PETROGENESIS OF JURASSIC VOLCANIC ROCKS IN PHAYAO PROVINCE, THAILAND

MARUTPHONG SRICHAN

MASTER OF SCIENCE
IN GEOLOGY

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CHIANG MAI UNIVERSITY
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A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEOLOGY

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Examination Committee:

....Chairperson
(Dr. Somboon Khositanont)

....Member
(Dr. Boontarika Srithai)

....Member
(Assoc. Prof. Dr. Phisit Limtrakun)

Advisor:

....
(Assoc. Prof. Dr. Phisit Limtrakun)

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Marutphong Srichan

หัวข้อวิทยานิพนธ์	ศิลากำเนิดของหินภูเขาไฟอายุจูแรสซิก ในจังหวัดพะเยา ประเทศไทย
ผู้เขียน	นายมารุตพงศ์ ศรีจันทร์
ปริญญา	วิทยาศาสตรมหาบัณฑิต (ธรณีวิทยา)
อาจารย์ที่ปรึกษา	รองศาสตราจารย์ ดร. พิสิษฐ์ ลิ้มตระกูล

บทคัดย่อ

หินภูเขาไฟในบริเวณจังหวัดพะเยาและพื้นที่ใกล้เคียงเป็นส่วนหนึ่งของแนวหินภูเขาไฟเชียงของ-ลำปาง-ตาก หินที่ได้ทำการศึกษาส่วนใหญ่ประกอบด้วยหินลาวาหลากและหินตะกอนภูเขาไฟ จากองค์ประกอบทางเคมีสามารถแบ่งออกเป็น 5 กลุ่ม ดังนี้

กลุ่ม I ประกอบด้วยหินลาวาหลาก จากการศึกษาส่วนประกอบทางเคมีพบว่ามีส่วนประกอบเป็นไรโอเดไซต์/เดไซต์และไรโอไรต์ รูปแบบธาตุหายากที่เทียบกับคอนไดรต์แสดงการเพิ่มขึ้นของธาตุหายากชนิดเบา โดย (La/Sm) มีค่าระหว่าง 3.039-3.831 และแสดงการลดลงของธาตุหายากชนิดหนัก โดย (Sm/Yb) มีค่าระหว่าง 3.765-4.215 ซึ่งแสดงลักษณะแอลคาไลน์

กลุ่ม II ประกอบด้วยหินลาวาหลากและหินตะกอนภูเขาไฟ จากการศึกษาส่วนประกอบทางเคมีพบว่ามีส่วนประกอบเป็นไรโอไรต์ รูปแบบธาตุหายากที่เทียบกับคอนไดรต์แสดงการเพิ่มขึ้นของธาตุหายากชนิดเบา โดย (La/Sm) มีค่าระหว่าง 2.764-4.456 และแสดงการลดลงเล็กน้อยของธาตุหายากชนิดหนัก โดย (Sm/Yb) มีค่าระหว่าง 2.253-3.381 ซึ่งแสดงลักษณะก้ำกึ่งระหว่างแคลก์-แอลคาไลน์กับแอลคาไลน์

กลุ่ม III ประกอบด้วยหินลาวาหลาก จากการศึกษาส่วนประกอบทางเคมีพบว่ามีส่วนประกอบเป็นไรโอไรต์ รูปแบบธาตุหายากที่เทียบกับคอนไดรต์แสดงการเพิ่มขึ้นของธาตุหายากชนิดเบา โดย (La/Sm) มีค่าระหว่าง 2.897-3.589 และแสดงความค่อนข้างขนานของธาตุหายากชนิดหนัก โดย (Sm/Yb) มีค่าระหว่าง 1.606-3.589 ซึ่งแสดงลักษณะก้ำกึ่งระหว่างแคลก์-แอลคาไลน์กับแอลคาไลน์

กลุ่ม IV ประกอบด้วยหินลาวาหลาก จากการศึกษาส่วนประกอบทางเคมีพบว่ามีส่วนประกอบเป็นไรโอไรต์ รูปแบบธาตุหายากที่เทียบกับคอนไดรต์แสดงการเพิ่มขึ้นของธาตุหายากชนิดเบา โดย (La/Sm) มีค่าระหว่าง 2.793-4.953 และแสดงความค่อนข้างราบของธาตุหายากชนิดหนัก โดย (Sm/Yb) มีค่าระหว่าง 0.638-1.526 ซึ่งแสดงลักษณะแคลก์-แอลคาไลน์

กลุ่ม V ประกอบด้วยหินตะกอนภูเขาไฟ จากการศึกษาส่วนประกอบทางเคมีพบว่ามีส่วนประกอบเป็นไรโอไรต์ รูปแบบธาตุหายากที่เทียบกับคอนไดรต์แสดงความกึ่งขนานของธาตุหายากชนิดเบา โดย (La/Sm) มีค่า 2.520 และแสดงความค่อนข้างราบของธาตุหายากชนิดหนัก โดย (Sm/Yb) มีค่า 0.752 ซึ่งแสดงลักษณะโทลิอิติก

การวิเคราะห์ข้อมูลทางธรณีเคมีพบว่าเกิดภายหลังการชนกันของแผ่นเปลือกโลกและเป็นแกรนิตอยด์ชนิด A_2 จากการเทียบเคียงลักษณะทางเคมีพบว่ามีความคล้ายกับหินภูเขาไฟชนิดแคลก์-แอลคาไลน์ อายุอีโอซีนถึงไมโอซีนและหินภูเขาไฟชนิดโพแทสสิก อายุไมโอซีน ซึ่งเกิดภายหลังการชนกันของแผ่นเปลือกโลกบริเวณอนาโตเลีย ประเทศตุรกี และมีความคล้ายกับหินไรโอไรต์ชนิด A_2 อายุไมโอซีน ซึ่งเกิดภายหลังการชนกันของแผ่นเปลือกโลกจนถึงการแยกตัวของทวีป บริเวณจาบาลชามา ตะวันตกของซาอุดิอาระเบีย ดังนั้นหินภูเขาไฟที่ทำการศึกษาครั้งนี้เกิดในช่วงปลายของสภาวะการชนกันของแผ่นเปลือกโลก หรือช่วงเริ่มต้นของการแยกตัวของทวีป

การหาอายุโดยใช้ U-Pb จากแร่เซอร์คอนของหินภูเขาไฟในบริเวณจังหวัดพะเยาพบว่ามีอายุอยู่ในช่วง 229.5±4 ถึง 221±2.3 ล้านปี (ไทรแอสซิกตอนปลาย) และ 189.9±1.8 ถึง 182.8±2.5 ล้านปี (จูแรสซิกตอนต้น) อย่างไรก็ตามพบว่าในหินที่มีอายุไทรแอสซิกตอนปลายมีแร่เซอร์คอนที่มีอายุจูแรสซิกตอนต้นปะปนอยู่ด้วย และลักษณะทางสัณฐานวิทยาแสดงการเจริญเติบโตสองช่วง นอกจากนี้ยังพบว่ามีค่าเฉลี่ยสองช่วงอายุคือ ไทรแอสซิกตอนปลายและจูแรสซิกตอนต้นอยู่ในตัวอย่างเดียวกัน ดังนั้นในบริเวณที่ทำการศึกษามีการประทุของภูเขาไฟในช่วงไทรแอสซิกตอนปลายและมีการปะทุอีกครั้งในช่วงจูแรสซิกตอนต้น

Thesis Title Petrogenesis of Jurassic Volcanic Rocks in Phayao Province, Thailand

Author Mr. Marutphong Srichan

Degree Master of Science (Geology)

Advisor Assoc. Prof. Dr. Phisit Limtrakun

ABSTRACT

The studied volcanic rocks in Phayao province and vicinity nearby are part of Chiang Khong-Lampang-Tak volcanic belt, which is one of the five belts pre-Cretaceous volcanic belts in Thailand. The studied rocks include lava flows and pyroclastic equivalents. Geochemical analyses from the least-altered rocks can be divided into five magmatic groups.

The Group I rocks are of lava flows and appear to be in rhyodacite/dacite and rhyolite compositions. The REE patterns show LREE enriched with (La/Sm)cn values in ranges of 3.039-3.831 and HREE depleted with (Sm/Yb)cn values in ranges of 3.765-4.215. Their REE patterns are typical of alkaline series.

The Group II rocks are lava flows and pyroclastic equivalents. They appear to be in rhyolite compositions. The REE patterns show LREE enriched with (La/Sm)cn values in ranges of 2.764-4.456 and HREE slightly depleted with (Sm/Yb)cn values in ranges of 2.253-3.381. Their REE patterns are characteristic of transitional subalkaline to alkaline series.

The Group III rocks are lava flows and corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.897-3.589 and subparallel HREE with (Sm/Yb)cn values in ranges of 1.606-3.589. Their REE patterns are typical of transitional subalkaline to alkaline series.

The Group IV rocks are lava flows and corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.793-4.953 and relatively flat HREE with (Sm/Yb)cn values in ranges of 0.638-1.526. Their REE patterns are characteristic of calc-alkaline series.

The Group V rocks are pyroclastic equivalents and corresponding to rhyolite composition. The REE patterns are slightly subparallel LREE with (La/Sm)cn values = 2.520 and relatively flat HREE with (Sm/Yb)cn values = 0.752. Their REE patterns are typical of tholeiitic series.

The geochemical data for the studied volcanic rocks most appear in the field of post-collisional setting and A_2-type granites. The Group I, II and IV rocks are analogous to the Miocene potassic volcanic rocks in the post-collisional at western Anatolia, Turkey (Ersoy *et al*., 2012). The Group I, II, III and IV rocks are similar to the Eocene-Miocene calc-alkaline volcanic rocks related to subduction roll-back processes associated with post-collisional extension at northwest Anatolia, Turkey (Ersoy *et al*., 2017). The III, IV and V rocks are analogous to the Miocene A_2-type rhyolites of within-plate setting at Jabal Shama in western Saudi Arabia. Accordingly, the studied volcanic rocks have been formed at the late stage of post-orogenic magmatism or the early stage of continental rifting.

The U-Pb zircon dating of the studied volcanic rocks indicate the formation age ranging from 229.5±4 to 221±2.3 Ma (late Triassic) and ranging from 189.9±1.8 to 182.8±2.5 Ma (early Jurassic). However, few of the zircon grains from late Triassic volcanic rock samples have aged in the early Jurassic period and show morphology in two continuous growth stages. One studied sample has two population ages in the late Triassic and early Jurassic period. Therefore, the volcanism in the studied areas has erupted in the late Triassic synchronously volcanism in Chiang Rai area. After that in the early Jurassic the volcanism has erupted again synchronously volcanism in Nan area.

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CHAPTER 1

Introduction

1.1 Pre-Cretaceous volcanic rocks in Thailand

Thailand is located on the southern margin of South-East Asia and divided into two main plates tectonic, Shan-Thai (Sibumasu) to the west and Indochina to the east (Gatinsky *et al*., 1978; Bunopas, 1981; Hutchison, 1989), which was sutured together by a closing of the Paleo-Tethys along the north-south direction and collided in the late Triassic (Figure 1.1). The Shan-Thai plate covers the western half of Thailand, eastern part of Myanmar, western Malaysia Peninsula and northern part of Sumatra, while the Indochina covers the eastern haft of Thailand, Laos People Democratic Republic, Cambodia, South Vietnam and eastern Malaysia Peninsular (Bunopas, 1981; Metcalfe, 1990; Barr and MacDonald, 1991; Panjasawatwong, 1991; Crawford and Panjasawatwong, 1996; Singharajwarapan and Berry, 2000; Metcalfe, 2000). However, the tectonic evolution in Thailand is still a subject of debate. The problems include locations of suture zones, the timing of continental collision, ages of an eruption of the volcanic and tectonic model. Therefore, the Pre-Cretaceous volcanic rocks are essential in depicting for the tectonic evolution of this region.

The Pre-Cretaceous volcanic rocks in Thailand can be subdivided into five major eruption events (Figure 1.2), including Chiang Rai-Chiang Mai, Chiang Khong-Lampang-Tak, Nan-Uttaradit, Loei-Phetchabun-Nakhon Nayok and Sra Kaew-Chanthaburi volcanic belts (Jungyusuk and Khositanont, 1992; Kosuwan, 2004; Panjasawatwong *et al*., 2006). The Chiang Rai-Chiang Mai volcanic belt extends from a western part of Chiang Rai pass the eastern part of Chiang Mai to Li of Lamphun province. The Chiang Khong-Lampang-Tak volcanic belt located to the east of Chiang Rai-Chiang Mai volcanic belt and spreading from Chiang Khong of Chiang Rai province

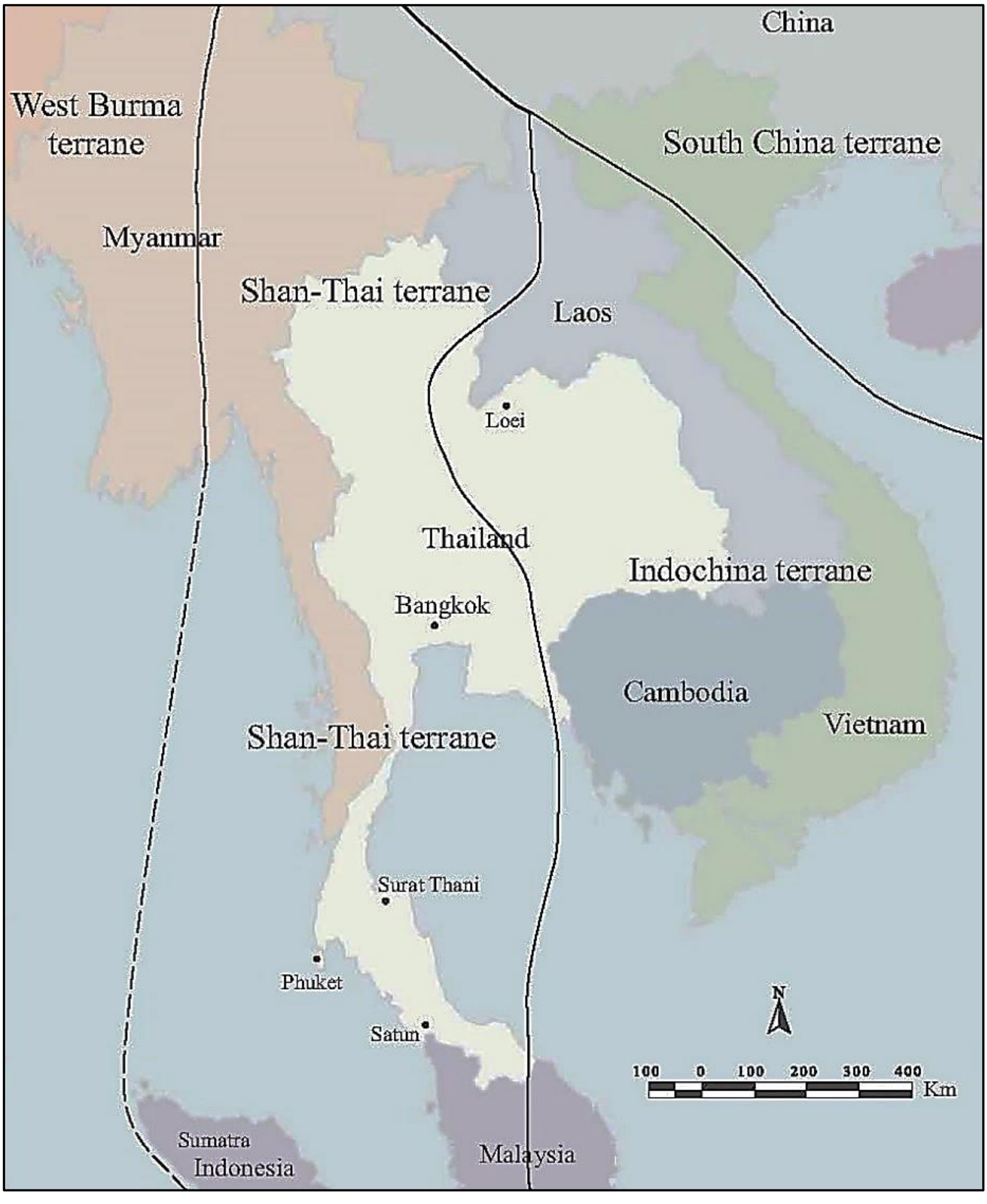


Figure 1.1 Map shows the boundary of tectonic terranes in Thailand and nearby regions (Department of Mineral Resources, 2014).

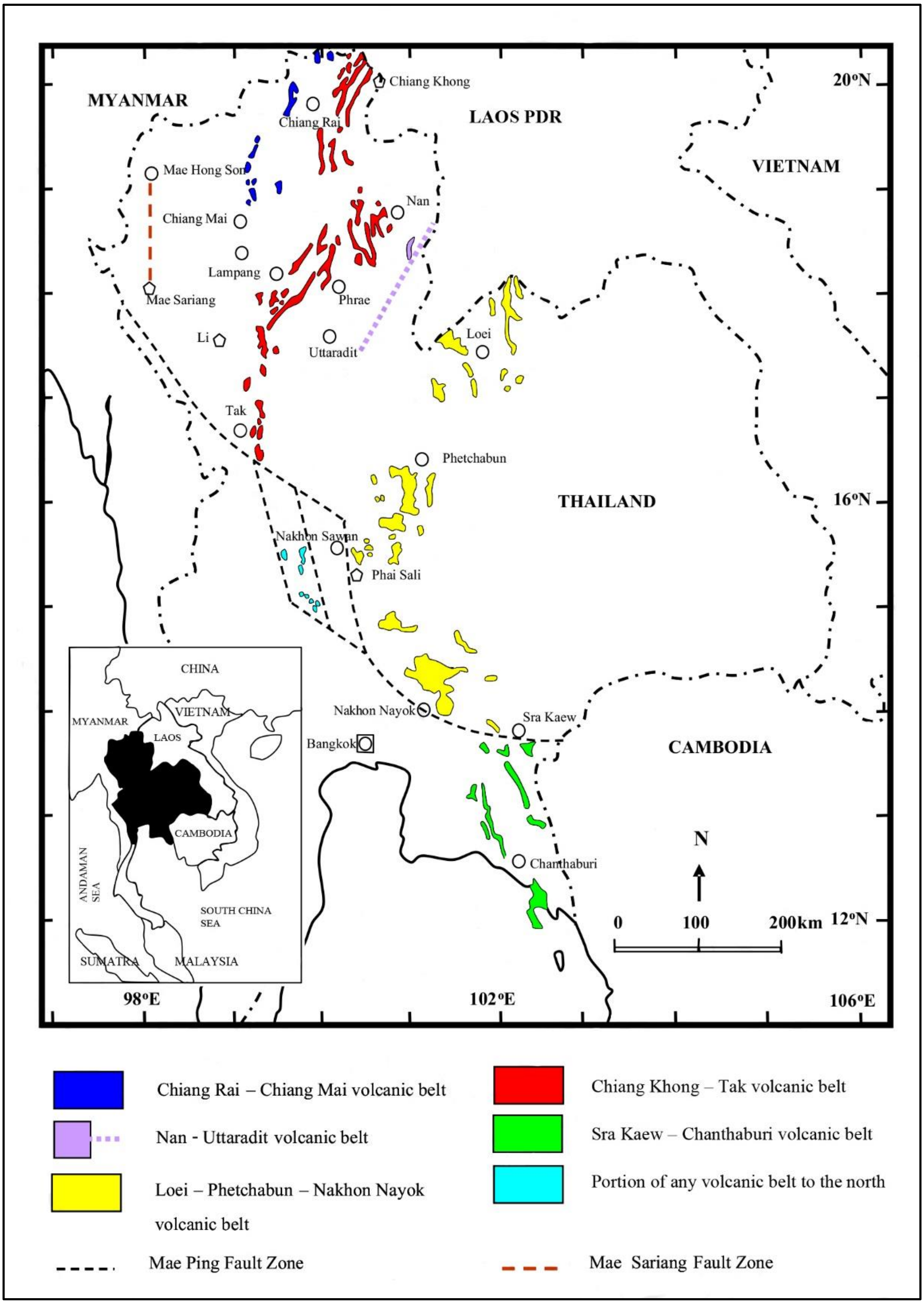


Figure 1.2 The Pre-Cretaceous volcanic rocks in Thailand (modified from Jungyusuk and Khositanont, 1992; Kosuwan, 2004; Panjasawatwong *et al*., 2006; Phajuy, 2008). The Mae Ping and the Mae Sariang fault zone are taken from Morley (2002) and Hisada *et al*., (2004).

via Lampang and Phrae to Tak province. The Nan-Uttaradit volcanic belt is located between the Chiang Khong-Lampang-Tak and the Loei-Phetchabun-Nakhon Nayok volcanic belt, extending from Nan to Uttradit province. The Leoi-Phetchabun-Nakhon Nayok volcanic belt runs in a north-northeast to south-southwest direction from Loei through Phetchabun and Nakhon Nayok province. The Sra Kaew-Chanthaburi volcanic belt forms a north-northwest to south-southeast trending zone from Sra Kaew through Chanthaburi to Ko Chang of Trat province in the eastern region.

The Chiang Rai-Chiang Mai volcanic belt occurred in Carboniferous ages (Braun and Hahn, 1976; Macdonald and Barr, 1978; Barr *et al*., 1990) or middle Permian to Permo-Triassic (Bunopas, 1981; Panjasawatwong, 1999; Phajuy, 2008). These volcanic rocks were composed of coarse-grained tuffs and agglomerates with few lava flows, pillow breccia/hyaloclastite and small ultramafic rocks (Macdonald and Barr, 1978; Phajuy, 2008). Chemical characteristic of mafic volcanic rocks indicates tholeiite and transitional tholeiite. The mafic volcanic rocks in Chiang Rai interpreted to be subduction setting (Macdonald and Barr, 1978). Barr *et al*. (1990) reported that the tholeiitic basalt in Chiang Mai has erupted from the continental within-plate setting. In addition, Panjasawatwong *et al*. (1995) and Phajuy *et al*. (2004; 2005) reported that the volcanic rocks were typically formed in the within-plate oceanic environment, oceanic islands and seamount in main ocean basin or mature back-arc basin. The conclusion is well supported by alkali basalt of an oceanic island and transitional tholeiite of mid-oceanic ridge in Phrao of Chiang Mai province (Phajuy *et al*., 2005). From Chiang Rai province the basalts and andesites were interpreted as the back-arc basin, oceanic island and mid-oceanic ridge (Phajuy, 2008).

The Chiang Khong-Lampang-Tak volcanic belt extends northward into southern China known as Lincang-Jinghong volcanic belt (Yang, 1998; Barr *et al*., 2006). This belt composes of various compositions from mafic to felsic represented by rhyolite, dacite, basalt/andesite, and pyroclastic equivalents. Stratigraphic correlation indicates that the volcanic rocks occurred in the Permo-Triassic period (Braun and Hahn, 1976; Charoenprawat *et al*., 1994). Few volcanic rocks erupted in Late Triassic to Early Jurassic periods (Jungyusuk and Khositanont, 1992). Barr *et al*. (2000; 2006) reported that rhyolites, andesites and basalts in Lampang were calc-alkalic and occurred on active continental margin in Middle Triassic with U-Pb zircon age of 240±1 Ma and in Late Triassic with age of 232.9±0.4 Ma. Panjasawatwong *et al*. (2003) demonstrated the tholeiitic series of mafic volcanic rocks along the northern end of this belt and reached a similar conclusion to Barr *et al*. (2006). Many researchers believe that the volcanic rocks in this belt have erupted in subduction environment or continental arc environment (e.g., Bunopas, 1981; Singharajwarapan, 1994; Crawford and Panjasawatwong, 1996). Khositanont (2008) presented the volcanic rocks from Tak, Lampang and Phrae areas that were erupted in Middle to Late Triassic with U-Pb zircon ages of 247±5 to 219±3 Ma. Srichan *et al*. (2009) proposed that these volcanic rocks are the post-collision origin in Late Triassic with U-Pb zircon ages of 223±8 to 220±4 Ma of tholeiitic and calc-alkalic series. Ruenthon (2010) reported that the felsic volcanic rocks in Nan province were erupted in Early Jurassic with U-Pb zircon age of 186±1.3 to 187±2.6 Ma. Wipakul (2012) studied geochemical volcanic rocks in Nan area and suggested alkali and transitional subalkalic to alkali series with U-Pb zircon ages of 181.7±2.1 to 184.1±2.4 Ma (Early Jurassic). These rocks represent post-collision volcanism together with rifting. Newly reported of Qian *et al*. (2016a; 2016b) presented the Chiang Khong rhyolite with U-Pb zircon age of 230.7±1.1 Ma and geochemical data suggest that they are formed by partial melting of juvenile mafic lower crust in post-collisional setting, including of andesites with U-Pb age of 229±4 Ma and originated from the enriched lithospheric mantle that had been modified by slab-derived fluid and recycled sediments. The formation was possibly related to the upwelling of the asthenospheric mantle, shortly after slab detachment which induced the melting of the metasomatized mantle wedge. Qian *et al.* (2017) reported the intermediate to acid rocks with U-Pb zircon age of 240±1.7 and 240.6±1.9 Ma. The calc-alkaline andesitic and dacitic might originate from mantle source by slab-derived fluids and recycled sediments, and calc-alkaline rhyolitic were derived from juvenile mafic crust. The volcanic rocks in this area formed in response to slab roll-back during a transition of the tectonic regime from subduction to continental collision between the Sibumasu and Indochina blocks.

The Nan-Uttaradit volcanic belt is believed to be mélange zone, extending along the Nan river from Uttaradit up to Nan. They may correlate with Changning-ShuangJiang suture zone in south China (Barr and Macdonald, 1987; Metcalft and Sone, 2008; Metcalft, 2011). This belt consists of gabbro, peridotite, serpentinite and dunite with minor mafic dikes and pillow lavas. In some areas metagabbro, epidote amphibolite and metabasalt were observed with reported to be an Ophiolite suite (Hutchison, 1975; Bunopas, 1981; Barr and Macdonald, 1987; Singharajwarapan and Berry, 1993). The other rocks in this area are felsic rocks and Middle Permian limestone (Bunopas, 1969). These rocks are found as blocks in serpentinite matrix (Panjasawatwong, 1991) it was described that the association of ultramafic rocks, volcanic rocks and sedimentary rocks are part of ophiolite belt. Many episodes of tectonism formed this belt within inner trench slope facies by subduction complex and interpreted to represent the Late Paleozoic suture between Shan-Thai and Indochina cratonic blocks (Thanasuthipitak, 1978; Bunopas, 1981; Macdonald and Barr, 1984; Hutchison, 1989). The Nan-Udtaradit volcanic belt has Ar-Ar age of 256 Ma for alkali basalt rock with geochemical evidence suggested that the tholeiite and alkali magma series related to oceanic within plate basalt, immature backarc basin basalt/andesite and oceanic island arc basalt/andesite (Panjasawatwong, 1991; Crawford and Panjasawatwong, 1996). This belt is representing the main Paleo-Tethys Ocean (Bunopas 1981; Panjasawatwong 1991; Singharajwarapan 1994; Hada *et al*., 1999; Singharajwarapan *et al*., 2000). Recently they were re-interpreted as the back-arc basin which opened in Carboniferous (Barr and Macdonald, 1987; Fontaine *et al*., 2002; Metcalfe, 2002) with K-Ar age of 344±22 Ma for mafic-ultramafic (Helmcke, 1985) or Permian (Sone and Metcalfe, 2008; Ferrari *et al*., 2008).

The Leoi-Phetchabun-Nakhon Nayok volcanic belt was developed as a consequence of subduction, suturing and subsequent continent-continent collision. Rb-Sr isochron ages and ^{40}Ar-^{39}Ar ages of Pre-Cretaceous volcanic rocks suggested two major periods of volcanic activities. Intasopa (1993) reported the Late Devonian to Early Carboniferous and Middle Triassic. The first volcanic activity started from Late Devonian to Early Carboniferous. The isotopic data of rhyolite from eastern Loei area, with Rb-Sr isochron age indicating at 374±33 Ma. The magmatic evolution is inferred to be related to the subduction event before suturing of Indochina and Cathaysia (South China). Khositanont (2008) reported U-Pb zircon ages of 425±7 and 433±4 Ma. The central Loei area basalts show Rb-Sr isochron age at 361±11 Ma which may indicate that the magmas were generated at a spreading center in the ocean between the Shan-Thai and Indochina cratonic blocks (Intasopa, 1993; Intasopa and Dunn, 1994). The second volcanic activity was in the western Loei area and may extend to Phetchabun area. The rocks compose of andesitic composition (Jungyusuk and Kositanont, 1992) and have ^{40}Ar-^{39}Ar ages at 237±12 Ma (Intasopa, 1993; Intasopa and Dunn, 1994). Andesite, basaltic andesite, basalt with associated diorite, granodiorite and granite were observed in the Phetchabun area. The ^{40}Ar-^{39}Ar ages of rocks are 238±4 Ma (Intasopa, 1993; Intasopa and Dunn, 1994). These rocks have erupted along active continental margin (Intasopa, 1993; Kamvong *et al*., 2006; Marhotorn *et al*., 2008; Nakchaiya, 2008). The U-Pb zircon ages of rocks were reported at 250±5 Ma and 254±10 Ma (Khositanont, 2008). Phajuy *et al*. (2005) reported that the basaltic dikes cut into Permian sedimentary rocks that formed in volcanic arc environment. In the Nakhon Nayok area, the volcanic rocks have geochemical signature related to arc magma (Kosuwan, 2004).

The Sra Kaew-Chanthaburi volcanic belt composed of serpentinite and hornblendite. This ultramafic was interpreted as part of the ophiolite belt (Suwannasing, 1973; Bunopas, 1981). Their geochemical characteristics are ocean island basalt and mid-oceanic ridge basalt (Yoshikura, 1990). It is possibly mélange zone and formed the Paleo-Tethys Ocean in the same period as Nan-Uttaradit volcanic belt (Crawford and Panjasawatwong, 1996; Wakita and Metcalft, 2005; Panjasawatwong *et al*., 2006; Kamvong *et al*., 2006).

1.2 Scope of study

The Jurassic volcanic rocks were mostly collected from Phayao and few are from Chiang Rai province. The volcanic rocks are known as the ms2 unit (Hahn, 1976). They are situated in the northern part of the Chiang Khong-Lampang-Tak volcanic belt. These rocks include volcanic rocks and pyroclastic equivalents. This study focuses on petrochemistry of the least-altered rocks and U-Pb geochronology. Petrographic study under the polarizing microscope is applied for mineral composition, texture alteration/weathering and resulting in the classification of rocks. Chemical compositions of the studied rocks are also used for identification of rocks and determine magma characteristic with interpretation for the tectonic setting. The U-Pb zircon age dating is applied in order to confirm the age of the studied volcanic rocks.

1.3 Research objectives

The main objectives of this study are

(1) to characterize the least-altered volcanic rocks in terms of petrography and geochemistry (major oxides, trace elements and rare earth elements)

(2) to determine the ages of eruption

(3) to discuss model for tectonic evolution

1.4 Location and accessibility

This study focuses on the volcanic rocks in Phayao province and the vicinity nearby. The study area are located in the topographic maps at scale 1:50,000, series L7018 (Royal Thai Survey Department, 1999). The areas can be easily accessed by vehicles from Chiang Mai province along highway number 118, turn right to highway number 120 to Wang Nua of Lampang province and turn left to highway number 1 to Phayao province (the total distance is 164 km). The studied volcanic rocks exposed along the mountain range in eastern, western, northern and southern part of Phayao area (Figure 1.3).

1.5 Physiography description

The study areas contain mountains and intermontane (Figure 1.3). The mountains are part of Phi Pun Nam mountain range cover an extensive area and are often separated by intermontane basins. The highest mountain is Doi Luang in the west at 1,694 meters with Pu Langka in the east at 1,641 meters above mean sea level. The intermontane basins are general at 300-400 meters above mean sea level. These basins contain Phayao Lake (Kwan Phayao). It is the largest lake in Northern Thailand with depth 1.5 meters and cover area of about 19.8 km^2. Ing and Yom rivers are distributed in these areas. The Ing river flows northward from Phayao lake to Mekong river (the total length is 164 km) and the Yom river flows southward through Pong District to Chao Phraya river (the total length is 787 km).

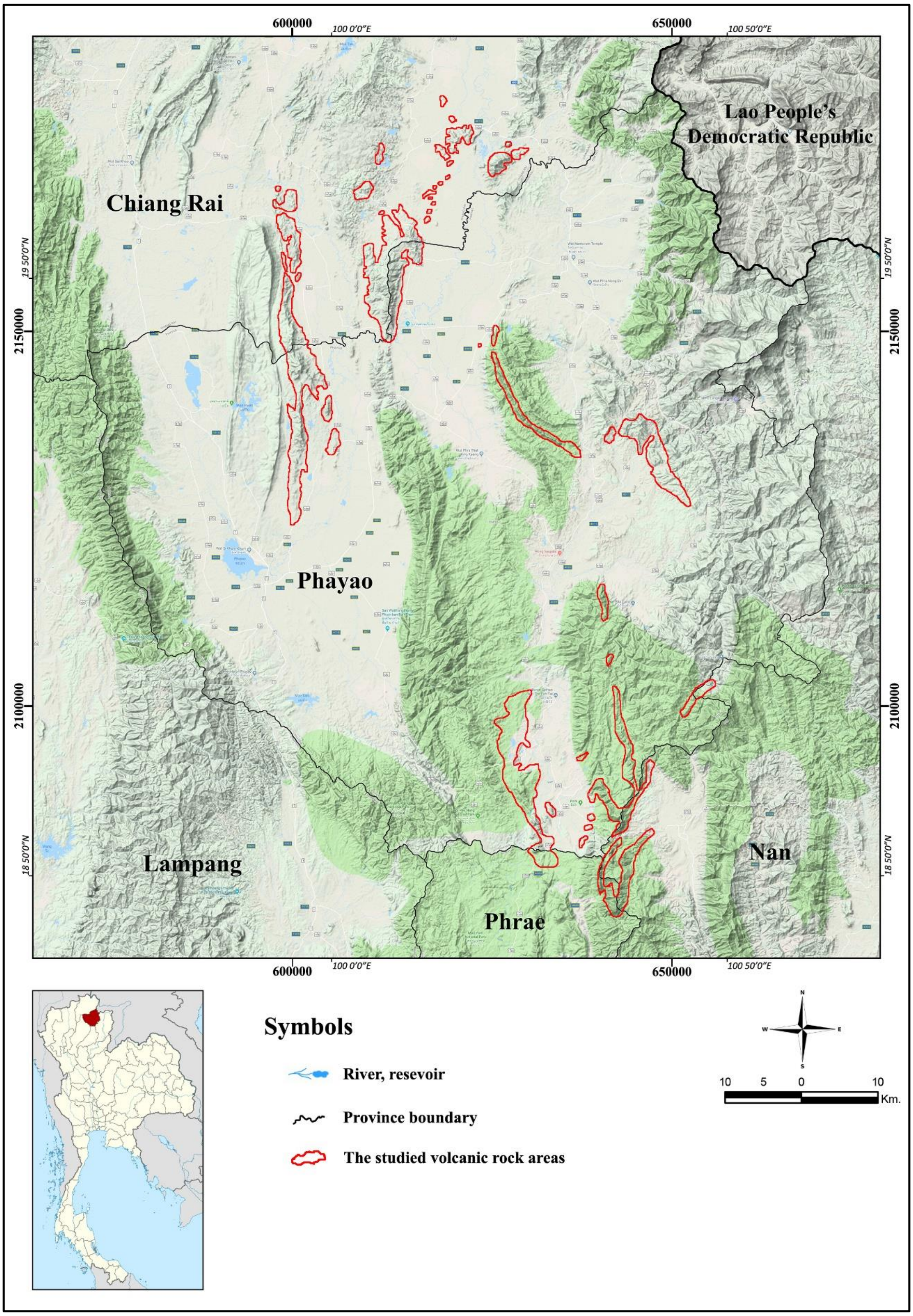


Figure 1.3 Topographic from Google map of Phayao province and the vicinity areas.

CHAPTER 2

Geological Setting

The geological setting of the studied areas was interpreted based on data available from geological map of Phayao province scale 1:250,000 (Department of Mineral Resources, 2007). This map composed of sedimentary, igneous and metamorphic rocks from Carboniferous to Quaternary period (Figure 2.1). The studied Jurassic volcanic rocks, crop out widespread in eastern, western, northern and southern part of Phayao province.

2.1 The Carboniferous-Permian rocks

The Carboniferous-Permian rocks are exposed along the eastern and southwestern part. These rocks mostly consist of sedimentary rocks including sandstone, grey to green tuffaceous sandstone, shale, chert, argillaceous limestone and massive grey limestone interbedded with shale and sandstone.

2.2 The Permo-Triassic rocks

The Permo-Triassic sedimentary rocks are exposed along the eastern part. They consisted of sandstone, tuffaceous sandstone, shale, chert, argillaceous limestone and oolitic limestone. Volcanic rocks are in the middle part, including rhyolite/rhyolitic tuff, andesite/andesitic tuff and volcanic breccia.

2.3 The Triassic-Jurassic rocks

The Triassic-Jurassic sedimentary rocks are widespread over the area. These rocks consist of arkose interbedded with thin shale, grey sandstone/conglomerate, red sandstone/siltstone/conglomerate interbedded with shale and mudstone, massive to thin grey mudstone interbedded with thin sandstone and shale, massive grey limestone interbedded with thin sandstone and mudstone. Igneous rocks can be divided into two

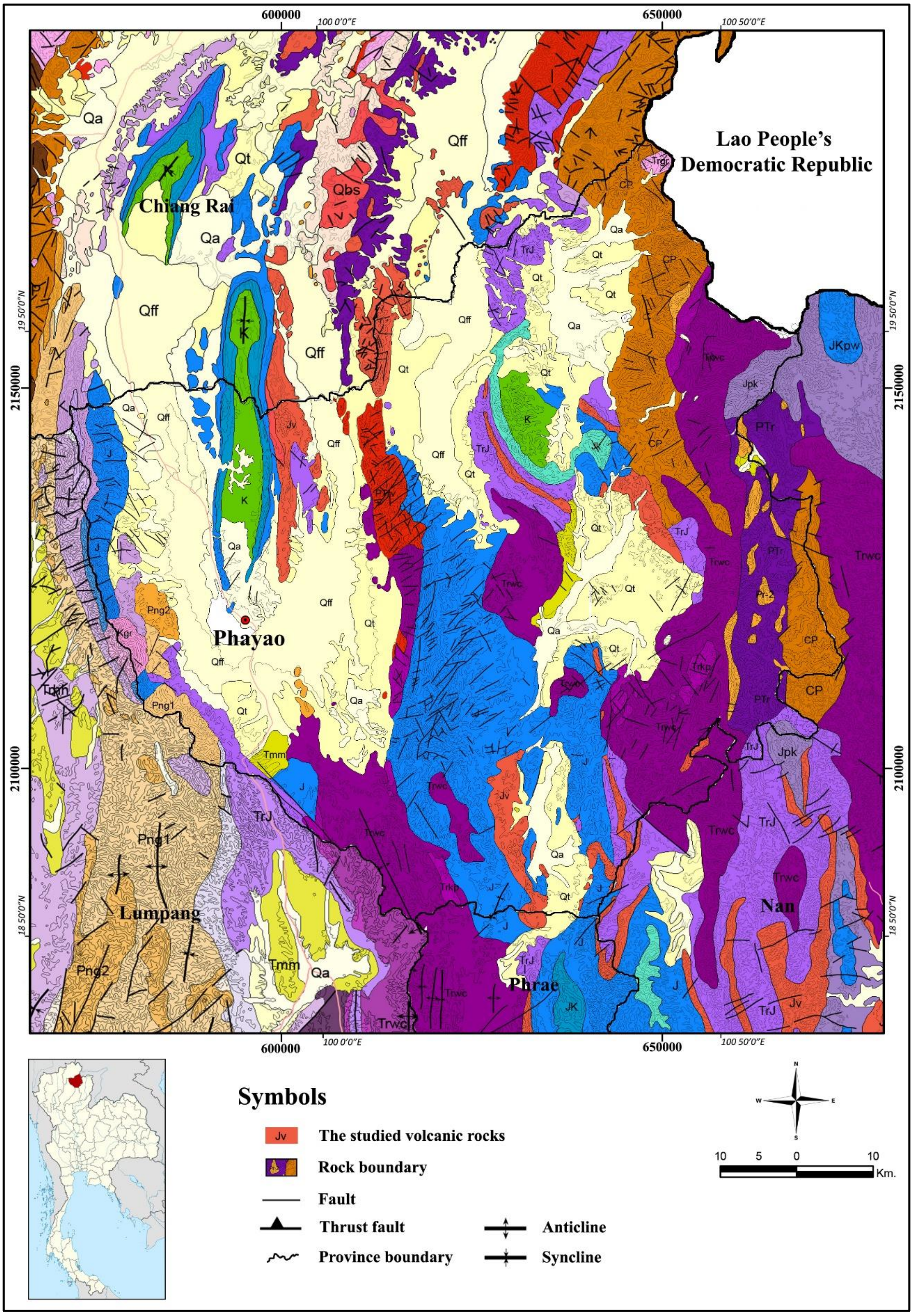


Figure 2.1 Geological map of Phayao province and the vicinity areas scale 1:250,000 (Department of Mineral Resources, 2007).

EXPLANATION

Sediment and Sedimentary Rocks

Cenozoic

Qa	Garvel, sand, silt and clay
Qff	Grey clay interbeddded with gravel
Qc	In-situ soil, gravel, sand, silt, laterite and rock fragments
Qt	Semi-consolidated rock, lignite and red to brown claystone and siltstone
Tmm	Conglomerate, light-grey sandstone and claystone

Jurassic

K	Red sandstone and claystone
JK	White arkose interbedded with very thin shale
Jk	Siltstone,, claystone andargillaceous limestone interbedded with very thin shale
Jpk	Red siltstone, greyish a-green to yellowish brown sandstone and conglomerate
J	Red conglomerate and sandstone interbedded with shale and claystone

Triassic-Jurassic

TrJ	Red conglomerate interbedded with shale and claystone

Triassic

Trwc	Dark-grey claystone interbedded with thin sandstone
Trkp	Massive grey limestone
Trhh	Dark-grey claystone with fossil Halobia and Daonella
Trpk	Massive dark-grey limestone, thin sandstone and claystone
Trpt	Red sandstone, siltstone and conglomerate

Permo-Triassic

PTr	Sandstone, tuffaceous sandstone, argillaceous limestone, oolitic limestone, shale and chert

Permian

Pr-2	Massive light-grey limestone and shale
Png2	Massive dark-grey limestone interbedded with shale and sandstone
Png1	Tuffaceous sandstone, grey to green sandstone shale

Carboniferous-Permian

CP	Sandstone, argillaceous limestone, shale and chert

Igneous Rocks

Cenozoic

Qbs	Basalt, basanite and nephilinite

Jurassic

Kgr	Biotite-hornblende granite, muscovite granite and granodiorite
Jv	Rhyolite, rhyolitic tuff and andisitic tuff

Triassic

Trgr	Biotite granite, tourmaline granite, granodiorite, biotite-muscovite granite, muscovite-tourmaline granite, biotite-tourmaline granite

Permo-Triassic

PTrv	Rhyolite, rhyolitic tuff, andesite, andesitic tuff, tuff and volcanic breccia

Figure 2.1 Continued.

types, plutonic and volcanic rocks. The plutonic rocks are exposed in northeastern and western part. They consist of granite, biotite-muscovite granite, tourmaline granite and granodiorite. The volcanic rocks are exposed in western, eastern, northern and southern part. They consist of rhyolite, rhyolitic tuff and andesitic tuff.

The nonmarine Mesozoic deposits in Chaing Rai-Phayao-Nan basins occurred in Late Triassic to Jurassic period (Table 2.1 and Figure 2.2). The total thickness of 1750 to 2000 meters. Hahn (1976) and Drumm *et al*. (1993) reported main five units (ms1-ms5). However, Drumm *et al*. (1993) separate unit Ms3 into six members based on depositional environments. The members ms3.1 and ms3.4 deposited on distal braided river, ms3.2 deposited on playa, ms3.3 and ms3.5 deposited on proximal alluvial fans, ms3.6 deposited on small river channels and periodical dryness. while Bunopas (1981) named five units (as; Chiang Muan Red Beds, Thoeng Volcanics, Phu Kradung, Phra Wihan and Sao Khua formation). The details of these rocks are as follows.

Table 2.1 The lithostratigraphic formations of the non-marine Mesozoic rocks in northern and northeastern Thailand (Hahn, 1976; Bunopas, 1981; Drumm *et al*., 1993).

Age		**Hahn, 1976**	**Bunopas, 1981**	**Drumm *et al.*, 1993**	
Middle Jurassic		ms5	Sao Khua Fm.	ms5	
		ms4	Phra Wihan Fm.	ms4	
Early Jurassic		ms3	Phu Kradung Fm.	ms3	ms3.6
					ms3.5
					ms3.4
					ms3.3
					ms3.2
					ms3.1
Late Triassic	**Rhaetian**	ms2	Thoeng Volcanics	ms2	
	Norian	ms1	Chiang Muan Red Beds	ms1	

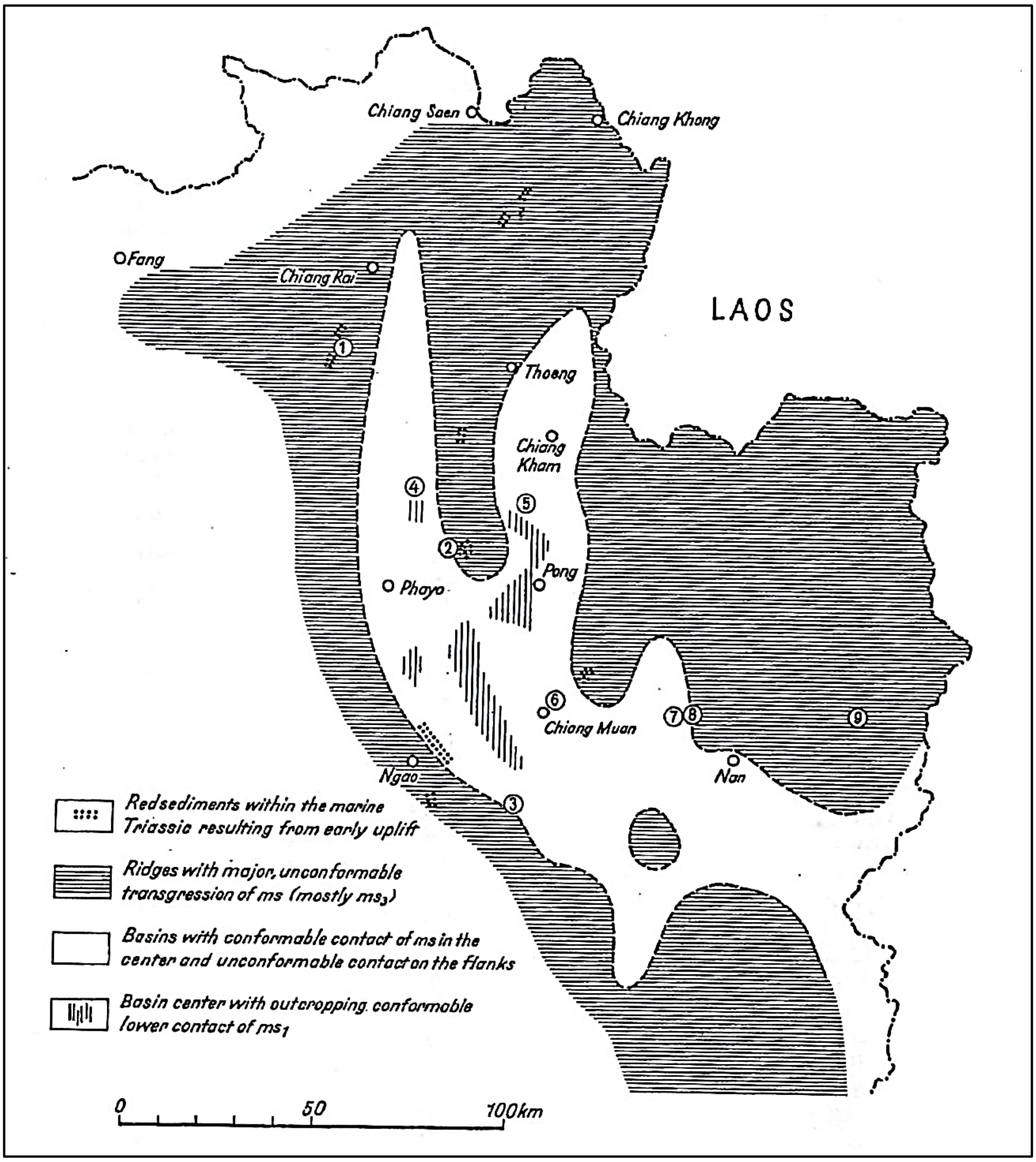


Figure 2.2 Palaeogeography of the nonmarine Mesozoic rocks in Chiang Rai-Phayao-Nan basins, No 1-9 are locations of stratigraphic columns of Figure 2.3 (Hahn, 1976).

2.3.1 Unit ms1

The maximum thickness is 300 meters deposited in the Late Triassic period. In the center part of the basin, the rocks comprise red shale and claystone interbedded with fine-grained sandstone of red, brown and grey color without basal conglomerate (sections 4, 5 and 6 of Figure 2.3). Towards the basin margins, the rocks become more clastic. The center part of the basin gives a detailed description of this marginal facies. Near the basin margins, the basal conglomerate was observed, interbedded with red sandstone and shale (section 7 of Figure 2.3). The basal conglomerate composed of red-yellow-green sandstone, grey-red-green claystone and shale, light red chert, milky quartz and light-color limestone. Towards the basin center, the rocks are interbedded with distal braided and fine clastic of playa facies. The lithology indicates an alluvial fan environment along the basin margins. On the top part of the unit transition to the volcanic rocks of unit ms2 is marked by very thick conglomerate containing pebbles similar to those in the basal conglomerate. In the Mae Kat River, Nan province thick limestone is directly overlaying by volcanic rocks of unit ms2. The limestone has become marble at contact with the volcanic rocks. In section 6 bed of light to dark grey limestone was found, presumably marine ingressions (Figure 2.3).

2.3.2 Unit ms2

This unit is the main focus of this study (Figure 2.4), the thickness is about 300-350 meters, deposited in Late Triassic (Hahn, 1976; Salyappongse *et al*., 2000; Fontaine *et al*., 2000; 2001), Late Triassic/Early Jurassic (Drumm *et al*., 1993), Jurassic (Department of Mineral Resources, 2007). Ruenthon (2010) and Wipakul (2012) reported that the unit ms2 in Nan province is Early Jurassic with U-Pb zircon dating. This rock unit is characterized by intermediate to felsic rocks (andesite, rhyodacite and rhyolite) and tuff. The rocks are less conformably on the nonmarine red beds in the center of the basin, unconformably overlie Triassic and Permian rocks at the margins and upland areas (sections 2, 3 and 8 of Figure 2.3). The bottom of volcanic rocks found basal breccia of unsorted fragment sandstone and shale derived from unit ms1. These volcanic rocks form the basis of discussion, concerning petrography, geochemistry and occurrence in chapters 4 and 5.

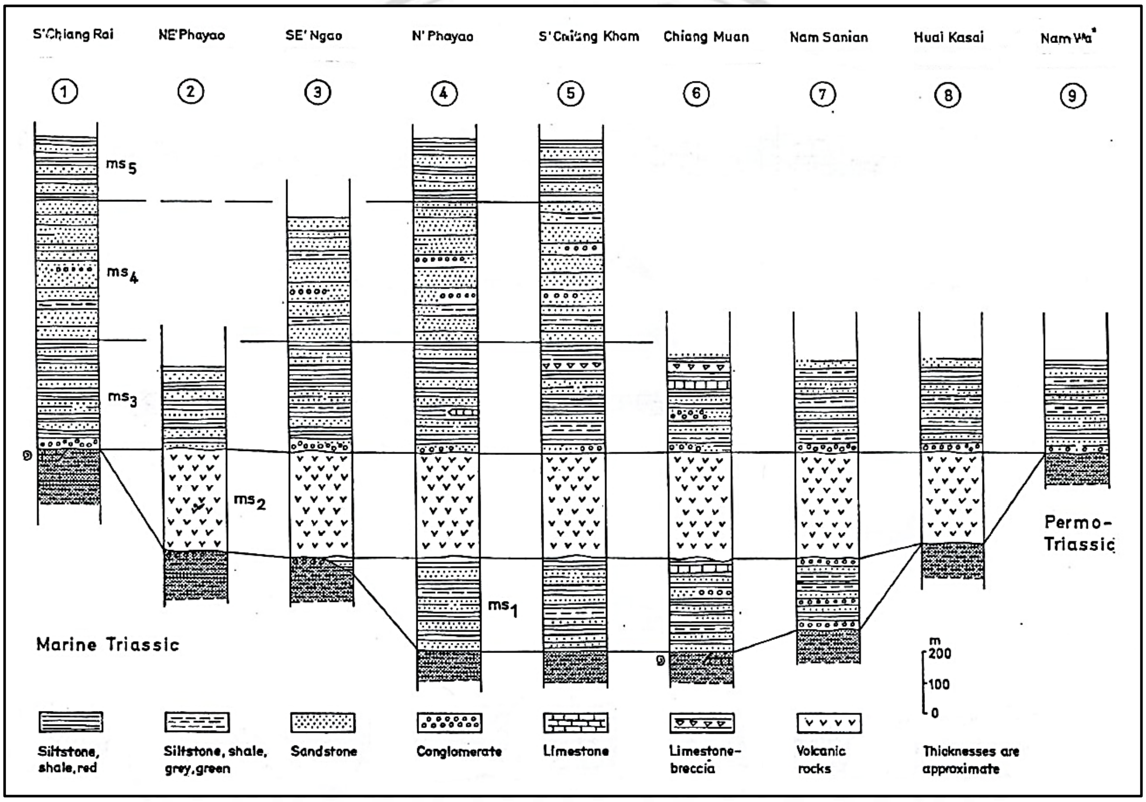


Figure 2.3 Stratigraphic columns of the nonmarine Mesozoic rocks in Chiang Rai-Phayao-Nan basins, No 1-9 are locations of Figure 2.2 (Hahn, 1976).

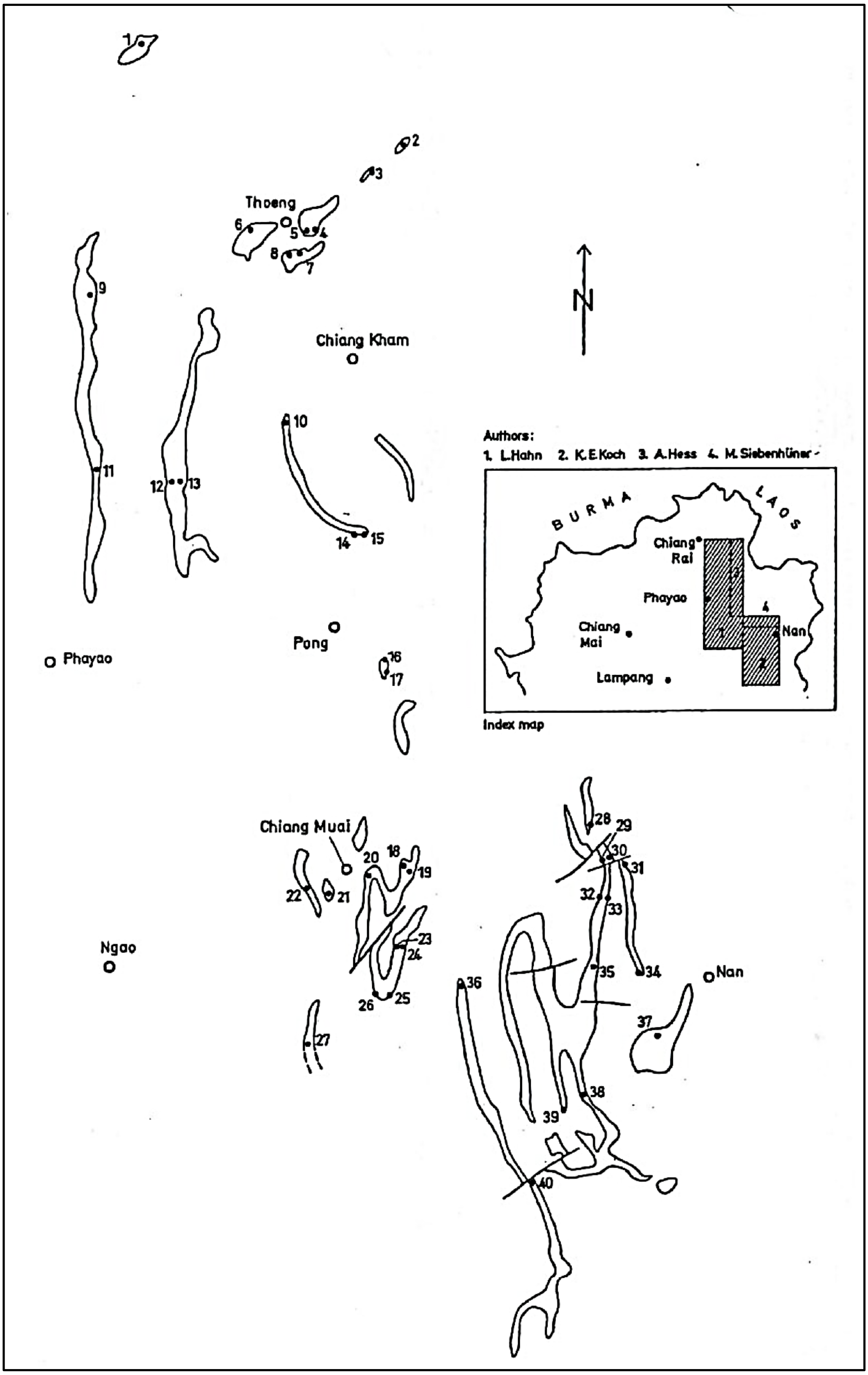


Figure 2.4 The volcanic rocks (ms2) in Chiang Rai-Phayao-Nan basins (Hahn, 1976).

2.3.3 Unit ms3

The thickness is around 300-400 meters deposited in the Early Jurassic period. The rocks mostly begin with the conglomerate of eroded volcanic materials. The conglomerate is overlain by reddish coarse and fine-grained sandstone and red claystone. There is a conspicuous gradation in grain size from bottom to top of the sequence. In the margins south of Chiang Rai and north of Nan basin, conglomerate at the bottom of this unit overlies Permo-Triassic limestone and shale (sections 1 and 9 of Figure 2.3). They compose of pebbles of limestone, quartzite, red sandstone and claystone. The composition of this rock is similar to the basal conglomerate of unit ms1 (Siebenhuner, 1968). Near Chiang Muan of Phayao province, limestone beds that similar to those occurring in unit ms1 was observed. These presumably are marine ingressions which also transgressed the uplift areas.

2.3.4 Unit ms4

The thickness is 400-500 meters deposited in the Middle Jurassic period. This unit is characterized by quartzitic, white and grey-green arkosic sandstone with a subordinate reddish-brown color. The sandstone is fine-grained, well-sorted with slightly medium to coarse-grained and interbedded with thin claystone. Few conglomeratic beds are presented with well-rounded pebbles of white quartz. Thick bed sandstone commonly shows cross-bedding and normal honeycomb weathering.

2.3.5 Unit ms5

The maximum thickness is 200 m deposited in the Middle Jurassic period. This unit compose of red to brown sandstone interbedded with red sandy claystone. These rocks are typical for the nonmarine red bed sequence. Sandstone is fine-grained and generally exhibit good bedding.

2.4 The youngest rocks and sediments

The youngest rocks consist of volcanic rocks of Pleistocene epoch (Barr and MacDonald, 1978; Sriprasert, 1997). The rocks mostly exposed in northern and western part. The volcanic rocks consist of basalt, nephelinite and basanite. These rocks unconformably overlie Permian and Permo-Triassic rocks. Recent sediments distribute in the eastern, western, northern and southern part. All sediments commonly found as a terrace, alluvial and basin deposit. These sediments consist of semi-consolidated rock, lignite, gravel, sand, silt, clay with fossil gastropod, ostracod, ancient elephant and fish.

CHAPTER 3

Occurrence, lithology and petrography

The studied volcanic rocks in Phayao province and the vicinity areas cover an area of approximately 430 km^2 (Figure 3.1). Fifty-three selected volcanic rock samples were collected from outcrops and in situ float rocks. These studied samples can be separated into five main groups by lithology, petrography and geochemistry. The rock names used in this chapter based on their chemical composition, occurrences, textural characteristics and/or mineral constituents (McPhie *et al.*, 1993), which will be described below.

This chapter presents the rock samples in term of occurrences, lithology and petrography. Petrography from the thin section under the petrographic microscope was prepared and studied at the Department of Geological Sciences, Faculty of Science, Chiang Mai University, Thailand. The thin sections were studied to characterize primary mineral compositions, alterations and textures. The results of the petrographic study are summarized in this chapter and individually reported in Table 3.1 and Appendix A.

3.1 Group I rocks

3.1.1 Occurrence

The Group I rocks are distributed in the Phu Kamyao of Phayao province. The samples were collected from outcrops along the mountain range in the western area (Figure 3.1). The Group I rocks are composed of lava flows, i.e. sample number 14 (Figure 3.2) and pyroclastic equivalents, i.e. sample number 18 (Figure 3.3). The chemical composition of this group is rhyodacite/dacite and rhyolite. The outcrops are brown color. The lava flows show flow banding and porphyritic texture. The pyroclastic equivalents present apparent porphyritic and welded textures. The studied rocks in this areas are associated with rhyolite, andesite, tuff and an agglomerate of Pu Po volcanic formation according to Tiyapairat and Mahapoom (1990).

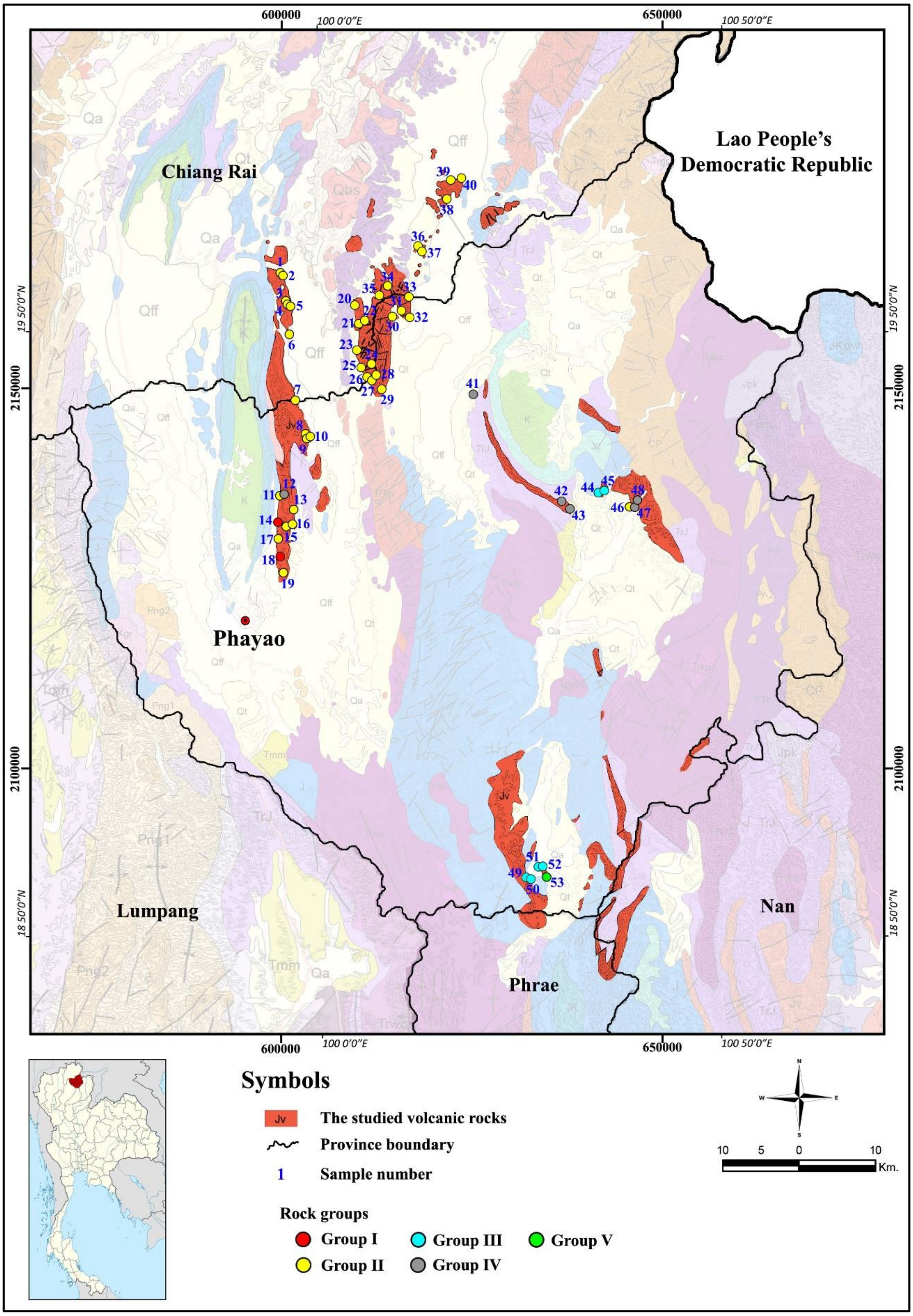


Figure 3.1 Map showing the distribution of Jurassic volcanic rocks in the Phayao province and vicinity areas with locations of selected samples.

Table 3.1 Petrographic features of representative the studied rocks.

Group	Magma series	Composition	Petrographic features
I	Alkaline	Rhyodacite/dacite	Lava flows, porphyritic with plagioclase, K-feldspar and opaque minerals. The very fine-grained groundmasses show flow banding, micropoikilitic and trachytic textures.
		Rhyolite	Pyroclastic equivalents, crystal fragments with plagioclase, K-feldspar, zircon and opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. The very fine-grained matrixes usually show eutaxitic, micropoikilitic, spherulitic and slightly trachytic textures.
II	Transitional subalkaline to alkaline	Rhyolite	Lava flows, porphyritic with quartz, plagioclase, K-feldspar, zircon and opaque minerals. The very fine-grained groundmasses show highly micropoikilitic texture.
			Pyroclastic equivalents, crystal fragments with quartz, plagioclase, K-feldspar, allanite, zircon, opaque and unidentified minerals. Lithic fragments are pumice, felsic and intermediate/ mafic volcanic rocks. The very fine-grained matrixes present non- to highly eutaxitic texture with the glass shards and show non- to highly micropoikilitic and spherulitic textures.
III	Transitional subalkaline to alkaline	Rhyolite	Lava flows, porphyritic with quartz, plagioclase, K-feldspar, zircon opaque and unidentified minerals. The very fine-grained groundmasses show flow banding and highly micropoikilitic texture.
IV	Calc-alkaline	Rhyolite	Lava flows, porphyritic with quartz, plagioclase, K-feldspar, zircon, opaque and unidentified minerals. The very fine-grained groundmasses show non- to highly micropoikilitic, spherulitic and slightly trachytic textures.
V	Tholeiitic	Rhyolite	Pyroclastic equivalents, crystal fragments consist of quartz, plagioclase, K-feldspar, opaque and unidentified minerals. Lithic fragments are pumice. The very fine-grained matrixes usually show eutaxitic, micropoikilitic and spherulitic textures.

Figure 3.2 Photograph is showing the outcrop of Group I rhyodacite/dacite at grid reference 599054E-2133757N.

Figure 3.3 Photograph is showing the outcrop of Group I Welded vitric tuff at grid reference 598758E-2129880N.

3.1.2 Lithology and petrography

Rhyodacite/dacite

Megascopically, the Group I rhyodacite/dacite shows flow banding and slightly porphyritic texture. The phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The groundmasses are very fine-grained and generally show reddish brown color. The rock turns white and light gray colors on weathering surfaces. Tiny veins sealed by white minerals have been occasionally observed. These rocks do not react with diluted hydrochloric acid.

Microscopically, these rocks show hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include plagioclase, K-feldspar and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of plagioclase (Figure 3.4) and K-feldspar with cumurocrysts of plagioclase + K-feldspar + opaque minerals. The very fine-grained groundmasses show flow banding with moderately to highly micropoikilitic texture and fine K-feldspar lath. The lath minerals present trachytic texture (Figure 3.5). The vesicles (amygdales) are filled with quartz and K-feldspar intergrowth. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the samples. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase phenocrysts/microphenocrysts size up to 0.125-0.75 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges and sieve texture.

K-feldspar phenocrysts/microphenocrysts size up to 0.075-0.75 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.25-1 mm across. They show irregular to subhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

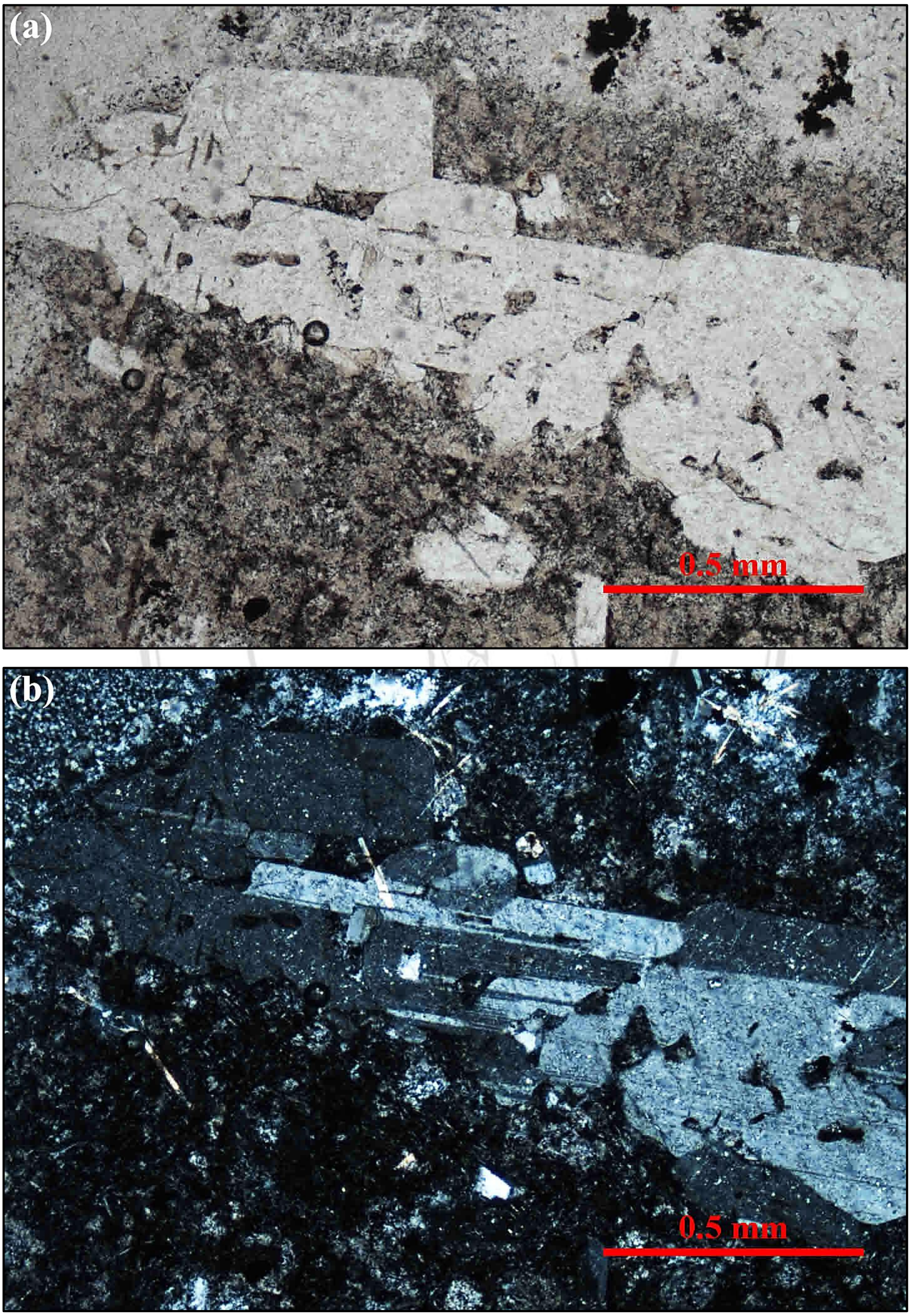


Figure 3.4 Photomicrographs of Group I rhyodacite/dacite (sample number 14) showing plagioclase glomerocrysts and the groundmasses made up of micropoikilitic texture. (a) Ordinary light (b) Crossed polars.

