Bulletin of Earth Sciences of Thailand

Preliminary Petrography and geochemistry of volcanic rocks in Lam Sonthi area, Lop Buri province, central Thailand

Saowaphap Uthairat[1, 2], Abhisit Salam[1*], Takayuki Manaka[3]

[1]*Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand*
[2]*Department of Mineral Resources, 75/10 Rama VI Rd., Ratchathewi, Bangkok 10400, Thailand*
[3]*Mineral Resources Research Group, Research Institute for Geo-Resources and Environment, Geological Survey of Japan (AIST), Tsukuba, Ibaraki 305-8567, Japan*

*Corresponding author e-mail: masoesalam@gmail.com

Abstract

Lam Sonthi area is located at Lop Buri province, central Thailand. The two volcanic units in this area are Khao Ruak volcanics and Khok Khli volcanics. Further geochemical analysis, the representatives include lavas from Khao Ruak volcanics (hornblende-plagioclase andesite) and selected large clasts of Khok Khli polymictic intermediate breccia (hornblende-plagioclase andesite). The result suggested that their composition is andesite which was identified as calc-alkaline affinity. Plots of tectonic diagram of Ti - Zr suggest that the rocks could have been originated in the volcanic arc setting. In addition, the N-MORB normalized patterns show negative Nb and Ta which could suggest that the magma is associated with subduction zone. Geochemical similarities of volcanics from both areas could suggest that they are probably derived from the same sources. Furthermore, U-Pb zircon ages of volcanics from Khok Khli are 204-205 Ma. This could be assumed that Khao Ruak volcanics might have similar age as well. Similar ages of volcanic rocks were also reported from Khao Kwang Fold-Thrust belt in Saraburi which is 207 Ma. This can also suggest that post-collision magmatism is not limited to plutonic but also volcanic rocks.

Keywords: volcanic rocks, calc-alkaline andesite, Loei-Phetchabun-Nakhon Nayok volcanic belt

1. Introduction

The study area is in Lam Sonthi district, Lop Buri province, central of Thailand (Figure 1). The geology of the area has not been properly mapped and classified. Several versions of geologic map of the Lam Sonthi area were published through the time by Geological Survey Division, Department of Mineral Resources (DMR), Amphoe Ban MI map sheet (Nakornsri, 1977) and geologic map of Lop Buri province (Vimuktanandana and Thiyaphairach, 2007). The geology in the area consists of Khao Luak Formation, Saraburi Group (Permian rocks), Huai Hin Lat Formation (Triassic rocks), Phu Kradung Formation (Jurassic rock), and the undifferentiated volcanic rocks (Permo-Triassic volcanics). The least version of geologic map is presented by Department of Geology, Chulalongkorn University (2016 and 2020). However, the more details of geology in Lam Sonthi area are still not clear. Therefore, this study aims to analyze the characteristics of volcanic rocks in Lam Sonthi area using petrography and geochemistry.

2. Tectonic setting

Thailand and its adjacent areas consist of two major terranes, Sibumasu terrane (part of its previous known as Shan-Thai; Bunopas, 1981) and Indochina terrane. They are separated by Sukhothai Arc (or Sukhothai Fold Belt) located at the eastern edge of Sibumasu terrane and Loei Fold Belt (LFB) at the western edge of Indochina terrane. LFB is defined as volcano-plutonic zone associated with important mineral deposits (e.g., gold, silver, copper, and iron). The Inthanon zone represents Paleo-Tethys between Sibumasu and Indochina terranes (Sone and Metcalfe, 2008). Nan-Uttaradit suture and its extension in the south of Sra Kaeo suture represent the back-arc basin (Wakita and Metcalfe, 2005).

Based on U-Pb zircon age data and whole rock chemistry, the Loei Fold Belt (LFB) and Sukhothai Arc have a complex magmatic history and widespread of Permo-Triassic magmatism. The magmatic rocks in the LFB are predominantly I-type affinity (Khin Zaw et al., 2007). The subduction of Sibumasu underneath the Indochina occurred during Late Permian, resulting in the emplacement of volcanic and plutonic rocks followed by the collision during the Late Triassic to Early Jurassic. In LFB, post-collision magmatism is widely represented by granitic rocks (Jungyusuk and Khositanont, 1992; Barr and Charusiri, 2011; Khin Zaw et al., 2014). However, volcanic rocks are less commonly reported.

