Stratigraphy and Petrochemistry of Volcanic Rocks at Suwan Prospect, Phitsanulok Province, central Thailand

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ABSTRACT

This study focuses on a host rock of the Suwan Prospect located about 6 km northwest of the Chatree gold mine in Phitsanulok-Phichit Provinces, Central Thailand. Gold-silver mineralization occurs as veins and stockworks hosted in volcaniclastic and volcanogenic-sedimentary rocks of Late Permian-Early Triassic age which is classified as a low sulfidation epithermal deposit base on mineralization texture, alteration pattern and sulfide mineral assemblages. Detailed field and petrographic observations of the main volcanic lithofacies of its hosted stratigraphic succession were carried out. From top to bottom, the hosted volcanic succession can be divided into 3 units, namely 1) Felsic volcanic unit (Unit 1), 2) Volcanogenic-sedimentary unit (Unit 2), and 3) Porphyritic andesite unit (Unit 3). Unit 1 consists predominantly of quartz-rich fiamme breccia, lithic-rich fiamme breccia and feldspar-phyric rhyolite breccia. The volcanogenic-sedimentary unit (Unit 2) consists of fine to coarse-grained sandstone, sandy-matrix polymictic breccia, polymictic intermediate-felsic breccia, mudstone and limestone lenses. Unit 3 comprises plagioclase-phyric andesite, plagioclase-hornblende-phyric andesite and monomictic andesitic breccia.

Keywords: Suwan Prospect, Volcanic Facies, Geochemistry, Epithermal deposit.

1. Introduction

The epithermal gold and silver deposits are occurred within the formations of igneous rocks, found in volcanic rocks that push upwards during the tectonic process. Major gold deposits in Thailand is in the Loei and Phetchabun Fold Belt (Crow & Khin Zaw, 2011; Salam, 2013) which extends from Laos PDR in the north and along the western side from Khorat Plateau to Cambodia in the south.

Some key previous studies include geotectonic and geochronology of volcanic-plutonic rocks in Loei-Phetchabun Fold Belt (Khositanont et al., 2013), petrochemical characteristic of igneous rocks in Phetchabun area (Salam, 2013) and relationship between Cu-Mo mineralization and epithermal gold and silver in the Chatree deposit (Tangwattananukul & Ishiyama, 2017). The major structures in Loei-Phetchabun Fold Belt are extended from north to south that has resulted from the collision of the Shan-Thai and Indochina terranes (Bunopas & Vella, 1983). Both the Shan-Thai and Indochina terranes contain Early to Late Paleozoic clastic sedimentary rocks, platform carbonates which have been overlain by Triassic volcanic and intruded by Triassic and Cretaceous granites (Salam, 2013). The nature of the collision of these two terranes is subduction and the effect is preserved as N-S and NW-SE trending fault zones. Uplifting, rotation and extension shown NNE-SSW trending fault zones in

Cenozoic (Bunopas & Vella, 1983; Bunopas, 1994; James & Cumming, 2007).

The study area (Fig. 1) of Suwan Prospect is located about 6 km north of the Chatree gold-silver mine. It is about 320 km north of Bangkok. It is located on the boundaries between Phitsanulok, Phichit and Phetchabun provinces on flat area, surrounded mostly by agricultural and farmland.

Prior to this study, there were several studies on the Chatree deposit including volcanic stratigraphy, facies architectures and geochemistry and geochronology (e.g. Cumming, 2004; Salam, 2013; Salam et al., 2014). For Suwan prospect, no any study has been undertaken particularly on volcanic stratigraphy and petrochemistry. This study aims at defining stratigraphy, petrochemistry of host volcanics and post-mineralization dykes for better understanding of the tectonic setting of the region.

2. Geological setting

The oldest rocks in and around the Suwan prospect area are Carboniferous rocks particularly in the east and southeast of the study area (Fig. 1) which mainly consist of siltstone, sandstone and conglomerate (Salam et al., 2014). Permian limestone also cropped out in the southeast. Both rock units form as basement for the Chatree volcanic sequence (Salam, 2013). The third oldest in regional area is Late Permian rocks consisting sandstone, siltstone, and shale mainly occur north of Chon Daen district. Rocks of Khorat Group mainly found northeast of the study are (Fig. 1) which form as high land, part of Khorat plateau. The most widespread rocks in and around the Suwan prospect is the Late Permian to Early Triassic volcanic of Chatree Volcanic Complex (Fig. 1; (Salam, 2013; Salam et al., 2014)). Most of intrusive rocks are found southeast and southwest of the area including Dong Kui Carboniferous granite, Early Triassic Wang Pong granite, Middle Triassic N-prospect granodiorite, and Early Triassic Khao Rub Chang pink granite (Salam, 2013; Salam et al., 2014).

3. Methodology

The following diamond drill holes were used in this study; DDH4065, DDH4066, DDH4067, DDH4069, DDH4080, DDH4102, DDH4119, DDH4138 and DDH4139. All together nine drill holes have been logged and sampling was made for further laboratory study. Diamond drill cores used in this study were provided by the Akara Resources Public Company Limited. Logging of drill cores has focused on host volcaniclastic sequences in term of lithology and stratigraphy.

Laboratory works focus on petrographic study, X-Ray fluorescence (XRF) and Inductive Coupled Plasma Mass Spectrometry (ICP-MS) for rare earth elements.

3.1 Petrographic study

Prior to petrographic study, all collected diamond drill cores samples were examined and described in details. All together 36 samples have been prepared for petrographic study in which thin sections were made for confirmation rocks types and facies determination. Petrographic studies were conducted using transmitted light and reflected light microscope at the Department of Geology, Faculty of Science, Chulalongkorn University.

3.2 X-Ray Fluorescence (XRF)

Whole-rock oxides and trace element analysis of all samples were carried out using XRF model PANalytical (Zetium) at the Department of Mineral Resources (DMR) and the Australian Laboratory Service (ALS). This method provided major oxide quantities useful for exploration including SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_3. These results were added to a classification diagram using GCD kit software.

3.3 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Whole-rock geochemical analysis was done for the total seven samples, including porphyritic andesite, monomictic andesite breccia and rhyolitic rock collected from various depths. This method was undertaken for trace (Rb, Sr, Cr, Cu, Ba, Ba, Bi, Sn, Zr, Mo, Nb, V, Zn, Ni, Pb, Th, Sc, U and Y) elements analyzing by ICP-MS at Australian Laboratory Service (ALS).

