# APPENDIX A

## Petrography of individual studied felsic to mafic volcanic/ hypabyssal rock samples

## Group I Rock

**Group I Rock : Felsic volcanic rock**

**Sample Number: KK-01**
**Location: Khao Kangkaew, Nakhon Sawan Province**
**UTM Grid Reference: 477248**
**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a grayish red color. It shows a highly porphyritic texture, with pinkish white plagioclase phenocrysts, of which sizes are up to 8.0 mm across (largely 2.0 mm across). White veinlets have occasionally been observed.

**Microscopic characters:** The sample is a moderately porphyritic rock. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar, amphibole, and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and plagioclase – amphibole cumulocrysts. The groundmass is glassy, and has experienced low-temperature recrystallization. It shows a trachytic texture and consists largely of plagioclase and quartz, and small amounts of amphibole and biotite. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures are sealed by quartz and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 3.0 mm across, and show anhedral to euhedral outlines and sieve textures. Both phases of plagioclase are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by calcite and quartz.

Potassium feldspar phenocrysts/microphenocrysts have sizes up to 1.0 mm across and largely show subhedral outlines. They are slightly altered to clay minerals.

Amphibole phenocrysts/microphenocrysts have sizes up to 1.6 mm across and show anhedral to euhedral outlines. They are highly altered to chlorite, opaque minerals, titanite/leucoxene, calcite and quartz.

Opaque phenocrysts/microphenocrysts have sizes up to 1.0 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene.

**Sample Number**: **KK-04**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 476267**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, with a grayish red color. It shows a highly porphyritic texture, with pinkish white plagioclase phenocrysts (sizes largely 2.0 mm across), subordinate blackish gray phenocrysts (sizes largely 1.0 mm across). Brown veinlets have occasionally been observed.

**Microscopic characters:** The rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar, amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and plagioclase – amphibole cumulocrysts. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and potassium feldspar, and small amounts of amphibole and biotite. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures are sealed by quartz and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.2 mm across and show subhedral to euhedral outlines. Both phases of plagioclase are slightly altered to sericite, chlorite, and opaque minerals, and moderately replaced by calcite and quartz.

Potassium feldspar phenocrysts/microphenocrysts have sizes up to 0.5 mm across and largely show subhedral outlines. They are slightly altered to clay mineral.

Amphibole phenocrysts/microphenocrysts have sizes up to 1.4 mm across, and show anhedral to euhedral outlines. They are highly altered to chlorite, opaque minerals, titanite/leucoxene, opaque minerals, calcite and quartz.

Opaque microphenocrysts have sizes up to 0.4 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene.

**Sample Number: KK-07**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 476265**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, with a grayish red color. It shows a highly porphyritic texture that is composed largely of pinkish white plagioclase phenocrysts (sizes largely 4.0 mm across), with subordinate blackish gray phenocrysts (sizes largely 0.1 mm) across. Secondary patches of calcite have rarely been observed.

**Microscopic characters:** The fine-grained rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are composed largely of plagioclase, with subordinate potassium feldspar, amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts, and plagioclase – amphibole and plagioclase – opaques cumulocrysts. The groundmass is glassy, and show a trachytic texture. It consists largely of plagioclase laths and potassium

feldspar and quartz. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been rarely detected. Tiny fractures are sealed by sericite and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped with swallow tails. Both phases of plagioclase are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by calcite.

Potassium feldspar microphenocrysts have sizes up to 0.5 mm across and largely show subhedral to euhedral outlines. Groundmass potassium feldspar grains are largely lath-shaped. Potassium feldspar microphenocrysts and groundmass potassium feldspar grains are slightly altered to clay minerals.

Amphibole microphenocrysts have sizes up to 0.5 mm across and show anhedral to subhedral outlines. They are highly to totally altered to chlorite, epidote minerals, opaque minerals and titanite/leucoxene.

Opaques microphenocrysts have sizes up to 0.3 mm across and largely show anhedral to subhedral outlines. They are moderately replaced by titanite/leucoxene.

**Sample Number: KK-08**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 479268**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a grayish red color. It shows a highly porphyritic texture, with pinkish white plagioclase phenocrysts (sizes largely 2.0 mm across) and subordinate blackish gray phenocrysts with sizes largely 0.5 mm across. Brownish white veinlets have occasionally been observed.

**Microscopic characters:** The fine-grained rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are composed largely of plagioclase, with subordinate opaque minerals and potassium feldspar. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and plagioclase – opaque cumulocrysts. The groundmass is glassy, and has experienced low-temperature recrystallization. It shows a felty texture and consists largely of plagioclase and quartz. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures are sealed by quartz, sericite and opaque minerals.



Plagioclase phenocrysts/microphenocrysts have sizes up to 1.2 mm across and show subhedral to euhedral outlines. Both phases of plagioclase are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by calcite.

Potassium feldspar microphenocrysts have sizes up to 1.2 mm across and largely show subhedral to euhedral outlines. Groundmass potassium feldspar grains are largely lath-shaped. Potassium feldspar microphenocrysts are slightly altered to clay minerals.

Opaque microphenocrysts have sizes up to 0.8 mm across and largely show anhedral to euhedral outlines. They are moderately altered to titanite/leucoxene.

**Sample Number: KK-09**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 478256**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, with a brownish gray color. It shows a highly porphyritic texture that consists of pinkish white plagioclase phenocrysts, with sizes up to 4.0 mm across, and subordinate blackish gray phenocrysts, with sizes up to 0.5 mm across. Black veinlets have occasionally been observed.

**Microscopic characters:** The fine-grained rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate amphibole and opaque minerals. They form as isolated crystals, plagioclase glomerocrysts, and plagioclase - orthopyroxene and plagioclase - opaques cumulocrysts. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase, opaque minerals and quartz. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures are sealed by quartz.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.2 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped with swallow tails. Both phases of plagioclase are slightly altered to sericite, chlorite, opaque minerals and slightly replaced by calcite.

Amphibole phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show anhedral to euhedral outlines. They are highly altered to chlorite, epidote minerals, opaque minerals, titanite/leucoxene and sericite.

Opaque microphenocrysts have sizes up to 0.4 mm across. They largely show anhedral to subhedral outlines and are interstitial to plagioclase grains. They are slightly altered to titanite/leucoxene.

**Sample Number: KK-11**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 480258**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a greenish gray color. It shows a slightly porphyritic texture containing white plagioclase phenocrysts, with sizes up to 2.0 mm across. White and black veinlets have occasionally been observed.

**Microscopic characters:** The rock sample has a moderatly porphyritic texture. The phenocrysts/microphenocrysts consist largely of plagioclase, with subordinate amphibole and opaque minerals. These phenocrysts/microphenocrysts may form as isolated crystals and plagioclase glomerocrysts. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz, and a small amount of opaque mineral. Secondary patches of chlorite, titanite/leucoxene, calcite and quartz have been observed in minor amount. Tiny fractures are sealed by quartz.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show subhedral outlines. Plagioclase phenocrysts/microphenocrysts are highly altered to sericite, chlorite, titanite/leucoxene, opaque minerals, calcite and quartz, whereas groundmass plagioclase grains are slightly altered to sericite.

Amphibole microphenocrysts have sizes up to 0.4 mm across and show anhedral to euhedral outlines. They are slightly altered to chlorite, epidote, titanite/leucoxene and opaque minerals.

Opaque microphenocrysts have sizes up to 0.2 mm across and show subhedral to euhedral outlines. They are slightly replaced by titanite/leucoxene.

**Sample Number: KK-12**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 482255**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a greenish gray color. It shows a moderately porphyritic texture, with pinkish white plagioclase phenocrysts (sizes 2.0 mm across) and subordinate blackish gray phenocrysts (sizes largely 0.5 mm across). White and black veinlets have occasionally been observed.

**Microscopic characters:** The rock sample shows a moderatly porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and plagioclase – amphibole cumulocrysts. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz, and a small amount of amphibole. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures are sealed by quartz and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.4 mm across and show subhedral to euhedral outlines. They are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by calcite and quartz.

Amphibole phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show anhedral to euhedral outlines. They are highly altered to sericite, chlorite, opaque minerals, titanite/leucoxene, calcite and quartz.

Opaque phenocrysts/microphenocrysts have sizes up to 1.0 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene and sericite.

**Sample Number: KK-13**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 482255**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample has a brownish gray color. It shows a moderately porphyritic texture, with abundant plagioclase phenocrysts (sizes up to 3.0 mm across) and subordinate blackish gray phenocrysts (sizes up to 0.5 mm across). White veinlets have occasionally been observed.

**Microscopic characters:** The rock sample shows a moderately porphyritic texture. The phenocrysts/microphenocrysts consist largely of plagioclase, with subordinate amphibole and opaque minerals. These phenocrysts/microphenocrysts may form as isolated crystals and as plagioclase glomerocrysts. The groundmass is glassy. It consists largely of plagioclase laths and quartz, with a small amount of opaque minerals. Secondary patches of chlorite, titanite/leucoxene, calcite and quartz have been observed. Tiny fractures are sealed by quartz and calcite.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show anhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are slightly altered to sericite, chlorite, calcite and opaque minerals.

Amphibole phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show anhedral to euhedral outlines. Amphibole phenocrysts/microphenocrysts are highly altered to chlorite, opaque minerals, titanite/leucoxene and calcite.

Opaque minerals show anhedral outlines and have sizes up to 0.4 mm across. They are moderately altered to chlorite and titanite/leucoxene.

**Sample Number: KK-19**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 487221**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Character:** The fine-grained rock sample has a greenish gray color and shows a highly porphyritic texture. It comprises abundant pinkish white plagioclase phenocrysts, with sizes up to 4.0 mm across, and subordinate blackish gray pheocrysts, with sizes up to 0.5 mm across. White veinlets have been partly observed.

**Microscopic characters**: The rock sample shows a highly porphyritic texture. The phenocrysts/microphenocrysts are composed mainly of plagioclase, with subordinate potassium feldspar, quartz, amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase and potassium feldspar glomerocrysts, and plagioclase-opaques, plagioclase-potassium feldspar and plagioclase-amphibole cumulocrysts. The groundmass is glassy, and has undergone high-temperature divitrification. It consists largely of plagioclase laths and spherulites. Groundmass spherulites are patchy and radiated texture with diameter up to 0.05 mm. Secondary patches of chlorite, titanite/leucoxene and epidote minerals have been observed in minor amount.

Plagioclase phenocrysts/microphenocrysts have sizes up to 3.0 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are slightly altered to sericite/clay minerlas, chlorite, opaque minerals, quartz and calcite.

Potassium feldspar microphenocrysts have sizes up to 0.8 mm across, and show subhedral to euhedral and embayed outlines, while groundmass potassium feldspar grains are anhedral to subhedral. They are slightly altered to clay minerals and moderately replaced by calcite and opaque minerals.

Quartz phenocrysts/microphenocrysts have sizes up to 0.5 mm across. They show anhedral to subhedral and embayed outlines.

Amphibole microphenocrysts have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are highly altered to sericite, chlorite, opaque minerals and titanite/leucoxene and replaced by calcite.

Opaque microphenocrysts have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are moderately altered to titanite/leucoxene and epidote minerals.

**Sample Number: KK-21**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 486218**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a brownish gray color. It shows a highly porphyritic texture, with abundant pinkish white plagioclase phenocrysts (sizes up to 5.0 mm across) and subordinate blackish gray phenocrysts (sizes up to 0.5 mm across). Brownish white veinlets have occasionally been observed.

**Microscopic characters**: The rock sample shows a highly porphyritic texture. Their phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar, amphibole, quartz and opaque minerals. The phenocrysts/microphenocrysts form as isolated crystals, plagioclase and quartz glomerocrysts, and amphibole-plagioclase and opaques-plagioclase cumulocrysts. The groundmass is glassy, and has undergone high-temperature divitrification. It consists largely of plagioclase laths and spherulites, and a small amount of zircon. Groundmass spherulites are patchy and radiated, with diameters up to 0.1 mm. Secondary patches of calcite, chlorite, titanite/leucoxene, quartz and epidote minerals have been observed in minor amount.



Plagioclase phenocrysts/microphenocrysts have sizes up to 2.2 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped, and show a swallow-tail feature. They are moderately altered to sericite and chlorite, and slightly replaced by calcite.

Potassium feldspar microphenocrysts have sizes up to 0.2 mm across and show subhedral to euhedral outlines. They are slightly altered to clay minerlas.

Amphibole phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show subhedral to euhedral outlines. Most amphibole grains are completely altered to chlorite, titanite/leucoxene, opaque minerals and calcite.

Quartz phenocrysts/microphenocrysts have sizes up to 1.5 mm across. They show anhedral to euhedral and embayed outlines.

Opaque microphenocrysts have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are moderately altered to titanite/leucoxene and slightly replaced by quartz.

**Sample Number: KK-22**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 480220**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The fine-grained rock sample has a greenish gray color. It shows a highly porphyritic texture, with abundant white plagioclase phenocrysts (sizes up to 4.0 cm across) and subordinate blackish gray phenocrysts (sizes up to 2.0 mm across). White and brown veinlets have been sporadically observed.

**Microscopic characters:** The rock sample displays a highly porphyritic texture. The phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate amphibole and opaque minerals. The phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and amphibole - plagioclase cumulocrysts. The groundmass is glassy. It contains abundant quenched plagioclase laths, quartz and opaque minerals. Secondary patches of calcite, chlorite, quartz, titanite/leucoxene and opaque minerals have been observed. Tiny fractures are abundantly sealed by quartz.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.4 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are moderately altered to common sericite, chlorite, opaque minerals, calcite and titanite/leucoxene, and minor quartz.

Amphibole microphenocrysts have sizes up to 0.6 mm across and show subhedral to euhedral outlines. They are highly altered to common chlorite and titanite/leucoxene, and minor of opaque minerals and quartz.

Opaque microphenocrysts have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are moderately altered to titanite/leucoxene.



**Sample Number**: **KK-23**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 480224**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The fine-grained rock sample has a brownish gray color and shows a moderately porphyritic texture, with abundant pinkish white plagioclase phenocrysts (sizes up to 2.0 mm across) and subordinate blackish gray phenocrysts (sizes up to 0.3 mm across). White veinlets have been rarely observed.

**Microscopic characters**: The rock sample shows a moderately porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar,

quartz, amphibole and opaque minerals. The phenocrysts/microphenocrysts form as isolated crystals. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz. Secondary patches of chlorite, titanite/leucoxene and epidote minerals have been observed in minor amount.

Plagioclase microphenocrysts have sizes up to 0.5 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped, with swallow tails. They are slightly altered to sericite, chlorite, opaque minerals and titanite/leucoxene.

Potassium feldspar microphenocrysts have sizes up to 0.1 mm across and show subhedral outlines. They are slightly altered to clay minerals.

Amphibole microphenocrysts show euhedal to anhedral outlines with sizes up to 0.3 mm across. They are highly altered to chlorite, titanite/leucoxene and opaque minerals.

Opaque microphenocrysts have sizes up to 0.2 mm across. They show euhedral outlines and are slightly altered to titanite/leucoxene.

Quartz microphenocrysts have sizes up to 0.3 mm across. They show anhedral to subhedral outlines.

**Sample Number**: **TK-01**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 598303**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a greenish gray color. It shows a highly porphyritic texture, with plagioclase phenocrysts (sizes up to 1.0 mm across). White veinlets have occasionally been observed.

**Microscopic characters:** The rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar and biotite. The phenocrysts/microphenocrysts form as isolated crystals. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz. Secondary patches of quartz, chlorite, titanite/leucoxene and epidote minerals have been observed.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show subhedral outlines. They are slightly altered to sericite, chlorite, titanite/leucoxene and opaque minerals.

Potassium feldspar microphenocrysts have sizes up to 0.4 mm across and show subhedral outlines. They are slightly altered to clay minerals.

Biotite microphenocrysts show subhedral outlines with sizes up to 0.2 mm across. They are highly altered to chlorite, epidote minerals, titanite/leucoxene and opaque minerals.

**Sample Number**: **TK-03**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 598303**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** This fine-grained rock sample displays a moderately porphyritic texture and has a greenish gray color. The phenocrysts have sizes up to 1.4 mm across and comprise abundant pale green plagioclase and occasional greenish black minerals. Brown and white veinlets have been rarely detected.

**Microscopic characters:** The rock sample shows a moderately porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase with subordinate biotite. The phenocrysts/microphenocrysts form as isolated crystals. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz. Secondary patches of quartz, chlorite, titanite/leucoxene and epidote minerals have been observed.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show subhedral outlines. They are slightly altered to sericite, chlorite, titanite/leucoxene and opaque minerals.

