Potential for Gold Skarn in the Taebaegsan Basin, Korea

태백산분지 내 스카른 금광상의 존재 가능성에 관한 연구

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by

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A Dissertation

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Abstract

Skarn deposits are classified as Au, Fe, Cu, W, and Pb-Zn type skarns. Gold skarn deposits are mined solely for their high gold contents. It is said that gold skarn deposit are becoming increasingly considered as critical gold resources as they recently have been mined on a large scale in some countries. This study in east central Korea, based on new theory and exploration technology is necessary because the presence of gold was confirmed in Fe, Cu, and Pb-Zn skarn deposits in Korea in the past. The Taebaegsan Basin is composed of calcareous rocks and sandstone-shale of Paleozoic age, which were all intruded by mid-late Cretaceous granitic rocks. The sedimentary units are highly folded, and have numerous high angle thrust faults. Various skarn ore deposits of Fe-(Cu), W-Mo, Pb-Zn as well as hydrothermal vein deposits are widely distributed in study area. To understand metal distribution and potential for gold skarn mineralization, geochemical analyses (ICP and EPMA for skarn ore and minerals respectively) were carried out. The gold content of ranges up to 22 ppm in the YeonhwaII Pb-Zn deposits and up to 14 ppm in the Geodo 78 adit. Gold was also observed in skarn samples, which were selected as potentially high gold by EPMA. The gold occurs in garnet skarn zones with an assemblage of hematite+pyrite+chalcopyrite in the Geodo 78 adit. The gold mineralization at the Geodo mine is in a relatively oxidized environments and is associated with a retrograde stage. In contrast, the gold only occurs in a pyroxene skarn zone in YeonhwaII deposit. This suggests that the YeonhwaII deposits formed in a more reduced environments and gold can be precipitated in the early stage of skarns. This is a relatively reduced

skarn and is associated with the prograde skarn stage. The geochemical composition of representative skarn samples of each skarn deposits is close to those of skarns from gold skarns (Ray and Webster, 1994). Moreover, the geochemical composition of garnet and pyroxene that coexist with gold correspond with major gold skarn geochemical compositions. The log fS_2 and log fO_2 of fluid, forming the retrograde stage of the Geodo gold skarn is approximately -4 ~ +5 and -23 ~ -25, respectively. Gold is closely associated with Cu sulfides and exists mainly in the form of electrum. The tectonic setting, geology and igneous activity of the Taebaegsan area represent a similar lithology and complex geologic history to other major gold skarn deposits world-wide which now yield significant gold. There is high potential for discovery of more of gold skarn occurrences in the Taebaegsan Basin.

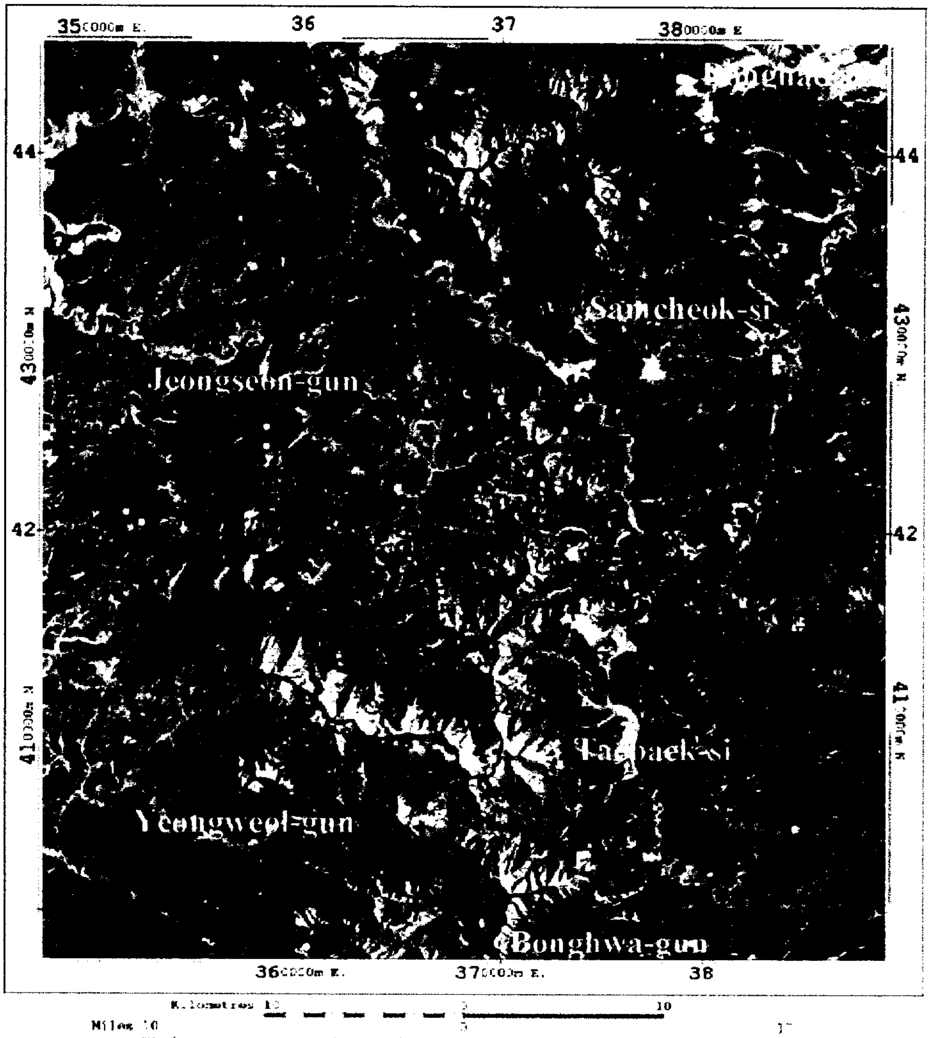

Figure 1. Satellite photograph of the Taebaegsan area.

1. Introduction

1-1. General Statement

A significant proportion of the mining industry has been centered on discovery of gold deposits recently; this includes discovery of additional deposits where gold occurs in skarn, such as at Fortitude and McCoy, Nevada. Not so many years ago, China has developed gold-bearing skarn deposits. Great progress has been explored and discovered for gold-bearing skarn deposits in the past, especially in the middle and lower Yangtze River Valley and adjacent regions. Therefore, this region has become the most important metallogenic belt of Au(Cu) skarn deposits in China. The total gold reserves in this belt have been estimated at more than 600t (Zhao et al., 1999). Although all skarn deposits contain some gold, only a few have been mined largely for contained gold.

In Korea, the huge carbonate sedimentary formations known as the Joseon Supergroup of Cambro-Ordovician in age are widely distributed in the eastern middle part of the Peninsula. They are deposited in the Taebaegsan Basin in which several important ore deposits (Sangdong W-Mo mine, Geodo Fe-Cu mine, Yeonhwa I and II Pb-Zn mines, Uljin Pb-Zn, Shinyemi Fe-Mo mine, and others) of economic value are found.

Since the Geological Investigation Corps of Taebaegsan Region (GICTR) carried out genral geology of Taebaegsan area. A lot of geologists have studied mineralization each type skarn deposit, however, someone have not been much paid attention to find gold potential in skarn. Occurrence of gold confirmed in Fe-(Cu), Pb-Zn skarn deposits in the past, but gold only has been producted to develop copper mines with byproduct in some mines. A few approach the gold skarn deposit and analysis Au contents contain in skarn minerals.

The purpose of this study is to understand general gold skarn minealization, to compare gold skarn in the Taebaegsan area with other major gold skarn deposits, and then finally confirm to gold potential in the Taebaegsan area (Fig. 2). The reviews of skarn deposits in Taebaegsan area are based on published papers and it include recent geochemical data for skarn minerals. To know potential of gold skarn mineralization, geochemical analyses (ICP and EPMA for skarn minerals) was carried out.

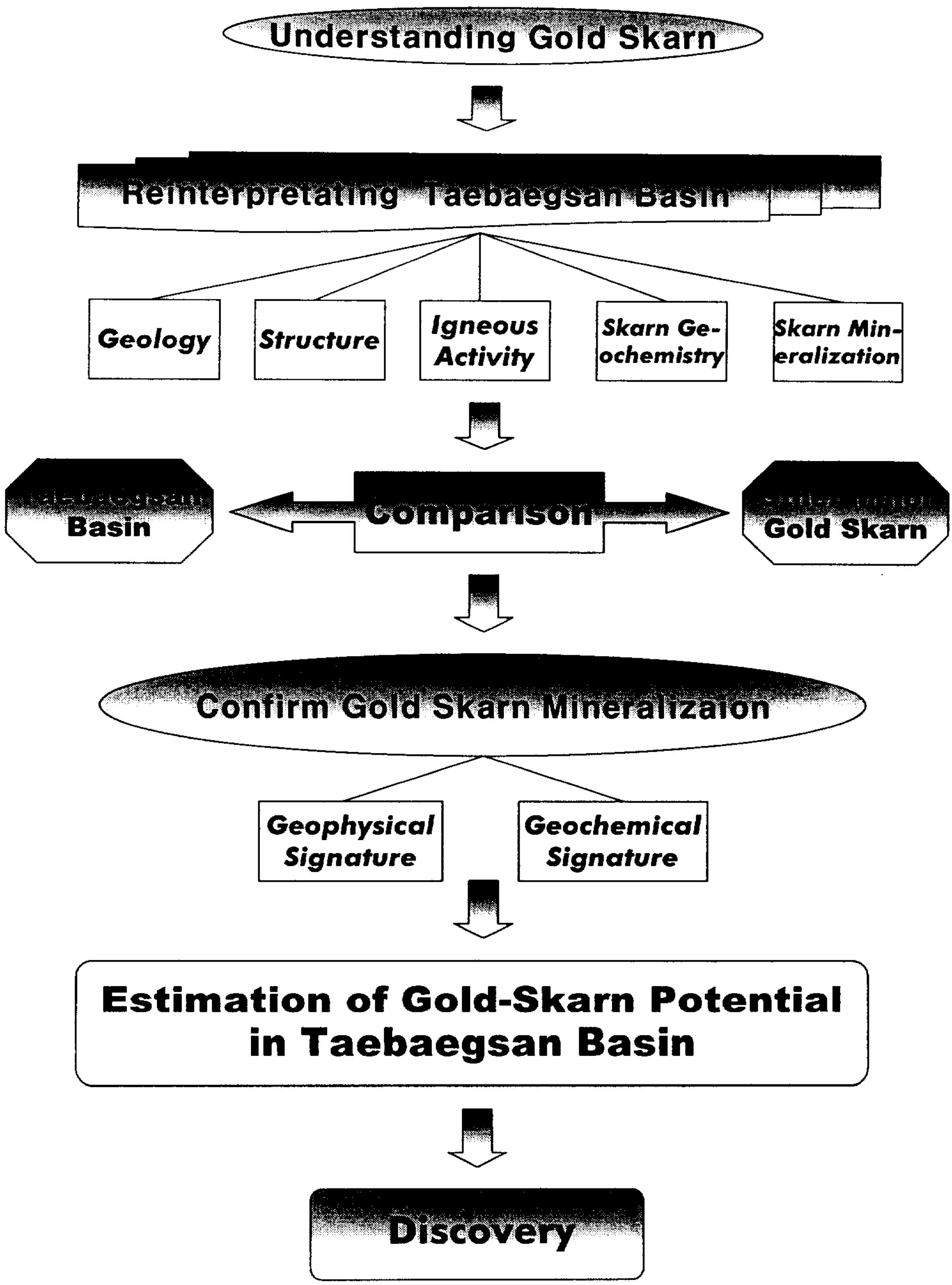

Figure 2. Flow diagram of this study.

1-2. Overview of Skarn Deposits

Skarns are coarse-grained calc-silicate rocks formed from carbonate-rich rocks, commonly limestones and dolostones, by hydrothermal-metasomatic processes initiated by the emplacement of small- to medium-sized discordant plutons. Groupings of skarn deposits can be based on descriptive features such as protolith composition, rock type, and dominant economic metals as well as genetic features such as mechanism of fluid movement, temperature of formation, and extent of magmatic involvement. The general trend of modern geologist are to adopt a descriptive skarn classification based on the dominant economic metals and then to modify individual categories based upon compositional, tectonic, or genetic variations. Six major skarn types (Fe, W, Cu, Zn-Pb, Mo, and Au) have considered significant modern study. In addition, some skarns are developing for industrial minerals such as garnet and wollastonite.

Skarns are an important source of many base and precious metals. The largest skarn deposits are the iron skarns. Iron skarns are mined for their magnetite content and although minor amounts of Cu, Co, Ni, and Au may be present, iron is typically the only commodity recovered (Grigoryev et al., 1990). Many deposits are very large (>500 million tons, >300 million tons contained Fe) and consist dominantly of magnetite with only minor silicate gangue minerals. Some deposits contain significant amounts of copper and are transitional to more typical copper skarns. Calcic iron skarns in oceanic island arcs are associated with iron-rich plutons intruded into limestone and volcanic wall rocks. In some deposits, the amount of endoskarn may exceed exoskarn. Skarn minerals consist dominantly of garnet and pyroxene.

Alteration of igneous rocks is common with widespread albite, orthoclase, and scapolite veins and replacements, in addition to endoskarn. In contrast, magnesian iron skarns are associated with diverse plutons in a variety of tectonic settings; the unifying feature is that they all form from dolomitic wall rocks. In magnesian skarns, the main skarn minerals, such as forsterite, diopside, periclase, talc, and serpentine, do not contain much iron; thus, the available iron in solution tends to form magnetite rather than andradite or hedenbergite.

Tungsten skarns are found on most continents in association with calc-alkaline plutons in major orogenic belts. Major reviews of tungsten skarns include Newberry and Einaudi (1981), Newberry and Swanson (1986). Tungsten skarns are associated with coarse-grained, equigranular batholiths (with pegmatite and aplite dikes) surrounded by large, high-temperature, metamorphic aureoles. These features are collectively indicative of a deep environment. Plutons are typically fresh with only minor myrmekite and plagioclase-pyroxene endoskarn zones near contacts. The high-temperature metamorphic aureoles common in the tungsten skarn environment contain abundant calc-silicate hornfels, reaction skarns, and skarnoid formed from mixed carbonate-pelite sequences. Such metamorphic calc-silicate minerals reflect the composition and texture of the protolith and can be distinguished from ore-grade metasomatic skarn in the field and in the laboratory. Newberry and Einaudi (1981) divided tungsten skarns into two groups: reduced and oxidized types, based on host rock composition (carbonaceous versus hematitic), skarn mineralogy (ferrous versus ferric iron), and relative depth (metamorphic temperature and involvement of oxygenated groundwater). Early skarn assemblages in reduced tungsten skarns are dominated by hedenbergitic pyroxene and lesser grandite garnet with associated disseminated fine-grained, molybdenum-rich scheelite (powellite). In oxidized tungsten skarns, andraditic garnet is more abundant than pyroxene, scheelite is molybdenum-poor, and ferric iron phases are more common than ferrous phases. In general, oxidized tungsten skarns tend to be smaller than reduced tungsten skarns, although the highest grades in both systems typically are associated with hydrous minerals and retrograde alteration.

Copper skarns are the most abundant skarn type in the world. They are particularly common in orogenic zones related to subduction, both in oceanic and continental settings. Most copper skarns are associated with I-type, magnetite series, calc-alkaline, porphyritic plutons, many of which have co-genetic volcanic rocks, stockwork veining, brittle fracturing and brecciation, and intense hydrothermal alteration. These are all features indicative of a relatively shallow environment of formation. Most copper skarns form in close proximity to stock contacts with a relatively oxidized skarn mineralogy dominated by andraditic garnet. Other minerals include diopside, idocrase, wollastonite, actinolite, and epidote. Hematite and magnetite are common in most deposits and the presence of dolomitic wall rocks is coincident with massive magnetite lodes which may be mined on a local scale for iron. As noted by Einaudi et al. (1981), copper skarns commonly are zoned with massive garnetite near the pluton and increasing pyroxene and finally idocrase and/or wollastonite near the marble contact. Sulfide mineralogy and metal ratios may also be systematically zoned relative to the causative pluton. In general, pyrite and chalcopyrite are most abundant near the pluton with increasing chalcopyrite and finally bornite in wollastonite zones near the marble contact. The largest copper skarns are associated with mineralized porphyry copper plutons. These deposits can exceed 1 billion tons of combined porphyry and skarn ore with more than 5 million tons of copper recoverable from skarn. The mineralized plutons exhibit characteristic potassium silicate and sericitic alteration which can be correlated with prograde garnet-pyroxene and retrograde epidote-actinolite, respectively, in the skarn. Intense retrograde alteration is common in copper skarns and in some porphyry-related deposits may destroy most of the prograde garnet and pyroxene (James, 1976). Endoskarn alteration of mineralized plutons is rare. In contrast, barren stocks associated with copper skarns contain abundant epidote-actinolite-chlorite endoskarn and less intense retrograde alteration of skarn.

Zinc-lead skarn deposits occur throught the world in a variety of geologic settings, typically as replacement bodies in limestones at distal deposits as well as proximal deposits. They are mined for ores of zinc, lead, and silver although zinc is usually dominant. They are also high grade (10-20% Zn+ Pb, 30-300g/t Ag). Related igneous rocks span a wide range of compositions from diorite through high-silica granite. They also span diverse geological environments from deep-seated batholiths to shallow dike-sill complexes to surface volcanic extrusions. The common thread linking most zinc skarn ores is their occurrence distal to associated igneous rocks. Zinc skarns can be subdivided according to several criteria including distance from magmatic source, temperature of formation, relative proportion of skarn and sulfide minerals, and geometric shape of the ore body. The occurrence of zinc skarns in distal portions of major magmatic/hydrothermal systems may make even small deposits potentially useful as exploration guides in poorly exposed districts. Thus, reports of manganese-rich mineral occurrences may provide clues to districts that have not yet received significant exploration activity.

Molybenum skarns commonly occur in silty carbonate or calcareous clastic rocks, and are typically associated with highly differentiated, silicic intrusives (with only 2-5% mafic minerals), similar in composition to intrusions associated with porphyry molybdenum deposits (Meinert, 1983). Most molybdenum skarns contain a variety of metals including W, Cu, Zn, Pb, Bi, Sn, and U and some are truly polymetallic in that several metals need to be recovered together in order for the deposits to be mined economically. Mo-W-Cu is the most common association and some tungsten skarns and copper skarns contain zones of recoverable molybdenum. Hedenbergitic pyroxene is the most common calc-silicate mineral reported from molybdenum skarns with lesser grandite garnet (with minor pyralspite component), wollastonite, amphibole, and fluorite. This skarn mineralogy indicates a reducing environment with high fluorine activities.

