CHAPTER 3

OCCURRENCE AND PETROGRAPHY

3.1 OCCURRENCE

The Late Triassic- Early Jurassic volcanic rocks in the Long District area cover an area of approximately 625 km^2 (Fig. 3.1). They are composed largely of felsic to mafic pyroclastic rocks, with minor volcanic rocks and hypabyssal rocks. The pyroclastic rocks may include pyroclastic fall and flow deposits, and resedimented pyroclastic-rich deposits. Of these pyroclastic rocks, volcanic breccias of primary and/or secondary origins are the most abundant rock types. The volcanic breccias are made up largely of andesitic and basaltic blocks that sit in the finer-grained matrix (Figs. 3.2 and 3.3). Their matrix constituents are also angular, with andesitic and basaltic compositions. The pyroclastic rocks commonly show grading beds (Fig. 3.4) of agglomerate/volcanic breccia, lapilli tuff, coarse tuff and fine tuff; flow folds have occasionally been observed in pyroclastic flow deposits (Fig. 3.5). The volcanic rocks include light gray rhyolite (Fig. 3.6), greenish andesite and grayish black basalt (Fig. 3.7). Spheroidal weathering has been operated in the pyroclastic, volcanic and hypabyssal rocks of the Long District area, giving rise to rounded volcanic clasts either embedded in the rock exposures or present as *in situ* float (Fig. 3.8). Many of these clasts were transported into streams and creeks. The samples presented in this project were collected from *in situ* float and float along streams and creeks (Fig. 3.9).

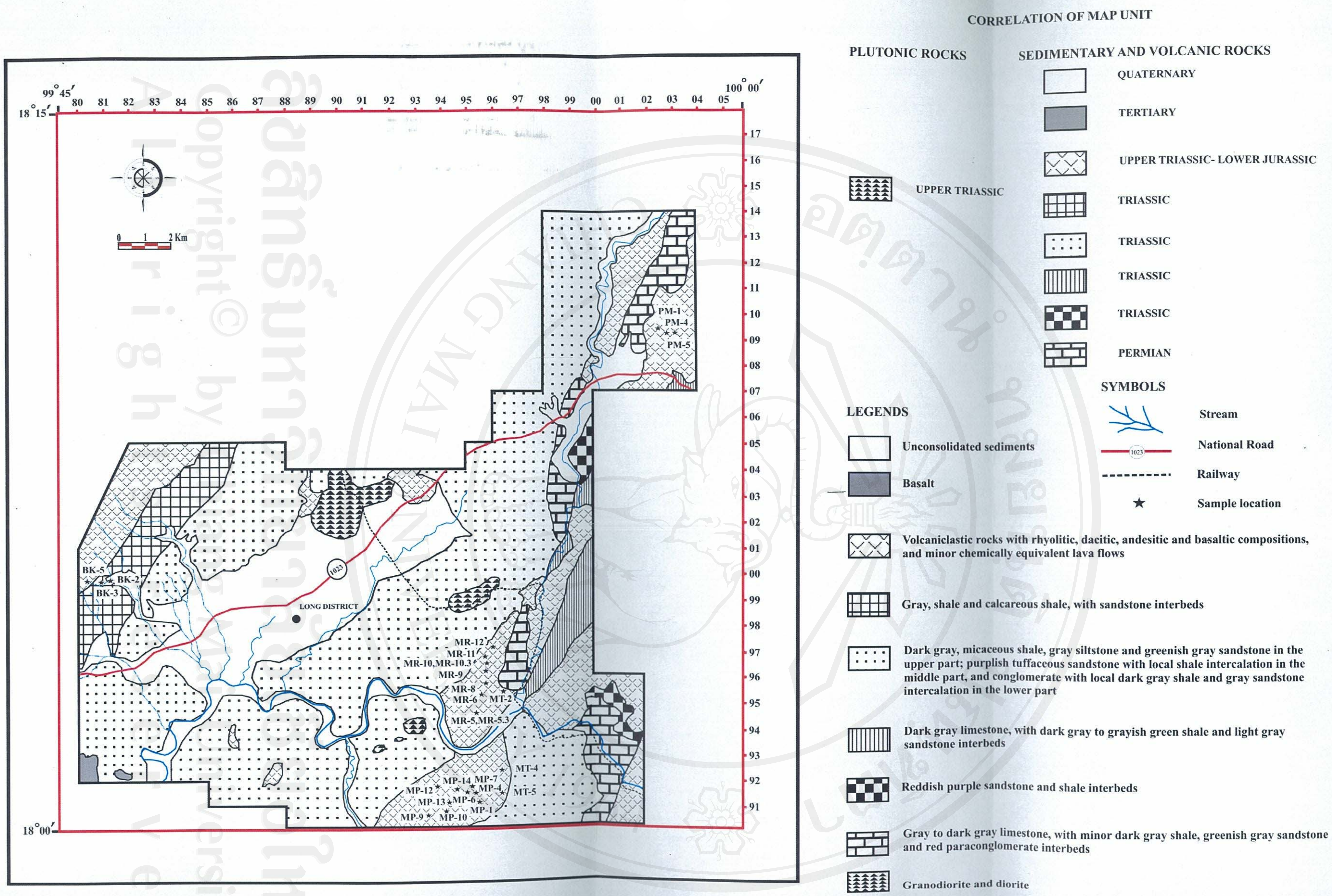


Figure 3.1 Map showing the distribution of Late Triassic – Early Jurassic volcanic rocks in the project area and the locations of samples presented in this study.

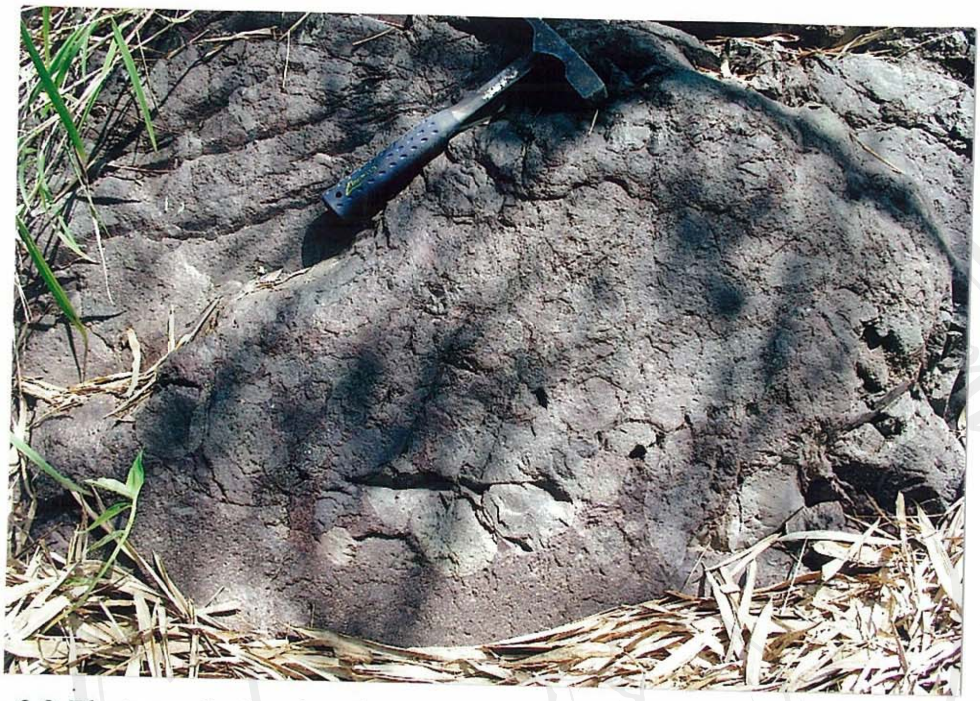


Figure 3.2 Photograph showing the exposure of pyroclastic breccia at grid reference 950917 (the hammer is 30 cm long).

Figure 3.3 Photograph showing the contact between tuff and pyroclastic breccia at grid reference 804996 (Hammer is 30 cm long).

Figure 3.4 Photograph showing grading beds of pyroclastic rocks at grid reference 011914 (the author, 160 cm tall, is to scale).

Figure 3.5 Photograph showing flow folds at grid reference 985783 (the hammer is 40 cm long).

Figure 3.6 Photograph showing the exposure of light gray rhyolite at grid reference 980945 (the author, 100 cm high, is to scale).

Figure 3.7 Photograph showing the outcrop of tuff that is overlain by a grayish black basaltic flow at grid reference 030092 (the hammer is 30 cm long).

Figure 3.8 Photograph showing *in situ* float of volcanic clasts at grid reference 935960 (the hammer is 40 cm long).

Figure 3.9 Photograph showing float rocks in the creek at grid reference 953917.

3.2 LITHOLOGY AND PETROGRAPPHY

3.2.1 Sample Selection

A number of the Late Triassic – Early Jurassic mafic volcanic rocks and hypabyssal rocks was collected from many localities of the Long District area. However, the samples presented in this study are only those considered to be least-altered, under the petrographic microscope. The least-altered samples in this account generally exclude the samples with

1) extensive development of mesoscopic domains of secondary minerals such as quartz resulted from silicification, epidote minerals and chlorite,
2) well-developed foliation or mineral layering,
3) abundant vesicles/amygdales, xenocrysts and xenoliths, and
4) quartz, epidote or calcite veining and/or patches totally more than 5 modal %.

Using the above criteria, twenty-five least-altered, mafic volcanic samples and two least-altered, mafic hypabyssal samples were selected to represent magma prior to eruption. The locations of these least-altered igneous samples are shown in Figure 3.1. Lithologic and petrographic studies have been carried out on these samples and the results of individual samples are given in Appendix and summarized below.

