CHAPTER III

GEOLOGY AND PETROGRAPHY

3.1 Physiography

Topographic map of the study area is shown in Figure 3.1. Half of the study area is a mountainous terrain, especially in the eastern part which dominated with high steep N-S trending limestone mountain with maximum height reaching about 400 to 500 meters. The central to western parts are occupied by small mountains of volcanic rocks coupled with rolling flat plane area with the elevation of about 300 to 400 meters high.

3.2 Geology

Geologic map of the study area is shown in Figure 3.2. The oldest rock unit in the area is exposed as high mountains on the eastern part and was mapped as Tak Fa Formation in Saraburi Group of Permian age. The Permian rock unit was cut by younger volcanic rocks which are composed of basalt, andesite and rhyolite porphyry, and pyroclastics (tuff and agglomerate). The basaltic rock occurs in flat area on the east central part of the study area. The andesite porphyry forms as small hills in the central part while the pyroclastic rocks occur in flat area and mountains in western part of the area. The rhyolite porphyry forms as small hills in the south-eastern part. Four varieties of intrusive rocks associated with volcanic rocks in the area were mapped as gabbro, diorite, quartz diorite and hornblende-biotite granodiorite. Diorite occurs as a large north-south elongated sill (1.5X6 km^2) intruded parallel to the bedding plane of Permian limestone on the east. The diorite was cut by a smaller quartz diorite sill on the south-east corner. Hornblende-biotite granodiorite forms as circular bodies exposed in the middle and west-central parts whereas gabbro occurs as small stock on the western part. Both hornblende-biotite granodiorite and gabbro intruded the older volcanic rocks. However no crosscutting relationship between these two intrusive rocks has been found in the field.

The Tak Fa Formation in the area is composed mainly of thick-bedded limestone partly interbedded with shale, slaty shale and sandstone. The limestone contains fossils of corals, brachiopods bryozoa and fusulinids, *Verbekina sp., Parafusulina sp. and Neoschwagerina sp.* which indicate the Artinskians-Kungurian age (Nakornsri,1981).

The basaltic rock covers about 25 km^2 in central part of the study area. It is very fine-grained, black. It overlies on the Permian limestone and has also been found as xenoliths in quartz diorite and basaltic andesite. Based on field relationship, it was cut by a 2-3 m. thick diorite dike. Flow structure has not been found in the basalt which might have been eroded away. This basaltic rock was proposed as the oldest volcanic rock in this area by Jungyusuk et al.(1985).

The pyroclastic rocks, covered about 60 sq. km. in the western part, comprise mafic agglomerate and tuff. This rock unit overlies the Permian limestone.

The andesite porphyry covers about 14 sq. km. in central part of the study area. It is fine-grained, grayish green, porphyritic and contains phenocrysts of hornblende. The rock contains xenoliths of basalt therefore it is younger than basalt.

The rhyolite porphyry occurs as small hills in southeastern part and covers about 5 sq. km. Cross-cutting relationship of this rock with other rock units has not been found in the field. The rock is yellowish brown, porphyritic and contains plagioclase phenocrysts.

As for the intrusive rocks, they are the main objective of this study. Therefore they will be described in detail in a separate topic below.

Main geological structures comprise fold, fault, bedding and flow structure of volcanic rocks. Synclinal fold was reported outside the study area with the fold axis oriented in the N-W direction (Jungyusuk et al.,1985). Faults occur in two directions, NW-SE and NE-SW. Bedding in the Permian limestone has the strike in the N-S direction with 10 – 30° east dipping . Finally, flow structure was found two directions, NE-SW and NW-SE (Junyusuk et al.,1985).

Figure 3.1 Topographic map shows general physiography of the study area.

3.3 Intrusive rocks

As been mentioned earlier, the intrusive rocks can be categorized into four types based on field relationship, texture, mineral composition and modal percentage of quartz, alkaline feldspar and plagioclase in QAP diagram (see Fig. 3.34 at later section). The four intrusive rocks from mafic to felsic compositions comprise gabbro, diorite, quartz diorite and hornblende-biotite granodiorite.

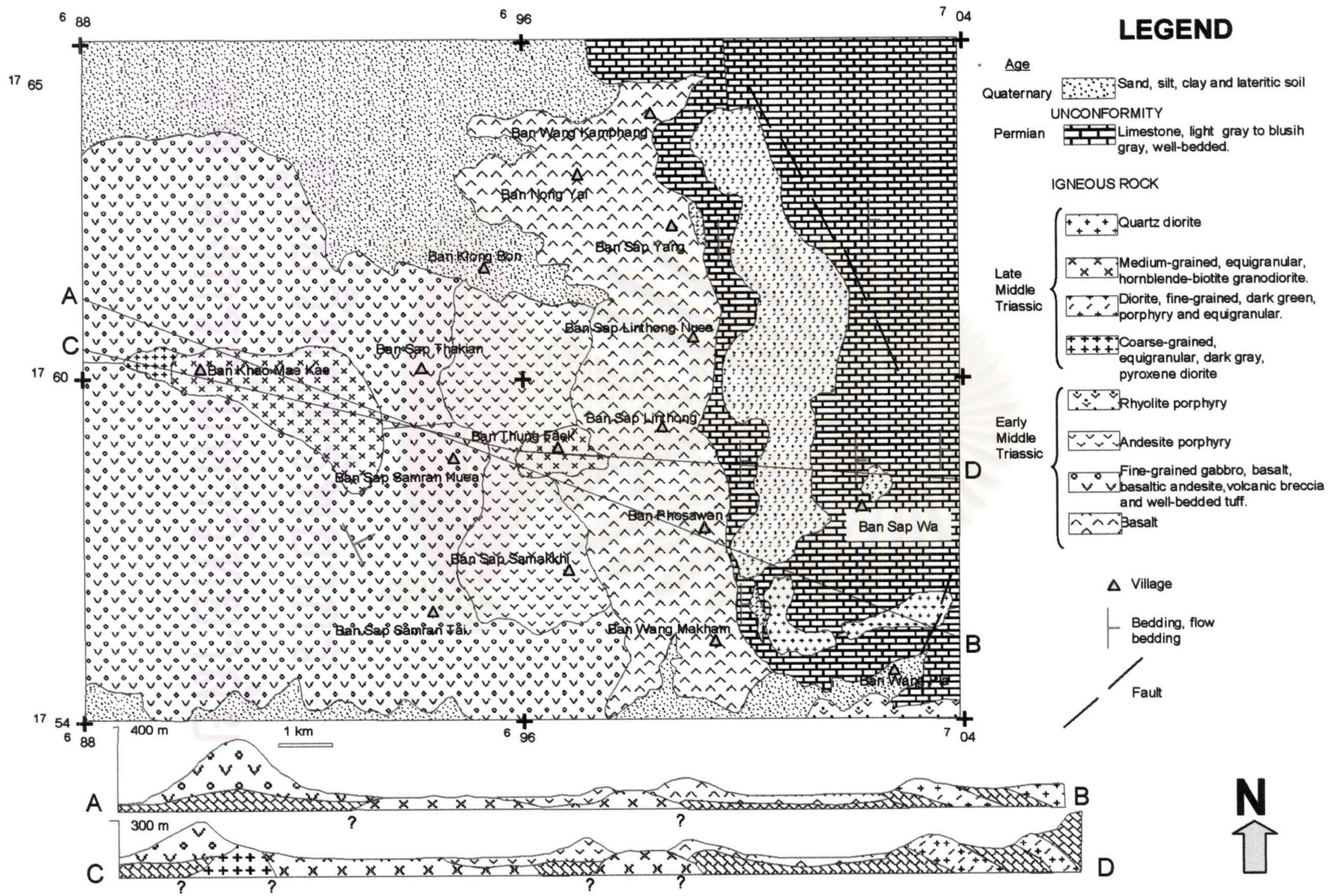


Fig. 3.2 The geologic map of the study area (modified after Jungyusuk et al., 1985).

3.3.1 Gabbro

This rock occurs as a small stock covering an area of about 500 sq. m. on the eastern side of Khao Mae Kae, west-central part of the study area (Figure 3.3). Based on field observation, this rock crosscuts the pyroclastic rocks. Moreover, it was later cut by a felsic dike (Figure 3.4).

The rock is dark gray, medium to coarse-grained (Figure3.5), phaneritic, holocrystalline, equigranular to slightly inequigranular (Figure 3.6). Intergranular poikilitic texture in which the plagioclase laths partially enclose pyroxene and opaque minerals are also found. Some crystals of clinopyroxene show the lamellar intergrowth (Figure 3.7).

Gabbro is composed of plagioclase (60-65 %), clinopyroxene (35-40 %), hornblende (1-2 %), K-feldspar (~1 %). Small amounts of biotite and quartz can be found and its content seems to increase eastward. Accessory minerals include apatite, zircon and opaque minerals, namely ilmenite and magnetite.

Plagioclase is generally subhedral to euhedral, andesine and labradorite in composition (An-content = 38 – 70), based on the SPMA analysis of 12 grains (see Appendix D-1). Its grain sizes range from 0.5 to 5 mm. Albite and calsbad-albite twins are common but its zoning is rare. Most crystals tend to align in the same direction. Plagioclase laths usually enclose accessory minerals (Figure 3.8).

Clinopyroxene is a main composition of this rock. Its composition based on EPMA results of 20 grains falls in the field of augite and salite (see Figure 3.9 and Appendix D-2) after Deer et al. (1966). It commonly shows corroded anhedral to subhedral grains of 0.5 to 4 mm in size (Figure 3.10). As mentioned above, some grains show lamellar intergrowth of clinopyroxene and orthopyroxene (Figure 3.7). Similar to plagioclase, pyroxene commonly contains inclusions of zircon, apatite and opaque minerals. Sieve texture is occasionally found in the core of pyroxene (Figure 3.11)

Small amount of hornblende occurs as anhedral crystals and some as partial replacement of pyroxene. The content of anhedral hornblende seems to decrease toward the contact of host volcanic rock. The EPMA analyses of two hornblende crystals give edenite composition (see Figure 3.12 and Appendix D-3) based on the hornblende nomenclature of Leak (1978).

Small amount of biotite occurs as anhedral crystals with the size smaller than 1 mm. It also occurs as partial replacement of hornblende in which the degree of replacement seems to increase eastward.

Quartz and K-feldspar commonly fill interstitially between plagioclase laths. Both minerals usually form as anhedral crystals with the size less than 1 mm. Their amounts seem to increase eastwardly similar to that found in biotite.

Accessory minerals found in this rock are apatite, zircon, ilmenite and magnetite. Most of them always occur as inclusions within pyroxene and plagioclase. Apatite shows a long prismatic euhedral crystal of different sizes. Zircon occurs as both anhedral and euhedral crystals in which some grain show slightly dark color due to its radioactive decay. Skeletal ilmenite and idiomorphic magnetite are commonly found together.

