Preliminary study on petrography and geochemistry of alkaline granitic rocks in Tha Takiap, Thailand

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Abstract

The Tha Takiap area is a part of the Eastern Granitic Belt which is widely ranging in composition from gabbro to granite rock, and also located on the Sukhothai Arc. Nine representative diamond drill core samples of the alkaline granitic rock from the Tha Takiap area are collected for petrographic and geochemistry analysis. Based on the petrographic study, the alkaline granitic rocks composed mainly of K-feldspar with minor amounts of quartz and plagioclase that were classified as alkali feldspar syenite to alkali feldspar quartz syenite according to QAPF diagram. Geochemical data of major oxides indicate that the rocks from the study area are alkaline syenite and classified as metaluminous. Trace elements and REE indicate that the alkaline granitic rocks are A_2 subtype of A-type granite. The samples from the Tha Takiap area show the depletion of some large ion lithophile elements (LILE) (Ba, Sr and Eu) and Ti that may reflect fractionational processes of plagioclase and/or feldspar and titanomagnetite. Nearly flat REE patterns might refer to mantle-derived magmatic source more than arc-derived magmatic source. In the comparison of geochemical data, the Tha Takiap granitic rocks show the distinct trace element and REE patterns to the alkaline granitic rock of Eastern Granitic Belt in Malaysia Peninsular. In contrast, similar trace element and REE patterns of the Tha Takiap granitic rocks have been observed in Xiaolonghe A-type granite of the Tenchong-Lianghe tin belt, southwestern China, which is interpreted to have formed under back-arc extensional setting. Therefore, the Tha Takiap alkaline granitic rocks possibly formed by back-arc extension related, and it is indicated that magma responsible for the ophiolite along the Sa Kaeo Suture has close tectonic (back-arc extension) and temporal (Late Permian) link to the alkaline magma at the Tha Takiap area

Keywords: Alkaline granite, A-type granite, Tha Takiap, Thailand

1. Introduction

Granitic rocks in Thailand can be divided into three north-south trending belts namely, Eastern Granitic Belt, Central Granitic Belt, and Western Granitic Belt (Figure 1a; Cobbing et al. 1986; Nakapadungrat and Putthapiban, 1992; Cobbing, 2011). The Eastern Granitic Belt is mainly composed of I-type granites (Beckinsale et al., 1979; Cobbing, 2011; Ng et al., 2015a) of Carboniferous to Late Triassic ages (Ng et al. 2015b; Gardiner et al., 2016; Wang et al., 2016; Qian et al., 2017; Fanka et al., 2018). These granitic rocks are ranging in composition from gabbro to granite, associated with mineralization especially precious (Au-Ag) and base (Cu-Pb-Zn) metals mineralization (Nakapadungrat and Putthapiban, 1992; Charusiri et al., 2002; Khin Zaw et al., 2014). The Central Granitic Belt is dominated by S-type granite of Late Triassic ages (Beckinsale et al., 1979; Cobbing, 2011; Ng et al., 2015b; Gardiner et al. 2016). Main phases of this granitic belt commonly host Sn and W deposits (Cobbing et al. 1986; Nakapadungrat and Putthapiban, 1992; Charusiri et al., 2002). The Western Granitic Belt is composed of the youngest granites, mainly Cretaceous S- and I-type granites (Beckinsale et al., 1979;

Nakapadungrat and Putthapiban, 1992; Cobbing, 2011). The granites in earlier phases tend to associate with Sn and W mineralization, whereas the later ones are associated with Au mineralization (Cobbing et al., 1986; Nakapadungrat and Putthapiban, 1992; Charusiri et al., 2002)

Alkaline granitic rocks have been reported with limit exposure of small plutons in Thailand and Malaysia, and they are reported to occur in a few areas within the Central Granitic Belt in the Northern Thailand (Pitfield, 1988; Nakapadungrat and Putthapiban, 1992; Cobbing, 2011), and the Eastern Granitic Belt in the Eastern Malay Peninsula (Ng et al., 2015a, b). The alkaline plutonic rocks are unsuitable to be categorized on I- and S-type classification (Whalen et al., 1987; Eby, 1990; Bonin, 2007), but they are generally classified into A-type granite (Litvinovsky et al., 2002, 2015).

This study focuses on the alkaline granitic rocks in the Tha Takiap area, Chachoengsao Province in Eastern Thailand (Figure 1a). The rocks are petrographically and geochemically investigated to improve understandings and develop concepts of tectonic settings as alkaline magmatism typically forms in specific tectonic setting.

