

A Mineralogical Study of the Skarn Minerals from the Shinyemi Lead-Zinc Ore Deposits, Korea

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Abstract : Skarn silicates from the Shinyemi lead-zinc ore deposits can be distinguished as following three mineral assemblages: 1) garnet-pyroxene-phlogopite-wollastonite assemblages, 2) garnet-pyroxene assemblages, 3) garnet-epidote assemblages

The assemblages are considered to be related with occurrences and kinds of ore minerals, and stage of mineralization in the deposits.

Microprobe analyses of some garnets from the deposits show strong chemical zoning which is due to the changing equilibrium condition during growth of garnet crystal.

Depositional condition of ore deposits and place of the ore-related igneous rock are discussed in the light of chemical composition of garnet and occurrence of skarns in the Shinyemi.

Introduction

The Shinyemi zinc-lead mine is located in the western part of the Taebaegsan mineral belt, which contains a number of important base metal deposits, including the Ulchin, Yeonhwa, Geodo, Sangdong and Imok mines. Among those the Shinyemi mine produces zinc, lead, copper and molybdenum sulfides and magnetite ores. The location map of the Shinyemi mine is presented in Fig. 1.

General geology and petrological studies on the Shinyemi have been made by Kim, et. al. (1965), Miyazawa (1977), and Kim and Kim (1978). The geology, petrochemical and mineralogical data, and production of the ore deposits are well summarized by Kim and Kim (1978) and Kim and Nakai (1980) have been reported the sulfur isotope compositions of sulfide minerals from the some base metal ore

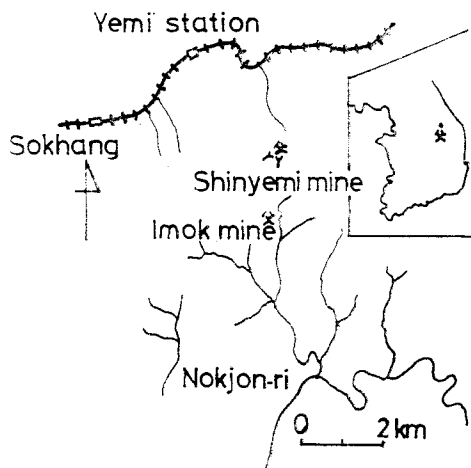


Fig. 1 Location map of the Shinyemi mine.

deposits including the Shinyemi in the Taebaegsan metallogenic belts.

Garnet-pyroxene-epidote skarns occur at or near contacts of the Shinyemi granodiorite with limestone of the Ordovician Maggol Formation. The skarn silicates are composed of the major

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garnet, pyroxene and epidote and minor scapolite, phlogopite, chlorite and brucite. Gangue minerals include calcite, rhodochrosite and

quartz. Both in the east and west ore fields at Shinyemi are dominated by brown to green garnet minerals. Small amount of pyroxene

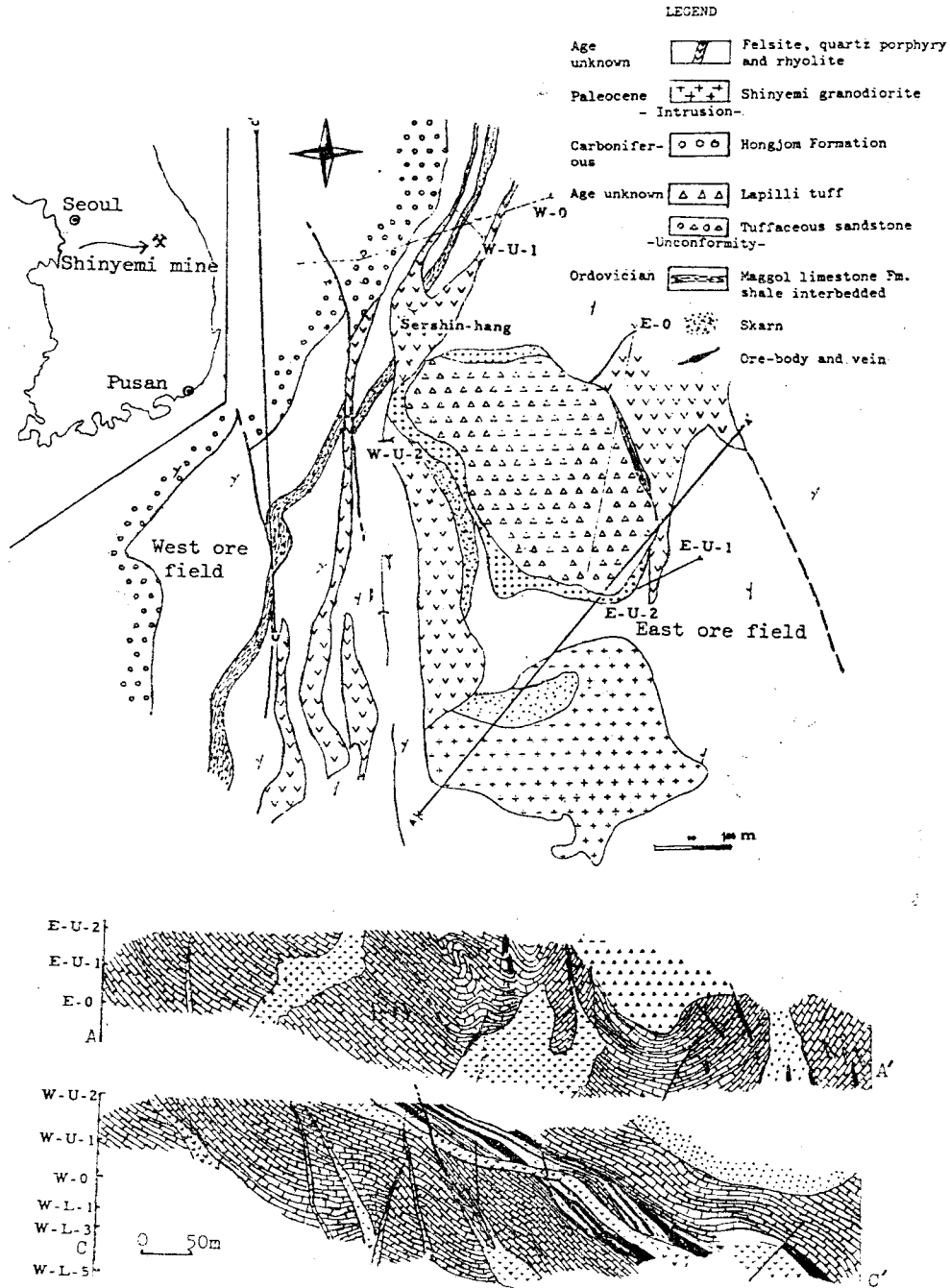


Fig. 2 Geologic map of Shinyemi ore deposits (after Kim and Kim, 1978)

occurs in the sulfide and magnetite orebodies limitedly in the west ore field, and epidote mainly in the east ore field. In this paper the characters of the garnet one of major and common skarn minerals in the Shinyemi ore deposits will be described mainly in terms of mineral chemistry and ore forming processes.

