RACHADAPISEKSOMPOJ RESEARCH FUND

A REPORT ON
COPPER SKARN DEPOSIT AT PHU LON, AMPHOE SANG KHOM
CHANGWAT NONG KHAI

BY

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CHULALONGKORN UNIVERSITY

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Project Title : Copper skarn Deposit at Phu Lon, Amphoe Sang Khom, Changwat Nong Khai

Name of the Investigators : Visut Pisutha-Arnond, Sirichai Sunmanee and Sudham Yaemniyom

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ABSTRACT

Based on the geological and petrographical studies and chemical analysis of drill-core and outcrop samples, the geology and mineralization at the Phu Lon area are revealed. The Phu Lon prospect is a Cu-Fe-Au-Ag skarn deposit of porphyry-related type. The copper- and iron-rich zones are hosted prodominantly in the garnet-pyroxene skarn that is developed metasomatically at the contact between the diorite-monzodiorite intrusions and a marble with minor calcsilicate unit. The main stage of iron mineralization probably took place during the prograde garnet-pyroxene skarn formation and was genetically related to the diorite-monzodiorite. The ore minerals include magnetite, minor chalcopyrite and pyrite, and occur in the form of massive patches or bands in the skarn. Quartz monzonite porphyry - monzonite dikes/stocks post-date the diorite-monzodiorite and the garnet-pyroxene skarn. Extensive alterations overprinting on both intrusive and volcanic rocks (i.e., potassic,

phyllic and propylitic) are probably related to the cooling of quartz monzonite porphyry - monzonite. Close accompanying the alterations, the main stage of copper mineralization and retrograde skarn alteration of epidote-chlorite-calcite commenced. The mineralization occurs in the form of chalcopyrite-pyrite-quartz veins/veinlet networks prodominantly in the skarn unit. Other associated minerals include magnetite, hematite and molybdenite. Trace amounts of gold and silver are chemically detected and probably associated with the copper mineralization. Their contents are comparable to those of the similar copper-gold deposit class. It is attractive for persuading further exploration.

ชื่อโครงการวิจัย : แหล่งแร่ทองแดง บริเวณหินแปรสัมผัสที่ภูโล้น อำเภอสังคม จังหวัดหนองคาย

ชื่อผู้วิจัย : วิสุทธิ์ พิสุทธอานนท์, ศิริชัย สรรมณี, สุธรรม แย้มนิยม

เดือนและปีที่ทำวิจัยเสร็จ: เมษายน 2531

<u>บทคัดย่อ</u>

จากการศึกษาทางธรณีวิทยา ศิลาวรรณนา และการวิเคราะห์ทางเคมีของแท่งหินจากหลุมเจาะและตัวอย่างหินพื้นผิว ทำให้ทราบถึงธรณีวิทยาแหล่งแร่ และสภาพการเกิดแหล่งแร่ที่บริเวณภูโล้น ภูโล้นเป็นแหล่งแร่ทองแดง-เหล็ก-ทองคำ-เงิน ในหินแปรสัมผัสสการ์นที่เกี่ยวพันธ์กับพอไพรี โซนที่มีทองแดงและเหล็กมากมักจะอยู่ในหินสการ์น ชนิดการ์เนต ไพรอกซีน ที่เกิดการแปรสภาพโดยการแทนที่บริเวณรอยสัมผัสระหว่างหินอัคนีแทรกซ้อน ชนิดไดออไรต์-มอนโซไดออไรต์ กับหินอ่อนที่แทรกสลับเล็กน้อยด้วยหินแคลก์ซิลิเกต ช่วงสำคัญที่แร่เหล็กตกผลึกมากน่าจะเกิดขึ้นพร้อม ๆ กับการเกิดโพรเกรด การ์เนตไพรอกซีน สการ์น และมีสายสัมพันธ์กับหินไดออไรต์-มอนโซไดโอไรต์ สินแร่เหล็กที่พบคือ แมกนีไทต์ และมีคาลโคไพไรต์ปนอยู่จำนวนเล็กน้อย สินแร่เหล็กมักเกิดในลักษณะที่เป็นแนวหรือแถบที่ค่อนข้างเนื้อแน่นในหินสการ์น ลำหินหรือผนังหินอัคนีชนิด ควอรตซ์ มอนโซไนต์ พอไพรี - มอนโซไนต์ แทรกดันขึ้นมาภายหลังหินไดออไรต์-มอนโซไดออไรต์ และหินการ์เนต ไพรอกซีน สการ์น การเปลี่ยนสภาพไปจากเดิมของหินอัคนีแทรกซ้อนและหินภูเขาไฟ (เช่น ขบวนการแปรสภาพ โพแตสซิก ฟิลลิก และโพรไพลิติก) น่าจะเกี่ยวพันกับการเย็น

ตัวของหิน ควอรตซ์ มอนโซไนต์ พอไฟรี-มอนโซไนต์ ในขณะที่มีการเปลี่ยนสภาพไปจากเดิมของหินอัคนีแทรกซ้อน และหินภูเขาไฟนั้น จะเป็นช่วงที่แร่ทองแดงตกผลึกมาก และเป็นช่วงที่มีการเปลี่ยนสภาพแบบ รีโตรเกรดสการ์นที่ได้แร่เอพิโดต-คลอไรต์-แคลไซต์ การเกิดแร่จะปรากฏในลักษณะสายแร่คาลโคไพไรต์-ไพไรต์-ควอรตซ์ เล็กๆ ที่ประสานไปมาอยู่ในสการ์น แร่อื่นๆ ที่เกิดร่วมอยู่ด้วยมี แมกมีไทต์, ฮีมาไทต์ และโมลิบดีไนต์ มีธาตุทองคำและเงินปนอยู่ด้วยในปริมาณที่สามารถตรวจสอบด้วยวิธีทางเคมี และเข้าใจว่าธาตุทองคำและเงินน่าจะเกิดร่วมอยู่กับการเกิดสินแร่ทองแดง ธาตุทองคำและเงินที่พบมีปริมาณที่ใกล้เคียงกับแหล่งแร่ชนิด ทองแดง-ทอง ที่พบทั่วไป ดังนั้นแหล่งแร่ที่ภูโล้นจึงน่าสนใจที่ควรจะดำเนินการสำรวจต่อไป

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INTRODUCTION

The Phu Lon prospect is situated near the Thai-Laos International Boundary at Ban Noi, Amphoe Sang Khom, Changwat Nong Khai (Figure 1). The Department of Mineral Resources (DMR) was conducted an exploratory core-drilling program in 1983 with the combined total depth of 1450 meters on this prospect, a follow-up of the detailed soil geochemical and geophysical surveys. The diamond drill-holes (DDHs) intersect several sections of interesting copper and iron mineralized zones. In the following years, native gold was found by panning in stream sediments draining from the Phu Lon I and II hills.

Of particular interest is that this area is attractive not only in terms of its valuable subsurface information but also of its potential as an economic mineral deposit. This project was therefore initiated with the purpose of delineating the geology and mineralization in this area. A few numbers of chemical analysis for gold, silver, copper and molybdenum were also carried out in order to fully evaluate the type and nature of this mineral prospect.

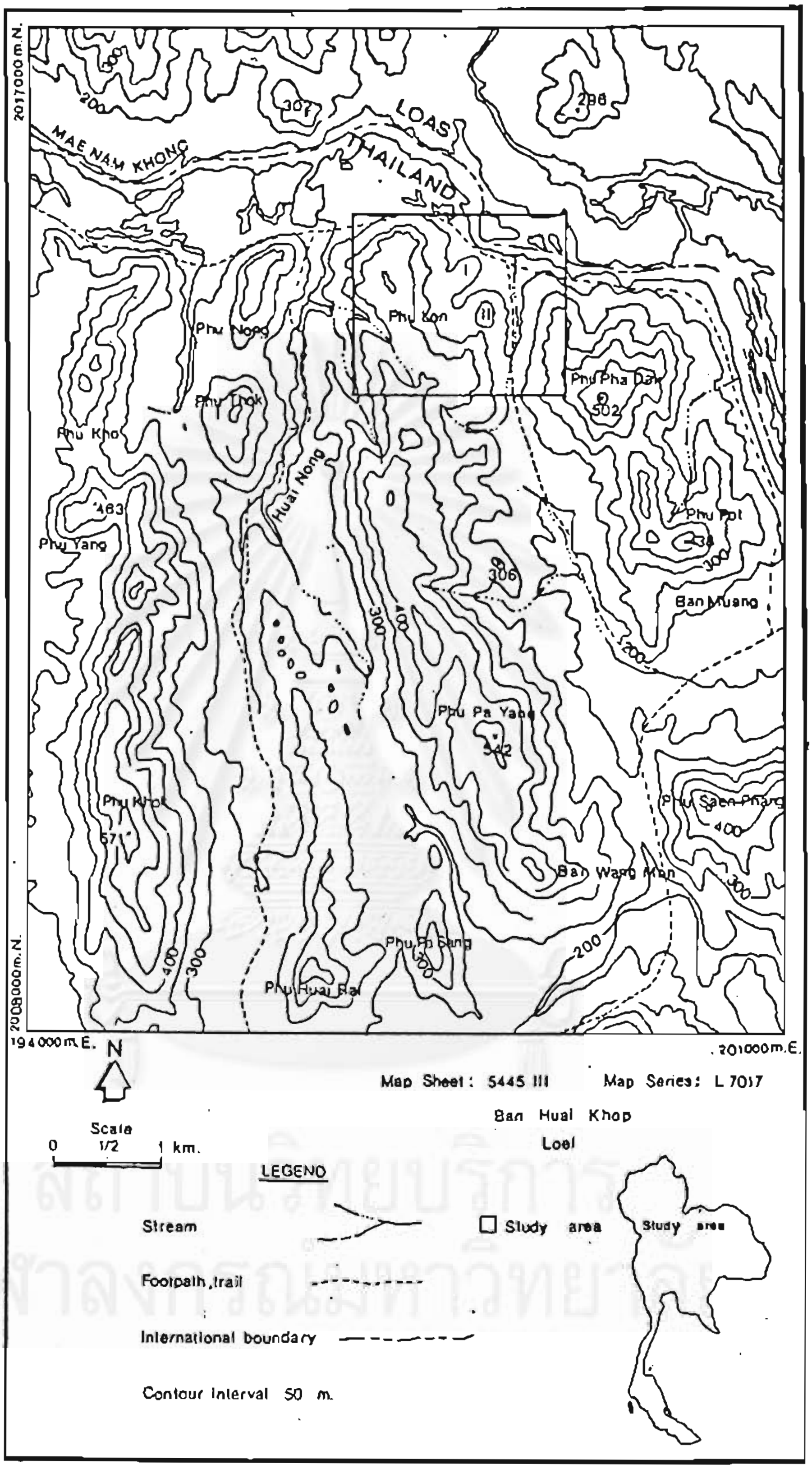

Figure 1 Topographic map showing location of the study area.

PROCEDURE

A flow chart for the study methodology is displayed in Figure 2. The data obtained from the literature survey include published and unpublished geological works related to the area (i.e., Yeamniyom et al., 1983; Yeamniyom, 1985; Chonglakmani et al., 1979; Dhitiprivat, 1977) and geological-log data. Most of these data are reconnaissance in nature.