The term "gold skarn" is used here in the economic sense suggested by Einaudi et al. (1981) and refers to ore deposits that are mined solely or predominantly for gold and which exhibit calc-silicate alteration, usually dominated by garnet and pyroxene, that is related to mineralization. This usage excludes deposits such as Big Gossan (Meinert et al., 1997) that contain substantial gold (>1 million ounces and > 1 g/t Au), but which are mined primarily for other commodities such as copper.

1-3. Characteristics of Gold Skarn

Most skarns, especially copper skarns, contain detectable gold raging from trace amounts to more than 100 g/t. Gold-bearing skarn deposits, defined as skarns containing an average grade of at least 1 g/t Au (Theodore et al., 1991), comprise two subtypes: gold skarns, which can be mined primarily for their gold content; and byproduct gold skarns, from which gold can be recovered only as a byproduct. Important examples of gold skarn deposits include: Nickel Plate (British Columbia), Fortitude and McCoy (Nevada). The Bingham district copper skarn is example of byproduct gold skarn.

Most gold-bearing skarns are calcic exoskarns. The vast majority of the deposits are found in Paleozoic and Cenozoic orogenic belts and island-arc settings, associated with I-type felsic and intermediate intrusion. The majority of gold production-reserves occur in skarns related to copper-mineralized porphyritic intrusions. These skarns are characterized by large size and low-gold grade. Gold is only recovered from these deposits as a by-product of large-scale copper mining and is not by itself a viable exploration target without grade enhancement by supergene enrichment. Most gold skarns contain only small amounts of copper, lead, and zinc, and thus are quite different from the more typical base metal skarns. gold skarns are also distinct in that they typically contain major amounts of arsenic, bismuth, and telllurium, elements which are not normally abundant in other skarn types.

Host rocks for gold skarns range in age from Cambrian or older (Cable mine, Earll, 1972) to Miocene (Thanksgiving mine, Callow, 1967) and usually contain a significant clastic or volcanicalastic component. In some cases the host rocks are allocthonous (Fortitude, Wotruba et al., 1986) and have been interpreted as accreted terranes (Hedley, Ray et al., 1988). It is not known whether a particular host-rock composition or overall tectonic setting is a necessary condition for formation of a gold skarn. Plutonic rocks range in composition from diorite, although it should be noted that most of the more gold-rich deposits are associated with relatively mafic, reduced diorite, and granodiorite plutons.

The major calc-silicate minerals in gold skarns are garnet and pyroxene, with pyroxene being dominant in the higher grade deposits. Garnets from gold skarns are aluminous to intermediate grandite in composition, with relatively few pure andradite garnet is common in most iron, copper, and zinc skarns. Pyroxenes from gold skarns range from diopside to hedenbergite in composition, although most of the higher grade deposits contain some iron-rich (>Hd_{50}) pyroxene. In addition, gold skarn pyroxenes can be significantly more aluminum rich than pyroxenes can be significantly more aluinum rich than pyroxene in other skarn types. Other important skarn minerals include potassium feldspar, biotite, idocrase, prehnite, apatite, sphene, and scapolite. Arsenopyrite and pyrrhotite are the most abundant sulfide minerals, with lesser and usually later marcasite and pyrite. Surprisingly large amounts of bismuth minerals (native bismuth, maldonite, wittichinite, hedleyite, joseite) and telluride minerals have been reported from some deposits. The intimate association of bismuth with gold in hand specimens, thin sections, and as a geochemical alnomaly (typically 50-500 ppm) is a useful exploration guide for some deposits. Mineral zonation on a deposit scale is common. Garnet typically is proximal to the main igneous contact whereas pyroxene is more aundant and more iron rich in distal zones. A manganese enrichment in pyroxene from distal skarn zones has been noted at some depostis (Myers and Meinert, 1991). Proximal skarn zones are usually more copper rich with Au, As, Bi, and Te commonly concentrated in distal pyroxene-dominant zones. Gold skarns can divide reduced type skarn and oxidized type skarn (Fig. 3). Reduced skarns characterized by abundant Fe^{2+}-bearing assemblages (hedenbergitic pyroxene, almandine-rich garnet, biotite, hornblende) and pyrrhotite, and oxidized skarns by Fe^{3+}-bearing assemblages (andraditic garnet, epidote), and pyrite.

Reduced Gold Skarns: The highest grade (5-15 g/t Au) gold skarn deposits are relatively reduced, are mined solely for their gold content, lack economic concentrations of other metals, and have a distinctive Au-Bi-Te-As geochemical association. Most high-grade gold skarns are associated with reduced (ilmenite-bearing, Fe_2O_3/(Fe_2O_3+FeO) << 0.75) diorite-granodiorite plutons and dike/sill complexes. They typically occur in clastic-rich protoliths rather than pure limestone and skarn alteration of dikes, sills, and volcaniclastic units is common. Reduced gold skarns are dominated by iron-rich pyroxene (typically > Hd_{50}), but proximal zones can contain abundant intermediate grandite garnet. Other common minerals include K-feldspar, scapolite, vesuvianite, apatite, and amphibole. Distal zones contain biotite±K-feldspar hornfels. Due to the clastic-rich, carbonaceous nature of the sedimentary rocks in these deposits, most skarn is relatively fine-grained. Examples of the reduced gold skarn are Nickel Plate, British Columbia and Fortitude, Nevada.

The Fortitude deposit is located in the Battle Mountain District of north-central Nevada and produced 77 Mt of Au from 10.9 Mt of ore at an

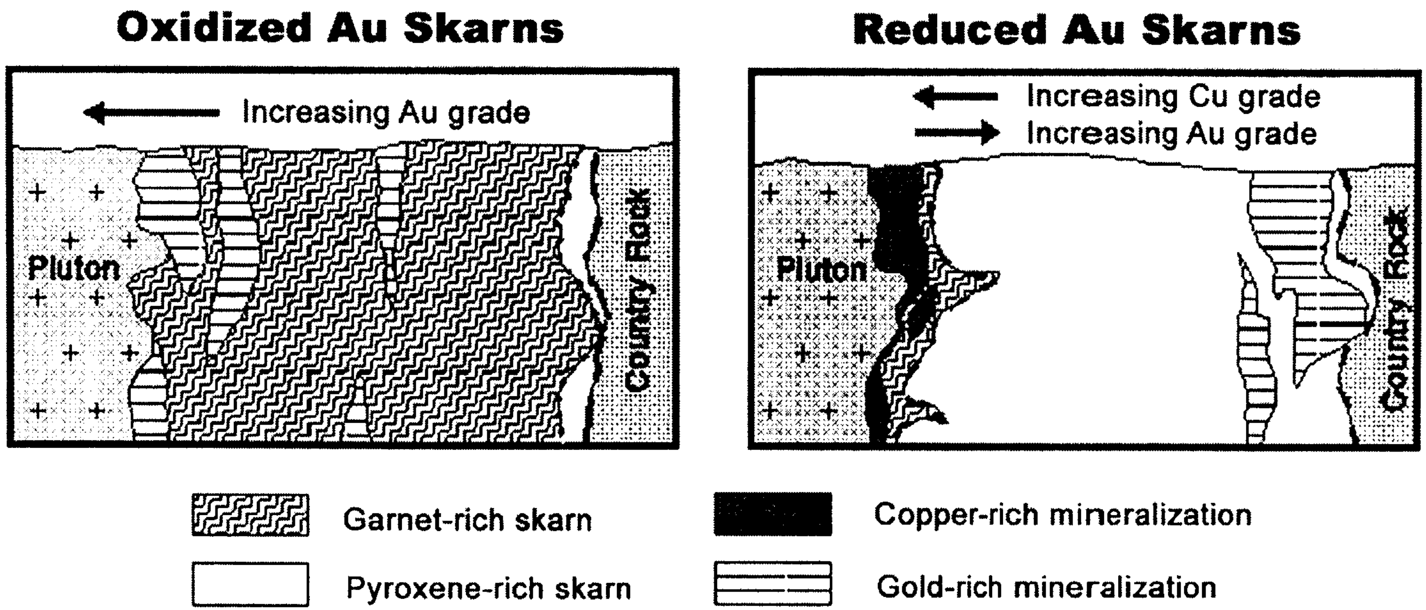

Figure 3. Schematic sections comparing the main features of "oxidized" and "reduced" gold skarns (after, British Columbia Geol. Survey).

average grade of 7.1 g/t Au (Doebrich & Theodore 1996). The Battle Mountain District contains several different skarn types ranging from a typical copper skarn with low gold grades, called the West Ore Body, to gold-rich, copper-poor skarns such as the Upper and Lower Fortitude ore bodies. The skarns nearest the intrusive body are dominated by garnet with minor pyroxene and are typically high in copper with low concentrations of gold(Fig. 4). The Fortitude deposit, like most high-grade Au skarns, has an unusual reduced skarn mineralogy and trace-element(Au-Bi-Te-As) signature that distinguishes it from most other skarn types. The reduced skarn mineralogy reflects the reduced nature of the associated Copper Canyon granodiorite [$Fe_2O_3/(Fe_2O_3+FeO) < 0.5$] that is quite distinct from typical oxidized porphyry copper deposit plutons. The more distal skarns contain more pyroxene than garnet and contain the highest concentrations of gold in the district (Myers, 1994). The distribution of most metals parallels the skarn zonation in the Antler Peak Limestone. Copper is highest in garnet-rich skarn near the intrusive contact, whereas gold is concentrated in pyroxene-dominant skarn, particularly where the pyroxene is iron-rich ($>Hd_{50}$) (Fig. 4).

The Nickel Plate mine in the Hedley district, British Columbia is the largest and highest grade gold skarn in Canada. Discontinuous production from 1904 until the mine closed in 1995 was 13.4 million tons averaging 5.3 g/t Au, 1.3 g/t Ag, and 0.02% Cu (Ray et al., 1996). Of this, more than 3 million tons of ore was mined underground at an even higher grade, averaging 14 g/t Au. Skarn formed in dominantly clastic rocks of the upper Triassic Nicola Group, that is part of the allochthonous Quesnel Terrane of the Intermontane Belt. Skarn is spatially and genetically associated with the

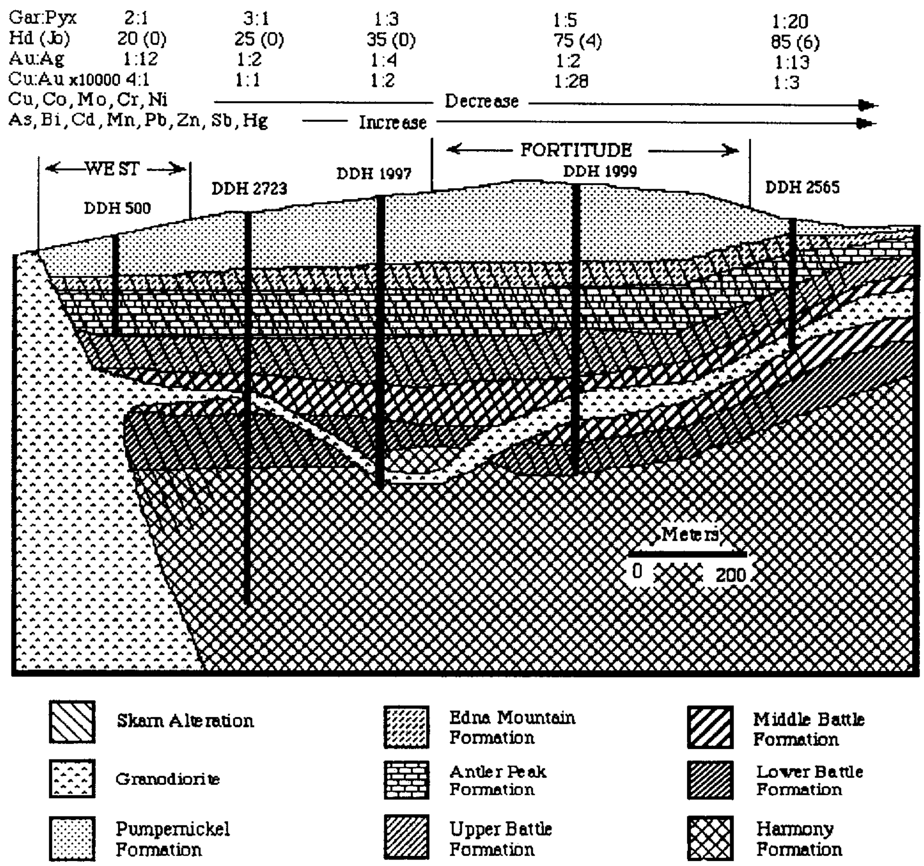

Figure 4. Generalized section across the Fortitude gold skarn deposits, Nevada (after Myers, 1991).

dioritic Hedley intrusions, that comprise the Toronto Stock and a series of dikes and sills, many of which exhibit strong endoskarn alteration with abundant pyroxene, biotite, garnet, amphibole, and K-feldspar (Fig. 5). The Toronto Stock is a very reduced ilmenite-bearing intrusion with an average Fe_2O_3/(Fe_2O_3+FeO) value of 0.15, the lowest of any gold skarn (Ray et al., 1995) and the lowest of any major skarn class (Meinert, 1995).

Oxidized Gold Skarns: Whereas the "classic" gold skarn deposit is characterized by low garnet:pyroxene ratios, hedenbergitic pyroxene, and abundant sulfides dominated by pyrrhotite and arsenopyrite, several skarns have been mined for gold that have a very different mineralogy and mineralization style. These deposits have been classified by Brooks et al. (1991) as oxidized gold skarns. Their essential features include high garnet:pyroxene ratios, relatively Fe-poor garnet and pyroxene, low total sulfides, pyrite≥pyrrhotite, and minor but ubiquitous occurrences of chalcopyrite, sphalerite, and galena. In addition, the highest gold grades are not associated with prograde garnet-pyroxene, but rather with later retrograde alteration including abundant K-feldspar (adularia) and quartz. Some of these deposits can be considered transitional to other types of gold mineralization such as epithermal deposits in which phase separation (boiling) can be an important precipitation mechanism (Hedenquist et al., 1996).

The McCoy gold skarn deposit is a representative example of the oxidized gold sskarn deposit. It is only 45 km southwest of the reduced Fortitude gold skarn in northcentral Nevada, but differs dramatically in regards to the style of mineralization and wallrock alteration. The McCoy deposit contains 15.6 Mt of ore averaging 1.44 g/t Au and an additional

30,430 tonnes averaging 14.6 g/t Au that was mined underground (Brooks 1994). Production is from garnet-rich skarn surrounding the 39 Ma Brown stock, a reduced ilmenite-series, hypabyssal, hornblende-biotite granodiorite. Brooks (1994) subdivided the Brown stock into five petrologically distinct phases and invoked mixing of discrete magmas to yield individual intrusive phases. Importantly, there are systematic correlations between individual intrusive phases and the mineralogy and gold grade of associated skarn. The Brown stock is estimated to have intruded to within 1.3 km of the surface and this shallow emplacement is reflected by the multitude of dikes and sills found on the margins of the main stock (Fig. 5). In addition, most of the early dikes and sills have been affected by garnet-pyroxene endoskarn. All other skarn at McCoy is garnet dominant and where pyroxene is present, it is diopsidic. Early garnet is Fe-poor and occurs as bedding replacements of argillaceous layers (skarnoid) and as cores to later metasomatic garnets, that are more Fe-rich. These compositional differences are important in that subsequent retrograde alteration selectively replaces certain stages and compositions of garnet and pyroxene (Brooks, 1994). Sulfide minerals associated with prograde skarn include pyrrhotite, pyrite, sphalerite, galena, arsenopyrite, chalcopyrite, bornite, gold, hedleyite, native bismuth, and hessite (Brooks, 1994).

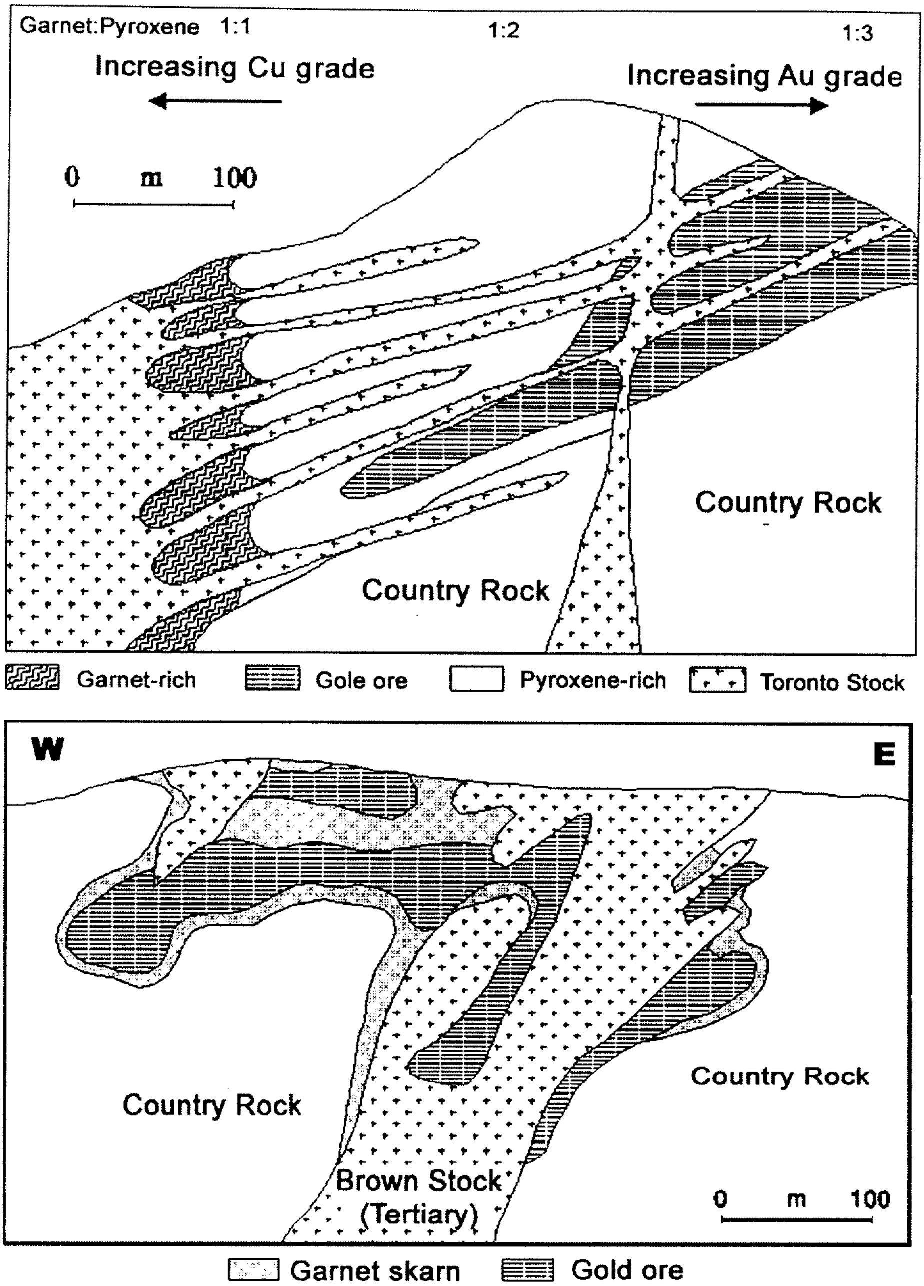

Figure 5. Generalized section across (upper) the Nickel Plate gold skarn (reduced), B.C. (after Ettlinger et al., 1992) and (below) the McCoy gold skarn, Nevada (after Kuyper, 1988; Brooks, 1994).

