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Occurrence of Ore Minerals and Fluid Inclusion Study around Hesperides Point, Livingston Island, Antarctica

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ABSTRACT. Numerous hydrothermal veins and breccias are developed around Hesperides Point, Livingston Island, South Shetland Islands. They cut the Miers Bluff Formation, a deformed turbidite sequence of ?Carboniferous-Triassic age. Major vein fabric is open-space filling texture such as symmetrical crustiform layering, comb structure and open vuggy. Vein structures indicate repeated opening of cracks and mineral precipitation of minerals. Based on vein structure and ore mineralogy, mineralization can be divided into four stages. Stage I ores mainly composed of pyrite and sphalerite with small amount of galena, chalcopyrite, arsenopyrite, bornite and hematite. Stage II ores compose sphalerite, galena and chalcopyite with small amount of pyrite and pyrrhotite. Stage III ores compose small amount of galena, sphalerite, chalcopyrite and pyrite. Stage IV ores occur as barren quartz veinlets, which cut earlier stage ores. NaCl equivalent salinity and homogenization temperature of fluid inclusion from quartz are as follows; Stage I: 0.8-3.43 wt.% (average 1.6 wt.%) , 202-289°C (average 240°C), Stage II: 1.6-5.2 wt.% (average 2.7 wt.%), 230-287°C (average 239°C), respectively. Fluid inclusion study reveals that ore fluids were relatively low temperature and low saline with a simple NaCl-H_2O system at the time of ore formation. Vein structure, ore mineralogy and fluid inclusion data suggest that the hydrothermal veins are polymetallic epithermal ore deposits.

Key Words: Livingston Island, ore mineralogy, fluid inclusion, hydrothermal, epithermal

Introduction

Livingston Island is the second largest one in the South Shetland Islands. On Hurd Peninsular, central part of Livingston Island, sulfide-bearing hydrothermal veins and breccias systems are developed along the northeastern part of seaside. Occurrence of copper- and molybdenum-bearing porphyry deposit was reported on the north of Barnard Point (Littlefair, 1978; Pride *et al.*, 1990). Littlefair (1978) also suggested that hydrothermal veins in Hurd Peninsula were formed from the outer periphery of mineralization of Banard Point.

Resent study on vein system developed in Hurd peninsular referred it to an epithermal system of adularia-sericite type ore deposits, and possibly related to midddle to late Cretaceous arc volcanism (Willan, 1994). Porphyry veinlets in Banard point were re-mapped as three distinct hydrothermal vein assemblages, related to exsolution from the cooling magma, and two post-Eocene episodes of fracturing and fluid-infiltration (Willan, 1994).

This study is focused on occurrence of ore minerals and fluid inclusion study for hydrothermal veins and breccias around Hesperdides Point, and comparison to mineralization of Banard Point.

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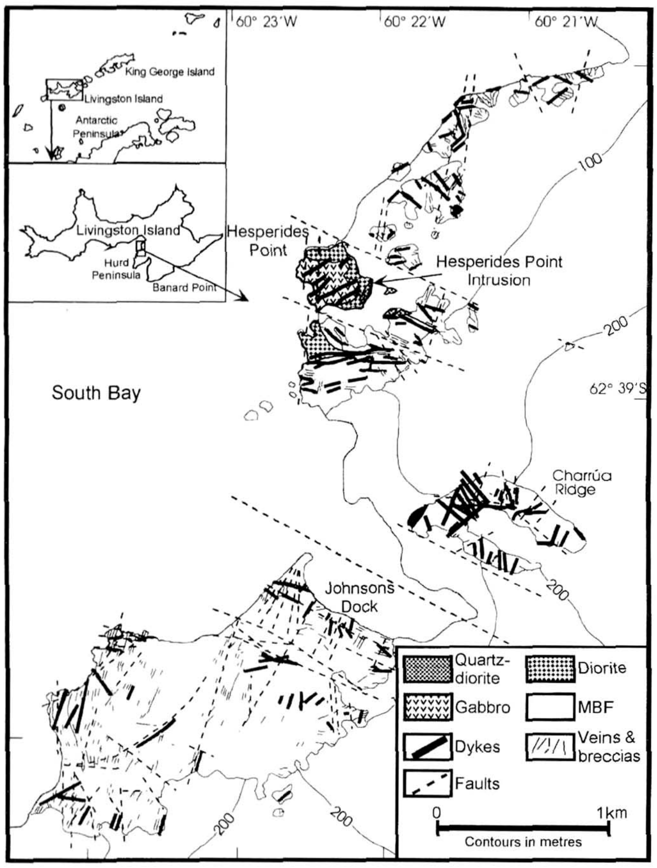

Fig. 1. Geologic map and variable orientation of veins, breccias and dykes around Hesperides Point (modified from Willan, 1994 and Kamenov, 1997).

General geology

Hurd Peninsula consists of the Miers Bluff Formation, Moores Peak Breccia, Hesperides Point Intrusion and numerous dykes (Fig. 1).