Field investigations were conducted during 10th-12th September, 1985, 16th-23rd January, 1987 and 1st-10th April, 1987 to examine surface geology of the Phu Lon area in Changwat Nong Khai and to study subsurface geology from the drill-core sample collection at the DMR's Branch Office in Amphoe Muang, Changwat Loei. A total depth of 1450 meters of continuous core samples from 12 DDHs were studied and sampling. Approximately 150 samples of cores and outcrops were collected for laboratory study.

At the Geology Department, Chulalongkorn University, most of the core and outcrop samples were slab-cut into half for a megascopic examination and locating areas on the slabbed surface where thin sections, polished sections and/or polished-thin sections should be made for the detailed petrographic study. Approximately 170 thin

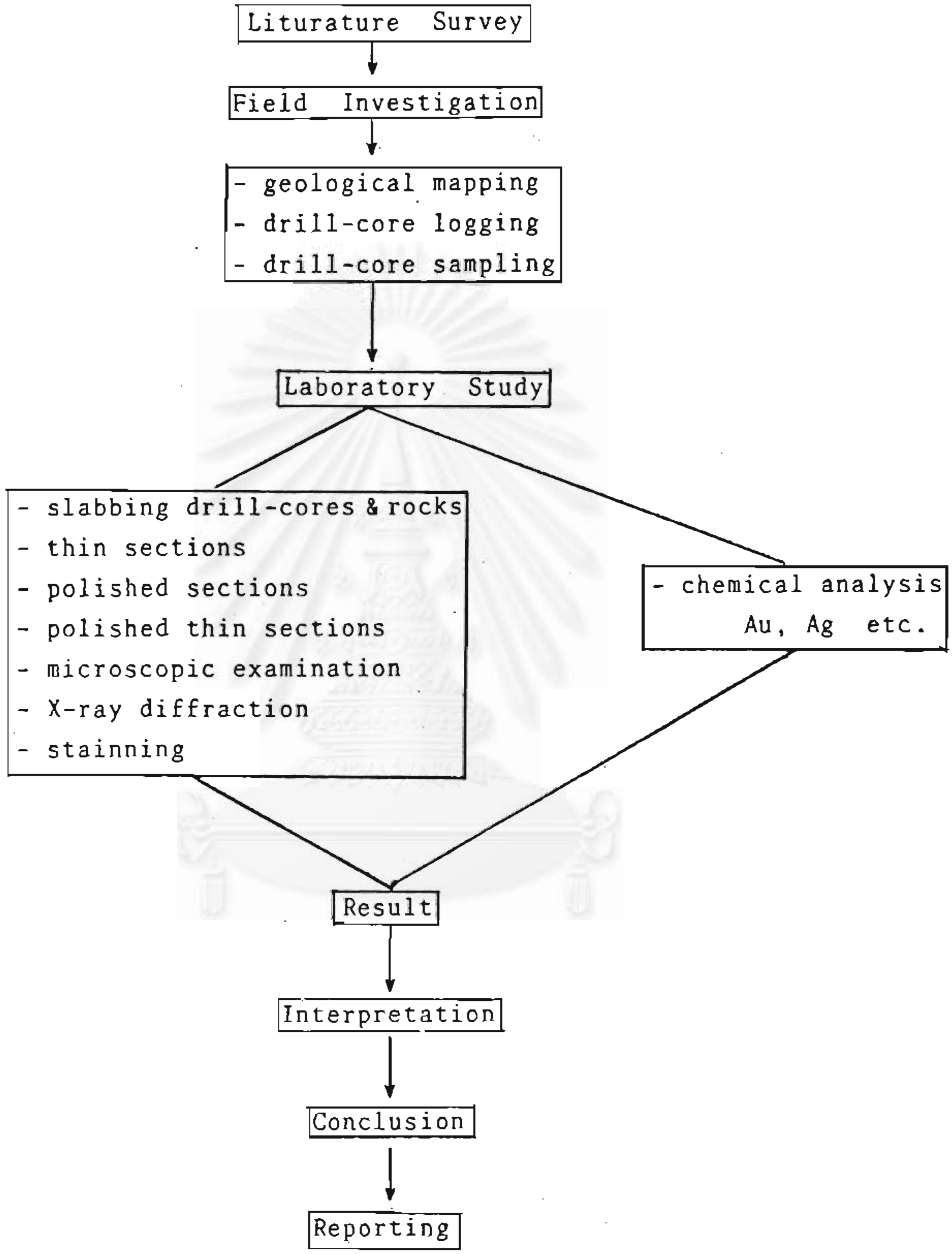

Figure 2 Flow chart of the study methodology.

sections and 40 polished sections and polished-thin sections were made in this study. The petrographic examination on those sections were undertaken under a polarizing transmitted-and reflected-light microscope. The complementary analyses by X-ray diffraction (XRD) and stainning technique were also performed on some samples.

The percentages of mineralogical constituents in the intrusive rocks were visually estimated from the thin sections. However, the names of all the intrusive rocks are classified on the basis of those recommened by IUGS Subcommission (after Streckeisen, 1974).

Of 150 core samples, 19 which represent varieties of mineralized and hydrothermally altered specimens, were selected for the chemical analysis. The sample preparation for the chemical analysis was performed at the Geology Department, Chulalongkorn University. One half of the selected samples (more than 100 gram) was crushed into small pieces by a jaw crusher. The crushed samples were subsequently pulverized in a tungsten carbide disc-mill. Special care was taken to avoid contamination during the sample preparation. The ground samples were sent for a chemical analysis by a reliable laboratory (SGS Far East Limited) for gold, silver, copper and molybdenum contents.

Gold in the ground samples was extracted and pre-concentrated by the fire-assay technique in a special high temperature furnace. The extracted gold product was subsequently dissolved into a solution which was analyzed by an atomic absorption spectrophotometry. Separate batches of the ground samples were used for the determination of silver, copper and molybdenum contents by means of conventional wet chemical analysis and AAS analysis.

Again, it should be emphasized that the purpose of the chemical analysis is to examine the possibility of gold, silver and molybdenum association with the copper and/or iron mineralizations as well as the variability of these metal contents in different rock types rather than to find the average grade of this mineral prospect. Hence, the sampling method was directed toward the selection of copper and/or iron-rich portions of the mineralized skarn and other mineralized rocks and to cover as many rock types and alteration assemblages as possible. On the contrary, in order to find the average grade (also tonnage) of this mineral prospect, a systematic drilling program and a systematic sampling procedure covering continuously the whole length of the drill-core are necessary. Such a work would require a large sum of money and is beyond the scope of this study. Nevertheless, the result of the chemical analysis should be a preliminary step for the evaluation of its economic potential and an initial guideline for future exploration.

GEOLOGICAL SETTING

The geological setting covering the Phu Lon area is displayed in Figure 3. Regionally the area is a part of the so called "Loei Fold Belt" (Bunopas and Vella, 1983). The area is covered for the most part by volcanic rocks of presumably Permo-Triassic in age (Chonglakmani et al., 1979). These volcanic rocks overly the north-south folded sequence of sedimentary rocks of Middle to Upper Paleozoic.

Intermediate to felsic intrusive rocks of roughly the same ages (Triassic) were intruded up to high levels in the sediments. The general fault or fracture systems are striking north-south, northwest-southeast and northeast-southwest directions.

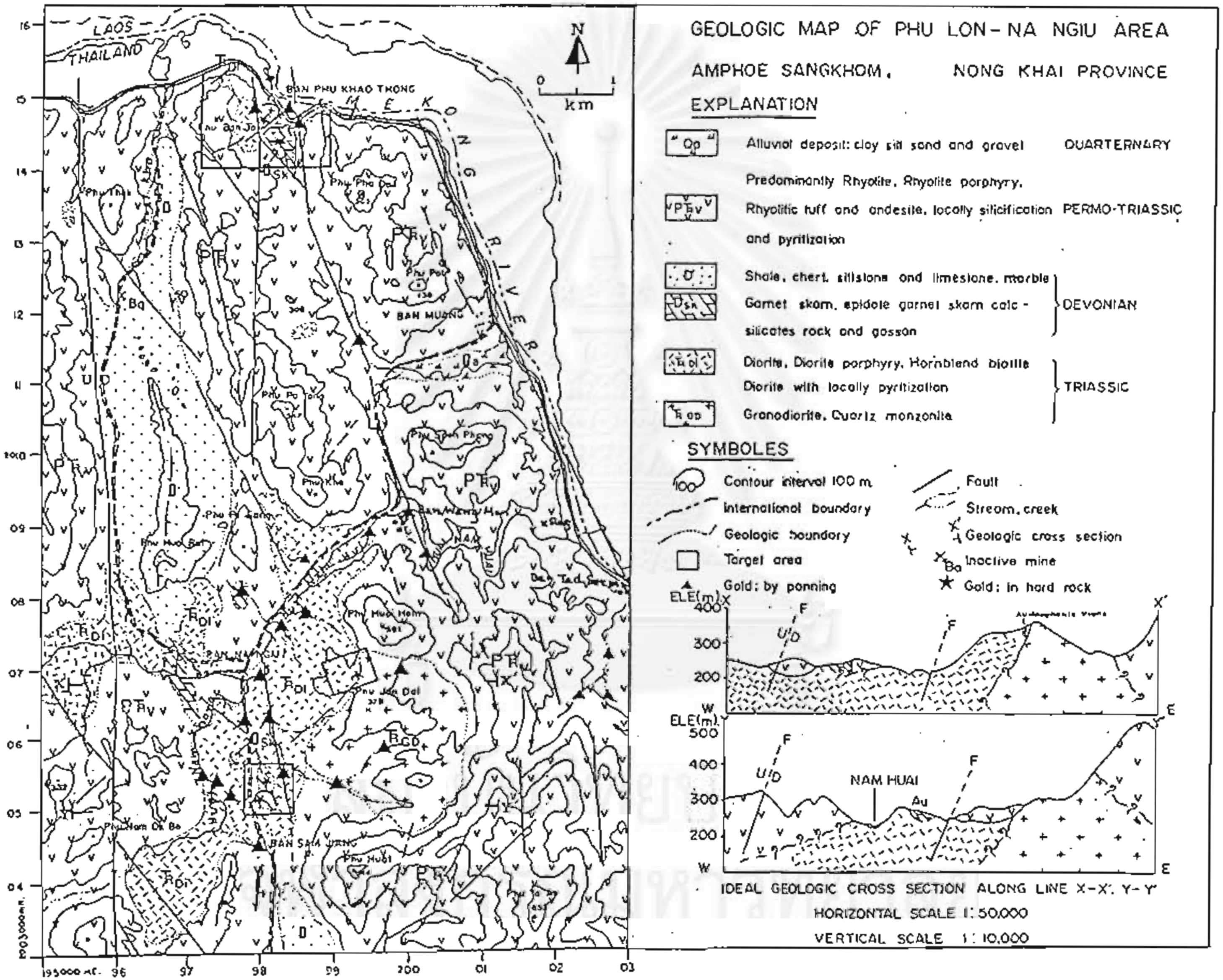

Figure 3 General geology of the Phu Lon - Na ngiu area, Amphoe Sang Khom, Changwat Nong Khai (after Muenlek et al., in press)

GEOLOGY OF THE PHU LON AREA

The geologic map covering the Phu Lon prospect is based mostly on those of Muenlek et al. (in press), Yeamniyom et al., (1983) and this study (Figure 4). As shown in the map, the middle part of the area, where the Phu Lon I and II is located, is underlain for the most part by skarn and intrusive rocks. They are garnet-pyroxene skarn, minor epidote-chlorite-calcite skarn, diorite-monzodiorite, diorite porphyry, quartz monzonite porphyry, monzonite and andesitic dike rock. Surrounding these intrusives and skarns, the area is covered mainly by volcanic rocks ranging from andesite porphyry, rhyolite, tuff and volcanic breccia. Small outcrops of marble with minor intercalated calcsilicate hornfels are exposed near the Mae Khong River. Quaternary unconsolidated sediments occupy the area along the stream and alluvial deposits of the Mae Khong River.