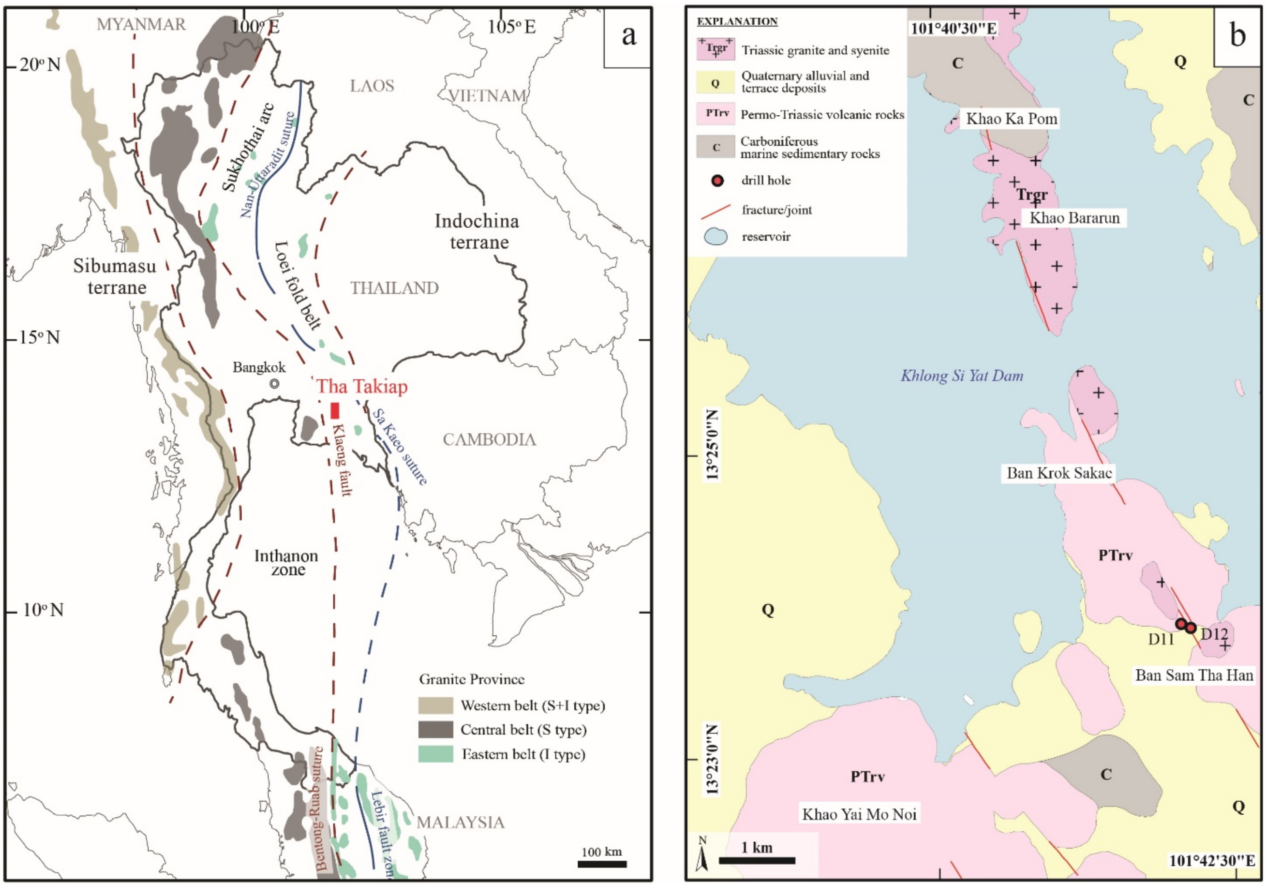

Figure 1. Geological setting of the study area. **(a)** Distribution of granite belts of Thailand and the neighboring Southeast Asia countries (Study area is shown in red square; granitic belt boundaries are shown in red dashed lines; and Nan-Uttaradit-Sa Kaeo suture is shown in blue line) (modified from Cobbing et al., 1992; Sone and Metcalfe, 2008; Metcalfe, 2011; Khin Zaw et al., 2014). **(b)** Geological map of Tha Takiap area (modified from Tiyapiract, 1996; Department of Mineral Resources, 2003. Note that all samples are collected from two drill holes (D11 and D12) shown in the map.

2. Geological Setting of Study Area

Tha Takiap study area is located on Sukhothai Arc (or zone), a Permo-Triassic arc system that is previously considered to have formed between the Sibumasu and the Indochina Terranes (Barr and Macdonald, 1991), and is currently identified to be a part of western margin of the Indochina Terrane (Sone and Metcalfe, 2008; Sone et al., 2012). The Sukhothai Arc is bounded by Inthanon zone to the west and Nan-Uttaradit-Sakaeo Suture which represents back-arc basin (Ueno and Hisada, 2001; Sone and Metcalfe, 2008; Hara et al., 2018) to the east, and widely intruded by granitic rocks of Eastern Granitic Belt (Figure 1a) and Permian-Triassic volcanic rocks.

Based on geological map of Tiyapiract (1996), the Tha Takiap area is made up of Carboniferous marine sedimentary rocks which were covered by Permian-Triassic volcanic rocks. The granitic rocks and syenite subsequently intruded into the Carboniferous sedimentary rocks along the NNW-SSE structure. Quaternary sediments partly cover these older rock units. Granite and syenite unit are exposed as small hills at Ban Sam Tha Han, Ban Krok Sakae, and along Khlong Si Yat Dam to Khao Bararun area (Figure 1b). The syenite sample from diamond drill holes near Ban Sam Tha Han (Figure 1b) of Tha Takiap area, yielded 260.8±2.6 Ma by LA-ICP-MS zircon U-Pb dating (Paipana, 2014).

3. Methodology

Alkaline granitic rock samples investigated in this study were collected from drill cores of two diamond drill holes (D11 and D12) in the Tha Takiap area (Figure 1b) which were provided by Department of Mineral Resources (DMR). Fresh or least-altered rock samples were collected for this study. Thin sections for petrographic study and powder samples for whole rock geochemistry were prepared at the Department of Geology, Chulalongkorn University. Petrographic study was performed using NIKON polarizing microscope.