The Miers Bluff Formation comprise turbiditic silicic sandstones, mudstones and conglomerates (Hobbs, 1968; Smellie *et al.*, 1995), probably Triassic age (Willan *et al.*, 1994). The base of the Miers Bluff Formation is not exposed and the age of sedimentation or deformation is poorly constrained by a U-Pb provenance age of 320Ma for detrital zircon (Loske *et al.*, 1988), a late Triassic whole rock Rb-Sr age, interpreted as diagenesis or metamorphism (Dalziel, 1972; Smellie *et al.*, 1984) and one set of arc volcanism in the late Jurassic. The formation is commonly overturned, younging from W to E with about 45°NW dips (Dalziel, 1992).

The Moore Peak Breccia conformably overlying the Miers Bluff Formation and is overlain by the Cretaceous Mount Bowles Formation. The Moores Peak Breccia could be either part of the Miers Bluff formation or a separate unit. The contact between the Moores Peak Beds and Mount Bowles Formation may be either unconformal or tectonic contact (Smellie *et al.*, 1995). Its distribution confined close to the False Bay, northeast of Hurd peninsula.

The Hesperides Point Intrusion is well exposed around Hesperides Point as small stock in the Miers Bluff Formation. It represent a composite pluton comprise three lithological unit, such as gabbro, diorite and quartz diorite. The whole-rock K-Ar age of diorite from the Hesperides Point Intrusion is 73±3 Ma (Kamenov, 1997).

Occurence of Ore Veins

Quartz veins, vein-breccias and country-rock breccias crop out sub-parallel to the western coastline of Hurd Peninsula more than 2km wide with striking NNE and dipping steeply east (Fig. 2-A). Veins extended up to 350m long with 1mm to 80 cm thick (average 7cm). They commonly display sharply defined planar shapes. Sharp changes in veinlet direction, vein splitting, pointed vein tips and sloped-off angular slivers of wallrock indicate a hydraulic origin for vein propagation (Willan, 1994). Breccias form NNE-striking planar bodies up to 400 m long, or equant areas up to 30 m across at intersections of NNE- and ESE-striking fractures. Complex polylithic breccias, between 1 and 8 m thick, comprise angular fragments of unaltered, locally derived wallrocks and pre-existing crustiform-banded quartz veins (Fig. 2-C, D, E, F). Heterolithic 'mill' breccias consist of variably rounded, intensely silicfied, epidotized, chloritized and sericitized rock fragments. Internal vein and breccia fabrics are dominated by open-space filling textures characteristic of epithermal environments (Willan, 1994).

The veins and breccias contain coarse-grained quartz (clear, milky and amethystine varieties; Fig. 2-B), chalcedonic quartz, chlorite and late vuggy cal-