Garnet samples investigated include 30 separated minerals of sulfide ores collected from the east and west ore fields of the Shinyemi mine. Chemical compositions of these minerals reported here were determined by JEOL-50A electron microprobe at Waseda University, Japan, and by wet analysis at Korea Research Institute of Geoscience and Mineral Resources, Seoul. Analyses by electron microprobe focused on lineal tracing and point analysis from margin to center of the garnet crystals to examine some spatial variations in chemical composition of these crystals.

Geologic setting

The Shinyemi mine area consists of the Cambro-Orovician Maggol Formation, tuffaceous sandstone of unknown age, the Carboniferous Hongjeom Formation, and granodiorite and dike rocks of Paleocene age (Fig. 2).

The Maggol Formations: The Maggol Formation, the uppermost unit of the Great Limestone Series, is widely distributed in the mine area. The Formation consists of gray crystalline limestone which is intercalated by thin layers of dark shale. The attitude of the formation is rather gentle showing $N20^{\circ}\sim 30^{\circ}E$ strike and $20^{\circ}\sim 25^{\circ}NW$ dip. The formation is intruded by the Shinyemi granodiorite and dikes of rhyolite, felsite, and quartz porphyry. The Shinyemi deposits is embedded in this formation along or near the contact with the granodiorite and the related dikes. At the vicinity of contact zone, the limestone was brecciated in part and the intercalated shale, dark gray

to chocolate-colored, has transformed to hornfels as seen in the west ore field.

The lapilli tuff and tuffaceous sandstone: These tuffaceous rocks crop out on the hill over the Shinyemi east orebodies. They overlie unconformably the Maggol Formation. The lapilli tuff contains bunch of breccias in part but very little in other part and grades upwards into tuffaceous sandstone. The formation has never been recognized in Paleozoic Formation in the Taebaegsan region.

The Hongjeom Formation: The Formation overlies unconformably the Maggol limestone, but no direct contact has been observed between the tuffaceous rocks and the Hongjeom Formation in the area. The Formation consists of tuffaceous sandstone, red shale and greenish gray sandy shale.

Shinyemi granodiorite and dike rocks: The granodiorite crops out in the Shinyemi east ore field and intrudes into the Maggol limestone. The age was determined by K-Ar method as 60 m. y. by Dr. Ueda of Tohoku University. The dating result has a significance on interpretation of metallogenic epoch of the Shinyemi deposit. Dike rocks of rhyolite, quartz porphyry and felsite are abundant in the vicinity of the ore deposits. Their trend is nearly north-south direction. The felsite seems to have related with the late stage of mineralization.

Shinyemi ore deposits

The Shinyemi deposits are emplaced in and near the contact zone between the Maggol limestone and the Shinyemi granodiorite cupola. The principal ore minerals are sphalerite, galena, chalcopyrite and molybdenite, and sulfide gangues are pyrrhotite, pyrite and arsenopyrite. Magnetite as oxide mineral also occurs in the west ore field. Skarn silicates consist of major garnet and minor pyroxene.

The Shinyemi deposits are divided into the west and east orebodies according to the mode of occurrence and location.

The west orebodies: The west orebodies are embedded in and parallel to the bedding planes of the upper part of the Maggol limestone which is interlayered by black to purplish red shales (Fig. 2). The limestone beds were mineralized by replacement through the skarnization and the shale layers altered to hornfels. The hornfels grade into unaltered black or purplish shales in the underground. Irregular blebs and veinlets of pyrrhotite are found in the hornfels. The ore minerals of the west orebodies are sphalerite, chalcopyrite and molybdenite which are accompanied with minor amounts of galena, pyrite and pyrrhotite. Scheelite is also found occasionally at the lower levels of the orebodies.

Skarn minerals consist mainly of grandite garnet, pyroxene and tremolite. The ore beds have a few centimeter to 15m in thickness and extend up to 200m.

The east orebodies: The east orebodies are emplaced in and near the contact zone of lower part of the Maggol limestone with the Shinyemi granodiorite, in the form of veins and small pipes along the fissures (Fig. 2). The east orebodies are accompanied by skarn minerals

in part but most of them are lacking in skarns, that is quite different from the west orebodies. Skarns are dominated with garnet and epidote. Ore minerals include major sphalerite and minor galena, chalcopyrite and molybdenite, with pyrite, pyrrhotite, marcasite, calcite as their gangue minerals.

Major fissures strike mostly $N30^{\circ}\sim 45^{\circ}W$, $60^{\circ}\sim 80^{\circ}NE$ and NS, and dip $60^{\circ}\sim 80^{\circ}NE$. Sphalerite is disseminated in the granodiorite as well as in the limestone. The predominant skarn mineral assemblage of the east orebodies, garnet-epidote, differs from that of the west orebodies which is garnet-pyroxene assemblage. The east orebodies include a total six orebodies most of which have different ore mineral assemblage and different attitude.

Occurrences of skarn

The skarns which contain the ore minerals belong to exoskarns formed by replacement of Maggol limestone. The Maggol Formation is divided into the upper formation consisting of impure limestone, purplish to black shale and dolomitic limestone, and the lower formation consisting of white crystalline marble and dolomitic limestone. Chemical compositions of typical limestones from the Shinyemi mine are presented in Table. 1.

Table 1. Chemical analyses of limestones from the Shinyemi mine
(Analyzed by X-ray fluorescence at Nagoya University)

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	CaO	MgO	Na ₂ O	K ₂ O	P ₂ O ₅
WLS (211)	5.87	0.24	1.69	3.02	0.20	47.09	1.72	—	0.36	0.05
ELS (212)	0.97	0.04	0.42	0.68	0.20	43.14	10.88	—	—	—

SiO₂, Fe₂O₃, Al₂O₃ and CaO contents of them are higher in the upper limestone formation (211) than in the lower one (212), and the sample 212 is a highly nonsiliceous dolom-

itic limestone. In the west ore field, limestone layers were replaced by skarn silicates and ore minerals, and shale was altered to hornfels (Fig. 3). In the east ore field, however, skarns

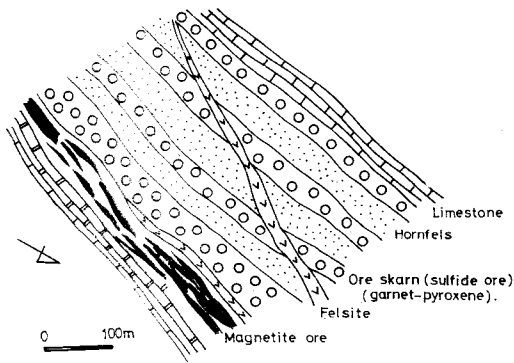


Fig. 3 Sketch of bedded skarns, west ore field of the Shinyemi mine.

