MAGNETIC SUSCEPTIBILITY AND GEOCHEMISTRY OF GRANITIC ROCKS IN CAMBODIA

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Abstract

Granitic rocks in Cambodia are divided into two groups, i.e. ilmenite-series in southern Cambodia and magnetite-series in northern Cambodia. Both groups belong to high-K calc-alkaline series, metaluminous to slightly peraluminous and display typical features of I-type granitic rocks. The ilmenite-series granitic rocks are characterized by high SiO_2 contents (70-75 wt. %) with abundance of quartz and K-feldspar, enrichment of LILEs, and strong negative anomalies of Ba, Sr, Eu (Eu/Eu*=0.1-0.5), Nb, and Ti. Chondrite-normalized REE patterns exhibit enrichment of LREE ($[La/Yb]_N$=1.4-17.6) with flat HREE patterns and flat to concave-upward MREE patterns. These granitic rocks have high $CaO+FeO+MgO+TiO_2$ and intermediate $Al_2O_3/(FeO+ MgO+TiO_2)$ with intermediate magnesium number (Mg# = 22-38) (Mg# = 100 x MgO/[MgO+Total FeO]). Geochemical features of the granitic rocks suggest partial melting of crustal igneous rocks of intermediate composition where plagioclase was a major fractionating and/or residual phase. On the other hand, the magnetite-series granitic rocks show wide range of SiO_2 contents (59-70 wt. %), higher TiO_2, Al_2O_3, CaO, and MgO contents than ilmenite-series granitic rocks, and small-negligible negative anomalies of Sr and Eu. The high $CaO+FeO+MgO+TiO_2$ and low $Al_2O_3/(FeO+ MgO+TiO_2)$ coupled with high Mg# (32-48) suggest partial melting of amphibolite-type source with presence of plagioclase. The granites of Cambodia were formed in subduction-related tectonic setting. The ilmenite-series granites range from volcanic-arc granites to syn- and post-collision granites while the magnetite-series granitic rocks belong to volcanic arc granites.

Keywords: Cambodia, Geochemistry, Granitic rocks, Magnetic susceptibility

Introduction

Cambodia is located in the southernmost Indochina craton. The granitic magmatism in this region is mainly controlled by tectonism, namely Indosinian orogeny (e.g. [1], [2], [3]). Granitic intrusions in Cambodia (Paleozoic to Cretaceous), in particular, have been related to the sequence of suturing and collision between the allochthonous fragments from Gondwanaland (e.g. [1], [2]). However, magnetic susceptibility and geochemical characteristics of these granitic rocks as well as origin of the granitic rocks and tectonic setting during emplacement of the granitic rocks were not studied yet. This is the first study that focuses on the systematic correlation between the magnetic susceptibility (ilmenite- and magnetite-series granitic rocks) and geochemical characteristics of the granitic rocks. The potential sources of the granitic rocks and tectonic setting during emplacement of the granitic rocks are also discussed.

Geological Background

Cambodia was tectonically located in the interval between two microplate collisions during Indosinian period [4]. Within the Indochina platform the following successive pre-Jurassic tectonic units are recognized: a core of pre-Devonian metamorphic rocks, partially surrounding Hercynian (Carboniferous) fold-belts, and an outer margin of Indosinian (late Permian-early Jurassic) fold belts [1].

During the Indosinian, the Indochina was rifted and drifted from eastern Gondwana in Devonian, and then connected, fused and collided with South China terrane in Carboniferous to form a super-terrane named Cathaysia (e.g. [3]). In Permian, another continental splinter, Sibumasu, separated and drifted northward from eastern Gondwana to subduct beneath Cathaysia opening back-arc basin at the western margin of Indochina and developing Sukhothai and Chanthaburi island arc [5]. The back-arc basin then was closed to form the Jinghong, Nan–Uttaradit and Sra Kaeo sutures [6] prior to the collision of Sibumasu and Cathaysia in late Permian-early Triassic (e.g. [1]). Three episodes of the Indosinian orogeny in the northern Thailand and Laos were reported by [7], i.e. phase I (Permian), phase II (late Triassic), and phase III (Jurassic). This gave rise to granitic intrusions and faulting and folding in the region including Cambodia (Figure 1)[2].

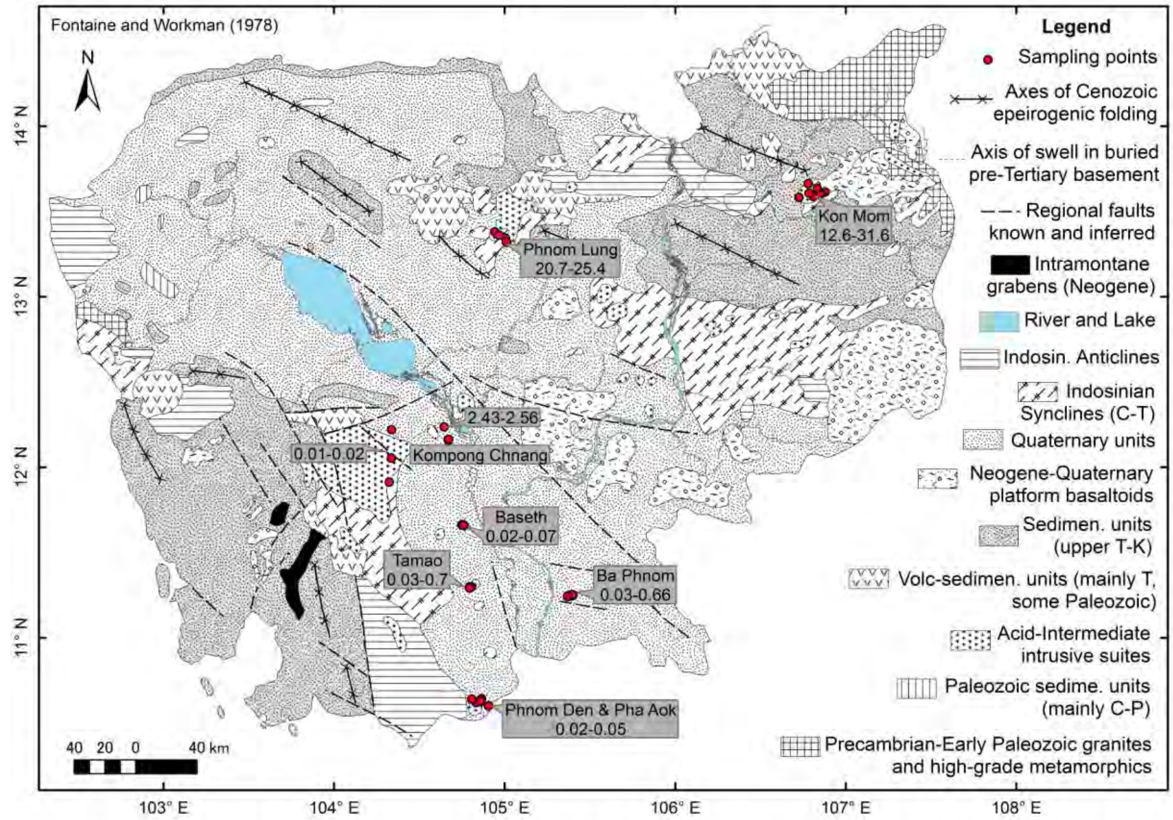


Figure 1. Geologic map of Cambodia [2] showing location of samples and their magnetic susceptibility (x 10^{-3} SI unit).

After the Indosinian, the Indochina platform remained essentially rigid, although affected by warping, block faulting, tear faulting and volcanism, while younger orogenic fold belts (Himalayan-Pacific) were formed in zones of crustal deformation all around its margin [1].

Samples and Analytical Methods

Fifty-one granitic rocks were collected from seven localities such as Phnom Den (including Pha Aok), Ba Phnom, Tamao, Baseth, Kompong Chnang, Phnom Lung (Rovieng), Kon Mom (Figure 1).

Magnetic susceptibility was measured in situ using a magnetic susceptibility-meter, KAPPAMETER model KT-6. The concentration of major and some trace elements of the collected samples were analyzed by ZSX Rigaku Primus II X-ray fluorescence spectrometer (XRF) at East Asia Environment Center of Kyushu University (target: Cr, voltage: 50 kv, current: 50 mA, mask: Cu for major elements and Al for minor elements). The result is calibrated using standard andesite of the Geological Survey of Japan (JA and JB). We ordered the measurement to ALS Minerals laboratory, Canada for bulk-rock analysis for trace elements including rare earth elements (REE) using an inductively coupled plasma mass spectrometer (ICP-MS). The rock powder for ICP-MS analysis was partially extracted by aqua regia digestion.

Petrography and Magnetic Susceptibility

There are geographically two clusters of granitic rocks in Cambodia (Figure 1). The granitic rocks in the Southern Cambodia occur as stocks, except those at Kompong Chnang which are considered as part of the Kchol massif, in the Tonle Sap-Mekong plain of Quaternary deposits. There are five localities of granitic outcrops in this group such as Phnom Den, Ba Phnom, Tamao, Baseth, and Kompong Chnang. On the other hand, other group of granitic rocks occurs at Kon Mom (Rattanakiri) and Phnom Lung (Rovieng, Preah Vihear) which belongs to volcano-sedimentary fold-belt and red terrane (weathered basaltoids) plateau respectively [2]. The granitic rocks at Phnom Den and Baseth are dated as Upper Cretaceous and Lower Jurassic respectively, while there is no actual age data from other granitic rocks in this study area [2].