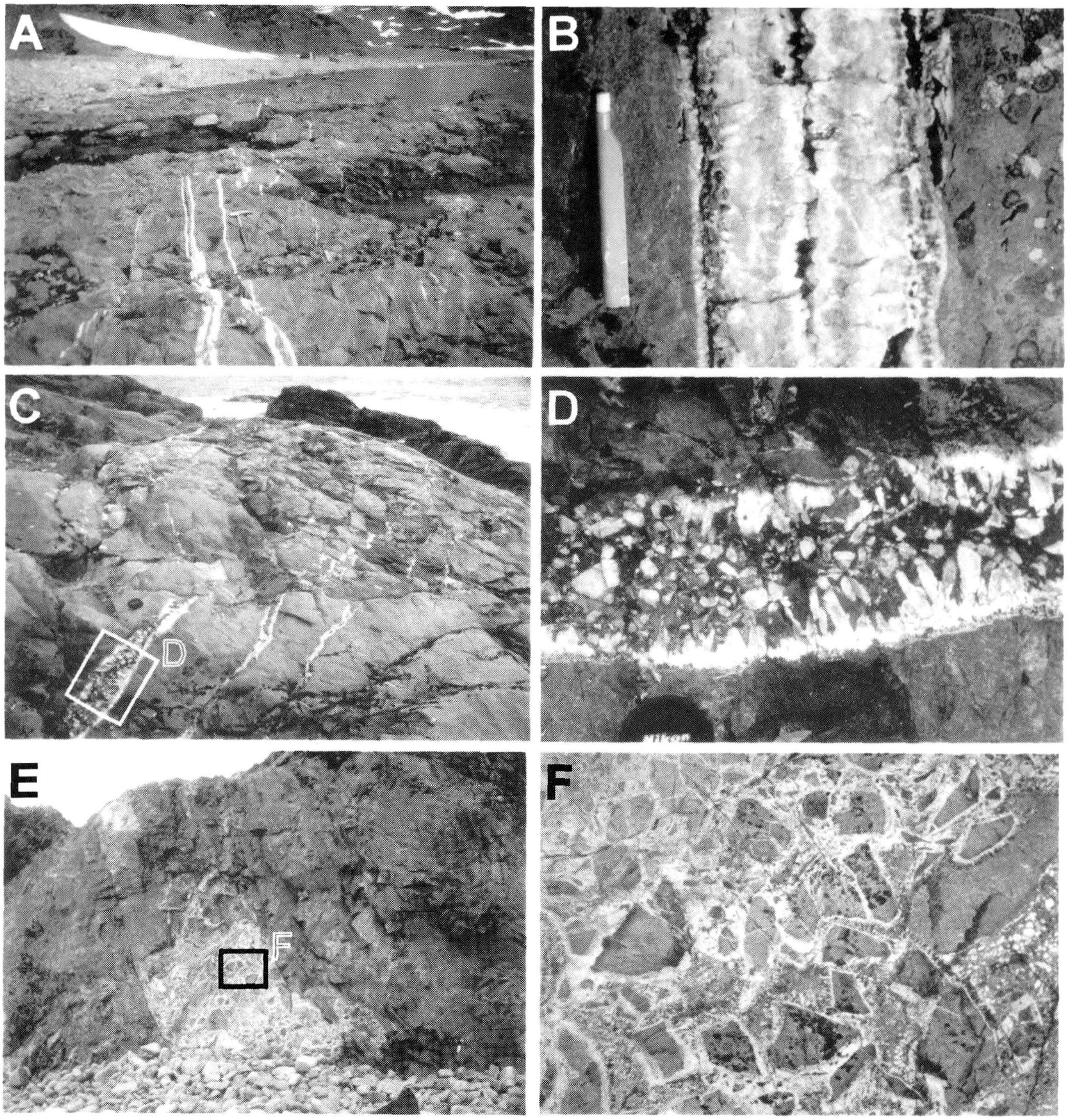

Fig. 2. Outcrops and rock slab photographs showing quartz veins and breccias

A: *Quartz veins developed along coastline of* Hurd Peninsular. B: Symmetric banding and crustification of quartz vein. C: Quartz veins are cut by minor fault. D: Enlarged photo of C showing vuggy quartz growth toward the center of open space. Open sapce is filled with calcite, early precipitated quartz, wall-rock fragments and small amount of sulfide minerals. E: Monolithic jigsaw breccia of angular aletered sandstone. F: Enlarge photo of E. Stock work texture developed in altered sandstone. Some open space filled with white-yellowhish or brownish colored coarse calcite crystals. G: Stockwork texture of quartz vein developed in altered sandstone. H: Enlarged photo of G. Some open sapce was filled by white, yellowish or brownish colored coarse grained calcite. I: Quartz vein is cut by fault. J: Quartz vein is cut by andesitic dyke. K: Typical ore vein developed in Hesperides Point. L: Rock slab of typical ore veins showing multi-stage precipitation of sulfides. Stage I ores ('I' in photo) occur in laminated shale as xenolith within stage II ores ('II' in photo). Stage III ores ('III' in photo) is composed of open space filling vuggy quartz and calcite with small amount of sulfide. Shale occurs as xenolith and is altered to chlorite and sericite ('Alt' in photo).