Biotite microphenocrysts show subhedral outlines with sizes up to 0.2 mm across. They are highly altered to chlorite, epidote minerals, titanite/leucoxene and opaque minerals.

**Sample Number TK-04**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 606304**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a greenish gray color. It shows a highly porphyritic texture, with plagioclase phenocrysts of which sizes are up to 1.0 mm across. White veinlets have occasionally been observed.

**Microscopic characters:** The rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar and opaque minerals. The phenocrysts/microphenocrysts form as isolated crystals. The groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz. Secondary patches of chlorite, titanite/leucoxene and epidote minerals have been observed in minor amount. Quartz and chlorite veinlets have been detected.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.2 mm across and show subhedral outlines. Groundmass plagioclase grains are lath-shaped. They are moderately altered to sericite, chlorite, titanite/leucoxene and opaque minerals.

Potassium feldspar microphenocrysts have sizes up to 0.1 mm across and show subhedral outlines. They are slightly altered to clay minerals.

Opaque microphenocrysts have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are moderately altered to titanite/leucoxene.

**Sample Number TK-30**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 554366**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample shows a porphyritic texture and has a greenish gray color. The phenocrysts comprise abundant plagioclase (sizes up to 4.0 mm across), greenish black crystals (sizes up to 1.0 mm across) and quartz (sizes up to 3.0 mm across). Groundmass consists of green and black crystals. Green and white veinlets have been observed.

**Microscopic characters**: The rock sample shows a highly porphyritic texture. Phenocrysts/microphenocrysts consist mainly of plagioclase, with subordinate quartz and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, whereas the groundmass is glassy, and has undergone low-temperature recrystallization. It consists largely of plagioclase and quartz. Secondary patches of calcite, chlorite, titanite/leucoxene, quartz and epidote minerals have been observed in minor amount. Tiny veinlets were sealed by chlorite, calcite and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.2 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains largely display lath-shapes. They are moderately altered to sericite and chlorite, and slightly replaced by calcite.

Quartz phenocrysts/microphenocrysts have sizes up to 3.0 mm across. They show subhedral to euhedral outlines and embayed outlines.

Opaque minerals have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are moderately altered to titanite/leucoxene and slightly replaced by quartz.

**<u>Group I Rock : Mafic volcanic rock</u>**

**Sample Number**: **KK-14**

**Location: Khao Kang Kaew, Nakhon Sawan**

**UTM Grid Reference: 483254**

**Rock Name: Andesite**

**Megascopic Characters:** The fine-grained rock sample shows a highly porphyritic texture and has a greenish gray color. The phenocrysts have sizes largely 2.0 mm across and comprise abundant plagioclase and occasional greenish black crystals, with sizes up to 0.5 mm across. Brown and pale green veinlets have been rarely observed.

**Microscopic characters:** The rock sample is highly porphyritic, and the phenocrysts/microphenocrysts comprise mainly of plagioclase, with subordinate clinopyroxene, amphibole and opaque minerals. These phenocrysts/microphenocrysts occur as isolated crystals, plagioclase glomerocrysts, and as clinopyroxene - plagioclase, clinopyroxene - opaques, clinopyroxene - amphibole, amphibole - opaques, amphibole – plagioclase - opaques and amphibole – plagioclase - clinopyroxene cumulocrysts. The groundmass is holocrystalline, and shows a slightly trachytic texture. It consists largely of plagioclase laths and clinopyroxene, with a small amount of opaque minerals. Secondary patches of chlorite and

titanite/leucoxene have been observed in minor amount. Tiny fractures sealed by quartz, opaque minerals, epidote minerals and chlorite.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.4 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are highly altered to sericite, chlorite and titanite/leucoxene.

Clinopyroxene phenocrysts/microphenocrysts have sizes up to 1.5 mm across and show anhedral to euhedral and corroded outlines. Groundmass clinopyroxene grains are anhedral outlines. Both of clinopyroxene phases are slightly altered to chlorite, epidote minerals, titanite/leucoxene and opaque minerals.

Amphibole microphenocrysts show anhedral to subhedral outlines and have sizes up to 1.0 mm across. Groundmass amphibole grains are anhedral. Amphibole microphenocrysts and groundmass amphibole grains are highly altered to chlorite, epidote minerals and opaque minerals.

Opaque minerals microphenocrysts have sizes up to 0.5 mm across and show anhedral to subhedral outlines. Groundmass opaque minerals are anhedral. Opaque minerals microphenocrysts and groundmass opaque minerals are altered to titanite/leucoxene.

**Sample Number**: **KK-15**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 485251**

**Rock Name: Andesite**

**Megascopic Characters:** The fine-grained rock sample displays a moderately porphyritic texture and has a dark greenish gray color. The phenocrysts have sizes up to 3.5 mm across and comprise abundant plagioclase and occasional greenish black crystals. Brown and pale white veinlets have been observed.

**Microscopic characters:** The sample is moderately porphyritic-textured, containing phenocrysts/microphenocrysts which are made up mainly of plagioclase, with subordinate amphibole, clinopyroxene, and opaque minerals. These phenocrysts/microphenocrysts may form as isolated crystals and as clinopyroxene - plagioclase, amphibole - clinopyroxene and amphibole - plagioclase cumulocrysts. The groundmass is holocrystalline, consisting of plagioclase laths and opaque minerals. Secondary patches of chlorite, titanite/leucoxene, calcite and quartz have been observed in minor amount. Tiny fractures sealed by epidote minerals and chlorite.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show subhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are highly altered to sericite, chlorite and titanite/leucoxene, and slightly replaced by calcite.

Amphibole shows anhedral to subhedral outlines and has sizes up to 1.0 mm across. It is highly altered to chlorite, epidote minerals and opaque minerals, and slightly replaced by calcite.

Clinopyroxene phenocrysts/microphenocrysts have sizes up to 1.6 mm across and show anhedral to euhedral outlines. They are slightly altered to chlorite, epidote minerals, titanite/leucoxene and opaque minerals.

Opaque minerals microphenocrysts have sizes up to 0.4 mm across and show subhedral to euhedral outlines. Groundmass opaque minerals are anhedral. Opaque minerals microphenocrysts and groundmass opaque minerals are altered to titanite/leucoxene and partly replaced by quartz.

**Sample Number**: **KK-17**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 488234**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The fine-grained sample has a dark greenish gray color and shows a moderately porphyritic texture. The phenocrysts comprise abundant plagioclase with sizes up to 1.5 mm across. Brown and white veinlets have been observed.

**Microscopic characters:** The rock sample shows a moderately porphyritic texture. The phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate clinopyroxene and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and clinopyroxene – plagioclase and plagioclase – opaque minerals cumulocrysts. The groundmass is holocrystalline, and slightly trachytic-textured. It consists largely of plagioclase laths and clinopyroxene, with a small amount of opaque minerals. Secondary patches of chlorite, pyrite, titanite/leucoxene, calcite and quartz have been observed in minor amount. Tiny fractures sealed by calcite, quartz and chlorite.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show subhedral to euhedral outlines and a sieve texture. Groundmass plagioclase grains are largely lath-shaped. They are moderately altered to sericite, chlorite and opaque minerals, and are slightly replaced by calcite.

Clinopyroxene phenocrysts/microphenocrysts have sizes up to 1.2 mm across and show subhedral outlines. They contain inclusions of lath-shaped plagioclase, giving rise to a subophitic texture. Groundmass clinopyroxene grains show anhedral outlines. Most clinopyroxene grains may be highly altered to chlorite, titanite/leucoxene and opaque minerals, and slightly replaced by calcite and quartz.

Opaque minerals microphenocrysts have sizes up to 0.4 mm across and show euhedral outlines. Groundmass opaque minerals are anhedral. Opaque minerals microphenocrysts and groundmass are slightly altered to titanite/leucoxene, and partly replaced by quartz.



**Sample Number**: **KK-18**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 488226**

**Rock Name: Andesite/Basalt**

**Megascopic Character:** The sample generally has a dark greenish gray color and shows a porphyritic texture. Phenocrysts/microphenocrysts consist largely of plagioclase, with sizes up to 6.0 mm across, and dark greenish black crystals, with sizes up to 2.0 mm across. Brown and white veinlets have been observed.

**Microscopic characters**: The rock sample displays a moderately porphyritic texture. The phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate clinopyroxene and amphibole, and minor opaque minerals. They form as isolated crystals, clinopyroxene glomerocrysts, and clinopyroxene – plagioclase and clinopyroxene – plagioclase - amphibole cumulocrysts. The groundmass is holocrystalline, and consists largely of plagioclase laths and clinopyroxene, with a small amount of opaque minerals. Secondary patches of chlorite, titanite/leucoxene and epidote minerals have been observed in minor amount. Tiny fractures and voids were sealed by chlorite and sericite.

Plagioclase phenocrysts/microphenocrysts have sizes up to 6.0 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. Both phases of plagioclase are strongly altered to sericite, chlorite, epidote minerals and opaque minerals.

Clinopyroxene phenocrysts/microphenocrysts have sizes up to 1.0 mm across and show subhedral outlines. Some grains contain inclusions of lath-shaped plagioclase, giving rise to a subophitic texture. Groundmass clinopyroxene grains are anhedral. Most clinopyroxene grains may be partly altered to chlorite, titanite/leucoxene and opaque minerals.

Amphibole microphenocrysts show anhedral to subhedral outlines and have sizes up to 1.0 mm across. They are highly altered to chlorite and opaque minerals.

Opaque minerals have sizes up to 0.5 mm across and show anhedral outlines. They are slightly altered to titanite/leucoxene.

**Sample Number**: **TK-12**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 614309**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** This fine-grained rock sample has a greenish gray color and shows a seriate texture. They largely comprise plagioclase, and green and black crystals, with sizes up to 4.0 mm across. Brown veinlets have been observed.

**Microscopic characters**: The rock sample shows a seriate texture and is composed largely of plagioclase with subordinate clinopyroxene and opaque minerals. Secondary patches of quartz, epidote minerals, calcite, chlorite and titanite/leucoxene have been observed. Tiny fractures were sealed by chlorite and opaque minerals.

Plagioclase grains have sizes up to 1.0 mm across and show anhedral to subhedral outlines. They are moderately altered to sericite, chlorite, titanite/leucoxene and epidote minerals.

Clinopyroxene grains have sizes largely up to 0.5 mm across and show anhedral to subhedral outlines. They may be slightly altered to chlorite, opaque minerals and titanite/leucoxene.

Opaque minerals have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number: TK-23**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 586317**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The rock sample is fine-grained and dense. It has a dark greenish gray color and shows a moderately porphyritic texture. The phenocrysts/microphenocrysts comprise abundant plagioclase and black crystals. White veinlets have been observed.

**Microscopic characters:** The rock sample shows a moderately porphyritic texture and phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate clinopyroxene and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals and as clinopyroxene glomerocrysts. The groundmass is holocrystalline, and shows a moderately trachytic texture. It consists largely of plagioclase laths and clinopyroxene, with a small amount of opaque minerals. Secondary patches of chlorite and titanite/leucoxene have been observed.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.5 mm across and show subhedral outlines. Groundmass plagioclase grains are largely lath-shaped. They are highly altered to sericite, chlorite and opaque minerals, and moderately replaced by epidote mineral.

Clinopyroxene microphenocrysts and groundmass clinopyroxene grains have sizes largely up to 0.6 mm across and show anhedral to subhedral outlines. Clinopyroxene microphenocrysts show corroded outlines. Both phases of clinopyroxene may be highly altered to chlorite, opaque minerals and titanite/leucoxene.

Opaque minerals microphenocrysts have sizes up to 0.2 mm across and largely show euhedral outlines. Groundmass opaque minerals are anhedral. Opaque minerals microphenocrysts and groundmass opaque minerals are slightly altered to titanite/leucoxene.

**<u>Group I Rock : hypabyssal rock</u>**

**Sample Number NKT-093**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0622551/UTM 1723115**

**Rock Name: Diorite/Gabbro**

**Megascopic Characters:** This medium-grained rock sample displays a seriate texture and has a greenish black color. It comprises abundant plagioclase (white color), with subordinate quartz and dark green mineral. Pyrite has been occasionally observed (sizes up to 1 mm across).

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of quartz, epidote minerals, chlorite, titanite/leucoxene and calcite have been detected.

Plagioclase has sizes up to 3.0 mm across and shows anhedral to euhedral outlines. It is highly altered to sericite, titanite/leucoxene, opaque minerals and calcite.

Potassium feldspar has sizes up to 2.0 mm across and shows subhedral outlines. It is slightly altered to clay minerals.

Unidentified mafic minerals have sizes up to 1.5 mm across and show anhedral to euhedral outlines. They are highly to totally altered to chlorite/serpentine, titanite/leucoxene, epidote minerals, opaque minerals and calcite.

Opaque minerals have sizes up to 1.0 mm across and largely show anhedral to euhedral outlines.

**Remark:** Plagioclase 98%, Potassium feldspar 2%, and quartz 0%

## Group II Rock

### Group II Rock : hypabyssal rock

**Sample Number: LS-020**

**Location: Lan Sak, Uthai Thani Province**

**UTM Grid Reference: 578277**

**Rock Name: Diorite/Gabbro**

**Megascopic Characters:** The medium-grained rock sample displays a seriate texture and has a medium dark gray in color. It comprises abundant plagioclase and quartz, and occasional greenish black crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase with subordinate biotite, quartz, clinopyroxene and amphibole, and minor opaque minerals and zircon. Secondary patches of epidote minerals, chlorite, titanite/leucoxene and quartz have been observed.

Plagioclase has sizes up to 3.0 mm across and shows subhedral to euhedral outlines. Some plagioclase grains have zonal pattern and embayed outlines. Plagioclase is slightly altered to sericite, titanite/leucoxene, opaque minerals and calcite.

Potassium feldspar has sizes up to 2.0 mm across and shows subhedral outlines. It is slightly altered to clay minerals.

Quartz grains have sizes up to 0.4 mm across and show anhedral outlines. They have sutured grain boundaries.

Biotite has sizes up to 1.5 mm across and shows anhedral to subhedral outlines. It shows yellowish brown to dark brown pleochroism. It contains inclusions of zircon and is highly altered to yellow – green amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Clinopyroxene has sizes up to 0.4 mm across and shows anhedral to subhedral outlines. It forms as inclusions in plagioclase and is highly altered to amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Amphibole has sizes up to 0.5 mm across and shows anhedral to subhedral outlines. It is slightly altered to chlorite, titanite/leucoxene and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and show anhedral to euhedral outlines. They are slightly altered to titanite/leucoxene.

Zircon has sizes up to 0.1 mm across and shows anhedral to euhedral outlines. It forms as isolated crystals and inclusions in biotite.

**Remark:** Plagioclase 92%, Potassium feldspar 6%, and quartz 2%

**Sample Number: LS-021**

**Location: Lan Sak, Uthai Thani Province**

**UTM Grid Reference: 578277**

**Rock Name: Diorite/Gabbro**

**Megascopic Characters:** The medium-grained rock sample displays a seriate texture, with a medium dark gray color. It comprises abundant plagioclase and quartz, and occasional greenish black crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase with subordinate biotite, quartz and clinopyroxene, and minor opaque minerals and zircon. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been observed.

Plagioclase has sizes up to 4.0 mm across and shows subhedral to euhedral outlines. It is slightly altered to sericite, titanite/leucoxene, opaque minerals and calcite.

Potassium feldspar has sizes up to 2.0 mm across and shows subhedral outlines. It is slightly altered to clay minerals.

Biotite has sizes up to 1.5 mm across and shows anhedral to subhedral outlines. It shows yellowish brown to dark brown pleochroism and contains inclusions of zircon. It is highly altered to yellow – green amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Quartz crystals have sizes up to 0.4 mm across and show anhedral outlines. They show sutured grain boundaries.

Clinopyroxene has sizes up to 1.0 mm across and shows anhedral to subhedral outlines. It forms as inclusions in plagioclase and is highly altered to yellow – green amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to euhedral outlines. They are slightly altered to titanite/leucoxene.

Zircon has sizes up to 0.1 mm. across and shows anhedral to euhedral outlines. It forms as isolated crystals and inclusions in biotite.

**Remark:** Plagioclase 93%, Potassium feldspar 5%, and quartz 2%

**Sample Number: LS-03**

**Location: Lan Sak, Uthai Thani Province**

**UTM Grid Reference: 582275**

**Rock Name: Diorite/Gabbro**

**Megascopic Characters:** The medium-grained rock sample displays a seriate texture and has a light gray color. It consists abundantly of plagioclase and quartz, with occasional greenish black crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate biotite, quartz, clinopyroxene and amphibole, and minor opaque minerals and zircon. Secondary patches of epidote minerals, clorite and titanite/leucoxene have been observed.

