

APPENDIX

Petrography of individual studied mafic igneous rock samples

Group I Rocks

Sample Number MS16B1

Rock name Microgabbro

Lithology

This non-foliated sample has green color, with a yellowish brown weathering surfaces. It has coarse grained texture, and tiny green veins (up to 0.5 mm across) are present in the sample.

Thin section description

This rock is coarse grained, seriate texture and composed largely of plagioclase, with subordinate amphibole and opaque minerals. Secondary patches of epidote, chlorite, pumpellyite and titanite. Tiny veins (up to 0.5 mm across) of chlorite, epidote, pumpellyite, quartz are cut through amphibole, plagioclase, and opaque minerals.

Plagioclase is subhedral-anhedral outlines, with averaged size 6.0 mm across. It is felty texture and some grains show sieve texture and corroded outline. It is medium to highly altered to largely of sericite, epidote, pumpellyite, titanite/leucoxene and minor carbonate, clay. Inclusion of amphibole is in some plagioclase grains. Some grains show slight kink-band feature.

Amphibole crystals are anhedral-subhedral outline and skeleton shape. Some grains show kink-band feature. Amphibole has a pleochroic formula as follows: X=yellow, Y =greenish brown, Z=green. The pleochroic formula suggests that they are hornblende. It has a lot of fracture and is medium altered to mainly of chlorite, Fe-Ti oxide, epidote, titanite/leucoxene. Inclusion of apatite is present in this rock sample.

Opaque minerals are anhedral (averaged size 0.5 mm across) and have irregular outlines.

Sample Number MS15B2

Rock name Microdiorite

Lithology

This non-foliated sample has white colored felsic minerals and green colored mafic minerals, with yellowish brown weathering surfaces. It is medium grained crystals. Some areas are rarely replaced by yellowish orange materials.

Thin section description

The rock sample is fine-medium grained texture, and made up principally of plagioclase, amphibole and small amounts of quartz, opaque minerals. Secondary patches of chlorite, epidote, titanite/leucoxene are present in the rock. Tiny veins (sizes up to 0.2 mm across) infilled with epidote, chlorite, pumpellyite are locally present in the rock.

Plagioclase is euhedral outline (averaged size 2.0 mm across) and equigranular. It shows felted plagioclase laths. It is medium replaced by sericite, titanite/leucoxene, chlorite, clay. Inclusion of apatite is present in plagioclase.

Amphibole has euhedral-subhedral (averaged sizes 1.0 mm across) and skeletal shape, with sieve texture (averaged sizes 5.0 mm across). Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish green, Z=green. The pleochroic formula suggests that they are Hornblende. They are slightly-medium altered to largely of chlorite, Fe-Ti oxide. Also, presents are inclusion of plagioclase, quartz in some grains.

Quartz is anhedral outline (averaged size 0.8 mm across). It shows interstitial texture to amphibole. Inclusion of apatite is present in some grains.

Opaque minerals are anhedral-euhedral outlines (averaged size 1.0 mm across) and have irregular outlines.

Sample Number MS12B3

Rock name Microgabbro

Lithology

The non-foliated rock sample has dark green. It shows medium-coarse grained texture. The rock is made up of dark green and white minerals. Dark green minerals are mafic minerals and white minerals are feldspars.

Thin section description

This rock is medium-coarse grained, seriate texture and composed largely of plagioclase, with subordinate amphibole and opaque minerals. Secondary patches of epidote, chlorite, titanite and tiny veins (up to 0.25 mm across) of chlorite, epidote are present in the rock sample.

Plagioclase has two grain sizes in this sample. First, plagioclase is medium grain, with averaged size 1.0 mm across. It is euhedral-subhedral outline, feldted plagioclase. Second, plagioclase is coarse grain, with averaged size 10.0 mm across. It is subhedral outline. Two types of plagioclase are highly altered to largely of sericite, epidote, titanite/leucoxene and minor carbonate, clay.

Amphibole crystals can be separated into two types by their shapes and sizes as follows: (1) coarse grain (sizes up to 5.0 mm across) and (2) medium grain (sizes up to 1.0 mm across). The coarse grains are subhedral outline, while the fine grains are anhedral outline. The amphibole grains are subequant and prismatic shape. Both the amphibole grains have a pleochroic formula as follows: X=green, Y=brownish yellow, Z=yellow. The pleochroic formula suggests that they are Hornblende. They are medium altered to mainly of chlorite, opaque minerals.

Opaque minerals are anhedral (averaged size 0.5 mm across) and have irregular outlines.

Sample Number MS14B3
Rock name Monzodiorite

Lithology

The non-foliated rock sample has medium grained, and is made up of black and white minerals. Its weathering surfaces have brownish yellow color. The rock is made up of dark green and white minerals. Dark green minerals are mafic minerals and white minerals are feldspars.

Thin section description

This rock is medium grained, seriate texture. It is made up mainly of plagioclase, amphibole and small amounts of opaque minerals, unidentified mafic minerals and quartz. Secondary patches of epidote, chlorite, titanite and tiny veins (up to 0.25 mm across) of chlorite, epidote are present in the rock sample.

Plagioclase is medium grain, with averaged size 4.0 mm across. It is subhedral outline and feldt plagioclase. It is medium-highly replaced by largely of sericite, epidote, titanite/leucoxene and minor carbonate, clay.

Amphibole is euhedral-anhedral outline. It is medium grain (averaged size 2.0 mm across), may form skeleton shape and sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish yellow, Z=green. The pleochroic formula suggests that they are hornblende. They are medium altered to largely of chlorite, biotite, Fe-Ti oxide.

Unidentified mafic minerals are euhedral outline (averaged size 1.5 mm across). It has many fractures and is extremely replaced by chlorite/serpentine, Fe-Ti oxide.

Quartz is anhedral outline (averaged size 1.0 mm across). It shows interstitial texture to amphibole.

Opaque minerals are anhedral (averaged size 2.0 mm across) and have irregular outlines.

Sample Number MS8B4

Rock name Microdiorite

Lithology

The non-foliated rock sample has medium grained texture. It has green color, with the weathering surfaces yellowish brown color. It has small amounts of veins (up to 0.5 mm across).

Thin section description

This rock is medium grained. It comprises mainly of plagioclase, amphibole and small amounts of opaque minerals, unidentified mafic minerals and quartz. It shows interstitial texture quartz to amphibole. Secondary patches of epidote, chlorite, titanite and tiny veins (up to 0.2 mm across) of chlorite, epidote are present in the rock sample.

Plagioclase is euhedral-subhedral outline, with averaged size 4.0 mm across. It is feldspathic plagioclase. It is medium-highly replaced by largely of sericite, epidote, titanite/leucoxene and minor carbonate, clay.

Amphibole is euhedral-anhedral outline and skeleton shape (averaged size 2.0 mm across), may form skeleton shape and sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish yellow, Z=yellowish green. The pleochroic formula suggests that they are Hornblende. They are medium altered to largely of chlorite, Fe-Ti oxide.

Unidentified mafic minerals are euhedral outline (averaged size 2.5 mm across). It has many fractures and is extremely replaced by chlorite/serpentine, Fe-Ti oxide.

Quartz is anhedral outline (averaged size 1.0 mm across). It shows interstitial texture to amphibole.

Opaque minerals are anhedral (averaged size 2.0 mm across) and have irregular outlines.

Sample Number MS9B4

Rock name Diorite

Lithology

This rock sample has green and white color, with a yellowish brown weathering surfaces. The green minerals are mafic minerals and the white minerals are felsic minerals. It has coarse grained texture.

Thin section description

This rock is coarse grained, seriate texture. It consists mainly of amphibole, plagioclase and small amounts of opaque minerals, quartz and apatite. It may form interstitial quartz. Secondary patches of chlorite, titanite, epidote and tiny veins (up to 0.2 mm across) of chlorite, epidote, opaque minerals, pumpellyite are present in the rock sample cut through plagioclase, amphibole.

Plagioclase is subhedral-anhedral outline, with averaged size 4.0 mm across. It is feldspar plagioclase. It is highly replaced by largely of sericite, epidote, titanite/leucoxene and clay.

Amphibole is euhedral-anhedral outline and skeleton shape (averaged size 4.0 mm across), may form skeleton shape and sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish yellow, Z=brownish green. The pleochroic formula suggests that they are. They are medium altered to largely of chlorite, titanite, Fe-Ti oxide.

Quartz is anhedral outline (averaged size 3.0 mm across) and may form skeletal shape (averaged size 6mm across). It shows partly interstitial texture to amphibole.

Opaque minerals are anhedral (averaged size 1.0 mm across) and have irregular outlines.

