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Hydrothermal alteration and mineralization of porphyry-skarn deposits in the Geunteut area, Nanggroe Aceh Darussalam, Indonesia

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Abstract: The Geunteut area is located 55 km south of Banda Aceh. The research was conducted to characterize the hydrothermal alteration and mineralization of the porphyry-skarn deposits. The alterations and mineralizations were described according to their association and zonation of the hydrothermal minerals, alteration intensity, texture and ore mineral paragenesis. The porphyry-skarn deposits in the Geunteut area are related to the magmatic activity in Middle Miocene by granodiorite and diorite intrusions (Intrusion Rock Units) that resulted in the hydrothermal alteration and mineralization. Hydrothermal alteration can be grouped into five zones: biotite-orthoclase-actinolite, epidote-chlorite-actinolite, garnet-clinopyroxene-tremolite, quartz-sericite and chlorite-calcite-clinoptilolite. The forming temperature of the hydrothermal alteration is between 120 – 360°C with the intensity ranging from very weak to totally altered. The porphyry-skarn deposits exhibit two episodes of mineralization. The early episode was related to the hypogene mineralization, as evidenced by the formation of magnetite, ilmenite, chalcopyrite and pyrite. The late episode was related to the supergene enrichment that allowed the formation of chalcocite, covellite, iron oxide and malachite.

Keywords: hydrothermal alteration, mineralization, porphyry, skarn, Geunteut

INTRODUCTION

The research was carried out in the Geunteut area, Aceh Besar District, Nanggroe Aceh Darussalam Province, Indonesia. This area is located about 55 km towards the south of Banda Aceh (Figure 1), between the coastal land of west Sumatra and the margin of Bukit Barisan Mountains. The topographical elevation ranges between 10 m to 1075 m above sea level.

This paper describes briefly the hydrothermal alteration and mineralization of the porphyry-skarn deposits in the Geunteut Area, including the association and zonation of the hydrothermal minerals, the alteration intensity, the texture and the ore mineral paragenesis.

METHODOLOGY

Detailed geological mapping and field observations of the hydrothermal alteration and mineralization were carried out, and more than 166 samples were collected. A detailed hydrothermal alteration and mineralization study was carried out using polarizing and ore microscopes, and X-ray diffractometer (XRD). The results of these studies were integrated with field mapping data.

REGIONAL GEOLOGY

The Sumatra Island is the northwest oriented physiographic expression, positioned on the western edge of Sundaland, of the southern extension of the Eurasian continental plate. The Sumatra island is interpreted to be constructed by collision and suturing of discrete microcontinents in late Pre-Tertiary times (Pulunggono & Cameron, 1984). Deformation, magmatic activity and mineralization in Sumatra is related to subduction zones of the Australian-Indian plate beneath the Eurasian plate. The present-day subduction rate of the Indian plate is between 6 and 7 cm/yr.

The regional tectonic setting of Sumatra and a simplified geological map of Banda Aceh is illustrated in Figure 2. The regional stratigraphy of the research area comprises theWoyla Group, which is of Late Jurrasic to Early Cretaceous age. The Woyla Group is divided into the West Woyla Group and the East Woyla Group (Bennett *et al.*, 1981). The research area is located within the West Woyla Group, consists of the Bentaro Volcanic Formation and the Lamno Limestone Formation. These formations were intruded into by the Geunteut Granodiorite (14.3 ± 0.5 Ma), and subsequently covered by recent alluvium.

GEOLOGY OF GEUNTEUT AREA

The stratigraphy of the Geunteut area is consist of the Volcanic Rock Unit comprising olivine basalt, pyroxene basalt, volcanic breccia and vitric tuff, aged between the Late Jurrasic-Early Cretaceous. Overlying the volcanic rock, is a unconformable Limestone Rock Unit. The limestone consists of mudstone and wackestone, aged between the Late Jurrasic-Early Cretaceous. Both of these units were intruded by the Intrusion Rock Unit consisting of granodiorite stock and a diorite dyke, dated as Middle Miocene. This intrusion caused contact metamorphism and a resulting metamorphic rock unit comprises hornfels and marble. All the rock units are overlain uncomformably by Recent alluvial sediments consisting of unconsolidated clay to boulder-sized materials.

The geological structures developed in this area are shear joints, breccias, mylonites and faults. All the faults have sinistral strike-slipe displacement. They are the i) Alur

Beuso fault, ii) Krueng Beuso fault, iii) Alur Pulo I fault and iv) Krueng Alublahan (Figure 3).

