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Contrasting Styles of Gold and Silver Mineralization in the Central and Southeastern Korea*

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ABSTRACT: Two distinct precious-metal mineralizations actively occur at central and southeastern Korea which display consistent relationships among geologic, geochemical and genetic environments. A large number of precious-metal vein deposits in the central Korea occur in or near Mesozoic granite batholiths elongated in a NE-SW direction. Whereas, gold and/or silver deposits in the southeastern Korea occur within Cretaceous volcanic and sedimentary rocks. However, most of the precious-metal deposits in the southeastern Korea show characteristics of the silver-rich deposits than the gold-rich deposits in the central Korea.

Two epochs of main igneous activities are recognized: a) Jurassic Daebo igneous activity between 121 and 183 Ma, and b) Cretaceous Bulgugsa igneous activity between 60 and 110 Ma. Precious-metal mineralization took place between 158 and 71 Ma, coinciding with portions of the two magmatic activities. Contrasts in the style of mineralization, together with radiometric age data and differences in geologic settings reflect the genetically variable natures of hydrothermal activities from middle Jurassic to late Cretaceous time. The compilation and re-evaluation of these data suggest that the genetic types of hydrothermal precious-metal vein deposits in the central and southeastern Korea varied with time. The Jurassic and early Cretaceous mineralizations are characterized by the Au-dominant type, but tend to change to the Au-Ag and/or Ag-dominant types at late Cretaceous. The Jurassic Au-dominant deposits commonly show several characteristics; prominent associations with pegmatites, simple massive vein morphologies, high fineness values in ore-concentrating parts, and a distinctively simple ore mineralogy such as Fe-rich sphalerite, galena, chalcopyrite, Au-rich electrum, pyrrhotite and/or pyrite. The Cretaceous precious-metal deposits are generally characterized by some features such as complex vein morphologies, low to medium fineness values in the ore concentrates, and abundance of ore minerals including Ag sulfosalts, Ag sulfides, Ag tellurides and native silver. Mineralogical and fluid inclusion studies indicate that the Jurassic Au-dominant deposits in the central area were formed at the high temperature (about 300° to 500℃) and pressure (about 4 to 5 kbars), whereas mineralizations of the Cretaceous Au-Ag and Ag-dominant deposits were occurred at the low temperature (about 200° to 350℃) and pressure (<0.5 kbars) from the ore fluids containing more amounts of less-evolved meteoric waters.

INTRODUCTION

Korean Peninsula contains a wide variety of geologic environments related to major tectonics, structural features and igneous activities (Gallagher, 1963). In particular, the precious-metal mineralized districts in central Korea consist of a large number of gold-silver mines around a 200 km elongated Jurassic granitic batholith along a NE-SW direction known as the Sinian direction. Kim (1971) suggests that the most gold-silver deposits were formed during the Jurassic with genetic relations to the Daebo igneous activities. In recent years, new quantitative data have been obtained on some of the gold-silver bearing quartz vein deposits such as fluid inclusion and stable isotope studies (Sugaki *et al.*, 1986; So and Shelton, 1987; So *et al.*, 1989), on chemical compositions of gold-bearing phases (Shikazono and Shimizu, 1986; Choi *et al.*, 1988; Choi and Wee, 1992; Choi *et al.*, 1994), and mineralization age (Shimazaki *et al.*, 1986; Park *et al.* 1986). However, researches of gold-silver mineralizations in Korea have been mostly limited to studies on individual ore deposits and mineralized districts (So *et al.*, 1987a and b; So *et al.*, 1989). Therefore, the aims of this study are to define the geological characteristics, the ratios of produced grades of silver and gold, vein morphology, associated metal, and mineral assemblages with particular emphasis on the gold-silver vein deposits in the central and southeastern areas. Also, systematic classifications and summaries of the gold-silver deposits are shown in the present paper based on the authors' data on these deposits.

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GEOLOGIC SETTING AND DISTRIBUTION OF PRECIOUS-METAL DEPOSITS

Tectonically, precious-metal deposits in Korea are widely distributed within the Gyeonggi metamorphic belt in the north to the Gyeongsang basin in the south. Generally, most of the deposits have a tendency to concentrate in ten metallogenic province (Kim, 1986). Geological settings in the central Korea consist of metamorphic rocks of the Precambrian Gyeonggi and Yeongnam metamorphic Complex (3, 000~800 Ma), the Paleozoic Ogcheon geosyncline, Jurassic Daebo igneous rocks (183~121 Ma), Cretaceous Gyeongsang Supergroup and Bulgugsa igneous rocks (110~60 Ma). The Daebo granitoids show wide elongated distributions along a NE-SW direction in the central Korea, and the Bulgugsa igneous rocks commonly intrude these rocks as stocks and dikes in southeastern Korea. Also, a number of precious-metal mineralized districts of the central Korea are generally distributed around the Jurassic Daebo granitoids, whereas those of the southeastern Korea are associated within the Cretaceous calc-alkaline igneous stocks or small plutons. The precious-metal deposits are hosted by a variety of rock types. Rocks in the Chungcheong province mainly consist of the Precambrian gneiss, schist and Jurassic Daebo granitoids, whereas gold-silver deposits of the Gyeongsang Province commonly occur within Cretaceous sedimentary rocks, volcanics, and late intrusive Bulgugsa granites and quartz porphyries.