Sample Number MS10B4

Rock name Gabbro

Lithology

The rock sample has green and white color, green minerals are mafic minerals and white minerals are felsic minerals. Weathering surfaces are brownish yellow color. It is coarse grained texture. Tiny white veins (up to 10 mm across) are present in this rock.

Thin section description

This rock is coarse grained and seriate texture. Its constituents are made up of amphibole and plagioclase. Secondary patches of chlorite/serpentine, titanite are present in the sample. Tiny veins (up to 0.6 mm across) and voids of epidote, chlorite/pumpellyite, titanite/leucoxene, quartz are infilled in this sample.

Amphibole (averaged size 6.0 mm across) is subhedral-anhedral outline, short prismatic and subequant. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=green, Z=deep green. The pleochroic formula implies that it is hornblende. It is medium to highly altered to chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide and some grains have fractures of brown minerals cut through them.

Plagioclase crystals have two grain sizes in this sample. First, plagioclase is euhedral-subhedral outline (averaged size 4 mm across). Second, plagioclase is subhedral (averaged size 10 mm across). Felted plagioclase and coarser grain sizes enclosed by finer grain sizes are present in the sample. It is medium replaced by titanite/leucoxene, chlorite/pumpellyite, sericite, clay and epidote.

Sample Number MS6.2B5
Rock name Monzodiorite

Lithology

This rock sample has white and green color, with yellowish brown weathering surfaces. The green color is mafic minerals and the white color is felsic minerals. It is medium grained crystals.

Thin section description

The rock sample is medium grained texture, and made up largely of amphibole and plagioclase. Secondary patches of chlorite, titanite/leucoxene, epidote are present in the rock. Tiny veins (sizes up to 0.4 mm across) are infilled with quartz, chlorite/pumpellyite, epidote. Also, presents are locally aggregates of epidote, calcite and chlorite in this sample.

Plagioclase is anhedral outline (averaged size 4.0 mm across) and seriate texture. It shows felted plagioclase and may form corroded outlines and sieve texture. It is medium replaced by sericite, titanite/leucoxene, chlorite, clay. Inclusion of apatite is present in plagioclase.

Amphibole has subhedral-anhedral (averaged sizes 2.0 mm across) and may form skeletal shape, with sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish green, Z=green. The pleochroic formula suggests that they are hornblende. They are medium altered to largely of chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide.

Sample Number MS6.3B5(B)
Rock name Andesite/Basalt

Lithology

This non-foliated sample has dark gray color, with a yellowish brown weathering surfaces. It has very fine grained texture, and tiny white veins (up to 0.5 mm across) are present in the sample.

Thin Section Description

This rock sample is very fine-grained, ophitic/subophitic and intergranular texture. Its constituents are plagioclase and amphibole, minor opaque minerals, and very small amount of apatite, epidote. Secondary patch of titanite, chlorite are commonly present in the rock. Tiny veins and fractures (sizes up to 0.2 mm across) mainly of calcite, with subordinate quartz, titanite, epidote, chlorite, Fe-Ti oxide are infilled in the sample.

Plagioclase has euhedral outlines and lath shapes (averaged size 0.2 mm across). It shows felted plagioclase and some areas shows intersertal texture to chlorite. It is slightly replaces by titanite, chlorite.

Amphibole is brown, euhedral to subhedral outlines (averaged size 0.6 mm across). It has prismatic and subequant shape. It is ophitic/subohitic and to plagioclase laths. A small amount of them are intergranular to plagioclase laths. Amphibole has a pleochroic formula as follows: X=pale brown, Y=brown, Z=dark brown. The pleochroic formula suggests that they are hornblende. The grains are slightly altered to titanite, chlorite.

Opaque minerals have irregular outlines (averaged size 0.2 mm across).

Sample Number MS6.3B5(D)

Rock name Monzodiorite

Lithology

This rock sample has white and dark green color, with yellowish brown weathering surfaces. The dark green color is mafic minerals and the white color is felsic minerals. It is coarse grained texture.

Thin section description

This rock sample is coarse grained texture, consists mainly of amphibole and plagioclase and small amounts of opaque minerals and apatite. Secondary patches of titanite/leucoxene, epidote, chlorite are present in the rock. Tiny veins (sizes up to 1.0 mm across) are infilled with quartz, titanite/leucoxene, chlorite/pumpellyite, epidote. Locally, presents are aggregates of consertal quartz (averaged size 0.2 mm across), epidote, calcite and chlorite in this sample.

Plagioclase is anhedral outline (averaged size 4.0 mm across) and may form corroded outlines and sieve texture. It shows felted plagioclase. Locally, consertal quartz crystals are embedded in some plagioclase grains. It is highly replaced by sericite, titanite/leucoxene, chlorite, clay, epidote. Inclusion of apatite is present in plagioclase.

Amphibole has subhedral-anhedral (averaged sizes 6.0 mm across) and may form corroded outlines, with sieve texture. Locally, consertal quartz crystals are embedded in some amphibole grains. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish green, Z=green. The pleochroic formula suggests that they are hornblende. They are medium to extremely altered to largely of chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide.

Opaque minerals are irregular outlines (averaged size 1.0 mm across). Their rims are mostly enclosed by titanite that may result from reaction rim.

Sample Number MS65B5

Rock name Microdiorite

Lithology

This rock sample has green color and minor white color. The green color is mafic minerals and the white color is felsic minerals. Weathering surfaces have yellowish brown. It is medium grained texture.

Thin section description

The rock sample is fine-medium grained, seriate texture. It consists largely of amphibole and plagioclase and minor opaque minerals and quartz. Secondary patches largely of titanite/leucoxene, chlorite, with subordinate epidote, are present in the rock. Tiny veins (sizes up to 0.2 mm across) infilled with epidote, chlorite/pumpellyite, calcite are locally present in this sample.

Amphibole has subhedral-anhedral (averaged sizes 1.0 mm across), prismatic and equant. It may form corroded outlines, with sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brown, Z=greenish brown. The pleochroic formula suggests that they are hornblende. They are slightly altered to largely of chlorite/serpentine, with subordinate titanite/leucoxene, Fe-Ti oxide.

Plagioclase is anhedral-subhedral outline (averaged size 0.8 mm across), corroded outlines. It shows feldspar texture. It is highly replaced by largely of sericite, titanite/leucoxene, with subordinate chlorite, epidote. Inclusion of apatite is present in plagioclase.

Quartz is anhedral (averaged size 1.0 mm across) and corroded outline, has non-undulatory extinction.

Opaque minerals are anhedral (averaged size 0.5 mm across) and irregular outlines.

Sample Number MS68B5

Rock name Microdiorite

Lithology

This rock sample has largely of green color and minor white color. The green color is mafic minerals and the white color is felsic minerals, with lath shapes. Weathering surfaces have yellowish brown. It is medium grained texture.

Thin section description

The rock is fine-medium grained texture. It is composed mainly of amphibole and plagioclase and small amounts of opaque minerals and quartz. Secondary patches of titanite/leucoxene, chlorite, epidote, are present in the rock. Tiny veins (sizes up to 0.2 mm across) infilled with epidote, chlorite/pumpellyite, calcite are locally present in this sample.

Amphibole has subhedral-anhedral (averaged sizes 1.0 mm across) and may form corroded outlines, with sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brown, Z=greenish brown. The pleochroic formula suggests that they are hornblende. They are slightly altered to largely of chlorite/serpentine, with subordinate titanite/leucoxene.

Plagioclase is anhedral outline (averaged size 1.0 mm across), corroded outlines and sieve texture. It shows felted plagioclase. It is highly replaced by largely of sericite, titanite/leucoxene, with subordinate chlorite, epidote. Inclusion of apatite is present in plagioclase.

Quartz is anhedral (averaged size 1.0 mm across) and corrode outline, has non-undulatory extinction.

Opaque minerals are anhedral (averaged size 1.0 mm across) and irregular outlines.

Sample Number MS5B6(13)

Rock name Diorite

Lithology

The rock sample has green color, with brownish yellow weathering surfaces. It is phaneritic and coarse texture.

Thin section description

This rock is coarse grained, seriate texture. It comprises mainly of amphibole and small amounts of titanite and plagioclase. Secondary patches of epidote, chlorite, titanite and tiny veins (up to 0.2 mm across) of epidote, chlorite are locally present in the rock sample.

Amphibole is euhedral-anhedral outline, (averaged size 6.0 mm across). It may form corrode outline and sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish green, Z= green. The pleochroic formula suggests that they are Hornblende .They are medium altered to largely of titanlite/leucoxene, chlorite, with subordinate Fe-Ti oxide.