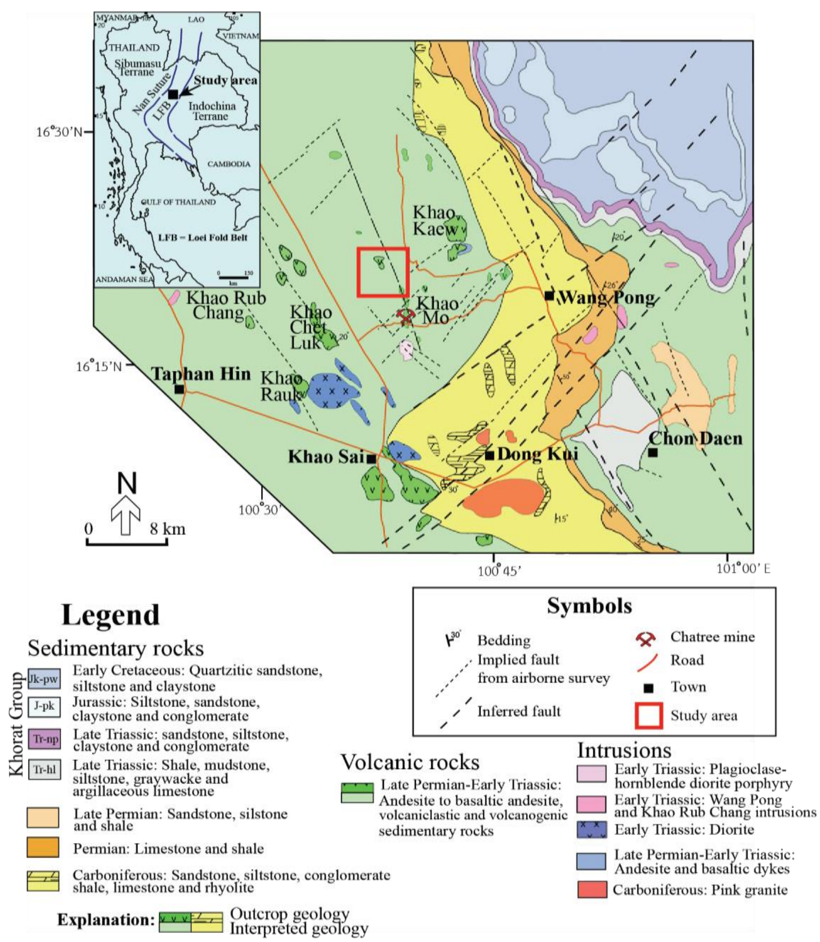

Figure 1. A simplified geological map of the Suwan Prospect, Phitsanulok Province, Central Thailand (after Salam, 2013).

This technique was additionally applied for rare earth elements analysis (REE: La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu). The samples for this analysis were carefully selected from the least altered samples from drill core samples. The concentration of elements were analyzed on a GCD kit software (Janousek et. al., 2006) to interpretation the whole-rock geochemical data for contemporary scientific term.

4. Volcanic stratigraphy

The Suwan Prospect is covered by thick quaternary sediments and outcrops which are strongly weathered. Thus, the description of the rock units of Suwan Prospect was made based heavily on diamond drill cores logging (nine drill

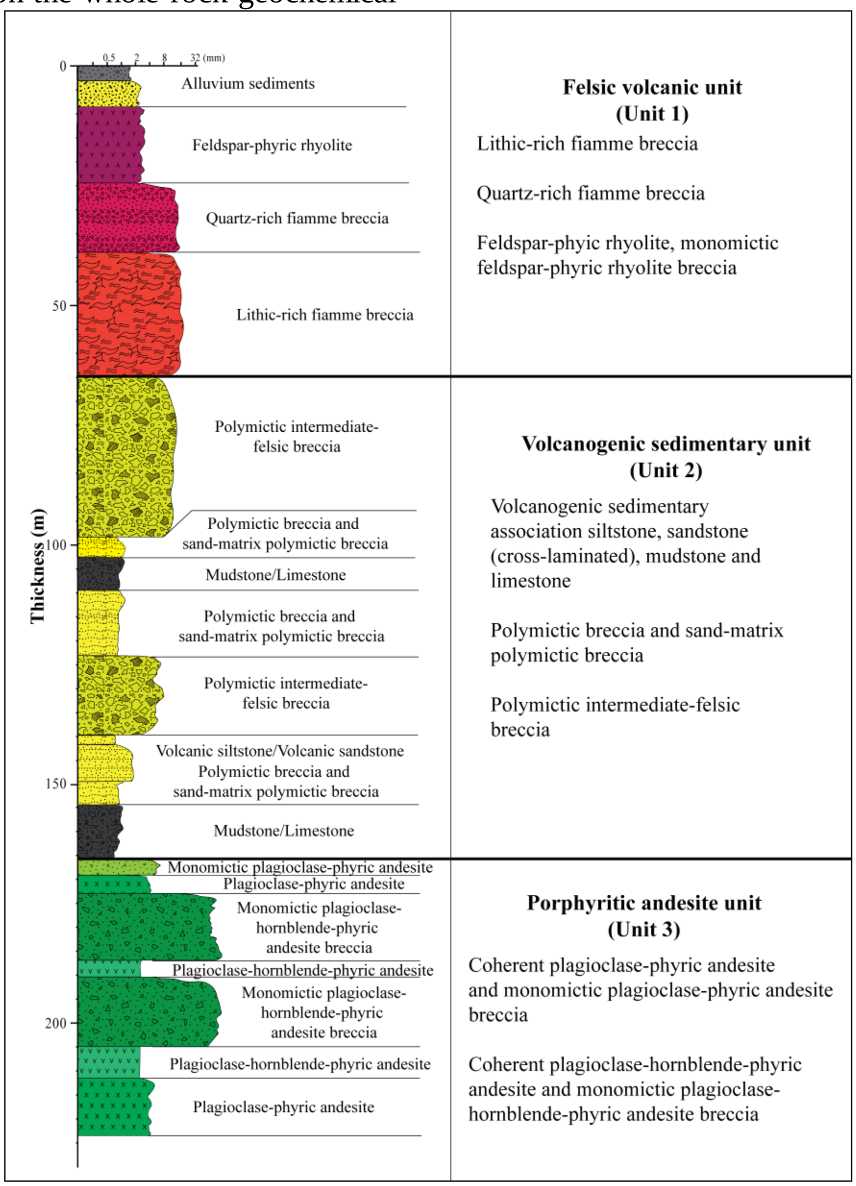

Figure 2. A summary stratigraphic unit of the Suwan Prospect, Phitsanulok Province, Central Thailand.

cores). This study follows the nomenclature of McPhie et al. (1993) in describing rock types. Based on current available drill holes the thickness of volcanic sequence at Suwan Prospect is approximately 200 m. The stratigraphy can be divided into three main units (Fig. 2). From bottom to top, they are porphyritic andesite unit (Unit 3), volcanogenic-sedimentary unit (Unit 2) and felsic volcanic unit (Unit 1) at the top. The summary stratigraphy of the Suwan prospecting area is given in Figure 2. The description will be started from bottom to the top of the units.

Porphyritic andesite unit (Unit 3):

This unit is predominantly with coherent rock including plagioclase-hornblende-phyric andesite, monomictic andesite breccia and minor plagioclase-phyric andesite (Fig. 2). The plagioclase-hornblende-phyric andesite is estimated to have a thickness of at least 50 meters. The upper contact is graded gradually to monomictic andesite breccias, basaltic andesite and polymictic breccias. Monomictic plagioclase-phyric andesite which forms at top of unit 3 in contact with unit 2 has thickness is highly variable although generally 2 m to 20 m. thick.

