiraoi	Todoroki	Koryu	Eniwa	Chitose	Kogane-sawa	Mitsu-yama	Kobetsuzawa	Otoyo	Toyohiro	Inatoyo	Tajima	Harima	Soya	Izumo	Jozankei	Toyotomi
native gold	(Au, Ag)	m	m					M	M	M	M	M	M					m	m	m			r
Ag sulphide	Ag_2S	m	m					M	M	M	M	M	M	m				m	m	m			r
Ag sulphosalts	$Ag(Sb,As)S$							m	m		M		r					m	m	m	m		
sphalerite	ZnS	M	M	m	m	m	m	m	m		m	m		m		m	m	M	M	M	M	m	M
galena	PbS	M	M	m	m	m	m		m		m	m		m		m	m	M	M	M	M	m	M
pyrite	FeS_2	M	M	m	m	m	m	m	m	m	m	m	M	m	m	m	m	M	M	M	M	m	M
marcasite	FeS_2							m					m	m				r	m	m	m		
pyrrhotite	$Fe_{1-x}S$													m				r	m	m	m		
magnetite	Fe_3O_4												m					m	m	m	m		
hematite	Fe_2O_3																	m	m	m	m		m
chalcopyrite	$CuFeS_2$	M	M	m	m	m	m	m	m		m	m	m	m		m	m	m	m	m	m	m	m
tetrahedrite	$Cu_3(Sb,As)S_{3.25}$		m		m	m		m	m	m	m	m	M			m	m	m	m	m	m		
enargite	$Cu_3(As,Sb)S_4$												M										
luzonite	$Cu_3(As,Sb)S_4$				m								M		m								
bismuthinite	Bi_2S_3								m				m		m								
emplectite	$CuBiS_2$												m										
schapbachite	$AgBiS_2$																	r					
petzite	Ag_3AuTe_2										m		m	m									
rickardite	Cu_7Te_5												m	m									
sylvanite	$AuAgTe_4$												m	m									
hessite	Ag_2Te										m			m									
altaite	$PbTe$										m			m									
freibergite											m		m								m		
native tellurium	Te												m										
aguilarite	Ag_4SeS										m												
berthierite	$FeSb_2S_4$																			m			
boulangerite	$5PbS\ 2Sb_2S_3$																		r		m		
jamesonite	$4PbS\ FeS\ Sb_2S_3$	m																m		m	m		
stibnite	Sb_2S_3										m	m	r	m						m			m
dyscrasite	Ag_3Sb													m									
arsenopyrite	$FeAsS$				m													r	m	m	m		
realgar	AsS											m	r	m									
orpiment	As_2S_3											m	r										
native arsenic	As																			m			
cassiterite	SnO_2																	r		r	m		
stannite	$Cu_2Sn(Fe,Zn)S_4$																				m		
canfieldite	$4Ag_2S\ SnS_2$																	r					
wolframite	$(Fe,Mn)WO_4$																		r		m		
quartz	SiO_2	m	m	m	m	m	m	M	M	M	M	M	M	m	m	m	m	M	M	m	m		
calcite	$CaCO_3$	m				m		m	m	m	m	m	m			m		m	m	M	m		
barite	$BaSO_4$	M	M	m	m	M	M						m		m	m		m	m	m	m		
rhodochrosite	$MnCO_3$							m	m			m	r					m	m	M	r		
rhodonite	$MnSiO_3$							m										m	m				
adularia	$KAlSi_3O_8$										m									m			
inesite								m												m			
secondary Ag								m	m				r					m	m				
Mn								m					m						m	m			
Cu			m										m										
Te													m										
Pb						m																	

M: major minerals, m: minor constituent, r: rare common Au–Ag paragenesis, an abundant copper as Cu–Sb sulphosalts, not as chalcopyrite, with quartz and barite in Mitsuyama group while sphalerite-galena-realger-orpiment with quartz and calcite in Koganesawa Group (SUGIMOTO, 1952). It may be regarded as an intermediate character between gold-quartz and lead-zinc mineralization. However, the major component of this type is always gold and silver. The description on Kobetsuzawa mine does not include native gold, so important portion of gold content of the mine may be derived from gold tellurides (ISHIBASHI, 1956). Characteristic minor elements are tellurium, bismuth and selenium in Chitose, Teine and Kobetsuzawa mines.

Type 3 is lead-zinc deposits including Toyoha mine. The particular situation of Otoyo mine which contains no other minerals than luzonite, bismuthinite and pyrite might be explained as an intermediate type between Teine and Toyoha deposits (SUGIMOTO, 1958). Silver, tin and tungsten are important minor constituent in Toyoha mine (YAJIMA, 1977; NARITA *et al.*, 1977). The rare occurrence of schapbachite is reported in an internal publication of Toyoha Mining Co. and a further discovery of bismuth mineral is expected.

Other minor constituents occurring in this district are antimony, arsenic and manganese.

2.3 Zonal distribution of ore deposits

There are many reports regarding the zonal distribution of ore deposits in west Hokkaido. AKIBA (1958) studied the relation between igneous activities and metallogenic province in west Hokkaido, commenting on the two belts arranged on both sides of Jozankei quartz porphyry, that is, Au–Ag belt on the east side and Cu–Pb–Zn belt on the west side. In Shakotan Peninsula, NARITA *et al.* (1965a) showed a zonal arrangement around Tertiary granitoids, such as Mn–(Cu)–Pb–Zn zone, Cu–Pb–Zn zone, massive iron sulphide and barite zone from inner to outer side (Fig. 1). Gold and silver are dispersed throughout the area in this zonation.

Several other examples of zonation are known in west Hokkaido, though being rather complicated or irregular in distribution and smaller in scale; Date—Horobetsu district (SUGIMOTO and YAMAGUCHI, 1955), Kameda Peninsula (SAWA *et al.*, 1958), Suttsu—Oshamambe district (AKIBA, 1958), Shimamaki—Imagane (NARITA *et al.*, 1965b), Kudo (YAMADA and YAMAYA, 1962), Yakumo (SUGIMOTO, 1962), and Jokoku (SAWA *et al.*, 1965). They are always accompanied by acidic intrusive rocks.

Besides the above-mentioned zonations, it is said that manganese is rich in western side of Yoichi—Hakodate line (SAITO *et al.*, 1967), where exist many workable manganese deposits of both vein and stratabound types. As for the indicative minor elements, ISHIBASHI (1958) stated that Sn and Mo are rich in the western part, while Te, Bi, Sb and As are relatively abundant in the eastern part of west Hokkaido.

In the Teine—Chitose district, the well arranged zonal distribution around quartz porphyry is observed. Pb–Zn vein type deposits are situated in the central part surrounded by the outer belt of Au–Ag vein type deposits (Fig. 1). Kuroko and massive barite deposits occur at the outer periphery but it is notable that they were formed in a different geological environment and in an earlier stage than these vein type deposits as mentioned in the first chapter.

The relation between igneous activity and mineralization together with zonal distribution of metals is summarized by SMIRNOV (1976). He says that, at the later stage of post-magmatic ore deposition related to granitic magma, there occurs, in general, the following zonation:

Mo–W/Sn/Cu–Pb–Zn–Co–Bi/Au/Sb–Hg

The zonation in the Teine—Chitose district is consistent with this generalized model. Sn and W are found in the center of this concentric zoning. An arrangement of Pb–Zn (Toyoha), Cu–Sb sulphosalt (Otoyo), Au–Ag–Cu–Sb–Bi (Teine) and gold-quartz (Chitose, Todoroki) is observed from inner to outer. There are two mineralization stages of antimony; one accompanied with Cu–Pb–Zn stage forming a tetrahedrite group and silver sulphosalt minerals, and the other, latest stage after a main sulphide deposition which brought stibnite, jamesonite and berthierite at Toyoha deposits. Jozankei quartz porphyry, including such rock facies as granite porphyry, granodiorite porphyry and dacite, is regarded as one of Neogene granitoids (NISHIKAWA, 1977). Furthermore, the affiliation between this granodiorite porphyry and ores of Toyoha deposits is shown

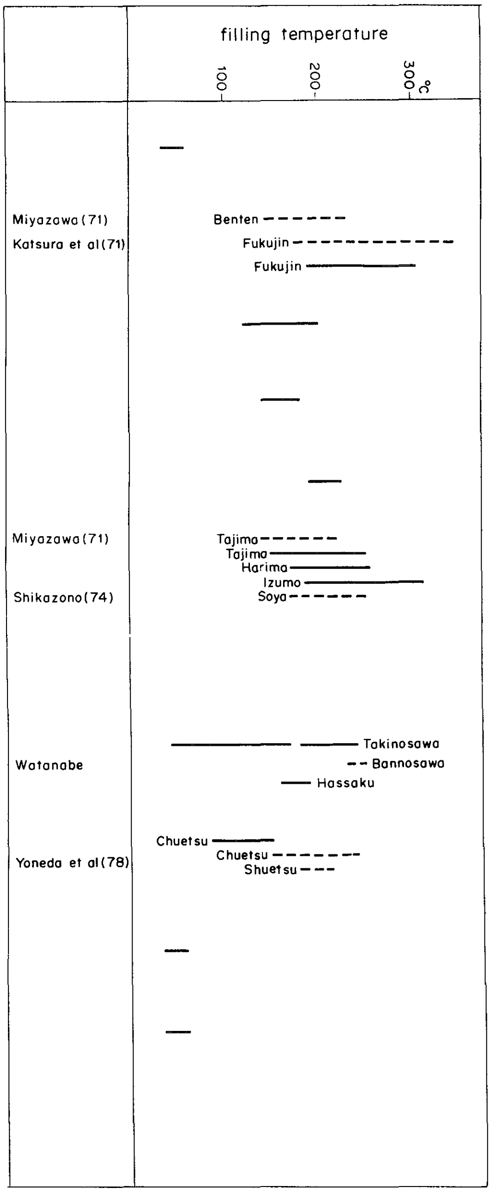


Fig. 3 Filling temperatures of fluid inclusions from the district.

by ISHIHARA and SASAKI (1978) from sulphur isotopic study. On the basis of these evidences, it may be reasonable to set the zonation of metallic ore deposits around quartz porphyry.