Structurally, three fault and/or fracture systems, namely, north-south, northwest-southeast and the northeast-southwest directions, have been recognized using an aerial photography, geophysical method, field observation and petrographic observation of the drill-cores and outcrop samples. Also including in this map is the locations of the diamond drill-holes (DDHs) and the

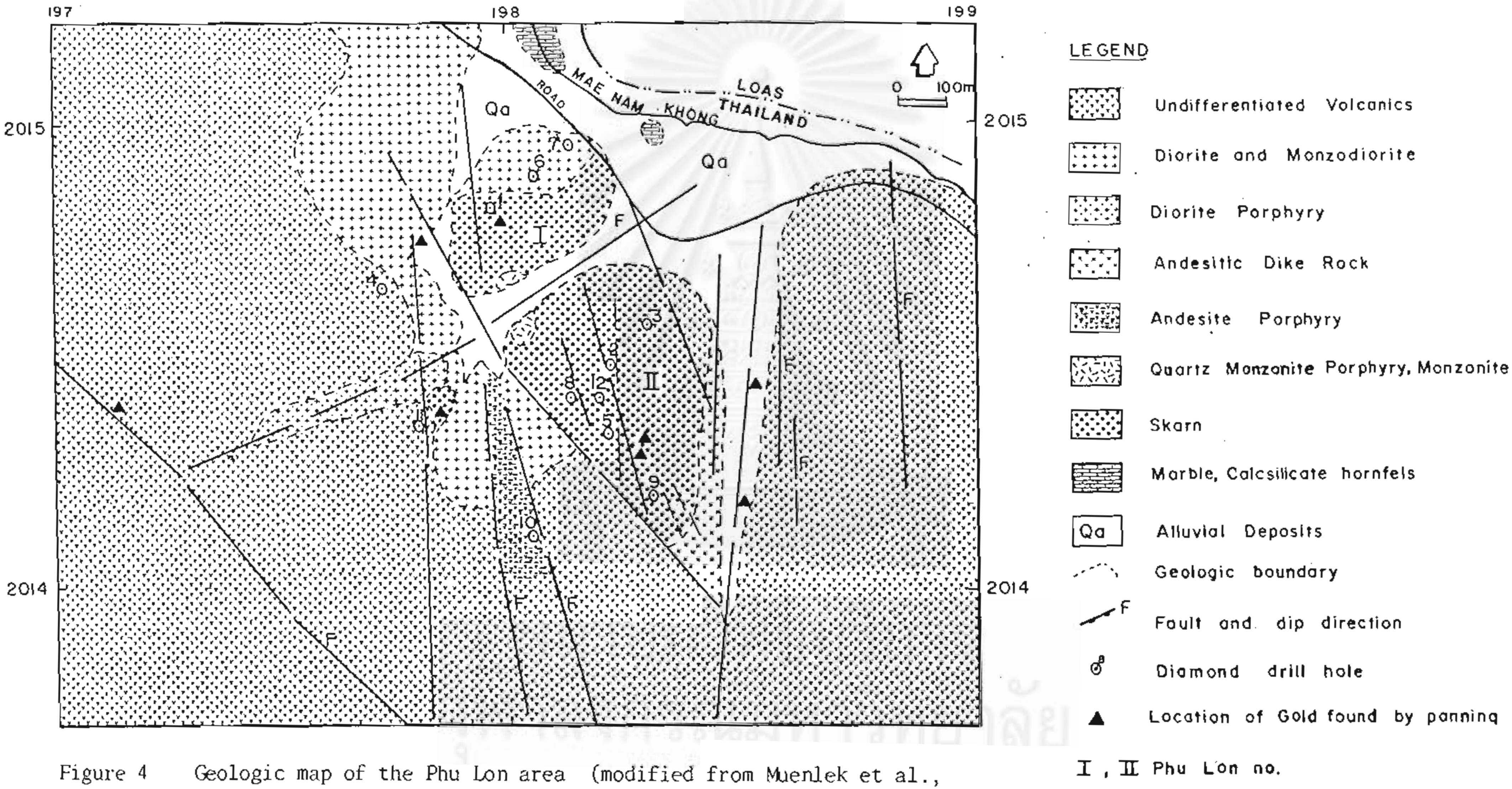

Figure 4 Geologic map of the Phu Lon area (modified from Muenlek et al., in press; Yeamniyom et al., 1983 and this study)

locations of free gold found by panning (Muenlek et al., in press.).

The rock types and their relationships resulting from core-mapping and petrographic examination are displayed as interpretative cross-sections in Figures 5 to 7. The rocks encountered by the 12 DDHs and those exposed on the surface are outlined in the following sections.

Diorite-Monzodiorite

These rocks are probably a major intrusive unit in the area and exposed not only on the surface near the Phu Lon I and II but also has been encountered most frequently in subsurface, especially by the DDH nos. 2, 3, 6, 7, 8 and 12 (Figures 5, 6 and 7).

The diorite, exposed on the surface and encountered by the DDH no. 7 (Figure 7), is a fine to medium-grained rock and greenish gray to gray color. It displays a slightly porphyritic texture. Mineral constituents are composed essentially of plagioclase, pyroxene, amphibole, biotite, potash feldspar and minor amounts of quartz and opaque minerals. The phenocrysts consist mainly of plagioclase having the grain size up to 2.5 mm.

Plagioclose constitutes approximately 57% by volume with the grain size ranging from 0.5 to 2.5 mm. It occurs generally as subhedral tabular crystals forming the

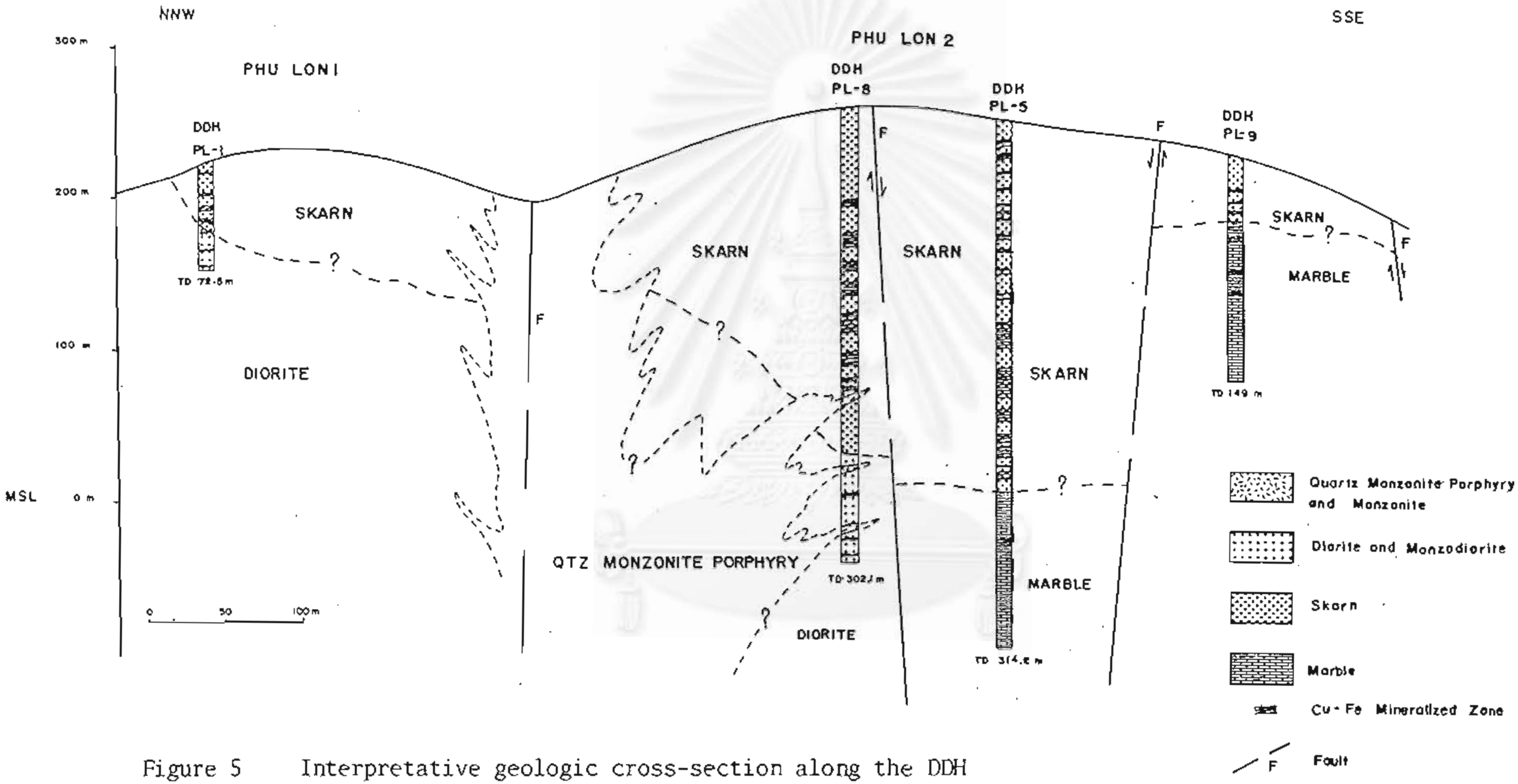

Figure 5 Interpretative geologic cross-section along the DDH nos. 1-8-5-9.