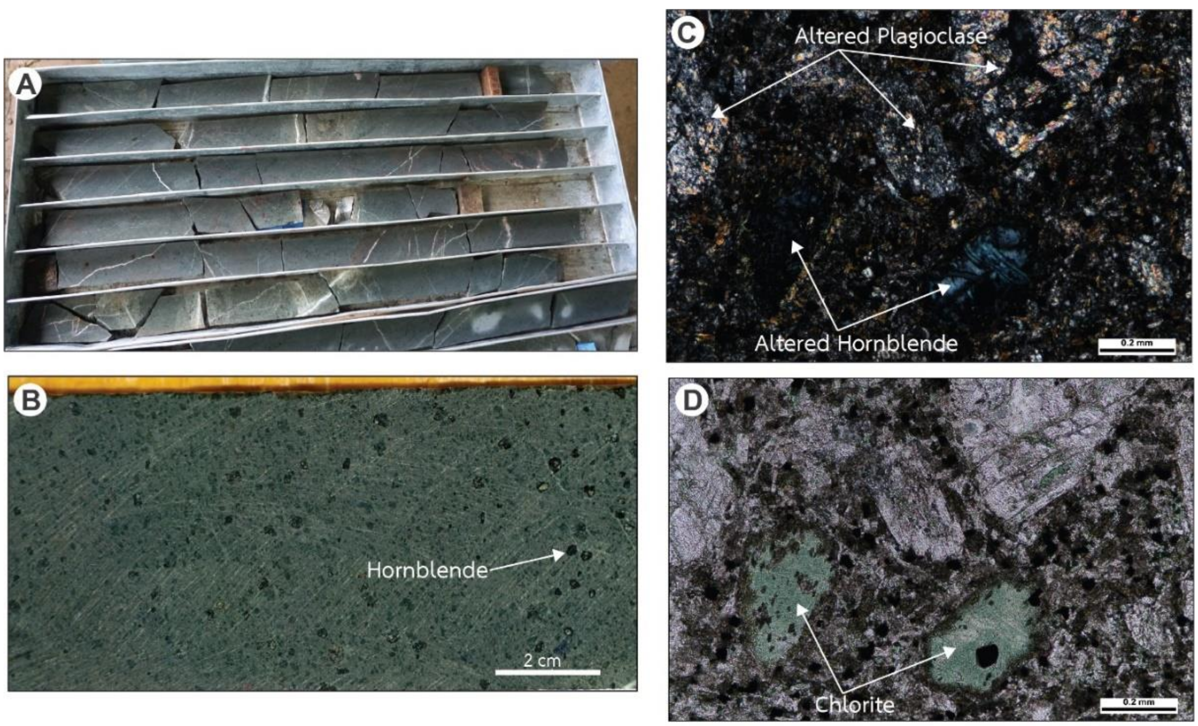

Figure 3. Characteristics of plagioclase-hornblende-phyric andesite of the Unit 3. (A) Photograph of diamond drill core showing andesite containing some quartz-calcite veins/veinlets. (B) Photograph close-up view of porphyritic andesite showing phenocryst of hornblende. (C and D) Photomicrograph showing plagioclase and hornblende phenocrysts in cross nicol and plane polarize respectively (Sample No. 4080-75.00m).

Volcanogenic-sedimentary rock unit (Unit 2):

Volcanogenic-sedimentary rock unit (Unit 2) is mainly comprised of laminated siltstone, sandstone, mudstone, limestone, polymictic intermediate-felsic breccia and sand-matrix polymictic breccia (Fig. 2). The thickness of the unit varies from 10 meters to 80 meters. This unit is overlain by unit 1 (felsic volcanic unit). The volcanic siltstone and volcanic sandstone are commonly presented in the middle parts of the unit and are typical lamination. The polymictic intermediate-felsic breccia and sand-matrix breccia are found at lower part and upper most of this unit.

Felsic volcanic unit (Unit 1):

Felsic volcanic unit (Unit 1) consists of lithic-rich fiamme breccia, quartz-rich fiamme breccia, monomictic feldspar-phyric rhyolite breccia, lithic-rich fiamme breccia and rhyolitic rock (Fig. 5). The thickness of this unit varies from 10 meters to 50 meters. This unit is overlying the polymictic intermediate-felsic breccia of Unit 2.

Petrography:

Porphyritic andesite unit (Unit 3):

The plagioclase-hornblende-phyric andesite is dark green to greenish gray with black phenocrysts in drill core sample (Fig. 3). Phenocrysts mostly are hornblende < 5 mm in diameter (Fig. 3). Phenocrysts content generally makes up about 10 to 30 vol. %. Under microscope, the rock composes of hornblende, pyroxene with groundmass dominated by feldspar, hornblende and minor quartz (Fig. 3). The phenocrysts partly altered to chlorite and opaque minerals and feldspar partly altered to sericite and calcite.

The plagioclase-phyric andesite is green to dark gray. No distinctive phenocrysts have been observed. This plagioclase-phyric andesite is fine-grained composes of plagioclase, hornblende and minor K-feldspar and quartz. Plagioclase occurs mostly as anhedral to euhedral form phenocrysts with up to 1 mm in size.

Monomictic plagioclase-hornblende-phyric andesitic breccia and monomictic plagioclase-phyric andesite mainly identified in Unit 3, above the coherent facieses (plagioclase-hornblende-phyric andesite and plagioclase-phyric andesite) (Fig. 3). However, there is no clear relationships with the coherency at the bottom of stratigraphy.

The monomictic plagioclase-hornblende-phyric andesitic breccias are characterized by jigsaw-fit textures in which majority clasts are angular ranging in size from 0.5 cm. to 5.0 cm. with fine sand-size matrix. The intervals of the monomictic andesite plagioclase-hornblende-phyric andesite breccia are 5-40 meters thick. The upper contact with tuffaceous sandstone is gradational contact.

Monomictic plagioclase-phyric andesite breccia forms at the top of unit 3 where it has sharp contact with the upper unit 2 (volcanogenic-sedimentary unit). This rock is characterized by greenish-gray rocks consisting clasts predominantly with angular to sub-angular ranging in size from 1-5 cm. The rock is poorly sorted. Most clasts are plagioclase-phyric andesite. The matrix is composed of fine grained (1-2 mm) of the same composition.

Volcanogenic-sedimentary rocks unit (Unit 2):

Tuffaceous siltstone and sandstone in Unit 2 are interbedded with mudstone and calcareous mudstone. The mudstone and/ or calcareous mudstone often contain fossils and some skeletal fragments of crinoid stems. The carbonate-mudstone-matrix breccia occurs as clastic rocks or fragmented which are corals, brachiopods and dark-gray mudstone and grayish-brown limestone. This unit has been presented in drill holes number DDH4119. These facies are average 15 m in thickness (10 – 25 m) and can be traced in drill core for 140 m and 170 m. Contacts are typically sharp and irregular or planar, although several upper contacts are unconformity with coherent andesitic basalt. Limestone and mudstone facies overlie or occur within facies of siltstone and sandstone or polymictic breccias.

