# CHAPTER III

# GEOLOGY OF THE STUDY AREA

The geologic map covering the study area is based on those of Hintong et al. (1981), Yavichai (1992) and data collected during the course of this study (Figure 3.1). The Khao Phra Ngam is situated at a contact zone between the Permo-Triassic diorite intrusion of Phra Ngam Diorite and Permian carbonate rocks of the Khao Khad Formation. Carbonate rocks are arranged linearly in N-S direction on the western part of diorite intrusion. A series of skarn rocks was developed along this contact zone which gave rise to minor copper mineralization. Shallow extrusive rock occurs as dike in carbonate rocks. Granodiorite was mapped as a late stage intrusion intruded into the older rocks. Quaternary unconsolidated sediments occupy the low lying area. Structurally, two fault and/or fracture systems, trending NE-SW and NW-SE, were recognized using aerial photographs, geophysical methods and field observation. Detailed descriptions of the rock units are given in the following paragraphs, namely, diorite unit, andesite unit, granodiorite unit, marble unit and skarn unit.

## 3.1 Diorite unit

Diorite unit is probably equivalent to Phra Ngam Diorite of Permo-Triassic age (Hintong et al., 1981). This unit probably forms as the major intrusive rock in this area and is exposed on the eastern part of the mountains. Because of its highly weathered nature, it is poorly exposed and covered by recent sediments on low lying area. A good exposure can be observed in the southern part at Wat Khao Phra Ngam (Figure 3.2). Parts of it situate in the military restricted area that was inaccessible. Majority of diorite intrusion is probably situated underneath the carbonate rocks of Khao Khad Formation. The geological boundaries between diorite and other rock types are mainly intrusive contact. Diorite is also cross-cut by granodiorite and quartz veins (Figure 3.3). The contacts appear rather sharp. It should be noted that diorite has been overprinted by hydrothermal alteration and/or metasomatism, especially near the skarn and mineralized zones.

Megascopically, diorite is a fine to medium-grained rock and light to dark gray in color. It displays hypidiomorphic granular texture with the grain sizes ranging from 1 to 2 mm (Figure 3.4). Mineralogically, the diorite is composed mainly of two essential minerals, plagioclase and hornblende, with minor K-feldspar, pyroxene and quartz. Sphene, apatite and opaque minerals are common accessory minerals.

Microscopically, tabular plagioclase is the most abundant constituent of the rock, making up of approximately 66 modal percent of its total volume (Table 3.1). Its sizes vary in length from 0.5 to 2.0 mm. The great majorities of plagioclase grains are characterized by distinct zonation with albite and albite-carlsbad twins (Figure 3.5). The An-contents of plagioclase are between An 30 and An 40 (andesine composition). Plagioclase is partially to almost entirely altere to sericite. The electronprobe microanalysis of plagioclase also indicates andesine composition (Table 3.2).

Hornblende is the predominant mafic mineral of the rock and makes up of approximately 25 modal percent of the total volume. Its sizes range from 0.2 to 1.0 mm. It occurs as anhedral crystals which always show strong pleochroism (yellowish green to olive green). Some large hornblendes show poikilitic texture containing feldspar and opaque mineral. Partial replacement of hornblende by chlorite is widespread.

Pyroxene is brownish green to pale green in color. The average grain size is about 0.5 mm. It constitutes about 2 percent of the total volume. Pyroxene is partially altered to hornblende (Figure 3.6). The electron probe microanalysis indicates augite composition (Table 3.3).

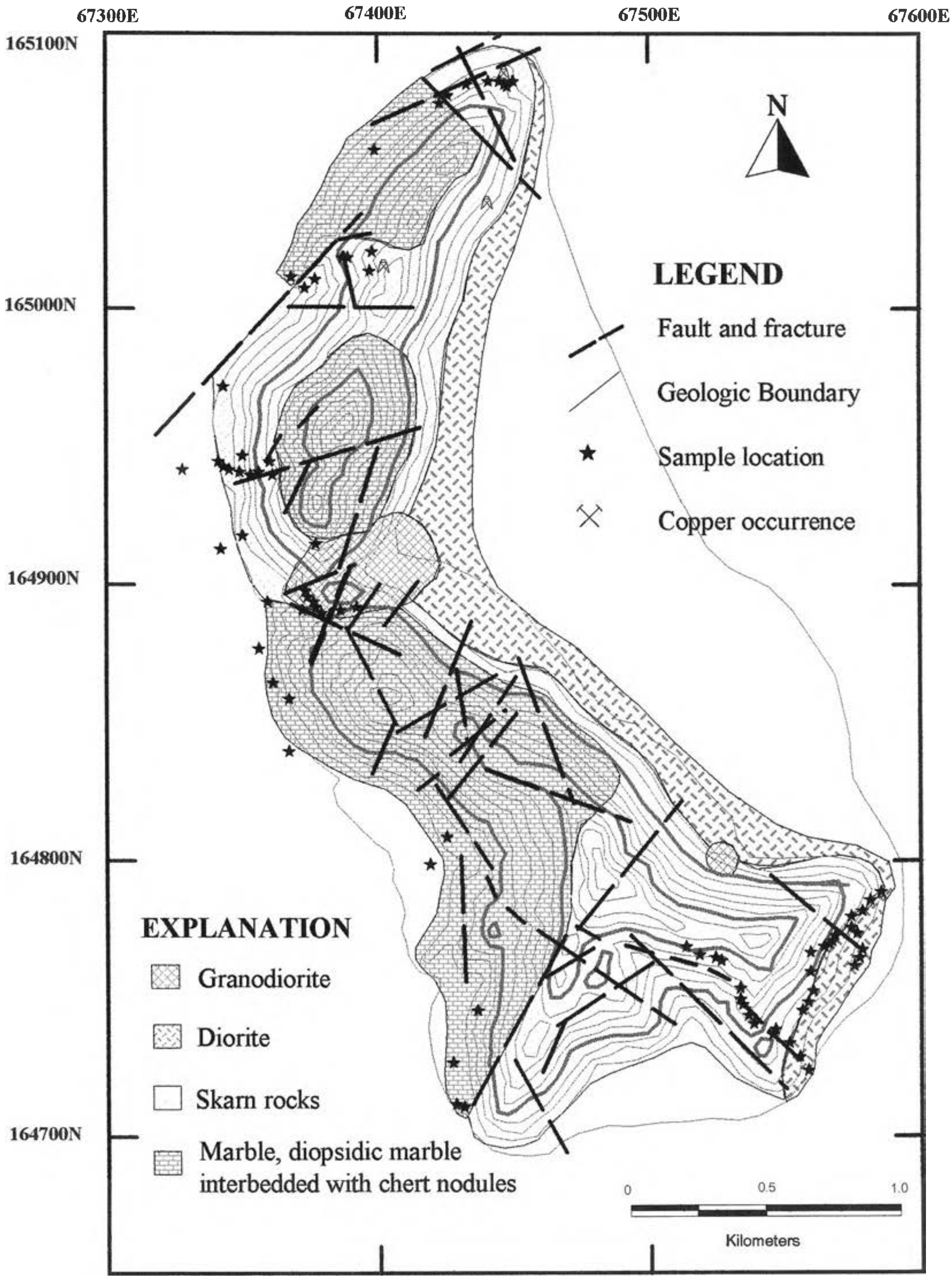


**Figure 3.1** Geological map of the Khao Phra Ngam area, Amphoe Muang, Changwat Lopburi (Modified after Yavichai, 1992).

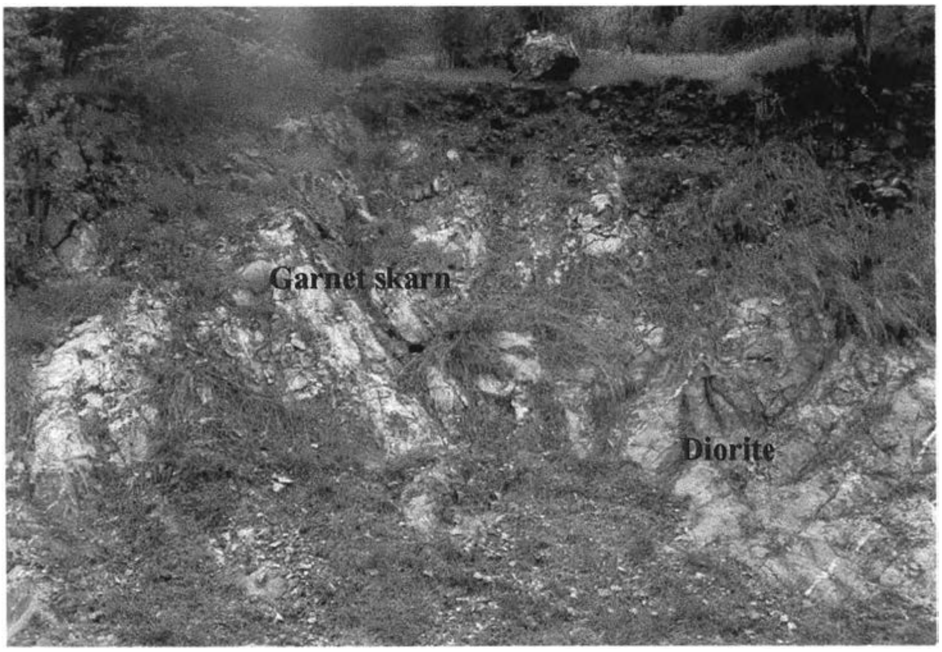


**Figure 3.2** An Exposure of diorite in contact with skarn at Wat Khao Phra Ngam (Looking North).

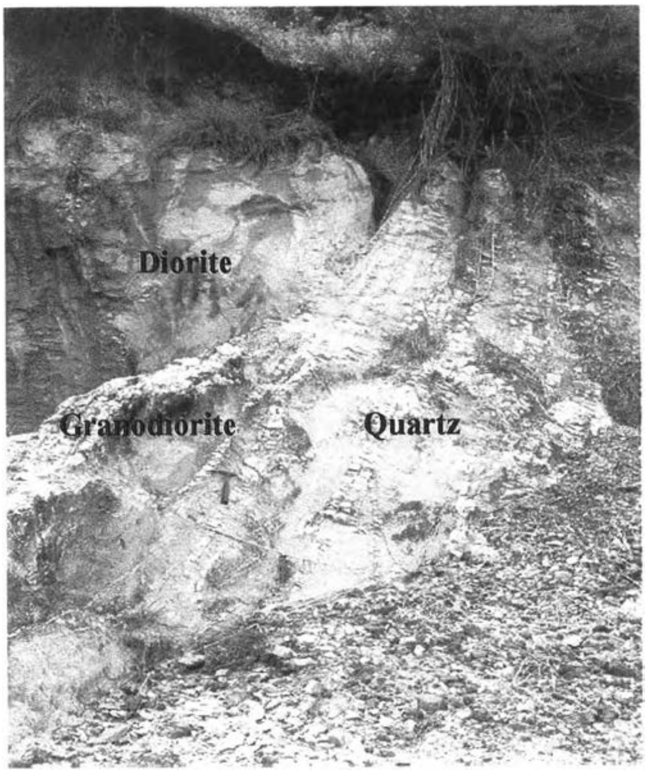


**Figure 3.3** An exposure of diorite showing network of quartz veins and granodiorite dikes crosscuttings.


**Figure 3.4** A specimen of diorite containing dark hornblende and white feldspar.

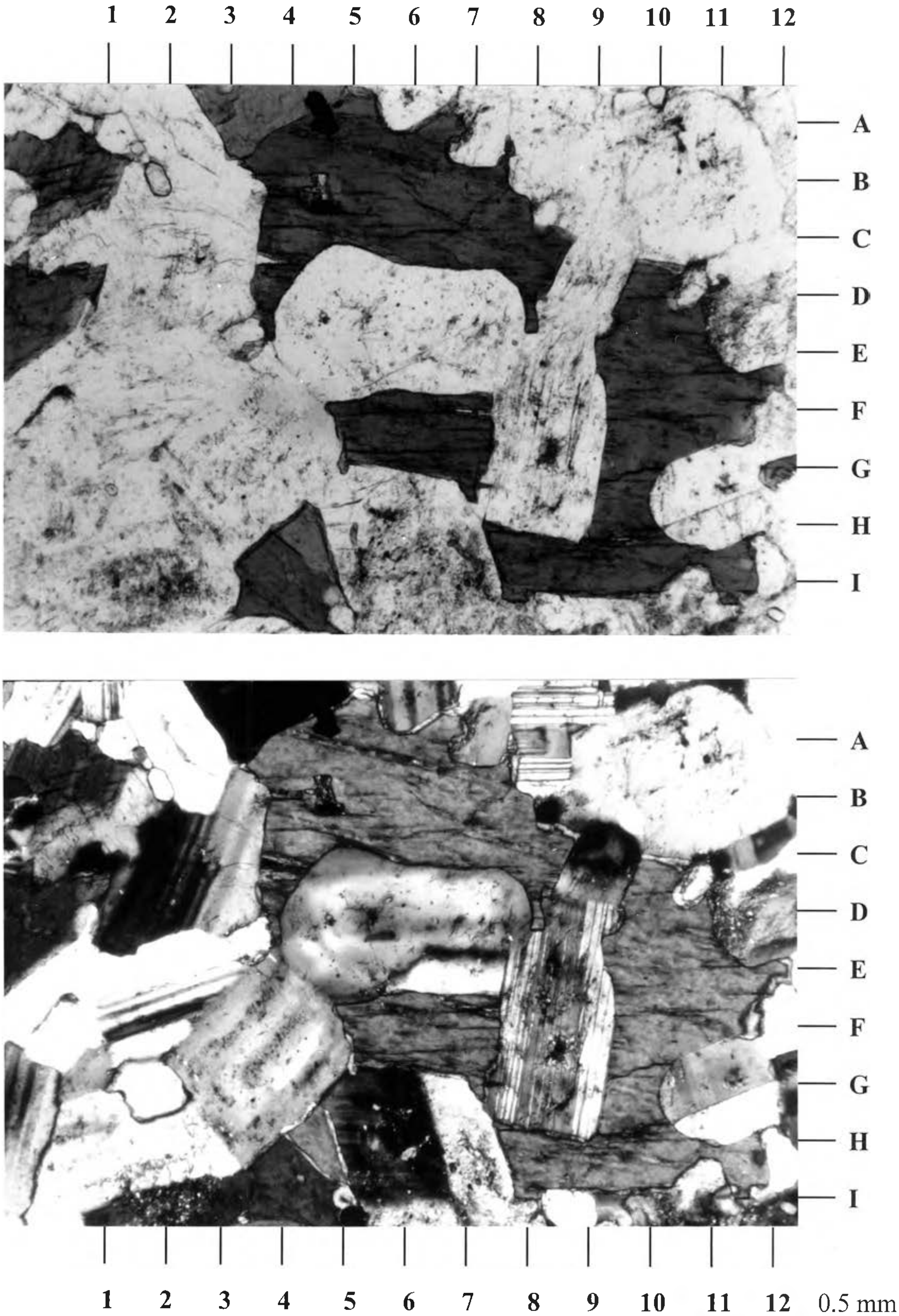


**Figure 3.5** Photomicrograph of medium-grained diorite showing yellowish green to olive green pleochroic hornblende (B6). Large hornblende crystal shows poikilitic texture containing feldspar and opaque minerals. (upper photo: plane-polarized light, lower photo: crossed nicols).

ount analysis the mineral constituents of diorite from Khao Phra Ngam area *

| | Size (mm.) | | % Abundance (average) |
|---|---|---|---|
| se | 0.5 - 2.0 | | 66.2 |
| de | 0.2 - 1.0 | | 25.0 |
| r | 0.1 - 0.2 | | 4.0 |
| | 0.1 - 0.3 | | 1.9 |
| | 0.1 - 0.2 | | 2.6 |
| ineral | 0.1 - 0.3 | | trace |
| | 0.2 - 0.3 | | 0.4 |
| | 0.1 | | trace |
| | after | plagioclase | |
| | after | hornblende, pyroxene | |
| | after | magnetite | |

ctions.

**Table 3.2** Electron Microprobe Analyses of plagioclase in diorite from Khao Phra Ngam area.

Color : gray

Form : euhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 3 analyses ) | [2]Cations on the basis of 8 oxygens | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 58.7940 | _ | 59.3260 | 59.1250 | Si | 2.6510 |
| $TiO_2$ | 0.0000 | _ | 0.0000 | 0.0000 | Ti | 0.0000 |
| $Al_2O_3$ | 25.1820 | _ | 25.4030 | 25.2740 | Al | 1.3375 |
| $Cr_2O_3$ | 0.0000 | _ | 0.0000 | 0.0000 | Cr | 0.0000 |
| MgO | 0.0220 | _ | 0.0330 | 0.0260 | Mg | 0.0017 |
| CaO | 6.9580 | _ | 7.4690 | 7.1530 | Ca | 0.3436 |
| MnO | 0.0140 | _ | 0.0610 | 0.0430 | Mn | 0.0016 |
| | | | | | $Fe^{3+}$ | 0.0098 |
| FeO (total | 0.2020 | _ | 0.2980 | 0.2630 | $Fe^{2+}$ | 0.0000 |
| BaO | 0.0100 | _ | 0.0450 | 0.0240 | Ni | 0.0000 |
| $Na_2O$ | 7.3770 | _ | 7.6570 | 7.5340 | Na | 0.6550 |
| $K_2O$ | 0.1310 | _ | 0.2070 | 0.1710 | K | 0.0097 |
| Total | 98.6900 | _ | 100.4990 | 99.6130 | Sum | 5.0085 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $(K_{0.01}, Na_{0.65}, Ca_{0.34}) Al (Si_{2.66}, Al_{0.34}) O_8$

End Member Composition : Or = 1.00, Ab = 65.34, An = 33.66

Name : **Andesine**

( Or = Orthoclase, Ab = Albite, An = Anorthite )

**Table 3.3** Electron Microprobe Analyses of clinopyroxene in diorite from Khao Phra Ngam area.

Color : gray

Form : euhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 3 analyses ) | [2]Cations on the basis of 6 oxygens | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 50.9150 | _ | 50.6010 | 51.0163 | Si | 1.9402 |
| $TiO_2$ | 0.2130 | _ | 0.3110 | 0.2513 | Ti | 0.0072 |
| $Al_2O_3$ | 1.1450 | _ | 1.6500 | 1.4673 | Al | 0.0658 |
| $Cr_2O_3$ | 0.0600 | _ | 0.1460 | 0.0996 | Cr | 0.0030 |
| MgO | 9.7160 | _ | 10.3270 | 10.0943 | Mg | 0.5723 |
| CaO | 23.0160 | _ | 23.4290 | 23.2860 | Ca | 0.9490 |
| MnO | 0.3090 | _ | 0.3570 | 0.3273 | Mn | 0.0105 |
| | | | | | $Fe^{3+}$ | 0.0000 |
| FeO (total | 12.4220 | _ | 12.7880 | 12.1453 | $Fe^{2+}$ | 0.3865 |
| NiO | 0.0550 | _ | 0.2000 | 0.1083 | Ni | 0.0016 |
| $Na_2O$ | 0.6660 | _ | 1.0740 | 0.8270 | Na | 0.0610 |
| $K_2O$ | 0.0020 | _ | 0.0650 | 0.0290 | K | 0.0014 |
| Total | 97.2050 | _ | 101.8770 | 99.6520 | Sum | 4.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $(Ca_{0.95}\ Mg_{0.58}\ Fe_{0.40}\ Na_{0.07})\ (Si_{1.94}\ Al_{0.06})\ O_6$

Name : **Augite**

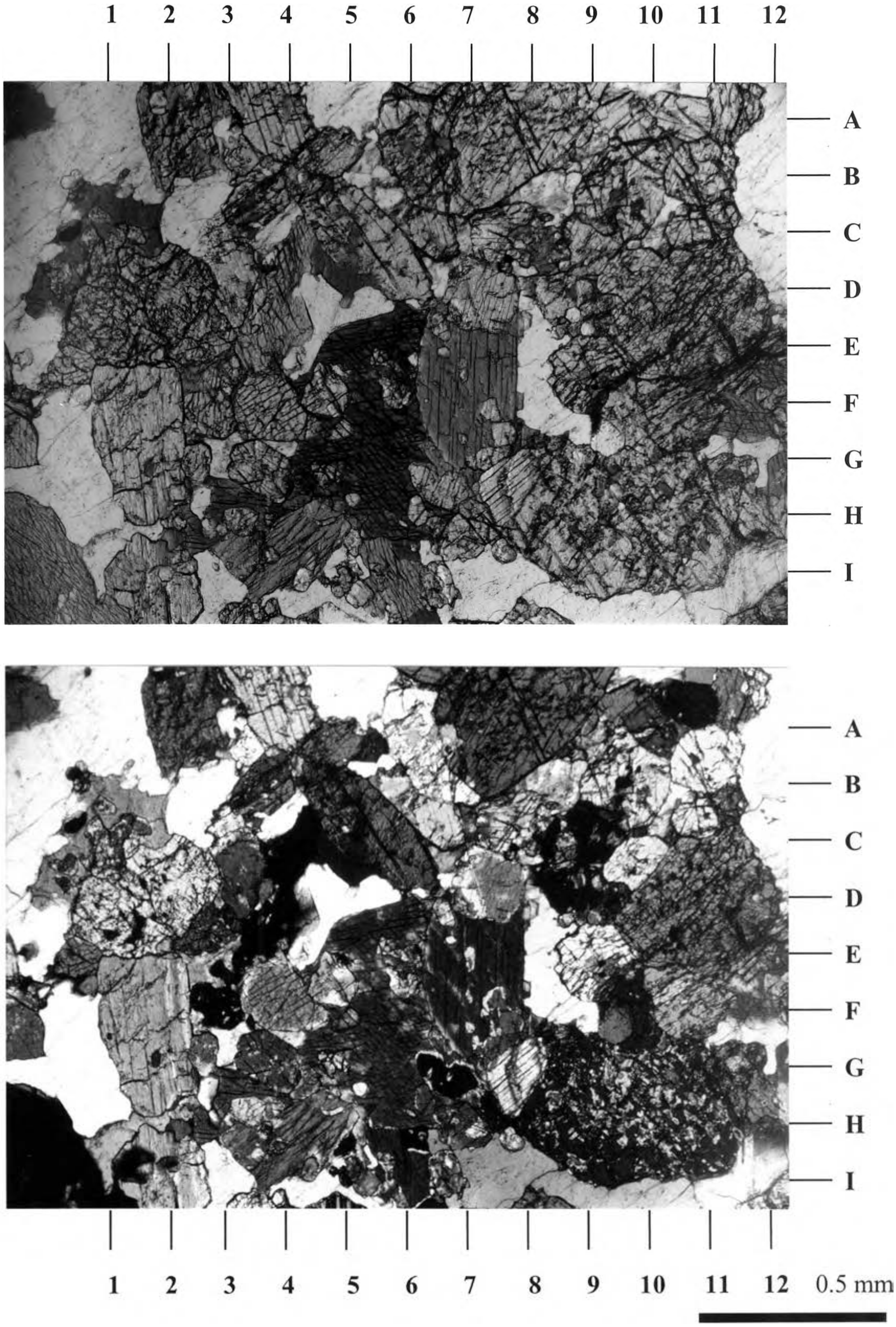


**Figure 3.6** Photomicrograph of medium-grained diorite showing pyroxene (F4) altered to hornblende (G5) (upper photo: plane-polarized light, lower photo: crossed nicols).