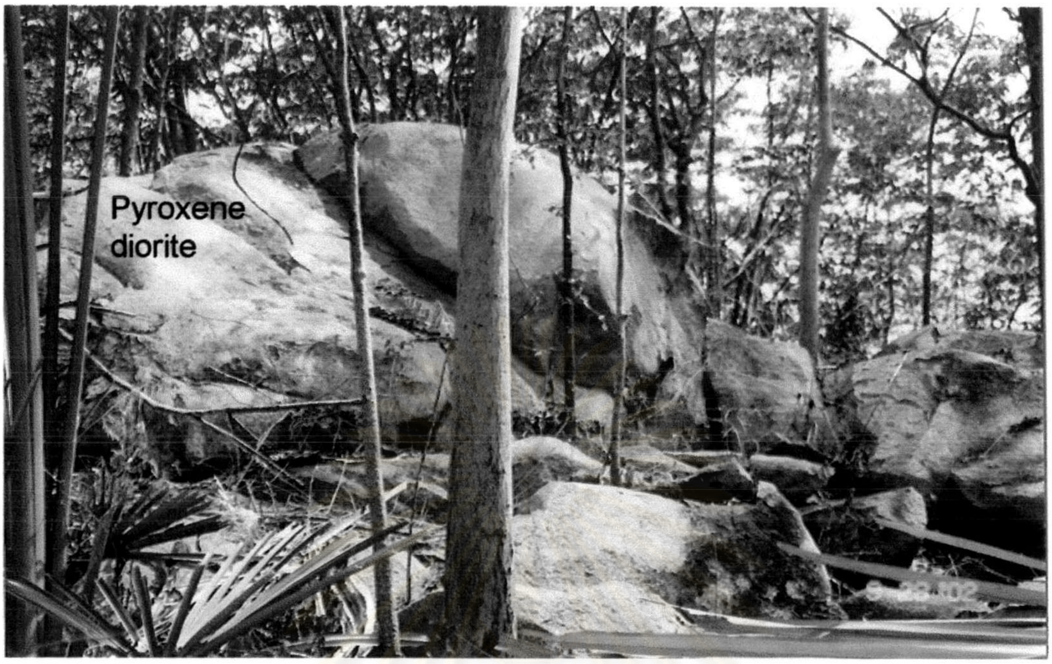


Figure 3.3 Natural exposure of gabbro.

Figure 3.4 Showing the Felsic dike cross-cutting the gabbro at Khao Mae Kae.

Figure 3.5 General features of gabbro.

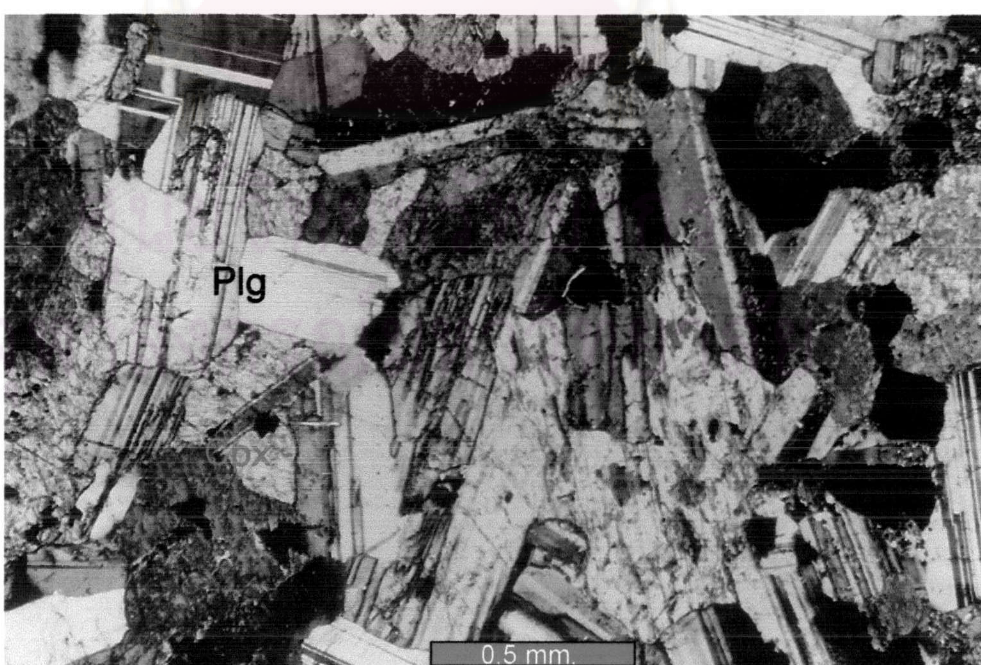


Figure 3.6 Showing general texture of gabbro (x-nicols).

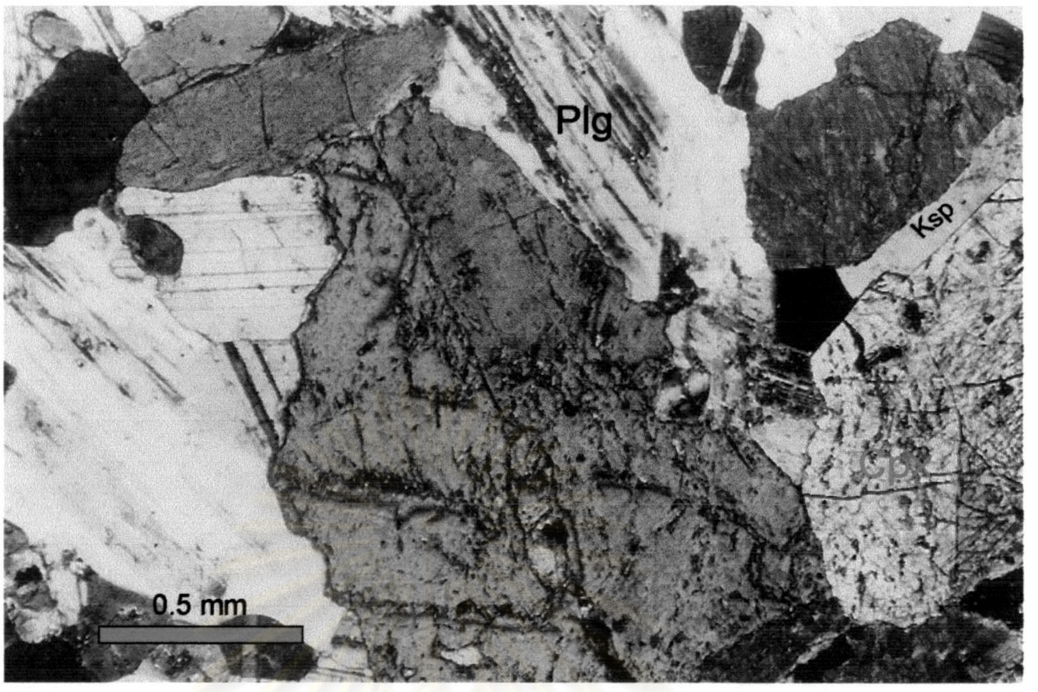


Figure 3.7 Lamellar intergrowth between clinopyroxene and orthopyroxene (x-nicols).

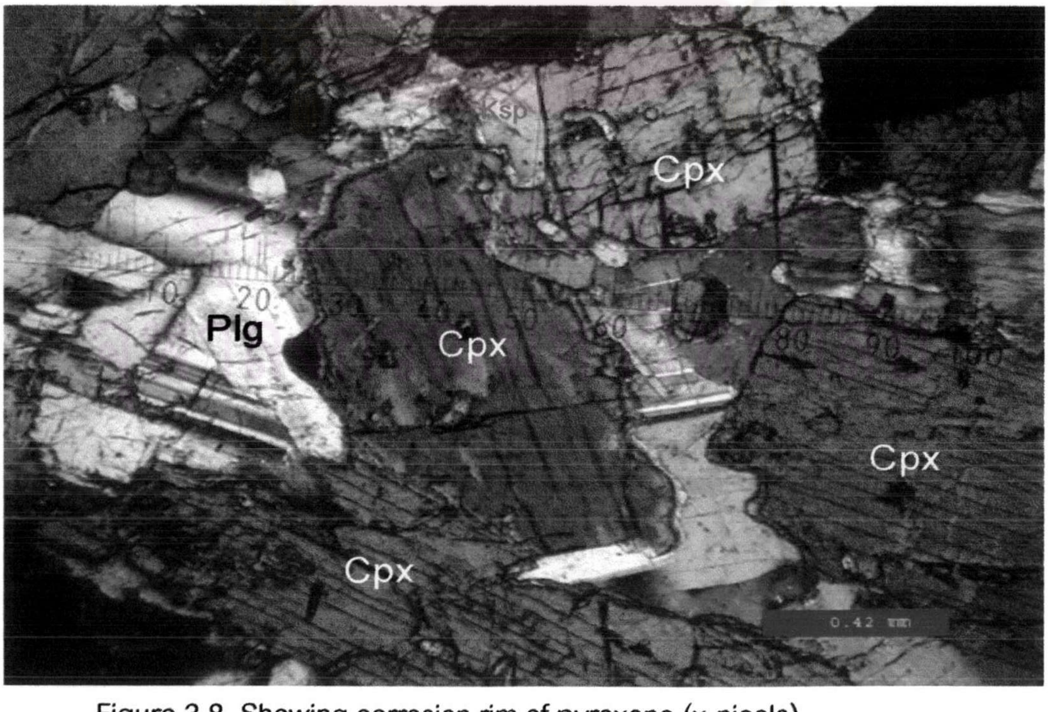


Figure 3.8 Showing corrosion rim of pyroxene (x-nicols).

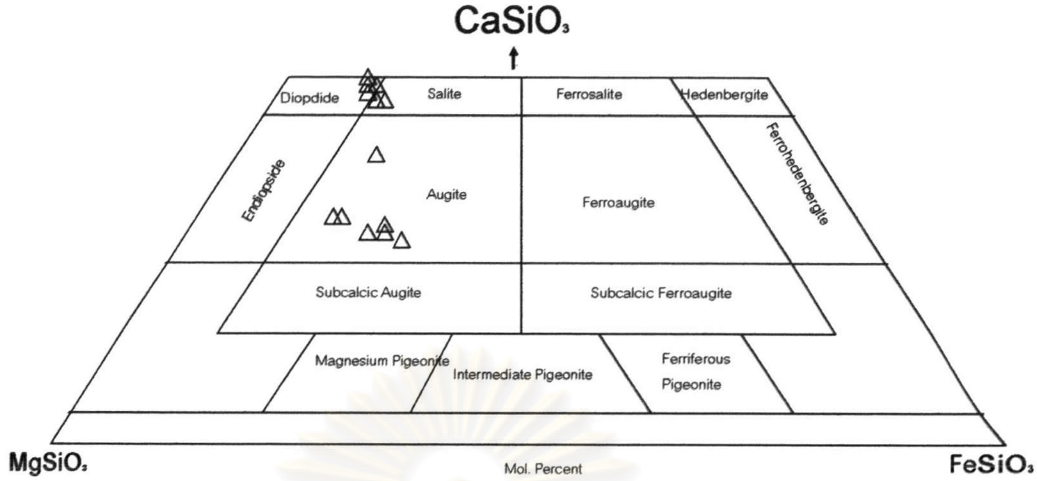


Figure 3.9 Pyroxene nomenclature after Deer et al. (1966).