Limestone is light grey and purple carbonate clasts (0.3 – 1.5 cm) in yellowish brown matrix. One sample of this rock type also constrains clast to matrix supported and are poorly sorted and jigsaw-fit fossiliferous clasts. Local domains of carbonate clasts are angular to sub-rounded shape

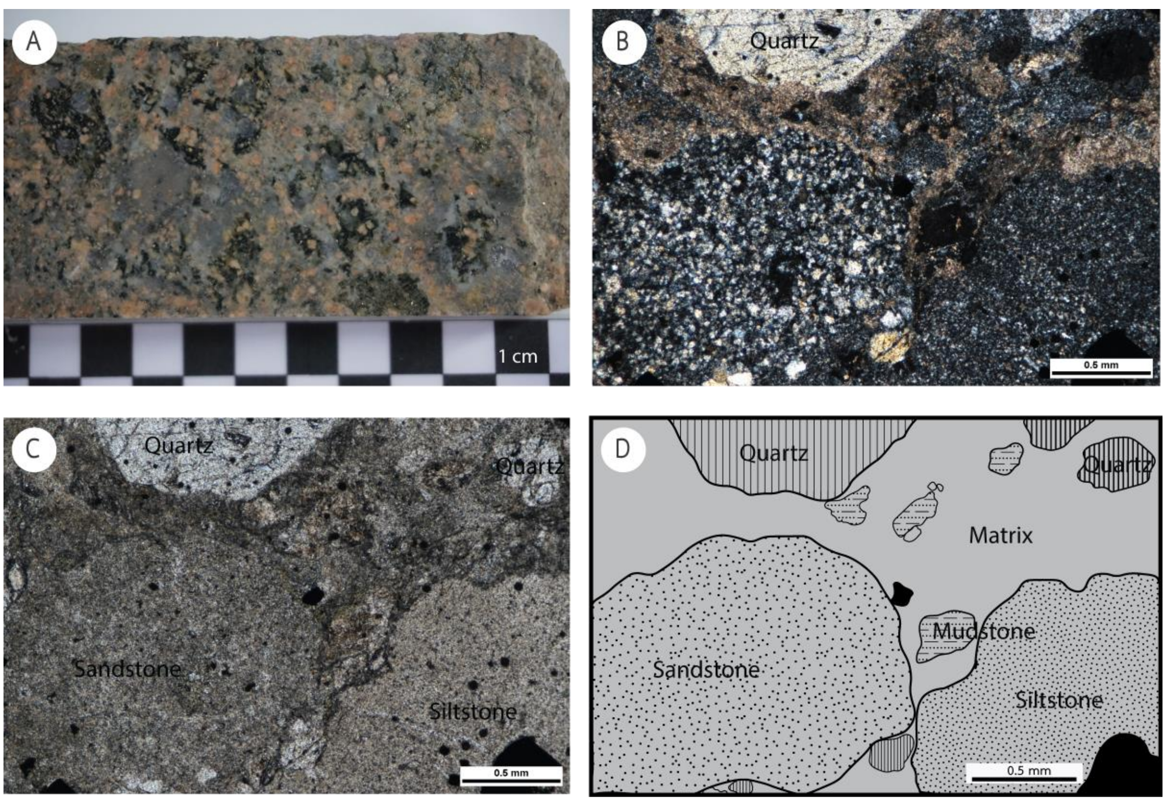

Fig. 4. Photograph showing polymictic breccia sample No. 4066-87.50m. **(A)** Drill core sample of polymictic breccia and highly altered (scale bar in centimeter). **(B)** Sandstone, siltstone and quartz clast, mud and sand matrix (cross nicol). **(C)** Polymictic clasts are disseminated by pyrite which altered by silicification (plane polarized light). and **(D)** Simple sketching textural of polymictic breccia.

Sand-matrix polymictic breccias

This rock is varying in colors from brownish orange, yellowish-gray and light-gray (Fig. 4). The rock is characterized by sandy matrixes (0.5-2 mm) and clasts from 1-2 cm consisting of sand, and silt component. It is poorly sorted, and clasts mainly composed of andesite, and rhyolite. The clast shapes are typically sub-angular to sub-round. It occurs at the lower part of the laminated siltstone/sandstone and displaying a sharp contact

Polymictic intermediate-felsic breccias

The polymictic breccias occurs almost at the middle and top of the unit 2 (Fig. 2). The lower one bounded by epiclastic rocks (tuffaceous siltstone, sandstone, and sand-matrix polymictic breccia) and estimated about 10 to 15 meters thick. The second one at the top of unit 2 is 30 to 35 meters thick and sharply overlaying by lithic-rich fiamme breccia of the unit 1 (Fig. 2). The rock is clast-supported comprising of angular to sub-round, poorly sorted. Majorities of clasts types are andesite/and or basaltic andesite with some sandstone, siltstone, and minor rhyolitic clasts. Clasts are less than 5 cm but can be up to 15 cm in diameter identified in some drill holes. Matrix contains of rock fragments and crystals of plagioclase, and quartz.

Felsic volcanic unit (Unit 1):

This unit is characterized by thick fiamme bearing breccia at the lower part of the unit and overlaid by feldspar-phyric rhyolite at the upper most of the unit. The contacts between quartz-rich fiamme breccia, lithic-rich fiamme breccia and feldspar-phyric rhyolite are commonly sharped contacts (Fig. 2).

Quartz-rich fiamme breccia

The rock is characterized by dark patches of fiamme or pumice in some cases which almost fiamme have been altered to chlorite. The lighter color surrounding fiamme clasts and some lithic fragments represent crystal-rich components in which pink or pinkish orange feldspar are clear observed (Fig. 4A).

From the top of this facies, the dominant lithology is poorly sorted grayish green to yellowish gray of the quartz-rich fiamme brecciate. There are also subordinate horizons of volcanogenic clastic. Locally, the dominant lithology is pale pink to brownish gray, matrix-supported, mostly monomictic and quartz-rich with one subordinate interval of clast-supported monomictic quartz-feldspar rhyolite breccia. The clast size average from granule to pebble and angular to subangular shapes. In general, under microscope, the texture is composed of crustal of quartz, feldspar, and opaque minerals. The crystal fragments are varied from 2 mm to 5 mm (Fig 5.). This texture is well pronounced in clast-rich and fine-grained groundmass. This fiamme breccia is characterized by quartz and feldspar crystal clast which presented in potassium feldspar staining technique. Most of them have an angular shape with altered to secondary mineral such as chlorite, sericite and clay minerals.

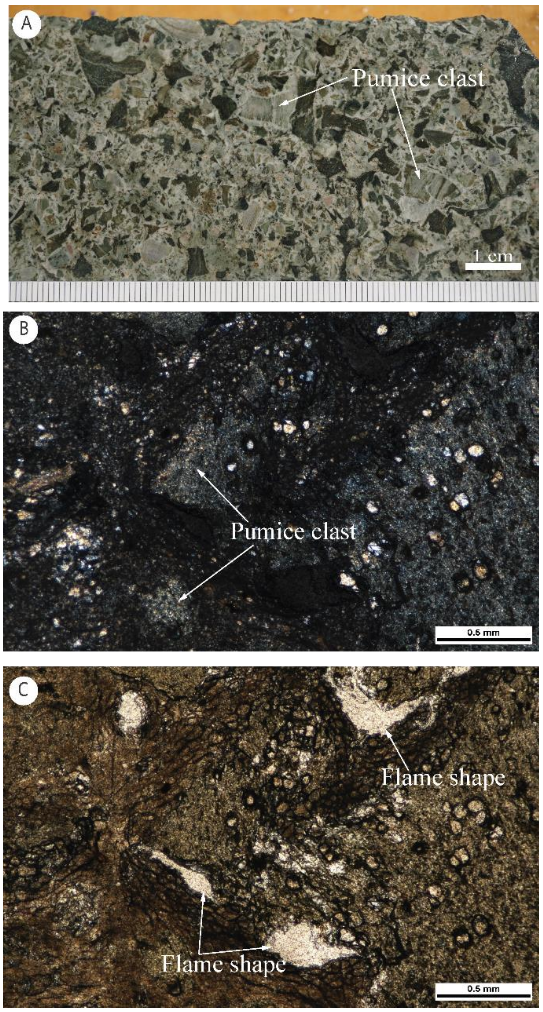

Figure 5. Quartz-rich fiamme breccia sample No. 4138-53.30 m. **(A)** Agular shape of pumice clasts with sand matrix-supported, poorly sorted and moderate compaction. **(B)** Anhedral to subhedral of quartz (cross nicol). **(C)** Flame texture of quartz and lithic rich (plane polarized light).