K-feldspar constitutes in minor amount, approximately 4 percent of the total volume. It is orthoclase with the average size of about 0.2 mm. K-feldspar was crystallized as discrete tabular crystals and interstitial anhedral grains.

Quartz is invariably late crystallization. It occurs as small anhedral grains with irregular crystal outline filling interstitially among other minerals. Its content is less than 5 percent by modal volume (Table 3.1).

Opaque minerals occur mainly as irregular grains, intergrowth with hornblende and plagioclase. The opaques probably are skeleton magnetite and iron oxides. Sphene forms as minute subhedral to euhedral crystals enclosed by hornblende and plagioclase (Figure 3.7). Apatite can also be observed.

The classification of diorite based on Streckeisen (1979) in QPK diagram is presented in Figure 3.8. It is rather obvious that the modal analysis data fall mainly within diorite field with only a few in quartz diorite field.

**3.2 Granodiorite unit**

Granodiorite forms irregular veins or dikes cross-cutting diorite, skarn and marble. It is mainly exposed in the central part, for instance, at Khao Chong Rom (Figure 3.9) and locally in southern part at Wat Khao Phra Ngam (Figure 3.10). The geological boundary between granodiorite and diorite is intrusive contact. Some diorite xenoliths embedded in granodiorite can be observed (Figures 3.11 and 3.12). The contacts between granodiorite, skarn and marble are fault contact and intrusive contact with thin reaction rim developed along contact zone. Granodiorite is probably equivalent to Soi Woi Intrusives of Upper Triassic age (Hintong et al., 1981).

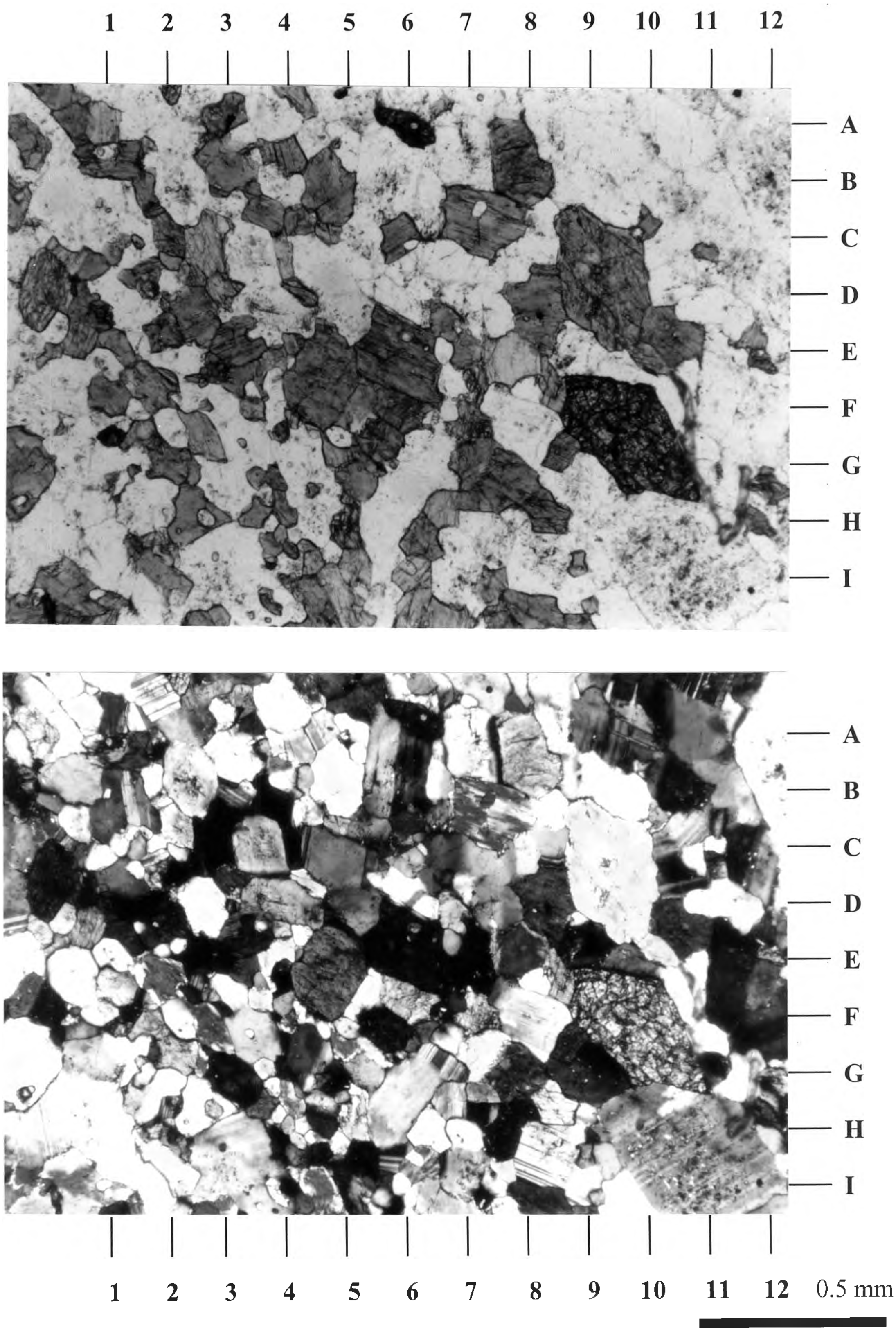


**Figure 3.7** Photomicrograph of fine to medium-grained diorite showing anhedral K-feldspar (D8), subhedral plagioclase (I11), subhedral hornblende (D10) and euhedral sphene (G10) (upper photo: plane-polarized light, lower photo: crossed nicols).

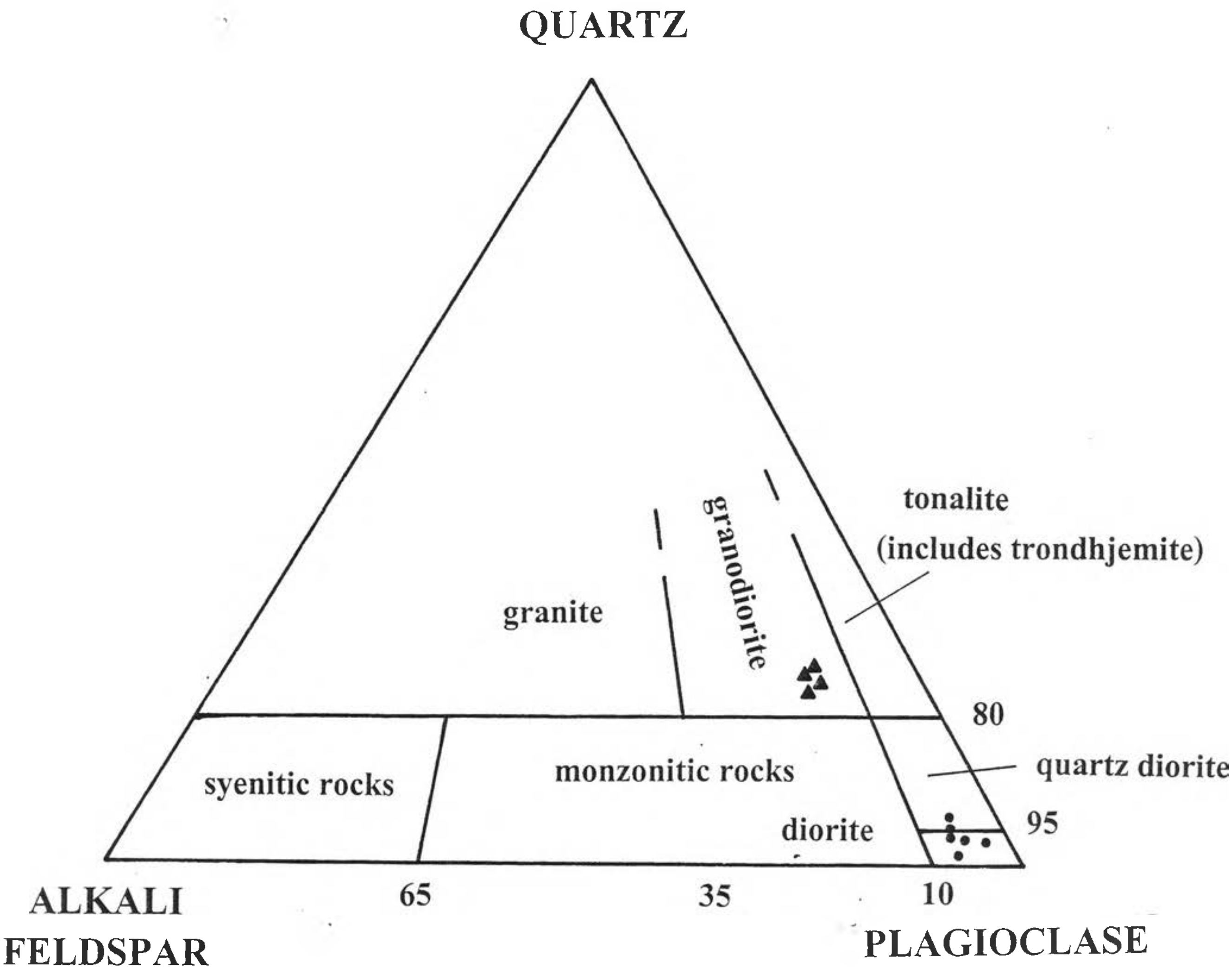


**Figure 3.8** Diorite (solid circle) and Granodiorite (triangle) plotted on QPK diagram. The classification is based on modal mineral compositions (After Streckeisen, 1979).

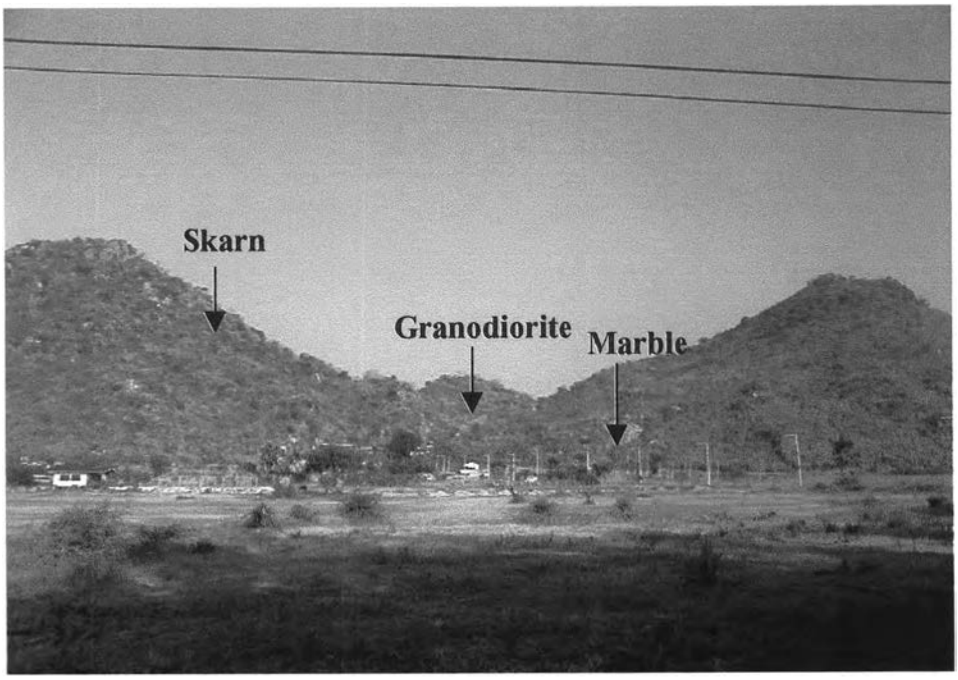


**Figure 3.9** Outcrop of granodiorite stock crosscutting marble and skarn at Wat Khao Chong Rom.

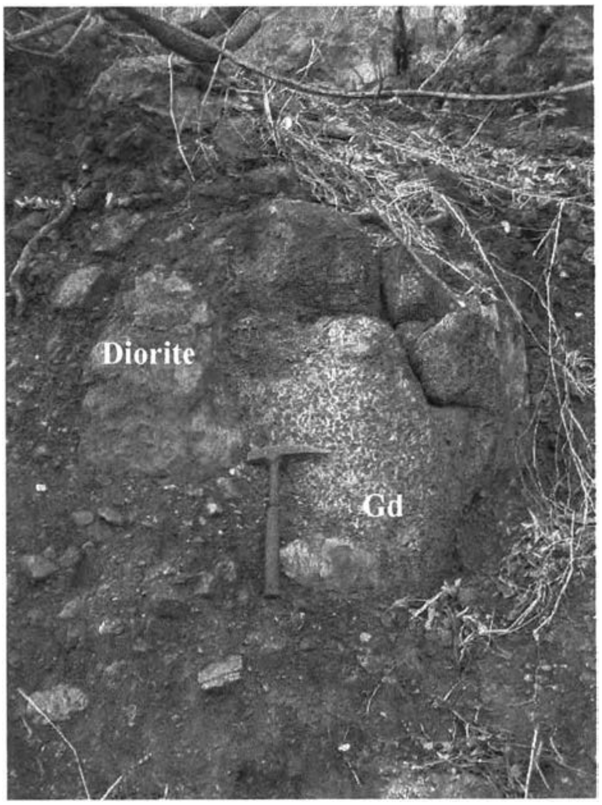


**Figure 3.10** Outcrop of granodiorite (Gd) dike crosscutting diorite at Wat Khao Phra Ngam.

**Figure 3.11** An exposure of granodiorite showing diorite xenolith at Wat Khao Chong Rom.

**Figure 3.12** An exposure of granodiorite showing diorite xenolith at Wat Khao Phra Ngam.

Megascopically, the rock typically is light to medium gray in color, fine to medium-grained (0.2 to 1.0 mm). It shows hypidiomorphic granular texture (Figure 3.13). Granodiorite consists predominantly of plagioclase, quartz, hornblende and minor proportions of K-feldspar and pyroxene. The accessory minerals are sphene, apatite and opaque minerals.

Under polarized microscope, plagioclase feldspar is the most abundant mineral constituent of approximately 55.5 modal percent of the total volume (Table 3.4). It occurs as subhedral tabular crystals having size ranging from 0.5 to 1.0 mm in length. Plagioclase commonly shows albite and albite-carlsbad twins and ranges in composition between An 20 and An 40 (oligoclase to andesine composition). Normal zoning can be observed. Sericite is a common alteration product of plagioclase. The electronprobe microanalysis of plagioclase indicates andesine composition with similar An content (An 37) to that (An 34) found in diorite (Table 3.5).

Quartz has the approximate grain size of 0.2 mm and forms small anhedral grains and aggregates filled interstitially. It constitutes up to 23.3 modal percent of the total volume (Table 3.4).

Hornblende generally occurs as anhedral to subhedral crystal (Figure 3.14). Grain sizes range from 0.2 to 0.5 mm and it constitutes approximately 10.5 modal percent of the total volume. It is pleochroic in shade of brown to green. Some grains show poikilitic texture containing feldspar, quartz and opaque minerals. Occasionally, some hornblendes are altered to chlorite.

Pyroxene is green to yellowish green in color. Its sizes vary from 0.5 mm to 1.0 mm. It constitutes up to 4 modal percent of the total volume. The pyroxene occurs as


ST. 34
CM.

**Figure 3.13** A specimen of granodiorite containning dark hornblende, quartz and feldspar.

**Table 3.4** Point count analysis the mineral constitutents of Granodiorite from Khao Phra Ngam area *

| Mineral Present | Size (mm.) | % Abundance (average) |
|---|---|---|
| <u>Major</u> | | |
| Plagioclase | 0.5 - 1.0 | 55.5 |
| Hornblende | 0.2 - 0.5 | 10.5 |
| Quartz | 0.1 - 0.3 | 23.3 |
| <u>Minor</u> | | |
| K-feldspar | 0.1 - 0.3 | 4.9 |
| Pyroxene | 0.5 - 1.0 | 3.6 |
| Opaque mineral | 0.1 - 0.3 | trace |
| Sphene | 0.2 - 0.3 | 2.2 |
| Apatite | 0.1 | trace |
| *Alteration Products* | | |
| Sericite | after plagioclase | |
| Chlorite | after hornblende, pyroxene | |
| Fe oxide | after magnetite | |

* based on 4 thin-sections.