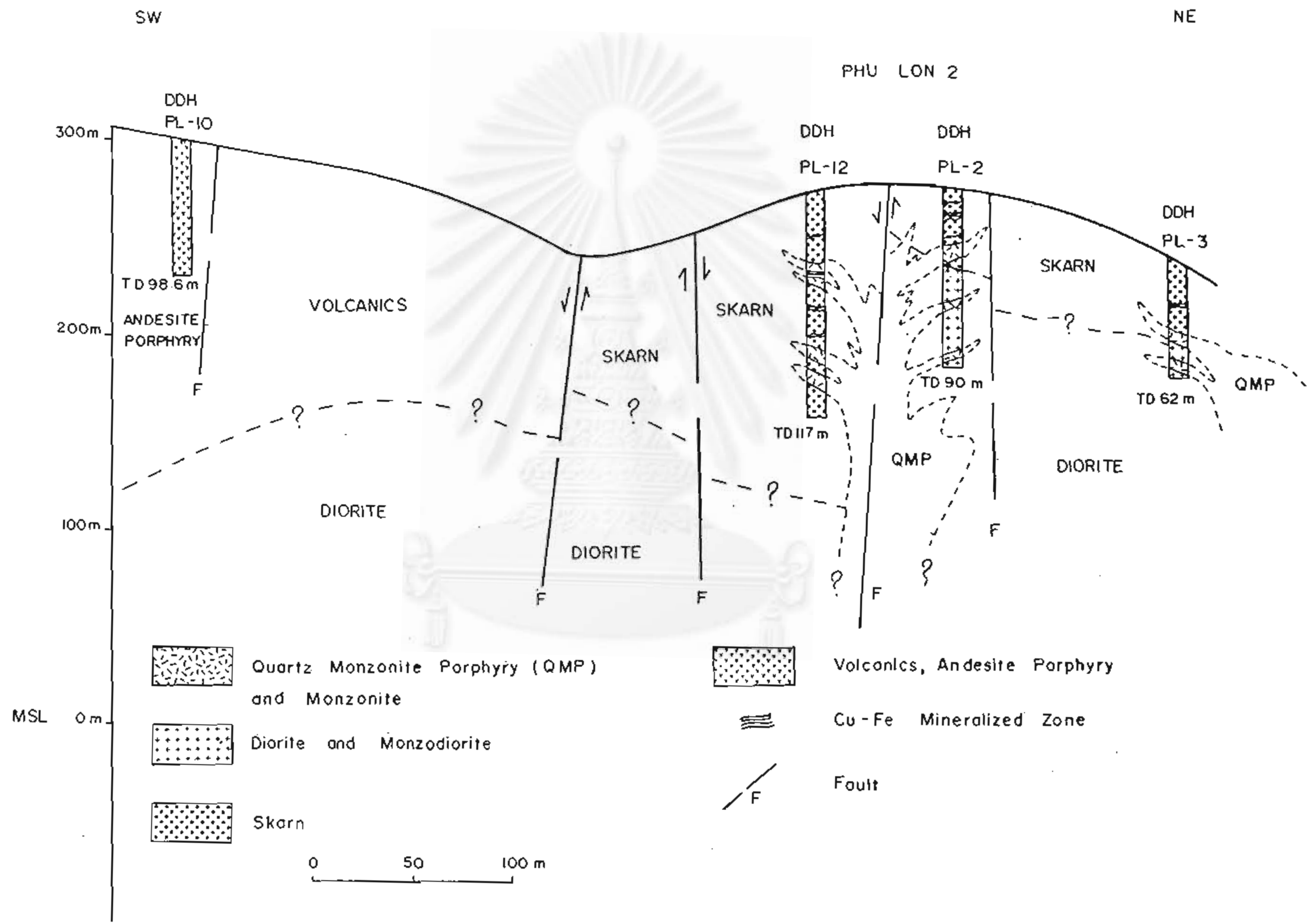

Figure 6 Interpretative geologic cross-section along the DDH nos. 10-12-2-3.

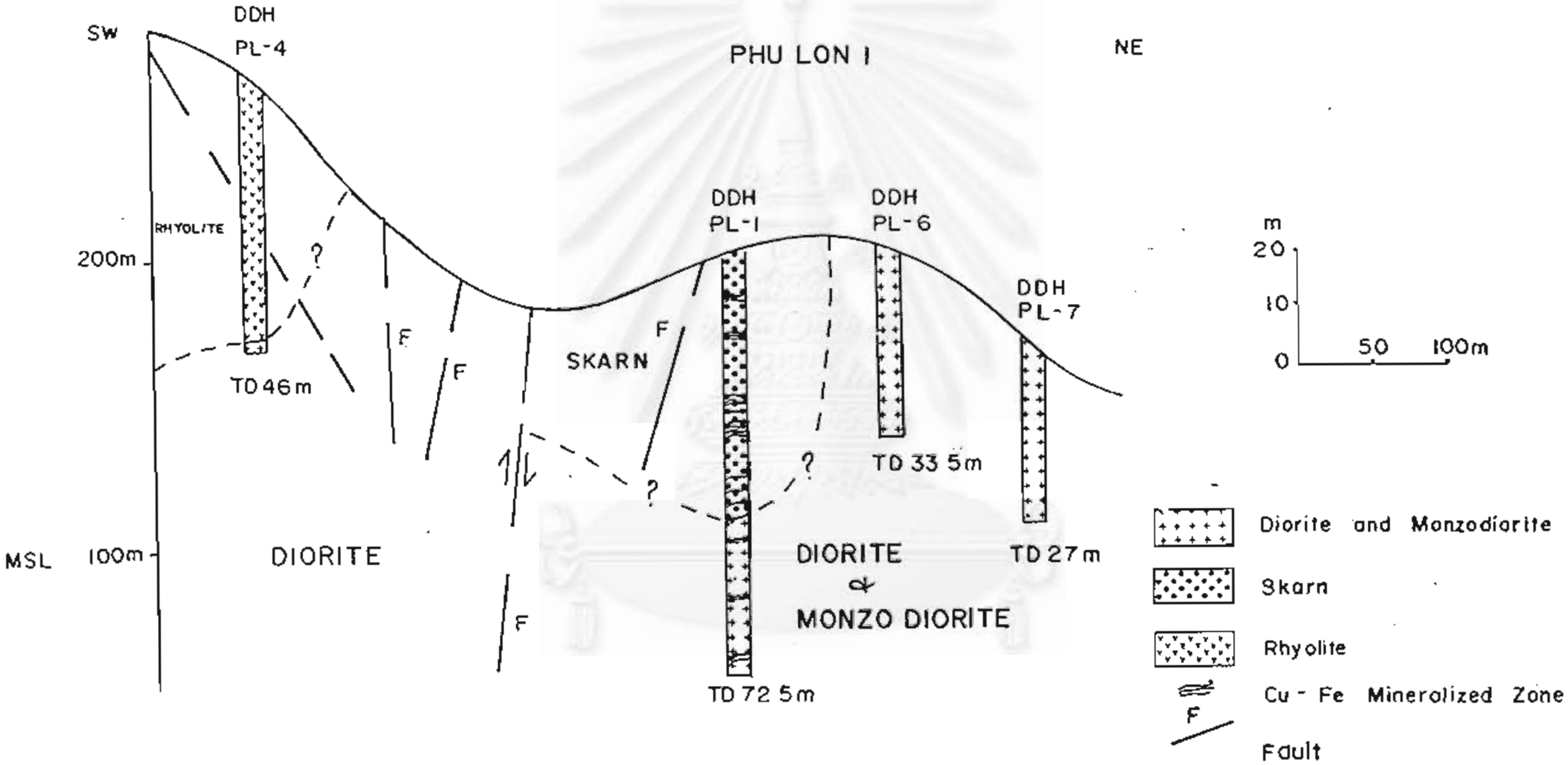

Figure 7 Interpretative geologic cross-section along the DDH nos. 4-1-6-7.

phenocrysts as well as constitutes of the groundmass. Its An content ranges from 33-43 percent (of andesine composition) and it shows a normal zonation. Much of the plagioclase is altered to sericite, epidote and clinozoisite, particularly in the core region.

Pyroxene constitutes approximately 5% by volume with the average grain size of about 0.5 mm. It occurs as augite and usually forms subhedral to euhedral crystals. Pyroxene forming as a core surrounded by hornblende is not uncommon. Some pyroxene crystals contain poikilitic inclusions of apatite and magnetite.

Amphibole makes up approximately 15% by volume with the grain size ranging from 1-2 mm. It usually occurs as hornblende which is frequently altered to biotite and chlorite. It commonly forms as subhedral to euhedral crystals and occasionally contains poikilitic inclusions of plagioclase, apatite, sphene and magnetite.

Biotite makes up approximately 10% by volume with the average grain size about 1 mm. It usually occurs as tabular to elongate flakes having reddish brown to pale green pleochroism. Evidences of amphibole partially to almost completely altered to biolite are ubiquitous and suggest that the majority of biotite, if not all, might have been transformed from amphibole. Some biotite flakes contain poikilitic inclusions of apatite, sphene and plagioclase.

Potash feldspar constitutes approximately 6% by volume with the grain size ranging from 0.3-0.8 mm. It occurs generally as orthoclase filling interstitially among the other early-formed minerals. It is less altered as compared with plagioclase.

Quartz makes up only 3% by volume with the average grain size of 0.4 mm. It normally forms anhedral grains filling interstitially among the other minerals. The myrmekitic quartz intergrowth in plagioclase and potash feldspar is fairly common whereas the granophyric to micrographic intergrowth of quartz grains in potash feldspar crystals is less common.

Apatite and sphene are among the common accessory minerals which occur as minute subhedral to euhedral crystals occasionally enclosed in biotite and plagioclase.

Opaque minerals are another common accessory minerals and may constitute a few percent by volume. They usually forms euhedral to subhedral cubic or diamond-shaped outlines. Majority of those opaque minerals probably are magnetite as judging from their strong magnetic susceptibility and crystal outlines.

The monzodiorite is encountered in the DDH nos. 2, 3, 6, 8 and 12. Among those DDHs, the no. 6 is the least altered. This intrusive phase is similar to diorite in terms of texture and mineralogical composition. The notable difference is, however, marked by the fact that the monzodiorite lacks of pyroxene but contains higher amounts of potash feldspar (18% by volume) and quartz (~ 4%) and lesser amounts of plagioclase (~ 55%) and mafic minerals (i.e., hornblende < 15%, biotite ~ 5%) as compared with the diorite. This monzodiorite is probably belonging to the same intrusive phase as the diorite except for its slightly more felsic nature.

The diorite-monzodiorite may grade into somewhat fine-grained nature or show porphyry texture (e.g., at the bottom of the DDH no. 4 and some outcrop samples). The fine-grained intrusive is characterized by plagioclase and hornblende phenocrysts in a fine-grained groundmass of mostly plagioclase laths that show their orientation or perhaps flow structure. Other subordinate to minor constituents in the groundmass are potash feldspar, quartz, hornblende, biotite, opaque minerals and sphene.

Diorite-monzodiorite porphyry is characterized by abundant phenocrysts of plagioclase and hornblende in a medium-grained groudmass of plagioclase, potash feldspar, quartz and hornblende. These textural evidences suggest that the diorite-monzodiorite is intruded at high levels or they are of hypabyssal nature.

It should be further noted that many of the intrusive rocks encountered by the DDHs and on the surface have been overprinted by hydrothermal alteration and/or metasomatism, especially on approaching the skarn and mineralized zone. Hence, rock naming, in many cases, is difficult.

Quartz Monzonite Porphyry - Monzonite

This intrusive unit is encountered by the DDH nos. 2, 3, 8 and 12 (Figures 5 and 6). In the subsurface, they form as irregular veins or dikes cross-cutting into diorite-monzodiorite and skarn unit. The rocks are medium to coarse-grained, light to pinkish gray in color. Microscopically, they consist predominantly of potash feldspar with subordinate plagioclase, quartz and minor amounts of hornblende, biotite, opaque minerals, sphene and apatite. Many of these rocks characteristically display a porphyritic texture in which phenocrysts of plagloclase and hornblende, minor feldspar and quartz constitute up to 35% by volume. The phenocrystic size is approximately 2 mm and that of the groundmass is around 0.2 mm.

Potash feldspar constitutes approximately 38% by volume with the grain size ranging from 0.1 - 1 mm. It occurs generally as orthoclase filling interstitially among the other early-formed minerals in the groundmass. It also forms as subhedral phenocrysts. Some potash feldspar grains are partially altered to sericite.

Plagioclase makes up around 35% by volume with the average grain size about 2 mm. Generally it occurs predominantly as phenocryst but a minor amount also occurs in the groundmass. It commonly forms subhedral tabular phenocrysts showing normal zonation with the An content about 36 (andesine in composition). It also forms anhedral grains in the groundmass. In places, much of the plagioclase is partially altered to sericite and clinozoisite.