3. Geology of Lam Sonthi area

Based on pre-existing geology maps (e.g., Nakornsri, 1977; Vimuktanandana and Thiyaphairach, 2007), recent works of students from Department of Geology, Faculty of Science, Chulalongkorn University (2020) and this study, the geology of Lam Sonthi area was compiled (Figure 1). Geology of Lam Sonthi area consists of five rock units: 1) sedimentary rocks (Unit I), 2) Limestone conglomerate (Unit II), 3) Khao Ruak volcanics (Unit III), 4) Polymictic conglomerate (Unit IV) 5) Clastic sedimentary rocks (Unit V). Unit I is the oldest rocks in the area occurring in Khao Ruak mountains range. It consists predominantly of fine-grained clastics (siltstone, mudstone and minor shale). Limestone occurs as lenses from few meters to few tens of meters thick. It is well exposed along road cut. This Unit is equivalent to the Khao Luak Formation (Nakornsri, 1977; Assavapatchara, 2006). Bunopas (1981) assigned Khao Luak Formation to the Saraburi Group. Recently Hara et al. (2020) reported the age of Khao Luak Formation of 276 Ma (Early Permian) from the detrital zircons using U-Pb zircon age dating technique for sandstone which was collected from Nong Phai, Phetchabun far north from the Lam Sonthi area. Limestone conglomerate (Unit II) found at the southern part of the area and it is best exposed at Khao Phaeng Ma. This unit mainly consists of limestone conglomerate in which majorities made up of limestone and minor mudstone in matrix of fine-grained clastic. This unit has almost north-south strikes with steep dipping angle. Nakornsri (1981) suggested that this conglomerate could be correlated with Late Triassic Huai Hin Lat Formation. In the field, the Khao Ruak volcanics (Unit III) overlie Unit II extending several km in north-south trending. Vimuktanandana and Thiyaphairach (2007) previously mapped volcanics in small area which are inferred as Permo-Triassic age. In this study, it has been found that the rock is quite widespread and consists of hornblende-plagioclase andesite, pyroxene-plagioclase basaltic andesite, monomictic andesitic sandstone, crystal-rich andesitic sandstone, and monomictic basaltic andesite breccia. Here this unit is known as Khao Ruak volcanics owing to its distribution area. Polymictic conglomerate (Unit IV) was assigned to Phu Kradung Formation of Lower Jurassic age in the map produced by DMR (e.g., Nakornsri, 1977; Vimuktanandana and Thiyaphairach, 2007) which include Unit III, Unit IV, and Unit V of this study. Polymictic conglomerate (Unit IV) is made up of conglomerate typically characterized by multiple types of clasts including volcanics, sandstone, siltstone, mudstone, limestone, and fragments of quartz vein in matrix of finer sediments of similar component. Based on field observation, volcanic rocks present at the upper part of the unit and here will be named as “Khok Khli volcanics” (see later section). This Khok Khli volcanics of Unit IV is particularly croped out at Khok Khli railway staion and west of Kuttaphet reservoir (Figure 1). Clastic sedimentary rocks (Unit V) overlie the Khok Khli volcanics. At the lower part, it consists of polymictic conglomerate dominated by both volcanics and limestone clasts characterized as clast supported conglomerate. However, the conglomerate gradually increases in matrix and become matrix supported at the upper part or coarse-grained sandstone in some parts of its extension. Fine-grained sandstone interbedded with thin mudstone and shale was found at the upper part of the unit, a typical rock of Phu Kradung Formation of Khorat Group. The rocks of this unit are mainly found close to Khao Phang Huei. It has been previously mapped as Phu Kradung Formation with the age of Lower Jurassic (Nakornsri, 1977; Vimuktanandana and Thiyaphairach, 2007).

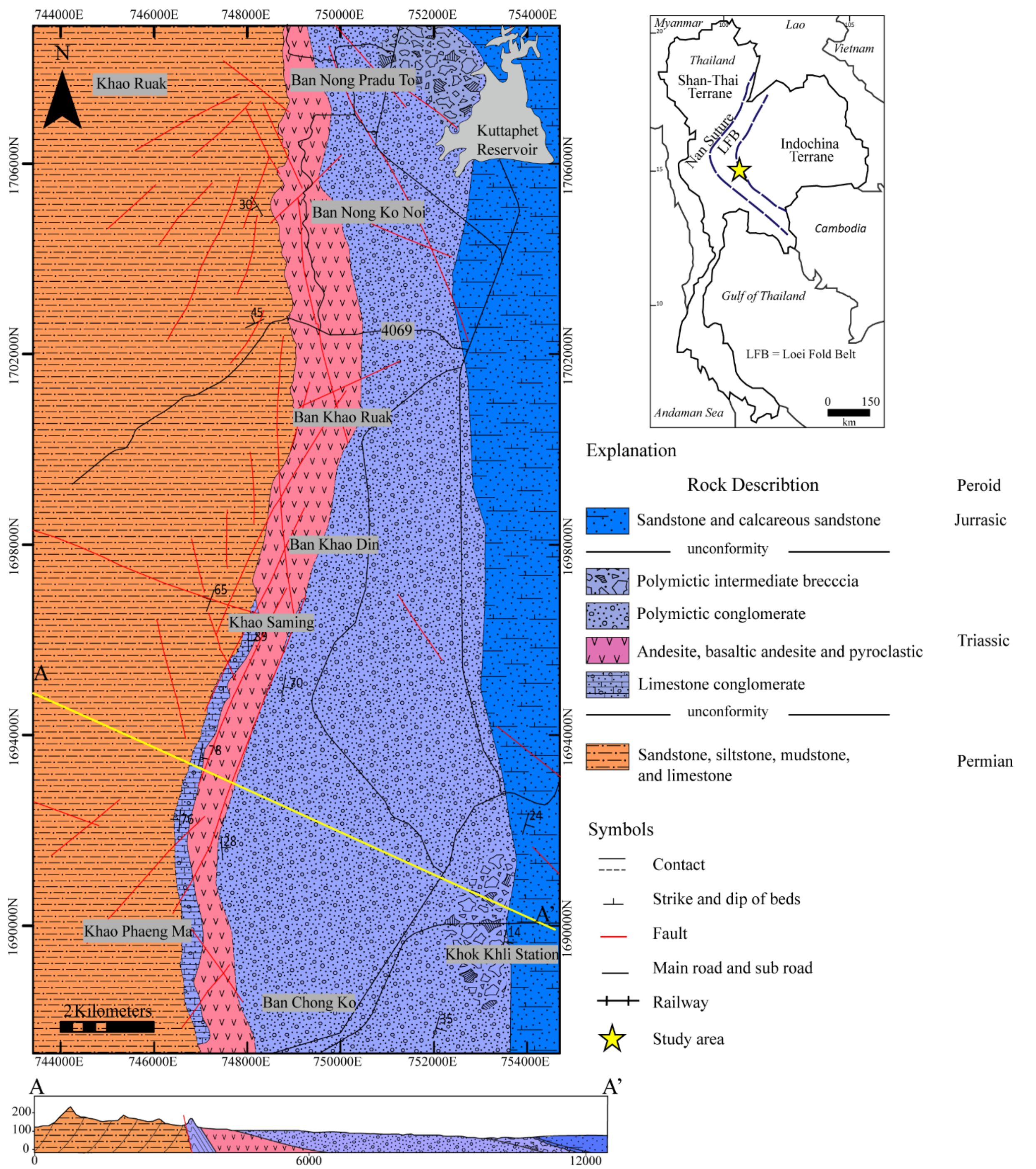

Figure 1. Geologic map of Lam Sonthi area, Lop Buri province

4. Sample collection and Methodology

The samples of volcanic rocks were collected from outcrop of Khao Ruak volcanics and for the Khok Khli volcanics, samples were specifically selected from clasts of lavas from polymictic intermediate breccia that clast size is larger than 10 cm.