Plagioclase is anhedral outline, with averaged size 1.0 mm across. It is highly replaced by largely of sericite, titanite/leucoxene and minor, epidote.

Titanite is euhedral-subhedral outline, with grain sizes up to 1.0 mm across. It may form aggregates.

Sample Number MS5B6(14)

Rock name Diorite

Lithology

The non-foliated rock sample has medium grained, and is made up of green and white minerals. Its weathering surfaces have brownish yellow color. The rock is made up of dark green and white minerals. Dark green minerals are mafic minerals and white minerals are feldspars.

Thin section description

This rock sample is medium grained, seriate texture. It is made up mainly of amphibole, plagioclase and small amounts of opaque minerals, quartz and titanite. Secondary patches of epidote, chlorite, titanite and tiny veins (up to 0.25 mm across) of chlorite, epidote are present in the rock sample.

Amphibole is euhedral-anhedral outline. It is medium grain (averaged size 2.0 mm across), may form skeletal shape and sieve texture. Amphibole has a pleochroic formula as follows: X=yellow, Y=brownish yellow, Z=brownish green. The pleochroic formula suggests that they are hornblende. They are medium altered to largely of chlorite, titanite/leucoxene, Fe-Ti oxide.

Plagioclase is subhedral outline and feldt plagioclase (averaged size 1.0 mm across). It is medium-highly replaced by largely of sericite, epidote, titanite/leucoxene and minor carbonate, clay.

Quartz is anhedral outline (averaged size 0.5 mm across). It shows interstitial texture to amphibole.

Titanite is anhedral (averaged size 0.5 mm across) and it may commonly form aggregates.

Group II Rocks

Sample Number MC69.1B1

Rock name Basalt

Lithology

The rock sample has mainly of green minerals, and minor white color distributed throughout the sample. Weathering surfaces is brownish yellow. It is fine-grained texture.

Thin Section Description

This rock sample is fine-grained, ophitic/subophitic texture. Its constituents are plagioclase and clinopyroxene, minor opaque minerals, and very small amount of apatite, epidote. Secondary patch of aggregated titanite, chlorite is commonly present in the rock.

Plagioclase has euhedral outlines and lath shapes (averaged size 0.4 mm across). It shows felted plagioclase and some areas shows intersertal texture to chlorite. It is unaltered- slightly altered to titanite and sericite.

Clinopyroxene is brown color, euhedral to subhedral outlines (averaged size 0.5 mm across). It has prismatic and subequant shape. It shows ophitic/subophitic to plagioclase laths. A small amount of them are intergranular to plagioclase laths. The grains are highly altered to largely of chlorite, with subordinate titanite.

Opaque minerals have anhedral and irregular outlines (averaged size 0.2 mm across).

Sample Number MC17.2B2
Rock name Microdiorite/Microgabbro

Lithology

The rock sample has dark gray and white, with brown weathering surfaces. It is fine grained texture.

Thin section description

This rock sample has fine-medium grained, seriate texture. Its constituents are largely of plagioclase, clinopyroxene and minor quartz, orthopyroxene, opaque minerals and olivine, brown amphibole. Tiny veins (up to 0.2 mm across) of chlorite are locally present in the sample. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals.

Plagioclase crystals have two grain sizes. First, plagioclase is euhedral outline and lath shape (averaged size 6.0 mm across). Second, plagioclase is subhedral and equant (averaged size 1.0 mm across). The coarser grain sizes enclosed by finer grain sizes of plagioclase and clinopyroxene are present in the sample. It is unaltered to very slightly altered to titanite/leucosene, chlorite/pumpellyite, sericite, clay. Inclusion of apatite is present some grains.

Clinopyroxene is colorless to pale pink. It has two grain sizes. First, clinopyroxene is anhedral outline and show twin and sieve texture (averaged size 5.0 mm across). Second, clinopyroxene is subhedral outline (averaged size 1.0 mm across). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is unaltered to very slightly altered.

Orthopyroxene is prismatic and subequant shape (averaged grain 2.0 mm. across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine. Orthopyroxene is slightly replaced by chlorite.

Olivine is brown, anhedral outline (averaged size 2.0 mm across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine, iddingsite.

Quartz is anhedral outline (averaged size 1.0 mm across). It has non-undulatory extinction.

Brown amphibole is sieve texture and plagioclase, clinopyroxene, quartz, opaque minerals embedded in brown amphibole. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are rounded outline, skeletal shape (averaged size 1.0 mm. across).

Sample Number MC18B2

Rock name Gabbro

Lithology

This non-foliated, non-porphyritic sample is dark green, with yellow to reddish brown weathering surfaces. It has a medium-grained texture and a very small amount of fractures in the rock sample.

Thin section description

This rock sample has medium grained, seriate texture. It is made up largely of plagioclase, clinopyroxene and minor orthopyroxene, opaque minerals, olivine and brown amphibole. Tiny veins (up to 0.2 mm across) of chlorite/serpentine are locally present in the sample. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals.

Plagioclase is subhedral outline (averaged size 8.0 mm across), with An-content in a range of 65-75 via optical method (Michael-Levy method). It is unaltered to very slightly altered. Inclusion of apatite is present some grains.

Clinopyroxene is colorless to pale pink and anhedral (averaged size 6.0 mm across). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is unaltered to very slightly altered. Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine.

Orthopyroxene is colorless to pale pink (averaged grain 6.0 mm. across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine. Orthopyroxene is slightly replaced by chlorite.

Olivine is brown color, anhedral outline (averaged size 5.0 mm across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine, iddingsite.

Brown amphibole is sieve texture and plagioclase, clinopyroxene, quartz, opaque minerals enclosed by brown amphibole are present in the sample. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are rounded outline, skeletal shape (averaged size 1.0 mm. across).

Sample Number MC37B3(B)

Rock name Microdiorite/Microgabbro

Lithology

This non-foliated, non-porphyritic sample is dark green, and has pyrite. Weathering surfaces are yellow to reddish brown color. It has a fine grained texture. Tiny white veins (up to 1.0 mm across) are present in the rock.

Thin section description

This rock sample has fine-medium grained, seriate texture. It consists mainly of plagioclase, amphibole and minor quartz, opaque minerals. Secondary patches of chlorite, titanite/leucoxene, epidote are present in the sample. Tiny veins (up to 1.0 mm across) of chlorite/serpentine, epidote are locally present in the sample.

Plagioclase crystals have two grain sizes, with An-content in a range of 60-75 via optical method (Michael-Levy method). First, plagioclase is euhedral outline and lath shape (size up to 5.0 mm across). Second, plagioclase is anhedral and subequant (averaged size 1.5 mm across). It is unaltered to very slightly altered to titanite/leucoxene, chlorite/pumpellyite, sericite, clay. Inclusion of apatite is present some grains.

Amphibole (averaged size 2.0 mm across) is subhedral-anhedral outline, short prismatic and subequant. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=green, Z=deep green. The pleochroic formula implies that it is hornblende. It is medium to altered to chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide. Inclusion of apatite is present some grains.

Quartz is anhedral outline (averaged size 2.0 mm across). It has non-undulatory extinction.

Opaque minerals are anhedral outline (averaged size 1.0 mm. across).

Sample Number MC37B3(D)

Rock name Diorite

Lithology

This non-foliated, non-porphyritic sample is dark green and violet distributed throughout the rock, with yellow to reddish brown weathering surfaces. It has a medium-grained texture.

Thin section description

This rock sample has medium-coarse grained, seriate texture. It is made up largely of plagioclase, amphibole and minor opaque minerals. Secondary patches of chlorite, titanite/leucoxene, epidote are present in the sample.

Felted plagioclase grains have two grain sizes, with An-content in a range of 65-70 via optical method (Michael-Levy method). First, plagioclase is euhedral outline averaged size 8.0 mm across). Second, plagioclase is subhedral outline (averaged size 3.0 mm across). It is slightly to moderately altered to titanite/leucoxene, chlorite/pumpellyite, sericite, clay. Inclusion of apatite is present some grains.

Amphibole (averaged size 4.0 mm across) is subhedral-anhedral outline, short prismatic and subequant. It is very highly altered to chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide.

Quartz is anhedral outline (averaged size 3.0 mm across). It has non-undulatory extinction.

Opaque minerals are anhedral outline (averaged size 1.0 mm. across).

Sample Number MC39B3

Rock name Diorite

Lithology

This non-foliated, non-porphyritic sample is dark gray, with yellow to reddish brown weathering surfaces. It has a medium-grained texture.