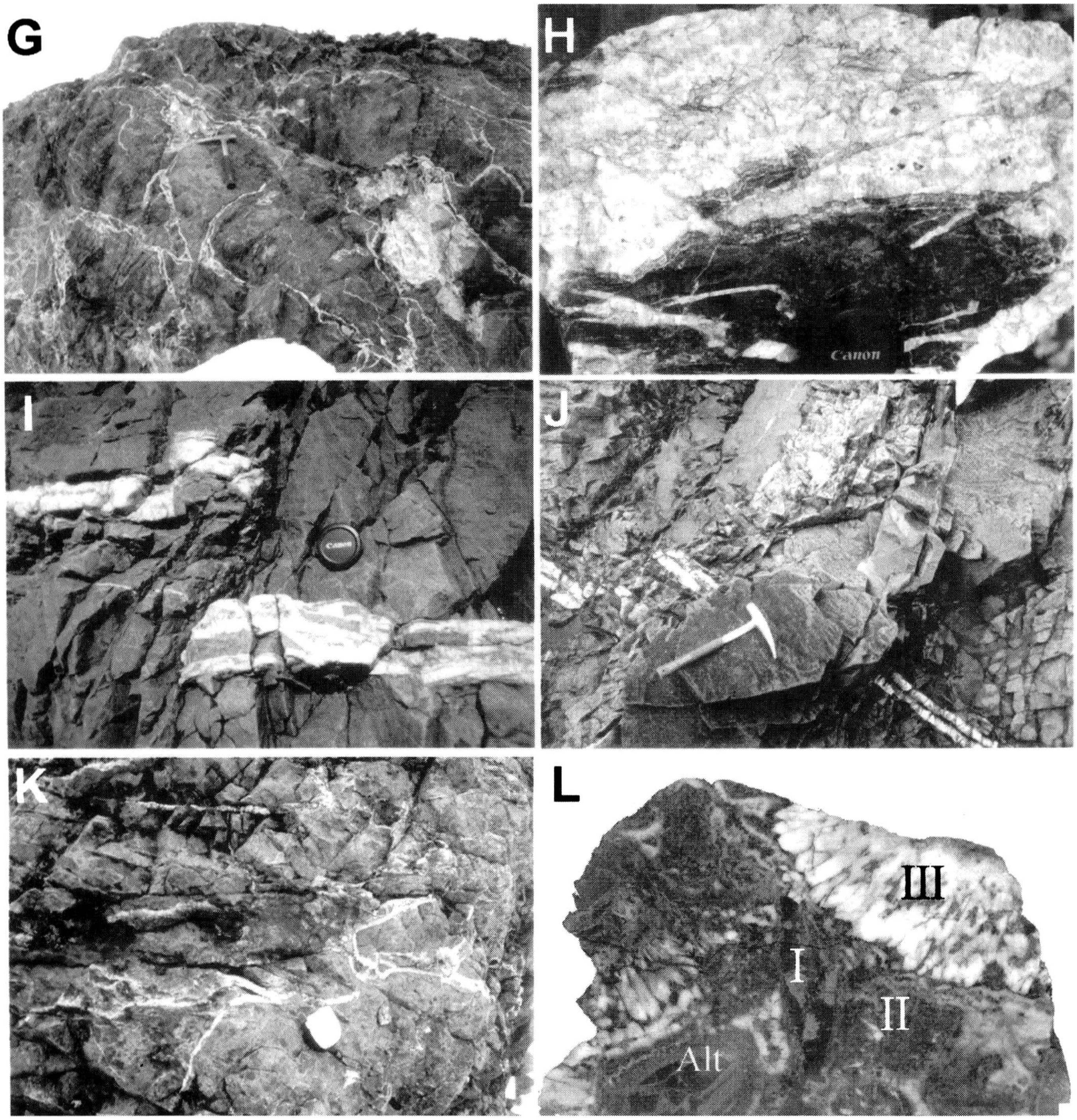

Fig. 2. Continued

cite (white, orange and black; Fig. 2-G, H), with variable amounts of chalcopyrite, galena, sphalerite, pyrite and epidote (Fig. 2-K, L). Many veins lack proximal wallrock alteration, cutting unaltered grey sandstone and mudstone. However, there are numerous, large (several hundred metres across) irregular areas of sandstone which are pervasively silicified, brecciated and cut by randomly oriented quartz + chalcopyrite veinlets, similar to crackle breccias, and some sandstones contain thin veinlets of K-feldspar.

The veins and breccias are cleanly cut by numerous local fault (Fig. 2-I) and basaltic-andesite dykes (Fig. 2-J), suggesting that hydrothermal activity preceded mid-late Cretaceous volcanism, although Rb-Sr evidence of mid-Cretaceous alteration indicates that hydrothermal activity and volcanism may have been coeval (Willan, 1994). Field relations, vein and breccia textures and mineralogy are similar to volcanogenic epithermal systems of quartz-adularia-sericite type (Heald *et al.*, 1987). These hydrothermal systems generally form within 2 million years or less of the peak of volcanism and may occur at depths of <1 to 2 km in basement beneath unconformable volcanic cover. The unusual lateral extent of Hurd Peninsula veins suggests that more than one hydrothermal centre may be exist.

Occurence of Ore Minerals

Sulfide enriched ore veins coated with iron and copper oxides mostly occurred in hydrothermal veins. Ores are divided into two types of assemblages based on main minerals: 1) pyrite-chalcopyrite enriched and small amount of sphalerite and galena, 2) galena-sphalerite-pyrite enriched and small amount of pyrite. The fact thst these mineral assemblages occure in unique vein indicates mineralization were overlapped multiply. Four mineral stages can br inferred based on texture and structure such as cut-cut relation and xenolith (Fig. 2-L).

Stage I: Stage I ore is composed of pyrite, chalcopyrite, sphalerite with small amount of galena, bornite, pyrrhotite, arsenopyrite and hematite. Gangue minerals are quartz, chalcedonic quartz and wall-rock alterantion products such as chlorite, epidote and sericite. Stage I ores occur as xenolith or rock fragments in stage II and III ore, or veinlets or massive pockets in wall-rock (gray sandstone and siltstone).

Stage II: Sulfide minerals in stage II include pyrite, sphalerite, galena and chalcopyrite. Gangue mineral is quartz only. Stage II ore minerals were precipitated around rock fragments of earler stage ore or wall-rock.

Stage III: Euhedral vuggy quartz were precipitated in the open space during this stage. Small amount of pyrite, galena and sphalerite were overgrown on the vuggy quartz.

Stage IV: Stage IV is barren quartz precipitation stage. The quartz veinlets cut ores of earlier stage.

Breccia vein: Sulfide minerals in breccia veins are mostly pyrite and chalcopyrite with small amount of galena and sphalerite. Galena and white, purple or light gray clacite were precipitated in open space of breccia veins.

The sulfide minerals observed in hydrothermal ore veins and breecia veins are chalcopyrite, galena, sphalerite, pyrite, bornite, hematite, arsenopyrite and pyrrhotite. The characteristics of the ore minerals under ore microscopy are as follows.

Pyrite: Pyrite is the most abundant sulfide minerals in all ore mineralization stage. It is replaced by stage II chlacopyrite and cut by sphalerite and galena (Fig. 3-A, B). Small amount of pyrrhotite and hematite blebs observed in the pyrite.

Chalcopyrite: Chalcopyrite is representative copper mineral in stages I and II. Chalcopyrite of stage I occurred as blebs in sphalerite, or as disseminated dots with pyrite in sandstone or mudstone. Stage II chalopyrite replaces or cut stage I pyrite (Fig. 3-A, B).

