Review Article

Sericitization-silicification of Chae Hom volcanics at Lampang in northern Thailand

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Abstract

The volcanic rocks of the Chae Hom area in Lampang, northern Thailand were investigated. Petrographic and geochemical analyses were performed to comprehend the alterations. The volcanic rocks in this study were co-magmatic and chemically transitional rhyolite to trachyandesite with calc-alkalic affinity. Their colors were highly variable due to two main alteration processes that included silicification and sericitization. The silicification process yields abundant quartz, whereas the sericitization yields abundant sericite and clay minerals. The sericite and clay minerals are most likely to be illite. The silicification process occurred after the sericitization process. Based on our petrochemical analysis, the Chae Hom volcanic rocks are considered to be of calc-alkaline affinity and post-collisional magmatic suite.

Keywords: Chae Hom volcanics, transitional rhyolite to trachyandesite, calc-alkalic rocks, silicification, sericitization, illite

1. Introduction

The Chae Hom volcanic rocks discussed in this paper were collected from a road-cut exposure (about 100 m long) at kilometer 41+300, highway number 1035, Chae Hom District, Lampang Province, northern Thailand. The interesting features of the volcanic rocks at this exposure are their highly variable colors, i.e. dark gray, grayish orange pink, grayish orange, pale yellowish brown, pale greenish yellow, and yellowish gray. In some places, dark mineral (tourmaline-dominated) tubes were observed. Petrographic investigations showed that most of the samples were similar in primary mineral assemblages, although they had variable colors. These features are possibly related to alteration. This study was undertaken to determine the alteration processes on the volcanic rocks by means of petrographic and geochemical data.

The volcanic rocks in Lampang area were classified into two groups based on their ages of eruption, i.e. Permo-Triassic volcanics (Department of Mineral Resources, 2007; Srichan, Crawford, & Berry, 2009) and late Cenozoic volcanics (Yan *et al.,* 2018). Data on the Chae Hom volcanics were first published at a scale of 1:250,000 by Piyasin (1972) and subsequently revised by Charoenprawat, Chuaviroj, Hingthong, and Chonglakmani (1994) and the Department of Mineral Resources (2007). The Department of Mineral Resources (2007) separated rocks in the study area into ten rock units as follows: Silurian-Devonian metamorphic rocks, Carboniferous sedimentary rocks, lower Permian sedimentary rocks, middle Permian sedimentary rocks, lower Middle Triassic sedimentary rocks, lower Upper Triassic sedimentary rocks, Tertiary sedimentary rocks, Quaternary semi-consolidated sediments, Quaternary unconsolidated sediments, and Permo-Triassic igneous rocks (Figure 1). The Silurian-Devonian metamorphic rocks consist of phyllite, quartzite, quartzo-feldspathic schist, and schist, with NE-SW foliation and a thickness of 321-1001 m. The Carboniferous sedimentary rocks are conglomerate, sandstone, siltstone, shale, chert, conglomeratic limestone, and massive limestone with a thickness of 52-169 m and unconformably overlie the Silurian-Devonian metamorphic rocks. The lower Permian sedimentary rocks consist of tuffaceous sandstone, sandstone, and shale in the lower parts and limestone in the upper parts. The Middle Permian sedimentary rocks are comprised massive limestone with sandstone and shale interbeds. The lower Middle Triassic sedimentary rocks unconformably overlie the Carboniferous sedimentary rocks.