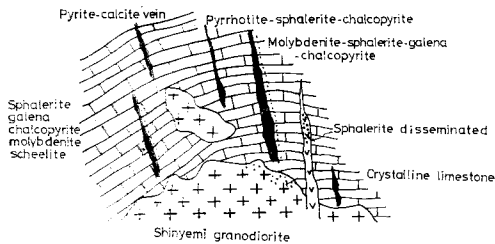


Fig. 4 Sketch of pipe and vein orebodies, east ore field, Shinyemi mine.

occur partly in and near the ore veins (Fig. 4). In general, zoning of the skarns at Shinyemi can be correlated with some of the model of Zharikov (1970) and Miyazawa (1977) although some difficulties exist in zonation of the Shinyemi skarns because of their complicated nature in field occurrences. Progressive skarnization of the Shinyemi deposits was shown from pyroxene through garnet to epidote in general sequence.

Skarn mineral assemblages

Skarns in Shinyemi can be classified into the following three mineral assemblages; 1) garnet-pyroxene-phlogopite-wollastonite assemblages formed by replacement of dolomitic limestone in association with magnetite orebody in the west ore field. 2) garnet-pyroxene assemblages formed by replacement of impure limestone in association with sulfide orebody in the west ore

field. 3) garnet-epidote assemblages formed by replacement of pure crystalline marble in and near ore veins in the east ore field.

1) Garnet-pyroxene-phlogopite-wollastonite assemblages: Skarns associated with the magnetite orebody of the west ore field, consist of garnet, pyroxene, phlogopite, and minor wollastonite. It was formed by replacement of dolomitic limestone of which had been partly altered to talc. Characteristically, magnetite occurs in this group and no sulfide minerals occur in the magnetite skarn orebody. The assemblages characterized by Mg-Si skarns show a different stage of skarnization compared with the mineral assemblages such as garnet, pyroxene and epidote. The magnetite orebody is indicated to be a product of the earliest ore mineralization in the Shinyemi deposits by the mode of occurrence and skarn mineral assemblage. According to Zharikov (1970), phlogopites in skarns were grouped into the following genetic groups; a) in altered skarns, magmatic stage, hypabyssal facies b) in altered skarns, magmatic facies of iron ore deposits, abyssal facies, c) in deposits of phlogopite (Fig. 5).

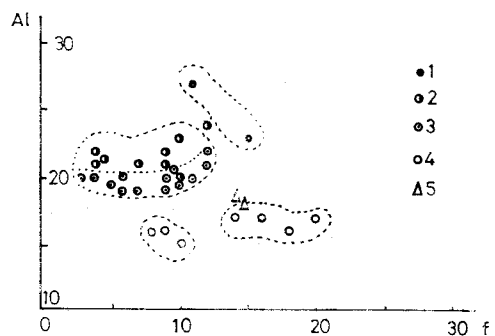


Fig. 5 Compositions of phlogopites in postmagmatic magnesian skarns (Zharikov, 1970)

- 1 : in altered skarns, magmatic stage, hypabyssal facies
- 2 : in altered skarns, magmatic stage, deposits of phlogopites
- 3 : in postmagmatic skarns, deposits of phlogopites
- 4 : in deposits of iron ores
- 5 : phlogopite from the Shinyemi mine

Table 2 Chemical compositions of the phlogopite from the west magnetite orebody of Shinyemi mine, (analyzed by X-ray fluorescence (JEOL SX-G011) at Nagoya University)

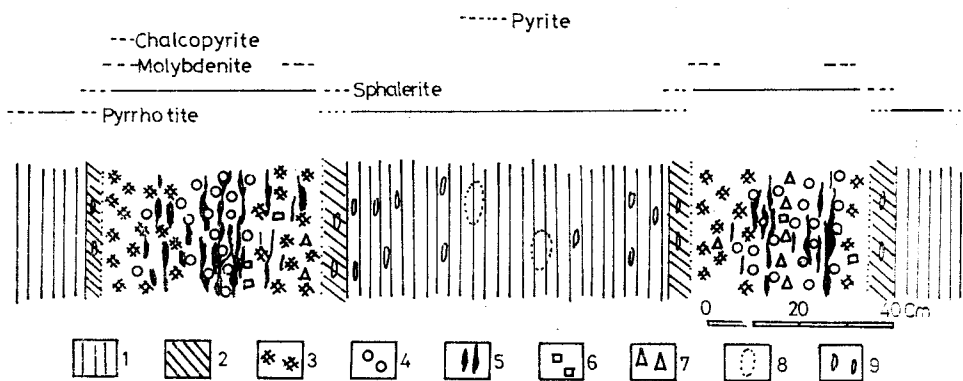
Sample No.	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
K-1	37.26	0.24	15.88	3.87	0.96	25.99	2.43	0.03	5.13	0.27
K-2	37.07	0.24	15.51	3.85	0.92	25.45	2.46	—	5.17	0.27

As shown in Fig. 5, his diagram of aluminousness versus ferroginousness represents that the strictly skarnal phlogopite differs from phlogopite in magnesian exoskarns of magmatic stage by their lower alumina content. According to the diagram, phlogopites from the Shinyemi belong to group IV, endoskarnal phlogopite in deposits of iron ores (Fig. 5). Analytical data of phlogopite are presented in Table 2.

2) Garnet-pyroxene assemblages : Garnet-pyroxene minerals in the west skarn orebody, which contains sulfide ores, replaced impure limestone selectively which alternates with hornfels, having a number of pyrrhotite lenses for which someone called "tiger rocks". Sulfide ores are composed mainly of sphalerite, molybdenite, pyrrhotite, chalcopyrite and minor scheelite, galena and pyrite, filling pore space between garnets, and garnet-pyroxenes. Since the replacement of the host rocks by sulfide

**Microphoto 1.** Zonal structure of Shinyemi garnet

ores depends on their compositions, the extent of the ore zone is also limited by the limestone. Hedenbergitic pyroxene are predominated with a small amount of clinozoisite and quartz. Zoning of skarn minerals in the west orebodies shows five to six layers of skarn and hornfels. The hornfels is divided into bands of chocolate and white in color. White band notably appe-

**Fig. 6** Zonation of bimetasomatic type of west orebody of the Shinyemi ore deposits.

- 1: chocolate-colored biotite-chlorite hornfels with many pyrrhotite lenses and veinlets, and with inclusions of limy skarns.
- 2: white-colored hornfels with clinopyroxenes, disseminated sphalerite and pyrrhotite veinlets and small lenses.
- 3: pyroxene and garnet 4: garnet 5: sulfide ores, mainly sphalerite
- 6: clinozoisite 7: epidote 8: inclusion of limy skarn 9: pyrrhotite lenses

ars in the side of skarn ore horizon (Fig.4). Hornfels is biotite-chlorite hornfels associated with a few pyroxenes. As can be seen in the Fig.6, the skarn ore horizons is divided into garnet-pyroxene, garnet-calcite and garnet-zoisite from margin to center. Pyroxene is replaced by garnet in part that are identified in many thin sections of the samples. Of the ore minerals, molybdenite and chalcopyrite appear on the marginal part of the skarn ore zone, whereas pyrrhotite in hornfels, and sphalerite in whole skarn zone. Sphalerite is also disseminated in the white band of the hornfels. It is proposed that pyrrhotite is early product in paragenesis and the other ore minerals are replaced from margin to center of skarn ore zone with time.