Plagioclase has sizes up to 4.0 mm across and shows subhedral to euhedral outlines. It is slightly altered to sericite, titanite/leucoxene, opaque minerals and calcite.

Potassium feldspar has sizes up to 2.0 mm across and shows subhedral outlines. It is slightly altered to clay minerals.

Biotite has sizes up to 1.0 mm across and shows anhedral to subhedral outlines. It shows yellowish brown to dark brown pleochroism and contains inclusions of zircon. It is highly altered to yellow – green amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Quartz crystals have sizes up to 0.4 mm across and show anhedral outlines. They show sutured grain boundaries.

Clinopyroxene has sizes up to 1.0 mm across and shows anhedral to subhedral outlines. It forms as inclusions in plagioclase and is highly altered to amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Amphibole has sizes up to 0.5 mm across and shows anhedral to subhedral outlines. It is slightly altered to chlorite, titanite/leucoxene and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and show anhedral to euhedral outlines. They are slightly altered to titanite/leucoxene.

Zircon has sizes up to 0.1 mm across and shows anhedral to euhedral outlines. It forms as isolated crystals and inclusions in biotite.

**Remark:** Plagioclase 94%, Potassium feldspar 5%, and quartz 1%

**Sample Number: LS-05**

**Location: Lan Sak, Uthai Thani Province**

**UTM Grid Reference: 573278**

**Rock Name: Diorite/Gabbro**

**Megascopic Characters:** The medium-grained rock sample displays a seriate texture, with a light gray color. It comprises abundant plagioclase and quartz, and subordinate greenish black crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate biotite, quartz, clinopyroxene and amphibole, and minor opaque minerals and zircon. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been observed.

Plagioclase has sizes up to 4.0 mm across and is subhedral to euhedral. It is moderately altered to sericite, chlorite, opaque minerals and calcite.

Potassium feldspar has sizes up to 2.0 mm across and shows subhedral outlines. It is slightly altered to clay minerals.

Biotite has sizes up to 0.8 mm across and shows anhedral to subhedral outlines. It shows yellowish brown to dark brown pleochroism and contains inclusions of zircon. It is highly altered to amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Quartz grains have sizes up to 0.2 mm across, show anhedral outlines and form as myrmekite intergrowth with plagioclase. They show sutured grain boundaries.

Clinopyroxene has sizes up to 0.5 mm across and shows anhedral to subhedral outlines. It form as isolated crystals and inclusions in plagioclase and is moderately altered to amphibole, chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Amphibole has sizes up to 1.5 mm across and shows anhedral to subhedral outlines. It shows yellow to green pleochroism and is highly altered to chlorite, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and show anhedral to euhedral outlines. They are slightly altered to titanite/leucoxene.

Zircon has sizes up to 0.05 mm. across and shows anhedral to euhedral outlines. It forms as isolated crystals and inclusions in biotite.

**Remark:** Plagioclase 98%, Potassium feldspar 1%, and quartz 1%

## Group III Rock

### Group III Rock : Mafic hypabyssal rock

**Sample Number**: **KK-16**

**Location: Khao Kang Kaew, Nakhon Sawan Province**

**UTM Grid Reference: 488234**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained sample generally has a dark greenish black color and shows a seriate texture. It consists largely of plagioclase (pale greenish white) with sizes up to 4.0 mm across and greenish black crystals.

**Microscopic characters**: The rock sample is seriate-textured, and consists mainly of plagioclase, with subordinate clinopyroxene, amphibole, orthopyroxene and opaque minerals. Patches of secondary chlorite, pyrite, titanite/leucoxene and quartz have been observed in minor amount.

Plagioclase grains have sizes up to 3.0 mm across and show subhedral to euhedral outlines. Most of them are highly altered to sericite, chlorite and opaque minerals.

Clinopyroxene grains have sizes up to 1.2 mm across and show anhedral to subhedral outlines. Some crystals contain inclusions of lath-shaped plagioclase, giving rise to a subophitic texture. They are slightly to moderately altered to chlorite, amphibole, titanite/leucoxene and opaque minerals.

Amphibole grains display anhedral outlines, with sizes up to 1.5 mm across. They are highly altered to chlorite, titanite/leucoxene and opaque minerals.

Orthopyroxene grains have sizes up to 0.5 mm across and show anhedral to subhedral outlines. They are slightly altered to chlorite, amphibole, titanite/leucoxene and opaque minerals.

Opaque minerals grains as a primary mineral have sizes up to 0.2 mm across and show subhedral to euhedral outlines. They are slightly replaced by titanite/leucoxene.

**Sample Number: TK-07**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 606304**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample shows a seriate texture and has a dark greenish black color. It has sizes up to 2.0 mm across and comprises abundant plagioclase and greenish black crystals. Brown and white veinlets have been sporadically observed. Pyrite and brown crystals are sporadically present.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate clinopyroxene and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been observed.

Plagioclase laths have sizes up to 1.4 mm across and show subhedral to euhedral outlines. They are moderately altered to sericite, chlorite and opaque minerals.

Clinopyroxene grains have sizes up to 3.0 mm across and show anhedral to subhedral outlines. Some crystals contain inclusions of lath-shaped plagioclase, giving rise to subophitic/ophitic textures. They are highly altered to chlorite, amphibole, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals grains have sizes up to 0.4 mm across and show anhedral to euhedral outlines. They are moderately replaced by titanite/leucoxene.

**Sample Number: TK-13**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 614309**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample generally has a dark greenish gray color and shows a seriate texture. It consists largely of grayish green and greenish black crystals, with sizes up to 3.0 mm across. Brown veinlets have been sporadically observed.

**Microscopic characters:** The rock sample is seriate-textured, and made up mainly of plagioclase, with subordinate clinopyroxene and opaque minerals. Patches of secondary chlorite, pyrite, titanite/leucoxene and quartz have been observed in minor amount.

Plagioclase grains have sizes up to 2.0 mm across and show subhedral to euhedral outlines. They are highly altered to sericite, chlorite, opaque minerals and titanite/leucoxene.

Clinopyroxene grains have sizes up to 2.0 mm across and show anhedral to subhedral outlines. They contain inclusions of lath-shaped plagioclases, giving rise to a subophitic texture. Clinopyroxene grains are moderately to highly altered to chlorite, amphibole, titanite/leucoxene and opaque minerals.

Opaque minerals grains show subhedral outlines, with sizes up to 0.2 mm across and are interstitial to plagioclase laths. They are slightly replaced by titanite/leucoxene.

**Sample Number: TK-15**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 614309**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample generally shows a dark greenish black color and a seriate texture. It consists largely of grayish green and greenish black crystals, with sizes up to 4.0 mm across. Pyrite and brown veinlets have been partly observed.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate clinopyroxene, and opaque minerals. Secondary patches of chlorite, titanite/leucoxene and opaque minerals have been observed.

Plagioclase grains have sizes up to 1.6 mm across and show subhedral to euhedral outlines. They show felty and ophitic/subophitic textures. They are highly altered to sericite, chlorite and titanite/leucoxene, and moderately replaced by opaque minerals.

Clinopyroxene grains have sizes largely 2.0 mm across and show anhedral to subhedral outlines. They contain inclusions of plagioclase laths forming ophitic/subophitic textures. Clinopyroxene grains are highly altered to amphibole, chlorite, opaque minerals and titanite/leucoxene.

Opaque minerals grains have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They occur as an interstitial mineral to plagioclase laths. They are slightly replaced by titanite/leucoxene.

**Sample Number TK-25**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 579305**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a dark greenish gray color and shows a seriate texture. It consists largely of grayish green and greenish black crystals, with sizes up to 3.0 mm across. Pyrite and brown veinlets have been observed.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate clinopyroxene and opaque minerals. Secondary patches of chlorite and titanite/leucoxene have been observed.

Plagioclase grains have sizes up to 2.0 mm across and show subhedral to euhedral outlines. They are highly altered to chlorite and sericite, and moderately replaced by opaque minerals.

Clinopyroxene grains have sizes up to 2.0 mm across and show anhedral to subhedral outlines. They contain inclusions of plagioclase laths, leading to ophitic/subophitic textures and are slightly altered to chlorite, amphibole, opaque minerals and titanite/leucoxene.

Opaque minerals grains have sizes up to 0.2 mm across and largely show anhedral outlines. They are interstitial to plagioclase laths and are slightly replaced by titanite/leucoxene.

**Group III Rock : mafic volcanic rock**

**Sample Number: TK-14**

**Location: Tha Takho, Nakhon Sawan Province**

**UTM Grid Reference: 614309**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The fine-grained rock sample displays a seriate texture and has a dark greenish gray color. The crystals have sizes up to 2.5 mm across and comprises abundant plagioclase (pale greenish white color) and occasional greenish black crystals. Brown and white veinlets have been rarely observed.

**Microscopic characters:** The rock sample shows a seriate texture and is composed largely of plagioclase, with subordinate clinopyroxene, orthopyroxene and opaque minerals. Secondary patches of epidote minerals, calcite, chlorite, titanite/leucoxene and quartz have been observed. Tiny fractures are sealed by chlorite, epidote minerals and opaque minerals.

Plagioclase grains have sizes up to 1.0 mm across and show anhedral to subhedral outlines. They are moderately altered to sericite, chlorite, titanite/leucoxene and epidote minerals.

Clinopyroxene grains have sizes largely 1.0 mm across and show anhedral to subhedral outlines. They contain inclusions of plagioclase laths in form of ophitic/subophitic textures. Clinopyroxene grains are highly altered to amphibole, chlorite, opaque minerals and titanite/leucoxene.

Orthopyroxene grains have sizes up to 1.0 mm across and show anhedral outlines. They are highly altered to epidote minerals and opaque minerals.

Opaque minerals grains have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number: TK-20**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 603309**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The rock sample is fine-grained, and shows a pophyritic texture. It is dark greenish gray, and consists abundantly of plagioclase (pale greenish white) and black crystals. White veinlets have been observed.

**Microscopic characters:** The rock sample shows a slightly porphyritic texture; and its phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals and as plagioclase glomerocrysts. The groundmass is holocrystalline, and consists largely of plagioclase laths and unidentified mafic minerals, with a small amount of opaque minerals. Secondary patches of chlorite, epidote minerals and titanite/leucoxene are obvious.

Plagioclase phenocrysts/microphenocrysts have sizes up to 4.0 mm across, subhedral to euhedral outlines and tend to align in subparallel manner. Groundmass plagioclase grains are largely lath-shaped,

and show a felty texture. Both plagioclase phenocrysts/microphenocrysts and groundmass plagioclase grains are highly altered to sericite and chlorite and slightly replaced by opaque minerals.

Unidentified mafic minerals occur as phenocrysts/microphenocrysts, have sizes up to 2.0 mm across and show anhedral to subhedral outlines. They are highly altered to chlorite/serpentine, epidote minerals, opaque minerals and titanite/leucoxene.

Opaque minerals microphenocrysts have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene.

## Group IV Rock

### Group IV Rock : Mafic hypabyssal rock

**Sample Number: TK-08**
**Location: Tha Tako, Nakhon Sawan Province**
**UTM Grid Reference: 606304**
**Rock Name: Microdiorite/Microgabbro**
**Megascopic Characters:** The fine- to medium-grained rock sample generally shows a dark greenish gray color and a seriate texture. The rock largely comprises grayish green and black crystals, with sizes up to 5.0 mm across. Pyrite and brown crystals have been partly observed.
**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase with subordinate clinopyroxene and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been observed.

Plagioclase laths have sizes up to 0.8 mm across and show subhedral to euhedral outlines. They are moderately altered to sericite, chlorite and opaque minerals.

Clinopyroxene grains have sizes up to 3.0 mm across and show anhedral to subhedral outlines. Some contain inclusions of lath-shaped plagioclase, giving rise to a subophitic/ophitic texture and are highly altered to chlorite, amphibole, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are moderately replaced by titanite/leucoxene.



**Sample Number NKT-022**
**Location: Khao Thong, Nakhon Sawan**
**UTM Grid Reference: 47P 0622150/UTM 1722279**
**Rock Name: Microdiorite/Microgabbro**
**Megascopic Characters:** The fine- to medium-grained rock sample shows a seriate texture and has a dark greenish gray color. It comprises abundant grayish green crystals and plagioclase (pale greenish white color), and occasional dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been rarely detected. Tiny fractures sealed by quartz, chlorite and titanite/leucoxene.

Plagioclase laths have sizes up to 0.8 mm across and show subhedral to euhedral outlines. They are slightly altered to sericite, chlorite, titanite/leucoxene, opaque minerals, quartz, epidote minerals and calcite.

Unidentified mafic minerals have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are highly to totally altered to epidote minerals, chlorite/serpentine, titanite/leucoxene and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are moderately replaced by titanite/leucoxene.

**Sample Number NKT-032**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference 47P0622045/ UTM 1724777**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample has a greenish black color and shows a seriate texture. It consists of abundant grayish green minerals, with subordinate pale green mineral, lath-shaped plagioclase and dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.0 mm across and show subhedral to euhedral outlines. They are moderately altered to sericite, and chlorite, and slightly replaced by titanite/leucoxene, opaque minerals, quartz, epidote minerals and calcite.

Unidentified mafic minerals have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are highly to totally altered to amphibole (actinolite), chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to euhedral outlines. They are moderately replaced by titanite/leucoxene.

**Sample Number NKT-033**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference 47P0622045/ UTM 1724777**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample has a greenish black color and shows a seriate texture. It is composed of abundant grayish green mineral, with subordinate pale green mineral, lath-shaped plagioclase and dusky brown crystals. Tiny white vienlets have been rarely observed.

**Microscopic characters:** The rock sample shows a seriate texture and is made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.0 mm across and show subhedral outlines. They are moderately altered to sericite, and slightly replaced by calcite and epidote minerals.

Unidentified mafic minerals have sizes up to 0.8 mm across and show anhedral to subhedral outlines. They are highly altered to amphibole (actinolite), chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. Their rims are moderately replaced by titanite/leucoxene.

**Sample Number NKT-042**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P0621796/ UTM 1724375**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a seriate texture and has a dark greenish gray color. It comprises mainly grayish green mineral, with subordinate plagioclase (pale greenish white) and occasional black crystals.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, quartz, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.0 mm across and show subhedral outlines. They are highly altered to sericite, quartz, chlorite and epidote minerals.

Unidentified mafic minerals have sizes up to 1.0 mm across and show anhedral to subhedral outlines. They are highly altered to amphibole (actinolite), chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.6 mm across and largely show anhedral to subhedral outlines. They are highly replaced by titanite/leucoxene.



**Sample Number NKT-061**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0621647/UTM 1722908**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a seriate texture and has a dark greenish gray color. It comprises mainly grayish green mineral, with subordinate lath-shaped plagioclase and dusky brown crystals. Brown and white veinlets have been rarely detected.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of calcite, epidote

minerals, quartz, chlorite and titanite/leucoxene have been detected. Fractures are sealed by epidote mineral, titanite/luecoxene, quartz and calcite.

Plagioclase laths have sizes up to 0.8 mm across and show subhedral outlines. They are slightly altered to sericite, chlorite, calcite and epidote minerals.

Unidentified mafic minerals have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are highly altered to chlorite/serpentine, amphibole (actinolite), titanite/leucoxene, epidote minerals and opaque minerals, and slightly replaced by quartz.

Opaque minerals have sizes up to 0.4 mm across and largely show anhedral to subhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number NKT-072**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference 47P 0621837/UTM 1722657**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample shows a seriate texture and has a greenish black color. It comprises abundant grayish green and pale green minerals, with occasional dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture and is composed mainly plagioclase, with subordinate amphibole and opaque minerals. Secondary patches of chlorite, quartz, and titanite/leucoxene have been observed in minor amount.

Plagioclase grains have sizes up to 3.0 mm across and show subhedral to euhedral outlines. They are highly altered to sericite, titanite/leucoxene, chlorite, opaque minerals, epidote minerals and quartz.

Amphibole grains have sizes up to 1.0 mm across and show anhedral to subhedral outlines. Amphibole grains are moderately altered to titanite/leucoxene, opaque minerals, chlorite and epidote minerals.

Opaque minerals show anhedral to subhedral outlines and have sizes up to 0.7 mm across. They are replaced by titanite/leucoxene.



**Sample Number NKT-082**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0622777/UTM 1722804**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** This fine-grained rock sample shows a seriate texture and has a dark greenish gray color. It comprises mainly grayish green mineral, with occasional dusky brown crystals. White veinlets have been rarely detected.

**Microscopic characters:** The rock sample shows a seriate texture and is made up largely of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite, titanite/leucoxene and quartz have been detected. Tiny fractures are sealed by chlorite, epidote minerals, opaque minerals and titanite/leucoxene.