HYDROTHERMAL ALTERATION

The mineralization and related alteration assemblages in the Geunteut area have been investigated by geological mapping and detailed petrographic studies and XRD analysis of a large number of samples. The hydrothermal alteration and mineralization at the Geunteut deposits are centred around the stock and are broadly synchronous with its emplacement. All of the rock samples were altered with variation in intensity and alteration types. The alteration intensity are described based on the percentage of the alteration, which ranges from very weak (1-10%), weak (11-30%), moderate (31-50%), strong (51-70%), very strong (71-90%), and total alteration (91-100%).

The temperature range of the alteration zone were based on the information compiled by Kingston & Morrison (1997). The alteration zones were characteristized by the mineral assemblages and their associations, which were formed at the same conditions. The hydrothermal alteration in the Geunteut area can be grouped into five zones: biotite-orthoclase-actinolite, epidote-chlorite-actinolite, garnet-clinopyroxene-tremolite, quartz-sericite and chlorite-calcite-clinoptilolite. The hydrothermal alteration zone map of Geunteut area is illustrated in Figure 4.

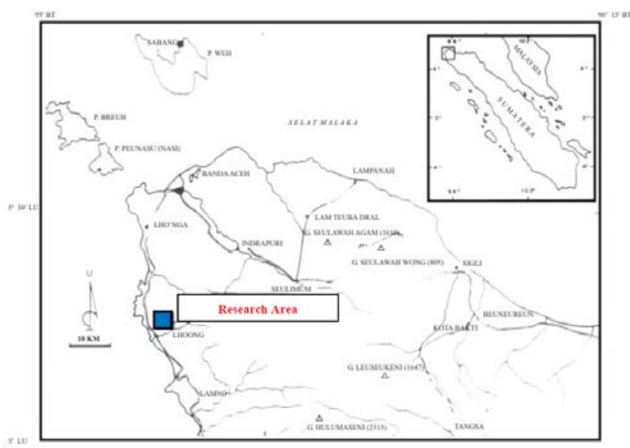

Figure 1: Location of the Geunteut area.

Biotite-orthoclase-actinolite zone

The earliest alteration is represented by biotite-orthoclase-actinolite mineral assemblages (Figure 5). Other alteration minerals observed are quartz, calcite, tremolite and opaque minerals. Generally this zone is present in olivine basalt, granodiorite and diorite. Alteration intensity is interpreted to be from moderate to total (33-100%). Forming temperatures of the hydrothermal alteration were thus between 310 – 360°C (Figure 6). The zone of biotite-orthoclase-actinolite are comparable with the potassic alteration type (Corbett & Leach, 1997).

Epidote-chlorite-actinolite zone

The second alteration is represented by epidote-chlorite-actinolite mineral assemblages (Figure 5). Other alteration minerals observed are quartz, calcite, orthoclase and opaque minerals. This zone is generally present in the pyroxene basalt, volcanic breccia, vitric tuff, granodiorite, diorite and hornfels. Alteration intensity is from weak to total (24%-100%). Forming temperature of hydrothermal alteration were thus 310 – 320°C (Figure 6). The zone of epidote-chlorite-actinolite are comparable with the inner propylitic alteration type (Corbett & Leach, 1997).