**Table 3.5** Electron Microprobe Analyses of plagioclase in granodiorite from Khao Phra Ngam area.

Color : gray

Form : euhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 3 analyses | [2]Cations on the basis of 8 oxygens | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 57.6970 | _ | 58.9050 | 58.3800 | Si | 2.6223 |
| $TiO_2$ | 0.0000 | _ | 0.0000 | 0.0000 | Ti | 0.0000 |
| $Al_2O_3$ | 24.6740 | _ | 26.7780 | 25.7810 | Al | 1.3650 |
| $Cr_2O_3$ | 0.0000 | _ | 0.0000 | 0.0000 | Cr | 0.0000 |
| MgO | 0.0080 | _ | 0.1210 | 0.0600 | Mg | 0.0040 |
| CaO | 6.5400 | _ | 8.4350 | 7.6620 | Ca | 0.3688 |
| MnO | 0.0060 | _ | 0.0400 | 0.0190 | Mn | 0.0007 |
| | | | | | $Fe^{3+}$ | 0.0104 |
| FeO (total | 0.2020 | _ | 0.3780 | 0.2770 | $Fe^{2+}$ | 0.0000 |
| BaO | 0.0330 | _ | 0.0940 | 0.0640 | Ni | 0.0000 |
| $Na_2O$ | 6.9130 | _ | 7.6610 | 7.1850 | Na | 0.6258 |
| $K_2O$ | 0.2000 | _ | 0.2210 | 0.2080 | K | 0.0119 |
| Total | 96.2730 | _ | 102.6330 | 99.6360 | Sum | 5.0088 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $(K_{0.01}, Na_{0.62}, Ca_{0.37}) Al (Si_{2.63}, Al_{0.37}) O_8$

End Member Composition : Or = 1.00, Ab = 62.00, An = 37.00

Name : **Andesine**

( Or = Orthoclase, Ab = Albite, An = Anorthite )

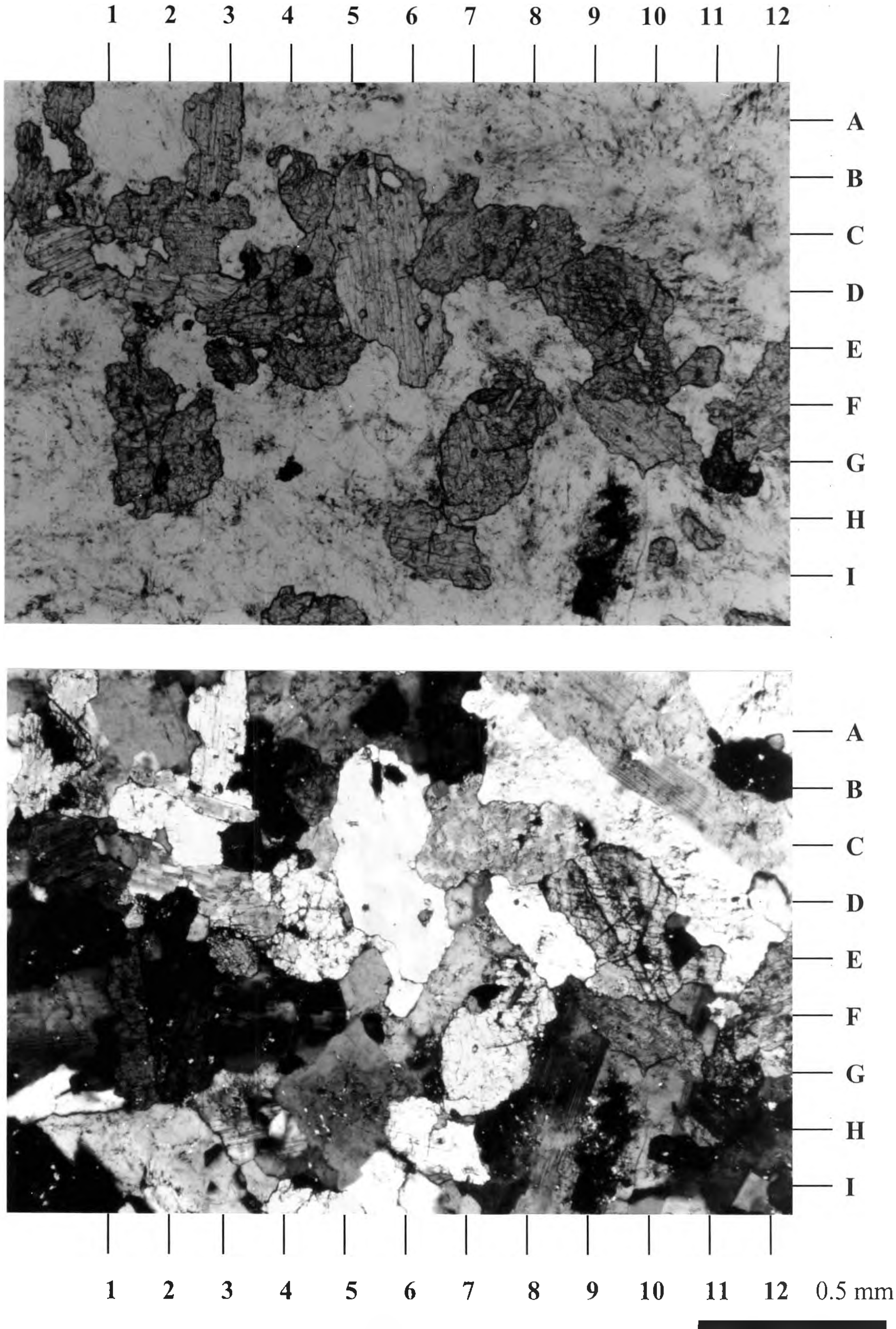


**Figure 3.14** Photomicrograph of medium-grained granodiorite showing brown and green pleochroic hornblende (C6), K-feldspar (F3), plagioclase (A10), quartz (F4) and sphene (E4) (upper photo: plane-polarized light, lower photo: crossed nicols).

subhedral crystal and some crystals show twinning. The electron probe microanalysis indicates augite composition similar to that found in diorite (Table 3.6).

K-feldspar occurs as orthoclase and microcline. Its grain sizes range from 0.1 mm to 0.3 mm. It usually forms anhedral to subhedral crystals and constitutes approximately 5 modal percent of the total volume The orthoclase frequently contains poikilitic inclusions of quartz.

Opaque mineral mainly occurs as an irregular grain which is probably magnetite. The other accessory minerals include sphene, apatite and iron oxide.

The classification of granodiorite in QPK diagram is present in Figure 3.8. Most of the modal analysis data fall within the granodiorite field following the Streckeisen's classification (1979).

### 3.3 Andesite unit

Andesitic volcanic rock is found locally as dyke crosscutting the diorite and skarn rocks at Wat Tung Singto (Figures 3.15 and 3.16). It is probably equivalent to Khao Yai Volcanics of Permo-Triassic age (Hintong et al., 1981).

The small volume of andesitic rock is generally green to dark green in color (Figure 3.17). It is holocrystalline, medium to coarse-grained and porphyritic texture. This andesitic rock contains large amount and varying size of phenocryst. The phenocrysts consist mainly of plagioclase and minor clinopyroxene. Plagioclase is occur as discrete, cluster and penetrating of subhedral grains which varies in size from 0.5 mm to 1.0 mm. Clinopyroxene phenocryst is found in rather small amount and small in size than

**Table3.6** Electron Microprobe Analyses of clinopyroxene in granodiorite from Khao Phra Ngam area.

Color : gray

Form : euhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 3 analyses ) | [2]Cations on the basis of 24 oxygens | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 52.7640 | _ | 53.3470 | 53.0000 | Si | 1.9943 |
| $TiO_2$ | 0.0070 | _ | 0.0980 | 0.0410 | Ti | 0.0012 |
| $Al_2O_3$ | 0.1530 | _ | 0.5840 | 0.3280 | Al | 0.0145 |
| $Cr_2O_3$ | 0.0420 | _ | 0.2650 | 0.1170 | Cr | 0.0035 |
| MgO | 13.0480 | _ | 13.1640 | 13.1250 | Mg | 0.0736 |
| CaO | 24.5190 | _ | 24.7490 | 24.6150 | Ca | 0.9924 |
| MnO | 0.0900 | _ | 0.4040 | 0.2190 | Mn | 0.0070 |
| | | | | | $Fe^{3+}$ | 0.0000 |
| FeO (total | 5.2890 | _ | 7.6520 | 6.8130 | $Fe^{2+}$ | 0.2144 |
| NiO | 0.0490 | _ | 0.0800 | 0.0660 | Ni | 0.0010 |
| $Na_2O$ | 0.3100 | _ | 0.5670 | 0.4710 | Na | 0.0344 |
| $K_2O$ | 0.0000 | _ | 0.0430 | 0.0250 | K | 0.0012 |
| Total | 97.7030 | _ | 99.4600 | 98.8210 | Sum | 4.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $(Ca_{1.00}\ Mg_{0.74}\ Fe_{0.22}\ Na_{0.04})\ (Si_{1.99}\ Al_{0.01})\ O_6$

Name : **Augite**

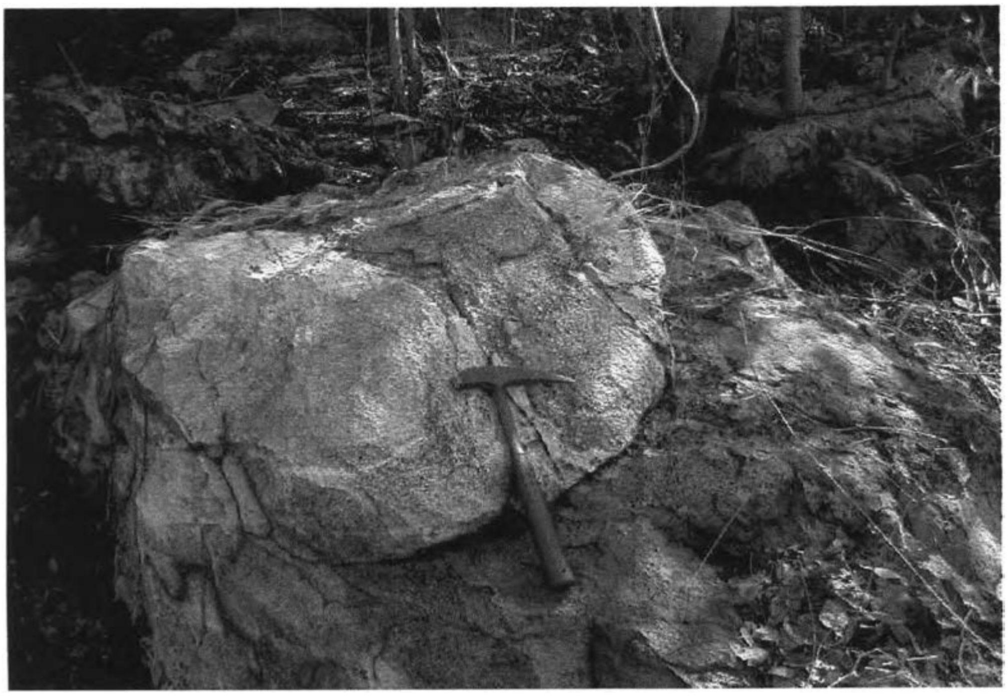

**Figure 3.15** An exposure of andesite in contact with diorite at Wat Thung Singto.

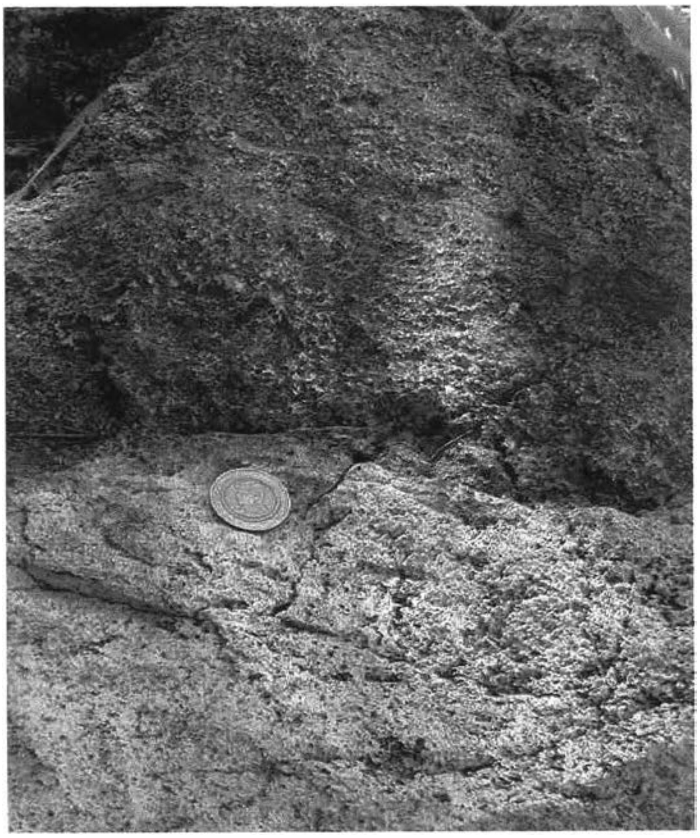

**Figure 3.16** A close-up view of contact zone.


**Figure 3.17** A specimen of andesite containing dark green clinopyroxene and feldspar.

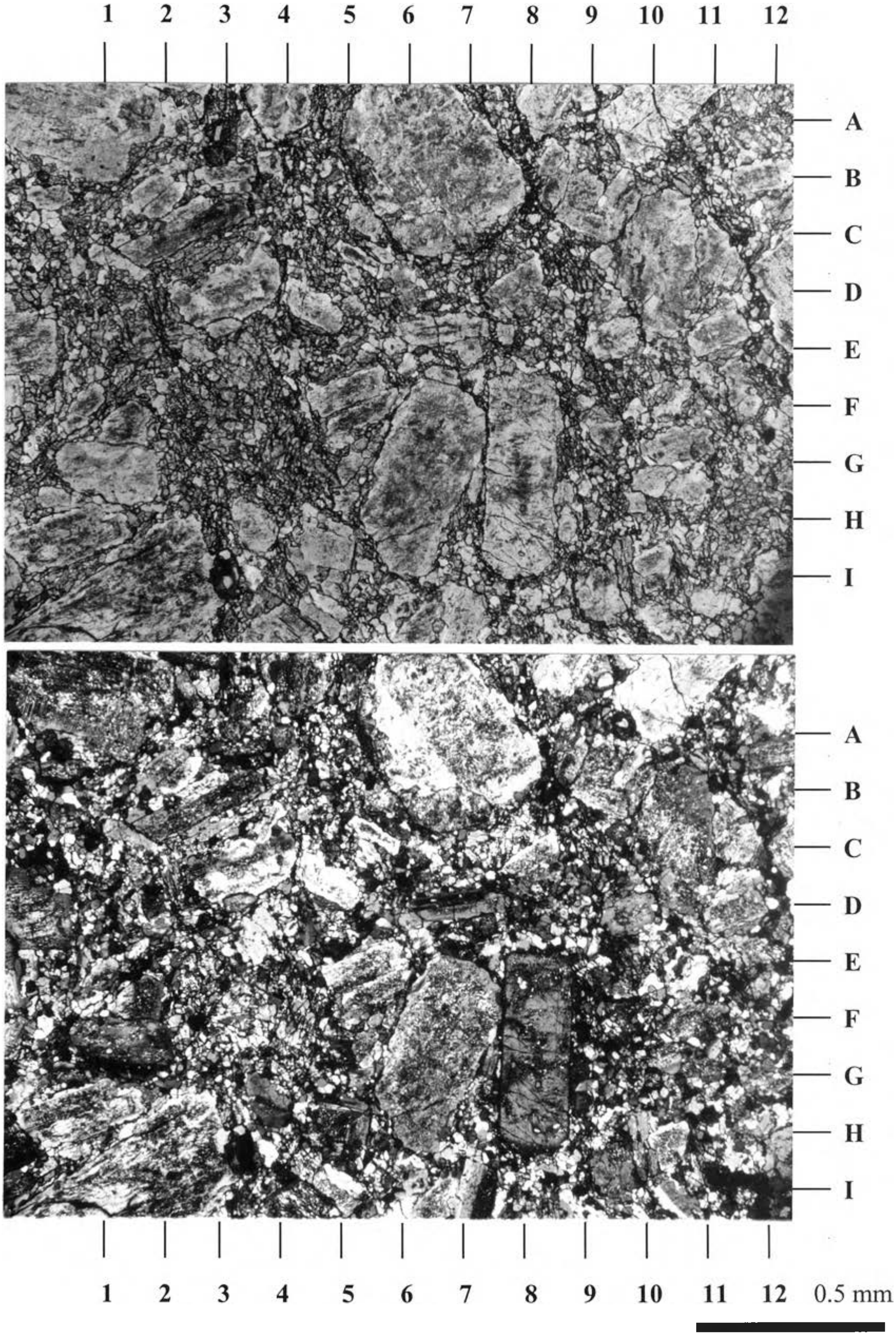


**Figure 3.18** Photomicrograph of andesite showing plagioclase phenocryst (F7) in the groundmass of microcrystalline plagioclase and clinopyroxene (upper photo: plane-polarized light, lower photo: crossed nicols).

plagioclase (Figure 3.18). Groundmass of the andesite composed of microcrystalline plagioclase and minor clinopyroxene. Plagioclase commonly altered to sericite.

## 3.4 Marble Unit

This unit is probably equivalent to Khao Khad Formation of Middle Permain age (Hintong, 1981). As earlier mentioned, Khao Khad Formation is characterized by massive to thick bedded limestone and dolomitic limestone intercalated with bedded and nodular chert. In the study area, however, this formation was likely to be effected by diorite intrusion in which transformed most of the limestones in the area into marble. This unit is, therefore, better called marble unit in this study. This unit crops out mainly in the western part the mountains which arrange in NE-SW trending in the north, for instance, at Ban Bo Kaeo, and NW-SE trending in the south, for instance, Khao Pha Daeng and Khao Phra Ngam (Figure 3.1). The boundaries between marble unit and granodiorite are intrusive and fault contacts. This unit consists mainly of marble and minor diopsidic marble (Figures 3.19-3.22). Chert is often formed as discontinuous beds or lens conformably with marbles. The bedding is moderately west dipping. Owing to the fact that bedding of marble is nearly parallel to the intrusive contact. It is likely that the intrusion of diorite might take place at relatively deep level which transformed the limestone into marble in a more ductile manner. If the intrusion of diorite occurs at relatively shallow level, the intrusive contact should be sharply discordant to bedding and the host rock is in a brittle fracture state rather than a ductile manner. Local development of reaction or bimetasomatic skarn (Einaudi et al, 1981) is commonly occurred as a white zone surrounding chert beds or nodules. This unit is superimposed by skarn unit upon approaching the diorite intrusion. Detailed description of rock types in this unit is outlined in the following paragraphs.

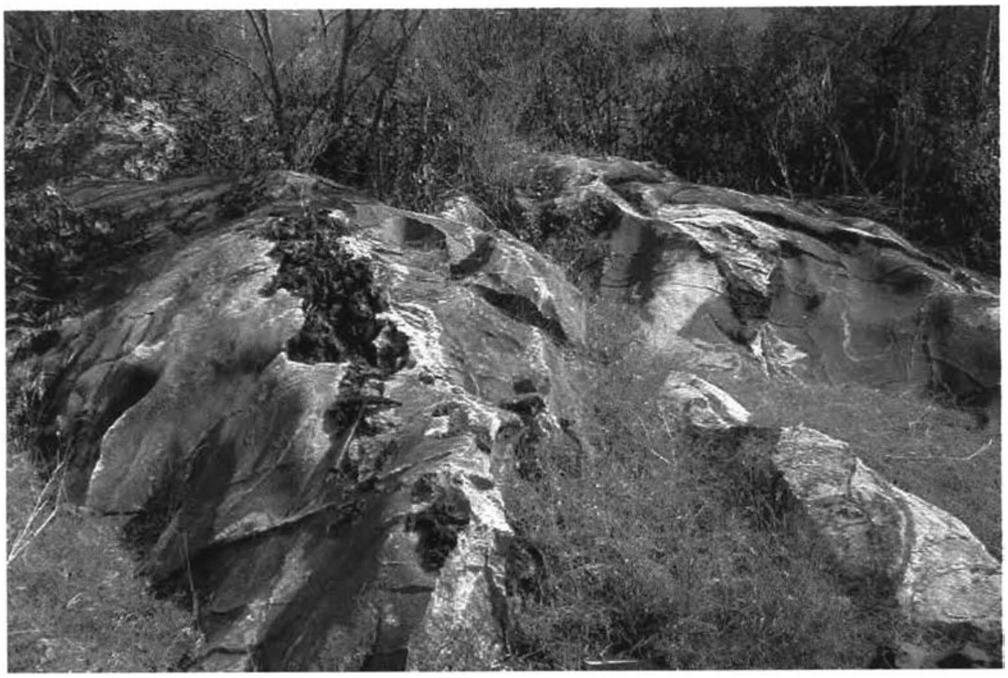

**Figure 3.19** An exposure of marble interbedded with chert lense or nodules. The chert lens are rimed by a white zone composed mainly of wollastonite.