Samples of lavas were selected and undergone petrographic study. The Khao Ruak volcanics can be grouped into hornblende-plagioclase andesite and pyroxene-plagioclase basaltic andesite while clasts from Khok Khli volcanics include plagioclase andesite, hornblende-plagioclase andesite, and pyroxene-plagioclase basaltic andesite. Further study, six samples of hornblende-plagioclase andesite from Khao Ruak volcanics and Khok Khli volcanics were selected for XRF whole-rock analysis. They were pulverized by a disc mill to clay size at the Department of Geology, Chulalongkorn university, then determined the loss on ignition by heating samples in high temperature furnace at 1,000 °C and mixing 1 gram of powder samples with a few lithium romide (LiBr) and 5 gram di-lithium tetraborate ($Li_2B_4O_7$). The samples, then, were fused and analyzed by XRF at DMR. The concentrations were calculated against the calibrations derived from 3 international standard reference materials (JGb-1, GBW03101, and JB-1a). Two samples representing each group were further analyzed for trace elements and rare earth elements. They were pulverized same as XRF analysis before being mailed to the ALS company. Moreover, 2 grams of each sample were dissolved by acid, then they were fused with Li Borate.

5. Petrography of volcanic rocks

5.1 Khao Ruak volcanics

Hornblende-plagioclase andesite crops out at the southwest of the area close to the Khao Phaeng Ma. It is light brown and displays porphyritic texture. It contains about 20% phenocrysts in finer grained groundmass. Phenocrysts compose mainly of plagioclase and subordinate hornblende. Grain size of phenocrysts is ranged from 0.5 – 1 mm. Hornblende phenocrysts show euhedral to subhedral crystal with rhombohedral shape. Plagioclase phenocryst shows euhedral to subhedral crystal with carlsbad twin. The groundmass occasionally shows glassy texture. Mafic minerals are partly altered to chlorite, whereas feldspar is selectively altered to sericite (Figure 2A). Pyroxene-plagioclase basaltic andesite can be observed to the north not far from hornblende-plagioclase andesite. Pyroxene-plagioclase basaltic andesite is grey to dark grey containing about 15% phenocrysts setting in

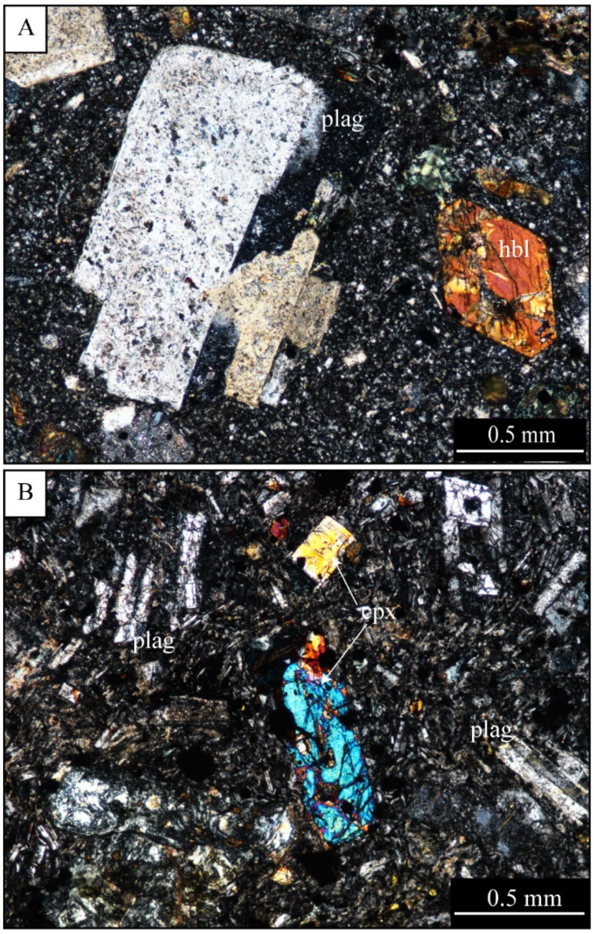

Fig. 2. Characteristic of Khao Ruak volcanics. (A) Photomicrograph of hornblende-plagioclase andesite showing plagioclase and hornblende surrounded by fine-grained groundmass. (B) Photomicrograph of pyroxene-plagioclase basaltic andesite showing plagioclase and clinopyroxene phenocrysts in fine-grained groundmass. Abbreviation; hbl=Hornblende, plag=Plagioclase, cpx=Clinopyroxene

finer groundmass. Phenocrysts are mainly plagioclase with subordinate pyroxene. Grain sizes of plagioclases vary from 0.4-1.5 mm with euhedral to subhedral crystals. Pyroxene (mostly clinopyroxene) has grain size of 0.3-1 mm which shows euhedral to subhedral crystal. Fine-grained groundmass typically shows trachytic texture. Some mafic minerals may have altered to chlorite and opaque minerals (Figure 2B).