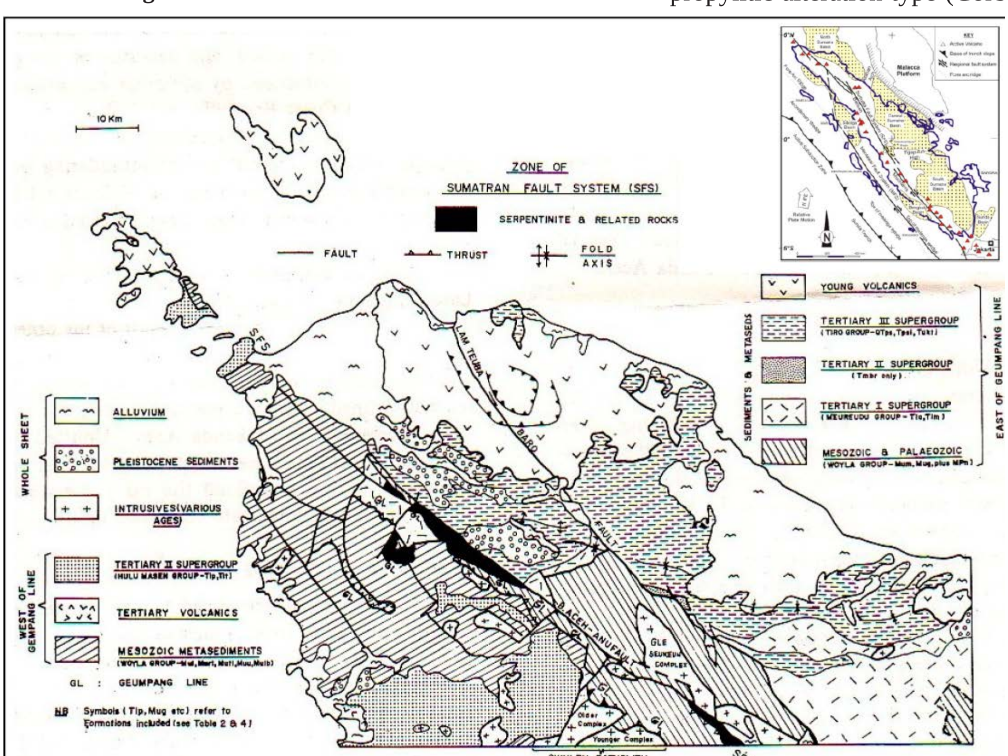

Figure 2: Regional tectonic setting of Sumatra and simplified geological map of Banda Aceh (Bennett *et al.*, 1981).

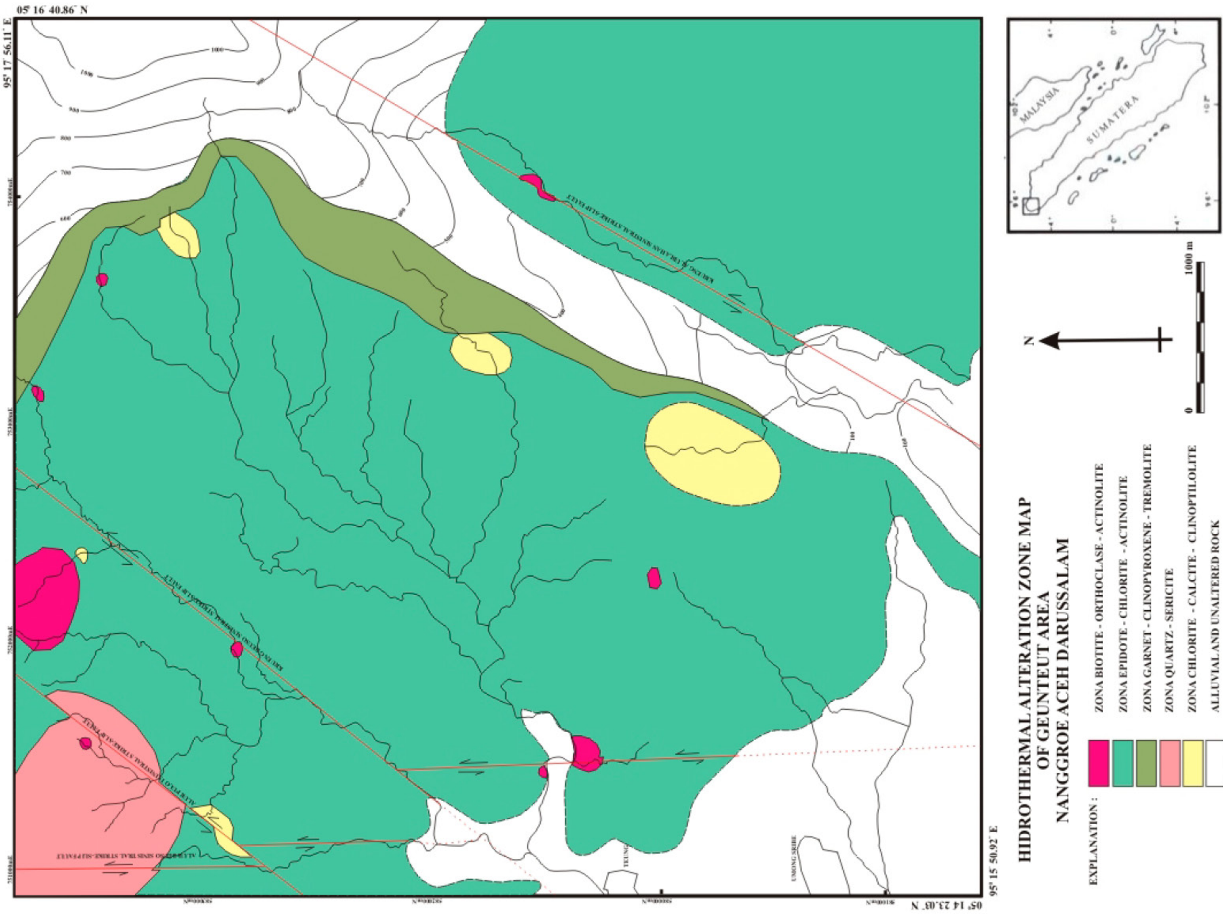

Figure 4: Hydrothermal alteration zone map of the Geunteut area.