Thin section description

This rock sample has medium grained, equigranular texture. It consists mainly of plagioclase, green amphibole and minor quartz, opaque minerals. Tiny veins (up to 0.4 mm across) of chlorite/serpentine, quartz are locally present in the sample.

Plagioclase is subhedral outline (averaged size 8.0 mm across), with An-content in a range of 65-75 via optical method (Michael-Levy method). It shows trachytic texture to partly pilotaxitic texture. It is very slightly altered to sericite. Inclusion of apatite is present some grains.

Green amphibole (averaged size 6.0 mm across) is subhedral-anhedral outline, short prismatic and subequant. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=green, Z=deep green. The pleochroic formula implies that it is hornblende. It is medium to altered to chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide and some grains have brown minerals enclosed them.

Quartz is anhedral outline (averaged size 3.0 mm across). It has non-undulatory extinction.

Opaque minerals are anhedral outline (averaged size 2.0 mm. across).

Sample Number MC40B3
Rock name Andesite/Basalt

Lithology

The sample is very fine grained texture. It has dark gray color, with brownish yellow weathering surfaces.

Thin Section Description

This rock sample is very fine-grained, may form intergranular texture. The sample is composed mainly of plagioclase, amphibole and minor opaque minerals and quartz. Secondary path of chlorite is commonly present in the sample.

Plagioclase laths have euhedral outlines. (averaged size 0.4 mm across). It has An-content 70 approximately via optical method (Michael-Levy method). The plagioclase grains show lath shape and felty texture. It is mostly unaltered. Also present is inclusion of apatite in some plagioclase crystals.

Amphibole is euhedral-anhedral outline (averaged size 0.6 mm across). It may form intergranular texture to plagioclase laths. Amphibole has a pleochroic formula as follows: X=yellow, Y=yellowish green, Z=green. The pleochroic formula suggests that they are Hornblende. They are medium altered to largely of chlorite, titanite/leucoxene, Fe-Ti oxide.

Opaque minerals are euhedral to subhedral outlines and may form irregular outlines (averaged sizes 0.4 mm across).

Sample Number MC20B4

Rock name Gabbro

Lithology

This non-foliated, non-porphyritic sample has dark green and white color, with yellow to reddish brown weathering surfaces. It has a coarse-grained texture. Tiny veins (size up to 1.0 mm across) are present in the sample.

Thin section description

The rock sample is coarse grained, seriate texture. It is composed of largely of plagioclase, clinopyroxene and small amount of opaque minerals and amphibole.

Plagioclase is subhedral-anhedral outline (averaged size 10.0 mm. across), with An-content in a range of 70-75 via optical method (Michael-Levy method). It is unaltered moderately altered to sericite, titanite/leucoxene, chlorite. Also, inclusions of clinopyroxene, apatite are present in some plagioclase grains.

Clinopyroxene is pale pink, show anhedral outline (averaged size 8.0 mm. across). It is medium replaced by brown amphibole, chlorite, titanite/leucoxene.

Green amphibole (averaged size 3.0 mm across) is subhedral-anhedral outline. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish yellow, Z=deep green. The pleochroic formula implies that it is hornblende. It is medium to altered to chlorite/serpentine.

Opaque minerals have anhedral outline and irregular shape and average size 4.0 mm.

Sample Number MC64B4

Rock name Gabbro

Lithology

This non-foliated, non-porphyritic sample is dark green, with yellow to reddish brown weathering surfaces. It has a medium-grained texture.

Thin section description

This rock sample has medium grained, seriate texture. It consists mainly of plagioclase and small amounts of clinopyroxene, green amphibole and minor opaque minerals, brown amphibole. Tiny veins (up to 0.4 mm across) of chlorite/serpentine, titanite/leucoxene are locally present in the sample.

Plagioclase is subhedral outline (averaged size 2.0 mm across), with An-content in a range of 60-75 via optical method (Michael-Levy method). It shows trachytic texture to partly pilotaxitic texture. It is slightly altered to sericite, chlorite. Inclusion of apatite is present some grains.

Clinopyroxene is colorless to pale pink and anhedral (averaged size 2.0 mm across). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is slightly altered to brown amphibole, chlorite. Fractures are commonly present in the crystals including chlorite/serpentine.

Unidentified mafic minerals are anhedral outline (averaged size 1.2 mm across). It is completely replaced by chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide. Fractures are commonly present in the crystals including chlorite/serpentine, iddingsite.

Green amphibole (averaged size 3.0 mm across) is subhedral-anhedral outline, short prismatic and subequant. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish yellow, Z=deep green. The pleochroic formula implies that it is hornblende. It is medium to altered to chlorite/serpentine, titanite/leucoxene, Fe-Ti. It is commonly cut across by tiny vein.

Brown amphibole is sieve texture. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are anhedral outline (averaged size 1.0 mm. across).

Sample Number MC64.3B4

Rock name Gabbro

Lithology

The rock sample has dark green and white, with brown weathering surfaces. It is medium grained texture.

Thin section description

This rock sample has medium grained, seriate texture. It is made up mainly of clinopyroxene, plagioclase, unidentified mafic minerals and minor opaque minerals and brown amphibole. Tiny veins (up to 0.2 mm across) of chlorite, titanite/leucoxene are locally present in the sample.

Clinopyroxene is colorless to pale pink. It show anhedral outline (averaged size 2.0 mm across) and herring bone texture. Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is slightly altered to brown amphibole, titanite/leucoxene, chlorite. Fractures are commonly present in the crystals including chlorite/serpentine.

Plagioclase is euhedral outline and lath shape (averaged size 1.5.0 mm across), with An-content in a range of 65-70 via optical method (Michael-Levy method). It shows trachytic texture. It is moderately altered to titanite/leucoxene, chlorite/pumpellyite, sericite, clay. Inclusion of apatite is present some grains.

Unidentified mafic minerals are anhedral outline (averaged size 1.5 mm across). It is completely replaced by chlorite/serpentine, titanite/leucoxene, Fe-Ti oxide. Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine, iddingsite.

Brown amphibole is sieve texture. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are rounded outline, skeletal shape (averaged size 1.4 mm. across).

Sample Number MC25B5

Rock name Microgabbro

Lithology

This non-foliated, non-porphyritic sample is dark green to brownish gray, with yellow to reddish brown weathering surfaces. It has a medium-grained texture and a very small amount of fractures in the rock sample.

Thin section description

This rock sample has fine-grained, equigranular texture. It is made up mainly of plagioclase, clinopyroxene, olivine and minor opaque minerals, orthopyroxene, brown amphibole.

Plagioclase crystals have two grain sizes. First, plagioclase is euhedral outline and lath shape (size up to 3.0 mm across). Second, plagioclase is equant (averaged size 1.0 mm across). The coarser grain sizes enclosed by finer grain sizes of plagioclase and clinopyroxene are present in the sample. It is unaltered to very slightly altered to titanite/leucoxene, chlorite/pumpellyite, sericite, clay. Inclusion of apatite is present some grains.

Clinopyroxene is colorless to pale pink. It has two grain sizes. First, clinopyroxene is anhedral outline (averaged size 6.0 mm across). Second, clinopyroxene is subhedral outline (averaged size 1.0 mm across). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is unaltered to very slightly altered.

Orthopyroxene is anhedral outline (averaged grain 0.2 mm. across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine.

Orthopyroxene is slightly replaced by chlorite, while some grains (grain sizes up to 0.3 mm across) are highly altered to titanite/leucoxene, Fe-oxide.

Brown amphibole is sieve texture. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are rounded outline, skeleton shape (averaged size 0.2 mm. across).

Sample Number MC44.2B8

Rock name Microgabbro

Lithology

This non-foliated, non-porphyrific sample is dark gray, with yellow to reddish brown weathering surfaces. It has a fine-grained texture.

Thin section description

This rock sample has fine-grained, equigranular texture. It consists largely of plagioclase, clinopyroxene, olivine and minor orthopyroxene, brown amphibole and opaque minerals. Tiny veins (size up to 0.2 mm across) of chlorite, calcite are locally present in the sample.

Plagioclase has two grain sizes. First, plagioclase is euhedral outline and lath shape (size up to 4.0 mm across). Second, plagioclase is equant shape and show felted plagioclase (averaged size 1.0 mm across). The coarser grain sizes enclosed by finer grain sizes of plagioclase and clinopyroxene are present in the sample. It is unaltered to very slightly altered to sericite. Inclusions of pyroxene, quartz, apatite are present some grains.

Clinopyroxene is anhedral outline (averaged size 1.0 mm across). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is slightly altered to brown amphibole.