Quartz constitutes approximately 14% by volume with its average grain size about 0.3 mm. It occurs principally as anhedral grain filling interstitially in the groundmass. A minor amount of quartz also appears as phenocryst displaying resorbed grain outline. Most of the quartz exhibit undulatory extinction.

Amphibole constitutes approximately 9% by volume with the average grain size about 1 mm. It occurs as hornblende and commonly forms as euhedral to subhedral phenocrysts. Some amphibole phenocrysts contain poikilitic inclusions of quartz, apatite and sphene, and frequently altered to biotite and chlorite.

Biotite constitutes up to 2% by volume with the average grain size about 1 mm. It occurs commonly as tabular or elongate flakes having reddish brown to pale green pleochroism. Evidences of hornblende portially to completely altered to biotite are ubiquitous and suggest that the majority of biotite, if not all, might have been an alteration product of hornblende.

Of particular note is that many of the quartz monzonite porphyry-monzonite are cut by late potash-feldspar-quartz-anhydrite-actinolite veins/veinlets or overprinted by potassium metasomatism (potassic alteration). Furthermore, at the contact between diorite-monzodiorite and quartz monzonite porphyry-monzonite, actinolite-rich zone are developed on the diorite-monzodiorite side.

Volcanic Rocks

The volcanic rocks overly extensively on the outlier of the intrusive and the skarn units (Figure 4). These volcanic rocks are cropped out locally and their composition and texture are quite variable. Therefore, all the volcanic rocks in the area are group under one category. They are also encountered by the DDH nos. 4, 10 and 11 (Figures 6 and 7). General description of some common volcanic rocks are outlined as follows:

Rhyolitic rocks:

The rhyolitic rocks probably are the most common volcanic rocks exposed on the surface and in the DDH nos. 4 and 11 (Figures 4 and 7). The rocks vary from light to medium gray to grayish pink in color and commonly show porphyritic texture.

Microscopically, the groundmass is extremely fine-grained and composed principally of quartz, sericite and feldspar. The megacrysts are variable in size and shape, and consist mainly of quartz, subordinate potash feldspar, plagioclase and volcanic rock-fragments. Quartz megacrysts invariably exhibit a resorbed outline. Occasionally spherulitic and axiolitic texture resulting from the devitrification of glass are observed in the groundmass. In places, devitrified glass shards are also found in the fine-grained groundmass suggesting that the rocks may grade into rhyolitic crystal tuff. Opaque minerals are fairly common in this type of rock, especially as closer to the mineralized zone. Many of these rocks are overprinted by hydrothermal alteration, particularly those in the DDH nos. 4 and 11.

Andesite porphyry:

The andesite porphyry is exposed locally on the surface and encountered by the DDH no. 10 (Figures 4 and 6). The rock is dark gray and contains abundant phenocrysts.

Microscopically, the phenocrysts are composed essentially of plagioclase having the size ranging from 0.1 to 1.5 mm. The groundmass is extremely fine-to fine-grained and mades up of plagioclase, potash feldspar, quartz and opaque minerals. The rock at the DDH no. 10 is suffered from hydrothermal alteration by which there is an extensive development of epidote, actinolite, sphene, chlorite, calcite and biotite (propylitic alteration).

Volcanic breccia:

This rock is found locally on the surface and comprises an aggregate of highly variable fragments of rhyolite, andesite, quartz, plagioclase and mineralized volcanics (i.e., highly disseminated with opaque minerals). These lithic fragments are setting in a very fine-grained matrix. The characteristic of the volcanic breccia seems to suggest that volcanism probably took place during the intrusions and mineralizations.

Marble and Calcsilicate Hornfels

The marble and calcsilcate hornfels unit is exposed near the Mae Khong river and encountered by the DDH nos. 5 and 9 in contact with the skarn unit (Figures 4 and 5).

The marble and calcsilicate hornfels unit is characteristically composed of coarse-grained equigranular-granoblastic calcite. Streaks or patches of phlogopite are occasionally observed. Bands or layers of idoclase, garnet, pyroxene, tremolite sometimes occur in the marble. In addition, some magnetite crystals are disseminated in the marble. The mineralogical composition of marble and calisilicate hornfels unit suggests that the original carbonate rock might have been slightly dolomitic in composition.

ALTERATIONS

Overprinting relationships indicate a prograde and retrograde alteration of skarn formation as well as extensive alteration within the intrusive and volcanic rocks. At lease two main paragenetic stages of skarn formation are recognized. They are prograde garnet-pyroxene skarn and retrograde epidote-chlorite-calcite skarn. As for the alteration overprinting on the intrusive and volcanic rocks, they are potassic, phyllic and propylitic types that are developed locally to extensively in those rocks.

Prograde Garnet-Pyroxene Skarn

This prograde skarn represents the majority of the skarn rocks exposed on the hills of Phu Lon I and II and those encountered by the DDH nos. 1, 2, 3, 5, 8, 9 and 12 (Figures 4, 5, 6 and 7). The prograde skarn is characterized predominantly by garnet with minor clinopyroxene. Local development of garnet-pyroxene skarn in the form of vein/veinlets or dissemination is also recognized in the diorite-monzodiorite (endoskarn) and marble (exsoskarn). The general zonation observed in those veins seems to follow from garnet-rich in the core and pyroxene-rich at the rim.

The garnet occurs as idioblastic to xenoblastic crystal aggregates. Most of the garnet in unmineralized zone is isotropic but many grains exhibit a zonal anisotropy. Much of the garnet contains poikiloblastic clinopyroxene. The clinopyroxene also occurs between the garnet grains and commonly forms as equigranular idioblastic crystal. Cracks, veinlets and vugs are fairly common in this skarn and they are usually filled with calcite, quartz, sulfides, magnetite and hematite.

The garnet-pyroxene skarn was probably formed during the prograde metasomatic stage following the contact metamorphic stage (formation of marble and calcsilicate hornfels) of the diorite-monzodiorite intrusions. Gradational contact from the diorite-monzodiorite into the garnet-pyroxene skarn unit as well as the overprinting relationship suggests their genetic relation. In contrast, cross-cutting relationships obviously indicate that the quartz monzonite porphyry-monzonite post-dates the diorite-monzodiorite and the prograde garnet-pyroxene skarn.

Retrograde Epidote-Chlorite-Calcite Skarn

This alteration essentially superimposes on the pre-existing garnet-pyroxene skarn. It occurs locally and, in most cases, closely associated with copper mineralization. The alteration is characterized by the partial transformation or replacement of garnet, especially along the cracks and grain boundary, into epidote plus chlorite and clinopyroxene into calcite plus chlorite. The garnet may turn pinkish and partially exhibits strong birefringent color. In many cases, the retrograde alteration may be represented by veinlet networks of calcite-chlorite-quartz cross-cutting into the garnet-pyroxene skarn. Other associated minerals include fluorite, magnetite, pyrite, chalcopyrite, hematite and actinolite.

Potassic Alteration

The potassic alteration overprints on the intrusive and volcanic rocks, such as those observed in the DDH nos. 1, 2, 3, 4, 8 and 11, and many outcrop samples. This type of alteration is characterized by a local to extensive development, as dissemination, replacement or cross-cutting veins/veinlets, of potash feldspar, biotite and quartz accompanying by accessing but nonessential albite, anhydrite and sericite. In fact, two different types of mineral assemblages indicating the potassic alteration are recognized in this system. They are biotite-quartz-albite and potash-feldspar-quartz-anhydrite-actinolite assemblages.

Biotite-quartz-albite assemblage:

This type normally overprints on diorite-monzodiorite and volcanics, such as those in the DDH nos. 1, 4 and 11. The assemblage is represented by the formation of fine-grained, equigranular biotite, albite and quartz disseminated or infiltrated into and/or recrystallized from the original rocks. They commonly occur in the groundmass portion and leave with the remnants of plagioclase phenocryst. The original phenocrystic plagioclase may be altered to sericite or replaced by biotite, whereas the hornblende and probably pyroxene are completely transformed into biotite.

Biotite most frequently occurs as small flakes (< 1 mm. in length) having brown to green pleochroism. Quartz and albite commonly form equigranular granoblastic polygonal grains. Other accompanying minerals include epidote, chlorite, sphene, opaque minerals (mostly fine-grained magnetite with only minor sulfides).

Potash-feldspar-quartz-anhydrite-actinolite assemblage:

This type normally overprints on quartz monzonite porphyry-monzonite, such as those in the DDH nos. 2, 3 and 8. The assemblage is characterized by the occurrence of potash feldspar, quartz, anhydrite and actinolite in the form of cross-cutting veins/veinlets or replacement in the original rocks.

In veins/veinlets, potash feldspar appears pinkish. Microscopically, quartz and potash feldspar usually form large mosaic interlocking grains, occasionally with interstitial anhydrite, actinolite, calcite, sulfides and magnetite. In places, a graphic intergrowth of quartz in potash feldspar is not uncommon. Other accompanying minerals are sphene, sericite, epidote and chlorite. The mineralogy and textural evidences suggest that those veins/veinlets are the alteration product of quartz monzonite porphyry-monzonite rather than a separate phase crystallized from a highly felsic melt.

In the replacement characteristic, quartz and potash feldspar commonly replace a finer-grained groundmass and leave with islands of phenocryst. Original andesine plagioclase might have been transformed into albite accompanying irregular patches of anhydrite inside its crystal. This evidence suggests that the formation of anhydrite might obtain its calcium component from plagioclase transformation and its sulfate component from a sulfur-bearing hydrothermal solution (i.e., a copper-sulfur-potassium-rich fluid).

Phyllic Alteration

The phyllic alteration occurs locally on the intrusive rocks and rhyolite, such as those in the DDH nos. 4, 8 and 11. This type of alteration is dominant by the formation of sericite and quartz without biotite in place of feldspar. Sericite commonly forms as very small flaks. Other associated minerals include chlorite, magnetite and sulfides.

Propylitic Alteration

The propylitic alteration extensively develops in the andesite porphyry of the DDH no. 10. This type of alteration is characterized by the presence of epidote, chlorite, calcite, actinolite. Other associated minerals are sericite, clinozoisite, quartz, sulfides and fine-grained magnetite. Epidote and chlorite commonly occur as irregular patches, whereas actinolite forms as small, long prismatic crystals to fibrous aggregates distributed throughout the rocks.

MINERALIZATION

Copper and iron-rich zones occur principally in the skarn unit, such as those observed in the DDH nos. 1, 5, 8 and 12 (Figures 5 and 6). In some drill-core sections, a rather massive magnetite-rich zone is encountered and clearly separates from a sulfide-rich zone, whereas in other sections they are mixed. Sparse copper and iron mineralizations also appear in intrusives, volcanics and marble. Cross-cutting and textural relationships reveal that several distinct mineralizing events took place in the skarn as well as the intrusive and volcanic rocks. They can be correlated to particular stages of the skarn development and the alteration (Figure 8).