2. The Overview of Taebaegsan Basin

The Taebaegsan area of east-central South Korea has a long history of metal production from carbonate sediments in the vicinity of multiple-age granitoids. This area is noted for a thick sequence of Lower Paleozoic rocks, unconformably overlain by Upper Paleozoic sediments. Two or three ages of granitoid and rhyodacite intrusions are associated with a variety of metal deposits, including gold, tungsten, copper, molybdenum, and lead-zinc (Fig. 6). Skarn deposits with variable gold content have been mined in the past. The Korean peninsula represents denudation remnant of deformed basement rocks and sedimentary successions as well as granitic intrusions and volcanics, concealing a long history of basin formation and crustal deformation.

2-1. Tectonic Setting

The Korean peninsula comprises three major Precambrian massifs: Nangrim, Kyeonggi, and Yeongnam massifs from north to south. The Kyeonggi and Yeongnam massifs are separated by the Ogcheon Fold belt (Fig. 7). On the northeast, the Ogcheon Basin is bounded by the Taebaegsan Basin that comprises the Joseon Supergroup (Cambro-Ordovician) and Pyeongan Supergroup (Carboniferous-Triassic). The Joseon Supergroup has been conventionally differentiated into five types of sequence based on distinct lithologic successions and geographic distribution: Tuwibong-type, Yeongwol-type, Jeongseon-type, Pyeongchang-type, and Mungyeong-type

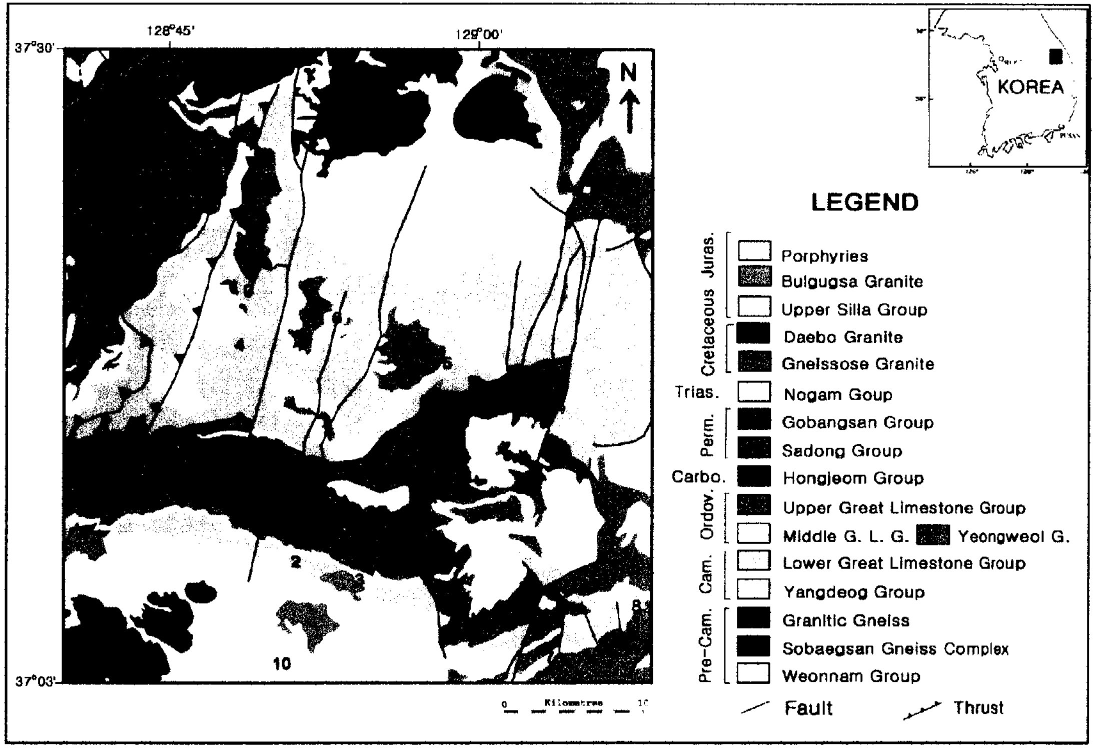

Figure 2. Geology and location of major mines in the Taebaegsan area (after KIGAM, 1973). 1-Shinyemi (Pb-Zn-Mo,Fe); 2-Sangdong (W); 3-Geodo (Fe-Cu-(Au)); 4-Dongnam (Fe-Mo); 5-Wondong (Pb-Zn-Mo, Fe); 6-Dunjeon (Au-Ag); 7-Yeonhwal (Pb-Zn); 8-Yeonhwall (Pb-Zn); 9-Dongwon (Au-Ag); 10-Keumjeong (Au-Ag)

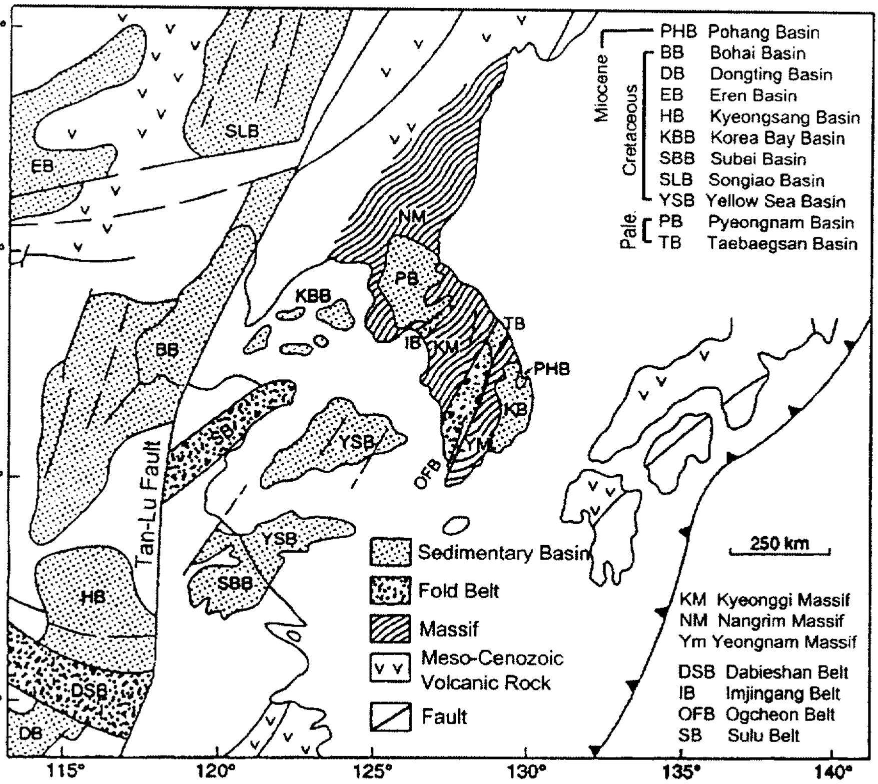

Figure 7. Outline of major sedimentary basins, orogenic belts, cratonic blocks (massifs), and other geologic features in the northeast Asian margin (after Chough et al., 2000).

sequences (Kobayashi et al., 1942). Recently, Choi (1998) proposed a revised stratigraphic nomenclature for the Joseon Supergroup: Taebaeg, Yeongwol, Yeongtan, Pyeongchang, and Mungyeong-type Joseon supergroups, respectively (Table 1). The lower Paleozoic sediments are mainly shallow marine in origin and consist predominantly of carbonates with lesser amounts of sandstone and shale, whereas the Pyeongan Supergroup consists thick clastic successions of marginal marine to nonmarine envirinments containing economically important coal measures (Cheong, 1969). The stratigraphic relationship between the Ogcheon Group and the Joseon Supergroup of the Taebaegsan Basin is poorly constrained. The Joseon Supergroup unconformably overlies the Yeongnam Massif and consists mainly of carbonate sequence that formed mostly in shallow marine and tidal environments, reflecting numerous sea-level fluctuations (Chough et al., 2000). The sequence is disconformably overlain by siliciclastic sequence of Pyeongan Supergroup which formed most likely in shallow marine, deltaic, and fluvial envirinments (Chough et al., 2000).

The Tabaegsan mountainous region contains a belt of low grade metamorphic and sedimentary rocks preserved between the uplifted Gyeonggi and Yeongnam Precambrian massifs. To the southwest of the mountains, these subsea rocks are of higher metamorphic grade and may contain some alkaline volcanic units. In the Taebaegsan region, toward the northeast end of the belt, the uplifted lower Paleozoic sequence hosts a variety of metal deposits, ranging from tungsten replacement bodies to iron and zinc-lead skarns to veins carrying gold and other metals. The host rocks are much less metamorphosed than to the southwest, except in contact aureoles around small plutons.

Table 1. Stratigraphic Nomenclature of the Cambro-Ordovician Joseon Supergroup in the Taebaegsan Area (Choi, 1998).

Geologic Age		Yeongwol		Taebaeg		Jeongseon		Pyeongchang	Mungyeong	
Ord.	Ashgill									
	Caradoc	Yeongwol Group	Yeonghung Fm	Taebaeg Group	Duwibong Fm Jigunsan Fm Maggol Fm	Yongtan Group	Haengmae Fm	Pyeongchang Group	Mungyeong Group	Carbonate strata
	Llanvirn						Jeongseon Fm			
	Arenig				Dumugol Fm					
	Tromadoc		Mungog Fm		Dongjeom Fm					
Cam.	Late		Wagog Fm Machari Fm		Hwajeol Fm Sesong Fm					
	Middle		Sambangsan Fm		Daegi Fm Myobong Fm					
	Early				Jangsan Fm					Kurangni Fm

Recent studies on geologic structure in the eastern part of the Taebaegsan Basin (Kim and Won, 1987; Kim et al., 1988; Kim and Kee, 1991; Kim and Lee, 1991; Kim, 1994; Kim et al., 1994) suggest that the sequence underwent four deformational stage. D_1 deformation event of unknown age generated NE-striking ductile shear zones with a reverse sense of slip between the Precambrian massif and early Paleozoic sequences, although there is a local difference in regional structure (Kim and Kee, 1991; Kim, 1994; Kim et al., 1994). During the D_2 deformation (Songrim orogeny), NE-trending folds and thrusts were generated with mostly a SE vergence. Then, D_3 deformation (Daebo event) produced NE-trending folds and thrusts with a SE vergence. The entire sequence experienced final D_4 deformation which caused E-W trending Folds and faults probably during the late Cretaceous to early Tertiary Bulgugsa event (Kim et al., 1994). Kwon et al. (1995) suggest that strike-slip shearing was dominant between the Precambrian basement and early Paleozoic sequence, rather than the thrust movement. K-Ar mica age of early Cambrian in mylonites of the boundary is meaningless due to excess Ar (Kwon et al., 1995).

Cluzel et al. (1990, 1991) have also suggested that N-S trending folds and thrusts formed during the Songrim orogeny and the E-W trending folds and faults (late Cretaceous D_4 structures of Kim et al., 1994) were generated by the Daebo event. The regional distribution of major geologic structures in the Taebaegsan Basin suggests that NNE- to NE-striking thrusts and the associated folds are widespread (Fig. 6). Regional geologic structure of the entire Taebaegsan Basin sequence suggests that the western part (Yeongwol area) is dominated by westward-dipping thrust faults whereas the eastern part (Taebaeg and Jeongseon areas) is dominated by oblique-slip faults and syncline with minor thrust. The Baegunsan syncline represents large-scale N-S compressional deformation regime in which the entire Joseon and Pyeongan supergroups are folded and offset by NNE-SSW-running strike-slip faults.

Based on anisotropy of magnetic susceptibility (AMS) of the Pyeongan Group sequence, Choi et al. (1997) argue that the maximum principal direction of tectonic stress in the Taebaeg region was NW-SE during the late Permian-early Triassic (Songrim orogeny). However, AMS cannot be correlated with the principal stresses, but may just reflect finite strain with some limitations (Borradaile, 1988, 1991). Kim et al. (1997) state that the NNE-striking Machari thrust is different from that in the eastern block. However, it can be seen that the paleomagnetic direction is not much different in both blocks (Kim et al., 1997).

2-2. Igneous Activity

In the Taebaegsan area all of these rocks are intruded by Jurassic Daebo-series granitoids and Cretaceous Bulgugsa-series granitoids. The Daebo granitic batholith is elongated in a NE-SW (the so-called Sinian) direction, and is believed to have formed under relatively deep-seated (7.8 to 3.4 kb) conditions. The ores with the highest gold-silver ratios appear related to Daebo intrusions. In contrast, the Cretaceous granitoids, which predominantly show porphyritic texture and calc-alkalic composition, mainly form stocks. These are reported to have formed at less than 2.8 kb (Cho and Kwon, 1994).

According the Cretaceous to Tertiary volcanics are much more widely distributed than reported so far, and geochronologically seem to show various age. However, the Cretaceous to Tertiary volcanic rocks distributed in the Taebaegsan mineralized area have been not so much geologically surveyed yet. There are a few published isotopic data of the Cretaceous to Tertiary volcanic rocks distributed in the Taebaegsan mineralized area. One is rhyodacite distributed in Uljin area, which yielded 49.3±2.0 Ma (Yun and Silberman, 1979), and other is a rhyolitic rock distributed in the Uljin Pb-Zn mine which yeilded 45.1±2.3 Ma (Kim and Lee, 1983) (Table. 2).

Yun and Silverman (1979) indicated that igneous rocks and related minera deposits in the Taebaegsan area tend to have younger ages towards east, citing the age of 94 Ma for the Shinyemi deposit. The age of the Shinyemi zinc-lead-molybdenum deposit is younger than that of the Sangdong tungsten deposit, but very close to 73Ma for the Yeonhwa II zinc-lead deposit. It is concluded that the metallogonic igneous events took

Table 2. K-Ar Isotope Ages Related to the Taebaegsan Area.

Localty	Ore type	Samples	Age(Ma)	Reference
Baegjeon	Au-Ag-Sb	Sericite	81-88	Lee&Park (1996)
Dunjeon	Au-Ag	Sericite	75.7±1.7	Park et al. (1988)
Dongwon	Au-Ag	Sericite	86±2.37	Park et al. (1988)
Geodo	Fe-Cu skarn	Phlogopite	98.39±2.20	Park et al. (1988)
		Muscovite	169	KIGAM(1972)
		Biotite	107±1	Yun (1983)
Dongnam	Fe skarn	Phlogopite	75.9±1.8	Park et al. (1988)
Sangdong	W-Bi-Mo skarn	Muscovite	81-84	Farrar et al. (1978)
		Sericite	82-84	Kim (1986)
Shinyemi	Zn-Pb-Mo skarn	Phlogopite	77.68±1.96	Park et al. (1988)
		Phlogopite	75	Sato et al. (1981)
		Sericite	60	Sato et al. (1981)
		Biotite	74.7±1.7	Yang (1991)
Wondong	Fe-Zn-Pb skarn	Phlogopite	53.1±3.2	Park et al. (1988)
Uljin	Pb-Zn skarn	Rhyodacite	49.3±2	Yun and Silverman (1979)
Jangseong		Rhyolite	62.69±1.15	Jin et al. (1989)
		Rhyolitic tuff	51.67±6.64	Jin et al. (1989)
YeonhwaII	Pb-Zn skarn	Muscovite	73	Yun (1979)
		Biotite	74.7±37	Kim (1986)
YeonhwaI	Pb-Zn skarn	Sericite	73.60±11.4	Park et al. (1988)
		Biotite	213	Yun and Silverman (1979)
Janggun	Mn-Pb-Zn skarn	Sericite	78	Lee (1980)

place in mid-Jurassic in the west, and in late Cretaceous to early Tertiary in the east along the southern margin of the Taebaegsan sedimentary basin and to the Yeonhwa-Uljin district, becoming younger gradually eastward. The sulfur isotopic compositions of sulfides from Taebaegsan area mines range from $\delta^{34}S$ values of -0.6 to 9.1 ‰ (Table. 3).

Consequently, the data mentioned above, suggest that the igneous activities including volcanism and plutonism have successively continued up to the late Cretaceous or the Tertiary in the Taebaegsan area.

Table 3. Average $\delta^{34}S$ Values of Ore Deposits in the Taebaegsan Area.

Ore deposit	Ore type	Age (Ma)	δ34S(‰)	Reference
Baegjeon	Au-Ag-Sb disseminated	81-88	+9.1	Lee&Park (1996)
Geodo	Fe-Cu skarn	98	-0.6	Lee (1985)
			-0.3	Sato et al. (1981)
Sangdong	W-Bi-Mo skarn	81-88	+3.7	Lee (1985)
			+4.7	Sato et al. (1981)
Shinyemi	Zn-Pb-Mo skarn	75-78	+4.2	Lee (1985)
			-1.4	Sato et al. (1981)
Uljin	Pb-Zn skarn	49	+4.2	Sato et al. (1981)
Yeonhwall	Pb-Zn skarn	73	+3.9	Lee (1985)
			+4.7	Sato et al. (1981)
Yeonhwal	Pb-Zn skarn	74	+3.9	Lee (1985)
			+3.8	Sato et. al. (1981)
Janggun	Mn-Pb-Zn skarn	78	+4.6	Lee et al. (1996)

Table 4. Summary of Stratigraphy, Igneous Activity, Tectonic Events and Mineralization in the Tabaegsan Area (Chang, 1990).

