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The Jinsan Gold Mine, Korea: A Mineralogical and Geochemical Study

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Abstract: The Cretaceous Jinsan gold-bearing hydrothermal veins occur within the Late Proterozoic to Mid Ordovician metasedimentary rocks, intruded by Early Cretaceous pink-feldspar granite(142 ± 2.0 m.y.). Electrum-galena-sphalerite mineralization was deposited in three stages of quartz and calcite veins. Quartz sulfide-bearing stage I and II evolved from initial high temperatures (near 360°C)to later lower temperatures(near 220°C)from lower salinity fluids(1.0 to 3.2 wt.% NaCl eq.). Fluid inclusion data from the post ore carbonate stage reflects much cooler(110° to 180°C). Evidence of boiling indicates pressure of<85 bars, corresponding to depths of 400m to 1050m assuming lithostatic and hydrostatic loads. Au-deposition was likely a result of boiling, coupled with declining temperatures. The $\delta^{34}S$ H_2S values calculated for sulfides are consistent with an igneous source of sulfur with a $\delta^{34}S_{\Sigma S}$ value near 4.0‰.

INTRODUCTION

Most Au-Ag vein deposits in Korea are associated with Jurassic and Cretaceous granites(Jin et al., 1981; Lee, 1981; Ishihara, 1981; Iiyama and Fonteilles, 1981; Shimazaki et al., 1981; Min et al.,1982; So and Shelton, 1987 d, e). Cretaceous granites have been shown to be higher level intrusion(<2 to 3km) than Jurassic granites(>5km) (Tsusue et al., 1981), providing an opportunity to investigate the influence of depth of emplacement on the post magmatic evolution of granitic gold systems.

Cutting the rocks of Ogcheon Group in this mining district are number of ore veins which contain gold, silver, copper, lead and zinc minerals. The Jinsan mine has a Au/Ag ratio of 0.5 to 1.5, with average ore grades of 7.0g/ton Au and 8.0g/ton Ag. Ore reserves are not known. The highest ore grades of Au and Ag in the representative samples are 317g/ton Au and 216g/ton Ag, respectively.

Few investigators have studied the geology of Korean Au-Ag deposits and little is known about the physical and chemical conditions of ore deposition(Kaneda et al., 1984; Mizuta et al., 1984; Shimazaki et al., 1984a, b, 1985; So et al., 1987a,b,c,d and e). The aims of the present study were to determine the nature of ore mineralization, to document the physical and chemical conditions of ore deposition.

GEOLOGICAL SETTING

The mining area is comprised of the Late Proterozoic to Mid Ordovician metasediments of the Ogcheon Group and locally Cretaceous Seodaesan Formation intruded by later intrusives(Fig.1).

The original units of the Ogcheon Group-(shale, sandstone, dolomite, limestone, tuff and lava) were intensely folded and variably metamorphosed during the Jurassic Daebo orogeny(Reedman & Um, 1975). Metamorphic

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grade varies from greenschist to amphibolite facies. Subdivisions of the Ogcheon Group are, in ascending stratigraphic order, the Majeonri, Changri, Munjuri and Odaesan Formations.

The Majeonri Formation distributed in the eastern part of the area consists mainly of banded crystalline limestone interlayered with thin black mudstone beds. The Changri Formation occurs throughout the mine area and consists mainly of black slate and phyllite, minor amphibolite and schist, and locally interbedded, thin, low-grade, uranium-bearing coaly beds. The Munjuri Formation contains chiefly quartz-chlorite schist and sandy phyllite with thin biotite schist layers. Thin beds of this Formation is often interlayered and interfaced with the Changri Formation. The Odaesan Formation consists of siliceous and argillaceous quartzite with intercalation of mica-quartz schist, and relatively minor discontinuous conglomeratic quartzite. The lowermost are composed of commonly conglomeratic quartzite having variable thickness.

The Seodaesan Formation(Cretaceous age) occurs above the erosional unconformity and consists of flow-textured welded tuff and lithic tuff, containing angular fragments of rhyolite and andesite.