The precious-metal vein deposits have been genetically reported as mesothermal to hypothermal Korean-type deposits to compare with epithermal gold-silver vein deposits in Japan (Tsuchida, 1944). Recently, the deposits were classified into three types on the basis of the fluid inclusions and stable isotope data; mesothermal deposits (Taechang, Boryeon, etc.), Korean-type deposits (Cheonbo, Ilbo, Daeheung, etc.), and epithermal deposits (Jeonjuil, Tongyeong, etc.) (Shelton *et al.*, 1988). Gold-silver mineralizations in the central Korea are mainly distributed along the direction from the northeast to the southwest (Kim, 1971). The pattern of this distribution is consistent with the Daebo igneous rocks in almost the same direction, and gold-silver vein deposits in this area are known to be related with the Daebo igneous activities. The main host rocks for gold-rich deposits in the Chungcheong Provinces are Precambrian gneisses, schists, phyllites and intrusive Jurassic granites. Only a few deposits such as Mugeug, Weolyu, and Hwagsan mines are located within Cretaceous granites, quartz porphyries, and tuffs (Table 1). In contrast, the Au-Ag and Ag-dominant deposits in the Gyeongsang Province are mainly hosted by the Cretaceous sedimentary units and plutonic-subvolcanic rocks. However, recently radiometric age data have revealed that the precious-metal mineralizations are genetically related to both the Daebo and Bulgugsa granitic activities (Shimazaki *et al.*, 1986; Park *et al.*, 1986).

The geological, geochemical and mineralogical informations of 33 ore deposits with fineness variations in produced ore grades are listed on Table 1. The precious-metal deposits of Chungcheong and Gyeongsang Provinces show wide variations in their general characteristic features. The gold-silver deposits in this study are mainly investigated by emphasizing chemico-mineralogical aspects, such as the quantities of associated sulfides, the silver to gold ratios, the data on the vein morphologies, host rocks and their mineralization ages. The typical gold-rich deposits in the Chungcheong Province are characterized by paragenetically early sulfide-poor quartz veins occurring minor base-metal sulfides, pyrrhotite, pyrite and arsenopyrite with rare amounts of electrum and native gold. The high fineness values for these deposits reflect paucities of silver phases. Whereas, the silver-rich and gold-silver deposits of the Gyeongsang and Chungcheong Provinces are characterized by the variable average and wide ranges of fineness values within individual deposit, suggestive of the differences in the mineralogy of these deposits. In these deposits, the early gold-bearing assemblages are dominated by base-metal sulfides, but the late assemblages are characterized by a variety of silver sulfides, sulfosalts or tellurides. Through field studies, relative proportions of vein texture associations for vein systems can be established. The precious-metal deposits may be classified into two styles on the basis of the characteristics of vein morphology, suggestive of differences in the formation environments such as the variable depth of ore formation (Dowling and Morrison, 1989). The massive veins are characterized by simple veins that are commonly homogeneous in composition with interlocking networks of quartz and ore minerals within metamorphosed host rocks and plutonic-level granitoids. The gold is relatively coarse and occurs as scattered isolated grains in the quartz. It is also associated with sulfides as inclusions and microcrack fillings. The veins are sometimes associated with pegmatites and are characterized as either buck or ribbon structure. The veins are predominantly composed of coarse-grained quartz with lesser amounts of muscovite, K-feldspar, and relatively simple base-me-

Table 1. Summary of gold-silver deposits from the central and southeastern areas.