Age (Ma)	Period	Formation	Igneous activity	Tectonic event	Mineralization
1.6	Quaternary				
66.4	Tertiary		Acid Volcanics		Carlin (?)
	Cretaceous	Jeoggagri Fm.		Bulgugsa Orogeny Thrusting &Faulting	Polymetalic-skarn
					Au-Ag veiins
144.4+5		Heungjeoun Fm.	Granites		
208±18	Jurassic	Banson Fm.	Granites		
	Triassic	Donggo Fm.		Daebo Orogeny Thrusting	
245±20		Gohan Fm.			
	Permian	Dosagog Fm.			
		Hambaegsan Fm.			
286±12		Jangseong Fm.			
	Carnoniferous	Geumcheon Fm.			
360±10		Manhang Fm.			
408±12	Devonian			Unconformity Folding	
438±12	Silurian				
	Ordovician	Duwibong Fm.			
		Jigwunsan Fm.			
		Maggol Fm.			
		Dumugol Fm.			
505±32		Dongjeom Fm.			
	Cambrian	Whajeol Fm.			
		Pungchon Fm.			
		Myobong Fm.			
570		Jangsan Fm.			
1600	Proterozoic	Taebaegsan Schist Complex	Granite		Sn pegmatite
2500		Taebaegsan Gneiss Complex			

2-3. Associated Deposits

Fe-Cu Deposits: Iron-Copper deposits in the Taebaegsan are Geodo and Dongnam deposits. The Geodo mine has been developed since in 1963. It produced only coper ores with substantial amount of gold. The deposit is a typical skarn-type one occurring around the Opyeong granite stock. The age of the stock is 107Ma (Kim, 1971). The geology of the mine area consists mainly of Cretaceous granitoids and Paleozoic to Mesozoic sedimentary rocks which belong to the sediments of the Taebaegsan Basin. Two intrusive monzodiorite and quartz monzodiorite of Cretaceous in age are largely exposed in the middle of mine area. Several intermediate to basic dikes intruded into the above rocks parallel to the main structural lineations. Skarns in the mine area were developed along the boundary between the monzodiorite and sedimetary rocks of the Myobong and Hwajeol formations. A simplified geological map of the deposit is shown as in Fig. 10. Two different mineralogical types of ore deposits are found in the area, that is, the Fe-Cu deposit in the Myobong Formation and the Au-Cu deposit in the Hwajeol Formation (Fig. 9). Chalcopyrite, chalcocite, native gold and bismuthinite are minor components in the skarn occurring in the Hwajeol Formation. Skarns seem to be derived from both granitic rocks and surrounding limestone, and much amount of epidote is formed in the former case. Common occurrence of hematite and rare of pyrrhotite indicate that relatively oxidizing fluid prevailed during the formation of the deposit.

The geology of the Dongnam mine comprises Cambro-Ordovician Myobong slate, Pungchon limestone, and Hwajeol Formation and Cretaceous intrusive rocks, such as diorite, porphyritic granite, quartz porphyry, and

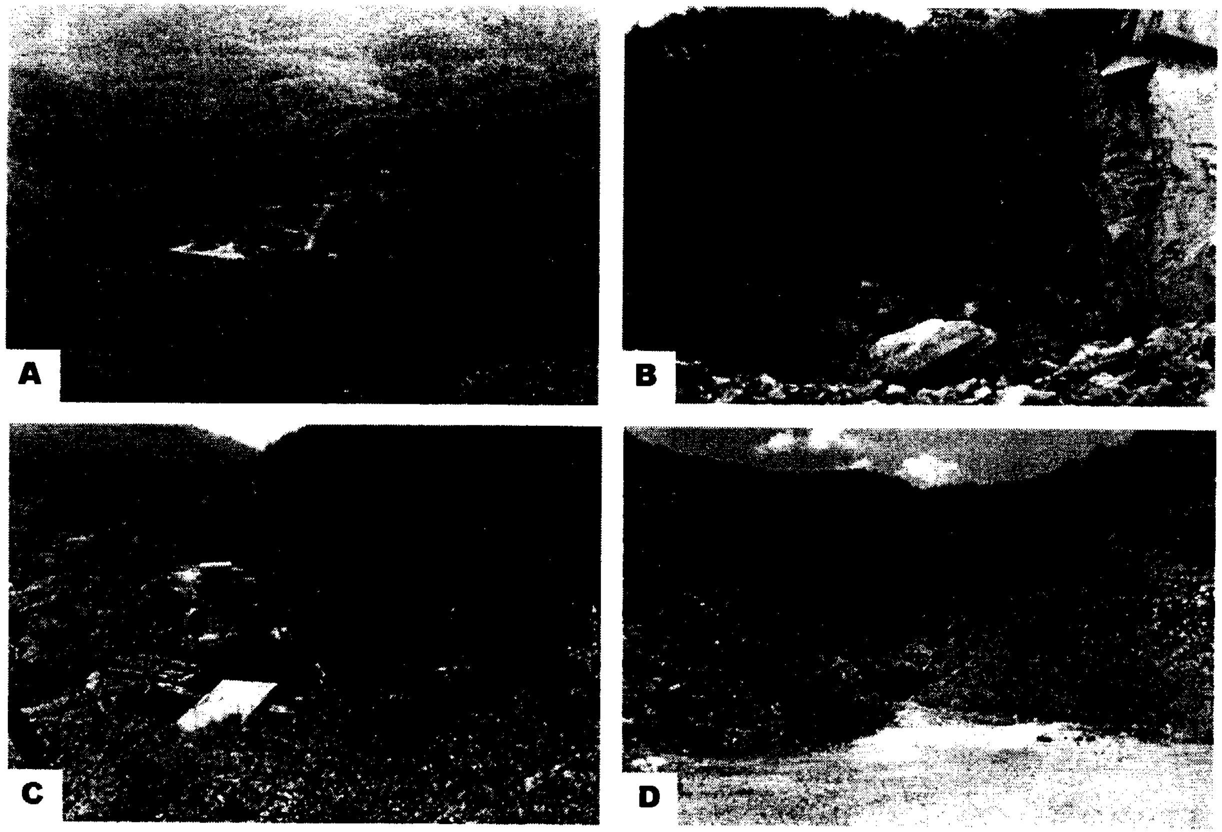

Figure 8. Photographs of skarn deposits in the Taebaegsan area. A; Geodo mine, B; zoned skarn in the Geodo outcrop, C; Dongnam mine, D; adit A of Dongnam mine.

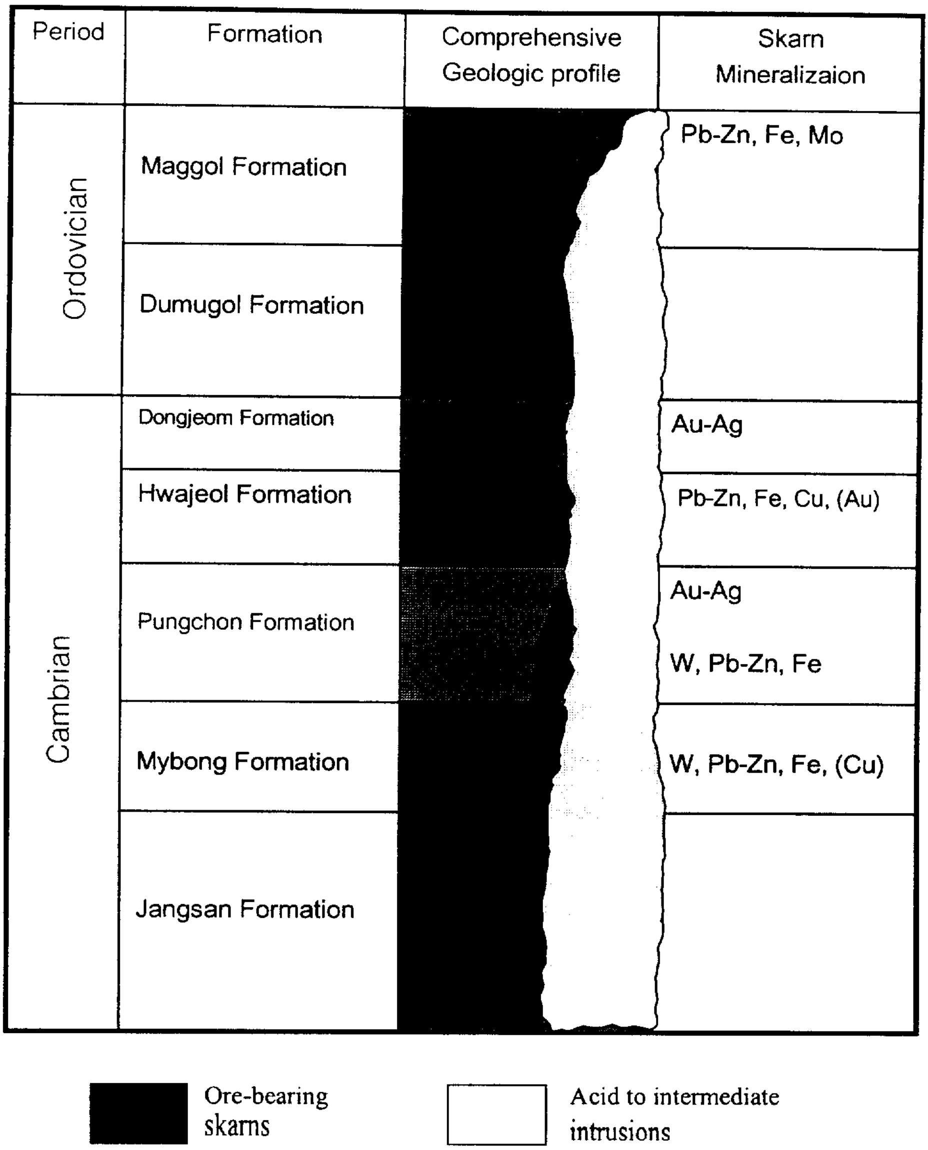

Figure 9. Comprehensive geological profiles of skarns in the Taebaegsan area.

acidic dyke. The main strike and dip of sedimentary rocks are N10°~50°E and 10°~20°SE, respectively, and they vary irregularly at the contact zone with the igneous rocks. The Myobong slate which is the oldest formation in the mine area is mainly distributed in the south-western part of the mine. The slate is dark gray or dark green to green. The matrix of the slate consists of fine-grained quartz and feldspar, chlorite, and sometimes pyrite. The slate was partly replaced with the skarn at the contact with the quatz porphyry. The Pungchon limestone overlies conformably the Myobong slate and consists mainly of gray, dark gray, and milky white limestone units. The limestone was recrystallized near the contact with diorite but not skarnized. The Hwajeol formation consists of shale, vermicular-shaped limestone, and gray limestone. The skarn were not developed in this formation. The diorite intruded the Pungchon limestone in the central part of the mine area. The lens-shaped diorite stock was divided into two parts by the fault of NNE direction. The diorite was replaced partly with the skarn (Chang et al., 1995).

Pb-Zn Deposits: Lead-Zinc skarn deposits occur throught the Taebaegsan Basin in a variety of geologic settings. Janggun deposits corresponds to the southern margin of the Taebaegsan mineralized area, which consists of a basement of the Pyonghae, Weonnam and Yulri Groups of Precambrian age. In the mine area, there is a sequence of metasedimentary rocks nearly 2,500m thick, consists of three main Cambro-Ordovician lithostratigraphic units, in ascending order: the Jangsan Quartzite; the Dueumri Schist; the Janggun limestone formation. Unconformably covering these formation are the Dongsugok Schist and the overlying Jaesan coal-bearing formation of

Permo-Carboniferous age. The Jangsan formation is considered to form a basal unit of the Cambrian sequence, corresponding to the Joseon Supergroup of the Taebaegsan Basin. The Janggun limestone, about 100 to 800 m thick, is the host rock of the Janggun mine, and is consists of calcareous limestone in the northern part, and dolomitic limestone in the southern part of the mine. The limestone is silicified pervasively and highly altered, with sericite, chlorite and clay minerals, and magnesian to calcic skarns developed at the contact between dolomitic limestone and iron ore deposits (Lee et al., 1998). The Chunyang granite, which has intruded into these formations, occurs in the western part of the mine area. K-Ar analysis of muscovite in the granite yielded an age of 133 Ma, corresponding to the Jurassic Daebo Orogeny in the Korean Peninsula (Kim, 1971). Scattered throughout the mine area are dyke swarms of andesitic to aplitic rocks and granophyre, which may represent the youngest rocks in the area, probably related to Cretaceous volcanism.

The Shinyemi mine, one of the most important base metal producers in southern Korea, is located in the western Taebaegsan area. The zinc-lead-molybdenum skarn deposit is thought to have formed in lower Paleozoic limestone in relation to felsic intrusive rocks. The K-Ar age data for the igneous rocks around the mine show very wide variation from 193 to 60 Ma (Kim, 1978). The Shinyemi deposit consists of many zinc-lead-molybdenum orebodies occurring in the Ordovician Maggol limestone in the forms of irregular pipe or vein (east ore bodies) and bed (west orebodies). Assemblages of the ore minerals are not different between the east and west orebodies, but skarn minerals of garnet are rich in the west orebodies which are intercalated with horfels layers. The Shinyemi deposit is different in the localty of limestone layers from other skarn deposits which occur in the interbedded limestone of the Myobong Slate Formation and in the Pungchon Limestone of Cambrian age. The difference in the occurrence of this ore deposit is characterized by showing an olivine(forsterite) as a diagnostic mineral for Mg-rich limestone.

A general characteristic of the Yeonhwa II zinc-lead deposits is the highly systematic localizaiton, occurring as moderately dipping tabular orebodies in accordance with bedding thrusts and/or bedding planes of the Cambro-Ordovician Pungchon limestone and Myobong slate, mostly along the contacts with the sill and dike of Late Cretaceous quartz monzonite porphyry. The orebodies occur in three groups: the Wolgok footwall, the Wolgok hangingwall (with respect to the sill), and the Seongok orebodies along the limeston beds. They are largely dominated by skarn and hydrous minerals (clinopyroxene, pyroxenoids, garnet, epidote, chlorite) in which varying quantities of sulfide minerals (sphalerite, galena, chalcopyrite and pyrrhotite) are associated. Sulfide ore minerals tend to occur in pyroxene zone rather than in garnet zone, that is consistent with the features in other zinc-lead skarns elsewhere (Burt, 1972). The preferential association of sphalerite with hedenbergite, for example, is due to a reducing condition caused by sulfidizing of hedenbergite that favors precipitation of the sphalerite.

W-Mo deposits: Sangdong W mine was one of the largest tungsten producer in the world, being located at the southeastern margin of the Ogcheon Belt. Scheelite mineralization occurs in stratabound skarns that replace interbedded limestones of the Myobong Slate Formation or the overlying Pungchon Limeston Formation, and also in a number of associated quartz veins. These sediments comprising the Sangdong W-Mo skarn orebodies overlie the Jangsan quartzite. The skarn orebodies in the Sangdong deposit are chiefly composed of four minerals; quartz, mica, amphibole and clinopyroxene, and the colors of the ore correspond to the relative proportions of these four minerals. The various Fe, Cu, Mo, W skarn occurrences and deposits throught Taebaegsan Basin are summarized in Table 5.

Au-(Ag) vein deposits: Dongwon Au-Ag deposits are composed of numerous gold and silver veins emplaced in sedimentary rocks of Cambrian Joseon Supergroup and granitoids of Cretaceous age. Ore veins of the mine can be divided into gold and silver veins on the base of vein structure, mineral assemblage and vein trends. Mutual relationships between gold and silver veins are uncertain. Gold veins are simple veins which are composed of base-metal sulfides, and electrum with quartz and ankerite. On the other hand, silver veins are complex amounts of oxides and pyrite with quartz; stage II, deposition of base-metal sulfide, small amounts of Ag-bearing minerals, calcite and quartz; stageIII, deposition of base-metal sulfides, electrum, Ag-sulfosalts, native silver, carbonates and quartz (Park and Park, 1990)

The Baegjeon Au-Ag deposits, small of disseminated-type gold deposits are formed as a result of epithermal processes associated a shallow-seated Cretaceous Yeogdun granitoids intrusion. The orebodies are formed by the replacement of carbonate menerals in thin-bedded oolitic limestone beds favorable for mineralization within the upper-most Cambrian Pungchon

Limestone. The mineralization can be recognized one stage, ore minerals composed of base metal sulfides, electrum, Ag-Sb-S, Ag-Cu-S, and Sb-S minerals. Gold-bearing minerals consist of electrum and submicroscopic invisible gold in pyrite and arsenopyrite. The mineralization of the Baegjeon deposits is similar to the Carlin-type deposits characterized by sediments-hosted epithermal bedding replacement disseminated gold deposits (Lee and Park, 1996).

The Dunjeon Au-Ag deposits consist of north and south ore body. The south ore deposits of the Dunjeon gold mine is a fissure-filling vein emplaced in the granitoids, skanized and hornfelsified rocks of Ordovician Dumugol formation. The north ore deposits of the Dunjeon gold mine is mainly consisted of desseminated stockworks emplaced in Ordovician Dongjeom quartzite. The K-Ar age of sericite as a wall rock alteration products is 75.7±1.7 Ma (Park and Lee, 1990).

Table 5. Brief Description of Mineral Deposits in the Taebaegsan Area.

Localty	Deposits	Intrusive rock	Country rock	Ore minerals	Gangue minerals	References
Sangdong	contact metasomatic W-Mo deposit	granite	Pungchon formation, Myobong formation	Po, Py, Bi, Ars, Gal, Mt	Qz, Cal, Amp, Ga, Cpx, Ep	Lee and Jeong (1990)
Yeonwha 1	contact metasomatic Pb-Zn deposit	quartz porphyry	Hwajeol formation Pungchon formation	Py, Po, Cp, Ars,St, Ag-ss, Mc, He	Qz, Sid, Dol, Cpx, Ep, Act, Ga, Rd	Yun (1979)
Yeonwha 2	contact metasomatic Pb-Zn deposit	quartz monzonite	Hwajeol formation Pungchon formation, Myobong formation	Sph, Gal, Cp, Po	Qz, Rh, Chl, Cpx, Ga, Fl	Yun (1979)
Uljin	contact metasomatic Pb-Zn deposit	rhyodacite	Pungchon formation, Myobong formation	Sph, Gal, Cp, Po	Qz, Rd, Chl, Cpx, Ga	Yun (1979)
Geodo	contact metasomatic Fe-Cu deposit	granodiorite quartz monzonite	Hwajeol formation Myobong formation	Sph, Bor, Po, Cc, Tt	Ga, Cpx, Phl, Act, Sc, Kf, Pl	Yoon (1984)
Dongnam	contact metasomatic Fe deposit	diorite	Pungchon formation, Myobong formation	Po, Py, Cp, Ars, Sch, Mc, Tt	Ga, Cpx, Ep, Phl, Qz, Cal	Seo (1983)

(continued)

(continued)

Localty	Deposits	Intrusive rock	Country rock	Ore minerals	Gangue minerals	References
Weondong	contact metasomatic Pb-Zn-Fe-Mo deposit	quartz porphyry	Hwajeol formation Pungchon formation, Magdong formation	Po, Py, Cp, Ptd, Ars	Ga, Cpx, Ep, Rd, Phl, Qz, Cal, Act, Chd, Chl, Ka, Fl	Kim (1983)
Shinyemi	replacement, contact metasomatic Pb-Zn deposit (60-193Ma)	quartz monzonite	Maggol formation	Gal, Cp, Po, Py, Ars, Sch, Mc, Tt	Cpx, Ga, Ep, Phl, Qz, Cal	Kim (1981)
Janggun	replacement, contact metasomatic Pb-Zn deposit	granite	Janggun limestone	Mt, He, Po, Ars, Py, Cp. Mc, Gal, Sph	Ga, Cpx, Qz, Cal, Chl, Dol, Phl	Lee (1998)

Abbreviation: Act-actinolite, Ags-Ag sulfosalts, Amp-amphibole, And-andradite, Ars-arsenopyrite, Bis-bismuthinite, Bor-bornite, Cal-calcite, Cc-Calcocite, Cp-chalcopyrite, Chl-chlorite, Cpx-clinopyroxene, Dol-dolomite, Ep-epidote, Fl-fluorite, Gal-galena, Ga-garnet, He-hematite, Ka-kaolinite, Kf-K feldspar, Mc-marcasite, Mt-magnetite, Mol-molybdenite, Phl-phlogopite, Pl-plagioclase, Py-pyrite, Po-pyrrhotite, Ptd-pentlandite, Qz-quartz, Rd-rhodonite, Shc-scheelite, Sid-siderite, Sph-sphalerite, St-stannite

3. Intrusions Related to Gold Skarn

3-1. Petrographic Description

The Paleozoic sedimentary rocks of Taebaegsan area have been intruded by granodiorite, quartz diorite stock and dikes. The stocks are porphyritic near their margins and grade outward to several associated porphyritic sills of quartz diorite. The sill exhibit hydrothermal allteration suggestive of a shallow level of intrusion in Geodo area (Fig. 10). The study of related intrusion was done by polarizing microscope. The petrographic characteristics of major intrusive rock types from Geodo and Dongnam mine as below.