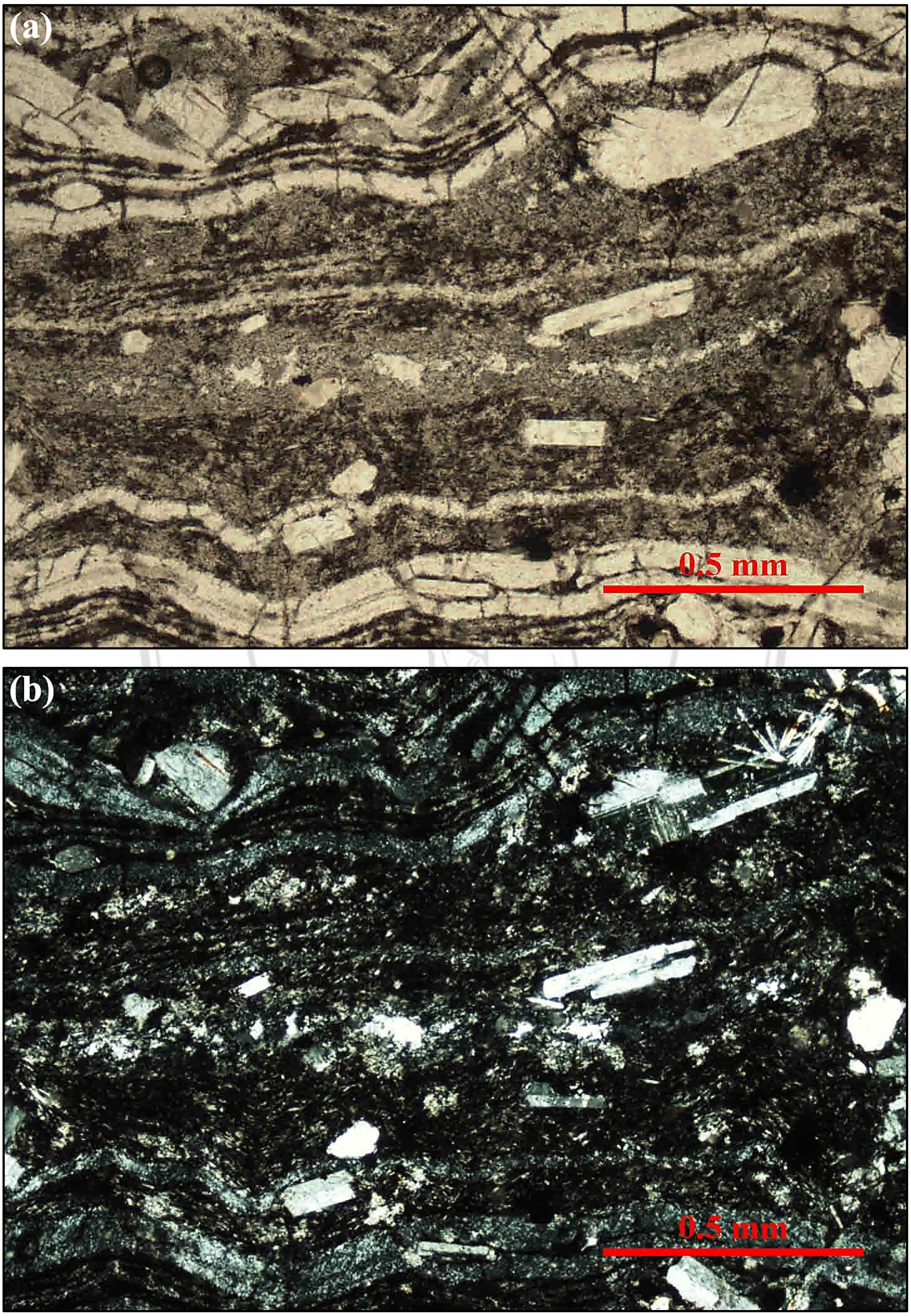


Figure 3.5 Photomicrographs of Group I rhyodacite/dacite (sample number 14) showing flow banding with the trachytic texture of the lath minerals. (a) Ordinary light (b) Crossed polars.

Welded tuff

Megascopically, the Group I tuff shows banded (eutaxitic texture) and slightly apparent porphyritic textures. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The matrixes very fine-grained and reddish brown color. The rock turns white color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopically, these rocks contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, zircon and opaque minerals. These fragments form as isolated grains, glomerocrysts of plagioclase with cumulocrysts of plagioclase + opaque minerals and K-feldspar + opaque minerals. The lath minerals show slightly trachytic texture. Lithic fragments are pumice and felsic volcanic rock. These fragments size up to 0.25-2.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding with micropoikilitic and spherulitic textures. The very fine-grained matrixes show moderately micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.1-0.3 mm across with semispherical to spherical shape. They might show elongate trains and often aligned along flow layering (Figure 3.6). Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.25-0.875 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1.5 mm across. They show anhedral to euhedral outlines. These crystals moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

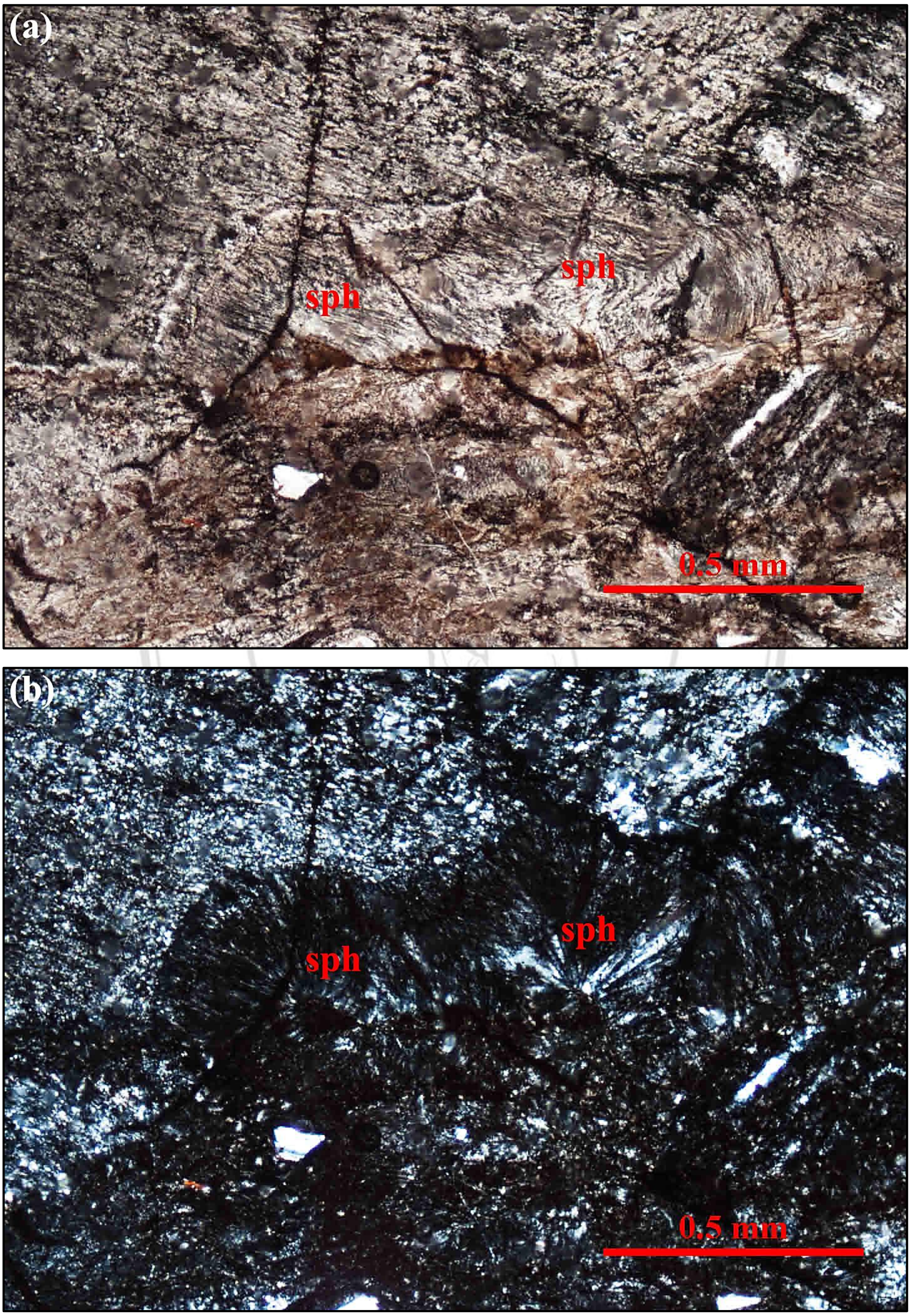


Figure 3.6 Photomicrographs of Group I welded vitric tuff (sample number 18) showing the spherulite (sph) elongate trains and often aligned along foliation layering.
(a) Ordinary light (b) Crossed polars.

Zircon crystals size up to 0.01 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by K-feldspar.

Opaque minerals size up to 0.125-0.5 mm across. They show irregular to euhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

3.2 Group II rocks

3.2.1 Occurrence

The Group II rocks are distributed in the Phu Kamyao, Chun of Phayao province and Pa Deat of Chiang Rai province. The samples were collected from both outcrops and in situ float rocks along the mountain range in the western, northern and few part in the eastern area (Figure 3.1). The Group II rocks are composed of lava flows, i.e. sample numbers 11 and 46 (Figures 3.7) and pyroclastic equivalents, i.e. sample numbers 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 13, 15, 16, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39 and 40 (Figure 3.8). The chemical composition of this group is rhyolite. The outcrops and in situ float rocks are gray, brown and green colors. The lava flows show slightly porphyritic texture. The pyroclastic equivalents are both of apparent porphyritic and fragmental textures. These rocks show non-welded and welded textures. The studied rocks in this areas are associated with rhyolite, andesite, tuff and an agglomerate of Pu Po volcanic formation according to Tiyapairat and Mahapoom (1990) and tuff, rhyolitic tuff, crystal, tuff, lithic tuff and welded vitric tuff of Kiu Kaeo volcanic formation with rhyodacite, rhyolite, andesite and tuff of rhyodacite, rhyolite, andesite and tuff of Doi Mon Yao volcanic formation (Tansuwan and Kosuwan 1988).

3.2.2 Lithology and petrography

<u>Rhyolite</u>

Megascopically, the Group II rhyolite shows a porphyritic texture. The phenocrysts/microphenocrysts of white color size up to ≤ 1.5 mm across. The groundmasses are very fine-grained and generally show reddish brown and greenish gray colors. The rock turns light green and brown colors on weathering surfaces. Tiny fractures

Figure 3.7 Photograph is showing the outcrop of Group II rhyolite at grid reference 645639E-2134159N.

Figure 3.8 Photograph showing the outcrop of Group II welded lithic tuff at grid reference 622556E-2177662N.

and cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopically, these rocks show hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon (Figure 3.9) and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of quartz and plagioclase with cumurocrysts of quartz + plagioclase (Figure 3.10). The very fine-grained groundmasses show moderately to highly micropoikilitic texture (Figure 3.11) and vesicles. The vesicles (amygdales) are filled with sericite, chlorite and Fe-Ti oxide. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide and few quartz veins have also been observed. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz phenocrysts/microphenocrysts size up to 0.025-1.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals. The crystals might show reaction rim.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.125 mm across. They mostly show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals, Fe-Ti oxide with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-0.875 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief.

Microphenocrysts of opaque minerals size up to 0.025-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

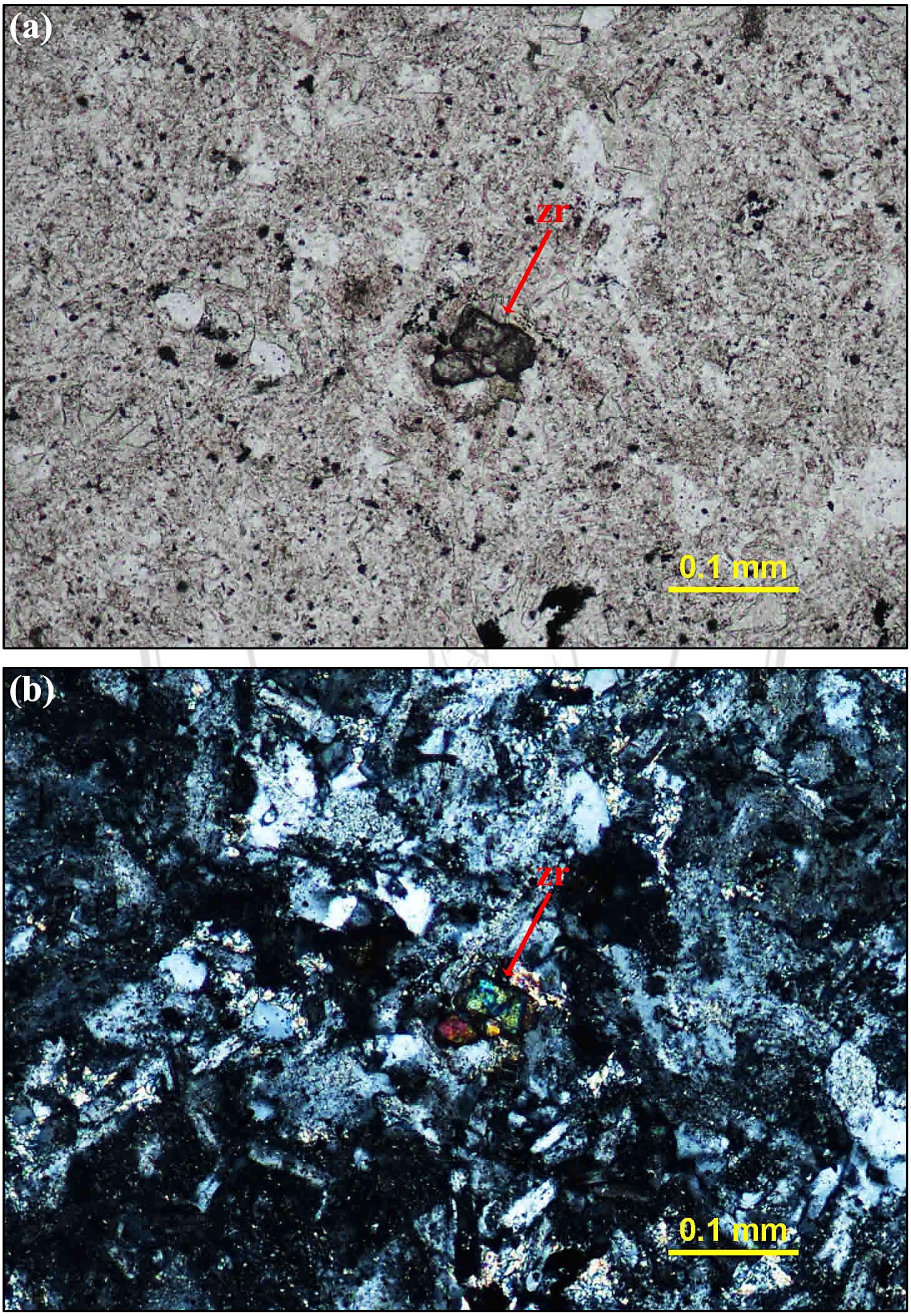


Figure 3.9 Photomicrographs of Group II rhyolite (sample number 46) showing zircon (zr) with the groundmasses made up of micropoikilitic texture. (a) Ordinary light (b) Crossed polars.

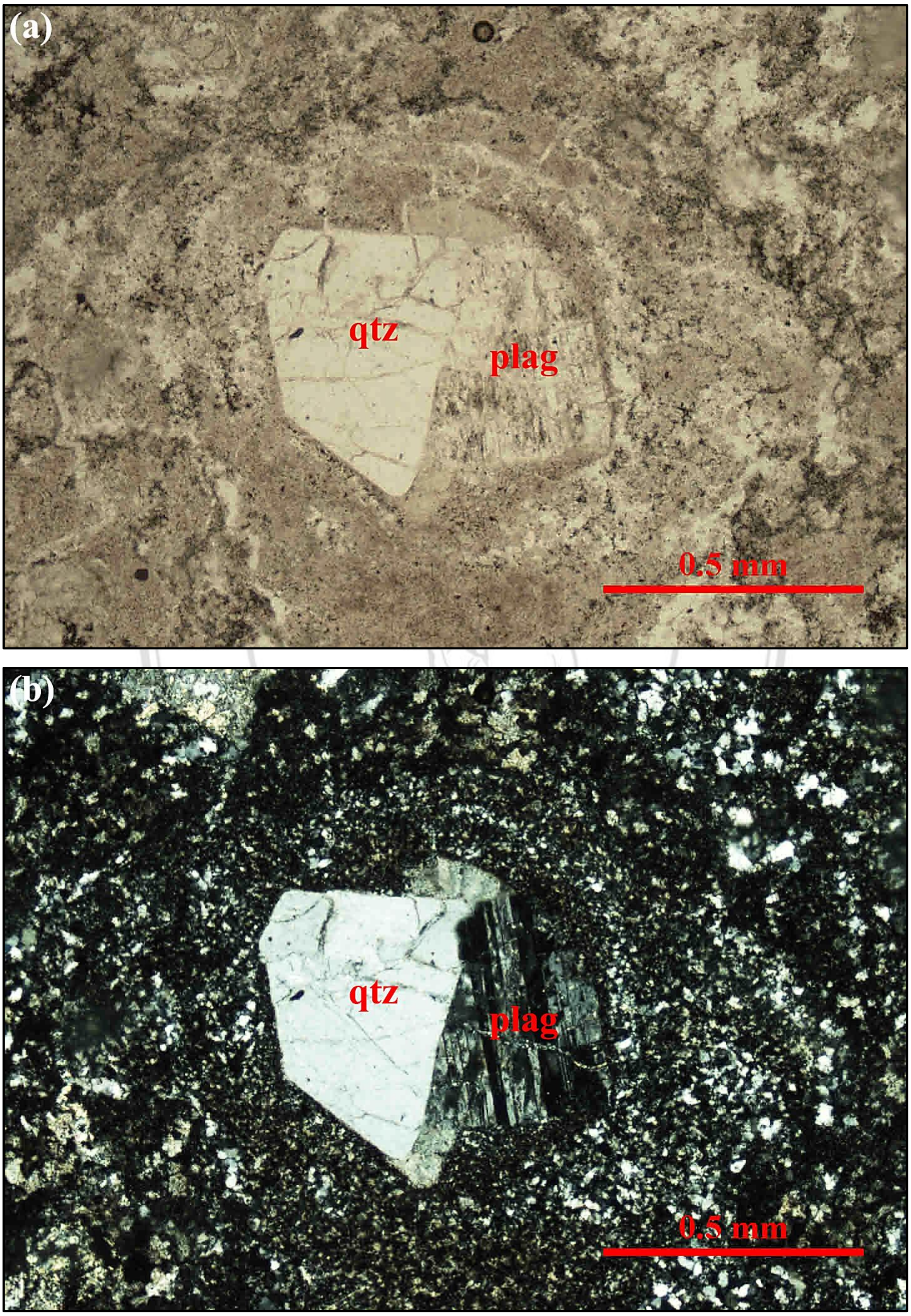


Figure 3.10 Photomicrographs of Group II rhyolite (sample number 11) showing cumurocrysts of quartz (qtz) and plagioclase (plag). (a) Ordinary light (b) Crossed polars.

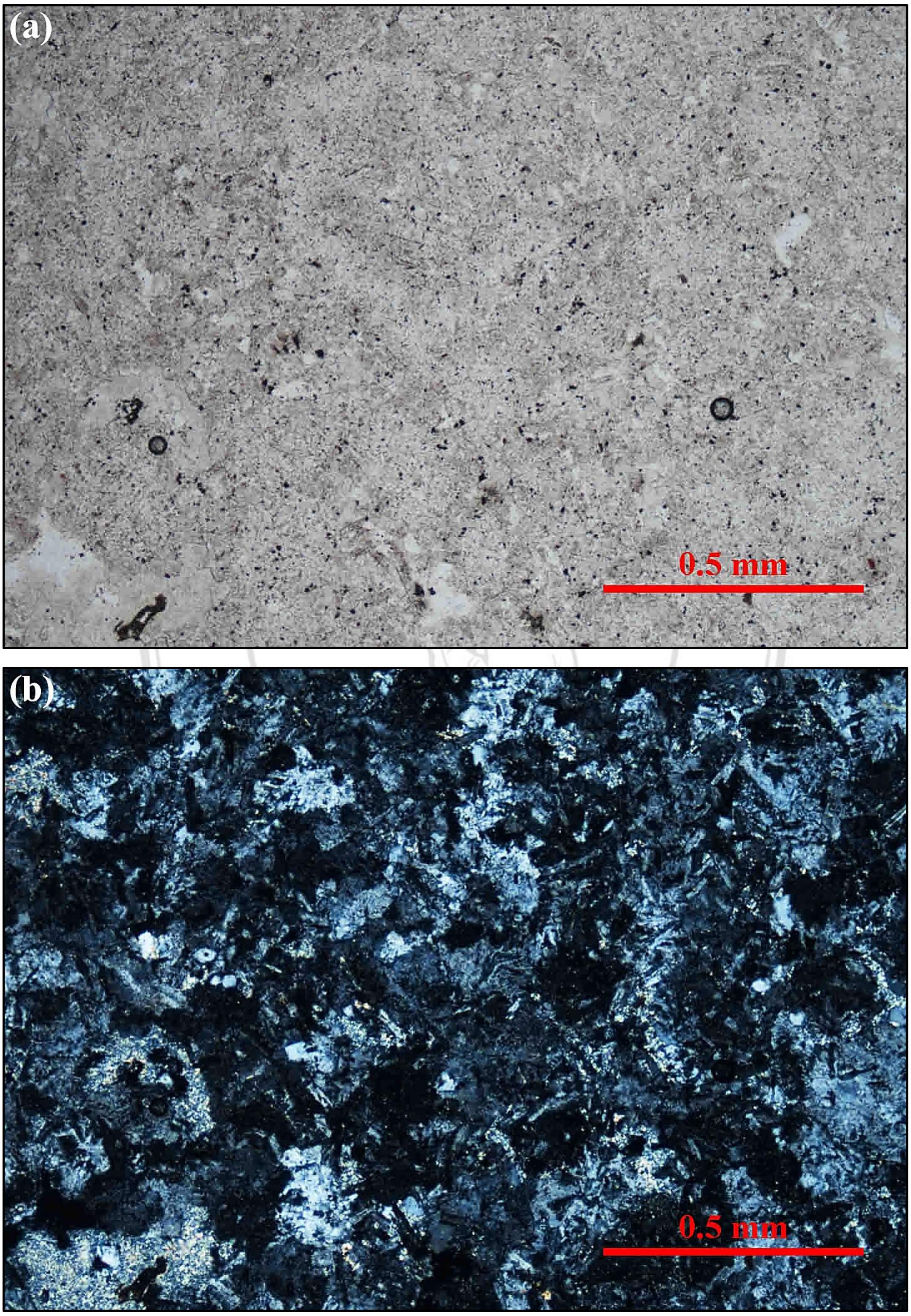


Figure 3.11 Photomicrographs of Group II rhyolite (sample number 46) showing well-developed micropoikilitic texture with fine K-feldspar lath enclosed by micropoikilitic quartz. (a) Ordinary light (b) Crossed polars.

Welded tuff

Megascopically, the Group II tuff shows banded (eutaxitic texture) and apparent porphyritic textures. The banded texture has colorless, white and yellowish brown colors (size up to ≤ 1 cm across). The apparent phenocrysts/ microphenocrysts of yellowish white and white colors size up to ≤ 1.5 mm across. The lath minerals present slightly trachytic texture. These rocks might show fragmental texture with crystal and lithic fragments. The crystals fragment of white and pink colors size up to ≤ 1 mm across. The lithic fragments have light to yellowish brown and black colors with size up to ≤ 3.5 mm across. The matrixes are very fine-grained and generally show reddish to dark brown and dark gray colors. The rock turns light to yellowish brown, brown, white and light gray colors on weathering surfaces. Tiny fractures have been occasionally observed. These rocks do not react with diluted hydrochloric acid.

Microscopically, these rocks contain abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar, zircon, opaque and unidentified minerals (Figure 3.12). These fragments form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumulocrysts of plagioclase + K-feldspar, plagioclase + opaque minerals, K-feldspar + opaque minerals and plagioclase + K-feldspar + opaque minerals. The lath minerals present slightly trachytic texture. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.1-3.75 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. They might thoroughly recrystallize with intergrowth of quartz and K-feldspar. The felsic volcanic rock fragments present flow banding with trachytic and micropoikilitic textures. These fragments show porphyritic with quartz microphenocrysts and spherulitic textures. They might present jigsaw-fit texture that separated by quartz and K-feldspar intergrowth. The very fine-grained matrixes show non- to highly micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments (Figure 3.13). The spherulites size up to 0.05-0.375 mm across with semispherical to

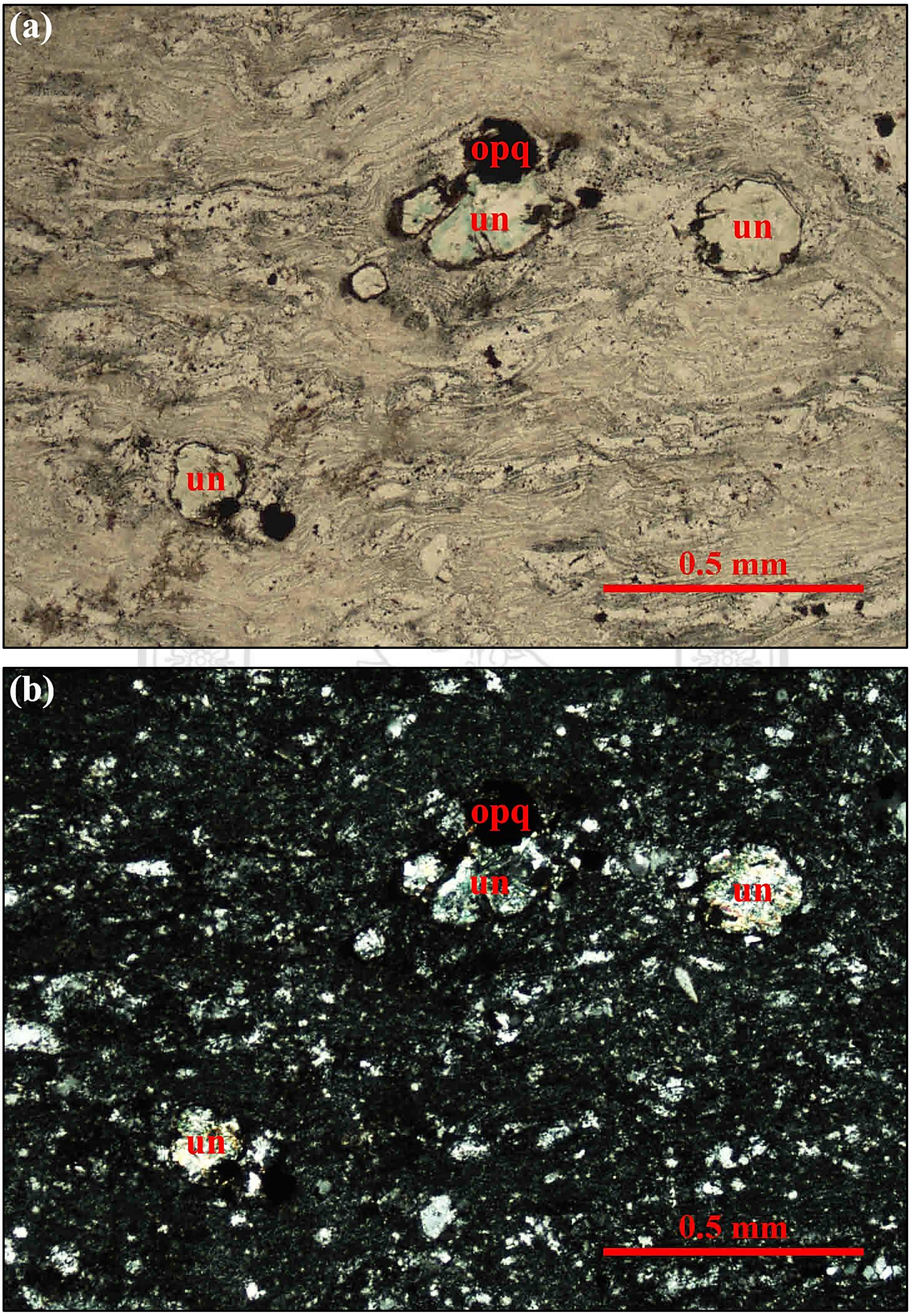


Figure 3.12 Photomicrographs of Group II welded vitric tuff (sample number 01) showing unidentified minerals (un) completely pseudomorph by sericite, chlorite and Fe-Ti oxide with the very fine-grained matrixes made up of eutaxitix texture [opq = opaque minerals]. (a) Ordinary light (b) Crossed polars.

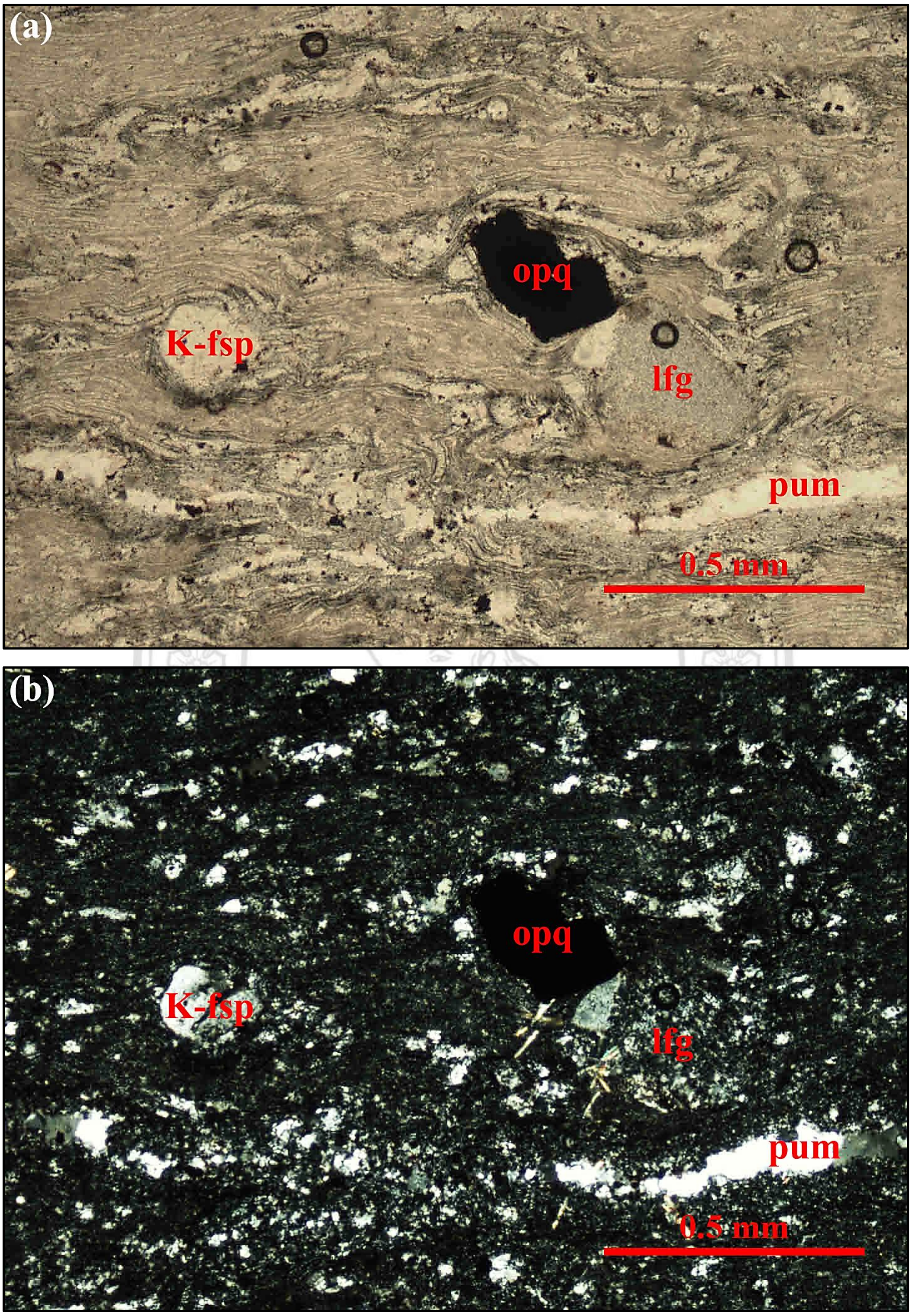


Figure 3.13 Photomicrographs of Group II welded vitric tuff (sample number 01) showing eutaxitic texture deflected around the edges of crystal and lithic fragments, the flattened and lenses of the pumice (pum) thoroughly recrystallized with intergrowth of quartz and K-feldspar [K-fsp = K-feldspar, opq = opaque minerals, lfg = lithic fragments]. (a) Ordinary light (b) Crossed polars.

spherical shapes. They might show elongate trains and often aligned along foliation layering. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the samples. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor to the higher amount.

Quartz crystals size up to 0.2-0.25 mm across. They mostly show anhedral outlines. The crystals present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.125-1.5 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar size up to 0.075-1.5 mm across. They show anhedral to euhedral outlines. Crystals slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon size up to 0.01 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by K-feldspar.

Opaque minerals size up to 0.025-0.5 mm across. They show irregular to subhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.05-0.25 mm across. They show subhedral to euhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Non- to slightly welded tuff

Megascopically, the Group II tuff shows both of apparent porphyritic and fragmental textures. The apparent phenocrysts/microphenocrysts of colorless, white, greenish white and pink colors size up to ≤ 2 mm across. The fragmental textures are crystal and lithic fragments. The crystal fragments have colorless, yellowish white, white and pink colors size up to ≤ 4 mm across. The lithic fragments have light to greenish gray, green, yellowish to reddish brown, brown, brownish black and black colors with size up to ≤ 8 mm across. The matrixes are very fine-grained and generally show yellowish-, reddish- to dark brown, brown, light green, brownish gray and gray colors. The rock turns white, pink, yellowish to reddish brown, brown, pink, light gray and gray colors on weathering surfaces. Tiny fractures and cavities sealed by colorless, yellowish white, white and light green minerals have been occasionally observed. These rocks do not react and slightly react with diluted hydrochloric acid.

Microscopically, these rocks contain abundant crystal- and lithic-rich fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz (Figure 3.14), plagioclase, K-feldspar, allanite, zircon (Figures 3.15), opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of quartz, plagioclase and K-feldspar with cumulocrysts of plagioclase + K-feldspar, plagioclase + opaque minerals and plagioclase + K-feldspar + opaque minerals. The lath minerals might show slightly trachytic texture. Lithic fragments are pumice (Figures 3.16-3.17) with felsic and intermediate/mafic volcanic rocks (Figure 3.18). These fragments size up to 0.025-5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with slightly to highly replaced by sericite and chlorite. The felsic volcanic rock fragments show flow banding with trachytic and micropoikilitic textures. These fragments present porphyritic texture. Intermediate/mafic volcanic rock fragments present porphyritic with plagioclase microphenocrysts and trachytic textures. The very fine-grained matrixes show non- to highly micropoikilitic texture. The matrixes dominated non- to slightly foliation (eutaxitic texture) with the platy and cuspate shape of glass shards (Figure 3.19). The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by calcite, Fe-Ti oxide with quartz and K-feldspar intergrowth. Few quartz veins have also been observed and secondary patches of sericite, chlorite, Fe-Ti oxide and epidote (Figure 3.20) appear in the minor to the higher amount.

Quartz crystals size up to 0.025-2.5 mm across. They show anhedral to euhedral outlines. These crystals might present rounded edges and embayed crystals.

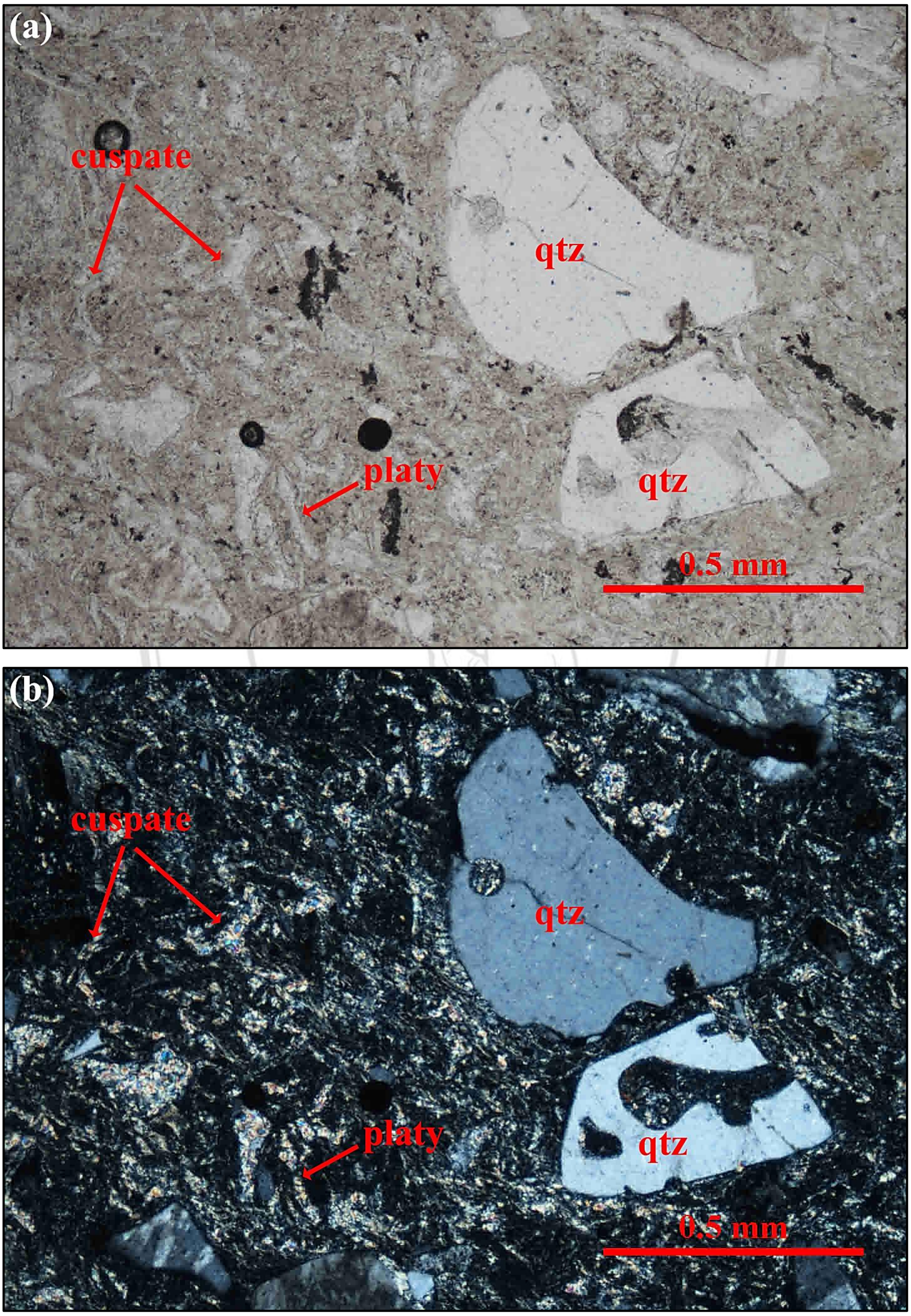


Figure 3.14 Photomicrographs of Group II crystal tuff (sample number 33) showing embayed quartz (qtz) with the platy and cuspate shape of glass shards. (a) Ordinary light (b) Crossed polars.

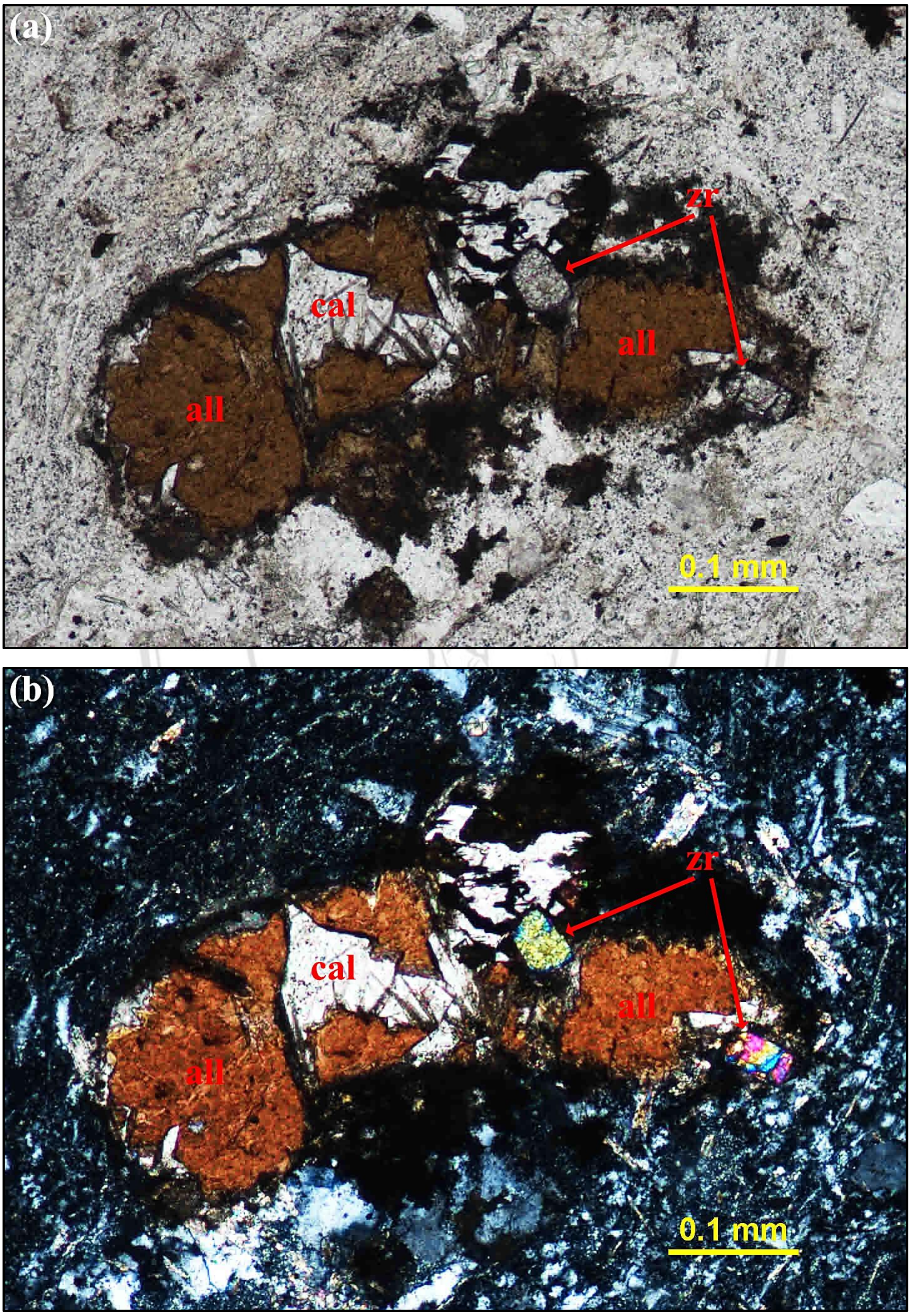


Figure 3.15 Photomicrographs of Group II welded crystal tuff (sample number 30) showing zircon (zr) enclosed by allanite (all) and calcite (cal) sealed in cracks. (a) Ordinary light (b) Crossed polars.

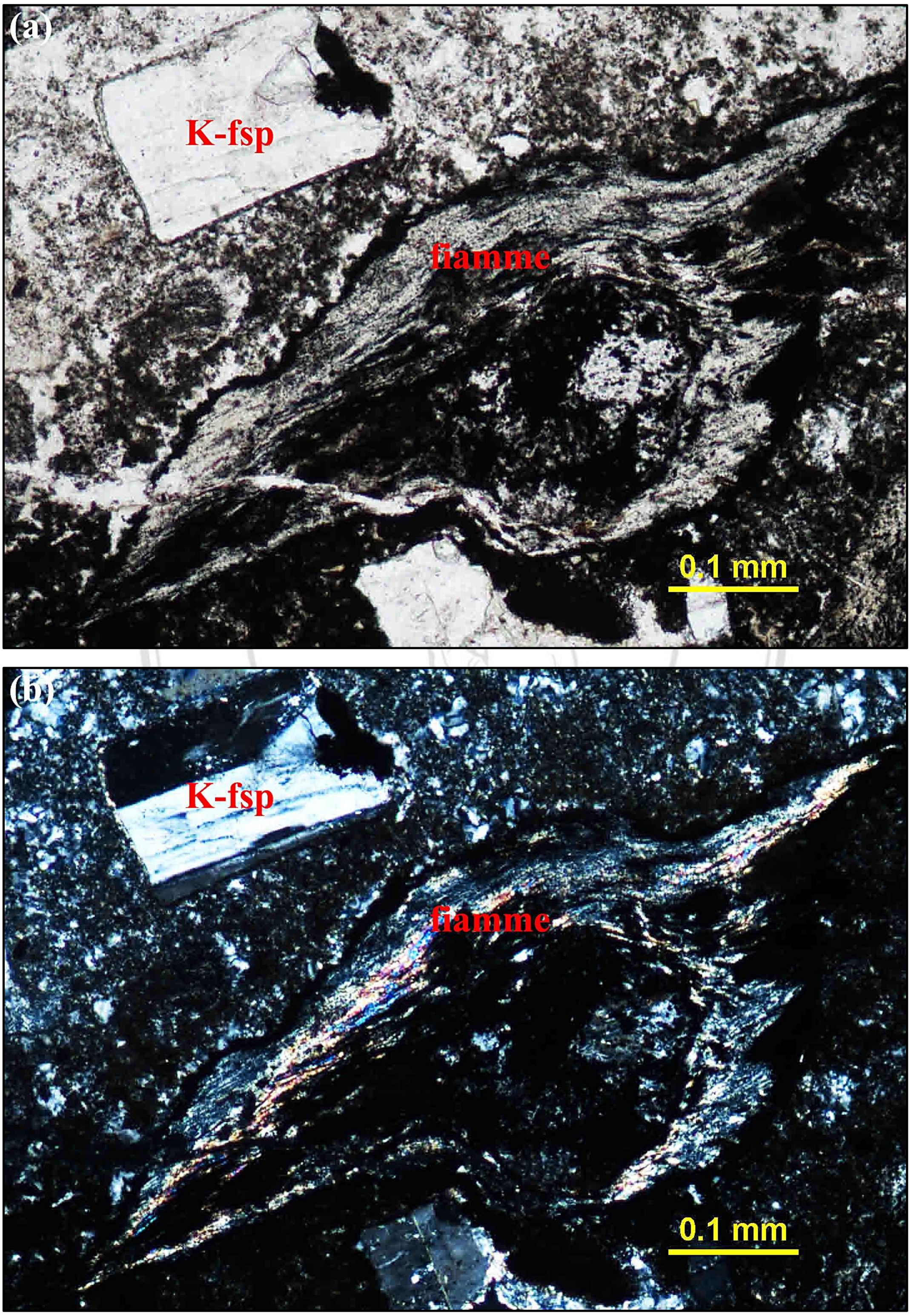


Figure 3.16 Photomicrographs of Group II lithic tuff (sample number 34) showing the fiamme-like shape of pumice and K-feldspar (K-fsp). (a) Ordinary light (b) Crossed polars.

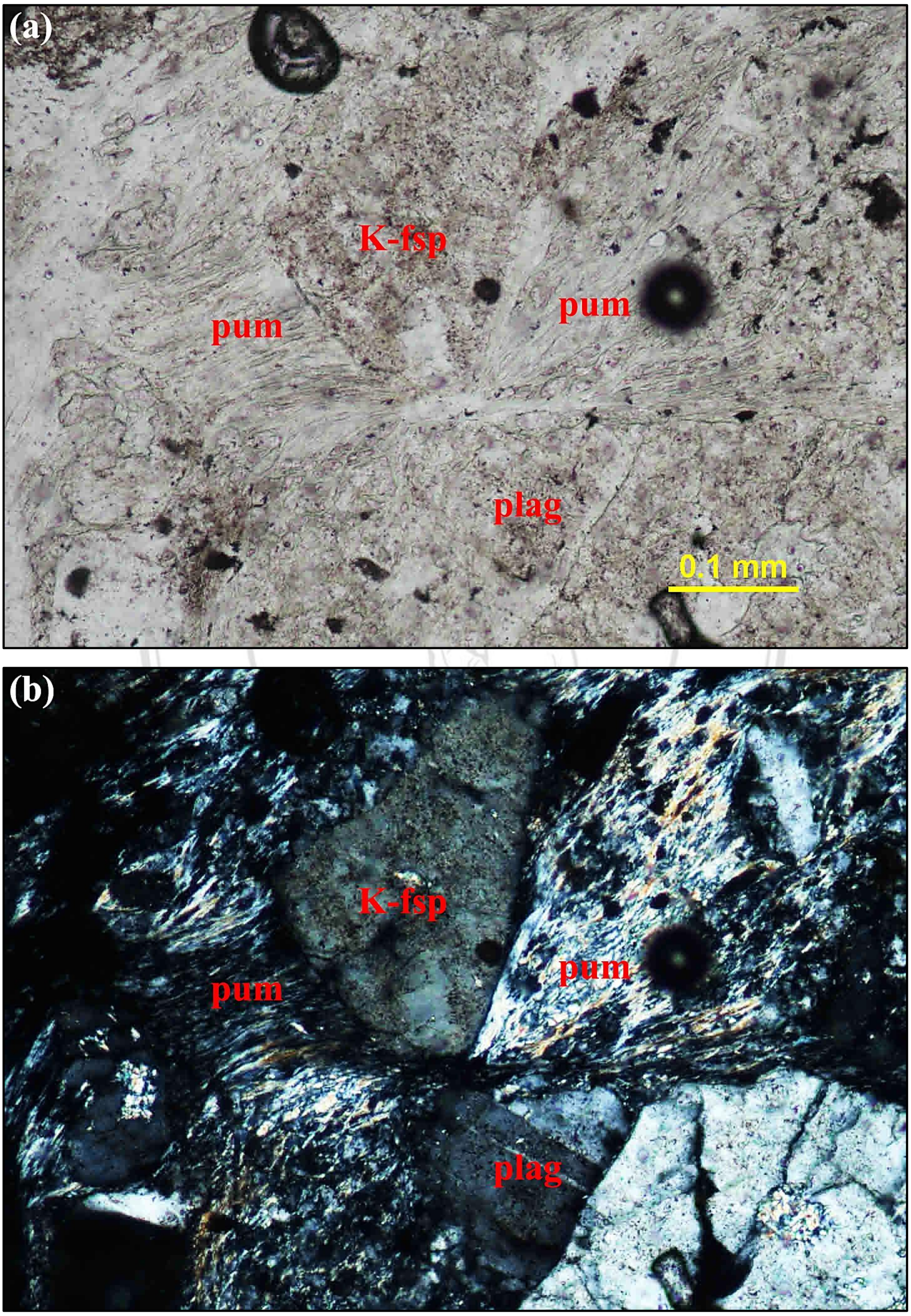


Figure 3.17 Photomicrographs of Group II crystal tuff (sample number 39) showing collapsed tube vesicle texture of the pumice wisps (pum) near the edges of plagioclase (plag) and K-feldspar (K-fsp). (a) Ordinary light (b) Crossed polars.

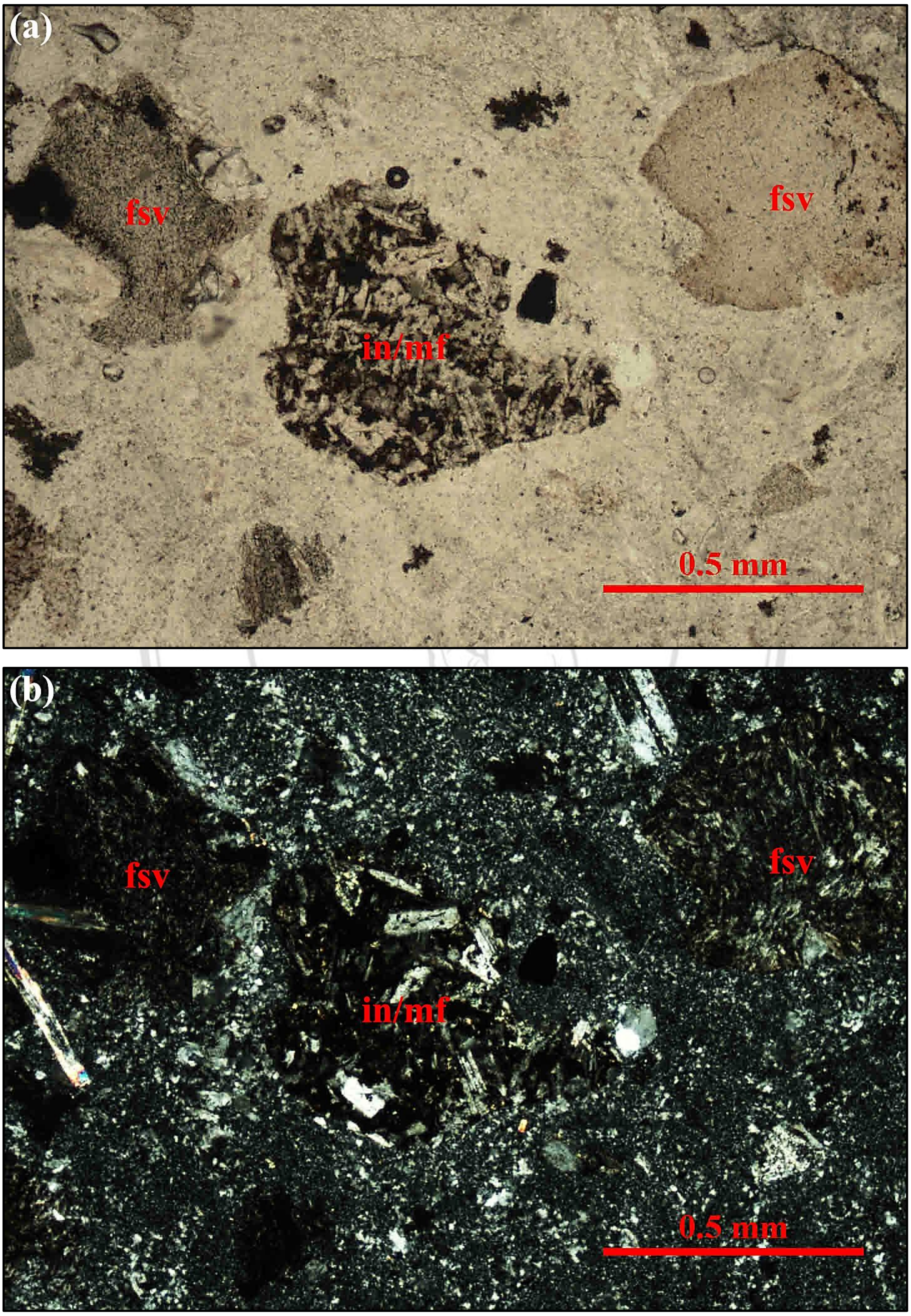
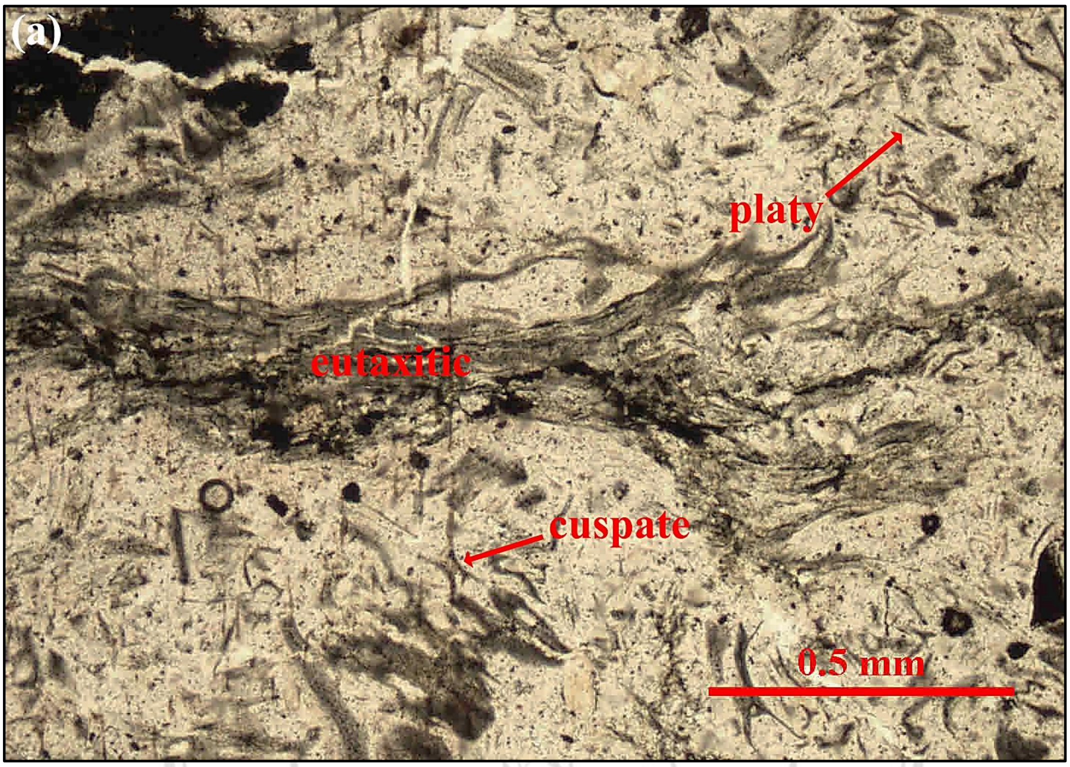


Figure 3.18 Photomicrographs of Group II lithic tuff (sample number 15) showing the very fine-grained matrixes with lithic fragments [fsv = felsic, in/mf = intermediate/ mafic volcanic rock]. (a) Ordinary light (b) Crossed polars.



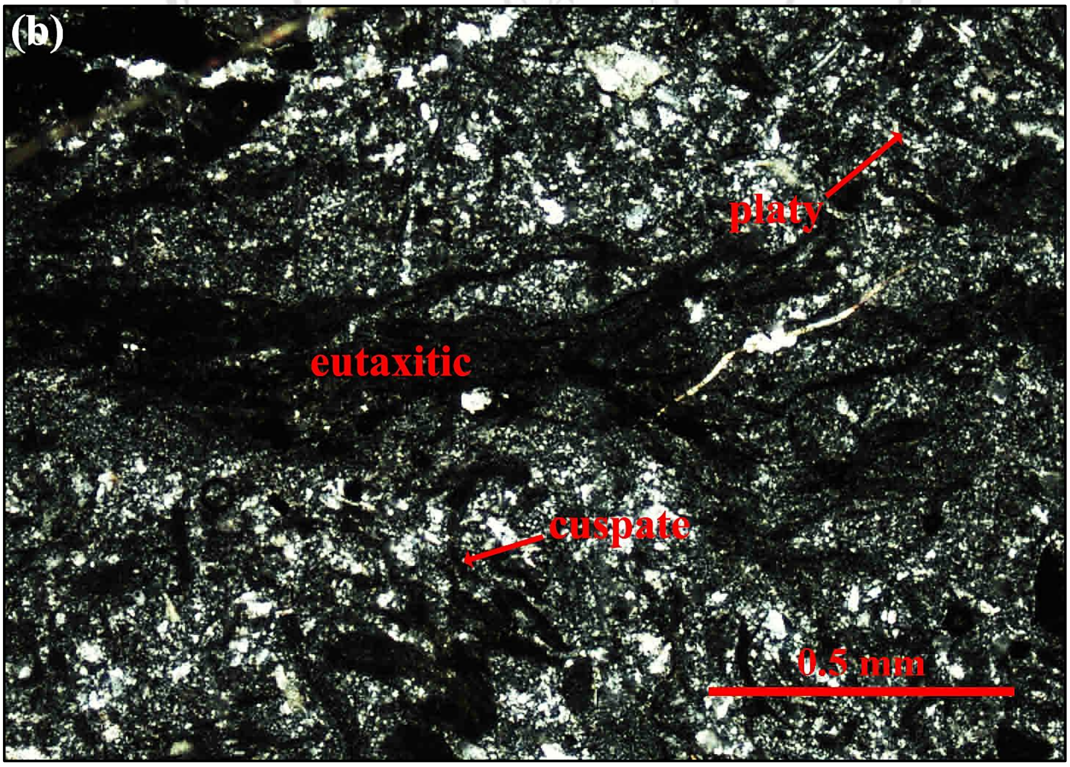


Figure 3.19 Photomicrographs of Group II welded lithic tuff (sample number 07) showing eutaxitic texture with the platy and cuspate shape of glass shards. (a) Ordinary light (b) Crossed polars.

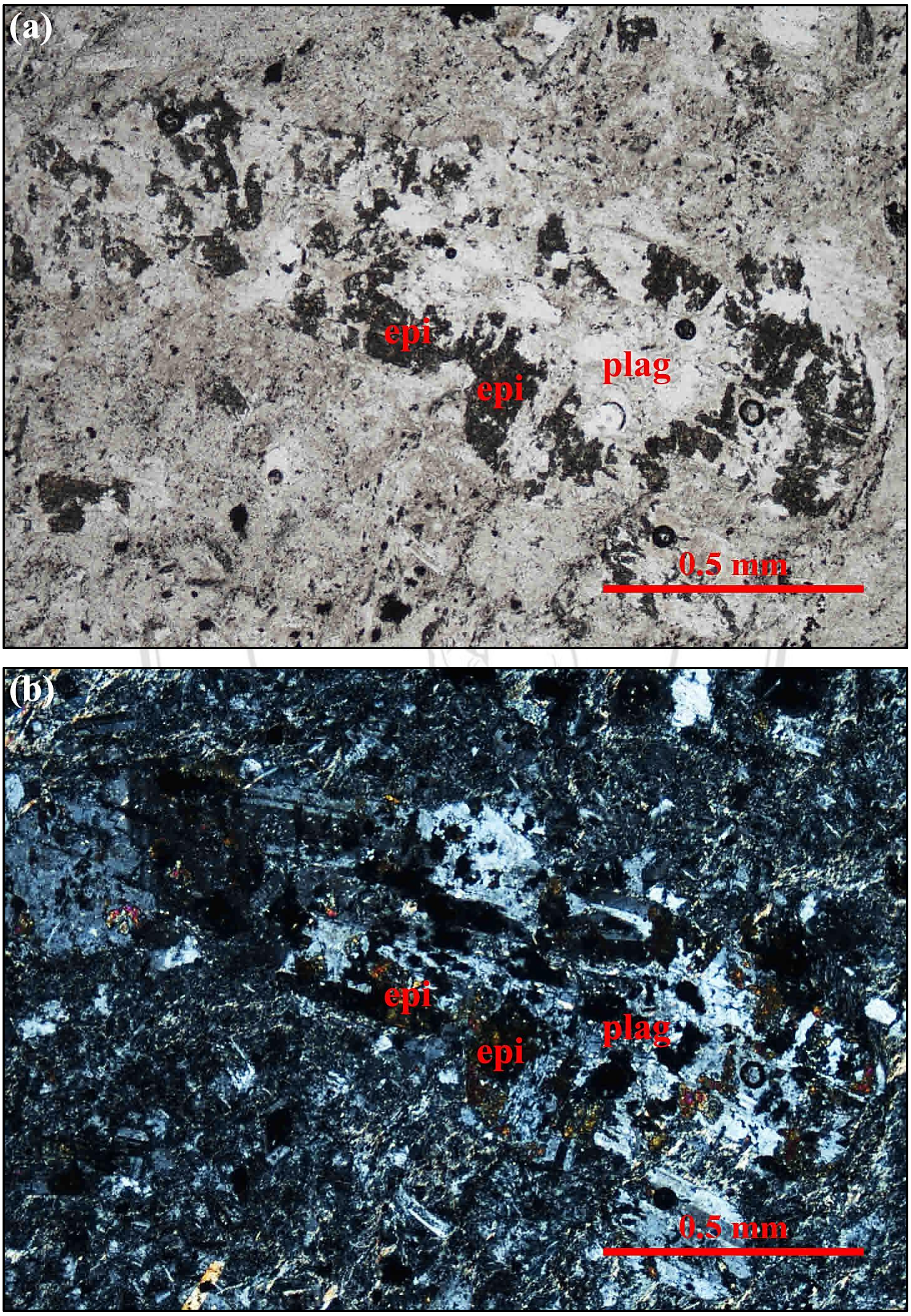


Figure 3.20 Photomicrographs of Group II crystal tuff (sample number 38) showing epidote (epi) replaced in plagioclase (plag) glomerocrysts. (a) Ordinary light (b) Crossed polars.

Plagioclase crystals size up to 0.125-1.25 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to highly replaced by sericite, chlorite, clay minerals, Fe-Ti oxide, calcite and epidote. The crystals might show rounded edges and sieve texture.

K-feldspar crystals size up to 0.025-1.5 mm across. They show anhedral to euhedral outlines. These crystals slightly to highly replaced by sericite, chlorite, clay minerals, calcite, Fe-Ti oxide and epidote. The crystals might show rounded edges and might completely pseudomorph by quartz and K-feldspar intergrowth with Fe-Ti oxide. Some of crystals present simple twining.

Allanite crystals size up to 0.1-0.25 mm across. They show irregular to euhedral outlines and very high relief. These crystals present a light brown color and cracks with sealed by calcite.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by allanite, K-feldspar and opaque minerals.

Opaque minerals size up to 0.025-0.5 mm across. They show irregular to euhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.025-0.3 mm across. They show euhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

3.3 Group III rocks

3.3.1 Occurrence

The Group III rocks are distributed in the Chiang Muan and Pong of Phayao province. The samples were collected from both outcrops and in situ float rocks along the mountain range in the southern and the eastern area (Figure 3.1). The Group III rocks are composed of lava flows, i.e. sample number 44, 45, 49, 50, 51 and 52 (Figures 3.21-3.22). The chemical composition of this group is rhyolite. The outcrops and in situ float rocks brown and pink colors. The lava flows show flow banding with porphyritic and spherulitic textures. The studied rocks in this areas are associated with rhyolite, rhyolitic tuff and tuff of Unit J_{1-3} according to Jonglakmanee and Khenwiset (1986) and rhyodacite, rhyolite,

Figure 3.21 Photograph showing the outcrop of Group III rhyolite at grid reference 632038E-2086902N.

Figure 3.22 Photograph showing the outcrop of Group III rhyolite at grid reference 640494E-2136148N.

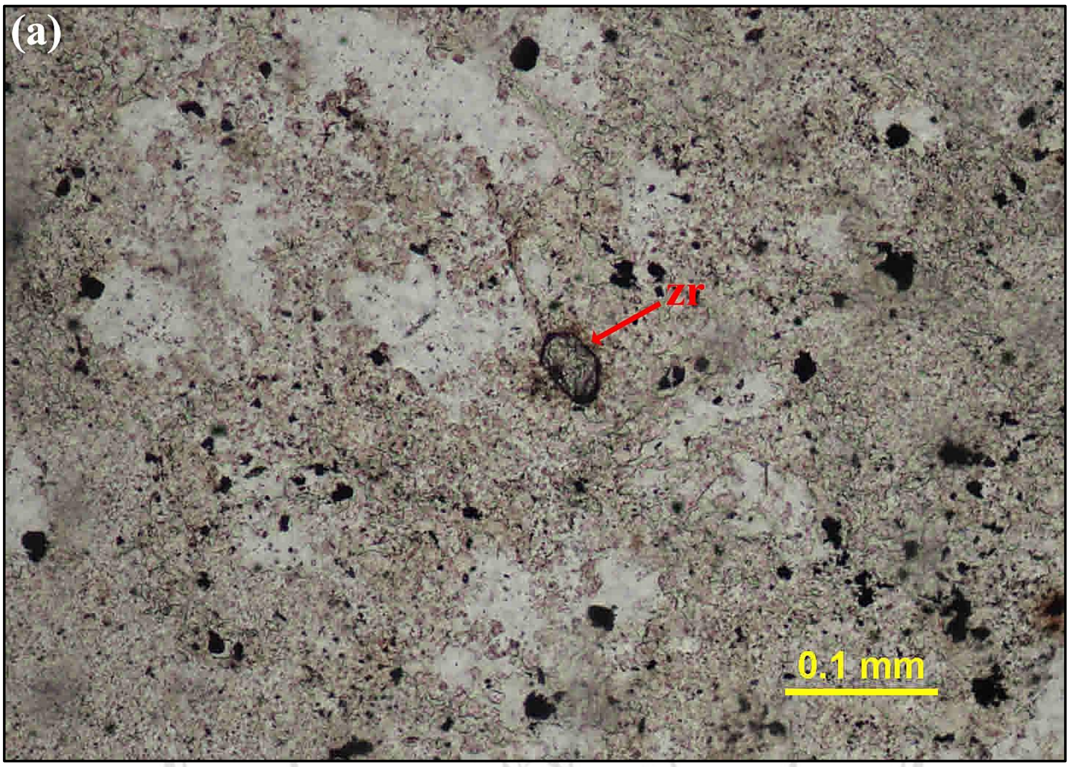
rhyolitic tuff, andecite and andecitic tuff of Doi Cha Hang formation (Imsamut and Wongprayun, 2003) with rhyodacite, rhyolite, andesite and tuff of Doi Mon Yao volcanic formation according to Tansuwan and Kosuwan (1988).

3.3.2 Lithology and petrography

Rhyolite

Megascopically, the Group III rhyolite shows flow banding with porphyritic and spherulitic textures. The flows banding have white and pink colors with size up to ≤ 2 mm across which are deflected around the edges of crystal and spherulites. The phenocrysts/microphenocrysts of colorless, white, pink and green colors size up to ≤ 1.5 mm across. The spherical spherulites (size up to ≤ 5 cm across) consist of colorless, white and brownish gray minerals. They might retain concentric zonation. The groundmasses are very fine-grained and generally show reddish to grayish brown and pink colors. The rock turns light-, yellowish-, to dark brown, light pink, gray and black colors on weathering surfaces. Fractures and cavities sealed by colorless, white and light green minerals have been occasionally observed. These rocks do not react to react with diluted hydrochloric acid.