Early Cretaceous pink-fldspar granite locally intrude rocks of the Ogcheon Group. K-Ar dates of biotite from pink-feldspar granite is 142±2.0m.y.(So, et al., 1987). Quartz porphyry containing metasediment xenoliths occur locally, showing graphic and spherulitic textures. Felsic dykes, and gold-or fluorite-bearing quartz veins intrude ubiquitous the above rocks.

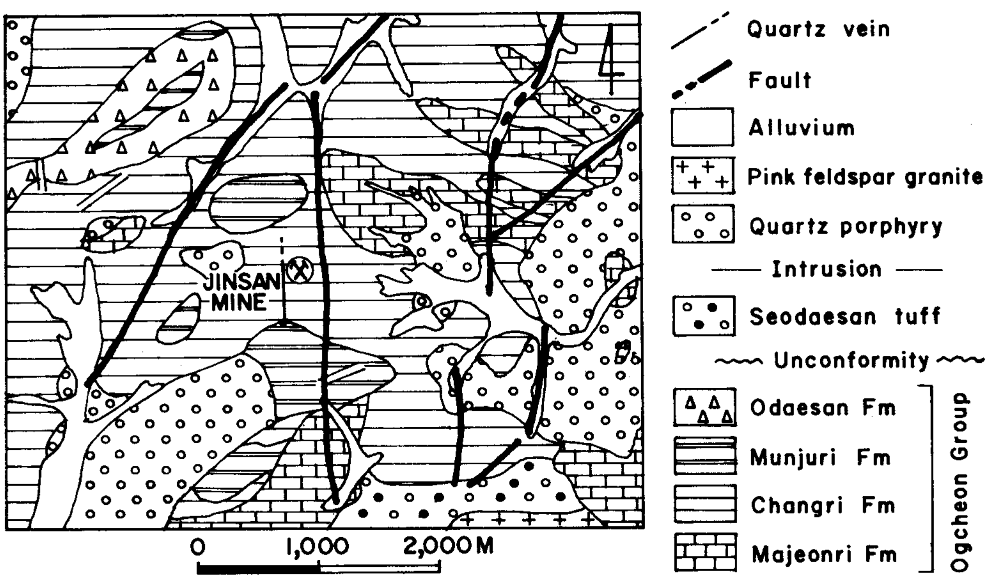

Fig. 1 Geologic map of the Jinsan mine area (modified after Hong and Choi, 1978).

ORE VEIN

The Jinsan mine consisted of several Au-bearing hydrothermal quartz veins and barren calcite vein. They were formed by narrow open space filling in the black slate of Changri Formation. The quartz veins arranged in N-S trend usually extend over 0.6km along the strike, dip 65°W, and vary in thickness from 0.1 to 1.5. The Yanghappan Vein is the only accessible at present.

The mineralization of hydrothermal Au-bearing quartz veins is simple metallic with local concentration of gold. The hypogene ore minerals, mainly sulfides, are poorly disseminated as compacted aggregates through the vein and are more less rich near the hanging-wall side of the vein. Chalcopyrite and pyrrhotite often occur as fine monomineralic veinlets penetrating wall-rock fractures and are disseminated around the wall-rock fragments in the vein. Pyrite is commonly disseminated in the alteration zone. Systematic spatial variation of ore minerals was poorly observed in the ore rich zone. There is the general metallic trend that varies inwardly from margin of the vein, in order of pyrite, chalcopyrite+pyrrhotite and galena+sphalerite. The gangue minerals are mainly quartz, fluorite and calcite. It is common to find subangular to angular fragments of the wall-rock highly silicified.

Gold ore shoots are not uniform over the entire length, but gold is more concentration in places, giving rise to definably small ore shoots at the portion where the vein is strongly swell and contains more wall-rock fragments. Mineralization age is considered to be correlated with the Jeonjuil Au-Ag mine in this mining district, based on the vein occurrence, mineralogy and fluid inclusion studies.