Galena: Galena is mostly precipitated in stage II with small amount in stage I. Stage I galena occurs in massive ore bodies within wall-rocks with chalcopyrite. Stage II galena replaces or cut pyrite of stage I (Fig. 3-A).

Sphalerite: Sphalerite occurs in stages I, II and III. Sphalerites of stage I and II contain many dots of chalcopyrite (Fig. 3-C), but raer in the stage III (Fig. 3-D). Chalcopyrite dots in stage I sphalerite randomly distributed over the whole part of sphalerite (Fig. 3-B), but those in stage II sphalerite alined to growth zone of sphalerite (Fig 3-C).

Bornite: Bornite occurrs as small, isolated grains in wall-rock.

Pyrrhotite: Pyrrhotite distributes in pyrite of stage I with small, bleb shape.

Arsenopyrite: Arsenopyrite only occurs in stage I as replacing chalcopyrite.

Hematite: Hematite occurs as small isolated grains in wall-rock (sandstone or siltstone).

The paragenesis of ore minerals based on occurrence of ore minerals is presented Fig. 4.

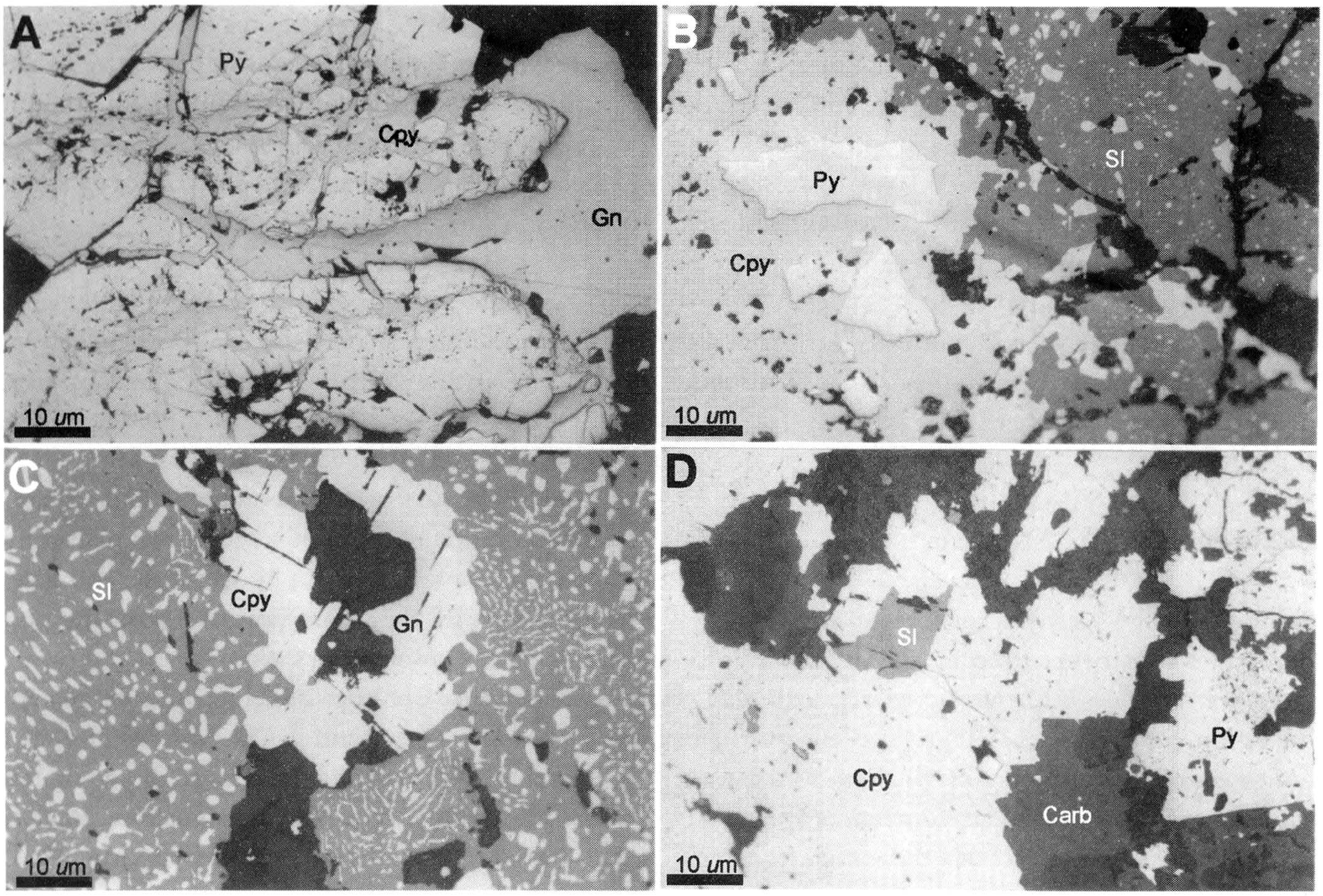

Fig. 3. Microphotographs showing paragenetic association among several sulfide minerals.
A: Stage I pyrite (Py) is replaced or cut by stage II galena (Gn) and Chalcopyrite (Cpy). B: Stage I sphalerite (Sl) and pyrite are replaced by stage II chalcopyrite. C: Stage II ore minerals assemblage. Sphalerite contains many stars of chlacopyrite. Some chalcopyrite precipitated along the rim of galena. D: Stage III ores assemblage.