3) Garnet-epidote assemblages: East orebody partly have garnet and epidote skarns which occur in and near ore veins along the fracture zones of the pure crystalline limestone. Predominant skarn minerals are brown garnet and green epidote. Garnet is brown, reddish brown, yellowish brown or green in color due to the chemical composition of Mn and Ti. Of the seven ore veins in the east deposits, four veins have no skarn, for example, No. 1 and 2 veins, at Dongshin-hang, New B and Main orebodies, and the other three ore veins have skarns for example molybdenite, New A- and No.1-orebodies. Ores consist mainly of sphalerite, galena, chalcopyrite, molybdenite and gangues of pyrrhotite, pyrite and marcasite.

Zonal structure of the garnet

According to Shoji (1977), the origin of zoning of garnet depends on chemical potential as follows.

$$\begin{aligned}\mu_i &= \mu_i^\circ + RT \ln a_i \\ &= \mu_i^\circ + RT \ln f_i\end{aligned}$$

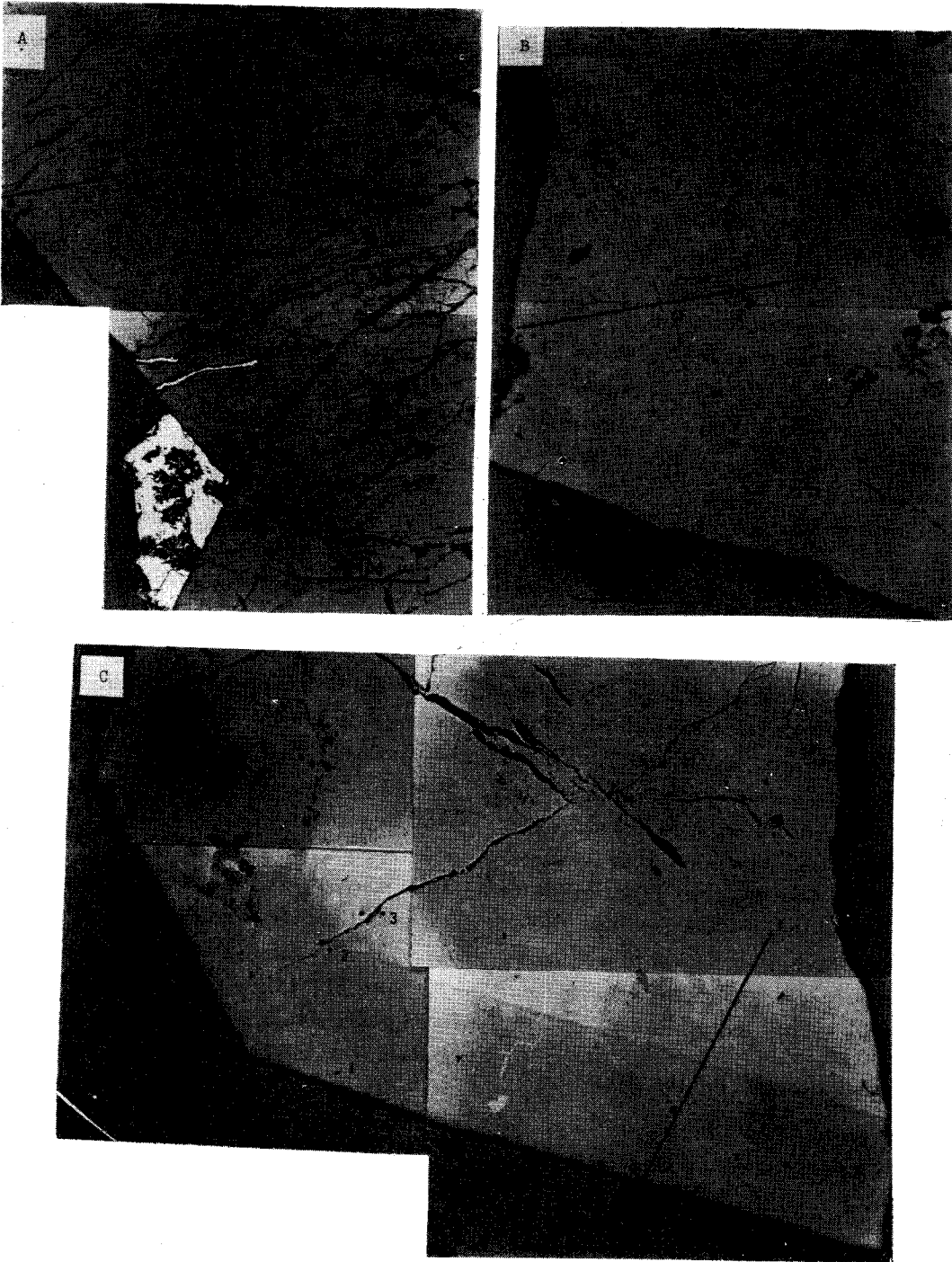
where T is temperature, a_i is activity of composition i of fluid, f_i is fugacity of composition

i of fluid, and R is gas constant. Zonal structure is formed by variation of density of element from center to margin in a crystal in accordance with crystal growth of solid solution changing with time and distance. At this time temperature is an important factor of chemical potential, so that zoning is apparently affected by temperature.

Garnet from the Shinyemi mine are grandite of 0.5 to 1 cm in diameter and are compositionally zoned (Microphoto. 1). Positions analyzed by microprobe are marked in microphoto. 2.

The most striking features were found from the present data are the variation of chemical composition from core to rim of garnet crystals, as already reported by Atherton and Edmunds (1966), Hollister (1966), Banno (1965), and Finlay and Kerr (1979). Garnet sample from the west (W-2) shows an increase of iron concentration in the center of the crystal, whilst manganese and aluminum are enriched toward the rim (Microphoto. 2C, Fig.7). On the other hand, the sample from the east (E-1) shows a decrease of iron in the core of the crystal (Microphoto. 2A, Fig.8). Mn^{+2} content, which is replaced by Ca^{+2} have the same trend as Al^{+3} in variation. Ca^{+2} and Si^{+4} do not show the variation in composition, but Al^{+3} and Mn^{+2} markedly vary from rim to core of the crystals. However, unzoned garnet from the west orebody does not show the variation of Fe^{+3} and Al^{+3} (Microphoto. 2B, Fig.9). The quantitative results by microprobe analyses of garnets from the Shinyemi deposits are listed in Table 3.