All samples for whole rock geochemical analysis were firstly crushed using jaw crusher and pulverized using tungsten carbide ring mill at Department of Geology, Chulalongkorn University.

Nine samples were well prepared as fused beads at DMR for major oxides analysis by a PANalytical (Zetium) wavelength dispersive X-ray fluorescence spectrometer (WDXRF). The international reference materials namely SY-2, NIM-S, G-2, JG-1a, and JB-1a were also used for calibration. In addition, loss on ignition (LOI) was determined by heating powder samples at 1,100 °C for an hour and reweighting. Gravimetric Titrations Technique of Rice (1982) was used to determine ferrous oxide (Iron (II) oxide: FeO).

Moreover, four representative samples out of the nine samples were analyzed for trace element and rare earth element (REE) using Inductivity Coupled Plasma Mass Spectrometer (ICP-MS) by SGS Canada Inc. The REE and trace elements were determined by a Perkin Elmer Elan 6100 ICP-MS. The international reference materials namely SY-4 and RTS-3a, and internal standard solution of 50 ppb Re and 10 ppb Rh were used for calibration. Analytical data are presented in Table 1. The geochemical Data Toolkit (GCDkit) program of Janousek et al. (2006) was used for handling geochemical data and interpretations.

4. Field observation and petrography

The landform of the study area is an undulating plain that is mostly used for agricultural activities (Figure 2a). The granitic rocks occur commonly as small hills. Outcrops of the granitic rocks are mostly found at the foot of hills, and often found nearby outcrops of low-grade metamorphic rocks (slate to phyllite). Since the granitic rocks on outcrops are highly weathered, all samples used in this study are chosen from the diamond drill cores (Figure 2b). Total nine granitic rock samples are collected from the two diamond drill holes for further petrographic and geochemical studies.

Table 1. Whole rock major and trace element data of granitic rocks in Tha Takiap area.

Sample No.	D11-2	D11-4	D11-6	D11-19	D12-1	D12-9	D12-13	D12-15	D12-25
TAS classification	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite
Major element (wt%)									
SiO_2	58.28	60.82	60.82	59.89	60.01	62.28	61.23	62.16	60.59
TiO_2	0.63	0.56	0.73	0.67	0.69	0.56	0.58	0.59	0.63
Al_2O_3	16.52	15.88	17.62	16.14	16.32	16.00	16.58	16.37	16.42
$Fe_2O_3^{(total)}$	7.64	6.87	4.59	7.75	8.01	6.94	6.58	6.23	7.09
FeO	3.86	5.10	3.32	5.45	5.74	5.02	4.74	4.57	5.29
MnO	0.18	0.18	0.13	0.22	0.19	0.18	0.17	0.15	0.17
MgO	0.32	0.17	0.41	0.31	0.33	0.19	0.26	0.23	0.31
CaO	2.14	2.84	2.79	2.98	2.87	2.51	2.49	2.29	2.61
Na_2O	4.78	4.95	5.58	5.12	4.99	4.84	5.21	5.08	5.06
K_2O	5.81	5.52	5.67	5.32	5.51	5.68	5.75	5.79	5.56
P_2O_5	0.13	0.12	0.12	0.16	0.13	0.11	0.10	0.11	0.13
LOI	2.98	1.57	1.10	1.05	0.56	0.37	0.69	0.65	1.10
Sum	99.40	99.49	99.56	99.61	99.60	99.67	99.63	99.65	99.66
A/CNK	0.92	0.82	0.86	0.82	0.84	0.86	0.86	0.87	0.86
A/NK	1.17	1.12	1.15	1.14	1.15	1.13	1.12	1.12	1.15
Trace element (ppm)									
Sc	-	<5.00	-	9.00	-	<5.00	-	-	6.00
V	-	<5.00	-	25.0	-	<5.00	-	-	<5.00
Cr	-	<10.0	-	20.0	-	<10.0	-	-	<10.0
Co	-	1.20	-	1.60	-	<0.50	-	-	2.90
Ni	-	5.00	-	11.0	-	<5.00	-	-	8.00
Cu	-	42.0	-	17.0	-	230	-	-	34.0
Zn	-	33.0	-	53.0	-	21.0	-	-	26.0
Ga	-	67.0	-	62.0	-	18.0	-	-	48.0
Rb	-	522	-	574	-	90.9	-	-	1250
Sr	-	9.40	-	8.10	-	10.0	-	-	7.40
Y	-	82.4	-	87.5	-	395	-	-	273.0
Zr	-	60.2	-	646	-	22.1	-	-	379
Nb	-	40.0	-	75.0	-	5.00	-	-	46.0
Cs	-	101	-	153	-	16.5	-	-	89.9
Ba	-	5.80	-	25.2	-	3.80	-	-	22.5
Hf	-	4.00	-	23.0	-	<1.00	-	-	16.0
Ta	-	17.6	-	20.4	-	3.20	-	-	60.8
Tl	-	2.70	-	3.00	-	0.70	-	-	8.90
Pb	-	68.0	-	60.0	-	77.0	-	-	174
Bi	-	6.7	-	7.70	-	8.20	-	-	4.40
Th	-	42.5	-	144	-	9.8	-	-	24.9
U	-	7.50	-	32.1	-	12.6	-	-	17.6
Rare earth element (ppm)									
La	-	15.7	-	46.5	-	59.3	-	-	43.9
Ce	-	35.8	-	107	-	17.8	-	-	74.3
Pr	-	4.30	-	11.8	-	16.6	-	-	14.2
Nd	-	17.3	-	42.2	-	70.0	-	-	58.4
Sm	-	7.10	-	10.7	-	24.3	-	-	21.7
Eu	-	0.15	-	0.15	-	1.38	-	-	0.75
Gd	-	8.52	-	9.44	-	29.9	-	-	27.1
Tb	-	1.80	-	1.90	-	5.81	-	-	5.53
Dy	-	11.9	-	12.9	-	37.0	-	-	35.9
Ho	-	2.45	-	2.85	-	7.17	-	-	7.12
Er	-	7.39	-	8.56	-	21.8	-	-	22.2
Tm	-	1.25	-	1.48	-	3.87	-	-	4.01
Yb	-	8.60	-	10.0	-	30.0	-	-	30.3
Lu	-	1.31	-	1.61	-	4.65	-	-	4.63
Ce/Ce*	-	1.07	-	1.12	-	0.14	-	-	0.73
Eu/Eu*	-	0.06	-	0.05	-	0.16	-	-	0.09
$(La/Yb)_N$	-	1.31	-	3.34	-	1.42	-	-	1.04