<u>Magnetite + Minor Chalcopyrite</u> (Iron Mineralization)

Majority of the magnetite plus minor chalcopyrite and pyrite probably precipitated contemporaneously and/or slightly after the formation of prograde garnet-pyroxene skarn. In the skarn, magnetite usually forms patches or bands of anhedral to euhedral crystal aggregates intimately intergrown with garnet and clinopyroxeme. In certain cases, euhedral magnetite crystals are partially embayed by garnet grains suggesting their contemporaneity. In other cases, magnetite and quartz may fill interstitially between garnet grains. Many of the magnetite crystals contains poikilitic inclusions of chalcopyrite

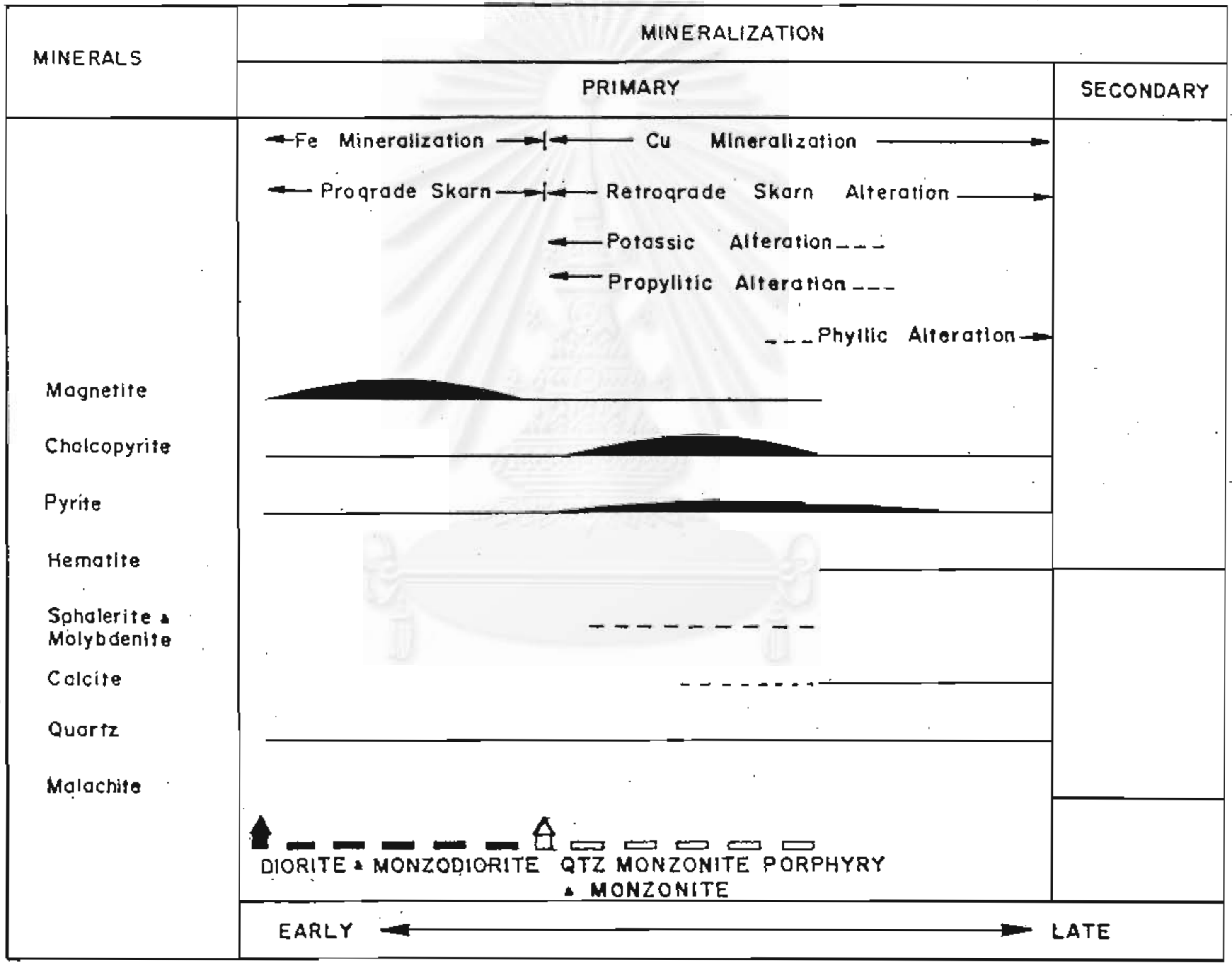

Figure 8 Sequences of igneous activities, mineralizations and alterations at the Phu Lon area.

and pyrite. No obvious retrograde alteration of the skarn has been observed directly related to the major magnetite precipitation.

In the marble near the skarn unit, magnetite forms subhedral to euhedral crystals or crystal aggregates intimately intergrown with calcite. No major magnetite mineralization has been recognized in the quartz monzonite porphyry-monzonite or their associated alterations.

Chalcopyrite + Pyrite (Copper Mineralization)

At least a major distinct chalcopyrite-pyrite mineralization took place after the major stage of magnetite precipitation. The chalcopyrite-pyrite stage correlates with the retrograde alteration of epidote-chlorite-calcite skarn. The style of mineralization appears in the form of chalcopyrite-pyrite-quartz veins/veinlet networks cross-cutting the garnet-pyroxene skarn or magnetite-rich skarn. In most cases, those veins/veinlet networks show a well developed retrograde alteration salvage. Infilling mineralization in open .vugs between garnet grains is also common in the skarn. Sparse chalcopyrite-pyrite-quartz veinlets also occur the intrusive part of the system and correlate well with potassic and propylitic alterations.

Pyrite usually occurs as subhedral to euhedral cubic and dodecahedral crystals, while chalcopyrite forms irregular masses or patches. Micro-fractures in pyrite grains are frequently filled by chalcopyrite. Other associated minerals in minor to trace amounts include hematite, magnetite, sphalerite, epidote, chlorite and calcite.

In some veinlets, hematite occurs as fibrous aggregates and forms rhythmic bands alternating with bands of pyrite-rich and calcite-quartz-rich. However, no obvious zonation could be observed in those veinlets. Hematite also occurs as replacement of magnetite and garnet. Sphalerite is recognized as inclusions or intimately intergrown with chalcopyrite. Epidote, chlorite and calcite are the common minerals retrograded from or replacing garnet and pyroxene. Calcite also forms as coarsely crystalline aggregate filling the remaining open spaces or late cross-cutting veinlets. Malachite and iron oxides are among the secondary minerals formed as oxidized ores in the skarn near surface.

No gold mineralization has yet been recognized in primary ore zone, eventhough some flakes of free gold has been found by panning is stream sediments or a certain amount has been detected by the chemical analysis (see the following section).

Molydenum Mineralization

Some molybdenite-quartz veinlets are sparsely distributed in potassic alteration zone of the potash feldspar-quartz-anhydrite-actinolite assemblage at the bottom of the DDH no. 8. Trace amount of very fine molybdenite plates also occurs in the skarn closely associated with chalcopyrite.

CHEMICAL ANALYSIS

Totally 19 samples of some mineralized drill-cores were chemically analyzed for gold, silver, copper and molybdenum contents. Of those samples, 10 samples are copper and/or iron-rich skarns, 2 samples of quartz monzonite porphyry with a sign of potassic alteration, 2 samples of pyrite-rich phyllic alteration, 2 samples of volcanic rock with overprinting potassic or propyritic alterations, 1 sample of potassic alteration, 1 sample of quartz-potash feldspar veins and 1 sample of rather fresh diorite with disseminated magnetite.

Result of Chemical Analysis

The result of the chemical analysis is tabulated in Table 1 together with the depth interval and the length of the analyzed core samples. From the Table 1, it is rather obvious that the copper and/or iron-rich skarns (nos. 1 to 10 on the list) contain gold contents between 0.25 and 2.8 gram/ton with an average of 0.98 gram/ton (N = 10), silver content between 5.9 and 27.1 gram/ton with an average of 11.5 gram/ton, copper content between 0.19 and 5.74% with an average of 2.11% and molybdenum content between 0.001 and 0.061% with an average of 0.008%. As for the other rock types, most of the detectable gold, silver, copper and molybdenum contents are

Table 1 Chemical analysis of some mineralized skarns and other rock types.

SAMPLE NO.*	DEPTH (m)	LENGTH (m)	Au (g/ton)	Ag (g/ton)	Cu (%)	Mo (%)	REMARKS
Copper/Iron-Rich Skarn							
1) 1-10	42.97 - 43.30	0.33	2.10	19.5	4.24	0.001	cpy-rich skarn
2) 5-19	271.75 - 271.85	0.10	2.80	27.1	5.74	0.061	cpy-rich skarn
3) 5-25	48.04 - 48.28	0.24	0.86	9.3	1.29	0.001	cpy-py-rich skarn
4) 5-21	215.58 - 215.79	0.21	0.32	7.3	0.26	0.003	cpy-mag-rich skarn
5) 5-28	18.30 - 18.68	0.18	0.25	5.9	0.19	0.001	oxidized, mag-rich skarn
6) 2-1	-	0.15	0.89	7.6	3.12	0.001	oxidized, malachite-rich skarn
7) 8-37	135.35 - 135.48	0.13	0.48	11.5	1.93	0.001	cpy-mag-rich skarn
8) 8-38	95.15 - 95.35	0.20	1.40	9.5	0.95	0.001	cpy-mag-rich skarn
9) 8-34	262.22 - 262.38	0.16	0.38	10.8	1.77	0.005	cpy-py-rich veinlets in skarn
10) 8-39	90.08 - 90.29	0.21	0.33	6.5	1.61	0.008	cpy-py-rich veinlets in skarn

Table 1 (Cont.)

SAMPLE NO.*	DEPTH (m)	LENGTH (m)	Au (g/ton)	Ag (g/ton)	Cu (%)	Mo (%)	REMARKS
Other Rock Types							
11) 8-24,28	301.00 - 301.20	0.20	0.13	1.5	0.20	0.002	K-alteration with anhydrite
12) 8-29	298.76 - 298.90	0.14	0.01	0.9	0.082	0.025	qtz-mon porphyry + K-alteration
13) 8-30	292.68 - 292.88	0.20	0.01	0.2	0.012	0.002	qtz-potash feldspar veins
14) 8-33	278.55 - 179.00	0.45	0.08	2.6	0.33	0.005	qtz-mon porphyry + K-alteration
15) 7-3	26.04 - 26.28	0.24	0.02	0.7	0.008	nil	fresh diorite + disseminated magnetite
16) 4-10	15.25 - 15.52	0.27	0.02	2.3	0.005	nil	py-rich phyllic alteration
17) 4-6	18.38 - 19.00	0.12	0.01	1.2	0.008	0.001	py-rich phyllic alteration
18) 4-9	43.18 - 43.44	0.26	0.02	0.9	0.005	nil	volcanics with K-alteration
19) 10-9	95.90 - 96.26	0.36	0.02	0.9	0.014	nil	volcanics with propylitic alteration

* the preceding number is the drill-hole number and the following number is the sample number in that drill-hole.

cpy = chalcopyrite, py = pyrite, mag = magnetite, mon = monzonite, qtz = quartz.

relatively lower than those in the skarns (i.e., 0.01 to 0.13 gram/ton for gold content, 0.2 to 1.5 gram/ton for silver content, 0.008 to 0.2% for copper content and nil to 0.025% for molybdenum content).

The contents of gold versus copper, silver versus copper and gold versus silver of all the samples are also plotted in Figures 9, 10 and 11. As shown in those plots, a fairly good positive correlation can be observed in each pair plot (i.e., correlation coefficients are 0.83 for gold versus copper, 0.87 for silver versus copper and 0.88 for gold versus silver). In other words, an increase in the copper contents is also reflecting in the increase of both gold and silver contents. These data seem to suggest that gold and silver might accompany the copper mineralization.