Province	Ore deposit	Commodities		Associated metal	Fineness in ores*		Major Fe sulfide	Vein morphology**	Host rock
		Major	Minor		Range	(average)			
Chungcheong Province	Seolhwa	Au	(Ag)	W, (Mo)	297-947	(823)	po	massive	granite
	Boryeon	Au	(Ag)		355-963	(766)	po	massive	gneiss, granite
	Taechang	Au	(Ag)	(Te), (Mo)	152-870	(658)	po	massive	gneiss, granite
	Samhwanghwag-M	Au	(Ag)	(Bi), (Te)		(625)	po	massive	gneiss
	Samhwanghwag-D	Au	(Ag)		355-688	(576)	po	massive	gneiss
	Geumpo	Au	(Ag)		178-807	(576)	po	massive	gneiss, schist
	Geumseong	Au	(Ag)		254-680	(408)	po	massive	gneiss
	Daeil	Au	(Ag)	(Bi), (Te)	198-223	(210)	po	massive	gneiss
	Ilbo	Au	(Ag)		38-643	(316)	py	massive	gneiss, schist
	Yeongbogari	Au	(Ag)	(Sb)	213-394	(292)	py	massive	gneiss, schist
	Daeheung	Au	(Ag)	(Sn), (Te)	53-526	(242)	py	massive	pegmatite, gneiss
	Hwagsan	Au	(Ag)		612-764	(684)	py	nonmassive	gneiss, quartz porphyry
	Juujinsan	Au	(Ag)		365-895	(601)	py	nonmassive	phyllite, schist
	Manmyeong	Au	(Ag)		310-839	(532)	py	nonmassive	granite
	Imcheon	Au	(Ag)	(Mo), (Te)	36-746	(283)	py	nonmassive	granite, gneiss
	Namsan	Au	(Ag)		12-746	(281)	py	nonmassive	granite, gneiss
	Jeoneui	Au	(Ag)		21-630	(216)	py	nonmassive	granite, schist
	Cheongju	Au, Ag			3-639	(332)	py	nonmassive	granite
	Yonghwa	Au, Ag		(Sb)	3-595	(156)	py	nonmassive	granite
	Namseong	Au, Ag			8-721	(104)	py	nonmassive	granite
	Mugeug	Au, Ag		Sb, (Mo)	1-653	(181)	py	nonmassive	granite
	Geumwang	Au, Ag		Sb, (Mo)	1-533	(145)	py	nonmassive	granite
	Geumbong	Ag	(Au)	Sb	3-402	(75)	py	nonmassive	granite
	Jeonjuil	Ag	(Au)	Sb	1-511	(43)	py	nonmassive	phyllite, schist
	Weolyu	Ag	(Au)	Sb, Ge	2- 25	(9)	py	nonmassive	quartz porphyry, tuff
Gyeongsang Province	Sangchon	Au	(Ag)			(362)	py	nonmassive	anorthosite
	Samjeong	Au	(Ag)	Sb	44-940	(334)	py	nonmassive	sandstone, shale, andesite
	Jisan	Au, Ag			191-360	(267)	py	nonmassive	gneiss, granite
	Geochang	Au, Ag			21-576	(185)	py	nonmassive	gneiss, porphyry
	Sanggo	Ag	Au	Sb	3- 14	(7)	py	nonmassive	gneiss, porphyry
	Seweon	Ag	Au	Sb		(1)	py	nonmassive	shale, sandstone, granite
	Seongju	Ag	Au	Sb	1-667	(3)	py	nonmassive	shale, sandstone
	Gahoe	Ag		Sb	0- 24	(4)	py	nonmassive	shale, sandstone, syenite

*Fineness = Au/(Au + Ag) × 1000 in ore grades or productions.

**Nonmassive vein in this study means relatively well-developed crustiform, drusy cavity, comb, breccia, fibre, and/or cockade structure. Massive vein means relatively well-developed buck and/or ribbon structure.

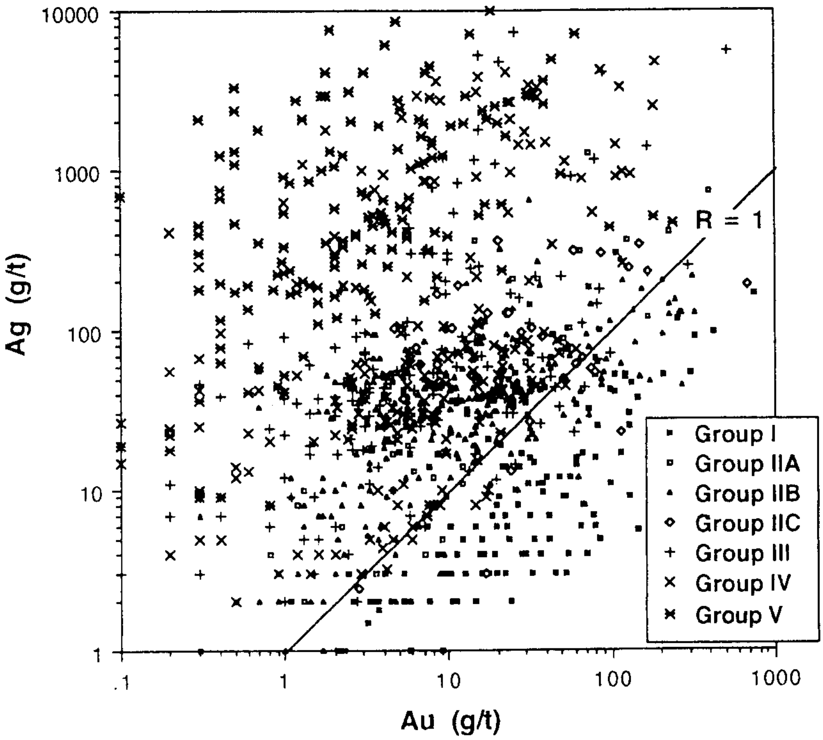

Fig. 1. Logarithmic plots of gold and silver (g/t) in production ore grades from 7 genetic groups.

tal sulfides. They also have narrow selvages of sericitic and chloritic alterations. In particular, most of the gold-bearing quartz veins in the Chungcheong province show similar characteristics with those of the mesothermal deposits of the California Mother Lode district. The nonmassive veins are represented by complex multiple veins that show relatively well-developed crustiform, drusy cavity, comb, breccia, fibre and cockade structure hosted in sedimentary and volcanic rocks as compared to the massive veins. These veins show extensive zones of propylitic, argillic, sericitic and silicic alterations, and mainly consist of quartz and carbonate with less amounts of fluorite, clay minerals, base-metal sulfides and complex silver-bearing sulfosalt assemblages. The structural and textural relationships among gold, sulfides and other vein minerals indicate that gold deposition has occurred over an early vein growth history.