MINERALOGY AND PARAGENESIS

The depositional relationships between the metallic and gangue minerals in macro and microscopic texture such as cross cutting and brecciation permit a breakdown into three difference mineralization stages which are characte-

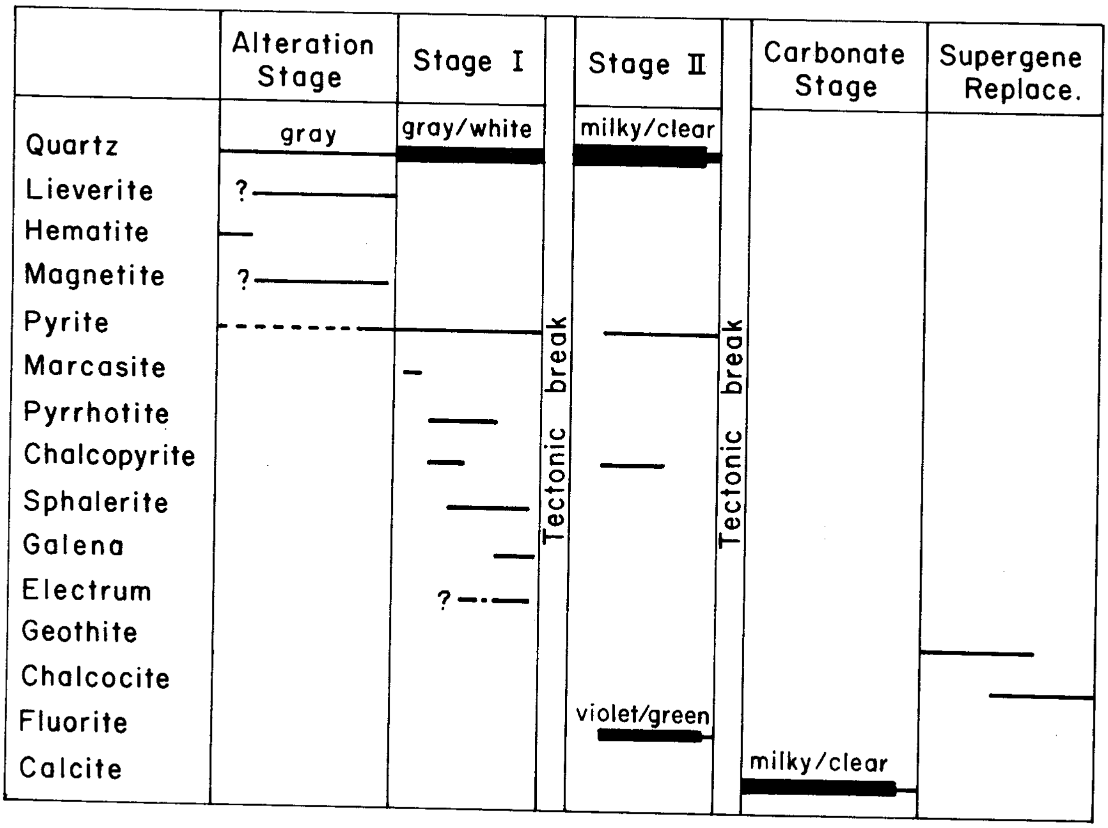

Fig. 2 Generalized paragenetic sequence of minerals from veins of the Jinsan mine. Width of lines corresponds to abundance.

rized by monoascendant character(Fig.2). These textures are indicators of movement during different periods of the deposition. The paragenetic relationships are well shown in Yanghappan Vein. In the first mineralization stage(stage Ⅰ), gray to white quartz is predominant gangue mineral associated with minor gold value and sulfides. The mineralogy for the second mineralization(stage Ⅱ) is represented by mainly milky to clear quartz, fluorite and minor amounts of sulfides. The latest phase of carbonate stage occurred after mineralization of the hydrothermal quartz veins. In this mineralization stage calcite was deposited along fissures in the quartz veins.

Stage I quartz vein (less than 0.3m in thickness) is crosscut, overlaped and for some part obliterated by later stage Ⅱ milky quartz vein. Stage I gray quartz vein occurred commonly as discontinuous segments and highly breccias in the stage Ⅱ vein.