3.2.2 Mafic Volcanic Rocks

Megascopically, almost all the studied mafic volcanic samples show slightly to highly megacrystic textures. The megacrysts in these samples are milky white to pale green plagioclase crystals (sizes up to 4 mm across), and grayish green, greenish to grayish black and black mafic minerals (sizes up to 3 mm across). The groundmass constituents are generally very fine- to fine-grained and dense, and have colors varying from green to black with different shades and tones. Tiny fracture infillings and cavity infillings, with different colors and tones of white, green, brown, gray and black, have occasionally been detected. Almost all the rocks show a slightly magnetic property and do not react with cold diluted hydrochloric acid.

Microscopically, the megacryst assemblages include (1) plagioclase + unidentified mafic mineral, (2) plagioclase + clinopyroxene, (3) clinopyroxene + unidentified mafic mineral, (4) plagioclase + clinopyroxene + unidentified mafic mineral, (5) plagioclase + clinopyroxene + unidentified mafic mineral + Fe-Ti oxide, (6) plagioclase + clinopyroxene + unidentified mafic mineral + Fe-Ti oxide + apatite, (7) plagioclase + unidentified mafic mineral + Fe-Ti oxide + apatite, and (8) plagioclase + clinopyroxene + Fe-Ti oxide + apatite. Of these megacrysts, plagioclase (Figs. 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16 and 3.17) is the most abundant, clinopyroxene (Figs. 3.10, 3.11, 3.12, 3.14, 3.15, 3.16, 3.17 and 3.18) and unidentified mafic mineral (Figs. 3.11, 3.12, 3.13, 3.14, 3.15, 3.17, 3.18, 3.19, 3.20 and 3.21) are subordinate to plagioclase, and Fe-Ti oxide (Figs. 3.14, 3.15 and 3.16) and apatite (Figs. 3.19 and 3.21) are minor. These megacrysts may occur as isolated grains; monomineralic clusters of plagioclase (Fig. 3.15), clinopyroxene and unidentified mafic mineral; and polymineralic clusters of (1) plagioclase + clinopyroxene (Fig. 3.11), (2) plagioclase + clinopyroxene + unidentified mafic mineral (Fig. 3.14), (3) plagioclase + clinopyroxene + unidentified mafic mineral + Fe-Ti oxide (Figs. 3.14 and 3.15), (4) clinopyroxene + unidentified mafic mineral (Fig. 3.18), (5) unidentified mafic mineral + apatite (Fig. 3.19), (6) plagioclase + unidentified mafic mineral + apatite + Fe-Ti oxide (Fig. 3.21), (7) clinopyroxene + Fe-Ti oxide, (8) plagioclase + clinopyroxene + Fe-Ti oxide, (9) plagioclase + unidentified mafic mineral + Fe-Ti oxide, (10) clinopyroxene + unidentified mafic mineral + Fe-Ti oxide, and (11) unidentified mafic mineral + Fe-Ti oxide. Apatite microphenocrysts are present as inclusions in plagioclase phenocrysts/microphenocrysts. The dominant plagioclase, clinopyroxene, and unidentified mafic mineral (most likely to be orthopyroxene) phenocrysts/microphenocrysts, and the lack of olivine phenocrysts/microphenocrysts suggest that the mafic volcanic rocks are either basalt or basaltic andesite (Thorpe, 1985; Wilson, 1989). The megacrysts are embedded in the holocrystalline groundmass with a felty texture (Figs. 3.12, 3.14, 3.15, 3.16, 3.19 and 3.21) and a trachytic texture (Figs. 3.13, 3.17 and 3.20), but for sample number MR-12 that has the altered glassy groundmass (Fig. 3.10).

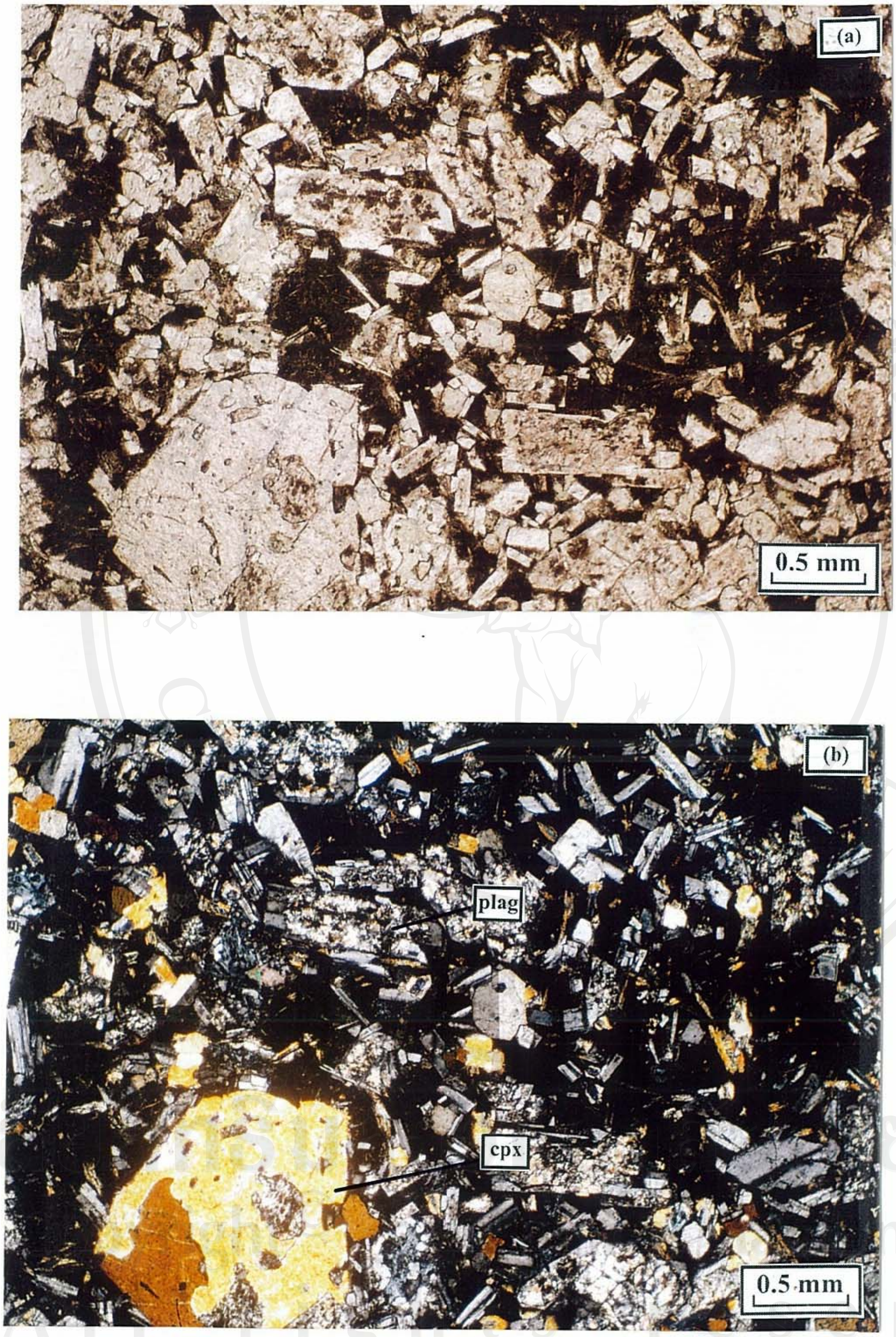


Figure 3.10 Photomicrographs of andesite (sample number MR-12) showing phenocrysts/microphenocrysts of plagioclase (plag), megacrysts of clinopyroxene (cpx), and altered glassy groundmass. (a) Ordinary light, (b) Crossed polars.