Microscopically, these rocks show hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon (Figure 3.23), opaque and unidentified minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of quartz and K-feldspar with cumurocrysts of quartz + plagioclase, plagioclase + K-feldspar and plagioclase + opaque minerals. The very fine-grained groundmasses show flow banding and slightly to highly micropoikilitic texture with fine K-feldspar lath (Figure 3.24). The groundmasses present spherulitic texture and vesicles. The spherulites size up to 0.2-2.5 mm across with semispherical to spherical shapes. They might grow on quartz crystal and are elongate trains with often aligned along flow layering. The vesicles (amygdales) are filled with sericite, chlorite, clay minerals, euhedral quartz, K-feldspar lath with quartz and K-feldspar intergrowth. They are similar to coalesced spherulites. The vesicles surrounded by smaller recrystallized spherulites which impart granular texture (Figure 3.25). Tiny fractures sealed by calcite, Fe-Ti oxide



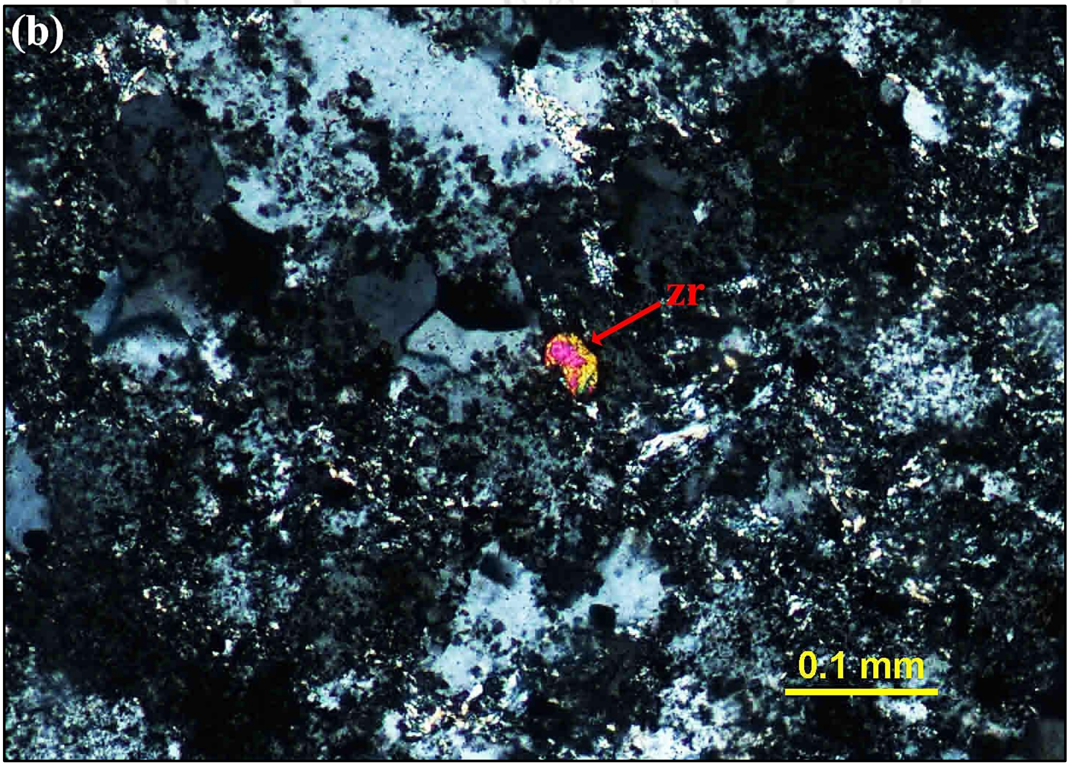


Figure 3.23 Photomicrographs of Group III rhyolite (sample number 51) showing zircon and the groundmasses made up of micropoikilitic texture. (a) Ordinary light (b) Crossed polars.

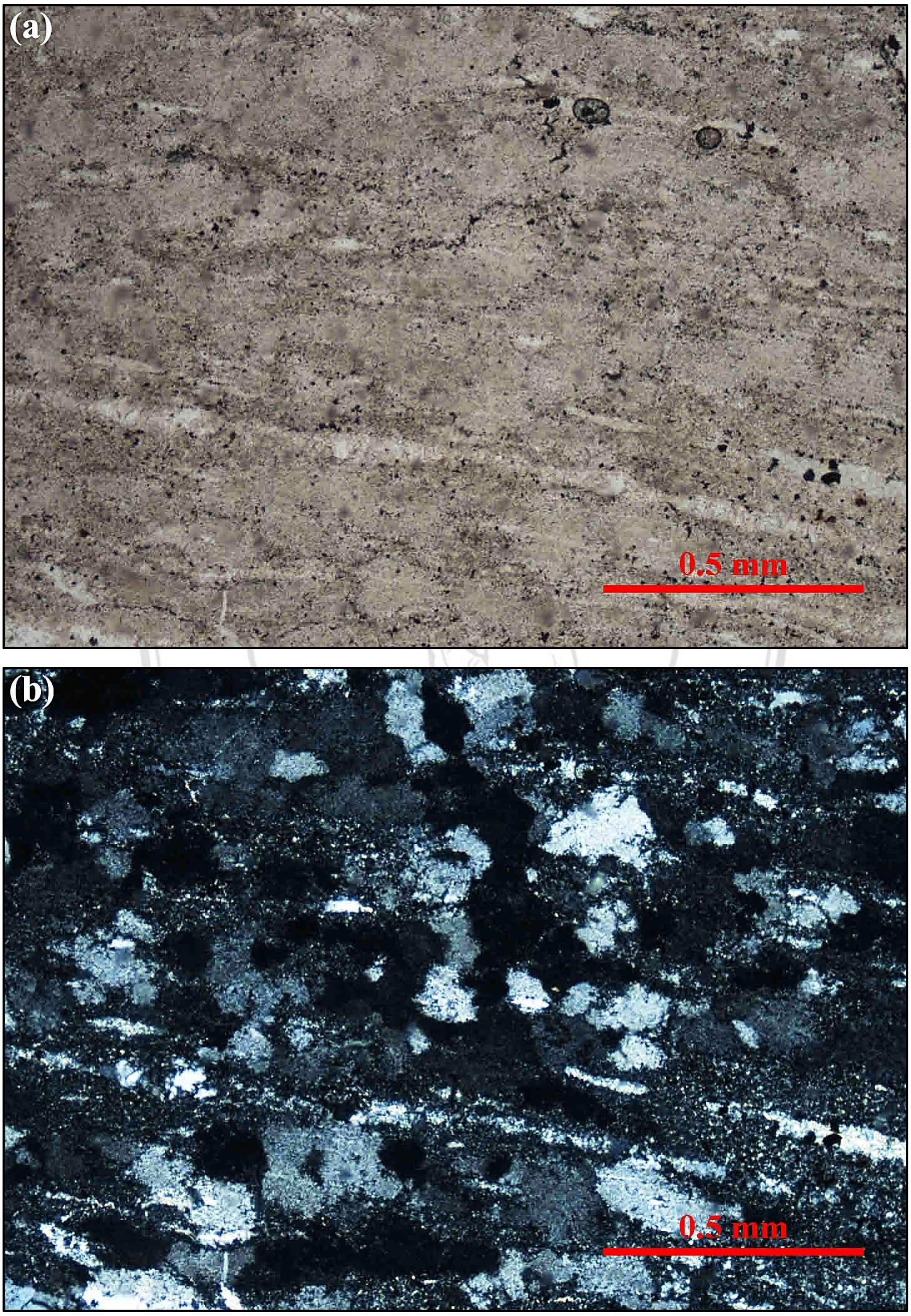


Figure 3.24 Photomicrographs of Group III rhyolite (sample number 51) showing flow banding and slightly to highly micropoikilitic texture (a) Ordinary light (b) Crossed polars.

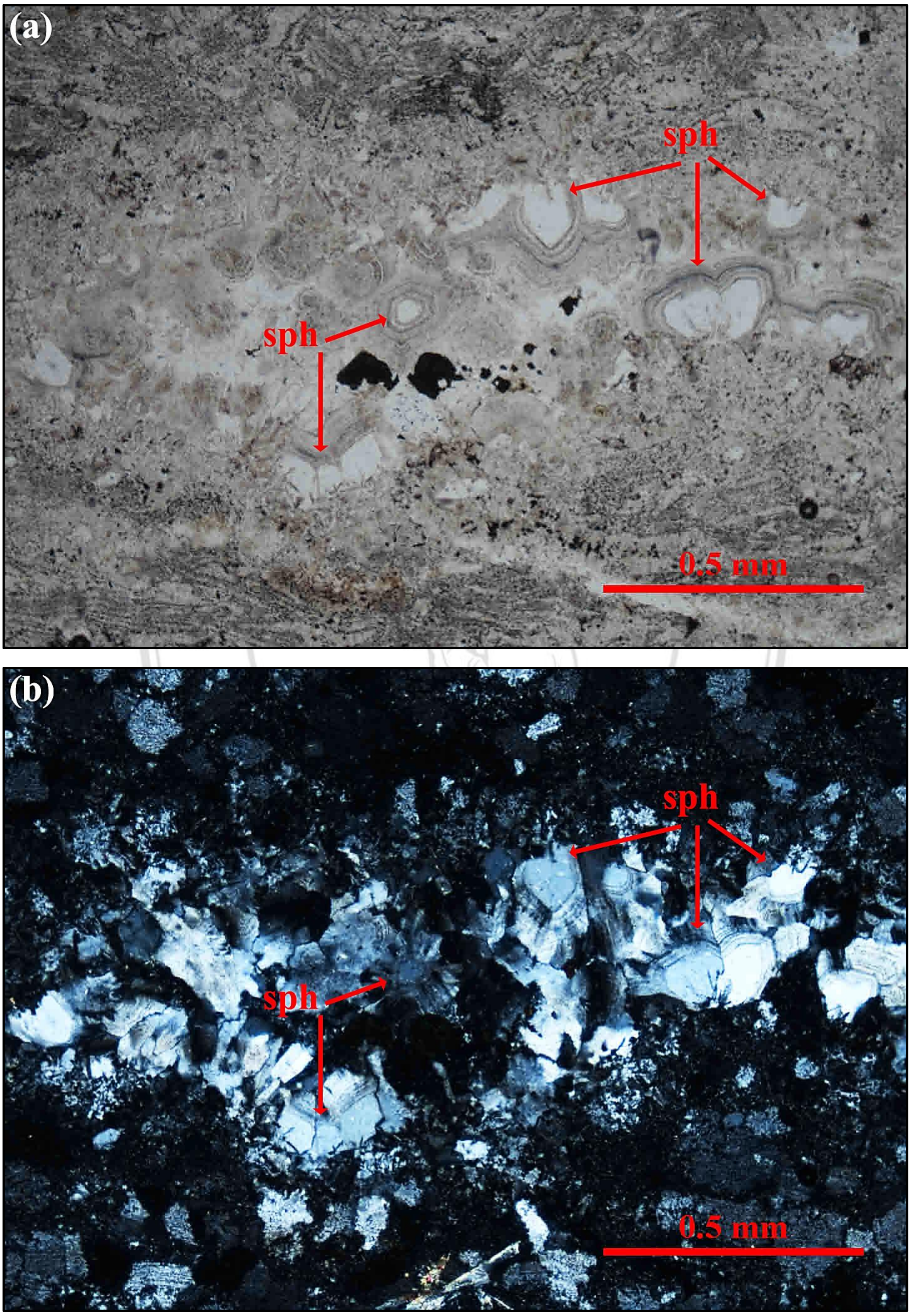


Figure 3.25 Photomicrographs of Group III spherulitic rhyolite (sample number 50) showing smaller recrystallized spherulites (sph) which impart granular texture. (a) Ordinary light (b) Crossed polars.

and euhedral quartz. Few quartz veins have also been observed in the samples. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-1.75 mm across. They show anhedral to euhedral outlines. These crystals present rounded edges and embayed crystals. The crystals might show reaction rim.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.625 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.125-2.25 mm across. They show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclose by opaque minerals.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.025-0.375 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Microphenocrysts of unidentified minerals size up to 0.05-0.25 mm across. They largely show anhedral to euhedral. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

3.4 Group IV rocks

3.4.1 Occurrence

The Group IV rocks are distributed in the Pong and Chun of Phayao province. The samples were collected from outcrops along the mountain range in the eastern and few part of the western area (Figure 3.1). The Group IV rocks are composed of lava flows, i.e. sample number 12, 41, 42, 43, 47 and 48 (Figures 3.26-3.27). The chemical composition of this group is rhyolite. The outcrops are pink, gray and brown colors. The lava flows show slightly flow banding and porphyritic texture. The studied rocks in this areas are associated with rhyodacite, rhyolite, andesite and tuff of Doi Mon Yao volcanic

Figure 3.26 Photograph is showing the outcrop of Group IV rhyolite at grid reference 624139E-2148648N.

Figure 3.27 Photograph is showing the outcrop of Group IV rhyolite at grid reference 637730E-2135546N.

formation according to Tansuwan and Kosuwan (1988) and few part of Pu Po volcanic formation (Tiyapairat and Mahapoom, 1990).

3.4.2 Lithology and petrography

Rhyolite

Megascopically, the Group IV rhyolite shows slightly flow banding and non- to porphyritic texture. The phenocrysts/microphenocrysts of colorless and white colors size up to $\leq$ 2 mm across. The lath minerals present slightly trachytic texture. The groundmasses are very fine-grained with generally show pink, light gray, gray and reddish brown colors. The rock turns white, dark gray, gray, yellowish to reddish brown and brown colors on weathering surfaces. Tiny fractures sealed by white and reddish brown minerals with cavities sealed by reddish brown minerals have been occasionally observed. These rocks do not react with diluted hydrochloric acid.

Microscopically, these rocks show hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon (Figure 3.28), opaque and unidentified minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of quartz, plagioclase and K-feldspar with cumurocrysts of quartz + plagioclase, quartz + opaque mineral, plagioclase + K-feldspar (Figure 3.29), K-feldspar + opaque minerals, quartz + plagioclase + K-feldspar and plagioclase + K-feldspar + opaque minerals. The very fine-grained groundmasses show non- to highly micropoikilitic with fine K-feldspar lath and spherulitic textures. The fine K-feldspar lath show slightly trachytic texture. The spherulites size up to 0.05-0.25 mm across. They are bulbous aggregates of anhedral quartz and K-feldspar. The spherulites might retained concentric zonation and made up of undulose quartz. Fe-Ti oxide, quartz and K-feldspar intergrowth with the mosaic of fine grains that occur between closely packed spherulites (Figure 3.30). Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the samples. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.05-1.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals. The crystals might show reaction rim.

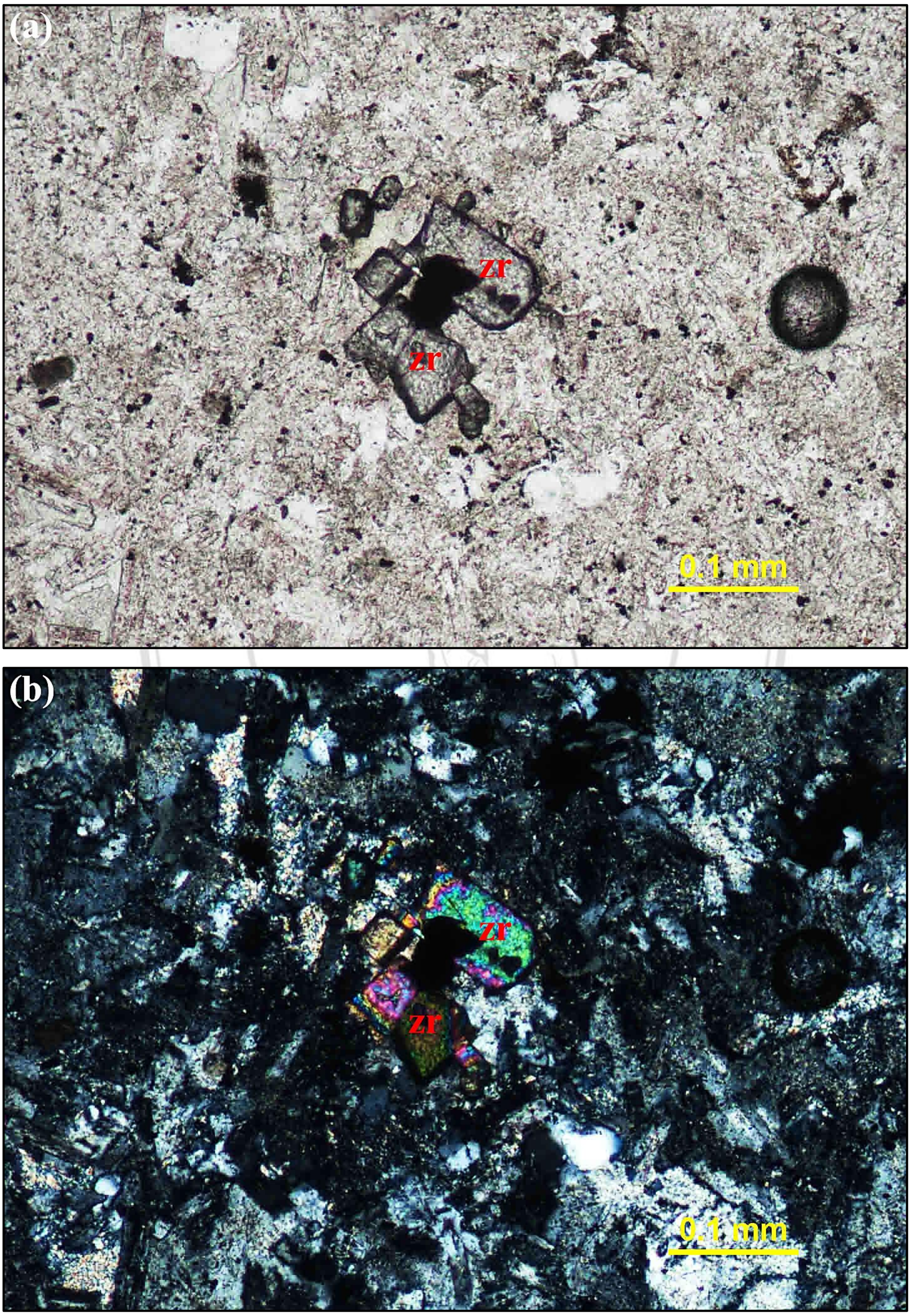
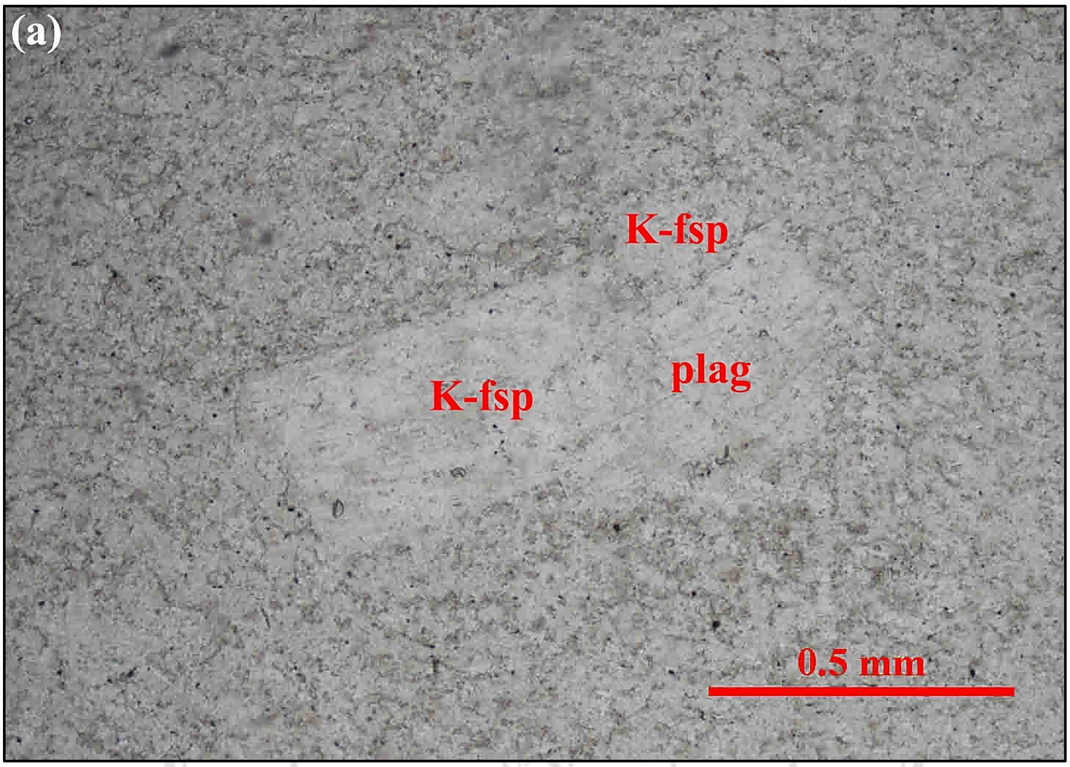


Figure 3.28 Photomicrographs of Group IV rhyolite (sample number 48) showing zircon (zr) and groundmasses made up of highly micropoikilitic texture.
(a) Ordinary light (b) Crossed polars.



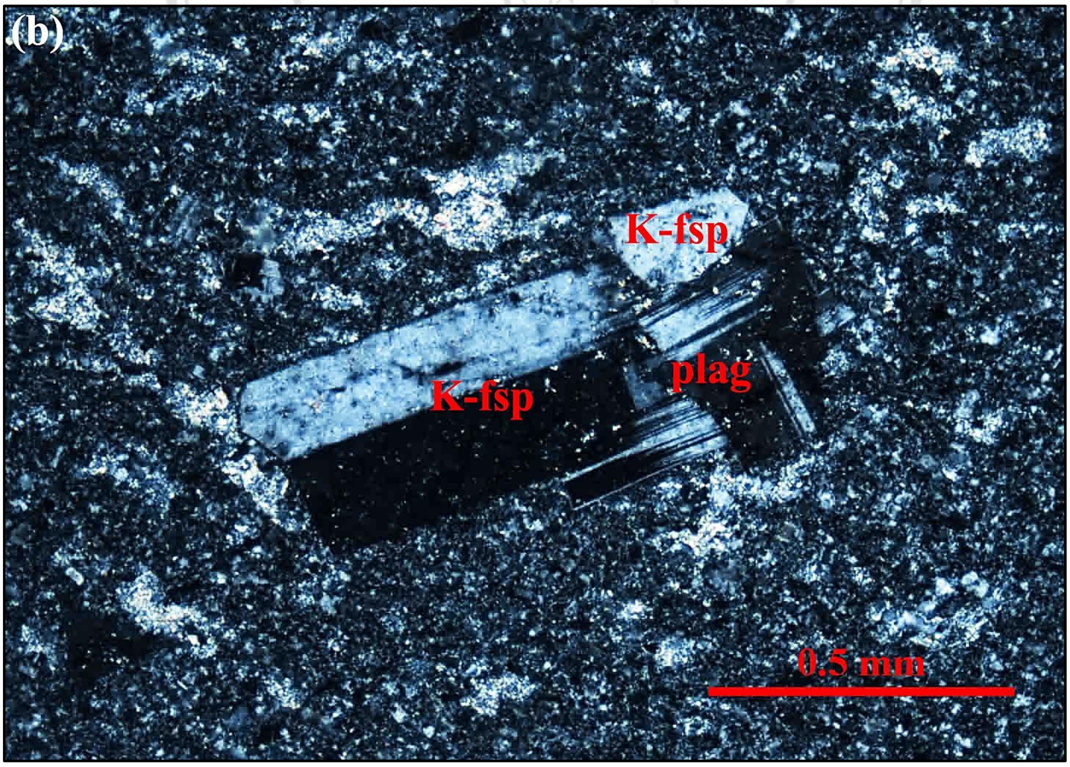


Figure 3.29 Photomicrographs of Group IV rhyolite (sample number 41) showing cumurocrysts of plagioclase (plag) + K-feldspar (K-fsp) and very fine-grained groundmasses. (a) Ordinary light (b) Crossed polars.

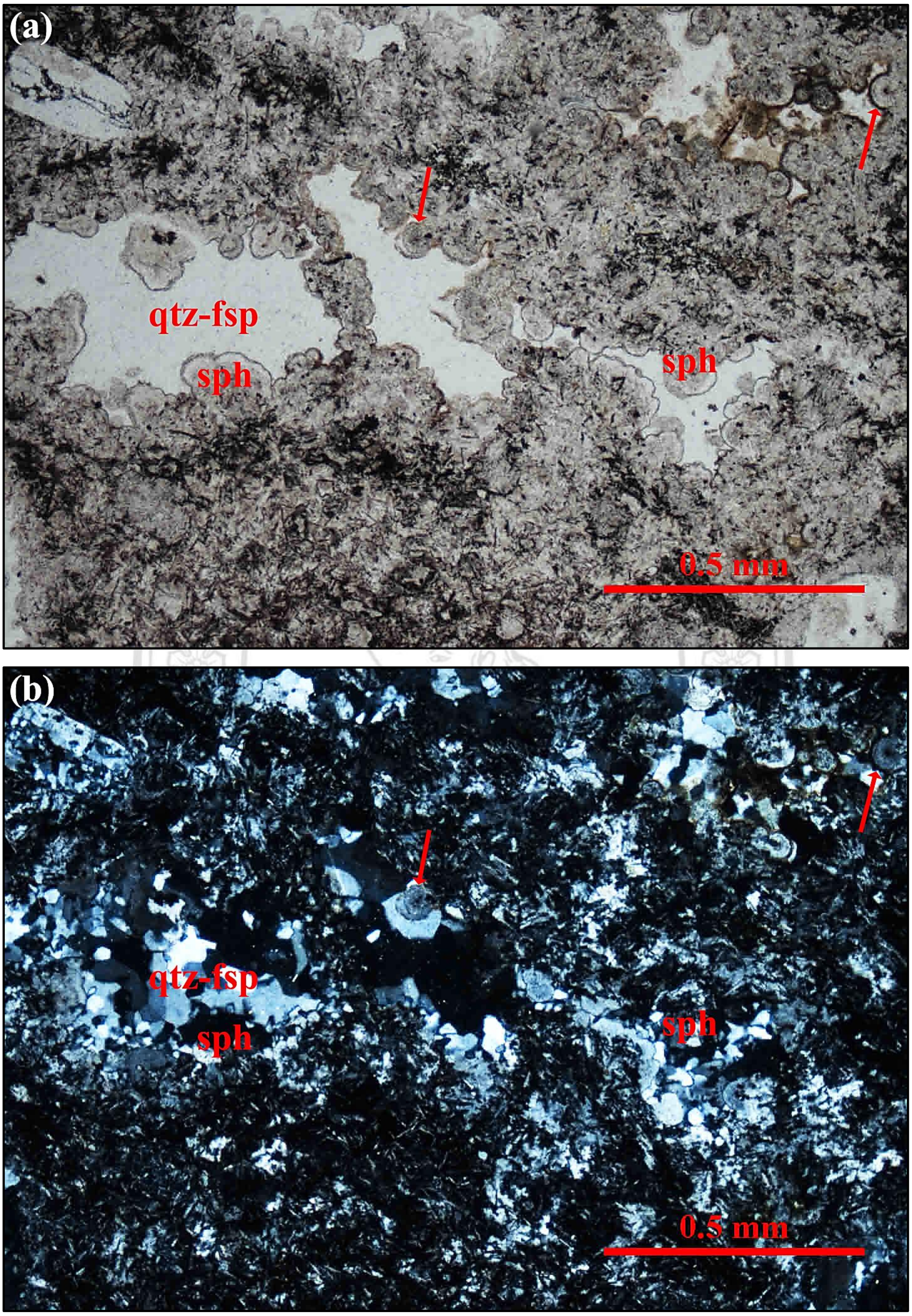


Figure 3.30 Photomicrographs of Group IV rhyolite (sample number 43) showing the spherulites (shp) made up from bulbous aggregates of anhedral quartz and K-feldspar (qtz-fsp), relict spherulites retain concentric zonation (arrow), quartz and K-feldspar intergrowth occur between closely packed spherulites. (a) Ordinary light (b) Crossed polars.

Plagioclase phenocrysts/microphenocrysts size up to 0.1-1.5 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to highly replaced by sericite, chlorite, clay minerals, Fe-Ti oxide with quartz and K-feldspar intergrowth. The crystals might show rounded edges and sieve texture.

K-feldspar phenocrysts/microphenocrysts size up to 0.1-1 mm across. They show anhedral to euhedral outlines. These crystals slightly to highly replaced by sericite, chlorite, clay minerals, Fe-Ti oxide with quartz and K-feldspar intergrowth. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.1 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by opaque minerals.

3.5 Group V rocks

3.5.1 Occurrence

The Group V rocks are distributed in the Chiang Muan of Phayao province. The samples were collected from outcrops along the mountain range in the southern area (Figure 3.1). The Group V rocks are composed of pyroclastic equivalents (Figure 3.31), i.e. sample number 53. The chemical composition of this group is rhyolite. The outcrops are brown color. The pyroclastic equivalents show apparent porphyritic texture. The studied rocks in this areas are associated with rhyolite, rhyolitic tuff and tuff of Unit J_{1-3} according to Jonglakmanee and Khenwiset (1986) with rhyodacite, rhyolite, rhyolitic tuff, andecite and andecitic tuff of Doi Cha Hang formation (Imsamut and Wongprayun, 2003).

3.4.2 Lithology and petrography

Welded tuff

Megascopically, the Group V tuff shows apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of colorless, white and pink colors size up to ≤ 2 mm across. The groundmasses are very fine-grained and generally show dark brown color. The rock turns white and light gray colors on weathering surfaces. Tiny fractures have been occasionally observed. These rocks do not react with diluted hydrochloric acid.

Figure 3.31 Photograph showing the outcrop of Group V welded vitric tuff at grid reference 634305E-2086729N.

Microscopically, these rocks contain abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of quartz and plagioclase with cumulocrysts of plagioclase + K-feldspar and K-feldspar + opaque minerals. Lithic fragments are pumice. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The very fine-grained matrixes show moderately micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.05-1.75 mm across with semispherical to spherical shapes. They might grow on quartz and K-feldspar crystals (Figure 3.32). Quartz and K-feldspar intergrowth are present. Secondary patches of Fe-Ti oxide, chlorite and sericite appear in the minor amount.

Quartz crystals size up to 0.125-2.125 mm across. They mostly show anhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.25-0.5 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar size up to 0.125-1.125 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.875 mm across. They show irregular to subhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.025-0.5 mm across. They show subhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

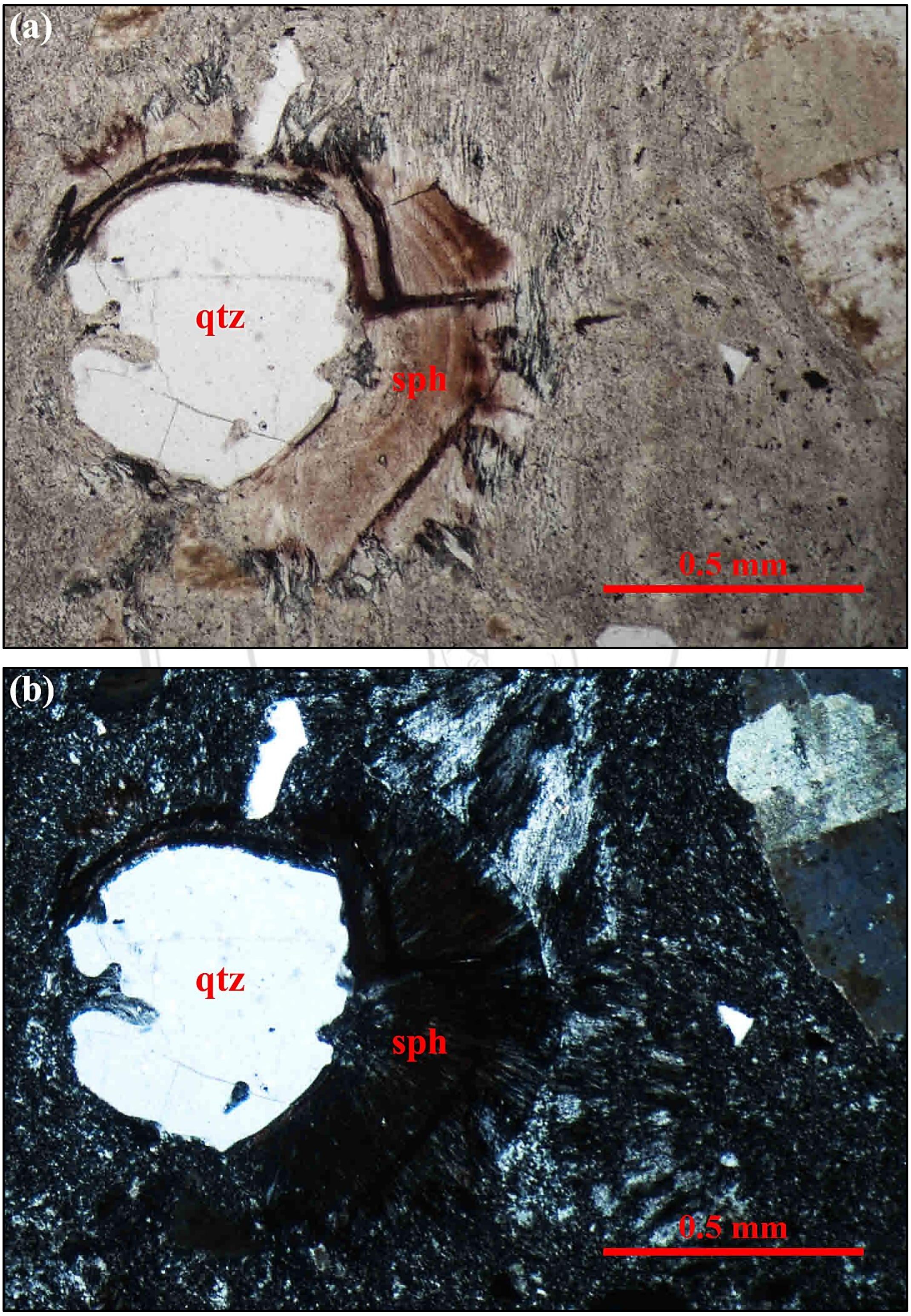


Figure 3.32 Photomicrographs of Group V welded vitric tuff (sample number 53) showing spherulites (sph) grown on quartz (qtz) crystal. (a) Ordinary light (b) Crossed polars.

CHAPTER 4

Geochemistry

The eighteen samples of the studied volcanic rocks were selected for whole-rock chemical analyzes. The chemical analyzes of major oxides were carried out by X-ray Fluorescence (XRF) Spectrometer. Trace and rare-earth elements analyzed by Multiple Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS). Advanced analytical techniques are given in Appendix B. The analytical results for major oxides are reported in Table 4.1. Trace and rare-earth elements are given in Table 4.2. The studied least-altered the studied volcanic rocks have mineral assemblages, experienced variable degrees of alteration and/or metamorphism (Chapter 3). Although the studied least-altered samples were carefully selected. The whole-rock chemical compositions are unlikely to represent the primary compositions derived from magma. Because the element mobility will take place during the secondary processes, especially the concentrations of mobile elements. The concentrations of immobile elements may be changed due to the mobility of mobile elements. However, the ratios of immobile elements in the primary rock are still constant. Therefore, only the immobile elements are used in interpreting the geochemical data in this study.

The concentrations of some major elements, such as Si, Ca and alkalis are sensitive to increasing/decreasing during the magmatic evolution. However, generally agreed that total iron and MgO are slightly removed from primary values. Following the previous work by Floyd and Winchester (1975), Pearce and Gale (1977), Winchester and Floyd (1977), Pearce and Norry (1979), Pearce (1982), Shervais (1982), Holm (1985) and Meschede (1986). Many studies have shown that the high field strength elements (Ti, Zr, Y, Nb, Ta, Th and P) and the transitional elements (Ni, Cr, V and Sc) are relatively immobile during the alteration of basaltic and more evolved lavas and intrusive. Zr is one of the incompatible immobile element in the altered rock samples (Cann, 1970; Green, 1980). It will be used as a fractionation parameter for the studied rock samples.

In addition, although occasional reports have appeared rare-earth elements (REE), exceptionally light rare earth elements (LREE), mobility during alteration and metamorphism (Floyd, 1977; Humphris *et al*., 1978; Hellman and Henderson, 1979; Whitford *et al*., 1988). The overwhelming consensus is that the REE patterns of carefully selected rock samples are probably slightly shifted from their primary patterns. The chemical composition, especially immobile incompatible elements; high field strength elements (HFSE), transitional elements and REE, have been focused to be used for the identification of rocks and determining magma characteristics. Because they are representative of magma. Moreover, the chemical compositions will provide for the interpretation of tectonic setting by using discrimination diagram and correlation with modern magma suites.

Table 4.1 Whole-rock analyzes of the studied least-altered the studied volcanic rocks.

Sample no.	14*	18*	01**	09**	11**	13**
Major oxide (wt%)						
SiO_2	71.540	73.532	73.289	76.882	78.836	71.893
TiO_2	0.422	0.215	0.306	0.203	0.051	0.225
Al_2O_3	15.068	14.157	14.350	12.121	9.879	14.098
FeO*	3.082	2.451	1.893	2.343	1.665	3.098
MnO	0.022	0.018	0.015	0.026	0.018	0.008
MgO	0.344	0.275	0.246	0.150	0.553	0.214
CaO	0.291	0.255	0.215	0.269	0.233	0.258
Na_2O	7.888	6.016	6.293	7.397	2.498	4.323
K_2O	1.006	3.077	2.790	0.321	2.659	5.231
P_2O_5	0.098	0.054	0.070	0.057	0.043	0.061
Original Sum	99.761	100.050	99.467	99.769	96.435	99.409
FeO*/MgO	8.959	8.913	7.695	15.620	3.011	14.477

FeO* =total iron as FeO

* = Group I; ** = Group II; *** = Group III; **** = Group IV; *****Group V

Table 4.1 Continued.

Sample no.	46**	44***	45***	49***	51***	12****
Major oxide (wt%)						
SiO_2	77.764	74.715	74.459	77.624	74.820	70.724
TiO_2	0.157	0.243	0.257	0.085	0.195	0.264
Al_2O_3	12.332	13.235	13.168	11.842	13.185	17.115
FeO*	1.218	2.152	2.232	1.258	1.967	2.001
MnO	0.002	0.017	0.033	0.014	0.031	0.024
MgO	0.187	0.353	0.341	0.224	0.330	0.154
CaO	0.090	0.149	0.135	0.147	0.135	0.199
Na_2O	3.740	3.927	4.655	3.609	3.014	7.933
K_2O	3.088	4.720	4.274	4.978	5.203	1.440
P_2O_5	0.041	0.067	0.062	0.044	0.050	0.062
Original Sun	98.619	99.578	99.616	99.825	98.930	99.916
FeO*/MgO	6.513	6.096	6.545	5.616	5.961	12.994

FeO* =total iron as FeO

* = Group I; ** = Group II; *** = Group III; **** = Group IV; *****Group V

Table 4.1 Continued.

Sample no.	41****	42****	43****	47****	48****	53*****
Major oxide (wt%)						
SiO_2	77.022	83.322	75.533	77.514	76.926	76.589
TiO_2	0.075	0.161	0.226	0.163	0.162	0.103
Al_2O_3	13.700	8.459	12.579	12.494	12.427	12.036
FeO*	0.970	1.339	2.036	1.686	1.201	1.206
MnO	0.005	0.026	0.020	0.007	0.002	0.005
MgO	0.273	0.352	0.181	0.176	0.175	0.186
CaO	0.093	0.152	0.188	0.094	0.090	0.143
Na_2O	2.907	1.561	5.907	3.491	3.054	3.039
K_2O	4.438	4.736	2.724	4.295	5.063	5.682
P_2O_5	0.039	0.057	0.067	0.043	0.045	0.043
Original Sun	99.488	100.165	99.461	99.963	99.145	99.032
FeO*/MgO	3.553	3.804	11.249	9.580	6.863	6.484

FeO* =total iron as FeO

* = Group I; ** = Group II; *** = Group III; **** = Group IV; *****Group V

Table 4.2 Trace and rare-earth elements with some selected ratios and chondrite-normalized ratios of the studied least-altered the studied volcanic rocks.

Sample no.	14*	18*	01**	09**	11**	13**	46**	44***	45***
Trace and REE elements (ppm)									
P	309.200	133.200	228.600	120.200	70.380	152.400	75.800	198.600	184.800
Sc	19.920	48.320	14.100	37.900	11.400	30.890	45.000	11.620	7.980
Ti	2381.000	1223.000	1770.000	1174.000	288.800	1258.000	892.500	1377.000	1353.000
V	6.859	2.658	6.250	19.590	2.773	0.133	ND	4.613	2.350
Cr	0.728	6.914	1.178	1.608	1.234	3.506	0.323	1.016	0.171
Mn	181.200	155.000	123.800	208.900	155.100	90.920	35.190	158.900	258.000
Co	15.460	58.600	21.860	39.830	31.200	36.070	27.180	20.720	23.990
Ni	1.894	6.719	0.992	1.322	2.577	3.378	1.444	2.061	1.326
Cu	7.740	8.435	2.608	8.457	9.104	3.123	1.555	6.078	4.988
Zn	19.640	29.670	42.890	40.590	53.750	122.900	68.920	57.800	65.990
Ga	16.310	9.077	17.270	7.567	10.630	17.690	26.900	20.870	21.210
Rb	37.650	82.180	62.390	7.687	79.310	195.300	88.760	159.000	130.800
Sr	408.100	250.700	211.900	111.900	168.600	206.900	26.100	110.600	93.600
Y	72.770	35.800	49.650	37.620	22.290	38.670	108.200	137.500	146.600
Zr	311.700	341.900	344.700	297.500	75.690	365.000	551.600	429.800	422.500
Nb	16.760	18.370	20.850	17.160	8.842	18.820	29.630	21.760	21.570
Cs	7.706	2.323	2.336	1.078	10.000	2.833	3.457	2.101	1.648
Ba	418.600	733.100	862.100	101.800	555.600	765.900	526.300	472.100	410.600
La	94.700	87.580	61.200	54.030	32.750	67.950	158.300	76.960	88.740
Ce	198.400	142.600	97.420	86.400	44.170	101.600	295.2	160.800	141.900
Pr	27.000	22.780	16.010	12.610	7.183	14.950	49.660	20.600	22.320
Nd	102.400	85.350	61.010	45.540	26.670	52.740	187.200	75.740	82.750
Sm	20.120	14.760	11.690	8.419	4.745	10.020	36.970	16.740	16.630
Eu	3.870	2.196	2.238	1.243	0.920	1.842	5.882	1.751	1.708
Gd	16.350	10.330	9.890	7.312	4.233	8.081	29.610	19.810	19.760
Tb	2.453	1.392	1.482	1.161	0.636	1.273	4.397	3.432	3.375
Dy	13.080	6.960	8.521	6.841	3.616	7.312	22.500	21.540	21.240
Ho	2.512	1.348	1.778	1.422	0.734	1.513	4.165	4.509	4.505
Er	6.734	3.857	5.103	4.066	2.046	4.421	11.540	12.530	12.530
Tm	0.973	0.588	0.776	0.639	0.311	0.693	1.811	1.873	1.873
Yb	5.938	3.891	5.058	4.152	2.028	4.642	12.150	11.580	11.410
Lu	0.861	0.599	0.754	0.622	0.298	0.700	1.832	1.646	1.634
Hf	8.011	8.591	8.691	7.618	2.889	9.122	15.200	12.200	12.000
Ta	1.199	1.367	1.496	1.331	1.097	1.330	2.227	1.670	1.644
W	78.490	323.500	142.500	271.000	187.300	202.000	185.900	118.300	131.700
Tl	0.333	0.655	0.493	0.097	0.565	1.007	0.511	0.842	0.702
Pb	30.540	37.840	14.110	15.740	12.310	26.470	10.560	30.980	23.960
Th	18.070	18.620	18.350	16.490	14.420	19.010	13.460	16.380	16.150
U	3.085	2.802	5.256	2.845	1.888	3.456	3.199	3.465	3.433
Selected element ratios									
Zr/TiO_2	0.074	0.159	0.113	0.147	0.148	0.162	0.351	0.177	0.164
Nb/Y	0.230	0.513	0.420	0.456	0.397	0.487	0.274	0.158	0.147
Nb/Zr	0.054	0.054	0.060	0.058	0.117	0.052	0.054	0.051	0.051
Y/Zr	0.233	0.105	0.144	0.126	0.294	0.106	0.196	0.320	0.347
[La/Sm]cn	3.039	3.831	3.380	4.143	4.456	4.378	2.764	2.968	3.445
[Sm/Yb]cn	3.765	4.215	2.568	2.253	2.600	2.398	3.381	1.606	1.619
[Ce/Yb]cn	9.281	10.180	5.350	5.780	6.050	6.080	6.749	3.857	3.455

ND = no detectable quantities

* = Group I; ** = Group II; *** = Group III; **** = Group IV; *****Group V

Table 4.2 Continued.

Sample no.	49***	51***	12****	41****	42****	43****	47****	48****	53*****
Trace and REE elements (ppm)									
P	74.020	140.600	155.400	90.390	164.400	217.900	78.670	111.100	93.650
Sc	31.220	14.950	5.396	16.860	48.530	10.610	36.430	24.000	39.120
Ti	507.300	1072.000	1447.000	532.000	916.600	1269.000	910.900	904.600	583.500
V	12.150	ND	0.761	ND	0.189	3.418	ND	ND	1.131
Cr	1.923	0.452	6.528	0.615	1.391	5.777	0.825	1.892	1.457
Mn	137.100	261.900	194.800	57.120	229.900	176.600	76.020	35.470	76.860
Co	28.190	26.670	26.280	12.750	32.720	45.470	27.340	29.950	25.240
Ni	2.298	2.735	9.947	1.045	1.919	2.450	0.964	1.805	3.491
Cu	7.363	5.498	8.210	2.156	5.276	8.696	0.799	2.666	19.590
Zn	55.090	63.800	14.680	61.250	54.490	34.330	107.100	127.600	62.620
Ga	18.760	19.210	12.960	20.710	9.276	13.290	25.240	22.520	22.250
Rb	191.600	197.600	22.030	94.590	108.500	50.280	124.900	137.300	299.500
Sr	106.500	78.070	364.000	95.630	78.530	103.800	26.330	21.850	76.800
Y	73.730	75.890	33.950	33.660	32.390	67.520	99.980	100.600	69.360
Zr	189.500	463.300	331.200	185.240	245.100	388.400	577.200	587.000	208.800
Nb	22.200	25.080	19.960	20.670	12.720	18.870	29.820	29.420	24.110
Cs	2.888	5.414	0.631	2.265	1.701	0.686	3.668	2.736	4.055
Ba	162.600	558.600	414.700	743.100	830.000	530.600	738.200	819.500	63.210
La	52.230	72.990	45.030	15.530	17.160	38.250	50.250	78.650	20.510
Ce	105.400	111.900	60.960	35.400	44.780	84.540	96.8	148.4	35.790
Pr	13.450	17.540	9.036	3.460	4.637	9.872	13.450	21.820	5.144
Nd	51.400	65.550	32.180	12.380	17.270	37.850	51.800	84.600	19.510
Sm	11.640	13.130	5.869	2.124	3.750	8.841	10.300	17.290	5.255
Eu	0.276	1.333	0.953	0.240	0.419	0.891	1.756	2.885	0.205
Gd	12.350	12.830	4.933	2.091	3.815	9.343	10.680	15.740	7.338
Tb	2.099	2.033	0.800	0.544	0.708	1.627	1.879	2.462	1.519
Dy	13.240	12.420	5.284	4.240	4.954	10.800	13.980	15.420	11.230
Ho	2.765	2.647	1.275	0.937	1.182	2.416	3.457	3.547	2.535
Er	7.789	7.791	4.294	2.928	3.880	7.341	11.230	11.230	7.631
Tm	1.174	1.211	0.727	0.518	0.663	1.192	1.886	1.881	1.223
Yb	7.298	7.922	5.037	3.697	4.643	7.947	12.730	12.590	7.764
Lu	1.050	1.181	0.768	0.579	0.706	1.183	1.948	1.946	1.117
Hf	7.659	12.910	8.422	5.016	6.962	11.290	16.070	16.170	8.177
Ta	1.877	1.944	1.344	1.211	1.114	1.642	2.321	2.339	1.935
W	174.400	191.200	103.100	67.440	213.400	258.700	175.100	213.500	162.600
Tl	0.875	0.905	0.219	0.533	0.835	0.503	0.748	0.800	1.658
Pb	27.650	26.680	22.970	13.130	8.532	36.430	11.370	8.267	44.170
Th	21.490	19.820	19.050	6.221	8.804	15.380	13.930	13.830	24.620
U	3.437	3.106	3.280	1.325	2.508	2.716	3.247	3.339	4.807
Selected element ratios									
Zr/TiO_2	0.223	0.238	0.125	0.247	0.152	0.172	0.354	0.362	0.203
Nb/Y	0.301	0.330	0.588	0.614	0.393	0.279	0.298	0.292	0.348
Nb/Zr	0.117	0.054	0.060	0.112	0.052	0.049	0.052	0.050	0.115
Y/Zr	0.389	0.164	0.103	0.182	0.132	0.174	0.173	0.171	0.332
[La/Sm]cn	2.897	3.589	4.953	4.720	2.954	2.793	3.150	2.937	2.520
[Sm/Yb]cn	1.772	1.842	1.295	0.638	0.897	1.236	0.899	1.526	0.752
[Ce/Yb]cn	4.012	3.924	3.362	2.660	2.679	2.955	2.112	3.274	1.280

ND = no detectable quantities

* = Group I; ** = Group II; *** = Group III; **** = Group IV; *****Group V

4.1 Magmatic affinities

The geochemical data on Zr/TiO_2 against Nb/Y discrimination diagram (Figure 4.1) and the chondrite-normalized REE patterns, N-MORB normalized multi-element spider diagrams (Figures 4.2-4.6) were applied for the studied volcanic rocks. These rocks can be divided into five magmatic groups as Group I (selected sample numbers 14 and 18) Group II (selected sample numbers 1, 9, 13 and 46), Group III rocks (selected sample numbers 44, 45, 49 and 51), Group IV (selected sample numbers 12, 41, 42, 43, 47 and 48), and Group V (selected sample number 53).

The Group I rocks consist of lava flows with Zr/TiO_2 and Nb/Y ratios in ranges of 0.074-0.159 and 0.230-0.513 respectively. They appear to be in rhyodacite/dacite and rhyolite compositions. The analytical results of REE patterns are light rare earth elements (LREE) enriched with chondrite-normalized (La/Sm)cn values in ranges of 3.039-3.831 and heavy rare earth elements (HREE) depleted with chondrite-normalized (Sm/Yb)cn values in ranges of 3.765-4.215. Their REE patterns (Figure 4.2) are typical of alkaline series.

The Group II rocks consist of lava flows and pyroclastic equivalents with Zr/TiO_2 and Nb/Y ratios in ranges of 0.113-0.351 and 0.274-0.487 respectively. They appear to be in rhyolite compositions. The analytical results of REE patterns are LREE enriched with chondrite-normalized (La/Sm)cn values in ranges of 2.764-4.456 and HREE slightly depleted with chondrite-normalized (Sm/Yb)cn values in ranges of 2.253-3.381. Their REE patterns (Figure 4.3) are characteristic of transitional subalkaline to alkaline series.

The Group III rocks are lava flows with Zr/TiO_2 and Nb/Y ratios in ranges of 0.164-0.238 and 0.147-0.330 respectively. They are corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.897-3.589 and subparallel HREE with (Sm/Yb)cn values in ranges of 1.606-3.589. Their REE patterns (Figure 4.4) are typical of transitional subalkaline to alkaline series.

The Group IV rocks are lava flows with Zr/TiO_2 and Nb/Y ratios in ranges of 0.125-0.362 and 0.279-0.614 respectively. They are corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.793-4.953 and relatively flat HREE with (Sm/Yb)cn values in ranges of 0.638-1.526. Their REE patterns (Figure 4.5) are characteristic of calc-alkaline series.

The Group V rocks are pyroclastic equivalents with Zr/TiO_2 and Nb/Y ratios = 0.203 and 0.348 respectively. They are corresponding to rhyolite composition. The REE patterns are slightly subparallel LREE with (La/Sm)cn values = 2.520 and relatively flat HREE with (Sm/Yb)cn values = 0.752. Their REE patterns (Figure 4.6) are typical of tholeiitic series.

The REE patterns of all rock groups have more significant negative Eu anomaly. These anomalies are significant plagioclase fractionation. Some studied rock samples have slightly negative Ce anomaly. It is also well-known that common igneous rocks show no Ce anomaly in the REE patterns. In general, Ce anomalies are produced by Ce fractionation from other REE due to the easy oxidation from Ce^{3+} to Ce^{4+}. Such conditions do not occur in the deep mantle, but are interpreted to suggest that their source materials were exposed near-surface environments (Meen, 1990; Koppi *et al*., 1996; Class and le Roex, 2008; Feng, 2010). Previous reports for negative Ce anomalies in igneous rocks found in intra-plate settings are well established, particularly under tropical weathering conditions and are attributed to variable REE mobility fractionating Ce from the other REE (Harris, 1985; Fodor *et al*., 1987; Price *et al*., 1991; Cotten *et al*., 1995; Takahashi *et al*., 2002; Patino *et al*., 2003; Chauvel *et al*., 2005; Ma *et al*., 2007; Bao and Zhao, 2008; Reagan *et al*., 2008). In addition, N-MORB normalized multi-element spider diagrams of all the studied rock groups show the prominent negative P and Ti anomalies (Figures 4.2-4.6). P anomaly may indicate the influence of apatite and/or hornblende in the fractionating assemblages of granite magmas. The negative anomaly for Ti may be attributed to fractionation of plagioclase and ilmenite and/or rutile (El-Bialy, 2010).

The variation diagrams for least-mobile elements of the studies volcanic rocks are plotted on variation diagrams versus Zr as a fractionation parameter (Figure 4.7 and 4.8). Zirconia variation diagram cannot be assigned to one particular magmatic groups, although four magmatic groups have been identified from chondrite-normalized REE patterns as previously discussed. Major oxides as Al_2O_3, TiO_2, FeO*, CaO, Na_2O and P_2O_5 exhibit general positive trends in the early stage and negative trends in the later stage with increasing of Zr content. MgO and K_2O show forms a broadly flat. Trace elements as Y, Nb and Hf show positive trends with increasing of Zr content. Positive trends of Nb and Hf vary between reasonably linear. Sr, Pb and Th present general positive trends in the first stage whereas exhibiting negative trends in the later stage with increasing of Zr content. Ba shows random variation. The patterns for FeO* and TiO_2 are suggestive of Fe-Ti oxide fractionation in the later stage but was not in an early stage. The patterns for P_2O_5 might have been indicated apatite fractionation in a later stage. However, the combination of linear and scattered trends on the variation diagrams indicates that several processes influenced the compositions of the rocks.

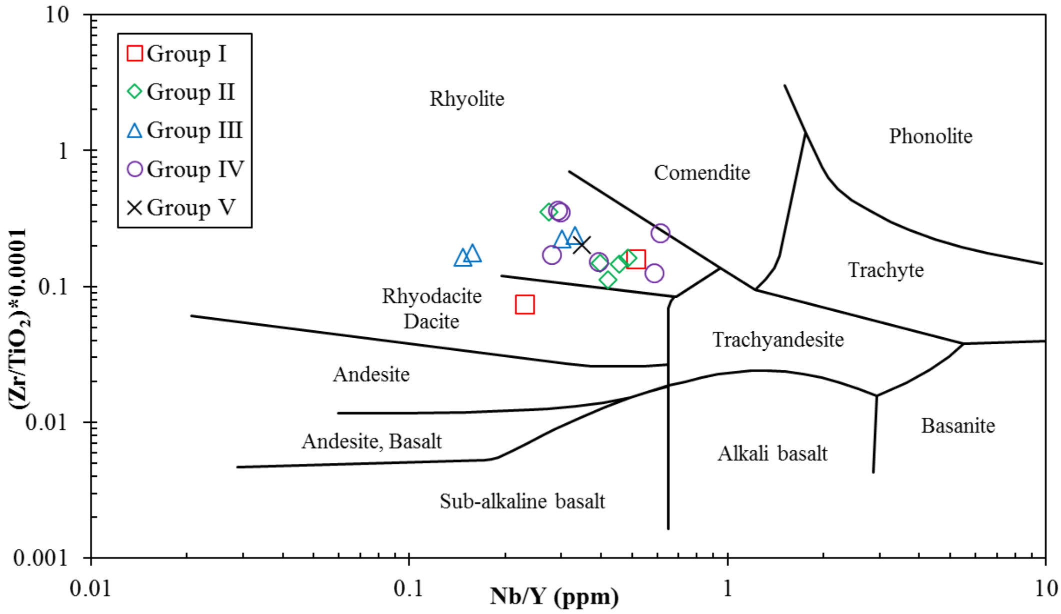


Figure 4.1 Classification of the volcanic rocks diagram for the studied least-altered the studied volcanic rocks (Winchester and Floyd, 1977).

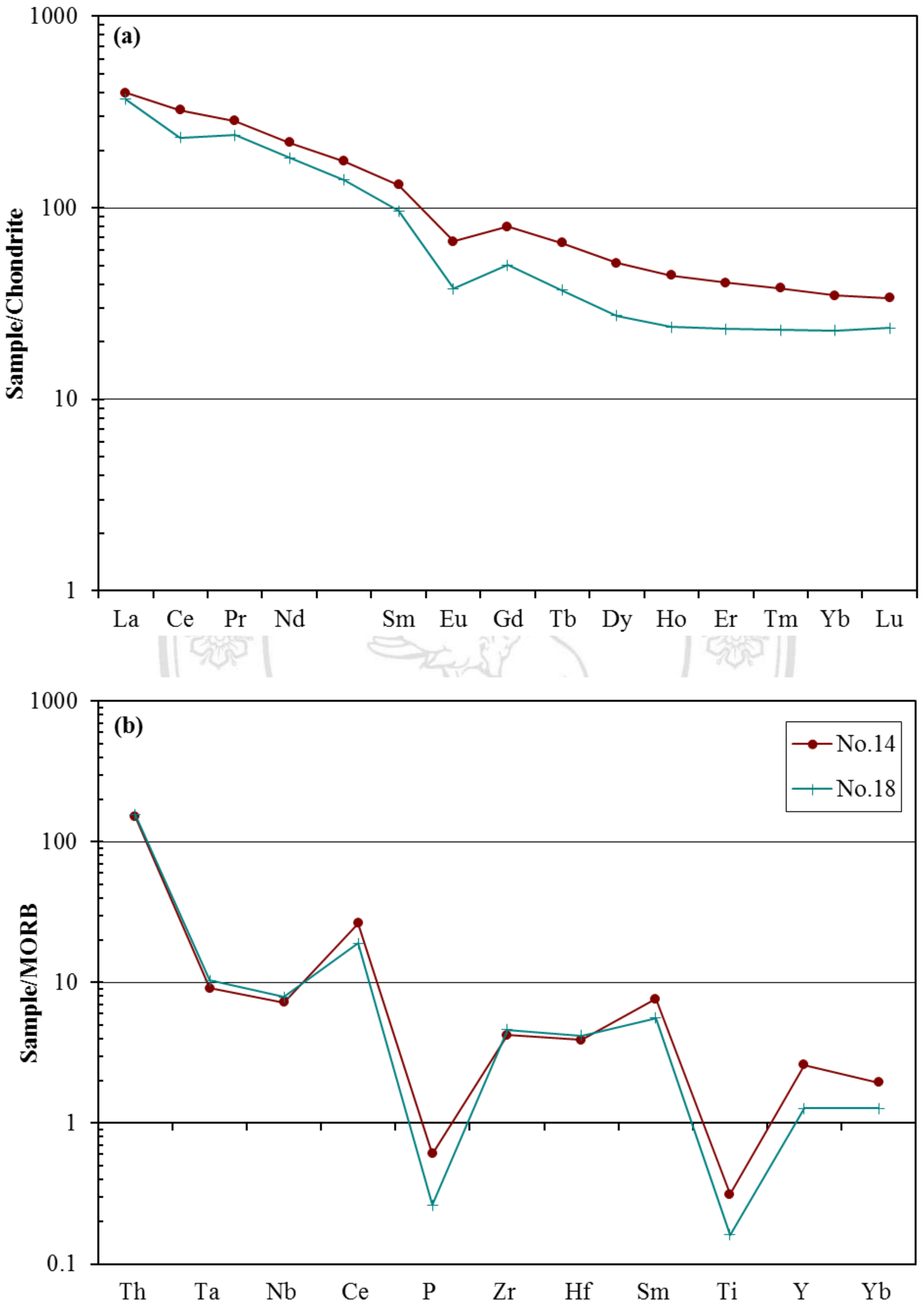


Figure 4.2 Chondrite-normalized REE patterns (a) and N-MORB normalized multi-element spider diagram (b) for the representatives of Group I (The normalizing values are those of Sun and Mcdonough, 1989).

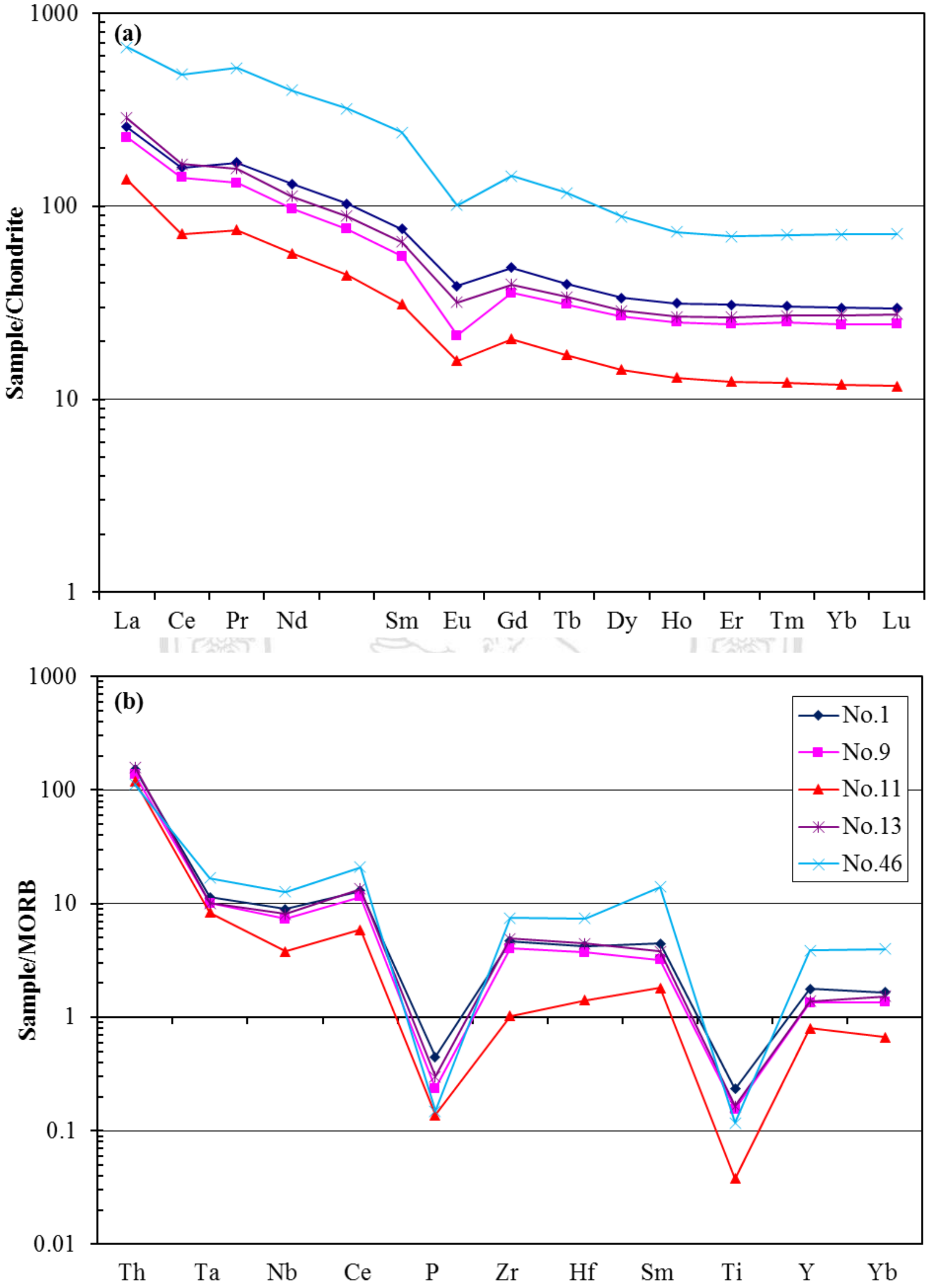


Figure 4.3 Chondrite-normalized REE patterns (a) and N-MORB normalized multi-element spider diagram (b) for the representatives of Group II (The normalizing values are those of Sun and Mcdonough, 1989).

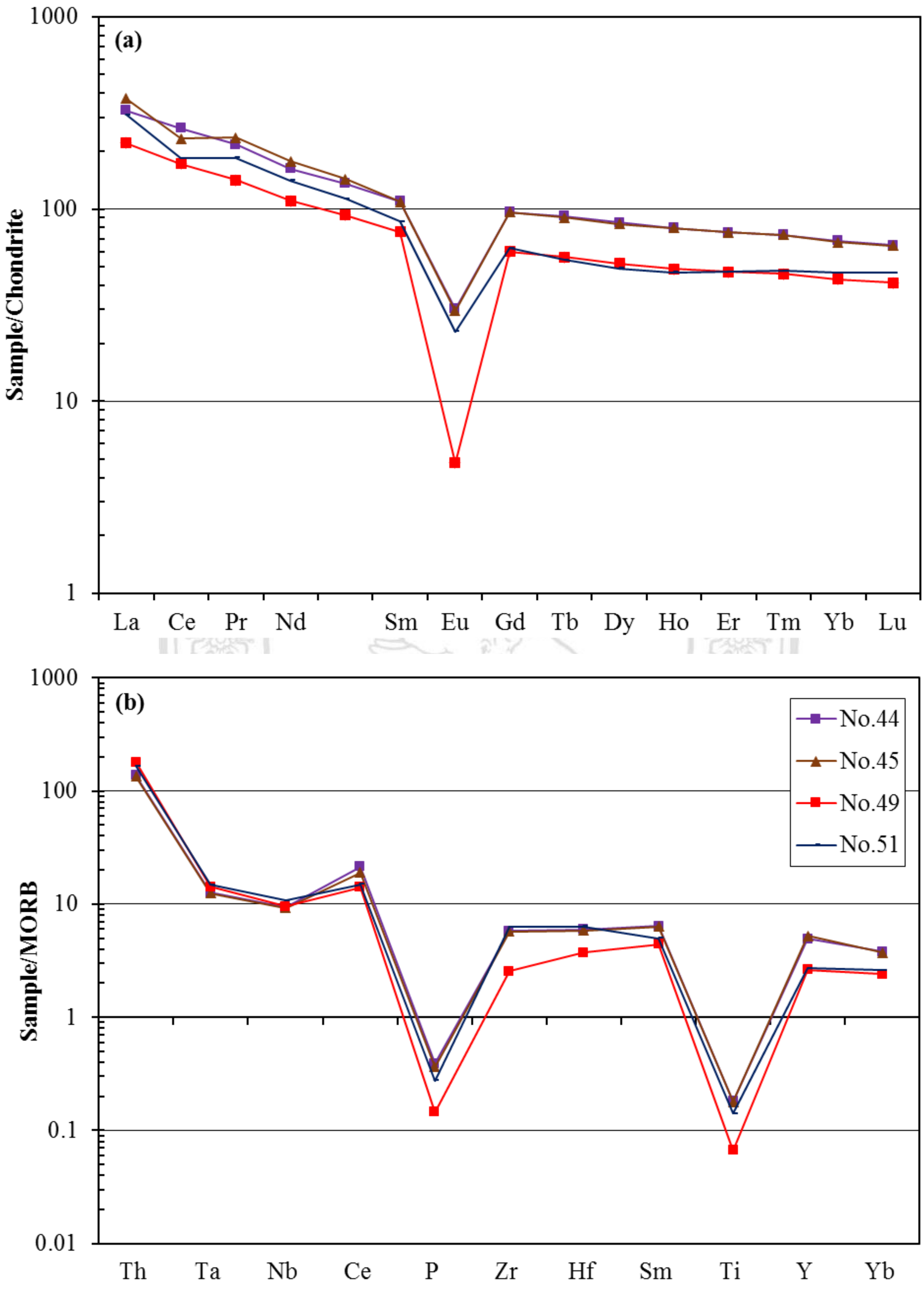


Figure 4.4 Chondrite-normalized REE patterns (a) and N-MORB normalized multi-element spider diagram (b) for the representatives of Group III (The normalizing values are those of Sun and Mcdonough, 1989).

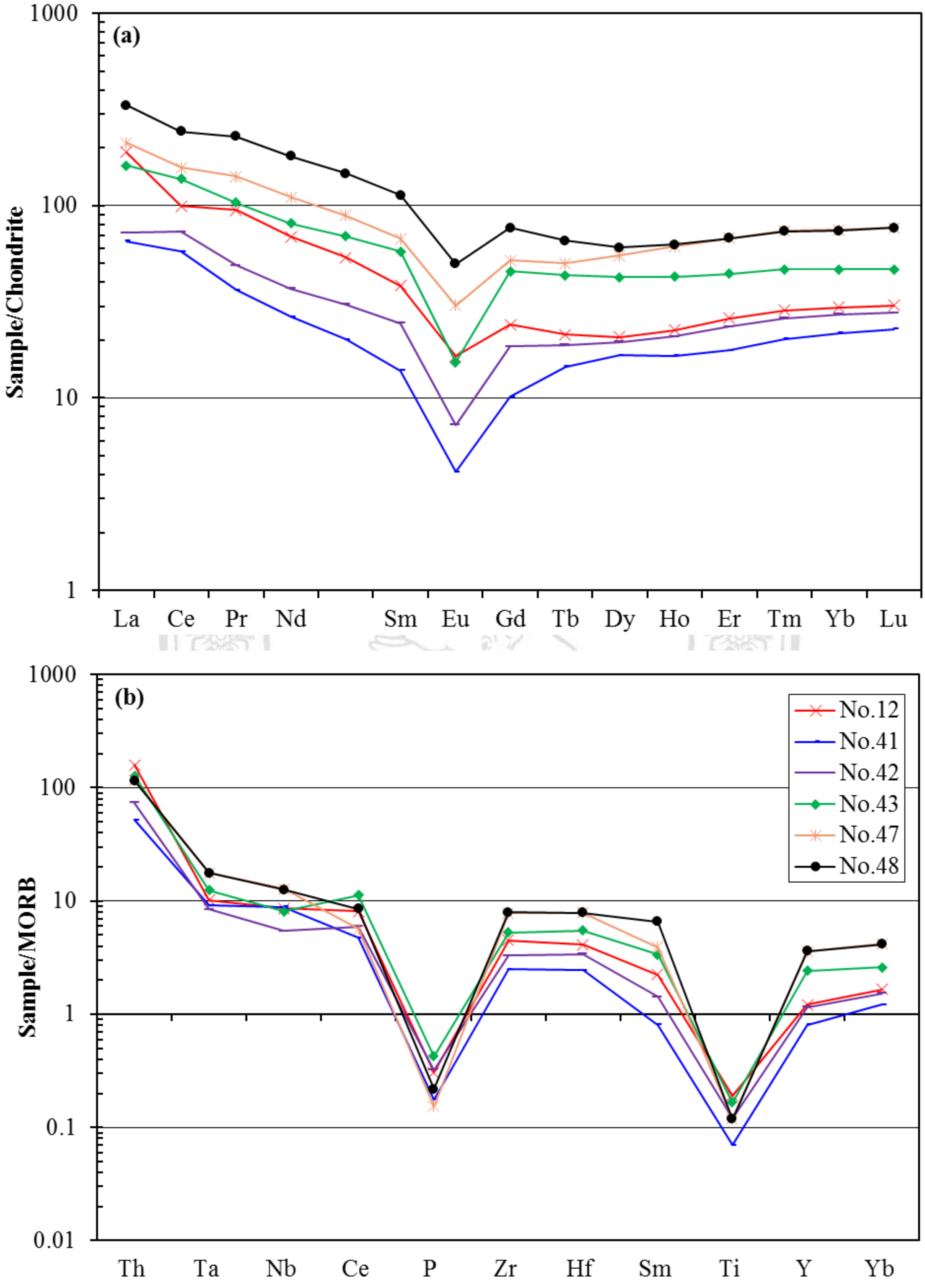


Figure 4.5 Chondrite-normalized REE patterns (a) and N-MORB normalized multi-element spider diagram (b) for the representatives of Group IV (The normalizing values are those of Sun and Mcdonough, 1989).