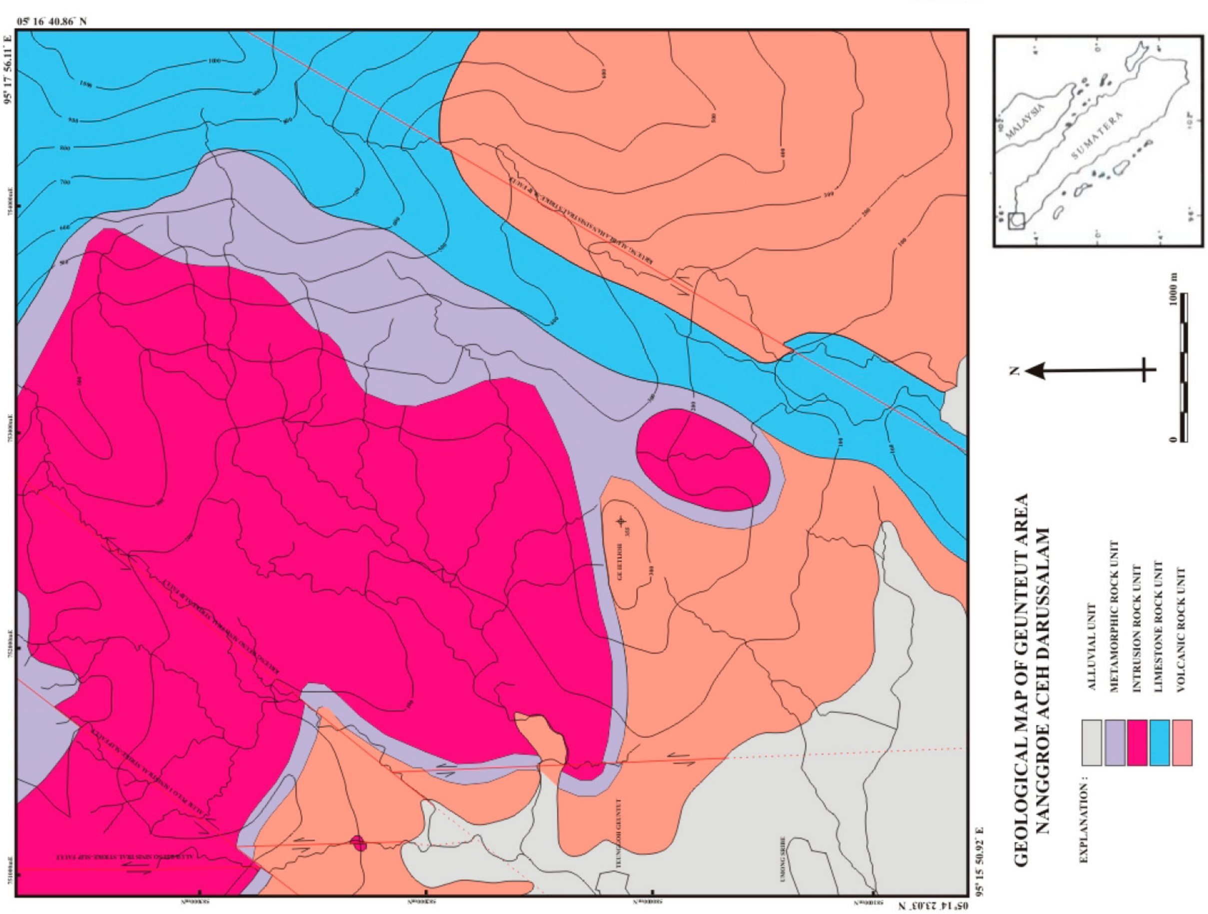

Figure 3: Geological map of the Geunteut area.

Garnet-clinopyroxene-tremolite zone

The third alteration is represented by garnet-clinopyroxene-tremolite mineral assemblages (Figure 5). Other alteration minerals observed are quartz, calcite, actinolite and opaque minerals. This zone is generally present in marble and overprinting the epidote-chlorite-actinolite zone. The alteration intensity is weak (19%-30%) and was formed between 310 – 360°C (Figure 6). Zone of garnet-clinopyroxene-tremolite are comparable with the skarn alteration type (Corbett & Leach, 1997).

Quartz-sericite zone

The fourth alteration is represented by quartz-sericite mineral assemblages (Figure 5). Other alteration minerals observed are calcite, pyrophylite, clay mineral and opaque minerals. This zone is generally present in granodiorite and seen overprinting the biotite-orthoclase-actinolite zone and the epidote-chlorite-actinolite zone. The alteration intensity was from very weak to strong (7%-56%). Forming temperatures of hydrothermal alteration are interpreted to be between 280° – 340°C (Figure 6). The zone of quartz-sericite are comparable with the phyllic alteration type (Corbett & Leach, 1997).

