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Preliminary Volcanic stratigraphy of the Khao Noi volcanic, Tha Takiap District, Chachoengsao Province, eastern Thailand

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Abstract

The Khao Noi volcanics (study area) is in Tha Takiap district, Chachoengsao Province. This volcanics is part of the Lampang Volcanic Belt, a potential host rocks for mineralization especially gold and antimony epithermal style. Based on field investigation and drill core logging, the volcanic sequence at Khao Noi has a thickness of 150 meters. The lowest unit (sedimentary unit-Unit 3) which forms as a basement for the Khao Noi volcanics sequence is characterized by laminated limestone, laminated sandstone, limestone breccia, and laminated mudstone. The volcanic sequence can be divided into two units namely, 1) Mafic-intermediate volcanic unit (Unit 2) consisting of plagioclase-phyric andesite, monomictic andesitic breccia, and 2) Felsic volcanic unit (Unit 1) comprising of crystal-rich pumice breccia, lithic-rich pumice breccia, and quartz-phyric andesite. The contact between Unit 2 and Unit 1 is sharp contact and compositionally change from mafic-intermediate to felsic composition. The Khao Noi volcanic architecture is mainly composed of mafic to felsic volcanic succession reflects in eruption style, proximal and distal from sources, depositional environments, and emplacement processes, relatively shallow marine which dominant below wave-base submarine to the subaerial setting. After the formation of the Late Carboniferous sedimentary unit (Unit 3), Unit 2 was deposited with predominantly of andesite and subsequently followed by the deposition of volcanics Unit 1. The volcanic facies architecture comprises interfingering proximal and distal facies association related to four main volcanic types; (1) Submarine andesite includes plagioclase-phyric andesite facies and monomictic andesitic breccia facies. (2) Shallow mafic-intermediate intrusions comprise plagioclase-phyric basalt and aphyric trachyte. (3) Submarine pumice pyroclastic surge comprises crystal-rich pumice breccia facies and lithic-rich pumice breccia facies, and (4) Syn-eruptive intrusion of quartz-phyric rhyolite facies.

Key words: volcanic facies, stratigraphy, Lampang volcanic belt, Sukhothai arc.

1. Introduction

Behaviors of the volcano are well recorded in successions and depositional environments, which can determine the tectonic setting (e.g. R. Cas & Wright, (2012; McPhie et al. (1993)). Moreover, the volcanic rocks are an important host rocks for the ore deposits especially volcanic-hosted massive sulfide (VMS) and epithermal deposits, the main sources for non-ferrous metals deposits (e.g., copper, lead, zinc, and gold).

The Lampang volcanic belt consists of voluminous volcanic rocks which partly overlapping with the Sukhothai Arc comprising of coherent rocks and syn-eruptive intrusion, pyroclastic, and volcaniclastic rocks (Barr and Macdonald, 1991; Wipakul et al., 2012).

The Khao Noi volcanic is in Khlong Takrao, Tha Takiap District, Chachoengsao Province, eastern Thailand (Figure 1A). It is the southern part of the Lampang volcanic belt of Barr and Macdonald (1991). This volcanics has been reported as an important host for minerals deposits especially antimony-fluorite-gold deposits (Paipana, 2014). Prior to this study, Paipana (2014) study mainly focused on general geology of hosted volcanics and antimony-fluorite-gold mineralization including sulfur isotope and geochronology. In this study, we will focus on lithofacies analysis to establish volcanic architectures of the Khao Noi volcanic.

Takiap District, Chachoengsao Province, eastern Thailand part of the Sukhothai arc.