EMPIRICAL CLASSIFICATION OF ORE DEPOSITS

The precious-metal deposits in the central and southeastern Korea have been formed in different geologic settings and at different times, and show a wide variety of produced grades of silver and gold. The silver to gold ratios of the precious-metal deposits can be explained by the specific natures of the geological settings of these deposits. Generally, statistical analyses of the data are not possible, and so only an empirical evaluation has been attempted. These precious-metal deposits can be categorized into three main groups according to their ratios of produced grades of silver and gold: Au-dominant deposits, Au-Ag deposits and Ag-dominant deposits. The ratios of produced grades of the silver and gold in Korea correlate with their geologic settings. Au-dominant deposits are more common and significant than Ag-dominant deposits in the Chungcheong Province, whereas in the Gyeongsang Province Ag-dominant deposits and Au-Ag deposits are prominent. Production ore grades of the silver and gold are expressed in g/t (parts per million) as shown in Fig. 1. A good correlation between the ore grades of gold and silver is shown in the Au-dominant deposits, whereas a broad correlation is shown in the Ag-dominant deposits and Au-Ag deposits. The distribution trends between the ore grades of gold and silver in these deposits were caused by incorporating silver phases rather than electrum and native gold. Most of the Au-Ag

Table 2. Summary of gold-silver deposits from the central and southeastern areas.

Group	Major commodities	Index metal	Ag/Au ratio in ore grades	Main Fe-S mineral	Character of vein	Alteration	Remarks
I	Au	(Bi, Te)	0.1- 4.0	po	simple	very weak	associated with pegmatite
IIA	Au	(Ag, Te)	0.5- 10.0	py	simple	very weak	associated with pegmatite
IIB	Au	(Ag, Te)	0.5- 10.0	py	complex	weak	
IIC	Au	(Ag)	0.1- 20.0	py	complex	moderate	xenothermal type
III	Au-Ag		1.0- 500.0	py	complex	moderate	orebody zoning
IV	Au-Ag		1.0- 700.0	py	complex	strong	orebody zoning
V	Ag	(Sb, Au)	10.0-2000.0	py	complex	strong	associated with quartz porphyry

and Ag-dominant deposits may be resulted in several mineralization stages accompanied by a respective pulse of mineralization after a silver mineralization stage, which may follow a gold or base-metal pulse. These characteristics suggest that there are wide variations of physicochemical conditions for transports and depositions of Au and Ag within ore-forming hydrothermal systems.

These deposits considered here can be subclassified into seven groups based on many combinations of the Ag/Au ratios, associated metals, vein morphologies and mineral assemblages: 1) pyrrhotite-type gold deposit (Group I), 2) pyrite-type gold deposit (massive vein: Group IIA), 3) pyrite-type gold deposit (nonmassive vein: Group IIB), 4) pyrite-type gold deposit (nonmassive vein: Group IIC), 5) argentite-type gold-silver deposit (Group III), 6) antimony-type gold-silver deposit (Group IV), 7) antimony-type silver deposit (Group V). Table 2 provides a criteria of tentative classification which can be used to explain variations within groups. Deposits from Groups I, IIA, IIB and IIC have low Ag/Au ratio in ore grades, whereas those from Groups III, IV and V show variations of Ag/Au ratio in ore grades. They reflect the relatively homogeneous compositions of the former groups, which are compared with wide intra-vein variations of the latter groups. Perhaps they indicate that rapid fluids change in composition by the response to varying P-T-X parameters in the epithermal environment with uniform compositions in the more stable meso/hypothermal environment.

MINERALOGICAL CHARACTERISTICS OF GOLD-SILVER DEPOSITS

A compilation and re-evaluation of chemical data for Au-Ag alloy suggest that the silver contents of this alloy are variable according to the genetic types of ore deposits (Morrison *et al.*, 1991; Shikazono, 1986). The distributions of gold and silver in precious metal deposits depend on speciations of gold and silver in the fluids, and the mechanisms of precipitation. The speciations of gold and silver in hydrothermal fluids depend upon temperature, pressure, redox state, pH and the activity of ligands (Cole and Drummond, 1986; Shikazono, 1985; Shikazono and Shimizu, 1987). Some mineralogical and geochemical differences that exist in the hydrothermal vein deposits can be explained and applied to the quite variations of the physicochemical conditions which existed during gold-silver deposition.

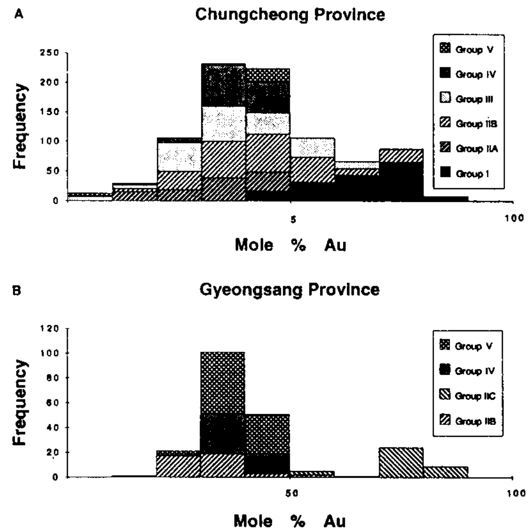

Fig. 2. Variation of Au content (mole %) in electrum from the deposits on each group in the Chungcheong and Gyeongsang Provinces.