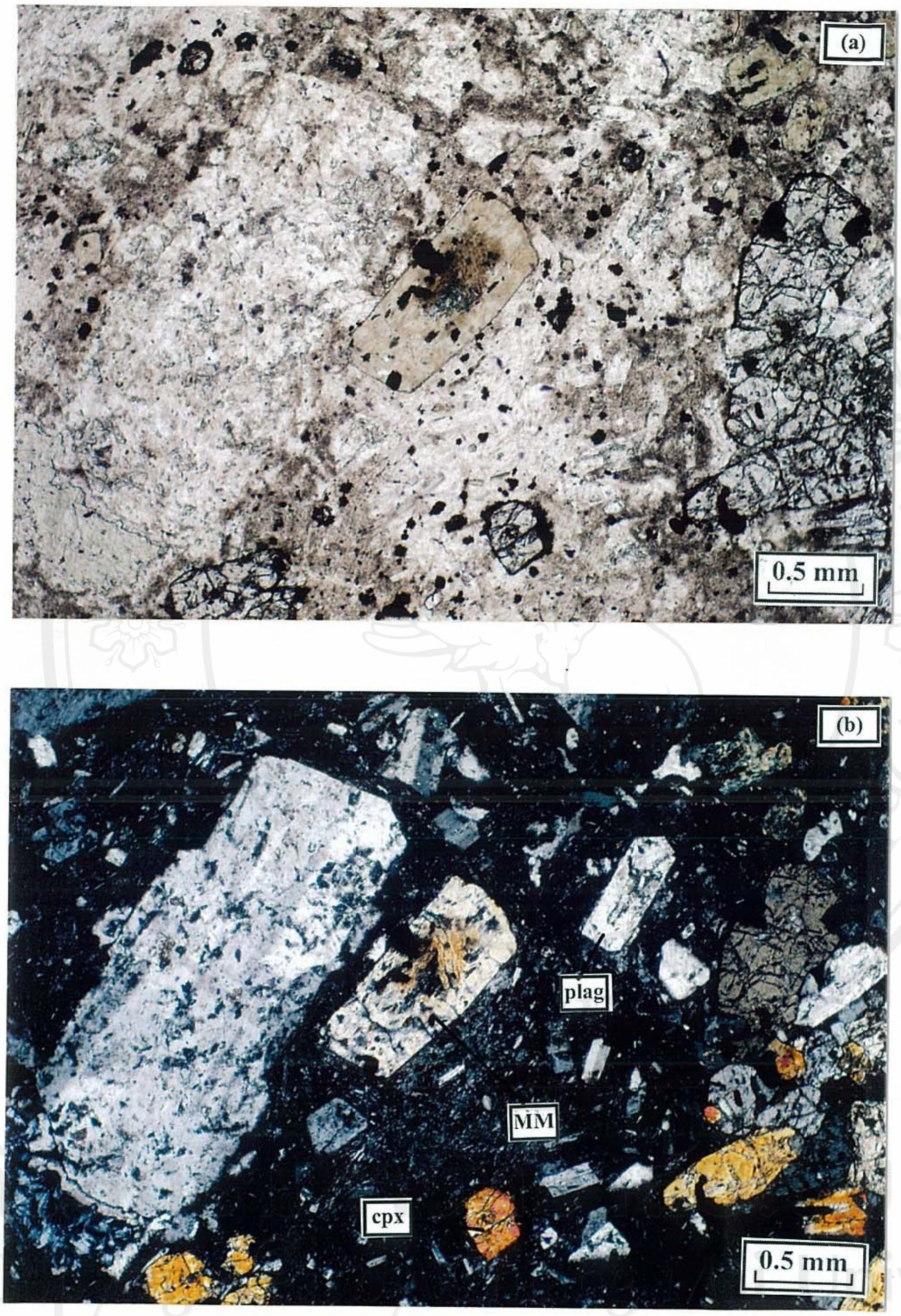


Figure 3.11 Photomicrograph of andesite (sample number PM-1) showing phenocrysts/microphenocrysts of plagioclase (plag), clinopyroxene (cpx) and unidentified mafic mineral (MM), and a polymineralic cluster of plagioclase (plag) and clinopyroxene (cpx) megacrysts at the right edge. (a) Ordinary light, (b) Crossed polars.

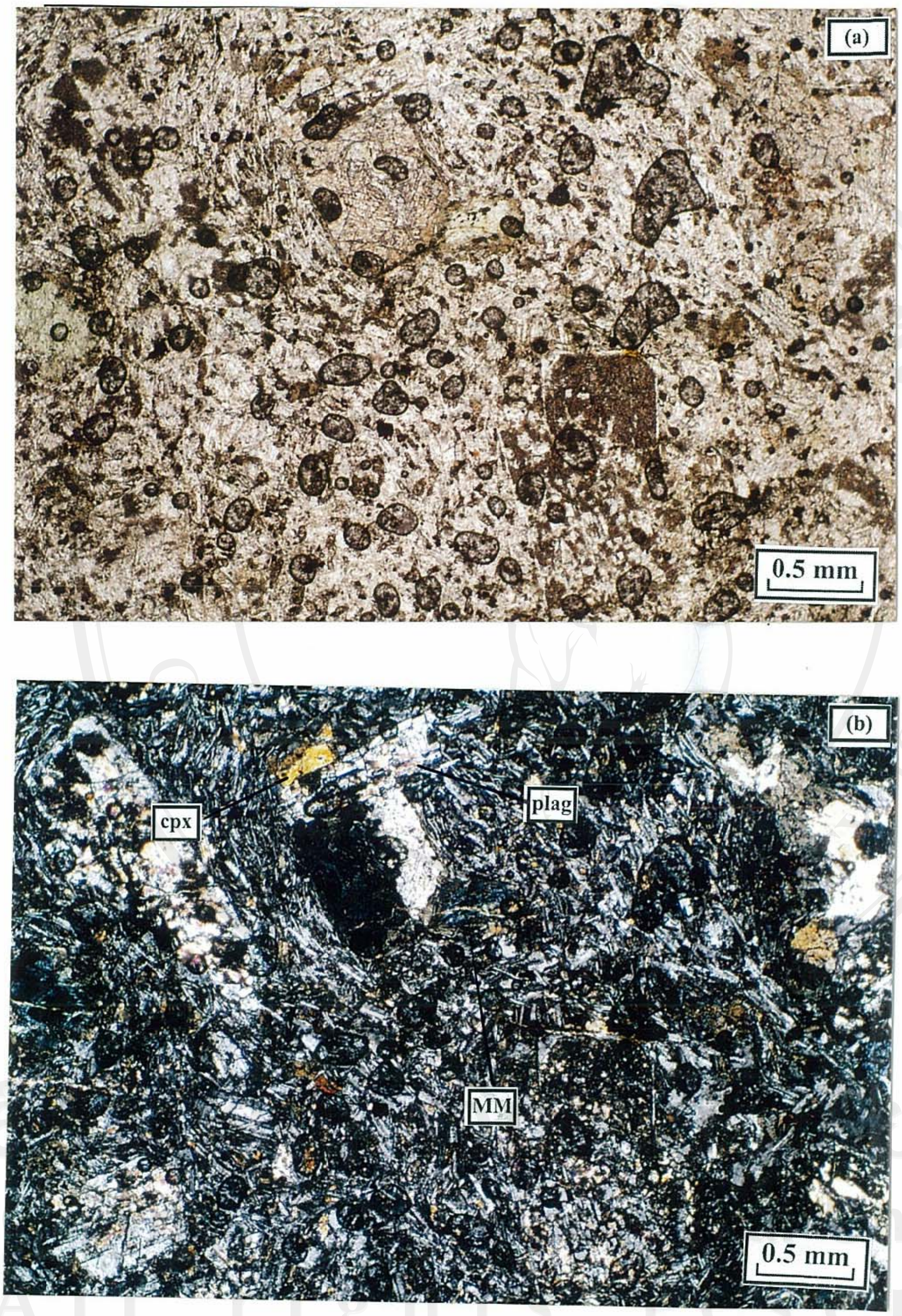


Figure 3.12 Photomicrographs of andesite/basalt (sample number MP-7) showing microphenocrysts of plagioclase (plag), clinopyroxene (cpx) and unidentified mafic minerals (MM) in the felty groundmass. (a) Ordinary light, (b) Crossed polars.

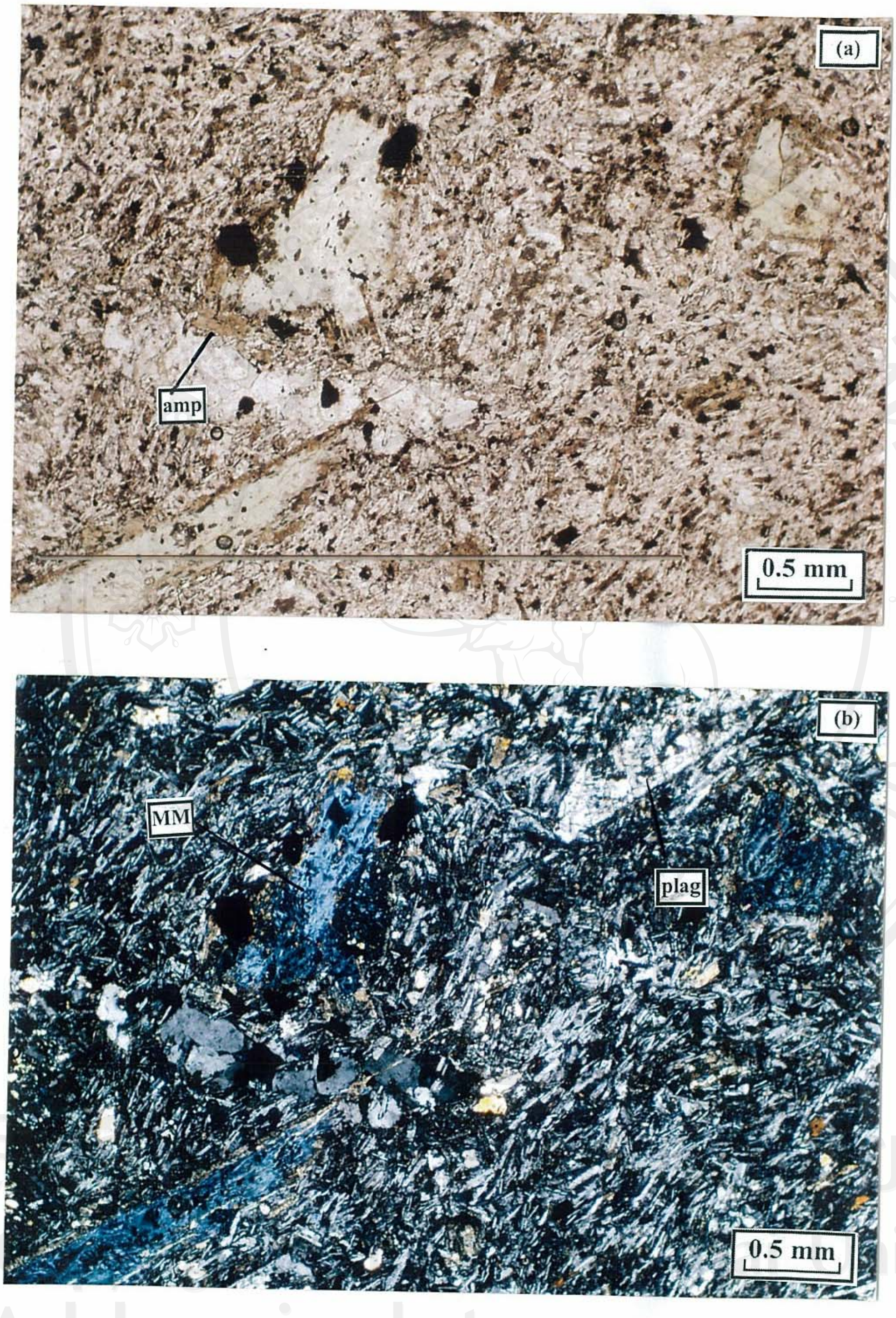


Figure 3.13 Photomicrographs of andesite/basalt (sample number MP-13) showing microphenocrysts of plagioclase (plag) and unidentified mafic mineral (MM) with amphibole (amp) rims in the trachytic groundmass. (a) Ordinary light, (b) Crossed polars.