Note: TAS=Total-alkali versus silica. $Fe_2O_3^{(total)}$ is total iron which were determined by XRF. FeO is ferrous oxide that were determined by gravimetric titrations technique. LOI, loss on ignition. A/CNK= molar ratio $Al_2O_3/(CaO+Na_2O+K_2O)$, A/NK= molar ratio $Al_2O_3/(Na_2O+K_2O)$, ΣREE= total REE content, LREE= La, Ce, Pr, Nd, Sm and Eu, HREE=Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu, $Ce/Ce^*=Ce_N/(La_N \times Pr_N)^{0.5}$, $Eu/Eu^*=Eu_N/(Sm_N \times Gd_N)^{0.5}$

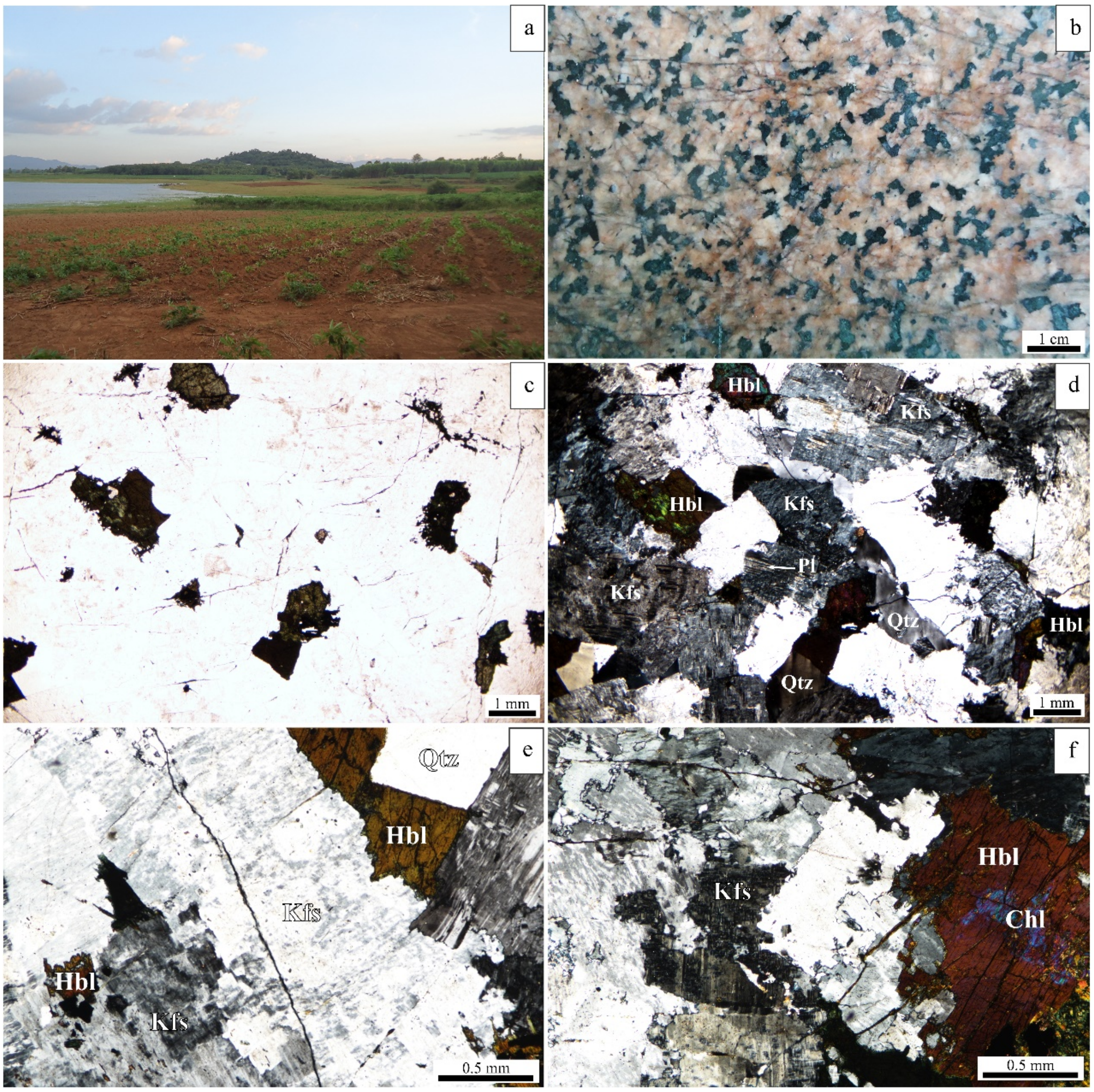

Figure 2. Field investigation and petrographic characteristics of Tha Takiap granitic rocks (now identified as syenite). **(a)** Undulating plain landform with small hill at Ban Sam Ta Han. **(b)** Photograph of diamond drill core of medium- to coarse-grained syenite. **(c)** and **(d)** Photomicrographs of syenite showing equigranular texture with K-feldspar with perthitic texture and grid twin, hornblende, quartz and plagioclase under plane polarized light **(c)** and cross polarized light **(d)**. **(e)** Photomicrograph of syenite, showing K-feldspar with perthitic texture and grid twin, quartz and hornblende (cross polarized light). **(f)** Photomicrograph of syenite, showing association of K-feldspar and hornblende which is partly replaced by chlorite (cross polarized light). Mineral abbreviations: Kfs (K-feldspar); Hbl (hornblende); Qtz (quartz); Pl (plagioclase); Chl (chlorite).