Other occurrences of tin minerals in the neighbouring district are known at Suttsu (ISHIBASHI, 1952) and Kutosan mines (KINOSHITA and TAKIMOTO, 1944). They are also regarded to have formed at the central part of the zonal distribution, though smaller in scale.

2.4 Fluid inclusion study

During the past twenty years, the study of fluid inclusions in minerals has been established as an effective method in petrology, mineralogy, geochemistry and especially in the research of economic mineral deposits to investigate the nature of mineral-forming solutions and the condition of formation (DEICHA, 1955; ROEDDER, 1967; YERMAKOV *et al.*, 1965). Thermometry by fluid inclusion is now prevailing in the various branches of geological sciences and is believed to be one of reliable methods among many geological thermometers.

In order to study the nature of ore solution, it is indispensable to analyse the content of liquid in inclusions but the method has not been well established yet to use in a routine work (ROEDDER, 1958; ROEDDER *et al.*, 1963). Now the cryoscopy of fluid inclusion is generally used in place of rather difficult chemical analysis, by which we can estimate the salinity of fluid in each inclusion as expressed by NaCl equivalent percent (ROEDDER, 1962; TAKENOUCHI, 1970, 1975–1976). Thus many data on mineral-forming solutions have been accumulated recently (ROEDDER, 1972; ENJOJI and TAKENOUCHI, 1976).

In this chapter, the result of fluid inclusion thermometry is briefly mentioned. The detailed description of thermometry on Chitose and Toyoha samples are given in the third and fourth chapters.

The result of temperature measurements of ore deposits in this district is shown in Fig. 3. The pressure correction for the filling temperature is about 10°C degrees, assuming a vapor pressure of 200 atm with 5 percent NaCl solution (LEMMLEIN and KLEVTSOV, 1961). As will be shown in the next chapter, the vapor pressure related to the formation of Fukujinzawa deposits of the Chitose mine is estimated to be about 85 atm at the lowest level of deposition. Much higher pressure may be unlikely in the case of fissure-filling type epithermal ore deposits. So the filling temperature is used here without pressure correction.

Filling temperatures measured by quartz and sphalerite of vein type deposits are in the range of about 150°–300°C. The lower range under 150°C of Teine and Todoroki mines are obtained from barite and calcite of later stage. As the temperature range of 250°–300°C is observed in a limited area, that is, in the deepest level of both Chitose and Toyoha mines, it is more suitable to say that the important portion of these deposits were formed in the range of 150°–250°C.

The lowest temperature in Minami–Shiraoi, Meiji and Matsukura mines are obtained from barite. So these temperature might not be considered to represent the whole range of formation temperature especially in Meiji mine. It is reported that the formation temperature of kuroko in Hokuroku district is in the range of 200°–300°C (URABE and SATO, 1978) and most probably in 200°–250°C (SATO, 1973/1974). Main ore body of Meiji deposits and sulphide minerals of Matsukura, Akaiwa and Minami–Shiraoi might be formed at about the same temperature range with those of kuroko in Hokuroku district. The formation temperature of barite ore body itself is less than 100°C.

3. Gold-silver deposits of Chitose mine

3.1 Ore deposits

Chitose mine is the representative gold-silver deposits located at the southern end of the Au–Ag zone. It is composed of typical gold-quartz veins which are known for its high Au and Ag content. Detailed and full description on geology and ore deposits are found in the papers by IGI and HATA (1954), FUJIMOTO (1961), HUNAHASHI and AKIBA (1970) and IKEDA and NAGAMATSU (1975), so only a brief comment is given here.

The mine is situated at the western side of Shikotsu Lake in the area composed of altered andesite, andesitic pyroclastics and tuffaceous mudstone which are correlated to Takinosawa and Otarunaigawa formations. Several ore deposits are found there arranged in northeast direction. Each one consists of vein swarm; the Fukujinzawa deposits of the most productive one for example, include more than ten veins. At the upper levels of Fukujinzawa vein swarm, veins show parallel arrangement running from east to west with subordinate veins of NE trend, and at the lower level they are gradually connected each other showing occasionally a cymoid loop and unite into one vein at the lowest 360 mL. Daikoku Sango vein, the champion vein of the mine is 750 meters in strike length and 460 meters in dip length with a mean thickness of 0.8 meters (IKEDA and NAGAMATSU, 1975), and in its upper half, gold and silver are especially concentrated.

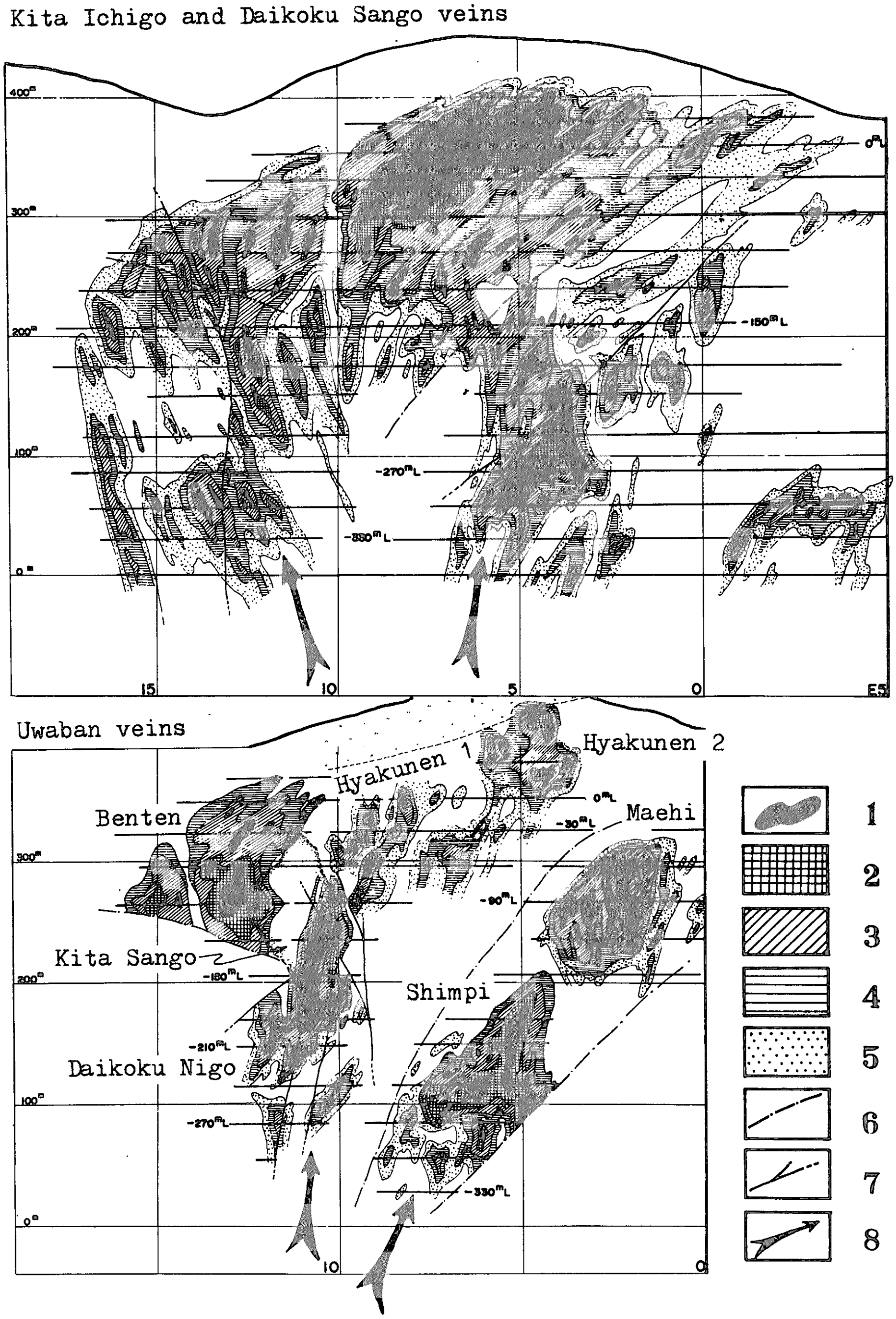
The vein is usually composed of quartz of three stages which takes a form of banded structure. Porcelain quartz of the first stage accompanies adularia and very little gold. The second stage is that of main mineralization and includes clear crystal of quartz and sulphide minerals associated with adularia and chlorite. Barren quartz at the central part of the vein represents the third stage. HUNAHASHI (1961) examined these vein quartz by petrofabric analysis and commented on the different tectonic conditions which prevailed between wall rock and veins during its formation.