The Au contents of electrums for alaskite-type Geumjeong mine and skarn-type Geodo mine are characterized by high values and limited variations in range 84.5~97.9 atomic % for Geumjeong mine and 94.3~94.8 atomic % for Geodo mine, as compared to the hydrothermal replacement deposit and the precious-metal vein deposit. Electrums of a Pb-Zn-Ag Taebaek deposit show extremely lower distributions than those in the Au-dominant deposit in Au conte-

Table 3. The Au content of electrum from gold-silver deposits.

Province	Type	Group	Ore deposit	Atomic % Au in electrum			N**
				Average	S.D.*	Range	
Gangweon Province	Alaskite		Geumjeong	93.06	5.76	84.5-97.9	37
	Skarn		Geodo	94.53	0.24	94.3-94.8	4
	Hydrothermal Replacement		Taebaek	10.81	6.86	5.8-29.7	12
Chungcheong Province	Hydrothermal Vein	I	Boryeon	71.86	5.21	62.0-78.5	24
			Taechang	67.27	6.14	61.4-75.8	42
			Seolhwa	78.76	6.50	69.7-86.5	6
			Samhwanghwag-M	76.35	10.22	51.0-92.4	25
			Samhwanghwag-D	56.46	4.96	51.6-65.9	6
			Daeil	52.56	3.75	47.1-62.4	28
			Geumpo	70.97	1.62	68.5-75.3	19
			Geumseong	56.97	10.68	40.8-71.4	16
		IIA	Ilbo	43.51	3.63	37.8-55.8	28
			Daeheung	35.57	8.29	16.1-50.5	45
			Yeongbogari	22.60	7.04	12.4-39.6	45
		IIB	Imcheon	60.75	13.85	16.9-82.8	50
			Hwagsan	55.95	1.56	53.2-58.8	38
			Juujinsan	43.98	3.89	38.6-50.0	65
			Jeoneui	28.61	6.11	17.8-38.7	28
			Namsan	30.21	4.18	18.7-35.9	26
			Manmyeong	31.54	4.65	20.8-38.7	28
		III	Cheongju	47.24	7.37	33.4-58.6	65
			Namseong	37.70	17.20	2.8-86.9	88
			Yonghwa	27.99	6.64	11.0-51.8	51
		IV	Mugeug	40.47	9.71	5.2-49.0	61
			Geumwang	35.98	6.06	11.2-49.9	66
			Geumbong	29.10	0.70	28.4-29.8	2
		V	Weolyu	27.22	12.63	8.6-48.3	15
			Jeonjuil	46.90	0.57	45.7-48.3	20
Gyeongsang Province		IIB	Sangchon	31.60	7.91	19.2-56.0	42
		IIC	Samjeong	73.87	8.66	42.7-81.1	37
		IV	Jisan	39.13	6.85	21.1-62.8	28
			Geochang	36.94	2.88	32.8-42.2	21
		V	Sanggo	38.23	3.46	33.7-47.4	32
			Seweon	39.04	4.04	28.7-43.2	15
			Seongju	37.92	4.11	28.6-44.0	38
			Gahoe		not found		

*Standard deviation.
**Number of spot analyses by electron microprobe.

nts, whereas this hydrothermal replacement deposit generally shows relatively similar gold contents to the chemical compositions of electrums in the Au-Ag vein deposits and in the Ag-dominant vein deposits.

The chemical compositions of electrums from 33 precious-metal vein deposits show somewhat different distribution patterns for 7 groups (Table 3). The electrums for Groups I and IIC generally show a consistent high Au content and limited range. The Au contents of electrums for these groups range from 40.8~92.4 atomic %, are mostly 50~80 atomic % on the average. The limited ranges of Au contents for electrums suggest some possible consistencies in the geochemical conditions of transport and deposition of

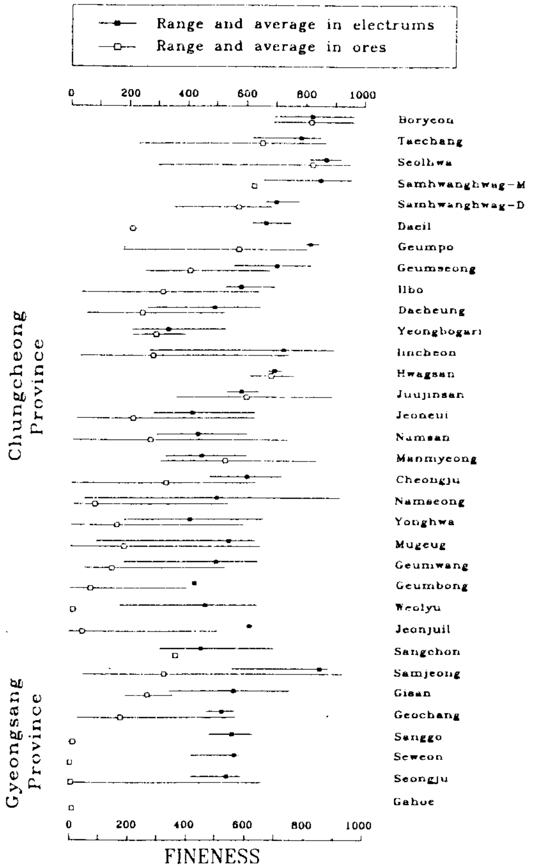

Fig. 3. The fineness values in ore grade and in electrum for the deposits in the Chungcheong and Gyeongsang Provinces.