The granitic rocks of the Tha Takiap area have gray to brownish gray colored, medium- to coarse-grained (1.0-5.0 mm) and equigranular texture. These rocks are composed mainly of K-feldspar (65-85%) and hornblende (15-30%). Minor amounts of quartz (0-20%), plagioclase (less than 3%) (Figure 2c-d), and accessory apatite, zircon and opaque minerals (less than 1-1%) are also found. K-feldspar is ranging in size from 1.0 to 5.0 mm, subhedral to anhedral crystal and commonly shows perthitic texture and grid twin (Figure 2e). Hornblende has size ranging from 0.5 to 3.0 mm with subhedral to anhedral crystal and is partly replaced by chlorite (Figure 2f). Quartz commonly occurs as anhedral crystal and ranges in size from 0.2 to 1.5 mm. Euhedral to subhedral apatite is commonly found as inclusions in hornblende and alkaline feldspars.

Five rock slabs from the Tha Takiap area are stained (Figure 3). Images of stained rock slabs are analyzed using Image Pro software (Figure 4). Modal analysis data are plotted on QAPF diagram for plutonic rock following the discrimination of Streckeisen (1976) (Figure 5) to determine a compositional range of granitic rocks from the study area. The granitic rocks of the Tha Takiap area are composed of alkaline feldspar syenite which is absent in quartz to alkaline feldspar quartz syenite.

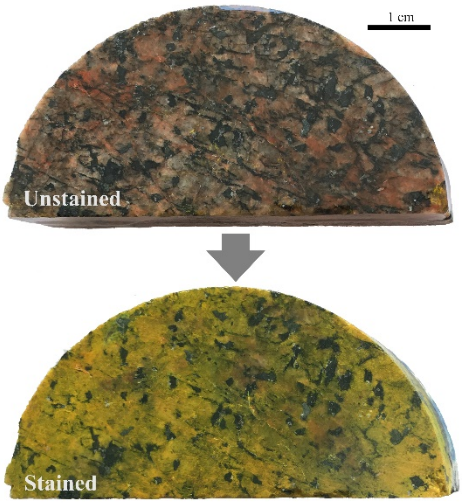

Figure 3. Photograph of unstained and stained rock slabs.

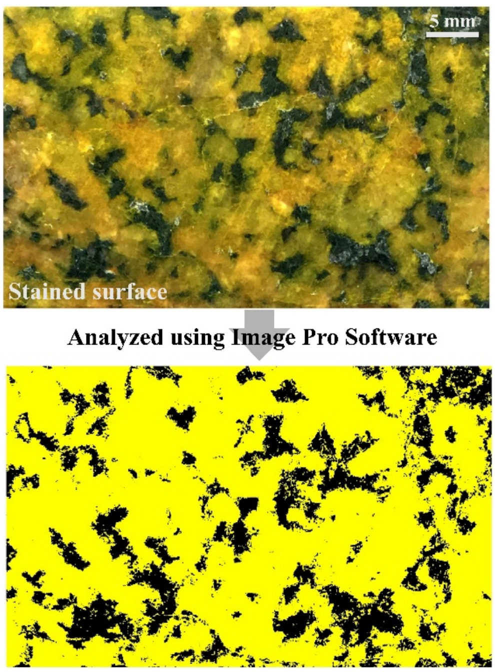

Figure 4. Photograph of stained surface which was analyzed using Image Pro software.