The amount of quartz decreases while chlorite increases at the lower part below 150 mL of Daikoku Sango vein, and also relative amount of silver decreases from Au:Ag ratio of 1: 10–20 at the shallower levels to the ratio of 1: 1–5, in addition to the general tendency of decline of gold and silver content at the lower levels. In Daikoku Nigo and Shimpi veins, high grade ore is formed even at deeper levels. IKEDA and NAGAMATSU (1975) proposed the flow direction of ore-forming solutions on the basis of iso-grade contour map (Fig. 4).

Regarding wall rock alteration, HUNAHASHI and AKIBA (1970) classified six facies around Fukujinzawa vein swarm and pointed out the intimate association of sericite-quartz assemblage with the ore shoot.

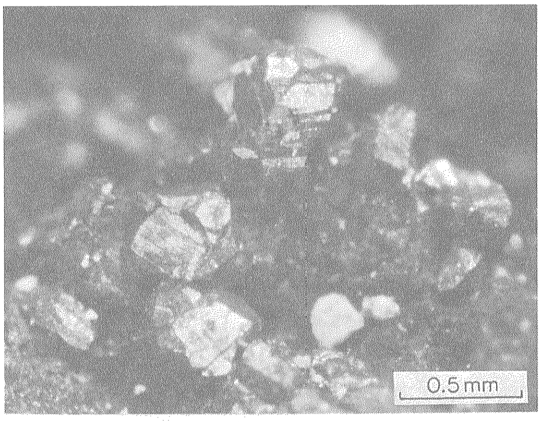
3.2 Ore minerals

All minerals described from the mine are listed in Table 3. Mineral assemblage is, in general, electrum-Ag minerals-sphalerite-galena-chalcopyrite-pyrite-tetrahedrite-quartz. Aggregations of fine-grained sulphide minerals form banded black streaks called "ginguro" (= silver black) in the quartz veins. In the ore shoot, electrum in often observed by the unaided eyes displaying tabular, scaly or dendritic forms. It contains 21.4 to 27.2 weight percent (YAJIMA and ONODERA, 1973) or 29.4 to 33.8 percent (YAMAOKA, 1971) of silver. Rare examples of idiomorphic crystal of electrum are reported by YAJIMA and ONODERA (1973). They have recognized several crystal forms such as octahedral, dodecahedral and also flattened one on (111) with triangular pits (Fig. 5).



1: more than 5000 g/cm, 2: 4999–2000 g/cm, 3: 1999–700 g/cm, 4: 699–300 g/cm, 5: 299–150 g/cm, 6: intersection between veins, 7: fault, 8: flow direction of ore-forming solution

Fig. 4 Au assay contour map of Fukujinzawa deposits (IKEDA and NAGAMATSU, 1975).



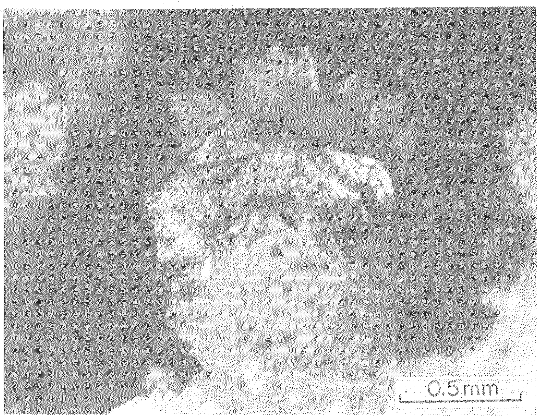


Fig. 5 Idiomorphic crystals of electrum from Chitose mine. Daikoku Nigo vein, −210 mL.

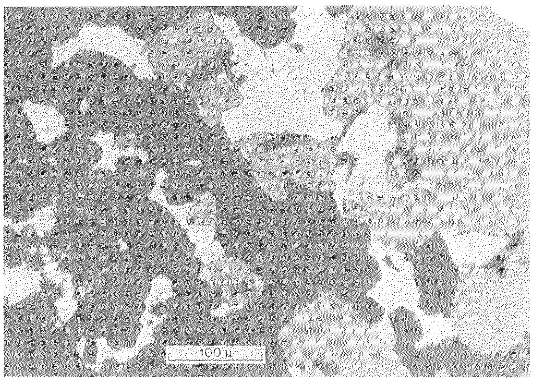


Fig. 6 Microphotograph showing electrum (bright white), galena (white) and sphalerite (grey) without any silver minerals. Daikoku Shimpi, −240 mL.

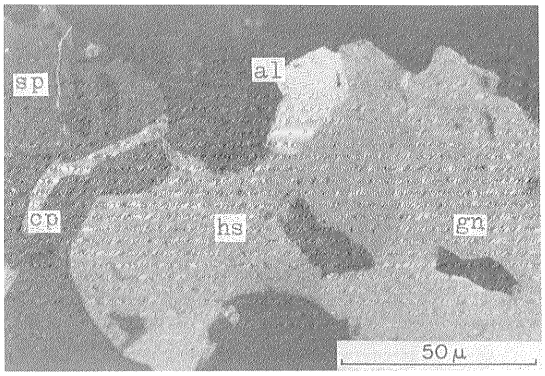


Fig. 7 Microphotograph showing hessite (hs), galena (gn), altaite (al), sphalerite (sp) and chalcopyrite (cp). Bifue vein, −180 mL.

Numerous silver minerals have been identified from the mine such as argentite, freibergite, polybasite-pearceite, proustite-pyrargyrite, stephanite and sternbergite. Pyrargyrite is especially concentrated at the top of Hyakunen Nigo vein under a cap rock of tuffaceous mudstone. As mentioned earlier, relative amount of silver decreases towards lower levels of the veins and electrum is often seen without any silver minerals (Fig. 6). Characteristic occurrence of tellurium- and selenium-containing silver minerals is described by YAMAOKA and NEDACHI (1971). Petzite, hessite and aguilarite from the ore of Daikoku Nigo vein coexisting with sphalerite, galena, chalcopyrite and pyrite were determined. Silver minerals from Bifue vein, located at 500 meters north to Daikoku Sango vein, are almost always hessite (Fig. 7) with a minor amount of argentite and altaite but the difficiency in gold content makes the vein unworkable.

FeS content of sphalerite coexisting with electrum and argentite is analysed by YAMAOKA (1971). A temperature estimation by an electrumtarnish method using Ag content in electrum and FeS content in sphalerite of electrum-argentite-sphalerite-pyrite assemblage, was made by him which showed a good coincidence with that measured by a homogenization method of fluid inclusions.

3.3 Fluid inclusion study

Inclusions mainly in quartz of the sulphide stage and some in the quartz of later barren stage were examined. In addition to normal two-phase fluid inclusions, gaseous ones were often observed. Rock crystals in vugs often include splendid negative crystals of gaseous inclusions which are easily recognizable macroscopically (Fig. 8). This heterogeneity is explained as a boiling phenomenon in a hydrothermal fluid system.

To detect gases under pressure in inclusions, the crushing stage method which had been devised by DEICHA (1950) and was improved by ROEDDER (1970), was applied. The result of crushing experiment of quartz grains showed more or less the presence of gas under pressure and it is inferred

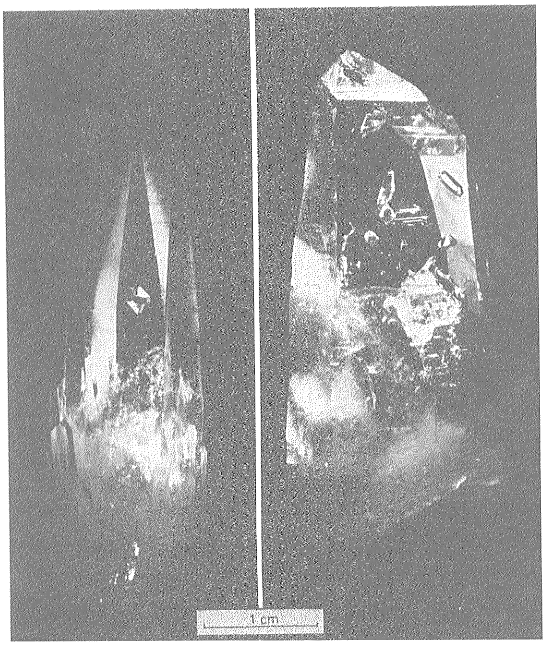


Fig. 8 Negative crystals of gaseous inclusions.

Lower half of each crystal is rich in normal two-phase liquid inclusions. Daikoku Nigo vein, −270 mL.