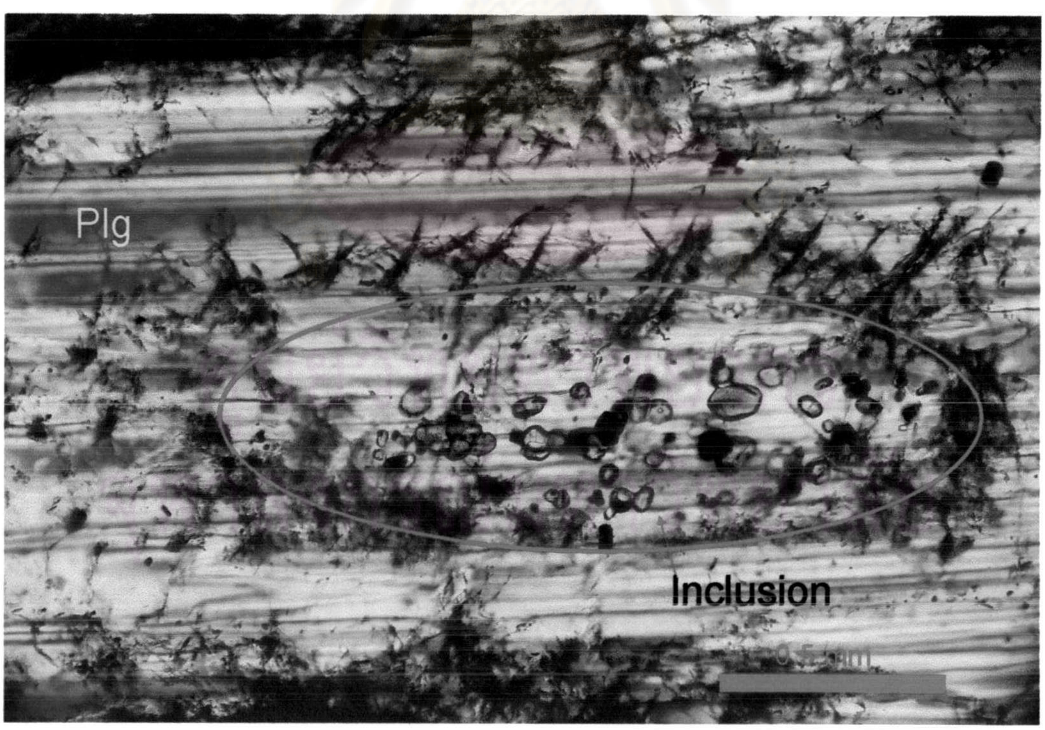


Figure 3.10 Plagioclase laths enclose accessory minerals. (photo taken from polished thin section, X-nicols)

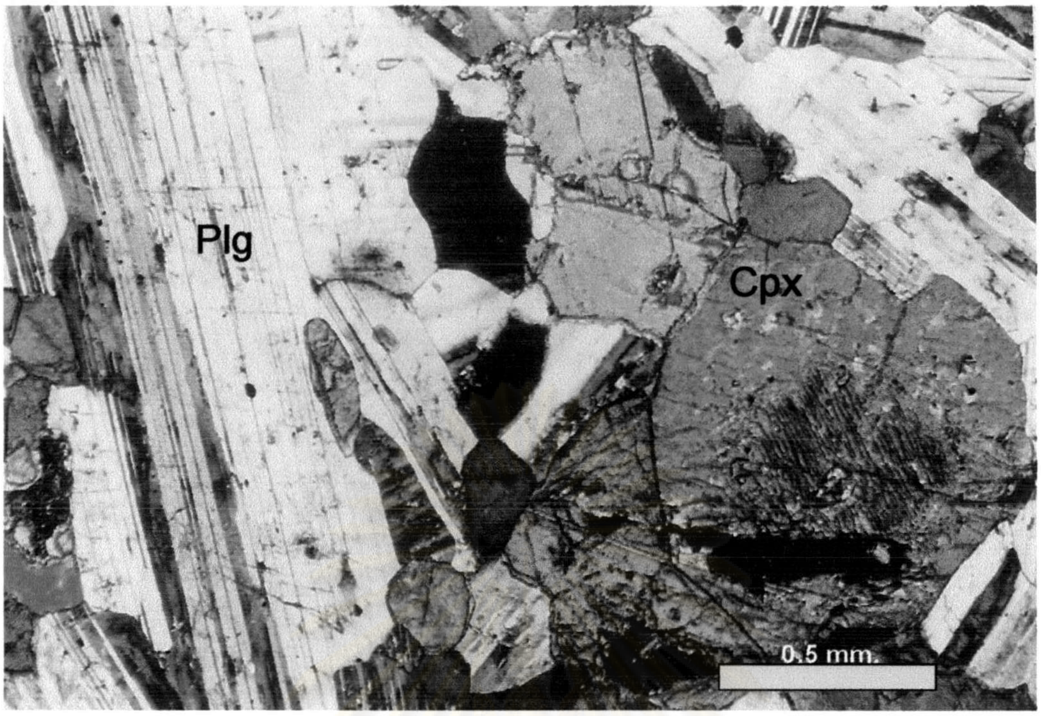


Figure 3.11 Sieve texture in pyroxene crystal (x-nicols).

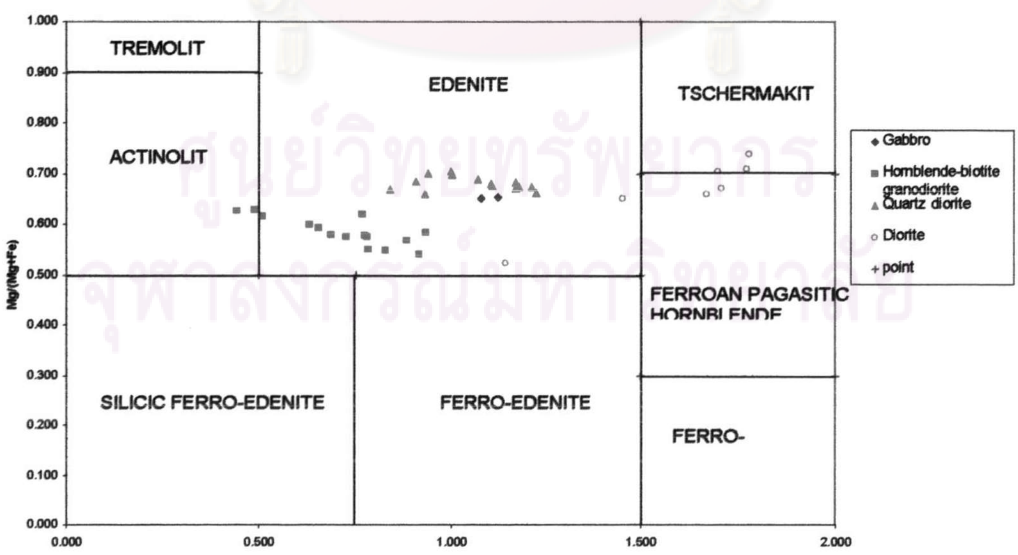


Figure 3.12 Hornblende nomenclature after Leak (1978).

3.3.2 Diorite

The rock crops out in eastern part of the study area (Figures 3.2 and 3.13) and intrudes as a large elongated sill parallel to limestone bedding in north-south direction and dip to the east (Figure 3.14). Its size is approximate 1 to 1.5 km. wide and 6.5 km long. General characteristics of diorite are fine-grained, greenish gray, phaneritic, holocrsyatalline with porphyritic (Fig. 3.15), subophitic and glomeromorphic texture (Figure 3.16). Micrographic textures are found in some parts of this rock (Figure 3.17). Phenocrysts are composed of two main minerals, hornblende and plagioclase, having the grain size of 1 to 5 mm. Some laths of plagioclase are partially enclosed by hornblende as subophitic texture. Both plagioclase and hornblende are commonly subjected to moderate alteration into clay mineral and chlorite, respectively.

The rock comprises plagioclase (60 – 65 %), hornblende (30 – 35 %), K-feldspar (2-3) and quartz (5-10 %). In addition, accessory minerals include sphene, apatite, zircon and opaque minerals. Some small grains of clinopyroxene (augite) occupy between plagioclase crystals (Figure 3.18). Moreover, small amount of secondary minerals, chlorite, clay and calcite, can also been found.

Microscopically, plagioclase generally shows subhedral to euhedral crystals with its composition, based on the analysis by EPMA of 11 grains (Appendix D-1), falling on andesine to labradorite (An-content = 40 - 68), except some crystals that are enclosed in hornblende show a bytwonite composition with An-content of 74 – 79. Its size varies from 0.5 to 1 mm., while the phenocryst has larger sizes (up to 2.5 mm.). Some plagioclase grains are altered into sericite.

Hornblendes in this rock are ferropagasite hornblende, edenite and tschermakite based on the EPMA analysis on 7 grains (Appendix D-3), after the nomenclature of Leak (1978). It shows subhedral to euhedral crystal. The grain size is about 0.5 to 5 mm. Single twined, multiple twined and penetrated crystals are the main characteristics of hornblende (Figure 3.19). It generally shows brown to reddish brown, green and greenish yellow color. Some grains show a distinctive lilac and purple-blue corona - zoning and corroded rim (Figure 3.20).

K-feldspar and pyroxene in diorite present as minor phases. K-feldspar occurs as anhedral crystals filled interstitially between plagioclase laths. Its size is about 0.5 – 1 mm. The K-feldspar grains are generally showed cloudy appearance. Moreover, granophyric texture can be found in this rock.

Quartz occurs as anhedral crystals occupied interstitially between plagioclase and hornblende. As mentioned above, minor granophyric texture of quartz and K-feldspar forms around the plagioclase crystals.

Accessory minerals in this rock comprise sphene, apatite, zircon, ilmenite, magnetite and pyrite. Apatite and zircon usually show euhedral, long and short column while sphene, magnetite and some grains of ilmenite show an anhedral, granular behavior. In addition, some ilmenite crystals show a skeletal texture and pyrite crystals show a cubic form. Finally, chlorite, clay and calcite occur as secondary minerals in this rock.