Olivine is colorless to pale pink and anhedral outline (averaged size 2.0 mm across). It has commonly corrode outline and sieve texture. Pleochroism is green to

brown. It has many fractures and moderately replaced by iddingsite, chlorite/serpentine, calcite.

Orthopyroxene is anhedral outline (averaged grain 1.0 mm. across). Orthopyroxene is slightly replaced by chlorite.

Brown amphibole is sieve texture. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are irregular outline, skeletal shape (averaged size 0.6 mm. across).

Sample Number MC45B8

Rock name Microgabbro

Lithology

This non-foliated, non-porphyrific sample is dark gray and minor white color. The weathering surfaces are yellow to reddish brown color. It has a medium-grained texture.

Thin section description

This rock sample has fine-medium grained size. It includes mainly of plagioclase, clinopyroxene, orthopyroxene and minor brown amphibole, quartz and opaque minerals. Tiny veins (size up to 0.2 mm across) of chlorite are locally present in the sample.

Plagioclase is trachyted, with An-content in a range of 65-75 via optical method (Michael-Levy method). Plagioclase has two grain sizes. First, plagioclase is euhedral outline (size up to 6.0 mm across). Second, plagioclase is lath and equant shape (averaged size 1.0 mm across). The coarser grain sizes enclosed by finer grain sizes of plagioclase and clinopyroxene are present in the sample. The coarse grains are slightly altered to titanite/leucoxene, chlorite, sericite, while the fine grains are unaltered. Inclusions of pyroxene, quartz, apatite are present some grains.

Clinopyroxene is anhedral outline (averaged grain 2.0 mm. across). Some grains show herring bone texture and character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It has many fractures including chlorite/serpentine and inclusion of opaque minerals in this sample.

Orthopyroxene is anhedral outline (averaged grain 2.0 mm. across). Orthopyroxene is slightly replaced by chlorite.

Olivine is colorless to pale pink and anhedral outline (averaged size 2.0 mm across). It has commonly corrode outline and sieve texture. It has many fractures and moderately replaced by iddingsite, chlorite/serpentine, calcite. Pleochroism green to brown.

Brown amphibole is sieve texture. The amphibole crystals have a pleochroic formula as follows: X=yellow, Y=greenish brown, Z=brown. The pleochroic formula implies that it is hornblende.

Opaque minerals are rounded outline, skeleton shape (averaged size 0.6 mm. across). It shows symplectitic intergrowth with unidentified mafic minerals. Some grains are embedded in clinopyroxene.

Sample Number MC47B8

Rock name Gabbro

Lithology

This non-foliated, non-porphyrific sample is dark gray to brownish gray, with yellow to reddish brown weathering surfaces. It has a medium-grained texture and a very small amount of fractures in the rock sample.

Thin section description

This rock sample has medium-grained size. It is made up mainly of plagioclase, clinopyroxene and minor opaque minerals, orthopyroxene. Grain size of plagioclase is mostly equigranular, while its pyroxene is seriate. Secondary patch of Fe-sulfide is present in this rock sample. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals resulting from reaction rim.

Plagioclase is subhedral-anhedral outline (averaged grain 2.0 mm. across), with An-content in a range of 65-75 via optical method (Michael-Levy method). It is unaltered to slightly altered to sericite. Some grains have inclusion of clinopyroxene and opaque minerals.

Clinopyroxene is colorless pale pink, anhedral outline (averaged grain 0.4 mm. across). Some grains show herring bone texture, twin and sieve texture. Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It has many fractures including chlorite/serpentine and inclusion of opaque minerals in this sample.

Orthopyroxene is anhedral outline (averaged grain 0.2 mm. across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine. Orthopyroxene is slightly replaced by chlorite, while some grains (grain sizes up to 0.3 mm across) are highly altered to titanite/leucoxene, Fe-oxide.

Opaque minerals are rounded outline, skeleton shape (averaged size 0.2 mm. across). It shows symplectitic intergrowth with unidentified mafic minerals. Some grains are embedded in clinopyroxene.

Sample Number MC48B8

Rock name Gabbro

Lithology

This non-porphyritic, medium-grained rock has a dark gray color. Weathering surfaces have a yellow to reddish brown color. It has a very small amount of fractures in the rock.

Thin section description

This rock sample is medium-grained, seriate texture. It is mainly of plagioclase, clinopyroxene, with a small amount of orthopyroxene and opaque minerals. Secondary patches of chlorite, green amphibole are present in small amount. Tiny vein (less than 0.5 mm thick) of epidote, chlorite are locally present in a small amount. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals resulting from reaction rim.

Plagioclase is subhedral-anhedral outline (averaged size 4.0 mm. across), with An-content in a range of 68-74 via optical method (Michael-Levy method). Plagioclase grains form mostly parallel or same direction. Some plagioclase grains show corroded outlines, embayment, and have inclusion of clinopyroxene in some grains. It is very slightly replaced by a small amount of titanite/leucoxene.

Clinopyroxene is pale pink, anhedral outline (averaged size 2.0 mm. across). It forms partly in space of trachytic plagioclase. Some grains show herring bone and have inclusions of opaque minerals in some cases. Clinopyroxene has size up to 4.0 mm which are highly to extremely altered to green amphibole, chlorite, while the finer clinopyroxene is very slightly altered. Some grains have fractures, alteration products along fractures are composed of green amphibole, epidote and serpentine.

Orthopyroxene is anhedral outline (averaged 2.0 size mm). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. Some grains have small amount of fractures that contain green amphibole, epidote and serpentine.

Opaque minerals have anhedral outline and irregular shape and average size 0.1 mm.

Sample Number MC53B8

Rock name Basalt

Lithology

The rock sample is non-foliated, and has a graying black color, with yellowish brown weathering surfaces. It shows very fine grains. Tiny white vein (less than 1mm thick) is present in small amount.

Thin Section Description

This rock sample is fine-grained, ophitic/subophitic texture. It comprises plagioclase and clinopyroxene, with small amount of opaque minerals and unidentified mafic minerals, and very small amount of apatite. Secondary patch of chlorite are commonly present in the rock.

Plagioclase has euhedral outlines and lath shapes (averaged size 0.2 mm across). It has An-content 70 approximately via optical method (Michael-Levy method). It is mostly unaltered. Also present are inclusion of clinopyroxene grains in some plagioclase crystals.

Clinopyroxene is colorless to pale pink, subhedral to anhedral outlines (averaged size 0.5 mm across). It is ophitic/subohitic to plagioclase laths. A small amount of them are intergranular to plagioclase laths. The grains are slightly altered to unaltered in some cases.

Unidentified mafic minerals are euhedral outline, with averaged size 1.0 mm across. It is totally replaced by chlorite/serpentine.

Opaque minerals are euhedral to subhedral outlines, and irregular outlines (averaged size 1.0 mm across).

Sample Number MC56B8

Rock name Gabbro

Lithology

This non-porphyritic, medium-grained rock has a dark gray color. Weathering surfaces have a yellow to reddish brown color. It has a very small amount of fractures, with white veins (less than 1 mm thick) of quartz are present in the rock.

Thin section description

This rock sample has medium-grained texture. It is made up largely of plagioclase, clinopyroxene and minor opaque minerals, orthopyroxene. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals resulting from reaction rim.

Plagioclase is subhedral outline (averaged grain 4.0 mm. across), with An-content in a range of 65-70 via optical method (Michael-Levy method). It is unaltered to slightly altered to sericite. Some grains have inclusion of clinopyroxene and opaque minerals.

Clinopyroxene is colorless pale pink, prismatic shape (averaged grain 4.0 mm. across). Some grains show herring bone texture, twin and sieve texture. Some crystals

show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is unaltered to very slightly altered.

Orthopyroxene is prismatic shape (averaged grain 0.2 mm. across). Fractures are commonly present in the orthopyroxene crystals including chlorite/serpentine. Orthopyroxene is slightly replaced by chlorite.

Opaque minerals are rounded outline, skeleton shape (averaged size 1.0 mm. across).

Sample Number MC60B8

Rock name Gabbro

Lithology

This non-foliated, non-porphyrific sample is dark gray to brownish gray, with yellow to reddish brown weathering surfaces. It has a medium-grained texture.

Thin section description

The rock sample is medium-coarse grained, seriate texture. It is composed of largely of plagioclase, clinopyroxene and small amount of opaque minerals and orthopyroxene. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals resulting from reaction rim.

Plagioclase is subhedral outline (averaged size 4.0 mm. across), with An-content in a range of 70-80 via optical method (Michael-Levy method). It is unaltered to very slightly altered. Also, inclusions of clinopyroxene, apatite are present in some plagioclase grains.

