

GEOCHEMISTRY AND ALTERATION OF LAMPANG - TAK VOLCANIC ROCKS, THAILAND

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Abstract

Volcanic rocks in southern Lampang and northern Tak are a part of the pre-Cretaceous Chiang Khong-Lampang-Tak volcanic belt situated in the northern region of Thailand. These studied rocks are composed of rhyolite and basalt with porphyritic texture, associated with pyroclastic rocks. Rhyolites consist of quartz and alkali-feldspar phenocrysts, while basaltic microphenocrysts are plagioclase and unidentified mafic minerals (pyroxene?) highly replaced by chlorite. Petrographically analysis describes alkali-feldspar altered to clay minerals, plagioclase was replaced by sericite, and volcanic glass devitrified to cryptocrystalline quartz. The Zr/TiO₂ and Nb/Y ratio suggest that these volcanic rocks are rhyodacite and alkali basalt. In addition, REE Patterns classified these volcanic rocks were generated from two magma series; 1) alkali basalts were from the mildly calc-alkaline magma, and 2) rhyodacites were exploded from the alkaline magma. A petrographical study suggests that mineral compositions were vastly altered to phyllosilicates agreeable with geochemical data that describe these volcanic rocks grain Si⁴⁺ and lose alkaline cations. The rhyodacites have a high sericitization index (SI) and Ishikawa alteration index (AI) related to sericitization, illitization, silicification, and chloritization processes, which are caused by mass transfer in the hydrothermal system and maybe affected by the metamorphic process. Meanwhile, Triassic(?) basalts with moderately high CCPI present chlorite, pyrite, and carbonates key minerals, resulting from weathering and alteration processes. These alteration processes may affect the potential of new georesources for the ceramic industry similar to central Lampang, especially clay minerals.

Keywords: Sericitization, illitization, chloritization, silicification, hydrothermal

Introduction

Chiang Khong-Lampang-Tak volcanic belt is one of four pre-Cretaceous volcanic belts in the upper part of Thailand: (1) Chiang Rai-Chiang Mai volcanic belt, (2) Chiang Khong-Lampang-Tak volcanic belt, (3) Nan-Uttaradit volcanic belt, and (4) Loei-

Phetchabun-Nakhon Nayok volcanic belt (Figure 1). The Chiang Khong-Lampang-Tak (CKLT) volcanic belt is to the extending from Chiang Khong District, Chiang Rai Province, via Lampang and Phrae Province to Tak Province (Barr *et al.*, 2000; Phajuy, 2001;

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Panjasawatwong *et al.*, 2003; Barr *et al.*, 2006; Qian *et al.*, 2013). It is a possible southern extension of the Lincang - Jinghong volcanic belt in China (Yang *et al.*, 1994; Yang, 1998; Barr *et al.*, 2006), which is a part of the Lancangjiang igneous zone in SW China, and the rocks in the southwestern Yunnan can be correlated with the Triassic Lampang-Phrae basin in Thailand (Feng *et al.*, 2005; Qian *et al.*, 2016). The CKLT volcanic belt was referred to as mafic to felsic volcanic and pyroclastic rocks associated with intrusive rocks in the Sukhothai Terrane (Panjasawatwong *et al.*, 2003; Srichan *et al.*, 2009). There is primarily shallow marine of Permian (Ngao Group and Uttaradit Group) - Triassic (Lampang Group) sedimentary rocks.

This work focuses on the slightly altered volcanic rocks in the southern part of Lampang Province, classified as the post-collision and continental rifting eruptions from calc-alkalic and alkali magma series (Srichan *et al.*, 2009; Phajuy and Singtuen, 2019).

The volcanic rocks in the studied area present alteration minerals in a wide range; therefore, this research will describe the relationship between geochemical characteristics and mineral alteration of rocks as well as the cause of the alteration process.