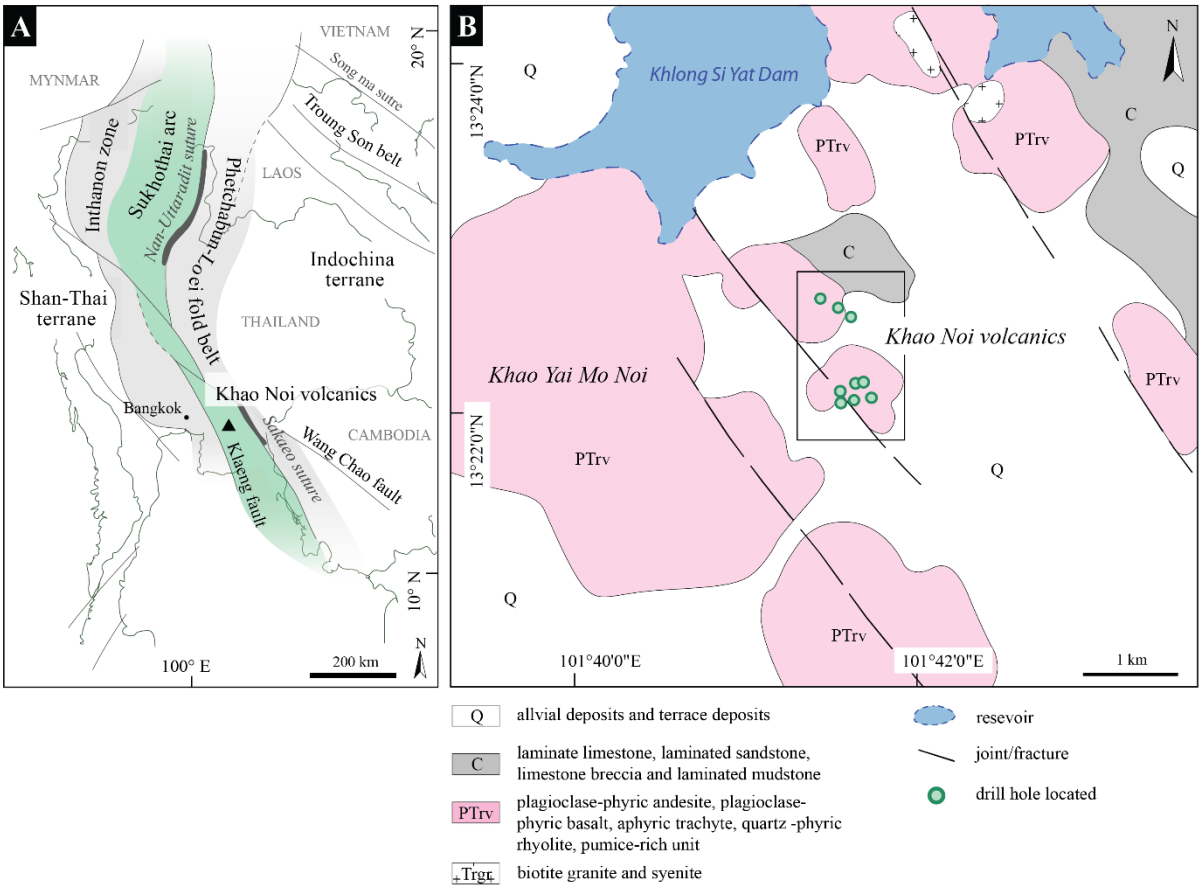

Figure 1. (A) The Khao Noi volcanic located on Sukhothai arc, which eastern of Inthanon zone and western Nan–Uttaradit–Sa Kaeo suture. **(B)** Geological map of the Khao Noi volcanic, eastern Thailand, showing distribution of Carboniferous rocks and Permo–Triassic igneous rocks

2. Geological setting

The oldest sedimentary rocks in regional area in the east of the study area comprising siltstone, sandstone, and limestone. This rock was dated by LA ICP-MS U-Pb zircon method from detrital zircon in sandstone obtaining a maximum age of Carboniferous (328 Ma; Paipana, 2014). In addition, Fontaine et al. (1999) reported that rocks associated the shallow marine fauna at Khao Yai Mo Noi ranging in age from Late Mississippian to Early Pennsylvanian (Carboniferous). This sedimentary sequence is overlain by the Permo-Triassic volcanic rocks comprising mainly andesite and rhyolitic tuff. Dykes swarm of andesitic composition was dated using LA ICPMS U-Pb zircon technique, yielded age of emplacement of 258 Ma (Early Triassic). In the northern part of area, along Khlong Si Yat Dam to Khao Bararun area (Figure 1B), granitic rocks occur as small hill which forms as a narrow north-south trending and was reported as syenite by Watcharamai (in published). Paipana (2014) dated this syenite sample from diamond drill holes near Ban Sam Tha Han using LA-ICP-MS zircon U-Pb method, yielded 260.8±2.6 Ma. Most of the area in southeast is covered by Quaternary alluvium and terrace sediments (Figure 1; Tiyapirach, 1996).