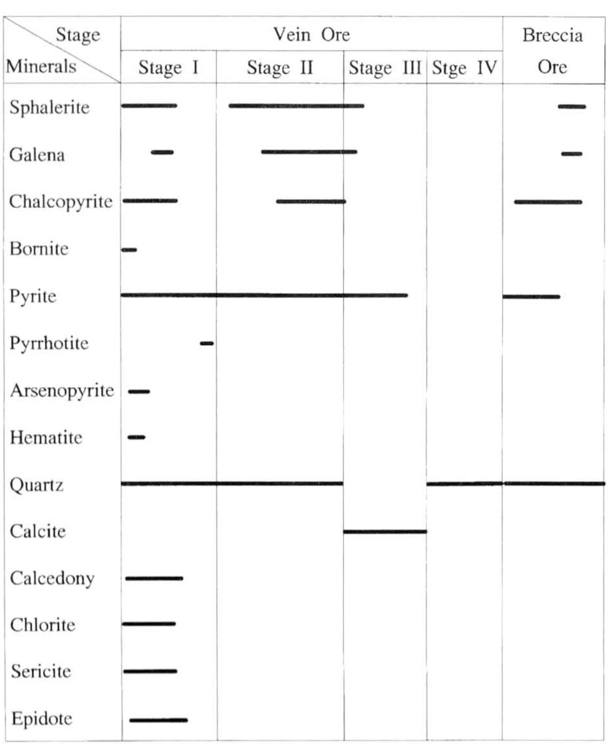

Fig. 4. Paragenetic sequence of hydrothermal veins and breccia ores.

Fluid Inclusion Study

Fluid inclusion study was undertaken to constrain the composition and P-T condition of ore-bearing fluid. For the fluid inclusion study, doubly polished segmente of quartz, sphalerite and calcite are prepared and observed at room temperature (approximately 20°C) through microscope. Heating and freezing experiments were accomplished by USGS-type gas flow heating/frezzing stage at the Department of Geological Science, Seoul National University.