Feldspar-phyric rhyolite

The feldspar-phyric rhyolite is formed at the top of the unit 1. The thickness varies from 1 meter to 100 meters and forms as coherent and breccia. Coherent feldspar-phyric rhyolite breccia occurs at the margins to coherent. This breccia facies is monomictic with finer clasts forming as matrix.

Feldspar-phyric rhyolite is generally show flow banded and massive layers that commonly have porphyritic texture. Interval of rhyolite in Suwan Prospect varies from 5 to 75 m in thickness. There are conformable with feldspar-rich fiamme breccia. Flow-banding of feldspar-phyric rhyolite occurs as massive layers and alternating with brownish-green quartz-feldspar rich bands and grayish-green chlorite ± sericite in the groundmass.

Petrographic studies of rhyolite suggest widespread spherulites, amygdule, phenocryst euhedral to subhedral, microcrystalline groundmass. This rock is by 5-20 % phenocryst, evenly distribution, euhedral, 1-3 mm of quartz and plagioclase phenocrysts in a very fine-grained groundmass of quartz-feldspar ± chlorite ± sericite ± calcite. The feldspar phenocrysts are variably altered to chlorite, sericite and calcite. Some feldspar-phyric rhyolites contain 3 mm feldspar phenocrysts in fine-grained groundmass of feldspar-quartz-sericite. Groundmass of flow-banding rhyolite may include microcrystalline quartz, feldspar, spherulite and combination of quartz, chlorite, sericite and carbonate.

Lithic-rich fiamme breccia

The lithic-rich fiamme breccia is about 30 meters thick and has a gradational contact with feldspar-phyric rhyolite at the top. The rock is ranging in grained size (fine to pebble) of pumice and lithic clasts. Majority of glass fragments have fiamme texture, but some pumice may also have been preserved. In Suwan prospecting area, this rock is poor-sorted, matrix-supported, massive stratified. The lithic-rich fiamme breccia mainly comprises of lithic fragments, fiamme/pumice clasts (30-50%), and crystals/crystal fragments including quartz, plagioclase (5-30%), vesicular volcanic lithic clasts (5-10%) and volcanic lithic clasts (20-50%). The lithic clasts are angular or elongate shape which in some cases have mosaic textures. Locally, fiamme breccias are deformed to green-pale gray feldspar-phyric clasts. The crystal fragments and matrix (shard and feldspar crystal fragments, 2-5mm) are silicified and compacted.

5. Geochemistry

The whole-rock geochemical results are shown in Table 1 and Table 2.

5.1 Major elements geochemistry

18 representative volcanic rocks were initially selected and prepared for XRF analysis. These samples were chosen carefully from fresh and less altered rocks. This method was made for major elements analysis. Subsequently, the results were plotted on diagrams of rock composition and classification. The total alkali-silica diagram (TAS) is one of the most useful classification schemes available for volcanic rock.

Diagram of the K/Al vs. (K+Na+2Ca)/Al molar ratios (Madeisky & Stanley, 1993; Madeisky, 1996) is typically used to evaluated K-metasomatism and mass transfer in relation with hydrothermal alteration minerals. In Figure 6, fresh rocks are usually plotted on or near to plagioclase K-feldspar and Ca-gain line. This diagram shows that the highly altered rocks from the study area display between albite/plagioclase and K-Na, Ca-loss with interlayered illite-smectite, whereas slightly altered rocks are plotted to the right of that zone. The line slop 1 that extends from the origin to 1,1 represents rocks that contain neither Ca nor Na (Warren et al., 2007).

Along this line, the data plot has only one sample of plagioclase-phyric andesite locating close to the interlayered illite-smectite zone. The molar value of K/Al is 0.02 to 0.27 that contain K-Na with Ca-loss and trending to smectite and kaolinite-chlorite phases. The molar value of (K+Na+2Ca)/Al is 0.31 to 1.81 which represents the range near plagioclase-albite-K-feldspar of fresh rocks. Most of all molar data are typically plotted on the albite-plagioclase area of fresh rock.

The corrected major elements are plotted SiO_2 against Na_2O+K_2O diagram, which is used for geochemical classification of volcanic rocks. However, the TAS diagram is unsuitable for altered volcanic rocks because of the alkalis are easily mobilized in alteration activity and aqueous solutions (Rollinson, 1995; Le Maitre, 2002). The major results on this plot demonstrate that the rocks have SiO_2 contents for 44.7-65.6 wt.% and Na_2O+K_2O for 3.1-8.6 wt.%. (Fig 7). Majority of plots show subalkaline/tholeiitic affinity, but some plots of plagioclase-phyric andesite, plagioclase-hornblende-phyric andesite and monomictic plagioclase-hornblende-phyric andesite breccia units are on alkaline field.

In order to classify the type of magma, the geochemical compositions were plotted in AFM diagram (Irvine & Baragar, 1971;Fig. 8). Majority of the plots are calc-alkaline series. However, some plots including plagioclase-hornblende-phyric andesite, hornblende-phyric andesite and late dyke andesite have tholeiite series.

5.2 Trace element geochemistry

Trace elements variation in the volcanic host rocks and post-mineralization dykes from study area (Table 2) present that they locate on andesite-basalt and sub-alkaline basalt of Winchester and Floyd (1977) diagram (Fig. 9A). The high field strength elements (HFSE: Zr, Ti, Nb) are described to be immobile during hydrothermal processes (Pearce, 1982). The Suwan Prospect host volcanic rocks and post-mineralization dykes were plotted mostly on the low Zr and Ti of island arc field and have single plot–of post mineralization dyke on the within-plate lavas field (Fig. 9B).

5.3 REE geochemistry

REE elements variation in the volcanic host rocks and post-mineralization from study area are explained by primitive mantle-normalized REE patterns (McDonough & Sun, 1995), and chondrites-normalized spider diagrams (Sun and McDonough, 1989). These diagrams are present in Figure 10 A and B and can be described into three magmatic suites of the variable REE patterns.

Suite 1 contains low Ti, P, Zr and Y with high LREE which represented to monomictic feldspar-phyric rhyolite breccia or felsic volcanic rock of the unit 1.

Suite 2 contains slightly high HREE with low LREE. Suit 2 is porphyritic andesite (unit 3) including plagioclase-hornblende-phyric andesite and monomictic basalt-andesite breccia.

Suite 3 contains relatively high LREE and HREE with lower Rb, Ba, Sr and Cs. This suite is post-mineralization dykes.

Table 1. The representative whole-rock geochemistry of least altered volcanic rocks of Suwan prospect.