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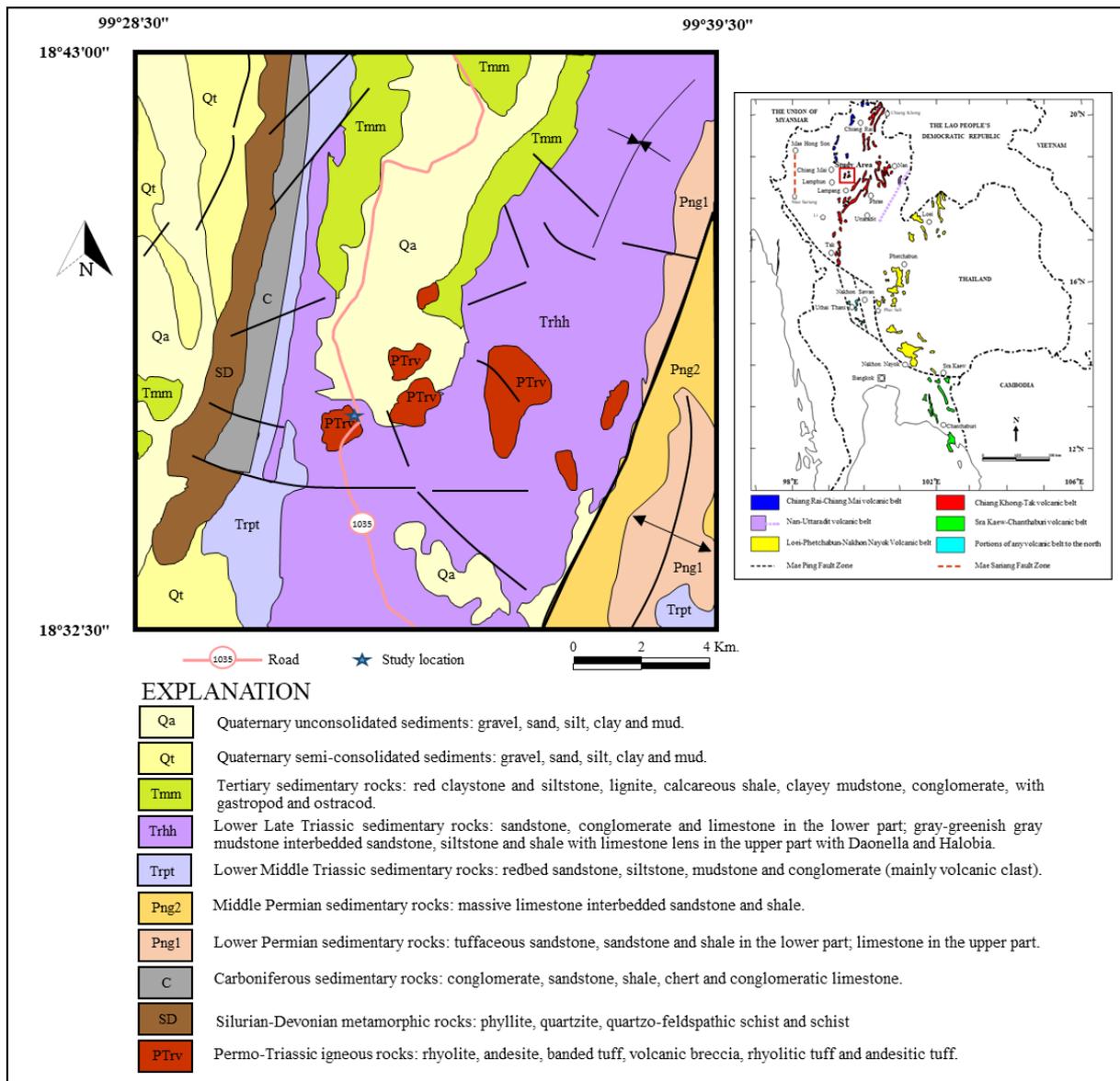Email address: patcharinkosuwan.j@cmu.ac.th

Figure 1.   Geological map showing the sampling site of volcanic rock samples (modified from Department of Mineral Resources, 2007). The location of the enlarged geological map and volcanic belts of Thailand are shown in the inset (modified from Boonsoong, Panjasawatwong, and Metparsopsan, (2011)).

They are made of sandstone and black shale in the lower parts and red conglomerate (mainly volcanic clasts), conglomeratic sandstone, sandstone, siltstone, shale, and mudstone with limestone lenses in the upper parts. Fossils in this rock unit are *Clararia* sp., and other bivalves. The lower Upper Triassic sedimentary rocks consist of sandstone, conglomerate, and limestone in the lower parts, gray-greenish gray mudstone and interbedded sandstone, siltstone, and shale with limestone lenses in the upper parts. Fossils of *Halobia* sp., *Posidonia* sp., and *Paratrachycerus* sp. were observed in the upper parts. The lower Upper Triassic sedimentary rocks conformably overlie the lower Middle Triassic sedimentary rocks, unconformably overlie the Permo-Triassic volcanic rocks, and both unconformably and conformably overlie the Permian strata.