Strong wall-rock alteration was formed during stage I mineralization. The maximum thickness of alteration halo is less than 1m. Wall-rock alteration and alteration of breccia fragments is pervasive and consists largely of silicification. Some of the wall rock, less frequently, are chloritized. During the alteration reactions, unhedral lieverite and magnetite occur as alteration products. Pseudomorphic magnetite replacing syngenetic hematite from the wall-rock occurs as lath forms.

Stage I quartz vein containing rarely druses consists of mainly gray to white quartz, and minor amounts of pyrite, chalcopyrite, pyrrhotite, sphalerite, galena, marcasite and electrum. Supergene minerals are goethite and chalcocite. Quartz is very dense and massive in appearance. Gray quartz commonly in the marginal parts of the vein. It often changes to dark gray chalcedonic quartz in some places. White quartz is in the form of coarse-grained massive appearance in the intermediate parts of the vein and occurs as tiny elongated quartz euhedra in small vugs.

Large unhedral pyrite is disseminated as aggregates and fine-grained euhedral grains are scattered within the gray quartz matrix. Microscopic pyrite veinlets are often observed. It is often associated with unhedral marcasite. Chalcopyrite closely integrown with pyrrhotite occurs as irregular mass which is often interstitial to grain boundaries of quartz and pyrite. Pyrrhotite is mostly hexagonal phase showing partially lamellae intergrowth. Reddish brown sphalerite containing small chalcopyrite blebs is poorly disseminated in the intermediate to central portions of the vein. Coarse-grained polycrystalline sphalerite grains (<1cm) intimately associated with galena often occurs within thin gray quartz veinlets penetrating along the wall-rock fractures. Sphalerite often included fine euhedral pyrite grains. Galena, where present, occurs rarely as euhedral to subhedral grains that are isolated within the gray quartz and penetrated along pyrite fracture and grain boundary. The corroded margins of pyrite grains are often observed in galena matrix. Later galena veinlets crosscut sphalerite. Supergene goethite replaced pyrite, chalcopyrite and sphalerite along the rims and fractures of them.

Gold occurs as pale yellow electurm is commonly in the form of mainly fine rounded grains and rarely massive appearance, and forms wire (up to 1.5cm in length) interstitial to grain boundaries of gray quartz in the stage I vein. It contains average 40 atom.% Au. Small gray quartz fragments associated with electrum grain are rarely included in the stage Ⅱ milky quartz vein.

Larger volumes of stage Ⅱ vein consists of milky to clear quartz, some fluorite and rare pyrite and chalcopyrite. This vein has a maximum thickness of 1.5m. Stage Ⅱ quartz vein shows characteristic structure such as rhythmic bands and comb structure. Milky quartz has a massive appearance and contains breccia of earlier materials associated with some ore minerals. Clear quartz showing rhythmic bands three layer overgrowing on the milky quartz. Pyrite(<2mm) is ubiquitous present through the vein and occurs rarely as euhedral grains in quartz vugs. Small irregular chalcopyrite is widely scattered as fine grained unhedral mass and its grains occur near the fragments of older materials from which they were plucked.

Fluorite, green and rare violet color, occurs as massive polycrystallined aggregates throughout the margins of vein and as euhedral cube on the vug quartz. Higher fluorite quantities are observed at the both marginal parts of vein.

The latest phase of tectonic activity occurred after stage Ⅱ mineralization. Calcite was deposited within later openings with variable attitudes in earlier quartz veins. Calcite vein consists of only milky calcite formed of rhombic or sheet in appearance. Clear rhombic calcite crystal occurs in calcite and quartz vugs.

FLUID INCLUSION STUDIES

The fluid inclusion study was initiated to examine variations in temperature and fluid composition in mineralization stages. The minerals examined for fluid inclusions were quartz, fluorite and calcite. Gold-bearing hydrothermal quartz veins are notoriously lacking in good material for fluid inclusion studies due to the strong predominance of poorly crystallized quartz containing only very tiny fluid inclusions. Most of the plates contained primary and secondary inclusions. Samples of fluorite and calcite contain large numbers of secondary inclusions close to or along fractures and cleavage planes.