Materials and Methods

Fifteen rock samples were collected from the Mae Phrik and Ban Tak areas in Permo-Triassic volcanic rocks, Triassic granitic rocks, and Quaternary sediments units for petrographic study, which are made up of rhyolite (3 samples), basalt (2 samples), pyroclastic rocks (8 samples), and granitic rocks (2 samples). Five studied samples, including rhyolite and basalt, were collected for geochemistry analysis. These samples were carefully determined under a polarizing microscope to describe mineral alteration and were prepared representative samples for geochemical analysis.

Chemical analyses of major oxides (SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , K_2O , and P_2O_5) and trace elements (Rb, Sr, Zr, Y, Nb, Ni, Cr, V, and Sc) were analyzed by a Phillip-MagixPro PW 2400 Wavelength Dispersive X-Ray Fluorescence spectrometer at the Department of Geological Sciences, Chiang Mai University. In addition, LOI was also analyzed by heating a platinum crucible containing a 1.0 g sample in a furnace at $1,000^\circ\text{C}$ for 12 h in a similar laboratory. The three interesting samples were selected for their low levels of trace elements (Hf, Th, and Ta) and rare earth elements (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm,

and Yb) and were analyzed using a Sodium Peroxide Fusion combined inductively coupled plasma Mass Spectrometer (ICP-MS) and inductively coupled plasma Optical Emission Spectrometer (ICP-OES) at the SGS-CSTC Standards Technical Services Co., Ltd., China. All geochemical data will be used to determine specific rock names, magma series, mineral alteration, alteration indices, and alteration processes.

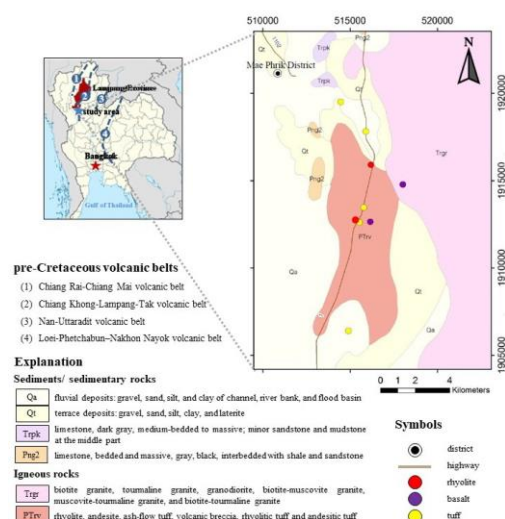


Figure 1 Geologic map of the studied area and location of collected samples (modified from Boripatkosol *et al.*, 1989a; 1989b)

Geologic Setting

The studied area sits along highway number 1, which runs from Thoen District (Lampang Province) to Tak Province. The rock units in this area are made up of sedimentary strata, volcanic rocks, and granitic intrusions. The sedimentary strata consist of Permian to Triassic rocks, which are partly overlain by quaternary sediments (Figure 1). The Permo-Triassic volcanic rocks are made up of rhyolite, andesite, ash-flow tuff, volcanic breccia, rhyolitic tuff, and andesitic tuff. In some areas, this volcanic rock unit occurred associate with basalt that also intruded through granitic rocks. The “Tak Batholith” granitic intrusions present in this area have formed in Triassic (213-256 Ma) and are grouped in the eastern granite belt (Beckinsale *et al.*, 1979; Khositantont, 2007). Basaltic dikes intruded this batholith after the upper Triassic - lower Jurassic due to relative age and law of cross-cutting (Singtuen and Phajuy, 2015; Phajuy and Singtuen, 2019).

Results and Discussion

Petrography

The samples were collected from in situ rocks and outcrops and road number 1, from Lampang Province to Tak Province (Figure 2(a)). The Mae Phrik and Ban Tak areas consist of granite, rhyolite (sample number LPT-1, LPT-2, and LPT-3), basalt (sample number LPT-4 and LPT-5), and welded tuff. The rhyolite exploded associated with welded tuff and volcanic breccia, while the basaltic dike intruded into granitic rocks that have been detected in felspar mine (Figure 2(b)).