The Tertiary sedimentary rocks are composed of red sandstone, shale, mudstone, claystone, lignite, calcareous shale, clayey mudstone, conglomerate, and diatomite with gastropods and ostracods, leaves, stems, fish bones, and *Viviparus* sp. They overlie the Upper Triassic igneous rocks and lower Middle Triassic sedimentary rocks. The Quaternary unconsolidated sediments and the Quaternary semi-consolidated sediments are gravel, sand, silt, clay and mud, and conformably overlie the Tertiary sedimentary rocks. The Upper Triassic, Chae Hom volcanic rocks are composed of lava flows, dikes, tuff and an agglomerate of rhyolitic and andesitic compositions. The volcanic samples were collected from this rock unit to investigate the alteration process and the source rock of kaolin. Arunsrisanchai and Potisat (1992) reported that the

alteration in rhyolite and rhyolitic tuff along the Sukhothai zone (Sukhothai-Phrae) were dominantly silicification. Although mineral alteration studies were done in the proximity of the Chae Hom area, no studies have been done in the Chae Hom area itself.

2. Materials and Methods

2.1 Sample preparation for petrography

Seven volcanic rock samples with different proportions of lighter-color and darker-color portions were collected to perform petrochemical studies. Standard thin sections were made at the Department of Geological Sciences, Chiang Mai University by cutting and polishing until the thickness was approximately 0.03 mm. Petrographic studies were done by polarizing microscope.

2.2 Analytical techniques for geochemistry

The volcanic samples in this study were prepared for whole-rock analyses by splitting into conveniently sized fragments using a hydraulic splitter. The weathered surfaces were sawed off. The fresh fragments were then crushed with a steel jaw crusher and cleaned with an air hose. Aliquots of approximately 30-50 g of the crushed fragments were pulverized for two minutes using a Rocklabs tungsten-carbide ring mill.

Chemical analyses of the major oxides, i.e. SiO_2, TiO_2, Al_2O_3, total iron (FeO and Fe_2O_3) as Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5, and some certain trace elements, i.e. Ba, Rb, Sr, Y, Zr, Nb, Pb, Ga, Zn, Cu, Ni, Cr, and Th, were carried out using a Rigaku 3270 X-ray fluorescence (XRF) spectrometer (wavelength dispersive system), with sample changer ASC80 and 60 automatic loader, installed at the Graduate School Laboratory, Kobe University, Japan. The standards used were synthetic metals, MM1 and MM2, and the Japanese national rock standards, JG-la, JPG-1, JR-2, JB-3, and JG-2 (Imai, Terashima, Itoh, & Ando, 1995). These chemical species were measured from fusion discs prepared with 0.5 g sample powder, 5 g anhydrous lithiumtetraborate ($Li_2B_4O_7$) and 1 drop of lithiumbromide (LiBr) for major oxides, and 2 g of sample powder and 4 g of anhydrous lithiumtetraborate for trace elements. Ignition loss was measured at the Department of Geological Sciences, Chiang Mai University by heating approximately 1 g of powered samples at 1000 °C for 10 h. The analyses for major oxides and trace elements of the studied volcanic samples are reported in Table 1.

Rare-earth elements (REE), i.e. La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, and Yb, were determined on the representative samples using high resolution inductively coupled plasma mass spectrometry installed at the School of Earth Sciences, University of Tasmania. Following the method described by Robinson, Townsend, Yu, and Munker (1999) the solution for measuring the REE was prepared by digesting 100 mg powder sample with 2 mL HF and 0.5 mL HNO_3 at 130 ℃ for 48 h and then evaporated to incipient dryness. One mL of HNO_3 was added and subsequently evaporated to incipient dryness. The residue was dissolved in 2 mL of HNO_3 followed by adding 10-20 mL of water. The final concentration of the sample was 10 mg/mL. The values for the REE concentrations in the representative volcanic rocks are given in Table 1.