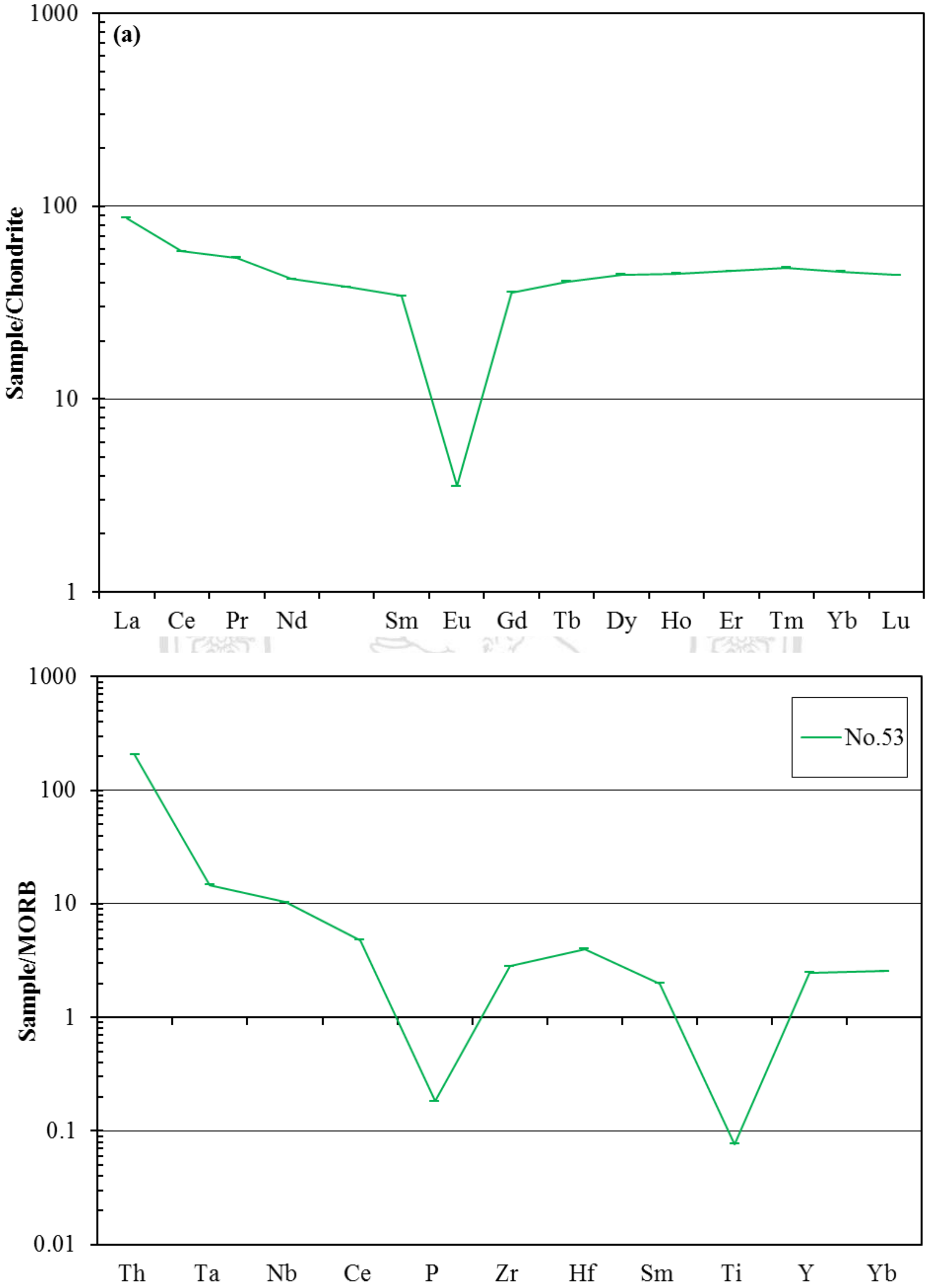


Figure 4.6 Chondrite-normalized REE patterns (a) and N-MORB normalized multi-element spider diagram (b) for the representatives of Group V (The normalizing values are those of Sun and Mcdonough, 1989).

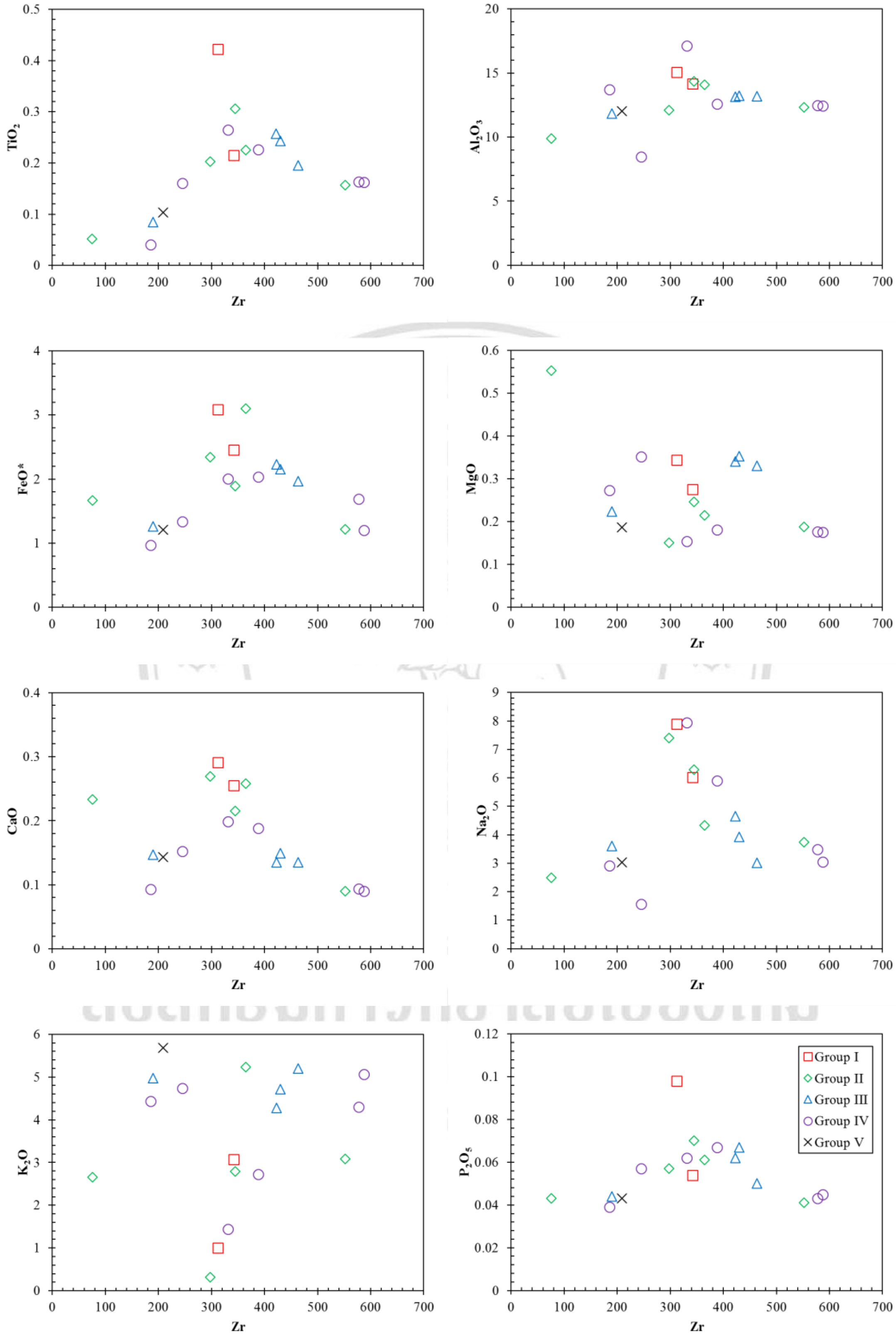


Figure 4.7 Zirconia variation diagrams for major oxides (wt%) of the studies volcanic rocks.

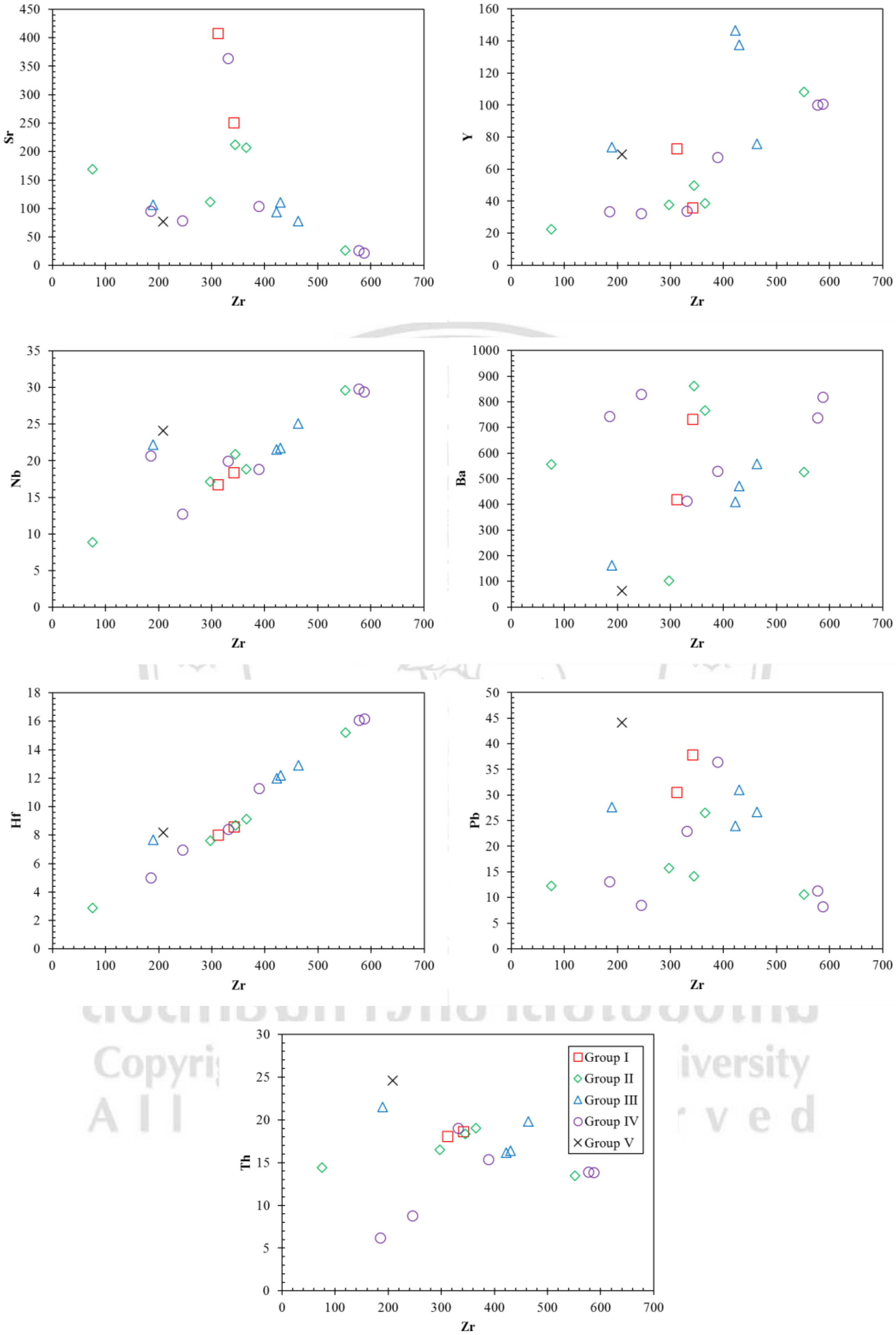


Figure 4.8 Zirconia variation diagrams for trace elements (ppm) of the studies volcanic rocks.

4.2 Tectonic setting of the eruption

Many tectonic discrimination diagrams have been applied to the studied volcanic rocks. In the plots of discriminates between the Y+Nb and Rb diagram the studied volcanic rock samples most appear in the field of post-collisional granites and few show in within plate granites (Figure 4.9). The A-type granites and granites of other types, most resulting of the studied volcanic rocks fall into A-type rather than I-, S- and M-type granite field (Figure 4.10). Using the diagram of Eby (1992) that discriminates A-type granitoids the data fall in the A_2-type (Figure 4.11). A_2-type represents magmas derived from continental crust or underplated crust that has been through a cycle of continent-continent collision or island-arc magmatism.

Although many tectonic discrimination diagrams have appeared in many workers (Holm, 1982; Prestvik, 1982; Duncan, 1987; Myers and Breitkopf, 1989; Parker *et al*., 2005). However, several studies have demonstrated that these diagrams may often fail to classify the tectonic setting of the formation unequivocally. In order to solve the problem, the classical principle of geology "Present is the key to the past" has been applied. In other words, if the tectonic interpretation is correct, there should be modern analogs (Panjasawatwong, 1991, 1999; Panjasawatwong *et al*., 1995; 2003; 2006; Phajuy *et al*., 2005; Singharajwarapan *et al*., 2000; Barr *et al*., 2000; Peng *et al*., 2008; Parker *et al*., 2012).

Extensive searches for modern analogs have been made in terms of chondrite-normalized REE and N-MORB normalized multi-element patterns (Figures 4.12-4.16). The representatives of modern tectonic as the Miocene potassic volcanic rocks in western Anatolia, Turkey was a result of delamination processes developed in the post-collisional setting (Ersoy *et al*., 2012). These rocks are analogous to the studied rocks of Group I, II and IV. Also, the Eocene-Miocene calc-alkaline volcanic rocks from northwest Anatolia, Turkey are related to subduction roll-back processes associated with post-collisional extension (Ersoy *et al*., 2017). These rocks in northwest Anatolia are similar to the studied rocks of Group I, II, III and IV. The Miocene rhyolites at Jabal Shama in western Saudi Arabia are analogous to the studied rocks of Group III, IV and V. These rocks have the geochemical signature of A_2-type rhyolites. These silicic rocks are not typically alkaline but alkali-calcic to calc-alkaline. They represent an example of rift-related silicic volcanism and possibly derived from a recycled mafic subducted slab in the depleted sub-continental mantle (Surour *et al*., 2016). Accordingly, a deduction can be drawn here that the studied, least-altered the studied volcanic rocks have been formed at the end of the post-collision environment or in an early continental rift environment.

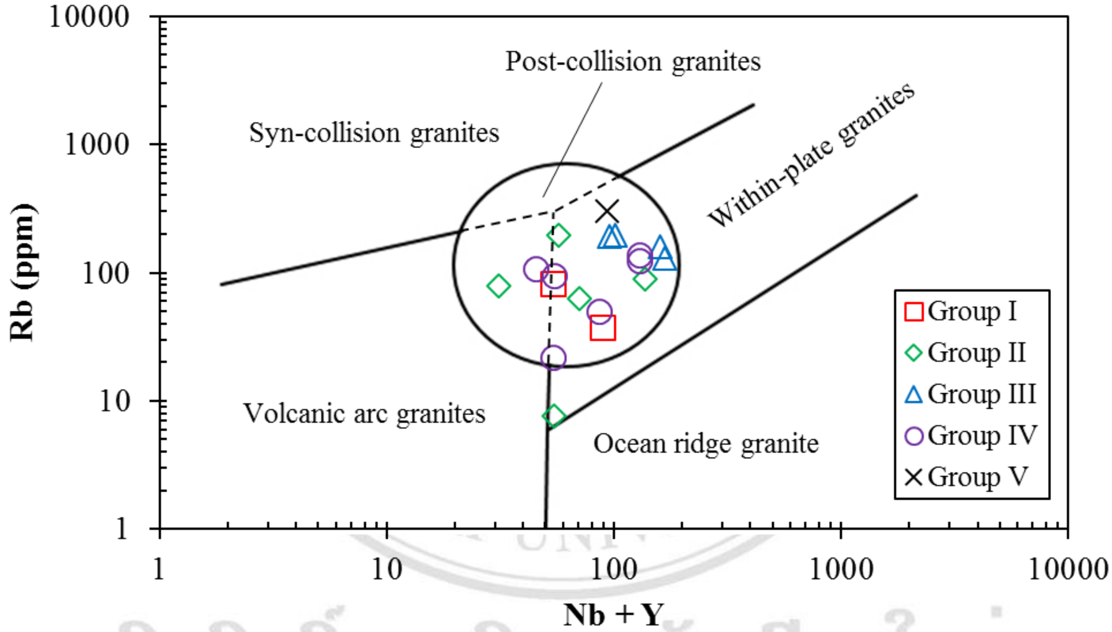


Figure 4.9 Trace element discrimination diagrams for the tectonic interpretation of granitic rocks (after Pearce, 1996).

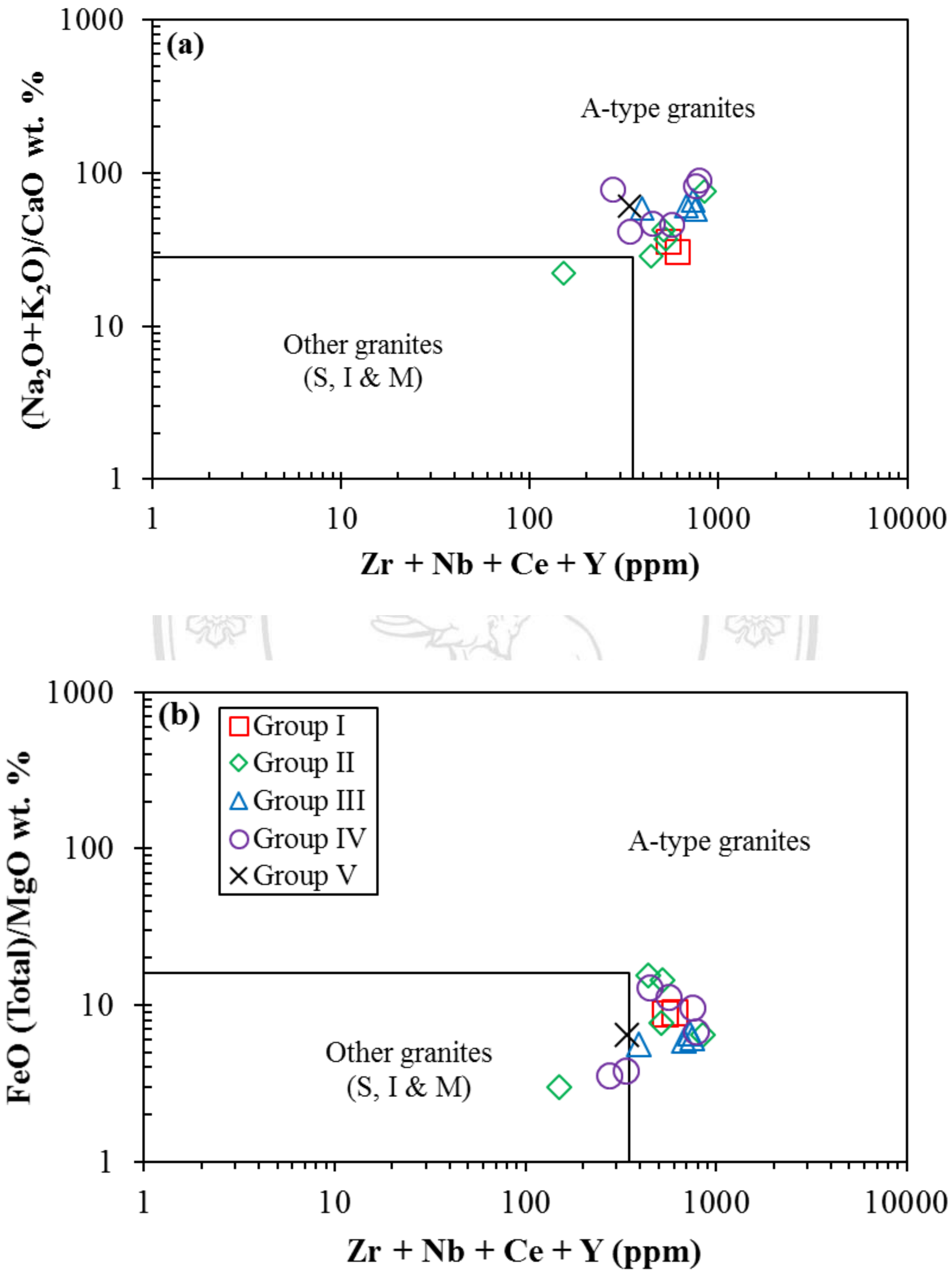


Figure 4.10 Discriminates between A-type granites and granites of other types (a) Zr+Nb+Ce+Y versus $(Na_2O+K_2O)/CaO$ and (b) Zr+Nb+Ce+Y versus FeO*/MgO (Whalen *et al.*, 1987).

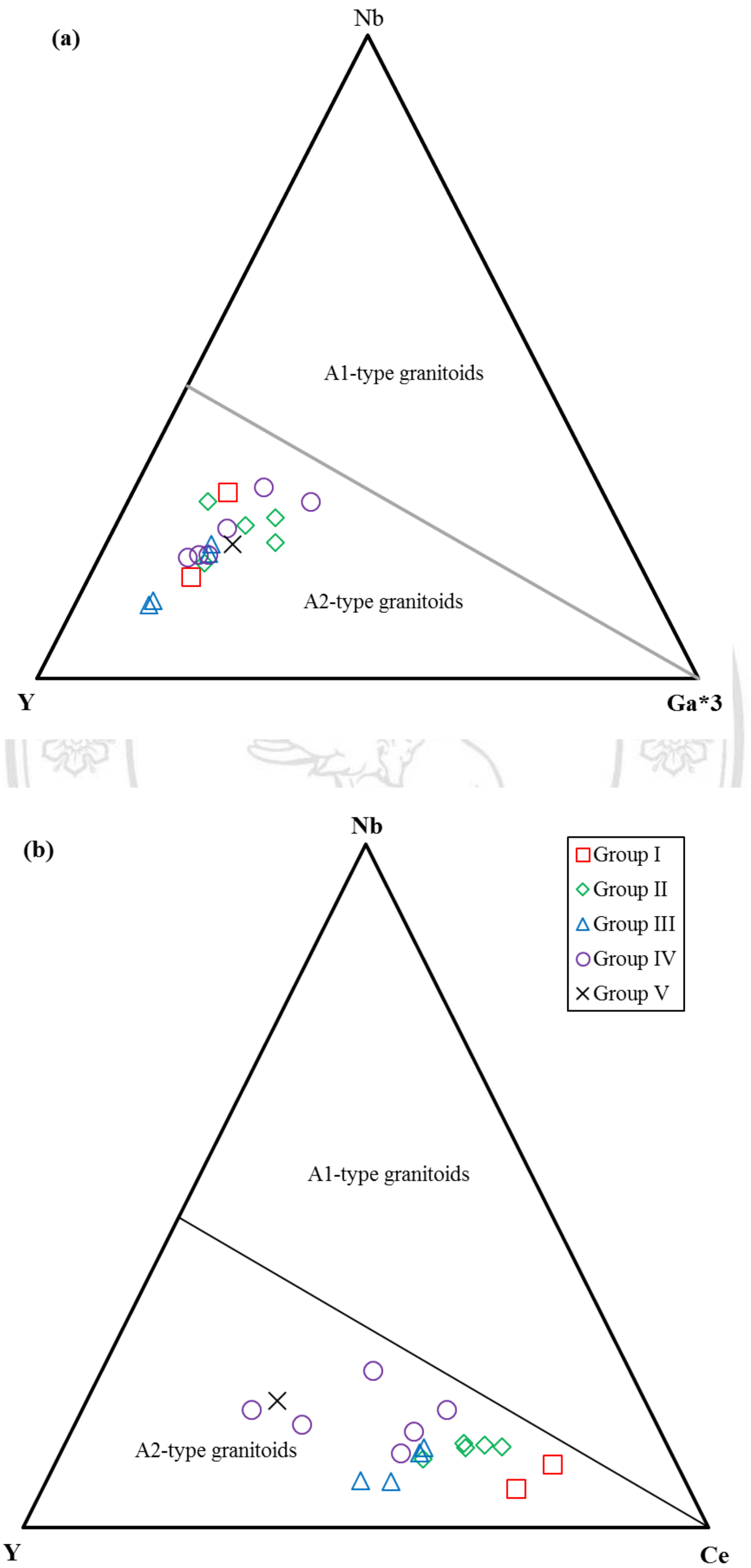


Figure 4.11 Ternary diagram for chemical subdivision of the A-type granitoids (a) Y-Nb-Ga*3 and (b) Y-Nb-Ce (Eby, 1992).

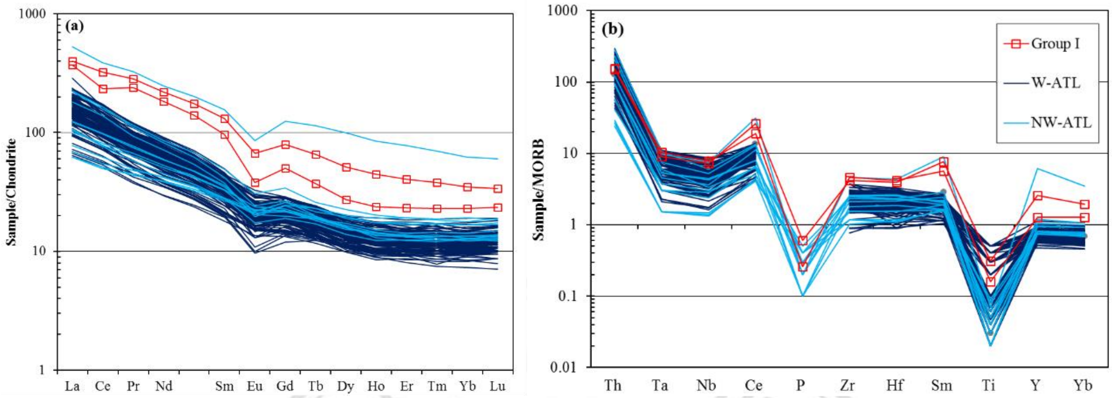


Figure 4.12 Plots of (a) chondrite-normalized REE and (b) N-MORB normalized multi-element patterns for the representatives of Group I with their modern tectonic setting, the Miocene potassic volcanic rocks in western Anatolia, Turkey (W-ATL) and the Eocene-Miocene calc-alkaline volcanic rocks from northwest Anatolia, Turkey (NW-ATL). Chondrite and N-MORB normalizing values are from Sun and McDonough (1989).

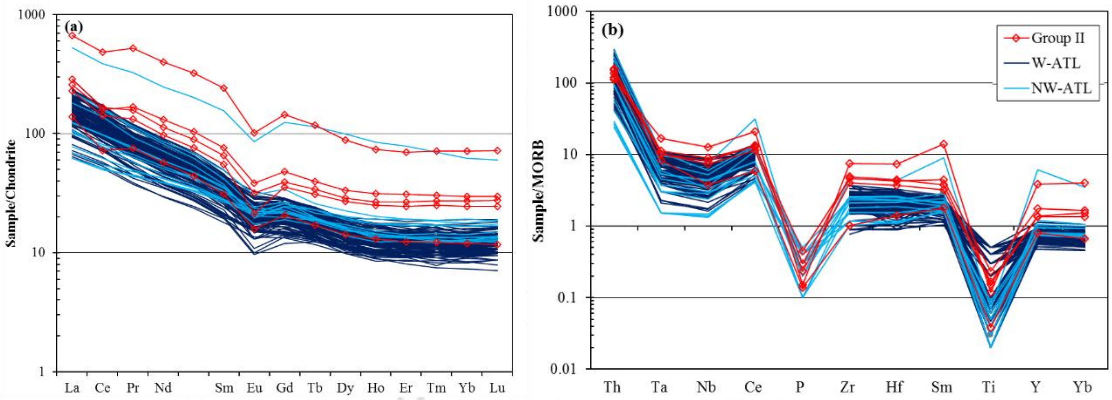


Figure 4.13 Plots of (a) chondrite-normalized REE and (b) N-MORB normalized multi-element patterns for the representatives of Group II with their modern tectonic setting, the Miocene potassic volcanic rocks in western Anatolia, Turkey (W-ATL) and the Eocene-Miocene calc-alkaline volcanic rocks from northwest Anatolia, Turkey (NW-ATL). Chondrite and N-MORB normalizing values are from Sun and McDonough (1989).

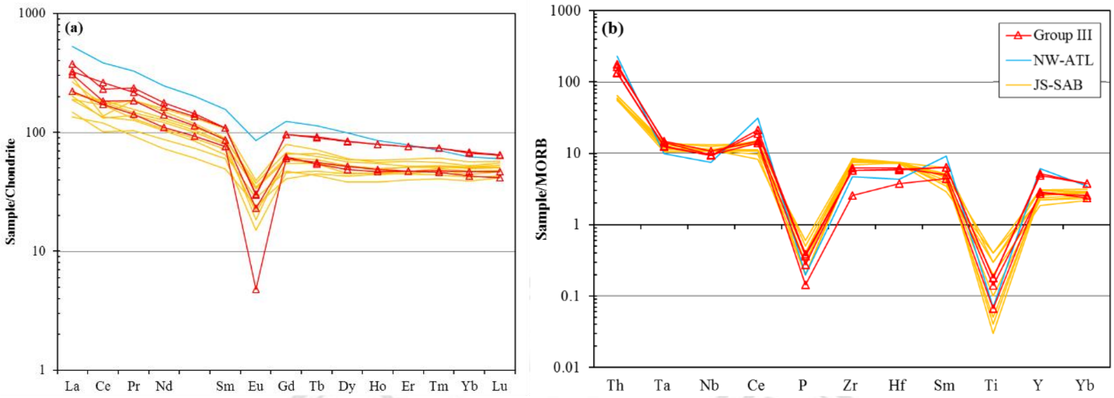


Figure 4.14 Plots of (a) chondrite-normalized REE and (b) N-MORB normalized multi-element patterns for the representatives of Group III with their modern tectonic setting, the Eocene-Miocene calc-alkaline volcanic rocks from northwest Anatolia, Turkey (NW-ATL) and the Miocene A_2-type rhyolites at Jabal Shama in western Saudi Arabia (JS-SAB). Chondrite and N-MORB normalizing values are from Sun and McDonough (1989).

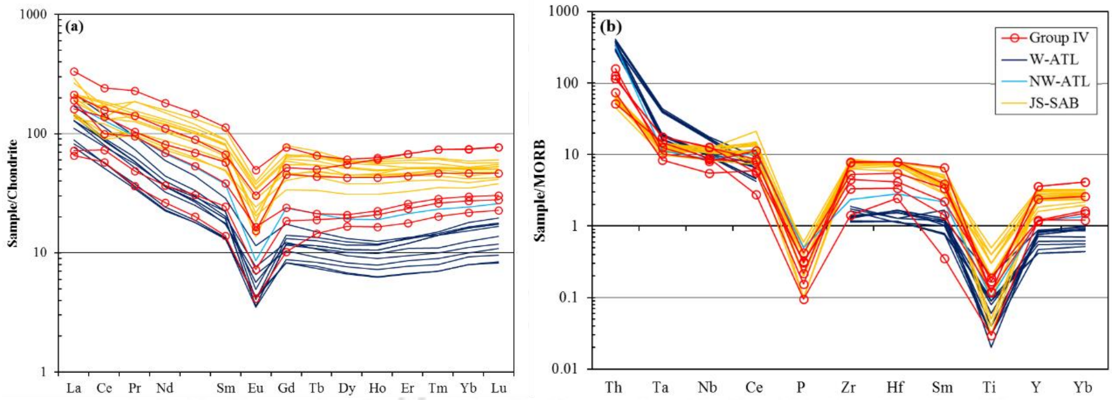


Figure 4.15 Plots of (a) chondrite-normalized REE and (b) N-MORB normalized multi-element patterns for the representatives of Group IV with their modern tectonic setting, the Miocene potassic volcanic rocks in western Anatolia, Turkey (W-ATL), the Eocene-Miocene calc-alkaline volcanic rocks from northwest Anatolia, Turkey (NW-ATL) and the Miocene A_2-type rhyolites at Jabal Shama in western Saudi Arabia (JS-SAB). Chondrite and N-MORB normalizing values are from Sun and McDonough (1989).

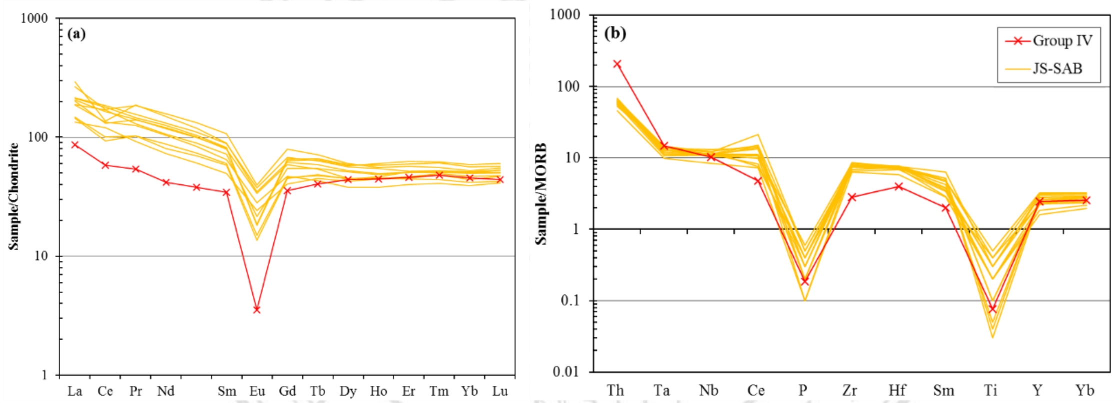


Figure 4.16 Plots of (a) chondrite-normalized REE and (b) N-MORB normalized multi-element patterns for the representatives of Group V with their modern tectonic setting, the Miocene A_2-type rhyolites at Jabal Shama in western Saudi Arabia (JS-SAB). Chondrite and N-MORB normalizing values are from Sun and McDonough (1989).

CHAPTER 5

Geochronology

The zircon grains were separated from eleven samples of the studied volcanic rocks in Phayao province. Advanced analytical techniques are given in Appendix B. The analytical results are listed within the supplementary and summarized in Table 5.1 and Figure 5.1. The zircons are mainly euhedral to subhedral prismatic crystals, usually transparent, less than 100 µm long (Figure 5.2). On cathodoluminescence (CL) images show concentric oscillatory, irregular or no zoning patterns from core to rim, without thickened and blurred (Figure 5.3-5.13 and Appendix C). The analytical laser spots location on zircon grains selected from CL images for U-Pb dating. All analyses weighted mean $^{206}Pb/^{238}U$ age of zircons were obtained in Figures 5.4-5.14. The U-Pb isotopic data from LA-ICP-MS are given in Appendix C.

Table 5.1 Summary of sampling locations and U-Pb zircon age of the studied volcanic rocks in Phayao province.

Sample no.	Rock type	Coordinate	Age dating (Ma)
09	Welded vitric tuff	47Q 603296E 2144317N	184.2±1.8
13	Welded vitric tuff	47Q 600866E 2134916N	227±2.8
14	Rhyodacite/dacite	47Q 599054E 2133757N	221±2.3
41	Rhyolite	47Q 624133E 2134159N	186±1.8
42	Rhyolite	47Q 637260E 2135619N	224.5±3.4
43	Rhyolite	47Q 637730E 2135546N	184±2
44	Rhyolite	47Q 640494E 2136148N	229.5±4, 182.8±2.5
46	Rhyolite	47Q 645639E 2134159N	189.9±1.8
48	Rhyolite	47Q 645785E 2134294N	186.3±1.8
49	Rhyolite	47Q 632038E 2086902N	188.9±1.8
53	Welded vitric tuff	47Q 634305E 2086729N	2478-520

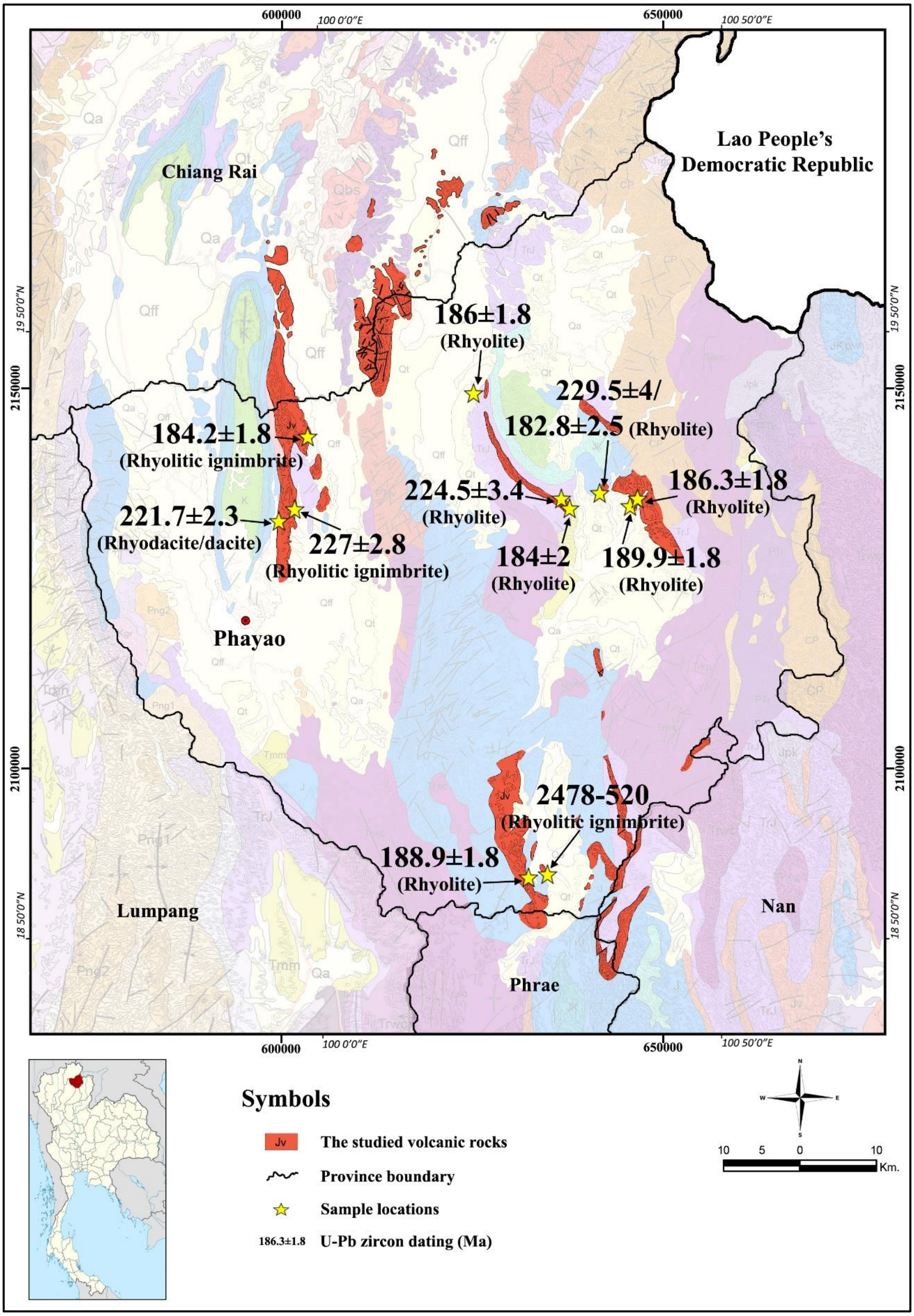


Figure 5.1 The widespread of the studied volcanic rocks in Phayao province and vicinity with U-Pb zircon ages.

In Sample number 09, twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral, mostly elongated to few stubby prismatic and have well-defined crystal terminations. They are transparent, colorless to light brown and have inclusion (Figure 5.2a). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth bands and itself sometimes containing another occasionally dark-zoned central core. They rarely have inherited cores (Figure 5.3). The ^{206}Pb/^{238}U ages ranging from 195 to 175 Ma. All analyses are concordant within errors and define a well-constrained Concordia weighted mean age of 184.2±1.8 Ma with the mean square weighted deviation (MSWD) = 1.08 (Figure 5.14).

Sample number 13 nineteen spots analyses were made from data plotted on a Concordia diagram. Zircon grains are mostly euhedral and some grains appear rounded to subrounded, stubby to elongated prismatic and have well-defined crystal terminations. They are transparent, colorless to light green and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2b). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth bands and itself sometimes containing another occasionally dark-zoned central core. Some zircons have inherited cores and rarely presented two continuous growth stages (Figure 5.4). The ^{206}Pb/^{238}U ages ranging from 238 to199 Ma. The Concordia weighted mean age of 227±2.8 Ma with MSWD = 0.42 (Figure 5.15).

Sample number 14 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to subhedral and appear rounded to subrounded, mostly elongated to few stubby prismatic and have well-defined crystal terminations. They are transparent, colorless to light brown and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2c). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth bands and itself sometimes containing another occasionally dark-zoned central core. Some zircons have inherited cores and rarely presented two continuous growth stages (Figure 5.5). The ^{206}Pb/^{238}U ages ranging from 233 to 215 Ma. The Concordia weighted mean age of 221.7±2.3 Ma with MSWD = 0.52 (Figure 5.16).

Sample number 41 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral, mostly elongated to stubby prismatic and have well-defined crystal terminations. They are transparent, colorless to light green and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2d). The internal structure revealed by CL images indicate that typical homogeneous (Figure 5.6). The $^{206}Pb/^{238}U$ ages ranging from 190 to 183 Ma. The Concordia weighted mean age of 186.3±1.8 Ma with MSWD = 0.19 (Figure 5.17).

Sample number 42 ten spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to anhedral and appear rounded to subrounded, mostly elongated prismatic and have well-defined crystal terminations. They are transparent, colorless to light green and have inclusion (Figure 5.2e). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth. Some zircons have inherited cores and rarely presented two continuous growth stages (Figure 5.7). The $^{206}Pb/^{238}U$ ages ranging from 229 to 213 Ma. The Concordia weighted mean age of 224.5±3.4 Ma with MSWD = 0.77 (Figure 5.18).

Sample number 43 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are rounded to subrounded and some grain appear subhedral, mostly elongated to stubby prismatic and have well-defined crystal terminations. They are transparent, colorless to light green and have inclusion (Figure 5.2f). The internal structure revealed by CL images indicate that typical homogeneous (Figure 5.8). The $^{206}Pb/^{238}U$ ages ranging from 179 to 179 Ma. The Concordia weighted mean age of 184±2 Ma with MSWD = 0.46 (Figure 5.19).

Sample number 44 thirty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are rounded to subrounded and some grains appear euhedral to subhedral, mostly elongated to stubby prismatic and some have well-defined crystal terminations. They are transparent, colorless to light green and have inclusion (Figure 5.2g). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth bands and itself sometimes containing another occasionally dark-zoned central core with some homogeneous. Some zircons have inherited cores and rarely presented two continuous growth stages (Figure 5.9). The $^{206}Pb/^{238}U$ ages of the older population ranging from 243 to 218 Ma. The Concordia weighted mean age of 229.5±4 Ma with MSWD = 1.5. The $^{206}Pb/^{238}U$ ages of the younger population ranging from 191 to 168 Ma. The Concordia weighted mean age of 182.8±2.5 Ma with MSWD = 1.5 (Figure 5.20).

Sample number 46 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to subhedral, mostly elongated to few stubby prismatic and have well-defined crystal terminations. They are transparent, colorless-light green to light brown and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2h). The internal structure revealed by CL images indicate that typical homogeneous (Figure 5.10). The $^{206}Pb/^{238}U$ ages ranging from 195 to 184 Ma. The Concordia weighted mean age of 189.9±1.8 Ma with MSWD = 0.5 (Figure 5.21).

Sample number 48 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to subhedral, mostly elongated to few stubby prismatic and have well-defined crystal terminations. They are transparent, colorless-light green to light brown and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2i). The internal structure revealed by CL images indicate that typical oscillatory zoning with fine growth bands and itself sometimes containing another occasionally dark-zoned central core (Figure 5.11). The $^{206}Pb/^{238}U$ ages ranging from 194 to 178 Ma. The Concordia weighted mean age of 186.3±1.8 Ma with MSWD = 1 (Figure 5.22).

Sample number 49 twenty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to subhedral, mostly stubby to elongated prismatic and have well-defined crystal terminations. They are transparent, colorless-light green to light brown and have inclusion (Figure 5.2j). The internal structure revealed by CL images indicate that typical homogeneous (Figure 5.12). The $^{206}Pb/^{238}U$ ages ranging from 196 to 185 Ma. The Concordia weighted mean age of 188.9±1.8 Ma with MSWD = 0.48 (Figure 5.23).

Sample number 53 thirty spots analyses were made from data plotted on a Concordia diagram. Zircon grains are euhedral to subhedral, mostly elongated prismatic and have well-defined crystal terminations. They are transparent, colorless to light brown and have inclusion. Some of the zircon grains have cracks and broken into pieces that result from pulverizing (Figure 5.2k). The internal structure revealed by CL images indicate that unconventional (Figure 5.13). The $^{206}Pb/^{238}U$ ages ranging from 2,478 to 520 Ma (Figure 5.24).

Generally, the studied volcanic rocks in Phayao province have the age of 189.9±1.8-182.8±1.8 Ma (Early Jurassic). Moreover, sample number 13, 14, 42 and 44 have the ages of 229.5±4-221±2.3Ma (Late Triassic) but one zircon grain in sample number 13 has the age of 199 Ma (Early Jurassic). Sample number 44 gives two population ages of 229.5±4 Ma (Late Triassic) and 182.8±2.5 Ma (Early Jurassic). Sample no.53 gives apparent ages ranging from 2478-520 Ma.

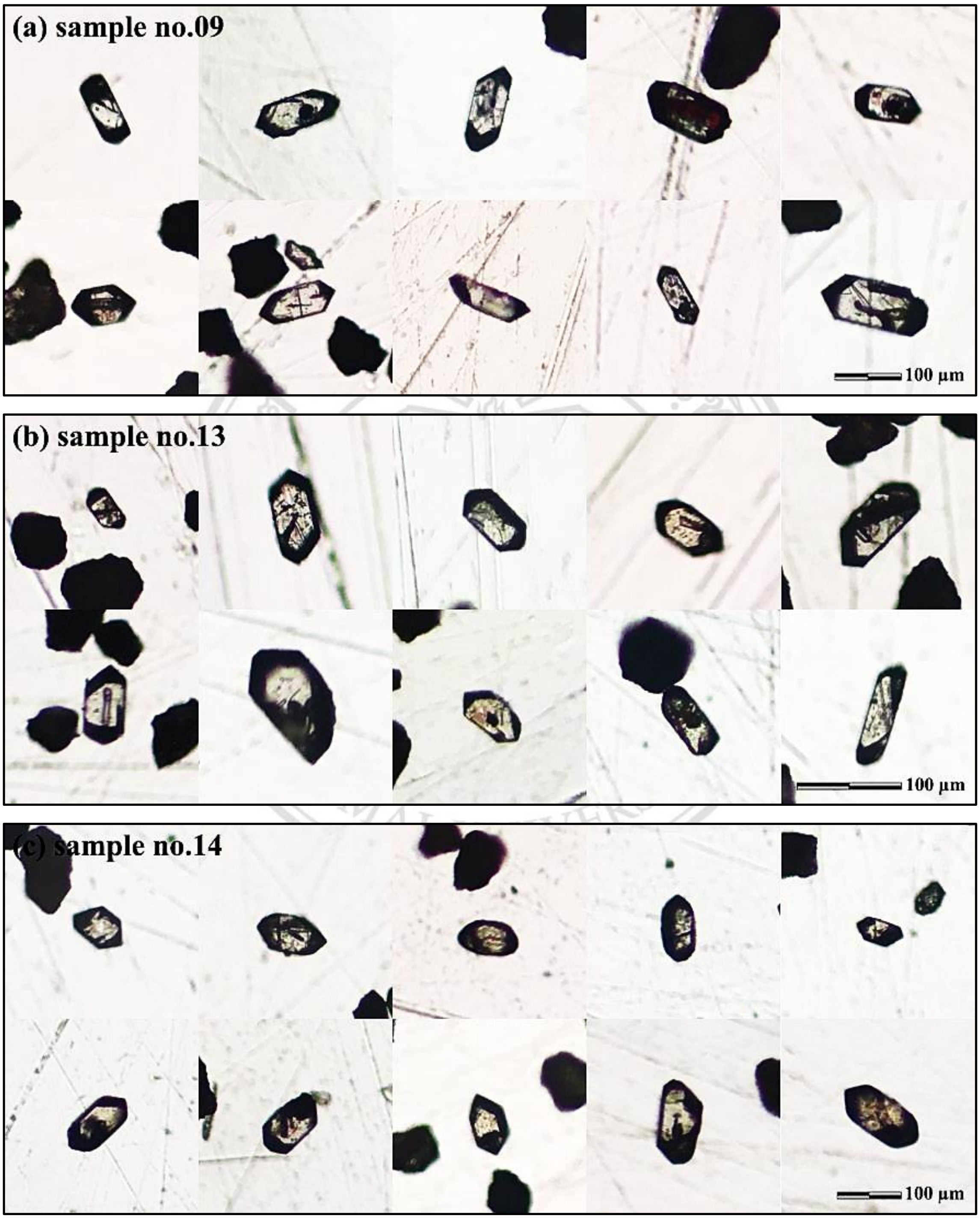
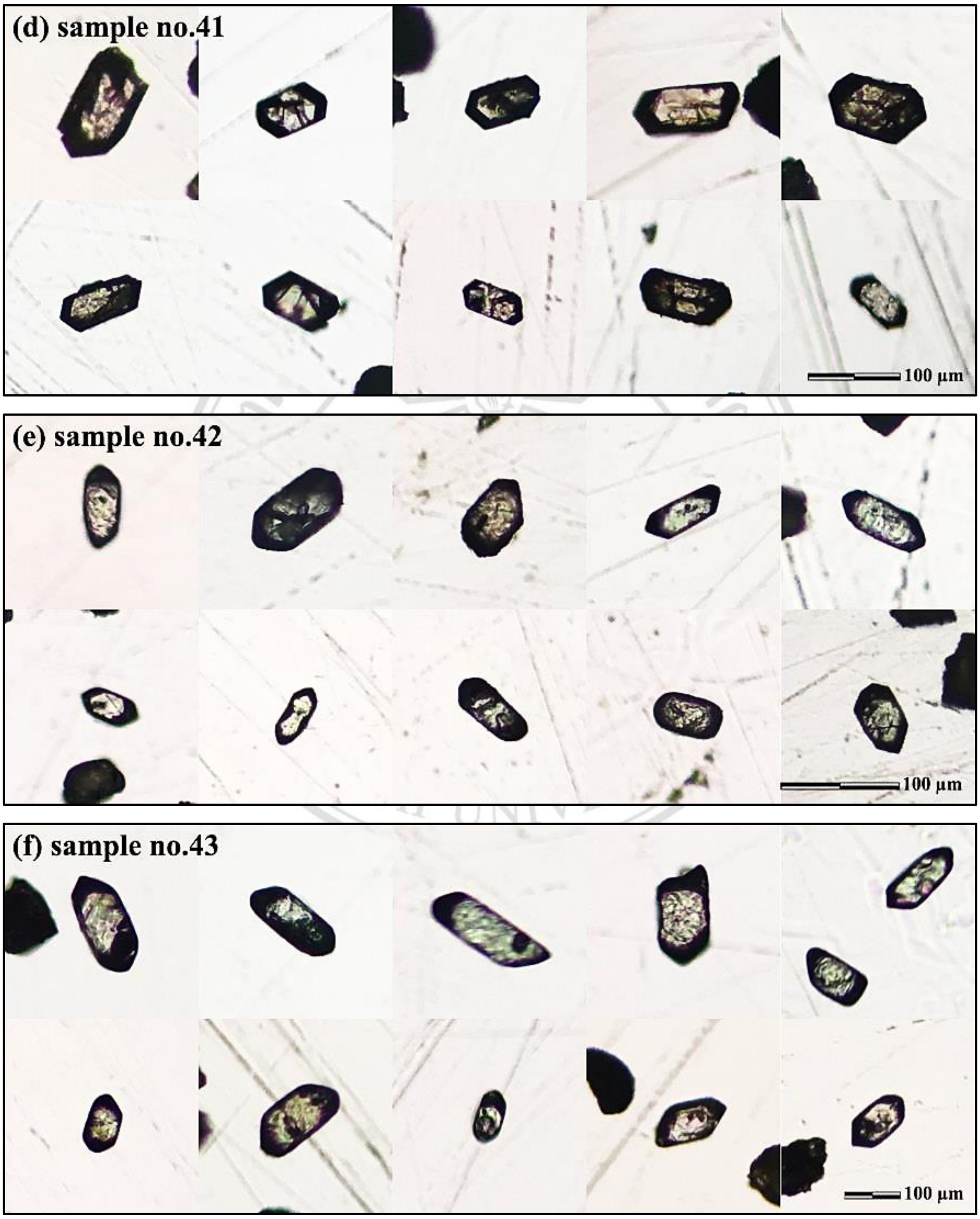


Figure 5.2 Zircon morphology under transmitted and reflected light polarizing microscope.



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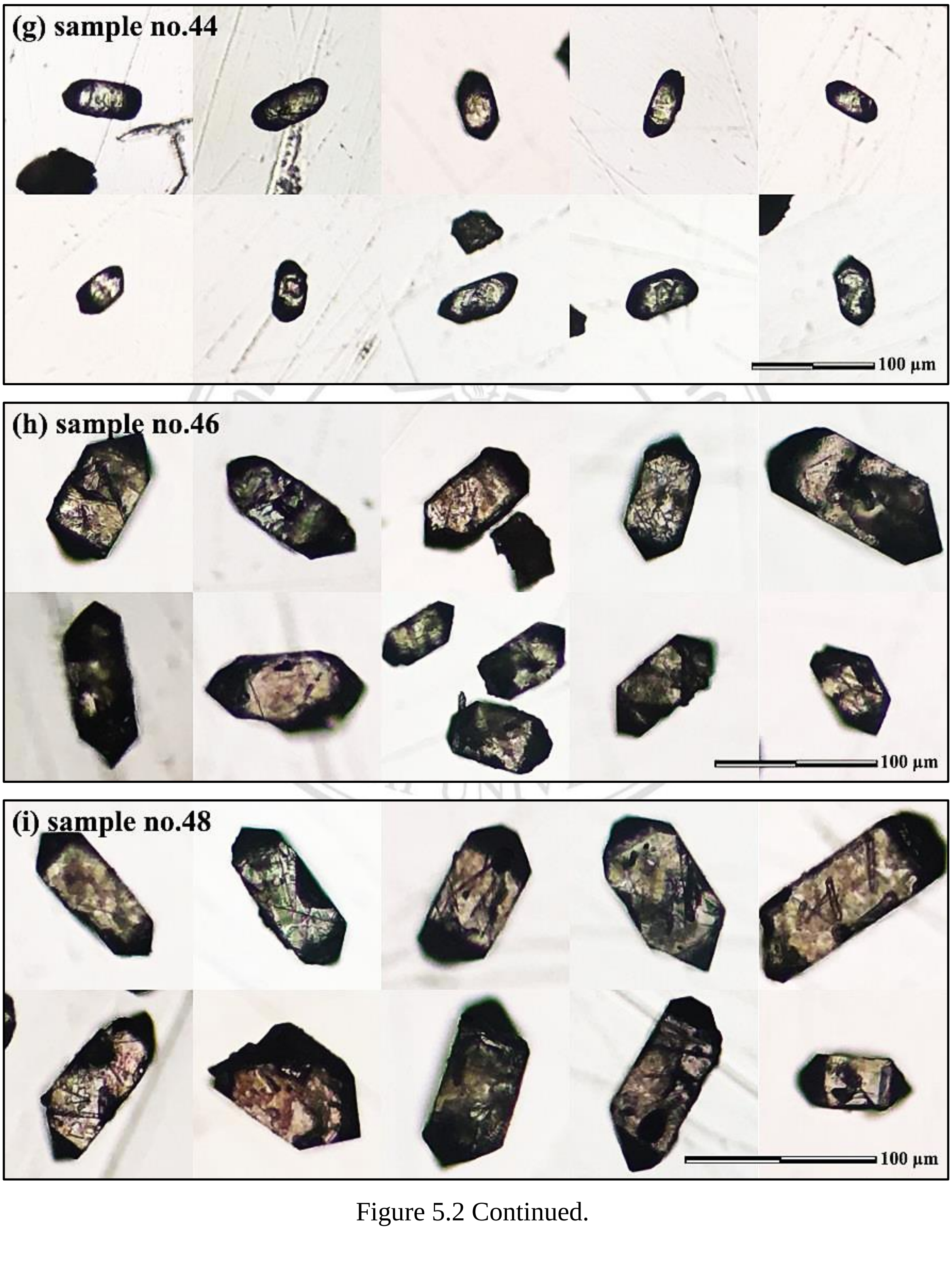
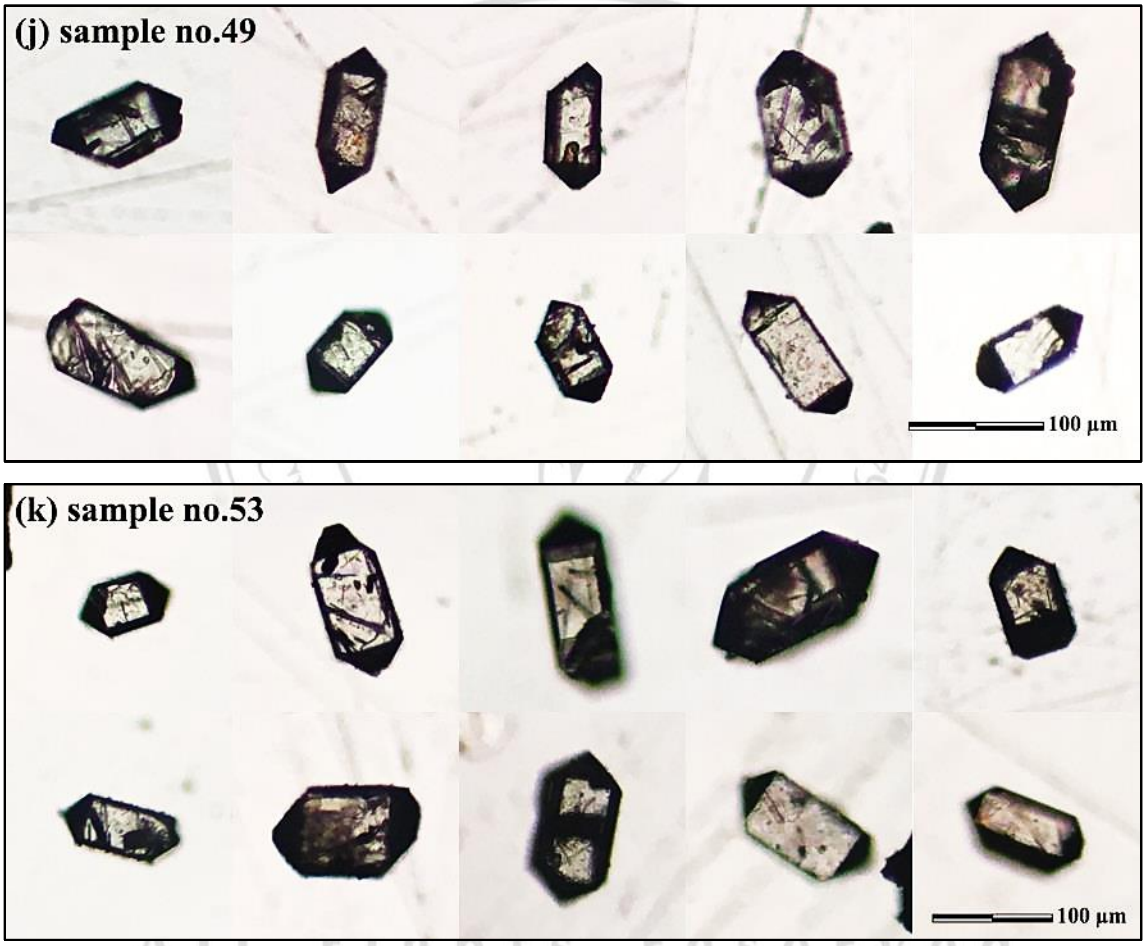


Figure 5.2 Continued.



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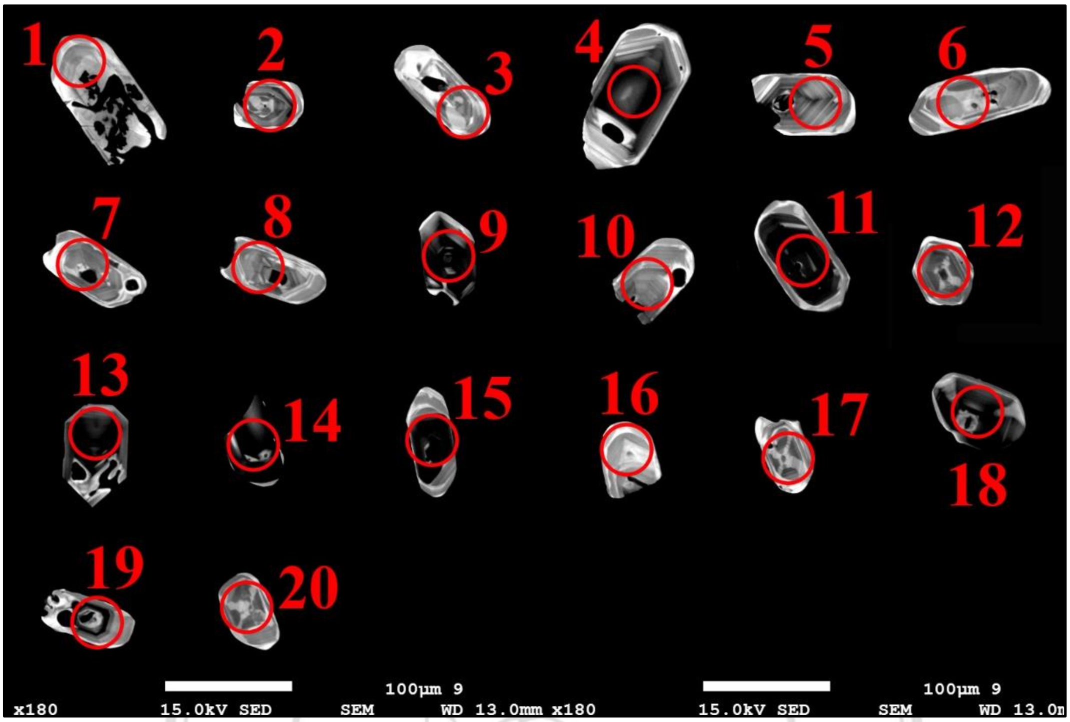


Figure 5.3 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 09.

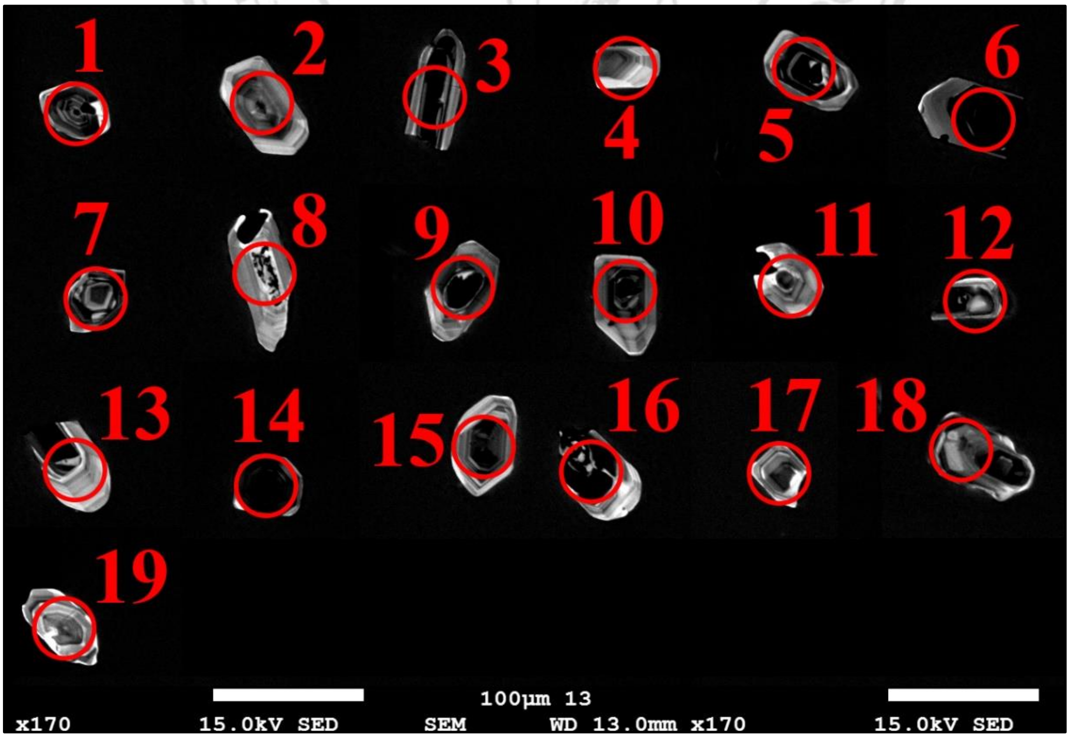


Figure 5.4 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 13.

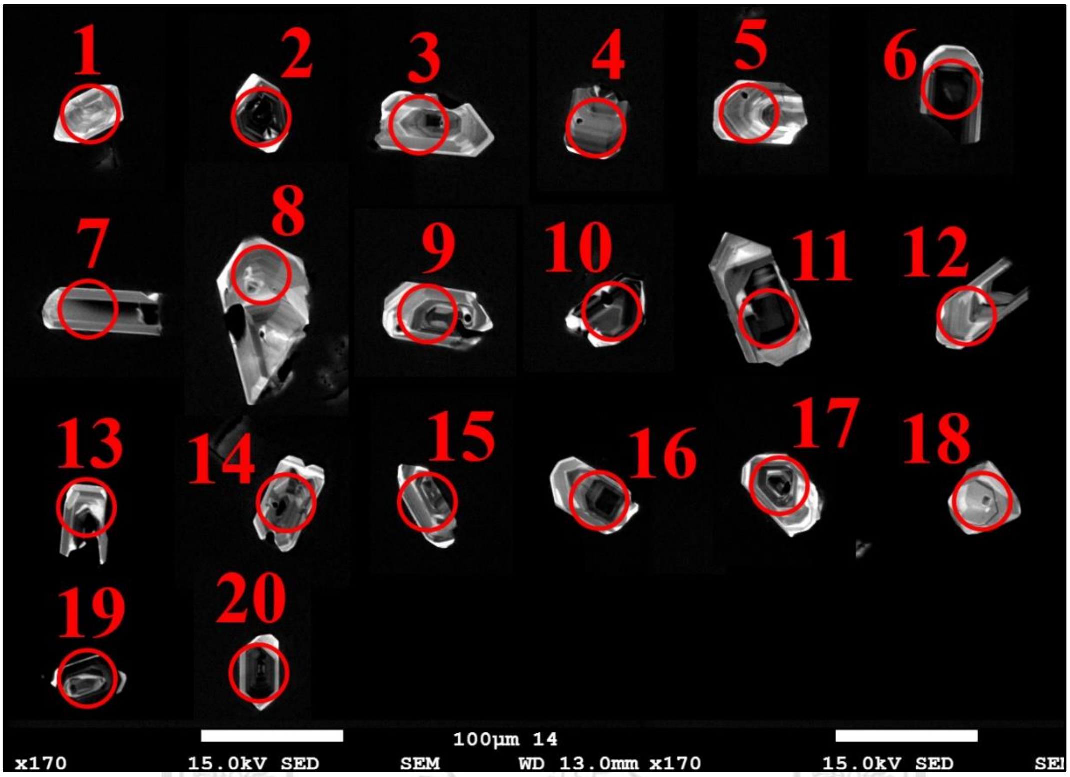


Figure 5.5 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 14.

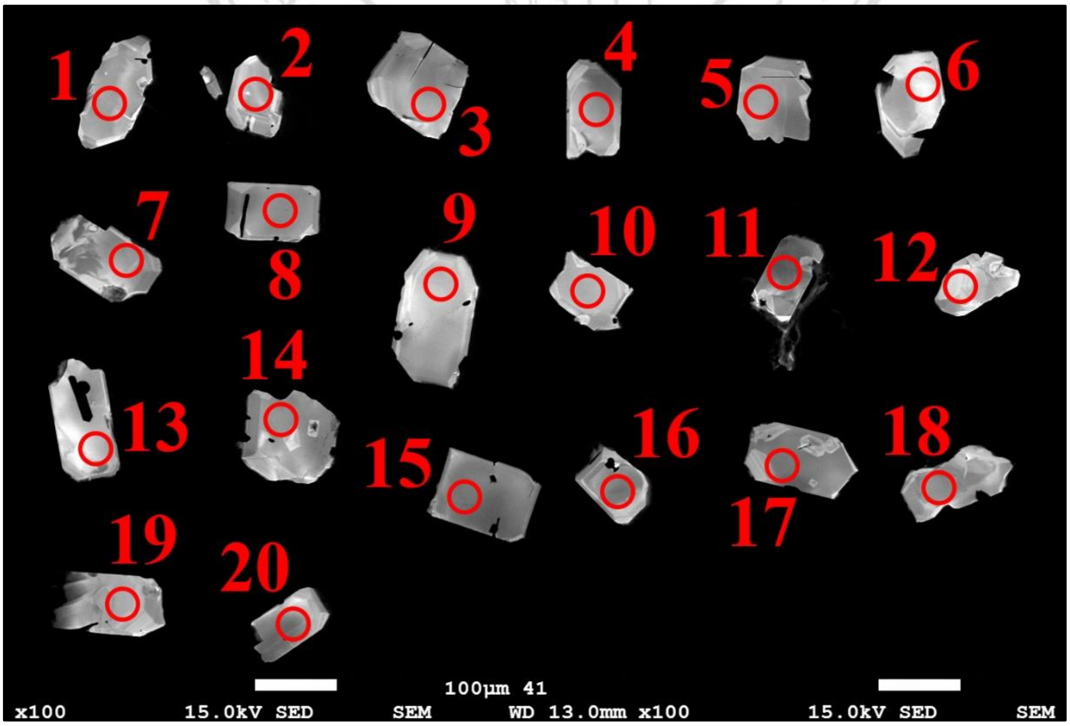


Figure 5.6 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 41.

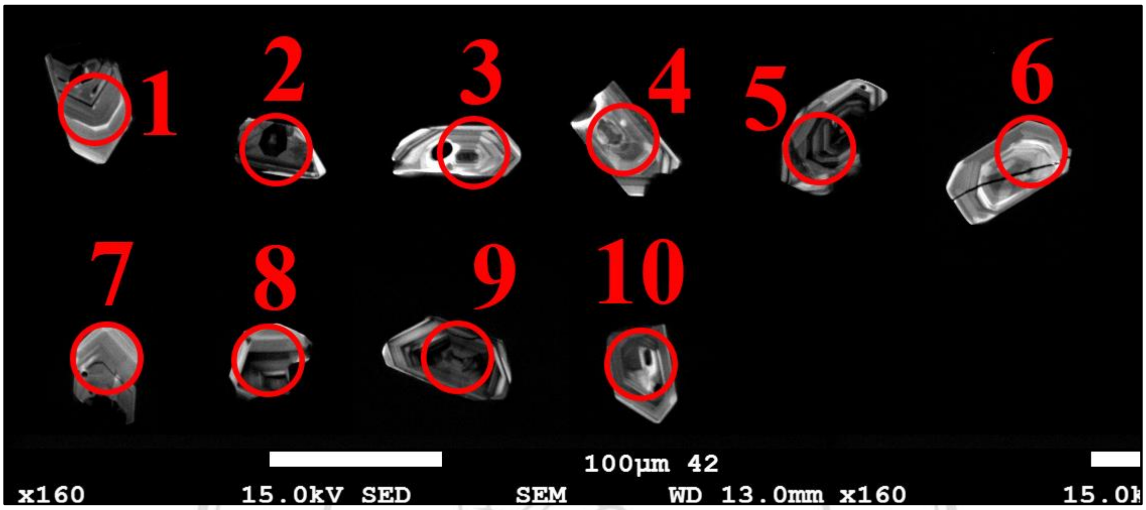


Figure 5.7 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 42.