The granitic intrusions is made up of biotite granite, tourmaline granite, granodiorite, biotite-muscovite muscovite - tourmaline granite, and biotite - tourmaline granite. The rhyolitic rocks demonstrate pale green to pale gray with porphyritic texture Figure 3(a-b) and pinkish-brown with a yellowish-brown weathering surface. The phenocrysts are made up of quartz, alkali-feldspars, and opaque minerals (pyrite), which are embedded in a very fine-grained groundmass. These rhyolites are associated with rhyolitic tuff, which displays pyroclastic and eutaxitic textures. Tuff comprises glass shards with subordinate quartz and alkali feldspar with small amounts of rock fragments. Basalt has a dark green color, and its weathered surface is cover by dark yellowish-brown Fe-oxide materials, presenting a slightly porphyritic texture. The microphenocrysts in the sample are large of plagioclase with a small amount of unidentified mafic mineral, which is mainly altered to chlorite Figure 3(c-d). The groundmass phase comprises plagioclase and unidentified mafic minerals (pyroxene?), presenting the ophitic/ subophitic intergrowth related to shallow intrusion. These basalts intruded into granitic intrusion, mainly made up of quartz, alkali feldspar, and plagioclase, with small muscovite. The accessory minerals include zircon, monazite, and apatite, which can be found in granitic rocks.

Geochemical Characteristics

Table 1 shows the analytical results for major oxides, trace elements, and REEs as well as a loss on ignition (LOI). The studied rocks were classified into two main groups, felsic and mafic volcanic rocks on the Total Alkali-Silica ($\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{SiO}_2$) diagram (Le Bas *et al.*, 1986) in Figure 4. The felsic group consists of rhyolite (LPT-1, LPT-2, and LPT-3), and mafic rocks are distributed in basaltic trachyandesite (LPT-5) and andesite (LPT-4).

According to the studied are quite altered, these rocks are classified as rhyodacite/ dacite (LPT-1, LPT-2, and LPT-3) and alkali basalt (LPT-4 and

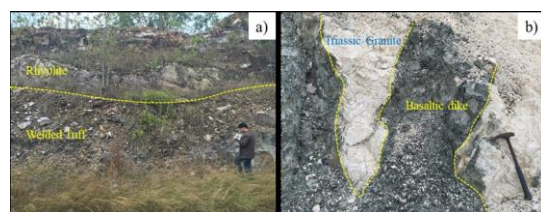


Figure 2. The outcrop of (a) rhyolite at grid reference 516181.7 E 1915922.3 N and (b) basalt at grid reference 518005.1 E 1914791.8 N

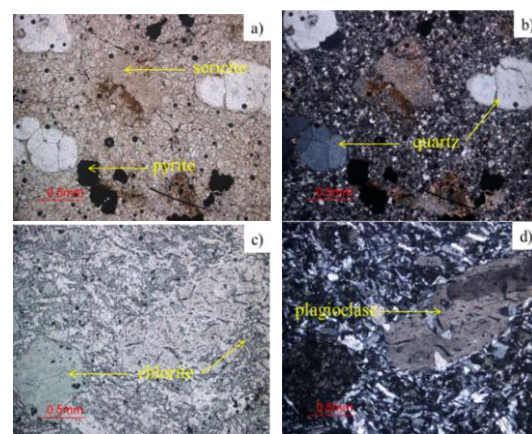


Figure 3. Photomicrographs of (a) rhyolite (sample number LPT-2) showing alteration minerals in ordinary light, (b) a porphyritic texture in crossed polars, (c) alteration minerals of basalt (sample number LPT-5) in ordinary light, and (d) phenocrysts in a very fine-grained groundmass via crossed polars