Most heating and freezing measurements were made on chaixmeca heating-freezing stage(Poty et al., 1976). Replicate measurements of homogenization temperature showed a reproducibility within ±2.0°C of temperature near 350°C. Replicate measurements of melting temperatures of H_2O and CO_2-rich standard fluid inclusions showed a reproducibility of ±0.2°C. The salinity data are based on freezing point depression in the system H_2O-NaCl(Potter et al., 1978).

Two types of inclusions are recognized on the basis of the phase proportions at room temperature. They are classified according to the terminology of Nash(1976).

Type Ⅰ : This common type of fluid inclusion contains two dominant phases, and aqueous liquid and a vapor bubbles which occupies 10 to 40 percent of the cavity volume. No daughter minerals have been found in any inclusions. The cavity of inclusions range from 4 to 30 μm in size. Type I inclusions are found in all minerals examined and occur as primary and secondary fluid inclusions. Primary inclusions are mainly in the form of isolated ellipsoidal inclusion and are away from healed fracture.

Type Ⅱ : Two-phase, vapor-dominated inclusion in which the liquid phase represents less than 40 percent of the inclusion volume at room temperature. These inclusions homogenize to the vapor phase, and occur as only primary inclusion. The cavity of inclusions are generally regular in shape, varing from faceted avoid to euhedral in form, they are generally less than 25μm in diameter and do not contain daughter minerals. The results of heating and freezing studies on inclusions from stage Ⅰ, Ⅱ and carbonate stage of the mineral paragenesis are presented in Figures 3 and 4.

Stage I minerals examined for fluid inclusions were gray and white quartz. Gray and white quartz contain only primary and secondary type I and rare primary type Ⅱ inclusions. The inclusions vary in size from 5 to 30 μm. In type I inclusions, vapor bubble usually make up 10 to 30 percent of the total volume of the inclusions. Altough fluid inclusions in stage I quartz are very small and hardly studied, the limited salinity data could be obtained from it on the freezing stage.

Homogenization temperatures of fluid inclusion for inclusion for stage I mineralization range from 228° to 356°C(230° to 355°C for type I and 270° to 315°C for type Ⅱ inclusions in gray quartz, and 228° to 356°C in white quartz)(Fig.3). The salinities obtained from stage I gray quartz and white quartz range from