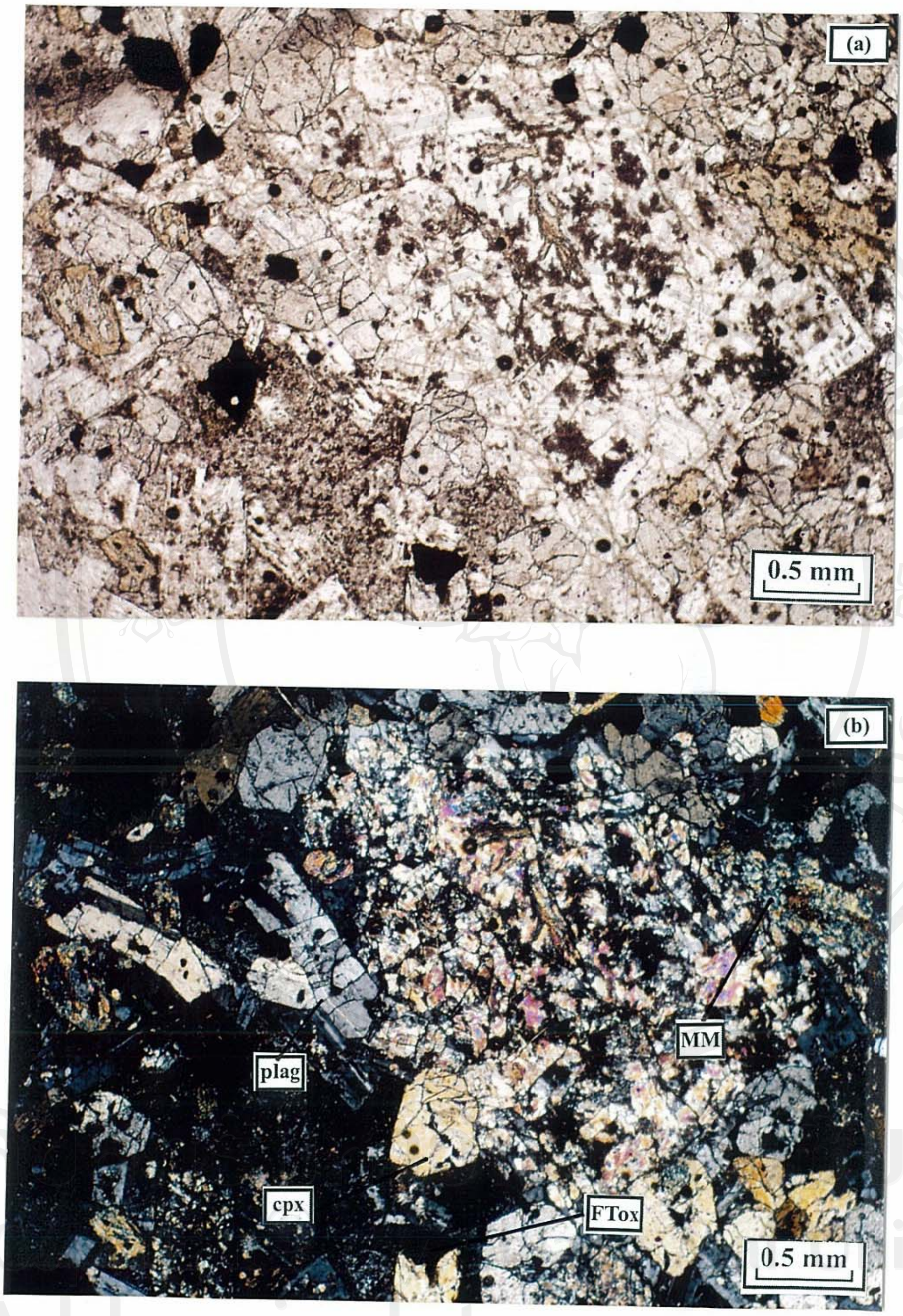


Figure 3.14 Photomicrograph of andesite (sample number MT-5) showing a polymineralic cluster of plagioclase (plag), clinopyroxene (cpx), unidentified mafic mineral (MM) and Fe-Ti oxide (FTox) megacrysts in the felty groundmass. (a) Ordinary light, (b) Crossed polars.

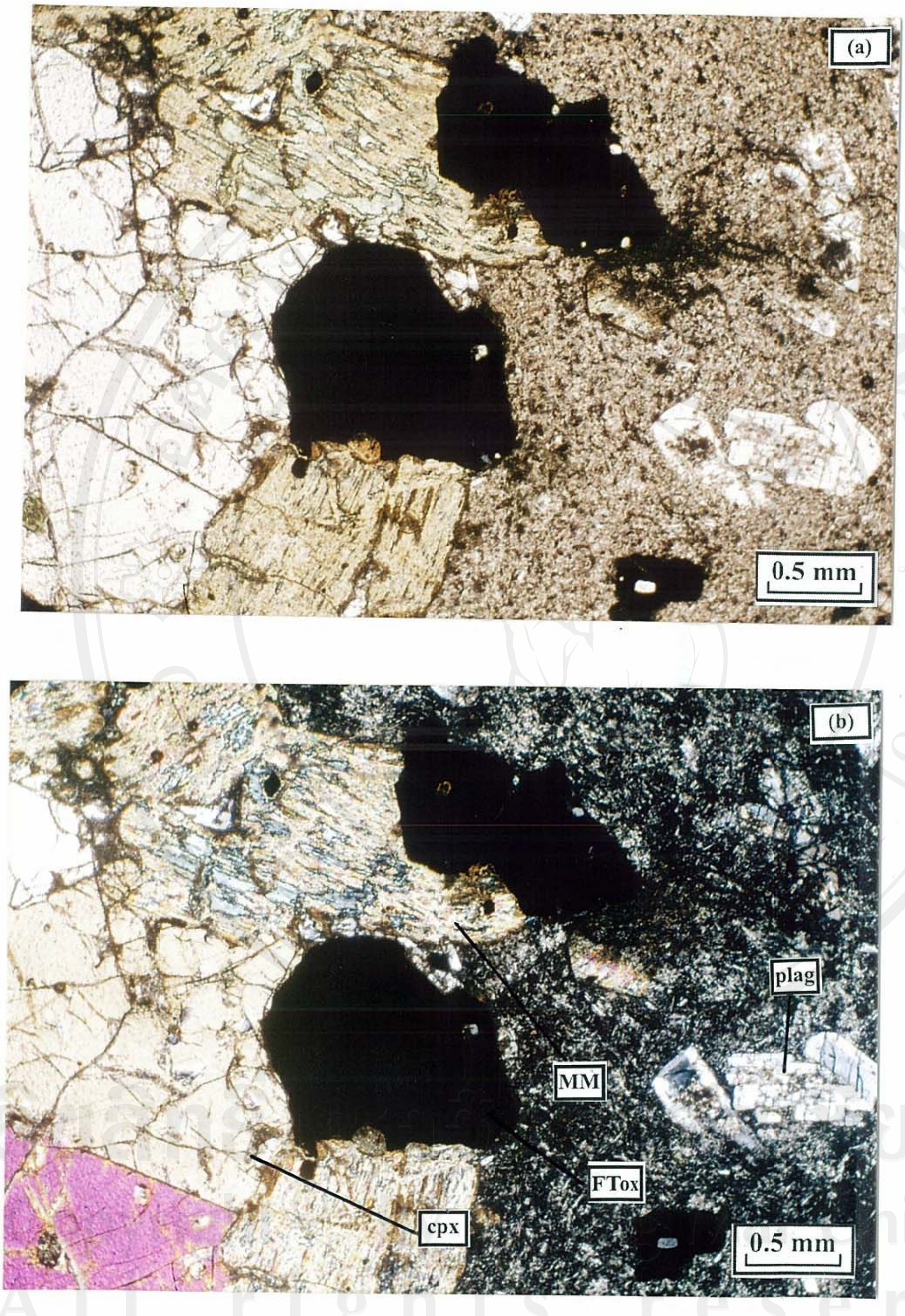


Figure 3.15 Photomicrographs of andesite (sample number MT-5) showing a portion of polymineralic cluster of plagioclase, clinopyroxene (cpx), Fe-Ti oxide (FTox) and unidentified mafic mineral (MM) megacrysts, and a monomineralic cluster of plagioclase (plag) megacrysts in the felty groundmass. (a) Ordinary light, (b) Crossed polars.