Sample No.	4066-87.30	4067-27.60	4067-39.50	4067-71.50	4067-75.60	4067-128.00	4080-53.60	4080-57.80	4080-88.50
Rock types	MFR	PAD	MPHA	PAD	PHA	PHA	PHA	PHA	PAD
P_2O_3	0.07	0.12	0.07	0.11	0.13	0.07	0.11	0.09	0.11
SiO_2	65.78	54.97	57.52	44.72	52.19	49.73	53.02	45.18	50.76
Al_2O_3	11.64	17.22	11.67	16.21	15.30	15.23	15.99	18.07	17.89
MnO	0.16	0.51	0.39	0.33	0.34	0.20	0.26	0.40	0.23
Fe_2O_3	3.68	8.71	8.55	7.78	7.01	7.29	7.83	7.21	9.31
Na_2O	1.15	0.70	0.10	1.58	0.81	1.42	1.00	0.10	5.00
CaO	4.80	0.26	4.51	8.38	6.06	13.27	6.49	7.40	7.36
MgO	1.99	3.99	3.92	4.53	3.22	2.23	2.20	3.31	3.07
TiO_2	0.28	0.54	0.37	0.48	0.47	0.34	0.50	0.46	0.53
K_2O	4.07	6.90	3.55	6.87	7.71	1.94	3.42	5.04	0.89
LOI	5.50	8.43	8.04	5.77	6.90	8.03	12.27	4.34	2.03
H_2O	0.23	0.36	0.35	0.21	0.22	0.26	0.20	0.21	0.21
Total	99.35	102.71	99.04	96.97	100.36	100.01	103.29	91.81	97.39

Table 1. (cont.)

Sample No.	4065-98.20	4067-112.70	4080-48.30	4080-75.00	4080-99.00	4080-97.00	4080-108.00	4069-125.50	4069-141.80
Rock types	HAD	PHA	PHA	HAD	PHA	PHA	PHA	ADD	PAD
P_2O_3	0.12	0.06	0.11	0.11	0.12	0.10	0.07	0.56	0.07
SiO_2	52.02	50.89	50.13	51.69	51.82	56.81	46.86	50.51	51.57
Al_2O_3	19.52	17.60	19.41	19.95	19.78	16.63	18.55	14.06	17.62
MnO	0.16	0.27	0.17	0.18	0.17	0.11	0.53	0.24	0.23
Fe_2O_3	9.27	8.61	9.32	9.41	9.46	7.73	8.89	13.17	6.37
Na_2O	2.55	4.55	2.24	2.75	2.74	2.59	2.18	3.71	2.42
CaO	9.10	5.29	3.92	6.79	8.16	9.31	7.58	7.06	5.49
MgO	3.33	6.21	5.05	3.66	3.32	2.26	5.77	3.73	3.76
TiO_2	0.58	0.36	0.58	0.59	0.59	0.47	0.39	2.94	0.36
K_2O	0.95	1.64	2.80	2.11	1.31	0.53	2.35	0.90	4.48
LOI	3.93	5.84	2.40	2.17	3.07	6.11	2.67	2.68	6.78
H_2O	0.41	0.22	0.17	0.20	0.20	0.19	0.19	0.20	0.40
Total	101.92	101.53	96.30	99.61	100.72	102.84	96.01	99.74	99.53

Abbreviation: HAD = Hornblende-phyric andesite, PHA = Plagioclase-hornblende-phyric andesite, ADD = Andesite dyke, PAD = Plagioclase-phyric andesite, MFR = Monomictic-feldspar-phyric rhyolite breccia, MPHA = Plagioclase-hornblende-phyric andesite breccia.

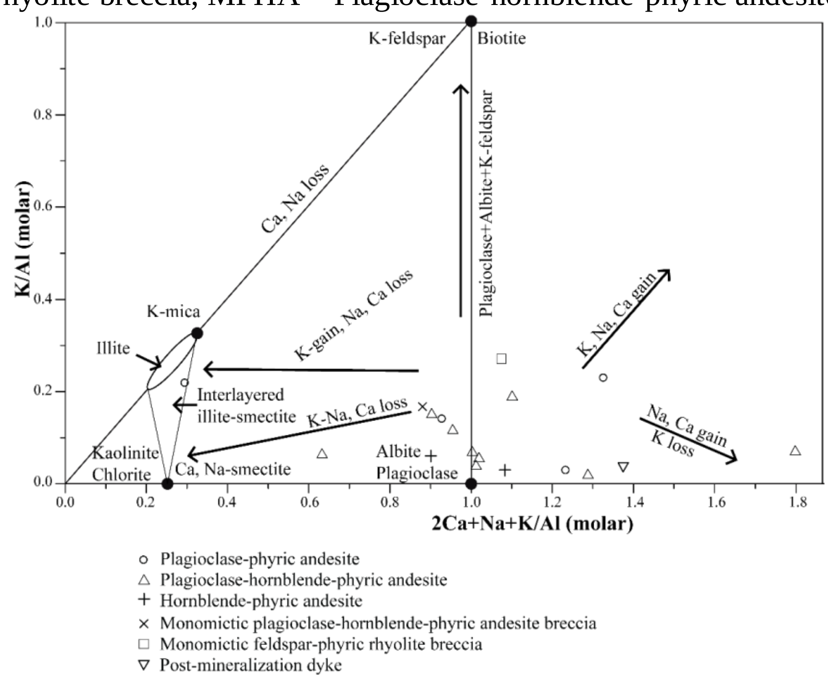

Figure 6. Molar K/Al vs molar (K+Na+2Ca)/Al (Madeisky, 1996; Warren et al., 2007). In this diagram, the alteration minerals kaolinite, illite and adularia plot on a boundary zone. Unaltered andesitic volcanic rocks typically have molar (K+Na+2Ca)/Al values, which is partly observed for the Suwan Prospect volcanic rock. Most of the Suwan Prospect rocks have molar (K=Na+2Ca)/Al>0.8 to 1.4 considered to be the least altered rocks.

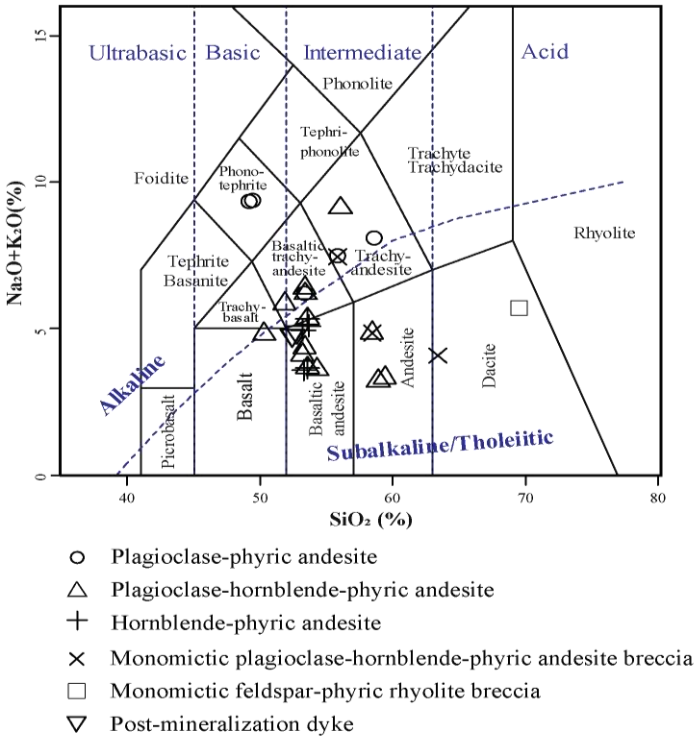

Figure 7. Diagram of total alkaline vs. silica (TAS) with subdivision of the alkaline and sub-alkaline/tholeiitic (Le Bas & Streckeisen, 1991).