5.2 Khok Khli volcanics

Polymictic intermediate breccia is a member of Khok Khli volcanic sequence (Figure 3A). It is characterized by thick to very thick beds of polymictic intermediate breccia interbedded with thin to medium beds of crystal-rich andesitic sandstone. Polymictic intermediate breccia is clast-supported. Clasts are pebble to boulder size ranging from 4-25 cm, angular to subangular. Clasts are poorly sorted (Figure 3B) and surrounded by purplish brown sandy size matrix. Under microscope, the matrix consists mainly of plagioclase, hornblende, and glass. Plagioclase grains are subhedral with their sizes are 0.1-0.5 mm (Figure 3C and D). The clasts are andesitic composition which show porphyritic texture. They could be classified as plagioclase andesite, hornblende-plagioclase andesite, and pyroxene-plagioclase basaltic andesite.

Plagioclase andesite shows porphyritic texture comprising fine-grained plagioclase phenocryst which show euhedral crystal, and their grain sizes are 0.2-0.5 mm. They are surrounded by finer pinkish grey feldspar groundmass which shows seriate texture (Figure 4A). Hornblende-plagioclase andesite shows porphyritic texture comprising mainly plagioclase and hornblende. The phenocrysts

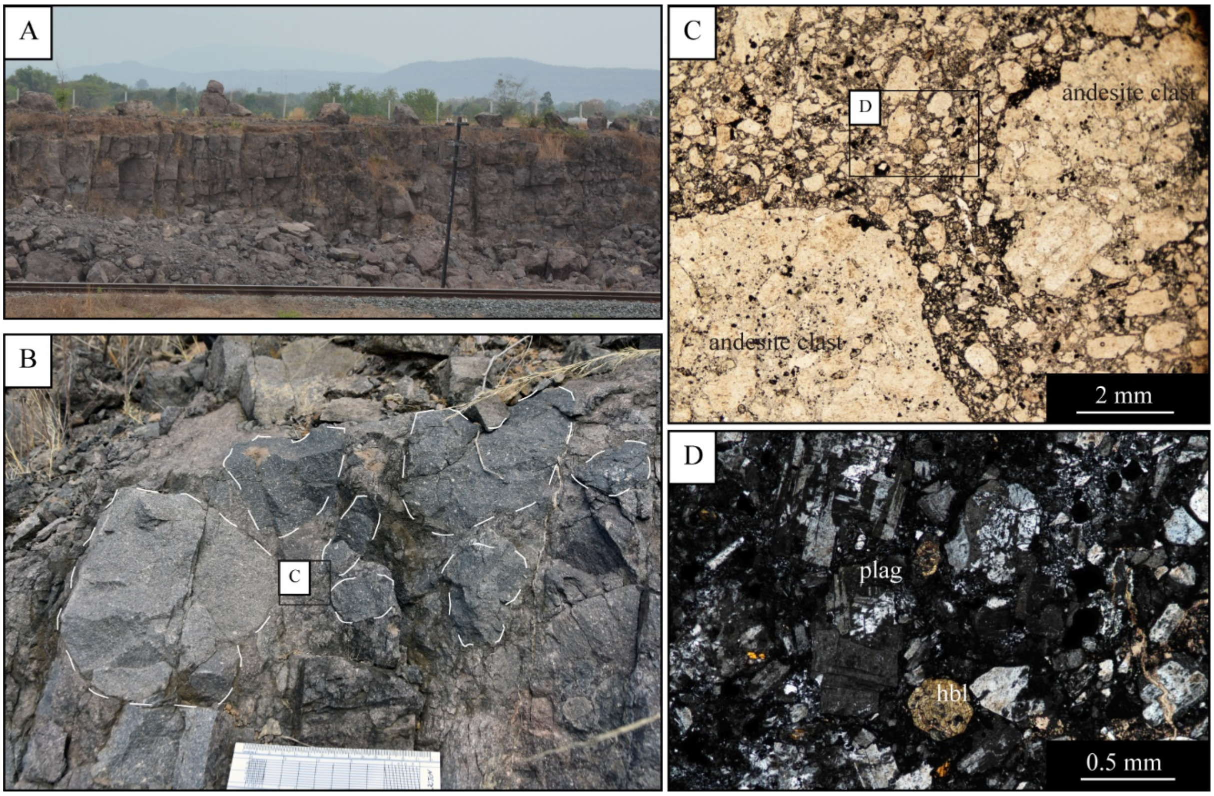

Figure 3. Characteristic of Khok Khli volcanic. (A) Photograph of Khok Khli volcanic outcrop. (B) Photograph of polymictic intermediate breccia showing andesite clasts. (C) Photomicrograph of polymictic intermediate breccia showing small andesite clasts sitting in matrix laying between large clasts. (D) Photomicrograph from area given in Figure C showing matrix containing feldspar (mostly plagioclases) and hornblende. Abbreviation; hbl=Hornblende, plag=Plagioclase.

are subhedral to euhedral and their grain sizes are 0.5-2 mm. They are surrounded by fine-grained feldspar groundmass which show trachytic texture (Figure 4B).

Pyroxene-plagioclase basaltic andesite shows porphyritic texture. Phenocrysts consist of plagioclase and clinopyroxene. Plagioclase phenocrysts are euhedral to subhedral and their grain sizes are 0.3-0.5 mm. Clinopyroxene micro phenocrysts are euhedral and their grain sizes are 0.1-0.2 mm. They are surrounded by fine-grained feldspar groundmass (Figure 4C).

6. Whole-rock geochemistry analysis

Major elements of samples from Lam Sonthi area are in Table 1 and trace elements and rare earth elements (REEs) are in Table 2. The bivariate plots for major oxides against SiO_2 (Figure 5) show that Khao Ruak volcanics have lower in TiO_2 and P_2O_5 concentration than Khok Khli volcanics (Figure 5A and B) but higher in CaO concentration (Figure 5C). Plotting of K_2O against SiO_2 shows that the rocks are medium-K (Figure 5D).