3. Volcanic stratigraphy

In this study, volcanics classification, facies and facies architecture were based on as outlined by McPhie et al. (1993). In general terms used in this section were based on terms defined by Cas & Wright (2012). For example, “coherent” is texture form from cooling and solidification of lava, facies association is lithofacies that are spatial, mineralogy and composition related. The host volcanic sequence (main sequence) is ranging in composition from andesite to rhyolite consisting of volcaniclastic with subordinate dykes of basalt to trachyte. Based on field investigation and diamond drill cores logging,

the rocks in study area can be divided into 3 units (Figure 2). which define a gentle east-dipping (30 to 40°).

Stratigraphically, from lower to upper unit (oldest to youngest)

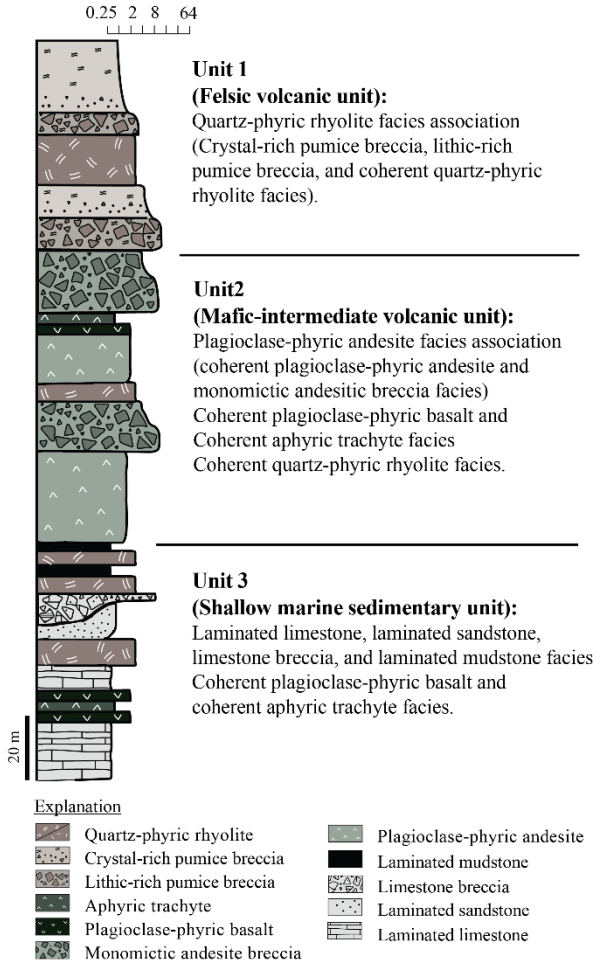

Figure 2. Simplified composite stratigraphy of the Khao Noi volcanics, Chachoengsao province, eastern Thailand.

Sedimentary unit (Unit 3):

This unit forms as basement of the Khao Noi volcanic sequence comprising laminated limestone, laminated sandstone, limestone breccia, and laminated mudstone (Figure 2.). The total thickness of this unit is estimated at 40 to 60 meters. Unit 3 also contains plagioclase-phyric basalt, aphyric trachyte, quartz-phyric rhyolite (Figure 4A) especially at the upper part of unit. The lower part of the Unit 3 consists mainly of laminated limestone up to 40 meters thick (Figure 4B, 4C), minor laminated sandstone (Figure 4H, 4I), and limestone breccia. In addition, laminated mudstone tends to form at topmost of the unit. The contact between Unit 3 and Unit 2 is sharp contacts.

Mafic-intermediate volcanic unit (Unit 2):

The mafic-intermediate volcanic unit is estimated at 60 to 80 meters thick consisting mainly of plagioclase-phyric andesite, monomictic andesitic breccia, plagioclase-phyric basalt and aphyric trachyte. The upper contact between plagioclase-phyric andesite and monomictic andesitic breccia is characterized by gradational contact with the present of quenching texture interpreted as hyaloclastite. It should be noted that the lower contact between Unit 2 and Unit 3 (below) is a sharp contact. The mafic - intermediate volcanics unit contains basalt and trachyte which might be occurred as dykes with presence of chilled margins and have sharp contacts with the host sequence. The mafic dykes are only a few meters thick, typically show tabular shape.

Felsic volcanic unit (Unit 1):

The youngest stratigraphic interval and commonly cropped out in the field as well intersecting in diamond drillholes. It consists mainly of crystal-rich pumice breccia and lithic-rich pumice breccia, and quartz-phyric rhyolite. This felsic volcanic unit is estimated at 60 to 80 meters thick, which directly overlies the mafic-intermediate volcanic unit (Unit 2). The lower contact between Unit 1 and Unit 2 is gradational.