The Phnom Den granite consists of quartz (up to 2.2 mm), K-feldspar (up to 1.6mm), plagioclase (up to 2mm), brown biotite, ± muscovite. It is medium-grained and porphyritic in texture with quartz, K-feldspar, and plagioclase as phenocrysts. Biotite occurs as reddish to dark brown flake (Figure 2A). Minor phases are apatite, zircon, and opaques.

A neighbor stock of porphyritic granite at Pha Aok generally contains quartz (up to 4.4 mm), K-feldspar (up to 4.6 mm), polysynthetically twinned plagioclase (up to 2 mm long), and reddish biotite as major phases. Accessory minerals include muscovite, zircon, apatite, and opaques. Metamict texture of zircon in biotite is common. Magnetic susceptibilities in these areas are similar and range from 0.02 to 0.05 x 10^{-3} SI unit.

The grey colored granite at Ba Phnom consists of quartz (up to 2.4 mm), K-feldspar (up to 2.5 mm), polysynthetically twinned plagioclase (up to 2.5 mm long), greenish brown to brown hornblende (up to 2mm long), and less biotite (Figure 2B1). Perthite is generally present. Chlorite is present as a partial alteration product of biotite and hornblende. Zircon is a common accessory mineral in addition to apatite, and opaques. Magnetic susceptibilities vary from 0.03 to 0.66 x 10^{-3} SI unit. The rock is associated with enclaves (Figure 4a). An enclave of basaltic trachyandesite in composition has plagioclase, orthoclase, hornblende, and biotite as major phases (Figure 4B2-3). Minor phases include tiny apatite, zircon, and opaques.

Another low magnetic susceptibility granite, i.e. 0.03-0.7 x 10^{-3} SI unit, is exposed in a zoo namely Phnom Tamao. It is porphyritic in texture consisting mainly of K-feldspar (up to 4.3 mm), quartz (up to 3 mm), polysynthetically twinned plagioclase (up 2.4 mm), and yellowish green to brown biotite flakes (Figure 2C). Accessory minerals include orthopyroxene, apatite, zircon, and opaques. Metamict and granophyric texture, myrmekite, and perthite were also observed.

The stock of Baseth consists of medium-grained two-mica granite. It consists of quartz (up to 1 mm), K-feldspar (orthoclase, microcline, and microperthite), polysynthetically twinned plagioclase (up to 1.5 mm), and brown biotite (Figure 2D). Minor phases include muscovite, apatite, zircon, and opaques. Chlorite and epidote are occasionally present. The magnetic susceptibilities are very low ranging from 0.02 to 0.07 x 10^{-3} SI unit.

The pink colored granite at Kompong Chnang consists of quartz (up 2.6 mm), K-feldspar (up to 3 mm), polysynthetically twinned plagioclase (up to 2 mm), yellowish brown to brown biotite (Figure 2E1). Minor phases include zircon, apatite, and opaques. Chlorite occurs as alteration product of biotite. Besides, metamict texture is common. In addition, two ranges of magnetic susceptibility were noticed, i.e. 0.01 x 10^{-3}-0.02 x 10^{-3} and 2.43 x 10^{-3}-2.56 x 10^{-3} SI unit. The rocks are commonly intruded by andesite dikes (Figure 4a) of relatively-high magnetic susceptibility (3.09 x 10^{-3}-3.77 x 10^{-3} SI unit). The dikes show porphyritic texture with plagioclase, biotite, hornblende, quartz as phenocrysts (Figure. 4E2). Groundmass is usually plagioclase. Minor phases are apatite and zircon.

Magnetite-series granitic rocks are found at Phnom Lung and Kon Mom in the northern part of the country (>3 x 10^{-3} SI unit [8]). The Phnom Lung granodiorite consists of polysynthetically twinned to zoning plagioclase (up to 2 mm), quartz (up to 1 mm), K-feldspar (commonly as groundmass), green to brown biotite, and hornblende (Figure 2F1). Apatite, zircon, and opaques occur as minor phases. Chlorite, occurred as partial alteration of biotite, was sometimes observed. The magnetic susceptibilities range from 20.7 x 10^{-3} to 25.4 x 10^{-3} SI unit. The rock is usually associated with enclaves. An enclave of basaltic trachyandesite in composition shows equigranular texture with plagioclase and hornblende as major phases while quartz and K-feldspar are the minor phases (Figure 2F2).

The magnetite-series monzonite and quartz monzonite of Kon Mom, whose magnetic susceptibilities range from 12.6 x 10^{-3}-31.6 x 10^{-3} SI unit, mainly consist of polysynthetically twinned to zoning plagioclase (up to 2.1 mm), K-feldspar and quartz commonly as groundmass, hornblende, and biotite (Figure 2G1-2). Accessory minerals are apatite, zircon, and opaques. Myrmekitic texture is common while metamict is rare. The granitic rocks is associated with enclaves. An enclave of trachybasalt in composition shows porphyritic texture with hornblende, biotite, and plagioclase as phenocrysts (Figure 2G3). Groundmass consists of plagioclase, biotite, and quartz. Besides, the rock is sometimes intruded by ryolite dikes with magnetic susceptibility of 10.1 x 10^{-3}-12.5 x 10^{-3} SI unit. The dikes exhibit porphyritic texture with plagioclase (up to 1 mm wide), hornblende, biotite, and quartz as phenocrysts (Figure 2G4-5). Plagioclase, quartz, and biotite also occur as groundmass.

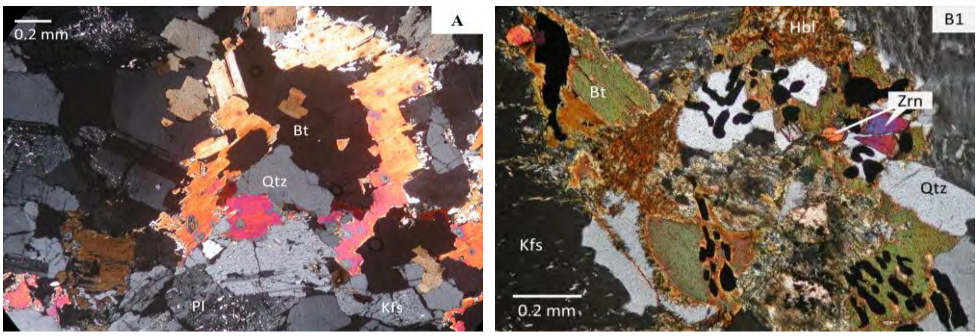
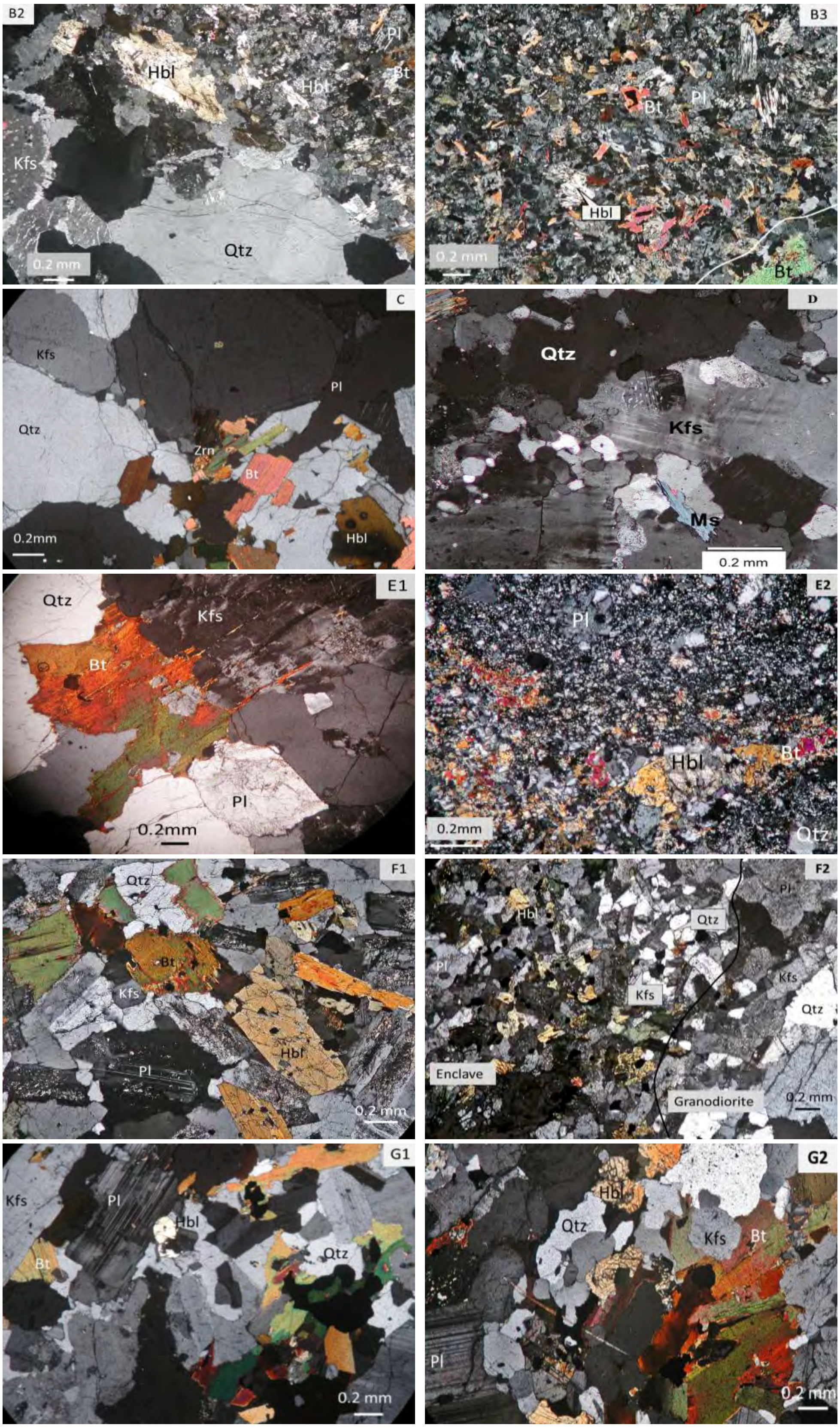