Geodo Mine: The Geodo stock, dikes, and sills are composed of phenocrysts of plagioclase, quartz, hornblende, biotite and in a fine grained groundmass of aforementioned minerals, plus potassium feldspar (Fig. 11). Accessory minerals include apatite, zircon, magnetite and opaque mineral. The petrographic characteristics of major rock types from representative igneous samples are described the following. Phenocrysts of granodiorite porphyry are euhedral plagioclase, anhedral-rounded quartz, unhedral to subhedral brown biotie, and subhedral to euhedral green hornblende. Plagioclase phenocrysts are larger (up to 5mm long) than others (less than 2mm in length). Plagioclases are zoned, and twinned in albite. Biotite is strongly pleochroic, pale yellowish brown to dark brown, containing inclusions of plagioclase and altering to chlorite along cleavages. Hornblende is weaky pleochroic, pale yellowish brown to pale alteration product. Orthoclase occurs mainly in groundmass which consists of the same

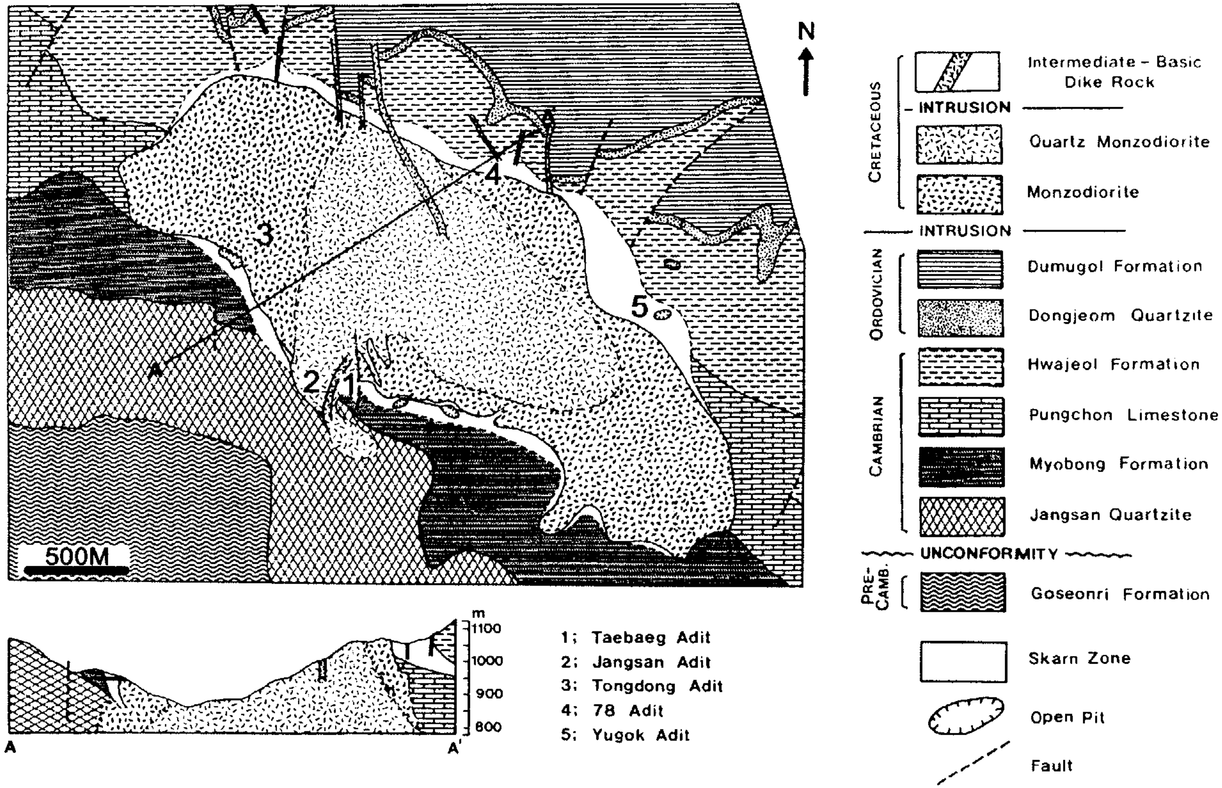

Figure 10. Geological map of Geodo mine area showing location of adits(1~5) (after Choi, 1989).

minerals as the phenocrysts. Biotite of biotite granite is 0.5~3.0 mm long in taular form, is strongly pleochroic, pale brown to dark brown and intergrows with muscovite along cleavages or rugged edges. Large anhedral K-feldspars, 2~8 mm, mostly of orthoclase, occurs in the interstices. Plagioclases show albite twin or combined calsbad-albite twin.

Dongnam Mine: The diorite chiefly consists of plagioclase and amphibole with minor amounts of orthoclase, quartz, biotite, pyroxene. Orthoclase is anhedral and occurs as interstitial grains. Pyroxene shows rather clear cleavages and coexists with plagioclase. Plagiclase altered to sericite. Biotite is brown to dark brown in color and altered to chlorite along its cleavage. Phenocrysts of quartz porphyry include plagioclase, biotite, and K-feldspar. Biotite, up to 2 mm thick, is strongly pleochroic, palereddish yellow to dark reddish brown. Pseudomorphic green biotite or chlorite after subhedral biotite, are more abundant. Plagioclase, the largest phenocryst up to 3 mm long, is euhedral to subhedral showing albite twin. K-feldspar is subhedral to euhedral orthoclase, up to 3 mm thick in tabular form, lacking noticeable twins and altered partly to cloudy sericite (Fig. 11-E).

3-2. Geochemical composition

The geochemical data of granitoids the Geodo and Dongnam mines were used the published data (Choi, 1989; Yun, 1979; Chang, 1988). The granitoids of Geodo and Dongnam mine are a reduced ilmenite-bearing intrusion with an average $Fe_2O_3/(Fe_2O_3+FeO)$ value of 0.27 to 0.53 (Table 6). Geodo granitoids are monzodiorite and quartz monzodiorite (Choi, 1989).

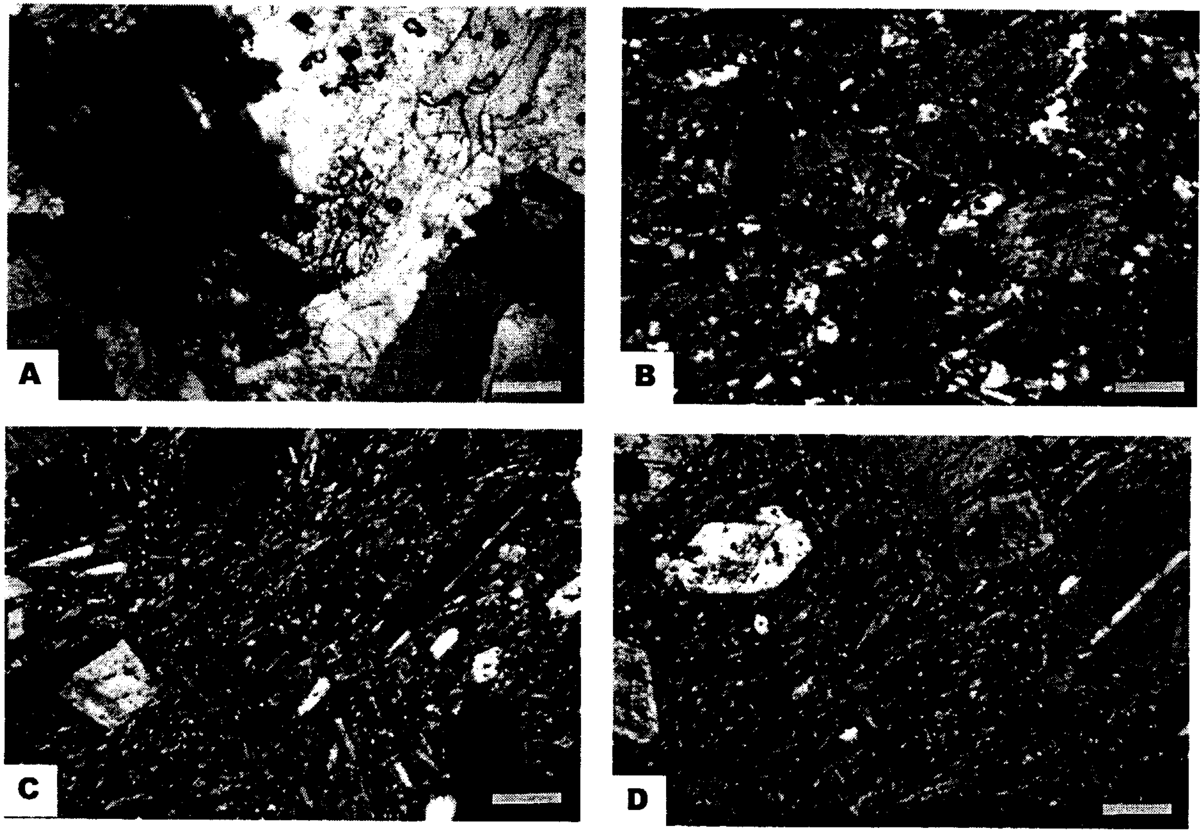

Figure 11. Photomicrographs of the igneous rocks in the Taebaegsan area. A, B, C, D; Geodo 78 adit, .D,E; Dongnam deposit, F,G; Geodo Tongdong adit.. Scale bar = 1 mm.

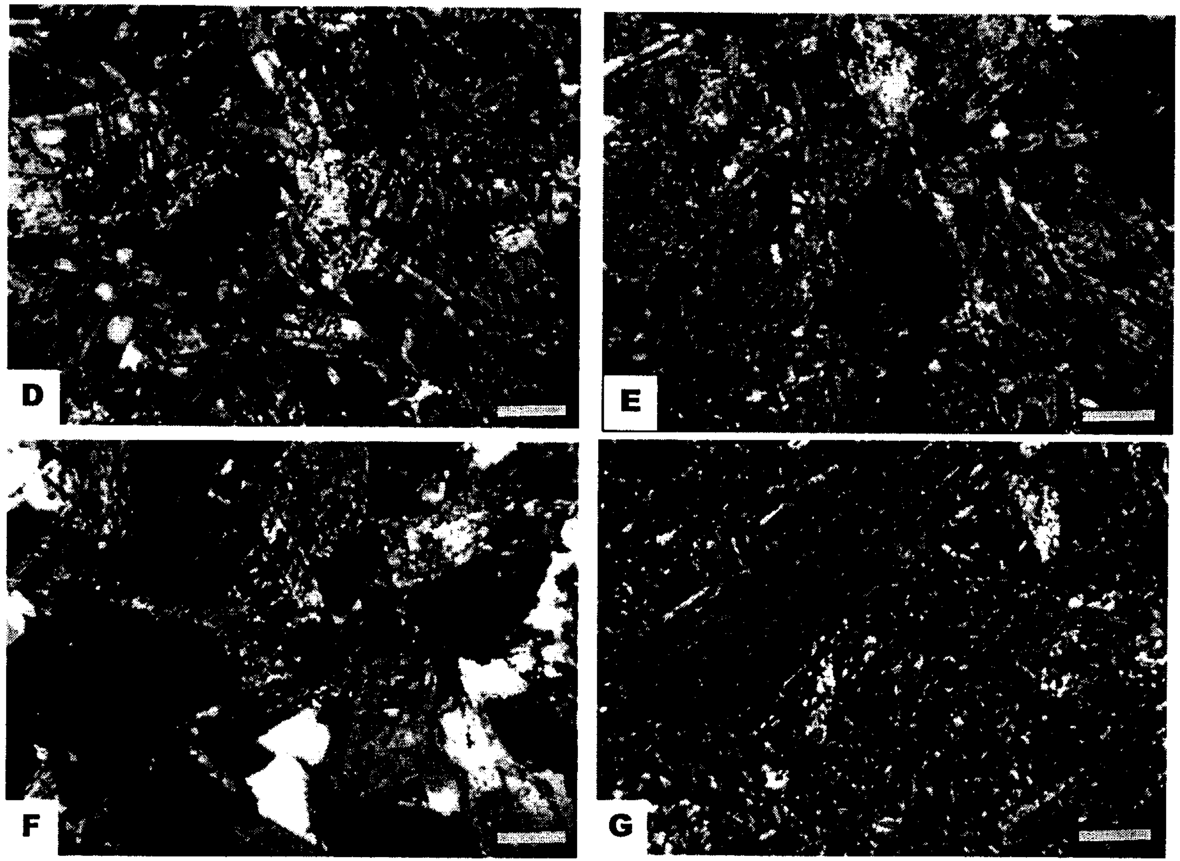

Figure 11. (Contined)

Table 6. Chemical Analyses of the Geodo and Dongnam Granitoids.

Sample	TB30	TB31	TB33	S25	S26	K18	DN826	DN801	DN811	D1
Localty	*Geodo mine*						*Dongnam mine*			
SiO2	53.53	50.76	62.62	63.82	60.90	60.50	53.78	53.37	55.54	57.30
TiO2	1.13	1.20	0.89	0.69	0.83	0.50	0.73	0.50	0.70	0.68
Al2O3	17.92	17.81	15.97	16.55	17.37	17.20	17.23	16.35	17.47	17.71
Fe2O3	2.67	1.76	2.44	1.33	1.49	1.87	1.83	2.40	2.16	2.40
FeO	4.44	4.80	2.19	3.00	3.36	2.88	3.54	3.80	3.31	3.07
MnO	0.11	0.08	0.05	0.05	0.07	0.05	0.35	0.32	0.28	0.20
MgO	5.98	7.00	3.18	2.70	3.24	3.23	7.19	8.43	5.98	4.77
CaO	7.56	6.02	3.86	3.94	4.27	3.60	7.31	7.19	6.47	5.62
Na2O	2.99	2.63	3.60	3.61	3.75	3.60	2.57	2.43	2.80	3.03
K2O	1.68	1.64	3.16	3.35	3.86	2.95	3.31	3.28	3.16	2.92
P2O5	0.10	0.12	0.04	0.01	0.01	0.20	tr	0.10	tr	tr
Total	99.87	97.86	99.41	100.21	100.13	99.56	99.84	99.95	99.81	99.90
Reference	Choi (1989)					Yun (1979)	Chang (1988)			

4. Gold Skarn and Occurrence in the Taebaegsan Basin

4-1. Mineral Chemistry

To know Au contents in skarn and ore minerals, We selected and analysis representative a total of 47 skarn and ore sample. Selected sample was analysis in CMR at Korea University and KORES by ICP. Metallic element data of 47 samples of the skarns are listed in Table 7. Gold is closely associated with Cu(Pb, Zn) sulfides and exists mainly in the form of native gold and electrum. Arsenides, tellurides, bismuthides and selenides are present in many ore deposits. Therefore, Cu, As, Bi, Te, Ag, Pb, Zn, Se, and Co are the major metals present in the deposits and are important geochemical ore-searching indicators (Zhao et al., 1999)..

The gold content of ranges up to 22 ppm in the YeonhwaⅡ Pb-Zn deposits and up to 14 ppm in the Geodo 78 adit. Au(Cu) skarn ores of the Taebaegsan area generally have a higher Cu content (o to 13%) in comparison with major gold skarn deposits.

Estimated physicochemical condition of formation based on the composition and stability field of major calc-silicate and sulfide minerals indicate that the hedenbergite skarn, pyrrhotite and arsenopyrite at Janggun deposits were deposited under similar conditious of sulfur fugacity (log $fS_2 \simeq -12$) , temperature (300℃) and oxygen fugacity (log fO_2 = -30) is estimated for hedenbergite.

Table 7. Geochemical Analyses of Skarn Minerals in the Taebaegsan Area.