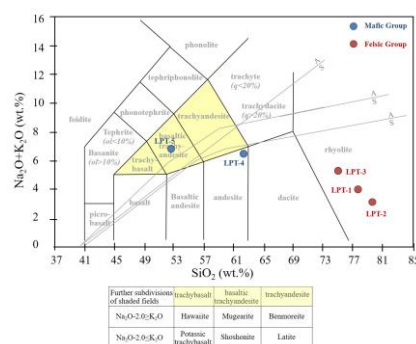


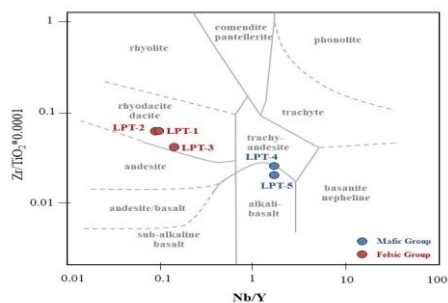
Figure 4. Total Alkali-Silica diagram for the chemical classification of volcanic rocks. (diagram modified from Le Bas *et al.*, 1986)

LPT-5) by immobile elements (Figure 5) in Zr/TiO_2 vs. Nb/Y diagram (Winchester and Floyd, 1977). The felsic group can be described as rhyodacite reasonable with petrographic analysis, especially quartz and alkaline feldspar phenocrysts.

Table 1. Whole-rock analyses for major oxides on a volatile-free basis, trace elements, loss on ignition, and rare earth elements (REEs)

Sample	LPT-1	LPT-2	LPT-3	LPT-4	LPT-5
Major oxides (wt%)					
SiO ₂	74.23	77.01	72.62	60.19	49.86
TiO ₂	0.23	0.23	0.37	0.92	1.82
Al ₂ O ₃	12.47	12.73	12.61	17.13	18.89
Fe ₂ O ₃ tt	2.48	3.38	3.38	4.91	8.28
MnO	0.03	0.02	0.08	0.09	0.13
MgO	0.45	0.58	0.69	6.05	8.32
CaO	1.73	0.08	2.11	0.62	1.06
Na ₂ O	1.79	0.54	4.22	6.42	6.43
K ₂ O	2.12	2.47	0.95	0.04	0.06
P ₂ O ₅	0.04	0.04	0.07	0.33	0.77
LOI	3.70	3.32	3.52	3.28	4.89
Sum	99.28	100.41	100.62	99.97	100.50
Trace elements (ppm)					
Ni	3.23	6.37	5.88	109.54	165.16
V	47.52	49.08	73.91	151.58	268.89
Rb	91.94	114.26	35.22	5.68	BD
Y	76.05	75.41	70.91	BD	BD
Nb	BD	BD	0.39	23.02	39.73
Hf	BD	4	4	BD	5
Th	2.71	2.21	7.01	46.51	54.52
Ta	BD	2	1.4	BD	1.1
Cr	10.38	3.86	3.03	184.32	616.87
Sr	63.08	61.61	92.06	171.82	75.42
Ba	909.89	982.09	729.10	498.68	331.03
Sc	6.53	0.42	9.76	1.44	3.50
Zr	198.66	191.84	243.35	198.48	326.42
Rare Earth elements, REEs (ppm)					
La		15.60	20.90		295.00
Ce		32.70	39.30		488.00
Pr		4.64	5.47		50.18
Nd		21.10	23.50		158.00
Sm		3.90	5.50		18.60
Eu		1.17	1.40		1.92
Gd		4.20	5.72		16.70
Tb		0.77	1.12		1.13
Dy		5.45	6.60		3.92
Ho		1.32	1.51		0.69
Er		3.81	4.16		2.33
Tm		0.73	0.82		0.35
Yb		4.10	4.70		2.40
Lu		0.77	0.86		0.53

BD = below detection limit.

**Figure 5. A plot of Zr/TiO₂ vs. Nb/Y for the studied volcanic rocks. (diagram modified from Winchester and Floyd, 1977)**

Alteration

Alteration indices, such as the Ishikawa alteration index (AI) and the chlorite-carbonate-pyrite index (CCPI), have been developed to measure sericite intensity chlorite, carbonate, and pyrite replacement of sodic feldspars associated with hydrothermal alteration proximal to the orebodies. In addition, silica will be in the form of cryptocrystalline quartz and microcrystalline quartz during the hydrothermal alteration.