3. Results

3.1 Petrographic study

In the field, the volcanic rock samples were made up of different proportions of light-colored and dark-colored portions (Figure 2) (Kosuwan, 2001). They were separated into two groups by color that possibly indicated the rock species which included Group I dark gray volcanic rocks with grayish orange pink specks/patches (samples CH-1, CH-2, and CH-4) and Group II grayish orange, pale yellowish brown, pale greenish yellow and yellowish gray volcanic rocks with grayish black specks/patches (samples CH-9, CH-11, CH-12, and CH-14). Although the rocks in Group I and II had different colors, they had similar petrographic features (mineral assemblages and textures) and geochemistry. The variety of rock colors were the result of alteration. The lighter-colored rocks were dominated by sericitization while the darker-colored were dominated by silicification. In the petrographic investigation, most of the volcanic rocks in Group I and II were generally very fine-grained and seriate-textured with grain sizes largely less than 0.1 mm across and consisted largely of quartz, plagioclase, and K-feldspar. Muscovite, biotite, chlorite, epidote minerals (zoisite/clinozoisite and epidote), titanite/leucoxene, tourmaline, zircon, Fe-Ti oxide mineral, hematite/iron hydroxide or pyrite or both were present in trace to small amounts. Of these constituents, plagioclase, K-feldspar, zircon, and some Fe-Ti oxide grains are primary, while the others are likely to be secondary. The darker-colored portions had much more secondary quartz and much less feldspars relative to the lighter-colored portions. Veinlets of clay minerals/fine white mica (sericite) were occasionally present.

Plagioclase and K-feldspar are largely anhedral to subhedral (grain sizes less than 0.1 mm across), and showed a felty arrangement. The petrographic analysis showed that plagioclase was slightly to moderately altered in the darker-colored rocks, but highly altered in the lighter-colored rocks. These crystals were mainly replaced by fine white mica, with minor secondary quartz, Fe-Ti oxide minerals, titanite/leucoxene, epidote minerals, tourmaline, pyrite or hematite/iron hydroxide or both. Secondary quartz occurred as isolated crystals, aggregates with non-sutured grain boundaries and as vermicular-shaped crystals in both plagioclase and K-feldspar with a similar appearance to microgranophyric intergrowths. K-feldspar was highly altered to abundant clay minerals impregnated with hematite/iron hydroxide and minor quartz, chlorite, epidote minerals, titanite/leucoxene, and Fe-Ti oxides. Primary Fe-Ti oxide was subhedral to euhedral and partly pseudomorphed by hematite/iron hydroxide. Primary biotite had brownish to greenish pleochroism and showed sheaf-like aggregates and subhedral outline. They sometimes had kink bands replaced by chlorite, epidote minerals, quartz, Fe-Ti oxide, titanite/leucoxene, pyrite, and hematite/iron hydroxide. Although biotite can occur as a primary mineral in volcanic rock, in this study some biotite was found as the secondary mineral. The secondary biotite had irregular outlines and formed veinlets passing through the secondary quartz. Tourmaline showed bluish to yellowish green pleochroism and

Table 1.   Whole-rock XRF analyses (recalculated to 100 wt% on volatile-free basis), REE analyses and some selected ratios of the studied volcanic rocks.