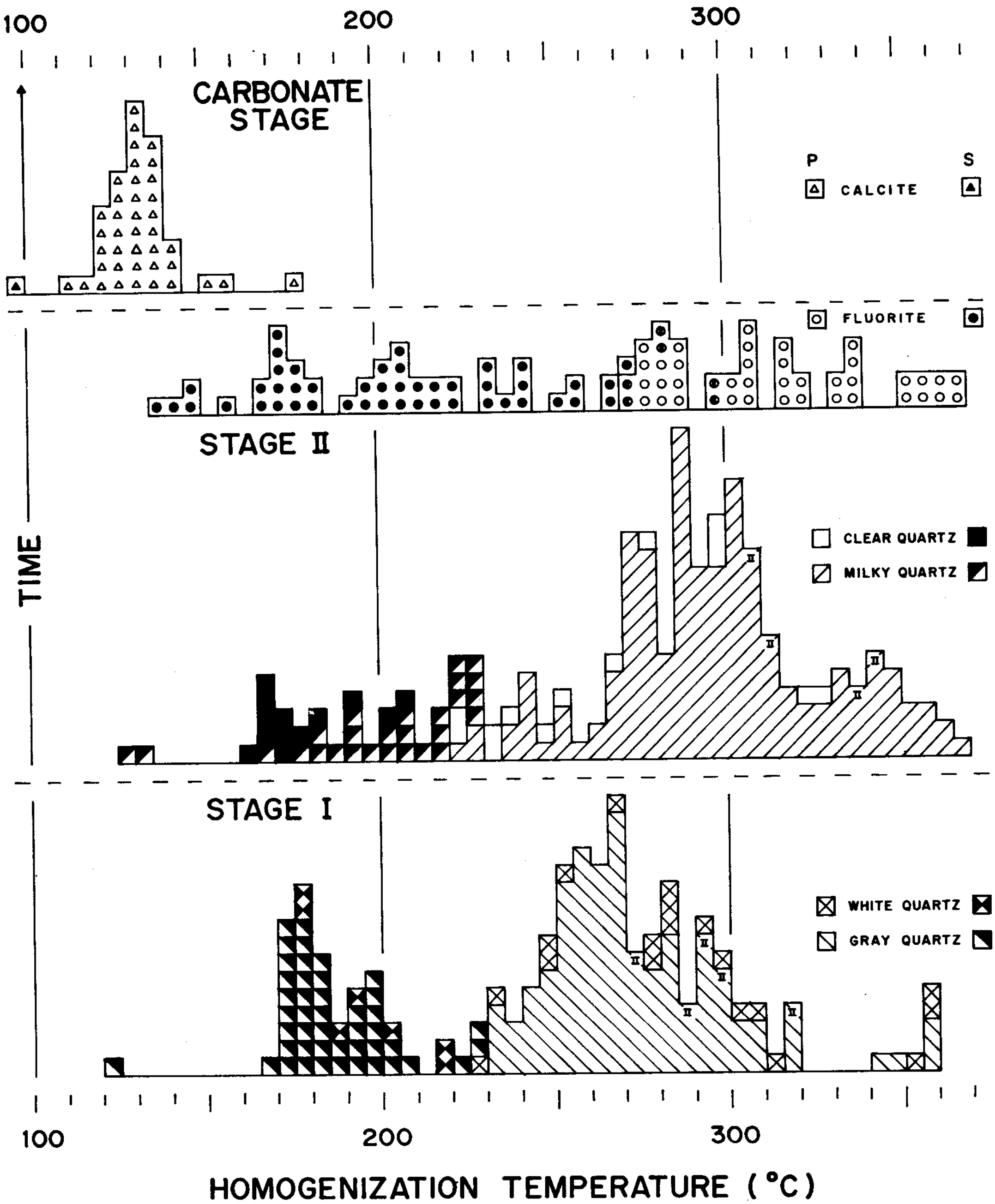

Fig. 3 Histograms of homogenization temperature data for fluid inclusions from I, II and carbonate stage minerals from the Jinsan Au mine.

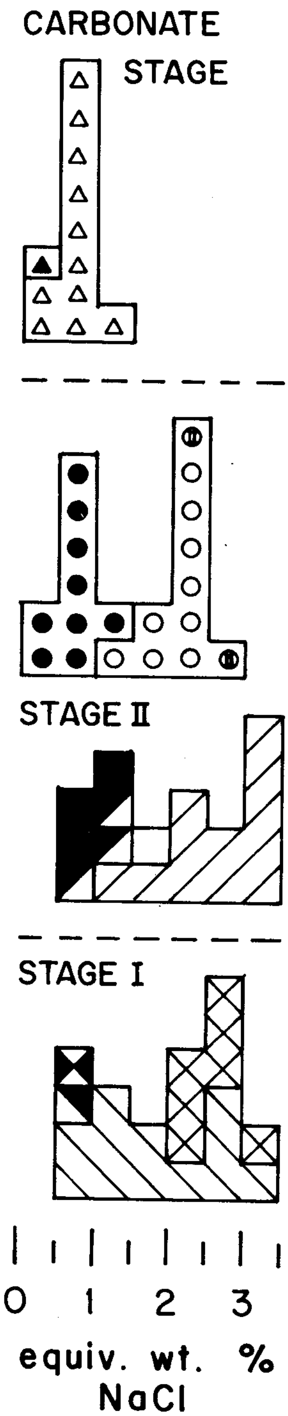

Fig. 4 Histograms of salinity data(equiv. wt% NaCl) for fluid inclusions from I, II and carbonate stage minerals of the Jinsan Au mine.