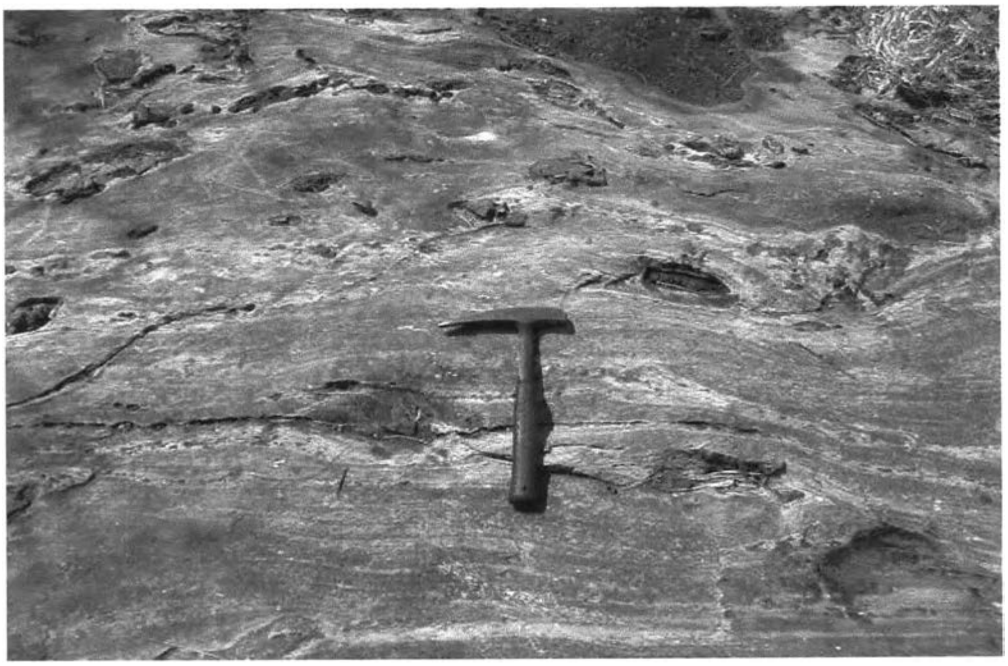

**Figure 3.20** An exposure of thin-bedded marble with elongate shape of nodule chert.

**Figure 3.21** An exposure of white and dark gray marbles.

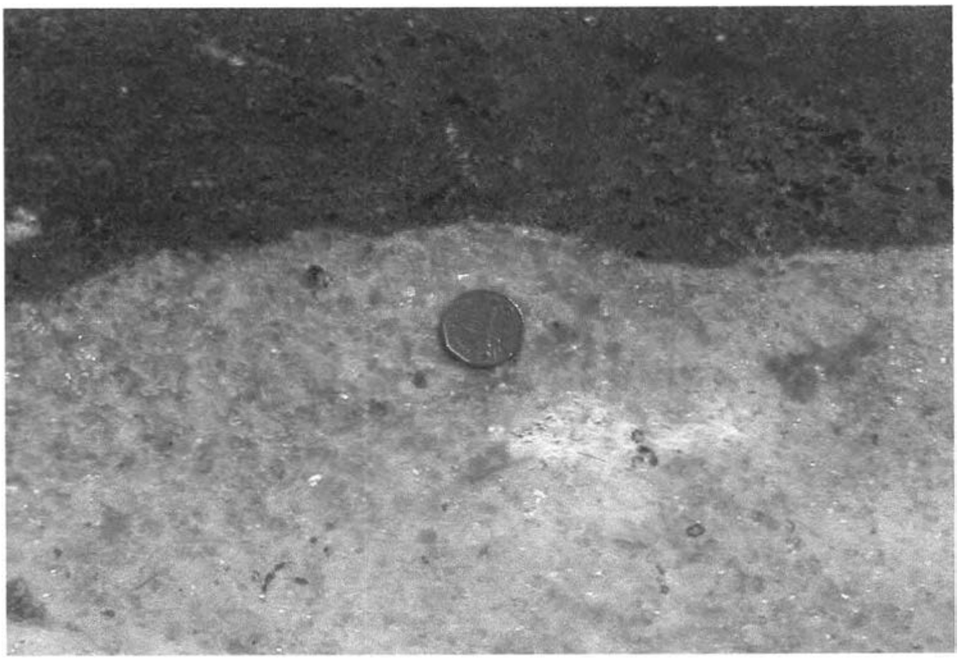

**Figure 3.22** A close-up view of marble showing coarse-grained calcite.

### 3.4.1 Marble

Marble probably constitutes the major rock types of this unit in the study area. It is a medium to coarse-grained, light to dark gray rock consisting of 80-90 % calcite, 2-5 % dolomite and minor graphite (Figure 3.23).

Microscopically the rock shows equigranular - granoblastic interlocking grains of anhedral to subhedral calcite and minor dolomite with many curved and sutured boundaries (Figure 3.24). Grain size range from 1.0–3.0 mm. Fine-grained graphite is observed along the calcite grain boundary. The marble was likely to be formed by the contact metamorphic recrystallization (isochemical metamorphism) of limestone and dolomitic limestone during the early stage of diorite intrusion.

### 3.4.2 Diopsidic Marble

Diopsidic marble normally develops as a narrow zone (about 1–5 m thick). This marble is a medium-grained, light gray rock, and characteristically composed of 80–85 % calcite, 5–10 % dolomite, 1–5 % diopside and 1 –2 % tremolite/actinolite (Figure 3.25). In thin-section, calcite occurs as granoblastic polygonal grains with straight to slightly curved boundaries. Grain sizes range form 1.0-2.0 mm. Some grains show sutured texture. Dolomite is also show granoblastic polygonal texture. Grain sizes range form 0.3-0.5 mm. Diopside and tremolite/actinolite are formed along dolomite grain boundaries (Figure 3.26).

Diopside marble may originate from a silty dolomitic limestone. Reaction between dolomite and quartz from a silty dolomitic limestone and may produce diopside with the rising temperature as follows:

$$\text{dolomite} + 2\ \text{quartz} = \text{diopside} + 2\ CO_2 \quad (3\text{-}1)$$

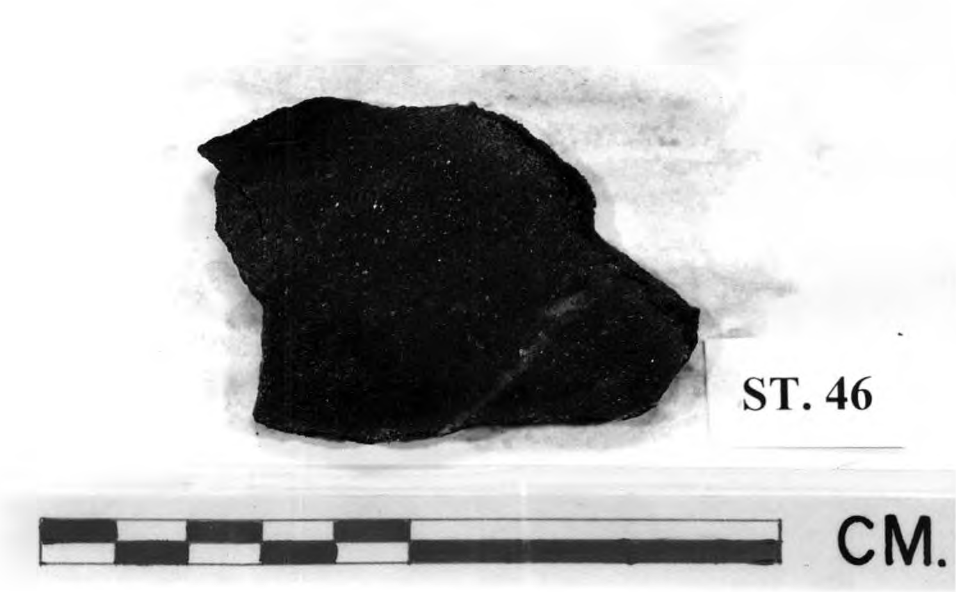


**Figure 3.23** A specimen of marble containing coarse-grained calcite and graphite.

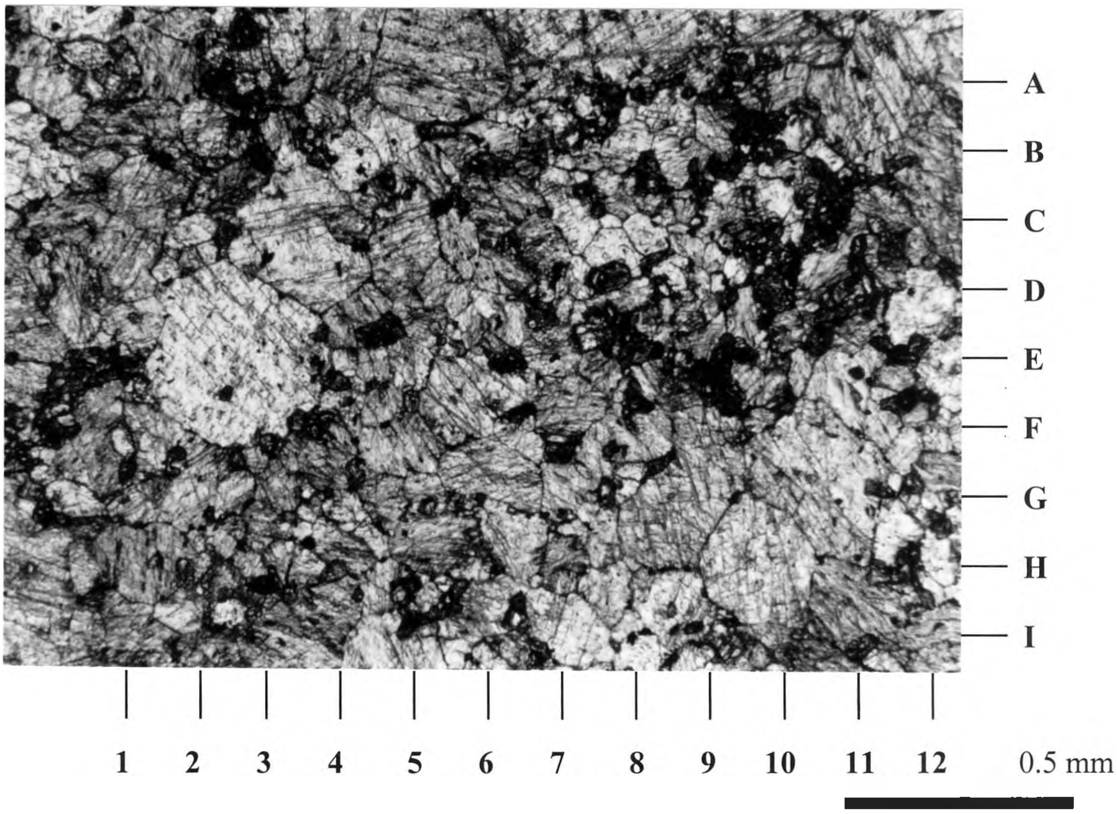


**Figure 3.24** Photomicrograph of marble showing interlocking grains of subhedral calcite (G9), dolomite (E3) and graphite (E10) along grain boundaries (cross nicols).

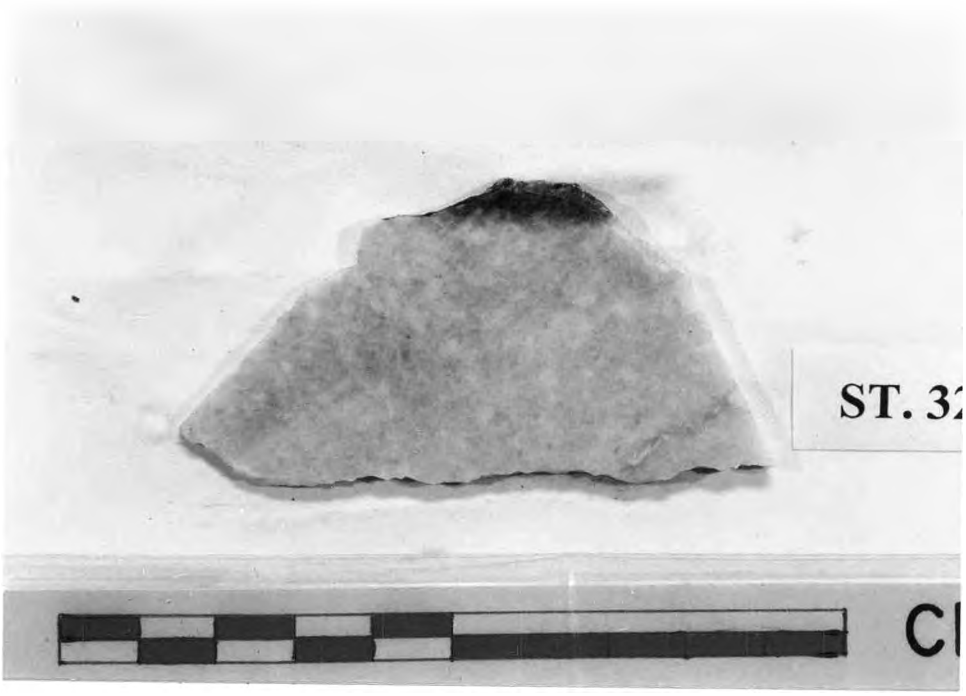

**Figure 3.25** A specimen of diopsidic marble containing coarse-grained calcite, dolomite and diopside.

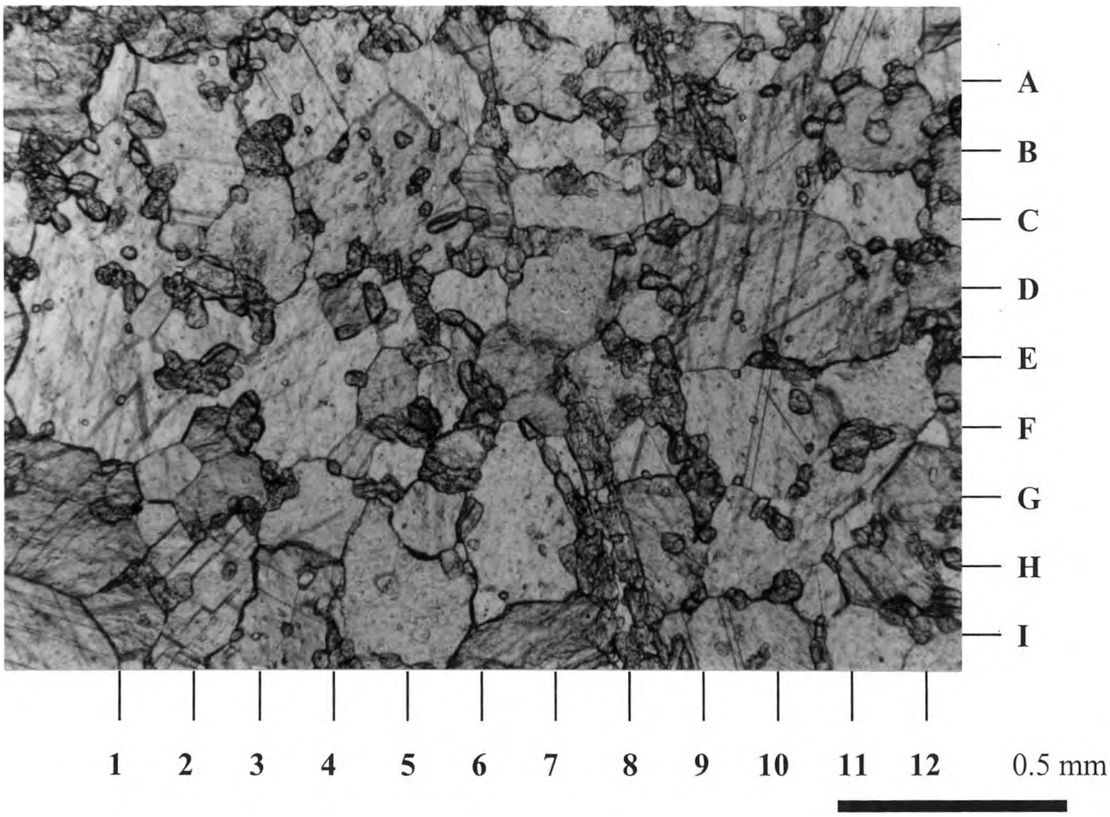


**Figure 3.26** Photomicrograph of marble showing interlocking grains of subhedral calcite (E3), dolomite (C7) with minute grains of diopside (C1) and tremolite (D4) (cross nicols).

### 3.4.3 Chert with Reaction Skarn.

Chert is an extremely fine-grained, light to dark gray rock and formed as discontinuous beds or nodules conformably with marbles. As effected by bimetasomatic process, chert nodules and chert beds are commonly rimmed by a white zone (2-10 cm), composed mainly of wollastonite and diopside (Figure 3.27). Microscopically, chert is composed of crypto-microcrystalline quartz that formed circular to elliptical banding (Figure 3.28). Wollastonite occurs as bladed and radiating fibrous crystals with crystallo-blastic texture. Diopside also occurs as rounded grains with dolomite and calcite. The textural evidences for replacement of quartz, calcite and dolomite by wollastonite and diopside are readily apparent. This textural evidences suggest a local exchange of chemical component of dissimilar lithologies (i.e., quartz from chert, calcite and dolomite from marble) has occurred during metamorphism. The local compositional control on calc-silicate mineralogy suggests that these features were not caused by igneous related metasomatism. The reaction of dolomite with quartz would directly form diopside as reaction 3-1.The formation of wollastonite is represented by the equation:

$$\text{calcite} + \text{quartz} = \text{wollastonite} + CO_2 \qquad (3\text{-}2)$$

The equilibrium curve for this reaction determined by Greenwood (1967) is show in Figure 3.29. The paragenetic relation suggests the rocks were thermally metamorphosed up to upper hornblende-hornfels facies (Winkler, 1965).

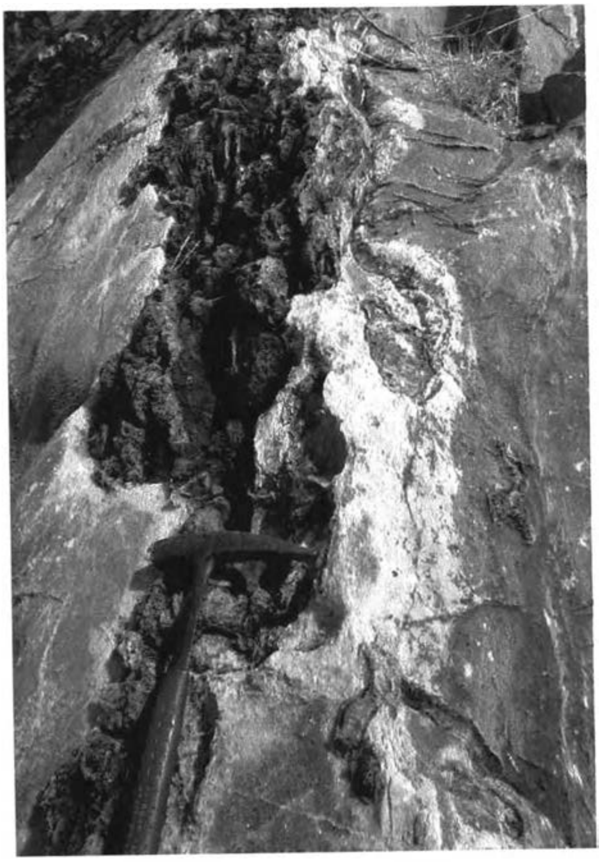

**Figure 3.27** An exposure of chert nodule showing partial replaced by wollastonite

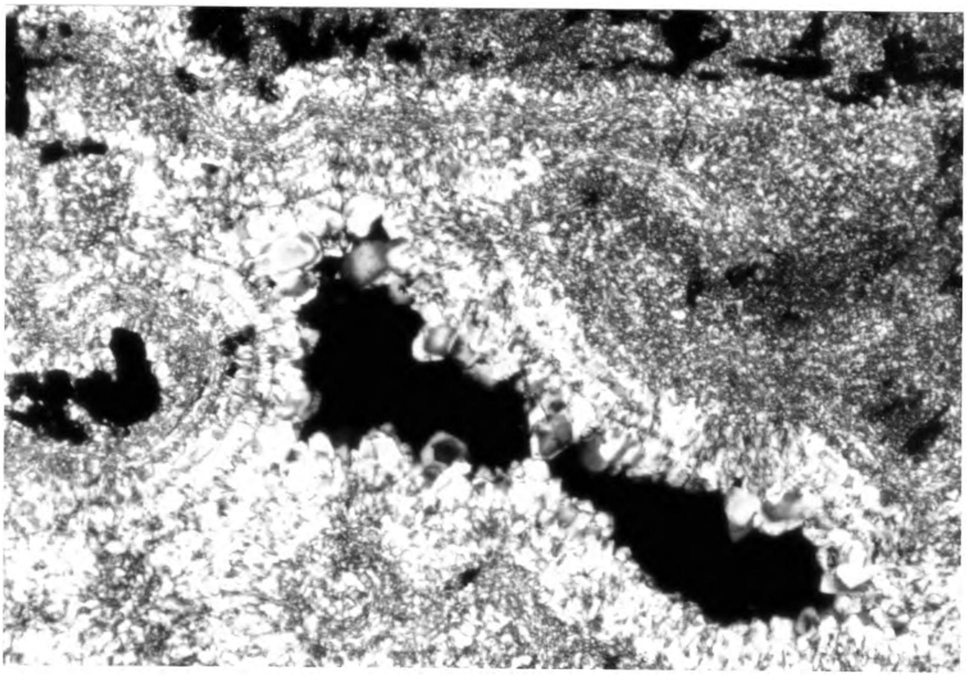

**Figure 3.28** Photomicrograph of chert showing circular to elliptical area of crypto-microcrystalline quartz (cross nicols)

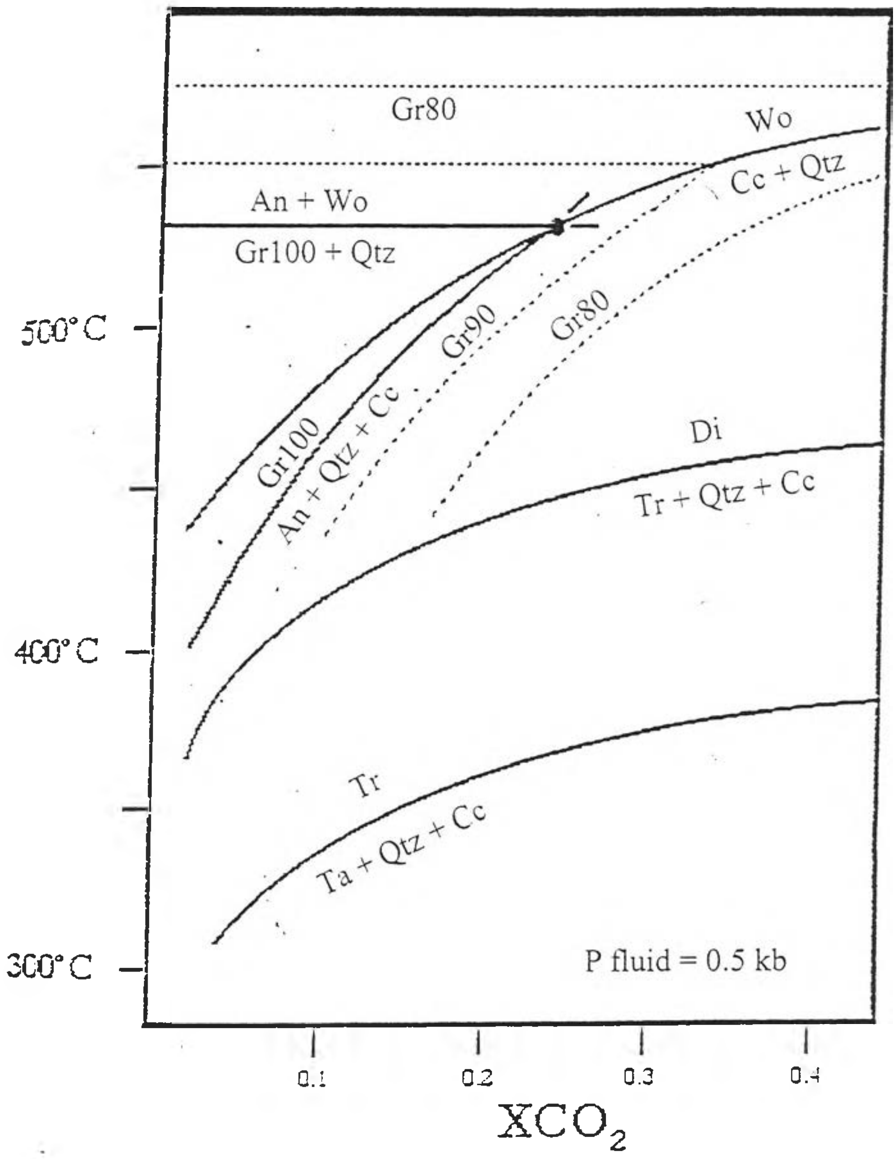


**Figure 3.29** Illustration of metamorphic equilibria for selected reactions in the system Ca-Ma-Al-Si-$H_2O$-$CO_2$ (Based on Winkler, 1965; Metz and Winkler, 1963, 1964; Metz and Trommsdorff, 1968, Greenwood, 1967 and Kerrick, 1974).