	CH-1	CH-2	CH-4	CH-9	CH-11	CH-12	CH-14
Major oxides (wt%)							
SiO_2	74.48	74.38	74.60	74.96	74.88	75.11	75.81
TiO_2	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Al_2O_3	14.32	14.27	14.31	14.15	14.23	14.20	14.50
FeO*	0.98	1.04	1.02	0.93	1.01	0.92	0.68
MnO	Tr	Tr	Tr	Tr	Tr	Tr	Tr
MgO	0.16	0.18	0.15	0.16	0.12	0.13	0.15
CaO	1.25	1.32	1.16	1.01	0.86	0.90	0.20
Na_2O	3.26	3.26	3.23	3.18	3.30	3.23	2.73
K_2O	5.42	5.41	5.41	5.48	5.48	5.39	5.81
P_2O_5	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Original sum	99.20	99.54	100.02	98.80	99.71	99.27	99.67
Loss on ignition	0.66	0.91	0.81	1.50	0.96	0.89	1.24
FeO* = total iron as FeO							
Trace elements (ppm)							
Ba	472	492	500	496	496	509	533
Rb	382	374	376	369	375	368	397
Sr	121	118	121	120	111	116	115
Y	20	20	26	25	20	20	21
Zr	102	99	100	98	96	96	98
Nb	19	18	18	18	18	18	18
Pb	137	131	171	133	122	112	218
Ga	17	17	18	17	15	16	15
Zn	31	29	31	30	30	26	98
Cu	Tr	Tr	Tr	Tr	Tr	Tr	2
Ni	5	6	4	5	6	6	6
Cr	Tr	Tr	Tr	Tr	Tr	Tr	Tr
Th	44	43	41	40	43	40	45
Some selected ratios							
Zr/TiO_2	0.101	0.099	0.100	0.097	0.096	0.095	0.098
Nb/Y	0.950	0.900	0.692	0.720	0.900	0.900	0.857
Y/Zr	8.68	8.68	8.64	8.66	8.78	8.62	8.54
Nb/Zr	0.196	0.202	0.260	0.255	0.208	0.208	0.214
Normative minerals were calculated based on $Fe_2O_3/FeO = 0.5$ (Middlemost, 1989)							
Quartz	31.47	31.22	31.95	32.67	32.25	33.15	36.68
Plagioclase	33.68	34.03	32.98	31.81	32.09	31.69	23.99
Orthoclase	32.33	32.28	32.35	32.76	32.76	32.23	34.71
Corundum	0.78	0.61	0.98	1.1	1.25	1.36	3.31
Hypersthene	0.69	0.76	0.67	0.65	0.59	0.58	0.52
Ilmenite	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Magnetite	0.78	0.84	0.83	0.75	0.81	0.74	0.55
Apatite	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Zircon	0.01	0.01	0.01	0.01	0.01	0.01	0.01
REE analyses and some selected ratios of the representative studied felsic volcanic rocks.							
La	18.2					17.1	
Ce	34.2					27.0	
Pr	4.09					4.10	
Nd	13.3					13.4	
Sm	2.98					3.18	
Eu	0.58					0.62	
Gd	2.63					2.89	
Tb	0.46					0.52	
Dy	2.68					3.02	
Ho	0.55					0.61	
Er	1.63					1.78	
Yb	1.64					1.83	
(La/Sm)cn	3.72					3.28	
(Sm/Yb)cn	1.97					1.88	

Tr = Trace.

formed fibrous, radiate, and sheaf-like aggregates or anhedral grains or both that poikilitically enclosed many smaller quartz inclusions. Primary apatite and zircon are accessory minerals. They were detected in very small amounts (1-2 grains) in each sample and had subhedral to euhedral outlines.

On the basis of petrographic observation, the paragenesis of the secondary minerals of Chae Hom rhyolite may be separated into two stages according to the abundant secondary minerals crystallization (Table 2). In the early stage, sericite (muscovite)/clay minerals and possibly chlorite were