In general, chemical composition of garnet from the calcareous contact rocks is represented by 40.8% of andradite and 51.5% of grossular (Wright 1938). The compositions are expressed by use of the Rickwood's scheme (1968) of recasting analyses of garnet into end member molecules.



Microphoto. 2 Polished sections of garnet crystals from the east orebody (E-1), and the west orebody (W-1, W-2)
A : east orebody, garnet B and C : west orebody, garnet.

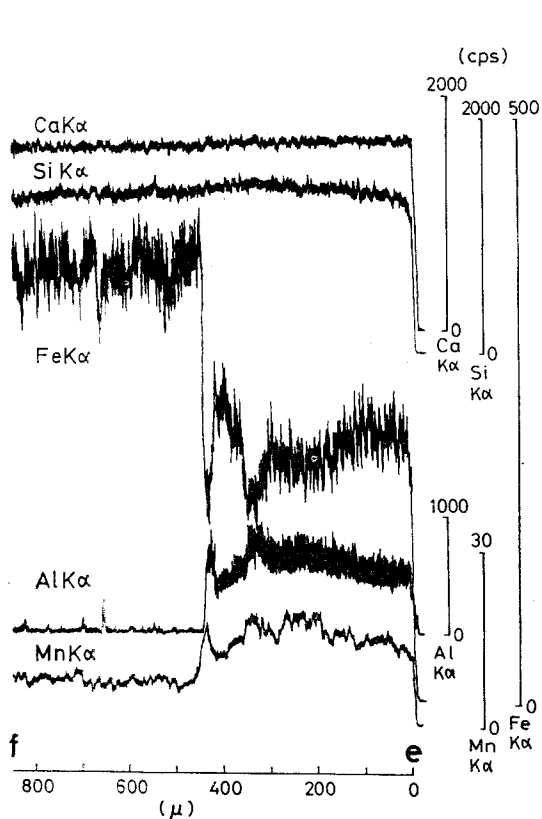


Fig. 7 Compositional profile from rim to core of garnet crystal (W-2).

Mole percent of garnets in the east orebody indicates $An_{20.07-57.48}$, $Gr_{39.81-776.46}$, $Sp_{37-3.15}$ and $Py_{0.15-6.71}$ and those from the west orebody have $An_{13.42-58.54}$, $Gr_{42.25-74.03}$, $Sp_{0.74-3.33}$, and $Py_{0.14-11.81}$. A total of 26 garnet analyses recasted by the scheme of Rickwood were fallen within the midfields between grossular and andradite in the triangular diagram of pyrope, grossular and andradite (Fig. 10). Garnet from the east orebody goes toward grossular in composition from rim to core of the crystals. Taylor and O'Neil (1977) pointed out that more Fe or andradite-rich garnet crystallized in more H_2O -rich C-O-H fluids ($X_{CO_2}=0.01$), whereas grossularite-rich garnet crystallized in less H_2O -rich fluids ($X_{CO_2}=0.035$). The chemical characteristics of garnets from the Shinyemi suggest

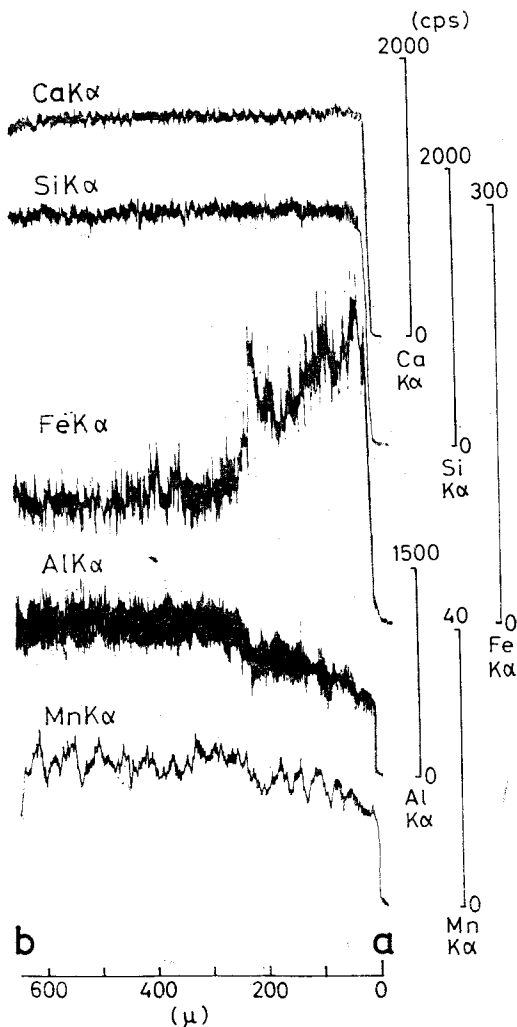


Fig. 8 Compositional profile from rim to core of garnet crystal (E-1.)

est that there are some differences of depositional and geological environment of skarnization between two ore fields. SiO_2 , CaO , Al_2O_3 and MnO of the garnets from the west orebody show negative trend toward core of the crystals in contrast with the positive trend of Fe_2O_3 (Fig. 11).

According to Atherton and Edmunds (1966), zonal structure of garnet is due to changing equilibrium conditions during growth of crystals. Hollister (1969) attributed it to the result of

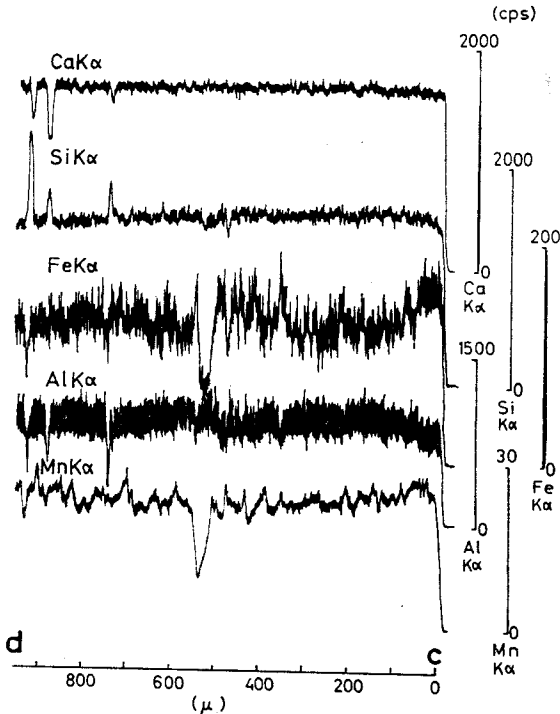


Fig. 9 Microprobe traverse showing relative concentrations of Ca, Si, Fe, Al and Mn elements of unzoned garnet crystal from the west orebody of Shinyemi mine (W-1).