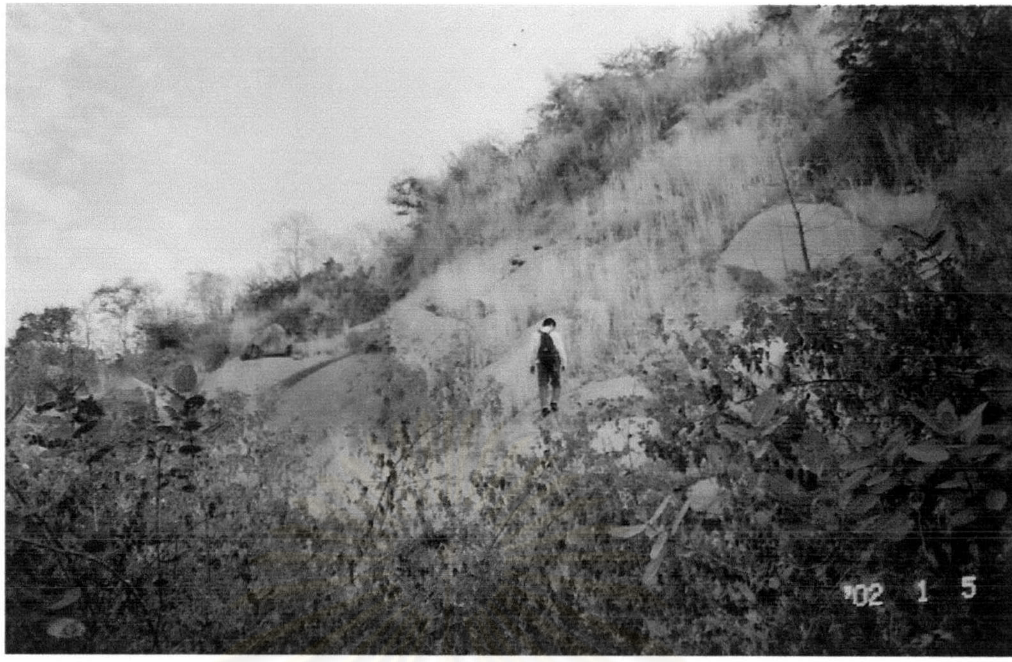


Figure 3.13 Quarry-exposure of diorite.

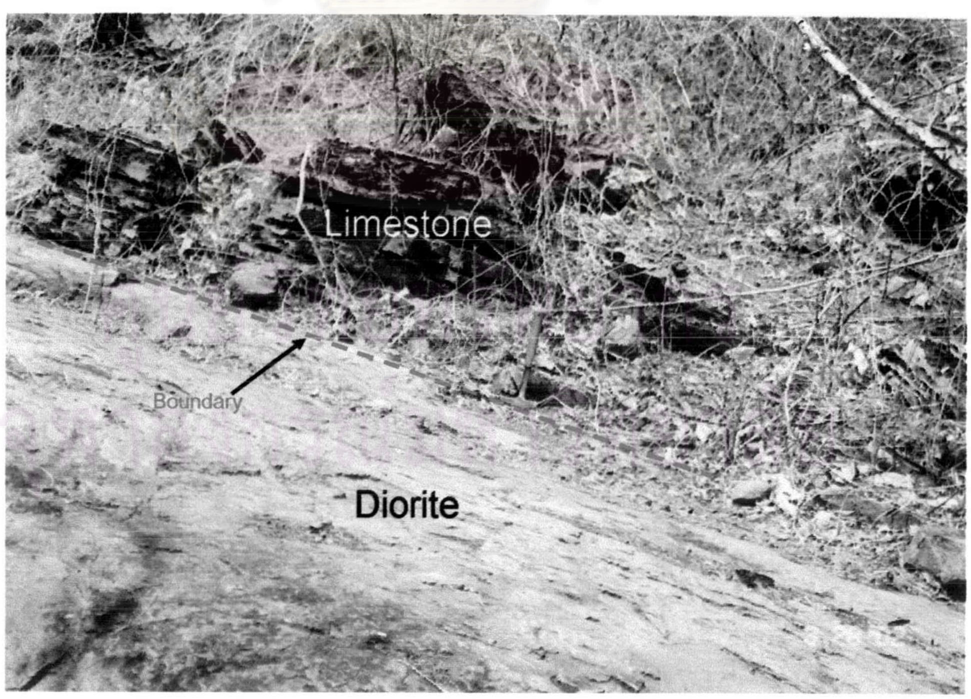


Figure 3.14 Field relationship of diorite and limestone.

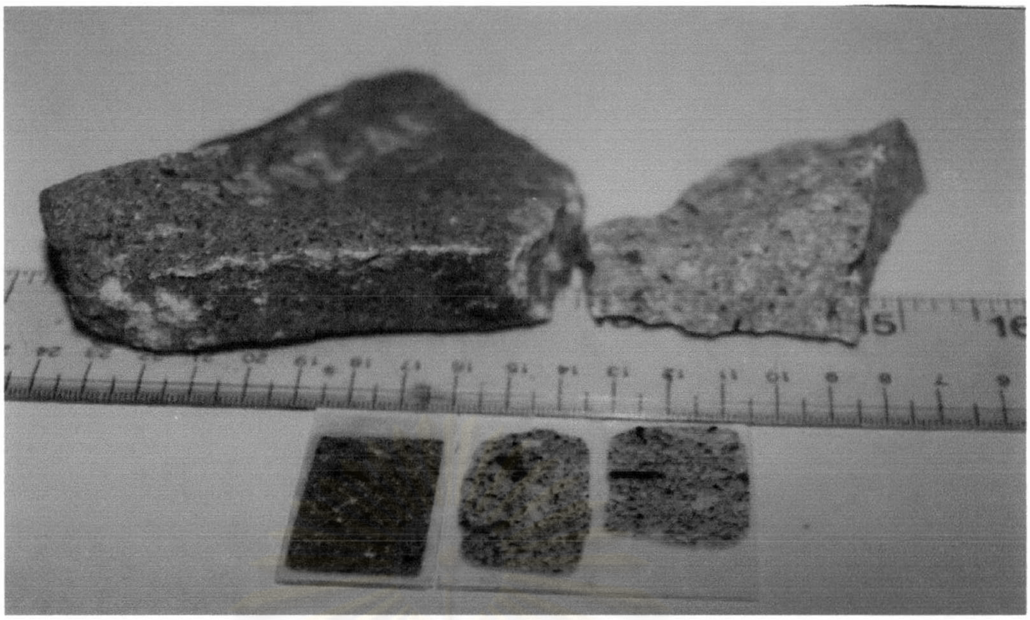


Figure 3.15 Specimens of diorite show porphyritic texture.

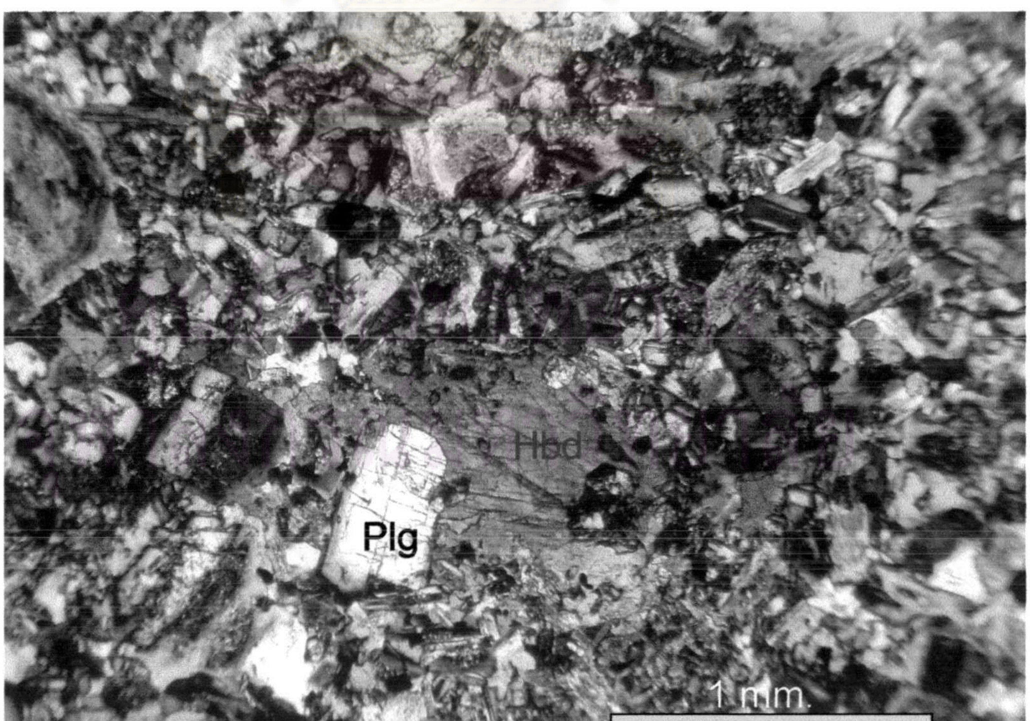


Figure 3.16 Showing subophitic texture in diorite (X-nicols).

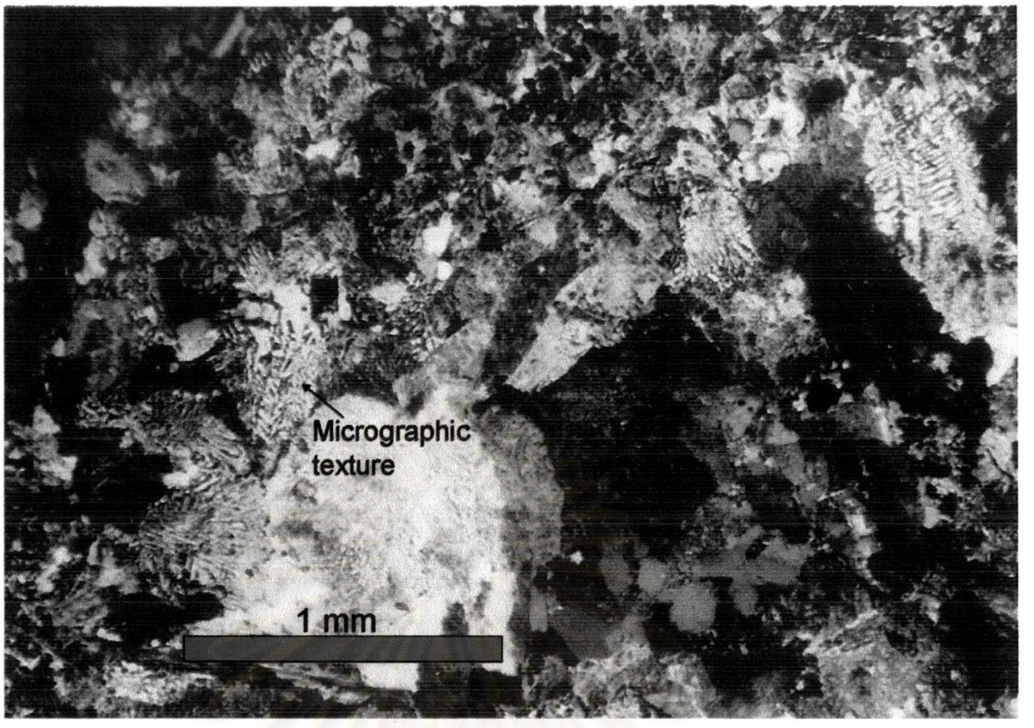


Figure 3.17 Showing micrographic texture in diorite (X-nicols).