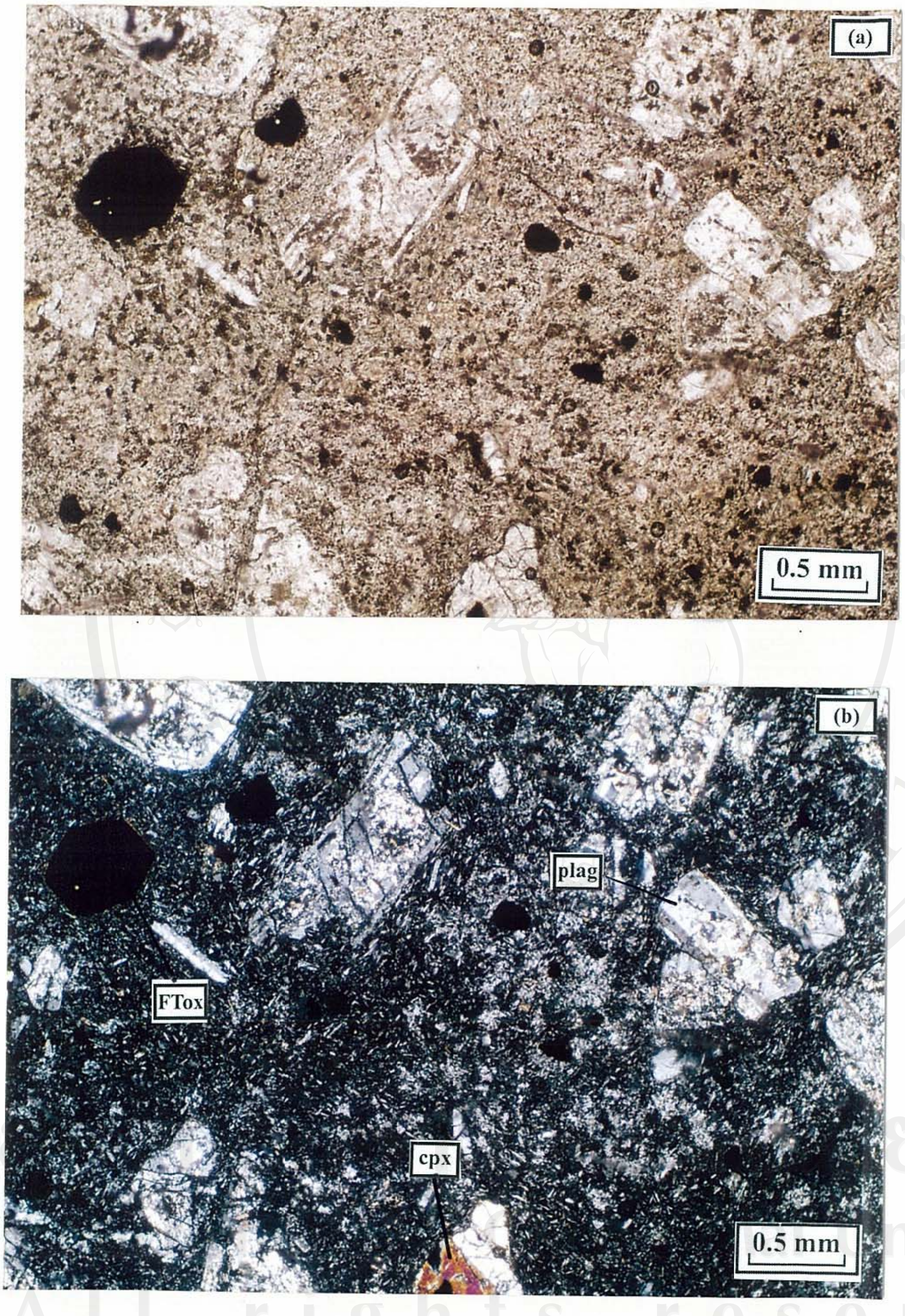


Figure 3.16 Photomicrographs of andesite (sample number MP-10) showing microphenocrysts of plagioclase (plag), clinopyroxene (cpx) and Fe-Ti oxide (FTox) in the felty groundmass. (a) Ordinary light, (b) Crossed polars.

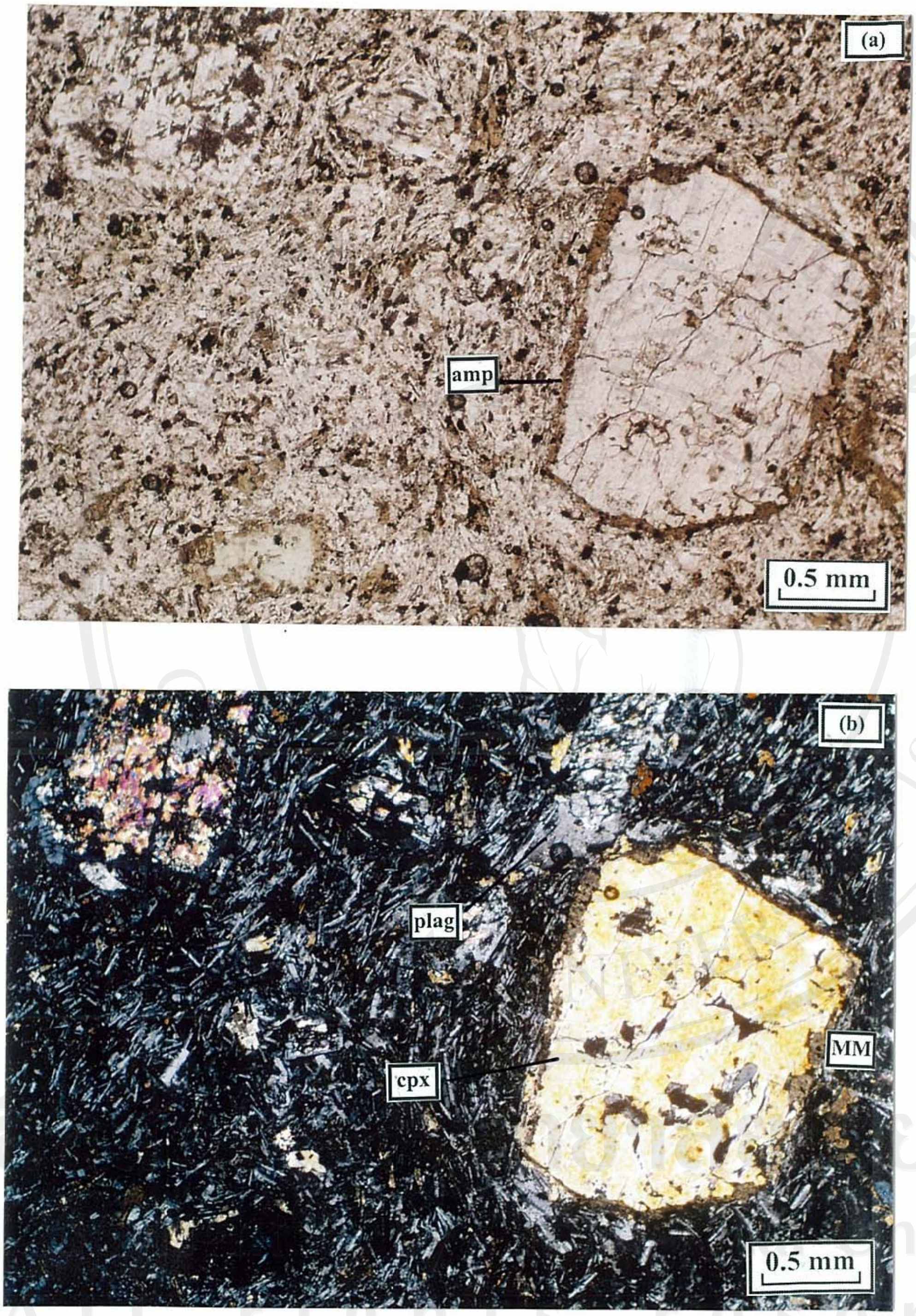


Figure 3.17 Photomicrographs of andesite/basalt (sample number MP-13) showing phenocrysts/microphenocrysts of plagioclase (plag), clinopyroxene (cpx) with amphibole (amp) rims, and unidentified mafic mineral (MM) in the trachytic groundmass. (a) Ordinary light, (b) Crossed polars.