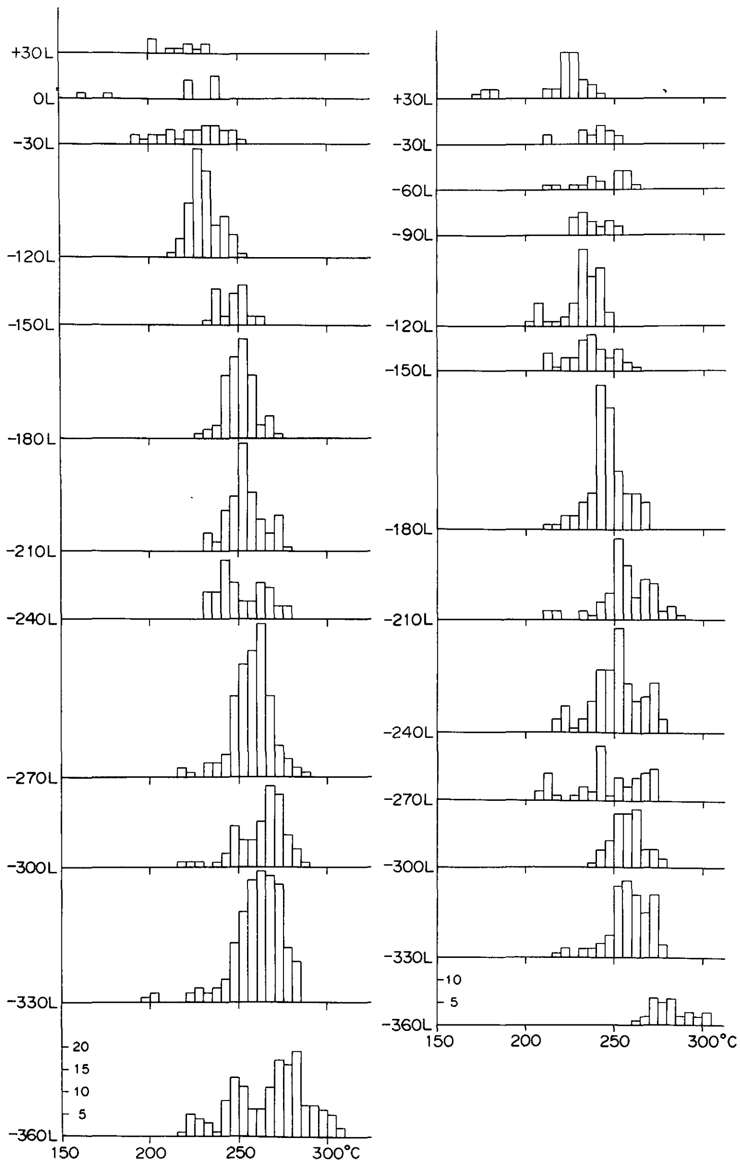


Fig. 9 Filling temperatures of fluid inclusions from Fukujinzawa deposits of Chitose mine.
Left: Daikoku Sango and Kita Ichigo veins. Right: Hyakunen Ichigo and Nigo, Daikoku Nigo, Daikoku Shimpi and Maehi veins.

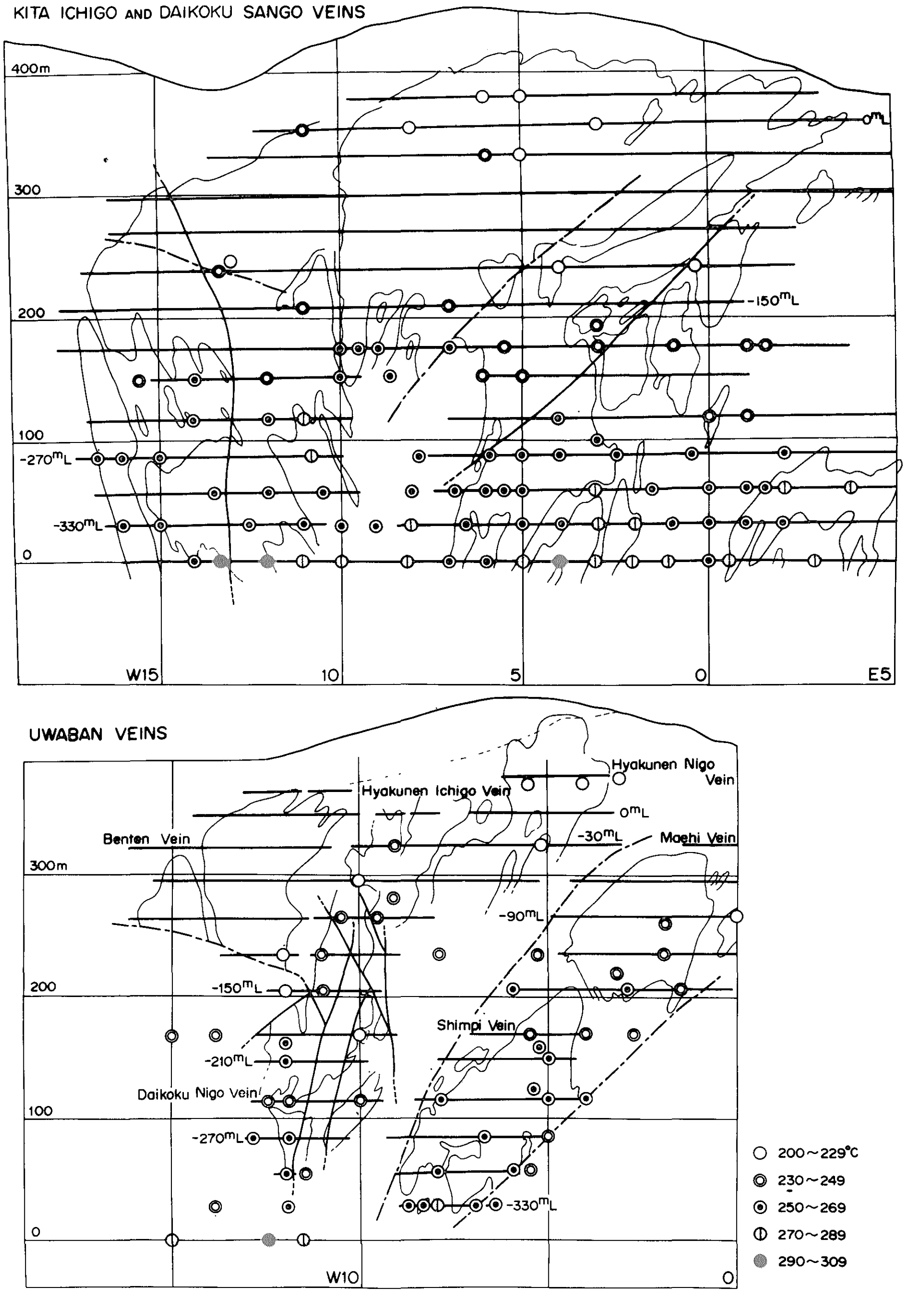


Fig. 10 Temperature distribution on profiles of Fukujinzawa veins of Chitose mine.