Clinopyroxene is pale pink, show corroded outline (averaged size 4.0 mm. across). It has inclusions of plagioclase, apatite in some cases. It is very slightly replaced by a small amount of chlorite, titanite/leucosene.

Orthopyroxene is anhedral outline (averaged 1.0 size mm). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host.

Opaque minerals have anhedral outline and irregular shape and average size 2.0 mm.

Sample Number MC63B8

Rock name Gabbro

Lithology

This rock sample is non-foliated, non-porphyritic texture. It has dark gray to brownish gray, with yellow to reddish brown weathering surfaces. It exhibits a medium-grained texture.

Thin section description

The rock sample is medium grained texture. It is made up largely of plagioclase, clinopyroxene and minor opaque minerals and orthopyroxene. Some plagioclase, pyroxene and opaque minerals are partly enclosed by yellow colored minerals resulting from reaction rim.

Plagioclase is subhedral outline (averaged size 5.0 mm. across), with An-content in a range of 68-75 via optical method (Michael-Levy method). It is unaltered to very slightly altered. Also, inclusions of clinopyroxene, apatite are present in some plagioclase grains.

Clinopyroxene is pale pink, show corroded outline (averaged size 4.0 mm. across). Inclusions of plagioclase, apatite are present in some cases. It is very slightly replaced by a small amount of chlorite, titanite/leucoxene.

Orthopyroxene is anhedral outline (averaged 2.0 size mm). Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. It is very slightly replaced by a small amount of chlorite, titanite/leucoxene.

Opaque minerals have anhedral outline and irregular shape and average size 1.5 mm.

CURRICULUM VITAE

Name: Ms. Kanjana Kanhayuwa
Date of Birth: 27 January 1987
Place of Birth: Lamphun, Thailand
Education: 2005 B.Sc. (Geology), Chiang Mai University
Publisher:

Kanhayuwa, K., Phajuy, B., and Wiriyaüksing, P., 2012, Petrography of igneous rocks in the Doi Ngaem area, Muaeng District, Chiang Rai Province, *In* proceedings, The 38th Congress on Science and Technology of Thailand (STT38), Chiang Mai, Thailand, p. 353.

PETROGRAPHY OF IGNEOUS ROCKS IN THE DOI NGAEM AREA, MUAENG DISTRICT, CHIANG RAI PROVINCE

Kanjana Kanhayuwa, Burapha Phajuy, Piyanut Wiriyasuksing,

Department of Geological sciences, Faculty of Science, Chiang Mai University,
Chiang Mai 50200, Thailand

*e-mail: somo27@hotmail.com

Abstract: The studied igneous rocks from the Doi Ngaem area, Tambon Nang Lae and Tha Sut, Muaeng District, Chiang Rai Province were studied for lithology and petrography for classification of rocks. These rocks can be divided into three igneous rock units. Firstly, felsic plutonic rocks include granites that are fine-grained and white to pale grey. They consist of abundant quartz, alkali feldspar and plagioclase and minor amounts of muscovite, biotite, zircon and apatite. This unit is distributed around the northern part of Doi Ngaem. Secondly, mafic plutonic rocks include gabbro, olivine-gabbro, gabbro-norite and norite. They are fine to coarse-grained, grey to blackish grey, massive. They possess magnetic property and show exfoliated fractures in some outcrops. These rocks are composed mainly of plagioclase with minor amounts of clinopyroxene, orthopyroxene and olivine, and small amount of opaque minerals and apatite. This unit is scattered in the central of the study area. Finally, volcanic rocks include rhyolites that are very fine-grained and greenish grey, dark green to greenish black. These rocks are made up mainly of quartz, alkali feldspar and plagioclase and minor amounts of green amphibole, opaque mineral and apatite. They show porphyritic texture that consists principally of alkali feldspar phenocrysts, with subordinate green amphibole phenocrysts. This group is spread in small area around the southwest of the study area.

Introduction: The studied igneous rocks are located in the Doi Ngaem area, Tambon Nang Lae and Tambon Tha Sut, Muaeng District, Chiang Rai Province. Doi Ngaem is a single mountain closed with Mae Fah Luang University. The study area is may be part of Chiang Rai-Chiang Mai volcanic belt that extends southward from the Changning-Menglian suture in China (Haoruo *et al.*, 1995; Yang *et al.*, 1994; Charusiri *et al.*, 1999; Ueno, 1999; Barr *et al.*, 2000; Metcalfe, 2002; Metcalfe *et al.*,

2008; and Fenget *et al.*, 2005). Chiang Rai-Chiang Mai volcanic belt is a scattered mafic igneous zone, distribution from western part of Chiang Rai Province through the northern part of Mae Hong Son Province and the northern part and eastern part of Chiang Mai Province (Ferrari *et al.*, 2008) to the southern part of Lamphun Province (Li District) (Panjasawatwong *et al.*, 1995; Phajuy, 2008).

Braun and Hahn (1976) reported in a geologic map of northern Thailand, scale 1:250,000, (sheet 6 Chiang Rai) that this area is composed of two igneous rock units, including Carboniferous granite (G.h unit) and Carboniferous tonalite, diorite and gabbro (B.h2 unit) (Fig.1a). Granites sit in the northern and southern parts of the study area, while tonalite, diorite and gabbro are distributed in the middle part. The study area is covered by two sedimentary rock units, including (1) Neogene sediments (ng) consist of gravel, sand, conglomerate, sandstone, shale and (2) Quaternary alluvial deposit (q). Triassic sediments (t) present in this area are made up of conglomerate, shale, sandstone, limestone, chert. However, Department of Mineral Resources (2550) reported in a geologic map of Chiang Rai Province, scale 1: 250000 that this area is made up of Permian-Triassic mafic igneous rocks (PTrb) that consist of quartz gabbro, diorite and dike (Fig. 1b). These rocks are overlain by Quaternary terrain deposit (Qt) and Quaternary alluvial deposit (Qa).

The aim of the study is to correctly clarify the igneous rocks in the study area and their distributions. That is a preliminary study for igneous petrogenesis of mafic igneous rocks in the northern region of Thailand.