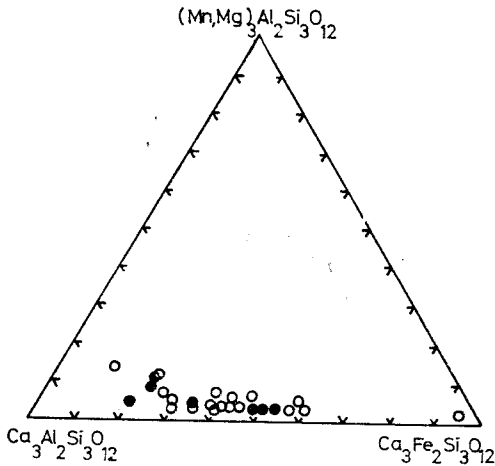


Fig. 10 Compositional characteristics of the Shinyemi garnets.
○ west orebody ● east orebody

depletion of the constituent elements of the garnet from the homogeneous matrix as the garnet grows by thermal changes. He explained the zoning by the Rayleigh fractionation.

Generally the migration of "Fe" is rapid in high temperature, but Al is vice versa. The variation already described in the composition of garnet might be dependent mainly on the changing of temperature in the time of metasomatism.

In this regard, the chemical zoning of the Shinyemi garnet, that is Fe-rich in core and Al-rich in rim, are interpreted as that there was an environment from high temperature of earlier stage to low temperature of later stage during the growth of garnets. If a suggestion by Taylor and O'Neil (1977) is considered, another possible interpretation can be presented, that is garnets in the west orebody crystallized in H₂O-rich C-O-H fluids during the early skarn formation.

From the fact mentioned above, it can be concluded that garnets from the east ore field were crystallized in the very contact between limestone and igneous rock in the hydrothermal stage under condition of an increasing temperature, whereas garnets in the west were formed under decreasing temperature condition at far from the related igneous rocks. This is also consistent with the interpretation by Atherton and Edmunds (1966) and Hollister (1969).

Optical properties of the garnets

Chemical compositions, formation temperatures and pressures influence the optical properties of the garnet. According to experimental work of Merwin (1915) and Allen and Fahey (1977), anisotropic garnet turns into isotropic one when the temperature reached at about 750° to 850°C. Miyazawa (1977) suggested that isotropic garnet is the product of early stage and deep place of skarnization, whereas anisotropic one is of later stage and shallow place products.

Garnets from both orebodies mostly manifests the anisotropic properties, indicating shallow

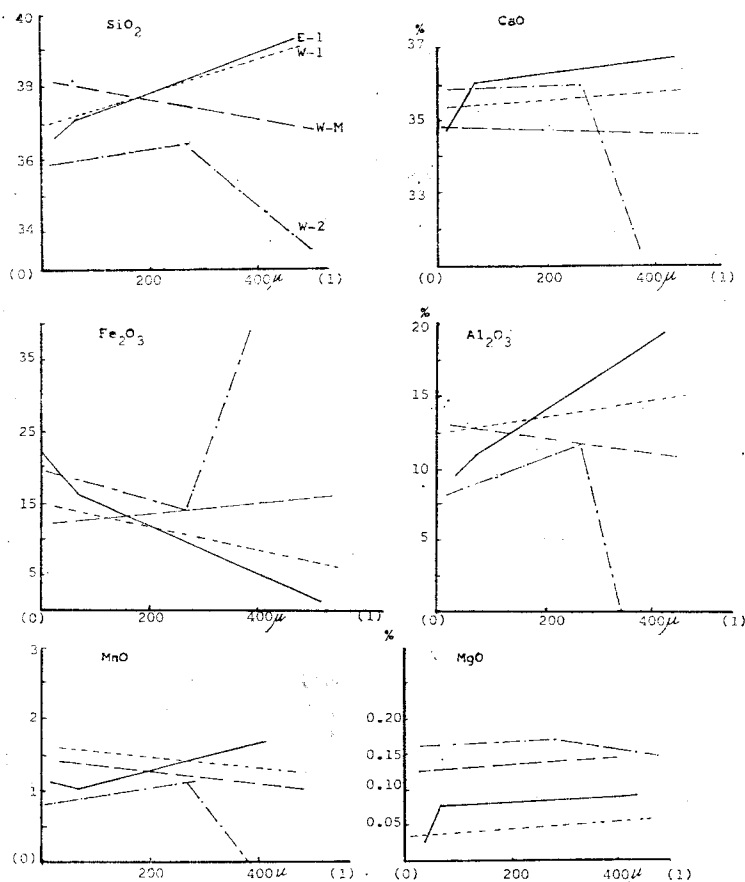


Fig. 11 Chemical variation from rim to core of garnet crystals from the Shinyemi oredeposits. (0) : rim (1) : core

E-1 : Sample from the east orebody

W-1, W-2, W-M : Sample from the west orebody.

types, supported by zonal texture of plagioclase of the granodiorite and occurrence of sill of granitic rock and few kind of dike rocks.

Formation temperatures of skarns range between 250°C and 1200°C as Pilipenko (1939), 400°~600°C (Burt, 1974) and 400°~800°C (Zharikov, 1970). Zharikov (1970) prepared the phase diagram of limy skarn as the function of temperature. Using his result, the formation temperatures of magnetite orebody in the west ore field can be estimated to range

500° (600) to 750(800)°C based on the garnet-pyroxene-wollastonite mineral assemblages, whereas those of sulfide orebodies in the west ore field and in the east ore field come under 500°~550(600)°C based on the garnet-pyroxene assemblage and, 450° (400)~500°C based on the garnet-epidote assemblage, respectively.

Geochemistry of sphalerite

Data of chemical composition of sphalerite determined by electron microprobe analyses

Table 3. Electron microprobe analyses of garnet from the Shinyemi ore deposits. The number in the bracket stands for the normalized value.

Locality Sample No.	East orebody (Dongshinhang)			West orebody (West 0 level)				
	E-1			W-1		W-2		
Analyzed point	1(outer)	2(intermediate)	3(inner)	1	3	1	2	3
SiO ₂	37.26 (36.19)	37.55 (36.62)	39.00 (38.10)	37.44 (36.84)	38.38 (38.57)	36.05 (35.77)	36.22 (36.57)	35.46 (35.45)
Al ₂ O ₃	10.06 (9.77)	11.07 (10.79)	17.51 (17.10)	12.96 (12.75)	14.40 (14.48)	8.28 (8.21)	11.75 (11.87)	0.08 (0.08)
Fe ₂ O ₃	18.54 (18.01)	16.35 (15.94)	7.29 (7.12)	13.87 (13.65)	9.62 (9.67)	19.37 (19.22)	14.0 (14.13)	31.33 (31.32)
MnO	1.10 (1.06)	1.04 (1.01)	1.53 (1.50)	1.59 (1.57)	1.46 (1.47)	0.90 (0.89)	1.11 (1.12)	0.35 (0.35)
MgO	0.04 (0.04)	0.09 (0.08)	0.10 (0.09)	0.04 (0.04)	0.05 (0.05)	0.16 (0.16)	0.17 (0.17)	0.16 (0.16)
CaO	35.95 (34.92)	36.46 (35.56)	36.93 (36.08)	35.73 (35.15)	35.59 (35.76)	36.03 (35.75)	35.79 (36.14)	32.66 (32.65)
Total	102.94	102.54	102.36	101.63	99.51	100.79	99.03	100.03
	mol. per cent. end-members							
Andradite	(57.48)	(46.03)	(20.07)	(40.07)	(27.40)	(55.23)	(39.95)	
Grossular	(39.81)	(51.48)	(76.46)	(57.87)	(69.28)	(42.25)	(57.02)	
Spessartine	(2.55)	(2.17)	(3.15)	(1.92)	(3.15)	(1.93)	(2.39)	
Pyrope	(0.15)	(0.32)	(0.32)	(0.14)	(0.18)	(0.60)	(0.63)	
Gr _x And _y	Gr41 And59	Gr53 And47	Gr76 And21	Gr59 And41	Gr72 And28	Gr43 And57	Gr50 And41	