The sericitization index (Kishida and Kerrich, 1987) has the most extensive range of their values; however, it can describe alkali cations' change. The chlorite carbonate-pyrite index was used for measuring chlorite, carbonate, and pyrite replacement in altered rocks (Large *et al.*, 2001). In addition, the alteration index or Hashimoto index (Ishikawa

Table 2. Alteration indices of studied volcanic rocks

Alteration indices (%)	LPT-1	LPT-2	LPT-3	LPT-4	LPT-5
AI	42.2867	82.9551	20.5588	46.3435	52.7954
SI	60.3480	394.0829	14.9451	0.5568	0.7775
HI	42.2867	82.9551	20.5588	46.3435	52.7954
CCPI	42.9243	56.8299	44.0874	62.8859	71.8967

et al., 1976) shows the input of K and Mg, and the exit of Ca and Na confirms possible locations specified by mineralization

$$\text{Alteration Index (AI)} = 100 \left\{ \frac{(K_2O + MgO)}{(K_2O + MgO + Na_2O + CaO)} \right\}$$

$$\text{Sericitization Index (SI)} = 100 \left\{ \frac{(K_2O)}{(Na_2O + CaO)} \right\}$$

$$\text{Chlorite Carbonate Pyrite Index (CCPI)} = 100 \left\{ \frac{(FeO + MgO)}{(K_2O + MgO + Na_2O + FeO)} \right\}$$

Alteration indices in Table 2, including Ishikawa alteration index (AI), Sericitization index (SI), Hashimoto index (HI), and chlorite-carbonate-pyrite index (CCPI), were calculated following those formulas suggest that AI of the studied volcanic rocks are not different significantly (20.5588% to 82.9551%) and similar to petrographically data (sericite, clays, chlorite, and pyrite). Furthermore, the felsic group (rhyolite; LP-1 and LP-2) has very high SI (14.9451-394.0829%), and moderate CCPI (42.9243-56.8299%) values can describe that these rocks were gained K^+ with losing Na^+ and Ca^{2+} during the alteration process (illitization), especially sample LP-2 (Figure 6). The sample LP-3 displays in the adularia-plagioclase line and low Molar K/Al. The studied mafic rocks (basalt and andesite) have low SI (0.5568-0.7775%) and high CCPI (62.8859-71.8967%) values presenting chlorite, carbonate, and pyrite replacement are significant in those. The sample LP-4 was plotted in the field of high Molar K/Al suggest that this rock shows adularization. On the other hand, sample LP-5 was plotted close to the plagioclase area with a high molar $(K+Na+2Ca)/Al$ value. The Molar K/Al vs. molar $(K+Na+2Ca)/Al$ diagram (Madeisky, 1996; Booden *et al.*, 2010) shows the alteration minerals kaolinite, illite, and adularia plot a line of slope 1. Unaltered igneous rocks typically have molar $(K+Na+2Ca)/Al$ values >1 . Potassium metasomatism decreases molar $(K+Na+2Ca)/Al$ and increases molar K/Al values, partly observed for the studied rocks (Figure 6). This diagram can assume as the felsic group gained K^+ and lose Na^+ and Ca^{2+} similarly to CCPI. This result is relatively consistent with some plagioclases' petrography altered to sericite, and alkali-feldspars were replaced by clay minerals in the selected volcanic rocks.

According to the verses of AI and CCPI, sample LPT-1 and LPT-3 are the most miniature

altered rocks, mafic and felsic groups were interpreted as related to the diagenetic alteration (Figure 7). In addition, sample LPT-2, LPT-4, and LPT-5 are affected by the hydrothermal alteration.

Discussion

The Lampang - Tak (Mae Phrik and Ban Tak areas) volcanic rocks consist of felsic and mafic groups that demonstrate porphyritic texture associated with volcanic tuff and breccia pyroclastic and eutaxitic textures. The phenocrysts of rhyolite