Figure 2. Representative petrography of the granitic rocks of Cambodia (in crossed polar). Qtz: quartz, Kfs: K-feldspar, pl: plagioclase, Bt: biotite, Hbl: hornblende, Ms: muscovite, Zrn: ziron; Ap: apatite.



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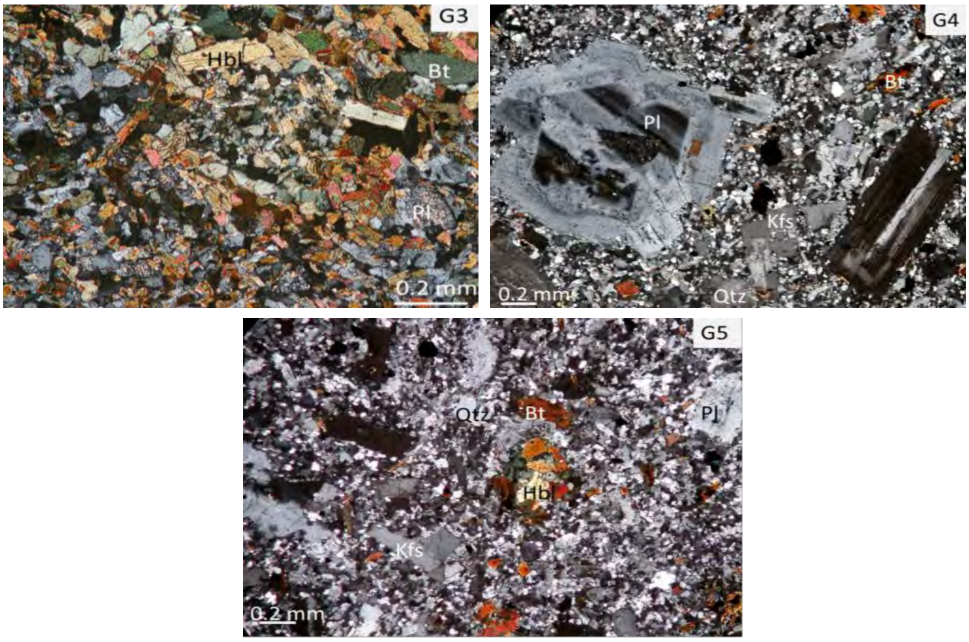

Figure 2. (Continued).

Geochemical Characteristics

Major and trace element concentrations of the analyzed samples are presented in Table 1. The granitic rocks of Cambodia range from granodiorites to granites with some monzonites and quartz monzonites from the northern part (Figure 3a). The A/CNK vs. A/NK diagram [9] defines the rocks as metaluminous to slightly peraluminous, and as of I-type affinity (Figure 3b). The K_2O vs. SiO_2 plot shows the variation between medium-K and shoshonite calc-alkaline affiliation [10] (Figure 4).

The Baseth granite has high SiO_2 and low MgO contents, and moderate-high concentrations of high-field strength elements (HFSEs) such as Nb, Ta, Zr, and Hf. For example, Nb content is generally higher than the average content of I-type (14 ppm) and felsic I-type (21 ppm) granites in the Lachlan Belt of southeastern Australia [13&14]. Nb content is up to 31.3 ppm which is similar to highly fractionated I-type granites in southern Vietnam (up to 40 ppm) (e.g. [15]). In the variation diagram, we observed some negative trends of TiO_2, FeO, MgO, P_2O_5, Ba, and Sr contents while other oxides and element almost remain constant (Figure 4). Primitive mantle-normalized spidergrams show strong enrichment in large ion lithophile elements (LILEs) (e.g. Cs, Rb, Th, U, K) and distinct negative anomalies of Nb, Ti, Ba, and Sr (Figure 5). Chondrite-normalized REE diagrams exhibit the fractionation between the light and heavy REEs with variation of ($[La/Yb]_N$=1.4-8.2, values of La&Yb are normalized to chondrite [16]) coupled with strong negative Eu anomalies (Eu/Eu*=0.1-0.4, Eu anomaly=Eu_N/ sqrt[Sm_N*Gd_N], values of Eu, Sm, and Gd are normalized to chondrite [16]) (Figure 6). Noteworthy is the depletion of middle REEs (MREEs) relative to heavy REEs (HREEs).

The major oxides concentrations of the Ba Phnom granite are characterized by high SiO_2, Na_2O, K_2O, and low MgO contents. TiO_2, CaO, FeO, MgO, P_2O_5, Ba, Sr, and Zr contents decrease as SiO_2 contents increase while others are scattered. Nb and Ta contents are very low while Zr and Hf contents are relatively high. Nb content is generally below 14 ppm. LILEs enrichment and negative anomalies of Ba, Nb, Sr, and Ti are observed in the spidergram (Figure 5). Chondrite-normalized REE patterns (Figure 6) are characterized by moderate light REEs (LREEs) enrichment with $(La/Yb)_N$ ranging from 5.4 to 8, flat MREEs and HREEs patterns, and strong negative Eu anomalies (Eu/Eu*=0.2-0.3).

An enclave of basaltic trachyandesite in composition has similar trace elements behavior but smaller negative anomalies of Sr, Ti, and Eu.

The granite of Phnom Den has high SiO_2 (73-74 wt. %), Na_2O, K_2O contents but low MgO and CaO contents. Al_2O_3, MgO, P_2O_5, Rb contents slightly decrease as SiO_2 contents increase while others are scattered. Primitive mantle-normalized spidergrams show the enrichment of LILEs and depletion of HSFEs. Nb content ranges from 12 to13 ppm with Nb/Ti varying from 0.022 to 0.025. REE patterns (Figure 6) are characterized by high enrichment of LREE ($[La/Yb]_N$=10-17) and moderate Eu anomalies (Eu/Eu*=0.3-0.4). The neighbor stock at Pha Aok has slightly lower SiO_2 content with similar contents of other major elements. HFSE (Nb, Ta, Zr, and Hf) contents are relatively higher, e.g. Nb is up to 21 ppm. Trace elements patterns in the spidergram are similar but Pha Aok granite has relatively higher content of trace elements. However, enrichment of LREE is smaller with $(La/Yb)_N$ of 3.3-3.4 while strong Eu anomalies are observed (Eu/Eu*=0.1).

The pink Kompong Chnang granite is characterized by high SiO_2 (72-73 wt. %), K_2O, Na_2O contents but low MgO content. However, they are scattered in the variation diagram. Trace elements behaviors are characterized by enrichment of LILEs and depletion of HFSEs coupled with moderate-high negative anomalies of Ba, Sr, Nb, and Ti (Figure 5). Enrichment of LREE is obviously observed ($[La/Yb]_N$ =6.9-10.8). This granite exhibits flat HREE patterns and moderate negative Eu anomalies (Eu/Eu*=0.3-0.5) (Figure 6).

The SiO_2 content of the Tamao granite is high with slightly higher TiO_2, MgO, and CaO contents in average than those of ilmenite-series granitic rocks in this study. In the spidergram, negative spikes of Ba, Sr, Nb, and Ti are observed coupled with enrichment of LILEs (Figure 5). Nb content ranges from 26-31 ppm and is higher than the average I-type and felsic I-type granitic rocks in the Lachlan Belt of southeastern Australia [14, 15]. The Tamao granite exhibits moderately fractionated REE patterns ($[La/Yb]_N$=5.9-9.8), flat HREE patterns, and strong Eu anomalies (Eu/Eu*=0.1-0.2) (Figure 6).