Sample no.	Au (ppm)	Ag (ppm)	As (%)	Bi (%)	Tl (%)	Te (%)	Zn (%)	Mn (%)\	Cu (%)	Fe (%)
C6-105	5.9	4.3	n.d.	n.d.	n.d.	n.d.	1.32	2.23	0.04	6.30
C7-01	5.1	0.1	0.00	0.00	n.d.	n.d.	0.00	1.87	0.00	3.10
C7-121	n.d.	4.6	n.d.	n.d.	n.d.	n.d.	1.93	0.19	0.07	15.60
C7-139	33.1	3.1	0.17	0.01	0.15	n.d.	0.71	16.61	0.07	26.40
C7-156	7.3	0.7	0.00	0.00	n.d.	n.d.	0.76	5.27	0.08	38.20
C7-160	n.d.	4.0	2.81	0.01	n.d.	n.d.	0.96	0.32	0.03	21.00
C7-198	3.7	2.4	0.01	0.00	n.d.	n.d.	4.00	1.72	0.15	17.20
D001	n.d.	4.2	n.d.	0.00	n.d.	n.d.	4.70	0.44	3.65	21.40
D002	n.d.	5.1	n.d.	n.d.	n.d.	n.d.	19.87	0.15	13.11	44.30
D004	n.d.	1.7	n.d.	0.02	n.d.	n.d.	10.63	0.48	0.17	41.20
B6-1	12.3	0.1	n.d.	0.00	n.d.	n.d.	0.02	6.77	n.d.	12.30
B6-2	3.4	n.d.	n.d.	0.00	n.d.	n.d.	0.11	1.58	n.d.	11.50
B6-3	7.0	n.d.	n.d.	0.00	n.d.	n.d.	2.62	2.55	n.d.	9.50
B12-1	7.8	0.4	0.00	0.00	n.d.	n.d.	4.46	4.46	0.02	17.90
B12-2	3.2	0.2	0.00	0.00	n.d.	n.d.	0.18	1.36	n.d.	13.20
B12-4	2.9	2.2	n.d.	0.01	n.d.	n.d.	0.20	1.33	n.d.	12.70
B18-1	17.6	0.1	n.d.	0.00	0.03	n.d.	4.07	8.35	0.01	13.80
B18-3	6.4	n.d.	n.d.	0.00	n.d.	n.d.	2.66	2.34	0.04	13.50
B18-5	3.4	7.9	0.01	0.03	n.d.	n.d.	2.84	1.44	0.01	5.40
B40-1	11.6	0.1	n.d.	0.00	n.d.	n.d.	0.02	4.29	n.d.	11.90
B40-2	22.8	2.9	n.d.	0.00	0.02	n.d.	0.26	12.37	n.d.	11.60

n.d.- not detected

Table 7. (continued)

Sample no.	Au (ppm)	Ag (ppm)	As (%)	Bi (%)	Tl (%)	Te (%)	Zn (%)	Mn (%)\	Cu (%)	Fe (%)
B46-1	9.80	0.26	n.d.	0.00	n.d.	n.d.	1.11	5.64	n.d.	19.10
B46-3	5.20	0.97	n.d.	0.00	n.d.	n.d.	29.65	3.57	0.06	17.60
B46-4	4.90	0.35	n.d.	0.01	n.d.	n.d.	3.11	1.82	0.00	10.60
101	0.04	0.46	0.01	n.d.	n.d.	n.d.	0.10	0.69	0.10	18.80
102	0.46	2.78	0.12	n.d.	n.d.	n.d.	0.48	8.31	0.06	32.60
103	0.09	3.60	0.03	n.d.	n.d.	n.d.	0.23	10.40	0.02	18.00
201	0.06	5.04	0.01	n.d.	n.d.	n.d.	3.08	2.14	0.01	13.40
202	0.02	2.56	0.02	n.d.	n.d.	n.d.	0.09	0.98	0.13	17.50
203	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.02	0.82	n.d.	11.90
1	0.06	0.39	0.02	n.d.	n.d.	n.d.	9.72	13.20	0.04	8.79
2	0.06	1.48	0.01	0.02	n.d.	n.d.	5.75	1.19	0.04	10.20
3	0.09	5.58	0.02	n.d.	n.d.	n.d.	6.85	18.00	0.04	13.20
4	0.24	5.84	0.39	n.d.	n.d.	n.d.	9.20	1.67	0.11	33.70
5	0.07	2.98	0.03	n.d.	n.d.	n.d.	0.02	0.01	0.06	41.30
01	4.54	3.60	n.d.	0.04	n.d.	n.d.	0.07	0.06	6.58	12.60
02	0.06	0.27	0.02	n.d.	n.d.	n.d.	n.d.	0.16	0.02	7.01
03	6.43	3.46	0.02	n.d.	n.d.	n.d.	0.05	0.02	5.99	12.00
04	14.10	7.58	0.03	n.d.	n.d.	n.d.	0.09	0.08	6.85	19.50
05	4.18	5.78	0.01	n.d.	n.d.	n.d.	0.13	0.05	12.40	29.30
TD01	0.05	0.74	0.06	n.d.	n.d.	n.d.	0.03	0.06	0.21	35.80
TD02	0.76	6.01	0.02	n.d.	n.d.	n.d.	0.06	0.11	1.67	9.03
TD04	0.14	0.93	n.d.	n.d.	n.d.	n.d.	0.01	0.20	0.08	14.90

Table 7. (continued)

Sample no.	Au (ppm)	Ag (ppm)	As (%)	Bi (%)	Tl (%)	Te (%)	Zn (%)	Mn (%)\	Cu (%)	Fe (%)
TD06	0.25	0.80	0.01	n.d.	n.d.	n.d.	0.10	0.13	1.34	50.50
TB02	0.67	5.41	0.03	n.d.	n.d.	n.d.	0.02	0.12	1.60	9.42

n.d.- not detected

4-2. Mineralogy of Gold Skarn

Skarn mineralogy has been the key to classifying skarn deposits and building genetic models for their formation. Mineralogical study of skarn was done by Polarizing Microscope and EPMA for chemical analyses. The characteristics of skarn minerals analyses are represented by the following description per mines.

Microscophy: Skarn minerals in the Geodo mine have been formed in two stages of early and late skarn stages, which are followed by alteration stage. Early skarns are characterized by massive medium- to fine-grained minerals both in endoskarn and exsoskarn zones. Late skarns are characterized by subhedral to euhedral minerals of medium- to coarse-grained texture(Fig. 12). Fe ore mineralization is associated with the late skarn stage. The final alteration is characterized by alteration of earlier skarn and open-space crystallization. Electrum precipitaed all of two stage. Ore minerals related in gold skarn in Geodo mine were pyrite, chalcopyrite (Fig. 13-B, D).

During skarnization, magnesian to calcic skarns and magnesian-iron carbonate minerals associated with magnetite, pyrrhotite, and base-metal sulfides were deposited in the Janggun Pb-Zn deposit. The skarn consisits mainly of olivine, chlorite, serpentine, talc, pholgopite, amphibole, clinopyroxene, garnet, wollastonite, and apatite, with variable (dolomite, magnesite, siderite and calcite). Ores of the skarn event are characterized by abundant magnetite, hematite and pyrrhotite. Magnetite ores and magnesian skarn of the deposits are characterized by several textural varieties such as massive, banded and mixed types. Sphalerite and galena with minor amounts

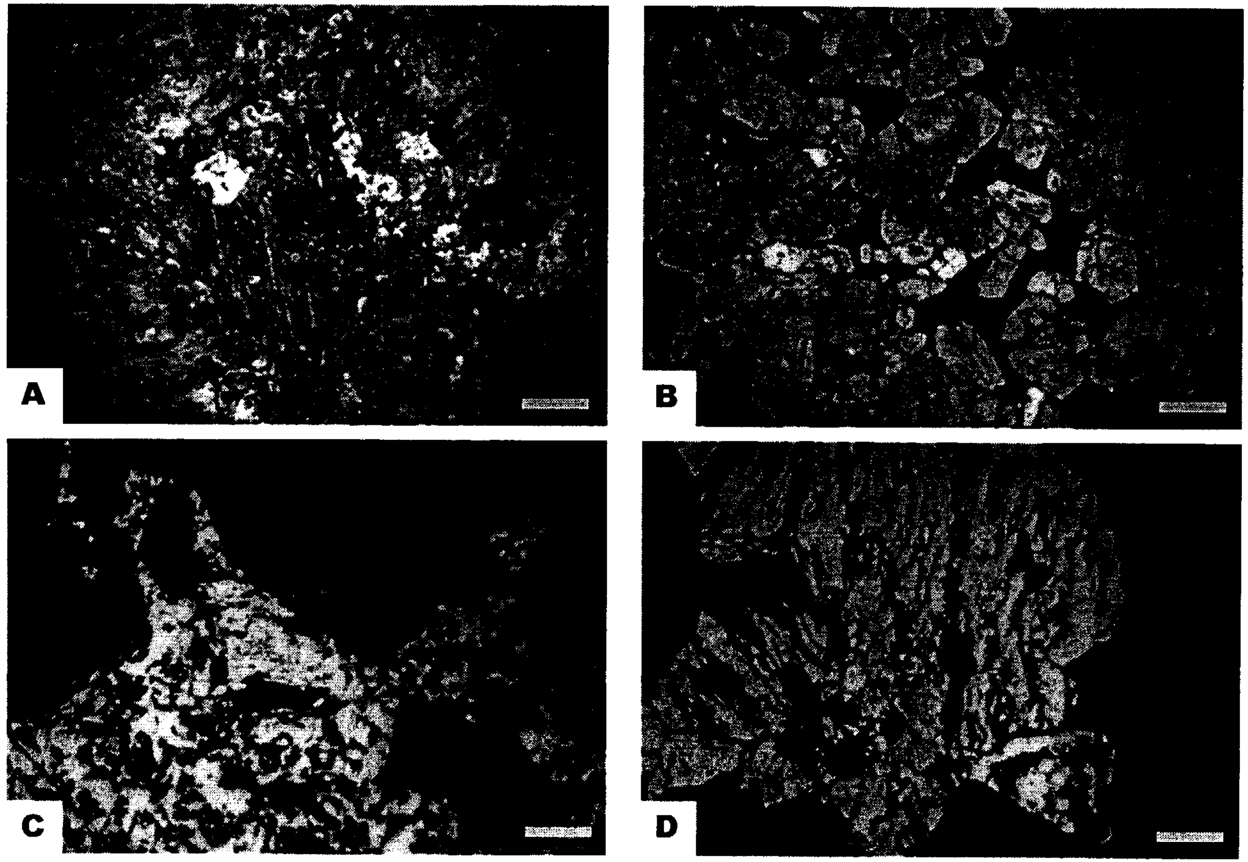

Figure 12. Photomicrographs of skarn minerals in the Geodo deposit. Scale bar = 0.1 mm.

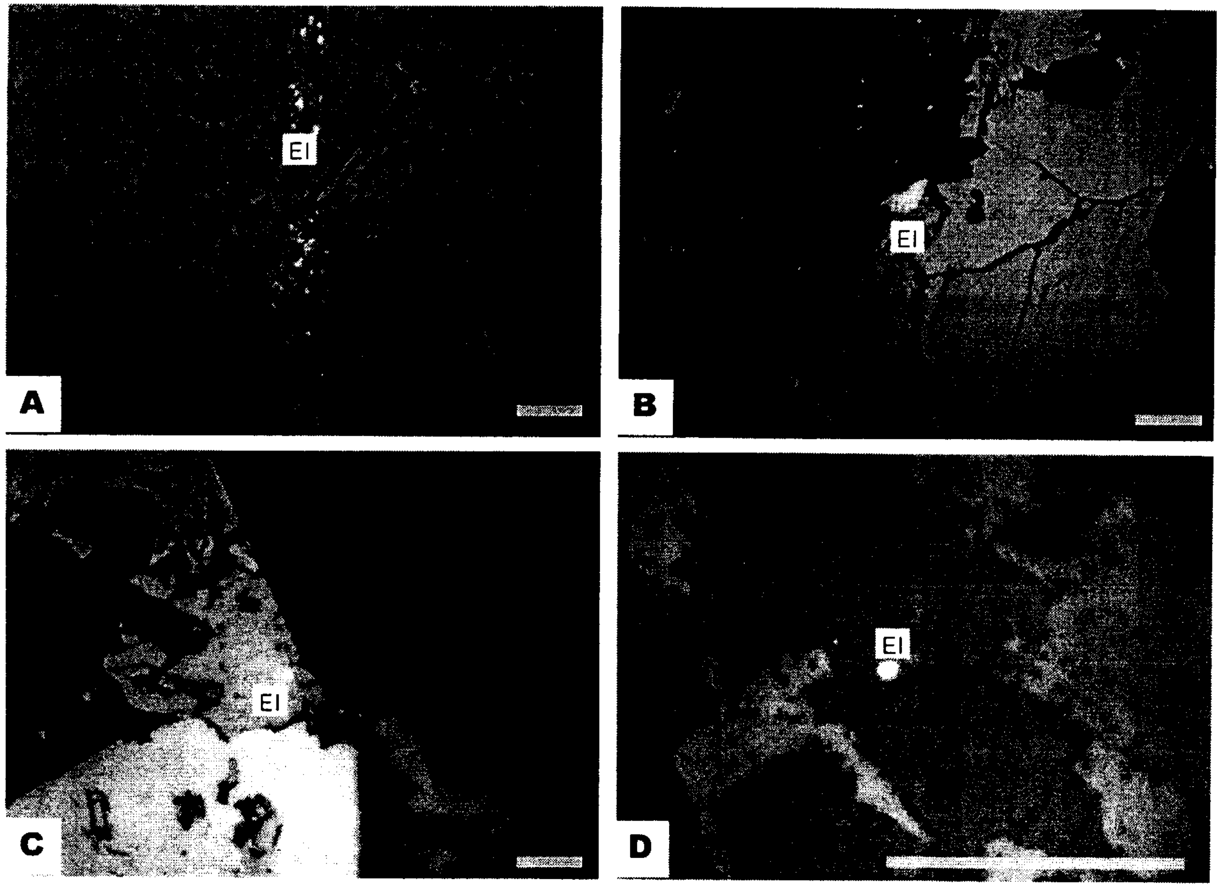

Figure 13. Photomicrographs of electrums in skarn minerals (El-electrum). Scale bar = 1mm.

Table 8. Representative Electron Microprobe Analyses (wt%) of Garnet in the Taebaegsan Area.

Sample No.	A30-1	A30-2	A30-3	A60-1	A40-4	A40-5	B12-1
SiO2	34.74	36.37	36.03	37.84	38.96	35.60	34.95
TiO2	0.01	0.00	0.01	0.02	0.63	0.46	0.03
Al2O3	17.11	18.91	17.73	5.83	6.52	6.12	11.01
FeO	19.26	16.55	15.77	20.21	18.30	20.32	17.19
MgO	1.12	0.01	2.12	0.07	0.15	0.19	0.04
MnO	2.45	2.20	2.34	0.29	1.01	0.43	2.69
CaO	22.60	23.04	22.45	32.59	32.07	33.62	31.53
Na2O	0.03	0.02	0.01	0.00	0.00	0.00	0.00
K2O	0.01	0.01	0.02	0.03	0.00	0.00	0.00
Total	97.33	97.11	96.48	96.88	97.64	96.74	97.44
Si	2.898	2.977	2.965	3.285	3.312	3.132	2.977
Ti	0.000	0.000	0.000	0.001	0.040	0.030	0.001
Al	1.682	1.824	1.719	0.596	0.653	0.634	1.112
Fe	1.343	1.132	1.085	1.467	1.301	1.495	1.232
Mg	0.139	0.001	0.260	0.009	0.019	0.024	0.005
Mn	0.173	0.152	0.163	0.021	0.072	0.032	0.195
Ca	2.019	2.020	1.979	3.031	2.921	3.169	2.897
Na	0.004	0.003	0.001	0.000	0.000	0.000	0.000
K	0.001	0.001	0.002	0.003	0.000	0.000	0.000
Sum	8.259	8.110	8.174	8.413	8.318	8.516	8.419
Cations based	*12 oxygens*	*(Mole percent)*					
Pyralspite	24.6	21.3	23.7	0.1	3	9.8	6.5
Grossular	38.2	49.9	41.9	34.7	36.2	55.9	41.6
Andradite	37.2	28.8	34.4	64.2	63.5	34.3	51.9

Table 9. Representative Electron Microprobe Analyses (wt%) of Pyroxene in the Taebaegsan Area.

Sample No.	A16-3	A40-2	B6-3-2	B6-3-1	B12-1-2	B6-1-1	B6-1-2
SiO2	45.43	51.45	52.63	50.63	47.82	48.91	49.43
TiO2	0.01	0.02	0.00	0.00	0.00	0.00	0.00
Al2O3	0.15	1.04	0.25	0.13	0.07	0.00	0.00
FeO	19.16	6.29	6.85	9.23	18.25	14.27	13.45
MgO	3.07	12.57	12.78	12.57	9.02	8.17	8.97
MnO	0.14	0.71	2.00	2.11	1.24	3.82	3.43
CaO	30.94	25.33	23.12	23.75	22.08	23.10	23.43
Na2O	0.01	0.04	0.06	0.02	0.04	0.00	0.00
K2O	0.00	0.01	0.02	0.00	0.00	0.00	0.00
Total	98.91	97.46	97.71	98.44	98.52	98.27	98.71
Si	1.879	1.971	2.011	1.957	1.922	1.957	1.957
Ti	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al	0.007	0.046	0.011	0.006	0.003	0.000	0.000
Fe	0.662	0.201	0.218	0.298	0.613	0.477	0.445
Mg	0.189	0.718	0.728	0.724	0.540	0.487	0.529
Mn	0.004	0.023	0.064	0.069	0.042	0.129	0.115
Ca	1.371	1.040	0.946	0.983	0.951	0.990	0.994
Na	0.000	0.003	0.004	0.001	0.003	0.000	0.000
K	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Sum	4.112	4.002	3.983	4.038	4.074	4.040	4.040
Cations based on 6 oxygens		*(Mole percent)*					
Johannsenite	0.5	2.4	6.3	6.3	3.5	11.8	10.6
Diopside	22.1	76.2	72.1	66.4	45.2	44.6	48.6
Hedenbergite	77.4	21.3	21.6	27.3	51.3	43.6	40.9

of pyrite, arsenopyrite, and marcasite also occure in this stage. Massive magnetite occurs intimately with massive anhedral pyrrhotite, subhedral pyrite and infrequenly with anhedral sphalerite.

Geochemical Analyses: Garnet and pyroxene are represented by their iron (Fe) end members, since the octahedral cations of the garnet and the pyroxene are composed of ferric (Fe^{+3}) and ferrous (Fe^{+2}) ions respectively.

Chemical compositions of clinopyroxene and garnet confirmed gold occurrence from the Taebaegsan area were determined using SHIMADZU, EPMA-1600 electron microprobes at Cooperative Laboratory Center in Pukyong National University. Averaged chemical compositions of garnets are given in Table 8, 9 and plotted in Fig. 14.

Garnet is the characteristic prograde silicate mineral of Geodo deposits. Garnets from Taebaegsan area display a relatively wide range of solid solution between grossular and andradite with up to 2.45 wt.% MnO (Table 8, Fig. 14). Garnet chemistry belongs to andradite ($An_{28.8\sim64.2}$) - grossular ($Gr_{34.7\sim55.9}$) series in composition, showing up to 24.6% of sum of pyralspite. Garnets from gold skarns are aluminous to intermediate grandite in composition, with relatively few pure andradite analyses (Meinert, 1989).

Pyroxene from gold skarns range from diopside to hedenbergite in composition, although most of the higher grade deposits contain some iron-rich ($>Hd_{50}$) pyroxene. Gold skarn pyroxenes can be significantly more aluminum rich than pyroxene in other skarn types.