Chlorite-calcite-clinoptilolite zone

The last alteration is represented by chlorite-calcite-clinoptilolite mineral assemblages (Figure 5). Other alteration minerals observed are quartz, albite, clay and opaque minerals. This zone is generally present in granodiorite, hornfels and overprinting garnet-clinopyroxene-tremolite zone. The alteration intensity is from strong to total (60%-100%). Forming temperature of hydrothermal alteration were betwen 120 – 150°C (Figure 6). The zone of chlorite-calcite-clinoptilolite are comparable with the sub propyilitic alteration type (Corbett & Leach, 1997).

MINERALIZATION

Mineragraphic analysis was conducted on the polished sections of skarn ore to determine the ore minerals and texture. The textural analysis was used for the interpretation of the paragenesis, the deposit type and the forming process of the ore minerals. The ore and gangue mineral assemblages show primary and secondary textures. The primary texture observed are inclusions and intergrowth textures, formed during the cooling of the silicate melt. The secondary textures observed are replacement and exolution textures, not related to the cooling of the silicate melt.

Inclusion texture was observed in sample RO 144, where chalcopyrite forms inclusion in pyrite, and sample RO 148 with chalcopyrite enclosed within magnetite (Figure 7F). Intergrowth texture was observed in sample RO 144, with intergrowth observed between magnetite and ilmenite and magnetite and chalcopyrite (Figure 7C). In sample RO 145 the intergrowth observed was between chalcopyrite and

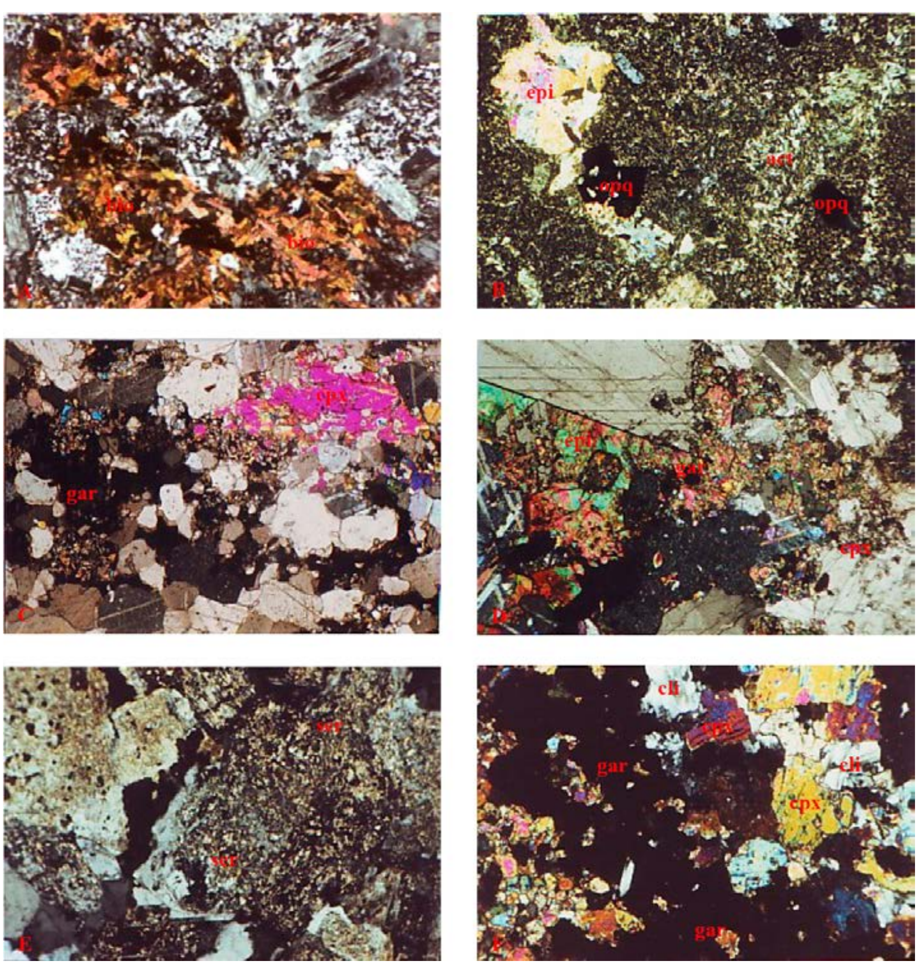

Figure 5: Petrographic photographs: A. Diorite, plagioclase altered by secondary biotite (bio). B. Pyroxene basalt, mafic mineral altered to epidote (epi) and opaque mineral (opq), groundmass altered to actinolite (act). C. Marble, calcite altered to garnet (gar) and clinopyroxene (cpx). D. Marble, calcite altered to epidote (epi), epidote overprinted by garnet (gar) and clinopyroxene (cpx). E. Granodiorite, plagioclase/k-feldspar altered to sericite (ser). F. Skarn composed of garnet (gar) and clinopyroxene (cpx), than overprinted by clinoptilolite (cli).