## 3.5 Skarn Unit

The metasomatic alteration of marble to form skarn rocks can be seen throughout the Khao Phra Ngam area. The skarn occurs on the western side of diorite body as contact aureoles continuously in N-S trending, for instance, at Ban Bo Kaeo, Wat Tung Singto and Wat Khao Phra Ngam (Figure 3.1). Relict bedding structures are found and shown in NE-SW and NW-SE trending with moderate west dipping conformably with the marble unit. The skarn unit forms a narrow zone from 1-5 m wide (Figures 3.30 and 3.31). Skarn is medium to coarse-grained rock with granoblastic texture. It is composed of garnet, clinopyroxene and wollastonite as essential minerals. The accessory minerals are calcite, quartz, plagioclase, and epidote. Detailed observation of the skarn rock reveals that this unit consists of four mineralogical zones, from marble to diorite as, (1) a 10 cm to 2 m outer zone of wollastonite + clinopyroxene $\pm$ calcite $\pm$ quartz $\pm$ garnet; (2) a 5–30 cm main zone of garnet + clinopyroxene $\pm$ wollastonite $\pm$ quartz; (3) a 30 cm to 2 m inner zone of garnet $\pm$ quartz $\pm$ feldspar and (4) a 10 cm to 1 m inner zone of plagioclase + quartz + pyroxene $\pm$ garnet. Evidences from outcrops and petrographic study reveal that these zones formed contemporaneously. The zonal arrangement from marble side to diorite side could be called, based on its dominant mineral assemblage as, wollastonite skarn, garnet-clinopyroxene skarn, garnet skarn and contaminated diorite. Wollastonite skarn, garnet-clinopyroxene skarn and garnet skarn are situated on the marble side and could be termed exoskarn whereas contaminated diorite is situated on the igneous side and could be called endoskarn (Einaudi et al., 1982). Detailed description of each skarn is as follows:

### 3.5.1 Wollastonite skarn

Wollastonite skarn is usually located closest to the marble. The contact between wollastonite skarn and marble is rather gradational. The thickness of this skarn varies from 10 cm to 2 m. The rock is a medium to coarse-grained with nematoblastic texture (Figure

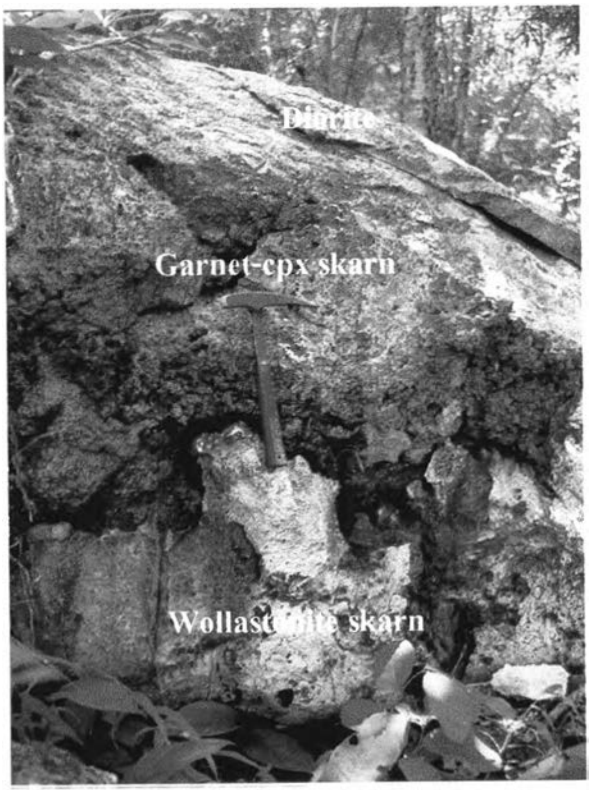


**Figure 3.30** A zonal arrangement of diorite, garnet skarn and wollastonite skarn at Wat Khao Chong Rom.

**Figure 3.31** A zonal arrangement of diorite, contaminated diorite, garnet skarn, garnet-clinopyroxene skarn, wollastonite skarn and marble at Wat Thung Singto.

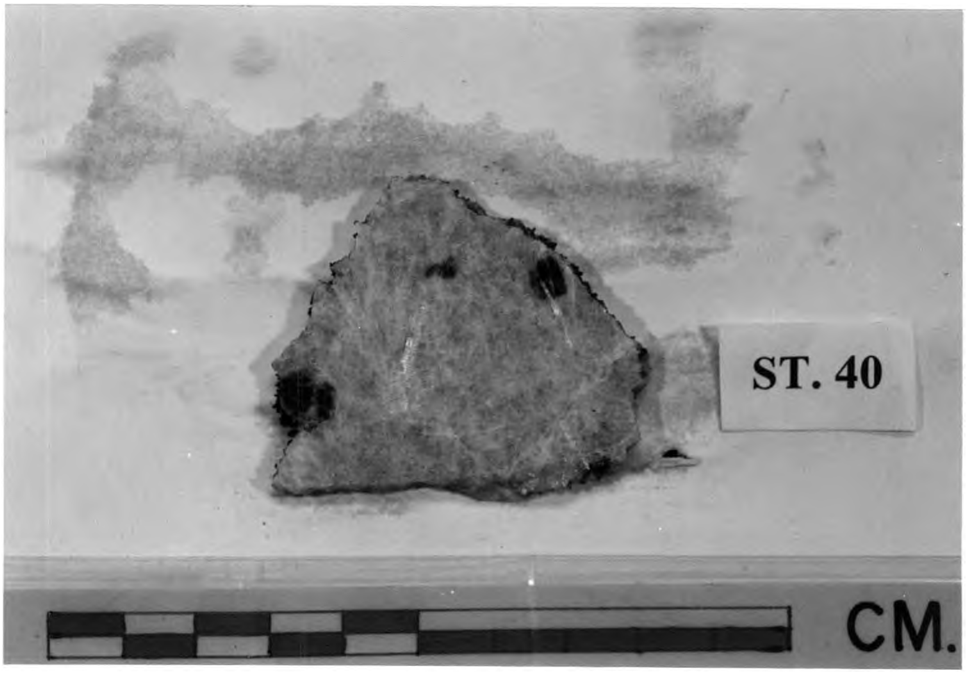


**Figure 3.32** A specimen of wollastonite skarn containing coarse fibrous wollastonite (white) and coarse-grained garnet (brown).

3.32). It is characterized by the predominant occurrence of 80–90 % wollastonite, 1–5 % clinopyroxene, 1–5 % calcite, 1–5 % garnet, 1–2 % quartz with accessory idoclase, zoisite and sulfides. In places, wollastonite skarn formed as narrow zone (0.5-1.0m) parallel to the marble and may be due in part to composition variation in the original limestone.

Microscopically, wollastonite is the main minerals. It occurs as tightly interlocking mass of bladed crystal, radiating fibrous crystal and shows crystalloblastic texture. wollastonite is commonly intergrown with clinopyroxene (Figure 3.33). Isotropic garnet first appears, distinctively replacing wollastonite (Figure 3.34). This replacement marks the boundary with garnet-clinopyroxene skarn. Other minor associated minerals are calcite and quartz filling vugs. Traces of sulfide minerals, mainly chalcopyrite and bornite, fill interstitially. The chemical analysis by electron microprobe reveals that it is almost pure wollastonite with traces of $Fe^{2+}$ and Mg substitution in its structure (Table 3.7 and Figure 3.35). The presence of wollastonite zone indicates the reaction,

$$\text{calcite} + SiO_2 = \text{wollastonite} + CO_2$$

in which calcite derived from the marble and silica from the diorite during the prograde metasomatism.

### 3.5.2 Garnet-clinopyroxene skarn

Garnet-clinopyroxene skarn is developed next to wollastonite skarn toward the diorite side. The boundary between wollastonite skarn and garnet-clinopyroxene skarn is gradational (Figure 3.36). The thickness of this skarn varies from 5-30 cm. Rocks are yellowish brown to reddish brown, fine to medium-grained with granoblastic texture (Figure 3.37). This skarn typically contains 50–70 % garnet, 30–50 % clinopyroxene, 1–5 % wollastonite, 1–5 % calcite, minor quartz, epidote and opaque minerals.

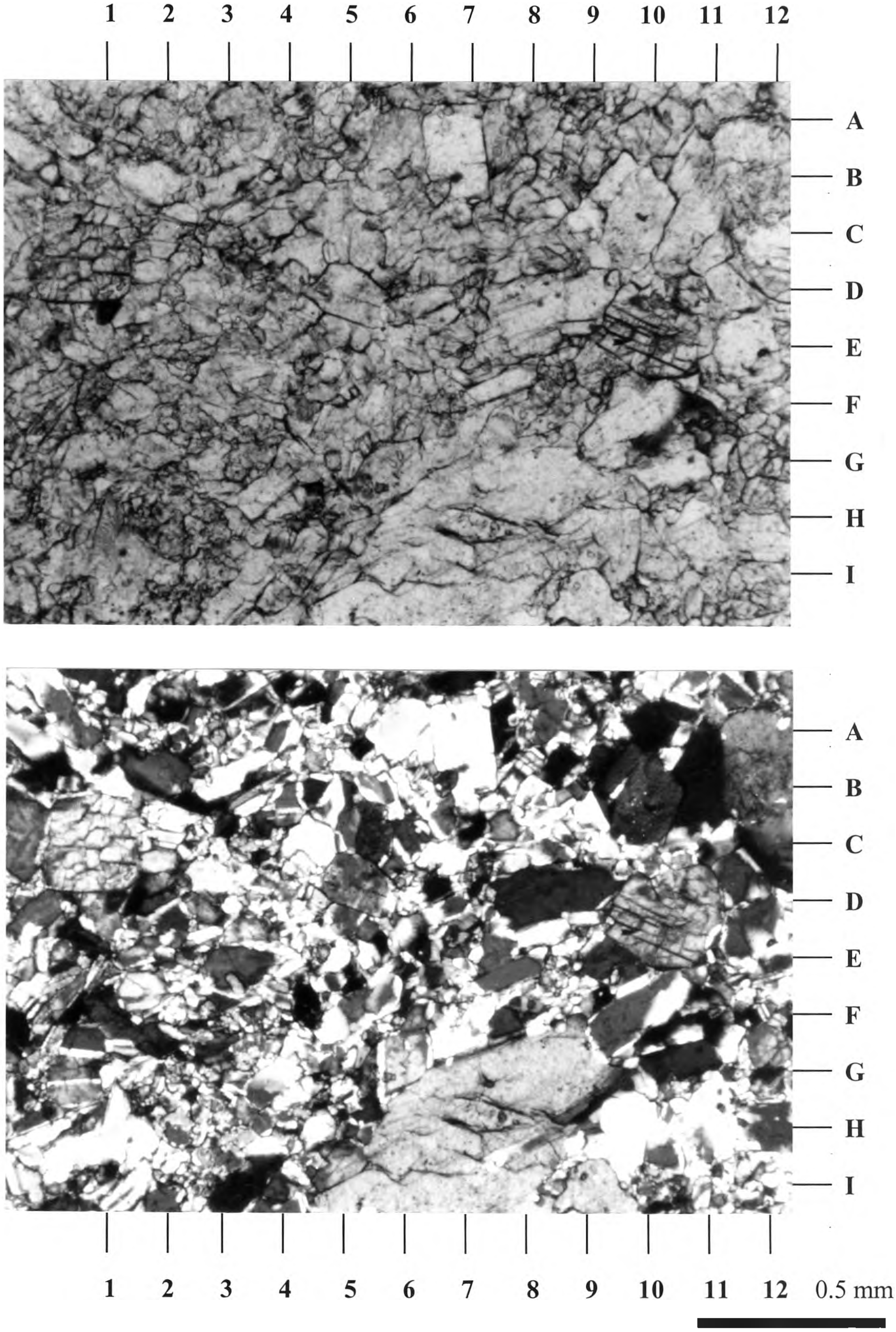


**Figure 3.33** Photomicrograph of wollastonite skarn showing wollastonite (D9) intimately intergrown with clinopyroxene (D11). (upper photo: plane-polarized light, lower photo: crossed nicols).

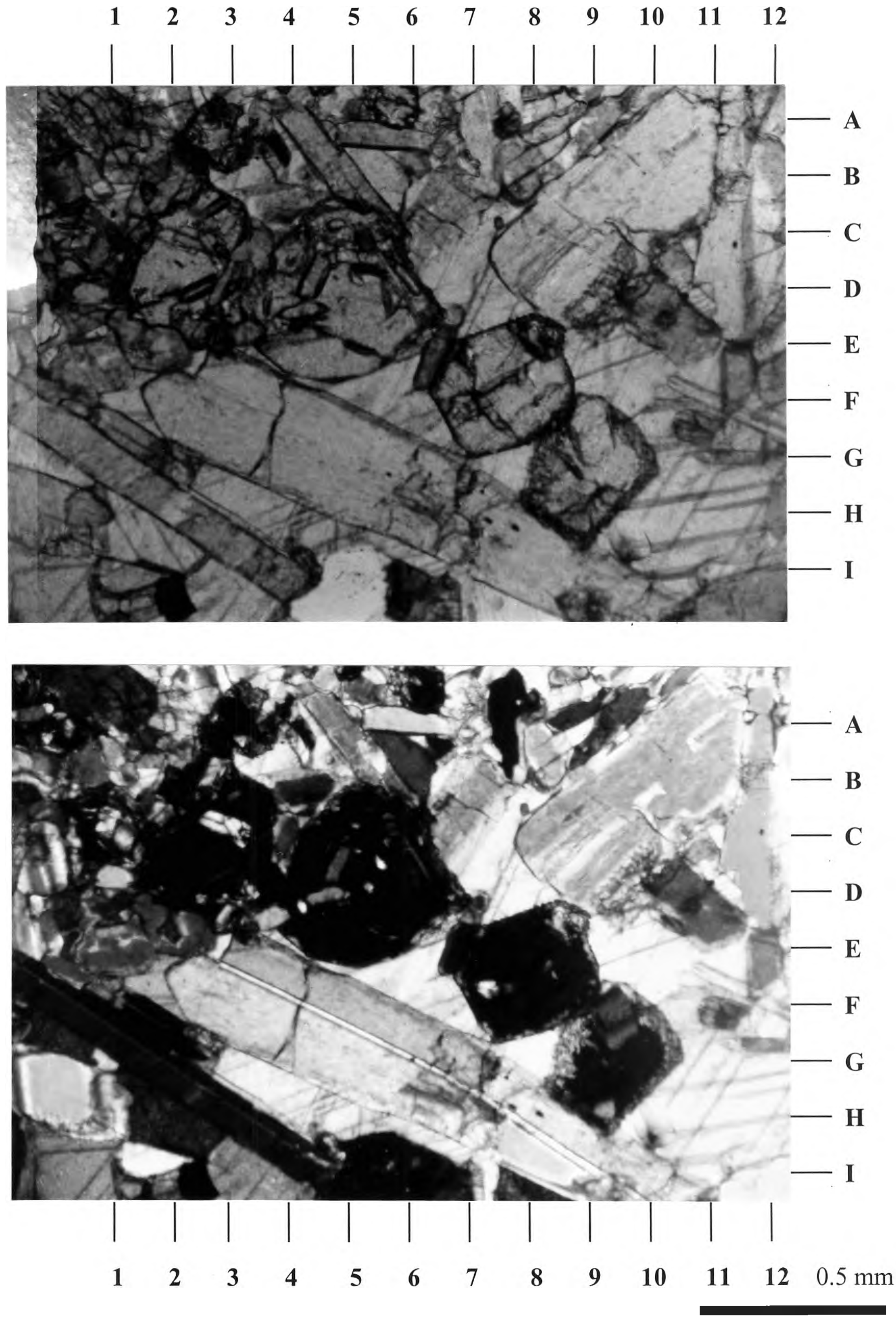


**Figure 3.34** Photomicrograph of wollastonite skarn showing garnet (C5) replaced wollatonite (D4) and calcite (F6) filling intersitially. (upper photo: plane-polarized light, lower photo: crossed nicols).

**Table3.7** Electron Microprobe Analyses of pyroxenoid in skarn from Khao Phra Ngam area.

Color : gray

Form : euhedral to subhedral crystals and radiating fibrous

Chemistry1 :

| Oxides | Range | | | Av. ( 6 analyses ) | [2]Cations on the basis of 3 oxegen | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 50.7859 | _ | 51.5479 | 51.1629 | Si | 0.9988 |
| $TiO_2$ | 0.0311 | _ | 0.0152 | 0.0306 | Ti | 0.0004 |
| $AL_2O_3$ | 0.0000 | _ | 0.1568 | 0.0768 | Al | 0.0018 |
| $CR_2O_3$ | 0.0000 | _ | 0.0111 | 0.0063 | Cr | 0.0001 |
| MgO | 0.0526 | _ | 0.1955 | 0.1298 | Mg | 0.0038 |
| CaO | 46.8437 | _ | 47.8365 | 47.3970 | Ca | 0.9914 |
| MnO | 0.0000 | _ | 0.0641 | 0.0271 | Mn | 0.0004 |
| | | | | | $Fe^{3+}$ | |
| FeO (total | 0.0000 | _ | 0.7457 | 0.1788 | $Fe^{2+}$ | 0.0029 |
| NiO | 0.0000 | _ | 0.0098 | 0.0018 | Ni | 0.0001 |
| $Na_2O$ | 0.0000 | _ | 0.0228 | 0.0093 | Na | 0.0004 |
| $K_2O$ | 0.0000 | _ | 0.0000 | 0.0000 | K | 0.0000 |
| Total | 97.6974 | _ | 100.6502 | 99.0203 | Sum | 2.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $CaSiO_3$

End Member Composition : $Wo_{99.28}$ $En_{0.38}$ $Fs_{0.34}$

Name : **Wollastonite**

( Wo = Wollastonite, En = Enstatite, Fs = Ferrosilite )

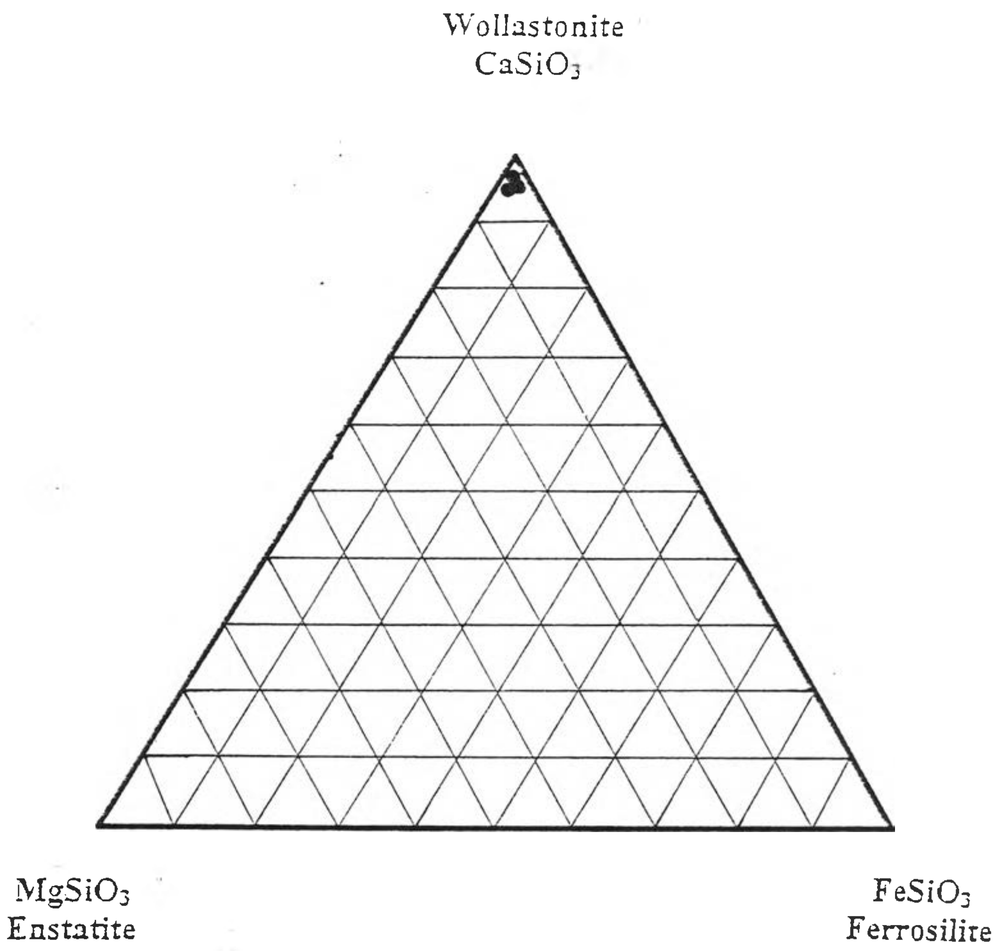


**Figure 3.35** Electron microprobe composition of pyroxenoids from the Khao Phra Ngam area (in mole percent).

**Figure 3.36** An exposure of garnet-clinopyroxene skarn showing a gradation contact with wollastonite skarn.


**Figure 3.37** A specimen of garnet-clinopyroxene skarn containing medium-grained garnet (brown) and clinopyroxene (green).