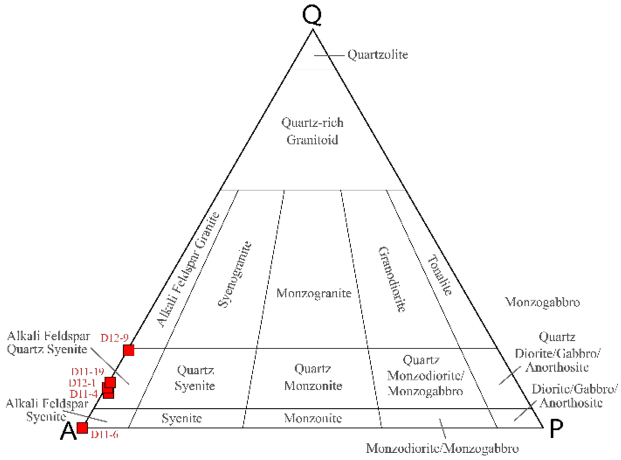

Figure 5. Modal QAPF diagram (Streckeisen, 1976) with plots of the granitic rocks from the Tha Takiap area (Q=quartz; A=K-feldspar; P=plagioclase).

5. Geochemistry

Based on major oxides data, SiO_2 contents of the granitic rocks from the Tha Takiap area have a narrow range from 58.28-62.28 wt.%. On the basis of their total-alkali (Na_2O+K_2O) versus silica (TAS) diagram by Cox et al. (1979) (Figure 6a), all of the rocks are classified as alkaline and fallen within syenite field. Based on the total molar alkali versus alumina content (A/NK (Al_2O_3/(Na_2O+K_2O) versus A/CNK (Al_2O_3/(CaO + Na_2O + K_2O)) diagram by (Shand, 1943) (Figure 6b), most of the granitic rocks are classified as metaluminous and are plotted in I-type granite field based on Alumina Saturation Index (ASI) (Chappell and White, 1974).

Plots of high field strength elements (HFSE), such as Ga, Zr, Nb, Ce, and Y (Whalen et al., 1987) (Figure 7a-d) show that granitic rocks of the Tha Takiap are A-type granite affinities. Moreover, ternary plots of A-type granite discrimination after Eby (1992) (Figure 8a-b) suggest that granitic rocks of Tha Takiap are classified as A_2 subtype.

The primitive mantle normalized and chondrite-normalized (Sun and McDonough, 1989) trace elements and REE spider diagrams are presented in Figure 9a-b. Samples from the Tha Takiap area show the depletion of some large ion lithophile elements LILE (Ba, Sr and Eu) and Ti, and the enrichment of Cs, Th, U, Ta, and Pb (Figure 9a).

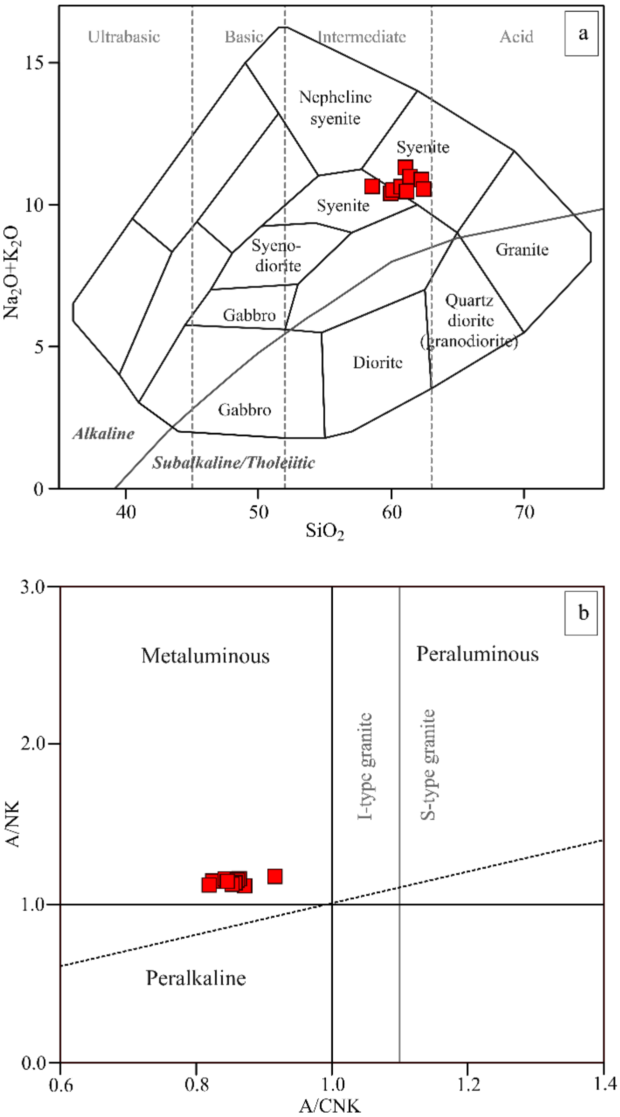

Figure 6. (a) Total-alkali versus silica (TAS) diagram of plutonic rock after Cox et al. (1979) and modified by Wilson (1989) for plutonic rocks showing rocks ranged in composition from syenite to granite within the field of alkaline, and differentiation trends. **(b)** A/NK versus A/CNK diagram (after Shand, 1943) and I- and S-type granite classification boundary based on alumina saturation index (ASI) (gray line) (after Chappell and White, 1974).