0.9 to 3.2 and 2.1 to 3.1 equivalent wt.% NaCl, respectively.

The stage II minerals examined for fluid inclusions were mostly milky and clear quartz and fluorite. Most of the quartz specimens examined are mainly collected massive fine-grained milky quartz through the vein. Altough some specimens of rhythmically overgrowing banded milky quartz are also collected for fluid inclusion study, they do not contain fluid inclusions. Extremely some clear quartz crystals which are later euhedral crystal projecting into a druse are examined in some location of vein. Type I and II fluid inclusions in milky quartz and only type I inclusions in clear quartz were observed in this study. The inclusions are less than 35 μm in cavity size and contain 10 to 20 percent vapor by cavity volume. Fluorite containing excellent fluid inclusions occurs as massive grains from marginal parts to vug within milky quartz vein. The inclusions are so abundant in the violet fluorite and occur as predominantly the secondary type I and rare primary type I and type II. Primary type I and II inclusions range from 5 to 18 μm in cavity size have bubbles occupying from 10 to 40 and 60 to 90 percent by cavity volume, respectively.

The homogenization temperatures of primary type I inclusions in stage II minerals range from 224° to 366°C. Milky and clear vug quartz have homogenization temperature ranging from 224° to 366°C(308° to 341°C for type II inclusions) and 324° to 329°C, respectively. The primary type I and type II fluid inclusions in fluorite homogenize to the gas phase at temperature, ranging from 278° to 366°C and 272° to 297°C, respectively. The salinities of fluid inclusions in stage II minerals range 1.2 to 3.2 equivalent wt.% NaCl. Milky and clear quartz have salinities ranging from 1.2 to 3.2 and 1.6 equivalent wt.% NaCl, respectively. The salinity obtained from fluorite ranges from 1.2 to 2.6 equivalent wt.% NaCl.

Rhombohedral calcite from stage III vein contain type I fluid inclusions. Most are less than

10 microns in diameter and vapor bubbles occupy 10 to 20 percent of the inclusion volume. Rhombohedral calcite yields fluid inclusion homogenization temperatures in the range 112° to 176°C. The salinities of fluid inclusions in calcite from carbonate stage range from 0.4 to 1.0 equivalent wt.% NaCl.

During the mineralization episodes, variation in temperatures of the hydrotheraml fluids are recorded by the fluid inclusion study. There is a indication that fluids responsible for quartz of stage Ⅱ(main range=260° to 360°C) show slightly higher temperature than fluids of stage Ⅰ minerals (main range=230° to 320°C). The fluid inclusion data display significant decreases in homogenization temperature and salinity between stages Ⅰ and Ⅱ quartz and carbonate-stage calcite(Fig.3). The variations in temperature were probably not continuous, as each stage represents a distinct period of mineralization separated in time. The temperature variations, therefore, reflect hydrothermal fluid pulses of variable temperatures being injected into vein at different times.

PRESSURE CONSIDERATION

Recent detailed studies of epithermal precious-metal deposits have combined fluid inclusion evidence for immiscibility with information on boiling-point curves to determine the pressures and corresponding depths at which mineralization occurred.

Commonly the inclusion data were interpreted using boiling-point curves for the system H_2O-NaCl(Hass, 1971), because the fluid composition was not known and properties of the system H_2O-NaCl were assumed to approximate those of the ore-forming fluid(Clifton et al., 1980 ; Radtke et al., 1980 ; Buchanan, 1981 ; Kesler et al., 1981). Most natural fluids are not simple solutions of NaCl and H_2O but contain significant amounts of other solutes ; such as K^+, Ca^+, SO^{-2}_2 and HCO^-_3. Although Potter and Clynne(1978) showed that many of the solutes present in natural inclusion fluids result in fluids that have thermodynamic properties rather close to those measured for simple NaCl-H_2O solutions with the same value for the depression of the freezing point, extrapolation to fluids containing significant quantities of CO_2 is hardly warranted.