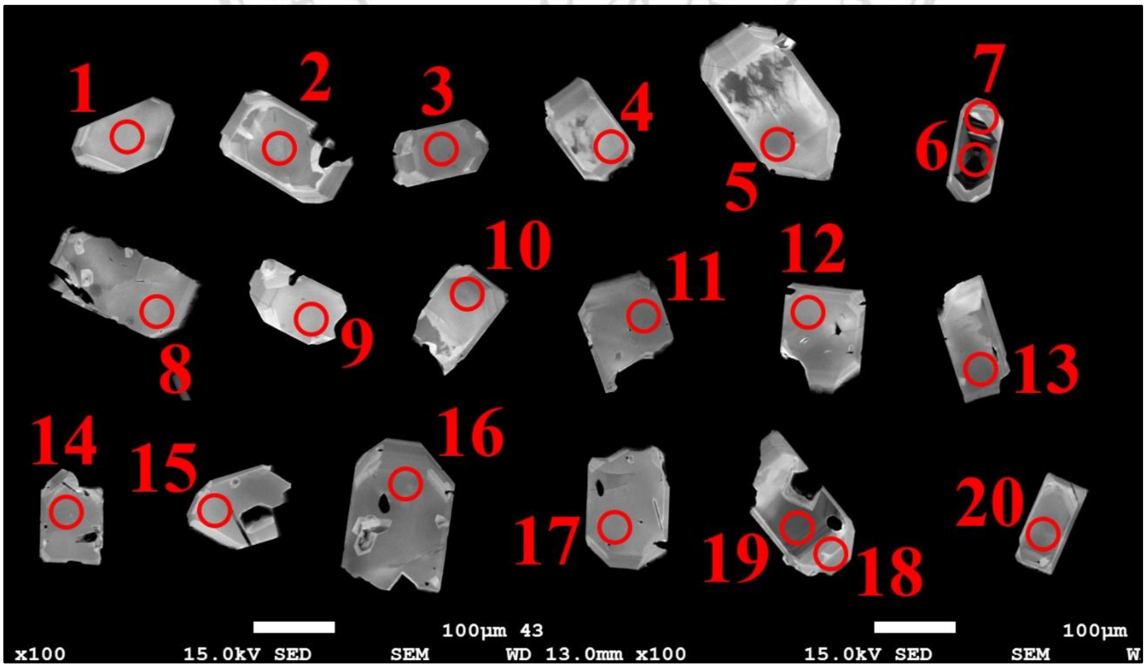


Figure 5.8 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 43.

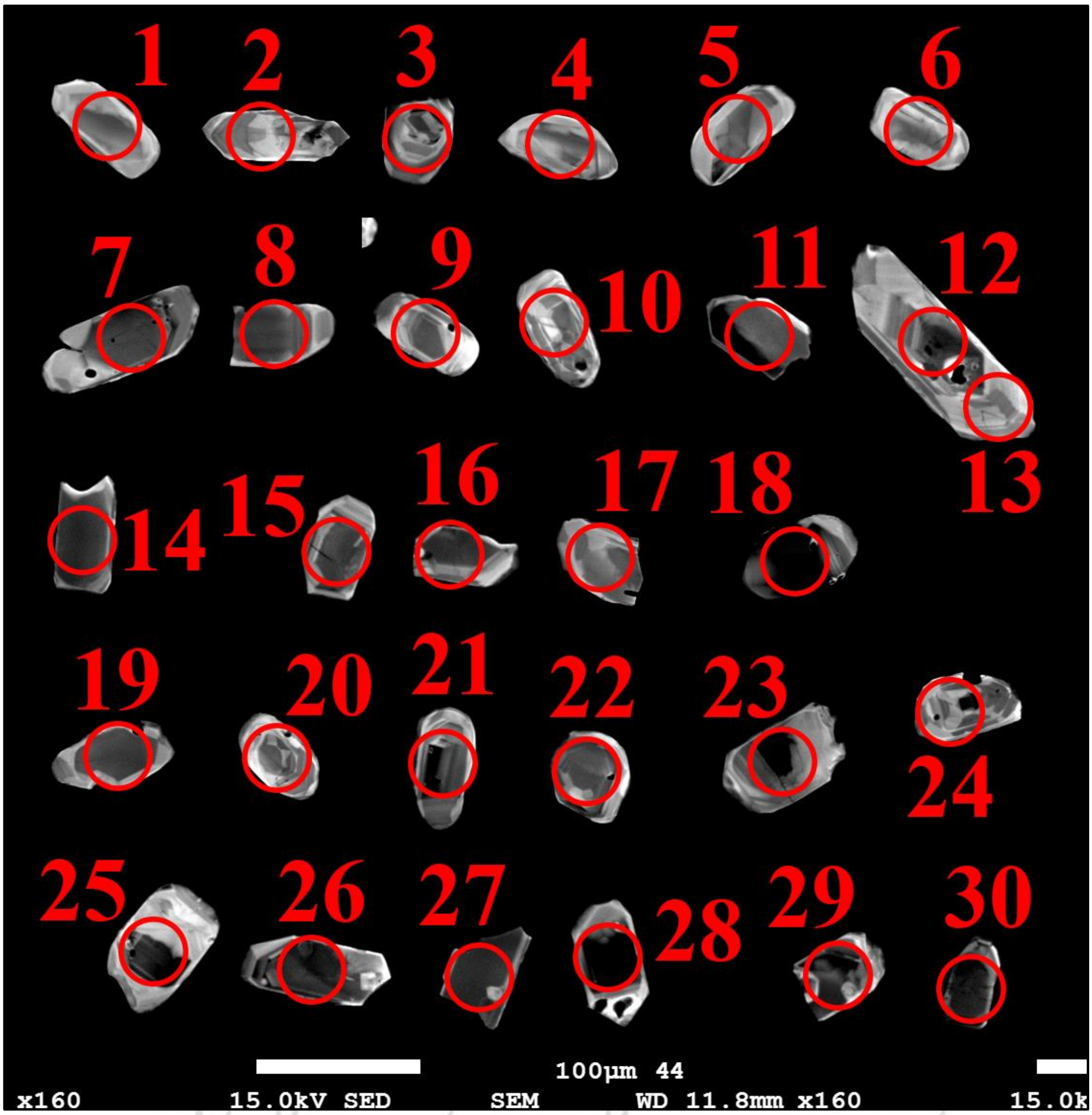


Figure 5.9 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 44.

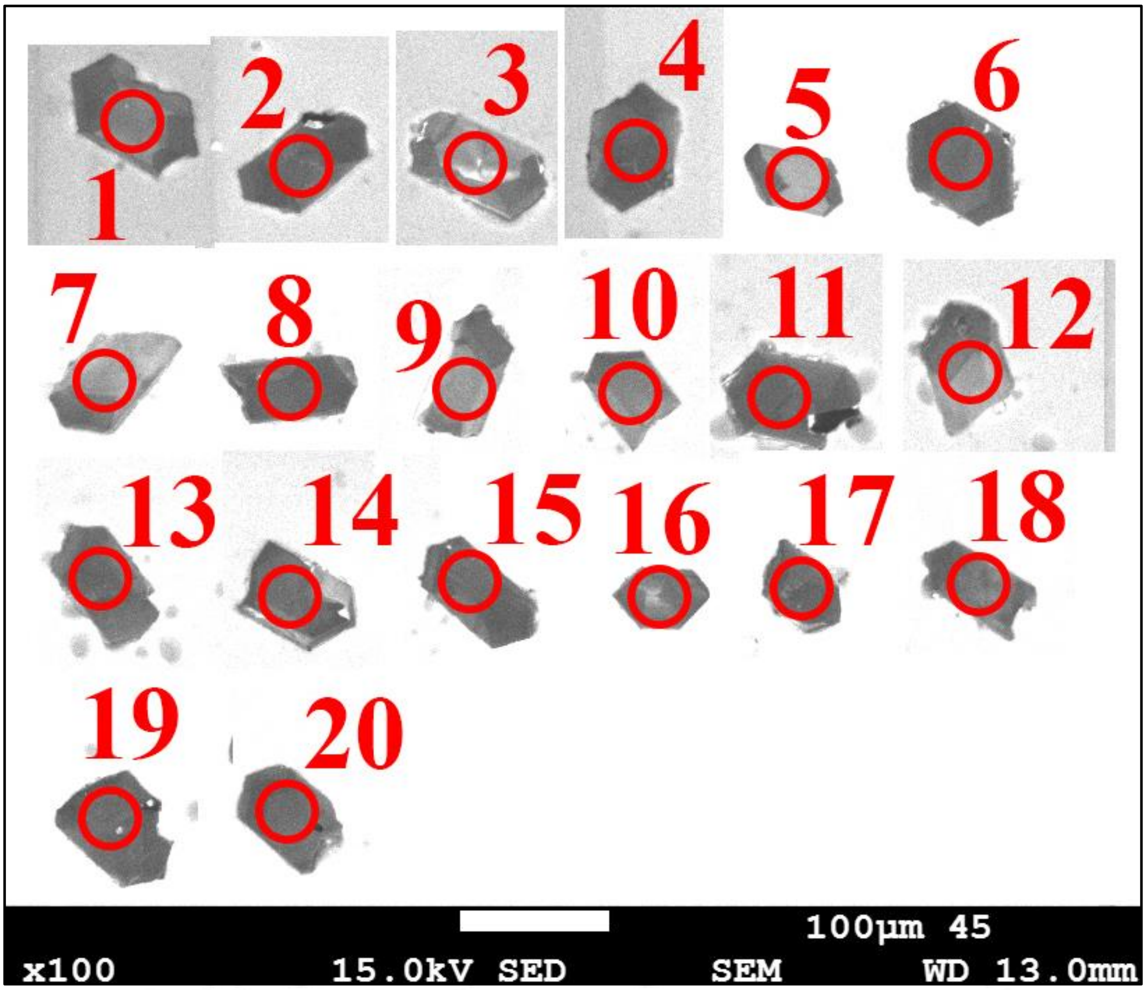


Figure 5.10 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 46.

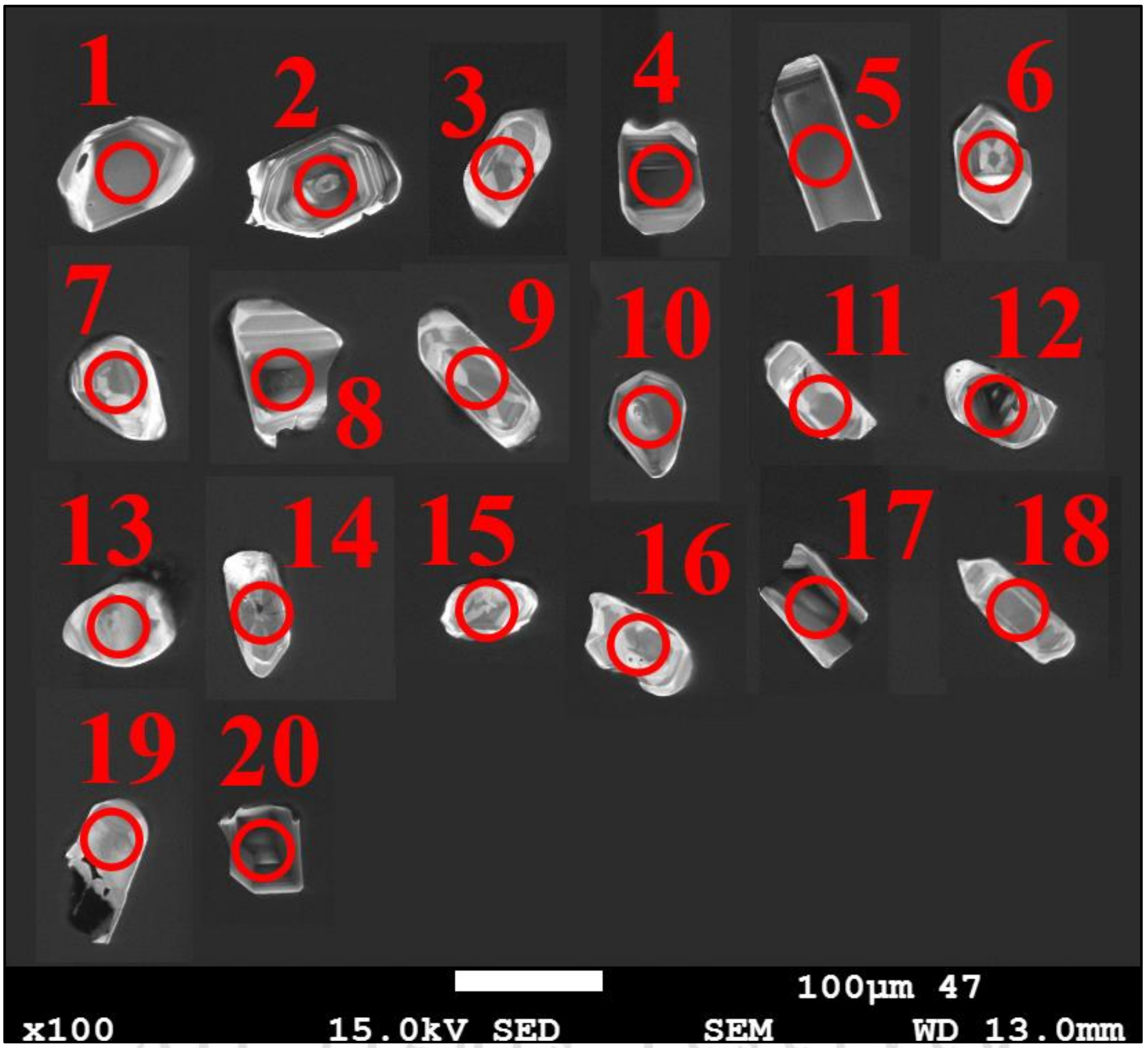


Figure 5.11 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 48.

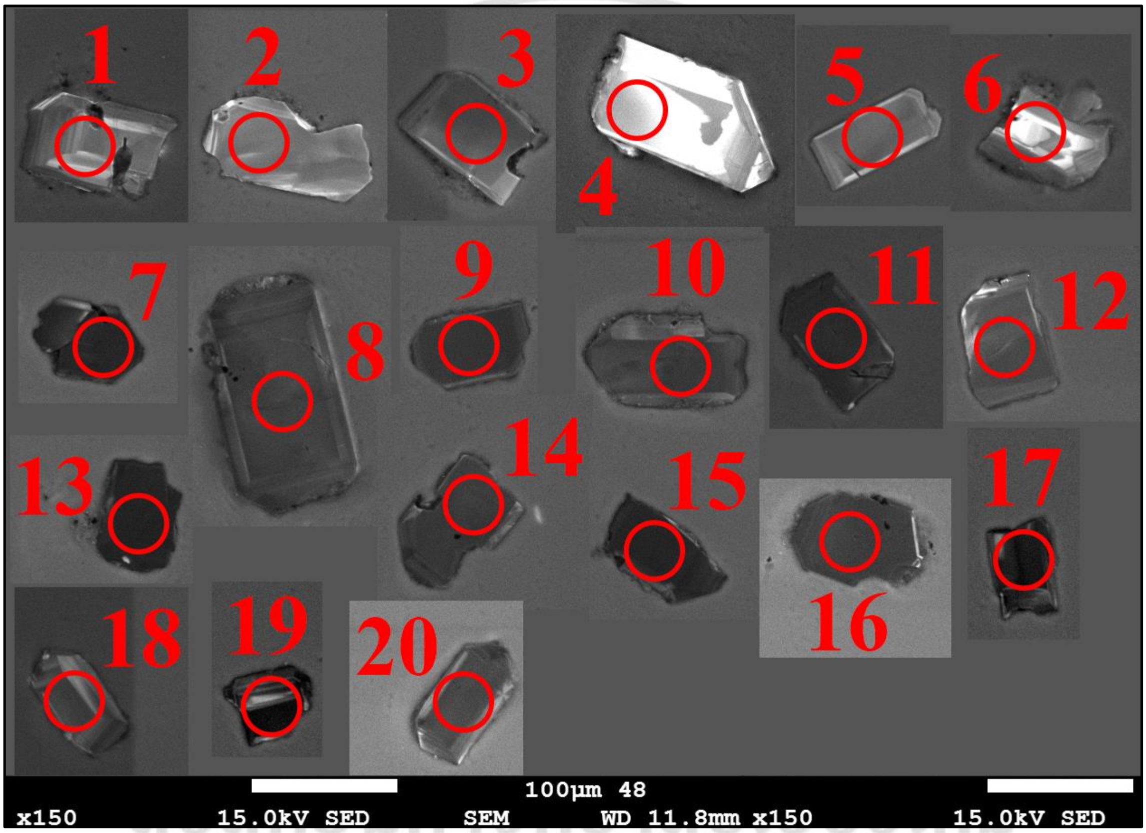


Figure 5.12 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 49.

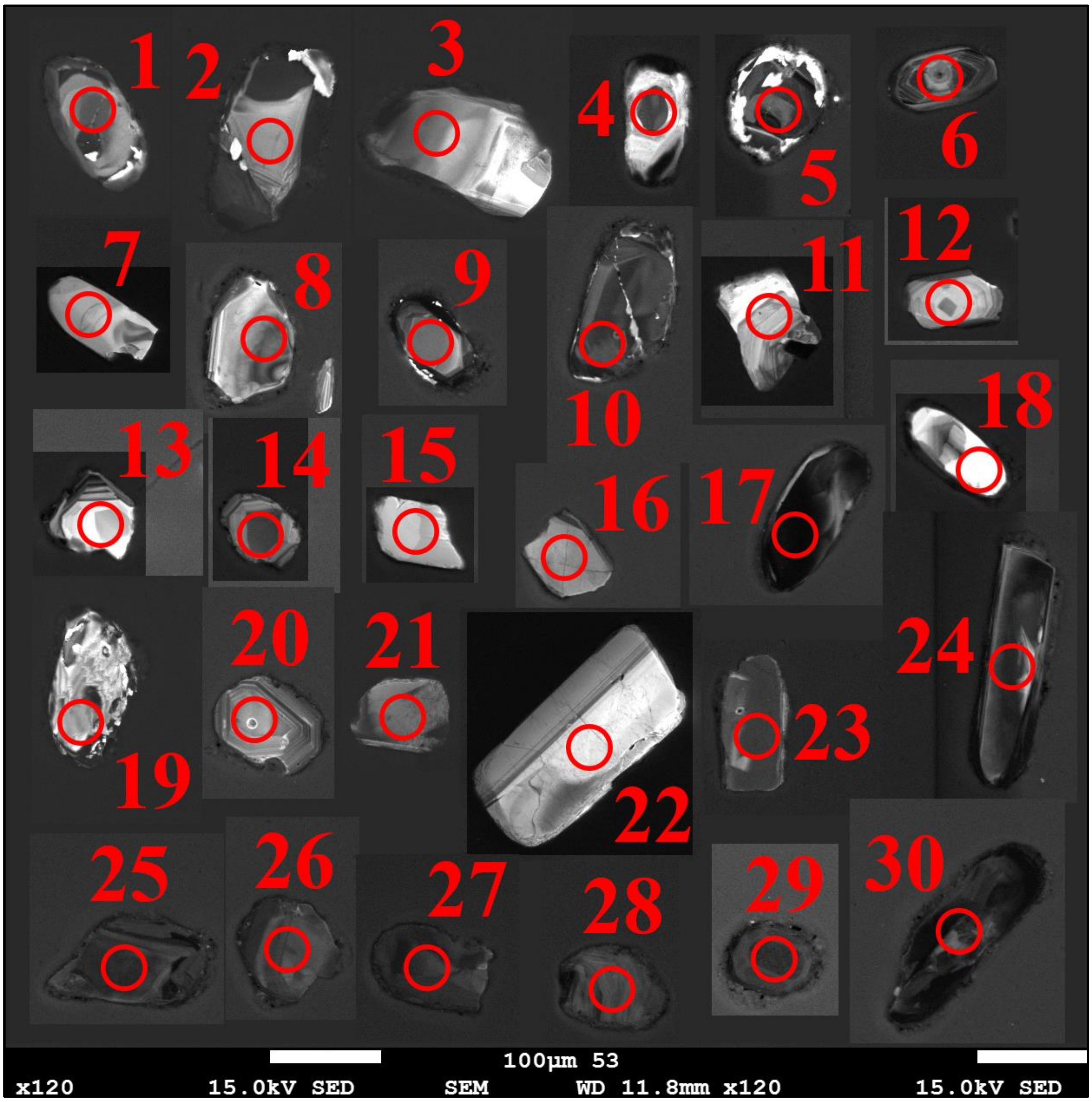


Figure 5.13 Cathodoluminescence (CL) images of zircons with selected laser spots for sample number 53.

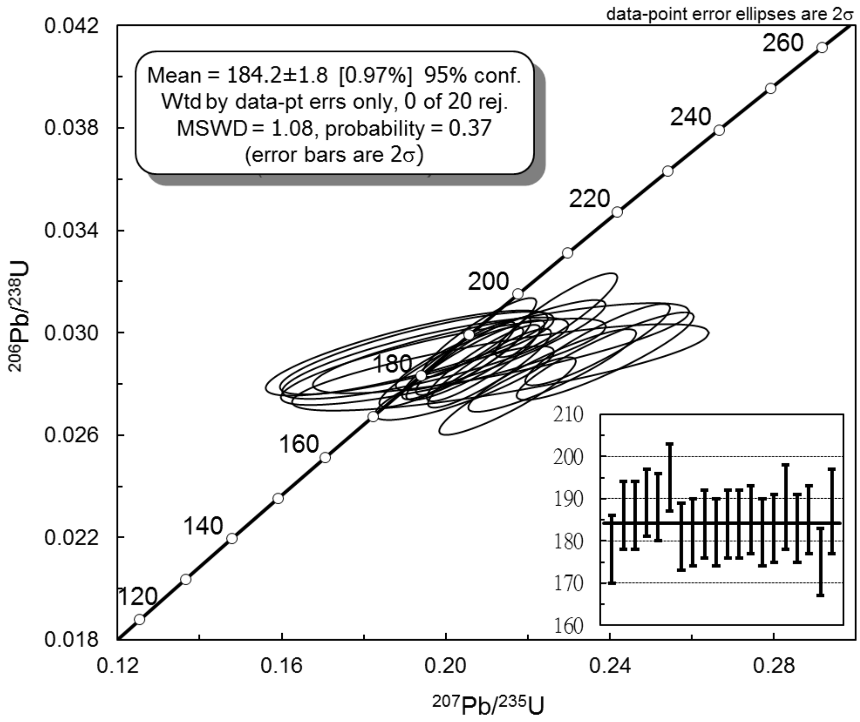


Figure 5.14 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 09.

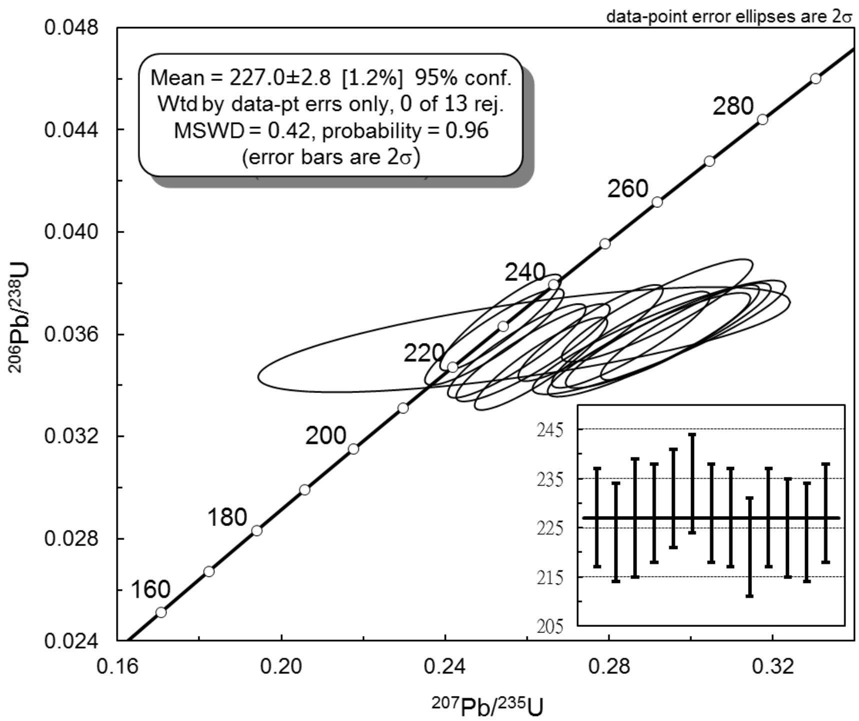


Figure 5.15 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 13.

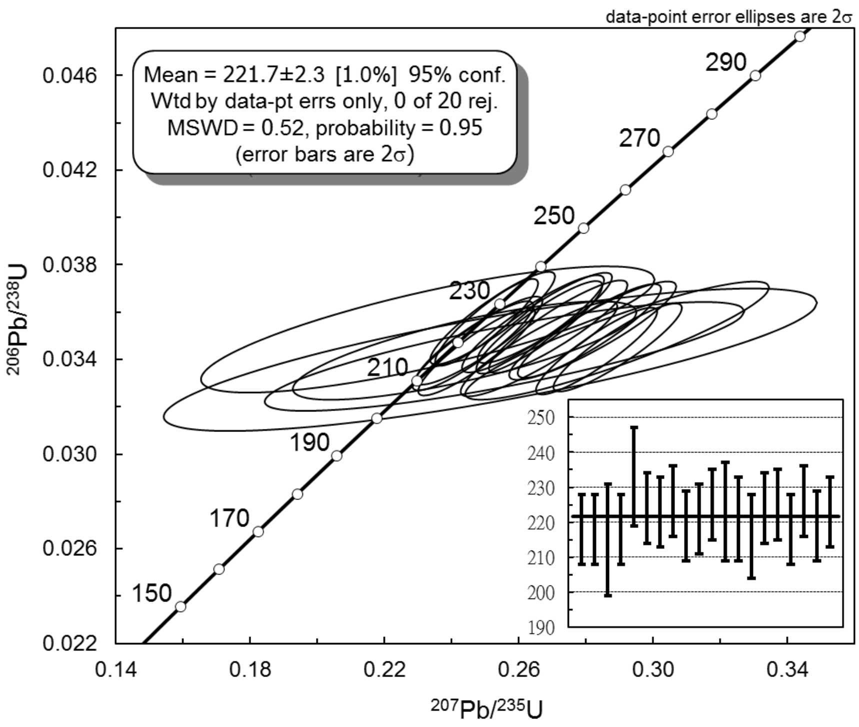


Figure 5.16 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 14.

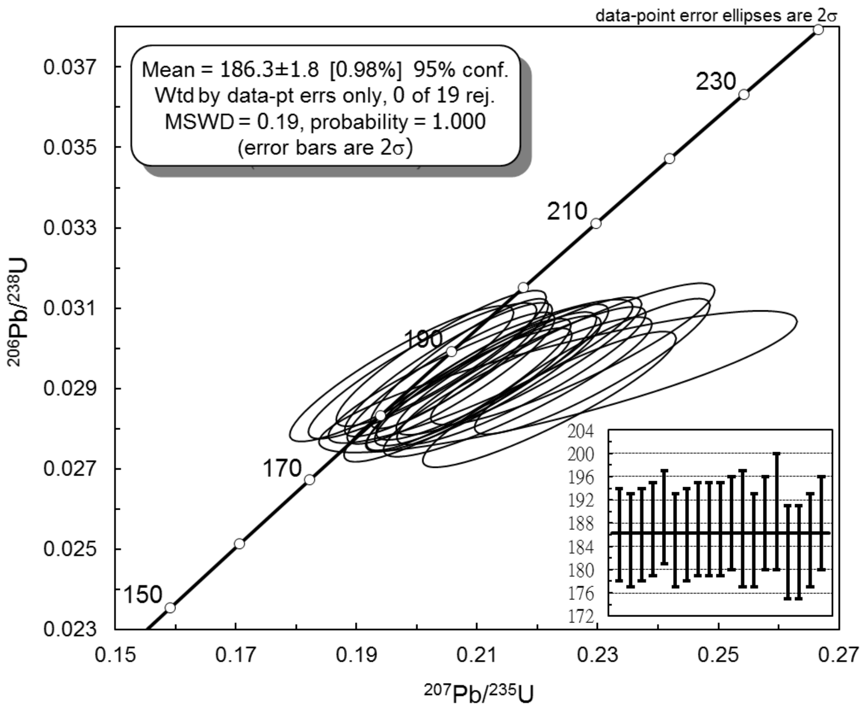


Figure 5.17 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 41.

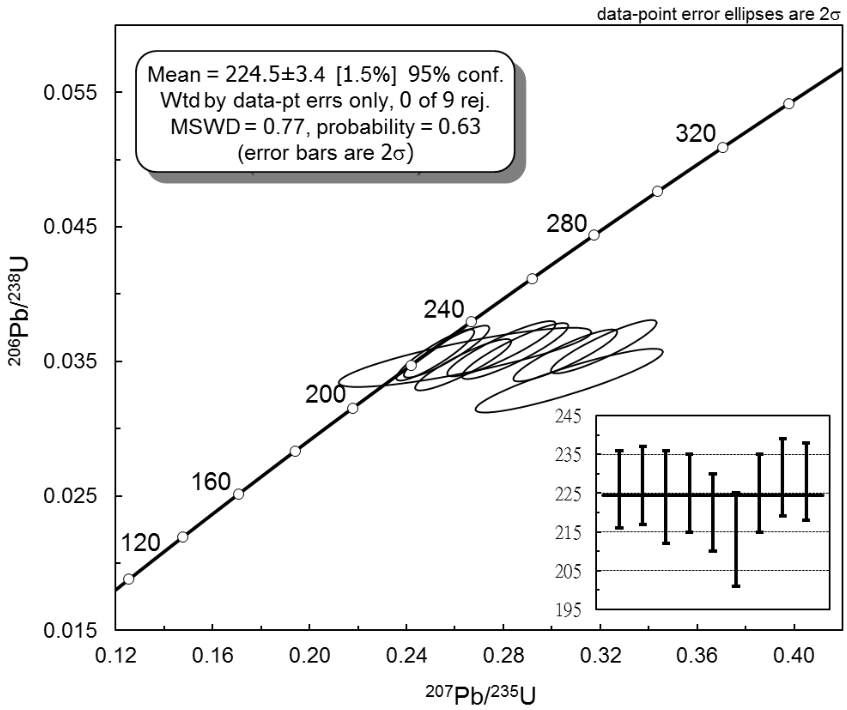


Figure 5.18 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 42.

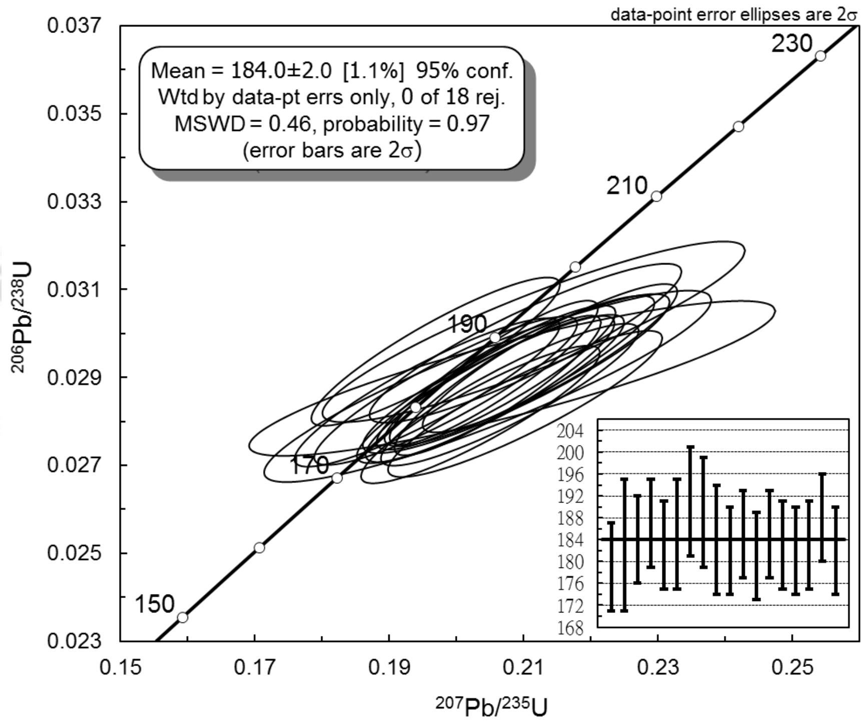


Figure 5.19 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 43.

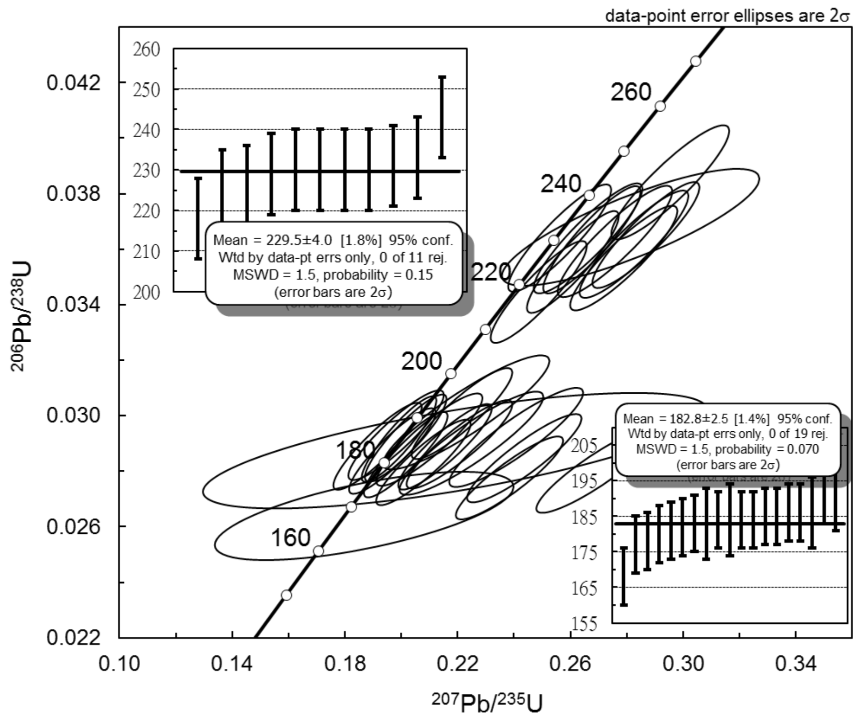


Figure 5.20 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 44.

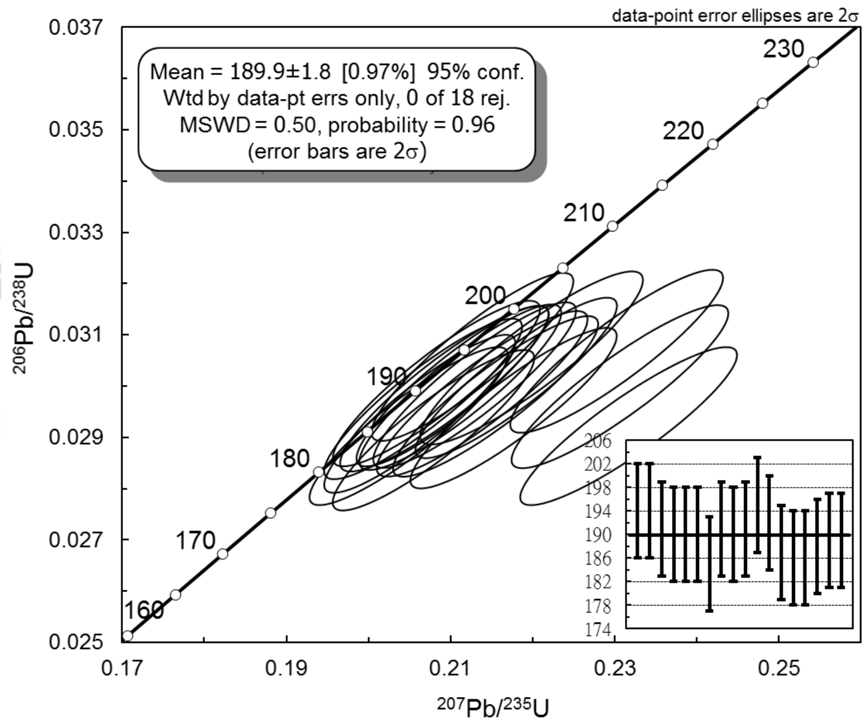


Figure 5.21 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 46.

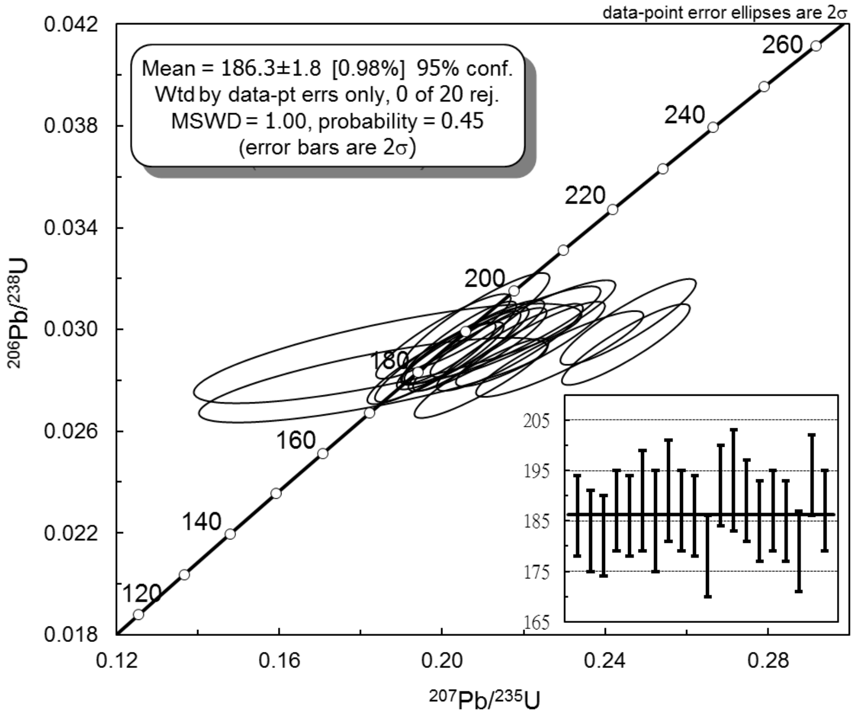


Figure 5.22 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 48.

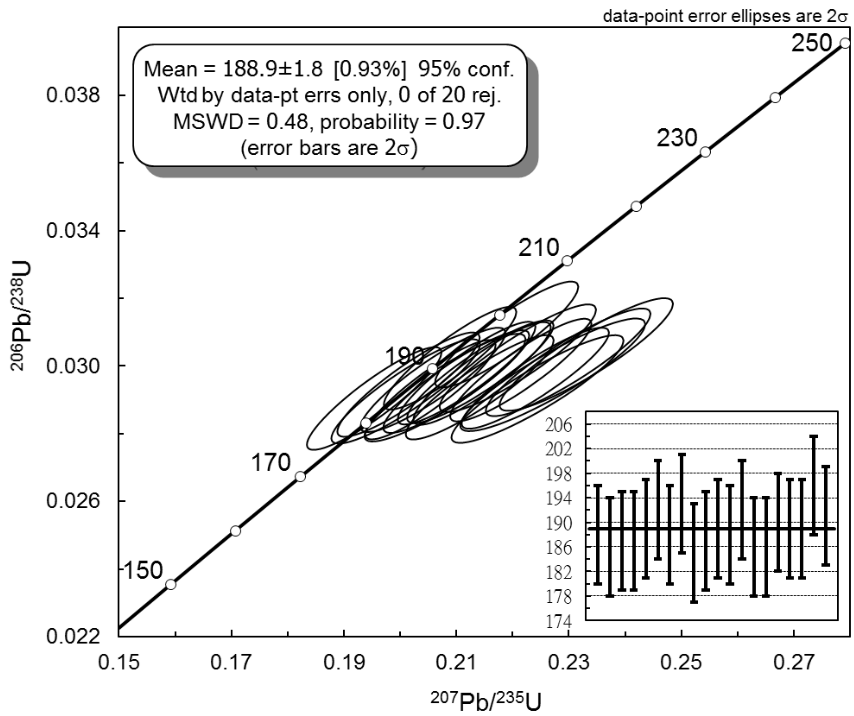


Figure 5.23 LA-ICP-MS zircon U–Pb Concordia diagram with insets showing the weight mean ages and weighted average diagram for sample number 49.

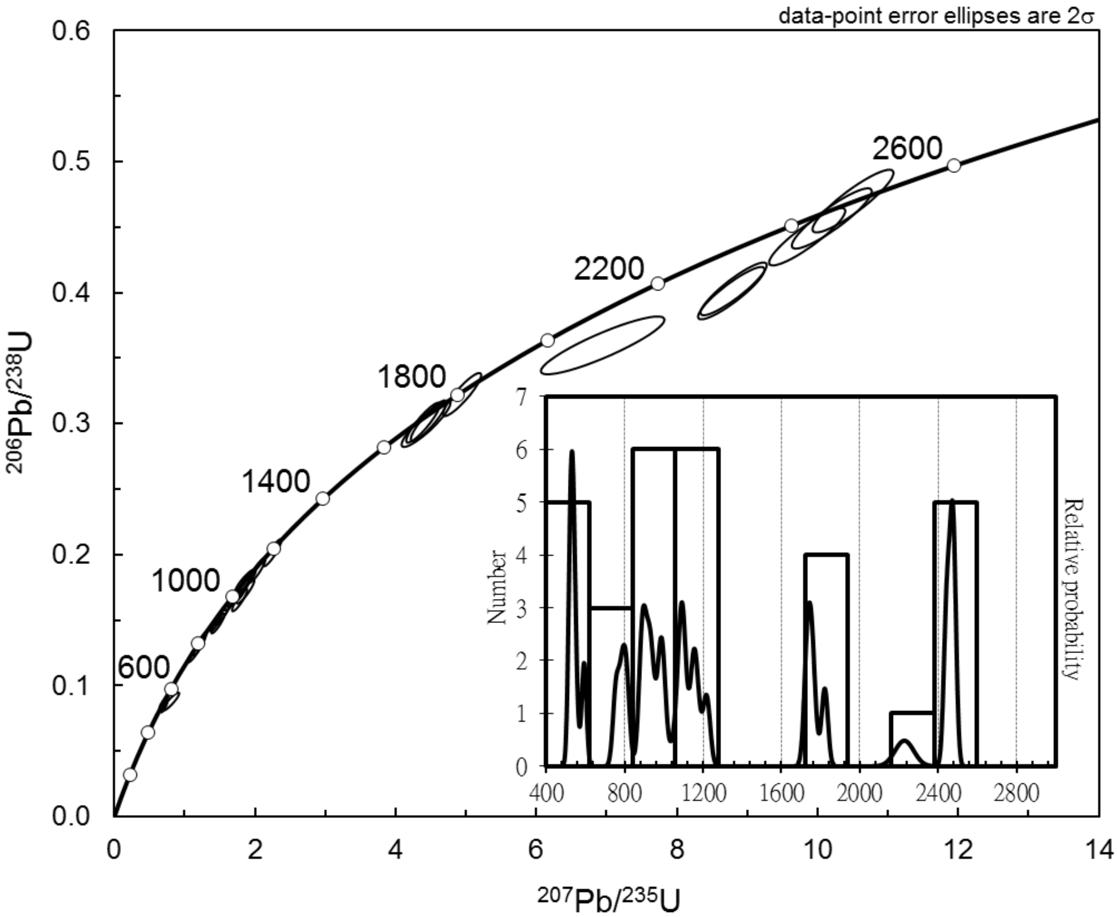


Figure 5.24 LA-ICP-MS zircon U–Pb Concordia diagram with relative probability diagram for sample number 53.

CHAPTER 6

Discussion and conclusion

The volcanic rocks discussed in this study were from Phayao province and vicinity areas. These rocks are the northern part of Chiang Khong-Lampang-Tak volcanic belt, which is one of the five belts pre-Cretaceous volcanic belts in Thailand. The rock samples include lava flows and pyroclastic equivalents. They can be separated into five groups base on petrography and chemical compositions.

6.1 Petrochemical characteristic

The petrography was studied to characterize primary mineral compositions, alterations and textures. These studied were selected the least-altered rocks for geochemical analyses. Geochemical analyses from the least-altered rocks can be divided into five magmatic groups.

The Group I rocks are of lava flows and appear to be in rhyodacite/dacite and rhyolite compositions. The REE patterns show LREE enriched with (La/Sm)cn values in ranges of 3.039-3.831 and HREE depleted with (Sm/Yb)cn values in ranges of 3.765-4.215. Their REE patterns are typical of alkaline series.

The Group II rocks are lava flows and pyroclastic equivalents. They appear to be in rhyolite compositions. The REE patterns show LREE enriched with (La/Sm)cn values in ranges of 2.764-4.456 and HREE slightly depleted with (Sm/Yb)cn values in ranges of 2.253-3.381. Their REE patterns are characteristic of transitional subalkaline to alkaline series.

The Group III rocks are lava flows and corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.897-3.589 and subparallel HREE with (Sm/Yb)cn values in ranges of 1.606-3.589. Their REE patterns are typical of transitional subalkaline to alkaline series.

The Group IV rocks are lava flows and corresponding to rhyolite composition. The REE patterns are LREE enriched with (La/Sm)cn values in ranges of 2.793-4.953 and relatively flat HREE with (Sm/Yb)cn values in ranges of 0.638-1.526. Their REE patterns are characteristic of calc-alkaline series.

The Group V rocks are pyroclastic equivalents and corresponding to rhyolite composition. The REE patterns are slightly subparallel LREE with (La/Sm)cn values = 2.520 and relatively flat HREE with (Sm/Yb)cn values = 0.752. Their REE patterns are typical of tholeiitic series.

The Group I, II and IV rocks are analogous to the Miocene potassic volcanic rocks in the post-collisional at western Anatolia, Turkey (Ersoy *et al*., 2012). The Group I, II, III and IV rocks are similar to the Eocene-Miocene calc-alkaline volcanic rocks related to subduction roll-back processes associated with post-collisional extension at northwest Anatolia, Turkey (Ersoy *et al*., 2017). The Group III, IV and V rocks are analogous to the Miocene A_2-type rhyolites of within-plate setting at Jabal Shama in western Saudi Arabia.

6.2 Ages and tectonic implications

6.2.1 Ages of the studied volcanic rocks

The U-Pb zircon dating of eleven the studied volcanic rock samples from Phayao province and vicinity areas (Figure 6.1) indicate the formation age ranging from 229.5±4 to 221±2.3 Ma (late Triassic) and ranging from 189.9±1.8 to 182.8±2.5 Ma (early Jurassic). The ages in late Triassic period have similar ages of 232.9±0.4 Ma, 229±4 Ma and 223±8 to 220±4 Ma in Chiang Rai area (Srichan *et al*., 2009; Barr *et al*., 2006; Qian *et al*., 2016a). The ages in the early Jurassic period have similar ages of 187±2.6 to 186±1.3 Ma and 184.1±2.4 to 181.7±2.1 Ma in Nan area (Ruenthon, 2010; Wipakul, 2012). However, some of the zircon grains from late Triassic volcanic rock samples have aged in the early Jurassic period and show morphology in two continuous growth stages. In the sample no.44 have two population ages in the late Triassic and early Jurassic period. Therefore, the first volcanism in the studied areas has erupted in the late Triassic synchronously volcanism in Chiang Rai area. After that in the early Jurassic the volcanism has erupted again synchronously volcanism in Nan area.

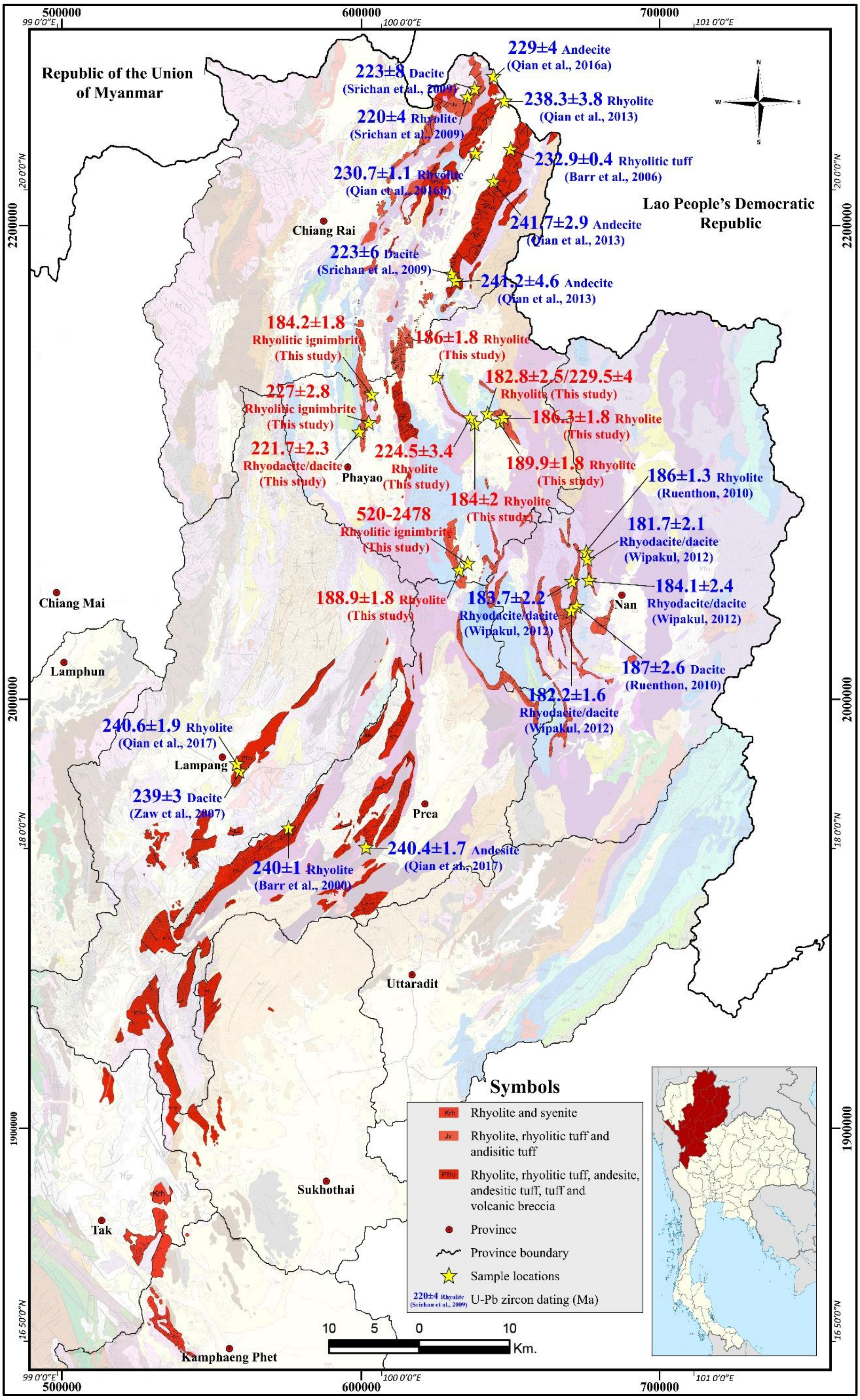


Figure 6.1 Simplified geological map showing the crystallization ages of the volcanic rocks along the Chiang Khong-Lampang-Tak volcanic belt.

In the sample no.53, the older ages from 2478 to 520 Ma (Precambrian to Cambrian) can be interpreted as the involvement of a Precanbrian crust in the magma genesis. Bodet and Schärer (2000) also reported the Precambrian ages, including 2.3-2.2 Ga, 2.0-1.9 Ga and 1.2-1.1 Ga of detrital zircons from the sands at Nu Jiang (Salween), Lancang Jiang (Mekong) and Red rivers, respectively. They also suggested the existence of the Precambrian basement in the Southeast Asia. Qian *et al*. (2013; 2016a) firstly reported Precambrian (1880±27 and 1316±35 Ma) ages from the Sukhothai terrane and presented the ages ranging from 1918 to 410 Ma, which indicates the existence of a Precambrian basement in Chiang Rai area.

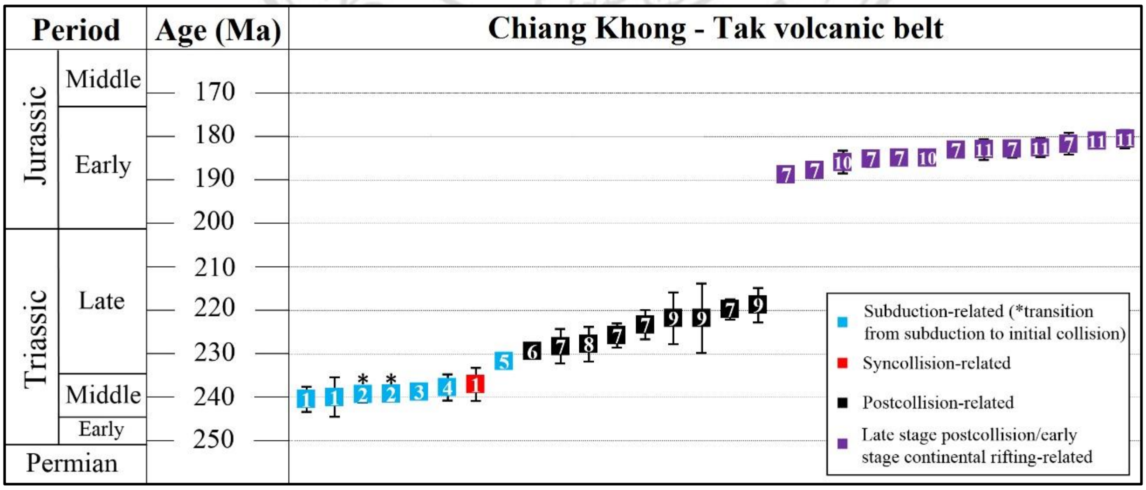
6.2.2 Tectonic implications

The formation time of the volcanic rocks along the Chiang Khong-Lampang-Tak volcanic belt has been debated with distinct comments having been proposed. The volcanic rocks in this volcanic belt were previously mapped as Permian to Early Triassic sequences (Braun and Hahn, 1976). The volcanic rocks in Lampang and Chiang Rai areas was the date at 241-239 Ma are indicative of origin in a subduction-related volcanic arc (Barr *et al*., 2000; Zaw *et al*., 2007; Qian *et al*., 2013). Newly modified of volcanic rocks in Lampang area at age 240 Ma formed in an arc setting in response to slab roll-back during the transition from subduction to the initial collision between the Sibumasu and Indochina blocks (Qian *et al*., 2017). Qian *et al*. (2013) also suggested that the rhyolite samples at 238 Ma might be the product of the tectonic transition from arc to syn-collisional stages. Barr *et al*. (2006) further proposed that the volcanic rocks formed in a mature continental margin volcanic arc with 232 Ma. After that from syn-collisional crustal thickening, the post-collision volcanic rocks occurred in this volcanic belt. The post-collision is consistent with the conclusions of recent studies in Chiang Rai area by Srichan *et al*. (2009) at the age from 223-220 Ma of volcanic rocks related to the gravitational collapse of the thickened crust and widespread extensional tectonism. Qian *et al*. (2016a; 2016b) suggest that the age at 230 and 229 Ma of the Chiang Khong volcanic rocks formed by post-collision extensional setting and formed a series of post-collisional volcanic rocks in response to the slab detachment after closure of the Paleo-Tethys.

In this work geochemical data for Jurassic volcanic rocks in the studied areas part of Chiang Khong-Lampang-Tak volcanic belt were studied from rhyolite and pyroclastic equivalents. In the Y+Nb and Rb diagram the volcanic rock samples most appear in the field of post-collisional setting and few in within plate setting (after Pearce, 1996). The discriminates diagram of Whalen *et al*. (1987) fall in A-type granites and appear in A_2-type of ternary diagram for chemical subdivision of the A-type granitoids (Eby, 1992). A-type granites probably result mainly from partial melting in the lower crust after extraction of an orogenic granite (Whalen *et al*., 1987). Martin (2006) reported the origin of A-type granites and rhyolites are ultimately relatable to mantle-derived melts and fluids in a zone undergoing extension. The A_2-type rocks are generated in the post-collisional (or late-collision) setting as well as during the lithospheric-plate sliding and at the late stages of evolution of hot rift structures (Grebennikov, 2014). This phenomenon is compositionally analogous to the Eocene-Miocene calc-alkaline volcanic rocks and the Miocene potassic volcanic rocks in post-collisional extension at Anatolia, Turkey (Ersoy *et al*., 2012; 2017) and the Miocene A_2-type rhyolites in post-orogenic to rift-related from Jabal Shama in western Saudi Arabia (Surour *et al*., 2016).

The synthesis of these data (Table 6.1) suggests that the volcanic rocks in the Chiang Khong-Lampang-Tak volcanic belt form in the Middle Triassic period of ~241 Ma (Qian *et al*., 2013). During the Middle Triassic or earlier period (prior to 240 Ma), the Paleo-Tethys Ocean easterly subducted under the Indochina Block (Figure 6.2a; e.g., Metcalfe, 2011; 2013; Qian *et al*., 2016c). In the Middle Triassic period (~240 Ma) volcanic rocks formed in an arc setting in effect to slab roll-back of a transition from subduction of Paleo-Tethys Ocean to the initial collision between the Sibumasu and Indochina blocks (Figure 6.2b; Qian *et al*., 2017). After that, the syn-collisional crustal thickening event (~240-230 Ma) have grown supported by the age of 238 Ma and 232 Ma from volcanic rocks in Chiang Khong area (Figure 6.2c; Barr *et al*., 2006; Qian *et al*., 2013). At the Late Triassic period the volcanic rocks at ages of 230-220 Ma formed in a series of post-collisional in effect to the slab detachment and post-collision extensional setting (Figure 6.2d; Srichan *et al*., 2009; Qian *et al*., 2016a; 2016b). The geodynamics in the orogenic relates the crustal thickness and later gravitational collapse. The change from crustal thickness to collapsing is generally believed to be stimulated by the removal of the mantle root from the overthickened crustal melting leading to asthenosphere upwelling or the tectonic forces relaxation and causes post-orogenic magmatism is usually followed by rifting magmatism (Coney and Harms, 1984; Dewey, 1988; Molnar *et al*., 1993; Vanderhaeghe and Teyssier, 2001; Kohn and Parkinson, 2002; Dilek and Altunkaynak, 2007). Finally, the volcanic rocks in this work have been formed at the late stage of post-orogenic magmatism or the early stage of continental rifting in the Early Jurassic at ages of 190-181 Ma (Figure 7.2e; Ruenthon, 2010; Wipakul, 2012; This study). The 30 Ma time-gap from late Triassic to early Jurassic probably implying the delayed effect of the post-collisional process on the basis of time-gap similarity the high-K calc-alkaline and shoshonite rocks from Tongshi intrusive complex, eastern North China craton in post-collitional magmatism (Lan *et al*. 2012).

Table 6.1 Summary of the reported crystallization ages of the volcanic rocks along the Chiang Khong-Lampang-Tak volcanic belt. Data source are from (1) Qian *et al*. (2013), (2) Qian *et al*. (2017), (3) Barr *et al*. (2000), (4) Zaw *et al*. (2007), (5) Barr *et al*. (2006), (6) Qian *et al*. (2016b), (7) this study, (8) Qian *et al*. (2016a), (9) Srichan *et al*. (2009), (10) Ruenthon (2010), (11) Wipakul (2012).



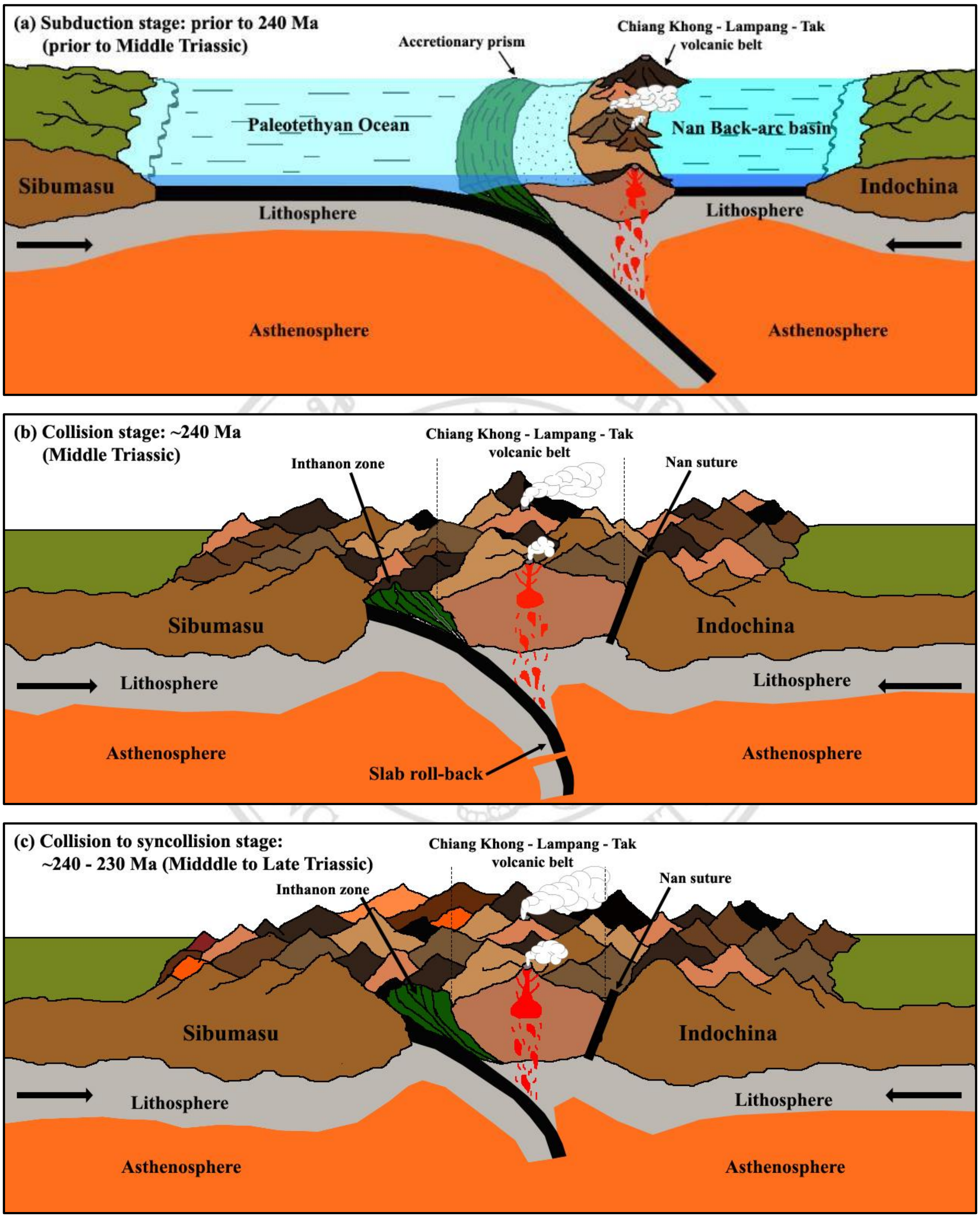


Figure 7.2 Tectonic evolution along the Ching Khong–Lampang–Tak volcanic belt (modified from Barr *et al*., 2000, 2006; Zaw *et al*., 2007; Srichan *et al*., 2009; Wipakul, 2012; Qian *et al*., 2013; 2016a; 2016b; 2017).

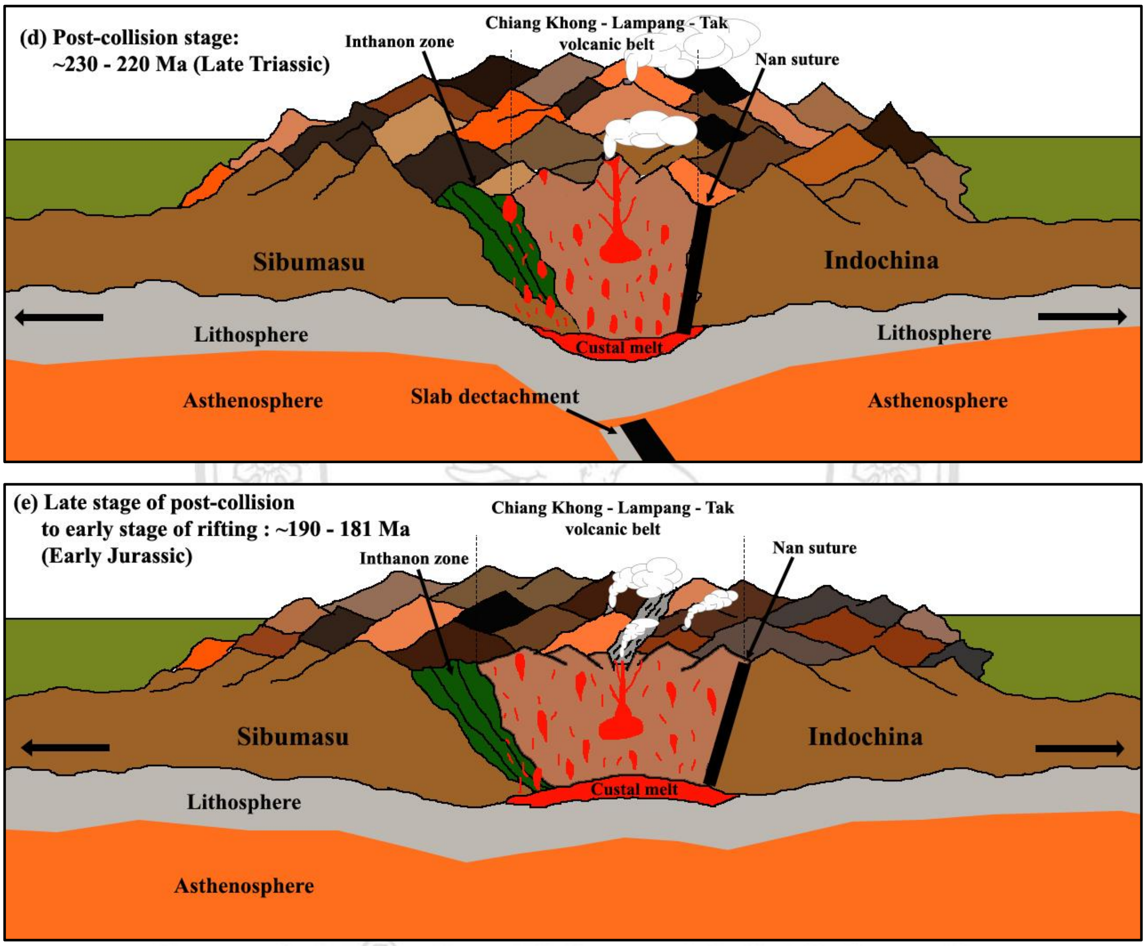


Figure 7.2 Continued.

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APPENDIX A

Petrography of individual the studied felsic volcanic rock samples

Sample number: 1

Grid reference: 47Q 599259E 2164851N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE PA DAET" Sheet 4948 II)

Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows banded (eutaxitic texture) and slightly apparent porphyritic textures. The banded texture has colorless and white color (size up to ≤ 1 cm across). The apparent phenocrysts/microphenocrysts of yellowish white and white color size up to ≤ 1.5 mm across. The matrixes are very fine-grained and generally show dark gray color. The rock turns light gray and yellowish brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumulocrysts of plagioclase + opaque minerals and K-feldspar + opaque minerals. The lath minerals show slightly trachytic texture. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.2-0.4 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). These fragments thoroughly recrystallized with intergrowth of quartz and K-feldspar. The felsic volcanic rocks fragments show micropoikilitic texture. The very fine-grained matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.625 mm across. They show anhedral to subhedral outlines. These Crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.075-1 mm across. They show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.5 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.05-0.2 mm across. They show subhedral to euhedral outlines. Crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 2
Grid reference: 47Q 599226E 2164848N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE PA DAET” Sheet 4948 II)
Rock name: Welded lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of yellowish white and white color size up to ≤ 2 mm across. The lithic fragments have brownish black color and size up to ≤ 4 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns light gray and yellowish brown color on weathering surfaces. Tiny fractures sealed by white minerals and cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumulocrysts of plagioclase + K-feldspar and plagioclase + K-feldspar + opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-4 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with slightly replaced by sericite and chlorite. The felsic volcanic rocks fragments show micropoikilitic and eutaxitic textures with glass shards. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly micropoikilitic texture. The matrixes usually dominated foliation (eutaxitic texture) with the platy and cuspate shape of glass shards.

The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.625 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.75 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.075-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.1-0.3 mm across. They show subhedral to euhedral outlines. Crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 3
Grid reference: 47Q 599442E 2161309N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE PA DAET" Sheet 4948 II)
Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows banded texture (eutaxitic texture). The banded texture has yellowish brown color (size up to ≤ 3 mm across). The matrixes are very fine-grained and reddish brown color. The rock turns light brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains with cumulocrysts of plagioclase + K-feldspar. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.1-3.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show flow banding and trachytic texture. These fragments present jigsaw-fit texture that separated by quartz and

K-feldspar intergrowth. The very fine-grained matrixes show moderately to highly micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture). The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites are elongate trains and often aligned along foliation layering. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Plagioclase crystals size up to 0.375-1.5 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-1.25 mm across. They show anhedral to subhedral outlines. These crystals moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.375 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 4

Grid reference: 47Q 599503E 2161146N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE PA DAET” Sheet 4948 II)

Rock name: Welded lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white and pink color size up to ≤ 1 mm across. The lithic fragments have light to yellowish brown and black color and size up to ≤ 3.5 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice and felsic volcanic rock. These fragments size up to 0.25-3.75 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show porphyritic texture with quartz phenocrysts/microphenocrysts. These fragments present micropoikilitic and spherulitic textures. The very fine-grained matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards and spherulitic texture. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.125-0.375 mm across with spherical shape. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Plagioclase crystals size up to 0.125-0.5 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1 mm across. They show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.125 mm across. They mostly show anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 5

Grid reference: 47Q 599493E 2160980N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE PA DAET” Sheet 4948 II)

Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows crystal fragments and highly spherulitic texture. The crystal fragments of white color size up to ≤ 1.5 mm across. The spherulites have spherical shape with white and reddish brown color (size up to ≤ 5 mm across). They might retain concentric zonation. Cuspate patches of white minerals that occur between closely packed spherulites. The matrixes are very fine-grained with generally show yellowish brown and light green color. The rock turns light gray and yellowish brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, zircon, opaque and unidentified minerals. These fragments form as isolated grains and cumulocrysts of plagioclase + K-feldspar. The very fine-grained matrixes show highly micropoikilitic and spherulitic textures. The matrixes slightly dominated foliation (eutaxitic texture). The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal fragments. The spherulites size up to 0.25-1.5 mm across with semispherical to spherical shape. They might grow on K-feldspar crystal with a cluster of quartz and K-feldspar. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.5 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.1-1 mm across. They show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by K-feldspar.

Opaque minerals size up to 0.025-0.25 mm across. They show irregular to anhedral outline. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.025-0.1 mm across. They mostly show anhedral outlines. These crystals completely pseudomorph by chlorite.

Sample number: 6

Grid reference: 47Q 599534E 2157105N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE PA DAET” Sheet 4948 II)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The lithic fragments have dark green, green, greenish gray, reddish brown and white color with size up to ≤ 2 mm across. The matrixes are very fine-grained and generally show a green color.

The rock turns reddish black and brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and highly lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase and K-feldspar. These fragments form as isolated grains and glomerocrysts of quartz. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.125-1.25 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show flow banding and micropoikilitic texture. The very fine-grained matrixes show slightly micropoikilitic texture. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz crystals size up to 0.05-0.375 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.125-0.375 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.05-0.25 mm across. They show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Sample number: 7
Grid reference: 47Q 601035E 2149019N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)
Rock name: Welded lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white and pink color size up to ≤ 4 mm across. The lithic fragments have black color with size up to ≤ 8 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns reddish brown color on weathering surfaces. Tiny fractures sealed by white minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, zircon and opaque minerals. These fragments form as isolated grains and cumulocrysts of plagioclase + K-feldspar. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.25-4.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding and trachytic texture. These fragments dominated porphyritic texture with quartz, plagioclase and K-feldspar phenocrysts/microphenocrysts. They might present micropoikilitic and spherulitic textures. The intermediate/mafic volcanic rock fragments present trachytic texture and vesicles. The very fine-grained matrixes show slightly micropoikilitic and spherulitic textures. The matrixes slightly dominated foliation (eutaxitic texture) with the platy and cuspate shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.25-0.5 mm across with semispherical in shape. They might show elongate trains and often aligned along foliation layering. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.5 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1 mm across. They show anhedral to euhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief. The crystals might encloses by K-feldspar.