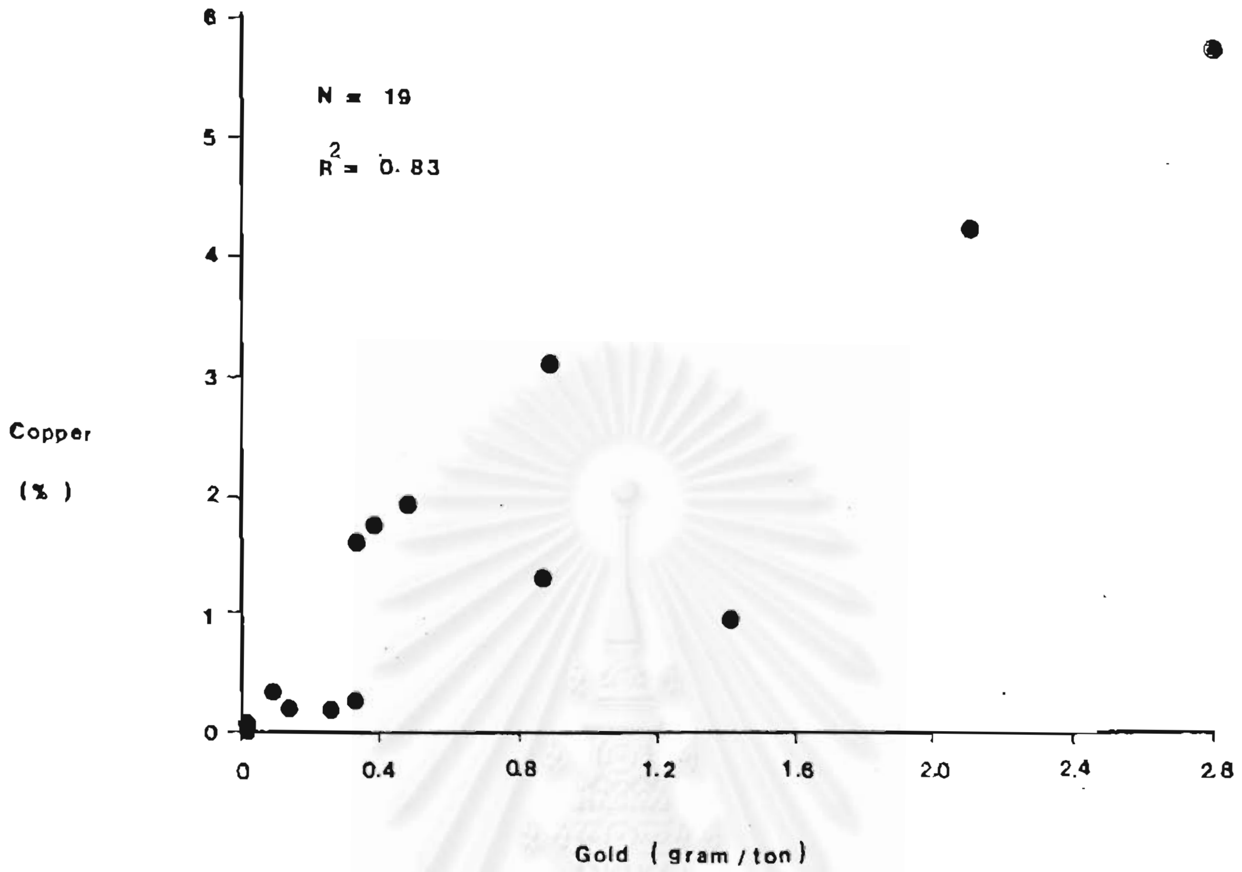

Figure 9 Plot of gold versus copper contents.

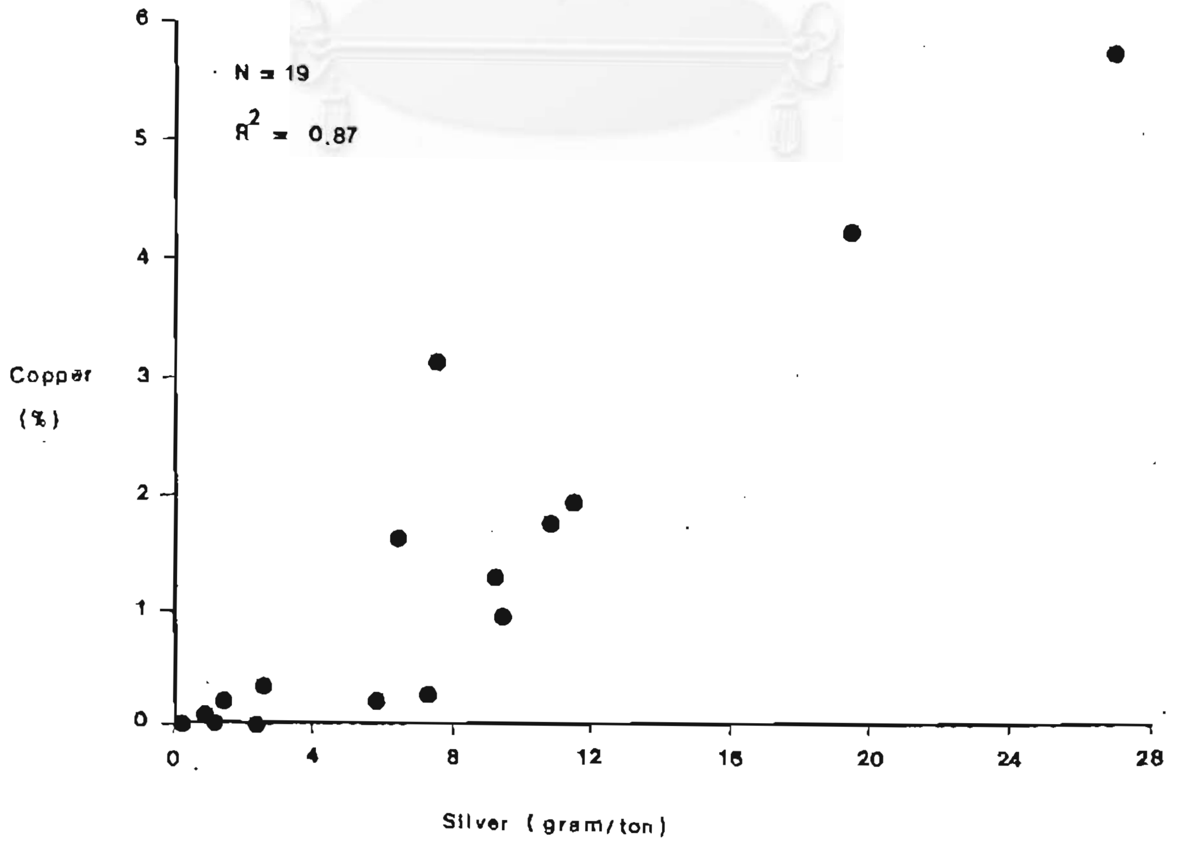

Figure 10 Plot of silver versus copper contents.

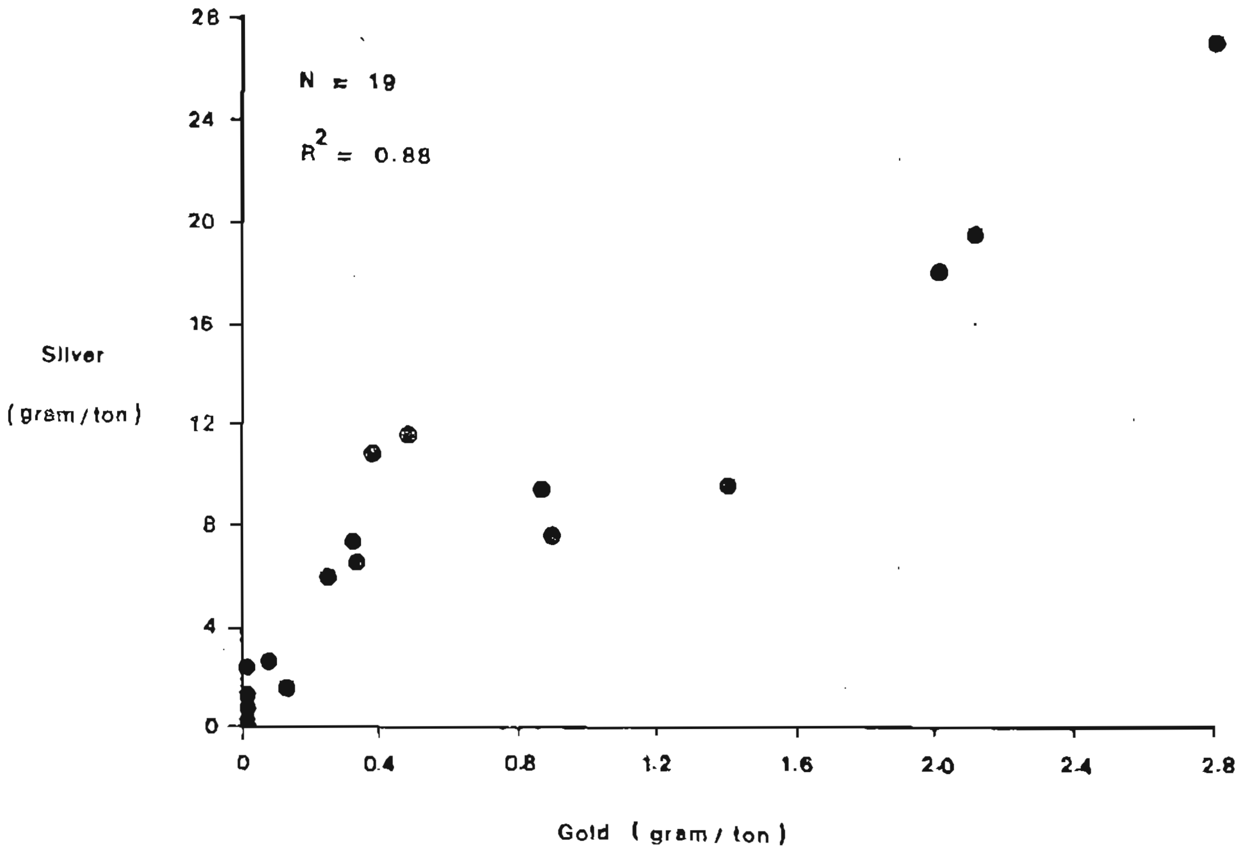

Figure 11 Plot of gold versus silver contents.

DISCUSSION AND INTERPRETATION

As mentioned previously, the gold, silver, copper and molybdenum contents obtained in this study are not the true ranges and average grades of this mineral prospect. It should, however, give an idea on what sort of grade to be used for comparison with other well-known mineral deposits of similar class.

It is apparent that the gold, silver and copper contents in the skarn of the Phu Lon prospect are comparable in terms of grade to those of the Red Dome gold skarn deposit, North Queenland, Australia (2.0 gram/ton gold, 4.6 gram/ton silver, 0.46% copper and 1.0% zinc with a geological ore reserve of 13.8 million tons; Torrey et al., 1986), Mamut porphyry copper deposit in Malaysia (0.5 gram/ton gold, 0.476% copper with a total are reserve of 179 million tons; Kosaka and Wakita, 1978), and the general porphyry copper-gold deposit type (see Figures 12 a, b, c). Judging from the grades, therefore, the mineralized skarn in this prospect is rather attractive for persuading further exploration.