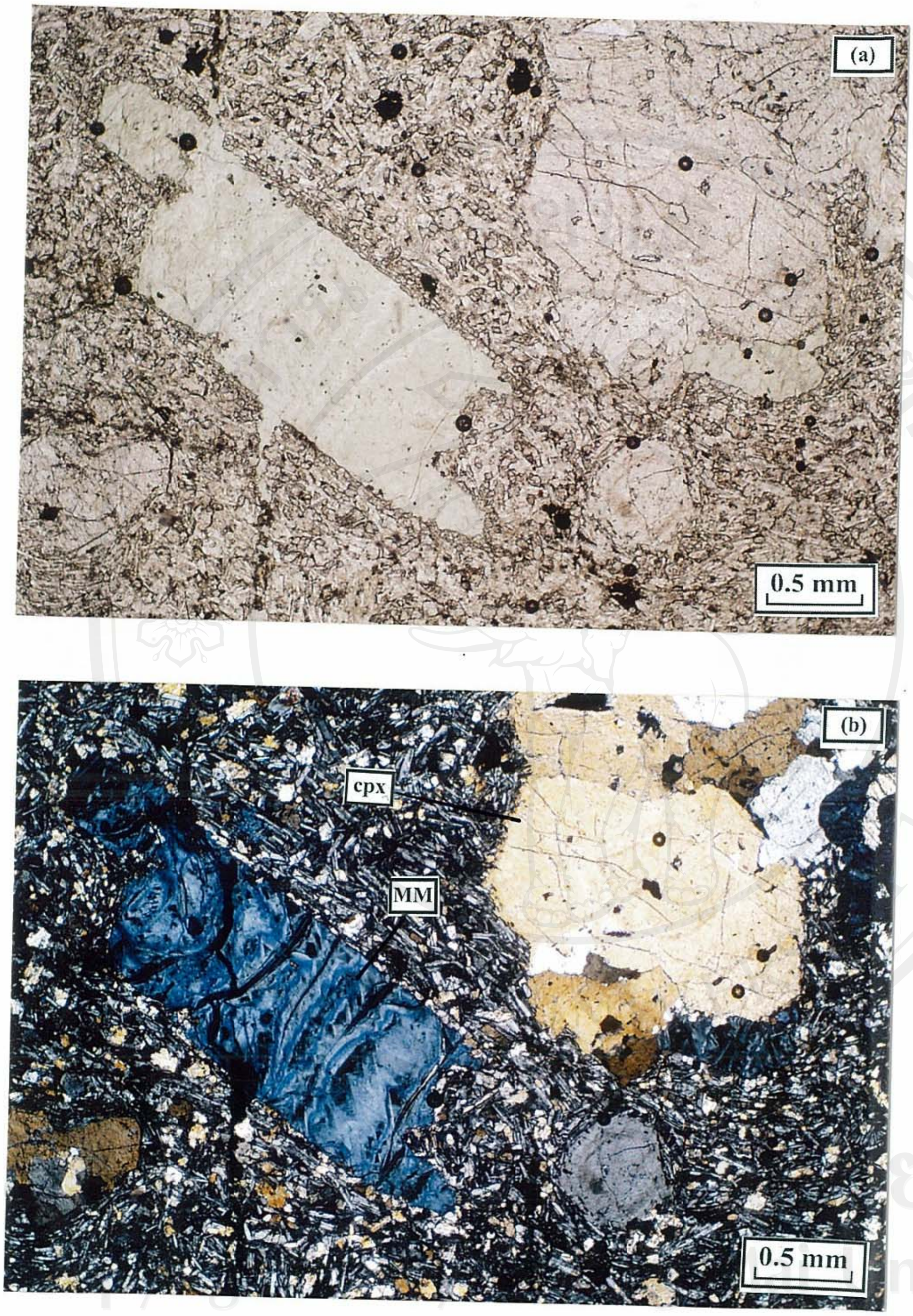
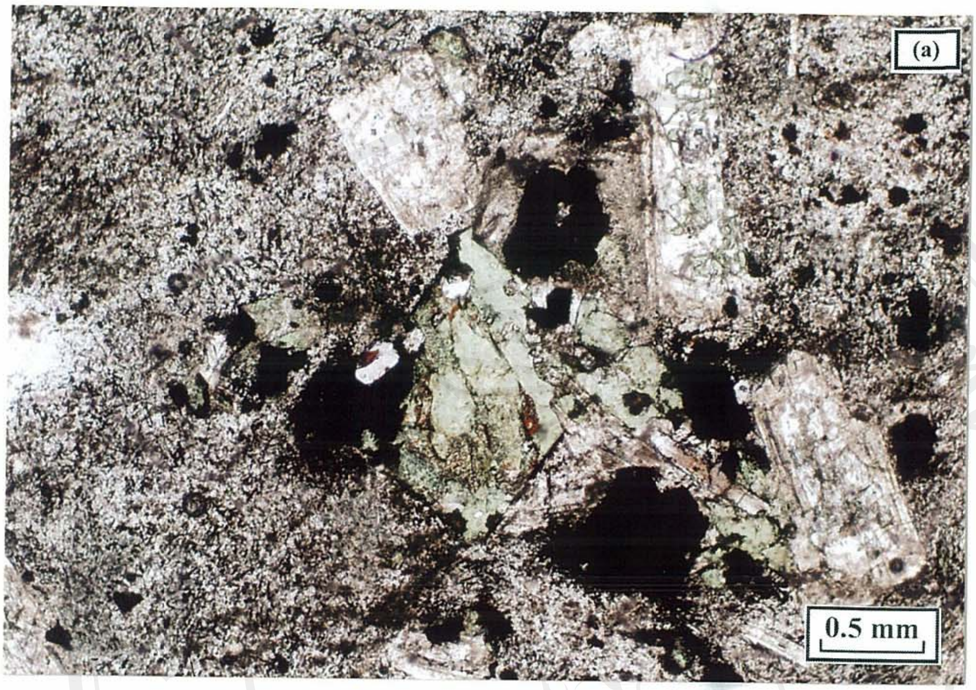


Figure 3.18 Photomicrographs of andesite (sample number MR-8) showing megacrysts of clinopyroxene (cpx) and unidentified mafic mineral (MM), and a polymineralic cluster of clinopyroxene (cpx) and unidentified mafic mineral (MM) megacrysts. The groundmass clinopyroxene grains are intergranular to plagioclase laths. (a) Ordinary light, (b) Crossed polars.



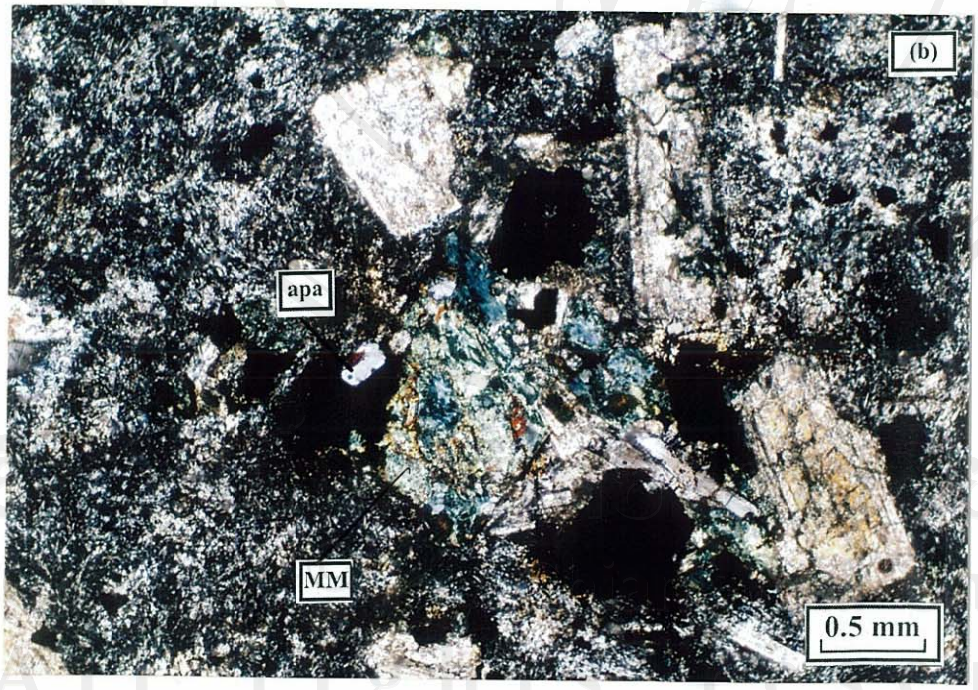
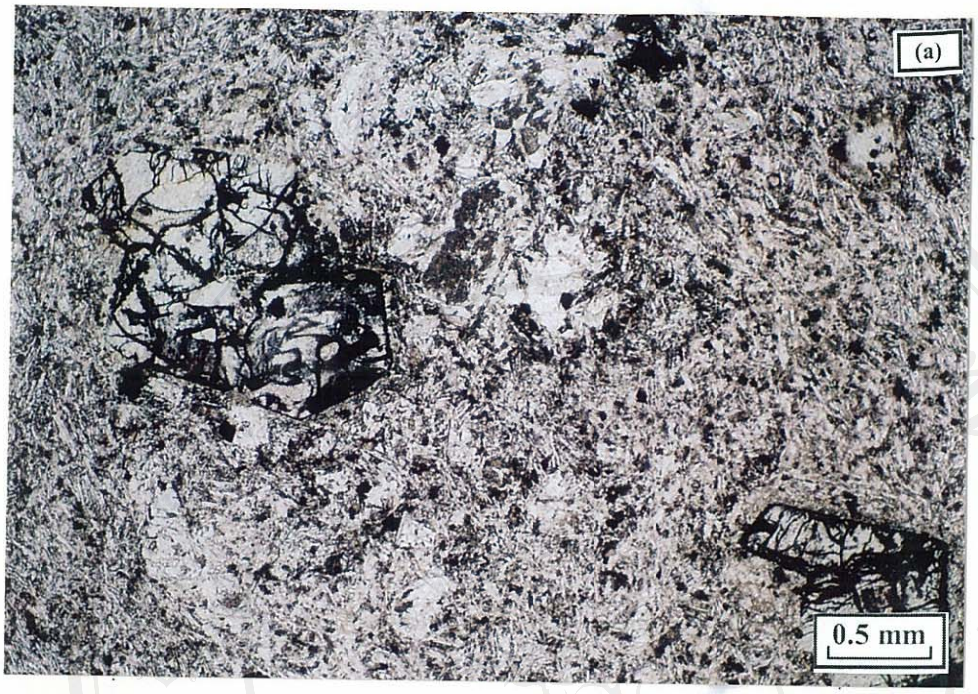


Figure 3.19 Photomicrographs of andesite (sample number MT-2) showing a polymineralic cluster of unidentified mafic mineral (MM) and apatite (apa) megacrysts in the felty groundmass. (a) Ordinary light, (b) Crossed polars.