The representative samples from both Khao Ruak volcanics and Khok Khli volcanics are plotted in the rock classification by plotting Zr/TiO_2 vs. Nb/Y. The diagrams show that all samples from Khao Ruak volcanics and Khok Khli volcanics are andesite (Figure 6).

REEs variations in the volcanic rocks from study area are presented by chondrite-normalized patterns (Sun and McDonough, 1989). The diagrams show that hornblende-plagioclase andesite of Khao Ruak volcanics have relatively flat REE patterns from Sm to Yb with chondrite-normalized Sm/Yb are 1.54 and slightly LREE enriched with chondrite-normalized La/Sm are 2.39 (Figure7A). The clasts from Khok Khli volcanics which hornblende-plagioclase andesite have slightly enriched from Sm to Yb with chondrite-normalized Sm/Yb are 2.12 and slightly enriched with chondrite-normalized La/Sm are 2.53 (Figure 7A).

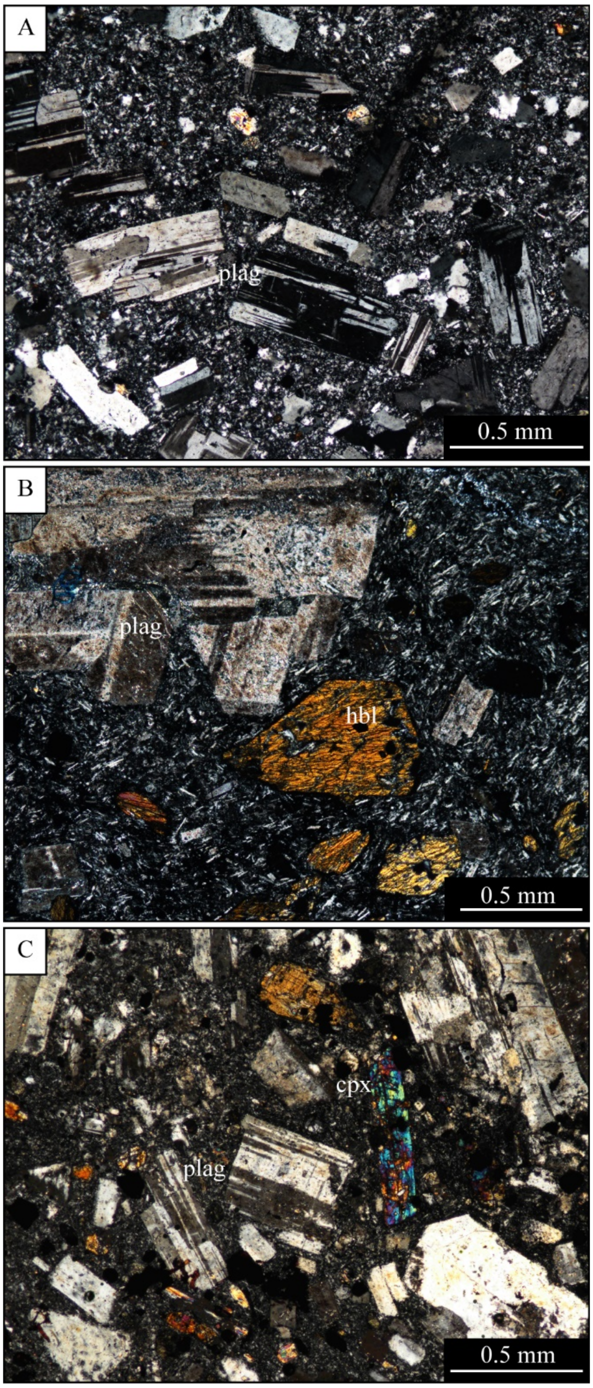

Figure 4. Characteristic of clasts from Khok Khli volcanics. (A) Photomicrograph of plagioclases andesite. (B) photomicrograph of hornblende-plagioclase andesite. (C) photomicrograph of pyroxene-plagioclase basaltic andesite Abbreviation; hbl=Hornblende, plag=Plagioclase, cpx=Clinopyroxene

Table 1 Major oxides and loss on ignition of volcanic rocks, Lam Sonthi area, Lop Buri province

ID Rock name	LST01 KR HBA	LST15 KR HPA	LST29 KR HPA	LST25 KK HPA	LST27 KK HPA	LST31 KK HPA
SiO2	61.82	62.03	62.34	58.77	56.85	59.31
TiO2	0.53	0.49	0.53	0.70	0.67	0.68
Al2O3	15.53	16.25	16.04	16.57	16.84	18.01
Fe2O3	5.25	5.04	5.92	6.56	6.13	6.06
MnO	0.06	0.09	0.06	0.15	0.16	0.10
MgO	1.62	2.30	2.34	3.75	3.09	2.03
CaO	5.40	3.36	3.22	2.22	2.86	1.41
Na2O	3.77	5.65	5.98	6.49	7.47	8.63
K2O	1.52	1.71	0.91	1.76	1.79	0.92
P2O5	0.15	0.12	0.13	0.22	0.21	0.24
LOI	3.86	2.45	1.68	2.05	3.13	1.83
Total	99.50	99.48	99.14	99.23	99.20	99.23

Abbreviation: KR HPA = Khao Ruak hornblende-plagioclase-phyric andesite, KK HPA = Khok Khli hornblende-plagioclase andesite.