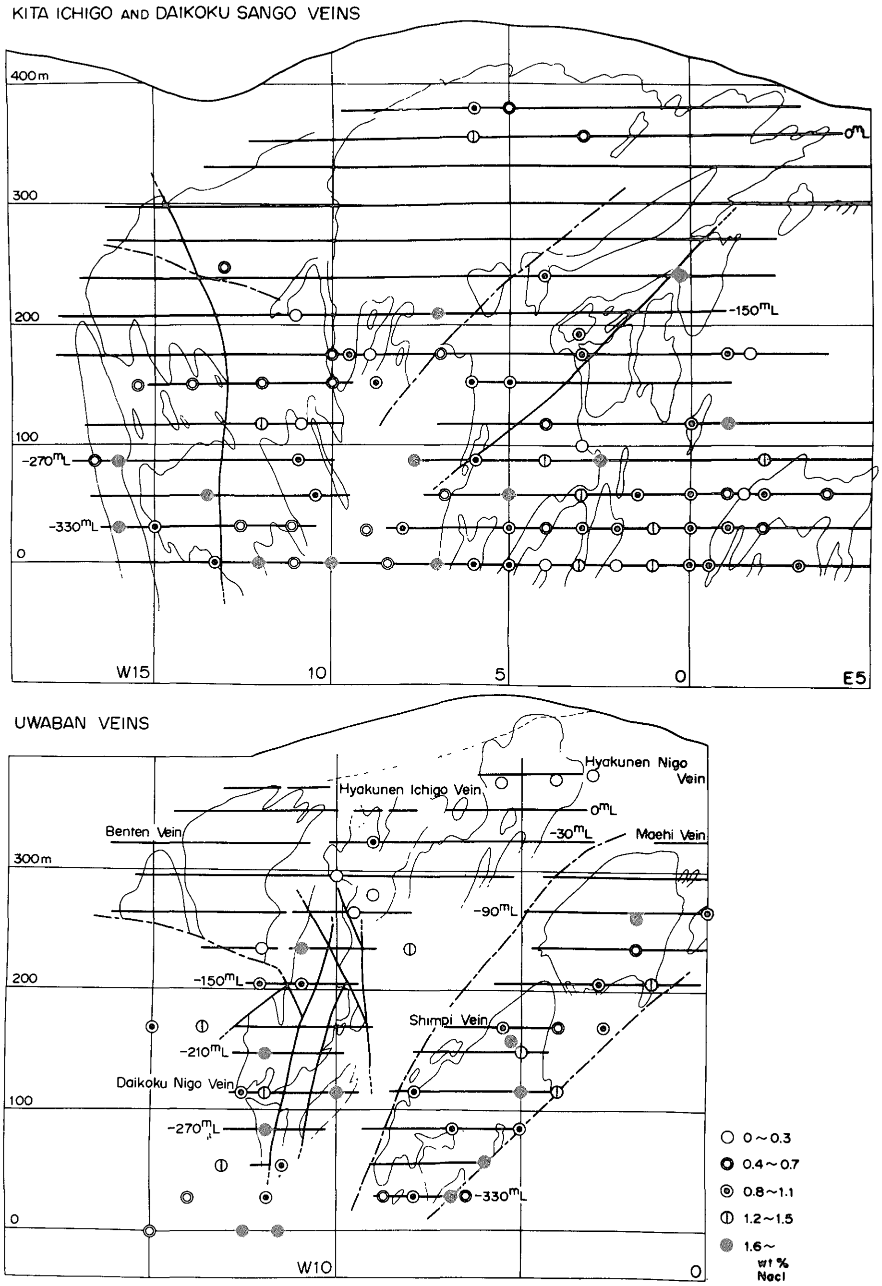


Fig. 11 Distribution of salinities of fluid inclusions on profiles of Fukujinzawa veins of Chitose mine.

to contain a small quantity of carbon dioxide. In the course of the study of about 2000 fluid inclusions, neither halite nor any daughter mineral was observed.

Measurements of filling temperature were carried out by using a heating stage, Type 1350, Leitz. Temperatures were calibrated against the melting point of salophen (191 °C) and saccharin (228 °C). The filling temperature was determined with an accuracy of ±1.5 °C.

The result of measurement is illustrated in Fig. 9. Histograms in the figure demonstrate the gradual increase of filling temperature towards lower levels. Data from every sampling points are projected on the profile of the veins in Fig. 10. The temperature range is clearly different between the upper half and the lower parts, and at the middle 180 mL, the temperature of 250 °C is dominant. It can be said that the upper half of Fukujinzawa deposits was formed at temperatures of 200 °–250 °C and the lower half at 250 °C–300 °C.

Homogenization temperatures of fluid inclusions in sphalerite were also determined from several samples. The results were in the uppermost temperature range obtained from inclusions in quartz.

YAJIMA and OHTA (1977) reported the salinity of fluid inclusions from the mine. The result is presented here with some modifications. Measurements of freezing temperature were carried out by the freezing microscope stage, Type NE, Nikon. Some amelioration was performed in order to minimize the temperature gradient within the sample chamber (OHTA and YAJIMA, 1977b), and the uncertainty in the freezing temperature determination generally came to ±0.1 °C.

Published data about the salinity of fluid inclusions from gold-quartz veins in Japan show rather low values in the range of 0.0 to 2.5 percent (ENJOJI and TAKENOUCHI, 1976). Similar result was obtained at Chitose deposits, where the measured salinity was in the range of 0.0 to 3.6

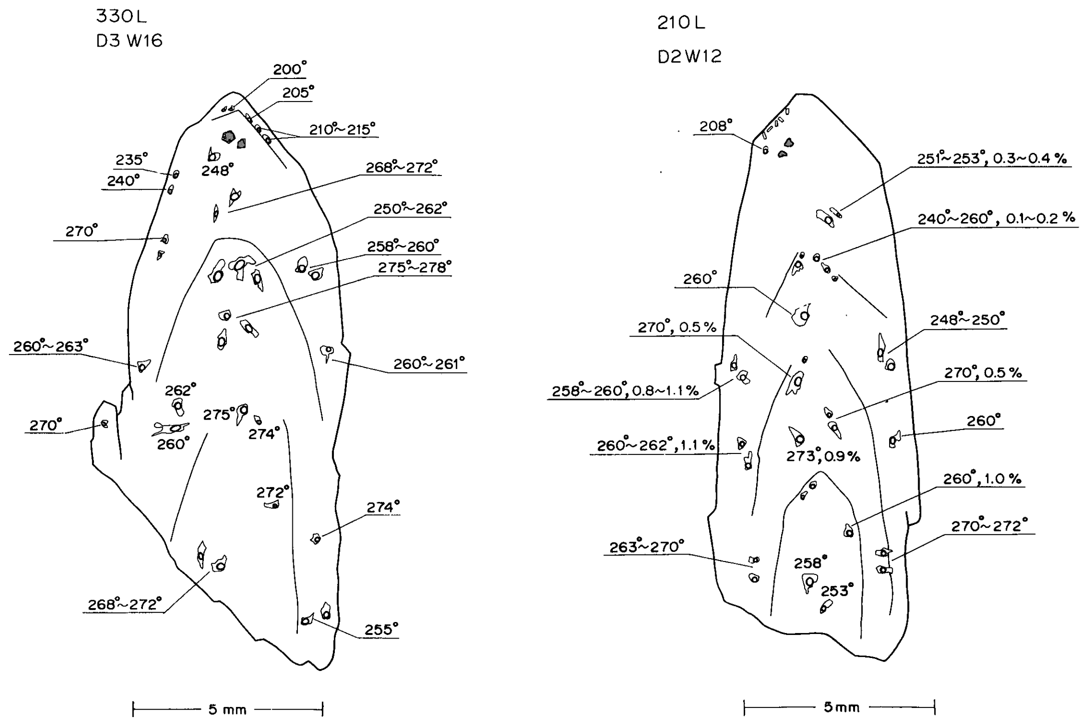
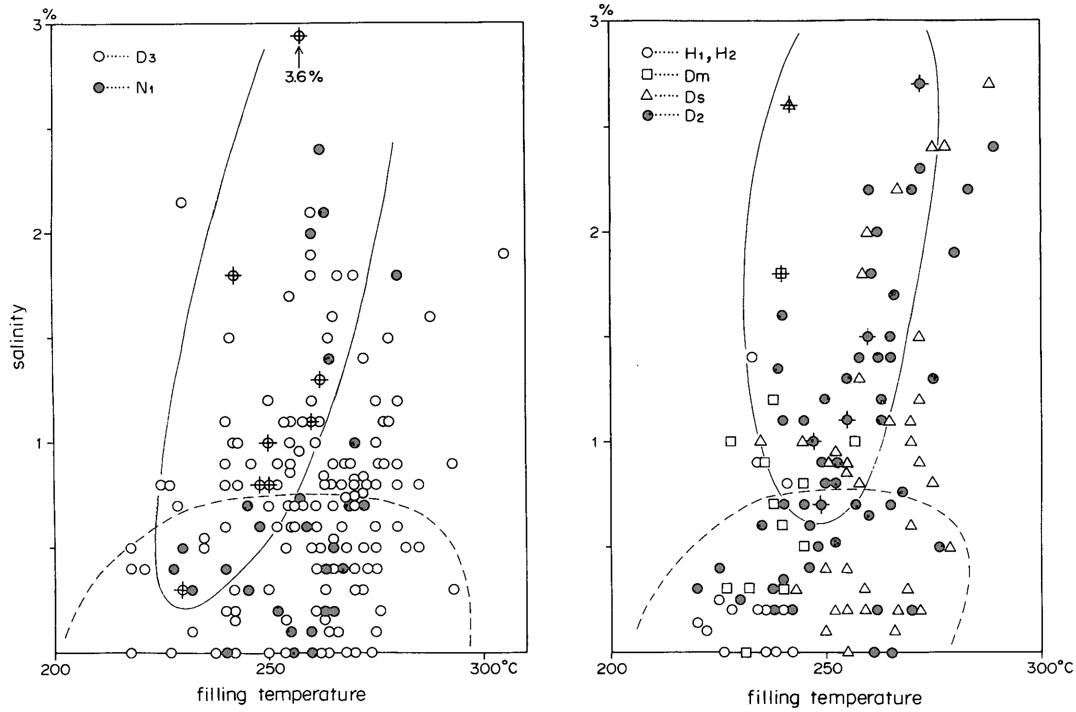


Fig. 12 Distribution of temperatures and salinities in a single crystal of quartz from Chitose mine.



D_3–Daikoku Sango vein, N_1–Kita Ichigo vein, H_1–Hyakunen Ichigo vein, H_2–Hyakunen Nigo vein, D_m–Daikoku Maehi, D_s–Daikoku Shimpi vein, D_2–Daikoku Nigo vein. Marks with a cross represent the data from the highest grade part in Fig. 4. Lower parts encircled by dashed lines include the data from the lowest grade part in the same figure.