The granitic rock samples of the Tha Takiap area exhibit nearly flat REE patterns with $(La/Yb)_N$ ratios ranging of 1.04-3.34 with prominent negative Eu anomalies (Eu/Eu*=0.05-0.16) in all of the patterns and weak negative or positive Ce anomalies (Ce/Ce*=0.73-1.12 (one exception having Ce/Ce*=0.14)) (Figure 9b).

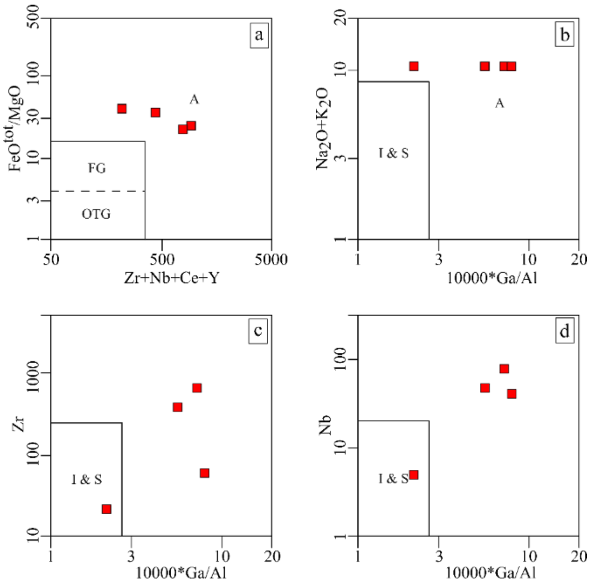

Figure 7. Bivariate plots after Whalen et al. (1987) of the granitic rocks from the Tha Takiap area showing the enrichment of HFSEs indicate that the granitic rocks are A-type granite affinities; **(a)** FeO^{tot}/MgO versus Zr+Nb+Ce+Y; **(b)** Na_2O+K_2O versus 10000*Ga/Al; **(c)** Zr versus 10000*Ga/Al; **(d)** Nb versus 10000*Ga/Al. (FG = field for fractionated felsic granites; OGT = field for unfractionated A-, I- and S-type granites; I=I-type; S=S-type; A=A-type)

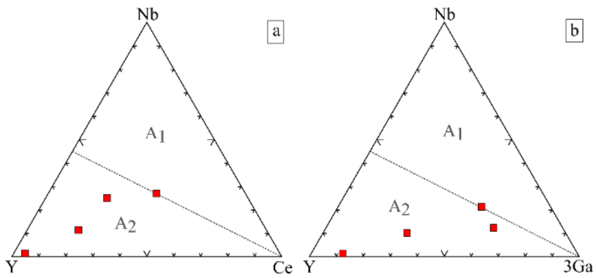

Figure 8. Ternary plots of A-type granite discrimination after Eby (1992) of the Tha Takiap granitic rocks showing all of the samples are plotted within A_2 field. **(a)** Y-Nb-Ce plot and **(b)** Y-Nb-3*Ga plot

6. Discussion

According to composition of continental crust of Rudnick and Gao (2003), flat chondrite-normalized REE patterns of the Tha Takiap granitic rocks (Figure 9b) indicate that source of the magma could not be mainly originated by Upper and Middle crusts. Also, it could not be directly originated by partial melting of mantle-derived magma due to high concentration of SiO_2 and low concentration of MgO (Jiang et al., 2017). The primitive mantle normalized spider diagrams of the Tha Takiap granitic rocks (Figure 9a) show the positive anomalies of U and Pb that reflect involvement of continental crust or island arc basalt derived material into magma (Niu and O'Hara 2009). On the other hand, the positive anomalies of Ta that reflect upper oceanic crust (Hofmann, 1988; Niu and O'Hara, 2009; Guo et al., 2015) are also involved in source magma. In combination with ternary plots of A-type granite discrimination after Eby (1992) (Figure 8a-b), the Tha Takiap granitic rocks are classified as A_2 subtype that might be generated by continental crust or underplate crust derived magmas after continent-continent collision or island arc magmatism (Eby, 1992). Negative anomalies of Ba, Sr and Eu possibly indicate that the magma is residual melt from plagioclase-rich magma and negative anomalies of Ti might be related to titanomagnetite fractionation process (Wilson, 2007; Niu and O'Hara, 2009; Gill, 2010). Weak positive and negative anomalies of Ce in the REE patterns are suggested to be an effect by mobilization of Ce^{3+} and Ce^{4+} that depend on oxidization condition (McLennan and Taylor, 2012).

Ng et al. (2015a, b) reported the data of the alkaline granitic rock (syenite) of the Eastern Granitic belt from Malaysia Peninsular, yielded 284±2 Ma of zircon U-Pb age which shows the distinct trace element and REE spider patterns to the alkaline granitic rock of Tha Takiap area (Figure 9a-b). The alkaline granitic rock (syenite) of Ng et al. (2015a) clearly exhibits depletion of Nb and Ta in the primitive mantle normalized spider diagrams (Figure 9a) that reflects continental crust or island arc basalts (Niu and O'Hara, 2009). In addition, more steep slope of REE pattern (Figure 9b) may reflect more influence of continental crust in the source rock (Rudnick and Gao, 2005) than the Tha Takiap granitic rocks. Significantly, the comparison of geochemical data from the both areas indicates that the magma origins of A-type granites in Eastern Granitic belt are locally different. Moreover, similar trace element and REE patterns of the Tha Takiap granitic rocks have been observed in Xiaolonghe granite of the Tenchong-Lianghe tin belt, southwestern China (Figure 9a-b) which is A-type granite and formed by extensional regime after microplate collision or back-arc extension related (Chen et al., 2015).