The Phnom Lung granodiorite is represented by intermediate SiO_2 (63.1-69.9 wt. %) and K_2O (1.8-2.3 wt. %) contents, and high MgO, CaO, Na_2O, FeO, Al_2O_3, FeO, and P_2O_5 contents. Spidergram exhibits gentle slope of LILEs, small negative anomalies of Nb, P and Ti, and small positive spike of Sr (Figure 5). The Phnom Lung rocks are characterized by slight LREE enrichment ($[La/Yb]_N$=3-7.5), small Eu negative anomalies (Eu/Eu*=0.9), and slight depletion of MREEs relative to HREEs (Figure 6). A basaltic-trachyandesitic enclave share similar trace elements behaviors but richer in HREEs and it has stronger negative Eu anomaly (Eu/Eu*=0.7).

The magnetite-series granitic rocks of Kon Mom exhibit wide range of intermediate SiO_2 contents (57-67.5 wt. %), and enrichment in other major oxides compared to ilmenite-series granites. TiO_2, FeO, MgO, and CaO contents show negative trend against SiO_2 while others are scattered (Figure 4). Nb content (up to 48.5 ppm) is generally higher than ilmenite-series-granites. Spidergram shows enrichment of LILEs and depletion of HFSEs coupled with negative anomaly of Ba and small negative spikes of Nb, P, and Ti (Figure 5). REE geochemistry from these granitic rocks is represented by the strong fractionation between LREE and HREE ($[La/Yb]_N$=9.3-15.1), small Eu anomalies (Eu/Eu*=0.1 in average), and slight depletion of MREEs relative to HREEs (Figure 6). The rhyolitic dikes and an trachybasaltic enclave share similar trace elements behaviors in the spidergram and REE plots. However, the dikes have relatively stronger Eu anomalies than the enclave and the granitic rocks of Kon Mom.

Table 1. Major and Trace Elements of the Granitic Rocks of Cambodia

Sample	BG1	BG2	BG3	BG4	BG5	BG6	BG7	BG8	BG9	BP1	BP2	BP3	BP4	BP5
SiO_2	75.6	72.7	73.6	74.6	71.6	75.4	73.6	74.3	73.8	75.2	73.4	74.5	74.4	73.8
TiO_2	0.1	0.2	0.2	0.1	0.4	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.2	0.1
Al_2O_3	12.5	12.8	12.8	13.5	13.3	13.3	13.3	13.2	14.4	11.9	12.5	12.5	12.5	13.1
FeO	1.4	2.3	2.0	1.3	3.4	1.2	1.9	1.6	1.2	1.5	2.2	1.5	1.9	1.8
MnO	0.03	0.10	0.04	BDL	0.11	BDL	0.02	0.02	BDL	BDL	0.003	0.003	BDL	BDL
MgO	0.7	0.9	0.8	0.8	1.6	0.7	0.9	0.7	0.6	0.5	0.7	0.6	0.6	0.6
CaO	1.0	1.1	1.4	1.6	1.8	1.0	1.2	1.0	0.6	0.9	1.3	0.9	1.1	0.8
Na_2O	3.5	2.8	3.5	4.6	3.9	3.6	3.3	3.5	3.2	4.0	3.7	4.0	3.7	3.8
K_2O	4.6	6.2	4.7	2.6	2.8	4.0	4.7	4.8	4.8	4.7	5.2	5.1	4.8	5.1
P_2O_5	0.03	0.13	0.07	0.06	0.16	0.03	0.08	0.04	0.01	BDL	0.03	BDL	0.02	BDL
LOI	0.5	0.5	0.7	0.7	0.8	0.5	0.5	0.5	1.0	0.9	0.4	0.7	0.4	0.6
Total	99.9	99.8	99.8	99.9	99.8	99.8	99.8	99.8	99.8	99.8	99.7	99.8	99.7	99.8
ASI	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.3	0.9	0.9	0.9	0.9	1.0
Ba	29.0	172.5	90.5	47.3	132.0	69.7	97.6	66.9	51.8	109.5	430.0	148.5	384.0	226.0
Ce	27.5	55.2	50.1	24.6	40.1	37.6	35.2	39.0	35.6	78.5	96.9	97.5	109.5	118.0
Co	2.6	3.7	3.7	1.8	6.8	1.7	4.0	1.9	1.0	0.9	2.1	0.8	1.9	1.1
Cr	130	80	90	40	60	30	130	40	10	70	60	60	50	60
Cs	15.3	14.5	34.8	10.9	59.7	13.9	25.7	17.0	14.7	3.8	12.0	12.7	9.0	3.8
Dy	6.7	4.3	5.2	3.0	5.2	7.4	3.8	5.3	6.5	14.5	10.5	156.5	10.2	9.8
Er	4.7	2.6	3.4	2.0	3.2	4.7	2.3	3.4	4.0	9.4	6.5	97.2	6.2	6.1
Eu	0.2	0.5	0.4	0.3	0.6	0.6	0.4	0.3	0.3	0.4	0.8	6.1	0.7	0.6
Ga	19.4	17.4	18.5	17.9	21.8	18.5	19.0	17.8	18.7	23.8	22.1	25.7	20.9	21.5
Gd	5.1	4.1	4.1	2.7	4.3	7.9	3.4	4.4	5.1	11.8	9.3	164.5	9.3	8.7
Hf	4.3	4.8	4.6	3.5	4.1	4.6	5.0	4.0	4.3	7.2	8.9	9.7	8.0	7.1
Ho	1.5	0.9	1.1	0.7	1.1	1.5	0.8	1.1	1.4	3.2	2.3	33.6	2.2	2.1
La	12.6	29.3	25.7	12.4	20.7	18.3	17.5	22.4	19.3	35.7	50.4	48.6	56.6	62.8
Lu	1.0	0.4	0.7	0.4	0.6	0.9	0.4	0.6	0.7	1.2	1.0	13.4	0.9	0.9
Mo	4	2	2	33	4	29	22	2	3	2	6	2	2	3
Nb	31.3	18.0	22.3	10.4	25.3	17.2	19.2	19.5	23.9	12.7	10.8	14.4	9.7	9.5
Nd	13.0	21.3	19.3	10.6	17.7	15.9	14.6	18.3	17.6	40.0	42.5	46.3	45.9	47.9
Pr	3.3	6.1	5.5	2.8	4.6	4.4	4.1	5.1	4.6	9.9	11.2	11.9	12.6	13.3
Rb	372	312	364	165	355	252	303	358	339	235	226	288	207	226
Sm	4.4	4.7	4.5	2.8	4.5	3.9	3.7	4.5	4.8	10.7	9.3	11.6	9.8	9.8
Sn	9	8	21	6	37	7	10	9	8	1	5	3	5	3
Sr	15.7	64.0	46.9	43.4	106.0	35.8	51.3	28.2	19.4	15.1	42.5	12.2	41.2	19.1
Ta	9.5	3.0	5.6	3.2	5.9	3.7	2.9	4.9	7.0	0.9	1.1	1.4	0.9	0.9
Tb	1.1	0.7	0.8	0.5	0.9	1.3	0.6	0.9	1.0	2.3	1.7	25.7	1.7	1.6
Th	30.3	26.5	33.2	37.8	20.2	73.5	35.2	31.1	31.3	21.7	29.2	301.0	19.6	20.6
Tl	0.9	0.8	1.1	0.6	1.3	1.5	0.8	0.9	0.9	0.6	0.7	8.7	0.6	0.6
Tm	0.9	0.4	0.6	0.4	0.6	0.9	0.4	0.6	0.7	1.4	1.0	15.3	0.9	0.9
U	21.2	10.0	15.7	14.7	11.6	30.4	14.9	19.0	12.5	5.2	7.3	74.0	5.5	5.7
W	3	11	5	85	60	36	49	2	23	4	3	3	3	4
Y	51.2	27.7	36.9	20.1	35.3	23.9	24.1	37.8	41.4	87.3	63.1	88.4	61.6	61.6
Yb	6.3	2.6	4.0	2.6	3.5	5.2	2.4	3.8	4.7	8.0	6.2	88.0	5.6	5.7
Zr	92	167	135	87	125	114	139	108	109	184	275	216	245	193
∑REE	98.3	169.6	139.0	89.6	128.5	119.2	141.4	111.8	113.7	192.0	281.2	304.0	250.6	198.7
Eu/Eu*	0.1	0.4	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.1	0.3	0.4	0.2	0.2
$(La/Yb)_N$	1.4	8.2	4.6	3.5	4.2	2.5	5.2	4.2	3.0	3.2	5.9	0.4	7.3	8.0
#Mg	32.1	27.7	28.7	38.0	32.1	36.1	32.4	31.6	34.0	26.2	24.5	27.3	25.0	24.4

BG: Baseth granite; BP: Ba Phnom; ASI: alumina saturation index (molar $Al_2O_3/[CaO + K_2O + Na_2O]$); LOI: loss on ignition; $Eu/Eu^* = Eu_N/\mathrm{sqrt}(Sm_N*Gd_N)$, and $(La/Yb)_N$ (normalized to chondrite [16]), #Mg=100[MgO/(MgO+Total FeO)]; BDL: below detection limit

Table 1. Major and Trace Elements of the Granitic Rocks of Cambodia- Major Elements in wt. %, Trace Elements in ppm (Continued)