Plagioclase laths have sizes up to 0.4 mm across and show subhedral to euhedral outlines. They are slightly altered to sericite, chlorite and titanite/leucoxene.

Unidentified mafic minerals have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are highly to totally altered to chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are moderately replaced by titanite/leucoxene.

**Sample Number NKT-091**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0622551/UTM 1723115**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a seriate texture and has a greenish black color. It comprises mainly grayish green mineral, with subordinate pale green mineral and occasional dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of calcite, epidote minerals, quartz, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 0.6 mm across and show subhedral outlines. They are moderately altered to sericite, and slightly replaced by chlorite, calcite and epidote minerals.

Unidentified mafic minerals have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are highly altered to chlorite/serpentine, amphibole (actinolite), titanite/leucoxene, epidote minerals and opaque minerals and slightly replaced by quartz.

Opaque minerals have sizes up to 0.3 mm across and largely show anhedral to subhedral outlines. They are highly replaced by titanite/leucoxene.

**Sample Number NKT-092**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0622551/UTM 1723115**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a seriate texture and has a dark greenish gray color. It consists largely of grayish green crystals, with subordinate pale green crystals and occasional dusky brown crystals.

**Microscopic characters**: The rock sample shows a seriate texture and is made up largely of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite, titanite/leucoxene and quartz have been detected. Tiny fractures are sealed by chlorite, epidote minerals, opaque minerals and titanite/leucoxene.

Plagioclase laths have sizes up to 1.6 mm across and show subhedral to euhedral outlines. They are moderately altered to sericite, chlorite and titanite/leucoxene.

Unidentified mafic minerals have sizes up to 0.2 mm across and show anhedral to subhedral outlines. They are highly to totally altered to chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number NKT-111**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0623478/UTM 1722899**

**Rock Name: Microdiorite/Microgabbro**

**Megascopic Characters:** The fine- to medium-grained rock sample displays a seriate texture and has a dark greenish gray color. It comprises abundant grayish green crystals, with subordinate pale green crystals and occasional dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, quartz, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.0 mm across and show subhedral outlines. They are highly altered to sericite, chlorite, quartz and epidote minerals.

Unidentified mafic minerals have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are highly altered to chlorite/serpentine, amphibole (actinolite), titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are highly replaced by titanite/leucoxene.

**<u>Group IV Rock : mafic volcanic rock</u>**

**Sample Number: TK-26**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 579305**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The rock sample is fine-grained and dense, and shows a porphyritic texture. It has a grayish black color and comprises abundant plagioclase (pale greenish white) and black crystals.

**Microscopic characters:** The rock sample shows a slightly porphyritic texture and their phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate clinopyroxene. These phenocrysts/microphenocrysts form as isolated crystals and as plagioclase glomerocrysts. The groundmass is holocrystalline, and consists largely of plagioclase laths, clinopyroxene and opaque minerals. Secondary patches of chlorite, titanite/leucoxene and opaque minerals have been observed. Voids and fractures are infilled by chlorite, titanite/leucoxene, opaque minerals and epidote minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 1.2 mm across and show subhedral outlines. Groundmass plagioclase grains largely display lath shapes and show a felty texture. They are highly altered to sericite and chlorite, and moderately replaced by opaque minerals and epidote minerals.

Clinopyroxene microphenocrysts and groundmass clinopyroxene grains have sizes largely up to 0.6 mm across and show anhedral to subhedral outlines. They are moderately altered to chlorite, opaque minerals and titanite/leucoxene.

**Sample Number TK-27**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 577311**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The rock sample is fine-grained, and shows a porphyritic texture. They have grayish black color and is composed of abundant plagioclase (pale greenish white) and black crystals.

**Microscopic characters:** The rock sample shows a slightly porphyritic texture; phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate clinopyroxene, orthopyroxene and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals and as plagioclase-clinopyroxene cumulocrysts. The groundmass is holocrystalline, and consists largely of plagioclase laths and clinopyroxene, with a small amount of opaque minerals. Secondary patches of chlorite, titanite/leucoxene and epidote minerals have been observed. Tiny fractures are sealed by sericite and epidote minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.5 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped, and show a felty texture. They are moderately altered to sericite, chlorite, opaque minerals and epidote minerals.

Clinopyroxene microphenocrysts have sizes up to 0.5 mm across and show anhedral to subhedral outlines. They contain inclusions of plagioclase laths in form of an ophitic/subophitic texture. They are slightly altered to chlorite, opaque minerals, titanite/leucoxene and epidote minerals.

Orthopyroxene phenocrysts/microphenocrysts have sizes up to 1.8 mm across and show anhedral to subhedral outlines. They are highly altered to amphibole, chlorite/serpentine, opaque minerals, titanite/leucoxene and epidote minerals.

Opaque microphenocrysts have sizes up to 0.8 mm across and show anhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number TK-37**

**Location: Tha Tako, Nakhon Sawan Province**

**UTM Grid Reference: 564364**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** The rock sample is fine-grained, and displays a seriate texture. It has a dark greenish gray color and consists of abundant plagioclase and black crystals. White veinlets have been recognized.

**Microscopic characters:** The rock sample shows a seriate texture, made up mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of chlorite, sericite, quartz, opaque minerals and titanite/leucoxene are present. Tiny fractures are sealed by chlorite, epidote, and quartz.

Plagioclase laths have sizes up to 0.5 mm across and show anhedral to subhedral outlines. Groundmass plagioclase grains are lath-shaped, and are highly altered to sericite and chlorite, and moderately replaced by opaque minerals and epidote minerals.

Unidentified mafic minerals grains have sizes up to 0.4 mm across and show anhedral to subhedral outlines. They are highly altered to epidote minerals, chlorite/serpentine, opaque minerals and titanite/leucoxene and moderately replaced by quartz.

Opaque minerals grains have sizes up to 0.2 mm across, exhibit subhedral outlines and are slightly altered to titanite/leucoxene.

**Sample Number NKT-031**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference 47P0622045/ UTM 1724777**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** This fine-grained rock sample displays a seriate texture and has a dark greenish gray color. It consists of abundant black crystals and plagioclase (pale greenish white), and occasional brownish black crystals that have sizes up to 0.5 mm across. White veinlets have been rarely detected.

**Microscopic characters:** The fine-grained rock sample shows a seriate texture and mainly comprises plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 0.6 mm across and show subhedral outlines. They are moderately altered to sericite, quartz and epidote minerals.

Unidentified mafic minerals grains have sizes up to 0.5 mm across and show anhedral to subhedral outlines. They are highly altered to amphibole (actinolite), chlorite/serpentine, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals grains have sizes up to 0.4 mm across and largely show anhedral to subhedral outlines. Their rims are moderately altered to titanite/leucoxene.

**Sample Number NKT-051**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0621676/UTM 1723349**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** This fine-grained rock sample displays a seriate texture and has a dark greenish gray color. It comprises abundant dark green mineral, with subordinate plagioclase (pale greenish white).

**Microscopic characters:** The rock sample shows a seriate texture, made up largely of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.2 mm across and show subhedral outlines. They are moderately altered to sericite and chlorite, and slightly replaced by titanite/leucoxene, opaque minerals, quartz, epidote minerals and calcite.

Unidentified mafic minerals grains have sizes up to 1.0 mm across and show anhedral to subhedral outlines. They are highly to totally altered to actinolite, chlorite/serpentine, titanite/leucoxene, epidote minerals, opaque minerals and calcite.

Opaque minerals grains have sizes up to 0.3 mm across and largely show anhedral to euhedral outlines. They are highly altered to titanite/leucoxene.

**Sample Number NKT-101**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0622499/UTM 1723376**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** This fine-grained rock sample displays a seriate texture and has a dark greenish gray color. It is composed abundantly of dark green mineral, with subordinate plagioclase (pale greenish white) and occasional dusky brown crystals. White veinlets have been rarely detected.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of calcite, epidote minerals, quartz, chlorite and titanite/leucoxene have been detected.

Plagioclase grains have sizes up to 2.0 mm across and show anhedral to subhedral outlines. They are highly altered to sericite, chlorite and epidote minerals.

Unidentified mafic minerals grains have sizes up to 0.8 mm across and show anhedral outlines. They are highly altered to chlorite/serpentine, actinolite, titanite/leucoxene, epidote minerals and opaque minerals, and slightly replaced by quartz.

Opaque minerals grains have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are highly altered to titanite/leucoxene.



**Sample Number NKT-112**

**Location: Khao Thong, Nakhon Sawan**

**UTM Grid Reference: 47P 0623478/UTM 1722899**

**Rock Name: Andesite/Basalt**

**Megascopic Characters:** This fine-grained rock sample displays a seriate texture and has a dark greenish gray color. It consists of abundant dark green mineral, with subordinate plagioclase (pale greenish white) and occasional dusky brown crystals.

**Microscopic characters:** The rock sample shows a seriate texture, composed mainly of plagioclase, with subordinate unidentified mafic minerals and opaque minerals. Secondary patches of epidote minerals, quartz, chlorite and titanite/leucoxene have been detected.

Plagioclase laths have sizes up to 1.0 mm across and show subhedral outlines. They are highly altered to sericite, chlorite, quartz and epidote minerals.

Unidentified mafic minerals grains have sizes up to 0.6 mm across and show anhedral to subhedral outlines. They are highly altered to chlorite/serpentine, actinolite, titanite/leucoxene, epidote minerals and opaque minerals.

Opaque minerals grains have sizes up to 0.2 mm across and largely show anhedral to subhedral outlines. They are highly altered to titanite/leucoxene.

## Group V Rock

### Group V Rock : Felsic volcanic rock

**Sample Number**: **KK-02**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 477253**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** The rock sample is generally fine-grained and dense, and has a dark greenish gray color. It shows a highly porphyritic texture, with pinkish white plagioclase phenocrysts (sizes up to 2.0 mm across). Brown and white veinlets have been observed.

**Microscopic characters:** The rock sample shows a highly porphyritic texture, and phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar, quartz, amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals, plagioclase glomerocrysts and as plagioclase – amphibole cumulocrysts. The groundmass is glassy, and has experienced low-temperature recrystallization, giving rise to abundant plagioclase, potassium feldspar and quartz, and a small amount of amphibole. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures sealed by quartz, calcite, sericite and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 3.0 mm across and show subhedral to euhedral outlines. They are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by calcite and quartz.

Potassium feldspar phenocrysts/microphenocrysts have sizes up to 0.4 mm across and largely show subhedral outlines. They are slightly altered to clay minerals.

Quartz phenocrysts/microphenocrysts have sizes up to 1.0 mm across. They show anhedral to subhedral and embayed outlines.

Amphibole phenocrysts/microphenocrysts have sizes up to 2.0 mm across and show anhedral to euhedral outlines. They are highly altered to chlorite, opaque minerals, titanite/leucoxene, calcite and quartz.

Opaque phenocrysts/microphenocrysts have sizes up to 0.3 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene.

**Sample Number**: **KK-20**

**Location: Khao Kangkaew, Nakhon Sawan Province**

**UTM Grid Reference: 486218**

**Rock Name: Rhyodacite/Dacite**

**Megascopic Characters:** This fine-grained rock sample has a pale blue green color and shows a pophyritic texture. Phenocrysts consist of pinkish white plagioclase, with sizes up to 2.0 mm across, and subordinate black mineral (sizes up to 0.3 mm across). White and brown veinlets have been rarely detected.

**Microscopic characters**: The rock sample shows a highly porphyritic texture, and phenocrysts/microphenocrysts are made up mainly of plagioclase, with subordinate potassium feldspar, quartz, amphibole and opaque minerals. These phenocrysts/microphenocrysts form as isolated crystals and plagioclase glomerocrysts. The groundmass is glassy, and has undergone high-temperature divitrification. It consists largely of plagioclase and spherulite. Groundmass spherulites are patchy and radiated, with diameter up to 0.1 mm. Secondary patches of quartz, calcite, chlorite and titanite/leucoxene have been detected. Tiny fractures sealed by quartz and opaque minerals.

Plagioclase phenocrysts/microphenocrysts have sizes up to 2.2 mm across and show subhedral to euhedral outlines. Groundmass plagioclase grains are largely lath-shaped. Both phases of plagioclase are slightly altered to sericite, chlorite and opaque minerals, and moderately replaced by quartz.

Potassium feldspar phenocrysts/microphenocrysts have sizes up to 0.6 mm across and largely show subhedral outline. They are slightly altered to clay minerals.

Quartz phenocrysts/microphenocrysts have sizes up to 1.0 mm across. They show anhedral to subhedral and embayed outlines.

Amphibole phenocrysts/microphenocrysts have sizes up to 0.8 mm across and show anhedral to euhedral outlines. They are completely altered to chlorite, opaque minerals, titanite/leucoxene, calcite and quartz.



Opaque phenocrysts/microphenocrysts have sizes up to 0.4 mm across and largely show anhedral to subhedral outlines. They are slightly altered to titanite/leucoxene.

# APPENDIX B

## ICP-MS Standard Analysis of Trace and Rare Earth Elements Analysis

| ug/g | SARM-4 | GSD-9 | W-2 | AGV-2 | BHVO-2 | GSR-2 | GSR-3 | GSR-1 |
|---|---|---|---|---|---|---|---|---|
| Sc | 39.620 | 10.350 | 36.360 | 12.410 | 31.800 | 8.450 | 13.850 | 5.606 |
| Ti | 1119.800 | 5410.100 | 6627.000 | 6079.700 | 16542.900 | 2947.100 | 14006.800 | 1653.900 |
| V | 218.200 | 91.760 | 275.100 | 115.100 | 320.000 | 89.630 | 168.700 | 21.380 |
| Cr | 28.590 | 86.530 | 92.850 | 20.860 | 278.400 | 31.890 | 137.100 | 5.820 |
| Mn | 1388.100 | 623.400 | 1311.800 | 749.100 | 1291.700 | 598.200 | 1347.300 | 457.400 |
| Co | 58.800 | 14.500 | 44.510 | 15.600 | 45.190 | 12.800 | 49.170 | 2.856 |
| Ni | 115.000 | 32.880 | 70.690 | 17.720 | 115.100 | 17.160 | 143.200 | 1.131 |
| Cu | 10.640 | 35.740 | 119.200 | 48.270 | 127.900 | 55.130 | 51.890 | 3.069 |
| Zn | 56.440 | 78.310 | 78.820 | 84.080 | 105.700 | 68.580 | 149.800 | 26.060 |
| Ga | 16.490 | 14.240 | 18.340 | 19.760 | 21.030 | 18.540 | 24.800 | 19.620 |
| Ge | 1.115 | 1.578 | 1.481 | 1.216 | 1.503 | 1.038 | 1.264 | 2.368 |
| Rb | 3.803 | 79.100 | 20.370 | 63.240 | 9.077 | 38.350 | 39.320 | 466.500 |
| Sr | 247.200 | 169.500 | 192.200 | 593.300 | 364.400 | 769.500 | 1127.100 | 103.100 |
| Y | 6.035 | 28.750 | 20.830 | 18.190 | 24.230 | 8.437 | 22.030 | 64.250 |
| Zr | 10.910 | 338.400 | 92.300 | 225.900 | 160.900 | 90.330 | 285.300 | 176.400 |
| Nb | 0.396 | 15.150 | 6.727 | 12.290 | 16.110 | 5.146 | 69.740 | 38.700 |
| Cs | 0.256 | 4.847 | 0.954 | 1.172 | 0.097 | 1.788 | 0.455 | 38.400 |
| Ba | 82.350 | 428.000 | 171.500 | 1131.700 | 129.500 | 1038.200 | 527.200 | 317.900 |
| La | 2.889 | 40.070 | 10.630 | 37.260 | 15.200 | 21.030 | 56.640 | 51.620 |
| Ce | 5.884 | 76.290 | 23.480 | 67.210 | 37.450 | 38.680 | 110.500 | 109.200 |
| Pr | 0.784 | 9.366 | 3.152 | 8.266 | 5.508 | 4.896 | 13.610 | 12.590 |
| Nd | 3.439 | 35.350 | 13.670 | 31.770 | 25.780 | 18.750 | 54.510 | 46.180 |
| Sm | 0.834 | 6.486 | 3.335 | 5.461 | 6.203 | 3.185 | 10.350 | 9.724 |
| Eu | 0.591 | 1.267 | 1.098 | 1.403 | 2.075 | 0.907 | 3.280 | 0.793 |
| Gd | 0.991 | 5.594 | 3.788 | 4.336 | 6.312 | 2.298 | 8.729 | 8.724 |
| Tb | 0.180 | 0.939 | 0.635 | 0.663 | 0.989 | 0.342 | 1.172 | 1.662 |
| Dy | 1.105 | 5.276 | 3.839 | 3.418 | 5.199 | 1.684 | 5.486 | 10.330 |
| Ho | 0.252 | 1.143 | 0.835 | 0.696 | 1.032 | 0.321 | 0.917 | 2.163 |
| Er | 0.685 | 3.032 | 2.186 | 1.775 | 2.535 | 0.796 | 1.957 | 6.472 |
| Tm | 0.098 | 0.442 | 0.325 | 0.251 | 0.334 | 0.114 | 0.224 | 1.060 |
| Yb | 0.655 | 2.907 | 2.046 | 1.591 | 1.968 | 0.716 | 1.236 | 7.411 |
| Lu | 0.108 | 0.452 | 0.304 | 0.250 | 0.280 | 0.108 | 0.164 | 1.162 |
| Hf | 0.359 | 9.191 | 2.671 | 5.062 | 4.517 | 2.501 | 6.467 | 6.244 |
| Ta | 0.067 | 1.185 | 0.498 | 0.825 | 1.191 | 0.346 | 4.492 | 7.141 |
| Pb | 2.092 | 22.510 | 7.653 | 12.690 | 1.522 | 9.832 | 4.426 | 31.980 |
| Th | 0.360 | 11.690 | 2.123 | 5.744 | 1.192 | 2.566 | 5.918 | 54.050 |
| U | 0.307 | 3.206 | 0.512 | 1.892 | 0.440 | 0.875 | 1.495 | 19.880 |