Figure 2.   Photographs showing the studied volcanic rock samples (Chae Hom rhyolite) with different proportions of lighter-color and darker-color portions in Group I and Group II.
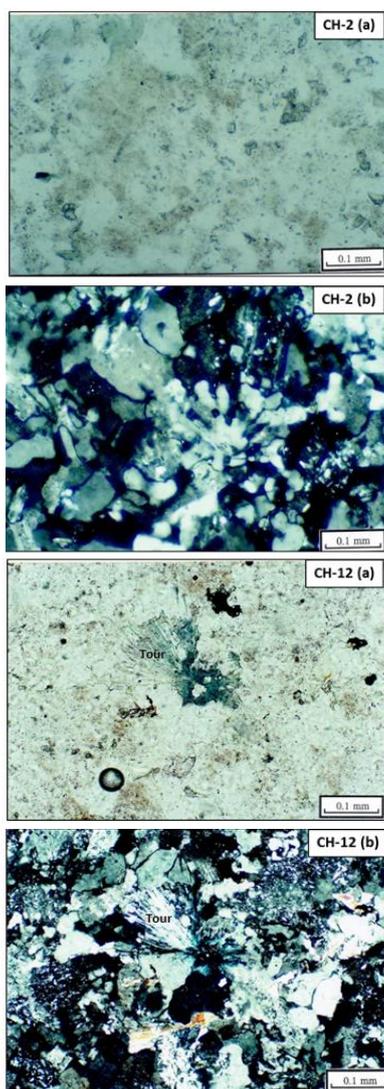

Figure 3.   Photomicrographs showing quartz occurs as vermicular-shaped crystals in both plagioclase and K-feldspar, simi-lar appearance to microgranophyric intergrowths, in Group I (CH-2), and seriated texture with sheaf tour-maline (Tour) in Group II (CH-12) rock samples; (a) ordinary light and (b) crossed polars.

developed first and then epidote minerals and Fe-Ti oxides. The occurrences of quartz and titanite, tourmaline and leu-coxene, biotite and hematite/iron hydroxides, and pyrite in a progressive manner developed in the late stage of crystal-lization. It can be summarized here that the volcanic rocks in this study experienced different degrees of alteration in pri-mary minerals, giving rise to sericite (muscovite)/clay mine-rals and quartz as abundant replacement minerals. The rocks prior to alteration were likely to be devitrified, glassy volcanic rocks.

3.2 Whole-rock geochemistry

While, the rocks underwent various degrees of al-teration and low-grade metamorphism, the concentrations of immobile elements possibly changed due to the dilution or enrichment of the mobile elements. However, the ratios of immobile elements in the primary rock and altered rock re-mained constant. Accordingly, only the elements considered as immobile elements and immobile-element ratios were used to interpret the geochemical data in this study. Furthermore, Zr is an incompatible immobile element; therefore, it was used as a fractionation parameter for the rock samples. In addition, although occasional reports have appeared on REE mobility, especially light REE, during hydrothermal alteration and low-grade metamorphism (Hellman & Henderson, 1979; Whitford, Korsch, Porritt, & Craven, 1988), the overwhelming consen-sus of opinion is that the REE patterns of carefully selected igneous samples probably shifted slightly from their primary patterns, but remain parallel/sub-parallel to the primary pat-terns.

Although the volcanic rocks in this study had va-rious colors, they were chemically similar (Table 1). These volcanic rocks had limited amounts of SiO_2 (74.4-75.8 wt%) and Na_2O+K_2O (8.5-8.8 wt%), which suggested they are co-magmatic and underwent similar degrees of crystal frac-tionation. Their position on the Na_2O+K_2O against SiO_2 plot of Le Bas, Le Maitre, Streckeisen, and Zanetti (1986) appear to be rhyolite (Figure 4). This is also true on the normative quartz-alkali feldspar-plagioclase plot of Streckeisen (1976) (Figure 5). In addition, the volcanic rocks formed a remarka-bly linear trend in between the alteration trends for silicifi-cation and sericitization in the ternary diagram. The trend was possibly formed by approximately 50% silicification and 50% sericitization. The two alteration processes are supported by the presence of quartz, sericite, and clay minerals as the prin-cipal alteration products. Owing to the secondary mineral pa-ragenesis discussed by petrographic evidence, sericitization took place prior to silicification.

The least-mobile Zr/TiO_2 and Nb/Y ratios of the rocks were in the ranges of 0.095-0.101 and 0.692-0.950, respectively; however, this implied that the rocks were transitional rhyolite to trachyandesite (Figure 6). The Zr/TiO_2 ratios were nearly constant which signified similar degrees of crystal fractionation (Winchester & Floyd, 1977) as shown by the total alkali-silica diagram. The co-magmatic nature and similar degrees of fractionation are well supported by the REE patterns and the two representative patterns are subparallel and have similar REE abundances. They have rather flat hea-vy REE patterns and light REE enrichment, with small nega-tive europium anomalies (Figure 7) which signified that the magma possibly underwent slight plagioclase fractionation.