Microscopically, Garnet is generally reddish brown in color and occurs as fine to medium–grained, subhedral to euhedral crystals with grain sizes ranging form 0.3-1.0 mm. Generally, garnet is optically isotropic. However, a small amount of optically anisotropic can be observed. It is developed by replacing wollastonite. Garnet is partially altered to epidote but the degree of alteration seems to be minor.

Clinopyroxene shows anhedral to subhedral crystals, granoblastic texture. Grain size ranges from 0.3-0.5 mm. It is always accompanied and intimately intergrown with garnet (Figure 3.38), although textures that indicate the replacement of clinopyroxene by garnet are also observed. Clinopyroxene is commonly altered to tremolite/ actinolite. The chemical analysis by electron microprobe indicates that clinopyroxene belongs to diopside–hedenbergite series in which its composition is close to diopside end-member (Table 3.8 and Figure 3.39). The diopside/ (diopside +hedenbergite) mole fractions of clinopyroxene range from 0.80 to 0.98.

Quartz and calcite is generally present but normally in minor amounts, replacing garnet and filling interstitially.

### 3.5.3 Garnet skarn

Garnet skarn is formed between clinopyroxene–garnet skarn and diorite. The boundaries are gradational. In places, garnet skarn superimposed on garnet-clinopyroxene skarn. Garnet skarn can be distinguished from garnet-clinopyroxene skarn by the decreasing of clinopyroxene content and the presence of the coarse-grained and zoned garnet. Thickness of this zone ranges form 30 cm to 2 m. Garnet skarn typically contains 80–90 % garnet, 5–10 clinopyroxene, 1–5 % calcite, 1–5 % quartz, minor epidote, feldspar and opaque minerals. Rocks are yellowish brown to greenish brown, medium to coarse–grained with granoblastic texture. Garnet is comparatively large in size and euhedral to

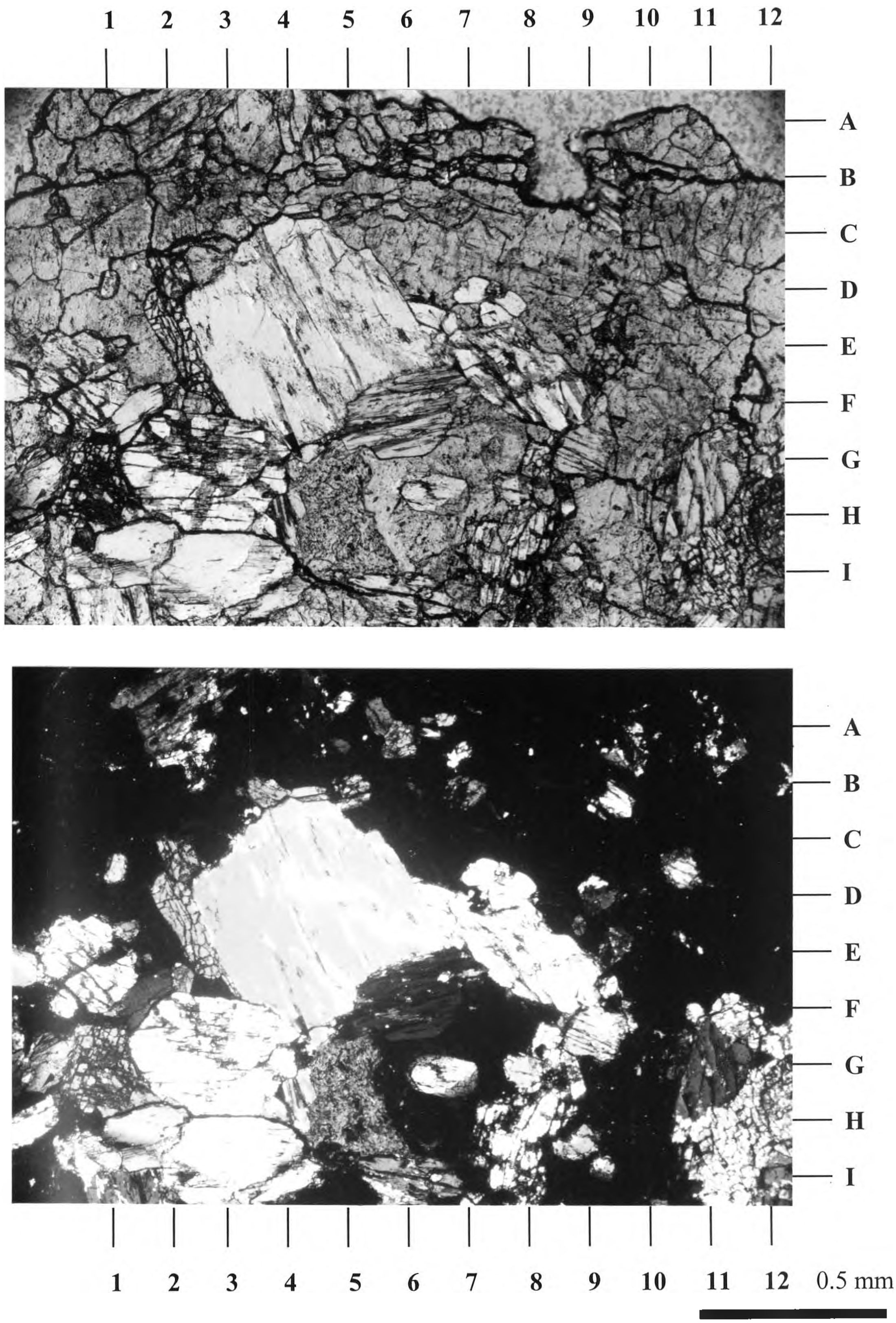


**Figure 3.38** Photomicrograph of garnet-clinopyroxene skarn showing garnet (G6) intimately intrgrown with diopside (E11) and replacing wollastonite (E8) (upper photo: plane-polarized light, lower photo:crossed nicols).

**Table 3.8** Electron Microprobe Analysis of clinopyroxene in skarn from Khao Phra Ngam area.

Color : green

Form : euhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 9 analyses ) | [2]Cations on the basis of 6 oxegen | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 52.4967 | _ | 55.2959 | 53.9364 | Si | 1.9836 |
| $TiO_2$ | 0.0045 | _ | 0.1375 | 0.0270 | Ti | 0.0007 |
| $Al_2O_3$ | 0.0193 | _ | 1.1102 | 0.3348 | Al | 0.0145 |
| $Cr_2O_3$ | 0.0000 | _ | 0.0283 | 0.0123 | Cr | 0.0004 |
| MgO | 14.5209 | _ | 17.9104 | 16.2039 | Mg | 0.8883 |
| CaO | 24.8871 | _ | 26.1620 | 25.5769 | Ca | 1.0079 |
| MnO | 0.0645 | _ | 0.6207 | 0.3811 | Mn | 0.0119 |
| | | | | | $Fe^{3+}$ | 0.0000 |
| FeO (total | 0.3979 | _ | 5.1931 | 2.7971 | $Fe^{2+}$ | 0.0860 |
| NiO | 0.0000 | _ | 0.0143 | 0.0043 | Ni | 0.0001 |
| $Na_2O$ | 0.0000 | _ | 0.2494 | 0.0918 | Na | 0.0065 |
| $K_2O$ | 0.0000 | _ | 0.0017 | 0.0002 | K | 0.0000 |
| Total | 92.3909 | _ | 106.7235 | 99.3658 | Sum | 4.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : Ca $(Mg_{0.90}\ Fe^{2+}_{0.10})\ Si_2\ O_6$

End Member Composition : $Di_{89.00}\ Hd_{9.81}\ Jo_{1.19}$

Name : **Diopside**

( Di = Diopside, Hd = Hedenbergite, Jo = Johannsenite )

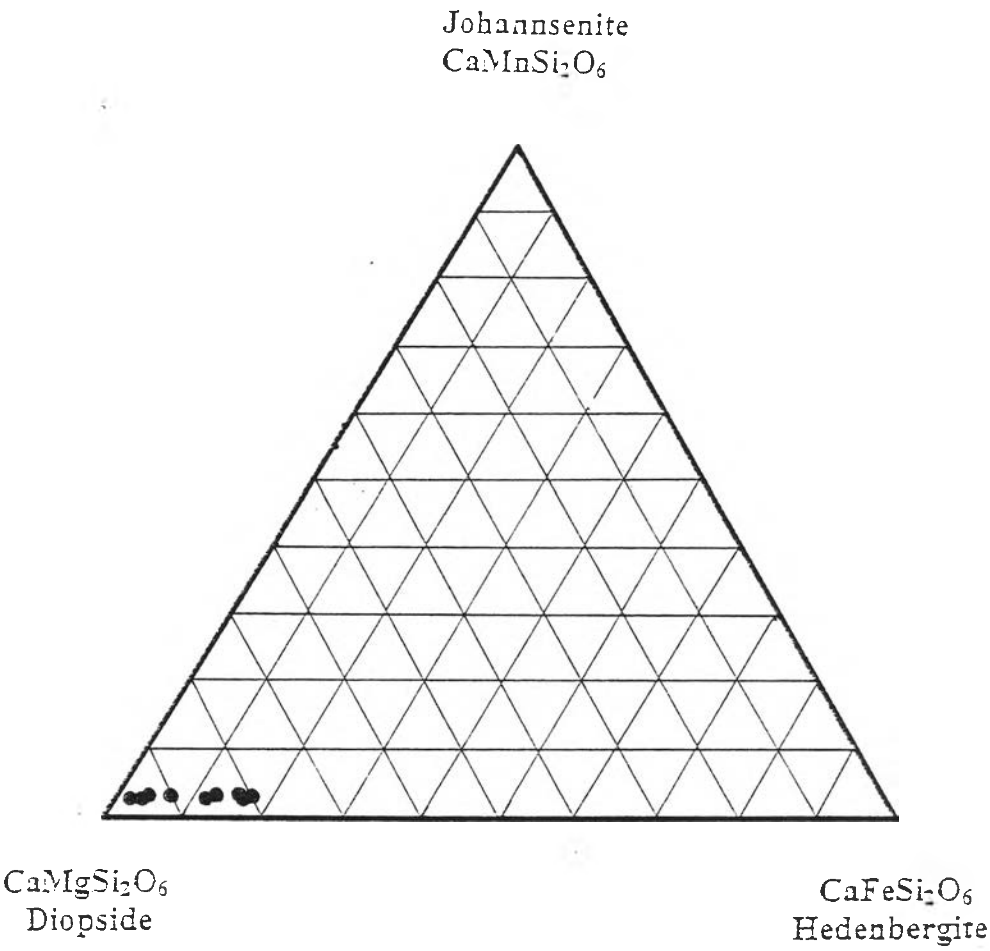


**Figure 3.39** Electron microprobe compositions of clinopyroxene from the Khao Phra Ngam area (in mole percent).

subhedral in shape. Two types of garnet have been recognized; the type I garnet is reddish brown mostly fine to medium–grained and subhedral crystal (Figure 3.40); the type II garnet is yellowish green, medium to coarse–grained and euhedral crystal (Figure 3.41). diopside always accompanies with garnet. Quartz, feldspar and calcite can be observed in the cavities.

Microsopically, garnet skarn comprises mostly garnet, minor diopside, quartz, calcite, feldspar and epidote. Garnet shows granoblastic polygonal texture. Grain sizes range from 0.5-5 mm. Both types of garnet also show a marked difference in their optical properties. Generally, the reddish brown type I garnet is optically isotropic whereas the yellowish green type II garnet is optically anisotropic and shows a zonal structure parallel to crystal faces. The anistropic garnet typically occurs as massive granular overgrowth or as rim on the earlier isotropic type I garnet (Figure 3.42). It seems to be formed in part by recrystallization of the early isotropic type I garnet.

The chemical analysis by electron microprobe reveals that the garnet has a broad composition in grossular–andradite series which contains less than 10 mole percent spressartine+almandine component (Tables 3.9 and 3.10). The main substitutions are $Al^{3+}$ for $Fe^{3+}$. Some samples are almost pure grossular and andradite. The mojorities are grossular-andradite solid solution. The isotropic type I garnet contains more than 0.50 andradite/(andradite+grossular) mole ratios whereas the anisotropic type II garnet contains less than 0.75 (Figure 3.43). That is isotropic type I garnet contains a slightly higher andraditic component than the anistropic type II garnet. These observations suggest a general trend of increasing in Al and decreasing in $Fe^{3+}$ during the development of garnet. There is also a slight compositional variation within an anisotropically zoned type II garnet grain (Figure 3.44 and Table 3.11). For example, the large euhedral garnet is normally yellowi1sh green in color and shows anisotropic birefringent zoning with more grossularitic component (Figure 3.45). The Raman spectra of brown zone indicate

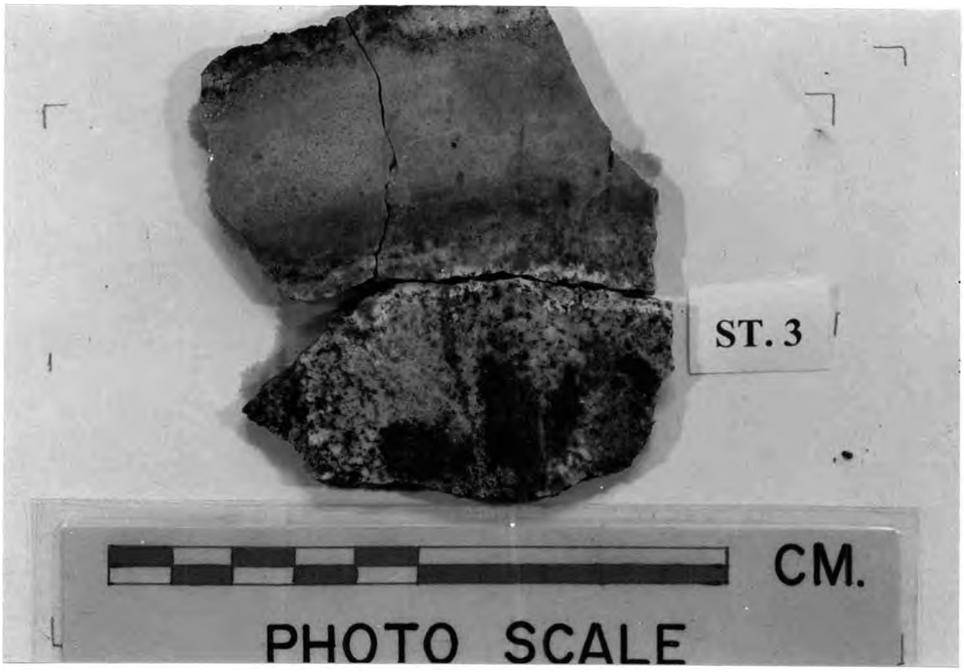


**Figure 3.40** A specimen of garnet skarn containing reddish brown, fine to medium-grained type I garnet in contact with contaminated diorite.


**Figure 3.41** A specimen of garnet skarn containing yellowish green, medium to coarse-grained type II garnet with quartz filling in cavities.

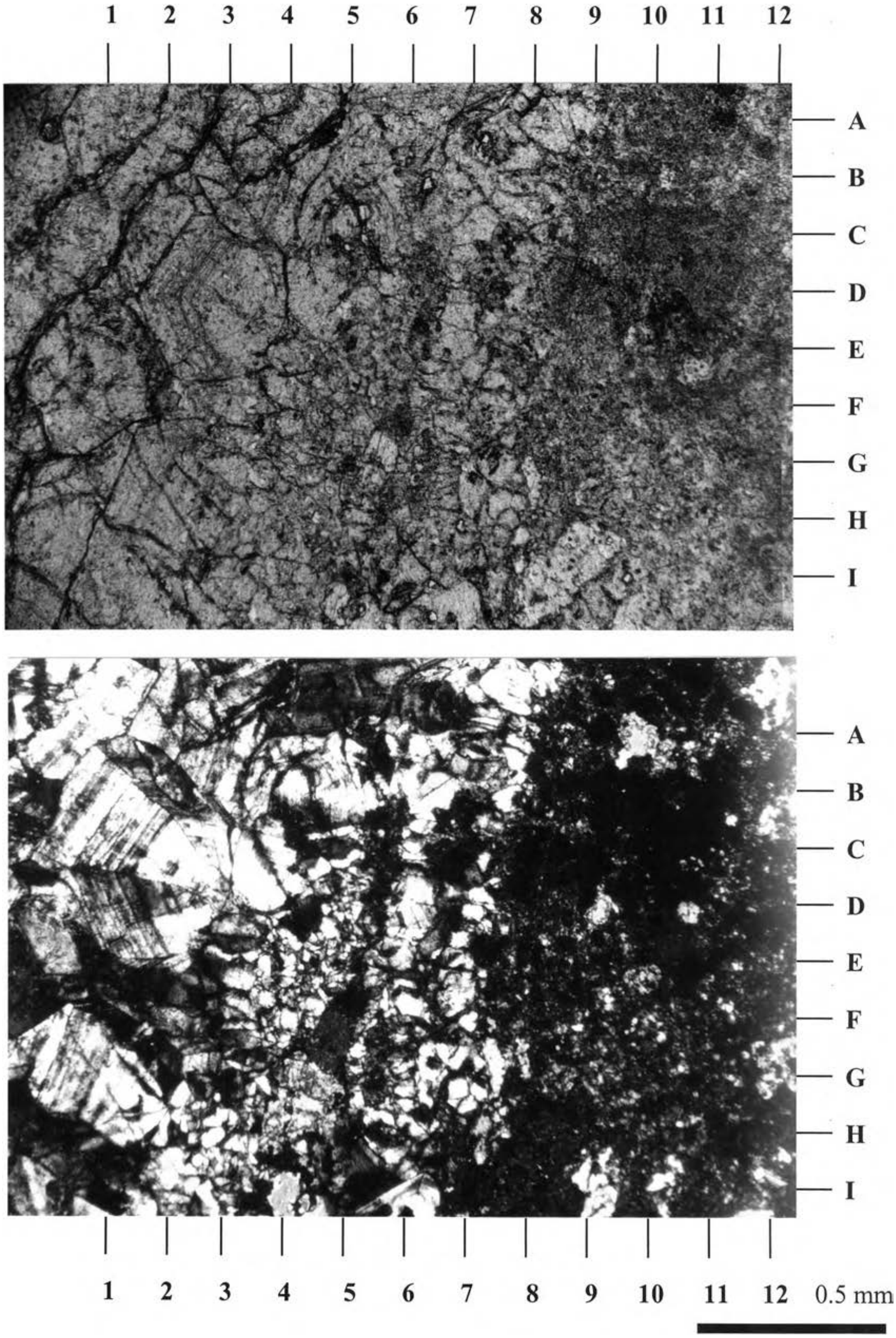


**Figure 3.42** Photomicrograph of garnet skarn showing anisotropic type II garnet (D3) overgrown on the isotropic type I garnet (C10) (upper photo: plane-polarized light, lower photo: crossed nicols).