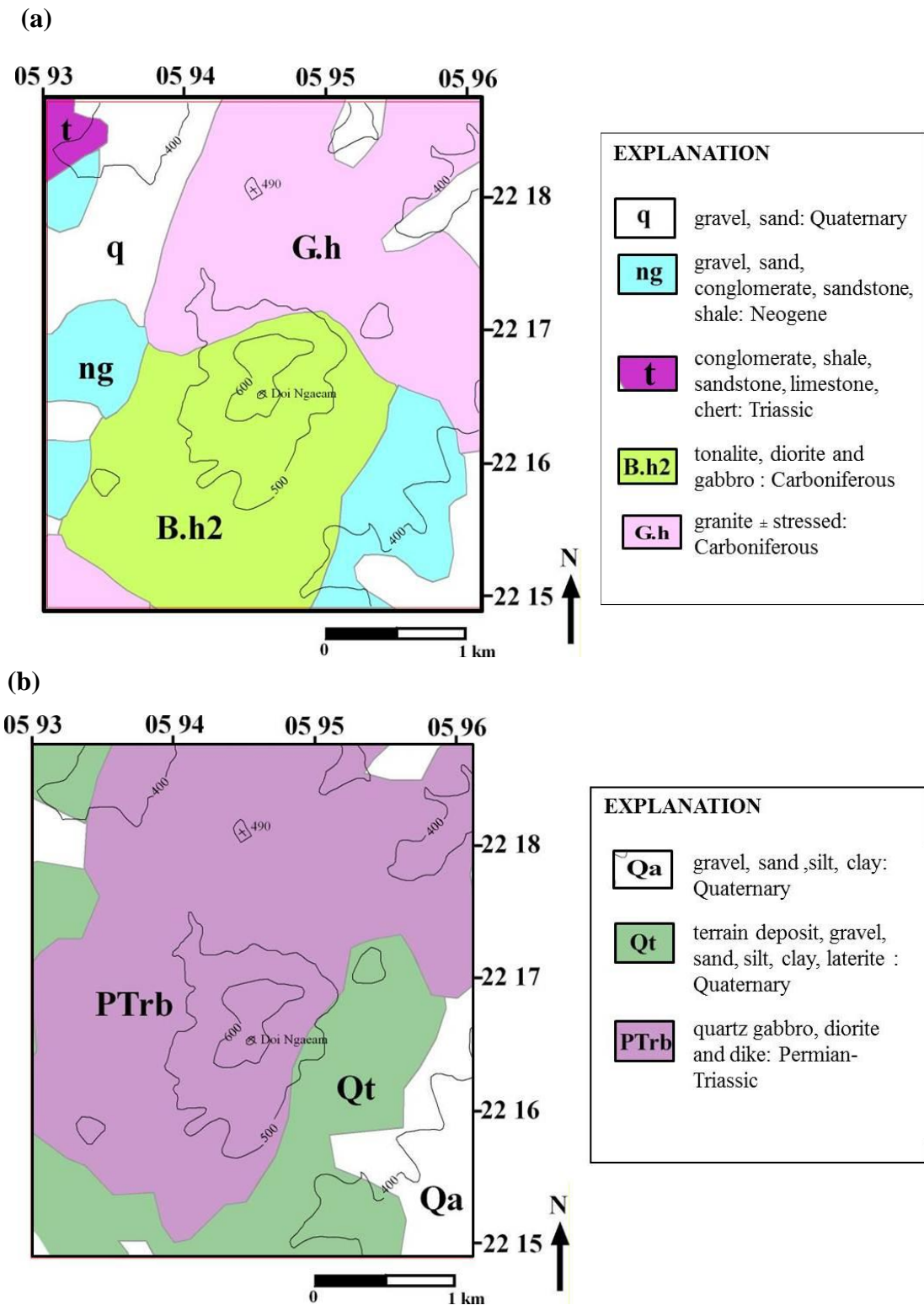


Fig 1. Geologic map of the Doi Ngaem area (a) modified from Braun and Hahn (1976) and (b) modified from Department of Mineral Resources (2550).

Methodology: This study includes field investigation, sample collection, lithology and petrography of igneous rocks. Thirty igneous rock samples were collected from outcrops and in situ float in the Doi Ngaem area along the road, location and field observation were finely recorded. The collected samples were study for lithology and petrography. Petrographic study was done under polarizing microscope for analyzing mineral compositions and texture of rocks. So, rock samples were made for thin section and re-selected under petrography to avoid altered rocks. The selected samples should be composed of primary minerals that crystallize from magma.

Field occurrence, lithology and petrography:

- **Field occurrence and lithology**

The Doi Ngaem is mainly covered by red to reddish brown clay or sand. Lithologically, the study area can be divided into three igneous rock units as follow: (1) felsic plutonic rocks, (2) mafic plutonic rocks and (3) volcanic rocks.

1) Felsic plutonic rocks are white to pale grey with yellow to reddish brown weathering surfaces and mostly have a fine-grained texture. Some samples show foliated texture. The outcrop of these felsic plutonic rocks are scattered around the northern part of Doi Ngaem.

2) Mafic plutonic rocks are dark grey to blackish grey, whereas the weathering surfaces are yellow to reddish brown, and are fine to coarse grained. They are dense and moderately magnetic. Exfoliation can be observed in some outcrops. These mafic plutonic rocks are distributed in the central, especially around a Doi Ngaem hilltop.

3) Volcanic rocks are greenish grey, dark green or greenish black, their weathering surfaces are pale grey. They are very fine-grained and contain many fractures. They are spread in small area around the southwest of the study area.

The contacts among three rock units or sedimentary rocks haven't been found in field investigation due to cover by high weathering. The geologic association of rocks in the study area is shown in figure 2.

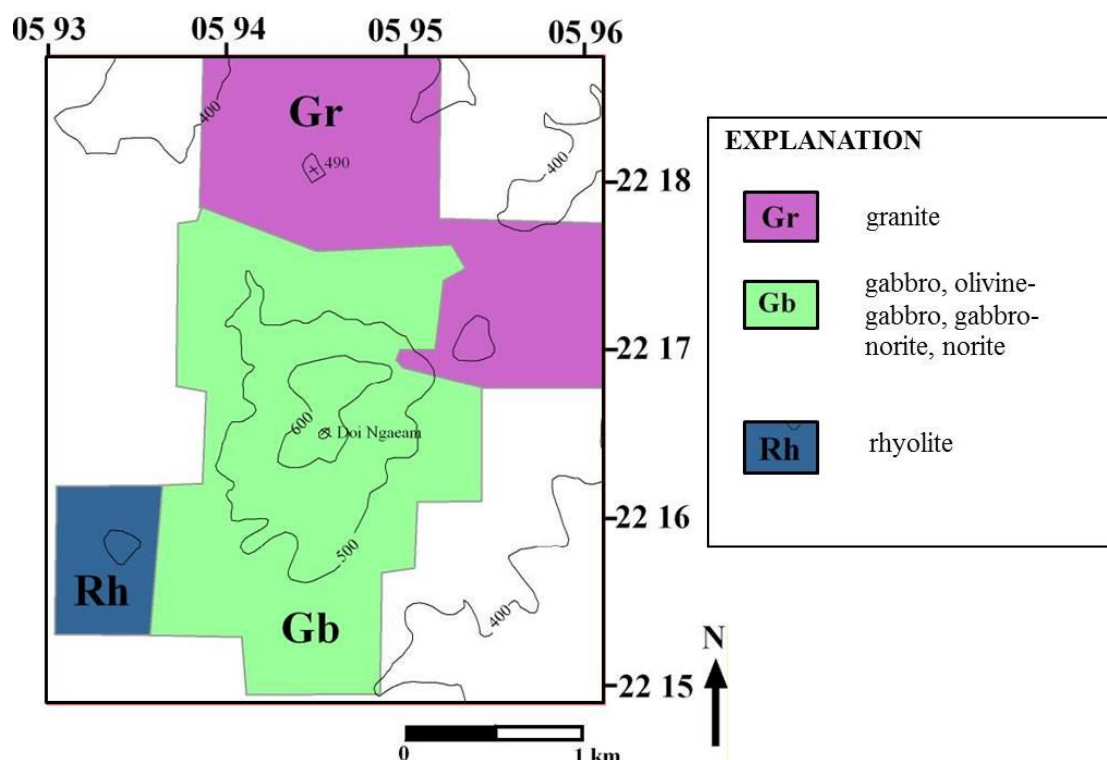


Fig 2. Geological map of the study area showing the distribution of igneous rocks.

• Petrography

Under polarizing microscope, the eighteen least-altered samples can be separated into three igneous rock types as follow: (1) granites, (2) gabbroic rocks and (3) rhyolite.

1) Granites are fine to coarse grained and some samples show equigranular fine-grained similar to aplite texture. These rocks are composed largely of quartz, plagioclase and alkali feldspar and minor amounts of muscovite, biotite, apatite and zircon. Quartz is anhedral, with sizes up to 1.5 mm across. Alkali feldspar shows anhedral outlines, with sizes up to 1.3 mm across. Inclusion, such as biotite, plagioclase and muscovite can be observed in the alkali feldspar crystals. Plagioclase has subhedral to anhedral crystals, with sizes up to 1.4 mm across. It is moderately to highly replaced by sericite and clay minerals. Biotite is subhedral to anhedral, with sizes up to 0.6 mm across. It is slightly altered by chlorite. Muscovite is anhedral and has sizes up to 1.2 mm across.

2) Gabbroic rocks contain plagioclase with An-content 65 approximately via optical method (Michael-Levy method). These rocks are composed of abundant plagioclase, with minor amounts of clinopyroxene, olivine and orthopyroxene and small amount of opaque minerals and apatite. Plagioclase is subhedral crystal, with sizes up to 1.9 mm across. It is slightly replaced by sericite. Clinopyroxene has anhedral outlines, with sizes up to 1.0 mm across and has a pink color to colorless. Some clinopyroxene crystals show herring-bone texture and reaction rim that enclosed by brown amphibole. Olivine is subhedral to anhedral crystals, with sizes up to 1.5 mm across. It is partly enclosed by brown amphibole resulting from reaction rim. They have many fractures and pink color to colorless. Olivine fractures are replaced by green amphibole, epidote and chlorite. Orthopyroxene has anhedral to subhedral outlines, with sizes up to 1.4 mm across. Fractures are commonly present in the orthopyroxene crystals. Some crystals show character of exsolution structure that is made up of lamellae clinopyroxene in orthopyroxene host. Alteration products along fractures are composed of green amphibole, epidote and serpentine. Opaque minerals have anhedral outlines and skeleton shapes, with sizes up to 0.8 mm across. Some grains show reaction rim and symplectic intergrowth with unidentified mafic minerals. The mineral composition in these gabbroic rocks is variable in proportion. So, these gabbroic rocks can be separated into 4 types by the mineral composition; gabbro, olivine-gabbro, gabbro-norite and norite.