# APPENDIX C

## Laser ablation ICP-MS U-Pb isotopic and trace element data for standard zircon

Appendix C-1: Laser ablation ICP-MS U-Pb isotopic and trace element data for standard zircon of the volcanic and hypabyssal rock analysis.

| Sample | $^{206}Pb/^{238}U$ age (Ma) | | Isotopic ratios | | | | | | Trace element data (in ppm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis no. | ($^{207}Pb$ corrected.) | +/-1 s | $^{206}Pb/^{238}U$ | % rsd | $^{208}Pb/^{232}Th$ | % rsd | $^{207}Pb/^{206}Pb$ | % rsd | Ti | Hf | Pb | Th | U |
| 91500 | 1027 | 20 | 0.1737 | 1.9% | 0.0503 | 4.0% | 0.0784 | 3.9% | 5 | 5967 | 15 | 29 | 88 |
| 91500 | 1047 | 17 | 0.1776 | 1.7% | 0.0533 | 3.0% | 0.0798 | 3.4% | 4 | 5705 | 16 | 31 | 89 |
| 91500 | 1051 | 13 | 0.1779 | 1.2% | 0.0503 | 2.6% | 0.0787 | 2.4% | 5 | 5820 | 16 | 31 | 87 |
| 91500 | 1054 | 17 | 0.1782 | 1.6% | 0.0544 | 2.9% | 0.0771 | 2.8% | 4 | 6044 | 15 | 29 | 83 |
| 91500 | 1058 | 16 | 0.1790 | 1.6% | 0.0541 | 3.0% | 0.0778 | 2.8% | 5 | 6065 | 14 | 28 | 77 |
| 91500 | 1059 | 14 | 0.1785 | 1.4% | 0.0518 | 2.9% | 0.0746 | 2.8% | 5 | 6040 | 17 | 34 | 93 |
| 91500 | 1060 | 15 | 0.1787 | 1.4% | 0.0562 | 2.8% | 0.0747 | 2.8% | 6 | 6141 | 17 | 33 | 94 |
| 91500 | 1060 | 17 | 0.1788 | 1.7% | 0.0522 | 2.9% | 0.0750 | 2.7% | 4 | 5423 | 15 | 29 | 83 |
| 91500 | 1060 | 17 | 0.1792 | 1.6% | 0.0528 | 4.9% | 0.0764 | 2.7% | 12 | 5822 | 14 | 28 | 78 |
| 91500 | 1061 | 17 | 0.1796 | 1.6% | 0.0551 | 3.0% | 0.0780 | 2.9% | 7 | 5635 | 17 | 32 | 95 |
| 91500 | 1061 | 17 | 0.1790 | 1.6% | 0.0576 | 3.0% | 0.0752 | 2.8% | 8 | 5909 | 11 | 19 | 58 |
| 91500 | 1062 | 15 | 0.1794 | 1.4% | 0.0509 | 2.9% | 0.0763 | 2.8% | 5 | 5694 | 16 | 31 | 87 |
| 91500 | 1062 | 15 | 0.1794 | 1.4% | 0.0543 | 3.0% | 0.0763 | 2.8% | 5 | 5780 | 17 | 32 | 92 |
| 91500 | 1063 | 14 | 0.1798 | 1.3% | 0.0519 | 2.8% | 0.0774 | 2.8% | 7 | 5645 | 16 | 31 | 87 |
| 91500 | 1063 | 16 | 0.1794 | 1.5% | 0.0530 | 2.9% | 0.0751 | 2.9% | 5 | 6004 | 14 | 28 | 78 |
| 91500 | 1064 | 15 | 0.1797 | 1.4% | 0.0541 | 2.6% | 0.0762 | 2.4% | 9 | 6074 | 17 | 33 | 94 |
| 91500 | 1064 | 15 | 0.1800 | 1.4% | 0.0514 | 2.7% | 0.0770 | 2.4% | 7 | 5880 | 16 | 32 | 88 |
| 91500 | 1065 | 16 | 0.1798 | 1.6% | 0.0547 | 3.1% | 0.0757 | 2.9% | 6 | 5994 | 14 | 27 | 77 |
| 91500 | 1065 | 14 | 0.1803 | 1.3% | 0.0549 | 2.8% | 0.0782 | 2.7% | 5 | 5922 | 16 | 32 | 88 |
| 91500 | 1065 | 15 | 0.1795 | 1.4% | 0.0540 | 2.8% | 0.0738 | 2.7% | 7 | 5971 | 17 | 33 | 92 |
| 91500 | 1066 | 17 | 0.1793 | 1.6% | 0.0523 | 3.1% | 0.0726 | 3.0% | 5 | 5946 | 14 | 27 | 76 |
| 91500 | 1066 | 14 | 0.1794 | 1.3% | 0.0552 | 2.5% | 0.0732 | 2.3% | 5 | 5606 | 17 | 33 | 90 |
| 91500 | 1066 | 15 | 0.1795 | 1.5% | 0.0549 | 2.9% | 0.0737 | 2.7% | 5 | 5364 | 15 | 29 | 83 |
| 91500 | 1067 | 17 | 0.1803 | 1.6% | 0.0515 | 3.0% | 0.0767 | 3.3% | 5 | 6042 | 14 | 28 | 79 |
| 91500 | 1067 | 15 | 0.1802 | 1.4% | 0.0543 | 2.8% | 0.0756 | 2.7% | 6 | 5571 | 15 | 30 | 84 |
| 91500 | 1068 | 16 | 0.1802 | 1.5% | 0.0546 | 3.0% | 0.0753 | 3.0% | 5 | 5770 | 11 | 20 | 60 |
| 91500 | 1068 | 15 | 0.1799 | 1.4% | 0.0530 | 3.1% | 0.0736 | 3.2% | 5 | 5513 | 15 | 29 | 82 |
| 91500 | 1069 | 17 | 0.1804 | 1.6% | 0.0520 | 2.9% | 0.0751 | 2.7% | 7 | 5675 | 16 | 31 | 89 |
| 91500 | 1069 | 18 | 0.1810 | 1.7% | 0.0576 | 3.1% | 0.0774 | 3.1% | 3 | 6067 | 15 | 29 | 84 |
| 91500 | 1070 | 15 | 0.1809 | 1.4% | 0.0519 | 2.6% | 0.0770 | 2.6% | 6 | 5997 | 16 | 33 | 91 |
| 91500 | 1072 | 14 | 0.1810 | 1.3% | 0.0544 | 3.0% | 0.0754 | 2.7% | 6 | 6035 | 17 | 34 | 93 |
| 91500 | 1074 | 16 | 0.1815 | 1.5% | 0.0542 | 3.0% | 0.0761 | 2.8% | 6 | 5612 | 16 | 31 | 87 |

Appendix C-1: Continued

| Sample | $^{206}Pb/^{238}U$ age (Ma) | | Isotopic ratios | | | | | | Trace element data (in ppm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis no. | ($^{207}Pb$ corrected.) | +/-1 s | $^{206}Pb/^{238}U$ | % rsd | $^{208}Pb/^{232}Th$ | % rsd | $^{207}Pb/^{206}Pb$ | % rsd | Ti | Hf | Pb | Th | U |
| GJ1 | 592 | 7 | 0.0962 | 1.2% | 0.0272 | 6.1% | 0.0603 | 2.1% | 5 | 7014 | 35 | 13 | 401 |
| GJ1 | 595 | 7 | 0.0967 | 1.1% | 0.0290 | 5.3% | 0.0603 | 2.1% | 5 | 7196 | 35 | 14 | 397 |
| GJ1 | 597 | 6 | 0.0969 | 1.1% | 0.0291 | 5.5% | 0.0594 | 2.1% | 5 | 6697 | 32 | 12 | 360 |
| GJ1 | 601 | 7 | 0.0976 | 1.1% | 0.0289 | 5.1% | 0.0591 | 2.0% | 2 | 6948 | 32 | 12 | 368 |
| GJ1 | 602 | 6 | 0.0979 | 1.1% | 0.0304 | 5.6% | 0.0598 | 2.1% | 4 | 6871 | 34 | 13 | 378 |
| GJ1 | 602 | 6 | 0.0978 | 1.1% | 0.0292 | 5.7% | 0.0592 | 1.9% | 5 | 6874 | 32 | 12 | 362 |
| GJ1 | 603 | 7 | 0.0980 | 1.1% | 0.0318 | 5.8% | 0.0603 | 2.0% | 5 | 6470 | 31 | 12 | 347 |
| GJ1 | 603 | 7 | 0.0983 | 1.1% | 0.0259 | 5.9% | 0.0628 | 1.9% | 2 | 6917 | 32 | 13 | 360 |
| GJ1 | 604 | 7 | 0.0983 | 1.1% | 0.0317 | 5.3% | 0.0603 | 1.9% | 5 | 6613 | 33 | 12 | 359 |
| GJ1 | 605 | 7 | 0.0985 | 1.2% | 0.0294 | 5.4% | 0.0617 | 1.8% | 4 | 7016 | 33 | 13 | 370 |
| GJ1 | 605 | 6 | 0.0985 | 1.0% | 0.0280 | 5.9% | 0.0606 | 2.0% | 5 | 7133 | 35 | 14 | 391 |
| GJ1 | 609 | 7 | 0.0990 | 1.1% | 0.0285 | 5.2% | 0.0599 | 1.8% | 4 | 7060 | 35 | 14 | 401 |
| GJ1 | 611 | 7 | 0.0994 | 1.1% | 0.0301 | 5.7% | 0.0609 | 2.0% | 3 | 7151 | 34 | 13 | 385 |
| GJ1 | 612 | 7 | 0.0995 | 1.1% | 0.0285 | 5.4% | 0.0592 | 1.8% | 4 | 6852 | 33 | 13 | 367 |
| GJ1 | 612 | 7 | 0.0996 | 1.1% | 0.0266 | 6.2% | 0.0598 | 2.0% | 3 | 6835 | 33 | 13 | 373 |
| Temora | 410 | 9 | 0.0657 | 2.2% | 0.0201 | 4.2% | 0.0563 | 5.1% | 8 | 8668 | 5 | 29 | 84 |
| Temora | 414 | 8 | 0.0663 | 2.0% | 0.0192 | 4.4% | 0.0555 | 4.7% | 10 | 8440 | 6 | 31 | 90 |
| Temora | 415 | 7 | 0.0663 | 1.6% | 0.0196 | 4.4% | 0.0538 | 4.3% | 6 | 9294 | 7 | 31 | 117 |
| Temora | 415 | 9 | 0.0665 | 2.1% | 0.0164 | 4.2% | 0.0544 | 4.6% | 16 | 7560 | 5 | 32 | 83 |
| Temora | 416 | 5 | 0.0665 | 1.2% | 0.0210 | 2.1% | 0.0528 | 2.4% | 9 | 9071 | 22 | 139 | 328 |
| Temora | 417 | 6 | 0.0669 | 1.6% | 0.0217 | 2.9% | 0.0557 | 3.6% | 19 | 7690 | 12 | 58 | 180 |
| Temora | 417 | 7 | 0.0672 | 1.7% | 0.0197 | 3.5% | 0.0583 | 3.6% | 11 | 8241 | 10 | 46 | 149 |
| Temora | 420 | 6 | 0.0675 | 1.5% | 0.0201 | 2.4% | 0.0575 | 3.5% | 7 | 8901 | 12 | 91 | 180 |
| Temora | 420 | 8 | 0.0676 | 2.0% | 0.0195 | 3.1% | 0.0574 | 4.5% | 7 | 8888 | 8 | 56 | 113 |
| Temora | 423 | 8 | 0.0673 | 1.9% | 0.0212 | 3.1% | 0.0502 | 4.8% | 15 | 7837 | 7 | 52 | 102 |
| Temora | 425 | 7 | 0.0680 | 1.8% | 0.0206 | 3.1% | 0.0546 | 3.7% | 18 | 7643 | 12 | 80 | 174 |
| Temora | 425 | 8 | 0.0679 | 2.0% | 0.0197 | 3.4% | 0.0524 | 4.8% | 12 | 8591 | 9 | 62 | 134 |
| Temora | 428 | 9 | 0.0684 | 2.2% | 0.0221 | 4.8% | 0.0522 | 6.2% | 14 | 8185 | 5 | 22 | 71 |
| Temora | 429 | 8 | 0.0684 | 1.9% | 0.0207 | 3.7% | 0.0513 | 4.8% | 9 | 9222 | 7 | 32 | 101 |
| Temora | 430 | 9 | 0.0688 | 2.2% | 0.0211 | 4.5% | 0.0538 | 5.3% | 15 | 7268 | 5 | 21 | 75 |

Appendix C-1: Continued

| Sample | $^{206}Pb/^{238}U$ age (Ma) | | Isotopic ratios | | | | | | Trace element data (in ppm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analysis no. | ($^{207}Pb$ corrected.) | +/-1 s | $^{206}Pb/^{238}U$ | % rsd | $^{208}Pb/^{232}Th$ | % rsd | $^{207}Pb/^{206}Pb$ | % rsd | Ti | Hf | Pb | Th | U |
| Mudtank | 678 | 38 | 0.1107 | 5.6% | 0.0346 | 11.4% | 0.0612 | 19.5% | 5 | 10981 | 1 | 3 | 6 |
| Mudtank | 692 | 42 | 0.1185 | 6.0% | 0.0318 | 11.9% | 0.0981 | 13.9% | 5 | 11313 | 1 | 3 | 7 |
| Mudtank | 694 | 39 | 0.1154 | 5.6% | 0.0454 | 11.7% | 0.0745 | 17.5% | 9 | 11320 | 1 | 3 | 7 |
| Mudtank | 707 | 32 | 0.1176 | 4.5% | 0.0417 | 9.7% | 0.0742 | 15.3% | 9 | 11096 | 1 | 3 | 10 |
| Mudtank | 724 | 21 | 0.1190 | 2.9% | 0.0348 | 7.3% | 0.0647 | 9.1% | 12 | 11063 | 2 | 8 | 20 |
| Mudtank | 726 | 37 | 0.1210 | 5.1% | 0.0360 | 11.2% | 0.0757 | 10.8% | 8 | 11105 | 1 | 3 | 8 |
| Mudtank | 730 | 43 | 0.1217 | 5.9% | 0.0278 | 16.2% | 0.0754 | 14.7% | 8 | 11328 | 1 | 3 | 8 |
| Mudtank | 732 | 40 | 0.1208 | 5.5% | 0.0308 | 13.5% | 0.0674 | 15.8% | 5 | 11271 | 1 | 2 | 6 |
| Mudtank | 737 | 32 | 0.1211 | 4.3% | 0.0402 | 8.7% | 0.0636 | 13.2% | 9 | 10313 | 1 | 4 | 10 |
| Mudtank | 740 | 52 | 0.1230 | 7.0% | 0.0267 | 25.2% | 0.0729 | 17.4% | 5 | 11760 | 1 | 2 | 4 |
| Mudtank | 748 | 32 | 0.1226 | 4.3% | 0.0330 | 12.7% | 0.0615 | 13.7% | 7 | 10737 | 1 | 3 | 8 |
| Mudtank | 752 | 53 | 0.1243 | 7.0% | 0.0267 | 20.4% | 0.0683 | 23.5% | 6 | 11709 | 1 | 2 | 4 |
| Mudtank | 757 | 38 | 0.1244 | 5.0% | 0.0277 | 13.1% | 0.0628 | 14.3% | 9 | 11289 | 1 | 3 | 10 |
| Mudtank | 769 | 48 | 0.1285 | 6.3% | 0.0383 | 13.6% | 0.0759 | 16.2% | 4 | 11232 | 1 | 2 | 6 |
| NIST610 | | | 0.2358 | 0.9% | 0.5346 | 1.2% | 0.9065 | 0.5% | | | | | |
| NIST610 | | | 0.2393 | 1.0% | 0.5267 | 1.2% | 0.9067 | 0.5% | | | | | |
| NIST610 | | | 0.2395 | 1.0% | 0.5179 | 1.2% | 0.9053 | 0.6% | | | | | |
| NIST610 | | | 0.2351 | 1.1% | 0.5267 | 1.2% | 0.9138 | 0.6% | | | | | |
| NIST610 | | | 0.2367 | 1.1% | 0.5206 | 1.2% | 0.9098 | 0.5% | | | | | |
| NIST610 | | | 0.2377 | 1.1% | 0.5138 | 1.2% | 0.9004 | 0.5% | | | | | |
| NIST610 | | | 0.2373 | 1.0% | 0.5063 | 1.2% | 0.9090 | 0.5% | | | | | |
| NIST610 | | | 0.2392 | 1.0% | 0.5012 | 1.2% | 0.9108 | 0.5% | | | | | |