4. Volcanic facies and facies associations:

(1) Plagioclase-phyric andesite facies association

The mafic-intermediate volcanic unit consists mainly of plagioclase-phyric andesite facies association including the coherent plagioclase-phyric andesite facies and monomictic andesitic breccia facies.

Coherent plagioclase-phyric andesite facies presents up to 20 meters thick with associated monomictic andesitic breccia facies that can be well observed in drill core at the center of Khao Noi (DDH23) (Figure 3A.). The rock is characterized by dark green color, porphyritic texture about 35–40 vol% of phenocryst (Figure 3H.). The plagioclase phenocrysts (35–45 vol. %) with sizes of 0.5–3 mm in length, and identification as andesine (An38–45). The plagioclases show euhedral shape, sieve texture with isolated crystals, some rounded, and hornblende-plagioclase cumulocrysts (5–10 vol. %). They are also surrounded by microlite plagioclase, glass, and fine-opaque crystals (Figure 3I.). At

intermediate zone has aligned amygdales with quartz and carbonate infilled.

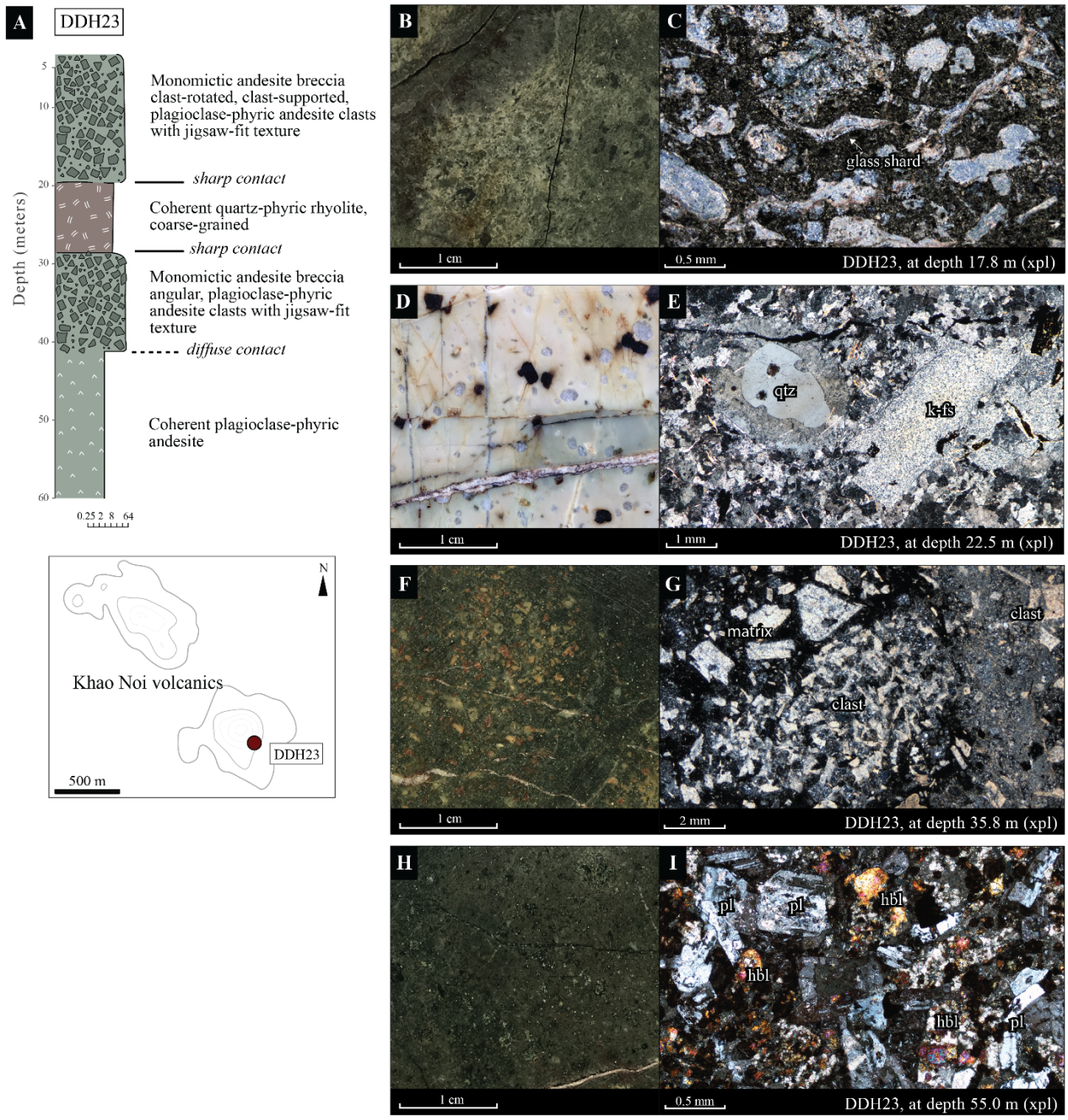

Figure 3. (A) The graphic log through a plagioclase-phyric andesite grading to monomictic andesitic breccia and coherent quartz rhyolite of drill hole DDH23. **(B)** Rotated-clasts exhibiting jigsaw-fit within a matrix of coarse-grained lithic and crystal fragments (at depth 17.8 m). **(C)** Cross-Polarized Photomicrograph plagioclase-phyric andesite clast showing flow-banded of glass shard and fine-grained margins. **(D)** The massive of coherent quartz-plagioclase porphyritic rhyolite containing an abundance of quartz and plagioclase phenocrysts and minor muscovite. **(E)** Cross-Polarized Photomicrograph plagioclase rhyolite showing K-feldspar and quartz phenocrysts surrounding by felsic groundmass. **(F)** Angular clasts of andesite with poorly distinguish of clasts boundary. **(G)** Cross-Polarized Photomicrograph of clast showing commonly porphyritic andesite. **(H)** Massive, and fine-grain, that contains 30 vol. % plagioclase phenocrysts (at depth 55.0 m). **(I)** Cross-Polarized Photomicrograph plagioclase-phyric andesite showing hornblende and plagioclase phenocrysts surrounding by microlite plagioclase groundmass. **Note:** qtz = quartz, hbl = hornblende, kfs = alkali-feldspar.