gold and silver from fluids. The chemical compositions of electrums for Groups IIA, IIB, III, IV and V show wide variation, ranging from 2.8~86.9 atomic % Au. They are mainly clustered at 20~60 atomic % Au. The most distinctive feature is wide ranges for Au contents of the electrums with individual deposits. A compositional variations and significant differences are shown on individual and adjacent grains of electrums, respectively. The Ag-rich contents of the electrums were generally the products of post-depositional overprinting processes, including silver mineralization in late stage. However, Groups IIA, IIB, III, IV and V have significantly lower Au contents of the electrums than Group I in the Chungcheong Province and Group IIC in the Gyeongsang Province (Fig. 2). Also, the fineness values in ore grades show same tendencies (in value and range) of the chemical compositions in electrums (Fig. 3). The electrums of Groups I and IIC show intimate associations with

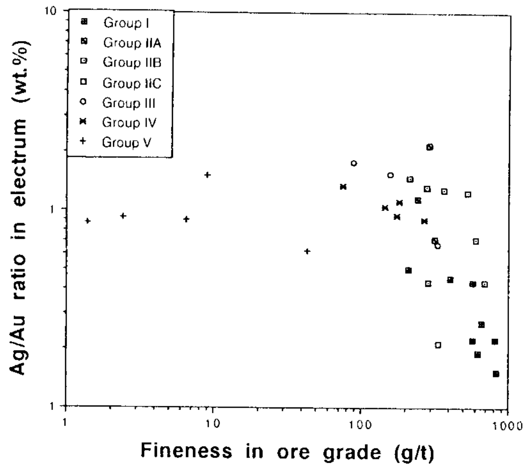

Fig. 4. The relationship between the average fineness value of ore grade and the average Ag/Au ratio in electrum.

pyrrhotite or loellingite, whereas those of Groups IIA, IIB, III, IV and V commonly coexist with pyrite. These results are interpreted as being the reflection of changes in sulfidation state and/or temperature.

Fig. 4 illustrates relationships between average fineness values of the ore grade and average Ag/Au ratios of the electrum. In Groups I, IIA, IIB, IIC and III, good negative correlations are shown between chemical data of the electrum and the fineness value in the range of 200~1000. These relationships imply that the Ag content of the electrum decreases with increasing fineness in ore grade. An exception to the overall pattern is Ag-rich deposits. No correlations are found in Groups IV and V. This trend is related to the absence of electrums and the abundance of silver-bearing phases such as argentite, native silver, polybasite and pyrargyrite.

The Fe contents of sphalerites coexisting with hexagonal pyrrhotites and pyrites are a sensitive indicator for the fugacities of sulfur or for the geobarometer (Barton and Toulmin, 1964; Scott and Barnes, 1971; Scott, 1973). Sphalerites from precious-metal deposits in the Chungcheong and Gyeongsang Provinces, have are less than 20 mole % in FeS contents. It is evident that the FeS contents of sphalerite from Groups I, IIA, IIB and IIC are relatively higher than those from Groups III, IV and V. In particular, sphalerites from the Au-Ag and Ag-dominant deposits corresponding to Groups III, IV, and V usually show distributions of extremely low Fe contents (<5 mole %). Recent data presented by Choi *et al.* (1994) indicate distinct populations of low FeS contents in sphalerites from Gyeongsang Province. On the contrary, the FeS contents of sphalerite from the Chungcheong

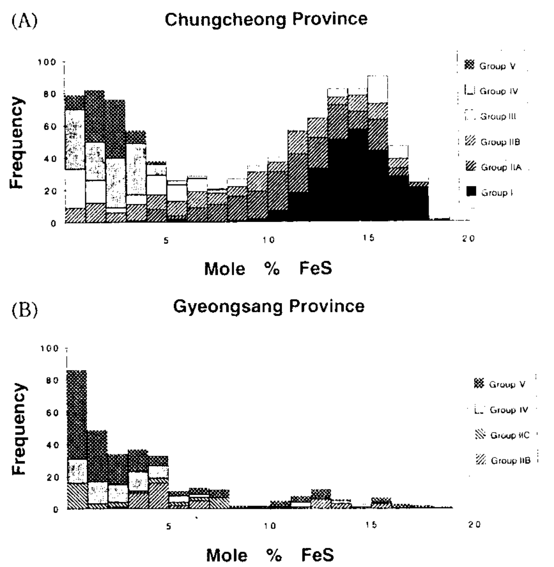

Fig. 5. Variation of FeS content (mole %) in sphalerite from the deposits on each group in the Chungcheong and Gyeongsang Provinces.