Fluid inclusions are subdivided into two types

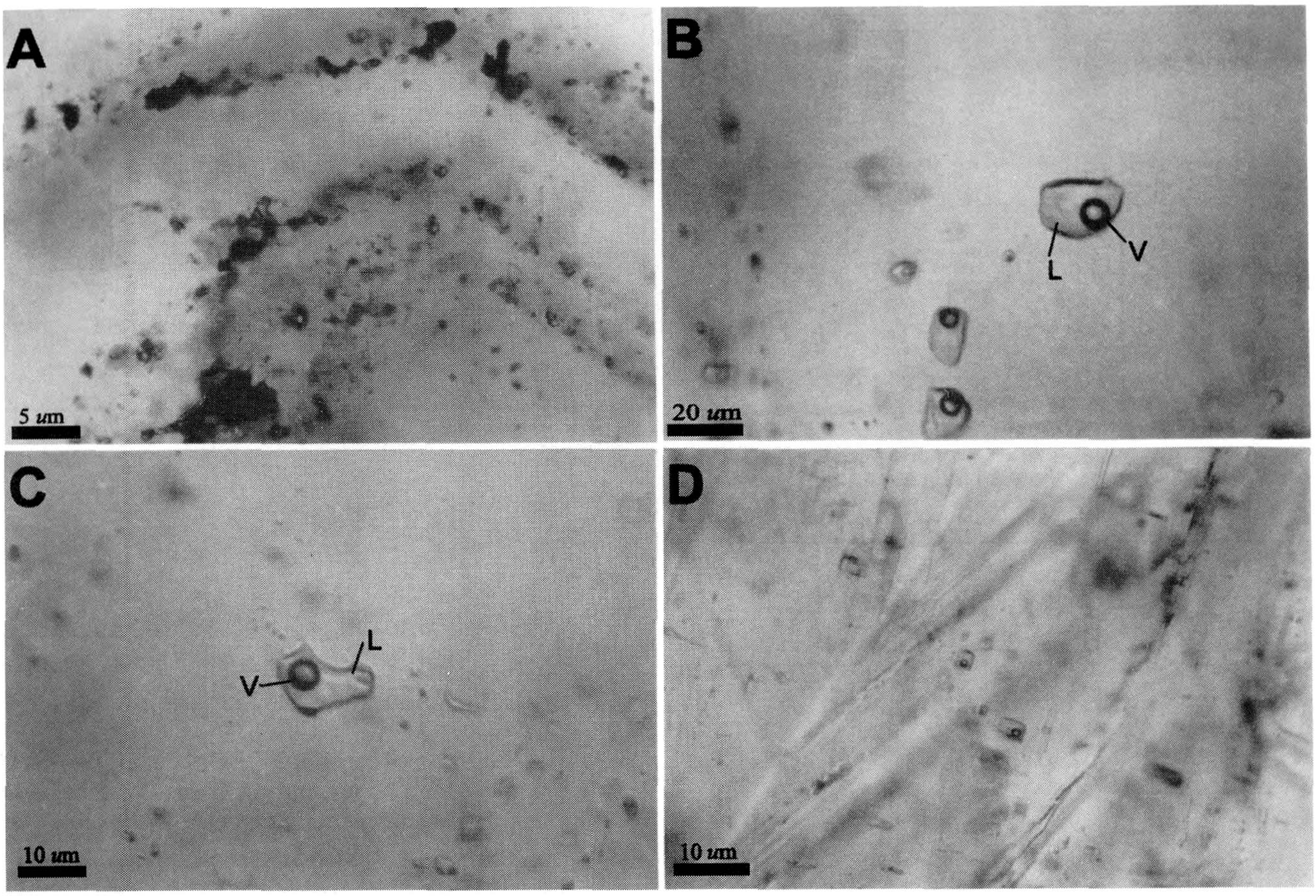

Fig. 5. Microphographs of fluid inclusions in quartz and calcite.
A: Fluid inclusions aligned parallel to growth zone of stage I quartz. B: Type I inclusions in stage II quartz are composed of liquid (L) and vapor (V) phase. C: Enlarged photos of A. D: Type II inclusions in stage III calcite.

based on kinds of phase observed at room temperature. Heating and freezing studies were done only for quartz sample because calcite and sphalerite are unclean and easily cleaved.

Fluid inclusion types

Type I inclusion: Type I inclusion composed of liquid and gas phases, which homogenized liqid phase during heating. Filling degree, volume percent of liquid phase to total volume, of type I inclusons in stage I is about 90 (Fig. 5-C), and those in stage II is 80 to 90 (Fig. 5-B). Primary inclusions of type I in Stage I are aligned along the growth zone of quartz (Fig. 5-A). It display negative crystal form of quartz or irregular shape. The size of type I inclusions in stage I and II ranges about 5 to 15 μm and about 10 to 30 μm, respectively.

Type II inclusion: Type II inclusion is gas-rich inclusion, and homogenized to gas phase on heating. Filling degree is about 10 to 30. The size of type II inclusions is about 5 μm. Type II inclusions occur only in the stage III calcite, and coexisting with type I inclusion, so the origin of type II inclusions is due to local boilling during the stage III calcite precipitation.

Heating and freezing experiment

Salinity of the fluid inclusions is estimated from ice melting point depression (Potter *et al.*, 1978; Roedder, 1962). The equivalent NaCl wt.% of stages I and II ranges 0.8 to 3.43 wt.% (average 1.6 wt.%) and 1.6-5.2 wt.% (average 2.7 wt.%), respectively (Fig. 6-A).

Homogenization temperatures of stage I is 202 to 289°C (average 240°C) and of stage II is 230 to 287°C (average 239°C) (Fig. 6-D).

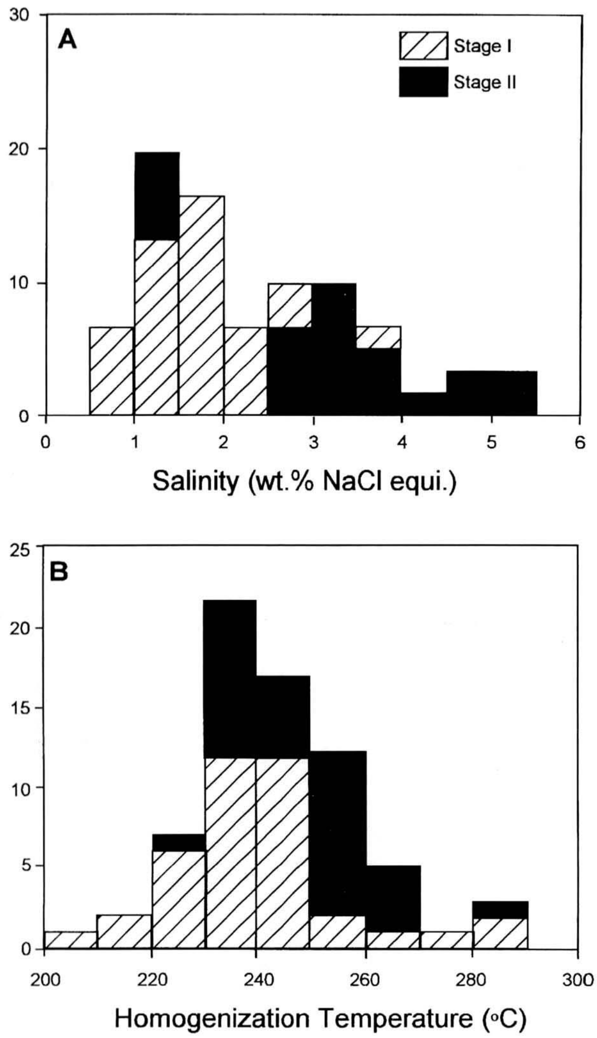

Fig. 6. Histograms showing salinity (A) and homogenization temperaures (B) of fluid inclusion of stages I and II quartz vein.