Table 4. Chemical compositions of sphalerite from the Shinyemi mine.

Sample No.	Analyzing Point	Composition						Composition (Mole %)				Remarks
		Zn	Fe	Mn	Cd	S	Total	ZnS	FeS	MnS	CdS	
E-1	13	58.2	8.1	0.6	0.2	33.7	100.8	84.95	13.84	1.04	0.17	Stage of mineralization, later
E-1	14	56.9	8.5	0.6	0.2	33.6	99.8	84.10	14.71	1.05	0.17	
E-1	15	57.6	8.4	0.5	0.2	33.6	100.3	84.53	14.43	0.87	0.17	
E-1	16	57.2	8.4	0.5	0.2	33.9	100.2	84.14	14.46	0.88	0.17	
E-2	1	52.3	13.0	0.9	0.3	34.0	100.5	76.06	22.13	1.56	0.26	
E-2	2	51.3	13.1	0.8	0.2	33.8	99.2	75.77	22.65	1.41	0.17	
E-2	3	51.1	13.3	0.9	0.3	33.8	99.4	75.24	22.92	1.58	0.26	
E-2	4	51.5	13.2	1.0	0.3	33.8	99.8	75.39	22.61	1.74	0.26	
W-1	5	58.0	6.4	1.0	0.3	33.8	99.5	86.75	11.20	1.78	0.26	earlier
W-1	6	58.0	6.4	1.2	0.3	33.8	99.5	86.45	11.17	2.12	0.26	
W-1	7	58.6	6.7	1.3	0.3	33.9	100.2	85.84	11.61	2.26	0.26	
W-1	8	57.7	6.7	1.3	0.2	33.7	99.6	85.85	11.67	2.30	0.18	
W-2	9	58.7	6.8	0.8	0.2	33.8	100.3	86.66	11.75	1.41	0.17	
W-2	10	58.6	6.3	1.1	0.2	33.6	99.8	86.94	10.94	1.94	0.17	
W-2	11	59.2	6.2	1.1	0.2	33.7	100.4	87.21	10.74	1.93	0.17	
W-2	12	58.6	6.5	1.1	0.2	33.9	100.3	86.64	11.25	1.93	0.17	

Chemical compositions were determined by JEOL JXA-50A electron microprobe at Waseda University.
Analyst: K. Ogwa, Waseda University, Japan

are presented in Table 4. Sphalerite from the orebodies has 75.24~84.95 mole % of ZnS and 13.84~22.92 mole % of FeS for the east, and 85.84~87.21% and 10.74~11.75 mole % of FeS for the west. FeS mole % of east sphalerite is higher than that of west ores.

Formation temperatures of the east orebodies appear to be 470~500°C as estimated by the curves of Kullgrud (1953), Einaudi (1968), Chernyshev and Anfilogov (1968). Temperatures determined by sphalerite is compatible with published data of isotopic temperature and mineral assemblages.

Related igneous rocks

Possible simple structural settings of skarns are skarn around intrusive, intrusive around skarn and intrusive unexposed, according to Burt (1972). Of three possible structural configurations of skarns, the Shinyemi west ore field may become to suitable example for the case of skarn around intrusive, though until now visibly related intrusive rock is not exposed except for a small granitic sill at the -3 and -5 levels.

Skarns are localized in places along the contact and especially along the particular favorable beds of limestone by intrusive rock invading. Though no visible igneous contact is found, it is presumed that an igneous contact is to be found at some unspecified depth based on field occurrence and on garnet study. It is an important problem to determine the location of igneous body, particularly for pursuing the continuity of orebodies in the bedding type of skarn deposits. In this regard, the author has chosen garnets and examined the chemical composition of them from each level of west orebody. Because the garnet occurs as one of the most common minerals in each level and only limited layers of the skarn zone surrounding compact hornfels. The data by wet analyses of

garnet grains obtained by hand picking are presented in Table 5.

Fe₂O₃ and Al₂O₃ contents of the garnet are plotted against the distance (Fig. 12). The two compositions are inversely proportional to distance except for one sample. On the basis of this diagram the ore-related igneous rocks are expected to be crop out -160m from the present level, -6 level, under the adoption of the data of relatively pure grossular which is formed in granite (Smith, 1923). Not much data of garnet analyses have been made until now, but this may be a useful guide to prospecting in the bedded deposits of contact replacement.

Mineralization

It is generally accepted that before the skarnization has been completed, ore deposition has begun in the next stage.

The occurrence of ore minerals are restricted to the skarn zone. This suggests that chemical and/or textural controls on ore deposition were effective in the bedded orebodies in the west ore field. Oxide and sulfide minerals were formed mainly after or partly at the same time with the skarn minerals in the west ore field. However, east ore field has a small pipe and veins, and localization of these orebodies is controlled apparently by faults of small scale.

Magnetite skarn orebody is cut across by sulfide veins in the west new adit indicating that the magnetite is an earlier product of mineralization than the sulfide minerals in the sequence of oxidation and sulfidization.

The four stages of mineralization at Shinyemi can be distinguished as the following order; (1) early magnetite mineralization (2) sulfide mineralization in the west skarn orebody (3) hydrothermal veining in the east ore field, and (4) later mineralization associated with felsite dike rocks. Most sulfide minerals fill the boundaries of garnet crystals and garnet and other

Table 5 Chemical composition of garnets by wet analysis from the Shinyemi mine. The number in the bracket stands for the normalized value.