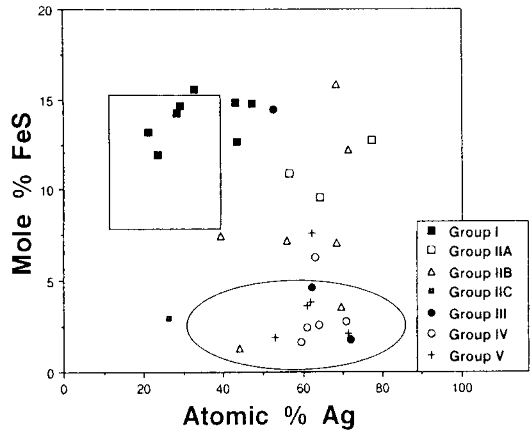

Fig. 6. Plot of average Ag content in electrums (atomic %) versus average FeS content (mole %) in sphalerites from the deposits on each group. Square and ellipsoidal areas represent the relationship of hypo/mesothermal and epithermal deposits in Japan, respectively.

Province reveal a bimodal distribution (Fig. 5). A systematic examination of mineral associations and the compositional variations of sphalerites suggests that differences of depositional environments such as temperature, sulfur fugacity and pressure cause the changes in Fe contents of sphalerites from gold and/or silver deposits.

Fig. 6 illustrates the relationship between the average Ag contents of electrums (atomic %) and the average FeS contents (mole %) of sphalerites from Korea-Japan precious-metal deposits (Shikazono and Shimizu, 1988). The chemical compositions of sphalerites and electrums from Group I and Groups III, IV and V in Korea are well consistent with distribution patterns of hypo/mesothermal and epithermal Au-Ag deposits in Japan, respectively. The deposits corresponding to Groups IIA, IIB and IIC seem to be genetically intermediate between hypo/mesothermal and epithermal Au-Ag deposits in compositions.

Many researches on the fluid inclusion and stable isotope have been done to interpret physicochemical environments of gold-silver deposits (Choi *et al.*, 1988; So *et al.*, 1987b; Shelton *et al.*, 1988; So *et al.*, 1989). Shikazono (1985) argues that the homogenization temperatures of the fluid inclusions on Japanese epithermal deposits are relatively well consistent with the temperatures measured by the electrum-sphalerite geothermometer of Barton and Toulmin (1964), Scott and Barnes (1971), and Barton and Skinner (1979). Accordingly, Groups I, IIA, IIB and IIC were generally formed under the conditions of notably high temperature and low fs_2 as compared to other types of deposits. Other deposits seem to be formed in similar depositional environments even though Groups III, IV, and V were formed under the conditions of relatively low temperature and fs_2.

On the basis of systematic examinations of results from this and previous researches on the fluid inclusion and stable isotope, precious-metal vein deposits in Korea can be divided into the hypothermal gold deposit and epithermal gold-silver deposit which were mineralized under the different environments (the forming temperature, the depth of ore formation, etc.). The Au-dominant deposits corresponding to Groups I, IIA, and IIB typically present the characteristics of the hypothermal deposits while some deposits in Group IIB show phases transferred to mesothermal deposits. Whereas, the Au-Ag deposits and Ag-dominant deposits which fall under Groups III, IV, and V generally show characteristics of epithermal deposits, while Group IIC represent characteristics of xenothermal deposit.

DISCUSSION AND SUMMARY

Two epochs of the precious-metal vein mineralizations are recognized by recent radiometric age data: a) Jurassic mineralization (121~183 Ma) associated with the Daebo granitoids, b) Cretaceous mineralizations (60~110 Ma) closely related to the Bulgugsa igneous activities. Contrasts between these two mine-

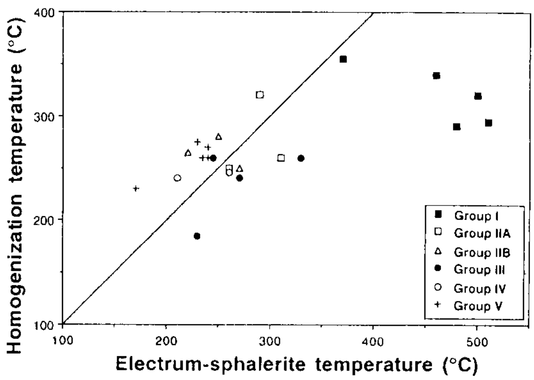

Fig. 7. Plot of the mineralization temperature from electrum-sphalerite geothermometry versus homogenization temperatures of fluid inclusions in minerals from the deposits for each group.

ralized epochs illustrate the diverse genetic natures of hydrothermal systems, and mineralizations occupied entirely different host rocks. The precious-metal vein mineralizations in the central Korea overlapped with two episodes of Daebo and Bulgugsa magmatic activities. In contrast, silver-rich mineralizations in the southeastern Korea took place over between 98 and 109 Ma during the Bulgugsa igneous activity.