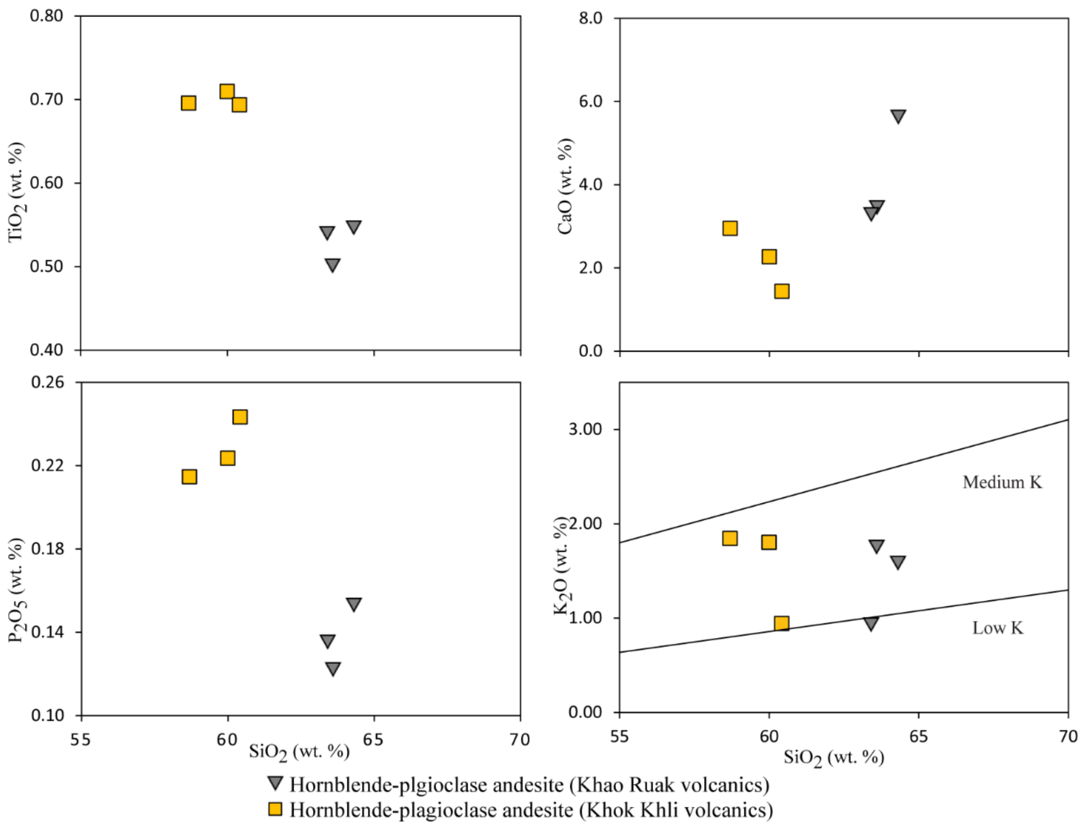

Figure 5. Major oxides binary diagrams plotted against SiO_2. A) TiO_2 vs SiO_2 showing Khao Ruak volcanics have lower concentration. B) CaO vs SiO_2 showing Khao Ruak volcanics have higher concentration. C) P_2O_5 vs SiO_2 showing Khao Ruak volcanics have lower concentration. G) K_2O vs SiO_2 showing volcanic rocks plotted into medium-K.

The N-MORB normalized multi element patterns show negative niobium (Nb) and tantalum (Ta) anomalies of all samples (Figure 7B) which are the characteristics of magma associated with subduction zone. The samples from Khao Ruak volcanics including hornblende-plagioclase andesite represent negative Rb, Th, Nb, Pr, Zr, and Eu anomalies and the enrichment of Ba, Ta, La, and Sr (Figure 7B). The sample from Khok Khli

Table 2 Trace elements and rare earth elements of volcanic rocks, Lam Sonthi area, Lop Buri province

ID Rock	LST15 KL HPA	LST25 KK HPA
Ba	427	320
Ce	26.8	44.7
Cr	90	20
Cs	0.73	0.49
Dy	3.7	4.86
Er	2.28	2.87
Eu	0.99	1.55
Ga	17.8	15.8
Gd	3.63	5.39
Hf	4.4	4
Ho	0.77	0.98
La	12.2	20.3
Lu	0.37	0.39
Nb	2.7	2.3
Nd	15.4	24
Pr	3.57	5.82
Rb	32.2	38.7
Sm	3.29	5.18
Sr	676	467
Ta	0.3	0.3
Tb	0.58	0.79
Th	3.45	4.86
Tm	0.35	0.4
U	1.31	0.91
V	92	127
W	1	101
Y	22.1	28.4
Yb	2.37	2.71
Zr	160	151

Abbreviation: as mentioned above

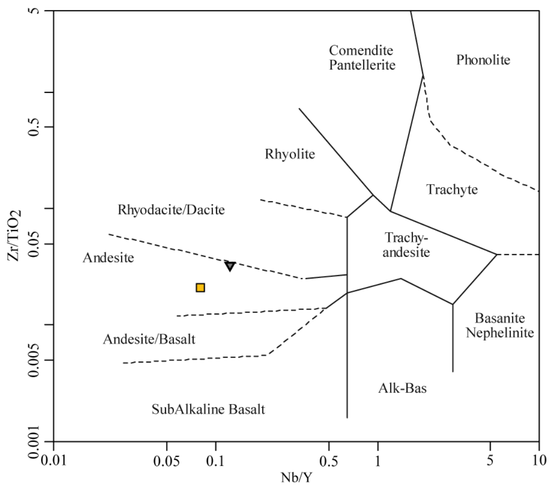

Figure 6. Rocks classified by trace elements plotting of Nb/Y vs. Zr/TiO2 (Winchester and Floyd, 1997).