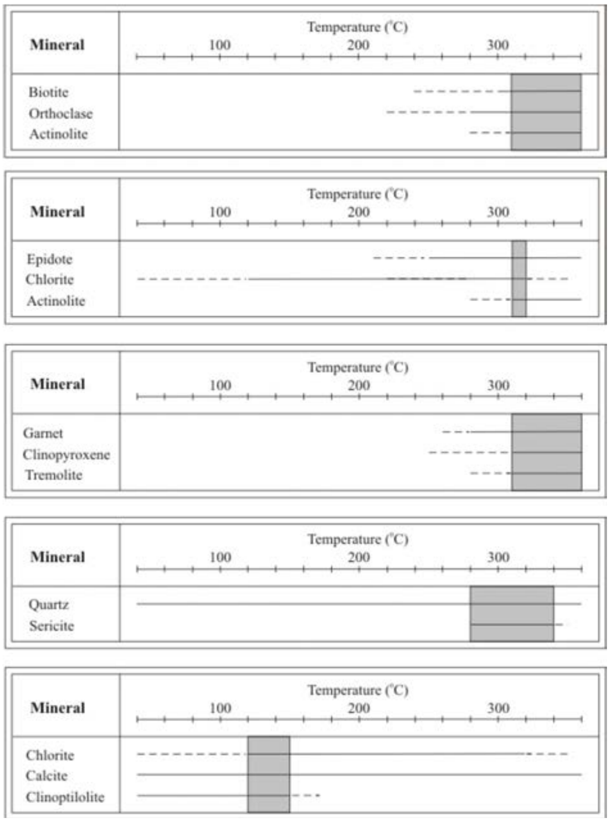

Figure 6: Temperature range of hydrothermal alteration zones.

pyrite, magnetite and ilmenite (Figure 7D) and magnetite and pyrite (Figure 7E), and in sample RO 148 the intergrowth observed was between chalcopyrite and magnetite.

Replacement texture was observed in the following samples;

1. sample RO 69, where pyrite has been replaced by magnetite (Figure 7A),
2. sample RO 75, where chalcopyrite was replaced by chalcocite, covelite, magnetite and gangue mineral (Figure 7B),
3. sample RO 144, where chalcopyrite and pyrite were replaced by chalcocite and gangue mineral,
4. sample RO 145, where chalcopyrite was replaced by ilmenite and chalcocite (Figure 7D), pyrite replaced by covelite, chalcocite and malachite (Figure 7E), and
5. sample RO 148, where chalcopyrite was replaced by pyrite.

Exolution texture was observed in sample RO 69, where exolution was between magnetite and ilmenite (Figure 7A). Based on the mineragraphic analysis of the ore mineral assemblage and their texture, the ore mineral paragenesis in Geunteut area is shown in Figure 8.