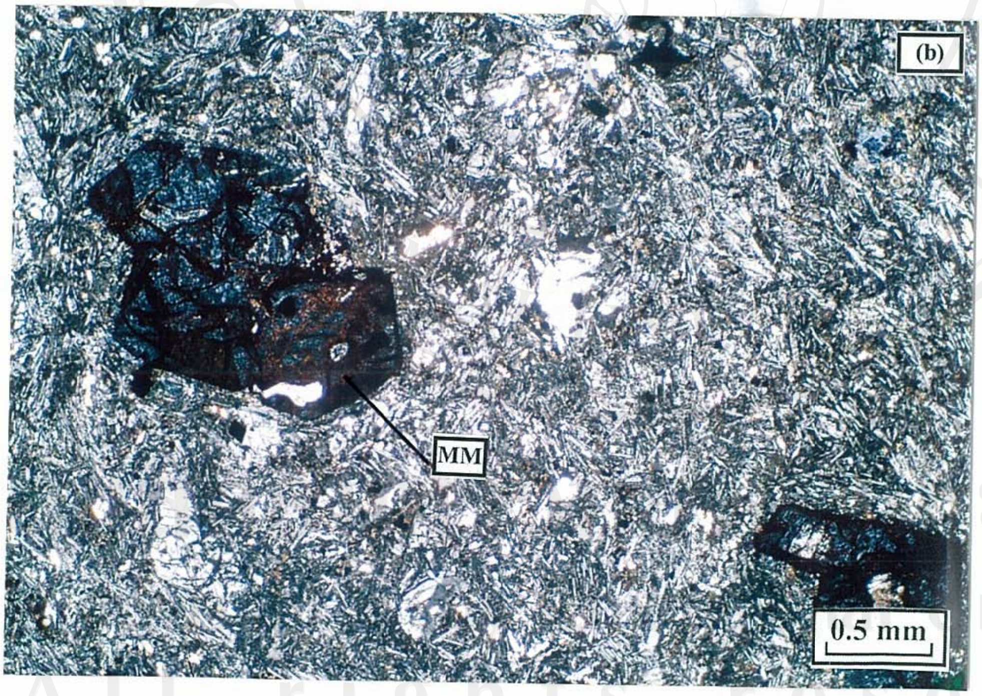
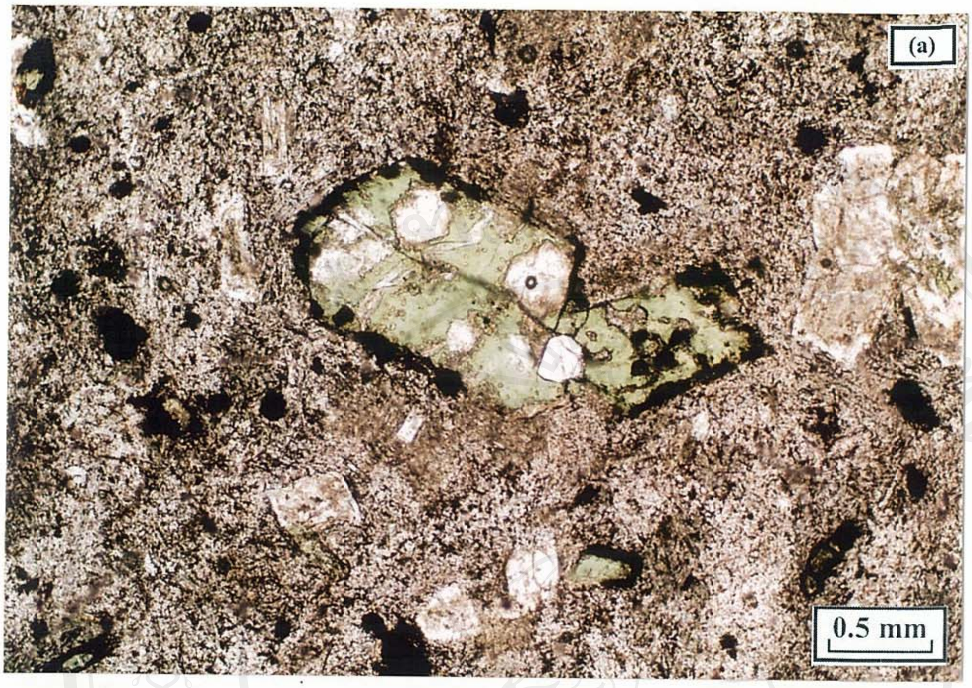


Figure 3.20 Photomicrographs of andesite (sample number MP-4) showing phenocrysts/microphenocrysts of unidentified mafic mineral (MM) in the trachytic groundmass. (a) Ordinary light, (b) Crossed polars.



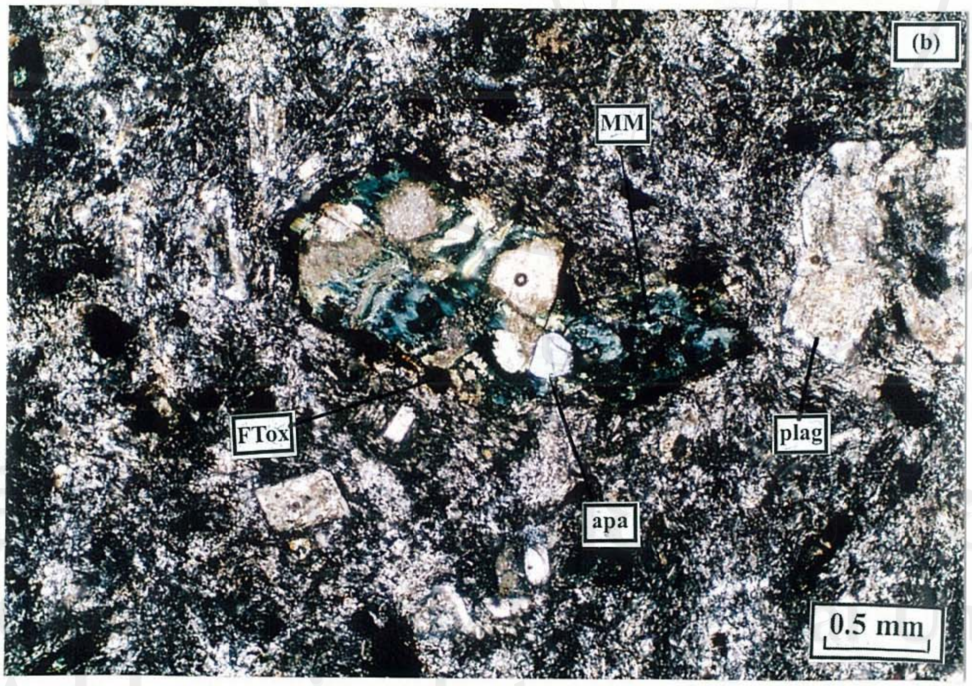


Figure 3.21 Photomicrographs of andesite (sample number MT-2) showing a polymineralic cluster of plagioclase (plag), unidentified mafic mineral (MM), Fe-Ti oxide (FTox) and apatite (apa) megacrysts in the felty groundmass. (a) Ordinary light, (b) Crossed polars.

In general, the groundmass constituents of the studied mafic volcanic rocks are composed largely of plagioclase laths, and contain minor clinopyroxene, unidentified mafic mineral, Fe-Ti oxide and interstitial quartz in different proportions. Secondary patches of sericite, chlorite/serpentine, clay minerals, epidote minerals (zoisite/clinozoisite and/or epidote), pumpellyite, carbonates, quartz, Fe-Ti oxide, hematite/iron hydroxide, sphene/leucoxene and/or amphibole(?) are rarely present. Tiny cavities and fractures that may be sealed by chlorite, epidote minerals (zoisite/clinozoisite and/or epidote), quartz, carbonates, hematite/iron hydroxide and/or Fe-Ti oxide have sparsely been observed in very few samples.

Plagioclase megacrysts and groundmass plagioclase crystals are anhedral to euhedral (largely subhedral) outlines. The plagioclase megacrysts have largely to almost totally been altered, while the groundmass plagioclase grains have undergone variable degrees of alteration. Their replacement minerals are commonly sericite, with minor chlorite, epidote minerals (zoisite/clinozoisite and/or epidote), clay minerals, sphene/leucoxene, carbonates, pumpellyite, quartz, white mica, Fe-Ti oxide, hematite/iron hydroxide and/or Fe sulfide.

Clinopyroxene megacrysts and groundmass clinopyroxene grains are anhedral to euhedral (largely anhedral – subhedral) outlines. The groundmass clinopyroxene grains in some samples are evidently intergranular to plagioclase laths (Fig. 3.18); ophitic/subophitic intergrowths between larger clinopyroxene and smaller plagioclase laths have been observed in sample number MP-7. Almost all the clinopyroxene phases are generally slightly to moderately altered, but for sample numbers MP-10 and MT-5 in which clinopyroxene crystals are totally altered. Their replacement minerals include abundant chlorite and/or ?amphibole, and minor Fe-Ti oxide, sphene/leucoxene, epidote minerals (zoisite/clinozoisite and/or epidote), hematite/iron hydroxide, carbonates and/or quartz. Amphibole commonly occurs at rims of clinopyroxene phenocrysts/microphenocrysts (Fig. 3.17).

Unidentified mafic mineral megacrysts show anhedral to euhedral outlines, but are largely subhedral. They are completely altered to abundant chlorite/serpentine, and minor Fe-Ti oxide, sphene/leucoxene, carbonates, quartz, epidote minerals (zoisite/clinozoisite and/or epidote), hematite/iron hydroxide and/or amphibole. In similar manner to clinopyroxene megacrysts, megacrysts of unidentified mineral are commonly rimmed with amphibole (Fig. 3.13). The euhedral unidentified mafic microphenocrysts have typical outlines of pyroxene. Their shapes and alteration nature signify that they are highly possible to be orthopyroxene.

Fe-Ti oxide crystals occur either as a megacryst phase or as a groundmass phase; some have secondary origins. They have anhedral to euhedral (largely anhedral to subhedral) outlines and are partially replaced by sphene/leucoxene and/or hematite/iron hydroxide. Apatite forms microphenocrysts and shows anhedral to subhedral outlines (Figs. 3.19 and 3.21).

3.2.3 Mafic Hypabyssal Rocks

Only two samples of hypabyssal rocks are presented in this study. Although two hypabyssal samples are taken into consideration, the lithologic description for sample number MR-9 cannot be made since there is no rock sample available after making a thin section and preparing a powdered sample for geochemical analysis. The available sample number BK-2 has a dark gray color and shows a moderately porphyritic texture. The phenocrysts are largely pale green crystals (sizes up to 2 mm across) and black crystals (sizes up to 1 mm across), and embedded in the fine-grained groundmass. Tiny veinlets of greenish black and pale green minerals have been locally detected in minor amount. The rock is slightly magnetic, and does not react with diluted hydrochloric acid, except for the veined minerals that slightly reacts with warm diluted hydrochloric acid.