Opaque minerals size up to 0.125-0.375 mm across. They mostly show anhedral outline. These minerals are both primary and secondary origins.

Sample number: 8

Grid reference: 47Q 603314E 2144381N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)

Rock name: Welded crystal tuff

Megascopic Characters: The rock sample shows apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 2 mm across. The matrixes are very fine-grained and reddish brown color. The rock turns light brown color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of K-feldspar with cumulocrysts of plagioclase + K-feldspar and plagioclase + opaque minerals. The lath minerals show slightly trachytic texture. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-1.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding and micropoikilitic texture. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show highly micropoikilitic and spherulitic textures. They usually dominated foliation (eutaxitic texture) with the platy and cuspate shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.025-0.5 mm across with spherical shape. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.25-1.25 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-1.125 mm across. They show anhedral to euhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges and completely pseudomorph by quartz and K-feldspar intergrowth with Fe-Ti oxide. Some of crystals present simple twining.

Opaque minerals size up to 0.125-0.25 mm across. They show anhedral to subhedral outlines. These minerals are both primary and secondary origins.

Sample number: 9

Grid reference: 47Q 603296E 2144317N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)

Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows slightly apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 1.5 mm across. The matrixes are very fine-grained and reddish brown color. The rock turns white and brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains, glomerocrysts of K-feldspar and cumulocrysts of plagioclase + K-feldspar. Lithic fragments are pumice and felsic volcanic rock. These fragments size up to 0.375-2 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show micropoikilitic texture with quartz and K-feldspar intergrowth. The very fine-grained matrixes show highly micropoikilitic and spherulitic textures. They slightly dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The matrixes might show jigsaw-fit texture with separated by quartz and K-feldspar intergrowth. The spherulites size up to 0.05-0.25 mm across with spherical shape. They might show elongate trains and often aligned along foliation layering. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.125-1 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-1.25 mm across. They show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.125-1 mm across. They show anhedral to euhedral outlines. These minerals are both primary and secondary origins.

Sample number: 10
Grid reference: 47Q 603288E 2144272N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)
Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1 mm across. The lithic fragments have yellowish brown color with size up to ≤ 3 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns pink and brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, zircon and opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-0.625 mm across. The pumice wisps show relict tube vesicle texture. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show flow banding with trachytic and micropoikilitic textures. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly to moderately micropoikilitic and spherulitic textures. The matrixes slightly dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.25-0.625 mm across with semispherical to spherical shape. They might grow on K-feldspar crystal. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.375 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.75 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclose by K-feldspar and opaque minerals.

Opaque minerals size up to 0.025-0.5 mm across. They mostly show anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 11

Grid reference: 47Q 599108E 2137512N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows a porphyritic texture. The phenocrysts/microphenocrysts of white color size up to ≤ 1.5 mm across. The groundmasses are very fine-grained and reddish brown color. The rock turns light green and brown color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase and K-feldspar. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of quartz and plagioclase with cumurocrysts of quartz + plagioclase. The very fine-grained groundmasses show moderately to highly micropoikilitic texture and vesicles. The vesicles (amygdales) are filled with sericite, chlorite and Fe-Ti oxide. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-1.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals. The crystals might show reaction rim.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.125 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-0.5 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Sample number: 12

Grid reference: 47Q 599055E 2137473N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows a porphyritic texture. The phenocrysts/microphenocrysts of white color size up to ≤ 2 mm across. The lath minerals present slightly trachytic texture. The groundmasses are very fine-grained with generally show pink and light gray color. The rock turns white color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, opaque and unidentified minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of plagioclase and cumurocrysts of plagioclase + K-feldspar. The very fine-grained groundmasses show moderately micropoikilitic texture with fine K-feldspar lath. The fine K-feldspar lath show slightly trachytic texture. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-0.625 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.5 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-1 mm across. They show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.125-0.5 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Phenocrysts/microphenocrysts of unidentified minerals size up to 0.2-0.5 mm across. They show anhedral to euhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 13
Grid reference: 47Q 600866E 2134916N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)
Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows slightly banded (eutaxitic texture) and apparent porphyritic textures. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The lath minerals present slightly trachytic texture. The matrixes is very fine-grained and generally show brown color. The rock turns light brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample that contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains with cumulocrysts of plagioclase + K-feldspar and plagioclase + opaque minerals. The lithic fragments are felsic volcanic rock size up to 0.5-3 mm across. These fragments show micropoikilitic texture. The very fine-grained matrixes present highly micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.05-0.25 mm across with semispherical to spherical shape. Quartz and K-feldspar intergrowth that occur between closely packed spherulites. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz crystals size up to 0.2-0.25 mm across. They mostly show anhedral outlines. The crystals present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.375-0.5 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.375-0.875 mm across. They show subhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show round edges. Some of crystals present simple twining.

Opaque minerals size up to 0.075-0.25 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.1-0.25 mm across. They show subhedral to euhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 14

Grid reference: 47Q 599054E 2133757N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)

Rock name: Rhyodacite/dacite

Megascopic Characters: The rock sample shows flow banding and slightly porphyritic texture. The phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The groundmasses are very fine-grained and reddish brown color. The rock turns white and light gray color on weathering surfaces. Tiny fractures sealed by white minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumurocrysts of plagioclase + K-feldspar. The very fine-grained groundmasses show flow banding and moderately to highly micropoikilitic texture with fine K-feldspar lath. The lath minerals present trachytic texture. The vesicles (amygdales) are filled with quartz and K-feldspar intergrowth. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz microphenocrysts size up to 0.075-0.175 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.125-0.75 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystal might show rounded edges and sieve texture.

K-feldspar phenocrysts/microphenocrysts size up to 0.075-0.75 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.25-1 mm across. They show irregular to subhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Sample number: 15

Grid reference: 47Q 599933E 2133540N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1 mm across. The lithic fragments have yellowish brown color with size up to ≤ 3 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns pink and brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and highly lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-1 mm across. The pumice wisps show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding with trachytic and micropoikilitic textures. These fragments dominated porphyritic texture and K-feldspar phenocrysts/microphenocrysts. They might present spherulitic and eutaxitic textures with glass shards. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly micropoikilitic texture with slightly the cuspate shape of glass shards. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.25-0.375 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.875 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.05-0.375 mm across. They mostly show irregular outlines. These minerals are both primary and secondary origins.

Sample number: 16

Grid reference: 47Q 600228E 2133326N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 0.5 mm across. The lithic fragments have reddish brown and black color with size up to ≤ 1 cm across. The matrixes are very fine-grained and olive green color. The rock turns brown color on weathering surfaces. Tiny fractures sealed by white minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and highly lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. Lithic fragments are felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-2 mm across. The felsic volcanic rock fragments show flow banding and micropoikilitic texture. These fragments dominated porphyritic texture with quartz, plagioclase and K-feldspar phenocrysts/microphenocrysts. They might present spherulitic and eutaxitic textures with glass shards. The intermediate/mafic volcanic rock fragments present porphyritic with plagioclase phenocrysts/microphenocrysts and trachytic textures. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Fractures are sealed by calcite and Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Plagioclase crystals size up to 0.125-0.375 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals and calcite. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-0.75 mm across. They show anhedral to euhedral outlines. These crystals highly replaced by sericite, chlorite, clay minerals and calcite. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.05-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 17

Grid reference: 47Q 599000E 2132744N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE MAE CHAI" Sheet 4947 I)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white and pink color size up to ≤ 1 mm across. The lithic fragments have reddish brown color with size up to ≤ 6 cm across. The matrixes is very fine-grained and grayish brown color. The rock turns white and brown color on weathering surfaces. Cavity sealed by colorless and light green minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and highly lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-3 mm across. The pumice wisps show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding and trachytic texture. They might present eutaxitic texture with glass shards. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly micropoikilitic texture. Quartz and K-feldspar intergrowth with the mosaic of fine grains are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.625 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.375 mm across. They mostly show subhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 18

Grid reference: 47Q 598758E 2129880N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE MAE CHAI” Sheet 4947 I)

Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows banded (eutaxitic texture) and slightly apparent porphyritic textures. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The matrixes very fine-grained and reddish brown color. The rock turns white color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, zircon and opaque minerals. These fragments form as isolated grains, glomerocrysts of plagioclase with cumulocrysts of plagioclase + opaque minerals and K-feldspar + opaque minerals. The lath minerals show slightly trachytic texture. Lithic fragments are pumice and felsic volcanic rock. These fragments size up to 0.25-2.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The felsic volcanic rock fragments show flow banding with micropoikilitic and spherulitic textures. The very fine-grained matrixes show moderately micropoikilitic and spherulitic textures. The matrixes usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.1-0.3 mm across with semispherical to spherical shape. They might show elongate trains and often aligned along flow layering. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.25-0.875 mm across. They show anhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1.5 mm across. They show anhedral to euhedral outlines. These crystals moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.01 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by K-feldspar.

Opaque minerals size up to 0.125-0.5 mm across. They show irregular to euhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Sample number: 19

Grid reference: 47Q 599799E 2126660N (Topographic map WGS84 at a scale of 1:50,000 "CHANGWAT PHAYAO" Sheet 4947 II)

Rock name: Vitric tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1 mm across. The lithic fragments have dark green color with size up to ≤ 2 mm across. The matrixes very fine-grained and olive green color. The rock turns light brown color on weathering surfaces. Tiny fractures sealed by white minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, K-feldspar and opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.125-0.375 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments consist of very fine-grained. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz crystals size up to 0.025-0.25 mm across. They mostly show anhedral outlines.

K-feldspar crystals size up to 0.025-0.25 mm across. They mostly show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.1 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 20

Grid reference: 47Q 608697E 2160192N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Vitric tuff

Megascopic Characters: The rock sample shows apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of white and pink color size up to ≤ 1 mm across. The matrixes very fine-grained and generally show a light green color. The rock turns reddish brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz and zircon. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.1-0.25 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments consist of very fine-grained. The very fine-grained matrixes usually dominated the cuspate shape of glass shards. Quartz and K-feldspar intergrowth are filled in vesicles. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz crystals size up to 0.125-0.375 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief.

Sample number: 21

Grid reference: 47Q 609018E 2159042N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)

Rock name: Volcaniclastic sandstone

Megascopic Characters: The rock sample has sand in grain size. These rock show banded texture between dark brown and gray color. The rock turns reddish brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample show banded texture with crystal and lithic fragments that are embedded in the silicified matrixes. The banded consist of between crystal- and lithic-rich fragments. Crystal fragments consist of quartz, plagioclase and opaque minerals. Lithic fragments are felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-0.375 mm across. The felsic volcanic rock fragments show very fine-grained and trachytic texture. They might dominate micropoikilitic texture. The intermediate/mafic volcanic rock fragments present trachytic texture. The matrixes are made up largely epidote, sericite, chlorite and Fe-Ti oxide. Cavities are sealed by sericite and chlorite.

Quartz crystals size up to 0.025-0.125 mm across. They mostly show anhedral outlines.

Plagioclase crystals size up to 0.1-0.2 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals and epidote.

Opaque minerals size up to 0.025-0.5 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Sample number: 22

Grid reference: 47Q 608995E 2159018N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)

Rock name: Volcaniclastic sandstone

Megascopic Characters: The rock sample has sand in grain size and gray color. The rock turns brown color on weathering surfaces. Cavities sealed by light green minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the silicified matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. Lithic fragments are felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-4 mm across. The felsic volcanic rock fragments show very fine-grained and micropoikilitic texture. They might dominate plagioclase and K-feldspar phenocrysts/microphenocrysts. The intermediate/mafic volcanic rock fragments present trachytic texture. The matrixes made up largely epidote, sericite, chlorite, Fe-Ti oxide and calcite. Cavities are sealed by sericite and chlorite.

Plagioclase crystals size up to 0.025-0.125 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals and epidote.

K-feldspar crystals size up to 0.025-0.25 mm across. They mostly show anhedral to subhedral outlines. These crystals highly replaced by sericite, chlorite, clay minerals and epidote. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.375 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 23
Grid reference: 47Q 609150E 2154475N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE CHUN" Sheet 5047 IV)
Rock name: Crystal tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1.5 mm across. The lithic fragments have black color with size up to ≤ 1 cm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns light gray and white color on weathering surfaces. Tiny fractures and cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumulocrysts of plagioclase + K-feldspar. Lithic fragments are felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.25-5 mm across. The felsic volcanic rock fragments show micropoikilitic and spherulitic textures. They might present porphyritic texture with plagioclase and K-feldspar phenocrysts/microphenocrysts. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes usually dominated the cuspate shape of glass shards. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase crystals size up to 0.125-0.625 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.5 mm across. They show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.5 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Sample number: 24

Grid reference: 47Q 610488E 2152936N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHUN” Sheet 5047 IV)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of colorless and white color size up to ≤ 1 mm across. The lithic fragments have brown color with size up to ≤ 5 mm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns yellowish brown and gray color on weathering surfaces. Tiny fractures and cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of K-feldspar and opaque minerals. Lithic fragments are felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.5-2.5 mm across. The felsic volcanic rock fragments show micropoikilitic texture with quartz and K-feldspar intergrowth. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly micropoikilitic texture. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

K-feldspar crystals size up to 0.125-0.5 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 25

Grid reference: 47Q 609697E 2152719N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHUN” Sheet 5047 IV)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 0.5 mm across. The lithic fragments have green and yellowish brown color with size up to ≤ 2 mm across. The matrixes are very fine-grained and light green color. The rock turns white color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz and opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.25-0.875 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show micropoikilitic texture. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes slightly dominated the cuspate shape of glass shards. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz crystals size up to 0.1-0.5 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Opaque minerals size up to 0.075-0.5 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 26
Grid reference: 47Q 610367E 2152750N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHUN” Sheet 5047 IV)
Rock name: Vitric tuff

Megascopic Characters: The rock sample shows slightly apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 1 mm across. The matrixes are very fine-grained and light green color. The rock turns white color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.375-1.25 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show micropoikilitic and spherulitic textures. The very fine-grained matrixes usually dominated the cuspate shape of glass shards. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz crystals size up to 0.075-0.125 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.125-0.25 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.75 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.1 mm across. They mostly show anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 27

Grid reference: 47Q 610352E 2152778N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE CHUN" Sheet 5047 IV)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of colorless and white color size up to ≤ 1 mm across. The lithic fragments have black color with size up to ≤ 5 mm across. The matrixes very fine-grained and generally show brown color. The rock turns yellowish brown weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains and glomerocrysts of plagioclase. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rock. These fragments size up to 0.25-3.75 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show trachytic and micropoikilitic textures. They might present eutaxitic texture. The intermediate/mafic volcanic rock fragments present porphyritic with plagioclase phenocrysts/microphenocrysts and trachytic textures. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.125-0.5 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges and sieve texture.

K-feldspar crystals size up to 0.125-1 mm across. They show anhedral to subhedral outlines. These crystals highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.075-0.5 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Sample number: 28

Grid reference: 47Q 610393E 2152781N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHUN” Sheet 5047 IV)

Rock name: Vitric tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of colorless and white color size up to ≤ 1 mm across. The lithic fragments have dark brown and black color with size up to ≤ 1.5 mm across. The matrixes are very fine-grained and greenish grey color. The rock turns white color on weathering surfaces. Fractures and cavities sealed by white and light green minerals have been occasionally observed. This rock reacts with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, allanite, zircon and opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.25-1.25 mm across. The pumice wisps show relict tube vesicle texture with slightly to moderately replaced by sericite and chlorite. The felsic volcanic rock fragments show flow banding and micropoikilitic texture. They might present eutaxitic texture with quartz and K-feldspar crystals. Quartz and K-feldspar intergrowth are present. Fractures are sealed by calcite and Fe-Ti oxide. Secondary patches of sericite, chlorite, Fe-Ti oxide and calcite appear in the moderately amount.

Plagioclase crystals size up to 0.25-0.875 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-0.875 mm across. They mostly show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Allanite crystals size up to 0.1-0.25 mm across. They show subhedral to euhedral outlines and very high relief. These crystals present a light brown color and cracks.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by allanite.

Opaque minerals size up to 0.05-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 29

Grid reference: 47Q 611797E 2150430N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE CHUN" Sheet 5047 IV)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows dendritic of manganese and fragmental texture. The crystal fragments of white color size up to ≤ 1 mm across. The matrixes are very fine-grained and generally show light green color. The rock turns white color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.1-0.4 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show eutaxitic texture and glass shards. The very fine-grained matrixes usually dominated the cuspate shape of glass shards. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz crystals size up to 0.05-0.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.125-0.25 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.05-0.125 mm across. They mostly show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.05-0.125 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Sample number: 30
Grid reference: 47Q 614064E 2159475N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)
Rock name: Welded crystal tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of colorless, white and pink color size up to ≤ 1.5 mm across. The lithic fragments have light to dark brown color with size up to ≤ 5 mm across. The matrixes are very fine-grained and brownish gray color. The rock turns light gray color on weathering surfaces. Cavities sealed by white and light green minerals have been occasionally observed. This rock slightly react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar, allanite, zircon and opaque minerals. These fragments form as isolated grains with glomerocrysts of plagioclase and quartz. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-2 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with slightly replaced by sericite and chlorite. The felsic volcanic rock fragments show micropoikilitic and eutaxitic textures with glass shards. The intermediate/mafic volcanic rock fragments present trachytic and porphyritic textures with plagioclase phenocrysts/microphenocrysts. The very fine-grained matrixes show slightly micropoikilitic texture. The matrixes slightly dominated foliation (eutaxitic texture) with highly the cuspate and slightly the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth are present. Fractures are sealed by calcite and Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz crystals size up to 0.25-2.5 mm across. They show anhedral to euhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.375-1.125 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals, calcite and Fe-Ti oxide. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1.5 mm across. They show anhedral to subhedral outlines. These crystals slightly to moderately replaced sericite, chlorite, clay minerals, calcite and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Allanite crystals size up to 0.2 mm across. They show irregular to anhedral outlines and very high relief. These crystals present a light brown color and cracks with sealed by calcite.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclosed by allanite.

Opaque minerals size up to 0.075-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 31

Grid reference: 47Q 615054E 2159579N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)

Rock name: Vitric tuff

Megascopic Characters: The rock sample show banded texture of light green color. The matrixes are very fine-grained and generally show green color. The rock turns light gray color on weathering surfaces. Fractures sealed by yellowish white to white minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz and K-feldspar. The very fine-grained matrixes show banding between vitric-rich and crystal-rich fragments. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz crystals size up to 0.025-0.05 mm across. They mostly show anhedral outlines.

K-feldspar crystals size up to 0.025-0.05 mm across. They mostly show anhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals.

Sample number: 32

Grid reference: 47Q 616164E 2159726N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)

Rock name: Welded lithic tuff

Megascopic Characters: The rock sample shows banded (eutaxitic texture) and fragmental textures. The crystal fragments of colorless and white color size up to ≤ 2 mm across. The lithic fragments have dark brown color with size up to ≤ 5 mm across. The matrixes are fine grain and reddish brown color. The rock turns pink and light brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar and opaque minerals. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.25-1 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The felsic volcanic rock fragments show micropoikilitic texture. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes usually dominated foliation (eutaxitic texture) with highly the platy and cuspate shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Quartz crystals size up to 0.25-1.75 mm across. They mostly show anhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.375-1 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.5-1.5 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.1-0.3 mm across. They show irregular to anhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Sample number: 33

Grid reference: 47Q 616273E 2161758N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of colorless, white and pink color size up to ≤ 2 mm across. The matrixes is very fine-grained and generally show light green color. The rock turns white and yellowish brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar and zircon. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.2-0.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The felsic volcanic rock fragments show flow banding and micropoikilitic texture. The very fine-grained matrixes usually dominated the cuspate shape of glass shards. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Quartz crystals size up to 0.25-1 mm across. They mostly show anhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.125-0.5 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-1.25 mm across. They mostly show anhedral to subhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.075 mm across. They mostly show euhedral outlines and very high relief.

Sample number: 34

Grid reference: 47Q 613524E 2162506N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1.5 mm across. The lithic fragments have light gray, reddish brown to brown color with size up to ≤ 1 cm across. The matrixes are very fine-grained and generally show dark brown color. The rock turns gray color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains, glomerocrysts of plagioclase with cumulocrysts of plagioclase + K-feldspar. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 1.25-5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The felsic volcanic rock fragments show flow banding with trachytic and micropoikilitic textures. They might present porphyritic texture with plagioclase and K-feldspar phenocrysts/microphenocrysts. The intermediate/mafic volcanic rock fragments present porphyritic with plagioclase phenocrysts/microphenocrysts and trachytic textures. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.1-0.3 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly to moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges and sieve texture.

K-feldspar crystals size up to 0.125-0.25 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.125-0.5 mm across. They show irregular to euhedral outlines. These minerals are both primary and secondary origins.

Sample number: 35
Grid reference: 47Q 612976E 2162469N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)
Rock name: Lithic tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white and pink color size up to ≤ 1 mm across. The lithic fragments have reddish to dark brown and black color with size up to ≤ 2 cm across. The matrixes are very fine-grained and gray color. The rock turns light gray color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase and K-feldspar. These fragments form as isolated grains and glomerocrysts of plagioclase. Lithic fragments pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.025-1.75 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show flow banding and micropoikilitic texture. The fragments present porphyritic texture with plagioclase and K-feldspar phenocrysts/microphenocrysts. The intermediate/mafic volcanic rock fragments present porphyritic texture with plagioclase phenocrysts/ microphenocrysts and trachytic textures. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz crystals size up to 0.05-0.125 mm across. They mostly show anhedral outlines.

Plagioclase crystals size up to 0.25-0.5 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges and sieve texture.

K-feldspar crystals size up to 0.125-0.375 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Sample number: 36
Grid reference: 47Q 617309E 2166243N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)
Rock name: Vitric tuff

Megascopic Characters: The rock sample shows slightly banded (eutaxitic texture) and slightly apparent porphyritic textures. The banded texture has yellowish to greenish brown color. The apparent phenocrysts/microphenocrysts of white color size up to ≤ 0.5 mm across. The matrixes very fine-grained and greenish gray color. The rock turns light gray and brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant lithic and slightly crystal fragments that are embedded in the glassy matrixes. Crystal fragments consist of zircon and opaque minerals. Lithic fragments are pumice. These fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The very fine-grained matrixes show highly micropoikilitic texture. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief.

Opaque minerals size up to 0.075-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 37

Grid reference: 47Q 617658E 2166109N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Vitric tuff

Megascopic Characters: The rock sample shows a fragmental texture. The lithic fragments have a light gray color with size up to ≤ 1 cm across. These fragments show jigsaw-fit texture. The matrixes are very fine-grained and greenish gray color. The rock turns light gray and white color on weathering surfaces. Cavities sealed by white and green minerals with cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant lithic fragments that are embedded in the glassy matrixes. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.125-5 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The felsic volcanic rock fragments show flow banding and micropoikilitic texture. They might present jigsaw-fit texture with separated by quartz and K-feldspar intergrowth. Fractures are sealed by quartz and K-feldspar intergrowth. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Sample number: 38

Grid reference: 47Q 621583E 2175972N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE THOENG" Sheet 5048 III)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows slightly apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of greenish white color size up to ≤ 1.5 mm across. The matrixes are very fine-grained and gray color. The rock turns light gray color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains and glomerocrysts of plagioclase. Lithic fragments are pumice and intermediate/mafic volcanic rocks. These fragments size up to 0.125-0.5 mm across. The pumice wisps show relict tube vesicle texture with highly replaced by sericite and chlorite. The pumice fragments might have alignment of flattened and lenses (fiamme). The intermediate/mafic volcanic rock fragments present flow banding. The very fine-grained matrixes show slightly micropoikilitic texture. Secondary patches of sericite, chlorite, Fe-Ti oxide and epidote appear in the moderately amount.

Quartz crystals size up to 0.125-1 mm across. They mostly show anhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.25-0.75 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals and epidote. The crystals might show rounded edges and sieve texture.

K-feldspar crystals size up to 0.05-0.5 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly to moderately replaced by sericite, chlorite, clay minerals and epidote. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.25 mm across. They show irregular to euhedral outlines. These minerals are both primary and secondary origins.

Sample number: 39

Grid reference: 47Q 622180E 2177663N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Crystal tuff

Megascopic Characters: The rock sample shows a fragmental texture. The crystal fragments of white color size up to ≤ 1 mm across. The lithic fragments have greenish gray and green color with size up to ≤ 4 mm across. The matrixes are very fine-grained and generally show a light green color. The rock turns light gray and reddish brown color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar and opaque minerals. These fragments form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumulocrysts of plagioclase + K-feldspar + opaque minerals. Lithic fragments are pumice and felsic volcanic rocks. These fragments size up to 0.25-4.5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The felsic volcanic rock fragments show very fine-grained with quartz and K-feldspar crystals. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the higher amount.

Plagioclase crystals size up to 0.25-0.5 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.25-0.75 mm across. They mostly show anhedral to subhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.125-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 40

Grid reference: 47Q 622556E 2177662N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE THOENG” Sheet 5048 III)

Rock name: Welded lithic tuff

Megascopic Characters: The rock sample shows banded (eutaxitic texture) and apparent porphyritic textures. The bended texture is fiamme shape of pumice with yellow and green color (size up to $\leq$ 4 mm across). The apparent phenocrysts/microphenocrysts of white color size up to $\leq$ 1.5 mm across. The matrixes are very fine-grained and generally show brown color. The rock turns light gray color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample contains abundant crystal and lithic fragments that are embedded in the glassy matrixes. Crystal fragments consist of plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of K-feldspar and cumulocrysts of plagioclase + K-feldspar. Lithic fragments are pumice with felsic and intermediate/mafic volcanic rocks. These fragments size up to 0.125-5 mm across. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture with highly replaced by sericite and chlorite. The felsic volcanic rock fragments show flow banding with trachytic and micropoikilitic textures. These rocks present porphyritic texture with quartz, plagioclase and K-feldspar phenocrysts/microphenocrysts. They might show eutaxitic texture with glass shards. The intermediate/mafic volcanic rock fragments present trachytic texture. The very fine-grained matrixes show slightly micropoikilitic texture. They usually dominated foliation (eutaxitic texture) with platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the moderately amount.

Plagioclase crystals size up to 0.25-1 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar crystals size up to 0.125-1.125 mm across. They show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.075-0.25 mm across. They show irregular to anhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.25 mm across. They mostly show anhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 41
Grid reference: 47Q 624139E 2148648N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHUN” Sheet 5047 IV)
Rock name: Rhyolite

Megascopic Characters: The rock sample shows slightly flow banding. The groundmasses are very fine-grained and gray color. The rock turns light gray color on weathering surfaces. Tiny fractures sealed by white minerals and cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon, opaque and unidentified minerals. These phenocrysts/microphenocrysts form as isolated grain, glomerocrysts of quartz and plagioclase with cumurocrysts of quartz + plagioclase, quartz + opaque minerals and plagioclase + K-feldspar. The very fine-grained groundmasses show slightly micropoikilitic texture. Quartz and feldspar intergrowth are present. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-0.5 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals. The crystals show reaction rim.

Plagioclase phenocrysts/microphenocrysts size up to 0.125-0.375 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar microphenocrysts size up to 0.125-0.375 mm across. They mostly show anhedral to euhedral outlines. These crystals slightly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclose by opaque minerals.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.075-0.75 mm across. They mostly show anhedral outlines. The crystals slightly replaced by sericite and chlorite. These minerals are both primary and secondary origins.

Sample number: 42

Grid reference: 47Q 637260E 2135619N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample has very fine-grained and gray color of groundmasses. The rock turns dark gray and brown color on weathering surfaces. Cavities sealed by reddish brown and pink minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of K-feldspar and cumurocrysts of plagioclase + K-feldspar. The very fine-grained groundmasses show highly quartz and K-feldspar intergrowth with the mosaic of fine grains. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.25-0.375 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase microphenocrysts size up to 0.25 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-0.75 mm across. They mostly show subhedral outlines. These crystals highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.025-0.5 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 43

Grid reference: 47Q 637730E 2135546N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows a porphyritic texture. The phenocrysts/microphenocrysts of colorless and white color size up to ≤ 1 mm across. The groundmasses are very fine-grained and reddish brown color. The rock turns white color on weathering surfaces. Tiny fractures sealed by reddish brown minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of plagioclase and K-feldspar with cumurocrysts of K-feldspar + opaque minerals, quartz + plagioclase + K-feldspar and plagioclase + K-feldspar + opaque minerals. The very fine-grained groundmasses show highly micropoikilitic with fine K-feldspar lath and spherulitic textures. The spherulites size up to 0.05-0.25 mm across. They are bulbous aggregates of anhedral quartz and K-feldspar. The relict spherulites retain concentric zonation. Fe-Ti oxide, quartz and K-feldspar intergrowth with the mosaic of fine grains that occur between closely packed spherulites. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-1.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.125 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges and sieve texture.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-0.5 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately replaced by sericite, chlorite, clay minerals and Fe-Ti oxide. The crystals might show rounded edges. Some of crystals present simple twining.

Sample number: 44

Grid reference: 47Q 640494E 2136148N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows slightly porphyritic texture. The phenocrysts/microphenocrysts of white and pink color size up to ≤ 0.5 mm across. The groundmasses are very fine-grained and reddish brown color. The rock turns light brown and pink color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, opaque and unidentified minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of quartz and K-feldspar with cumurocrysts of quartz + plagioclase and plagioclase + K-feldspar. The very fine-grained groundmasses show highly micropoikilitic texture with fine K-feldspar lath. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.25-0.625 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-0.5 mm across. They show anhedral to subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-0.375 mm across. They mostly show anhedral outlines. These crystals highly replaced sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

Microphenocrysts of opaque minerals size up to 0.025-0.25 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Microphenocrysts of unidentified minerals size up to 0.1-0.25 mm across. They show anhedral to subhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 45

Grid reference: 47Q 640501E 2135985N (Topographic map WGS84 at a scale of 1:50,000 "BAN WAEN KHONG" Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows slightly porphyritic texture. The phenocrysts/microphenocrysts of white and pink color size up to $\leq$ 0.5 mm across. The groundmasses are very fine-grained and generally show reddish brown and pink color. The rock turns light brown and pink color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains with cumurocrysts of plagioclase + K-feldspar and plagioclase + opaque minerals. The very fine-grained groundmasses show highly micropoikilitic texture with fine K-feldspar lath. Quartz and K-feldspar intergrowth are present. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz microphenocrysts size up to 0.125-0.25 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-0.375 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.125-0.5 mm across. They mostly show anhedral to subhedral outlines. These crystals highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges. Some of crystals present simple twining.

Microphenocrysts of opaque minerals size up to 0.025-0.25 mm across. They show irregular to subhedral outlines. These minerals are both primary and secondary origins.

Microphenocrysts of unidentified minerals size up to 0.05-0.25 mm across. They show anhedral to subhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 46

Grid reference: 47Q 645639E 2134159N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample has very fine-grained and greenish gray color of groundmasses. The rock turns yellowish brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon and opaque minerals. The very fine-grained groundmasses show highly micropoikilitic texture. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz microphenocrysts size up to 0.025-0.125 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts size up to 0.75 mm across. They mostly show anhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges.

K-feldspar phenocrysts size up to 0.5-0.875 mm across. They mostly show anhedral outlines. These crystals highly replaced by sericite, chlorite, clay minerals with quartz and K-feldspar intergrowth. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.05 mm across. They mostly show euhedral outlines and very high relief.

Microphenocrysts of opaque minerals size up to 0.025-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 47

Grid reference: 47Q 645759E 2134276N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample has very fine-grained and gray color of groundmasses. The rock turns reddish brown color on weathering surfaces. Tiny fractures sealed by reddish brown minerals have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon and opaque minerals. The very fine-grained groundmasses show highly micropoikilitic texture. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz microphenocrysts size up to 0.25-0.1 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase microphenocrysts size up to 0.1-0.25 mm across. They mostly show anhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.1-0.75 mm across. They mostly show anhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.1 mm across. They mostly show euhedral outlines and very high relief.

Microphenocrysts of opaque minerals size up to 0.025-0.125 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 48
Grid reference: 47Q 645785E 2134294N (Topographic map WGS84 at a scale of 1:50,000 “BAN WAEN KHONG” Sheet 5047 I)
Rock name: Rhyolite

Megascopic Characters: The rock sample has very fine-grained and gray color of groundmasses. The rock turns yellowish to reddish brown color on weathering surfaces. Tiny fractures have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon and opaque minerals. The very fine-grained groundmasses show highly micropoikilitic texture. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz microphenocrysts size up to 0.05-0.1 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.1-0.375 mm across. They mostly show anhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.125-0.5 mm across. They mostly show anhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025-0.1 mm across. They mostly show euhedral outlines and very high relief.

Microphenocrysts of opaque minerals size up to 0.025-0.1 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 49
Grid reference: 47Q 632038E 2086902N (Topographic map WGS84 at a scale of 1:50,000 "AMPHOE CHIANG MUAN" Sheet 5046 I)
Rock name: Rhyolite

Megascopic Characters: The rock sample shows a porphyritic texture. The phenocrysts/microphenocrysts of colorless, white and pink color size up to ≤ 1.5 mm across. The groundmasses are very fine-grained and reddish brown color. The rock turns light brown and black color on weathering surfaces. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of K-feldspar and cumurocrysts of plagioclase + K-feldspar. The very fine-grained groundmasses show flow banding with slightly to moderately micropoikilitic and spherulitic textures. The spherulites size up to 0.2-0.5 mm across with semispherical to the spherical shape. They might grow on quartz crystal and are elongate trains with often aligned along flow layering. Few quartz veins have also been observed in the sample. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.25-1.75 mm across. They mostly show anhedral outlines. These crystals present rounded edges and embayed crystals. The crystals show reaction rim.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.25 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.25-2.25 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.05 mm across. They mostly show euhedral outlines and very high relief.

Microphenocrysts of opaque minerals size up to 0.05-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 50
Grid reference: 47Q 632051E 2086901N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHIANG MUAN” Sheet 5046 I)
Rock name: Spherulitic rhyolite

Megascopic Characters: The rock sample shows flow banding with porphyritic and spherulitic textures. The flow banding has white color and size up to ≤ 1 mm across which are deflected around the edges of crystal and spherulites. The phenocrysts/microphenocrysts of white and pink color size up to ≤ 1.5 mm across. The spherical spherulites (size up to ≤ 1 cm across) consist of white and colorless minerals. The groundmasses are very fine-grained and reddish brown color. The rock turns yellowish to dark brown color on weathering surfaces. Cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include plagioclase, K-feldspar, zircon and opaque minerals. These phenocrysts/microphenocrysts form as isolated grains, glomerocrysts of

K-feldspar with cumurocrysts of plagioclase + K-feldspar and plagioclase + opaque minerals. The very fine-grained groundmasses show flow banding and highly micropoikilitic texture with vesicles. The vesicles are similar to coalesced spherulites. They are surrounded by smaller recrystallized spherulites which impart granular texture. Quartz and K-feldspar intergrowth are present. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase phenocrysts size up to 0.375-0.75 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts size up to 0.25-0.625 mm across. They mostly show subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Zircon crystals size up to 0.025 mm across. They mostly show euhedral outlines and very high relief. The crystals might enclose by opaque minerals.

Microphenocrysts of opaque minerals size up to 0.025-0.25 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 51

Grid reference: 47Q 633824E 2087347N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHIANG MUAN” Sheet 5046 I)

Rock name: Rhyolite

Megascopic Characters: The rock sample shows flow banding and slightly porphyritic texture. The flow banding has pink color and size up to ≤ 2 mm across which are deflected around the edges of crystal. The phenocrysts/microphenocrysts of white, pink and green color size up to ≤ 1.5 mm across. The groundmasses are very fine-grained and grayish brown color. The rock turns gray color on weathering surfaces. Fractures and cavities sealed by white minerals have been occasionally observed. This rock reacts with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include quartz, plagioclase, K-feldspar, zircon, opaque and unidentified minerals. The very fine-grained groundmasses show flow banding and highly micropoikilitic texture with vesicles. The vesicles (amygdales) are filled with sericite, chlorite and euhedral quartz. Quartz and K-feldspar intergrowth present. Tiny fractures sealed by calcite and euhedral quartz. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Quartz phenocrysts/microphenocrysts size up to 0.125-0.5 mm across. They show anhedral to euhedral outlines. These crystals present rounded edges and embayed crystals.

Plagioclase phenocrysts/microphenocrysts size up to 0.25-1.625 mm across. They mostly show subhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts/microphenocrysts size up to 0.125-0.5 mm across. They mostly show anhedral outlines. These crystals highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

Zircon crystals size up to 0.03-0.05 mm across. They mostly show euhedral outlines and very high relief.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.025-0.375 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Microphenocrysts of unidentified minerals size up to 0.1-0.2 mm across. They mostly show euhedral. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

Sample number: 52

Grid reference: 47Q 633807E 2087366N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHIANG MUAN” Sheet 5046 I)

Rock name: Spherulitic rhyolite

Megascopic Characters: The rock sample shows highly spherulitic texture. The spherical spherulites have brownish gray color and size up to ≤ 5 mm across. They might retain concentric zonation. The groundmasses are very fine-grained and generally show pink color. The rock turns a light pink color on weathering surfaces. Cavities sealed by colorless, white and light green minerals with cavities have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The sample shows hypocrystalline and porphyritic texture. The phenocrysts/microphenocrysts include plagioclase, K-feldspar and opaque minerals. The very fine-grained groundmasses show flow banding and highly micropoikilitic texture. The groundmasses present highly spherulitic texture and vesicles. The spherulites size up to 0.5-2.5 mm across with spherical in shape. They might show elongate trains with often aligned along flow layering. The vesicles (amygdales) are filled with K-feldspar lath, quartz and K-feldspar intergrowth, sericite, chlorite and clay minerals. Tiny fractures sealed by Fe-Ti oxide. Secondary patches of sericite, chlorite and Fe-Ti oxide appear in the minor amount.

Plagioclase phenocrysts size up to 0.75 mm across. They mostly show anhedral outlines. These crystals commonly present polysynthetic twinning with highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar phenocrysts size up to 0.5 mm across. They mostly show anhedral outlines. These crystals highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

Phenocrysts/microphenocrysts of opaque minerals size up to 0.05-0.375 mm across. They show irregular to anhedral outlines. These minerals are both primary and secondary origins.

Sample number: 53
Grid reference: 47Q 634305E 2086729N (Topographic map WGS84 at a scale of 1:50,000 “AMPHOE CHIANG MUAN” Sheet 5046 I)
Rock name: Welded vitric tuff

Megascopic Characters: The rock sample shows apparent porphyritic texture. The apparent phenocrysts/microphenocrysts of colorless, white and pink color size up to ≤ 2 mm across. The groundmasses are very fine-grained and generally show dark brown color. The rock turns white and light gray color on weathering surfaces. Tiny fracture have been occasionally observed. These rock does not react with diluted hydrochloric acid.

Microscopic Characters: The rock that contains abundant crystal and pumice fragments that are embedded in the glassy matrixes. Crystal fragments consist of quartz, plagioclase, K-feldspar, opaque and unidentified minerals. These fragments form as isolated grains, glomerocrysts of quartz and plagioclase with cumulocrysts of plagioclase + K-feldspar and K-feldspar + opaque minerals. The pumice fragments have alignment of flattened and lenses (fiamme). The pumice wisps might show relict tube vesicle texture. The very fine-grained matrixes show moderately micropoikilitic and spherulitic textures. They usually dominated foliation (eutaxitic texture) with the platy shape of glass shards. The eutaxitic texture compacted and deformed from alignment flattened welded pumice and shards which are deflected around the edges of crystal and lithic fragments. The spherulites size up to 0.05-1.75 mm across with semispherical to spherical shape. They might grow on quartz and K-feldspar crystals. Quartz and K-feldspar intergrowth are present. Secondary patches of Fe-Ti oxide, chlorite and sericite appear in the minor amount.

Quartz crystals size up to 0.125-2.125 mm across. They mostly show anhedral outlines. These crystals commonly present rounded edges and embayed crystals.

Plagioclase crystals size up to 0.25-0.5 mm across. They show subhedral to euhedral outlines. These crystals commonly present polysynthetic twinning with moderately replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges.

K-feldspar size up to 0.125-1.125 mm across. They mostly show anhedral to subhedral outlines. These crystals moderately to highly replaced by sericite, chlorite and clay minerals. The crystals might show rounded edges. Some of crystals present simple twining.

Opaque minerals size up to 0.025-0.875 mm across. They show irregular to subhedral outlines. The crystals slightly replaced by sericite, chlorite and Fe-Ti oxide. These minerals are both primary and secondary origins.

Unidentified minerals size up to 0.025-0.5 mm across. They mostly show subhedral outlines. These crystals completely pseudomorph by sericite, chlorite and Fe-Ti oxide.

APPENDIX B

Methodology

Advanced analytical techniques of eighteen volcanic rock samples were prepared for whole-rock chemical analysis X-ray Fluorescence (XRF) Spectrometer and Multiple Collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS) were applied. The selected twelve samples were prepared for U-Pb geochronology used Scanning Electron Microscope (SEM) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS). All procedures were done at the Institute of Earth Sciences, Academia Sinica and Department of Geosciences, National Taiwan University, Taiwan.

The powder samples for these analyses from the large block of rocks samples, splitting and crushing to small chips using Jaw Crusher (Figure 7.1). The broken pieces are thoroughly washed in clean water to remove dust and dried in an oven. Then carefully selected approximately 200 grams of the least-altered from fresh chips. Next, the chips were pulverized by Rocklabs Tungsten Carbide Ring Mill for powder (Figure 7.2). The powder samples 100 grams for whole-rock chemical analysis should be pulverized within 2 minutes and 100 grams for U-Pb geochronology pulverized within 1.5 minutes. Be carefully contaminated of powder, after pulverized sample must always clean by acetone for each sample. The process was proceeded at Department of Geological Sciences, Faculty of Science, Chiang Mai University, Thailand.

7.1 Whole-rock chemical analysis techniques

The techniques for whole-rock chemical analyses of both X-Ray Fluorescence (XRF) Spectrometer and Multiple Collector Inductively Coupled Plasma Spectrometry (MC-ICP-MS) are explained in this section. These techniques analyzed for major oxides, trace and rare-earth elements of the studied rocks. The results are significant for igneous petrogenesis terms of the conditions of the rocks formed, classification of rocks, identification of the tectonic setting and modeling processes of magmatic evolution.

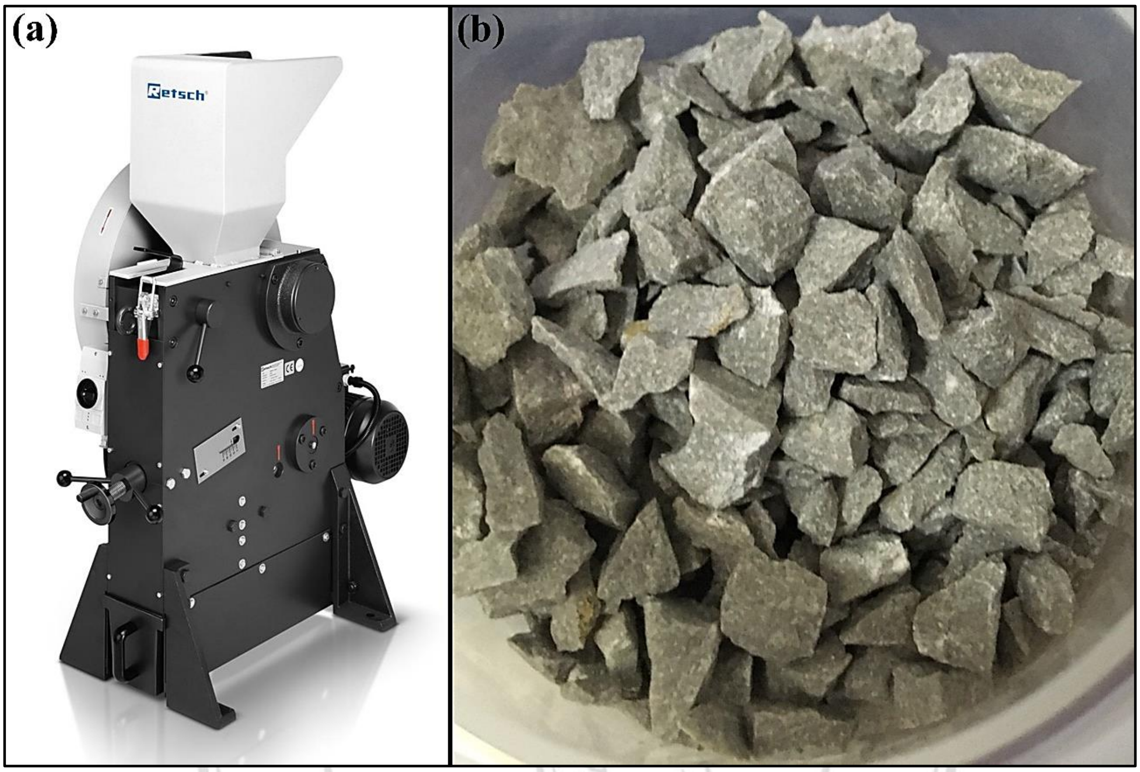

Figure 7.1 Machinery for powder prepare (a) Jaw Crusher and (b) rock chips.

Figure 7.2 Showing (a) Rocklabs Tungsten Carbide Ring Mill and (b) powder samples.

7.1.1 X-Ray Fluorescence (XRF) spectrometer

This technique is analyzed for major oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, Na_2O, K_2O and P_2O_5). X-ray Fluorescence Spectrometer RIGAKU/RIX2000 installed at the X-ray laboratory of Department of Geosciences, National Taiwan University. The specification of the machinery is made up of Rh, Cr, W, Mo tube with LiF200, PET, Ge, TAP standard and used in an elemental range of Be through U. The X-ray generator are at 60 kV and current of 80 mA at maximum load 3kW. Sample changers for 50 samples and 100 samples are also available for automated operation. These results were obtained from glass discs prepared by mixing 0.5000±0.0001 grams of powder samples pulverized within 2 minutes with 5.0000±0.0005 grams of spectromelt A10 (Figure 7.3). Then pour the mixture into a platinum crucible and put it in TK-4100 Bead & Fuse-Sampler machine (Figure 7.4). Next turn on the monitors for a fuse and set the control to 800°C in 60 sec and 1168°C in 420 seconds. Fusion machine is made of homogeneous fused and spherical glass discs. At the end of the 480 seconds remove the platinum crucible on cooling plate to room temperature. Remove the glass discs from platinum crucible by turning upside down and tapping (Figure 7.5). After that put glass discs in XRF mould and analyses were performed on X-ray Fluorescence Spectrometer RIGAKU/RIX2000 (Figure 7.6). It takes about 7 minutes for each sample.

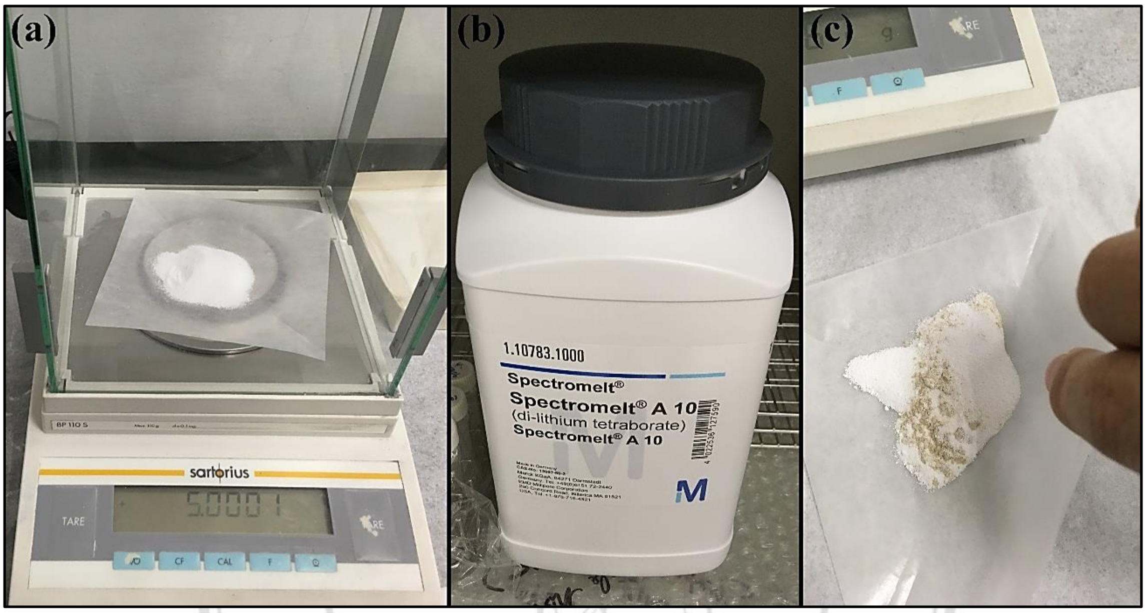

Figure 7.3 Weighting by (a) balance with (b) spectromelt A10 and (c) powder samples for mixing.

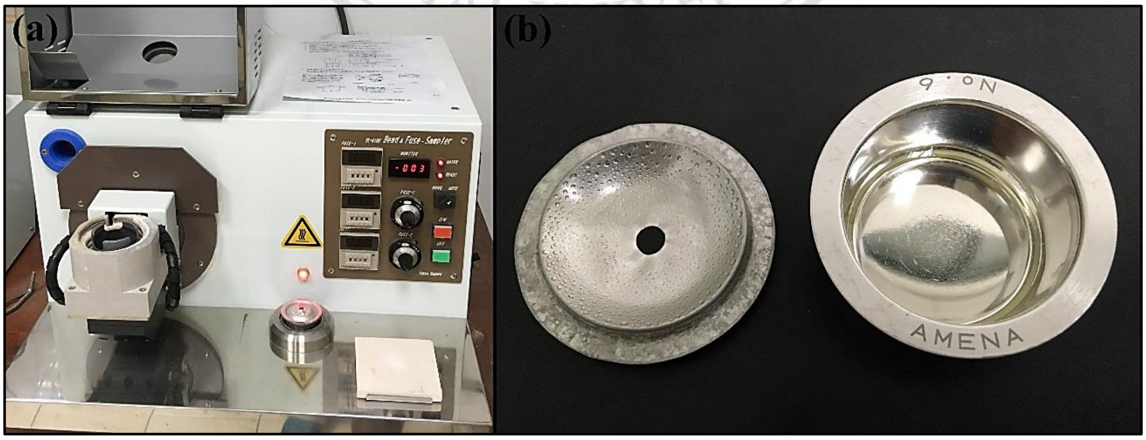

Figure 7.4 (a) Fuse machine installed with (b) platinum crucible.

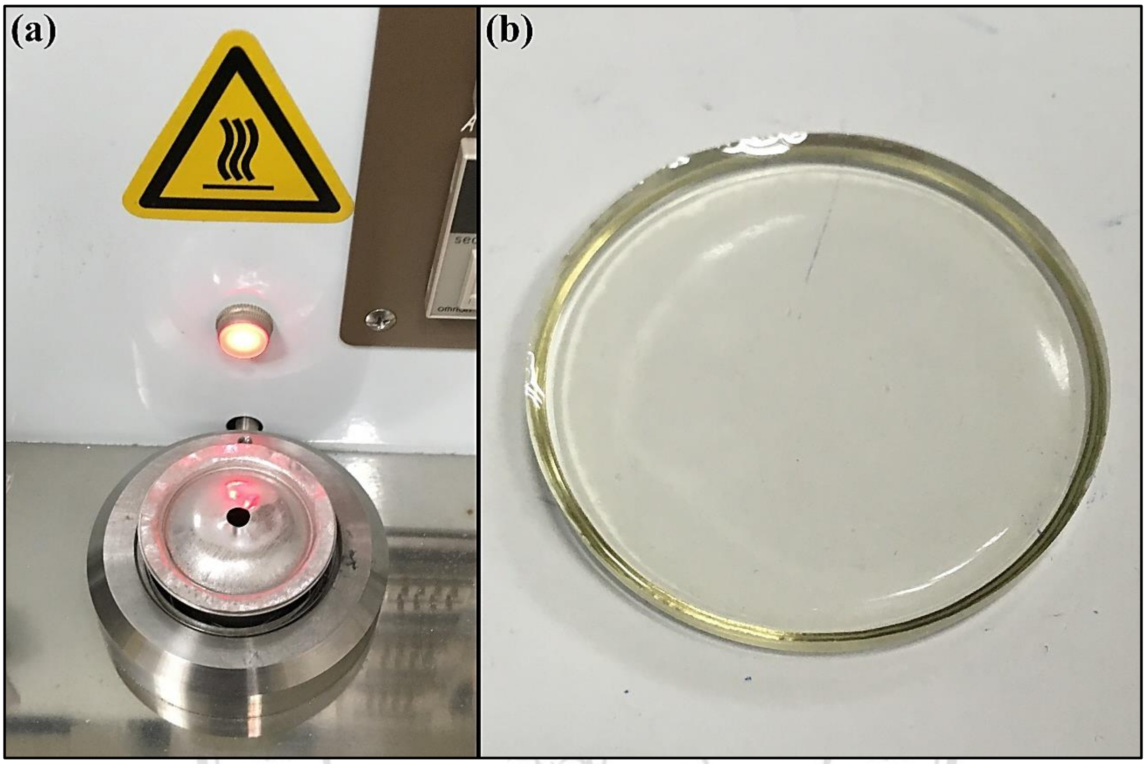

Figure 7.5 (a) Platinum crucible on cooling plate and (b) glass discs.

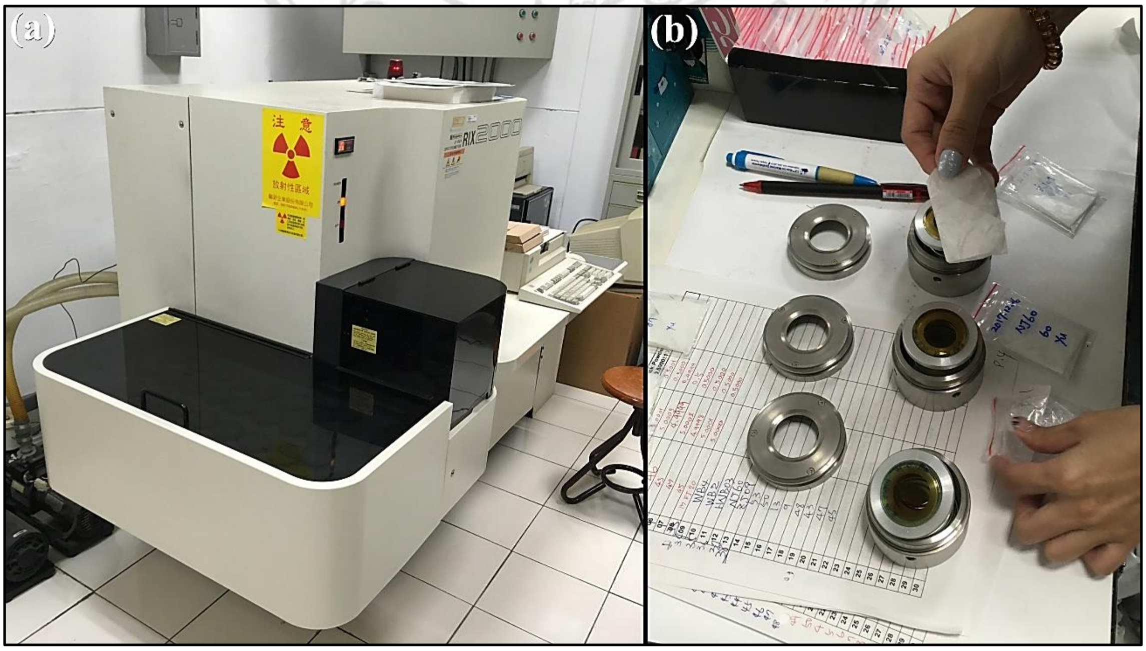

Figure 7.6 (a) X-ray Fluorescence Spectrometer with (b) glass discs in XRF mold.

7.1.2 Multiple Collector Inductively Coupled Plasma Spectrometry (MC-ICP-MS)

This technique analyses for trace and rare-earth elements (P, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Ti, Pb, Th and U). The Nu Plasma II Multiple Collector Inductively Coupled Plasma Spectrometry installed at the geochemistry laboratory of Institute of Earth Sciences, Academia Sinica Taiwan. These elements were obtained from glass discs after XRF analyzed. First, blowing the bottles by an ionizing air blower and weighting broken glass discs 0.04±0.005 grams into it, please do not forget to note the net weight of glass discs (Figure 7.7). Add 30 drops of 1:1 HNO_3 (nitric acid) and 25 drops of HF (hydrofluoric acid) in bottles with glass discs. Next, heating bottles (with cover) on a hot plate for dissolve reaction at 140^{o}C for overnight (Figure 7.8). Then drying solution with no cover at 160^{o}C for about 2 hours, if the solution is dried add 1.5 ml of 1:2 HNO_3 into the bottles (Figure 7.9). Finally, heating bottles with cover for dissolve reaction again at 140^{o}C for overnight.

Calculating for dilution from net weight in first step (dilution weight (g) = net weight×500). After that diluting solution from bottles heated from last night to 50 ml bottles by 2%HNO_3 and up to weight from calculated±0.01 gram (Figure 7.10). The next step pours solution from 50 ml bottles into 12 ml tubes, to weight 2.5-3.0 grams and do not forget to note it. Add 2%HNO_3 in 12 ml tubes up to double weight±0.01 gram of the previous notes (Figure 7.11). Continue to add Rh+Bi (internal standards) up to triple weight±0.01 gram of the previous notes and cover tubes by parafilm (Figure 7.12). Finally, analyzed for trace and rare-earth elements on Nu Plasma II Multiple Collector Inductively Coupled Plasma Spectrometry (Figure 7.13). The following details of all steps can be found in Multi-Collector ICP-MS software version 1.0.2 (Nu Instruments, 2010).

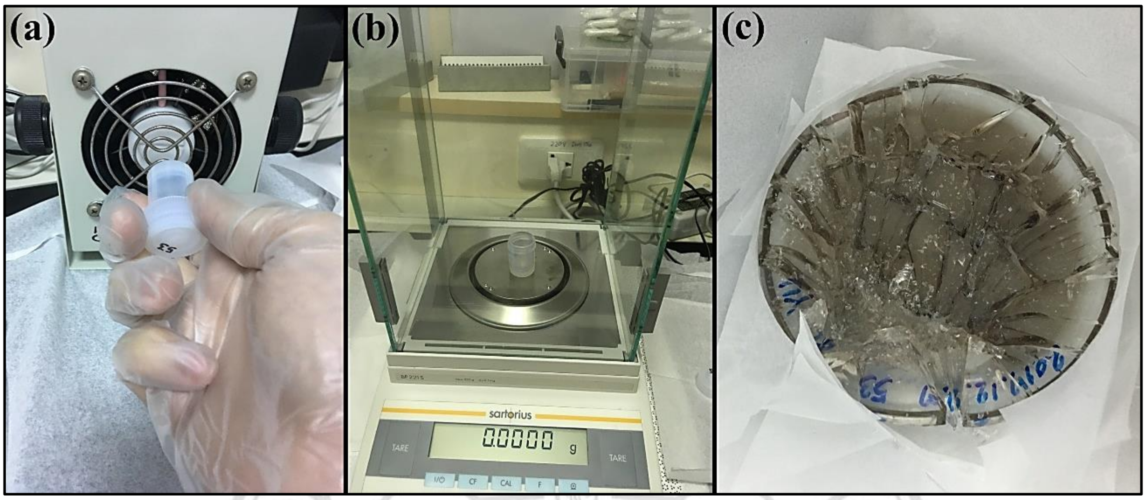

Figure 7.7 Blowing the bottles with (a) ionizing air blower and weighting by (b) the balance of (c) broken glass discs.

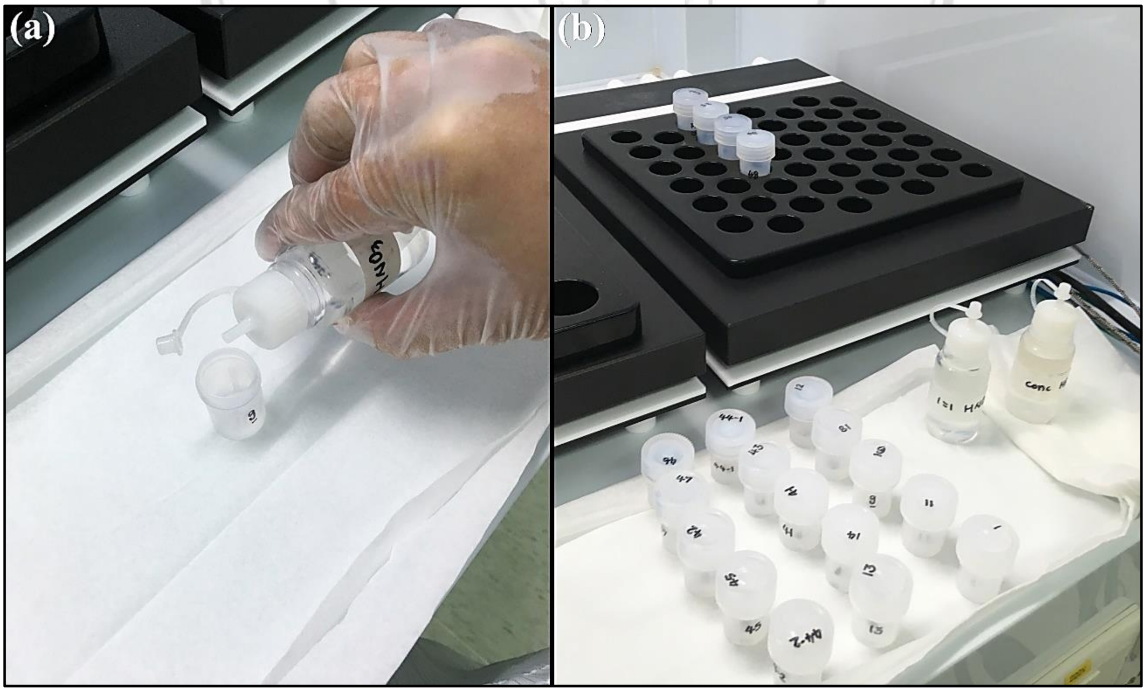

Figure 7.8 Add (a) 30 drops of 1:1 HNO_3 with 25 drops of HF and heating with (b) the cover on a hot plate.

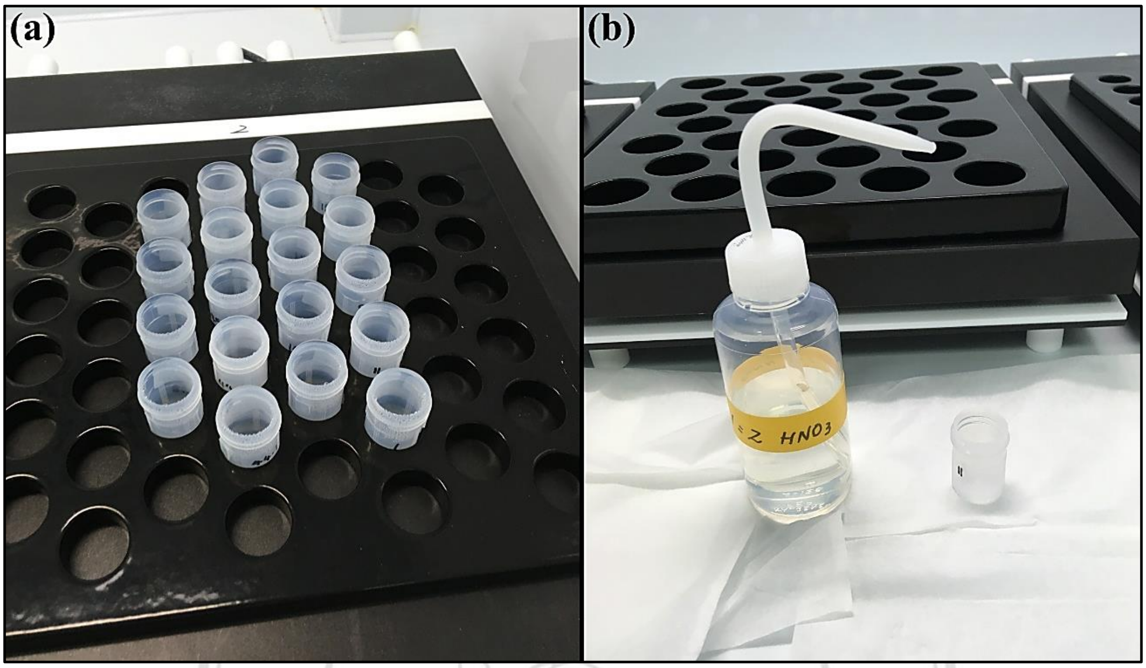

Figure 7.9 Drying solution with (a) no cover and add (b) 1.5 ml of 1:2 HNO_3.

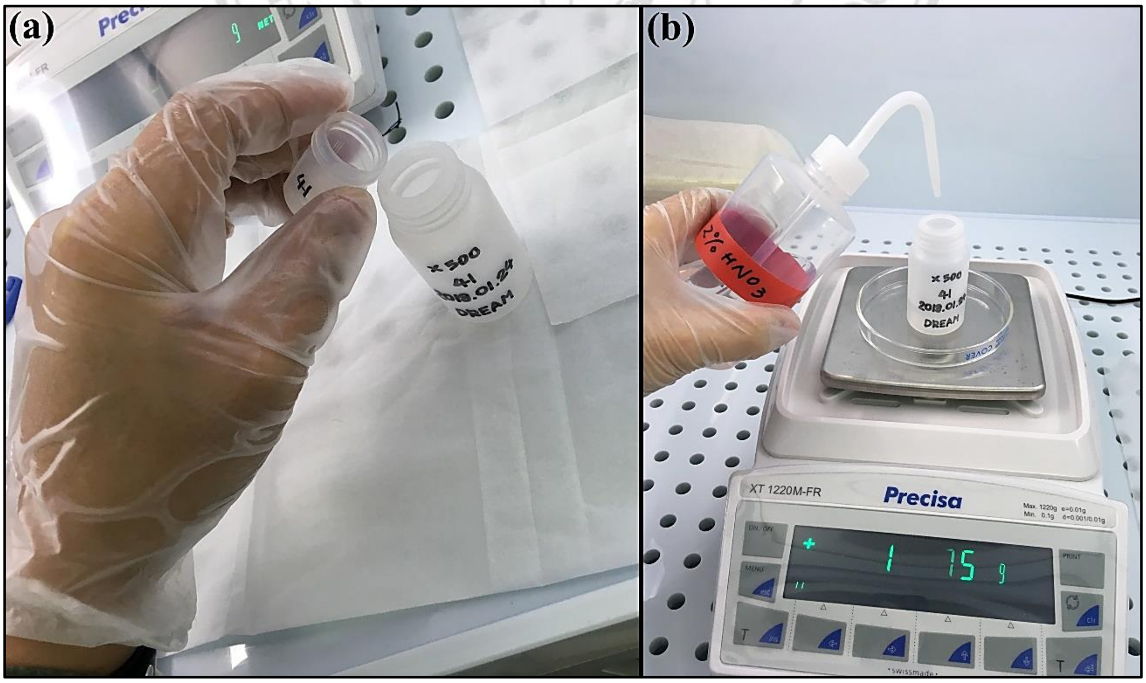

Figure 7.10 Diluting solution from (a) bottles heated to 50 ml bottles with (b) 2%HNO_3 and weighting by balance.

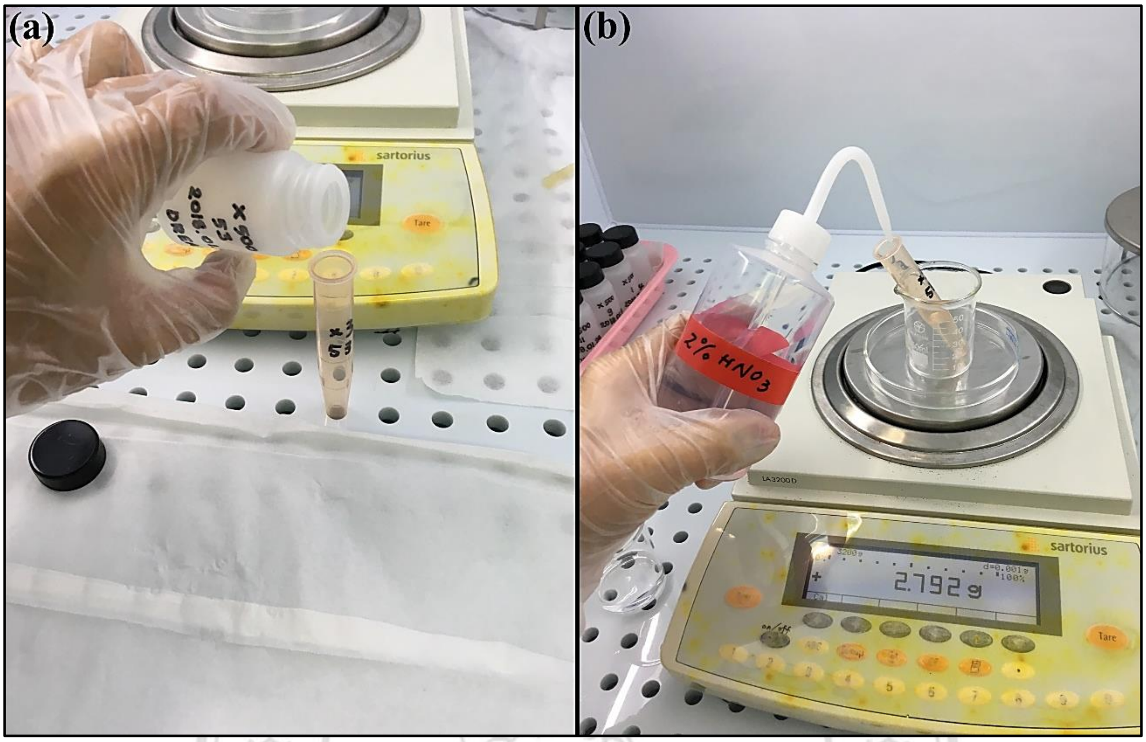

Figure 7.11 Pour solution from (a) 50 ml bottles into 12 ml tubes and add (b) 2%HNO_3 in 12 ml tubes weighting by balance.

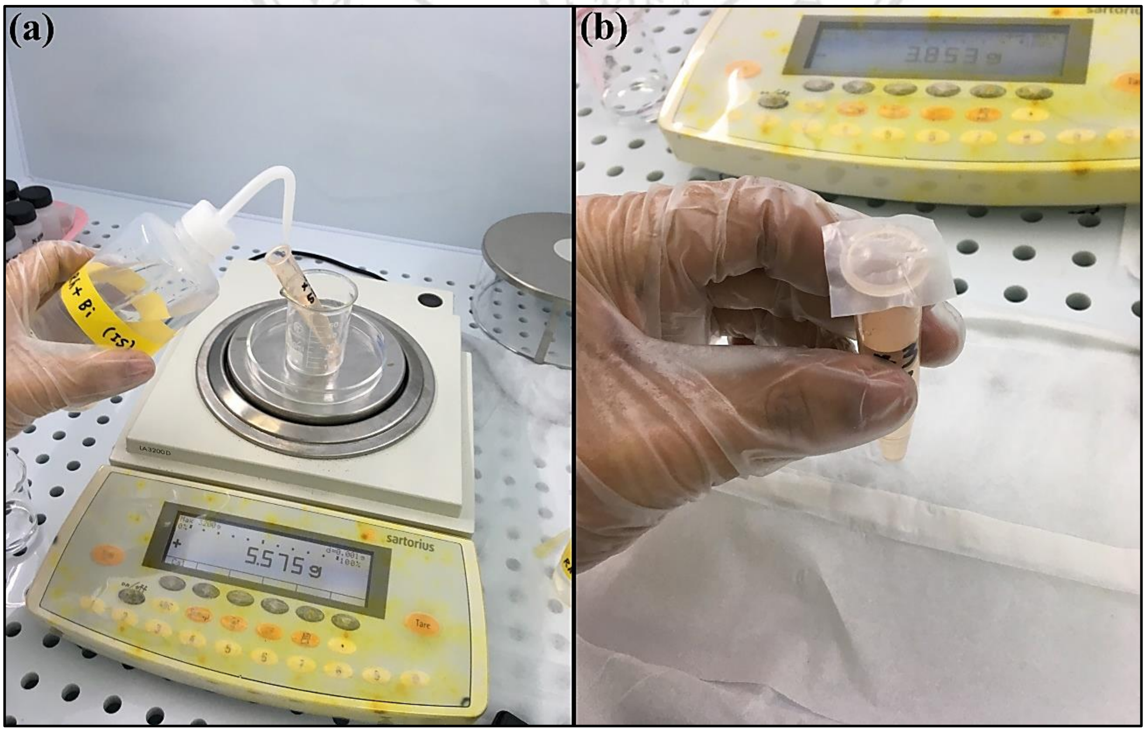

Figure 7.12 Add (a) Rh+Bi to 12 ml tube and cover tube by (b) parafilm.