Fig. 13 Temperature-salinity relation of fluid inclusions from Fukujinzawa deposits, Chitose mine.

percent equivalent NaCl and more than 90 percent of the measured values fell within 0.0 to 2.0 percent. The results of the measurements are illustrated in Fig. 11. The close relation between high salinity and ore shoot is observed, though the data regarding the upper half of Daikoku Sango vein are not sufficient. It might be also pointed out that the distribution pattern of salinity is generally consistent with the flow direction of ore solution proposed by IKEDA and NAGAMATSU (1975).

A few examples of temperature and salinity measurements in a single crystal of quartz is shown in Fig. 12. Although the crystals belong to those of the third stage, filling temperature of inclusions in cores of each crystal is coincident with that which is measured on the second stage quartz of the same position.

Fig. 13 shows the relationship between filling temperature and salinity. A rather steep inclination of the distribution pattern is observed as a whole. Two encircled areas in each figure include the points which correspond to the highest and the lowest grade parts in Fig. 4.

The maximum temperature difference between the deepest and the shallowest parts was measured to be 100°C and its vertical distance is about 400 meters. Thus the temperature gradient in the hydrothermal fluid system is about 2.5°C/10 m.

3.4 Formation condition

Fluid inclusion study of quartz from Fukujinzawa deposits showed the temperature of 300° to

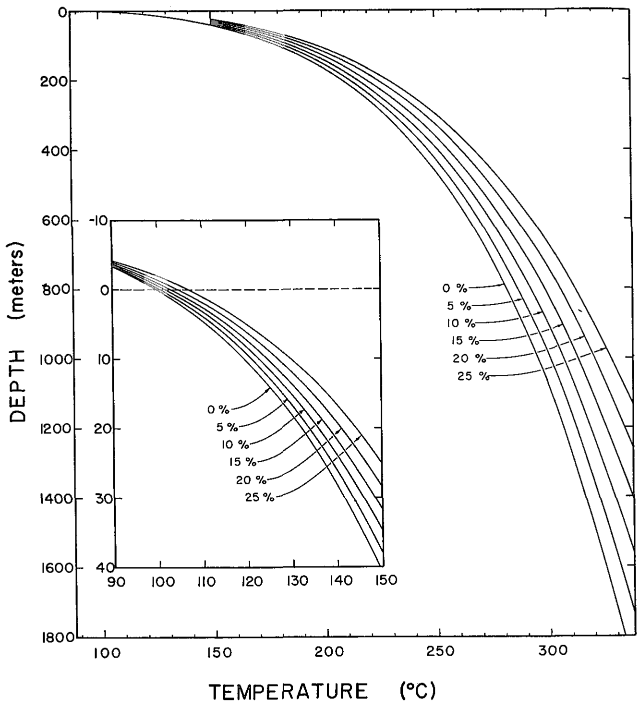


Fig. 14 Boiling-point curves for H_2O liquid (0 percent) and for brine of constant composition given in wt percent NaCl (HAAS, 1971).

200 °C and the salinity of 3.6 to 0.0 percent. Active boiling was evidenced by gaseous inclusions. One of the possible reasons for boiling is a sudden depression in pressure which can be caused by opened fractures. Abundance of gaseous inclusions might be explained by a geyser-like phenomenon within a hydrothermal fluid system. HAAS (1971) calculated the effect of salinity on the temperature-depth relations of a brine of constant composition at hydrostatic pressure. Provided that the deposition occurred in open fractures, the temperature of 300 °C and the salinity of 2.0 percent which were measured at the lowest level of the deposits, correspond to the depth of about 1050 meters on his boiling-point curve (Fig. 14). The vapor pressure and the density of this point are calculated as 84.9 atm and 0.734 g/cc, respectively. With the assumption that open fractures existed at the time, it can be said that Fukujinzawa deposits were formed at the depth between 1000 and 500 meters.

The recent investigations on the geochemical environment at the time of gold-silver deposition revealed that oxygen fugacity of Au–Ag deposition most probably was higher than that for Pb–Zn mineralization and oxidation process seem to have occurred (SHIKAZONO, 1973, 1974). Oxidation could be caused by the mixing with sub-surface waters. A steep distribution in the relationship between salinity and temperature also implies the mixing of the fluid with cold water.

According to the geophysical study on the terrestrial heat flow in Hokkaido (EHARA and YOKOYAMA, 1971), an extremely high heat flow region is known in west Hokkaido. Chitose mine together with Eniwa and Koryu mines, is located at the eastern fringe of this region and, thus, is not far from a low heat flow region of the Sapporo—Tomakomai lowland belt. Furthermore, thermal springs at Chitose mine show very low temperature (SAKO *et al.*, 1977) contrary to those of Toyoha mine located at the high heat flow area. Fukujinzawa deposits are situated at the distance of 15 kilometers from a southernmost outcrop of Jozankei quartz porphyry, and it is possible to say that the site of ore deposition was initially far from the heat source in addition to the critical situation to be located at the boundary between high and low heat flow regions.

Gold forms very stable complexes as chloride and, thus, is expected to be transported a long distance and to be deposited after precipitation of most other metals (HELGESON and GARRELS, 1968). This model of transportation and deposition agrees well with the formation of zonal distribution in the Teine—Chitose district. The gold-containing hydrothermal fluid might have been carried far from its source and deposited as a result of the relatively rapid decrease in temperature at the low heat flow region. It may be accelerated by mixing of cold meteoric water and the mixing has played still important role to result an increase of oxygen fugacity.

4. Lead-zinc deposits of Toyoha mine

4.1 Ore deposits

The mine is situated at the central part of this district where sediments, pyroclastic rocks and lavas of Jozankei Group and Toyoha Group occur as their type locality. Koyanagizawa Formation, correlated to upper Jozankei Group, is composed of altered basaltic andesite and rhyolite lavas. Motoyama Formation corresponding to lower Shiraigawa Formation consists of tuffaceous silt, mudstone and sandstone, and it overlies Koyanagizawa Formation with basal conglomerate. Nagato Formation corresponding to middle Shiraigawa to Takinosawa Formations is characterized by a large quantity of pyroclastics and lavas of altered andesite, dacite and rhyolite. These three formations are the host rocks of ore deposits (AKOME and HARAGUCHI, 1963, 1967; MIYAJIMA *et al.*,

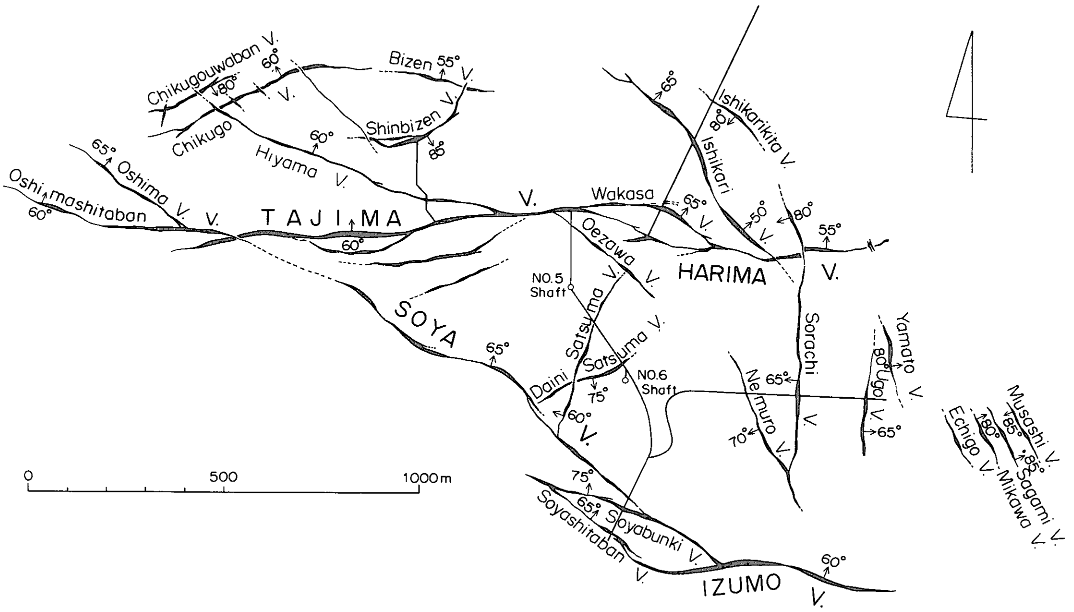


Fig. 15 Disposition of veins at Toyoha deposits.

1971; HASHIMOTO *et al.*, 1977).

Epithermal fissure-filling type ore deposits of the mine are mainly composed of sphalerite, galena and pyrite accompanied by minor amount of hematite, magnetite and silver minerals. More than 15 veins are known and they are classified into three fracture systems as E–W, NW–SE and N–S (Fig. 15). Tajima, Harima, Chikugo and Bizen veins belong to E–W system. The NW–SE system includes Oshima, Hiyama, Soya, Soyabunki and Izumo veins. Sorachi vein of N–S trend is economically important because of its high grade ore. Ishikari and Nemuro veins are grouped here in the N–S system despite their NW trend as they are branch veins of Sorachi and have similar mineral paragenesis with that of Sorachi. The veins of NW–SE and N–S systems cut across those of E–W trend, so the mineralization at Toyoha deposits is divided into the earlier and the later stages.