# APPENDIX D

## Published Data/ Work

# VOLCANIC/HYPABYSSAL ROCKS IN NAKHON SAWAN AND UTHAI THANI PROVINCES, THAILAND: AGE DATING

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**ABSTRACT:** Petrography and U-Pb zircon dating of the least-altered felsic to mafic volcanic/hypabyssal rocks in the area of Tha Tako District, Nakhon Sawan and the western part of Uthai Thani Provinces are presented. The felsic to mafic volcanic/hypabyssal rocks exposed in several isolated N-S trending hills and mountains of the area and occurs as lava flows, stocks and dikes, and possibly form parts of any volcanic belts previously recognized in northern Thailand. Volcanic rocks of the lava-flow facies range in composition from andesite to latite and rhyolite, and hypabyssal rocks occur as stocks of various sizes comprising granite, granodiorite and diorite. Most volcanic rocks have porphyritic textures, and most hypabyssal rocks have seriate texture. The phenocrysts/microphenocrysts in porphyritic samples are commonly plagioclase and may include clinopyroxene, alkali-feldspar, amphibole and Fe-Ti oxide. The matrix of lava flows ranges texturally from felty to trachytic with a few samples having felty to ophitic/subophitic textures, whereas that of hypabysal samples is holocrystalline. The primary matrix constituents are largely plagioclase and variable proportions of clinopyroxene, Fe-Ti oxide, amphibole, quartz and alkali feldspar. Two carefully selected samples were analyzed by U-Pb zircon dating method that yielded two different ages: Early Carboniferous (345.5 ± 3.4 Ma) for predominately felsic volcanic rocks in the area of Tha Tako District, Nakhon Sawan Province, and Late Triassic (225.4 ± 1.9 Ma) for predominately hypabyssal rocks exposed along the western part of Uthai Thani Province.



**Introduction:** The pre-Cretaceous felsic to mafic volcanic/hypabyssal rocks in Thailand may be separated into four belts (Fig. 1) from west to east as Chiang Rai - Chiang Mai volcanic belt, Chiang Khong - Tak volcanic belt, volcanic rocks in Nan - Uttaradit volcanic belt, and Loei - Phetchabun - Nakhon Nayok volcanic belt. The Chiang Rai - Chiang Mai volcanic belt forms a broad zone from the western part of Chiang Rai Province through the eastern part of Chiang Mai Province to Li District, Lamphun Province. The Chiang Khong - Tak volcanic belt is in the east of the Chiang Rai - Chiang Mai volcanic belt, extending from Chiang Khong District (Chiang Rai Province) to Tak Province via Lampang and Phrae Provinces. The Nan - Uttaradit volcanic belt is located between the Chiang Khong - Tak volcanic belt and Loei - Phetchabun - Nakhon Nayok volcanic belt, extending from Nan to Uttaradit Provinces. The Loei - Phetchabun - Nakhon Nayok volcanic belt runs in NNE-SSW direction from Loei through Phetchabun to Nakhon Nayok Provinces.

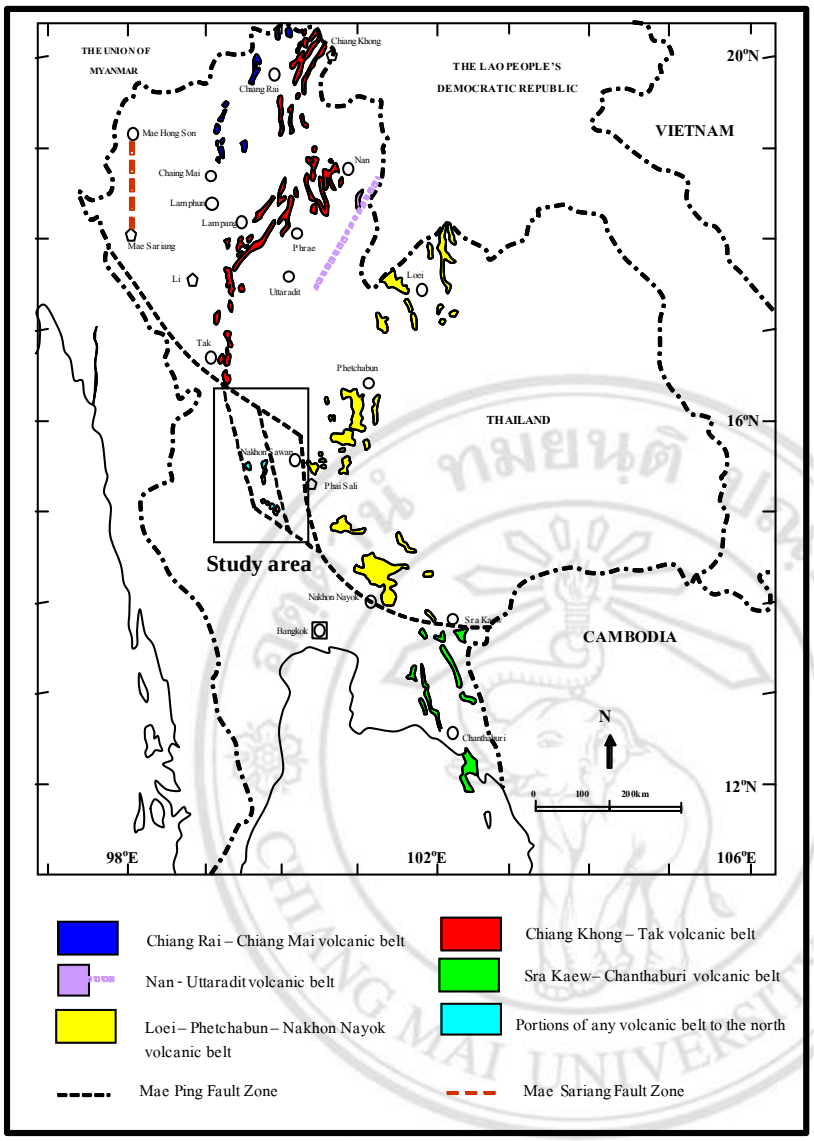



Figure 1: Distribution of pre-Cretaceous mafic volcanic rocks in Thailand (modified from Kosuwan, 2004; Panjasawatwong et al, 2006). The Mae Ping Fault Zone and the Mae Yuam Fault Zone are taken from Morley (2002) and Hisada et al, (2004) respectively



This study is aimed to clarify the occurrences, field relationship to other rock types, petrochemical features, timing of formation and tectonic settings of the volcanic rocks in the felsic to mafic volcanic/hypabyssal rocks in Uthai Thani and Nakhon Sawan Provinces, Thailand. These are part of informative data in depicting the tectonic evolution of Thailand and exploration of mineral resources in Thailand. The felsic to mafic volcanic/hypabyssal rocks along the Upper Central Plain Thailand are the portion of any volcanic belt in the north and have the most problems concerning field relationship, ages, occurrences, and tectonic settings of formation because the occurrence of these rock were cross cut and transferred by the Mae Ping fault zone.

Morley (2002) studied the Mae Ping fault zone that exposed around the Lan Sang national park, on the Tak-Mae Sot highway. The trace of the faults is interrupted in central Thailand. Their Pliocene-Recent thermal sag basin deposits associated with underlying late Tertiary rift create a flat topography which cover the fault, whose outcrop trace are apparent in the hilly regions to the west. In one part of the Central Plains elongate upper and lower Paleozoic outlines trending N-S to NNW-SSE poke through thin Pliocene-Pleistocene sediments. These outliers are interpreted here as representing a strike-slip duplex geometry. The duplex, known as a region of uplift called the Chai Nat ridge, lies between two major Tertiary sedimentary basins, the Phetchabun and Suphan Buri basins. The duplex formed at a major right-stepping bend in the Mae Ping fault zone and demonstrates that left-lateral fault displacement was not responsible for creating the Tertiary rift basins because the ridge developed at a restraining bend in the fault is consistent with left-lateral motion, and the right-lateral motion was relatively minor, because the right-stepping geometry is ideal for the creation of a pull-apart basin, yet the main Tertiary basins lie north and south of the Chai Nat ridge, not on the ridge. However, minor episodic right-lateral reactivation might have occurred numerous times during the Miocene-Pliocene, perhaps associated with phase of inversion (Morley, 2001). The trace of the Mae Ping fault zone is believed to strike NW-SE, though Cambodia, in the vicinity of Ton Le Sap lake, and though the Mekong delta (Lacassin et al, 1997) and is currently undergoing episodic, low-strain-rate-dextral motion.

The majority of the outcrops within the Chai Nat ridge are lower to upper Paleozoic slaty to phyllitic igneous, volcaniclastic, and metasedimentary rocks. The rocks have been though at least the Permo-Triassic Indosinian Orogeny, which itself has several deformation episodes (Charusiri et al, 1993). Carbonate rocks of Silurian-Devonian and Permo-Triassic ages have been mapped with the Chai Nat duplex, these rocks display a wide range of characteristics, including: recrystallized marbles with little remaining primary sedimentary fabric; massive carbonates, partially recrystallized and heavily veined; well-bedded massive carbonates that contain fossils of fusulinids, brachiopods and coral and well-bedded carbonates interbedded with shales. Granite is intruded by heavily altered mafic dyke, that in places have taken on a subvertical, north-south-striking shear-zone-related foliation. Apatite fission-track dating of the granite outcrop shows rapid cooling in the Miocene, with a central age of 18 $\pm$ 1 Ma (Morley et al, 2007).



**Geological Setting:** The felsic to mafic volcanic/hypabyssal rocks in the area of Nakhon Sawan and Uthai Thani Provinces are the portion of any volcanic belt in the north. Igneous rocks, including plutonic, volcanic and volcaniclastic rocks are widespread in several isolated N-S trending hills and mountains in the study area and occur as lava flows, stocks, and dikes. They are distributed in the western part of Uthai Thani Province, and area of Tha Tako and Phi Sali Districts, Nakhon Sawan Province. Intrusive rocks are granite, granodiorite and diorite that occur as stocks of various sizes and some may intrude the older sedimentary rocks of Permian and Silurian-Devonian in ages. The volcanic and volcaniclastic rocks range in composition from andesite to dacite and rhyolite that form as lava flows and ejectas and overlie Permian and pre-Permian

rocks. Igneous rocks in this area are believed to have been formed during the period between the post-Permian and the pre-Jurassic (Figure 2).

Boonsue (1986) studied igneous rocks in the study area that were classified as extrusives and intrusives. They were distributing as north-south trending chains of small hills or mountains or outline of stocks in sedimentary rocks. The compositions of these rocks are ranging form intermediate to silicic. Evidences from field, petrography and geochemical studies suggested that the intrusive rocks are shallow emplaced and are related to the capped volcanic rock. The rhyolitic pyroclastic rocks are generally late in sequence of igneous activities. They are interbedded with sandstone, shale and carbonate rocks of the Middle Triassic in ages. The volcanic rocks are andesite and rhyolitic tuff. The former is overlain by rhyolitic tuff at Khao Khot Yang whereas the latter is interlayered with the sedimentary sequence. The Triassic rocks overlie unconformably on the Paleozoic rocks. It is even possible from the present study to indicate that the activities took place between post-Permian and middle Triassic based on the stratigraphic succession and the paleontological evidence. Geochemical data and their variation diagrams indicate that these plutonic and volcanic rocks belong to same differentiation trend of calc-alkaline series of intermediate to silicic rocks, arcs of the continental margin type seem to be more favorable so have been developed in the Loei fold belt or the Sukhothai fold belt.

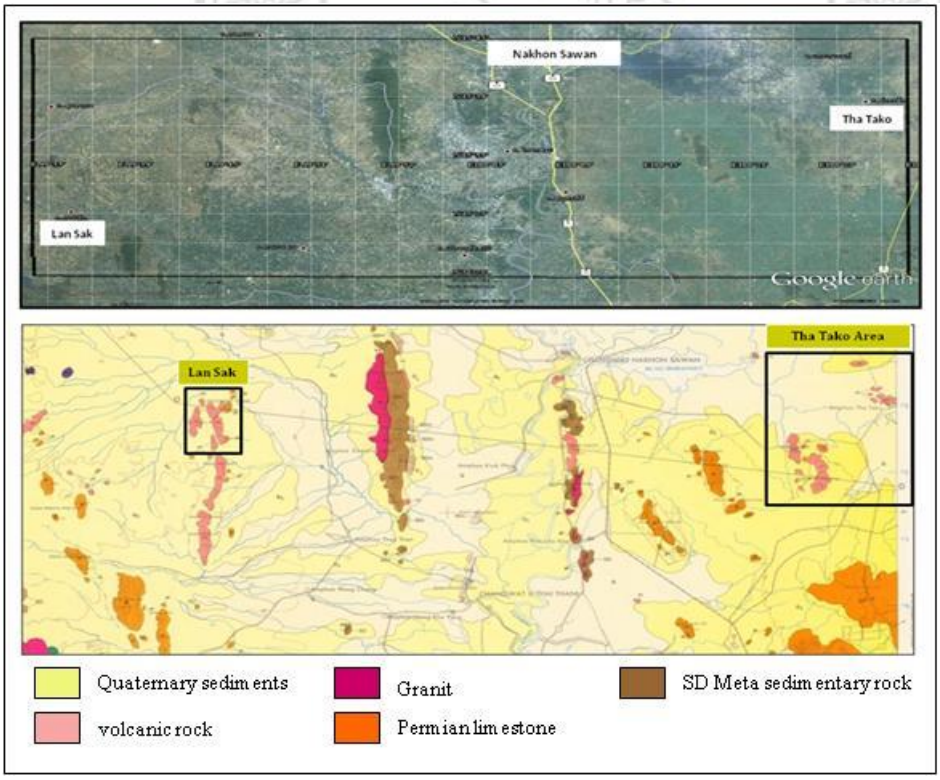



Figure2: Geological map show volcanic rock in Tha Tako and Lan Sak area

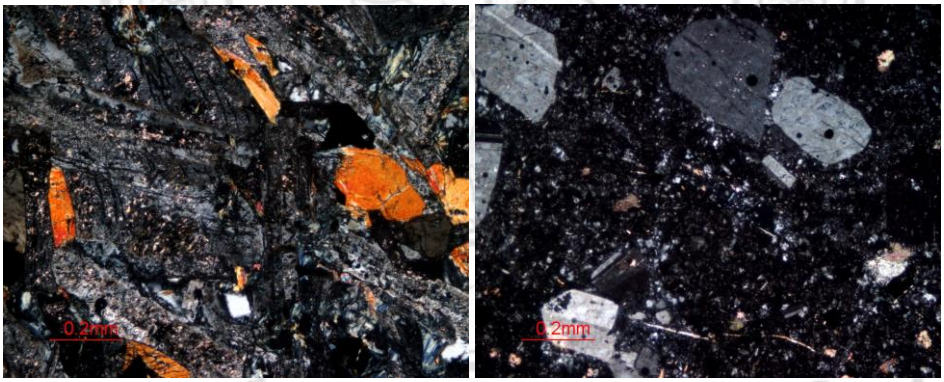
**Methodology:** Field investigation and collection of least-altered felsic to mafic volcanic samples were carried out in the study area. Petrographic studies of the least-altered samples were done by using transmitted light microscopy via thin section. Isotope

analyses for U–Pb dating of samples in order to determine initial ratios and ages were applied by using LA-ICPMS zircon geochronology.