Figure 7.13 Multiple Collector Inductively Coupled Plasma Spectrometry (MC-ICP-MS).

7.2 U-Pb geochronology techniques

The technique is one of oldest and most refined of the radiometric dating schemes. The results can be used to date rocks that formed and crystallized from about 1 million years to over 4.5 billion years ago with routine precisions in the 0.1-1 percent range. The U-Pb dating is usually performed on zircon. This mineral collected uranium (U) and lead (Pb) atoms into the crystal structure. Uranium and lead have radiogenic by process of radioactive decay after formation of the mineral. Thus the current ratio of uranium to lead can be used to determine its ages. The procedure of this method comprises grain mounting, Scanning Electron Microscope (SEM) and Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and are explained in the following section.

7.2.1 Grain mounting

Powder samples pulverized within 1.5 minutes to aim for zircon grains. Using sieves no 100-200 mesh for sieved the powder samples because the majority of the zircon grains have a size between 50 to 150 µm (Figure 7.14). Continue for gravity separation using gold pan vibration and slope them in water (Figure 7.15). A divider separates the heavier and lighter minerals with wash into different step containers. The heavy minerals such as zircon, magnetite and apatite are moved to the lower portion of a gold pan and can be retained into step containers. Lighter minerals such as quartz and feldspars wash into the margin of a gold pan. Then the samples are dried in an oven and keep in tubes. This procedure was proceeding in laboratory room at the Department of Geological Sciences, Faculty of Science, Chiang Mai University, Thailand.

The zircon grains (following zircon morphology in Pupin, 1980) selected on Petri dishes under transmitted and reflected light polarizing microscope for handpicking by needle touch to zircon grains and put in sample treys over 100 grains per a sample (Figure 7.16). This process was carried out in micro-specimen processing laboratory at Institute of Earth Sciences, Academia Sinica, Taiwan. The zircon grains should be euhedral, transparent, clean surface, without cracks, inclusion and pitting. Then carefully move the sample to electron microprobe analysis laboratory at Department of Geosciences, National Taiwan University for mounting. First, clean the mounting plate (9×9 cm glass) surface thoroughly and cut a piece of double-sided tape, paste it on the glass. Drew circle line diameter 1.5 cm on the tape, alignment marks pass circle (straight line) and mark direction together. Then put the row mask template (made from fibre-free solid polypropylene plastic cover sheet on double-sided tape) to overlap the circle line on double-sided tape and picked zircon grains by needle from sample treys under dissecting microscope into row mask template (Figures 7.17 and 7.18). The front of row should begin from alignment marks and collocate over 100 zircon grains for the beautiful pattern (Figure 7.19). When ending a row for one sample, move row mask template to the next row. In the circle area should have four rows of four samples (Figure 7.20).

Next step prepare of the mounting plate and mounted grains for the pouring of epoxy. Remove the row mask template from mount plate and place the epoxy mould block (2.5 cm diameter) on the tape cover the circle line (Figure 7.21). Do not forget to coat the mould block with vaseline for easy to remove from mount plate. Press the mould block firmly against the tape. Continue preparing the epoxy for pouring into the mount mould by the following steps. First, mixing epoxy resin and epoxy hardener in beaker used ratio in Table 7.1 (Figure 7.22). Then move beaker with epoxy into the pumping machine for leak out air bubbles in the epoxy wait for 2-3 minutes. After that slowly pour epoxy without bubbles in the mould block at the tape surface and wait for stable overnight (Figure 7.23).

The next day removes the mount (solid epoxy) from mould block, begin polish by silicon carbide grinding paper grit 180 (80 µm particle size) and P4000 (5µm particle size) for remove tape on the surface and made it smooth (Figure 7.24). After that polish on polishing equipment with diamond suspension 3µm and 1 µm in particle size (Figure 7.25). Examine the mount under the bionocular microscope after each polishing step and stop if it clean to surface (Figure 7.26). Do not forget after each step (change the particle size) must clean the mount in water with bransonic cleaner (Figure 7.27).

Figure 7.14 Sieves no 100-200 mesh.

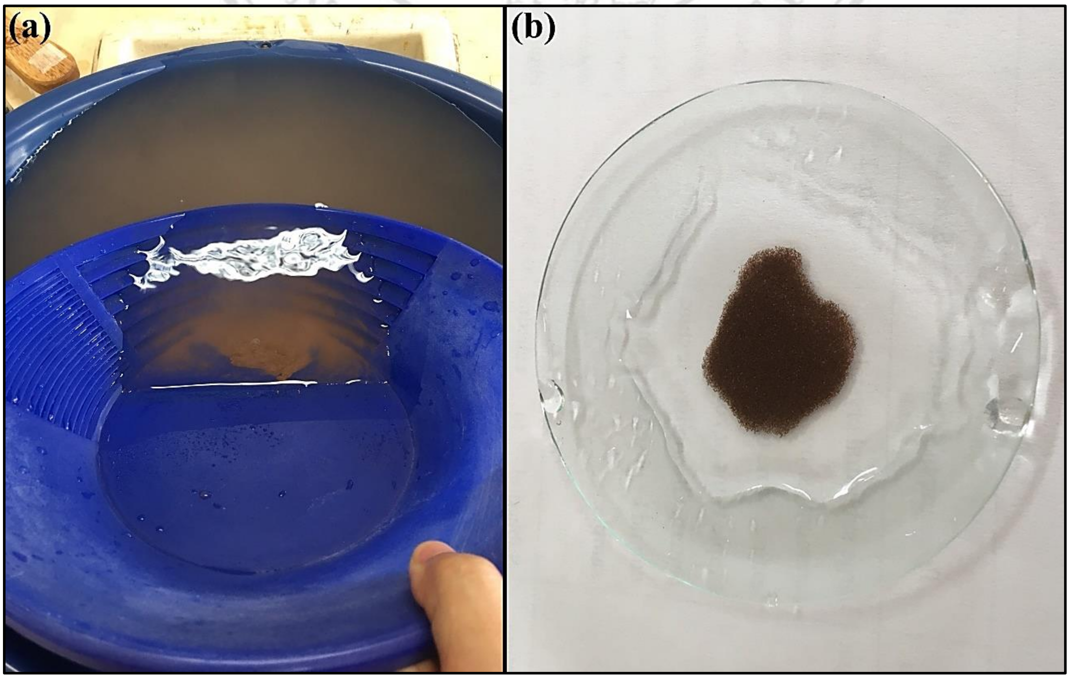

Figure 7.15 Gravity separation using (a) gold pan vibration and slope in water (b) heavy minerals are present.

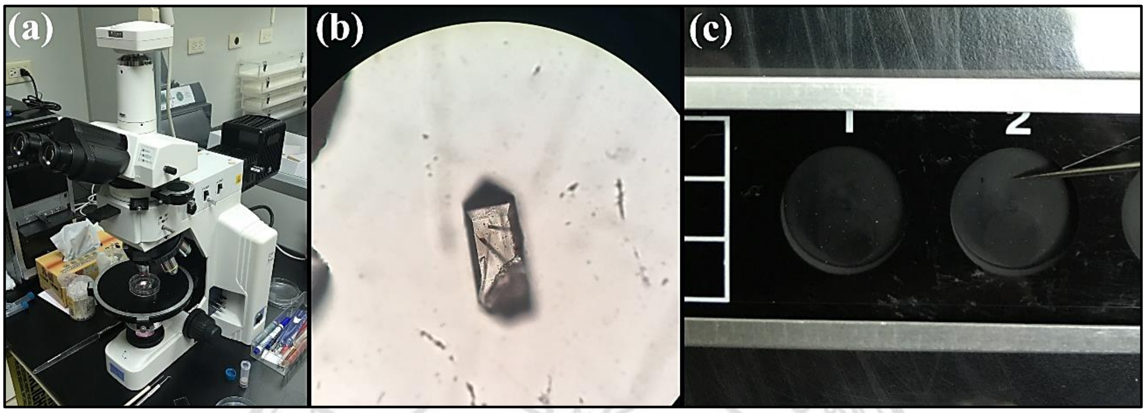

Figure 7.16 Picking zircon grains under (a) transmitted and reflected light polarizing microscope, showing (b) zircon grain under the microscope and put in (c) sample trey.

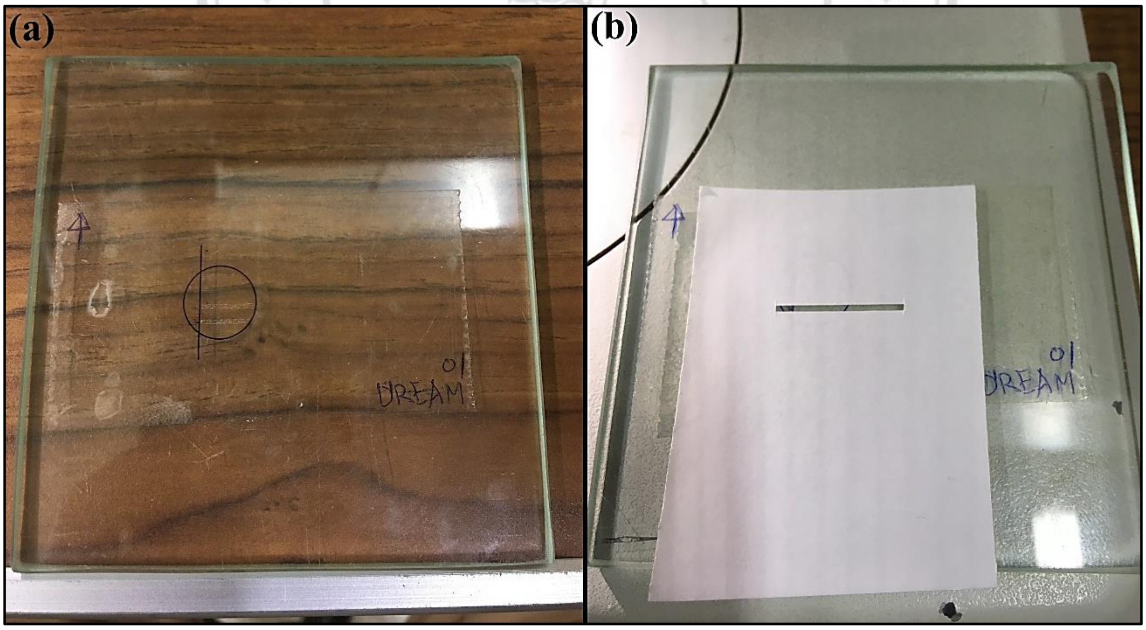

Figure 7.17 (a) Mount plate paste double-sided tape with a circle and straight line, put (b) the row mask template to overlap the circle line.

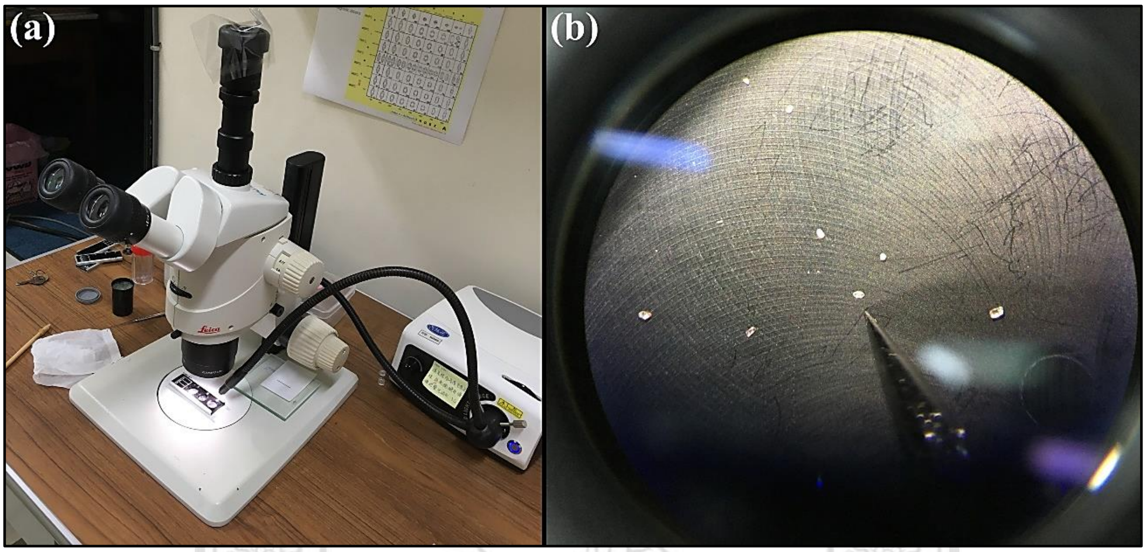

Figure 7.18 (a) Dissecting microscope using picked (b) zircon grains from sample treys.

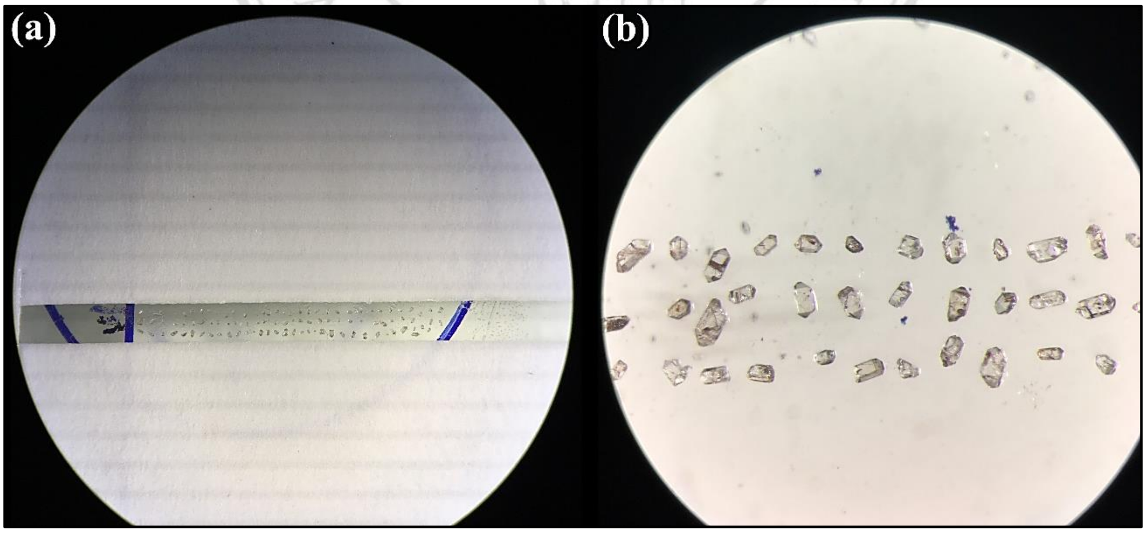

Figure 7.19 (a) Zircon grains into row mask template and collocate for
(b) the beautiful pattern.

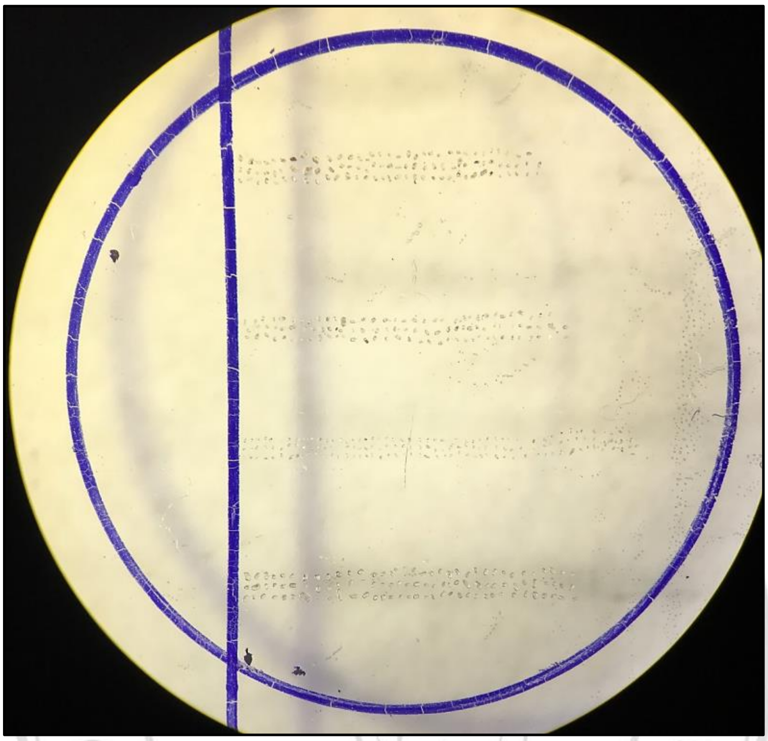

Figure 7.20 Four rows of four samples in the circle area.

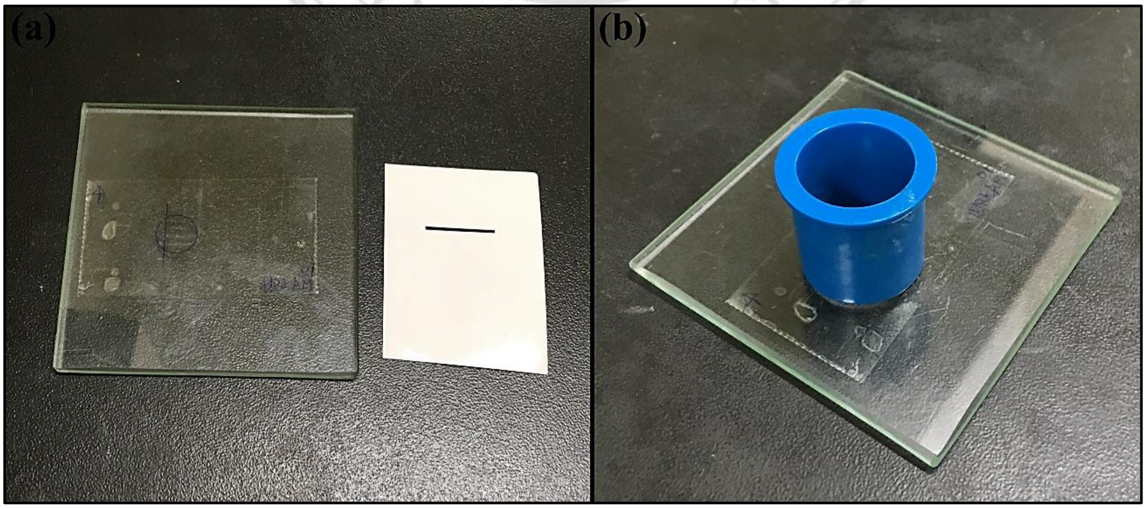

Figure 7.21 (a) The row mask template removing and place (b) the epoxy mold block over circle line.

Table 7.1 Ratio of the mixture.

Target of mount	Epoxy resin (ml)	Epoxy hardener (ml)
0.5	1.875	0.25
1	3.75	0.5
1.5	5.625	0.75
2	7.5	1
2.5	9.375	1.25
3	11.25	1.5
3.5	13.125	1.75
4	15	2

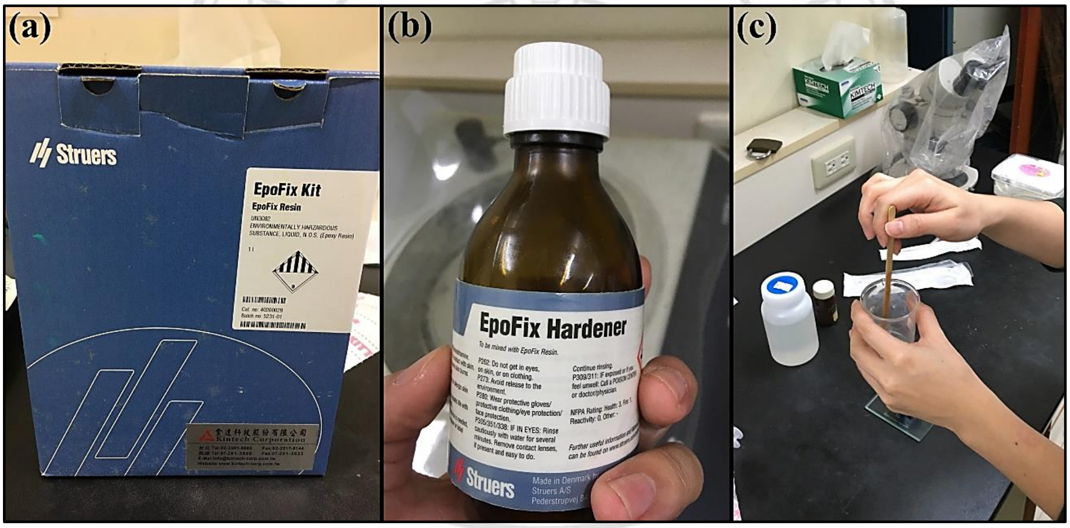

Figure 7.22 (a) Epoxy resin and (b) epoxy hardener mixing in (c) a beaker.

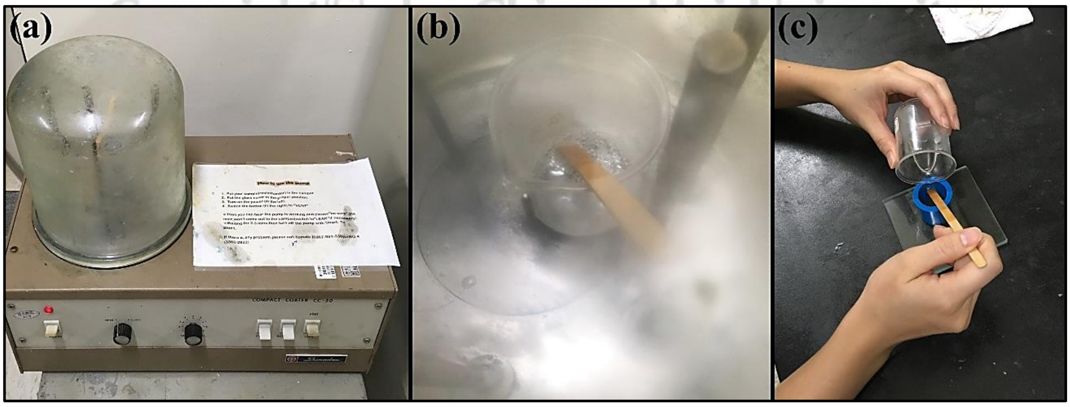

Figure 7.23 Using (a) the pumping machine for leak out (b) air bubbles in the epoxy and pour in (c) the mold block.

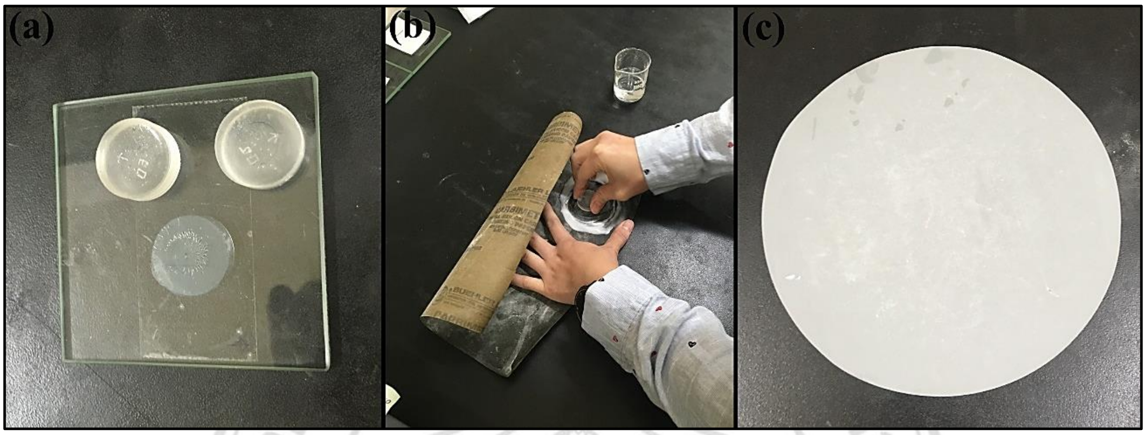

Figure 7.24 Remove (a) the mount from mold block begin (b) polish by (c) silicon carbide grinding paper grit 180 and P4000.

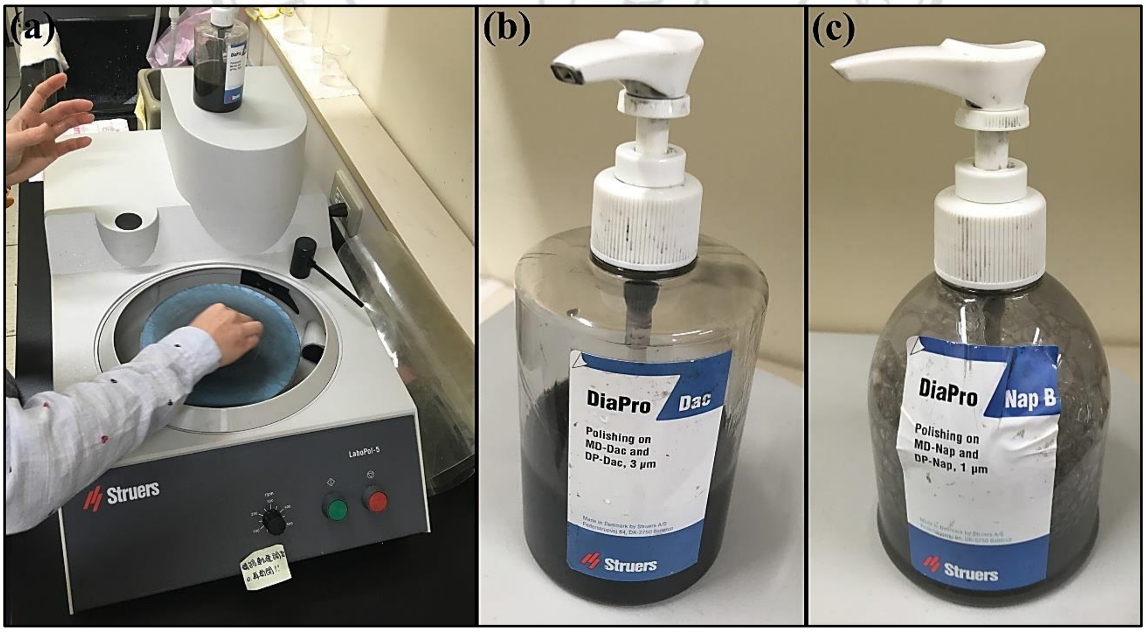

Figure 7.25 Polish on (a) polishing equipment with diamond suspension (b) 3µm and (c) 1 µm.

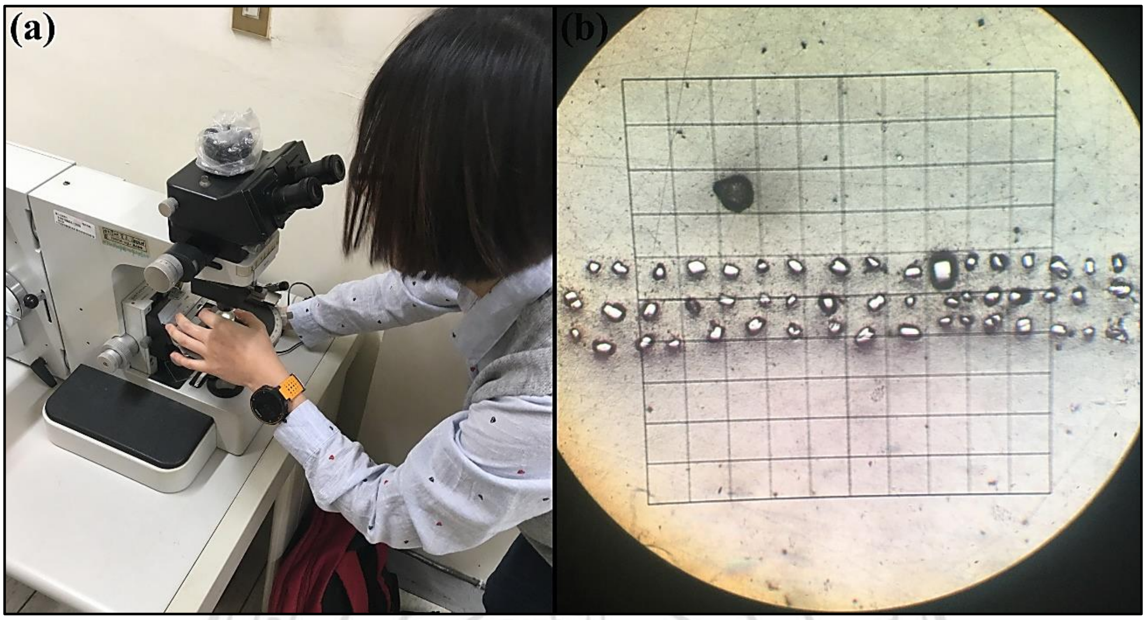

Figure 7.26 Using (a) bionocular microscope for a check (b) mount surface.

Figure 7.27 Clean the mount in water with bransonic cleaner.

7.2.2 Scanning Electron Microscope (SEM)

The completed mount making was coated by carbon coating surface with 20-30 nm thickness of carbon using Quorum Q150TE machine (Figure 7.28) installed at electron probe microanalyzers laboratory of Institute of Earth Sciences, Academia Sinica, Taiwan. Next step put the mount with carbon coating in JSM-7100F Field Emission Scanning Electron Microscope (Figure 7.29). Adjust focus and magnification of an image, select SED mode for secondary electron detector (SED) and CL mode for cathodoluminescence (CL) image (Figure 7.30). SED images used the inelastically-scattered electrons close to zircon grains surface for topographical information and CL images used to examine internal structures, growth and quality of zircon grains. The following details of steps can be found in JSM-7100F Field Emission Scanning Electron Microscope software (JEOL, 2012).

7.3.3 Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

After finish imaging with SEM, choose around 20 the best zircon grain (large grain, homogeneous, without a pit and crack) from CL image (Figure 7.31). When completed, remove carbon coat from the mount by polishing equipment with diamond suspension 1 µm in particle size and clean it in 5%HNO_3 with bransonic cleaner (Figures 7.32 and 7.33). Next install the mount with zircon standards (GJ, 91500 and PLS) following on the detail in Table 7.2 within Laser Ablation Inductively Coupled Plasma Mass Spectrometry at LAICP mass spectrometer laboratory (Figure 7.34). The experimental analysis order is GJ(1), GJ(2), 91500, PLS, 10 zircon grains sample, GJ(1) and GJ(2), if analysis ages of standards are discordant from ages on Table 7.2, it should be calibrated again. The detail of steps can be followed in Photo Machines-Chromium 2.2 software (Teledyne Tecnologies, 2013) using for the spot laser shooting on zircon grains (Figure 7.35), ICP-MS MassHunter software (Agilent Technologies, 2014) for selected parameter (Figure 7.36) and GLITTER version 4.4.4 software (Achterbergh *et al*., 2005) for select well data and fit concordant curves (Figure 7.37). Finally using Isoplot software for creating U-Pb Concordia, weighted average and probability density diagrams (Figures 7.38-7.40).

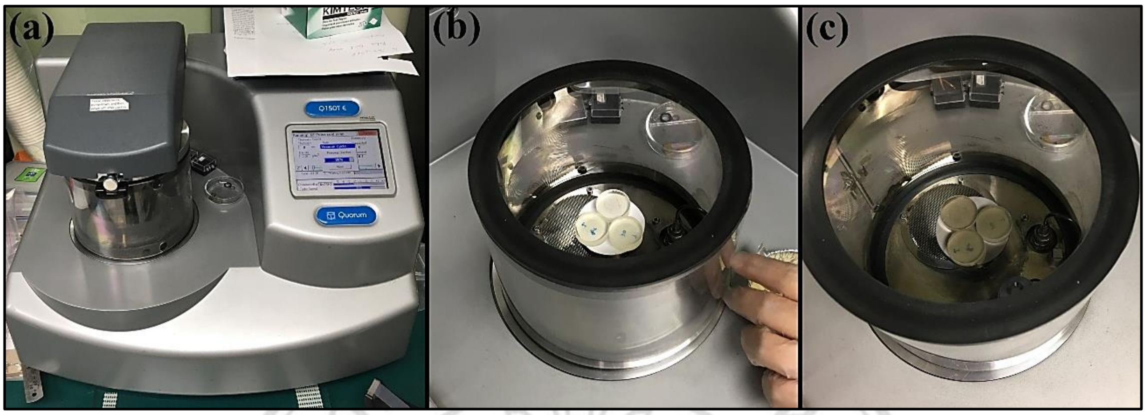

Figure 7.28 Making carbon coating by (a) Quorum Q150TE machine, the mounts (b) before and (c) after coating.

Figure 7.29 Scanning Electron Microscope.

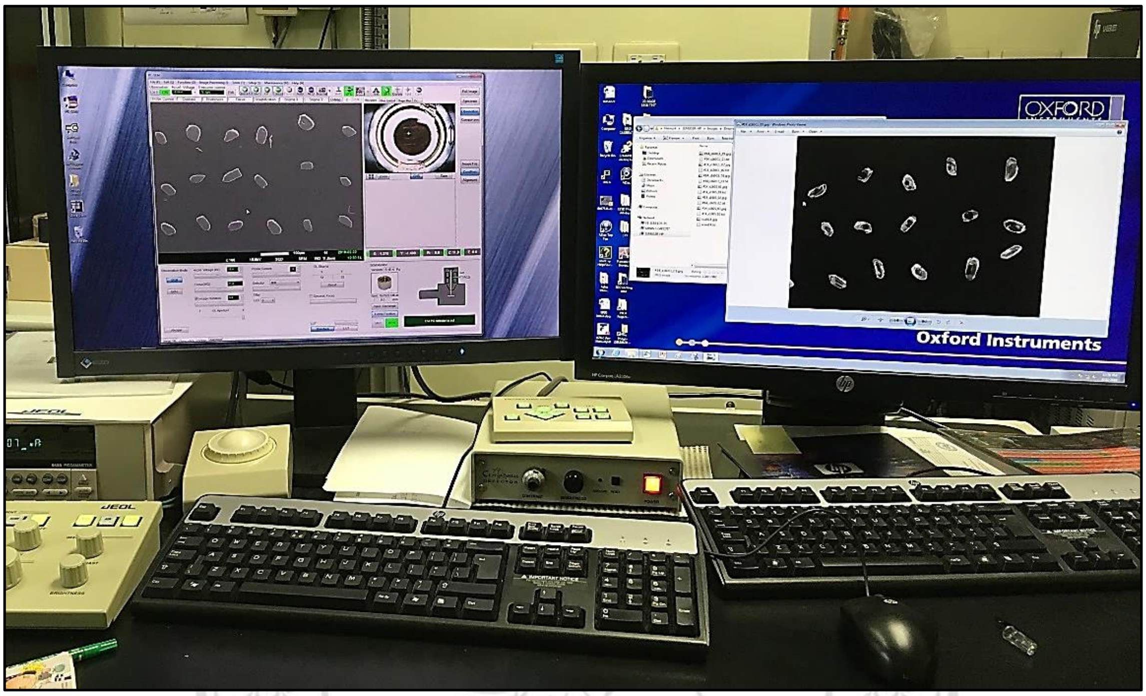

Figure 7.30 Secondary electron detector (SED) in the left screen and CL mode for cathodoluminescence (CL) image in the right screen.

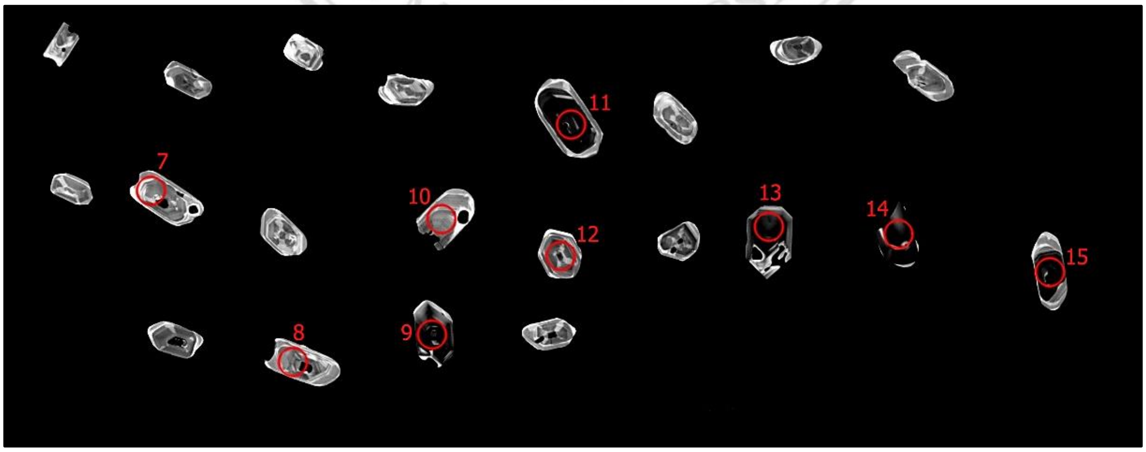

Figure 7.31 Choose 20 zircon grain from CL image.

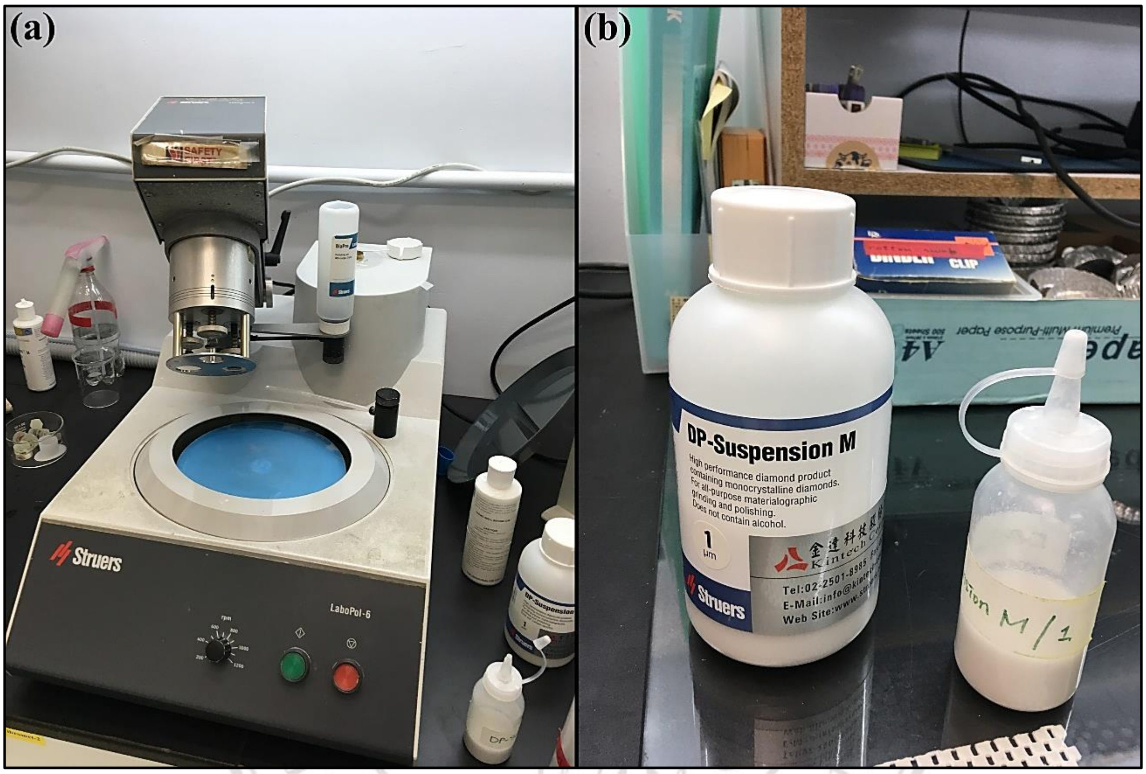

Figure 7.32 Using (a) polishing equipment with (b) diamond suspension for removing carbon coating in mount surface.

Table 7.2 The zircon standards were used to calibrate the U-Th-Pb ratios.

Standard	**Isotope**	**Age (Ma)**	**Note**
GJ (1)	^{206}Pb/^{238}U	600±6	GJ(1) and GJ(2) should not difference of age over 30 Ma (Elhlou *et al*., 2006)
GJ (2)	^{207}Pb/^{206}U	≤30	
91500	^{206}Pb/^{238}U	1065±20	Wiedenbeck *et al*. (1995, 2004)
	^{207}Pb/^{206}U	1040-1100	
PLS	^{206}Pb/^{238}U	337±10	Sláma *et al*., 2008

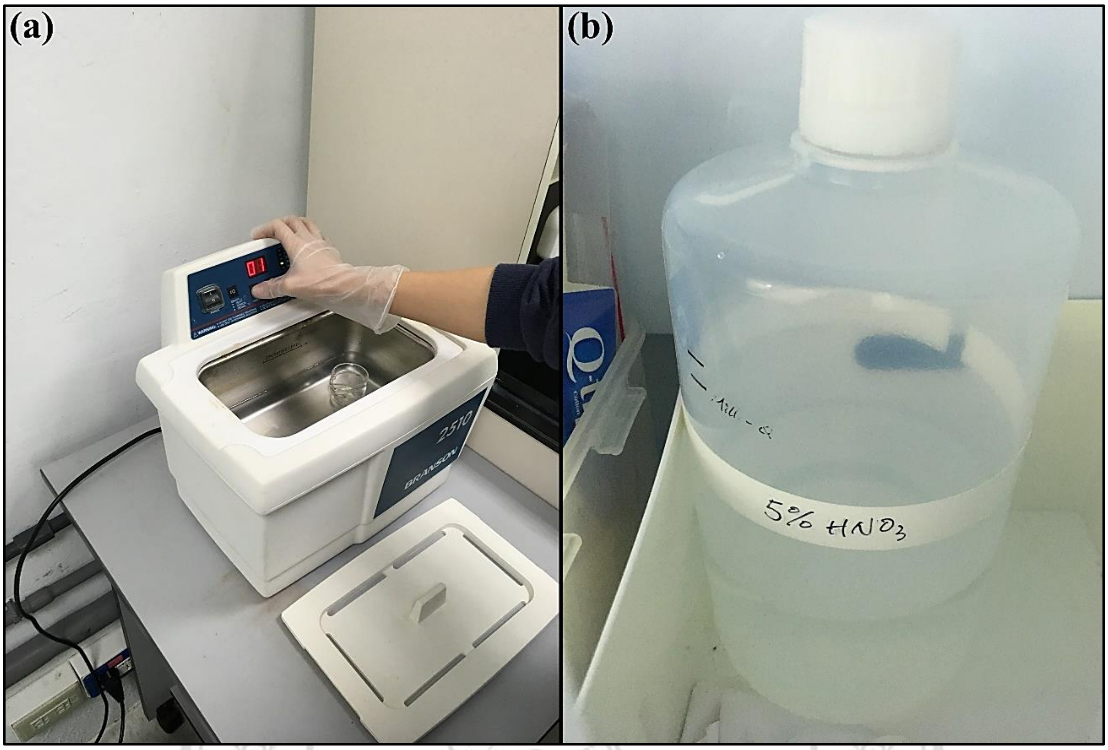

Figure 7.33 Cleaning mount by (a) bransonic cleaner in (b) 5%HNO_3.

Figure 7.34 Laser Ablation Inductively Coupled Plasma Mass Spectrometry.

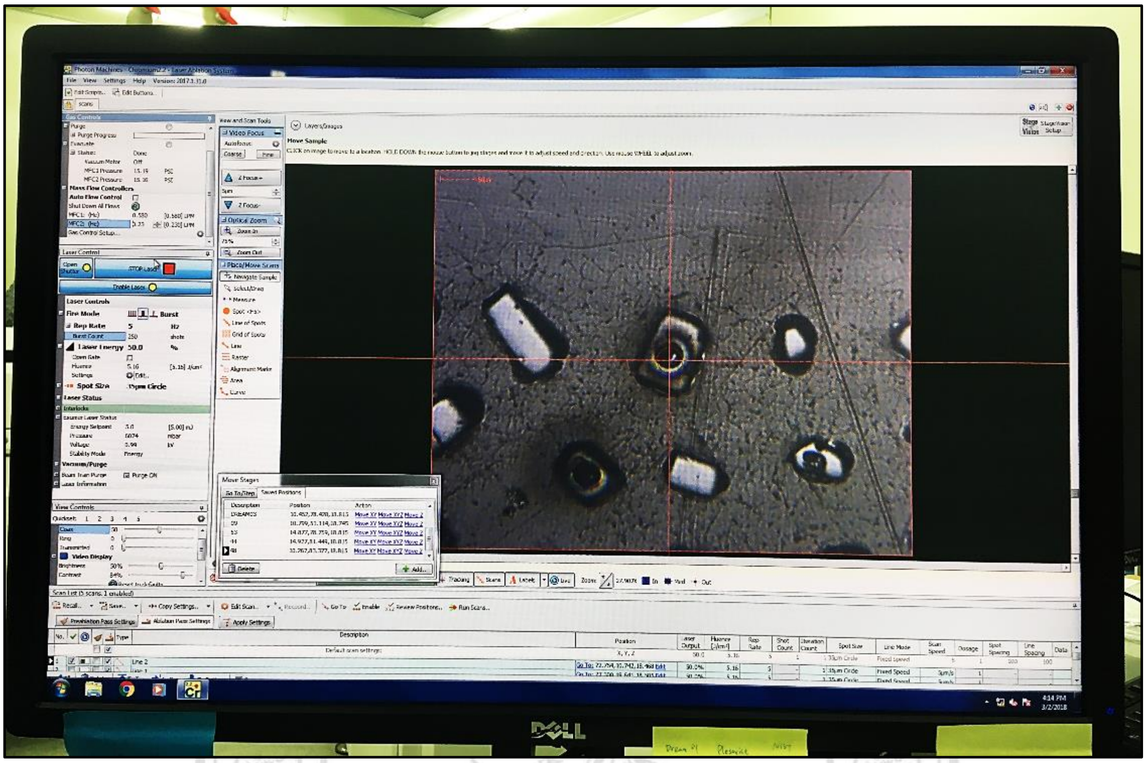

Figure 7.35 Photo Machines-Chromium 2.2 software using for the spot laser shooting on zircon grains.

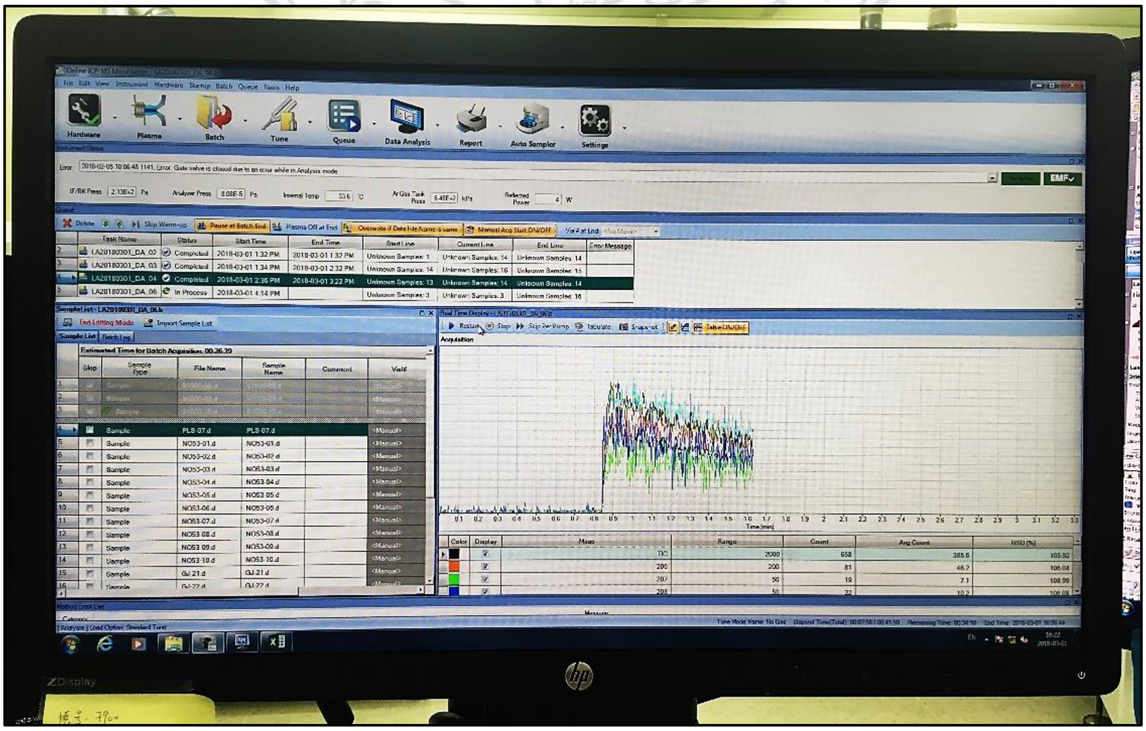

Figure 7.36 ICP-MS MassHunter software using for the selected parameter.

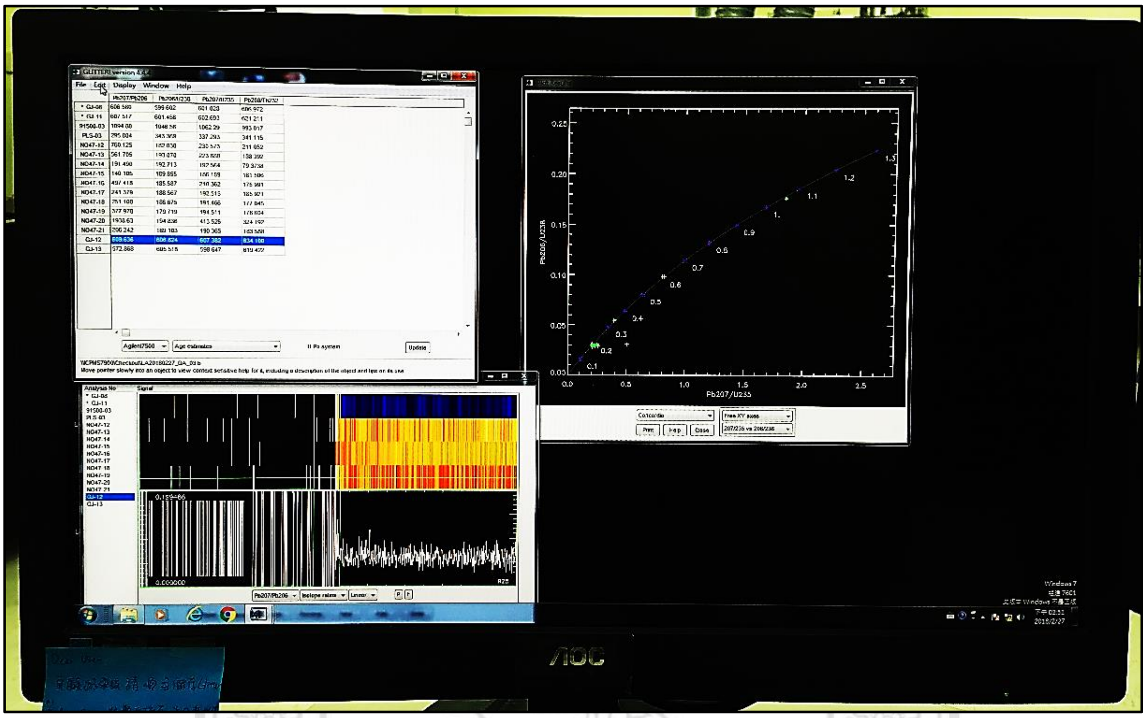

Figure 7.37 GLITTER version 4.4.4 software using for good select data and fit concordant curves.

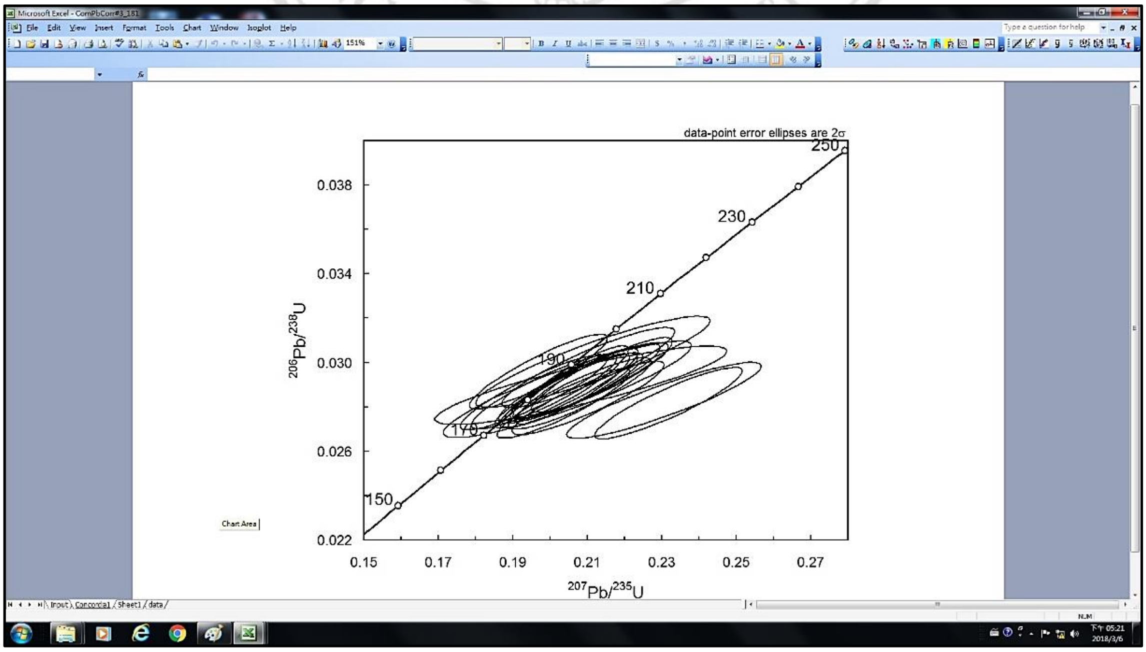

Figure 7.38 Isoplot software for creating U-Pb Concordia diagram.

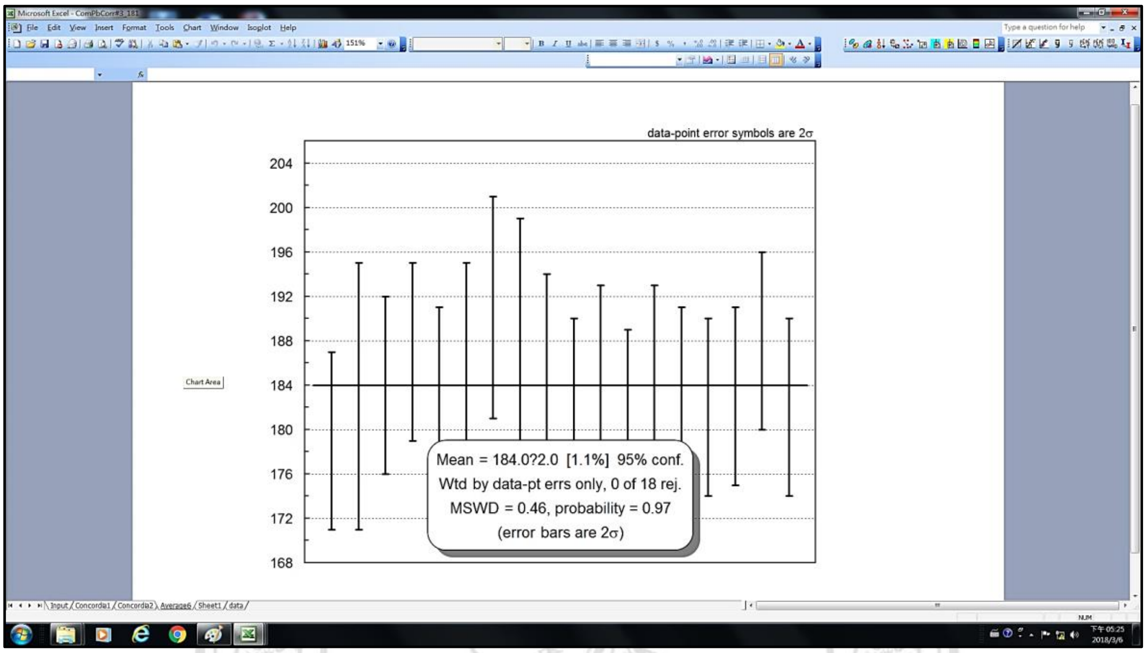

Figure 7.39 Isoplot software for creating the weighted average diagram.

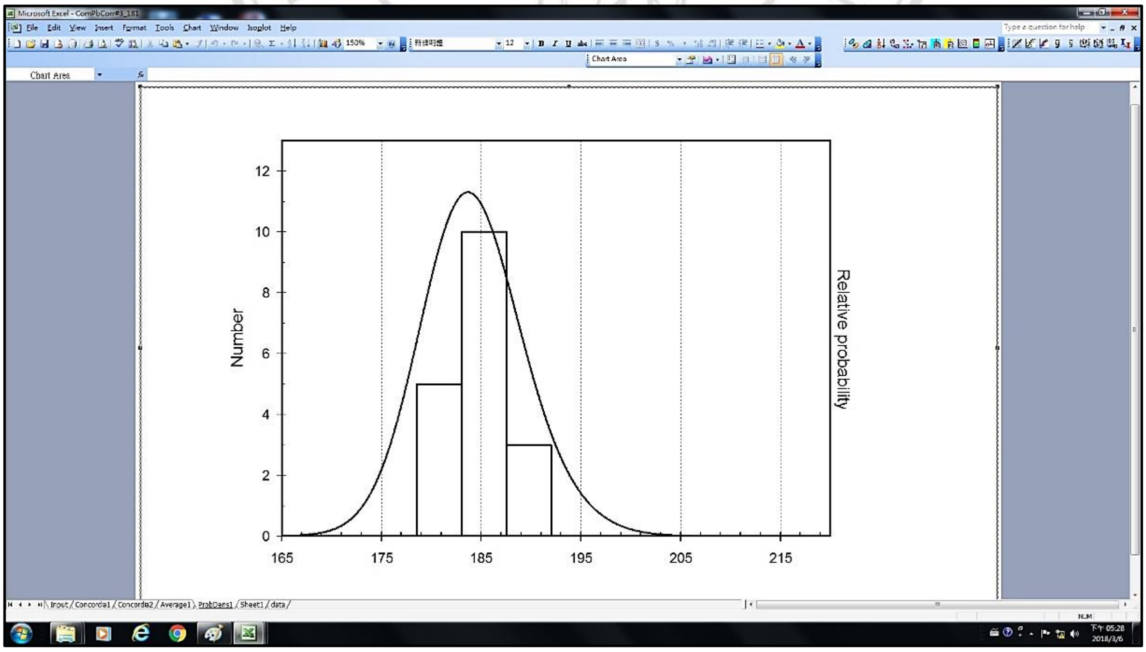

Figure 7.40 Isoplot software to creating probability density diagrams.

APPENDIX C

Cathodoluminescence (CL) images and LA-ICP-MS U-Pb isotope data

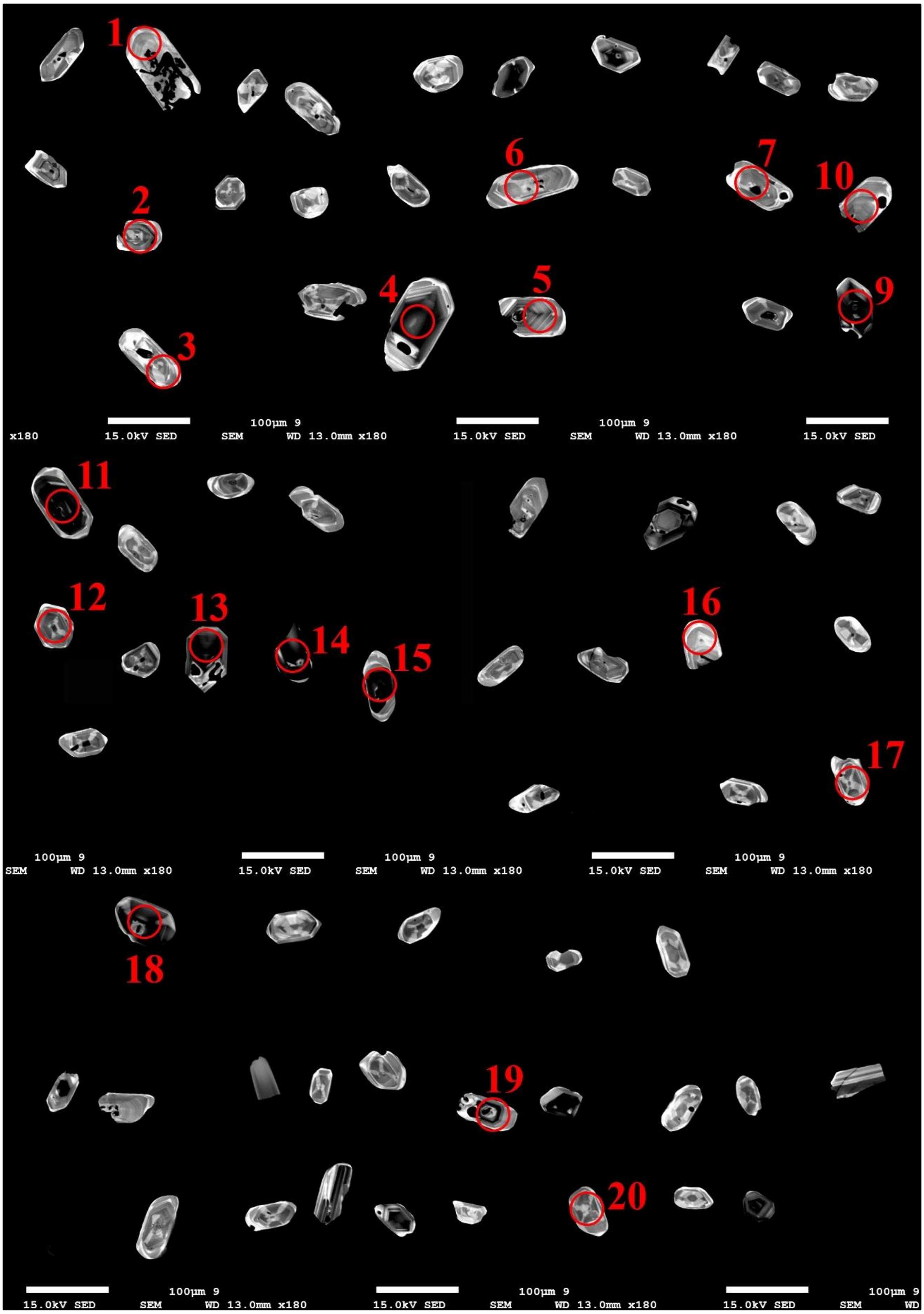

Figure 9.1 Cathodoluminescence (CL) images of zircons for sample number 09.

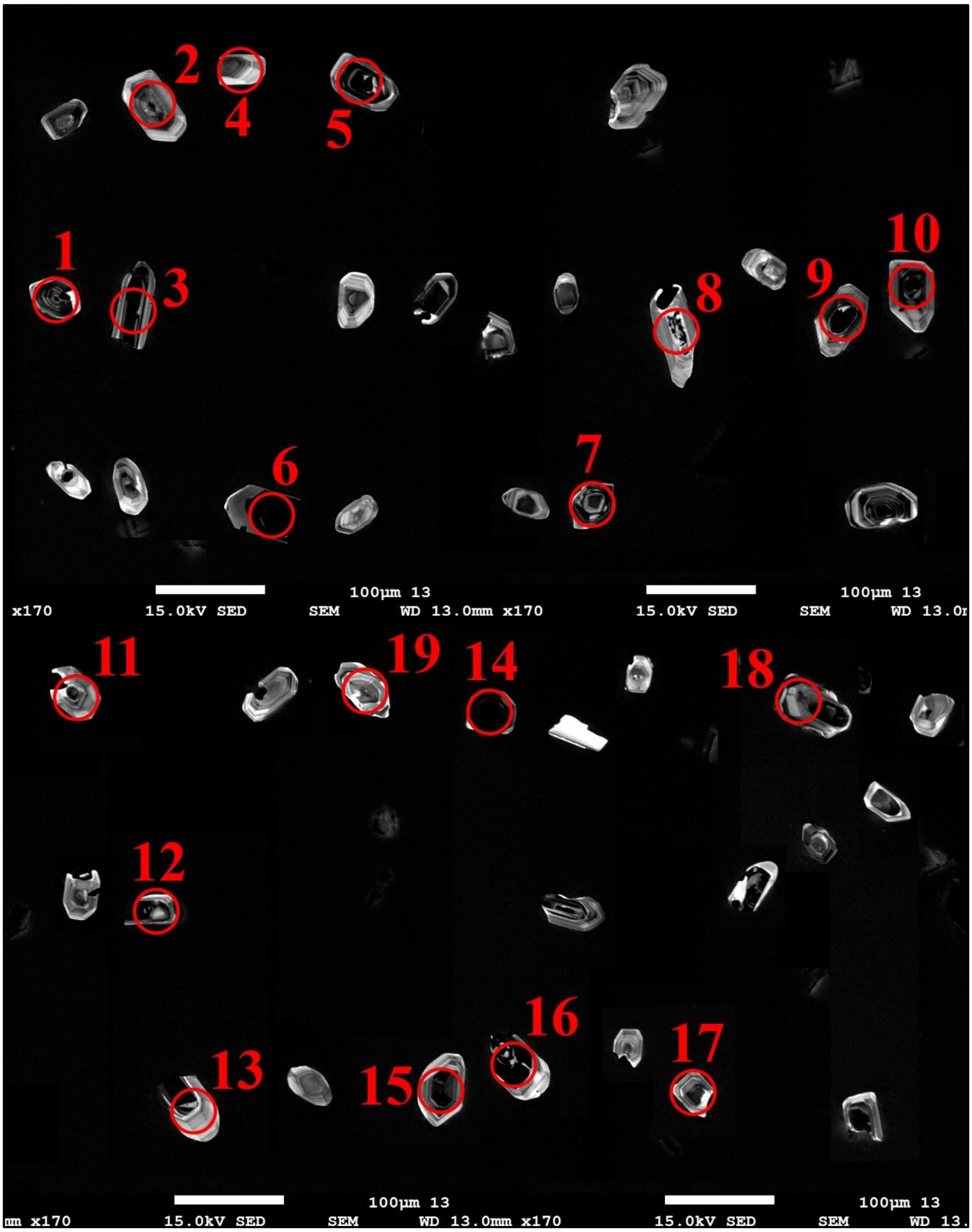

Figure 9.2 Cathodoluminescence (CL) images of zircons for sample number 13.

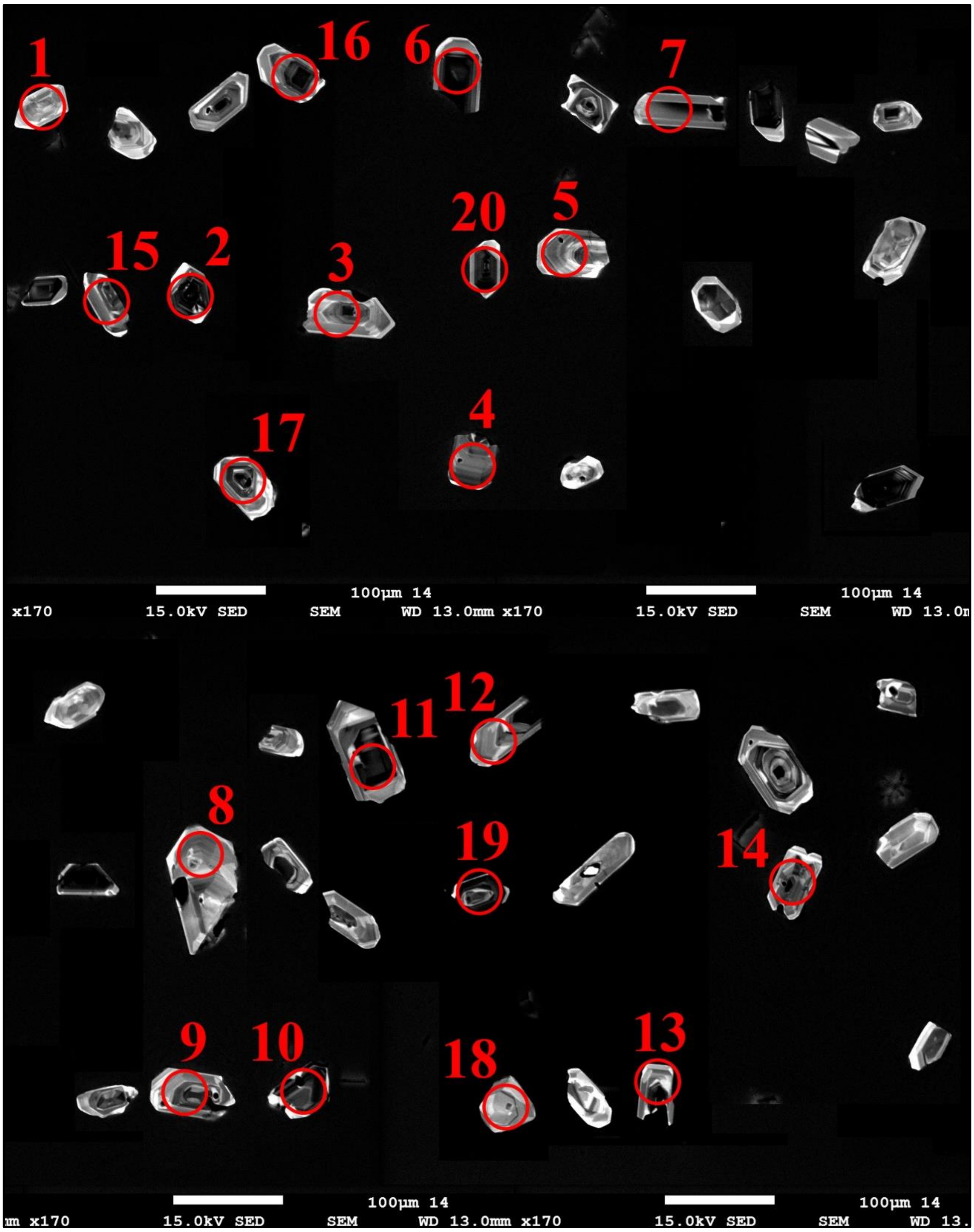

Figure 9.3 Cathodoluminescence (CL) images of zircons for sample number 14.