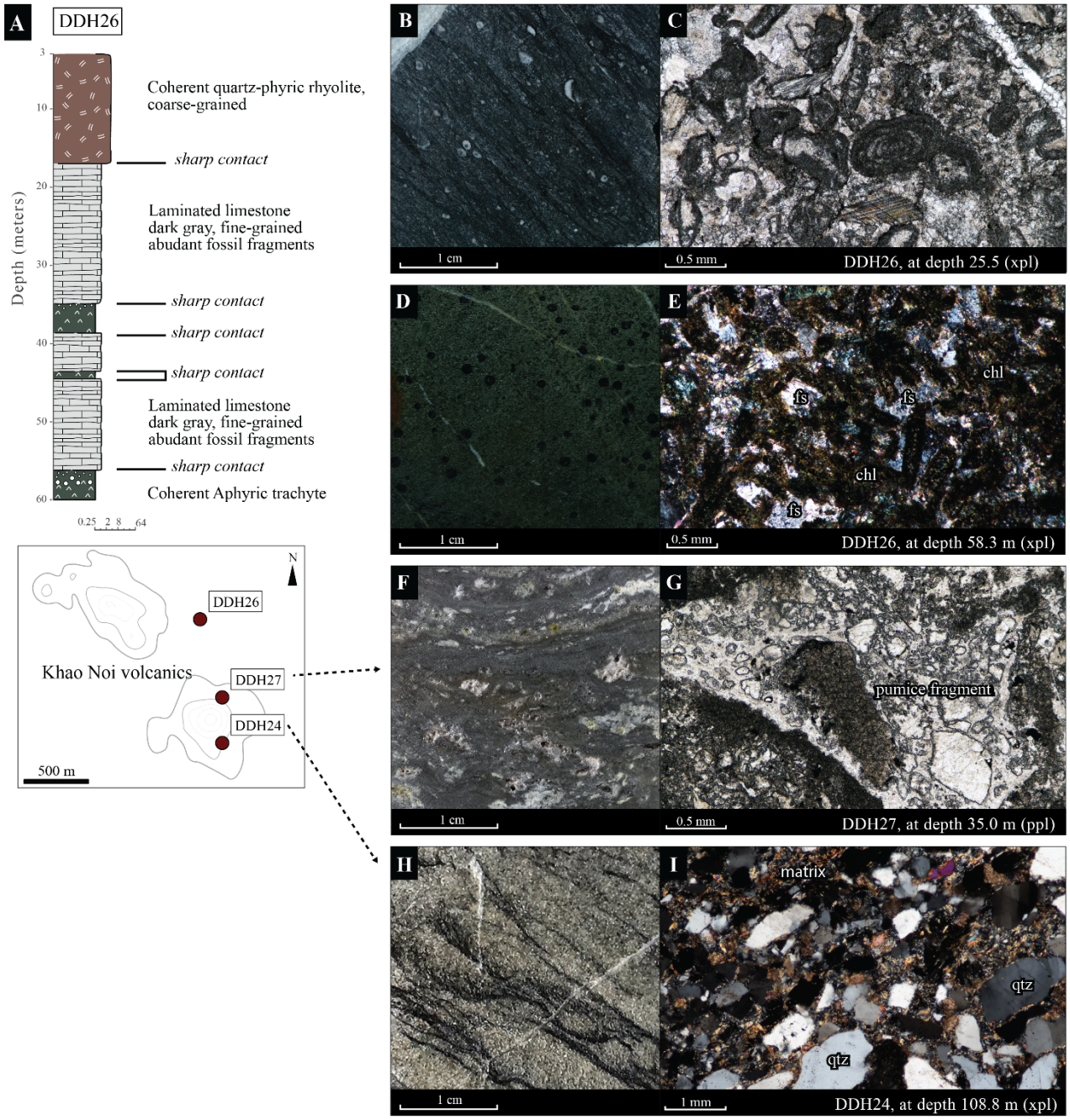

Figure 4. (A) Graphic log through a coherent plagioclase-phyric basalt intersected laminated limestone and covered by coherent quartz-phyric rhyolite in drill hole DDH26. **(B)** Dark gray limestone interbedded with dark mudstone, associated with fossil fragments (at depth 25.5 m). **(C)** Polarized Photomicrograph sample from (B) abundance of fossils fragment set in less carbonate cement. **(D)** Plagioclase-phyric basalt showing sparsely phenocrysts with medium grained. **(E)** Cross-Polarized Photomicrograph plagioclase-phyric basalt showing mafic minerals replace by chlorite set in plagioclase ground mass. **(F)** Many pumice clasts have an irregular shape, flame-like shape surrounding by the matrix that is crystal-rich and nearly identical to clast composition top of sequence. **(G)** Polarized Photomicrograph quartz pumice contain of quartz, feldspar and tube pumice set in crystals and glass. **(H)** Fine laminated sandstone interlayered with black mud layers. **(I)** Cross-Polarized Photomicrograph sample from (H) subangular sand-size-grains with mostly clear quartz, feldspar, and clay (at depth 108.8 m).

Monomictic andesitic breccia facies at the top of unit 3 with sharp contact and the lower part occurs as layers at the top of coherent plagioclase-phyric andesite. The monomictic andesitic breccia is 8 to 40 meters thick, massive, display in dark green to gray colors, typically jigsaw-fit texture, clast- supported (Figure 3B.). The clast is mainly composed of plagioclase-phyric andesite, grain size decreases from 25 cm to 3 cm, commonly flow-banded, angular, rotated that show fine-grained margins (Figure 3C.). The matrix comprises fine- grained crystal of plagioclase, quartz, and glass shards.

(2) Coherent plagioclase-phyric basalt facies