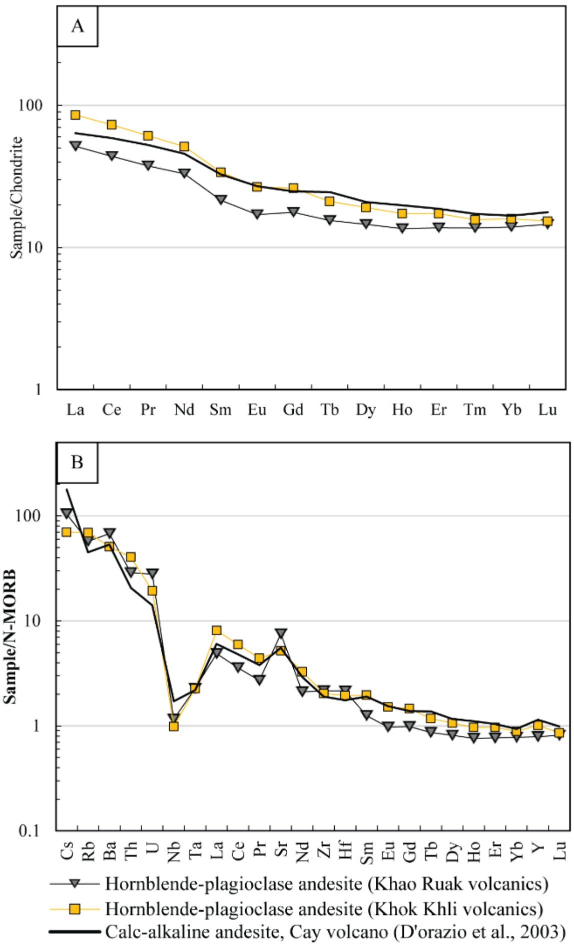

Figure 7. Plots of samples from Lam Sonthi area and andesite from Cay volcano. (A) Chondrite-normalized patterns using normalizing of values of Sun and McDonough (1989). (B) N-MORB normalized trace elements pattern using normalizing of values of Sun and McDonough (1989).

volcanics, hornblende-plagioclase andesite represents negative Rb, Nb, Pr, and Eu depleting and the enrichment of Ta, La, and Sr (Figure 7B).

The AFM diagram which is a plot of FeO, MgO and sum of Na_2O and K_2O shows that the rocks are typically calc-alkaline series (Figure 8A). Plotting of Ti against Zr (Figure 8B) in the discrimination diagram indicates that rocks in this area are volcanic arc setting. Furthermore, the chondrite and N-MORB normalized multi element patterns of the mordern volcanic rocks are used to compare with the volcanic rocks of the study area in order to clarify the tectonic setting. They are chemically analogous to the calc-alkaline andesite from the Cay volcano which is related to subduction zone (D'Orazio et al., 2003) as shown in Figure 7A and B.

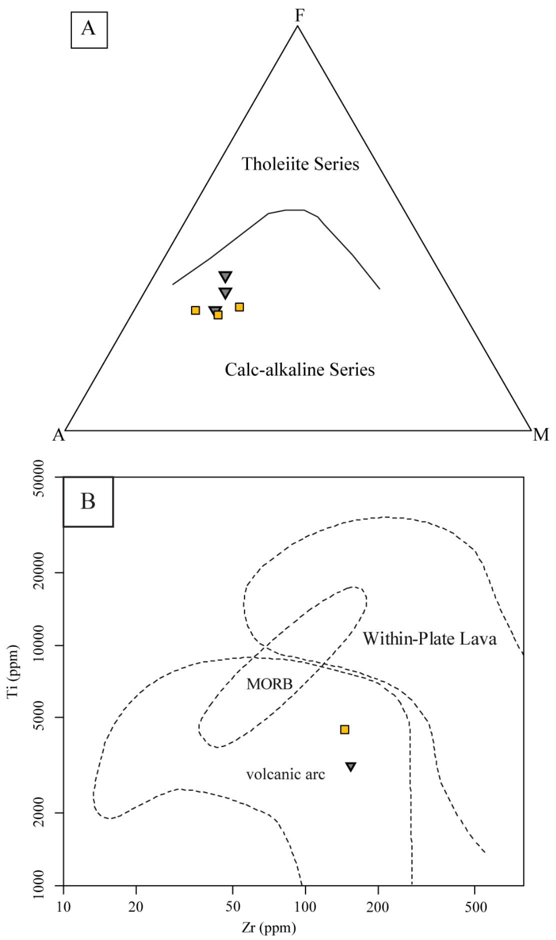

Figure 8. (A) AFM plot by Irvine and Baragar (1971). (B) The Ti-Zr discrimination diagrams by Pearce (1982): MORB = mid-oceanic ridge basalt.

7. Discussion

Based on field investigation and petrography, the Khok Khli volcanics are interpreted to be deposited as resedimentation volcaniclastic supportive by evidence of mudstone clasts in the lower volcaniclastic sequence and variety of volcanic clasts in the upper part of this sequence. However, the geochemical data of the clasts of polymictic intermediate breccia indicates that the clasts of Khok Khli volcanics have similar characteristic as volcanic rocks of Khao Ruak volcanics. Consequently, the Khok Khli volcanics could be implied that they were derived from the magma source which is similar with Khao Ruak volcanics and they might transport and deposit equivalent with Khao Ruak volcanics. Recently, the Khok Khli volcanics were reported to have U-Pb zircon ages of 204 to 205 Ma (Late Triassic) (Yan et al., 2019). According to the Late Triassic age of Khok Khli volcanics, it could be implied that the age of Khao Ruak volcanics could be Late Triassic as well.