Sample	BP6	BP7	BP en	PD1	PD2	PD3	PD4	PD5	PD6	PD7	PA1	PA2	PA3	PA4
SiO_2	72.4	70.0	53.4	73.7	73.7	74.0	73.6	74.6	73.2	73.8	72.5	72.1	71.9	72.0
TiO_2	0.3	0.4	1.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2
Al_2O_3	13.3	13.3	16.0	13.6	13.6	13.6	14.0	13.3	13.0	13.5	13.7	13.8	13.8	14.4
FeO	2.5	3.4	9.3	1.4	1.5	1.2	1.2	1.4	1.7	1.4	2.1	1.66	2.7	2.5
MnO	0.02	0.03	0.21	0.07	0.13	BDL	0.01	0.002	0.01	0.07	0.001	0.002	0.02	0.02
MgO	0.7	1.0	4.9	0.6	0.6	0.6	0.7	0.6	0.9	0.6	0.7	0.64	0.8	0.8
CaO	1.1	2.3	7.0	0.9	0.9	0.4	0.4	0.8	0.5	0.9	1.2	1.50	1.3	0.9
Na_2O	3.8	3.6	5.1	4.0	3.9	3.3	2.8	4.0	1.7	3.9	3.5	3.67	3.5	3.7
K_2O	4.7	4.8	1.5	4.5	4.3	5.0	5.1	4.5	6.2	4.4	5.2	5.73	4.8	4.8
P_2O_5	0.03	0.09	0.26	0.02	0.02	0.02	0.02	0.01	0.04	0.02	0.01	0.01	0.01	0.01
LOI	0.7	0.8	1.6	1.1	1.1	1.2	1.6	0.6	2.6	1.1	0.5	0.5	0.7	0.5
Total	99.6	99.6	100.0	99.8	99.8	99.3	99.5	99.9	99.9	99.9	99.7	99.8	99.7	99.7
ASI	1.0	0.9	0.7	1.0	1.1	1.2	1.3	1.0	1.3	1.0	1.0	0.9	1.0	1.1
Ba	593	N.A	377.0	432.0	430.0	492.0	476.0	444.0	482.0	N.A	125.5	127.5	131.5	N.A
Ce	113	N.A	70.8	48.5	49.0	42.7	46.7	48.6	49.9	N.A	97.1	110.5	156.5	N.A
Co	3	N.A	20.1	1.0	1.2	1.2	0.8	1.0	0.5	N.A	1.0	1.9	1.8	N.A
Cr	100	N.A	100	70	90	60	50	60	20	N.A	50	60	40	N.A
Cs	10	N.A	7.1	3.9	3.4	3.1	4.3	3.6	7.4	N.A	11.0	10.3	14.4	N.A
Dy	13	N.A	8.4	3.1	3.1	3.0	2.5	3.4	2.1	N.A	14.9	17.5	152.0	N.A
Er	8	N.A	5.4	1.8	1.8	1.7	1.4	1.9	1.1	N.A	8.7	10.9	94.8	N.A
Eu	1	N.A	1.6	0.4	0.4	0.4	0.3	0.4	0.5	N.A	0.4	0.4	3.6	N.A
Ga	22	N.A	23.0	17.4	17.5	16.1	17.5	16.3	24.5	N.A	21.9	22.3	25.3	N.A
Gd	11	N.A	7.6	2.9	3.1	3.0	2.4	3.4	3.0	N.A	12.4	14.4	158.0	N.A
Hf	11	N.A	4.2	3.1	3.3	3.0	3.5	3.5	3.7	N.A	5.3	20.1	9.1	N.A
Ho	3	N.A	1.9	0.6	0.7	0.6	0.5	0.7	0.4	N.A	3.0	3.7	32.0	N.A
La	59	N.A	37.9	24.9	25.5	22.0	24.0	25.0	25.8	N.A	40.5	48.9	71.1	N.A
Lu	1	N.A	0.8	0.3	0.3	0.2	0.2	0.3	0.2	N.A	1.3	1.5	13.7	N.A
Mo	2	N.A	2	9	7	5	3	3	157	N.A	<2	2	2.0	N.A
Nb	13	N.A	9.3	13.1	13.4	12.0	14.1	12.9	13.2	N.A	21.2	18.6	28.1	N.A
Nd	50	N.A	33.5	18.1	18.2	16.2	17.3	18.0	19.2	N.A	45.6	53.9	76.1	N.A
Pr	13	N.A	8.4	5.3	5.3	4.7	5.1	5.3	5.5	N.A	12.1	13.9	20.1	N.A
Rb	218	N.A	95	189	196	202	232	152	327	N.A	377	291	291	N.A
Sm	11	N.A	7.3	3.7	3.7	3.3	3.4	3.7	3.9	N.A	12.7	14.8	20.4	N.A
Sn	5	N.A	2	3	5	3	6	2	6	N.A	14	10	16	N.A
Sr	46	N.A	526.0	73.2	72.4	47.3	37.7	81.9	32.0	N.A	43.4	45.8	47.9	N.A
Ta	1	N.A	0.6	1.3	1.1	1.0	1.4	1.1	1.5	N.A	2.6	9.9	3.9	N.A
Tb	2	N.A	1.3	0.5	0.5	0.5	0.4	0.6	0.4	N.A	2.4	2.8	25.2	N.A
Th	23	N.A	4.0	12.7	13.4	12.1	14.3	13.7	15.6	N.A	35.9	57.6	580.0	N.A
Tl	1	N.A	<0.5	0.7	0.7	0.8	0.9	0.6	1.3	N.A	1.1	1.1	7.1	N.A
Tm	1	N.A	0.8	0.3	0.3	0.3	0.2	0.3	0.2	N.A	1.4	1.7	14.5	N.A
U	6	N.A	14.2	3.3	3.5	2.6	4.3	3.6	3.2	N.A	7.5	11.4	97.0	N.A
W	5	N.A	5	13	8	3	5	2	4	N.A	4	48	8	N.A
Y	80	N.A	53.4	18.5	19.3	17.8	14.7	19.0	11.3	N.A	86	112	151	N.A
Yb	8	N.A	4.9	1.6	1.7	1.5	1.4	1.8	1.1	N.A	8.9	10.3	88.1	N.A
Zr	352	N.A	145	86	95	79	92	95	101	N.A	129	112	208	N.A
∑REE	360	N.A	149.9	87.6	96.7	80.5	93.4	96.8	102.1	N.A	137.9	122.3	296.1	N.A
Eu/Eu*	0.3	N.A	0.7	0.3	0.3	0.3	0.3	0.3	0.4	N.A	0.1	0.1	0.2	N.A
$(La/Yb)_N$	5.6	N.A	5.6	11.2	11.0	10.5	12.1	10.0	17.6	N.A	3.3	3.4	0.6	N.A
#Mg	21.9	22.3	34.6	28.8	28.4	32.2	36.5	29.6	34.4	29.7	24.8	27.8	22.0	23.1

BP en: Ba Phnom's enclave, PD: Phnom Den, PA: Pha Aok, N.A: not available

Table 1. Major and Trace Elements of the Granitic Rocks of Cambodia- Major Elements in wt. %, Trace Elements in ppm (Continued)