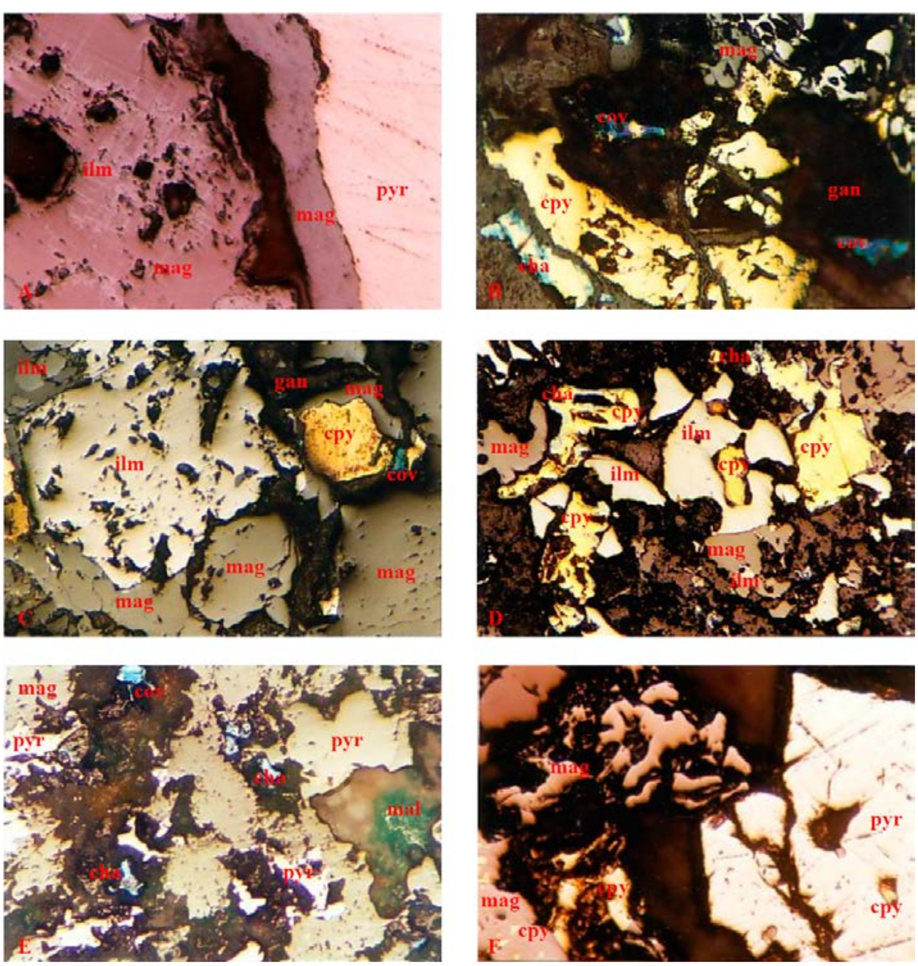

Figure 7: Mineragraphic photographs: A. Replacement texture, pyrite (pyr) replaced by magnetite (mag), and exolution texture of magnetite (mag) and ilmenite (ilm). B. Replacement texture, chalcopyrite (cpy) replaced by chalcocite (cha), covellite (cov), magnetite (mag) and gangue mineral (gan). C. Intergrowth texture between magnetite (mag), ilmenite (ilm), chalcopyrite (cpy), and replacement texture, chalcopyrite (cpy) replaced by covellite (cov) and gangue mineral (gan). D. Intergrowth texture between magnetite (mag), ilmenite (ilm), chalcopyrite (cpy), and replacement texture, chalcopyrite (cpy) replaced by covellite (cov). E. Intergrowth texture between magnetite (mag) and pyrite (pyr), and replacement texture, pyrite (pyr) replaced by covellite (cov), chalcocite (cha) and malachite (mal). F. Inclusion texture, inclusion of chalcopyrite (cpy) in magnetite (mag), and replacement texture, chalcopyrite (cpy) replaced by pyrite (pyr).

DISCUSSION

Porphyry copper deposit systems are hydrothermal deposits that have a genetic relationship between cooling and emplacement of shallow porphyry intrusion, with extensive dispersed alteration and mineralization (Einaudi, 1995; Pollard *et al.*, 1997). Porphyry deposits related to the skarn alteration type are related to the emplacement of a shallow porphyry intrusion in calcareous rock.

Skarns are rocks comprising Ca-Fe-Mg-Mn silicates formed by the replacement of carbonate-bearing rocks during regional or contact metamorphism and metasomatism (Einaudi *et al.*, 1981), in response to the emplacement of a intrusion of varying compositions. Skarns can therefore be regarded as a specific type of alteration within a porphyry environment.

Skarn evolution occurs in response to three main sequential processes: prograde isochemical skarns, prograde metasomatic skarns, and retrograde skarns (Corbett & Leach, 1997). Prograde isochemical skarns develop in settings in which intrusions (Intrusion Rock Unit) are emplaced into calcareous sediments (Limestone Rock Unit) and the Volcanic Rock Unit with little or no introduction of chemical components, that result in the formation of hornfels and marble (Metamorphic Rock Unit) also causing hydrotermal alteration in this volcanic rocks. The skarns development is controlled predominantly by temperature and host rock composition and texture within a predominantly conductive regime.

Prograde metasomatic skarns are characterized by the exchange of H_2O, silica, aluminium and iron, exsolved from the crystallizing intrusion, with CO_2, calcium and magnesium derived from the calcareous sediments (Corbett & Leach, 1997). Minerals (garnet, clinopyroxene, tremolite) formed during metasomatic processes overprint and commonly replace, earlier metamorphic mineral phases and are characteristically coarser grained.

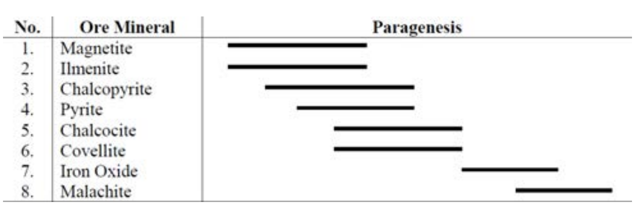

Figure 8: Ore mineral paragenesis in the Geunteut area.