As for the wall rock alteration, OKABE and BAMBA (1976) discriminated four facies around Tajima vein and reported that sericite-quartz-pyrite assemblage had a close relation to the mineralization.

4.2 Ore minerals

Pyrite, sphalerite and galena are the predominant ore minerals throughout the deposits and they are usually accompanied by minor amounts of chalcopyrite, tetrahedrite and pyrrhotite. However, the earlier and the later veins have contrasting mineral assemblages.

The earlier veins have a spotted occurrence of hematite-magnetite and argentite-native silver. A little amount of arsenopyrite, wurtzite and graphite is known at lower levels of Harima vein. Galena in the earlier veins rarely contains silver sulphosalt minerals. Rare occurrence of cassiterite and jamesonite (Fig. 16) in Tajima and wolframite in Harima are also known. It is confirmed that reduction of hematite to magnetite and deposition of argentite, jamesonite, cassiterite and wolframite in the earlier veins were all caused by the later mineralization (YAJIMA and OHTA, in press).

Among the later veins, a zonal distribution of minerals is observed. The veins of eastern side, Sorachi and Izumo, include large amounts of pyrrhotite, arsenopyrite, marcasite and wurtzite together with wolframite, cassiterite, stannite group minerals, silver sulphosalts, lead sulphosalts

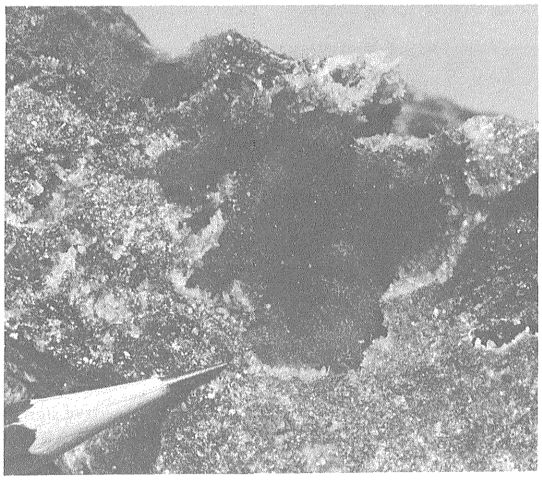
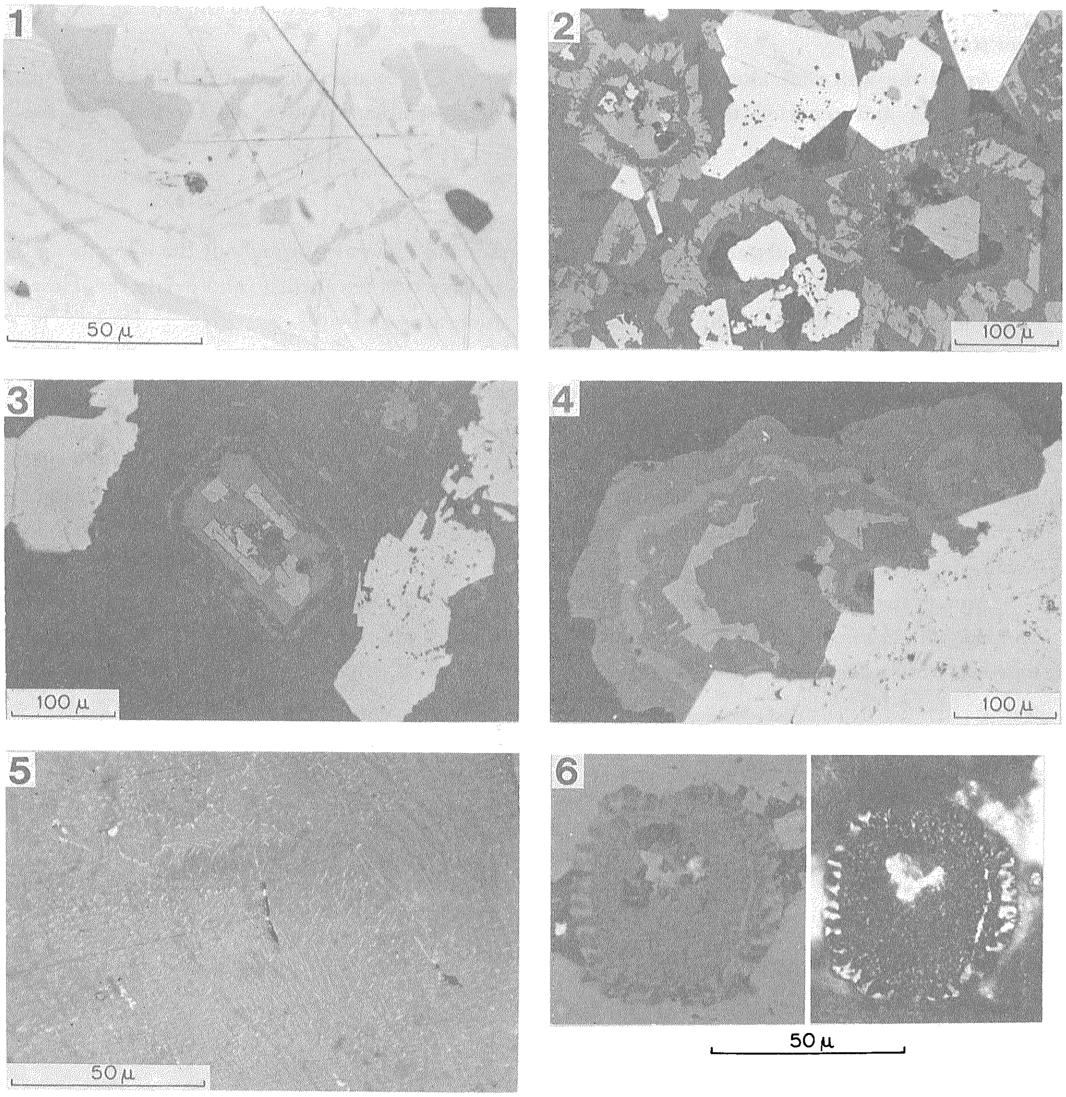


Fig. 16 Occurrence of jamesonite in vugs. Each fibre has a diameter of one to five micron. Tajima vein, −350 mL.

and graphite, while the western side veins, Soya, Hiyama and Oshima, are characterized by manganese carbonate minerals as well as antimony and arsenic minerals. Argentite is rare in these veins, whereas silver sulphosalt minerals such as miargyrite, polybasite, pyrargyrite, freibergite and stephanite, are usually found in galena and sphalerite (photo 1 in Fig. 17). Stannite group minerals (photos 2, 3, 4, 5 in Fig. 17) and lead sulphosalts are not well determined yet. Furthermore, stibnite, berthierite and native arsenic are recognized (OHTA, 1979).

Coaly substance and rutile are found in ores of Ishikari, Sorachi, Izumo and Soyabunki veins. They are confirmed to be derived from their host rock, black mudstone, and sometimes coaly



1: Miargyrite in galena, 2: Atoll-like stannite in sphalerite, 3: Zonal growth of stannite and chalcopyrite in sphalerite, 4: Colloform texture of zincian stannite (inner) and sakuraiite-like mineral (outer) in sphalerite with dotted chalcopyrite, 5: Exsolved chalcopyrite in stannite, 6: Graphite in wurtzite, left-open nicol, right-crossed nicol. Rutile is included at the core of graphite.

Fig. 17 Microphotographs showing occurrence of some minerals from Toyoha deposits.

substance changed into graphite by the influence of hydrothermal solution (YAJIMA, 1978) (photo 6 in Fig. 17).

4.3 Fluid inclusion study

Several reports on fluid inclusion study of Toyoha deposits have been published and they were summarized by ENJOJI and TAKENOUCHI (1976). EL SHATOURY *et al.* (1975) studied fluid inclusions in quartz phenocrysts of rhyolite from the mine, suggesting a mixing of meteoric water with hydrothermal solution at least in the veins of E–W trend. YAJIMA and OHTA (in press) made detailed studies of fluid inclusions in Tajima, Harima and Izumo veins, so only a brief description is given here according to their result. Temperature and salinity of ore-forming solutions at the time of deposition of the major three veins are reported as follows:

Izumo vein ....300°–200°C, 4.2–1.0 percent
Harima vein ....250°–200°C, 2.2–1.0 percent
Tajima vein....................250°–150°C, 1.5–0.2 percent or lower

Soya vein is considered to have about the same condition in temperature and salinity with those of Tajima (SHIKAZONO, 1974, 1975).

Boiling of fluid as expressed by the existence of gaseous inclusions is occasionally observed in samples of ores and gangues from Toyoha mine, contrary to the case of Chitose.