Multiple ganerations of garnet are present in some deposit. Both isotropic and anisotropic varieties are common. In Geodo deposits, early garnet is colorless, anisotropic, zoned toward more Al-rich rim composition (Fig. 15, 16). This suggest that andraditic garnet overgrow to grossularic

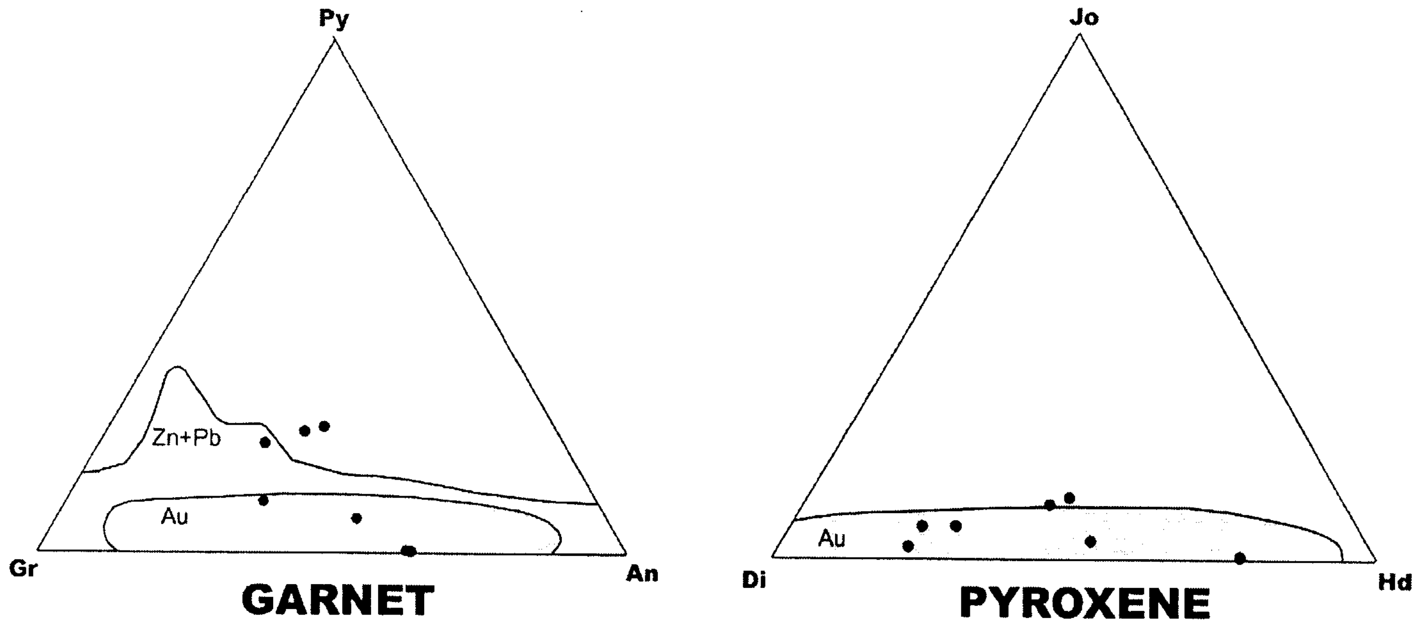

Figure 14. Ternary diagrams showing Electron microprobe analyses (mole %) of garnet and pyroxene from Taebaegsan area. Fields of typical garnets and pyroxenes from Zn+Pb and Au skarns indicated with a solid line (after Meinert, 1992). Gr-grossular, Ad-andradite, Py-pyralspite, Di-diopside, Hd-hedenbergite, Jo-johannsenite. Black dots are from this study.

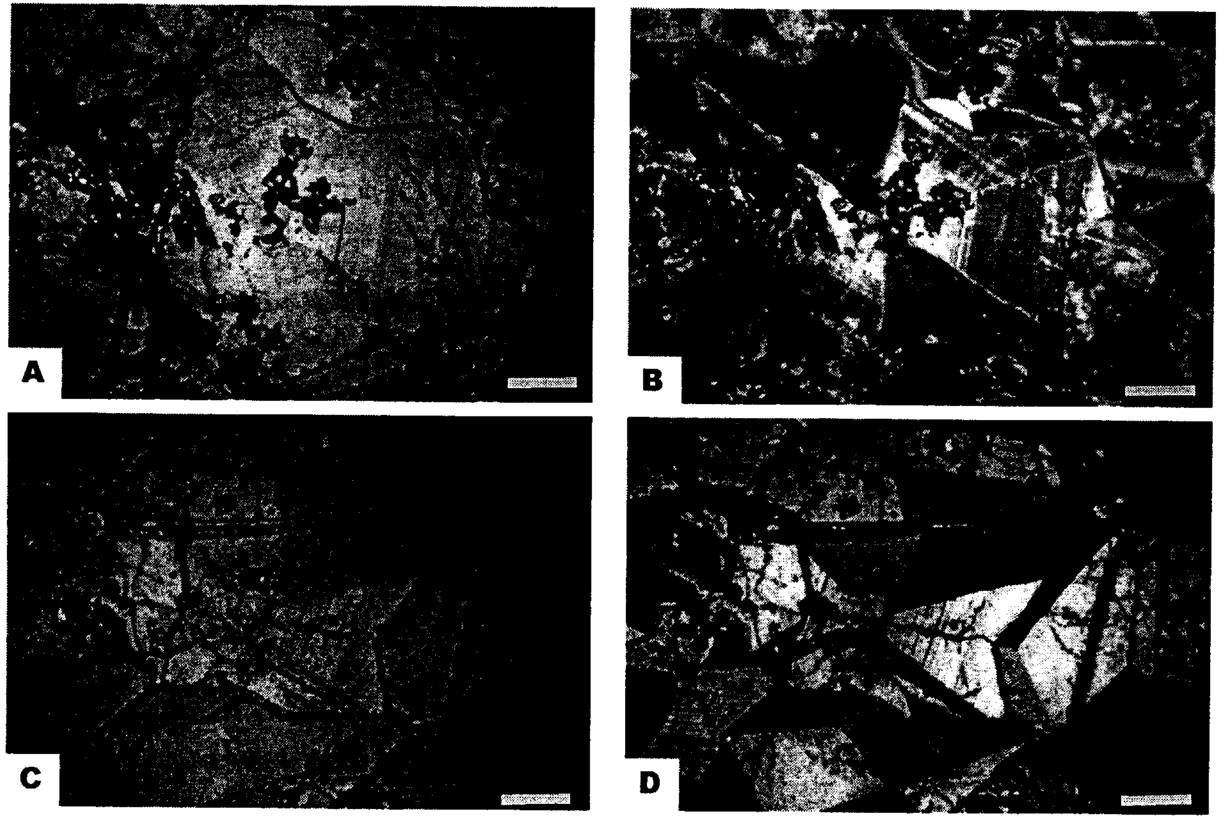

Figure 15. Photomicrographs showing complexly zoned garnets from Geodo deposit. A, C; Open nicol, B, D; Cross nicol. Scale bar = 0.5 mm.

grossularic garnet toward rim. Figure 18 BEI image of Electrum which boundary distributed between hematite and pyrite from Geodo deposits. The electrum chemical composition show more high Au/Ag ratio in core toward rim. The average Au/Ag ratio of electrum is 85:15.

For comparison, mean values for analysed skarn minerals related to W, Fe, Au, Cu skarns throughout British Columbia, Canada are also compare in these figures (Fig. 20). Solid lines are field of gold skarn and other skarn from British Columbia. Some analized data are consistent with the field of gold skarn.

Estimated physicochemical condition of formation based on the composition and stability field of major calc-silicate and sulfide minerals indicate that the hedenbergite skarn, pyrrhotite and arsenopyrite at Janggun deposits were deposited under similar conditious of sulfur fugacity (log fS_2 $\simeq$ -12) , temperature (300℃) and oxygen fugacity (log fO_2 = -30) is estimated for hedenbergite.

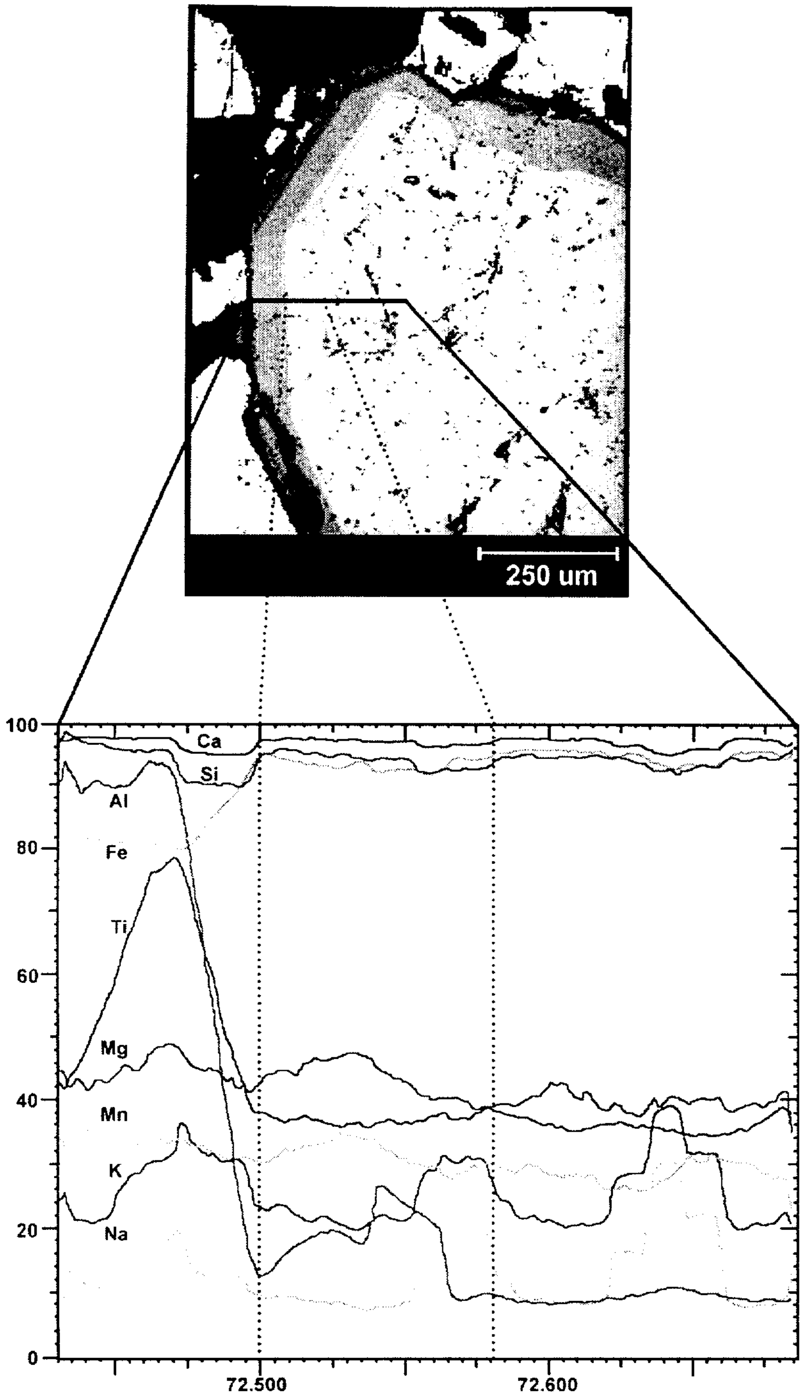

Figure 16. Compositional zoning profiles of garnet from Geodo Mine.

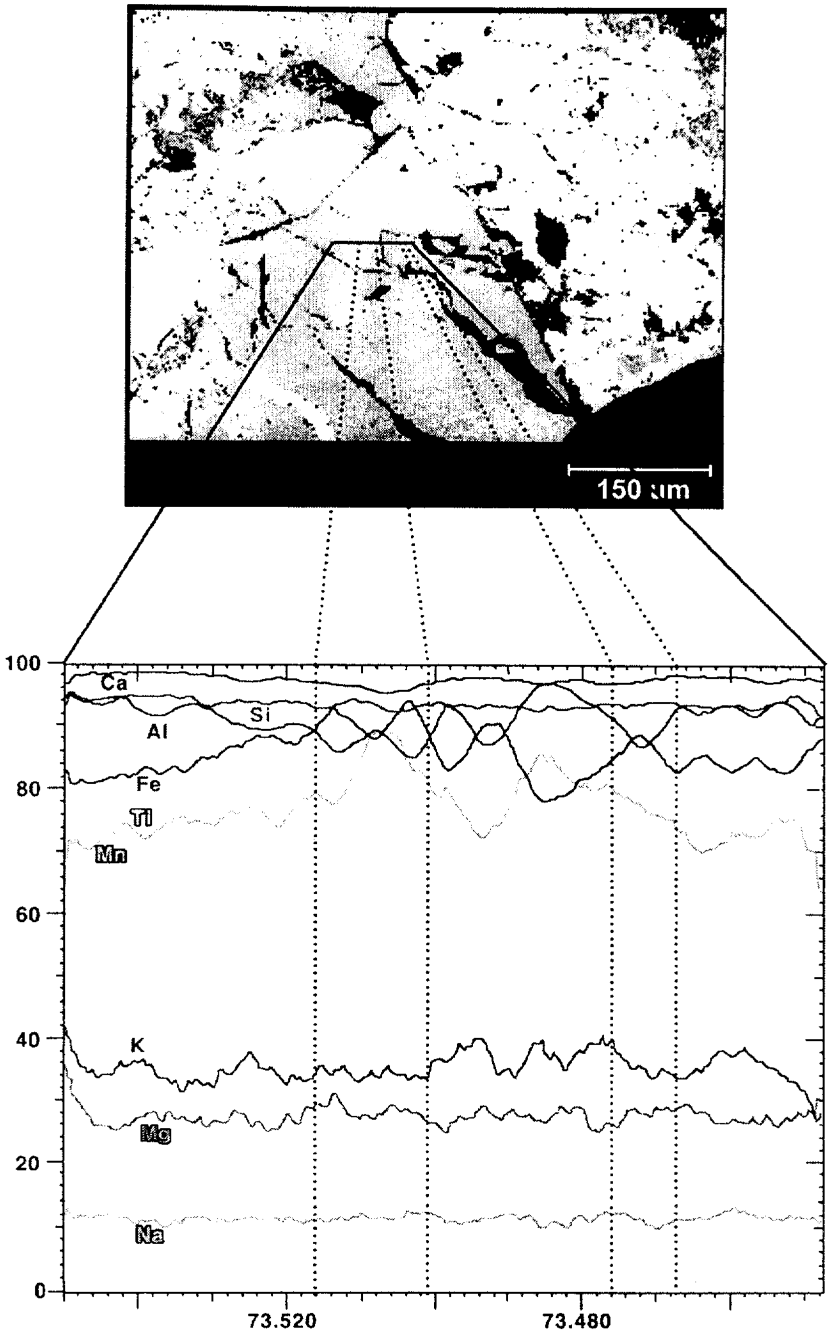

Figure 17. Compositional zoning profiles of garnet from Yeonhwa II mine.

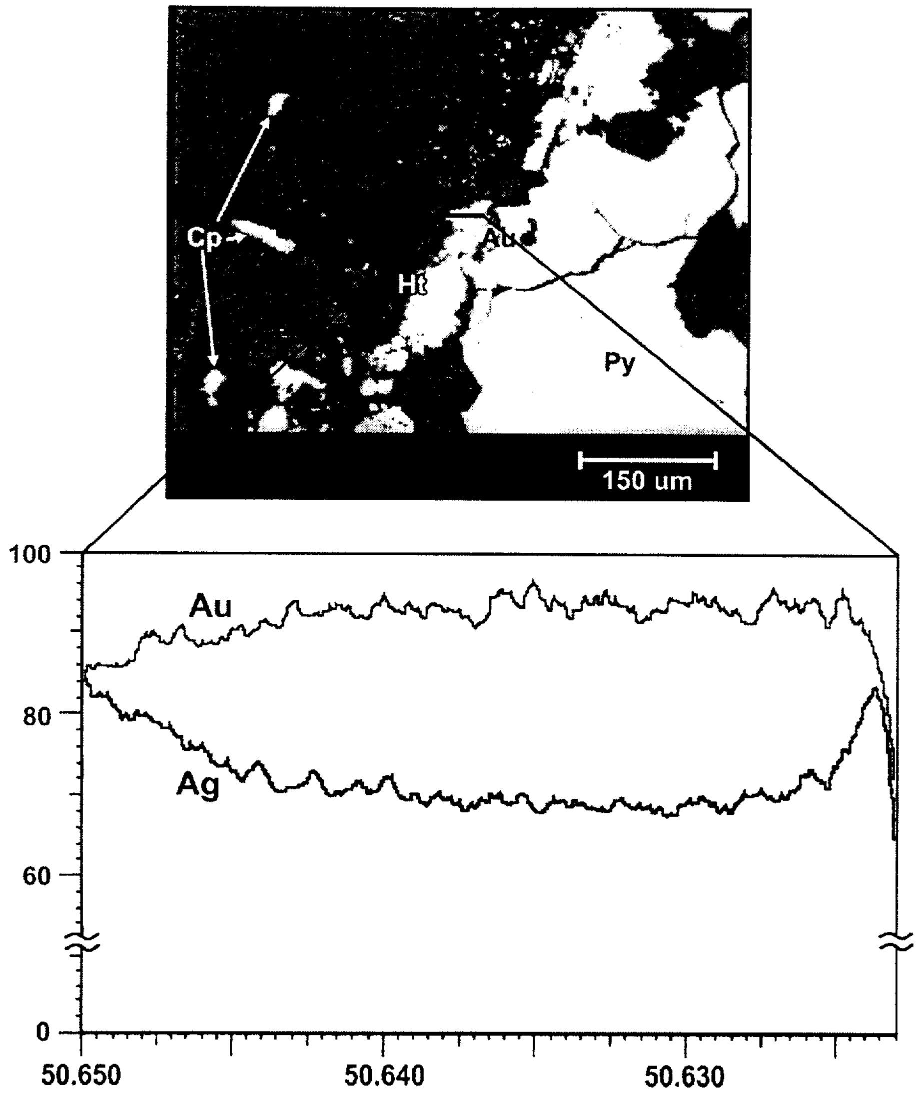

Figure 18. Compositional zoning profiles of Au from Geodo mine. Py; pyrite, Cp; chalcopyrite, Ht;hematite.