**Table3.9** Electron Microprobe Analyses of type I garnet in skarn from Khao Phra Ngam area.

Color : reddish brown

Form : anhedral to subhedral crystals

Chemistry[1] :

| Oxides | Range | | | Av. ( 11 analyses ) | [2]Cations on the basis of 12 oxegen | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 35.0640 | _ | 39.3541 | 36.5774 | Si | 2.9532 |
| $TiO_2$ | 0.0000 | _ | 1.2129 | 0.2508 | Ti | 0.0152 |
| $Al_2O_3$ | 2.3471 | _ | 19.8651 | 9.8230 | Al | 0.9348 |
| $Cr_2O_3$ | 0.0000 | _ | 0.0305 | 0.0068 | Cr | 0.0004 |
| MgO | 0.0000 | _ | 3.1209 | 0.4193 | Mg | 0.0504 |
| CaO | 32.8239 | _ | 36.3024 | 34.5641 | Ca | 2.9902 |
| MnO | 0.0032 | _ | 0.4538 | 0.1871 | Mn | 0.0127 |
| | | | | | $Fe^{3+}$ | 1.0413 |
| FeO (total | 3.6306 | _ | 24.6824 | 15.4209 | $Fe^{2+}$ | 0.0000 |
| NiO | 0.0000 | _ | 0.0003 | 0.0000 | Ni | 0.0000 |
| $Na_2O$ | 0.0000 | _ | 0.0327 | 0.0097 | Na | 0.0015 |
| $K_2O$ | 0.0000 | _ | 0.0034 | 0.0003 | K | 0.0000 |
| Total | 73.8688 | _ | 125.0585 | 97.8287 | Sum | 8.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $Ca_3$ ( $Al_{0.93}$ $Fe^{3+}_{1.04}$ $Mg_{0.40}$ ) $Si_3$ $O_{12}$

End Member Composition : $Py_{1.67}$ $Al_{0.00}$ $Gr_{44.57}$ $An_{53.32}$ $Uv_{0.02}$ $Sp_{0.42}$

Name : **Grossularite-Andradite garnet**

(Py = Pyrope, Al = Almandine, Gr = Grossular, An = Andradite, Uv = Uvarovite, Sp = Spessartine)

**Table3.10** Electron Microprobe Analyses of type II garnet in skarn from Khao Phra Ngam area.

Color : yellowish green

Form : euhedral to subhedral crystals and zoning

Chemistry[1] :

| Oxides | Range | | | Av. ( 31 analyses ) | [2]Cations on the basis of 12 oxegen | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 35.4250 | _ | 38.5510 | 37.3831 | Si | 2.9683 |
| $TiO_2$ | 0.0043 | _ | 1.0532 | 0.3442 | Ti | 0.0205 |
| $Al_2O_3$ | 4.7413 | _ | 19.0915 | 12.7181 | Al | 1.1903 |
| $Cr_2O_3$ | 0.0000 | _ | 0.0549 | 0.0081 | Cr | 0.0005 |
| MgO | 0.0000 | _ | 0.1198 | 0.0520 | Mg | 0.0061 |
| CaO | 33.5210 | _ | 36.2947 | 35.1306 | Ca | 2.9889 |
| MnO | 0.1210 | _ | 0.5721 | 0.3136 | Mn | 0.0210 |
| | | | | | $Fe^{3+}$ | 0.8009 |
| FeO (total | 4.5509 | _ | 22.1369 | 12.0600 | $Fe^{2+}$ | 0.0000 |
| NiO | 0.0000 | _ | 0.0089 | 0.0004 | Ni | 0.0000 |
| $Na_2O$ | 0.0000 | _ | 0.2073 | 0.0198 | Na | 0.0030 |
| $K_2O$ | 0.0000 | _ | 0.0028 | 0.0000 | K | 0.0000 |
| Total | 78.3635 | _ | 118.0931 | 98.0299 | Sum | 8.0000 |

[1] Analyzed at University of Manchester, England

[2] Recalculated following Droop (1987)

Formula : $Ca_3$ ( $Al_{1.20}$ $Fe^{3+}_{0.08}$ ) $Si_3$ $O_{12}$

End Member Composition : $Py_{0.02}$ $Al_{1.20}$ $Gr_{58.20}$ $An_{40.90}$ $Uv_{0.02}$ $Sp_{0.70}$

Name : **Grossularite-Andradite garnet**

(Py = Pyrope, Al = Almandine, Gr = Grossular, An = Andradite, Uv = Uvarovite, Sp = Spessartine)

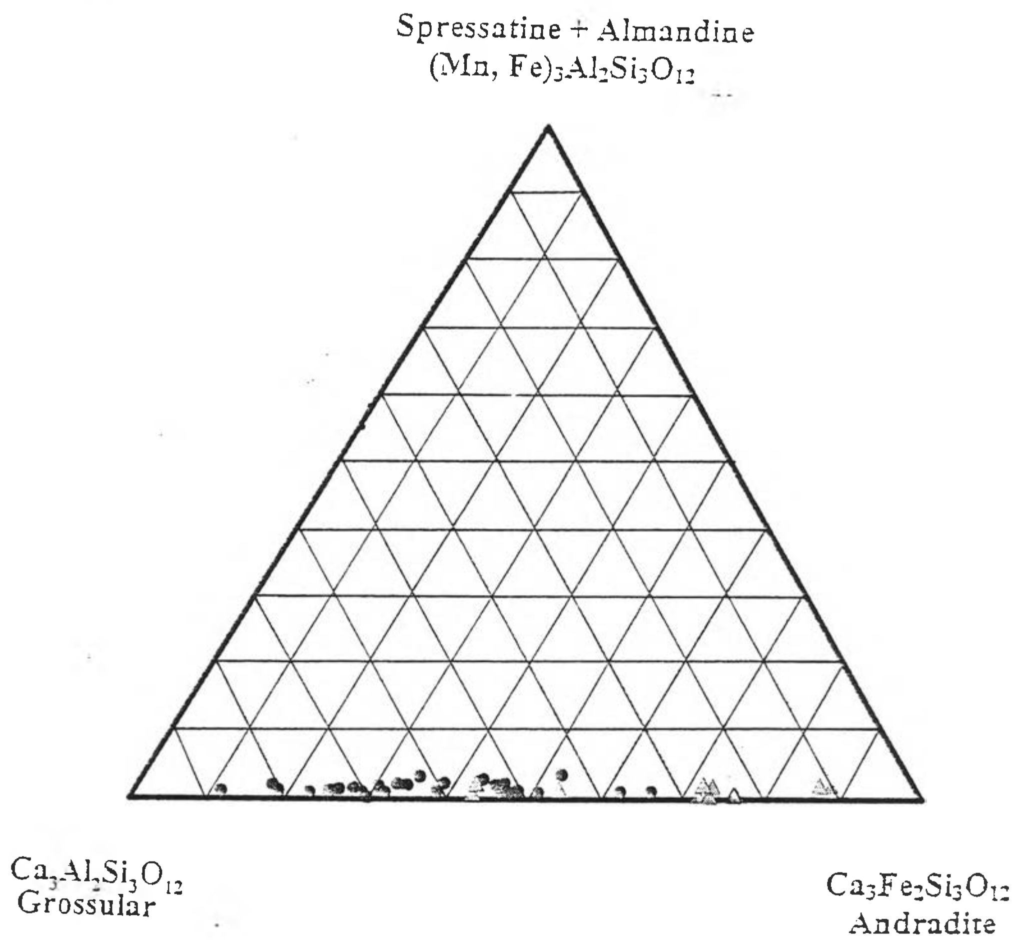


**Figure 3.43** Electron microprobe compositions of type I garnet (triangle) and type II garnet (circle) from the Khao Phra Ngam area (in mole percent).

**Table 3.11** Electron Microprobe Analyses of Zoning Garnet

| Sample no. | ST 49-13 | ST 49-14 | ST 49-15 | ST 49-16 |
|---|---|---|---|---|
| Locality | North Quarry | North Quarry | North Quarry | North Quarry |
| $SiO_2$ | 37.27 | 37.18 | 37.18 | 37.32 |
| $TiO_2$ | 0.06 | 0.63 | 0.68 | 1.02 |
| $Al_2O_3$ | 14.84 | 11.71 | 11.40 | 13.53 |
| $Cr_2O_3$ | 0.02 | 0.03 | 0.05 | 0.01 |
| MgO | 0.04 | 0.06 | 0.05 | 0.06 |
| CaO | 35.04 | 34.43 | 34.60 | 34.68 |
| MnO | 0.42 | 0.35 | 0.32 | 0.42 |
| $Fe_2O_3$ | 0.00 | 0.00 | 0.00 | 0.00 |
| FeO | 9.88 | 13.25 | 13.62 | 10.78 |
| NiO | 0.00 | 0.00 | 0.00 | 0.00 |
| $Na_2O$ | 0.00 | 0.01 | 0.03 | 0.01 |
| $K_2O$ | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 97.57 | 97.65 | 97.93 | 97.83 |

ST. 49-13 Formula : $(Ca_{2.97}\ Mn_{0.03})\ (Al_{1.38}\ Fe^{3+}_{0.62})\ Si_3\ O_{12}$

End Member composition : $Py_{0.20}\ Al_{0.14}\ Gr_{64.54}\ An_{33.92}\ Uv_{0.27}\ Sp_{0.93}$

ST. 49-14 Formula : $(Ca_{2.95}\ Mn_{0.05})\ (Al_{1.14}\ Fe^{3+}_{0.86})\ Si_3\ O_{12}$

End Member composition : $Py_{0.20}\ Al_{0.64}\ Gr_{54.69}\ An_{44.01}\ Uv_{0.10}\ Sp_{0.36}$

ST. 49-15 Formula : $(Ca_{2.96}\ Mn_{0.04})\ (Al_{1.07}\ Fe^{3+}_{0.93})\ Si_3\ O_{12}$

End Member composition : $Py_{0.20}\ Al_{0.40}\ Gr_{52.85}\ An_{45.87}\ Uv_{0.15}\ Sp_{0.53}$

ST. 49-16 Formula : $(Ca_{2.97}\ Mn_{0.03})\ (Al_{1.30}\ Fe^{3+}_{0.73})\ Si_3\ O_{12}$

End Member composition : $Py_{0.26}\ Al_{0.32}\ Gr_{63.29}\ An_{35.14}\ Uv_{0.04}\ Sp_{0.95}$

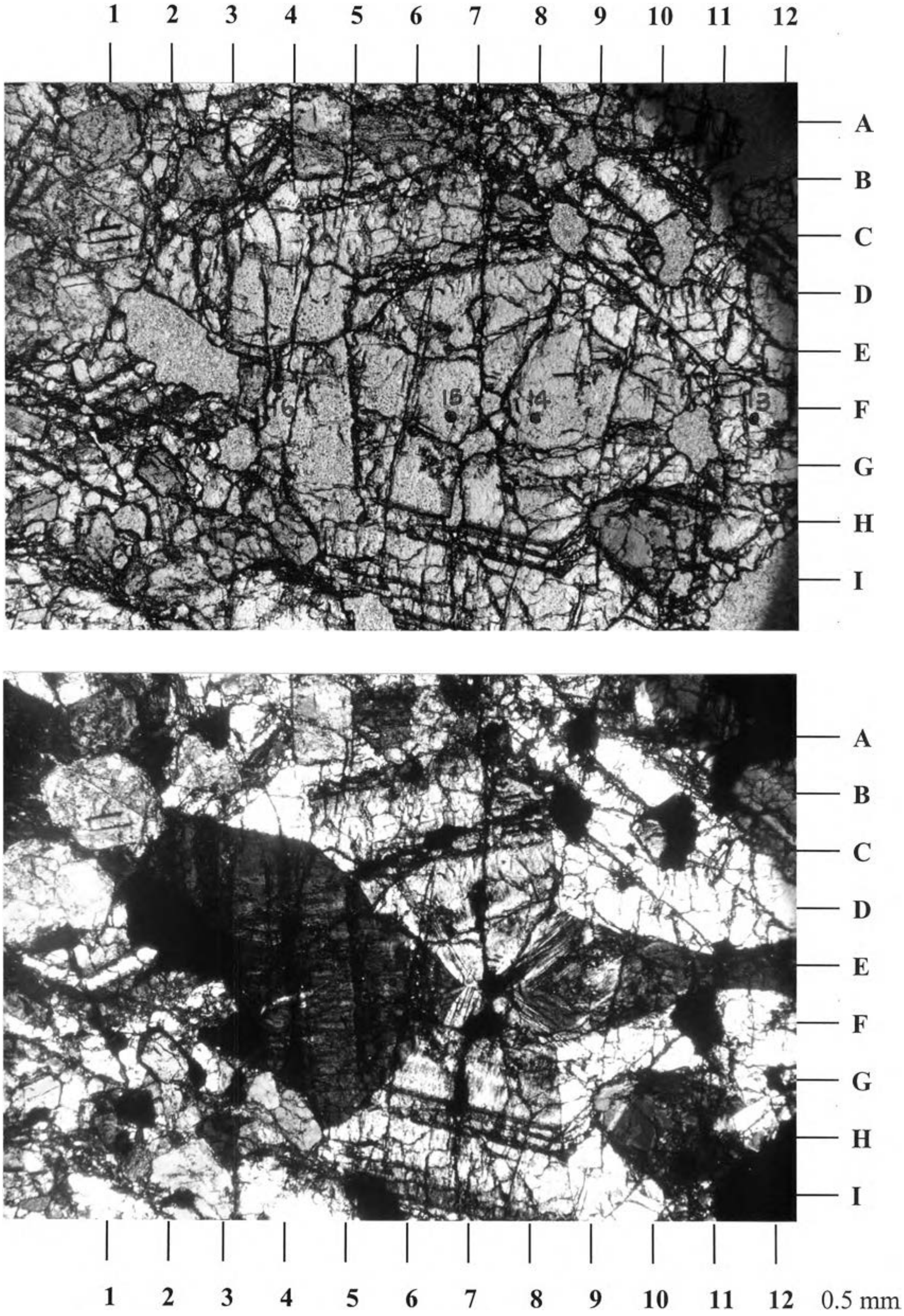


**Figure 3.44** Photomicrograph of garnet skarn showing zonal structure which displays a slight compositional variation (the numbers, indicate the position of electron microprobe analysis in Table 3.10, upper photo: plane-polarized light, lower photo: crossed nicols).

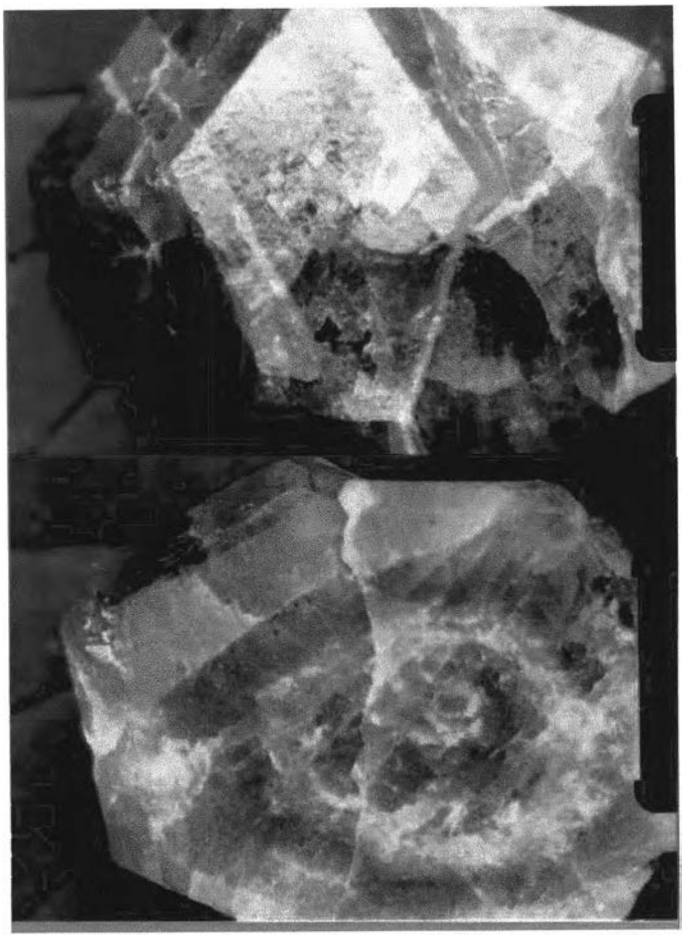

**Figure 3.45** A single crystal of large euhedral garnet showing the characteris tically colored zones.

andraditic-rich composition whereas those of the green zone reveals grossularitic-rich constituent. Garnets in garnet skarn are comparatively rich in $Fe_2O_3$, CaO and poor in $Al_2O_3$ than garnet in garnet-clinopyroxene skarn and wollastonite skarn (Table 3.12).

The amount of clinopyroxene is small relative to garnet. Clinopyroxene is diopside and occurs as anhedral to subhedral with grain sizes ranging from 0.1-0.5 mm. Diopside is often altered to tremolite/actinolite, but the degree of alteration is not as intense as that in clinopyroxene–garnet skarn. Clinopyroxenes in garnet skarn are comparatively rich in MgO than clinopyroxene in garnet-clinopyroxene skarn (Table 3.13).

Epidote occurs as alteration product of garnet. Other accessory mineral including calcite, quartz and plagioclase replacing garnet or occurring interstitially.

### 3.5.4 Contaminated Diorite (Endoskarn)

Diorite near the contact zone is partly altered. The alteration extends irregularly into igneous rocks for distances up to 1 m. It is usually developed parallel to the contact zone which generally coincides with the distribution of garnet skarn. This zone was likely to be effected by metasomatism, therefore, better termed endoskarn. The boundary between garnet skarn and contaminated diorite is gradational contact (Figure 3.46). Contaminated diorite is a medium to coarse-grained rock, light to dark gray in color and displays hypidiomorphic texture (Figure 3.47). The mineralogy of contaminated diorite is composed predominantly of plagioclase, hornblende, pyroxene, quartz with minor K-feldspar, garnet, sphene and small amount of chlorite and epidote. It differs from diorite by the presence of significant amount of quartz and pyroxene with minor garnet.