Sample	Kch1	Kch2	Kch3	Kch4	Kch5	Kch dike1	Kch dike2	TM1	TM2	TM3	TM4	PL1	PL2
SiO_2	72.6	73.1	73.0	72.1	72.8	61.6	60.1	73.8	74.1	71.0	70.8	63.1	69.9
TiO_2	0.1	0.1	0.1	0.1	0.1	0.6	0.7	0.3	0.3	0.1	0.4	0.7	0.4
Al_2O_3	13.6	13.8	14.0	14.2	14.3	14.2	15.6	12.0	12.5	14.9	13.5	15.0	13.9
FeO	1.8	1.3	1.6	1.6	1.3	5.0	5.4	2.7	2.5	1.1	3.0	4.2	3.1
MnO	0.04	BDL	0.03	0.03	BDL	0.10	0.09	0.03	0.05	BDL	0.11	0.09	0.09
MgO	0.6	0.7	0.6	0.6	0.7	2.6	3.1	0.9	0.8	0.7	1.0	3.8	2.5
CaO	1.3	1.4	0.8	1.4	1.4	10.0	9.5	1.5	1.1	1.4	1.7	5.8	3.5
Na_2O	4.1	3.1	4.1	4.2	3.1	3.7	2.9	3.5	3.3	3.5	3.7	3.9	3.3
K_2O	4.9	5.8	4.8	5.0	5.5	1.4	1.7	4.2	4.1	6.4	4.8	1.8	2.3
P_2O_5	0.02	0.03	0.02	0.02	0.02	0.21	0.19	0.13	0.15	0.04	0.21	0.35	0.09
LOI	0.6	0.5	0.7	0.4	0.5	0.2	0.3	0.6	0.8	0.6	0.5	0.9	0.8
Total	99.7	99.8	99.7	99.7	99.8	99.7	99.6	99.7	99.8	99.7	99.7	99.7	99.8
ASI	0.9	1.0	1.1	1.0	1.0	0.5	0.6	0.9	1.0	1.0	0.9	0.8	1.0
Ba	560.0	234.0	551.0	226.0	457.0	N.A	N.A	174.5	123.0	250.0	196.5	313.0	342
Ce	77.8	62.3	61.3	34.1	50.3	N.A	N.A	92.9	99.8	25.1	80.8	36.6	21
Co	0.9	0.9	0.8	1.6	1.1	N.A	N.A	3.2	2.8	1.2	3.1	13.3	8
Cr	40	40	30	20	40	N.A	N.A	50	50	50	40	50	70
Cs	7.8	5.6	6.2	7.6	8.0	N.A	N.A	13.3	22.3	10.2	16.9	1.6	1
Dy	5.0	3.6	3.4	2.9	4.0	N.A	N.A	6.0	9.5	2.4	6.8	2.8	3
Er	2.9	2.6	2.1	2.1	2.4	N.A	N.A	3.3	5.1	1.4	3.6	1.6	2
Eu	0.6	0.4	0.6	0.3	0.6	N.A	N.A	0.5	0.5	0.5	0.5	0.9	1
Ga	17.5	13.4	17.8	13.5	18.1	N.A	N.A	20.2	20.7	18.3	22.0	17.7	13
Gd	5.0	3.3	3.3	2.0	3.7	N.A	N.A	5.6	8.3	1.9	6.0	2.8	2
Hf	5.8	4.3	4.7	3.5	4.6	N.A	N.A	6.6	5.9	17.0	6.5	3.1	4
Ho	1.0	0.8	0.7	0.6	0.8	N.A	N.A	1.2	1.8	0.5	1.3	0.5	1
La	41.4	37.4	29.5	22.6	26.0	N.A	N.A	45.4	46.6	13.2	39.0	17.0	10
Lu	0.4	0.4	0.3	0.4	0.4	N.A	N.A	0.5	0.8	0.3	0.6	0.3	0
Mo	2.0	<2	<2	<2	<2	N.A	N.A	<2	<2	<2	<2	<2	2
Nb	14.8	5.1	12.4	4.9	12.6	N.A	N.A	27.5	30.9	7.6	26.3	6.2	2
Nd	31.0	21.7	23.3	14.3	20.4	N.A	N.A	32.9	39.3	9.4	30.4	16.3	10
Pr	8.7	6.4	6.7	4.3	5.6	N.A	N.A	9.7	11.1	2.7	8.7	4.3	2
Rb	222.0	186.5	219.0	192.5	214.0	N.A	N.A	316.0	379.0	369.0	351.0	44.1	36
Sm	6.1	4.2	4.7	2.9	4.3	N.A	N.A	6.9	9.5	2.1	6.8	3.3	2
Sn	2	1	2	1	4	N.A	N.A	12	17	6	15	1	1
Sr	73.1	63.6	68.4	63.8	75.8	N.A	N.A	56.7	40.9	63.5	61.7	599.0	196
Ta	1.4	0.8	1.0	0.8	1.1	N.A	N.A	3.6	4.8	1.1	3.4	0.5	0
Tb	0.8	0.6	0.6	0.4	0.6	N.A	N.A	1.0	1.6	0.4	1.2	0.5	0
Th	23.4	23.2	23.8	29.2	24.3	N.A	N.A	44.7	50.9	13.0	40.8	4.1	5
Tl	0.6	<0.5	0.6	<0.5	0.6	N.A	N.A	0.7	1.0	0.8	0.9	<0.5	<0.5
Tm	0.5	0.4	0.3	0.3	0.4	N.A	N.A	0.5	0.9	0.2	0.6	0.3	0
U	5.0	6.3	6.0	5.8	4.9	N.A	N.A	10.3	16.3	5.5	9.9	1.0	1
W	4	4	4	5	6	N.A	N.A	4	1	2	1	3	1
Y	29.9	26.0	19.9	20.5	23.9	N.A	N.A	35.8	56.8	14.6	39.6	15.6	18
Yb	2.8	2.5	2.1	2.4	2.5	N.A	N.A	3.3	5.7	1.5	3.8	1.6	2
Zr	174.0	102.0	140.0	81.0	148.0	N.A	N.A	207.0	178.0	712.0	208.0	123.0	116
∑REE	176.8	104.5	142.1	83.4	150.5	N.A	N.A	210.3	183.7	713.5	211.8	124.6	118
Eu/Eu*	0.3	0.3	0.5	0.4	0.5	N.A	N.A	0.2	0.2	0.7	0.2	0.9	0.9
$(La/Yb)_N$	10.8	10.7	10.1	6.9	7.6	N.A	N.A	9.8	5.9	6.4	7.4	7.5	3.0
#Mg	25.6	35.0	26.5	28.6	35.4	34.6	36.6	25.2	24.9	37.1	26.1	47.5	44.7

Kch: Kompong Chnang, TM: Tamao, PL: Phnom Lung

Table 1. Major and Trace Elements of the Granitic Rocks of Cambodia- Major Elements in wt. %, Trace Elements in ppm (Continued)

Sample	PL en	KM1	KM2	KM3	KM4	KM5	KM6	KM dike1	KM dike2	KM en
SiO_2	55.82	67.5	59.9	57.0	62.2	58.8	59.8	70.3	69.3	51.0
TiO_2	0.701	0.4	1.0	1.1	0.7	1.1	0.9	0.4	0.3	1.1
Al_2O_3	16.191	14.9	15.5	15.3	17.3	15.3	16.5	14.1	15.0	14.4
FeO	8.365	2.6	5.0	6.8	3.6	5.0	5.3	2.4	2.3	9.3
MnO	0.37	0.03	0.10	0.15	0.06	0.09	0.12	0.03	0.03	0.30
MgO	4.753	1.7	3.3	4.4	1.7	4.6	3.1	1.2	1.2	8.7
CaO	6.601	2.0	5.0	5.7	3.8	4.6	4.9	1.5	1.5	8.3
Na_2O	4.852	4.0	4.1	3.8	4.3	4.4	4.1	3.6	3.7	3.9
K_2O	1.174	5.8	4.9	4.5	5.3	4.4	3.9	5.9	5.8	1.8
P_2O_5	0.10	0.15	0.48	0.43	0.29	0.52	0.40	0.08	0.08	0.59
LOI	0.829	0.5	0.2	0.3	0.3	0.6	0.4	0.2	0.3	0.2
Total	99.8	99.5	99.4	99.5	99.5	99.4	99.5	99.6	99.6	99.6
ASI	0.8	0.9	0.7	0.7	0.9	0.8	0.8	0.9	1.0	0.6
Ba	240.0	446.0	615.0	410.0	689.0	406.0	465.0	193.5	211.0	84.9
Ce	29.7	70.3	63.5	66.1	75.4	108.5	82.3	89.6	87.8	64.8
Co	22.3	5.1	12.0	17.8	6.2	11.6	12.8	4.4	4.0	31.0
Cr	90	120	120	130	120	150	90	130	100	310
Cs	1.0	18.3	18.1	17.6	16.5	21.5	20.0	28.3	26.0	8.7
Dy	5.5	2.6	4.0	4.0	3.8	5.2	4.7	4.1	4.0	4.9
Er	3.6	1.5	2.2	2.2	2.2	3.0	2.7	2.6	2.4	2.6
Eu	1.0	0.7	1.3	1.2	1.3	1.2	1.1	0.6	0.6	1.3
Ga	16.6	17.0	18.8	18.7	19.3	21.0	19.2	16.8	16.5	19.1
Gd	4.4	2.6	4.4	4.3	4.0	5.0	4.9	3.8	3.7	5.1
Hf	1.8	6.2	6.8	6.4	9.0	7.7	7.7	10.0	9.1	4.8
Ho	1.2	0.5	0.8	0.8	0.7	1.0	0.9	0.9	0.8	0.9
La	11.7	34.9	30.0	30.6	36.3	52.3	37.4	42.9	42.0	29.5
Lu	0.7	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.4
Mo	5	15	5	6	7	9	6	15	14	2
Nb	2.1	24.0	18.6	25.2	24.5	48.5	22.3	31.8	30.6	16.1
Nd	15.8	25.1	28.7	29.8	30.5	41.6	36.1	31.9	30.9	31.9
Pr	3.9	7.4	7.7	7.9	8.6	12.3	9.6	9.8	9.4	8.2
Rb	26.1	343.0	265.0	244.0	287.0	342.0	249.0	336.0	382.0	115.5
Sm	4.1	4.1	5.6	6.0	5.8	7.5	7.0	5.7	5.4	6.8
Sn	2	3	2	3	3	4	3	4	5	2
Sr	233	425	501	440	435	562	513	144	148	577
Ta	0.2	1.7	1.3	1.7	1.7	4.2	1.6	3.1	2.9	1.0
Tb	0.8	0.4	0.7	0.7	0.6	0.9	0.8	0.7	0.7	0.8
Th	1.6	45.0	33.8	28.8	27.0	66.9	32.8	110.0	113.5	4.6
Tl	<0.5	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tm	0.6	0.3	0.4	0.4	0.4	0.5	0.4	0.5	0.4	0.4
U	1.1	10.0	7.1	7.8	10.2	23.3	10.1	36.0	36.2	1.6
W	3	8	8	9	5	5	8	26	21	4
Y	34.3	14.8	20.8	22.4	21.6	29.8	27.3	25.7	23.0	27.0
Yb	4.2	1.7	2.3	2.2	2.4	3.5	2.9	3.3	3.0	2.8
Zr	46	241	277	265	370	281	300	311	297	186
∑REE	50.2	242.7	279.3	267.2	372.4	284.5	302.9	314.3	300.0	188.8
Eu/Eu*	0.7	0.6	0.8	0.7	0.8	0.6	0.6	0.4	0.4	0.7
$(La/Yb)_N$	2.0	15.1	9.4	9.8	10.8	10.8	9.3	9.4	10.1	7.5
#Mg	36.2	38.9	40.0	39.0	32.4	48.2	37.2	32.8	33.4	48.2