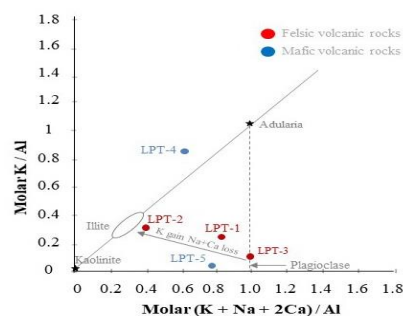


Figure 6. Plots of K/Al vs. $(K+Na+2Ca)/Al$ (Madeisky, 1996; Booden *et al.*, 2010) by the alteration minerals kaolinite, illite, and adularia plot on a line of slope 1. Unaltered rocks typically have $(K+Na+2Ca)/Al > 1$. Potassium metasomatism leads to decreasing $(K+Na+2Ca)/Al$ and increasing K/Al values

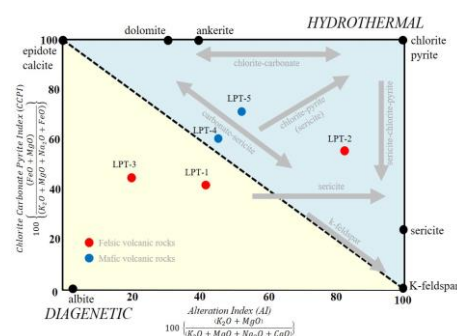


Figure 7. Plots of Chlorite-Carbonate-Pyrite Index versus Alteration Index of studied volcanic rocks on the alteration box plot (modified from Large *et al.*, 2001) showing the relative degree of alteration and general alteration mineralogy

consist of alkali-feldspar and quartz, while microphenocrysts of basalt comprise plagioclase and unidentified mafic minerals (totally altered chlorite). Petrographically study suggests that plagioclase, pyroxene, alkali-feldspar, the volcanic glass were replaced by secondary sericite, chlorite, clay minerals, and cryptocrystalline quartz, respectively.

Geochemical data classified these volcanic rocks as rhyodacite and alkali basalt by immobile elements classification that different from major oxides classification (rhyolite, andesite, and basalt). Thus, these volcanic rocks were gain Si^{4+} and lose alkaline cations. REEs identified these two groups generated from different magma series; mildly calc-alkaline and alkaline magma series (Figure 8).

Rhyodacites have Zr/TiO_2 against Nb/Y ratios in ranges of 0.0631-0.0809 and 0.1120-0.1631, respectively, corresponding subalkalic series. Two rock group representatives show relatively flat REE patterns from Sm to Yb, chondrite-normalized $\text{Sm}/\text{Yb} = 1.03$ -1.27, and slightly LREE enriched, with chondrite-normalized $\text{La}/\text{Sm} = 2.32$ -2.44 (Figure 8) REE patterns of rhyolite show mildly calc-alkaline magma series and suggest that these rocks have been formed within a plate on the rifting stage (Phajuy and Singtuen, 2019).

Alkali basalts have Zr/TiO_2 against Nb/Y ratios in ranges of 0.0170-0.0208 and 2.4277-2.6089, respectively, corresponding alkaline series. Mugearite represents this group and presents relatively flat REE patterns from Sm to Yb, chondrite-normalized (Taylor *et al.*, 1977) $\text{Sm}/\text{Yb} = 8.40$, and slightly LREE enriched, with chondrite-normalized $\text{La}/\text{Sm} = 9.67$ (Figure 8) REE patterns of the mafic group show alkaline magma series and suggest that these rocks have been formed as a post-collision (Phajuy and Singtuen, 2019).

Rhyodacites present a very high SI with moderately high AI, HI, and CCPI, suggesting that the studied felsic volcanic rocks are related to sericitization, illitization, chloritization, carbonatization, and pyritization. The rhyodacites can also be described as alkali cation's change (K^+ , Na^+ , Ca^{2+}) and silicification, which is generally produced by adding silica from silica-rich fluids (e.g. hydrothermal fluid), similar to Cha Hom rhyolite. Janejai (1999) and Donmuang *et al.* (2014) determined that sericite and clay minerals in Muang Lampang and Chae Hom's altered rhyolite are most likely illite. In addition, Chae Hom rhyolite is related to silicification and sericitization that abundant quartz, sericite, and clay minerals (Jundee *et al.*, 2019). Alkali basalts display high CCPI that can describe the mafic volcanic rocks have secondary chlorite (by weathering) reasonable with pyroxene perfectly altered to chlorite under

a microscope. similar to alkali basalt in Sisaket, NE Thailand (Singtuen *et al.*, 2021).