The coherent plagioclase-phyric basalt intersects monomictic andesitic breccia, laminated limestone (Unit 3). The plagioclase-phyric basalt ranges in thickness from 2 up to 5 m and displays green-gray to dark in color, weakly porphyritic to medium-grained (Figure 4D.). The phenocrysts about 3–5 vol. % of the rock commonly isolated plagioclase (4–8 mm in length), anhedral, and some rounded. The medium to coarse groundmass with ophitic texture consists of plagioclase laths, minor slightly altered dark brown mafic minerals that were replaced by chlorite, glasses, and opaque mineral (Figure 4E.).

(3) Coherent aphyric trachyte facies

These coherent facies ranging in thickness from 2 to 5 m, intersect monomictic andesitic breccia facies and coherent plagioclase-phyric basalt facies. At place fine-grained margins and vesicles near contacts with coherent plagioclase-phyric basalt. This rock characterized by pale greenish-gray to dark colors, commonly trachytic texture, comprises fine-grained alkali-feldspar, lath crystals (80–90 vol. %, <0.2 mm), altered brown glass, and ferromagnesian minerals.

(4) Quartz-phyric rhyolite facies association

Crystal-rich pumice breccia facies located at the uppermost part of felsic volcanic units, and lower contact with diffusive beds overlain coherent quartz-phyric rhyolite (DDH27). The rock was characterized by 30 meters thick beds, normal-graded, diffusive, discontinuous lamina, matrix-supported, and comprise pumice clasts, glass shards, crystal grains (Figure 4F.). Petrographic studies show pumice clast of about 50–60 vol%, tube pumice fragments (Figure 4G.) and coherent quartz-phyric rhyolite clast. The dark-colored matrix that contrasts with clasts contains crystal grains belonging to glass shard, quartz, and feldspar.