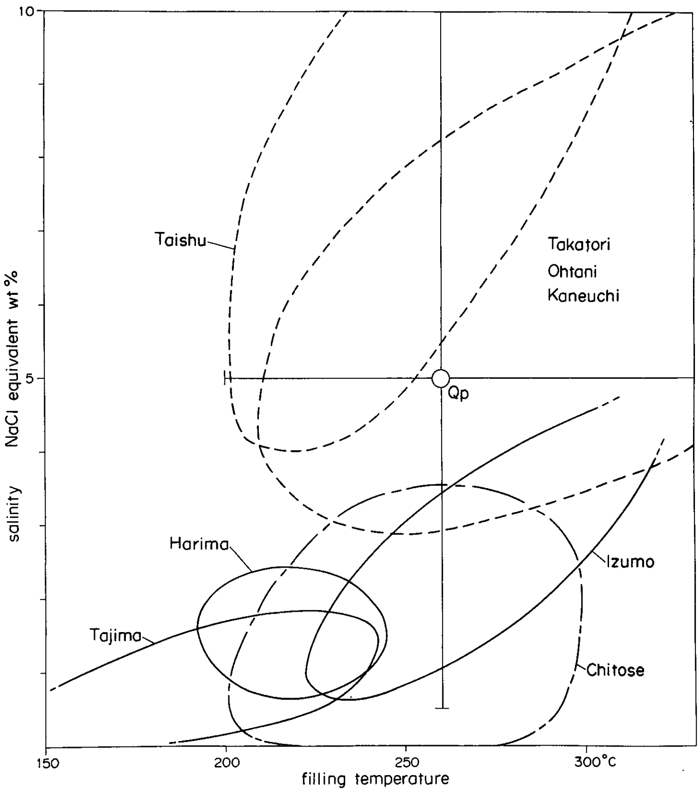


Fig. 18 Distribution of temperature and salinity of fluid inclusions from epithermal (Chitose and Toyoha, this study), mesothermal (Taishu, IMAI, 1978) and hypothermal (Takatori, ENJOJI, 1972; IMAI, 1978) deposits. Crossed lines represent the ranges measured by those in rhyolite from Toyoha mine (EL SHATOURY *et al.*, 1975).

Distribution of temperature and salinity of inclusions are illustrated in Fig. 18 together with those of Chitose, Takatori (hypothermal) and Taishu (mesothermal) deposits. Temperature and salinity ranges of inclusions in rhyolite (El Shatoury *et al.*, 1975) are also shown in the same figure by crossed lines. Fluids in rhyolite show close similarity with those related to hypothermal and mesothermal deposits. However, the condition at which mineralization actually occurred at Toyoha deposits is still in the range of epithermal condition.

4.4 Formation condition

Recently Yajima and Ohta (1979) examined geological environment, mineral zoning among veins of two stages and also the result of fluid inclusion study, and suggested that the mineralization proceeded, on the one hand, from Harima to Tajima and Chikugo at the earlier stage and on the other hand, from Izumo to Sorachi and from Izumo to Soya and Oshima at the later stage, and that deposition of most of the sulphide minerals occurred under reducing conditions.

Taking account of subterranean thermal structure in this district (Ehara and Yokoyama, 1971; Takeuchi *et al.*, 1975), they considered that ore-forming solution came up from southeastern deep, and proposed a model for the formation of Toyoha deposits. The model explains well the occurrence of overall minerals and the behaviour of some elements in the mine, for example, occurrences of argentite, cassiterite, wolframite and antimony sulphosalt minerals in the earlier veins and also the reduction of hematite to magnetite. It is said that the ores formed at the later stage may be superior to those deposited at the earlier stage both in amount and in quality.

They showed that both sulphur and oxygen fugacities at the time of deposition are not much different between earlier and later veins, for instance, f_{S_2} was between 10^{-10} and 10^{-17}, while f_{O_2} had the range of 10^{-35} to 10^{-45}, respectively. Thus, the decrease in temperature might be an important factor which controlled mineral deposition. Compared to the formation process of Fukujinzawa deposits of Chitose mine, Toyoha deposits are thought to be formed under rather slow and gradual changes in temperature because they are located at very high terrestrial heat flow area. Extensive secondary alteration of ores (Shikazono, 1975) might be caused by the geothermal conditions which changed very little to this day.

Summary

(1) West Hokkaido is divided into three geological sub-provinces which can be correlated with reasonable closeness to metallogenic sub-provinces. The first sub-province is characterized by the terrestrial sediments of early Miocene age and includes polymetallic vein-type and replacement-type ore deposits. The second one is an upheaved area where enormous quantity of pyroclastic rocks together with polymetallic vein-type ore deposits are found. In subsiding through of the third sub-province, stratabound type deposits of manganese occur as well as kuroko type deposits.

(2) The Teine—Chitose district is in an upheaved area where pyroclastic rocks of Miocene age and Pliocene to Quaternary volcanic rocks spread over older basement rocks associating with quartz porphyry intrusives. Neogene formations of the district are classified as Jozankei, Toyoha, Toyama Groups and Nishino Formation in ascending order. The former two groups provide the site of ore deposition. A number of polymetallic deposits in this district show a distinct zonal arrangement around Jozankei quartz porphyry which is considered to be one of Neogene granitoids. Toyoha mine is a representative deposits of the inner Pb–Zn zone. The outer Au–Ag zone includes Todoroki, Teine, Chitose mines and others. Tellurium is a characteristic element in the Au–Ag

zone, whereas, tin and tungsten are known in the Pb–Zn zone. Sb, As and Mn are distributed throughout the district in variable amounts. It is concluded that there are zonation of base metal deposits in this district from geological, mineralogical, geochemical and geophysical evidences.

(3) Kuroko and kuroko-type barite deposits occur around this zonation, but they are formed in an earlier stage than the vein-type deposits and also in a different geological environment.

(4) Teine deposits demonstrate a prominent feature with regard to metal content and mineral paragenesis. The deposits differ from that of Chitose and Todoroki in the small amount of quartz and from Toyoha deposits in abundance of copper. This characteristic was interpreted as an intermediate character between Au–Ag and Pb–Zn deposits.

(5) Formation temperature was measured by fluid inclusions. An important portion of the ore deposits in this district was concluded to be formed at temperatures between 150° and 250°C except massive barite deposits. Much higher temperature was observed at deeper levels of Chitose and Toyoha deposits. Barite deposits have been formed at temperatures lower than 100°C.

(6) Chitose mine is situated at the southern end of the zonation and consists of typical gold-quartz veins. In Fukujinzawa deposits, formation temperature and salinity measured by fluid inclusions are in the range of 200°–300°C and of 0.0 to 3.6 percent, respectively. Assuming the existence of open fractures, the deposits were formed at depths between 500 and 1000 meters. The steep distribution in temperature-salinity diagram suggests the mixing of saline solutions with cold meteoric water. The hydrothermal solution was transported to a distance and encountered cold meteoric water at about the boundary area between the high and low heat flow regions, and precipitated gold and silver to form the veins of Chitose mine.

(7) Toyoha mine is located at the center of the zonation and includes typical lead-zinc vein-type deposits. More than 15 veins occur in major three directions such as E–W, NW–SE and N–S. Veins of E–W trend were formed earlier than those of NW–SE and N–S trend. Decreasing tendency in temperature and salinity of fluid inclusions towards the west is apparent and mineral zoning was recognized in both vein groups. The sequence of mineralization in space and time was deduced from these observations together with the subterranean thermal structure.

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The languages used in each paper are indicated in parenthesis with abbreviations as follows. (J): written in Japanese. (JwE): written in Japanese with English abstract. (F): written in French. The paper without such indications are written in English. References with a notation (*) are those for Table 3.

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地名英和対応表

Akaiwa	赤岩	Chitose	千歳	Eniwa	恵庭
Inatoyo	稲豊	Jozankei	定山渓	Kobetsuzawa	小別沢
Koryu	光竜	Kutosan	倶登山	Matsukura	松倉
Meiji	明治	Minami-Shiraoi	南白老	Morino	盛能
Otoyo	大豊	Shakotan	積丹	Shiraoi	白老
Suttsu	寿都	Teine	手稲	Todoroki	轟
Toyoha	豊羽	Toyohiro	豊宏	Toyotomi	豊富

西部北海道，手稲—千歳地域における新第三紀鉱化作用

矢島 淳吉

要　旨

西部北海道の東部に位置する手稲—千歳地域には，定山渓石英斑岩を軸として分布する金属鉱床の累帯配列が認められる．豊羽鉱山は内側の鉛亜鉛帯における代表的な鉛亜鉛の鉱脈鉱床であり，千歳鉱山は外側の金銀帯に属する典型的な含金石英脈鉱床である．

千歳鉱床の流体包有物から得られた温度，塩濃度はそれぞれ200°-300℃，0.0-3.6%であり，鉱床の最下部において得られたデータから見積もられた熱水溶液の蒸気圧，密度は，それぞれ84.9気圧，0.734 g/cc であった．静水圧のみが働いていたと仮定すれば，この値は 1,050m の深度を与える．

豊羽鉱床においては，前期鉱脈では東側から西側へ，後期鉱脈においては南東側から北西側へ，それぞれ，流体包有物の温度，塩濃度の低下及び鉱物の累帯分布が認められる．この事実と，鉱山東南方深部に推定されている熱源の存在とから，豊羽鉱床の形成過程に関するモデルを構築した．

地質学的背景，鉱物共生関係，流体包有物の解析結果などに加えて地下の熱構造を総括的に検討した結果からみても，本地域に金属鉱床の累帯配列を設定することは妥当であると思われる．

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