The Lampang - Tak volcanic rocks are distributed in very complex tectonics, presenting with the Mae Ping strike-slip faults (Morley, 2002) and multi-stage volcanic explosive (Phajuy and Singtuen, 2019). Therefore, these volcanic rocks maybe affected by the movement of Mae Ping fault (Bruhn *et al.*, 1994; Meller and Kohl, 2014). In addition, the rocks maybe related to hydrothermal alteration caused by Triassic eastern granite intrusions (Mahawat, 1982) and Triassic (?) basaltic dike (Figure 9).

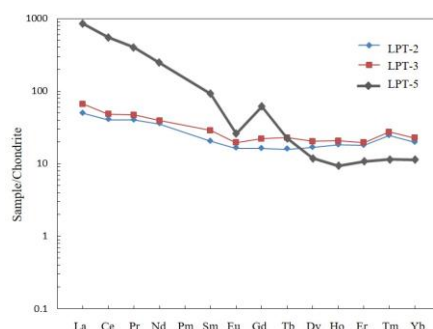


Figure 8. Chondrite-normalized patterns for the representatives of the studied volcanic rocks

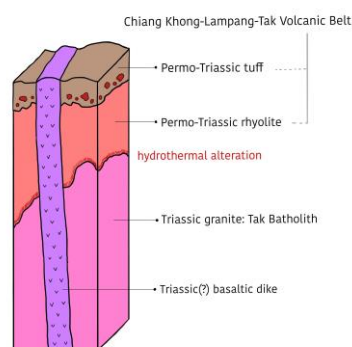


Figure 9. Alteration model of the studied volcanic rocks related

The Mae Phrik area of Lampang Province and Ban Tak of Tak Province have high potential in economic geology as feldspar mines and dimension stone manufacture, especially in granitic resources. This work can be used to assess the potential of clay minerals deposit and compare with another well-known in central Lampang, or Chae Hom, for creating new geo-resources serves to the ceramic industry. However, the mineralogical study should be more taken with those altered minerals mentioned previously.

Conclusions

Volcanic and pyroclastic rocks in the southern part of Lampang were grouped in the pre-Cretaceous Chiang Khong - Lampang - Tak volcanic belt, a one-fourth volcanic belt of Thailand. The studied rocks associated with granitic rocks intruded into Permo-Triassic volcanic rocks during the Triassic period, and then basaltic dike cut into those rocks.

These studied volcanic rocks are grouped into felsic and mafic rocks, which present porphyritic texture. Rhyolites show alkali-feldspar and quartz phenocrysts, while basalts demonstrate plagioclase and unidentified mafic minerals (pyroxene) microphenocrysts. In addition, volcanic tuff with pyroclastic and eutaxitic textures are made up of volcanic glass, quartz, alkali-feldspar, and rock fragments. Petrographic data present plagioclase, alkali-feldspar, pyroxene, and volcanic glass were replaced by sericite, clay minerals, chlorite, and cryptocrystalline quartz, respectively.

According to immobile elements classification, volcanic rocks were classified as rhyodacite and alkali basalt. Rare earth elements (REEs) and trace elements suggest that rhyodacite were exploded from mildly calc - alkali magma, and alkali basalts were generated from alkaline magma. Na_2O , K_2O , FeO , CaO , and MgO are used to analyze altered minerals and alteration indices, suggesting that rhyodacite with very high SI is related to sericitization, illitization, and silicification. On the otherhand, alkali basalt with highly moderate CCPI implicated with chlorite-carbonates-pyrite according to mineral alteration and weathering. In comparison, rhyodacite alteration maybe resulted from hydrothermal alteration, wethering, and metamorphose. Thus, the alteration of these volcanic rocks maybe related to Triassic granite intrusion and basalts dike as well as Mae Ping fault activities.

Acknowledgments

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