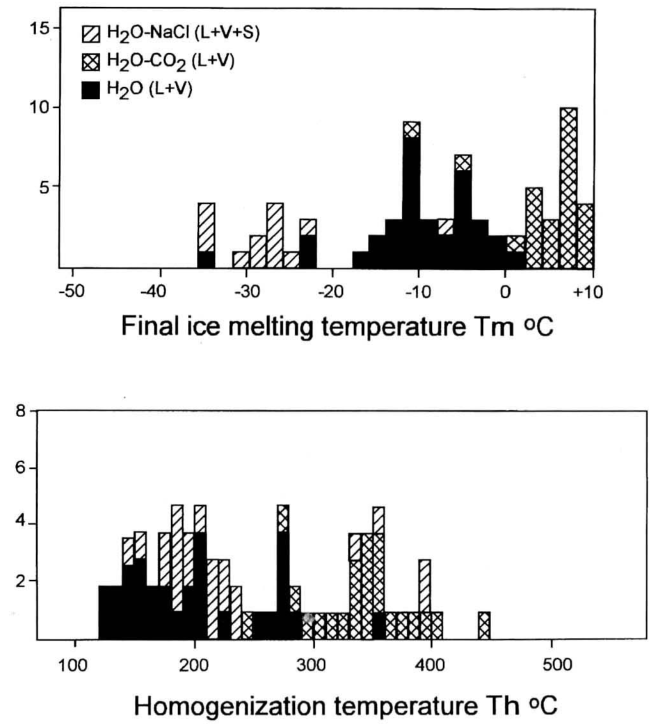

Fig. 7. Histograms showing final ice melting temperatues (A) and homogenization temperaures (B) of fluid inclusions from quartz vein in Banard Point and False Bay.

Discussion

Ore forming conditions can be delineated from the characteritics of occurences of ore deposit and ore forming fluid. Former study indicates that the mineralization of Hurd Peninsula is assimilar to that of Barnard Point in respect of the occurrence and mineralogy of ore deposit. Therefore, Hurd Peninsula and Banard Point ore deposit seem to be derived from unique ore forming fluid. The origin of ore mineralization in Banard Point is suggested as porphyry copper deposit related to intrusion of Banard Point tonalite (Littlefair, 1978) or magmatic fluid derived from Banard Point Intrusion (Willan, 1994). The mineralization age of Banard Point ore deposit is same as that of Banard Point Intrusion, 46Ma.

Hydrothermal ore veins and breccias around Hesperides Point are cut by Hesperides Point Intrusion and later stage basic to intermediate dykes. This fact indicates that the mineralization age of Hurd Peninsula is earlier than Hesperides Point Intrusion (73Ma). The structure of ores and ore forming minerals around Hesperides Point are assimilar to those of Banard Point. Beside abundant ore mineral of Banard Point is Cu-Mo, that of Hurd Peninsula is not only Cu but also Pb-Zn.

Based on fluid inclusion study, fluid composition and homogenization temperature at Hesperides Point is assimilar to those of latest stage of Banard Point district (Fig. 7). The composition of ore forming fluid of Banard Point quartz veins, however, is more complicated than that of the Hesperides Point such as simple H_2O, high saline and CO_2-beaing fluid (Armstrong and Willan, 1996). This represent ore forming fluid of the Hesperides Point is different from that of the Banard Point.

Accoding to Sulfur stable isotopic study (Willan and Spio, 1996), epithermal veins in Hurd Peninsula are isotopically homogeneous and indicate derivation from a deep circulating, neutral-chroride hydrothermal plume containing magmatic sulphur. Sulfides in Eocene tonalite pluton are slightly ^{32}S-enriched and regared as exsolving directly from cooling magma.

Conclusions

1. Hydrothermal veins and breccias around Hesperides point cut the Miers Bluff Formation, are cut by Hesperides Point Intrusion and dykes.

2. Vein structure indicates repeated crack opening and mineral precipitation. Ore forming mineralization can be divided into four stage based on vein structure and ore mineralogy. Stage I ores are mainly composed of pyrite and sphalerite with small amount of galena, chalcopyrite, arsenopyrite, bornite and hematite. Stage II ores comprise sphalerite, galena and chalcopyite with small amount of pyrite and pyrrhotite. Stage III ores are composed of small amount of galena, sphalerite, chalcopyrite and pyrite. Stage IV is barren quartz veinlets which cut ores of earlier stage.

3. NaCl equivalent salinity and homogenization temperature of fluid inclusions from quartz are as follows: Stage I; 0.8-3.43 wt.% (average 1.6 wt.%), 202-289°C (average 240°C), Stage II; 1.6-5.2 wt.% (average 2.7 wt.%), 230-287°C (average 239°C), respectively. Fluid inclusion study reveals that ore fluids were relatively low temperature and low saline with a simple $NaCl-H_2O$ system at the time of ore formation.

4. Vein structure, ore mineralogy and fluid inclusion data suggest that the hydrothermal veins are polymetallic epithermal ore deposits.

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