PL en: Phnom Lung’s enclave, KM: Kon Mom, KM en: Kon Mom’s enclave

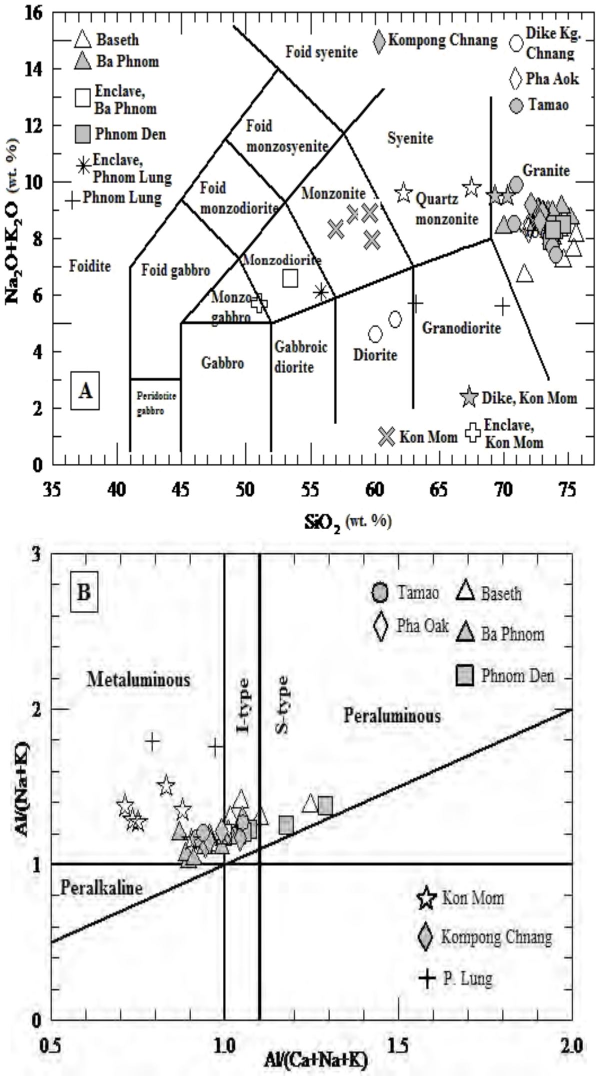

Figure 3. A. Nomenclature [11] of the granitic rocks of Cambodia and their associated volcanic units; B. Alumina saturation [12] and types of granitic rocks [9] of Cambodia

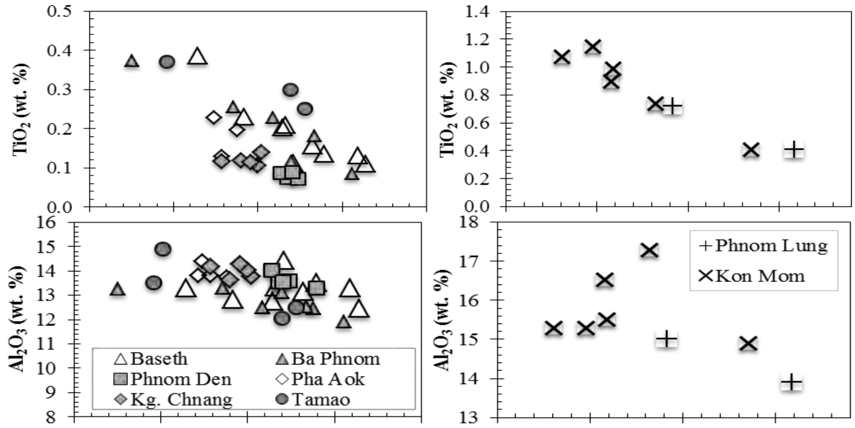

Figure 4. Variation diagrams of major elements and selected trace elements for the ilmenite- (left) and magnetite-series (right) granitic rocks of Cambodia

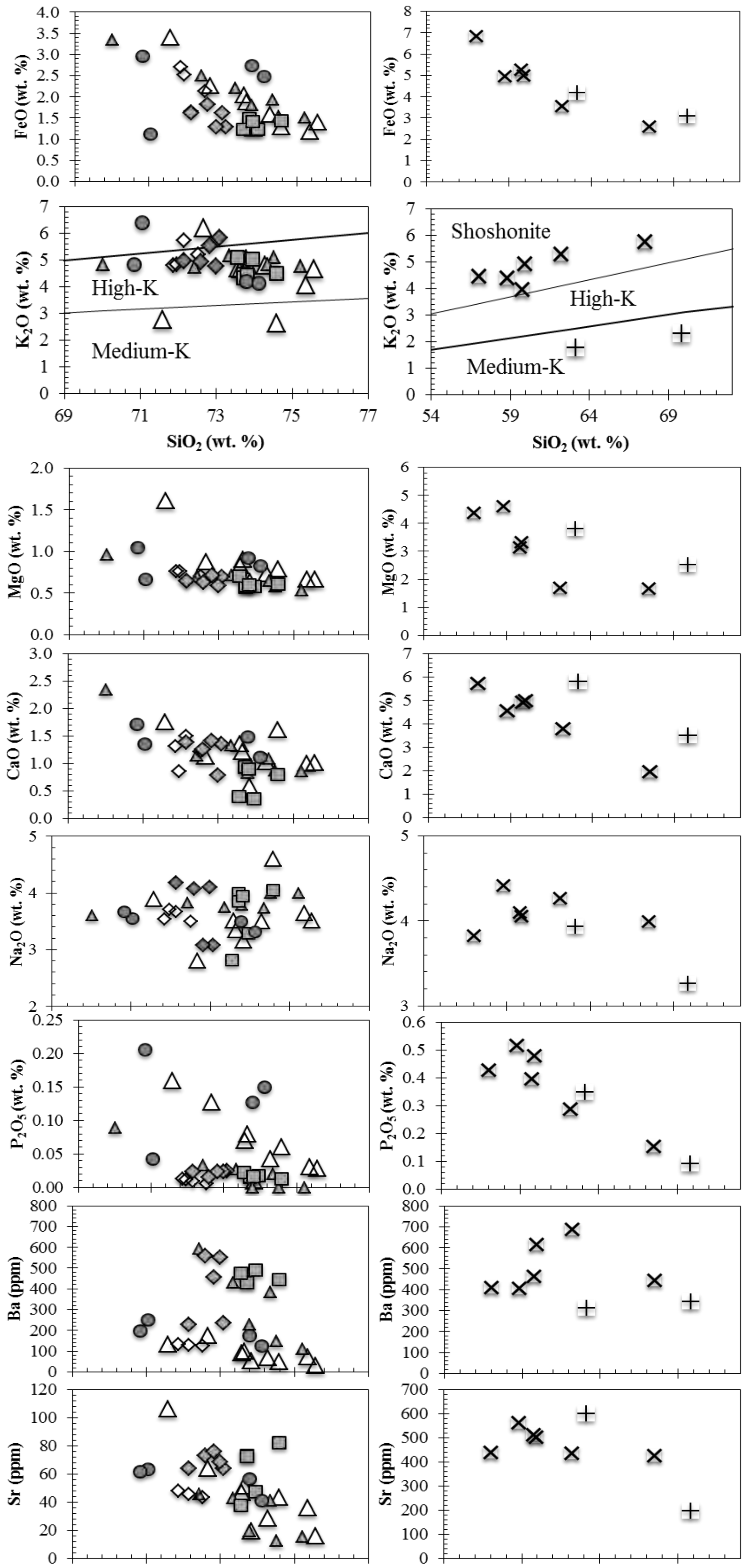

Figure 4. Variation diagrams of major elements and selected trace elements for the ilmenite- (left) and magnetite-series (right) granitic rocks of Cambodia