CO_2 hydrates of fluid inclusions has been not detected during freezing studies in minerals from each mineralization stages in the Jinsan mine. The inclusion data are interpreted in terms of the H_2O-NaCl system. Type Ⅰ and type Ⅱ fluid inclusions are intimately associated in some samples of stage Ⅰ white quartz, and stage Ⅱ quartz and fluorite. All of the type Ⅱ inclusions could not be measured because of its small cavity size. The coexistence of type Ⅰ and type Ⅱ fluid inclusions in these samples, which homogenized at similar temperatures, indicates that the hydrothermal fluids were boiling periodically.

Therefore no pressure corrections are necessary in these inclusions because they may be trapped along the two-phase boundary of the H_2O-NaCl system. The data of Hass(1971) and Sourirajan and Kennedy(1962) for the system H_2O-NaCl, combined with the coexistence temperature (270° to 307°C) of type Ⅰ and type Ⅱ fluid inclusions and salinity data for Au-bearing stage Ⅰ mineralization, suggest a maximum pressure of less than 85 bars(fluids density≒0.734 g/cm³) during the ore deposition. This pressure corresponds to maximum depth of about 1050 to 400m respectively, assuming hydrostatic and lithostatic loads. Pressures obtained using the system H_2O-NaCl and depths of formation calculated from pressures would represent minimum values, and the pressures and depth would be greater if the inclusions contained any non-condensble gases.

SULFUR ISOTOPE STUDY

Recent studies have shown the utility of stable isotopes in elucidating the origin and hydrothermal history of vein-type Au-Ag deposits(Taylor, 1973; Rye et al., 1974; O'Neil & Silberman, 1974; Casadevall & Ohmoto, 1977; So & Shelton, 1987a, b). In this study we measured the S isotope composition of vein minerals. Standard techniques of extraction and analysis were used(Grinenko, 1962). Data are reported in Standard δ notation relative to the CDT for S. The analytical error is approximately ±0.1‰ for S.

Sulfur isotope analyses were performed on 7 hand-picked minerals(Table 1). Stage I pyrite has $\delta^{34}S$ values of 5.9 to 6.5‰; galena, 1.6 to 2.6‰; sphalerite, 6.0‰. Two pyrite-galena pairs with equilibrium textures have $\Delta^{34}S$ values of 3.6 to 3.7‰, yielding equilibrium isotope temperatures of 252±36℃ to 259±37℃(Ohmoto & Rye, 1979) in agreement with homogenization temperatures of primary inclusions in associated quartz(Table 1).

Table 1 Sulfur isotope data of stage I sulfides.

Sample	Mineral	$\delta^{34}S$%	$\Delta^{34}S_{py-gn}$	T℃	Th℃*
J-5	py	6.2	3.6	259±37	236 to 272
	gn	2.6			
J-14	sp	6.0			
J-21	gn	1.6			
J-46	py	5.9	3.7	252±32	240 to 267
	gn	2.2			
J-50	py	6.5			

* Fluid inclusions in associated gray quartz

Abbreviations : py=pyrite; gn=galena; sp=sphalerite

Assuming depositional temperatures of 300° to 250℃ for stage I sulfides (based on fluid inclusion and paragentic constraints), calculated $\delta^{34}S$ valued for H_2S during stage I is 3.5 to 5.3‰.

The presence of pyrrhotite ± pyrite and alteration assemblage muscovite+quartz+K-feldspar indicate sulfur in the fluid was dominantly H_2S. Therefore, the $\delta^{34}SH_2S$ value of 3.5 to 5.3‰ is nearly equal to the $\delta^{34}SH_2S$ value of the fluid.

Ohmoto and Rye(1979) have shown that a magmatic fluid phase in equilibrium with a hydrous granitic melt(log fo_2=-12, 1000 bars, 800℃, initial $\delta^{34}S_{melt}$ value near 0‰) will have a $\delta^{34}S_{fluid}$ value near 4‰. We therefore interpret the source of sulfur in the Jinsan veins as an igneous source, possibly the nearby Cretaceous granite.

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