The sample number BK-2 contains abundant plagioclase and clinopyroxene, and occasionally unidentified mafic mineral megacrysts. These megacrysts occur as isolated grains, monomineralic clusters, and polymineralic clusters of plagioclase +

unidentified mafic mineral + clinopyroxene, plagioclase + clinopyroxene, and clinopyroxene + unidentified mafic mineral. The groundmass constituents have largely undergone alteration, however, the relatively unaltered portion is still existent as irregular patches. The least-altered groundmass portion is fine-grained, with grain sizes largely in a range of 0.05 – 0.15 mm across. It is made up largely of felty plagioclase laths and clinop yroxene, with subordinate unidentified mafic mineral. The severely altered portion contains secondary patches of sericite, epidote minerals (zoisite/clinozoisite and epidote), pumpellyite, chlorite/serpentine, Fe-Ti oxide and sphene/leucoxene. Tiny veined minerals are carbonates, chlorite and epidote minerals (zoisite/clinozoisite and epidote). The rock is classified as gabbro/diorite, following the classification scheme of the IUGS Subcommission on the Systematics of Igneous Rocks (Streckiesen, 1976). Since the rock is fine-grained, the name 'gabbro/diorite' has been modified by the prefix 'micro' as 'microdiorite/microgabbro'.

The sample number MR-9 is a seriate-textured, fine-grained rock that contains plagioclase and clinopyroxene as the principal constituents (Fig. 3.22). Secondary patches of chlorite, sphene/leucoxene and carbonates are present in minor amount. Tiny cavities sealed by quartz and tiny fractures sealed by carbonates have been occasionally detected. In the same manner as the sample number BK-2, the sample number MR-9 is classified as microdiorite/microgabbro.

Plagioclase crystals in the sample number BK-2 are largely subhedral and almost totally altered, whereas those in the sample number MR-9 largely show subhedral to euhedral outlines and have experienced variable degrees of alteration. The alteration minerals include common sericite, and uncommon chlorite, carbonates, pumpellyite, epidote minerals (zoisite/clinozoisite and epidote), Fe-Ti oxide and/or sphene/leucoxene.

All generations of clinopyroxene crystals in the sample number BK-2 are anhedral to subhedral, while clinopyroxene crystals in the sample number MR-9 are anhedral to euhedral. The clinopyroxene crystals in both samples are slightly altered to chlorite, Fe-Ti oxide and/or sphene/leucoxene.

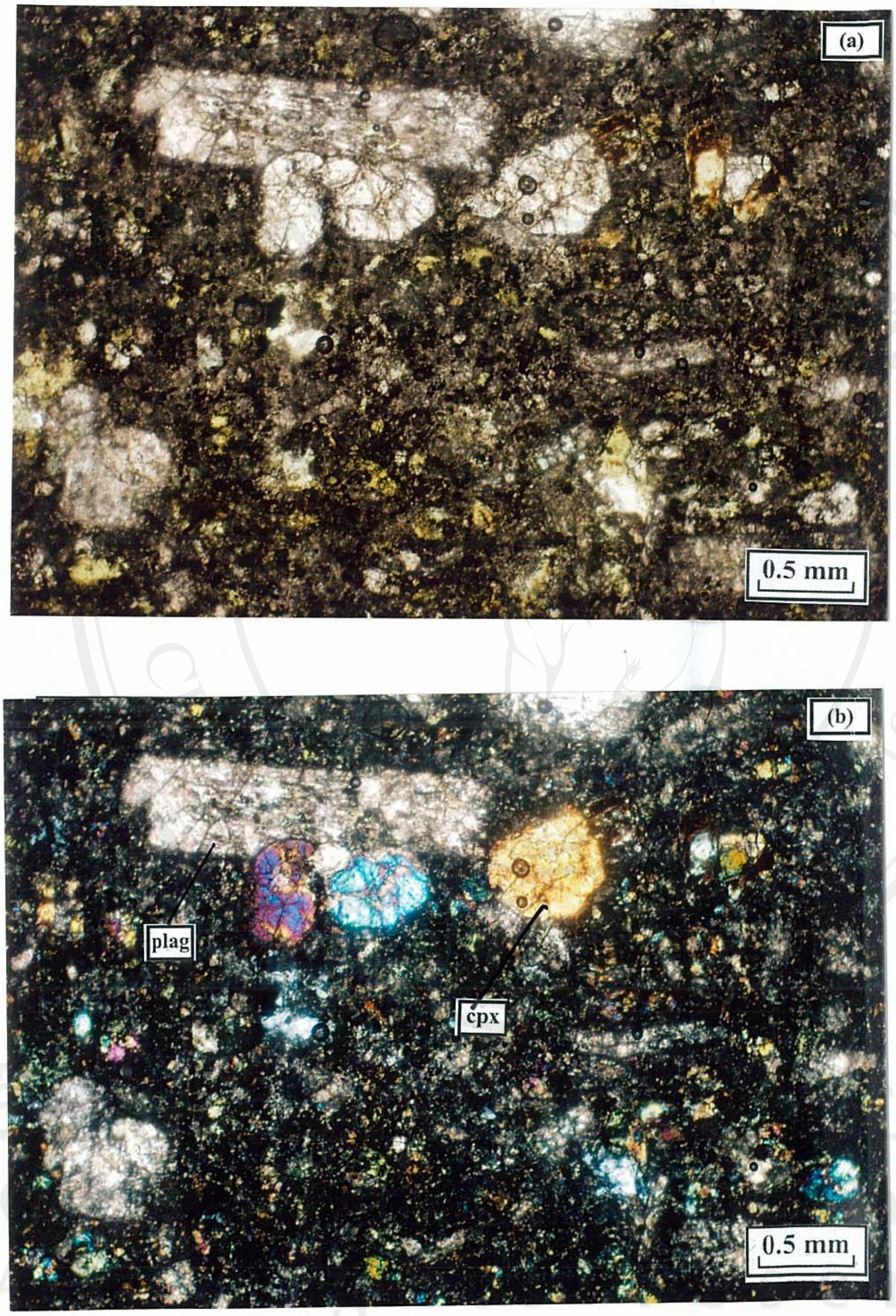


Figure 3.22 Photomicrographs of microdiorite/microgabbro (sample number BK-2) showing microphenocrysts of plagioclase (plag) and clinopyroxene (cpx). (a) Ordinary light, (b) Crossed polars.

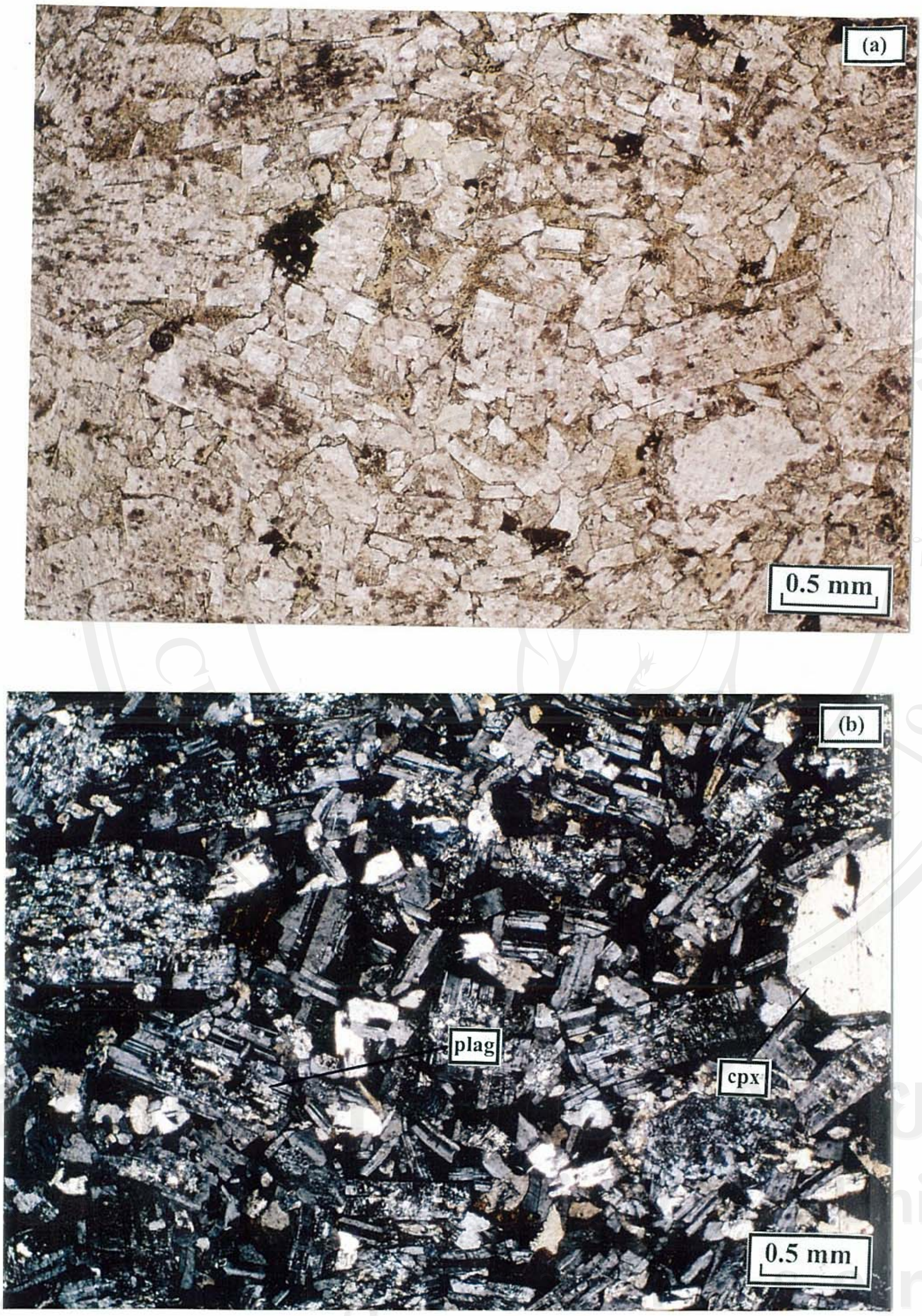


Figure 3.23 Photomicrographs of microdiorite (sample number MR-9) showing a seriate texture, and crystals of plagioclase (plag) and clinopyroxene (cpx). (a) Ordinary light, (b) Crossed polars.