Retrograde skarns form in settings in which temperatures decline and fluid compositions become dominated by meteoric waters, especially where skarns develop at shallow crustal levels. Retrograde alteration is characterized by the replacement of earlier prograde anhydrous minerals by late stage hydrous mineral phases such as epidote, amphiboles, chlorite and clays. This reflects the leaching of calcium and introduction of volatiles (Corbett & Leach, 1997). This is the main mineralization event. Sulfides and minor iron oxides occur as disseminations, or within veins which transect prograde skarns and may form massive replacements of marble. The sulfides are interpreted to have been deposited in response to either decreasing temperatures, neutralization of hydrothermal solution (especially at the marble contact), or changes in oxidation state of the fluids. Evolution model of skarn deposits in Geunteut area is shown in Figure 9.

Assemblages and association of alteration minerals in the Geunteut area reflect conditions of neutral or near neutral pH that contain medium-high chloride fluids (Cl), low CO_2 and condition of acid pH. Conditions of neutral to near neutral pH are characterized by biotite-orthoclase-actinolite zones and epidote-chlorite-actinolite zone, garnet-clinopyroxene-tremolite zone and chlorite-calcite-clinoptilolite zone. The condition of acid pH was characterized by the quartz-sericite zone. The hydrothermal alteration minerals were form at temperatures of 120 - 360°C.

Based on ore mineral paragenesis, mineralization in the Geunteut area took place in two episodes: early hypogene and late supergene episodes. The early episode was related to hypogene mineralization as evidenced by the formation of magnetite, ilmenite, chalcopyrite and pyrite. The late episode was related to the supergene enrichment that was evidenced by the formation of chalcocite, covellite, iron oxide and malachite.

The deposit system in the Geunteut area can be grouped into porphyry copper deposits related to the skarn deposits, and characterized by the presence of biotite-orthoclase-actinolite assemblages which indicate porphyry copper deposits and garnet-clinopyroxene-tremolite assemblages which indicate skarn deposits.

<table>
<tr><td colspan="2">Evolution Model of Skarn Deposits (Corbett & Leach, 1997)</td><td>Evolution Model of Skarn Deposits in the Geunteut area</td></tr>
<tr><td colspan="2">Prograde Isochemical Skarns</td><td>Occurrence of contact metamorphism forming hornfels and marble. Also a sequence of alteration zones in the intrusion and non-reactive wall rock ranging from biotite-orthoclase-actinolite zone (potassic) and epidote-chlorite-actinolite zone (inner propylitic)</td></tr>
<tr><td colspan="2">Prograde Metasomatic Skarns</td><td>Occurrence of metasomatic processes overprinting and replacing earlier metamorphic phases, characterized by garnet-clinopyroxene-tremolite zone (skarn)</td></tr>
<tr><td rowspan="3">Retrograde Skarns</td><td>Phyllic Overprinting</td><td>Characterized by quartz-sericite zone (phyllic) that partly overprintg biotite-orthoclase-actinolite zone (potassic) and epidote-chlorite-actinolite zone (inner propylitic)</td></tr>
<tr><td>Sub-Prophylitic Overprinting</td><td>Characterized by chlorite-calcite-clinoptilolite zone (sub propyilitic) that overprint garnet-clinopyroxene-tremolite zone (skarn)</td></tr>
<tr><td>Mineralization</td><td>Occurrence of mineralization of skarn deposits, consisting of magnetite - ilmenite - chalcopyrite - pyrite - chalcocite - covellite - iron oxide - malachite</td></tr>
</table>

Figure 9: Evolution model of skarn deposits in the Geunteut area.

CONCLUSION

Hydrothermal alteration and mineralization of the Geunteut area can be concluded as follows:-

- Hydrothermal alteration in the Geunteut area are found in most of rock units. Variations of alteration intensity range from very weak (7%) to totally altered (100%).
- Hydrothermal alteration in the Geunteut area can be grouped into five zones: biotite-orthoclase-actinolite, epidote-chlorite-actinolite, garnet-clinopyroxene-tremolite, quartz-sericite and chlorite-calcite-clinoptilolite. Forming temperature of hydrothermal alteration are estimated to be between 120 – 360°C.
- Mineralization in the Geunteut area occured in two episodes: early episode is related to hypogene mineralization as evidenced by the formation of magnetite, ilmenite, chalcopyrite and pyrite, and the late episode which was related to the supergene enrichment as indicated by the formation of chalcocite, covellite, iron oxide and malachite.
- Deposit systems in the Geunteut area can be grouped into porphyry copper deposits that are related to the skarn deposits, and characterized by the presence of biotite-orthoclase-actinolite assemblages, which indicate porphyry copper deposits, and garnet-clinopyroxene-tremolite assemblages that indicate skarn deposits.
- Hydrothermal alteration and mineralization in the Geunteut area are related to the magmatic activity of the granodiorite and diorite intrusions (Intrusion Rock Units) of the Middle Miocene.

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