As for the mineralization in other rock types, all the gold, silver, copper and molybdenum contents are comparatively too low to justify its economic potential. However, Until some more deep drill-holes penetrating

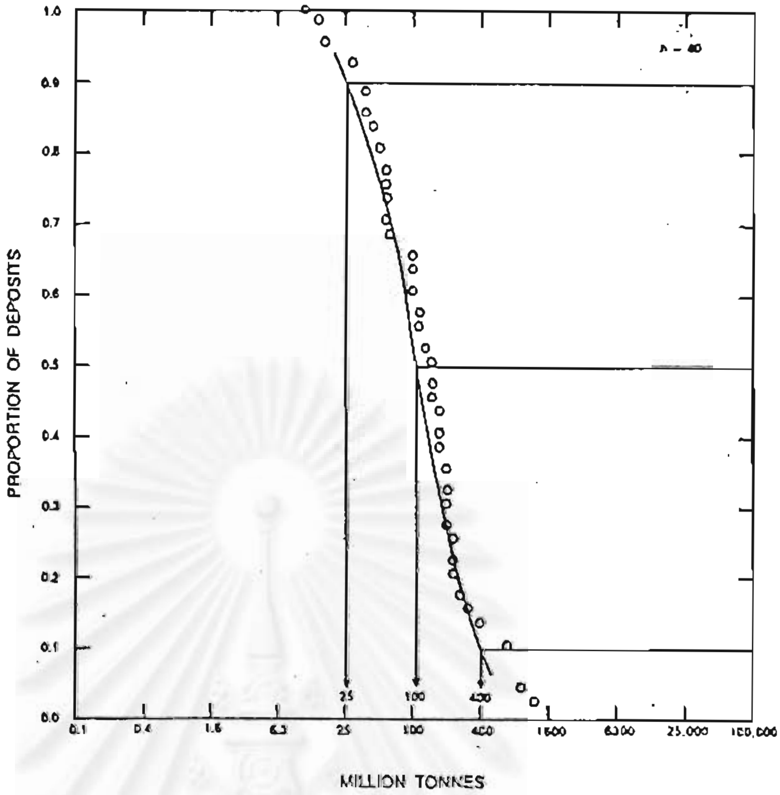

Figure 12a Tonnages of porphyry Cu-Au deposits (Singer and Cox, 1986).

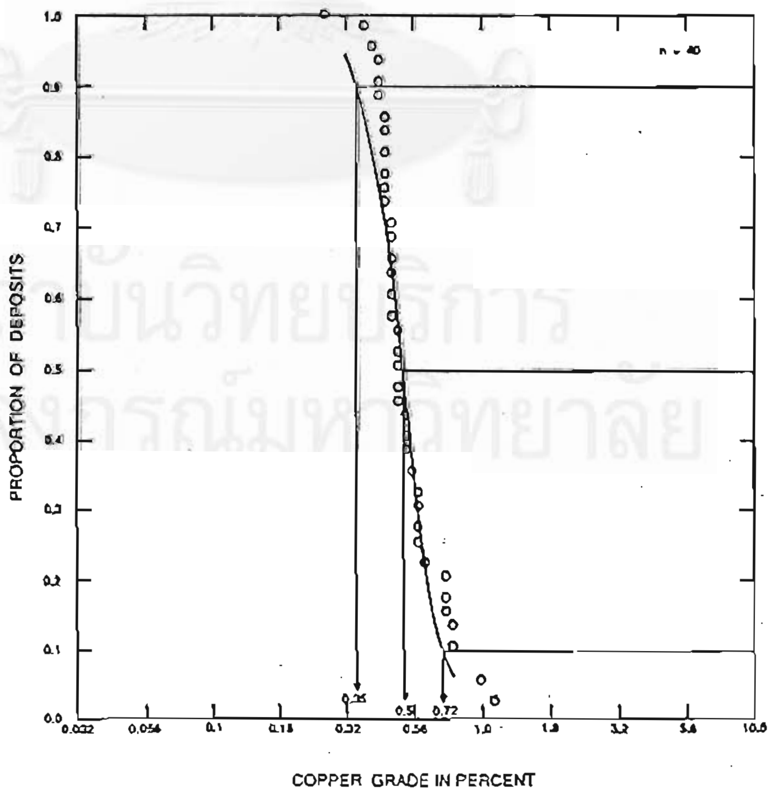

Figure 12b Copper grades of porphyry Cu-Au deposits (Singer and Cox, 1986).

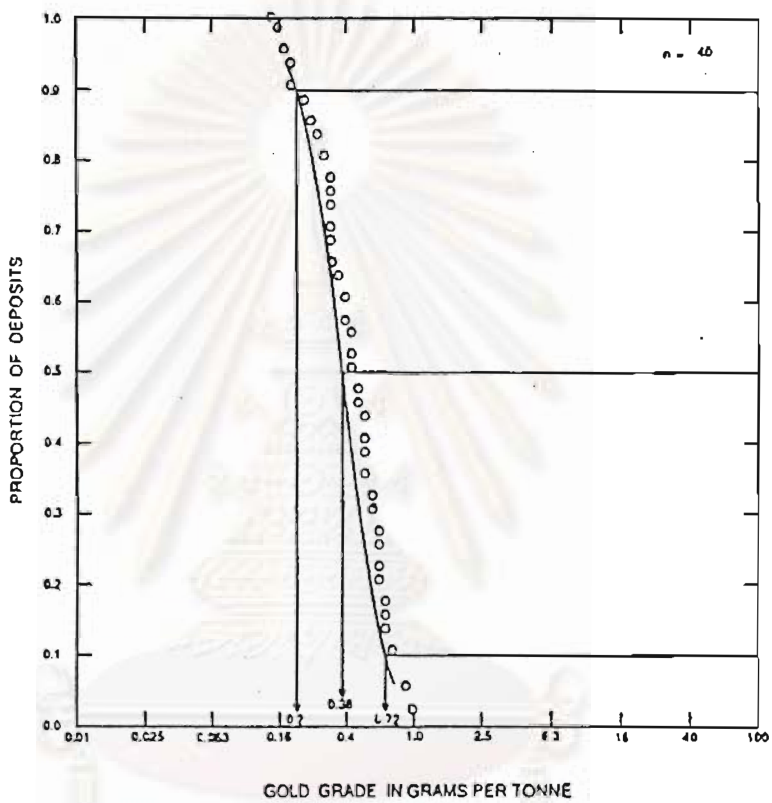

Figure 12c Gold grades of porphyry Cu-Au deposits (Singer and Cox, 1986).

into intrusive rocks, especially quartz monzonite porphyry dikes/stocks or other more felsic phases have been carried out, the mineralization potential in the intrusive rocks can not be completely ruled out yet.

Of particular interest is that a typical porphyry-style mineralized veinning is observed in the skarn in the DDH no. 8. Also intense potassic alteration accompanied by sparse quartz-molybdenum veinlets is observed in the bottom of the DDH no. 8. Hence, a good consideration should be paid on the likelihood of a significant and deep mineralized porphyry system in the intrusive rocks underneath.

General Model for Igneous Activities and Mineralization of the Phu Lon Area.

In Permo-Triassic during which the "Loei-Folded Belt" was still an active and mobile belt, various phases of diorite to monzodiorite were intruded up to shallow levels and into a slightly dolomitic limestone. These intrusives thermally metamorphosed the limestone into a white saccharoidal marble and calcsilicate hornfels. Contemporaneously with the diorite-monzodiorite intrusions, many of them were reached closer to the surface and formed andesitic dike rock and andesite porphyry. These dioritic rocks probably were originated from an iron-rich melt as suggested by their abundant disseminated magnetite in rather fresh portions of the rock. Therefore, shortly after diorite intrusions, carapace shell crystallization and thermal metamorphism, an iron-rich aqueous fluid of the same magmatic origin might have been migrated upward to the contact zone and caused extensive Fe-Si-Ca metasomatism of host and intrusive rocks (prograde garnet-pyroxene skarn) and the majority of magnetite mineralization in the skarn.

Subsequent to the prograde skarn formation and major magnetite deposition, quartz monzonite porphyry to monzonite (as well as their extrusive equivalents) were intruded into the pre-existing rocks. Aqueous fluids derived from the late crystallization of quartz monzonite porphyry and monzonite were probably of K-Cu-S-rich phases. These aqueous solutions might have been responsible for the potassic alterations of the potash-feldspar-quartz-anhydrite-actinolite type within their own porphyry dikes/stocks, of the biotite-quartz-albite type in diorite-monzodiorite and volcanic rocks as well as propyritic alteration at a distance away. Contemporaneously or shortly after the potassic alteration, chalcopyrite-pyrite (plus minor magnetite) mineralization and retrograde skarn alteration took place where ever the brittle fractures or open spaces had developed in the skarn and host rocks.

Later cooling of the plutons might generate a convective circulation cell of meteoric water into the system and cause local phyllic alteration, further retrograde alteration of the skarn and remobilization and precipitation of calcite, hematite quartz and pyrite in late veins/ veinlets.

Weathering and erosions have exposed the skarn and intrusive rocks, and decomposed magnetite and sulfides into oxidized copper-iron ores on the Phu Lon area at the present time.

Comparision with other Skarn Deposits

The Phu Lon copper-iron skarn prospect most closely resembles the porphyry-related copper type in the classification of skarn deposits (Einaudi et al., 1981). The skarn is Fe-rich, generally oxidized (abundant Fe^{3+} phases) and relates to multiple porphyritic intrusions. Also the skarn is calcic and has a well-developed porphyry-style mineralization and alterations.

CONCLUSIONS

The major conclusions made in this study are summarized below:

1. The diorite to monzodiorite are the major intrusives in the Phu Lon area and responsible for the formation of contact metamorphic marble and calcsilicate hornfels, and subsequent metasomatic garnet-pyroxene skarn.

2. The main stage of iron mineralization probably took place during the prograde garnet-pyroxene skarn formation. The mineralization occurs in the form of patches or bands and makes up essentially of magnetite with minor chalcopyrite and pyrite.

3. Cross-cutting relationships reveal that quartz monzonite porphyry-monzonite post-dates the diorite-monzodiorite and the prograde skarn formation.

4. At least three types of alteration, namely potassic, phyllic and propylitic, overprint extensively on the intrusive and volcanic rocks. All of them are genetically related to quartz monzonite porphyry-monzonite.

5. Two different mineral assemblages characterizing the potassic alteration are recognized in this system: the biotite-quartz-albite and the potash-feldspar-quartz-anhydrite-actinolite. The former assemblage overprints on the diorite-monzodiorite whereas the later assemblage on the quartz monzonite porphyry-monzonite.

6. The main stage of copper mineralization occurs in the form of chalcopyrite-pyrite-quartz veins/veinlet networks and dissemination. It took place contemporaneous with the retrograde skarn alteration of epidote-chlorite-calcite. The mineralization is temporally associated with potassic and propylitic alterations and is genetically related to the quartz monzonite porphyry-monzonite.

7. The copper skarn carries gold and silver in such the amounts that are comparable to those of the similar copper-gold deposit class. It is therefore attractive for persuading further exploration.

8. The Phu Lon prospect is a copper-iron-gold-silver deposit of porphyry-related type (Einaudi et al., 1981).

SUGGESTION FOR FURTHUR WORK

Deep drill-holes penetrating into the intrusive rocks, especially the quartz monzonite porphyry dikes/stocks, are highly recommended to fully understand the system and explore for a possible deep porphyry system.

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