Table 2. Par33genesis of secondary minerals of Chae Hom rhyolite

Par3genesis of secondary minerals in Chae Hom rhyolite						
Muscovite (Sericite)	-------					
Clayminerals	-------					
Chlorite	?-?-?-					
Epidote mineral		-------				
Fe-Ti oxide minerals			-------			
Titanite				?-?-?-		
Leucoxene					?-?-?-	
Hematite/Iron hydroxide						?-?-?-
Quartz				-------		
Tourmaline					-------	
Biotite						?-?-?-
Pyrite							-------
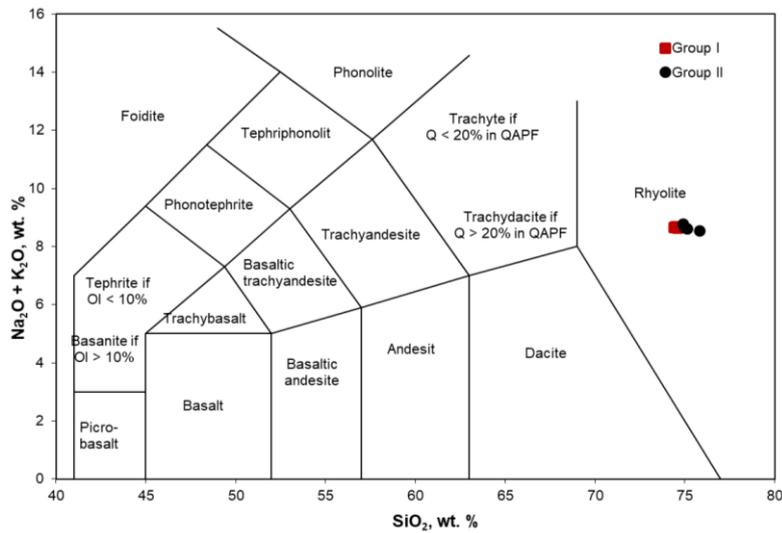
Figure 4. A plot of SiO_2 against Na_2O+K_2O for the studied volcanic rocks. Field boundaries for different rock types are taken from Le Bas et al. (1986). Note that Q = normative quartz, and Ol = normative olivine.
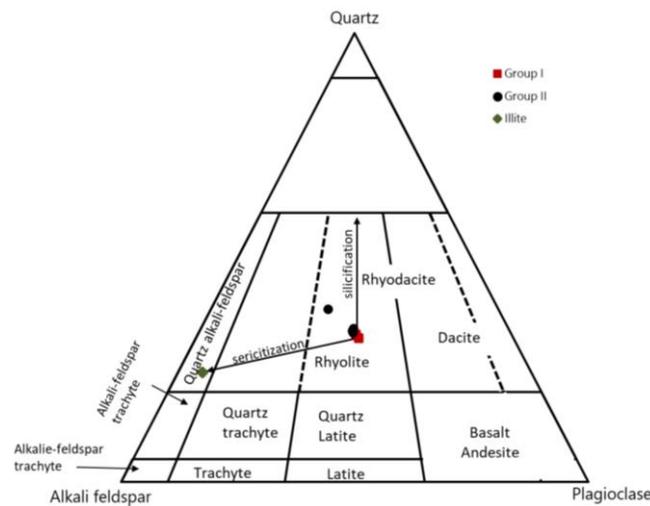