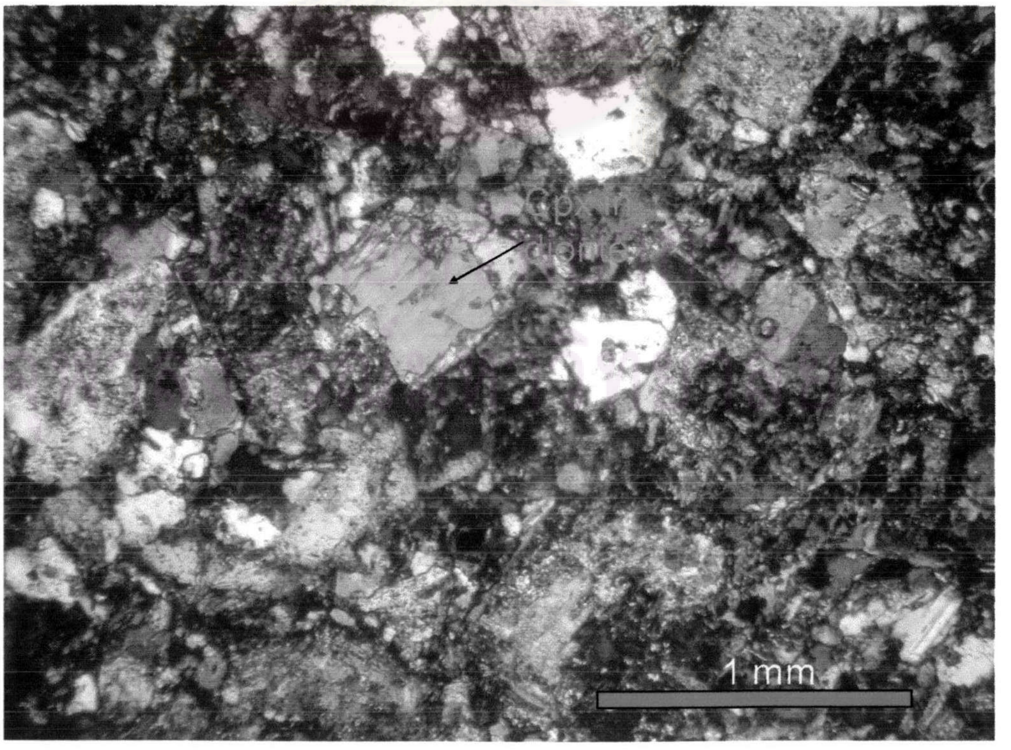


Figure 3.18 Showing pyroxene in diorite (X-nicols).

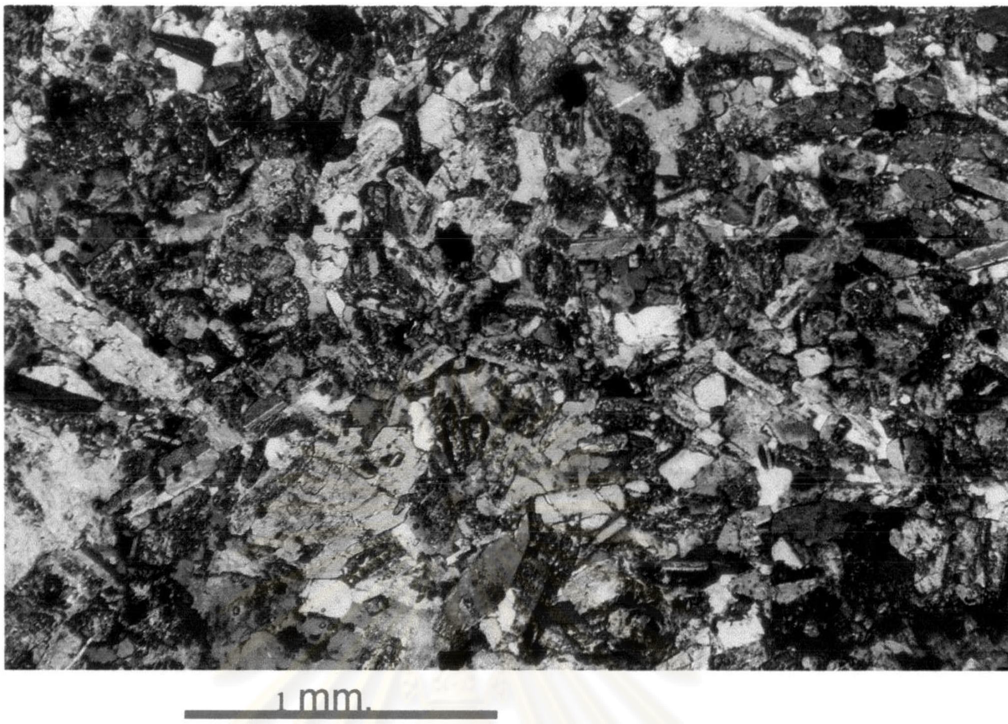


Figure 3.19 Showing general crystal habits of hornblende including euhedral, subhedral, anhedral and twinning (X-nicols).

Figure 3.20 Hornblende in diorite showing lilac and purple-blue corona -zoning and corroded rim (X-nicols).

3.3.3 Quartz diorite

This intrusive rock, which crops out in the south-eastern corner of the study area (Figures 3.2 and 3.21), covers an area about 3 km^2. The rock contains a lot of xenoliths of basalt, andesite and diorite. This intrusive rock has previous been mapped as diorite by Jungyusuk et al., (1985) though it shows a distinctively different color from that of the diorite, in addition, the crosscutting relationship in the field clearly reveals that they are not a contemporaneous intrusion but the quartz diorite post-dated the diorite.

This leucocratic rock is fine-grained, slightly porphyritic (Figure 3.22) with the phenocrysts of hornblende, plagioclase and subordinate K-feldspar (Figure 3.23). The distinctively different aspect as compared to the diorite is that this rock contains higher amount of modal percentage of quartz. The rock is characterized by subophitic, granophyric and graphic textures (Figures 3.24 and 3.25).

The main rock-forming minerals are composed of plagioclase (50 – 55 %), hornblende (10 – 20 %), K-feldspar (5 – 10 %), quartz (15 – 20 %). Other accessory minerals include sphene, apatite, zircon, calcite and opaque minerals.

The plagioclase is generally subhedral with the composition varying from andesine to labradorite (An-content = 36-68), based on the EPMA analyses of 10 grains (Appendix D-1). This variation was observed from normal zoned plagioclase crystals in which the core is usually more calcic than the rim. Calsbad-albite twins are relatively more common while the albite twin is rarely present. Its grain size is approximately 0.5 to 2 mm.

Unlike diorite, hornblende in quartz diorite is subhedral rather than euhedral and ranges in size from 0.5 to 2 mm. Some crystals show either broken or corroded grains which enclose laths of plagioclase, the so-called subophitic texture. In addition, the lilac and purple-blue corona–zoning are not found in this rock. The composition of hornblende as determined by EPMA on 12 grains is edenite (Appendix D-3). K-feldspar occurs subhedral and euhedral crystals in phenocryst and groundmass. Its sizes range from 0.5 to 2 mm and it generally associates with quartz in the form of micrographic and granophyric textures.

Most of the quartz grains form as anhedral crystal. As mentioned above, it is usually formed an intergrowth with K-feldspar in the form of granophyric and micrographic textures.

Similar to diorite, the accessory minerals in this rock comprise sphene, apatite, zircon and opaque minerals Moreover, clay, chlorite and calcite are also present as secondary minerals

Figure 3.21 Quarry-exposure of quartz diorite.

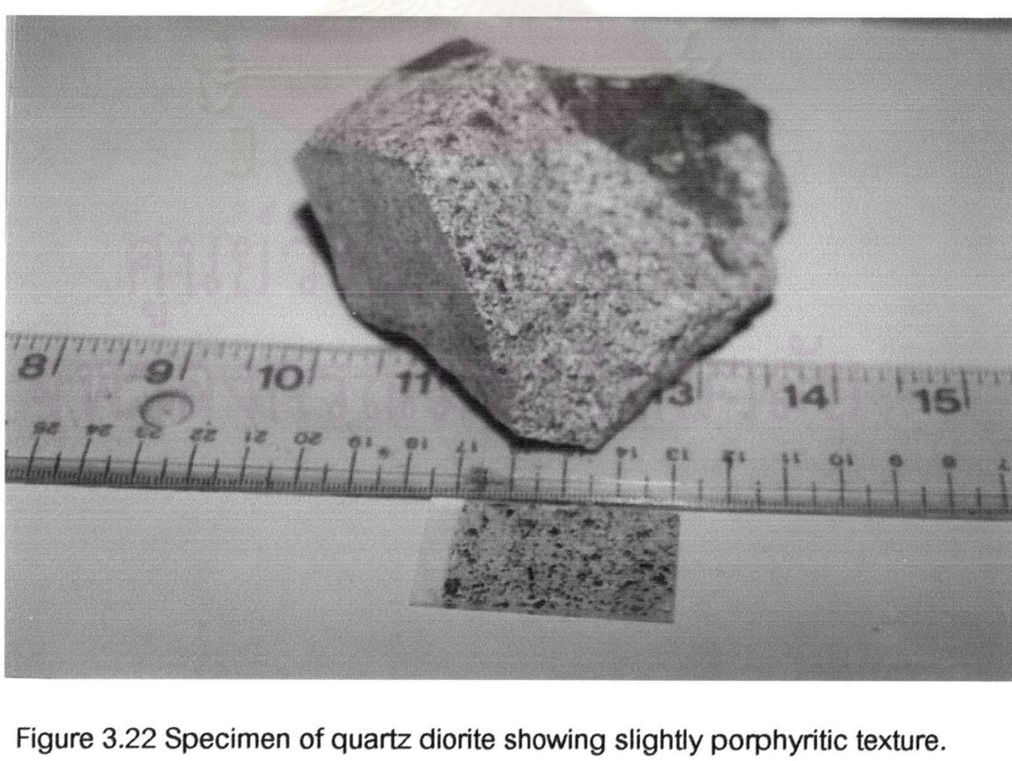


Figure 3.22 Specimen of quartz diorite showing slightly porphyritic texture.

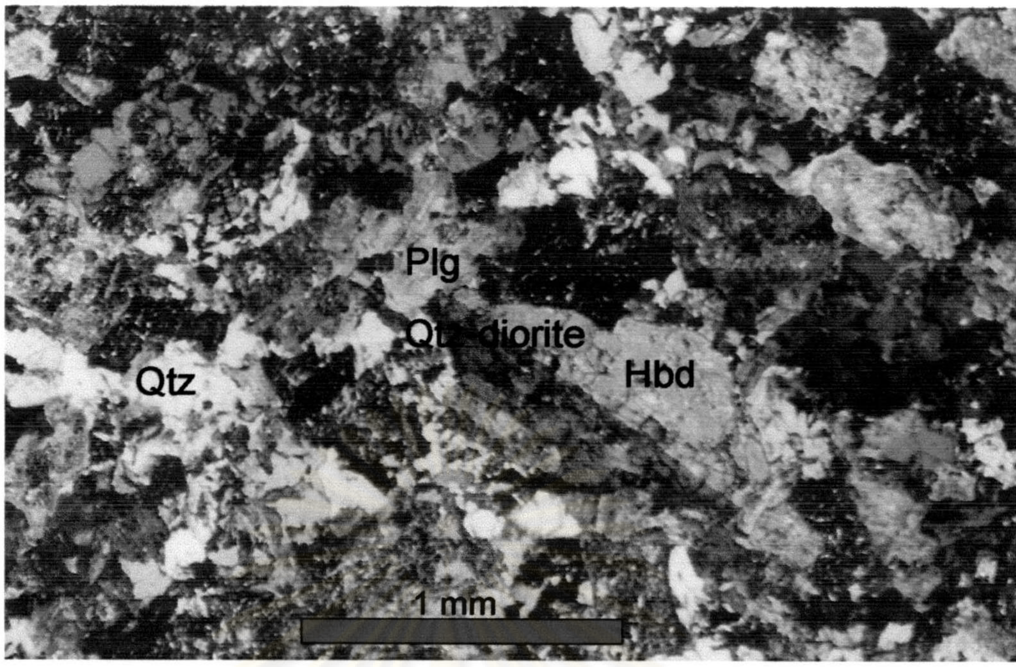


Figure 3.23 Showing phenocryst of hornblende in quartz diorite (x-nicols).