Vein morphology, mineral assemblage, geochemistry, alteration, and style of mineralization from Groups I and IIA are markedly different from Groups IIB, IIC, III, IV and V. The data of electrum-sphalerite geothermometry and fluid inclusion indicate that gold mineralizations corresponding to Groups I, IIA and IIB occurred at temperatures between 250 and 500℃, whereas the gold and/or silver deposits of Groups III, IV and V were formed from a temperature range of 170~300℃ (Fig. 7). The Au-dominant mineralization from Groups I and IIA is clearly hypothermal in nature and features, suggestive of a deep-level emplacement by host rocks, electrum-sphalerite geothermometry, fluid inclusion and stable isotope studies. Until quite recent, researchers have reported that gold and/or silver deposits related with the Bulgugsa igneous activity were located only within the Gyeongsang basin. But, according to results from previously reported age datings, considerable numbers of gold-silver deposits in the central Korea are related with the igneous activity in the Cretaceous period.

Gold and/or silver deposits in Korea show that characteristics of the Au-Ag mineralization are remarkably consistent with mineralization epochs. The mineralization epochs of Group I and Group II which are related with Daebo igneous activity are 145~156 Ma (Group I) and 129~158 Ma (Group IIA). Whereas, the other characteristic mineralization epoch is 94~108 Ma for Group IIB, 73~109 Ma for Group III, 98 Ma for Group IV, and 71~98 for Group V. Therefore, the Au-dominant deposit is only related with the Daebo igneous acitivity, whereas the other types of deposits such as the Au-Ag, and Ag-dominant deposits are related with the Bulgugsa igneous activity tend to change gradually according to mineralization epochs. Accordingly, the Au-dominant deposit transforms to the Au-Ag deposit and the Ag-dominant deposit as the mineralization progresses from mid-Cretaceous to late Cretaceous period. This result tends to be well consistent with the depth of intrusion of surrounding igneous rock bodies. For example, it was reported that the emplacement pressures of the Daebo granites range from 3.4 to 7.8 kb and those of the Bulgugsa are less than 2.8 kb (Cho and Kwon, 1994), based on the amphibole geobarometer of Schmidt (1992). The precious-metal vein deposits in Korea evolved under the different conditions of hydrothermal activities at each times. Therefore, the differences of the depth of intrusion directly influence on Au-Ag-forming environments. Accordingly, the Au-dominant mineralization (129~158 Ma) in the central Korea, was progressed at the deep depth of several tens km or more at the time of the Daebo igneous body intruded. The Au-dominant mineralization occurred at relatively deep level during the early stage of the Bulgugsa igneous activity (94~108 Ma), futhermore, the depth of ore formation progressively changed to shallow environment with time accompanying the Au-Ag (73~109 Ma) and Ag-dominant mineralization (71~98 Ma).

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한국 중부와 동남부지역 금·은광화작용의 성인적 특성

최선규·최상훈

요 약: 한반도 중부지역과 동남부지역에 분포하는 금-은 광상들의 광화작용은 쥐라기 중기로부터 백악기 말기에 걸쳐서 진행되었으며, 이들 광상은 유형별로 산출지역 및 산출시기에 연관된 지질학적·지화학적 생성환경의 차이를 나타내고 있다. 중부지역 금-은 광상은 북동-남서의 방향성을 갖고 산출분포하는 중생대 화강암류 및 주변 선캠브리아기 변성암류내에 분포하지만, 동남부지역 금-은 광상은 백악기 퇴적암 및 화산암류내에 주로 배태되고있다. 이는 한반도 대표적인 화성활동인 쥐라기 대보화성활동 및 백악기 불국사 화성활동과 각각 밀접한 성인적 연관성을 시사하고 있다. 이러한 각 광상들의 광화작용 특성(광물공생관계, 조직, 구조 등)과 연대측정결과 및 지질학적 분포특성은 쥐라기 중기로부터 백악기 말기에 이르기까지 광상형성과 연관된 열수유체의 성인적 차이를 의미하고 있다. 즉, 쥐라기로부터 초기 백악기에는 금광단일형 광상의 광화작용이 우세하게 진행되었으나, 후기 백악기에 이르면서 금-은혼합형광상 및 은광단일형 광상의 광화작용이 우세하게 야기되었음을 알 수 있다. 쥐라기 금광단일형 광상들은 괴상의 맥상 산출특성 및 단순한 광석 광물 공생관계를 보여주는 단성광맥으로 높은 fineness 값을 나타내지만, 백악기 금-은혼합형 광상과 은광단일형 광상은 다양하고 복잡한 구조 및 조직특성을 갖는 복성 광맥내에 함은황염 및 황화광물과 함은tellurides 및 자연은 등을 포함하는 등 상대적으로 복잡한 광석광물 공생관계를 보여준다. 한편 황화광물의 지질온도계와 유체포유물 연구의 결과등에 의하면 백악기 금-은혼합형 광상과 은광단일형 광상은 천부(<0.5 kb)에서 천수가 우세한 광화유체로부터 200~350℃ 온도조건하에서 주된 광화작용이 진행되었지만, 쥐라기 금광단일형 광상은 마그마기원의 열수용액으로부터 고온(300~500℃) 및 고압(≈4~5 kb)의 생성환경하에서 광화작용이 진행되었음을 시사한다.