Lithic-rich pumice breccia facies located at the lower part of the felsic volcanic unit that directly overlies monomictic andesitic breccia facies (unit 2), and intercalated with crystal-rich pumice breccia. The thickness is 2 to 5 meters. These facies consist of distinct graded beds, each bed is about 50 centimeters thick and contain white, dark gray, 30 % pumice clasts, tube pumice fragments, and local clast of coherent quartz-phyric rhyolite facies. The pumice clasts are commonly fluidal shape, white-pale gray in colors with highly vesicular (20–30 vol. %), clast size in a range of 1–5 cm. The matrix composed of glass shard, and crystal fragments that are commonly fiame shape.

Coherent quartz-phyric rhyolite facies intersects monomictic andesitic breccia facies (Unit 2) and laminated limestone facies (Unit 3). Locally coherent quartz-phyric rhyolite breccia occurs at margins intrude crystal-rich pumice breccia. This coherent rock is up to 50 meters thick and displays in gray color, moderately porphyritic (25–30%) (Figure 3D.). Quartz phenocrysts (2 mm up to 8 mm) show embayed edge, fine boundary layer that formed around the crystals, and contain alkali-feldspar partly replaced by sericite. Large quartz phenocrysts may isolate up to 11 mm in length, set in the felsic microcrystalline groundmass (Figure 3E.).

5. Facies interpretation

Proximal mafic-intermediate volcanism

The early volcanism creates by plagioclase-phyric andesite facies associations occurs about 50% of the Khao Noi volcanic. The coherent plagioclase-phyric andesite was interpreted base on geometry, thickness and contacts relation to represent multiple generation of subaqueous lava domes and sills (Figure 6B). The round shape and embayment of feldspar phenocrysts indicate that they have been resorbed probably due to disequilibrium conditions caused by the fast rise through the crust and rapid depressurization of magma prior to eruption (McPhie and Allen, 2003; Gill, 2010). This coherent plagioclase-phyric andesite gradational contacted into hyaloclastite suggests quench fragmentation. The margins of andesitic lavas comprise monomictic andesitic breccia occurring as autoclastic facies and is characterized by jigsaw-fit texture of blocky to rotated clasts. This feature is characteristics of autoclastic facies that occur as hyaloclastites with no sediment matrix. This monomictic andesitic