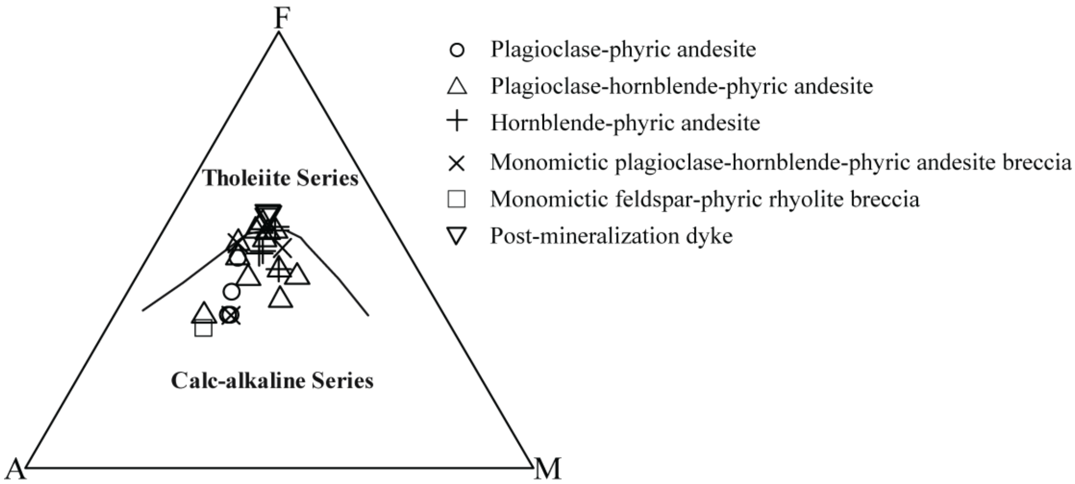

Figure 8. AFM diagram (Irvine & Baragar, 1971), showing the calc-alkaline and tholeiite series. Most of Suwan Prospect data plotted in the field of calc-alkaline series.

Table 2. Trace elements and REE composition (in ppm) determined by ICP-MS analysis of least altered Suwan Prospect host volcanic rocks.

Sample No.	4069-125.50	4080-97.00	4065-98.30	4080-75.00	4080-99.00	4067-71.50	4066-87.30
Rock types	ADD	PHA	PHA	HAD	PHA	PAD	MFR
V	327.000	261.000	335.000	318.000	308.000	247.000	81.000
W	103.000	376.000	163.000	77.000	111.000	1.000	2.000
Y	48.200	9.300	12.000	12.000	11.900	9.800	10.200
Yb	4.480	1.040	1.320	1.380	1.310	1.040	1.020
Zr	207.00	19.000	27.000	25.000	24.000	20.000	31.000
Ba	88.20	50.40	171.50	362.00	184.00	1250.00	1200.00
Ce	37.300	5.700	8.000	7.200	7.200	4.800	8.100
Cr	10.000	10.000	20.000	20.000	10.000	30.000	90.000
Cs	0.030	0.250	0.240	0.520	0.530	0.110	0.860
Dy	8.210	1.580	2.140	2.090	1.980	1.670	1.510
Er	5.000	1.080	1.370	1.230	1.330	1.050	1.010
Eu	2.530	0.490	0.600	0.600	0.600	0.400	0.460
Ga	23.000	20.300	18.500	19.800	19.800	15.800	9.900
Gd	8.560	1.520	1.880	1.830	1.730	1.510	1.480
Hf	5.100	0.700	0.900	0.800	0.800	0.700	1.000
Ho	1.730	0.340	0.460	0.430	0.450	0.360	0.350
La	14.400	2.400	3.900	3.100	3.000	1.800	4.000
Lu	0.670	0.160	0.220	0.210	0.200	0.170	0.170
Nb	7.600	0.600	0.700	0.600	0.600	0.500	0.700
Nd	26.300	4.400	5.700	5.600	5.400	3.900	5.300
Pr	5.420	0.840	1.150	1.050	1.030	0.730	1.070
Rb	8.50	8.70	11.20	29.00	18.50	78.70	57.10
Sm	7.320	1.220	1.580	1.730	1.560	1.260	1.300
Sn	4.000	4.000	1.000	2.000	2.000	2.000	3.000
Sr	172.00	424.00	498.00	702.00	517.00	248.00	130.00
Ta	0.700	0.700	0.300	0.100	0.200	<0.1	<0.1
Tb	1.370	0.240	0.330	0.310	0.320	0.260	0.240
Th	1.620	0.170	0.260	0.240	0.230	0.180	0.440
Tm	0.710	0.140	0.200	0.190	0.180	0.160	0.160
U	0.550	0.070	0.110	0.100	0.080	0.070	0.150

Abbreviation: HAD = Hornblende-phyric andesite, PHA = Plagioclase-hornblende-phyric andesite, ADD = Andesite dyke, PAD = Plagioclase-phyric andesite, MFR = Monomictic-feldspar-phyric rhyolite breccia.

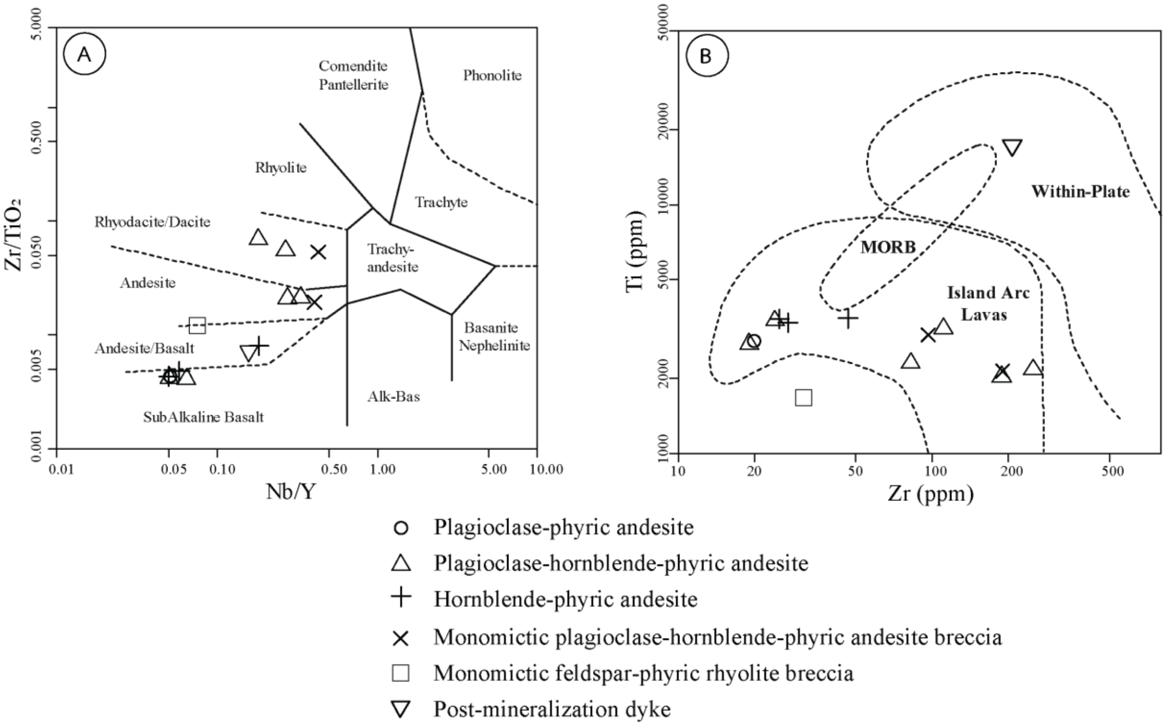

Figure 9. (A) Nb/Y and Zr/TiO_2 diagram for Suwan Prospect volcanic host rocks (after Winchester and Floyd, 1977) and **(B)** Plot of Ti vs. Zr the fields of island arc lavas, within-plate lavas for different tectonic setting (after Pearce, 1996).