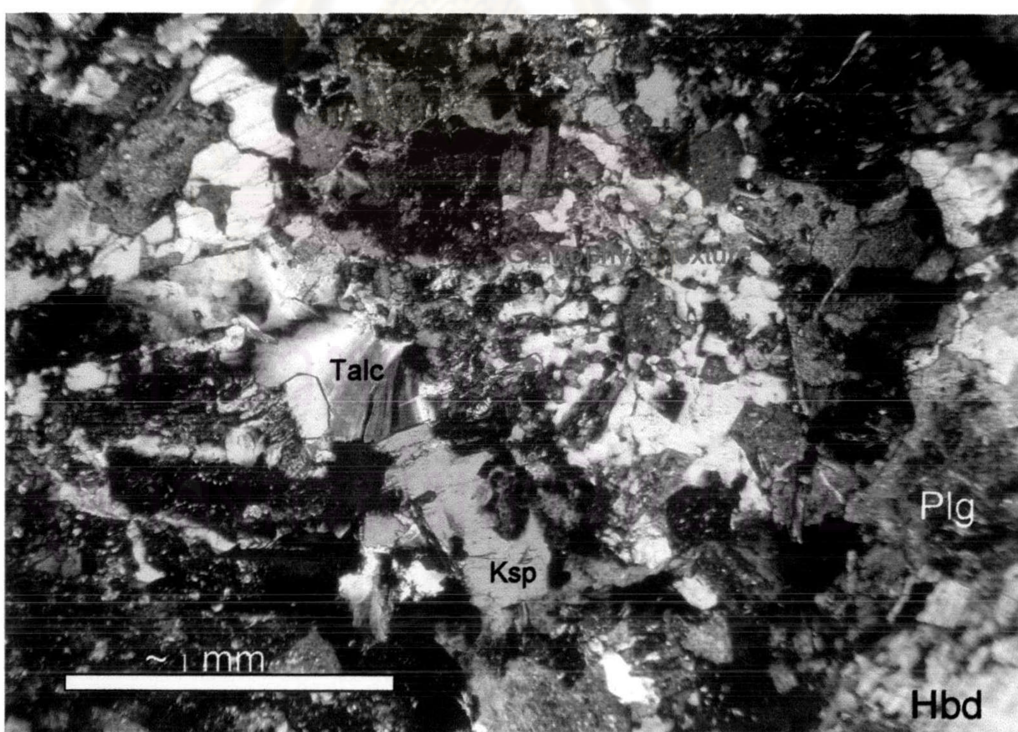


Figure 3.24 Showing typical ganophyric texture of in quartz diorite (x-nicols).

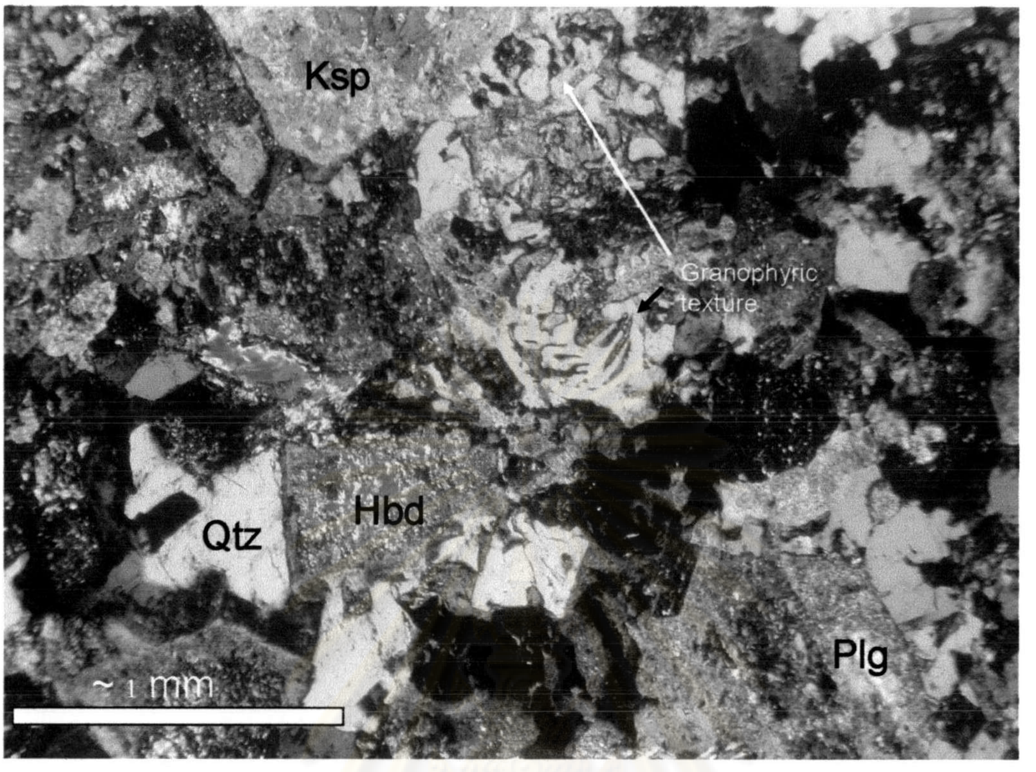


Figure 3.25 Showing relationship among minerals in quartz diorite (x-nicols).

3.3.4 Hornblende-biotite granodiorite

The hornblende-biotite granodiorite is the most felsic intrusive rock found in the study area. It crops out as small stocks about 2 x 5 km^2 in the west and about 1X1 km^2 in central parts of the study area (Figures 3.2 and 3.26). It is fine to medium-grained, grayish white (Figure 3.27), phaneritic, holocrystalline, equigranular with subophitic and interstitial textures. The amounts of hornblende and biotite this rock unit seem to increase from east to west while K-feldspar increases from west to east. In addition, small amount of pyroxene is found on the western edge of stock (Figure 3.28).

The mineral composition of hornblende-biotite granodiorite are plagioclase (55-60 %), hornblende (10-15 %), biotite (5-10 %), K-feldspar (3-5 %), quartz (10-15 %) and pyroxene (1-2 %). Apatite, sphene, zircon, and opaque minerals are accessory minerals.

Plagioclase crystals commonly show normal concentric zoning (Figure 3.29) with subhedral to euhedral shape varying in size from 1.5 to 2 mm. Its chemical compositions are andesine and labradorite (An-content = 34 - 53), based on the EPMA analyses of 13 grains (Appendix D-1). Some crystals show a sieve texture. In addition, some grains are partly enclosed by hornblende (Figure 3.30).

Hornblende dominantly occurs as subhedral to corroded anhedral crystals that show strong pleochroism from yellow to green (Figures 3.31 a-b). Its grain size varies from 0.5 – 1.5 mm. There are the remnant of small clinopyroxene (augite) grains in some hornblende crystals. The main composition of hornblende, based on the EPMA analyses of 14 grains (Appendix D-3), is edenite with subordinate actinolite. One of the distinctive feature of hornblende in this rock is that it is always partially replaced by biotite (Figure 3.32). Occationally, hornblende crystals partially enclose laths of plagioclase, the so-called subophitic texture, and may contain inclusions of other accessory minerals, especially zircon grains. Single twinning and lamellae-multiple twinning are also found in this rock.

Biotite is always formed as replacing phase in hornblende grain (Figure 3.32) in the form of small flakes. It is brown to reddish pleochroic. The amount of biotite seems to decrease from east to west (close to pyroxene diorite).

Quartz and alkali feldspar usually occur as anhedral crystal filled interstitially between plagioclase and other mafic minerals. Their amounts seem to decrease westward whereas that of pyroxene increases westward.

Sphene and apatite commonly occur as inclusions in plagioclase whereas zircon and opaque minerals prefer to be enclosed in hornblende and biotite.

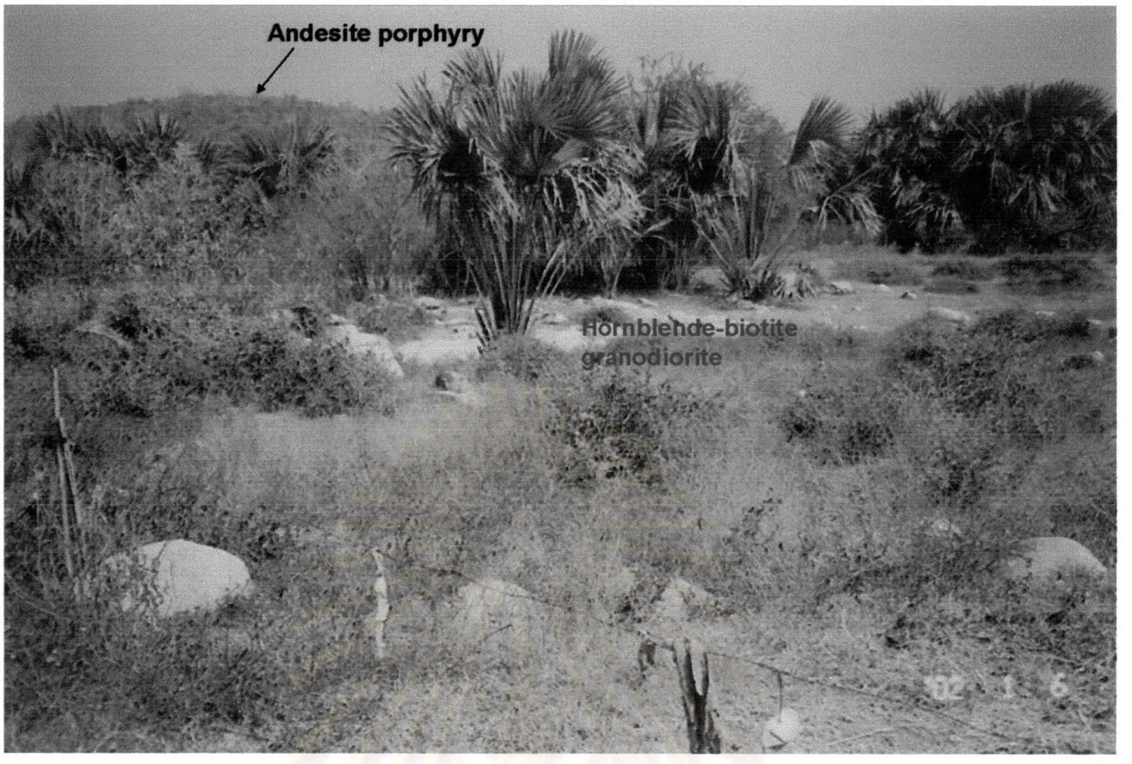


Figure 3.26 Natural exposure of hornblende-bioitite granodiorite.