Microscopically, plagioclase is the most abundant constituent up to 40–70 %. Grain sizes range from 0.5–1.0 mm. Plagioclase crystal are commonly elongate and displays

**Table 3.12** Chemical Composition of Garnet (as determined by electron microprobe)

| **Sample no.** | **ST. 40** | **ST. 43** | **ST. 7-2** | **ST. 11** | **ST. 1-3** | **ST. 25** |
|---|---|---|---|---|---|---|
| **Rock** | Wol SK. | Wol SK. | Gar-Cpx SK | Gar-Cpx SK. | Gar SK. | Gar SK. |
| **Optical property** | iso | iso | iso | iso | aniso | aniso |
| $SiO_2$ | 36.94 | 39.35 | 37.61 | 37.14 | 35.87 | 36.43 |
| $TiO_2$ | 0.49 | 0.12 | 0.91 | 0.13 | 0.11 | 0.43 |
| $Al_2O_3$ | 12.54 | 19.86 | 17.1 | 13.68 | 5.6 | 11.66 |
| $Fe_2O_3$ | 12.16 | 3.63 | 5.75 | 10.98 | 20.7 | 12.93 |
| MnO | 0.03 | 0.15 | 0.35 | 0.21 | 0.16 | 0.27 |
| MgO | 0.35 | 0.3 | 0.05 | 0.34 | 0.02 | 0.08 |
| CaO | 35.23 | 36.3 | 36.2 | 35.43 | 33.67 | 35.17 |
| Total | 97.74 | 99.71 | 97.97 | 97.91 | 96.13 | 97.02 |
| | Formulas on the basis of 12 (O) | | | | | |
| Si | 2.94 | 2.99 | 2.94 | 2.94 | 2.97 | 2.93 |
| Ti | 0.03 | 0.01 | 0.05 | 0.01 | 0.01 | 0.02 |
| Al | 1.18 | 1.78 | 1.57 | 1.27 | 0.55 | 1.10 |
| $Fe^{+3}$ | 0.81 | 0.23 | 0.38 | 0.73 | 1.44 | 0.87 |
| Mn | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 |
| Mg | 0.04 | 0.03 | 0.01 | 0.04 | 0.00 | 0.01 |
| Ca | 3.00 | 2.95 | 3.03 | 3.00 | 3.02 | 3.03 |

**Table 3.13** Chemical Composition of Clinopyroxene (as determinated by electron microprobe)

| **Sample no.** | **ST. 7** | **ST. 11** | **ST. 1** | **ST. 6** |
|---|---|---|---|---|
| **Rock** | Gar-Cpx SK. | Gar -Cpx SK. | Gar SK. | Gar SK. |
| $SiO_2$ | 53.50 | 54.26 | 55.30 | 53.39 |
| $Al_2O_3$ | 0.02 | 1.11 | 0.04 | 0.19 |
| FeO | 4.54 | 0.67 | 0.40 | 3.08 |
| MnO | 0.52 | 0.64 | 0.28 | 0.62 |
| MgO | 15.11 | 17.34 | 17.50 | 15.82 |
| CaO | 23.34 | 25.67 | 26.16 | 25.39 |
| Total | 97.03 | 99.69 | 99.68 | 98.49 |
| | Formulas on the basis of 6 (O) | | | |
| Si | 1.99 | 1.99 | 2.00 | 1.98 |
| Al | 0.00 | 0.05 | 0.00 | 0.01 |
| $Fe^{+2}$ | 0.14 | 0.02 | 0.01 | 0.10 |
| Mn | 0.02 | 0.00 | 0.01 | 0.02 |
| Mg | 0.84 | 0.93 | 0.94 | 0.88 |
| Ca | 1.01 | 1.01 | 1.01 | 1.01 |

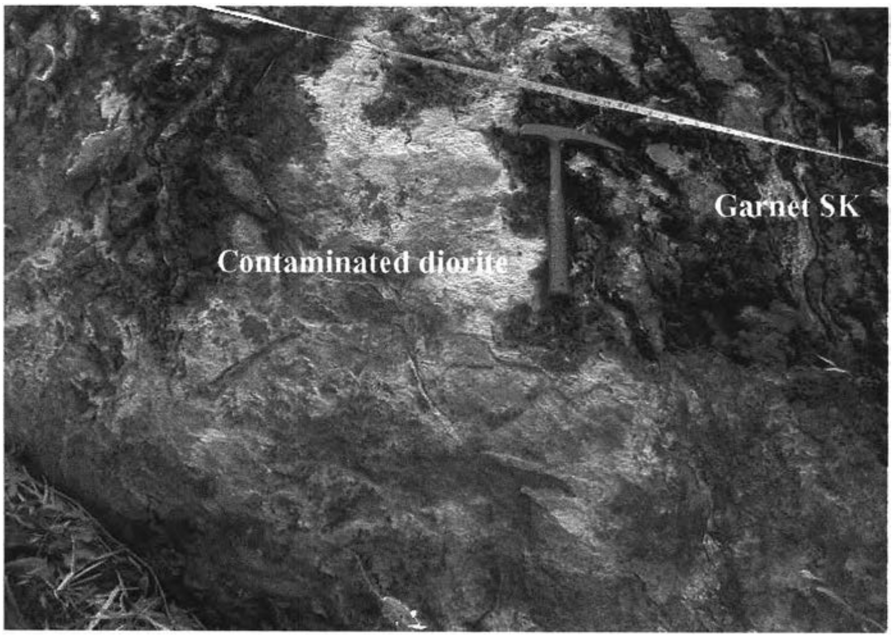


**Figure 3.46** An exposure of contaminated diorite in contact with garnet skarn.


**Figure 3.47** A specimen of contaminated diorite containing medium-grained hornblende, clinopyroxene, plagioclase feldspar and fine-grained quartz veinlets.

albite and albite-carsbad twins (Figure 3.48). Most of plagioclase is probably the original constituent of diorite. Plagioclase is partially altered to sericite.

Quartz abundance is highly variable, from 30–50 %. It has the approximate grain sizes of 0.3 mm and forms as medium anhedral grains to interstitial aggregates. Majority of quartz was probably introduced during metasomatism.

Hornblende occurs as anhedral to subhedral crystal. Grain sizes range from 0.2-0.5 mm. Some grains show poikilitic texture containing feldspar and quartz. Most of horblende is probably the original constituent of the diorite. It is commonly altered to chlorite.

Pyroxene replaces both hornblende and plagioclase. Pyroxene is green to yellowish green in color. The average grain size is about 0.2 mm and commonly elongate. The elongate crystals are distinctively twined. Its constituent ranges from 5–20 %. Pyroxene is normally diopside and likely to be introduced during the prograde metasomatism.

Garnet appears in minor amount. It occurs as isotropic irregular crystal replaced after hornblende. Sphene forms as minute subhedral to euhedral crystal enclosed by plagioclase. Opaque mineral can be observed. It is probably the iron oxide.

### 3.5.5 Retrograde alteration

Retrograde alteration is superimposed on the prograde skarn. It occurs as minor amount locally along fracture and intrusive contact. This alteration is characterized by partial replacement of garnets, especially along cracks and grain boundaries, by epidote plus chlorite, the replacement of clinopyroxene by tremolite/actinolite plus chlorite and the replacement of wollastonite by quartz.

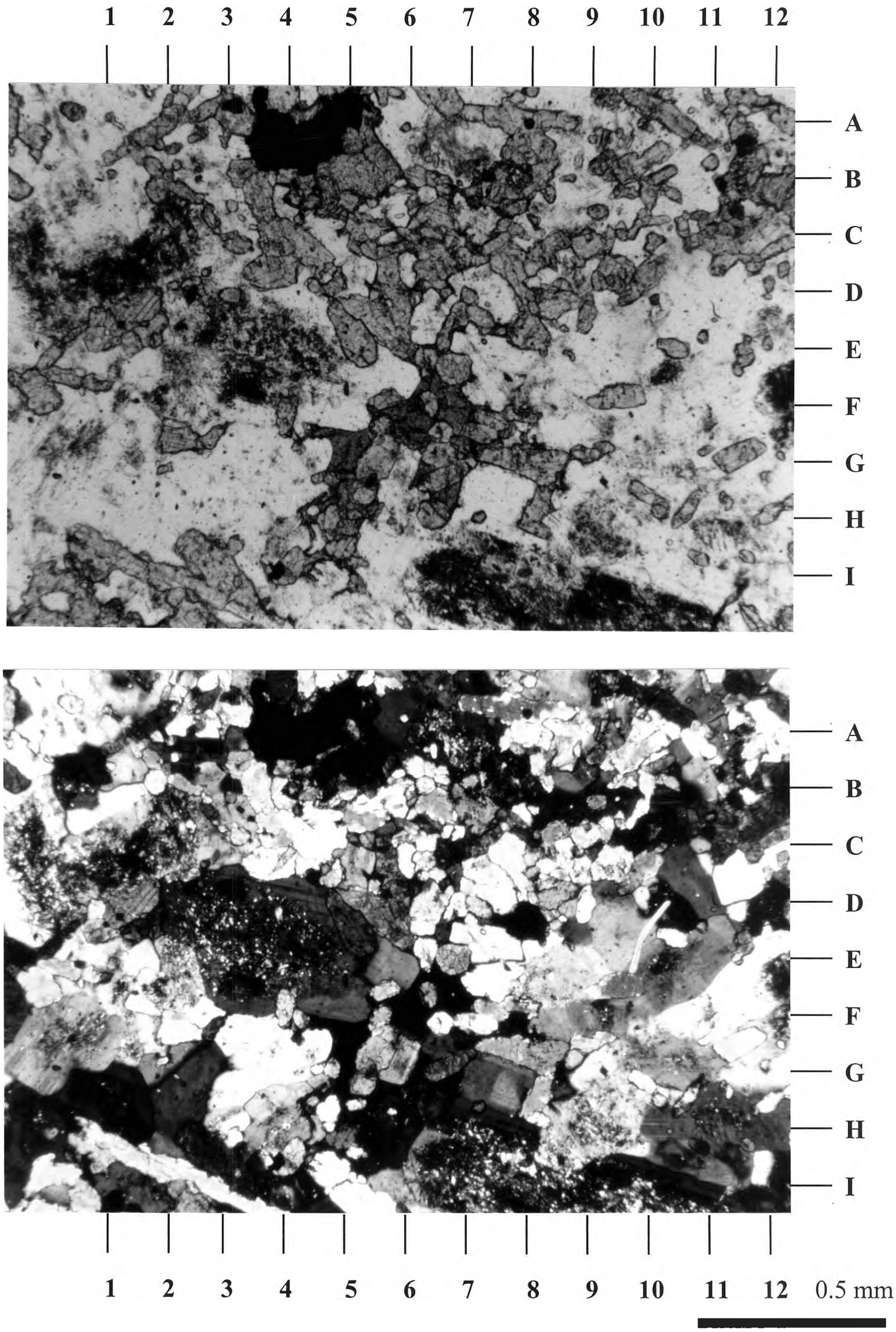


**Figure 3.48** Photomicrograph of contaminated diorite showing subhedral plagioclase (E7), subhedral clinopyroxene (E4), anhedral garnet (D6) and anhedral quartz (F1) (upper photo: plane polarized light, lower photo: crossed nicoles)

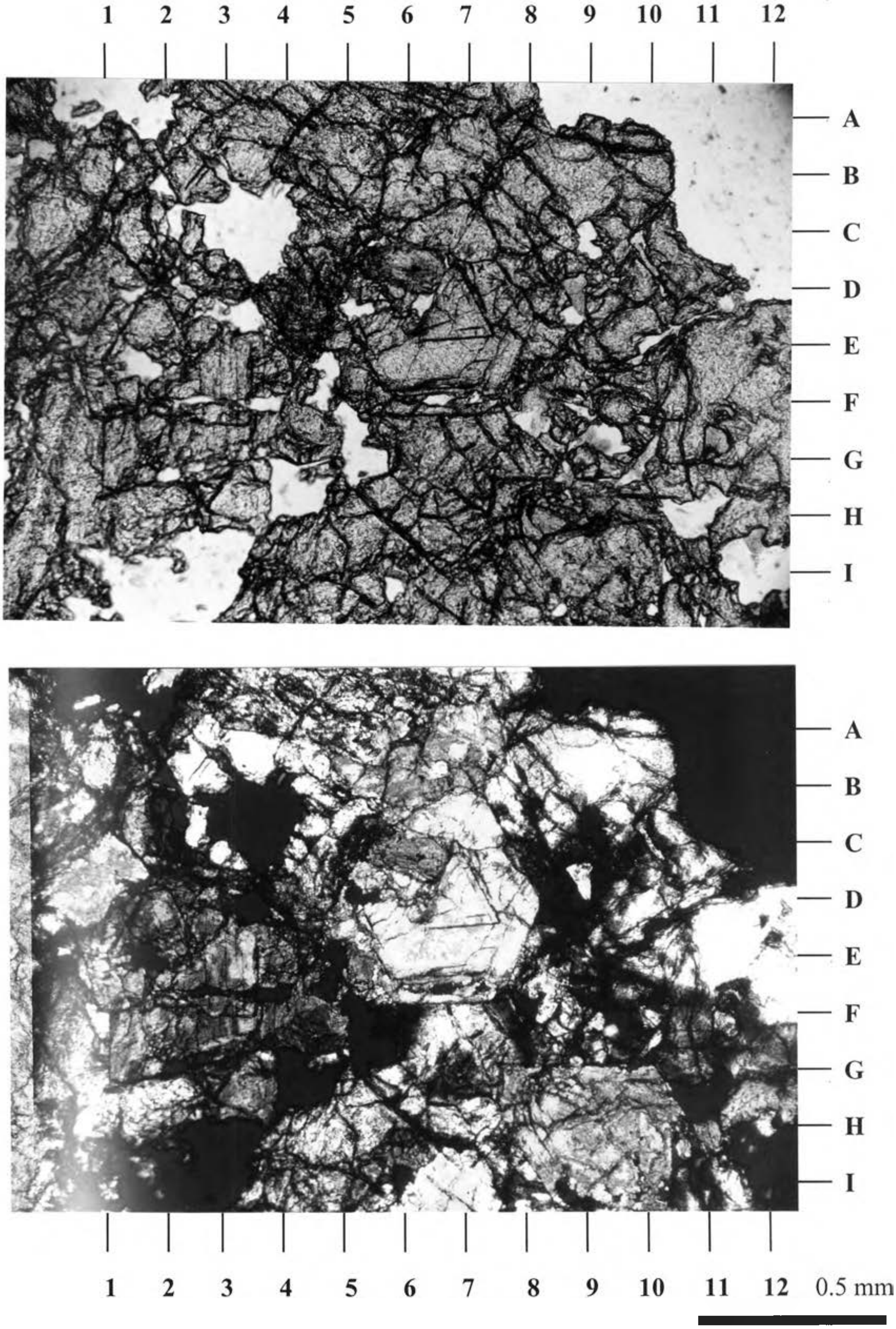


**Figure 3.49** Photomicrograph of garnet skarn showing zonal structure of garnet partially replaced by epidote (E7)(upper photo: plane-polarized light, lower photo: crossed nicols).

**Figure 3.50** An exposure of retrograde wollastonite skarn containing wollastonite, epidote and quartz.

The replacement of garnet by epidote occurs along fractures of garnet skarn in association with quartz and chlorite and formed coarse-grained epidote after garnet in wollastonite skarn. In thin-section, zoned garnet is partially replaced by epidote (Figure 3.49). Also, retrograde epidote plus quartz are common in wollastonite skarn (Figure 3.50).texture relationships in this instance suggest that epidote replaces garnet. Clinopyroxene is altered to tremolite/actinolite plus chlorite (Figure 3.51). The texture implies progress of the reverse of reaction (3-2):

$$\text{diopside} + 3CO_2 + H_2O = \text{tremolite} + 3\ \text{calcite} + \text{quartz}$$

Quartz is abundant in the retrograde wollastonite skarn. Its occurs by replacing wollastonite and showns relict of fibrous crystals (Figure 3.52).

### 3.6 Copper mineralization

Minor copper occurrence is observed in the northern part of the mountain in the form of secondary malachites and azurite filling fractures and coating on the surface of skarn (Figure 3.53). Trace of primary copper mineralization was also observed in wollastonite skarn at Wat Thung Singto.

The copper minerals consist mainly of chalcopyrite and bornite with minor covellite together with sphalerite and pyrite. Covellite occurs along fractures in bornite grains suggesting that it is the alteration product of bornite (Figure 3.54). Both chalcopyrite and bornite fill interstitially between wollastonite and diopside without accompanying retrograde alteration. This evidence suggests that the primary sulfide mineralization probably took place contemporaneous with wollatonite skarn. Laser Raman spectroscope analysis also indicated chalcopyrite, bornite, covellite and sphalerite.

No iron mineralization has been found in the study area. However, pockets, lenses and crosscutting veins or dikes of iron ore were found in garnet skarn and garnet-clinopyroxene skarn at Khao Thab Kwai area, 7 km north of the study area (Sindhusen, 1986). The Khao Thab Kwai iron mineralization is probably hosted in the same contact aureole as that in the study area. The primary mineral is mainly magnetite in which its majority has been altered to hematite. Minor occurrence of malachite and azurite was also reported coating on surface of skarns and iron ore.

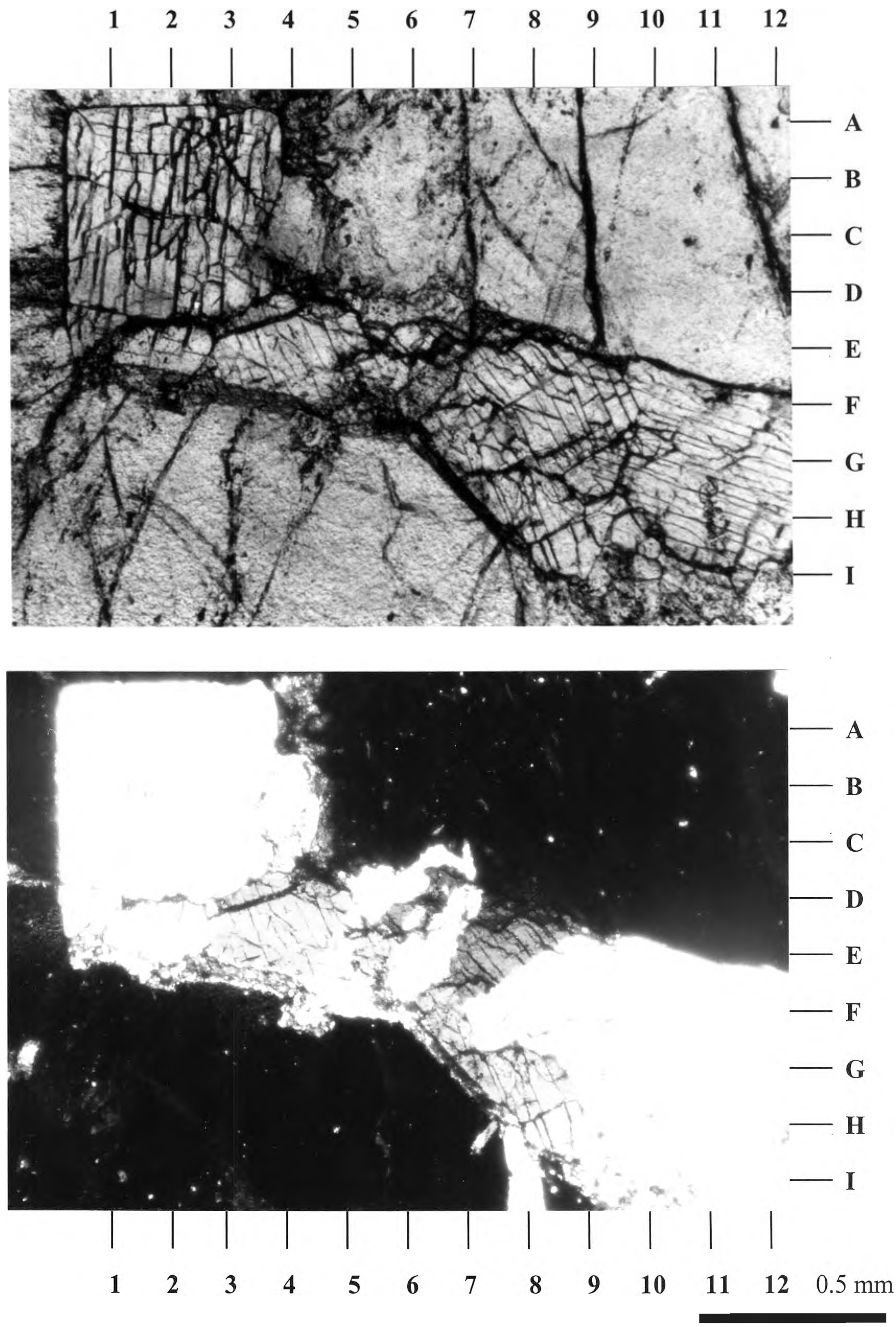


**Figure 3.51** Photomicrograph of garnet-clinopyroxene skarn showing partially replacement of clinopyroxene (G8) by tremolite/actinolite (F5) around grain boundaries (upper photo: plane-polarized light, lower photo: crossed nicols).

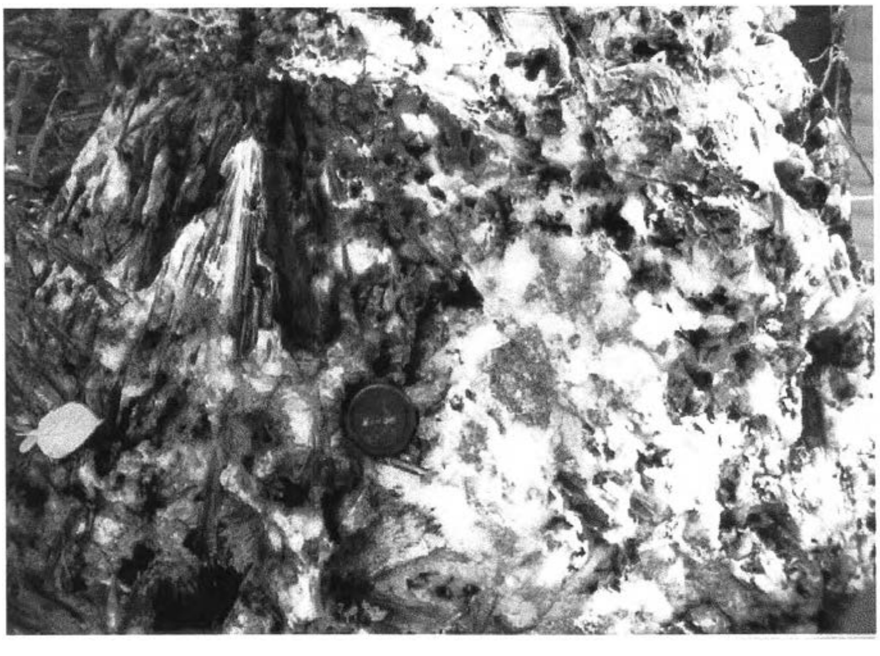

**Figure 3.52** An exposure of retrograde wollastonite skarn showing quartz replaced wollatonite (upper) and close-up view (lower).

**Figure 3.53** An exposure of garnet skarn showing malachite and azurite filling along fracture and coating on the surface.

**Figure 3.54** Photomicrograph of wollastonite skarn showing an intergrown of chalcopyrite (yellow),bornite (pinkish) and covellite along fracture.