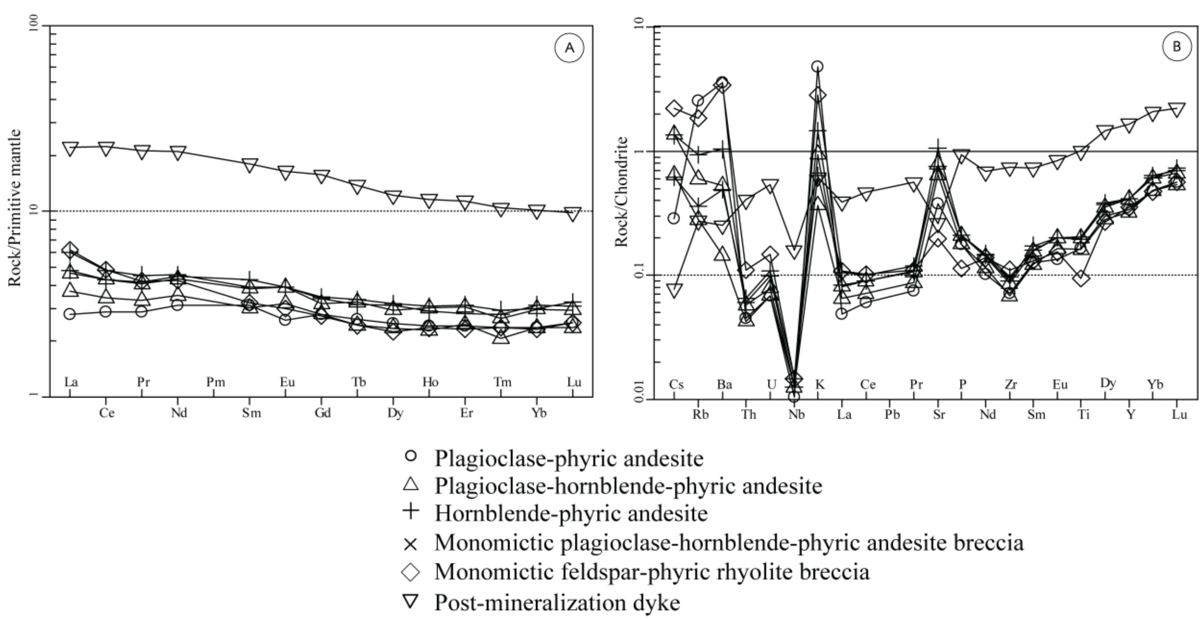

Figure 10. (A) Chondrite-normalized REE patterns and **(B)** OIB normalized trace element spider diagram of host volcanic rocks and post-mineralization dykes from Suwan Prospect. (Chondrite and N-MORB values are after Sun and McDonough, 1989).

6. Discussion and conclusion

6.1 Discussion

Volcanogenic environments have complex and diverse facies associations and stratigraphic relationships. The depositional environment has been proposed volcanic facies associations at the Suwan Prospect comprised three compositionally different volcanic units are porphyritic andesite unit, volcanogenic sedimentary rock unit and felsic volcanic unit. The porphyritic andesite unit is deposited at the bottom of their stratigraphic sequences and presents deposition of monomictic andesite breccia. The porphyritic andesite unit can be compared with Chatree deposit that was earliest event depositional event.

This event was followed by the deposition of the volcanic sedimentary unit which are siltstone, sandstone, mudstone and breccias. These processes include subaqueous deposition from subaerial pyroclastic flows that entered water, and subaqueous resedimentation of unconsolidated aggregates (Jutzeler et al., 2014). The volcanogenic sedimentary rock unit is presented at the middle of stratigraphic sequences in the study area. This sequence is very thick, laterally continuous layer (e.g. laminated siltstone) and graded bedding and may have been accumulated during periods of relatively minor volcanic activity (Salam, 2013). The latest event represented by the uppermost of sequence occurs as felsic volcanic facies association (rhyolite dominated facies). Its comprised feldspar-phyric rhyolite, quartz-rich fiamme breccia, lithic-rich fiamme breccia and volcanic sandstone.

The bottom volcanic sequence (mainly porphyritic andesite and monomictic andesite breccia) hosts minor mineralization in the study area. It mainly occurs as small veins, veinlets and stockworks (Salam personal communication). However, vein density is higher in the lower monomictic andesite breccia. The host volcanic sequences are mostly andesitic in composition, sometimes basaltic or rhyolitic rocks. The magmatic source was indicated to be the oceanic and continental margin volcanic arcs and were described for Permian-Triassic volcanic rocks in the study area (Salam et al., 2014). The suggested evolutionary sequence in oceanic arc from island arc tholeiite erupted at early stage of arc development has been confirmed only for the study area.

The volcanic islands in the study area are rarely preserved, because of undergo rapidly erosion as well as subsidence or subaerial erupted of the volcanic rocks and weathering processes. In simple volcanic arc(Mitchell & Garson, 1981), facies are either basaltic lavas or andesite lava flow breccias formed by auto-brecciation of submarine andesitic flows. These are commonly overlain by or interbedded with thick very coarse submarine sediment and mud flow deposits formed by erosion of subaerial volcanoes. Laterally equivalent rocks further from the volcanic arc are turbidites and mudstone; toward the volcanoes the marine volcanogenic rocks are locally interbedded with reef talus, fringing or barrier reef limestone, and lagoonal, fluviatile and conglomerate deposits surrounding subaerial eruptive centers. In complex oceanic volcanic arcs, the volcanogenic successions is similar to those of continental margin arcs although the composition of the clastic material reflects the highly various nature of the volcanic rocks, with tholeiite basalts and calc-alkaline andesites, dacites and rhyolites both occurring in parallel belt as a result of subduction controlled in type of the magmatism (Mitchell & Garson, 1981). For the Suwan Prospect, the volcanogenic succession can be described to the result of subduction-related and island arc by the tectonic setting (Salam et al., 2014).

6.2 Conclusion

Volcanic facies at the Suwan Prospect are associated with coherent (non-fragmental facies), autoclastic, epiclastic and pyroclastic facies. The volcanic rocks comprise; Porphyritic andesite facies association; Monomictic andesite breccia facies association; Volcaniclastic sedimentary facies association; Fiamme breccia facies association; Felspar-phyric facies association. The lower volcanic sequence is intermediate-mafic rocks that are mostly andesitic rocks and present stratigraphically beneath the volcaniclastic sedimentary rocks of the middle sequence. The upper sequences are mostly pyroclastic volcanic rocks such as monomictic rhyolite breccia, lithic-rich fiamme breccia, quartz-rich fiamme breccias and feldspar-phyric rhyolite breccia that are presented as felsic volcanic sequence.

The Suwan Prospect volcanic sequences have been informal stratigraphic division. Identification of district scale is difficult because of the paucity of bedding and facing data and the general lack of extensive marker layers.

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