Figure 5. QAP ternary diagram of Streckeisen (1976) showing the positions of the studied volcanic rocks that form a linear trend (Q = normative quartz, A= normative orthoclase, and P = normative plagioclase). The composition of illite (solid green diamond) used for constructing the trend for sericitization is taken from Deer, Howie, and Zussman, (1992).
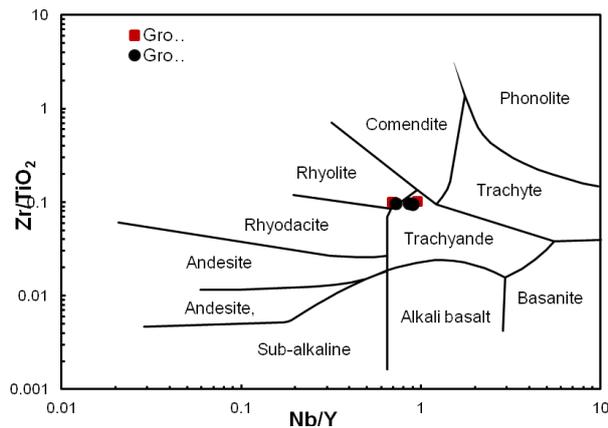
Figure 6.   A plot of Zr/TiO_2 against Nb/Y for the studied volcanic rocks. Field boundaries for different rock types are taken from Winchester and Floyd (1977).
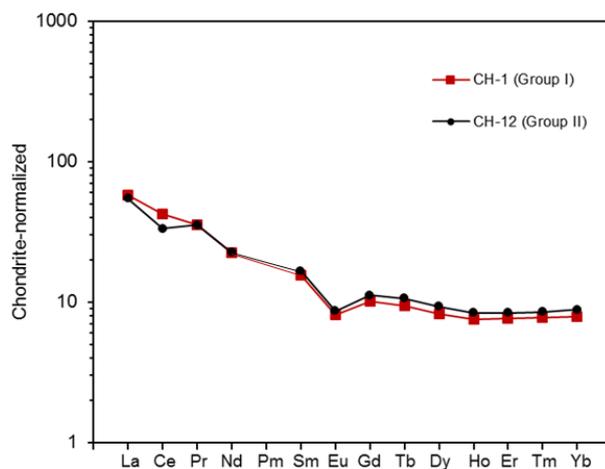

Figure 7.   Chondrite-normalized REE patterns for the representative studied volcanic rocks (Samples CH-1 and CH-12). Normalizing values are those of Taylor and Gorton (1977).

Their chondrite-normalized Sm/Yb and La/Sm ratios were 1.88-1.97 and 3.28-3.72, respectively. The patterns were typical of calc-alkalic rocks.

4. Conclusions

The volcanic rocks presented in this paper are from Chae Hom, Lampang, northern Thailand. The lithology of these volcanic rocks in this area is characterized by darker and lighter colors, which possibly indicated a differentiated magma eruption. Although, their colors are highly different, their petrographic and geochemical features were similar. The variation in color is contributed to alteration. Group I was more influenced by the silicification process which resulted in a darker color, while the lighter color of Group II was caused by the sericitization process. The principal alteration products in this volcanic suite are quartz, sericite, and clay minerals. The occurrences of these minerals are according to the silicification and sericitization processes indicated by the geochemistry. Evidence from the petrographic study showed that the plagioclase was replaced by secondary muscovite (sericite) and after that replaced by secondary quartz. Consequently, silicification occurred after sericitization, using mineral paragenesis. The sericite and clay minerals are most likely to be illite as mentioned by Janejai (1999) and Donmuang, Asnachinda, Limtrahun, Rattanasatien, and Khandarosa (2014) who studied clay minerals in the altered rhyolite in a nearby area.

The original rocks had a glassy texture which possibly occurred from volcanic eruption. Subsequent devitrification and alteration gave rise to the volcanic rock presented here. The volcanic rocks in this study were co-magmatic and chemically transitional rhyolite to trachyandesite using the least-mobile Zr/TiO_2 and Nb/Y ratios. They had rather flat REE patterns and light REE enrichment which is typical of calc-alkalic rocks. Calc-alkalic rocks were affirmed by Srichan, Crawford, and Berry (2009). In addition, the geochemistry features of volcanic rocks in the Chiang Khong–Lampang–Tak Volcanic Belt are strong compositional analogies with other post-collisional magmatic suites and are more typical of volcanic belts formed in a rapidly evolving post-collisional, basin-and range-type extensional setting.

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