**Results:**

**Petrography**

Petrographic studies were carried out on 48 least-altered felsic to mafic volcanic/hypabyssal rocks. They are composed of andesitic basalt, rhyolite and diorite/microdiorite. The Tha Tako area is composed of largely felsic to mafic volcanic rocks with minor amount of hypabyssal rocks. They show porphyritic texture with phenocrysts/microphenocrysts assemblages of plagioclase with subordinate K-feldspar and Fe-Ti oxide. These phenocrysts/microphenocrysts may form as isolate, plagioclase glomerocrysts and as plagioclase-Fe-Ti oxide cumulocrysts. The groundmass is holocrystalline and consists largely of plagioclase lath, K-feldspar, quartz and small amount of Fe-Ti oxide. Secondary patches of chlorite/serpentine, titanite/leucoxene and epidote minerals have been observed in minor amount. The Lan Sak area is abundantly of hypabyssal rocks with minor amount of felsic to mafic volcanic rocks. The rock samples are seriate-textured and consist mainly of plagioclase with subordinate clinopyroxene, orthopyroxene and Fe-Ti oxide. Patches of secondary chlorite/serpentine, pyrite, titanite/leucoxene and quartz have been observed in minor amount (Figure 3).




(a) (b)

Figure 3: Photomicrograph of seriated texture in diorite/microdiorite in Lan Sak (a) and porphyritic texture in basaltic andesite in Tha Tako (b)



**Isotope Study**

The LA-ICP-MS zircon geochronology were performed at the University of Tasmania using LA-ICP-MS method that is now widely used for measuring U, Th and Pb isotopic data. The method outlined in detail in Meffre et al. (2008). Two selected samples were collected from the area of Lan Sak and Tha Tako, and were analyzed by U-Pb zircon dating method that yielded two different ages: Early Carboniferous (345.5 ± 3.4 Ma) for predominately felsic volcanic rocks in the area of Tha Tako District, Nakhon Sawan Province, and Late Triassic (225.4 ± 1.9 Ma) for predominately hypabyssal rocks exposed along the western part of Uthai Thani Province (Figure4 and Table1).

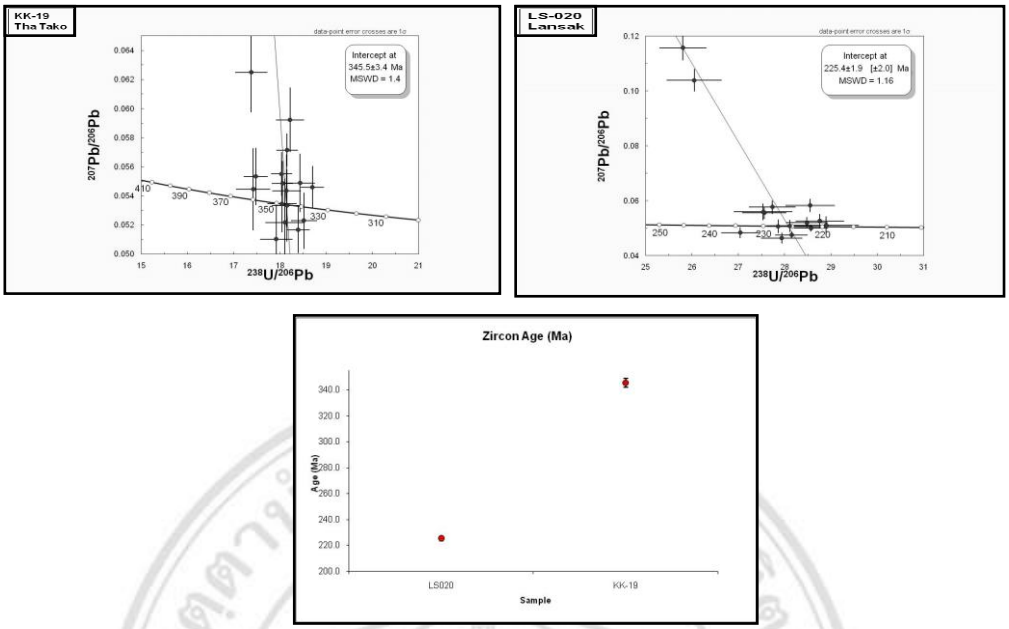



Figure 4: Plots of $^{207}Pb/^{206}Pb$ zircon ages for individual LA-ICP-MS analysis from the selected samples

Table 1. Summary of geochronological U-Pb zircon data and sample location

| **Sample** | **Rock name** | **Study area** | **$^{207}Pb/^{206}Pb$ zircon age (Ma ± 2σ)** |
|---|---|---|---|
| KK-19 | Rhyolite | Tha Tako, Nakhon Sawan Province | 345.5 ± 3.4 |
| LS-020 | Diorite | Lansak, Uthai Thani Province | 225.4 ± 1.9 |

**Discussion and Conclusion:** From field investigation and petrographic study show that the felsic to mafic volcanic rocks were found abundantly in the area of Tha Tako, Nakhon Sawan Provinces while the hypabyssal rocks were found largely in the area of Lan Sak, Uthai Thani. Most of andesitic basalt to rhyolite samples are show porphyritic texture and have Early Carboniferous (345.5 ± 3.4 Ma) in age. Diorite/microdiorite samples are seriate-textured and have Late Triassic (225.4 ± 1.9 Ma) in age. It is suggested that the timing of formation of felsic to mafic volcanic rock in this study area were erupted in Carboniferous followed by diorite/microdiorite intrusion during late Triassic.

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**Key words:** U-Pb zircon dating, Nakhon Sawan-Uthai Thani Volcanics

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**VOLCANIC/HYPABYSSAL ROCKS IN NAKHON SAWAN AND UTHAI THANI PROVINCES, THAILAND: A REVIEW**

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## ABSTRACT

Petrography and U-Pb zircon dating of the least-altered felsic to mafic volcanic/hypabyssal rocks in the area of Tha Tako District, Nakhon Sawan and the western part of Uthai Thani Provinces are presented. The felsic to mafic volcanic/hypabyssal rocks exposed in several isolated N-S trending hills and mountains of the area occur as lava flows, stocks and dikes, and possibly form parts of any volcanic belts previously recognized in northern Thailand. Volcanic rocks of the lava-flow facies range in composition from andesite to latite and rhyolite, and hypabyssal rocks occur as stocks of various sizes comprising granite, granodiorite and diorite. Most volcanic rocks have porphyritic textures, and most hypabyssal rocks have seriate texture. The phenocrysts/microphenocrysts in porphyritic samples are commonly plagioclase and may include clinopyroxene, alkali-feldspar, amphibole and Fe-Ti oxide. The matrix of lava flows ranges texturally from felty to trachytic with a few samples having felty to ophitic/subophitic textures, whereas that of hypabysal samples is holocrystalline. The primary matrix constituents are largely plagioclase and variable proportions of clinopyroxene, Fe-Ti oxide, amphibole, quartz and alkali feldspar. Two carefully selected samples were analyzed by U-Pb zircon dating method that yielded two different ages: Early Carboniferous (345.5 ± 3.4 Ma) for predominately felsic volcanic rocks in the area of Tha Tako District, Nakhon Sawan Province, and Late Triassic (225.4 ± 1.9 Ma) for predominately hypabyssal rocks exposed along the western part of Uthai Thani Province.

**Key words:** U-Pb zircon dating, Nakhon Sawan-Uthai Thani Volcanics

# Geochemistry of Mafic to Felsic Volcanic/Hypabyssal Rocks from Nakhon Sawan and Uthai Thani Provinces, Central Thailand

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**ABSTRACT**

The felsic to mafic volcanic and hypabyssal rocks in Nakhon Sawan and Uthai Thani Provinces are possibly the portion of Chiang Khong - Tak volcanic belt and Loei - Phetchabun - Nakhon Nayok volcanic belt, Thailand. They are least-altered, and probably have been formed in Carboniferous and late Triassic. Geochemically, the studied rock samples can be separated into five magmatic groups: Group I-II-III-IV-V. These magmatic groups are different in the values of $Zr/TiO_2$ and Nb/Y ratios. The $Zr/TiO_2$ and Nb/Y values for Group I-to-V are 0.01-0.08 and 0.09-0.33, 0.05-0.09 and 0.39-0.43, 0.004-0.009 and 0.05-0.12 and 0.038-0.039 and 0.20-0.21, respectively. The rock types of Group I are calc-alkalic rhyodacite/dacite, andesite/basalt and gabbro, Group II rocks are calc-alkalic diorite, Group III and Group IV rocks are tholeiitic andesite/basalt and microdiorite/microgabbro and Group V rocks are shoshonitic rhyodacite/dacite. Accordingly, the magmatic affinity and Ta-Nb anomaly on normal mid-oceanic ridge basalt (N-MORB) normalized multi-elements plot indicates that they have been characterized as subduction-related magma.

Keywords: Geochemistry, Nakhon Sawan-Uthai Thani, felsic to mafic volcanic/hypabyssal rock

## INTRODUCTION

The pre-Cretaceous felsic to mafic volcanic/hypabyssal rocks in Thailand may be separated into four belts (Fig. 1) from west to east as Chiang Rai - Chiang Mai volcanic belt, Chiang Khong - Tak volcanic belt, volcanic rocks in Nan - Uttaradit volcanic belt, and Loei - Phetchabun - Nakhon Nayok volcanic belt. The Chiang Rai - Chiang Mai volcanic belt forms a broad zone from the western part of Chiang Rai Province through the eastern part of Chiang Mai Province to Li District, Lamphun Province. The Chiang Khong - Tak volcanic belt is in the east of the Chiang Rai - Chiang Mai volcanic belt, extending from Chiang Khong District (Chiang Rai Province) to Tak Province via Lampang and Phrae Provinces. The Nan - Uttaradit volcanic belt is located between the Chiang Khong - Tak volcanic belt and Loei - Phetchabun - Nakhon Nayok volcanic belt, extending from Nan to Uttaradit Provinces. The Loei - Phetchabun - Nakhon Nayok volcanic belt runs in NNE-SSW direction from Loei through Phetchabun to Nakhon Nayok Provinces.

This study is aimed to clarify geochemistry of felsic to mafic volcanic/hypabyssal rocks in Nakhon Sawan and Uthai Thani Provinces. These are part of informative data in depicting the tectonic evolution of Thailand and exploration of mineral resources in Thailand.

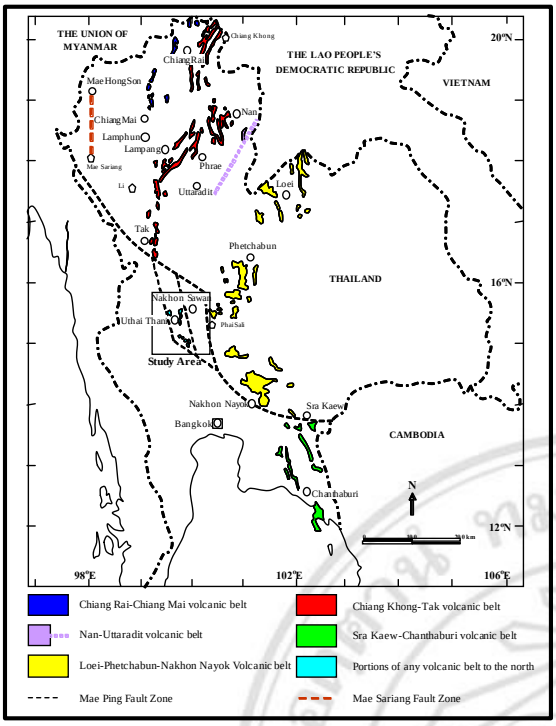


Fig.1 Distribution of pre-Cretaceous mafic volcanic rocks in Thailand (modified from Jungyusuk and Khositanont, 1992; Kosuwan, 2004; Panjasawatwong, *et al.,* 2006; Phaejuy, 2008 and Boonsoong, *et al.,* 2011). The Mae Ping Fault Zone and the Mae Sariang Fault Zone are taken from Morley (2002) and Hisada, *et al.,* (2004) respectively.

## GEOLOGICAL SETTING

The felsic to mafic volcanic/hypabyssal rocks in the area of Nakhon Sawan and Uthai Thani Provinces are the portion of any volcanic belt in the north. Igneous rocks, including plutonic, volcanic and volcaniclastic rocks are widespread in several isolated N-S trending hills and mountains in the study area, and occur as lava flows, stocks, and dikes. They distribute in the western part of Uthai Thani Province, and area of Tha Tako and Phi Sali Districts, Nakhon Sawan Province. Intrusive rocks are granite, granodiorite and diorite that occur as stocks of various sizes, and some may intrude the older sedimentary rocks of Permian and Silurian-Devonian ages. The volcanic and volcaniclastic rocks range in composition from andesite to dacite and rhyolite that form as lava flows and ejectas. They overlie Permian and pre-Permian rocks. Igneous rocks in this area have been formed during the period Carboniferous and late Triassic based on the zircon dating. The present study possibly indicates that the igneous activities took place between post-Permian and middle Triassic based on the stratigraphic succession and the paleontological evidence. The studied felsics to mafic volcanic/hypabyssal rocks have been developed in the Chiang Khong - Tak volcanic belt and Loei - Phetchabun - Nakhon Nayok volcanic belt.

## METHODOLOGY

Field work was conducted in the study area, and then petrographic studies of the least-altered samples were carried out by using transmitted light microscopy via thin section.

The fifty-four carefully selected felsic to mafic volcanic/hypabyssal rocks were prepared for whole-rock chemical analysis by powdering. These powder samples were chemically analyzed for major oxides, trace elements, rare-earth elements (REE) and loss on ignition (LOI).

The Chemical analyzes of major oxides ($SiO_2$, $TiO_2$, $Al_2O_3$, FeO*, MnO, MgO, CaO, $Na_2O$, $K_2O$ and $P_2O_5$) were performed by using an Automated Philips PW 1480 X-Ray Fluorescence (XRF) Spectrometer with a Phillips MagixPro PW 2400 Wavelength Dispersive Sequential X-ray Spectrometer, installed at the Department of Geological Sciences, Faculty of Sciences, Chiang Mai University, Chiang Mai, Thailand.

The Chemical analyzes of trace elements (Ga, Ge, Cs, Ba, Rb, Sr, Y, Zr, Nb, Ni, Cr, V, Sc, Hf, Pb, Ta, Th and U) and the REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu) were analyzed by using a Thermo Scientific XSERIES 2 Inductively Coupled Plasma Mass Spectrometry (ICP-MS) installed at the Key Laboratory of Isotope Geochronology and Geochemistry, the Guangzhou Institute of Geochemistry, Chinese Academy Sciences (CAS), Guangzhou, China.

## GEOCHEMISTRY

The chemical compositions of the studied least-altered mafic to felsic volcanic/hypabyssal rocks were used for rocks nomenclature by plot on the $Zr/TiO_2$-Nb/Y diagram of Winchester and Floyd (1977) (Fig. 2). They can be divided into five groups by magmatic series that difference in styles of REE patterns and N-MORB normalized multi-elements patterns as Group I rocks (calc-alkalic), Group II rocks (calc-alkalic), Group III rocks (tholeiitic), Group IV rocks (tholeiitic) and Group V rocks (shoshonitic).

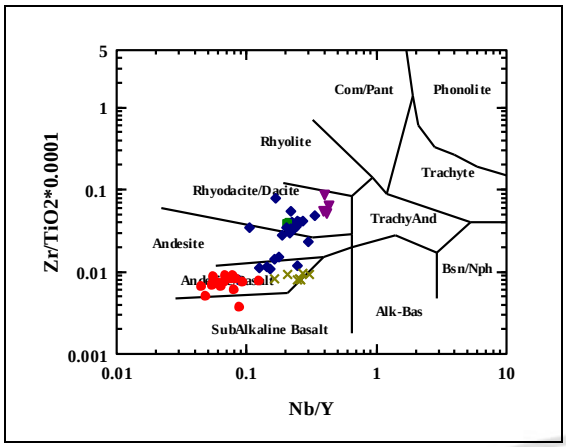


Fig. 2 Plot of $Zr/TiO_2$ against Nb/Y for the studied least-altered felsic to mafic volcanic/hypabassal rocks that divided into five magmatic groups as Group I (diamond), Group II (triangle), Group III (cross), Group IV (circle) and Group V (square). Field boundaries for different magma types are taken from Winchester and Floyd (1977).

## Group I rocks

Group I rocks are composed of twenty three rock samples and have $Zr/TiO_2$ and Nb/Y ratios in the ranges of 0.01 to 0.08 and 0.09 to 0.33 respectively, corresponding to subalkalic rhyodacite/dacite and only a few in subalkalic andesite/basalt. Group I rocks are felsic to mafic volcanic rocks; only one sample (NKT-093) is mafic hypabyssal rock (gabbro).

The relationships between incompatible-element pairs, such as Nb-Zr and Y-Zr, are linear, with ratios of Nb/Zr = 0.04 ± 0.007 and Y/Zr 0.20 ± 0.060 (Fig. 3). These signify that the rocks in this group are essentially co-magmatic.