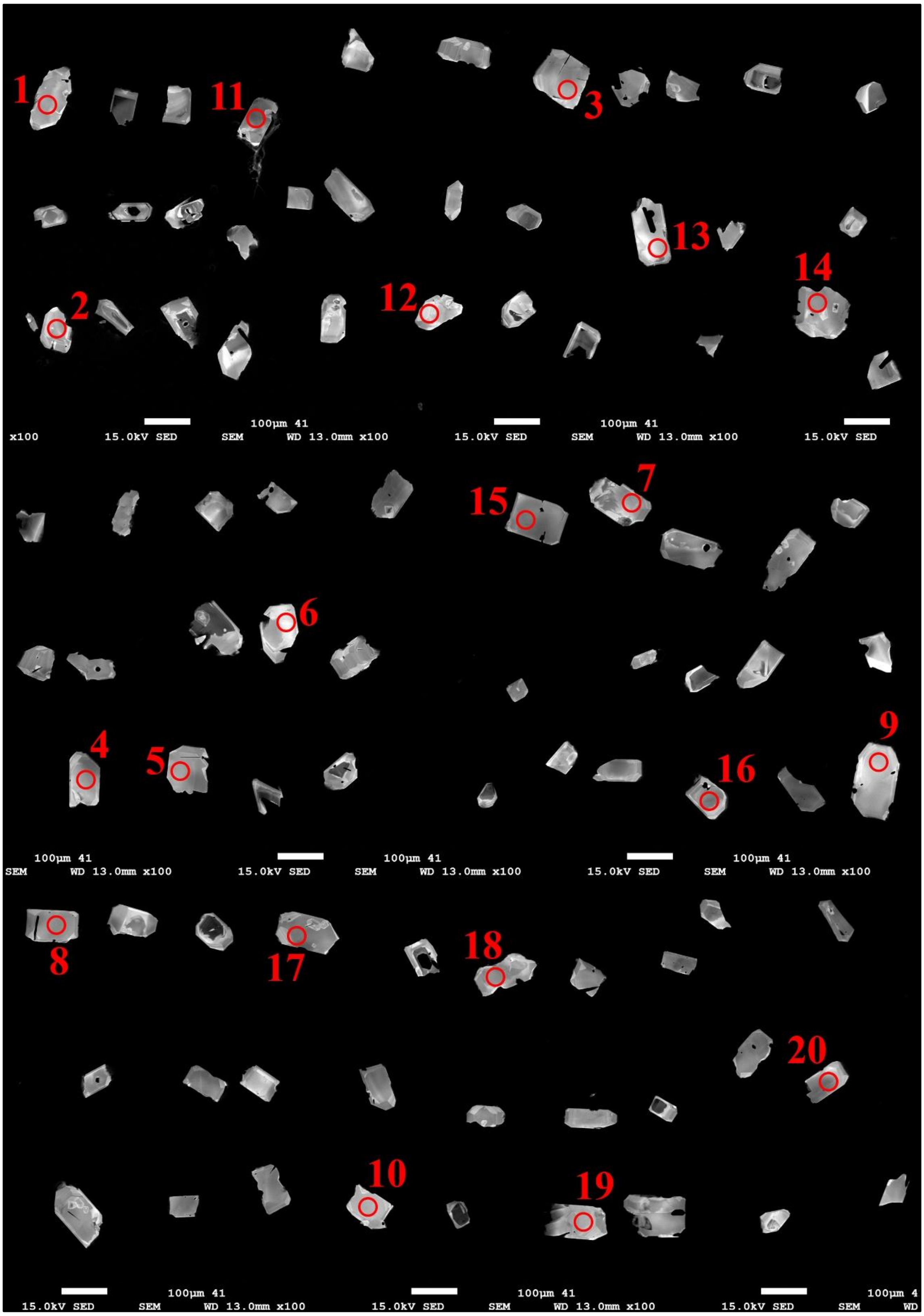

Figure 9.4 Cathodoluminescence (CL) images of zircons for sample number 41.

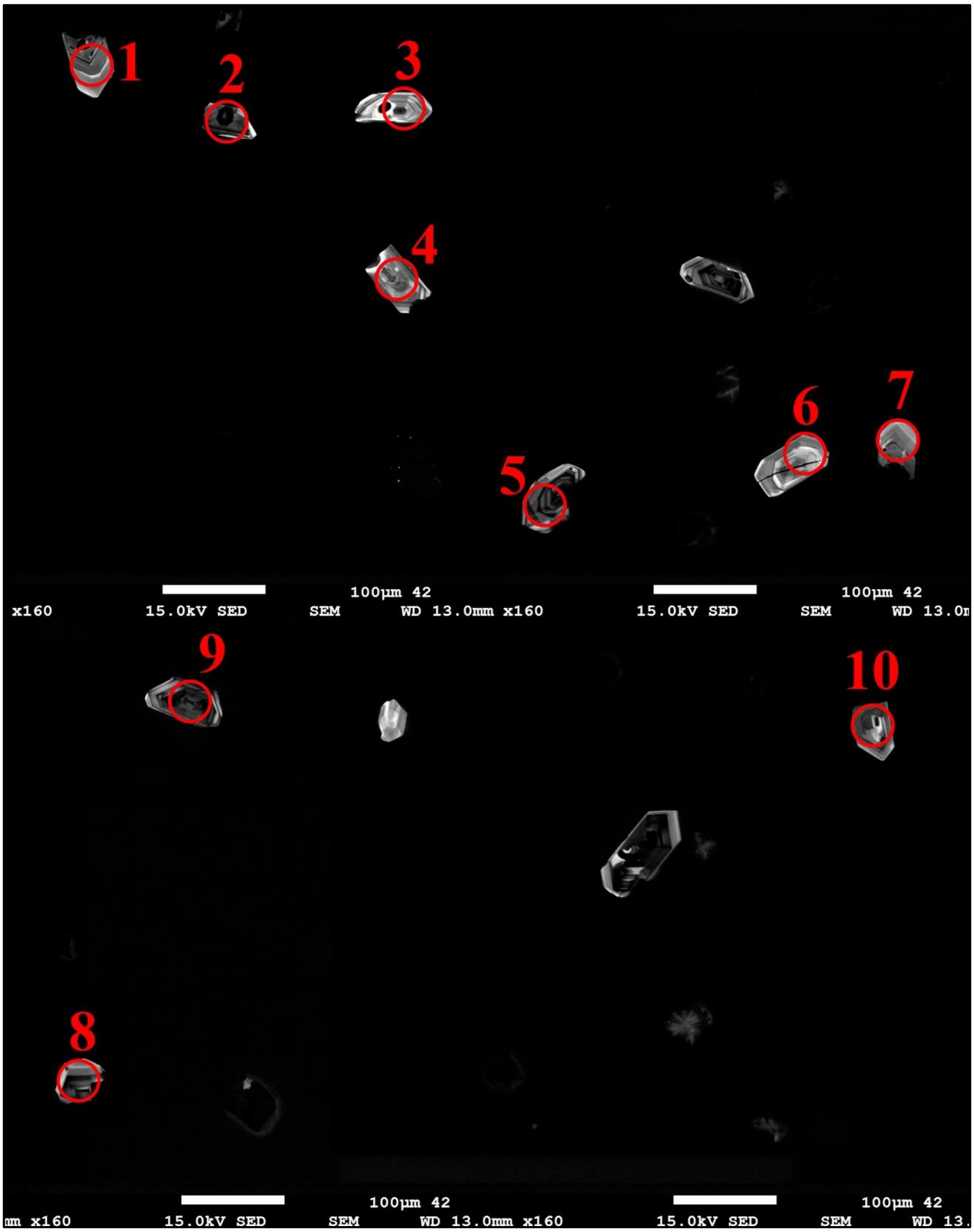

Figure 9.5 Cathodoluminescence (CL) images of zircons for sample number 42.

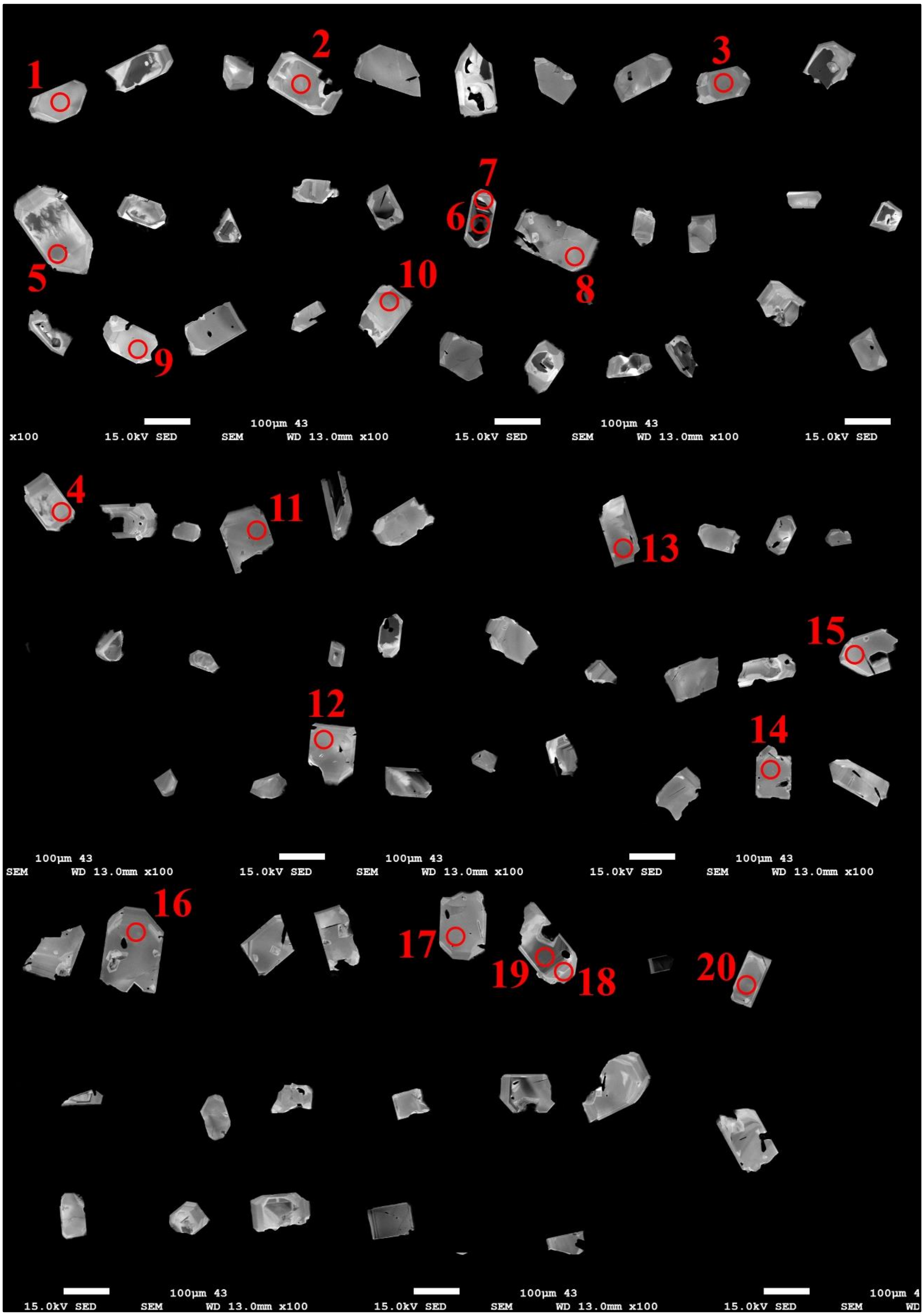

Figure 9.6 Cathodoluminescence (CL) images of zircons for sample number 43.

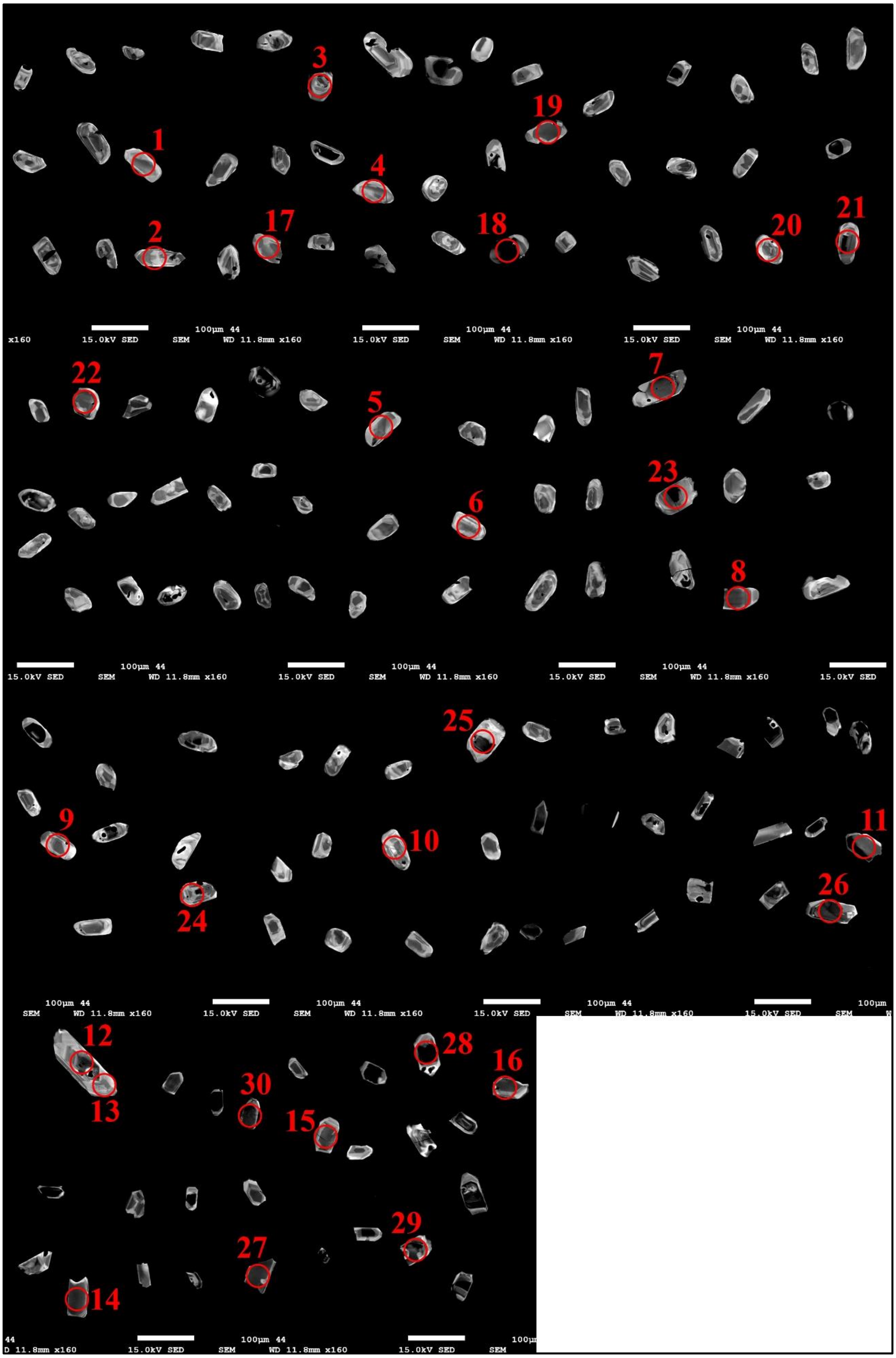

Figure 9.7 Cathodoluminescence (CL) images of zircons for sample number 44.

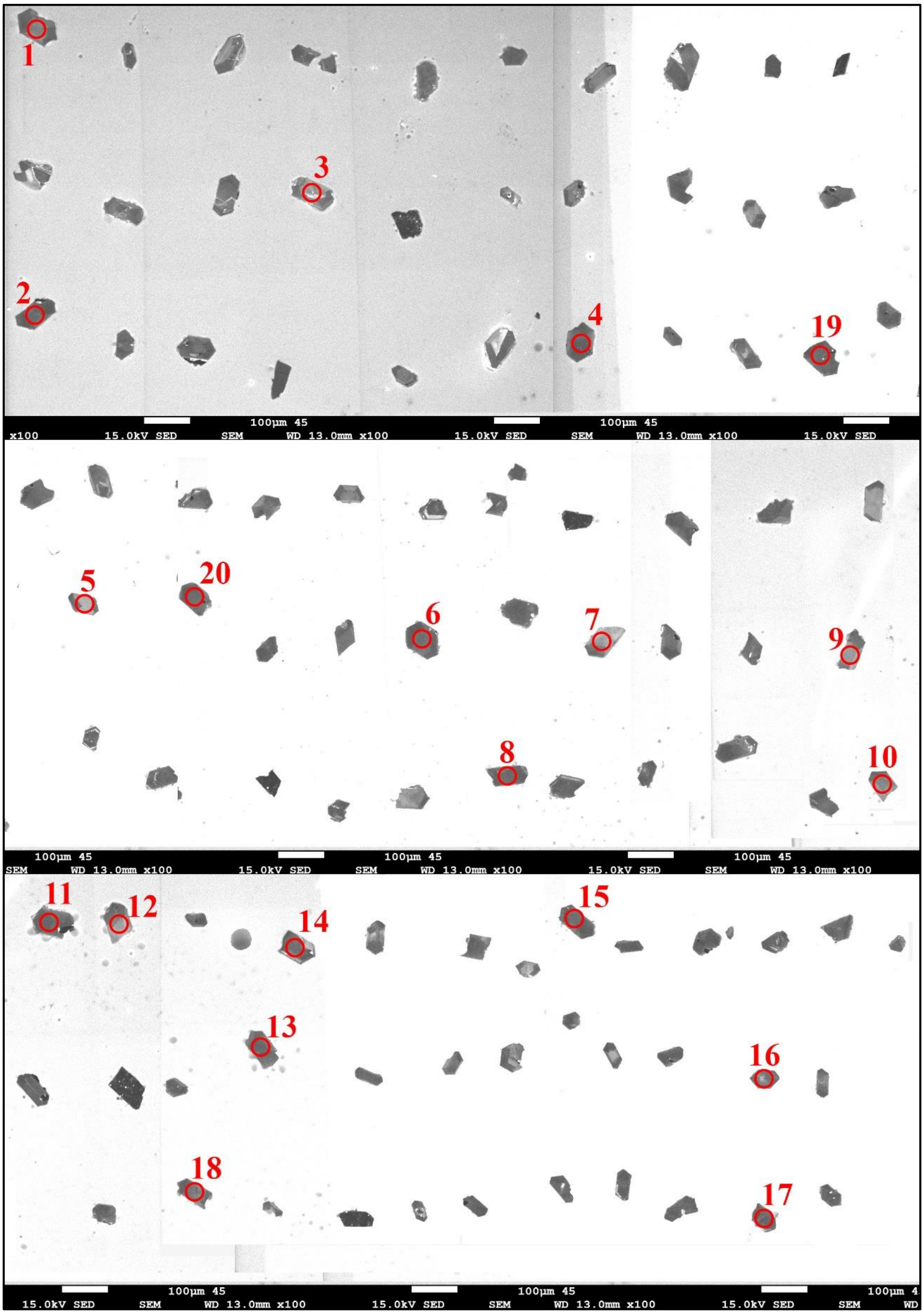

Figure 9.8 Cathodoluminescence (CL) images of zircons for sample number 46.

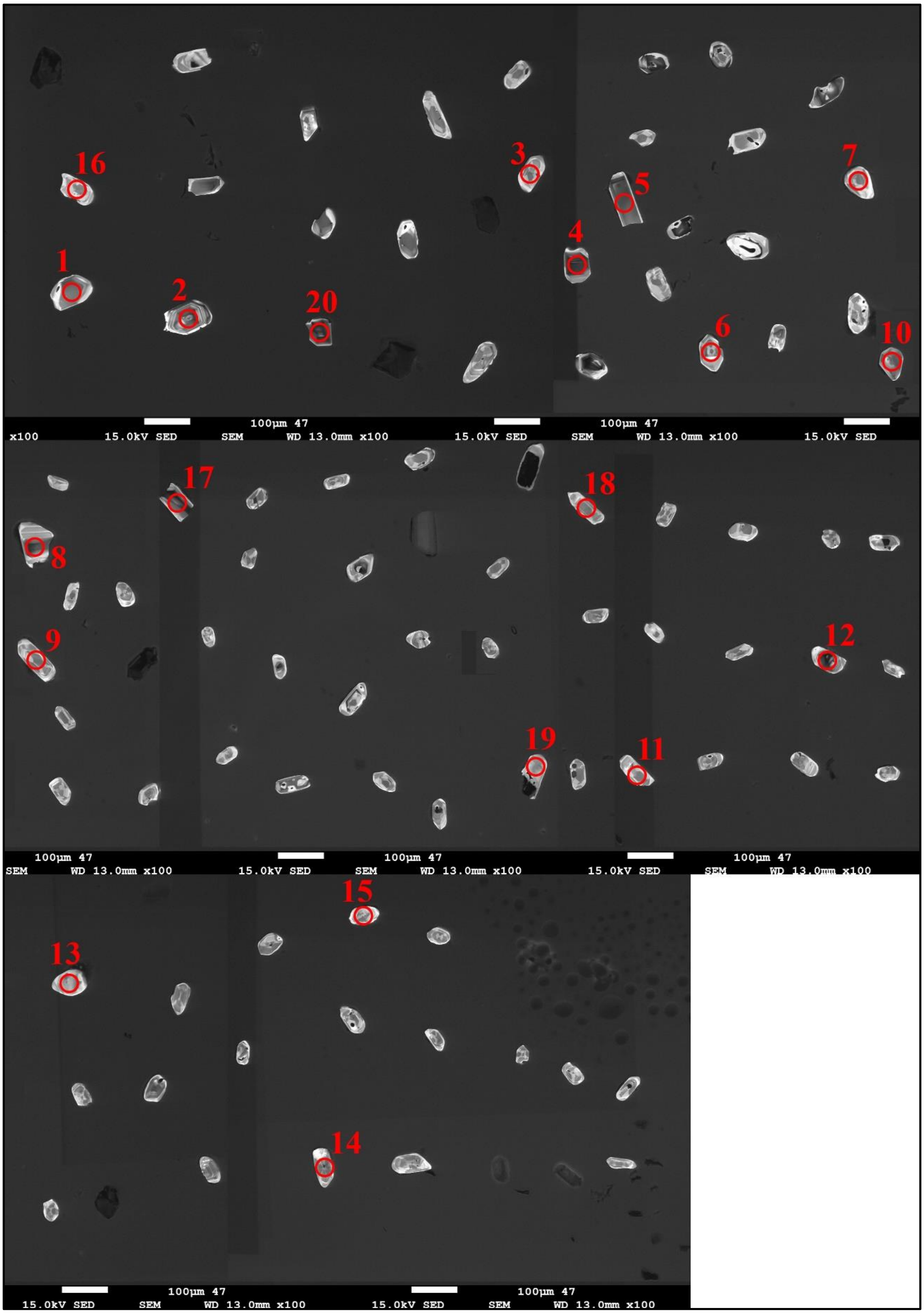

Figure 9.9 Cathodoluminescence (CL) images of zircons for sample number 48.

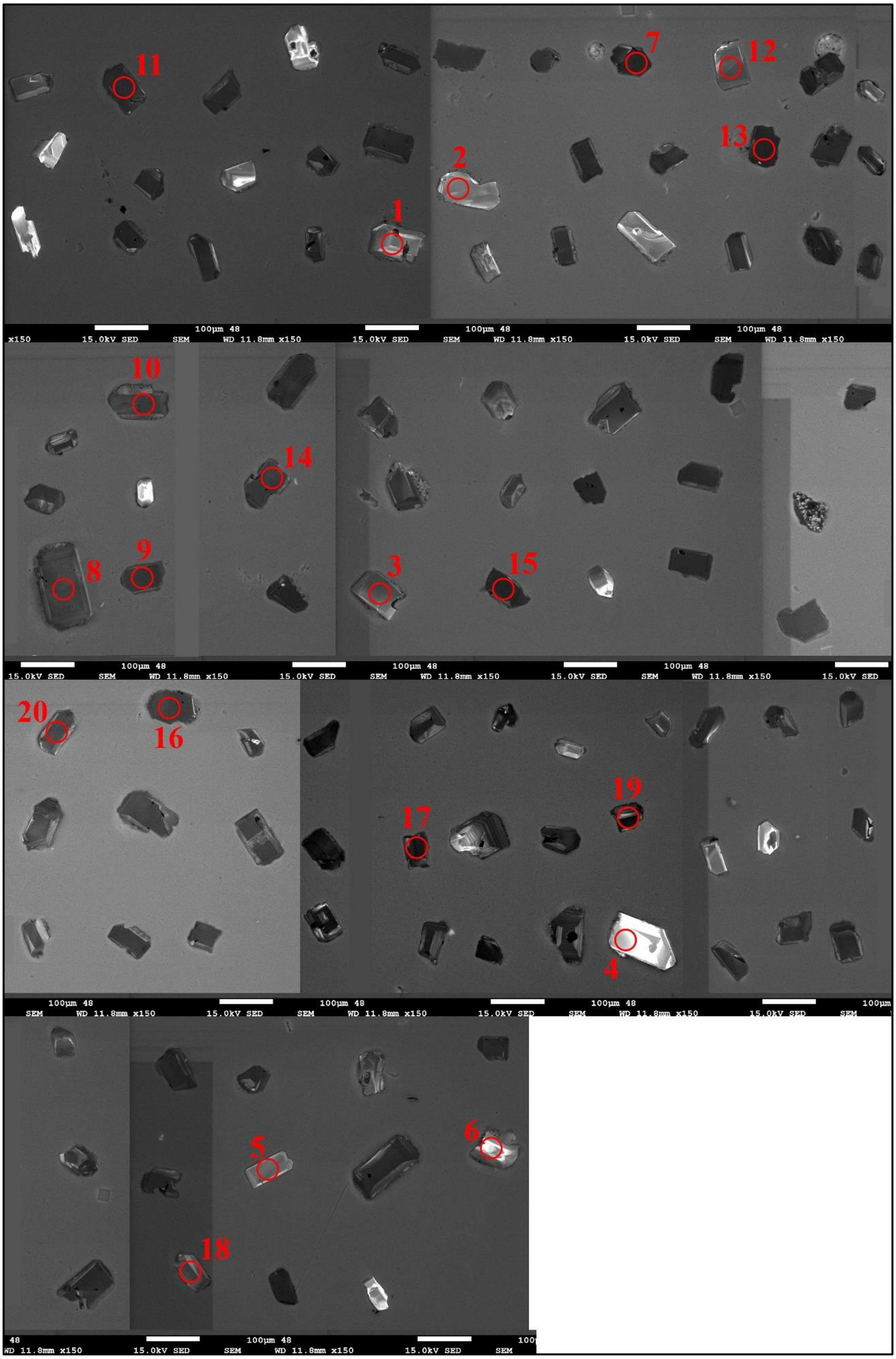

Figure 9.10 Cathodoluminescence (CL) images of zircons for sample number 49.

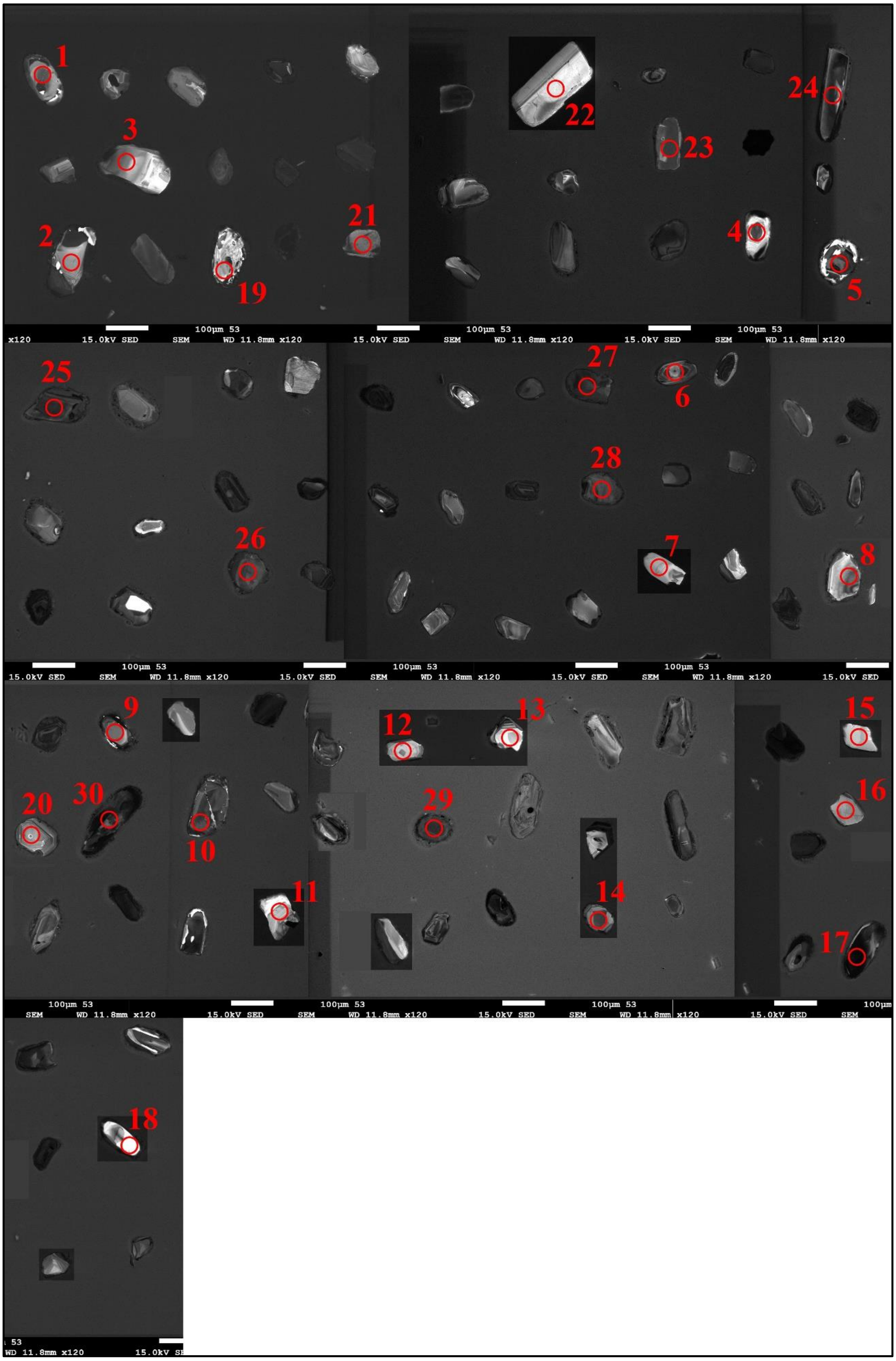

Figure 9.11 Cathodoluminescence (CL) images of zircons for sample number 53.

Table 9.1 LA-ICP-MS U-Pb isotope data for zircons from representative the studied volcanic rocks in Phayao province.

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO09-01	0.05291	0.00148	0.20457	0.00893	0.02804	0.00059	0.00879	0.00017	0.85	4.56	0.01	325	57	189	8	178	4	177	3
NO09-02	0.04792	0.00257	0.19299	0.01366	0.02921	0.00066	0.00927	0.0002	0.82	1.63	0.01	95	102	179	12	186	4	186	4
NO09-03	0.04731	0.00266	0.19054	0.01407	0.02921	0.00068	0.00928	0.00024	0.82	1.75	0.01	65	105	177	12	186	4	187	5
NO09-04	0.05065	0.00063	0.20823	0.00567	0.02982	0.00063	0.00945	0.0003	0.9	1.22	0.01	225	26	192	5	189	4	190	6
NO09-05	0.0582	0.00083	0.23703	0.00722	0.02954	0.00065	0.00959	0.00032	0.9	1.41	0.01	537	28	216	6	188	4	193	6
NO09-06	0.05365	0.00064	0.22697	0.00608	0.03069	0.00067	0.00848	0.0003	0.9	1.13	0.01	356	24	208	5	195	4	171	6
NO09-07	0.05745	0.0011	0.22597	0.00837	0.02853	0.00066	0.01076	0.00043	0.9	1.76	0.01	509	38	207	7	181	4	216	9
NO09-08	0.05402	0.00429	0.21336	0.02077	0.02865	0.00069	0.00896	0.00017	0.8	1.33	0.01	372	161	196	17	182	4	180	3
NO09-09	0.05094	0.00064	0.20314	0.00564	0.02892	0.00062	0.00896	0.00033	0.9	1.08	0.01	238	26	188	5	184	4	180	7
NO09-10	0.05094	0.00094	0.20136	0.00718	0.02867	0.00064	0.00921	0.00037	0.9	1.9	0.01	238	38	186	6	182	4	185	7
NO09-11	0.04877	0.00276	0.19505	0.01427	0.02901	0.00065	0.00918	0.00019	0.81	1.68	0.01	137	111	181	12	184	4	185	4
NO09-12	0.05195	0.00086	0.20724	0.0069	0.02894	0.00064	0.0095	0.0003	0.9	1.79	0.01	283	34	191	6	184	4	191	6
NO09-13	0.05956	0.00111	0.23888	0.00883	0.02909	0.0007	0.00983	0.00042	0.9	1.26	0.01	588	36	218	7	185	4	198	8
NO09-14	0.05339	0.00071	0.21067	0.00614	0.02862	0.00063	0.00868	0.00032	0.9	0.88	0.01	345	27	194	5	182	4	175	6
NO09-15	0.05264	0.00064	0.20919	0.00565	0.02882	0.00061	0.0093	0.0003	0.9	1.41	0.01	313	25	193	5	183	4	187	6
NO09-16	0.05244	0.00152	0.2134	0.01046	0.02952	0.00072	0.00958	0.00046	0.9	1.89	0.01	305	60	196	9	188	5	193	9
NO09-17	0.05011	0.00316	0.19944	0.0162	0.02887	0.00069	0.00911	0.00019	0.82	1.94	0.01	200	128	185	14	183	4	183	4
NO09-18	0.05156	0.00065	0.20676	0.00574	0.02909	0.00062	0.00916	0.00031	0.9	1.16	0.01	266	26	191	5	185	4	184	6
NO09-19	0.05665	0.00085	0.21507	0.00681	0.02753	0.00062	0.0084	0.00034	0.9	1.37	0.01	478	30	198	6	175	4	169	7
NO09-20	0.05267	0.00365	0.21351	0.01876	0.0294	0.00072	0.00922	0.00019	0.81	1.87	0.01	315	141	196	16	187	5	186	4
NO13-01	0.17248	0.01114	0.86196	0.10372	0.03626	0.00256	0.00919	0.0012	0.9	0.4	0.01	2582	102	631	57	230	16	185	24
NO13-02	0.05255	0.00459	0.25932	0.02654	0.03579	0.00084	0.01123	0.00024	0.71	1.3	0.01	309	186	234	21	227	5	226	5
NO13-03	0.05377	0.00073	0.26148	0.00768	0.03528	0.00078	0.01082	0.00037	0.9	2.51	0.01	361	28	236	6	224	5	218	7
NO13-04	0.05909	0.00137	0.29227	0.01263	0.03588	0.00091	0.00996	0.00047	0.9	1.59	0.01	570	47	260	10	227	6	200	9
NO13-05	0.05979	0.00072	0.29737	0.00792	0.03607	0.00076	0.01178	0.00041	0.9	1.04	0.01	596	24	264	6	228	5	237	8
NO13-06	0.05044	0.00053	0.25358	0.00606	0.03646	0.00077	0.01084	0.00034	0.9	0.88	0.01	215	23	229	5	231	5	218	7
NO13-07	0.05543	0.00832	0.26919	0.04484	0.03522	0.00095	0.01098	0.00045	0.66	1.37	0.01	430	315	242	36	223	6	221	9
NO13-08	0.10131	0.00989	0.43712	0.05163	0.03129	0.00086	0.00913	0.0002	0.8	0.98	0.01	1648	176	368	36	199	5	184	4
NO13-09	0.0573	0.00092	0.2918	0.00954	0.03693	0.00082	0.01204	0.00057	0.9	1.35	0.01	503	33	260	7	234	5	242	11
NO13-10	0.05543	0.00065	0.27553	0.00723	0.03605	0.00077	0.01178	0.00043	0.9	1.14	0.01	430	24	247	6	228	5	237	9

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO13-11	0.08868	0.00329	0.4585	0.02961	0.0376	0.00128	0.01001	0.00077	0.9	1.62	0.01	1397	67	383	21	238	8	201	15
NO13-12	0.06661	0.00786	0.33641	0.04623	0.03663	0.00105	0.01118	0.00024	0.73	1.61	0.01	826	244	294	35	232	7	225	5
NO13-13	0.05092	0.00063	0.25204	0.00694	0.0359	0.00077	0.01111	0.00036	0.9	1.48	0.01	237	27	228	6	227	5	223	7
NO13-14	0.05482	0.00061	0.26343	0.00663	0.03485	0.00074	0.00996	0.00032	0.9	1.05	0.01	405	23	237	5	221	5	200	6
NO13-15	0.05784	0.00073	0.28538	0.00791	0.03579	0.00077	0.0116	0.0004	0.9	1.26	0.01	524	26	255	6	227	5	233	8
NO13-16	0.08921	0.0152	0.41999	0.08382	0.03414	0.00128	0.01009	0.00026	0.81	1.18	0.01	1409	336	356	60	216	8	203	5
NO13-17	0.05906	0.00102	0.28981	0.01013	0.03559	0.00083	0.00958	0.00041	0.9	1.35	0.01	569	35	258	8	225	5	193	8
NO13-18	0.05284	0.00063	0.25751	0.00689	0.03535	0.00075	0.01087	0.0004	0.9	1.27	0.01	322	25	233	6	224	5	219	8
NO13-19	0.05943	0.00102	0.2945	0.01025	0.03595	0.00084	0.0106	0.00049	0.9	1.86	0.01	583	35	262	8	228	5	213	10
NO14-01	0.056	0.001	0.26598	0.00954	0.03445	0.00082	0.00938	0.00034	0.9	1.6	0.01	452	37	239	8	218	5	189	7
NO14-02	0.05976	0.00069	0.28313	0.00738	0.03436	0.00075	0.01069	0.00031	0.9	1.01	0.01	595	23	253	6	218	5	215	6
NO14-03	0.05366	0.00703	0.2515	0.03975	0.03399	0.00123	0.01064	0.00049	0.8	1.52	0.01	357	256	228	32	215	8	214	10
NO14-04	0.05144	0.00351	0.24384	0.02092	0.03438	0.00085	0.01081	0.00027	0.78	2.01	0.01	261	144	222	17	218	5	217	5
NO14-05	0.09531	0.00515	0.48326	0.03705	0.03677	0.00109	0.01079	0.00029	0.84	1.88	0.01	1534	96	400	25	233	7	217	6
NO14-06	0.05457	0.00071	0.26607	0.00768	0.03536	0.0008	0.01087	0.0004	0.9	1.42	0.01	395	27	240	6	224	5	219	8
NO14-07	0.05807	0.00103	0.28198	0.01017	0.03522	0.00085	0.01028	0.00042	0.9	1.51	0.01	532	39	252	8	223	5	207	8
NO14-08	0.05116	0.00072	0.25215	0.00761	0.03575	0.0008	0.01122	0.00041	0.9	1.92	0.01	248	32	228	6	226	5	226	8
NO14-09	0.05165	0.00071	0.24629	0.00736	0.03458	0.00077	0.01093	0.0004	0.9	1.87	0.01	270	32	224	6	219	5	220	8
NO14-10	0.05173	0.00077	0.24814	0.00773	0.0348	0.00076	0.01157	0.00061	0.9	1.73	0.01	273	34	225	6	221	5	233	12
NO14-11	0.05106	0.00056	0.25038	0.00627	0.03557	0.00075	0.01059	0.00031	0.9	0.81	0.01	244	25	227	5	225	5	213	6
NO14-12	0.04789	0.00461	0.23286	0.0276	0.03527	0.00109	0.01119	0.0006	0.79	2.04	0.01	94	199	213	23	223	7	225	12
NO14-13	0.06028	0.00239	0.28929	0.01849	0.0348	0.00102	0.01097	0.00081	0.9	1.53	0.01	614	86	258	15	221	6	221	16
NO14-14	0.05435	0.00504	0.25574	0.02919	0.03413	0.00094	0.01066	0.00023	0.83	1.53	0.01	386	206	231	24	216	6	214	5
NO14-15	0.05569	0.00081	0.2717	0.00843	0.03539	0.0008	0.01016	0.00036	0.9	1.69	0.01	440	32	244	7	224	5	204	7
NO14-16	0.05398	0.00083	0.26422	0.00865	0.03551	0.00084	0.01015	0.00046	0.9	1.3	0.01	370	35	238	7	225	5	204	9
NO14-17	0.05227	0.00068	0.24743	0.00712	0.03434	0.00076	0.01047	0.00037	0.9	1.49	0.01	297	30	224	6	218	5	211	7
NO14-18	0.05431	0.00079	0.26773	0.00818	0.03576	0.00078	0.01145	0.00042	0.9	1.93	0.01	384	32	241	7	226	5	230	8
NO14-19	0.06083	0.00073	0.28942	0.00782	0.03451	0.00076	0.01047	0.00042	0.9	1.33	0.01	633	26	258	6	219	5	211	8
NO14-20	0.0579	0.00083	0.28101	0.00873	0.03521	0.00081	0.01006	0.00046	0.9	1.27	0.01	526	32	251	7	223	5	202	9

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO41-01	0.05243	0.00093	0.21141	0.00751	0.02924	0.00068	0.00913	0.00031	0.9	1.91	0.01	304	44	195	6	186	4	184	6
NO41-02	0.05199	0.00083	0.20862	0.00692	0.0291	0.00067	0.00866	0.00029	0.9	1.63	0.01	285	40	192	6	185	4	174	6
NO41-03	0.05378	0.00109	0.21735	0.00843	0.02932	0.0007	0.00864	0.00032	0.9	2.43	0.01	362	49	200	7	186	4	174	6
NO41-04	0.05052	0.00085	0.20526	0.00703	0.02947	0.00068	0.00898	0.00032	0.9	2.14	0.01	219	42	190	6	187	4	181	6
NO41-05	0.04974	0.00086	0.20406	0.00711	0.02975	0.00069	0.00873	0.00032	0.9	1.97	0.01	183	44	189	6	189	4	176	6
NO41-06	0.05554	0.00296	0.22342	0.01619	0.02917	0.00072	0.00909	0.00019	0.85	2.14	0.01	434	132	205	13	185	4	183	4
NO41-07	0.05097	0.00086	0.20567	0.00703	0.02926	0.00067	0.00888	0.00035	0.9	1.85	0.01	239	42	190	6	186	4	179	7
NO41-08	0.04878	0.00098	0.19751	0.00758	0.02937	0.00069	0.009	0.00037	0.9	2.12	0.01	137	51	183	6	187	4	181	7
NO41-09	0.05242	0.00099	0.21254	0.00787	0.02941	0.00069	0.00908	0.00038	0.9	2.07	0.01	304	47	196	7	187	4	183	8
NO41-10	0.04951	0.001	0.20096	0.00773	0.02944	0.00069	0.00895	0.00039	0.9	2.22	0.01	172	51	186	7	187	4	180	8
NO41-11	0.05624	0.00096	0.2291	0.00797	0.02955	0.00069	0.00978	0.00033	0.9	2.11	0.01	462	41	209	7	188	4	197	7
NO41-12	0.04468	0.00115	0.18324	0.00827	0.02974	0.00071	0.00917	0.00035	0.9	2.73	0.01	-36	57	171	7	189	4	185	7
NO41-13	0.0519	0.00149	0.21058	0.01031	0.02943	0.00073	0.00955	0.0004	0.9	3.07	0.02	281	72	194	9	187	5	192	8
NO41-14	0.05258	0.00102	0.21105	0.00797	0.02912	0.00069	0.00878	0.00032	0.9	2.37	0.01	311	48	194	7	185	4	177	6
NO41-15	0.0507	0.00067	0.20708	0.00602	0.02962	0.00066	0.00899	0.00031	0.9	1.38	0.01	227	33	191	5	188	4	181	6
NO41-16	0.05487	0.00128	0.22585	0.00962	0.02986	0.00072	0.01258	0.00064	0.9	1.9	0.01	407	57	207	8	190	5	253	13
NO41-17	0.05604	0.00112	0.222	0.00858	0.02873	0.00069	0.00909	0.00036	0.9	2.38	0.01	454	48	204	7	183	4	183	7
NO41-18	0.05201	0.00099	0.20684	0.00772	0.02884	0.00068	0.00867	0.00035	0.9	2.09	0.01	286	47	191	6	183	4	174	7
NO41-19	0.05414	0.00122	0.21674	0.00909	0.02904	0.00071	0.00942	0.00042	0.9	2.64	0.01	377	55	199	8	185	4	190	8
NO41-20	0.05324	0.00106	0.21694	0.00831	0.02956	0.0007	0.00941	0.00041	0.9	2.2	0.01	339	49	199	7	188	4	189	8
NO42-01	0.05207	0.00066	0.25654	0.00722	0.03573	0.00079	0.0108	0.00033	0.9	1.51	0.01	288	28	232	6	226	5	217	7
NO42-02	0.05774	0.00084	0.2848	0.00898	0.03577	0.00085	0.00999	0.00041	0.9	1.24	0.01	520	31	254	7	227	5	201	8
NO42-04	0.05427	0.00328	0.26419	0.0213	0.0353	0.0009	0.01103	0.00023	0.85	1.51	0.01	382	134	238	17	224	6	222	5
NO42-05	0.05149	0.00059	0.25189	0.00659	0.03548	0.00078	0.01096	0.00036	0.9	1.25	0.01	263	26	228	5	225	5	220	7
NO42-06	0.05498	0.00079	0.2634	0.00812	0.03475	0.00078	0.01225	0.00043	0.9	1.93	0.01	411	32	237	7	220	5	246	9
NO42-07	0.06633	0.00188	0.30714	0.01581	0.03357	0.00097	0.00778	0.0005	0.9	1.79	0.01	817	58	272	12	213	6	157	10
NO42-08	0.06253	0.00081	0.30553	0.00877	0.03544	0.00079	0.01014	0.00037	0.9	1.03	0.01	692	27	271	7	225	5	204	7
NO42-09	0.06459	0.0008	0.32143	0.00893	0.03609	0.00081	0.01066	0.00042	0.9	0.93	0.01	761	25	283	7	229	5	214	8
NO42-10	0.05635	0.00088	0.2792	0.00917	0.03594	0.00084	0.01116	0.0005	0.9	1.43	0.01	466	34	250	7	228	5	224	10

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO43-01	0.05909	0.00156	0.2306	0.01068	0.0283	0.0007	0.00923	0.0004	0.9	2.08	0.12	570	53	211	9	180	4	186	8
NO43-02	0.05242	0.00095	0.20357	0.00727	0.02816	0.00064	0.00866	0.00037	0.9	1.04	0.06	304	38	188	6	179	4	174	7
NO43-03	0.05156	0.00211	0.20465	0.0136	0.0288	0.00089	0.00694	0.0004	0.9	2.28	0.13	266	87	189	11	183	6	140	8
NO43-04	0.05149	0.00091	0.20589	0.00727	0.029	0.00067	0.0089	0.00036	0.9	1.72	0.1	263	38	190	6	184	4	179	7
NO43-05	0.05269	0.00096	0.21391	0.00775	0.02944	0.00069	0.00907	0.00038	0.9	1.77	0.1	315	39	197	6	187	4	182	8
NO43-06	0.05188	0.00073	0.20613	0.00628	0.02882	0.00065	0.00867	0.00035	0.9	1.06	0.06	280	30	190	5	183	4	174	7
NO43-07	0.05967	0.00103	0.23177	0.00809	0.02817	0.00066	0.0092	0.00041	0.9	1.47	0.09	592	35	212	7	179	4	185	8
NO43-08	0.05209	0.00127	0.20888	0.00933	0.02909	0.00074	0.00859	0.00041	0.9	1.99	0.12	289	52	193	8	185	5	173	8
NO43-09	0.05109	0.00192	0.21149	0.01285	0.03004	0.00084	0.01006	0.00092	0.9	1.33	0.08	245	81	195	11	191	5	202	18
NO43-10	0.0512	0.00129	0.21026	0.00949	0.02978	0.00074	0.00902	0.00045	0.9	2.12	0.13	250	54	194	8	189	5	181	9
NO43-11	0.05023	0.00287	0.20021	0.01485	0.02891	0.00068	0.00912	0.0002	0.8	2.12	0.13	206	120	185	13	184	4	183	4
NO43-12	0.05013	0.00107	0.19839	0.008	0.0287	0.00069	0.00932	0.00036	0.9	2.19	0.13	201	46	184	7	182	4	188	7
NO43-13	0.05121	0.00073	0.20555	0.00634	0.02911	0.00067	0.00915	0.00032	0.9	1.49	0.09	250	30	190	5	185	4	184	6
NO43-14	0.05368	0.00112	0.21021	0.00834	0.0284	0.00068	0.00892	0.00036	0.9	2.03	0.12	358	44	194	7	181	4	179	7
NO43-15	0.05209	0.00107	0.20938	0.00821	0.02915	0.0007	0.00932	0.00037	0.9	1.92	0.11	289	43	193	7	185	4	188	7
NO43-16	0.05175	0.00108	0.20505	0.00813	0.02874	0.00069	0.00895	0.00037	0.9	2.24	0.13	274	44	189	7	183	4	180	7
NO43-17	0.04951	0.0011	0.19562	0.00807	0.02866	0.00069	0.00874	0.00037	0.9	2.04	0.12	172	48	181	7	182	4	176	7
NO43-18	0.05173	0.00097	0.20499	0.00757	0.02874	0.00068	0.00882	0.00038	0.9	2.2	0.13	273	40	189	6	183	4	177	8
NO43-19	0.04826	0.00097	0.19689	0.00756	0.02959	0.00069	0.00922	0.00042	0.9	1.79	0.11	112	44	182	6	188	4	186	8
NO43-20	0.05271	0.00104	0.20792	0.00784	0.02861	0.00066	0.00966	0.00049	0.9	1.51	0.09	316	42	192	7	182	4	194	10
NO44-01	0.04809	0.0008	0.19158	0.00641	0.0289	0.00064	0.00901	0.00027	0.9	1.76	0.01	104	39	178	5	184	4	181	5
NO44-02	0.06208	0.00104	0.24365	0.0083	0.02847	0.00065	0.0091	0.00028	0.9	1.84	0.01	677	36	221	7	181	4	183	6
NO44-03	0.05342	0.00086	0.22153	0.0073	0.03008	0.00067	0.01021	0.00033	0.9	1.96	0.01	347	36	203	6	191	4	205	7
NO44-04	0.0497	0.00077	0.19684	0.00628	0.02873	0.00063	0.00858	0.00027	0.9	1.57	0.01	181	36	182	5	183	4	173	5
NO44-05	0.05113	0.00072	0.20159	0.00607	0.0286	0.00063	0.0092	0.00029	0.9	1.22	0.01	247	32	186	5	182	4	185	6
NO44-06	0.05324	0.00086	0.20786	0.00685	0.02832	0.00063	0.00929	0.00031	0.9	1.71	0.01	339	36	192	6	180	4	187	6
NO44-07	0.05527	0.00815	0.21906	0.03654	0.02874	0.00085	0.00896	0.00036	0.71	1.17	0.01	423	329	201	30	183	5	180	7
NO44-08	0.04955	0.0006	0.1992	0.00541	0.02916	0.00063	0.00853	0.0003	0.9	0.89	0.01	174	28	184	5	185	4	172	6
NO44-09	0.06967	0.00109	0.26918	0.00869	0.02802	0.00062	0.00932	0.00038	0.9	1.38	0.01	919	32	242	7	178	4	188	8
NO44-10	0.05227	0.00098	0.20996	0.0077	0.02914	0.00068	0.0092	0.00039	0.9	1.76	0.01	297	42	194	6	185	4	185	8

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO44-11	0.05547	0.00270	0.28139	0.01866	0.03679	0.00086	0.01147	0.00023	0.83	1.58	0.01	431	110	252	15	233	5	230	5
NO44-12	0.05579	0.00074	0.29544	0.00855	0.03841	0.00084	0.01238	0.00037	0.90	2.19	0.01	444	29	263	7	243	5	249	7
NO44-13	0.05106	0.00069	0.25621	0.00747	0.03640	0.00079	0.01141	0.00036	0.90	2.03	0.01	244	31	232	6	230	5	229	7
NO44-14	0.05342	0.00062	0.26764	0.00706	0.03634	0.00079	0.01047	0.00034	0.90	0.93	0.01	347	26	241	6	230	5	211	7
NO44-15	0.05308	0.00072	0.26628	0.00788	0.03639	0.00081	0.01185	0.00041	0.90	1.74	0.01	332	31	240	6	230	5	238	8
NO44-16	0.05236	0.00066	0.24877	0.00697	0.03446	0.00075	0.01074	0.00036	0.90	1.64	0.01	301	29	226	6	218	5	216	7
NO44-17	0.04905	0.00086	0.19816	0.00692	0.02930	0.00066	0.00933	0.00034	0.90	1.97	0.01	150	41	184	6	186	4	188	7
NO44-18	0.05007	0.00068	0.20157	0.00592	0.02920	0.00064	0.00971	0.00035	0.90	1.45	0.01	198	31	186	5	186	4	195	7
NO44-19	0.05624	0.00143	0.22488	0.01043	0.02901	0.00076	0.00846	0.00044	0.90	1.85	0.01	462	56	206	9	184	5	170	9
NO44-20	0.05524	0.00097	0.22064	0.00767	0.02897	0.00065	0.00975	0.00041	0.90	1.71	0.01	422	39	202	6	184	4	196	8
NO44-21	0.05977	0.00125	0.24077	0.00971	0.02922	0.00073	0.00983	0.00039	0.90	1.64	0.01	595	45	219	8	186	5	198	8
NO44-22	0.05413	0.00082	0.21553	0.00679	0.02888	0.00063	0.00901	0.00027	0.90	1.61	0.01	376	34	198	6	184	4	181	5
NO44-23	0.05135	0.00520	0.18684	0.02166	0.02639	0.00065	0.00830	0.00031	0.66	1.59	0.01	257	227	174	19	168	4	167	6
NO44-24	0.06230	0.00100	0.23840	0.00778	0.02776	0.00061	0.00922	0.00033	0.90	1.43	0.01	684	34	217	6	177	4	186	7
NO44-25	0.05370	0.00169	0.22304	0.01207	0.03012	0.00084	0.00951	0.00051	0.90	1.95	0.01	358	71	204	10	191	5	191	10
NO44-26	0.05698	0.00069	0.28681	0.00776	0.03651	0.00078	0.01158	0.00038	0.90	1.49	0.01	491	27	256	6	231	5	233	8
NO44-27	0.05665	0.00071	0.28258	0.00789	0.03618	0.00079	0.01148	0.00043	0.90	1.14	0.01	478	28	253	6	229	5	231	9
NO44-28	0.05515	0.00077	0.27584	0.00831	0.03628	0.00082	0.01186	0.00052	0.90	1.12	0.01	418	31	247	7	230	5	238	10
NO44-29	0.05671	0.00072	0.27895	0.00778	0.03568	0.00077	0.01196	0.00044	0.90	1.89	0.01	480	28	250	6	226	5	240	9
NO44-30	0.05324	0.00060	0.26088	0.00666	0.03554	0.00075	0.01074	0.00039	0.90	1.33	0.01	339	25	235	5	225	5	216	8
NO46-01	0.05046	0.00052	0.21266	0.00503	0.03057	0.00067	0.00905	0.00028	0.90	2.49	0.01	216	21	196	4	194	4	182	6
NO46-02	0.05221	0.00057	0.21987	0.00555	0.03055	0.00069	0.00899	0.00033	0.90	1.80	0.01	295	22	202	5	194	4	181	7
NO46-03	0.05145	0.00053	0.21294	0.00505	0.03002	0.00066	0.00904	0.00030	0.90	2.06	0.01	261	21	196	4	191	4	182	6
NO46-04	0.05579	0.00057	0.23064	0.00540	0.02999	0.00065	0.00957	0.00033	0.90	1.74	0.01	444	20	211	4	190	4	193	7
NO46-05	0.05043	0.00264	0.20091	0.01299	0.02890	0.00059	0.00911	0.00017	0.71	2.72	0.01	215	107	186	11	184	4	183	3
NO46-06	0.05110	0.00053	0.21119	0.00503	0.02998	0.00066	0.00917	0.00033	0.90	1.89	0.01	245	21	195	4	190	4	185	7
NO46-07	0.05196	0.00056	0.21385	0.00525	0.02985	0.00066	0.00935	0.00036	0.90	2.55	0.01	284	22	197	4	190	4	188	7
NO46-08	0.05176	0.00054	0.20792	0.00502	0.02914	0.00064	0.00905	0.00036	0.90	1.99	0.01	275	22	192	4	185	4	182	7
NO46-09	0.05027	0.00054	0.20828	0.00516	0.03005	0.00066	0.00922	0.00038	0.90	2.04	0.01	207	22	192	4	191	4	186	8
NO46-10	0.05069	0.00055	0.20927	0.00520	0.02995	0.00066	0.00918	0.00039	0.90	2.04	0.01	227	22	193	4	190	4	185	8

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO46-11	0.05082	0.00051	0.21024	0.00478	0.03000	0.00064	0.00887	0.00025	0.90	2.10	0.01	233	20	194	4	191	4	178	5
NO46-12	0.05444	0.00055	0.23024	0.00530	0.03068	0.00065	0.00962	0.00027	0.90	2.51	0.01	389	20	210	4	195	4	194	5
NO46-13	0.05968	0.00237	0.24506	0.01344	0.02978	0.00062	0.00920	0.00017	0.82	1.73	0.01	592	77	223	11	189	4	185	3
NO46-14	0.05244	0.00053	0.21800	0.00502	0.03016	0.00064	0.00905	0.00027	0.90	1.97	0.01	305	20	200	4	192	4	182	5
NO46-15	0.05078	0.00051	0.20625	0.00476	0.02946	0.00063	0.00862	0.00027	0.90	1.86	0.01	231	21	190	4	187	4	173	5
NO46-16	0.05087	0.00053	0.20490	0.00494	0.02922	0.00063	0.00843	0.00028	0.90	2.01	0.01	235	22	189	4	186	4	170	6
NO46-17	0.05751	0.00059	0.23170	0.00540	0.02922	0.00063	0.00917	0.00030	0.90	1.85	0.01	511	20	212	4	186	4	185	6
NO46-18	0.05339	0.00055	0.21768	0.00514	0.02957	0.00064	0.00862	0.00028	0.90	2.02	0.01	345	21	200	4	188	4	173	6
NO46-19	0.05245	0.00054	0.21549	0.00511	0.02980	0.00064	0.00903	0.00032	0.90	1.77	0.01	305	21	198	4	189	4	182	6
NO46-20	0.05038	0.00052	0.20666	0.00493	0.02975	0.00064	0.00883	0.00032	0.90	1.58	0.01	213	24	191	4	189	4	178	6
NO48-01	0.05084	0.00079	0.20506	0.00664	0.02926	0.00066	0.00909	0.00027	0.90	1.76	0.01	234	32	189	6	186	4	183	5
NO48-02	0.05007	0.00072	0.19831	0.00607	0.02872	0.00064	0.00930	0.00028	0.90	1.42	0.01	198	30	184	5	183	4	187	6
NO48-03	0.05017	0.00086	0.19837	0.00686	0.02868	0.00066	0.00959	0.00031	0.90	1.63	0.01	203	36	184	6	182	4	193	6
NO48-04	0.06046	0.00070	0.24511	0.00643	0.02941	0.00065	0.00911	0.00026	0.90	0.91	0.01	620	22	223	5	187	4	183	5
NO48-05	0.05181	0.00084	0.20868	0.00695	0.02921	0.00067	0.00969	0.00032	0.90	1.66	0.01	277	33	192	6	186	4	195	6
NO48-06	0.05229	0.00131	0.21481	0.00986	0.02979	0.00078	0.00820	0.00037	0.90	1.92	0.01	298	52	198	8	189	5	165	7
NO48-07	0.04657	0.00394	0.18660	0.01946	0.02906	0.00080	0.00926	0.00042	0.78	1.64	0.01	27	159	174	17	185	5	186	8
NO48-08	0.05307	0.00117	0.21982	0.00930	0.03003	0.00078	0.00785	0.00039	0.90	1.58	0.01	332	45	202	8	191	5	158	8
NO48-09	0.05462	0.00090	0.22167	0.00749	0.02943	0.00068	0.00894	0.00032	0.90	1.61	0.01	397	33	203	6	187	4	180	6
NO48-10	0.05361	0.00087	0.21660	0.00735	0.02930	0.00070	0.00854	0.00035	0.90	1.20	0.01	355	33	199	6	186	4	172	7
NO48-11	0.04741	0.00371	0.18306	0.01750	0.02801	0.00068	0.00890	0.00027	0.78	1.25	0.01	70	149	171	15	178	4	179	5
NO48-12	0.05880	0.00072	0.24568	0.00681	0.03030	0.00069	0.00945	0.00029	0.90	0.82	0.01	560	24	223	6	192	4	190	6
NO48-13	0.04984	0.00083	0.20842	0.00734	0.03034	0.00077	0.00439	0.00018	0.90	1.14	0.01	188	35	192	6	193	5	89	4
NO48-14	0.04886	0.00081	0.20029	0.00677	0.02973	0.00068	0.00907	0.00030	0.90	1.53	0.01	141	35	185	6	189	4	182	6
NO48-15	0.05716	0.00106	0.22886	0.00841	0.02904	0.00069	0.00880	0.00031	0.90	1.59	0.01	498	37	209	7	185	4	177	6
NO48-16	0.05102	0.00088	0.20747	0.00722	0.02949	0.00068	0.00925	0.00033	0.90	1.66	0.01	242	36	191	6	187	4	186	7
NO48-17	0.05126	0.00059	0.20605	0.00541	0.02916	0.00064	0.00888	0.00031	0.90	0.86	0.01	253	24	190	5	185	4	179	6
NO48-18	0.05414	0.00083	0.20968	0.00675	0.02809	0.00064	0.00903	0.00033	0.90	1.60	0.01	377	31	193	6	179	4	182	7
NO48-19	0.11765	0.00179	0.49596	0.01598	0.03058	0.00071	0.01624	0.00097	0.90	1.26	0.01	1921	25	409	11	194	4	326	19
NO48-20	0.05023	0.00063	0.20419	0.00574	0.02949	0.00066	0.00924	0.00036	0.90	0.98	0.01	206	26	189	5	187	4	186	7

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO49-01	0.05045	0.00057	0.20583	0.00526	0.02959	0.00063	0.00927	0.00027	0.90	2.33	0.01	216	24	190	4	188	4	187	5
NO49-02	0.04984	0.00060	0.20098	0.00540	0.02925	0.00063	0.00946	0.00028	0.90	2.41	0.01	188	26	186	5	186	4	190	6
NO49-03	0.05288	0.00058	0.21414	0.00537	0.02937	0.00063	0.00813	0.00024	0.90	1.84	0.01	324	23	197	4	187	4	164	5
NO49-04	0.05138	0.00065	0.20797	0.00585	0.02936	0.00065	0.00888	0.00029	0.90	2.36	0.01	258	27	192	5	187	4	179	6
NO49-05	0.05540	0.00074	0.22712	0.00672	0.02974	0.00068	0.00833	0.00032	0.90	2.15	0.01	428	28	208	6	189	4	168	6
NO49-06	0.05301	0.00060	0.22091	0.00568	0.03023	0.00065	0.00956	0.00031	0.90	2.08	0.01	329	24	203	5	192	4	192	6
NO49-07	0.05482	0.00057	0.22402	0.00535	0.02964	0.00061	0.00998	0.00039	0.90	1.68	0.01	405	22	205	4	188	4	201	8
NO49-08	0.05573	0.00067	0.23308	0.00630	0.03034	0.00068	0.00951	0.00039	0.90	2.01	0.01	442	25	213	5	193	4	191	8
NO49-09	0.04880	0.00054	0.19538	0.00489	0.02904	0.00062	0.00920	0.00033	0.90	2.25	0.01	138	24	181	4	185	4	185	7
NO49-10	0.04963	0.00056	0.20148	0.00517	0.02945	0.00063	0.00918	0.00033	0.90	2.19	0.01	178	25	186	4	187	4	185	7
NO49-11	0.05226	0.00053	0.21456	0.00499	0.02978	0.00062	0.00997	0.00028	0.90	2.02	0.01	297	22	197	4	189	4	201	6
NO49-12	0.05156	0.00057	0.20997	0.00530	0.02954	0.00062	0.00992	0.00029	0.90	2.25	0.01	266	24	194	4	188	4	200	6
NO49-13	0.05011	0.00050	0.20887	0.00481	0.03023	0.00062	0.00996	0.00029	0.90	1.95	0.01	200	22	193	4	192	4	200	6
NO49-14	0.05551	0.00069	0.22441	0.00625	0.02932	0.00065	0.01047	0.00039	0.90	2.31	0.01	433	26	206	5	186	4	211	8
NO49-15	0.05083	0.00051	0.20537	0.00474	0.02930	0.00060	0.00967	0.00029	0.90	1.95	0.01	233	22	190	4	186	4	195	6
NO49-16	0.05375	0.00054	0.22144	0.00513	0.02988	0.00062	0.00980	0.00030	0.90	1.53	0.01	361	21	203	4	190	4	197	6
NO49-17	0.05157	0.00053	0.21181	0.00500	0.02979	0.00062	0.00967	0.00030	0.90	1.98	0.01	266	22	195	4	189	4	195	6
NO49-18	0.05208	0.00057	0.21424	0.00532	0.02983	0.00062	0.00918	0.00030	0.90	1.96	0.01	289	23	197	4	189	4	185	6
NO49-19	0.05133	0.00053	0.21893	0.00520	0.03093	0.00064	0.00978	0.00032	0.90	2.05	0.01	256	22	201	4	196	4	197	6
NO49-20	0.05537	0.00064	0.22986	0.00598	0.03011	0.00065	0.01005	0.00039	0.90	1.99	0.01	427	24	210	5	191	4	202	8
NO53-01	0.14000	0.00440	6.94414	0.35961	0.35975	0.00902	0.10155	0.00235	0.89	0.98	0.01	2227	48	2104	46	1981	43	1955	43
NO53-02	0.07858	0.00099	1.86364	0.05246	0.17202	0.00383	0.04991	0.00182	0.90	2.22	0.01	1162	23	1068	19	1023	21	984	35
NO53-03	0.07218	0.00082	1.53135	0.03920	0.15388	0.00324	0.04622	0.00141	0.90	0.89	0.01	991	21	943	16	923	18	913	27
NO53-04	0.15854	0.00152	8.80624	0.19291	0.40289	0.00823	0.11428	0.00352	0.90	1.59	0.01	2440	15	2318	20	2182	38	2187	64
NO53-05	0.15923	0.00153	8.77343	0.19352	0.39964	0.00817	0.11385	0.00362	0.90	1.46	0.01	2448	15	2315	20	2167	38	2179	66
NO53-06	0.10718	0.00158	4.43176	0.14207	0.29990	0.00723	0.06800	0.00469	0.90	5.94	0.01	1752	24	1718	27	1691	36	1330	89
NO53-07	0.07241	0.00085	1.47254	0.03885	0.14751	0.00312	0.04535	0.00154	0.90	0.90	0.01	997	22	919	16	887	18	896	30
NO53-08	0.07825	0.00084	2.02867	0.04948	0.18804	0.00391	0.05827	0.00203	0.90	0.85	0.01	1153	19	1125	17	1111	21	1145	39
NO53-09	0.16206	0.00161	10.2029	0.23270	0.45666	0.00941	0.12694	0.00455	0.90	0.60	0.01	2477	15	2453	21	2425	42	2415	82
NO53-10	0.16141	0.00158	9.85227	0.22184	0.44274	0.00897	0.12738	0.00481	0.90	2.27	0.01	2470	15	2421	21	2363	40	2423	86

Table 9.1 Continued

Sample analysis no.	Isotope ratio											Corrected age (Ma)							
	$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$		ρ r	$^{238}U/^{232}Th$		$^{207}Pb/^{206}Pb$		$^{207}Pb/^{235}U$		$^{206}Pb/^{238}U$		$^{208}Pb/^{232}Th$	
	Ratio	1σ	Ratio	1σ	Ratio	1σ	Ratio	1σ		Ratio	1σ	Age	1σ	Age	1σ	Age	1σ	Age	1σ
NO53-11	0.0736	0.0009	1.68322	0.04584	0.16587	0.00354	0.05455	0.00183	0.9	3.94	0.03	1031	22	1002	17	989	20	1074	35
NO53-12	0.05833	0.00075	0.6894	0.01942	0.08572	0.00183	0.02621	0.00083	0.9	1.69	0.01	542	25	532	12	530	11	523	16
NO53-13	0.06602	0.00102	1.13296	0.03623	0.12446	0.00276	0.03856	0.00128	0.9	1.46	0.01	807	29	769	17	756	16	765	25
NO53-14	0.06682	0.00077	1.23422	0.03202	0.13397	0.00283	0.04195	0.00137	0.9	1.84	0.01	832	22	816	15	810	16	831	27
NO53-15	0.05849	0.00113	0.70422	0.02605	0.08733	0.00199	0.02685	0.00091	0.9	0.66	0.01	548	38	541	16	540	12	536	18
NO53-16	0.0782	0.00085	1.78201	0.04396	0.16529	0.00348	0.05068	0.00171	0.9	1.14	0.01	1152	19	1039	16	986	19	999	33
NO53-17	0.07616	0.00076	1.8169	0.04169	0.17304	0.00358	0.05432	0.00188	0.9	2.6	0.01	1099	18	1052	15	1029	20	1069	36
NO53-18	0.06725	0.00083	1.20378	0.03314	0.12983	0.00283	0.03665	0.00143	0.9	0.33	0.01	846	23	802	15	787	16	728	28
NO53-19	0.0664	0.00226	0.80338	0.04862	0.08775	0.00283	0.02678	0.00083	0.91	152.7	0.49	819	63	599	27	542	17	534	16
NO53-20	0.06055	0.00067	0.80443	0.02026	0.09635	0.00203	0.02852	0.00106	0.9	1.03	0.01	623	22	599	11	593	12	568	21
NO53-21	0.11129	0.00109	4.94398	0.11121	0.32222	0.00672	0.09837	0.00288	0.9	2.53	0.01	1821	16	1810	19	1801	33	1896	53
NO53-22	0.0722	0.00094	1.55957	0.04467	0.15668	0.00343	0.04693	0.00138	0.9	0.62	0.01	992	24	954	18	938	19	927	27
NO53-23	0.0614	0.0007	0.71087	0.01843	0.08397	0.00181	0.02676	0.00085	0.9	1.43	0.01	653	22	545	11	520	11	534	17
NO53-24	0.07053	0.00072	1.44852	0.03371	0.14897	0.00311	0.04605	0.00138	0.9	1.89	0.01	944	19	909	14	895	17	910	27
NO53-25	0.10588	0.00103	4.3898	0.09806	0.30074	0.00624	0.08849	0.00276	0.9	1.32	0.01	1730	16	1710	18	1695	31	1714	51
NO53-26	0.16212	0.00159	10.5037	0.23558	0.46994	0.00979	0.13082	0.00413	0.9	2.19	0.01	2478	15	2480	21	2483	43	2485	74
NO53-27	0.08087	0.00083	2.24519	0.05262	0.20136	0.00422	0.05948	0.00194	0.9	1.28	0.01	1218	18	1195	16	1183	23	1168	37
NO53-28	0.10724	0.00109	4.46879	0.10404	0.30225	0.00635	0.08462	0.00284	0.9	1.74	0.01	1753	17	1725	19	1702	31	1642	53
NO53-29	0.07525	0.0013	1.8595	0.06192	0.17921	0.00394	0.05394	0.00115	0.88	5.15	0.01	1075	31	1067	22	1063	22	1062	22
NO53-30	0.07569	0.00077	1.86402	0.04366	0.17862	0.00374	0.05352	0.00191	0.9	1.98	0.01	1087	18	1068	15	1059	20	1054	37

CURRICULUM VITAE

Name Mr. Marutphong Srichan

Date of Birth 24 May 1989

Place of Birth Phayao Province

Education 2012 B.Sc. (Geoscience), Mahidol University

Experiences
2010 Internship Program, Sirindhorn museum
2011 Internship Program, Department of Primary Industries and Mines
2012 Trenching Survey, Department of Mineral Resources
2013 Geologist, Thanachol Geotech Part., Ltd., Chanthaburi
2014-2015 Geologist, Panya Consultants Co., Ltd. Bangkok
2018 Geochemical Research Laboratory, the Institute of Earth Sciences, Academia Sinica and Department of Geosciences, National Taiwan University, Taiwan.

International Conferences

24-25 November 2015 The 5th GEOINDO 2015 International Conference "Geology, Geotechnology and Mineral Resources of INDOCHINA"

14-15 November 2016 The 3rd International Conference on Tectonics of Northwestern Indochina

10 February 2017 The 6th International Graduate Research Conference

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