	East ore body				West ore body							
					W-L-1				W-L-3			
	E-U-1	E-O-1	E-L-2	E-L-e	W-O(a)	A	B(b)	W-L-2 (c)	A(α)	B	C	W-L-5(e)
SiO ₂	37.3 (37.39)	37.1 (37.4)	36.34 (36.36)	36.06 (36.28)	35.24 (35.33)	37.22 (37.19)	36.16 (36.57)	35.04 (35.30)	36.32 (36.35)	36.82 (36.83)	37.2 (37.15)	35.58 (35.79)
Al ₂ O ₃	15.95 (15.98)	17.46 (17.59)	10.78 (10.79)	14.96 (15.05)	9.96 (9.99)	13.27 (13.25)	12.69 (12.83)	15.47 (15.58)	16.79 (16.81)	15.46 (15.46)	16.79 (16.77)	10.4 (10.46)
Fe ₂ O ₃	8.74 (8.76)	8.68 (8.74)	17.33 (17.34)	11.88 (11.95)	19.47 (19.52)	14.47 (14.44)	13.57 (13.73)	9.25 (9.32)	5.20 (5.21)	10.45 (10.45)	9.62 (9.61)	16.48 (16.58)
MnO	1.03 (1.03)	1.42 (1.43)	0.05 (0.05)	1.16 (1.17)	0.77 (0.77)	0.90 (0.90)	1.16 (1.17)	1.68 (1.69)	0.39 (0.39)	1.29 (1.29)	1.29 (1.29)	0.90 (0.90)
MgO	1.85 (1.85)	1.11 (1.12)	0.23 (0.23)	0.28 (0.28)	0.35 (0.35)	0.50 (0.50)	1.08 (1.09)	1.23 (1.24)	3.47 (3.47)	1.20 (0.77)	0.77 (0.77)	1.03 (1.04)
CaO	34.89 (34.97)	33.49 (33.74)	35.21 (35.23)	35.06 (35.27)	33.95 (34.04)	33.82 (33.76)	34.21 (34.60)	36.59 (36.86)	35.72 (35.75)	34.76 (34.77)	34.46 (34.42)	35.01 (35.22)
Total	99.26	99.94	99.94	99.40	99.74	100.18	98.87	99.26	99.89	99.89	100.13	99.40
Andradite	23.90	51.12	35.05	24.08	58.54	43.28	39.06	24.61	13.42	30.64	27.73	46.74
Grossular	69.16	47.00	63.05	67.11	38.34	52.75	54.31	67.72	74.03	66.04	66.51	47.50
Spessartine	2.93	0.98	0.37	2.11	1.72	2.01	2.50	3.33	0.74	2.85	2.81	1.89
Pyrope	4.02	0.89	1.08	6.71	1.39	1.96	4.09	4.34	11.81	0.47	2.95	3.87
Gr _x And _y	Gr74 An26	Gr48 An52	Gr64 An36	Gr74 An26	Gr40 An60	Gr55 An45	Gr58 An42	Gr73 An27	Gr85 An32	Gr68 An32	Gr71 An29	Gr50 An50

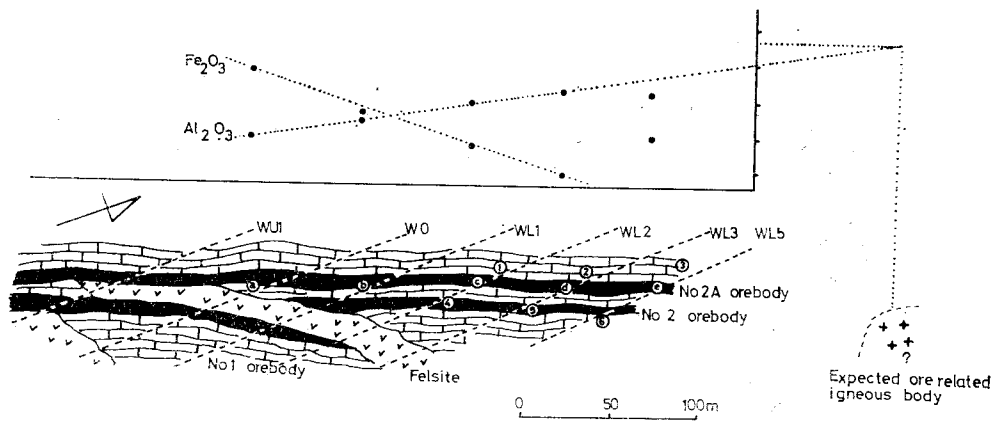


Fig. 12 Estimation of location of igneous body based on the relation between depth and chemical composition from the west orebody, Shinyemi mine.

skarn silicates. This gives a strong evidence of the later stage of sulfide mineralization than that of skarn silicification. Paragenesis and field occurrences also support this conclusion. It should be noted that granodiorite and felsite, in which sphalerite and pyrite are disseminated, are genetically related with the ore mineralization. Thus, sulfide mineralization age is related to the Cretaceous-early Tertiary igneous activity deduced from age of Shinyemi granodiorite (60m.y.).

Conclusions

Skarn silicates were formed by replacement of the Maggol limestone at the contact with the Shinyemi granodiorite in the Shinyemi ore deposits. Skarns include major garnet, minor pyroxene and epidote, and subordinate scapolite, phlogopite, chlorite and brucite.

The skarns can be classified into the three mineral assemblages.

1) Garnet-pyroxene-phlogopite-wollastonite assemblage, associated with magnetite ores 2) Garnet-pyroxene assemblage in the west bedding type sulfide orebody, and 3) Garnet-epi-

dote of the pipe and vein type sulfide orebody in the east ore field.

Zoned grandite garnets have Fe rich cores and Mn and Al rich rims in the west orebody, and Mn and Al rich cores and Fe rich rims in the east orebody, suggesting the different depositional condition of skarn formation in the both orebodies.

Formation temperatures of the skarns are estimated 500~750°C for the magnetite orebody and 500~550°C for sulfide orebody in the west ore field, and 450~500°C for the east sulfide orebody based on the skarn mineral assemblages.

Related igneous rocks, not exposed until now are expected to be crop out -160m from the present level (-6 level) on the basis of garnet compositions.

The four stages of mineralization can be distinguished as the following order; (1) early magnetite mineralization, (2) sulfide mineralization in the west skarn orebody, (3) hydrothermal sulfide veining in the east orebody, and (4) later mineralization associated with dike rocks.

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新禮美 鉛-亞鉛鑛床産 스카른鑛物の 鑛物學的 研究

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요약: 新禮美鑛床의 스카른 鑛物은 1) 石榴石-輝石-金雲母-硅灰石 組合, 2) 石榴石-輝石 組合, 3) 石榴石-綠廉石 組合으로 區分된다. 이들 鑛物組合은 鑛石鑛物의 産出狀態, 鑛石鑛物의 種類 그리고 鑛化作用의 時期와 밀접한 關係가 있다.

石榴石結晶의 分析에 의하면 石榴石結晶의 累帶構造는 結晶의 成長時에 平衡條件의 變化에 기인한 化學的 累帶構造(chemical compositional zoning)이다. 그리고 鑛床의 生成環境과 關係火成岩의 位置를 스카른鑛物의 産出狀態와 스카른 鑛物中 石榴石의 化學成分의 검토에 의해 추정해 보았다.