Figure 3.27 Specimen and staining slab of hornblende-biotite granodiorite.

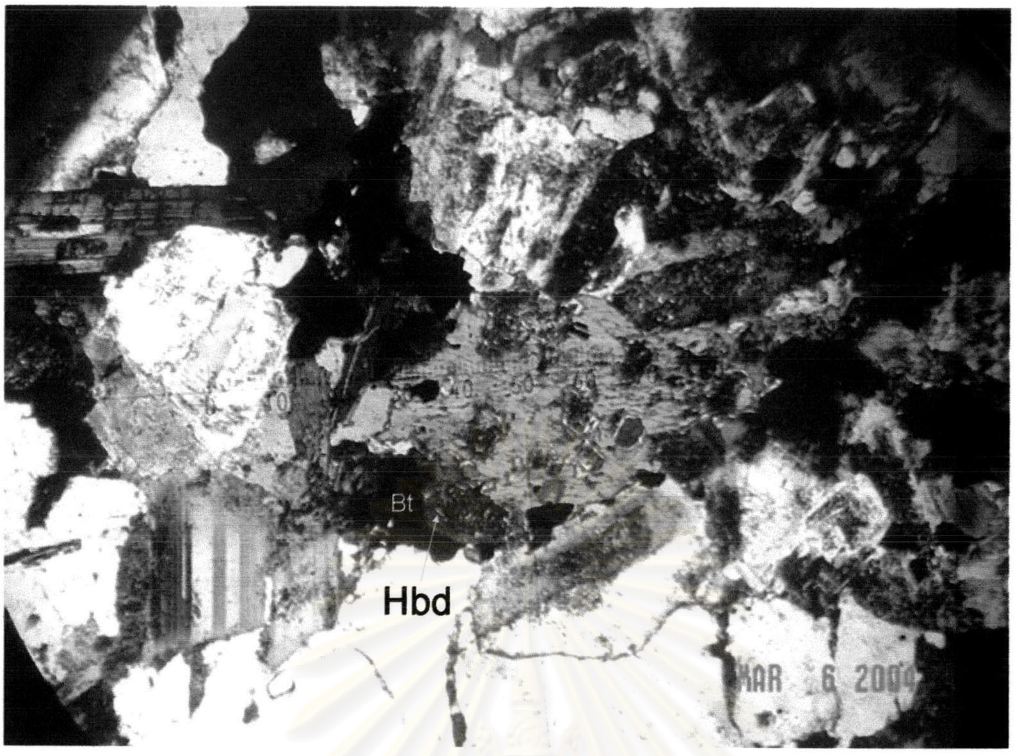


Figure 3.28 Corroded pyroxene in hornblende-biotite granodiorite (x-nicols).

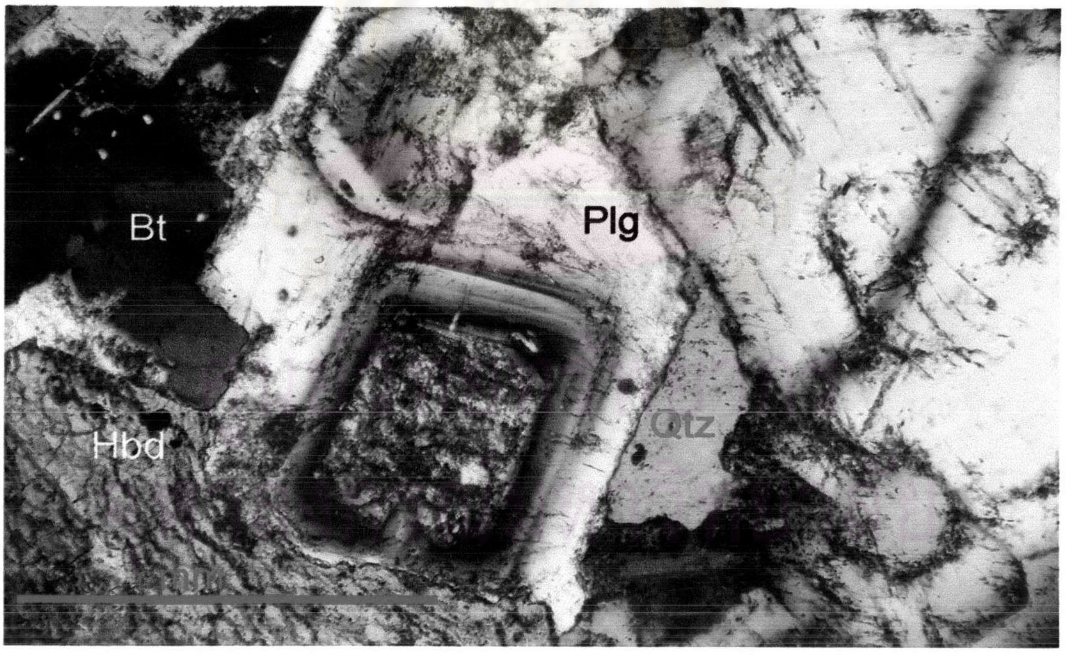


Figure 3.29 Showing relationship among hornblende, biotite, Zoned plagioclase and interstitial quartz in hornblende-biotite granodiorite(x-nicols).

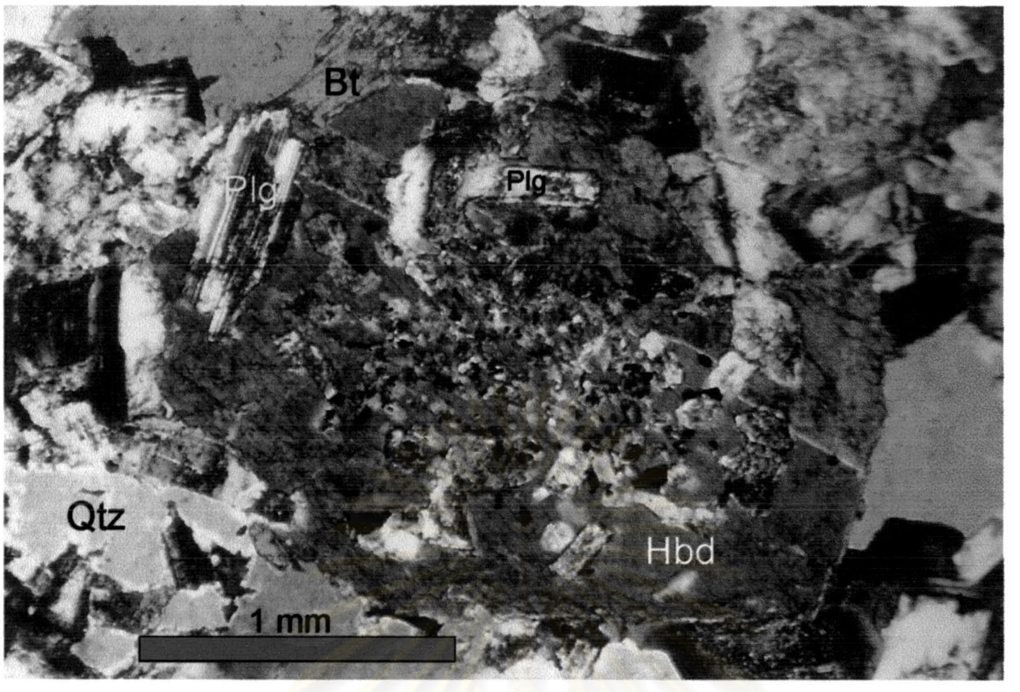
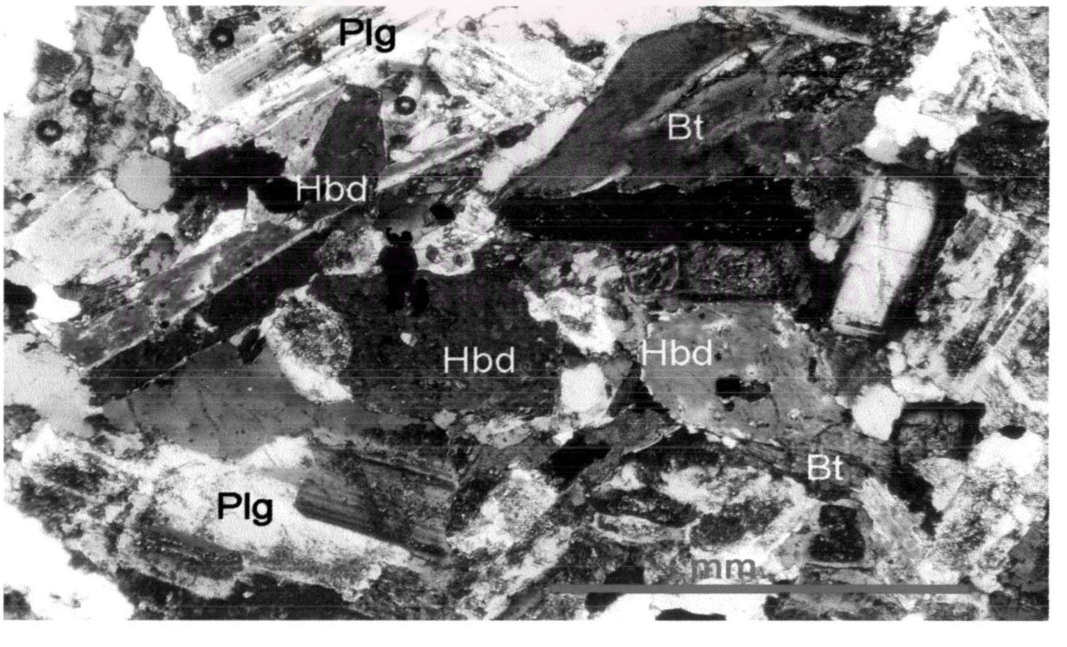


Figure 3.30 Poikiloblast twinned hornblende enclosing plagioclase, apatite, zircon and opaque minerals and partially enclose plagioclase (x-nicols).