3) Rhyolites are composed mainly of quartz and minor amount of alkali feldspar and plagioclase. It shows porphyritic texture that consists of abundant alkali feldspar phenocrysts, with subordinate green amphibole phenocrysts and very fine-grained groundmass. Quartz as groundmass phase is anhedral crystals, with sizes up to 0.3 mm across and show micropoikilitic intergrowth with feldspar laths. Alkali feldspar as phenocryst and groundmass constituents have subhedral to anhedral outlines, phenocrysts have average of sizes up to 0.4 mm across. Plagioclases as groundmass constituents have subhedral to anhedral crystals. They are moderately replaced to scapolite, sericite and clay minerals. Green amphibole phenocrysts show subhedral to anhedral outlines and have grain size average 0.1 mm across. They partly are altered to chlorite. Opaque minerals are anhedral crystals and have skeleton shapes.

Photomicrographs of the study igneous rocks are shown in figure 3.

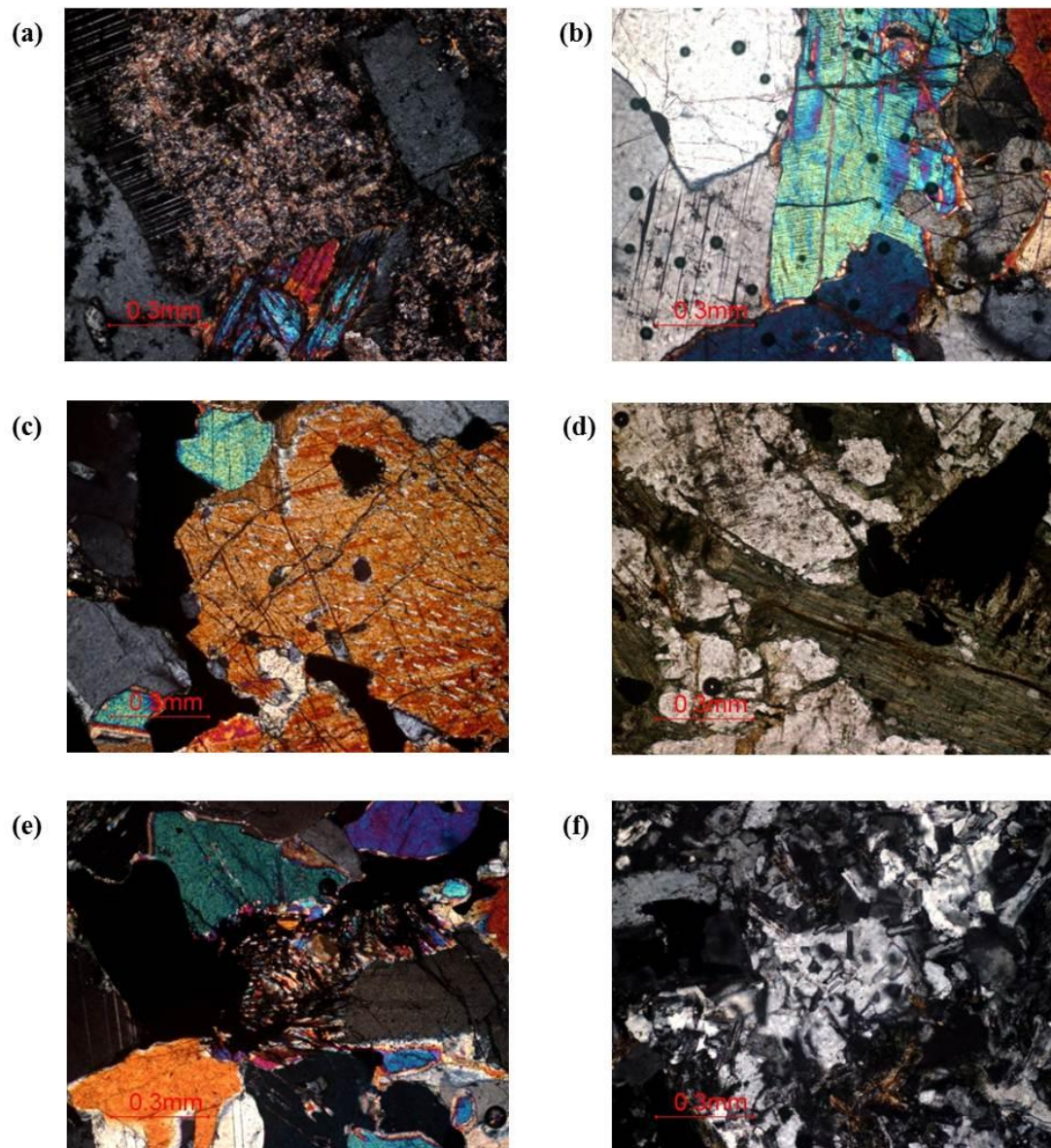


Fig 3. Photomicrographs of the studied igneous rocks illustrate typical rock textures and mineralogy (a) granite: altered plagioclase by sericite (b) gabbro: herring bone texture in clinopyroxene (c) norite: character of exsolution structure that are lamellae clinopyroxene in orthopyroxene (d) gabbro: green amphibole after clinopyroxene (e) gabbro: symplectic intergrowth of opaque minerals and unidentified mafic minerals (f) rhyolite: micropointilitic quartz.

Conclusion: The studied igneous rocks in Doi Ngaem area, Tambon Nang Lae and Tha Sut, Mueang District, Chiang Rai Province can be divided into three igneous rock units: felsic plutonic rocks, mafic plutonic rocks and volcanic rocks. The contact among three units or between sedimentary rocks weren't found in the field survey.

Felsic plutonic rocks are granites that are fine-grained and white to pale grey. Foliation can be observed in some area. The granites consist of abundant quartz, alkali feldspar and plagioclase and minor amounts of muscovite, biotite, apatite and zircon. This unit is distributed in the northern part of the study area.

Mafic plutonic rocks include gabbro, olivine-gabbro, gabbro-norite and norite. They are fine to coarse-grained, grey to blackish grey color and dense. They possess magnetic property and show exfoliated fractures in some outcrop. These rocks are composed mainly of plagioclase, with minor amount of clinopyroxene, orthopyroxene and olivine and small amount of opaque minerals and apatite. This unit is scattered almost all of the study area, around Doi Ngaem to the south of this area.

Volcanic rocks include rhyolites that are very fine-grained and greenish grey, dark green to greenish black. They show a lot of fractures itself. These rocks are made up mainly of quartz, alkali feldspar and plagioclase and minor amount of green amphibole, opaque mineral and apatite. The rocks show porphyritic texture that consists principally of alkali feldspar phenocrysts, with subordinate green amphibole phenocrysts. This group is spread in small area around the southwest of the study area.

References:

1. Barr, S.M., Macdonald, A.S., Dunning, G.R., Ounchanum, P., Yaowanoyothin, W. the Geological Society of London 2000;157:553-563.
2. Braun F, Hahn, C., 1976, Geological map of Thailand 1:250,000, Chiang Rai District, Thailand
3. Charusiri. P., Xu, X., Pan, G., Daorerk, V., Zhuang, Z., Li, X. *In* proceedings, The International Symposium on Shallow Tethys (ST) 5 Chiang Mai, Thailand, Chiang Mai University 1999:242-264.

4. Department of Mineral Resources, 2007, Geological map of Thailand 1:250,000, Chiang Rai District, Thailand.
5. Feng, Q., Chonglakmani, C., Helmcke, D., Ingavat-Helmcke, R, Liu, B. Asian Earth Sciences 2005;24:777-786.
6. Ferrari, O.M., Hochard, C., Stampfli, G.M. Tectonophysics 2008;451:346-365.
7. Haoruo, W., Boulter, C.A., Baojia, K., Stow, D.A.V., Zhongcheng, W. Tectonophysics 1995;242:267-280.
8. Metcalfe, I. Asian Earth Sciences 2002;20:551-566.
9. Metcalfe, I., Sone, M. Comptes Rendus Geoscience 2008;340:166-179.
10. Panjasawatwong, Y., Kanpeng, K., Ruangvatanasirikul, K. Proceedings of the International Conference on Geology, Geotechnology and Mineral Resources of Indochina, KhonKaen, Thailand 1995:225–234.
11. Phajuy, B., Panjasawatwong, Y., Osataporn, P. Asian Earth Sciences 2005;24:765-776.
12. Ueno, K. In Proceedings, The International Symposium on Shallow Tethys (ST) 5, Chiang Mai, Thailand, Chiang Mai University 1999:45-54.
13. Yang, K., Mo, X., Zhu, Q. Southeast Asian Earth sciences 1994;10:245-262.

Keywords: Felsic plutonic rocks, Mafic plutonic rocks, Volcanic rocks, Petrography, Chiang Rai Province