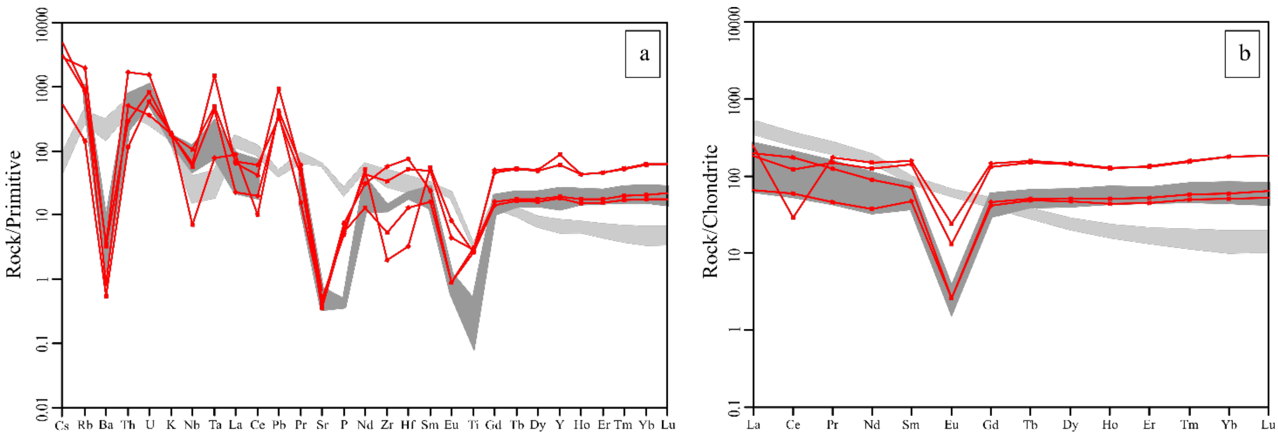

Figure 9. Spider diagrams of the granitic rocks in the study area plotted using normalized values of Sun and McDonough (1989). **(a)** Primitive mantle-normalized spider diagrams and **(b)** chondrite-normalized REE patterns of the Tha Takiap granitic rocks. Dark gray shade patterns are data of Xiaolonghe A-type granite which was formed under extensional regime after microplate collision or back arc extension from Chen et al. (2015), and light gray shade patterns are data of alkaline granitic rock (syenite) of Eastern Granitic Belt from Malaysia Peninsular from Ng et al. (2015a).

The above comparisons indicate that the Tha Takiap syenite was formed under back-arc extensional environment, and the age of the syenite is confined to Late Permian (ca. 260 Ma; Paipana, 2014). Such tectonic environment and timing can be compared to geological context in the region. Hara et al. (2020) found that ultramafic rocks of the ophiolite suite at Pailin in West Cambodia, which is SE extension of Sa Kaeo Suture, had formed at back-arc extensional setting during 285-270 Ma. Although age of the syenite at Tha Takiap is 10 Ma younger than the ophiolites, two areas share similar tectonic environment (i.e., back-arc extensional setting). This may indicate that alkaline magma responsible for the syenite in the Tha Takiap area had genetic link to the magma formed the ophiolite along the Sa Kaeo Suture. In addition, it is manifested that arc-related magmatism of the Sukhothai Arc was active during 250-200 Ma (e.g., Srichan et al., 2009), suggesting that the Tha Takiap syenite proceeds the beginning of the arc magmatism of the Sukhothai Arc by 10 Ma.

7. Conclusion

1. Based on the petrographic and geochemical results, the granitic rocks in the Tha Takiap area were classified as syenitic rocks.

2. The syenite of the Tha Takiap area could be assigned as A-type granite using I-, S- and A-type classification scheme of Whalen et al. (1987), and the syenite is further subdivided into A_2 subtype in classification diagrams of Eby (1992).

3. Flat REE pattern of the Tha Takiap granitic rocks reflect possibility of mantle-derived magmatic source rather than arc-derived magmatic source, however, some positive anomalies of trace elements (i.e., Ta) may indicate minor involvement of continental crust into the source magma.

4. Similar trace element and REE patterns of the A-type Xiaolonghe granites and Tha Takiap granitic rocks suggest that the most suitable tectonic setting for the formation of the Tha Takiap granitic rocks is back-arc extensional tectonic setting.

5. The alkaline magma responsible for the Tha Takiap syenite was formed in similar tectonic setting of the Sa Kaeo Suture (i.e., back-arc extension) and similar magma source (i.e., mantle-derived magma). Timing of the alkaline magmatism at Tha Takiap (ca. 260 Ma) can be placed between the formation of ophiolites of Sa Kaeo Suture (285-270 Ma) and main period of the arc-related magmatism of the Sukhothai Arc (250-200 Ma).

Acknowledgements

Sample and research fund were support by Department of Mineral Resources, Thailand. We also would like to thank Mineral Resources Analysis and Identification Division, DMR for XRF whole-rock analysis.

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