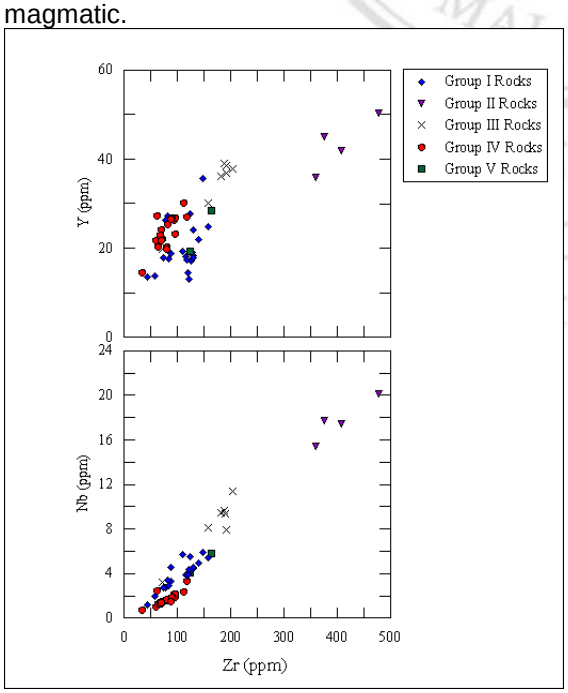


Fig.3 Plots of Y and Nb against Zr for the studied least-altered felsic to mafic volcanic/hypabassal rocks.

Chondrite-normalized values for La and Lu are ranges of 21.68 - 107.43 and 6.09 - 19.31, respectively. Their REE patterns (Fig. 4) are typical of calc-alkalic rocks, i.e. light REE (LREE) enrichment and relatively flat heavy REE (HREE), with chondrite-normalized La/Sm [(La/Sm)cn] and Sm/Lu [(Sm/Lu)cn] ranging from 1.89 to 5.38 and 1.15 to 2.48, respectively. The rocks generally show flat patterns with negative Nb and Ta anomalies on N-MORB normalized multi-element patterns (Fig. 5). This indicates that they have been characterizes as subduction-related magma.

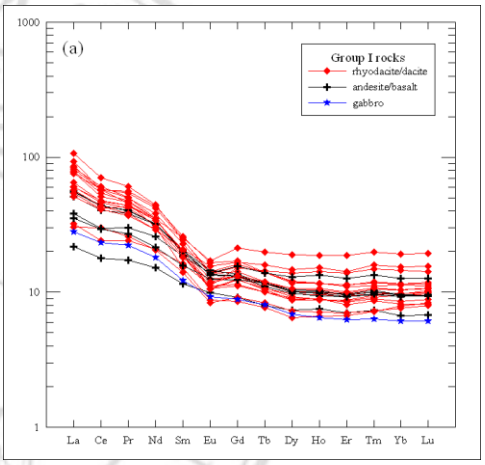


Fig.4 Chondrite-normalized REE patterns for the studied least-altered Group I rocks. Normalizing value used are those of Taylor and Gorton (1977).

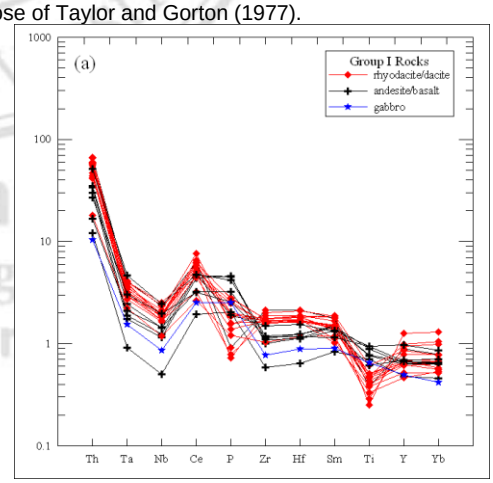


Fig.5 N-MORB normalized patterns for the studied least-altered Group I rocks. Normalizing value used are those of Sun and McDonough (1989).

## Group II rocks

Group II rocks are composed of four rock samples and have $Zr/TiO_2$ and Nb/Y ratios in the ranges of 0.05 to 0.09 and 0.39 to 0.43 respectively, corresponding to subalkalic

rhyodacite/dacite. They are classified as intermediate hypabyssal rocks (diorite).

The relationships between incompatible-element pairs for Group II rocks, such as Nb-Zr and Y-Zr, are linear, with ratios of Nb/Zr = 0.04 ± 0.005 and Y/Zr 0.11 ± 0.010. These signify that the Group II rocks are essentially co-magmatic. Chondrite-normalized values for La and Lu are range of 180 - 218 and 17.9 – 24.2, respectively. Their REE patterns (Fig. 6) are typical of calc-alkalic rocks, i.e. LREE enrichment and relatively flat HREE with (La/Sm)cn and (Sm/Lu)cn ranging from 3.24 to 4.79 and 2.29 to 2.54, respectively. N-MORB normalized multi-element patterns (Fig. 7), the rocks generally show flat patterns with

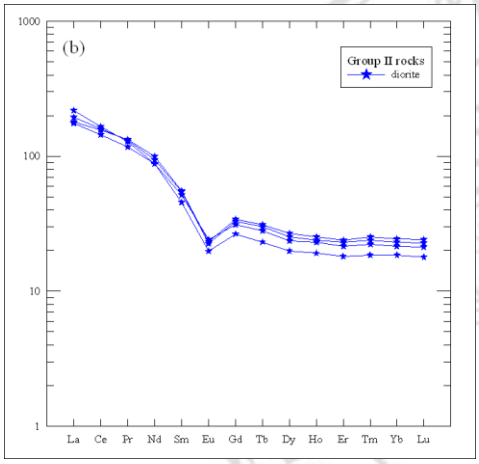


Fig. 6 Chondrite-normalized REE patterns for the studied least-altered Group II rocks. Normalizing value used are those of Taylor and Gorton (1977).

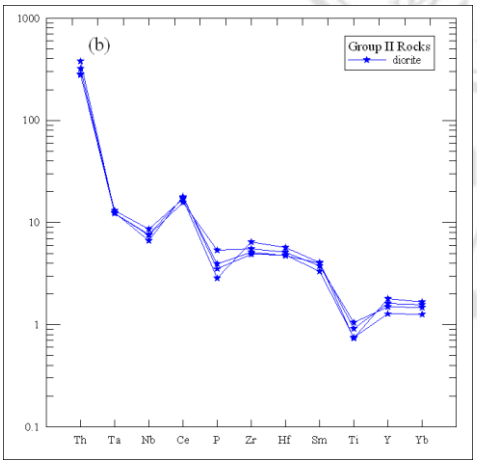


Fig.7 N-MORB - normalized patterns for the studied least-altered Group II rocks. Normalizing value used are those of Sun and McDonough (1989).

negative Nb and Ta anomalies. This indicates that they have been characterizes as subduction-related magma.

**Group III rocks**

Group III rocks are composed of seven rock samples and have $Zr/TiO_2$ and Nb/Y ratios in the ranges of 0.009-0.010 and 0.16 to 0.30 respectively, corresponding to subalkalic andesite/basalt. Accordingly, Group III rocks are classified as intermediate to mafic volcanic rocks (andesite/basalt) and intermediate mafic hypabyssal rock (microdiorite/microgabbro) by their textures and mineral compositions. The relationships between incompatible element pairs for Group III rocks, such as Nb- Zr and Y-Zr, are Nb/Zr = 0.048 ± 0.007 and Y/Zr = 0.206 ± 0.030. These signify that the Group III rocks are essentially co-magmatic.

Chondrite-normalized values for La and Lu are in the range of 22.6 - 53.4 and 11.5 - 18.8, respectively. Their REE patterns (Fig. 8) are typical of tholeiitic rocks, i.e. LREE and HREE relatively flat, with (La/Sm)cn and (Sm/Lu)cn ranging from 1.18 to 1.53 and 1.38 to 1.85, respectively. The N-MORB normalized multi-element patterns (Fig. 9), the rocks generally show flat patterns with negative niobium anomalies. This indicates that they have been crystallized from MORB-like magma that contain crustal signature. The negative niobium anomalies of diorite/gabbro might have ascended from the accumulate nature of diorite/gabbro protolith.

**Group IV rocks**

Group IV rocks are composed of eighteen rock samples and have $Zr/TiO_2$ and Nb/Y ratios in the ranges of 0.004 to 0.009 and

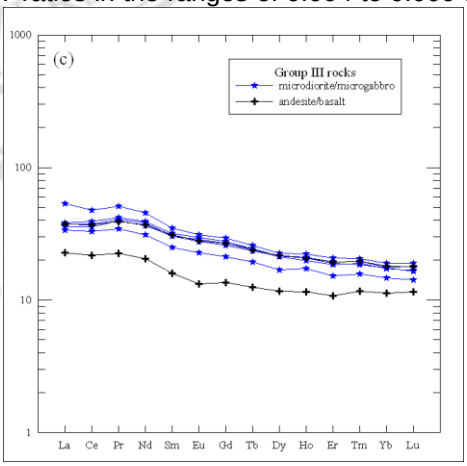


Fig.8 Chondrite-normalized REE patterns for the studied least-altered Group III rocks. Normalizing value used are those of Taylor and Gorton (1977).

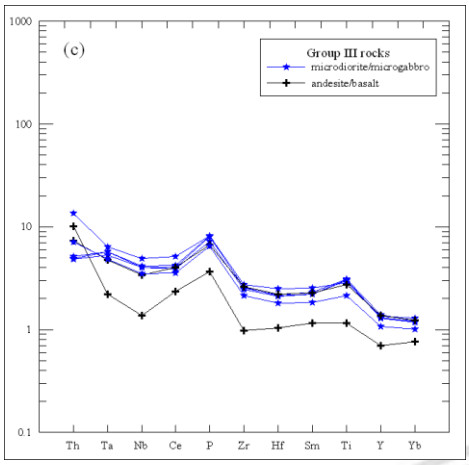


Fig.9 N-MORB - normalized patterns for the studied least-altered Group III rocks. Normalizing value used are those of Sun and McDonough (1989).

0.05 to 0.12, respectively, corresponding to subalkalic andesite/basalt and one sample subalkalic basalt. Accordingly, Group III rocks are classified as intermediate to mafic hypabyssal rocks (microdiorite/microgabbro) and intermediate mafic volcanic rock (andesite/basalt) by their textures and mineral compositions.

The relationships between incompatible-element pairs for Group IV rocks, such as Nb-Zr and Y-Zr, are Nb/Zr = 0.022 ± 0.005 and Y/Zr = 0.309 ± 0.058. These signify that the Group IV rocks are essentially co-magmatic.

Chondrite-normalized values for La and Lu are range of 11.5 - 28.3 and 7.03 - 15.6, respectively. Their REE patterns (Fig. 10) are typical of tholeiitic rocks, i.e. LREE and HREE relatively flat, with (La/Sm)cn and (Sm/Lu)cn ranging from 0.87 to 1.49 and 1.25 to 1.84, respectively. The N-MORB normalized multi-element patterns (Fig. 11), the rocks generally show flat patterns with negative niobium

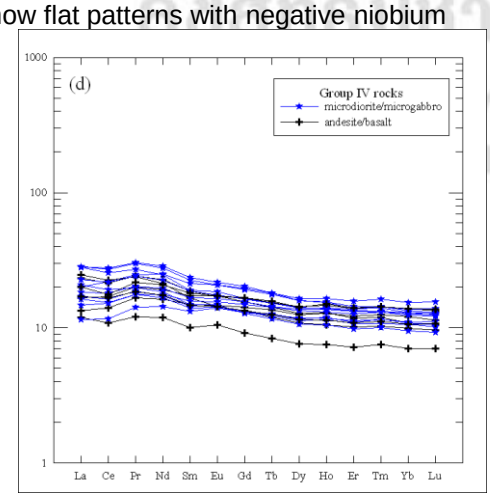


Fig.10 Chondrite-normalized REE patterns for the studied least-altered Group IV rocks. Normalizing value used are those of Taylor and Gorton (1977).

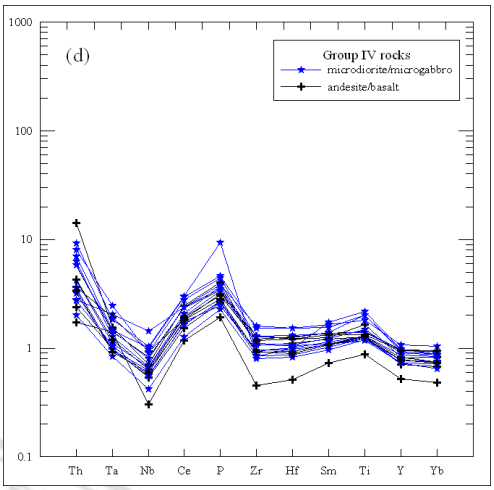


Fig.11 N-MORB - normalized patterns for the studied least-altered Group IV rocks. Normalizing value used are those of Sun and McDonough (1989).

anomalies. These indicates that the subalkalic andesite/basalt rocks have been crystallized from MORB-like magma that contain crustal signature. The negative niobium anomalies of diorite/gabbro might have ascended from the accumulate nature of diorite/gabbro protolith.

**Group V rocks**

Group V rocks are composed of two felsic volcanic samples and have $Zr/TiO_2$ and Nb/Y ratios of 0.038 to 0.039 and 0.20 to 0.21, respectively, corresponding to subalkalic rhyodacite/dacite.

Chondrite-normalized values for La and Lu are range of 80.5 - 188.0 and 9.34 - 12.6, respectively. Their REE patterns (Fig. 12) are typical of shoshonitic rocks, i.e. steep REE pattern, LREE enrichment and relatively flat HREE, with (La/Sm)cn and (Sm/Lu)cn ranging from 3.78 to 3.89 and 2.28 to 3.84, respectively. The N-MORB normalized multi-element patterns (Fig. 13), the rocks generally show flat patterns with negative Nb and Ta anomalies. This indicates that they have been characterizes as subduction-related magma.

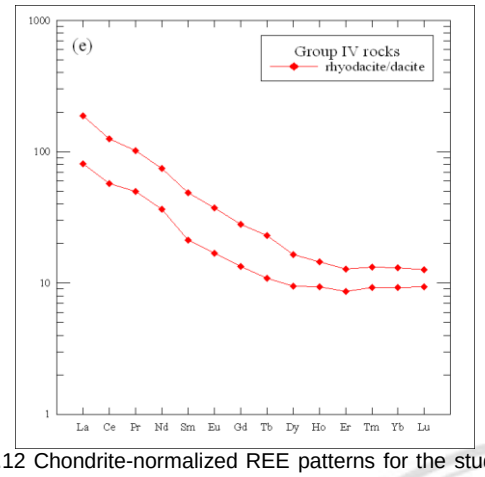


Fig.12 Chondrite-normalized REE patterns for the studied least-altered Group V rocks. Normalizing value used are those of Taylor and Gorton (1977).

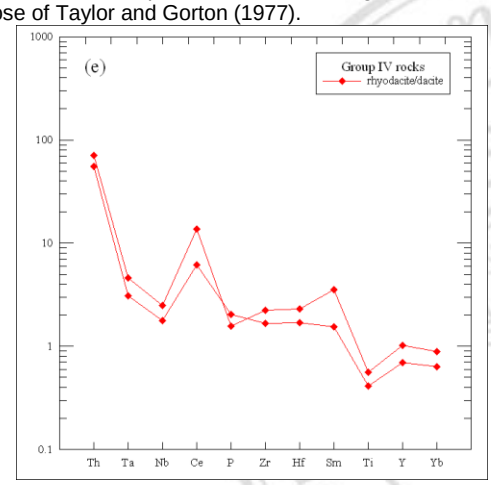


Fig.13 N-MORB - normalized patterns for the studied least-altered Group V rocks. Normalizing value used are those of Sun and McDonough (1989).

## CONCLUSION

The studied rock samples comprise of Group I, Group II, Group III, Group IV and Group V with $Zr/TiO_2$ and Nb/Y values of 0.01-0.08 and 0.09-0.33, 0.05-0.09 and 0.39-0.43, 0.004-0.009 and 0.05-0.12 and 0.038-0.039 and 0.20-0.21, respectively. The Group I rocks are calc-alkalic rhyodacite/dacite, andesite/basalt and gabbro and Group II rocks are calc-alkalic diorite. Group III and Group IV rocks are tholeiitic andesite/basalt and microdiorite/microgabbro. Group V rocks are shoshonitic rhyodacite/dacite. Accordingly, the magmatic affinity and Ta-Nb anomaly on normal mid-oceanic ridge basalt (N-MORB) and normalized multi-elements plots indicate that they have been characterized as subduction-related magma.

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