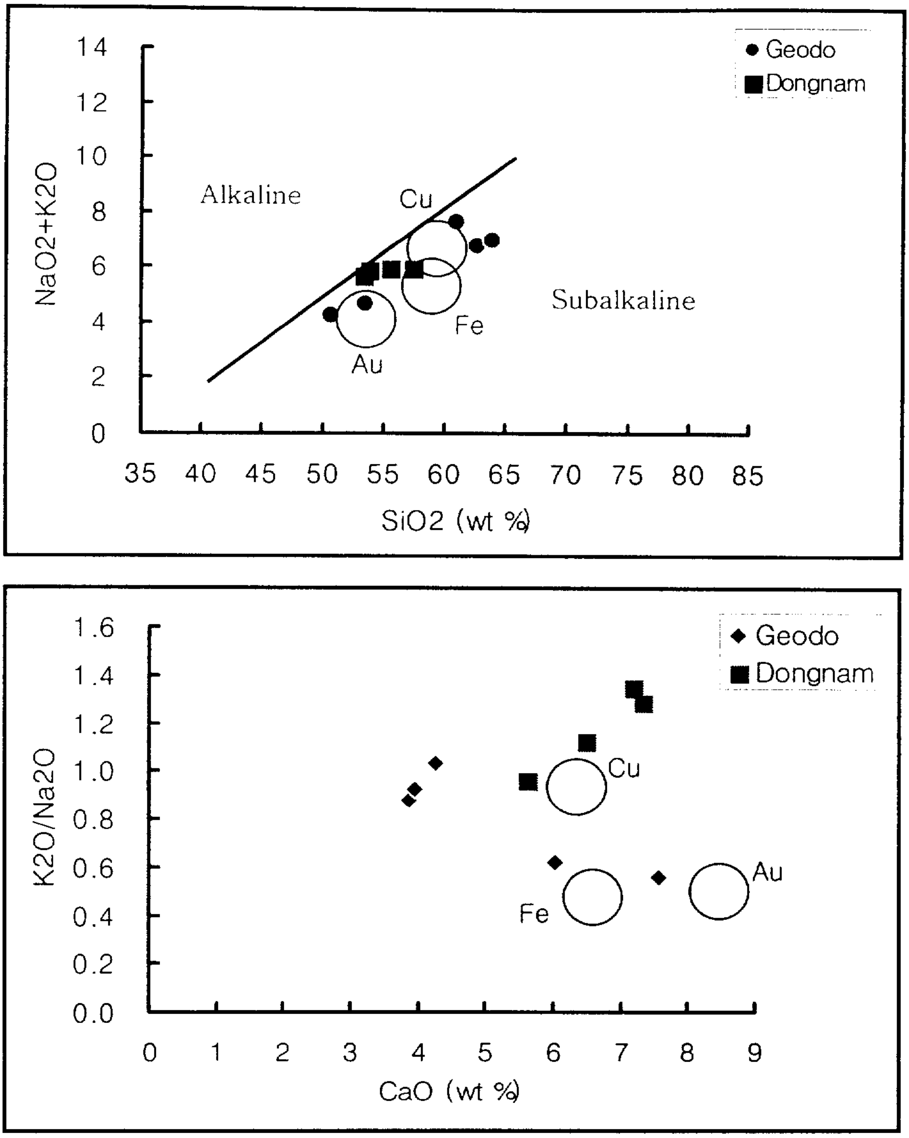

Figure 19. Plots of major elements of granitoids from Geodo and Dongnam mine. Fields of typical gold skarn and other type skarns (from Ray et al., 1995).

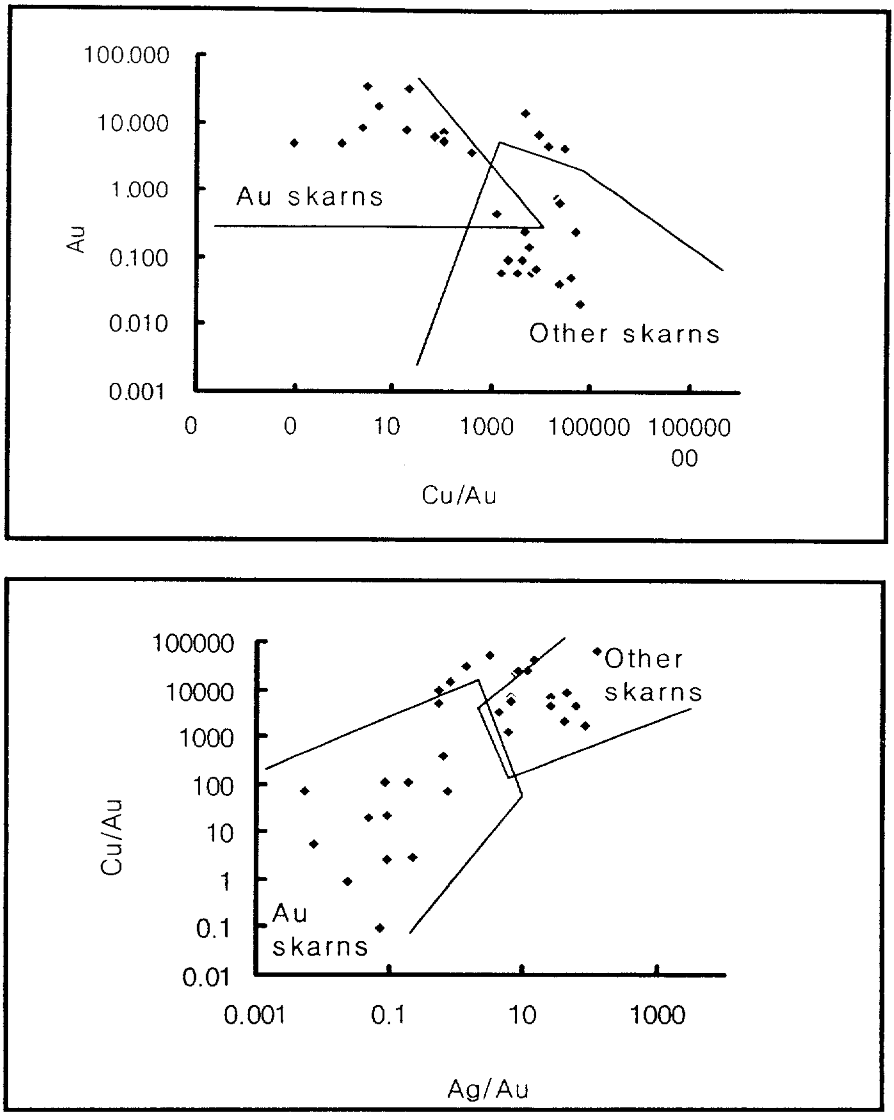

Figure 20. Plots of metal ratios in skarn minerals from Taebaegsan area (squre dots: this study). Fields of typical gold skarn and other skarn (from Ray and Webster, 1994).

5. Discussion

Concentration of significant Au and Cu resources in the Taebaegsan area and adjacent regions is closely related to their geologic and tectonic setting. Although the Au (Cu) skarns in this area are similar in comparison to the gold skarns in such areas as Nikel Plate, British Columbia, Canada, and Fortitude and McCoy, Nevada, USA (Ettlinger et al., 1992; Meinert, 1989; Ray et al., 1996), there are certain geological and geochemical differences and similarities between them. Important similarities that Taebaegsan shares with other gold skarns include the presence of abundant potassic alteration, association of gold mineralization with retrograde alteration, presence of late quartz-pyrite and gold grades in excess of 1 ppm. However, some differences between Taebaegsan and other gold skarns exist. Oxidized skarn mineralogy, and relatively high base metal contents are the most important differences between Taebaegsan and the major gold skarn deposits. As seen in Table 10, the differences in oxidation state among four gold skarns correlates well with gold grade, alteration style, and skarn mineralogy, and thus may be a useful diagnostic parameter in studying and classifying gold skarn deposits.

Tectonic environment: Tectonic structure must have contrubuted to make the limestone sheared or brecciated as well as to provide channel ways of fluids for forming the skarn and ore mineralizaion. Au (Cu) skarns in this Taebaegsan area occur in the island-arc volcanics (Park and So, 1972), and the gold skarns in British Columbia of Canada and the western USA occur in the island-arc or back-arc environments (Ray, 1998). Therfore, there are distinct similarities between the tectonic environments of the Au skarns in the Taebaegsan area compared to western North America.

Host rocks: Au (Cu) skarns are hosted by limestone, dolostone, shale, slate strata up to a few hundred meters thick, and the host rocks of the Au skarns of island-arc type are limestone, calcreous clastic or volcaniclastic strata (Meinert, 1989). Similar host rocks of Au skarns have controlled the skarn types and their oxidation environments. The presence of dolomite in the carbonate sequence is an important consideration as a source of Mg for the development of the magnesian skarn.

Related intrusion: The intrusions related to the Au (Cu) skarns of the Taebaegsan Basin are diorite, quartz diorite, granodiorite and quartz porphyry. And, the related intrusions of the island-arc type Au skarns are commonly relatively reduced gabbro, diorite, quartz diorite and granodiorite, with low Fe_2O_3/FeO ratios (<0.5) and low $^{87}Sr/^{86}Sr$ initial ratios (0.7038; Meinert, 1989).

Au-bearing skarns: Meinert (1989) have divided gold skarns into two types (reduced and oxidized). The abundance of pyroxene relative to garnet and the high ferrous/ferric ratios reflect the generally reduciong environment of gold skarns (Meinert, 1989; Meinert et al., 1997). Pyroxene-rich gold skarns tend to be hosted by siltstone-dominant packages and form in hydrothermal systems that are sulfur-rich and relatively reduced. Garnet-rich Au skarns tend to be hosted by carbonate-dominant packages and develop in more oxidizing and/or more sulfur-poor hydrothermal systems (Ray, 1998). Geodo deposits is relatively oxidized environment, the other hand, Yeonhwa II deposits is reduced environment. Only several sulfur isotope data of sulfide minerals are available (Table 3). Lee (1985) reported +1.66, -1.58

and -1.96 permils from pyrrhotite, sphalerite and chalcopyrite respectively. He pointed out relatively lighter values shown by sulfide minerals of this ore deposit than sulfur isotopes values obtained from other skarn ore deposits. Pyrite and pyrrhotite separated from one specimen of this deposit show +1.62 and +0.78 respectively. These values close to zero permil are assumed to indicate relatively pure sulfuric fluid originated from magma source, which was not more or less contaminated due to a short distance of transporting fluid. This may assume that Geodo deposit is oxidized relatively more than Yeonhwa deposit (+3.9 - +4.7 $\delta^{34}S$(‰)). Au skarns of the island-arc type are calcic, most of which are reduced, such as those in Nickel Plate, British Columbia, Canada and Fortitude, Nevada. However, oxidized Au skarns locally exist, such as those in McCoy, Nevada, USA (Ettlinger et al., 1992).

Ores: Au(Cu) skarn ores of the Taebaegsan area generally have a higher Au content (4 to 33 ppm) and a higher Cu content (o to 13%) in comparison with gold skarns in the island arc setting. The associated sulfides are composed mainly of pyrite, chalcopyrite. The gold skarns of the island-arc type have a low Cu, Pb, Zn (Ag) content, generally with Cu<0.5%, but have a higher Au content (2 to 15 g/t, median grade 8.6 g/t; Theodore et al., 1991).

As seen in Table 10, the differences in oxidation state among these four gold skarns correlates well with gold grade, alteration style, and skarn mineralogy, and thus may be a useful diagnostic parameter in studying and classifying gold-bearing skarn deposits.

Table 10. Comparisons of Au-Skarn deposits: Major Au-Skarns Depsits and Taebaegsan Area.

	Hedley district, BC	Fortitude, Nevada	McCoy, Nevada	Geodo, Korea
Skarn type	Reduced Au skarn	Reduced Au skarn	Oxidezed Au skarn	Oxidized Au skarn
Host rocks	Triassic siltstone, tuff, limestone lense	Pennsylvanian-Permian conglomerate, siltstone, limestone	Triassic limestone, dolostone, quartzite	Cambro-Ordovician limestone
Intrusive rocks	Dioritic intrusion (194-219Ma)	Granodiorite porphyry (38.5 Ma)	Granodiorite (38Ma)	Dioritic intrusion (73-107Ma)
Biotite Mb/Mg+Fe	0.35-0.55	0.65-0.70	0.47-0.65	
Ga : Px	0.2	0.4	2	2
Garnet Comp.	Ad 15-82	Ad30-100	Ad10-100	Ad28-63
Pyroxene Comp.	Hd0-100	Hd-100	Hd0-60	Hd21-77
Au Grade (g/t)	9	6.9	1.5	7.3
Cu Grade (g/t)	0.1	0.1	0.1	
Au (g/t) : Cu (%)	90	69	15	
Alteration with Au	Prograde Skarn	Prog.>>Retro.	Retro.>>Prog.	Retro.>>Prog.
Skarn mineralogy	And, Bt, Ga, Amp, K-f, Ep, Di	Bt, Px, Act, K-f, Ep, Chl	Ga, Px, Ep, Wo, Sc, Ad	Ga, Px, Ep, Bt, Chl
Opaque mineralogy	Ars, Loe, Py, Sph, Hed,Bi, Au, Gal, Dol	Po, Cp, Py, Ars, Mc, Sph, Gal, Bis	He, Py, Po, Au, Cp, Sph, Gal	He, Py, Au, Cp, Sph
Geochemical Signature	As, Bi, Tel, Co	As, Bi, Te, Cr, Ni	As, Bi, Te, Pb, Zn	Au, Ag, As, Sb
Iron Sulfide	Po>>Py	Po>>Py	Py>>Po	Py>>Po
K-Alteration in skarn	Common	Abundant	Abundant	Abundant

Abbreviation: Act-actinolite, Ad-adulalia, Amp-amphibole, And-andradite, Ars-arsenopyrite, Bt-biotite, Bis-bismuthinite, Bor-bornite, Cal-calcite, Cc-Calcocite, Cp-chalcopyrite, Chl-chlorite, Cpx-clinopyroxene, Dol-dolomite, Ep-epidote, Fl-fluorite, Gal-galena, Ga-garnet, He-hematite, Ka-kaolinite, Kf-K feldspar, Mc-marcasite, Mt-magnetite, Mol-Molybdenite, Phl-phlogopite, Pl-plagioclase, Py-pyrite, Po-pyrrhotite, Ptd-pentlandite, Qz-quartz, Rd-rhodonite, Shc-scheelite, Sid-siderite, Sph-sphalerite, St-stannite

6. Conclusion

1. Skarn deposits are classified as Au, Fe, Cu, W, and Pb-Zn type skarns by dominant economic metals. Gold skarn deposits are mined solely for their high gold contents.

2. The Taebaegsan Basin is composed of calcareous rocks and sandstone-shale of Paleozoic age, which were all intruded by mid-late Cretaceous to Tertiary granitic rocks. The sedimentary units are highly folded, and have numerous high angle thrust faults. Various skarn ore deposits of Fe-Cu, W-Mo, Pb-Zn as well as hydrothermal vein deposits are widely distributed in study area.

3. The result of geochemical analysis in the Taebaegsan skarn deposits, the gold content of ranges up to 22 ppm in the Yeonhwa Ⅱ Pb-Zn deposits and up to 14 ppm in the Geodo 78 adit. Au(Cu) skarn ores of the Taebaegsan area generally have a higher Au content (4 to 33 ppm) and a higher Cu content (o to 13%) in comparison with gold skarns in the island arc setting.

4. The log fS_2 and log fO_2 of fluid, forming the retrograde stage of the Geodo gold skarn is approximately -4 ~ +5 and -23 ~ -25, respectively. Gold is closely associated with Cu sulfides and exists mainly in the form of electrum.

5. The geochemical composition of some skarn samples and related granitoids in the Taebaegsan Basin are close to those of skarns from gold skarns British Columbia, Canada. Moreover, the geochemical composition of garnet and pyroxene that coexist with gold correspond with major gold skarn geochemical compositions.

6. Important similarities between Taebaegsan area and other gold skarn deposits are the presence of abundant potassic alteration, association of gold mineralization with retrograde alteration, presence of late quartz-pyrite and gold grades in excess of 1 ppm. Au (Cu) skarns in the Taebaegsan area occur in the island-arc volcanics and the gold skarns in British Columbia, Canada and Nevada, USA occur in the island-arc or back-arc environments. Therefore, there are distinct similarities between the tectonic environments of the gold skarns in the Taebaegsan area compared to western North America.

7. The tectonic setting, geology and igneous activity of the Taebaegsan area represent a similar lithology and complex geologic history to other major gold skarn deposits. There is high potential for discovery of more of gold skarn occurrences in the Taebaegsan Basin, Korea.

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태백산분지 내 스카른 금광상의 존재 가능성에 관한 연구

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스카른 광상은 금 스카른, 철 스카른, 구리 스카른, 텅스텐 스카른 및 연-아연 스카른 등으로 분류되며, 그 중 금 스카른은 타 광상에 비하여 금의 품위가 높아 금 자체만을 대상으로 개발되고 있다. 최근 여러 국가에서 스카른 금광상이 대규모 금 자원으로서의 중요성이 증대되고 있으며, 또한 국내에서도 과거 철, 구리, 및 연-아연 스카른 광상에서 금의 존재가 확인된 바 있으므로 새로운 이론과 탐사 기술에 의한 연구의 도입이 요청되고 있는 실정이다.

태백산 지역의 지질은 고생대의 석회암질, 셰일 및 사질 암층 등으로 이루어져 있고, 여러 곳에서 백악기 이후의 화강암류에 의하여 관입되어 있으며, 습곡과 스러스트 단층이 많이 발달해 있다. 이로 인해 규모가 크고 작은 접촉교대 내지 열수광상이 산재한다. 이러한 조건으로 외국의 대표적인 스카른 금광상과의 지질 및 광화작용의 특성을 비교하여 태백산 분지 내에서 스카른 금광상의 존재 가능성을 살펴보기 위해 기존 자료의 재해석과 선별된 시료의 화학분석을 통해 금의 부존을 확인하였다. 이를 위해 대표적인 광산별 스카른 및 광석광물을 선정하였으며, ICP 분석 및 전자현미분석을 실시한 결과, 제 2 연화광산의 휘석 스카른 대에서는 3~22 ppm까지의 금이 검출되었으며, 거도 광산 78갱에서도 4~14 ppm까지의 금이 검출되었다. 일부 금의 함량이 높은 시료에 대한 전자현미경 관찰에서도 엘렉트럼을 확인할 수 있었다. 거도 광산 78갱에서의 엘렉트럼은 석류석 스카른 대에서 적철석-황철석-황동석

의 공생관계로 존재하며, 특히 황동석이 풍부한 시료에서 금의 함량이 높게 나타났다. 이는 거도 광산의 스카른 금광화작용은 상대적으로 산화 환경에서 형성되었음을 알 수 있다. 이와 대조적으로 제 2 연화광산의 스카른 금광화작용은 황화광물이 아닌 휘석 스카른에서 금의 함량이 높게 나타났으며, 이로 인해 제 2 연화광산은 보다 환원 환경이며, 엘렉트럼은 초기의 스카른 광물 형성 단계에 침전되었음을 시사한다. 각각의 스카른에 대한 미량원소 분석결과를 Ray and Webster(1994)이 제안한 원소별 상관관계 표에 도시할 때 일부 스카른 광상은 스카른 금광상 영역에 도시되었다. 또한 엘렉트럼과 함께 공생하는 석류석과 휘석의 화학조성을 기존의 스카른 금광상에서 산출된 자료와 대비해 볼 때 태백산 지역의 금을 함유한 스카른 광상은 외국의 대표적인 스카른 금광상의 영역에 일치된다. 거도 광산의 금을 함유한 스카른대의 형성 조건은 광물 공생조합의 특성으로 볼 때 스카른 형성 온도를 400℃로 가정할 때 log fS_2=-4~-5과 log fO_2=-23~-25이며 탄산가스 분압은 약 1기압이다.

태백산 분지 내의 일부 스카른 광상은 관계화성암과 스카른 광화작용 등의 지구화학적 특성으로 볼 때 외국의 대표적인 스카른 금광상의 광화작용과 유사한 특성을 띠며, 동시에 국부적으로 높은 품위의 금을 함유하고 있어 스카른 금광상의 잠재력이 높다고 할 수 있다.