Additionally, U-Pb zircon ages of the Saraburi-Khao Yai rhyolites were presented as 213-188 Ma (Late Triassic to Early Jurassic) (Meffre et al. cited by Morley et al., 2013). The other report is the Khao Yai rhyolite which is massive volcanic body in the south of Khao Khwang Fold-Thrust belt, Saraburi. The rocks were reported to have U-Pb zircon age of 207 Ma (Late Triassic) (Arboit et al., 2016). Morley et al. (2013) suggested that Late Triassic age of rhyolite relates to the collision of Sibumasu and the combined Sukhothai-Indochina terrane which also produced the S-type western belt granite in Thailand. In the past ten years, there was little reports of Late Triassic volcanics until recent works by Arboit et al. (2016) and Yang et al. (2019), which focused on ages dating and extended our understanding of Late Triassic volcanics in the Loei Fold Belt.

The volcanic rocks in Lam Sonthi area have calc-alkaline affinity and volcanic arc setting in geochemistry. The chondrite normalized REEs pattern characterized by slightly LREEs enriched and detectable negative Eu anomaly. The N-MORB normalized pattern indicates enrichment of LILEs (Ca, Rb, Ba, and Sr) as well Th and U over HFSFs (Nb, Ta, Zr, and Hf), which are typically observed in subduction-related magmas (D'Orazio et al., 2003).

8. Conclusions

The geochemical data indicates that the clasts of Khok Khli volcanics were derived from the similar magma source of the Khao

Ruak volcanics. The composition of volcanic rocks in Lam Sonthi area is mainly andesite with calc-alkaline affinity, which is indicative of volcanic arc environment. Enrichment of LILEs and low abundance of Nb and Ta indicate a subduction-related magmatic setting. the age of volcanic rocks in this area is Late Triassic

Acknowledgement

Thank to Department of Mineral Resources for giving access to XRF analysis. The author would like to acknowledge financial support from the graduate school Chulalongkorn University.

References

Arboit, F., Collins, A. S., Morley, C. K., Jourdan, F., King, R., Foden, J., and Amrouch, K. 2016. Geochronological and geochemical studies of mafic and intermediate dykes from the Khao Khwang Fold–Thrust Belt: Implications for petrogenesis and tectonic evolution. *Gondwana Research* 36: 124-141.

Assavapatchara, S. 2006. On the lithostratigraphy of Permian rocks in Thailand - implication for depositional environments and tectonic setting.

Barr, S. M., and Charusiri, P. 2011. Volcanic rocks. In M. F. Ridd, A. J. Barber, and M. J. Crow (eds.), The Geology of Thailand, London: The Geological Society.

Bunopas, S. 1981. Paleogeographic histrory of western Thailand and adjacent parts of Southeast Asia: A plate Tectonics Interpretation. Ph.D. thesis, Victoria University of Wellington.

Hara, H., Tokiwa, T., Kurihara, T., Charoentitirat, T., and Sardsud, A. 2020. Revisiting the tectonic evolution of the Triassic Palaeo-Tethys convergence zone in northern Thailand inferred from detrital zircon U–Pb ages. *Geological Magazine*: 1-25.

Hutchison, C. S. 1989. Geological evolution of South-east Asia. Clarendon Press Oxford.

Jungyusuk, N., and Khositanont, S. 1992. Volcanic rocks and associated mineralization in Thailand.

Khin Zaw, Meffre, S., Lai, C.-K., Burrett, C., Santosh, M., Graham, I., Manaka, T., Salam, A., Kamvong, T., and Cromie, P. J. G. R. 2014. Tectonics and metallogeny of mainland Southeast Asia—a review and contribution. *Gondwana Research* 26(1): 5-30.

Khin Zaw, Peters, S. G., Cromie, P., Burrett, C., and Hou, Z. J. O. G. R. 2007. Nature, diversity of deposit types and metallogenic relations of South China. 31(1-4): 3-47.

Metcalfe, I. 1988. Origin and assembly of south-east Asian continental terranes. Geological Society, London, Special Publications 37(1): 101-118.

Morley, C. 2014. The widespread occurrence of low-angle normal faults in a rift setting: Review of examples from Thailand, and implications for their origin and evolution. *Earth-Science Reviews* 133: 18-42.

Morley, C. K., Ampaiwan, P., Thanudamrong, S., Kuenphan, N., and Warren, J. 2013. Development of the Khao Khwang Fold and Thrust Belt: Implications for the geodynamic setting of Thailand and Cambodia during the Indosinian Orogeny. *Journal of Asian Earth Sciences* 62: 705-719.

Nakornsri, N. 1977. AMPHOE BAN MI[Geologic map]. Series: ND47-4. Scale: 1:250000. First ed.

Geological Survey Division, Department of Mineral Resources.

Nakornsri, N. 1981. Geological Survey Report no.3. Geological Survey Division, Department of Mineral Resources:

Sone, M., and Metcalfe, I. 2008. Parallel Tethyan sutures in mainland Southeast Asia: New insights for Palaeo-Tethys closure and implications for the Indosinian orogeny. *Comptes Rendus Geoscience* 340(2-3): 166-179.

Ueno, K., and Hisada, K.-i. 2001. The Nan-Uttaradit-Sa Kaeo Suture as a Main Paleo-Tethyan Suture in Thailand: Is it Real? *Gondwana Research* 1(4): 804-806.

Vimuktanandana, S., and Thiyaphairach, S. 2007. GEOLOGICAL MAP OF CHANGWAT LOP BURI [Department of Mineral Resources].

Wakita, K., and Metcalfe, I. 2005. Ocean Plate Stratigraphy in East and Souutheast asia. *Journal of Asian Earth Sciences* 24: 679-702.

Yan, Y., Zhao, Q., Zhang, D., Charusiri, P., Huang, B., and Zhang, P. 2019. Palaeomagnetism of Late Triassic volcanic rocks from the western margin of Khorat Basin, Thailand and its implication for ambiguous inclination shallowing in Mesozoic sediments of Indochina. *Geophysical Journal International* 219(2): 89