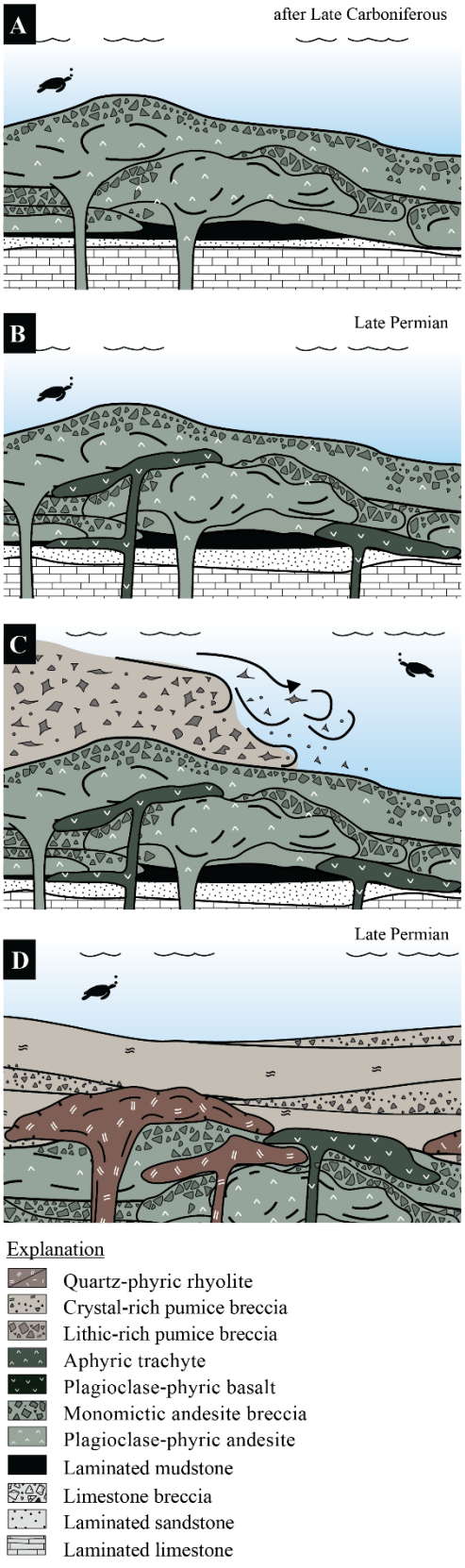

Figure 5. Evolution of the facies model in Khao Noi volcanic showing position and depositional environment. **(A)** Subaqueous, andesite lava domes and sills volcano effusive overlying shallow marine sedimentary unit. **(B)** The mafic intrusion of the basalt and aphyric trachyte dykes intruded andesitic lavas and domes. **(C)** Subaerial to shallow-marine volcanic eruptions generate subaqueous syn-eruptive pyroclastic mass-flow deposits. And **(D)** Syn-eruptive felsic intrusion of co-magmatic rhyolite sills and dykes.

breccia suggested that emerge margins of plagioclase-phyric andesite lavas reached the seafloor and have been quench brecciated due to fast cooling into the seawater (Pichler, 1965) (Figure 5A).

The two different units of coherent plagioclase-phyric basalt and aphyric trachyte were emplaced as dykes. The plagioclase-phyric basalt dykes have medium to coarse grain to nearly aphyric texture, with mega plagioclase phenocryst which may indicate the residence time to grow the phenocryst (Figure 5B.). Whereas the aphyric trachyte dykes may erupted directly without much residence in subvolcanic system and may have faster eruption rate.

The similar composition of both units suggests that the mafic dykes are co-magmatic. These mafic dykes also have fine grain, and chilled margins contacts intruded marine sedimentary unit and mafic to intermediate unit, as consequently interpreted as late dykes. That is the plagioclase-phyric andesite facies association and mafic dykes are interpreted to have been deposited as lavas domes, sills and dykes that occur in proximal volcanic section.

Distal felsic volcanism

The felsic volcanic unit, the uppermost of the Khao Noi volcanic succession, comprises in addition to thin beds of crystal-rich pumice breccia, lithic-rich pumice breccia and coherent quartz-phyric rhyolite. The diffusive and graded bedding crystal-rich pumice breccia interbedded with lithic-rich pumice breccia suggests that both facies was deposited in subaerial to the shallow subaqueous environment of pyroclastic flows that are similar to the gravity debris flows by sediment moving on the slope. The fluidal clasts are evidence of hot clast settling into water-supported environment. The thickness and fluidal clast shape of juvenile pumice-rich clast suggests that the pyroclasts was derived from syn-eruptive pyroclastic eruption, that is interpreted to have been fed from fire fountain eruption (Cas & Wright, 2012; Simpson & McPhie, 2001) (Figure 5C.).

The coherent quartz-phyric rhyolite intruded in crystal-rich pumice breccia and marine sedimentary units. The round shape and embayment

of quartz and feldspar phenocrysts indicates that they have been resorbed probably due to disequilibrium conditions (McPhie and Allen, 2003; Gill, 2010). These rhyolites were emplaced as dykes and sills. Their gradational contacts into breccia suggest quench fragmentation (Gifkins et al., 2002), that took a place shortly after pyroclasts unit formed. Within the dominantly quartz-phyric rhyolite intruded in all unit are evidence of dykes and sills that occur in distal felsic volcanic section (Figure 5D.).

6. Conclusion

On the basis of previous work, field investigation, lithofacies, and stratigraphy of the rocks of the Khao Noi volcanic, Chachoengsao province, southeast Thailand. The Khao Noi volcanic is divided into seven volcanic facies. Furthermore, these facies are grouped into two facies associations to reconstruct the volcanism. The volcanic succession overlie the middle Carboniferous limestone and terrigenous sediments, where the proximal of mafic to intermediate subaqueous volcano has intruded at least two events. The Khao Noi volcanic began erupting on shallow marine during late Carboniferous to late Permian. The massive lava flowed with minor hyaloclastites. Finally, during Late Permian distal from felsic volcanic erupted creates an abundance of syn-eruptive pyroclastic rocks and felsic intrusion rocks. The poorly and well sorting of fine to coarse-grained and pumice fragments is characteristics of both gas- and water-supported eruption and settling from pyroclastic flows and resedimented pyroclasts fragments.

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