(Figure 3.31 a)



(Figure 3.31 b)

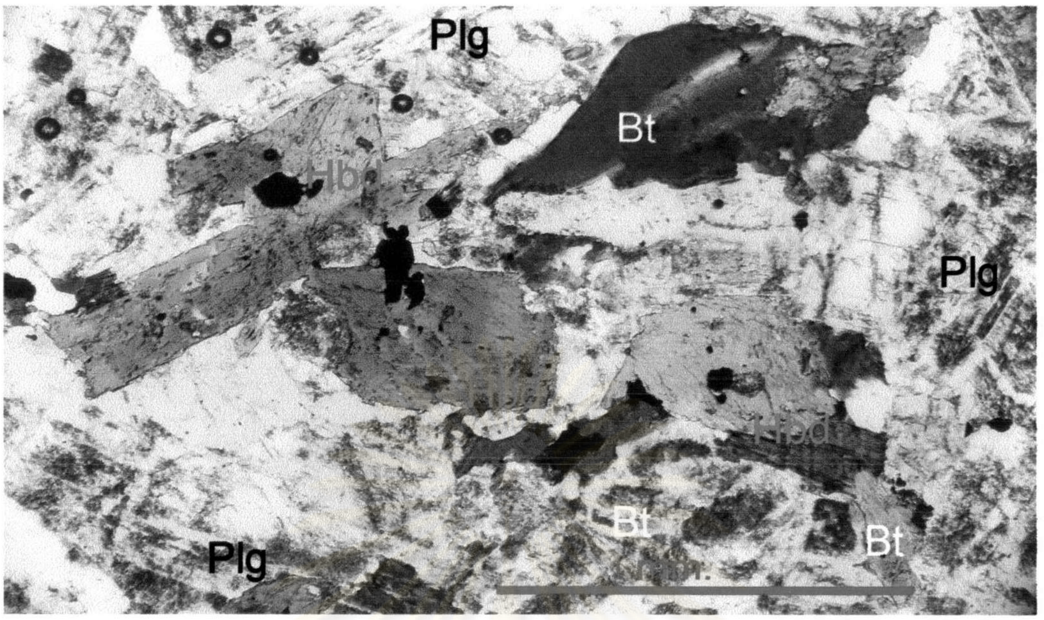


Figure 3.31 (a-b) Characteristic of hornblende and general texture of hornblende-biotite granodiorite (X-nicols, plain polarized light).

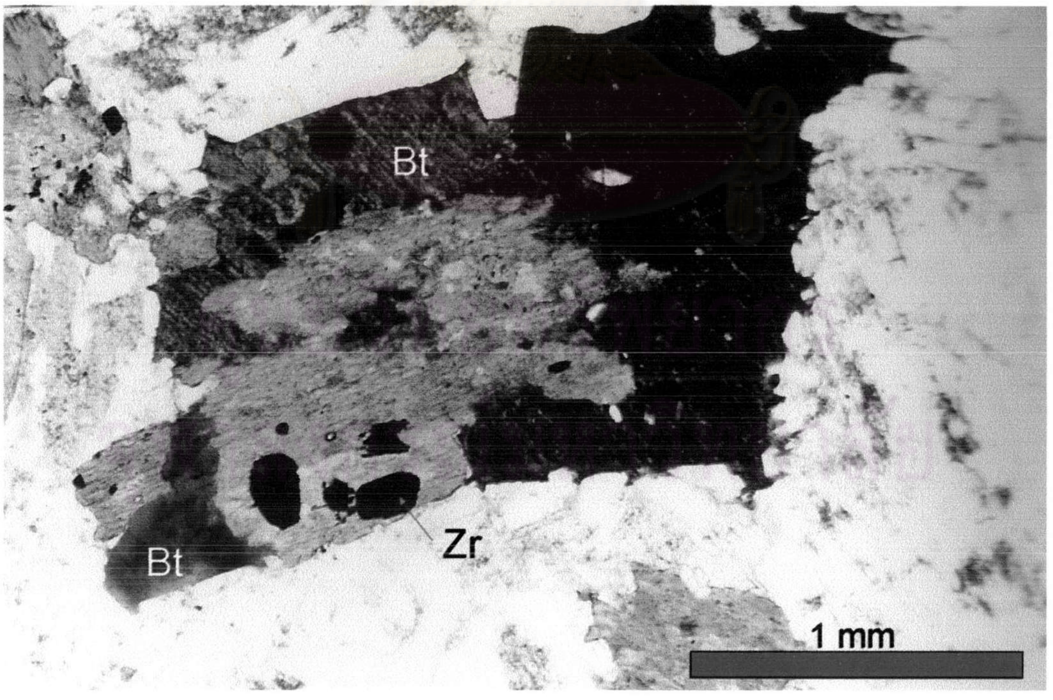


Figure 3.32 Typical co-exist hornblende and biotite showing partial replacement in hornblende-biotite granodiorite (x-nicols).

3.4 Discussion on petrographic study

The summary of petrographic characteristic throughout the study area is shown in Figure 3.33. The grain size variation may suggest variety of conditions of crystallization in each rock. That is the coarser-grained gabbro and hornblende-biotite granodiorite might crystallize in more equilibrium condition than the two finer-grained diorite and quartz diorite.

There are two dominant factors control the growth rate of crystals, mass transfer and heat transfer. The heat transfer acts as driving force and it is faster than mass transfer (Hibbard, 1995). At a low thermal gradient or slow change of temperature, magma may be cool down slowly resulting in an equilibrium condition because rate of mass transfer close to heat transfer in this condition. Consequently, crystals have enough time to recruit surrounding elements for its complete formation. Gabbro and hornblende-biotite granodiorite, on one hand, may crystallize at this condition so both of them have a coarse to medium grained, more equigranular texture. On the other hand, diorite and quartz diorite may crystallize at steep thermal gradient resulting in a relatively finer-grained, granophyric texture and micrographic texture. These texture indicate in-equilibrium condition or under-cooling (Candela, 1997).

In addition, the formation of phenocrysts in diorite and quartz diorite, as noted by Hibbard (1995), may suggest the crystallization under an environment of low nucleation density because temperature of magma body was held therein. Until the temperature decreased rapidly, resulting under-cooling condition or steep thermal gradient. Then rapid crystallization might have taken place, resulting fine-grained matrix surrounding phenocrysts.

Plagioclase zoning is very common in hornblende-biotite granodiorite, less common in quartz diorite and diorite whereas it is lacking in gabbro. This characteristic may suggest a different crystallizing condition between them. That is it was more equilibrium during the crystallization of gabbro while they were less equilibrium during the crystallization of the other rock types.

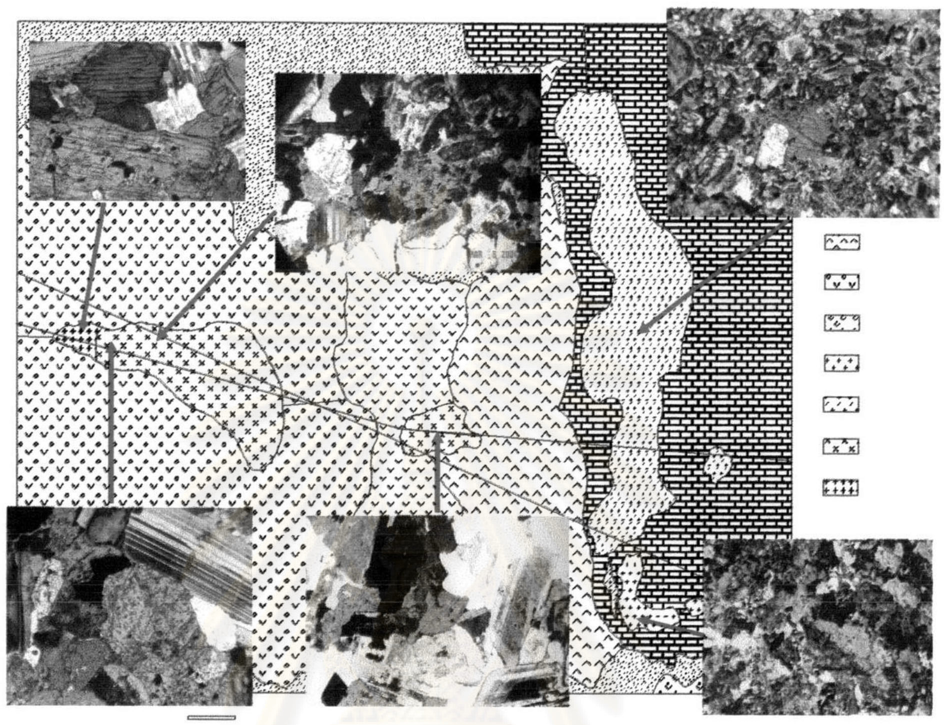


Figure 3.33 Summary of petrographic characteristics throughout the study area.

3.5 Modal analysis

Owing to their coarse-grained nature, modal percentage of plagioclase, K-feldspar and quartz were point-counted from the stained slabs of gabbro (5 slabs) and granodiorite (3 slabs). The results are plotted in QAP diagram after Streckeisen (1976) in Figure 3.34. As shown in Figure 3.33, five points of gabbro slabs fall almost in the grabbro field and all three point of granodiorite slabs fall in the granodiorite field.

These results have been confirmed the correct nomenclature of each intrusive rock type used in this study.

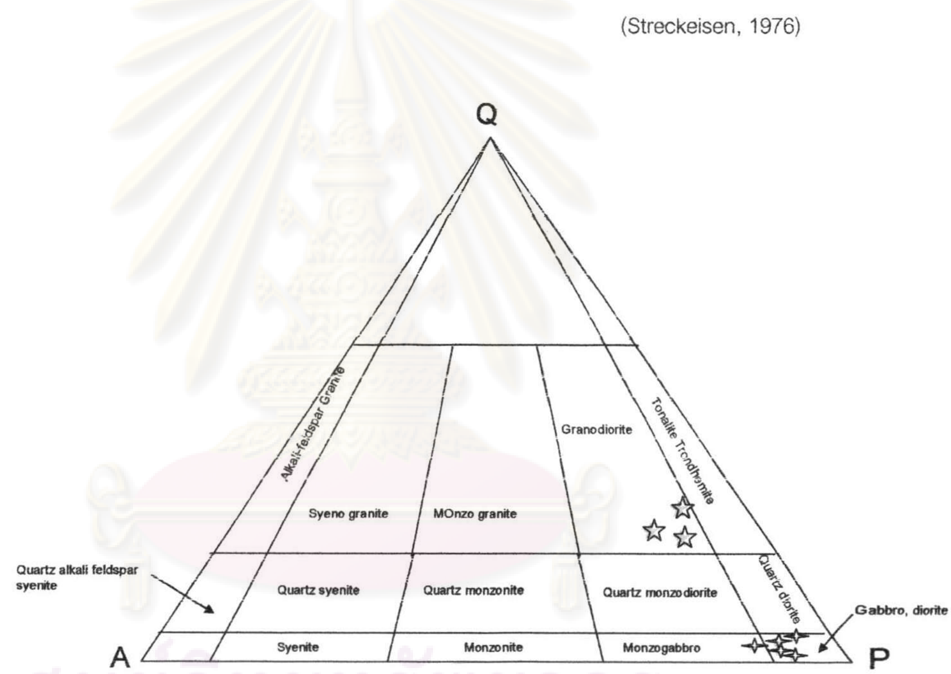


Figure 3.34 QAP diagram shows the results of plot of gabbro (5 samples) and hornblende-biotite granodiorite (3 samples).