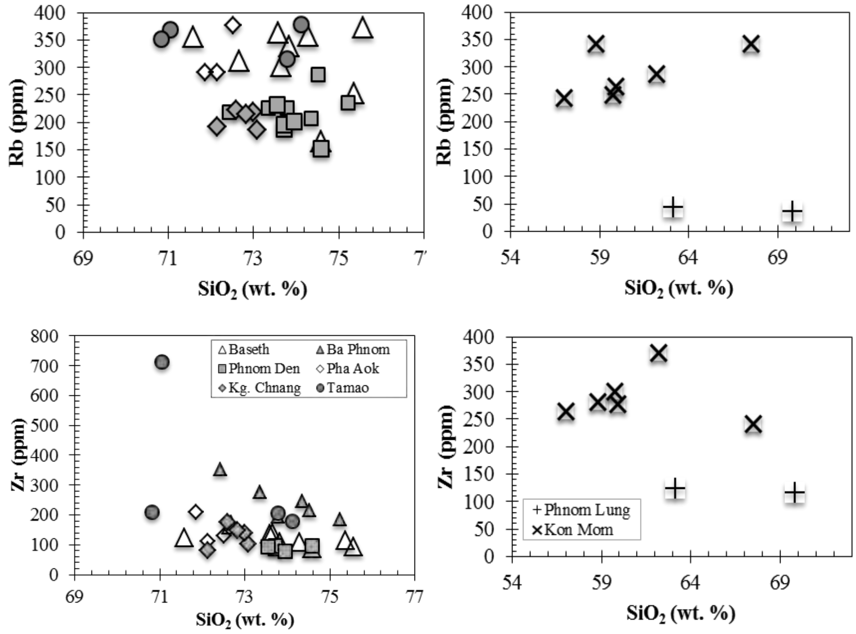

Figure 4. Variation diagrams of major elements and selected trace elements for the ilmenite- (left) and magnetite-series (right) granitic rocks of Cambodia

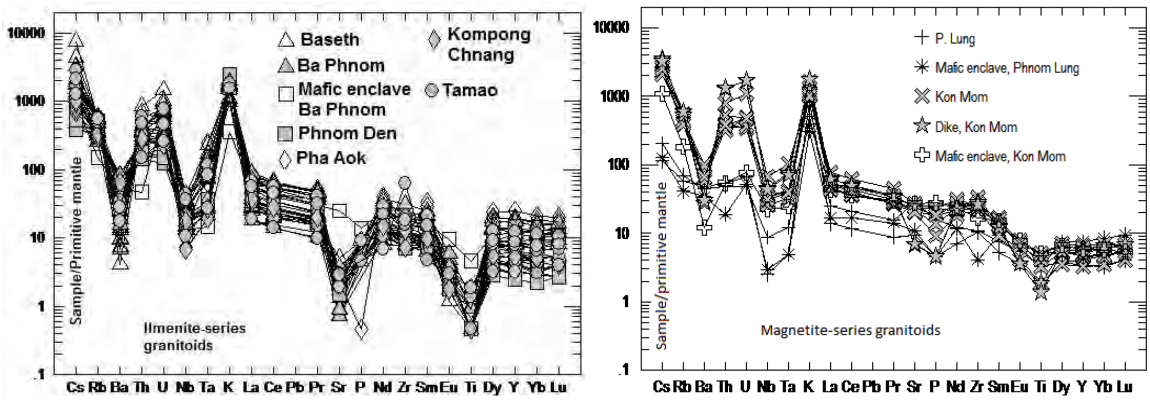

Figure 5. Primitive mantle-normalized spidergrams for the granitic rocks of Cambodia. Normalizing values after [16].

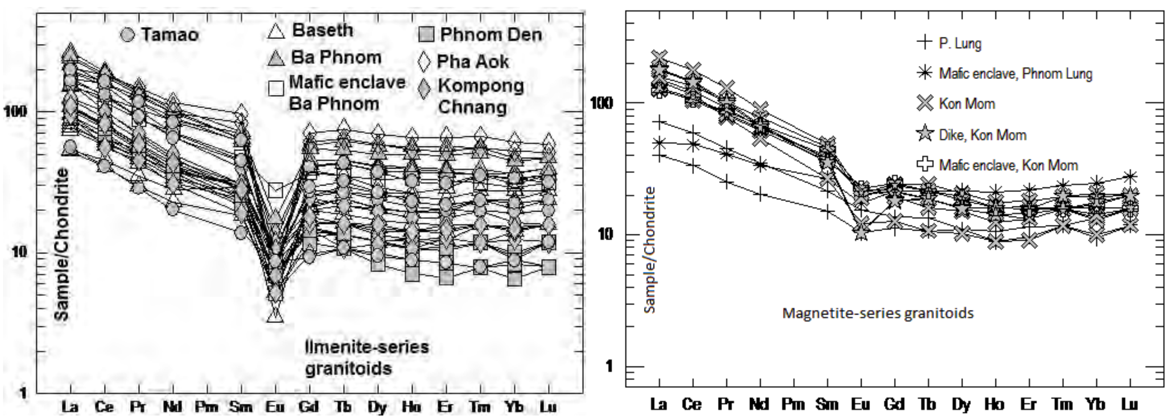

Figure 6. Chondrite-normalized REE patterns for the granitic rocks of Cambodia. Normalizing values after [16].

Discussions

Petrogenetic Consideration

There are obviously ilmenite-series granites in southern Cambodia and magnetite-series granitic rocks in northern Cambodia based on magnetic susceptibility of the granitic rocks [8]. The ilmenite-series granites are rich in quartz, K-feldspar while the magnetite-series granitic rocks have abundance of plagioclase and hornblende compared to the former. The studied granitic rocks of Cambodia are characterized by low $(La/Yb)_N$ ratios (<20) and high Yb_N (>4.5) (Figure 9A). Coupling with Nb negative anomalies, they hence show affinity to post-Archean arc-related granitic rocks [17].

Fractional Crystallization

The negative trends of TiO_2, FeO, MgO, P_2O_5, Ba, and Sr contents observed on the variation diagrams of most of the samples are compatible with their evolution through crystal fractionation. Strongly negative Ba and Sr anomalies associated with negative Eu anomalies indicate fractionation of K-feldspar and plagioclase either in magma chamber or during magma ascent. In contrast, fractionation of plagioclase did not play a vital role in the petrogenesis of the magnetite-series granitic rocks, especially those of Phnom Lung, indicated by small or no negative anomalies of Eu and Sr. Negative trends of TiO_2 and P_2O_5 against SiO_2 (Figure 4) are attributed to removal of titanite and apatite respectively. The depletion MREEs with respect to HREEs observed in some localities can be related to fractionation of hornblende and/or titanite (e.g. [18], [19]). This is also supported by the negative correlations between FeO, MgO, and SiO_2 contents (Figure 4).

Potential Sources

All granitic rocks in this study show high-K calc-alkaline affinity, and are characterized by negative anomalies of Ba, Sr, Nb and Ti, and the enrichment in Rb, Th, K, La, and Cs in the spidergrams. These features are typical of crustal melts, e.g. granitic rocks of Lachlan Fold Belt [13], Himalayan leucogranites [20], Dalat granites of southern Vietnam [15], Kontum complex of central Vietnam ([21]&[22]). The high Na_2O contents (>3.2 wt. %) from almost all samples coupled with the metaluminosity of the granitic rocks support I-type affinity ([13]&[14]). Compared to the granitic rocks of the Lachlan Fold Belt [13] and those of Malay Peninsula [23], most of the granitic rocks of Cambodia plot in the field of I-type (Figure 7). It is noteworthy that a few granites at Baseth, Phnom Den, and Kompong Chnang show transitional composition between I- and S-type granites reflecting the heterogeneity of their sources. The small and no Eu anomalies, high CaO and Sr contents from the magnetite-series granitic rocks suggest melting of a plagioclase-bearing source.

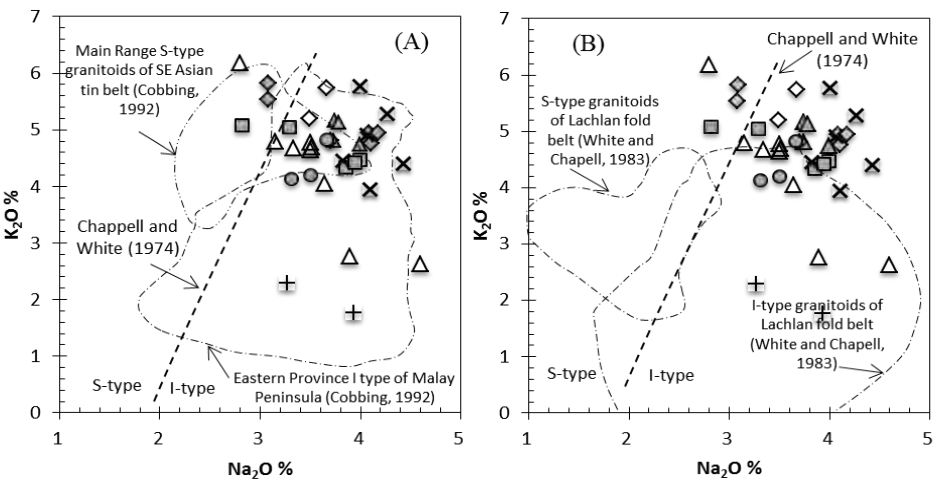

Figure 7. A plot of Na2O vs K2O (wt. %) compared to (A) granites from Malay Peninsula [23] and (B) to granitic rocks of the Lachlan Fold Belt [24]; discrimination line [25].

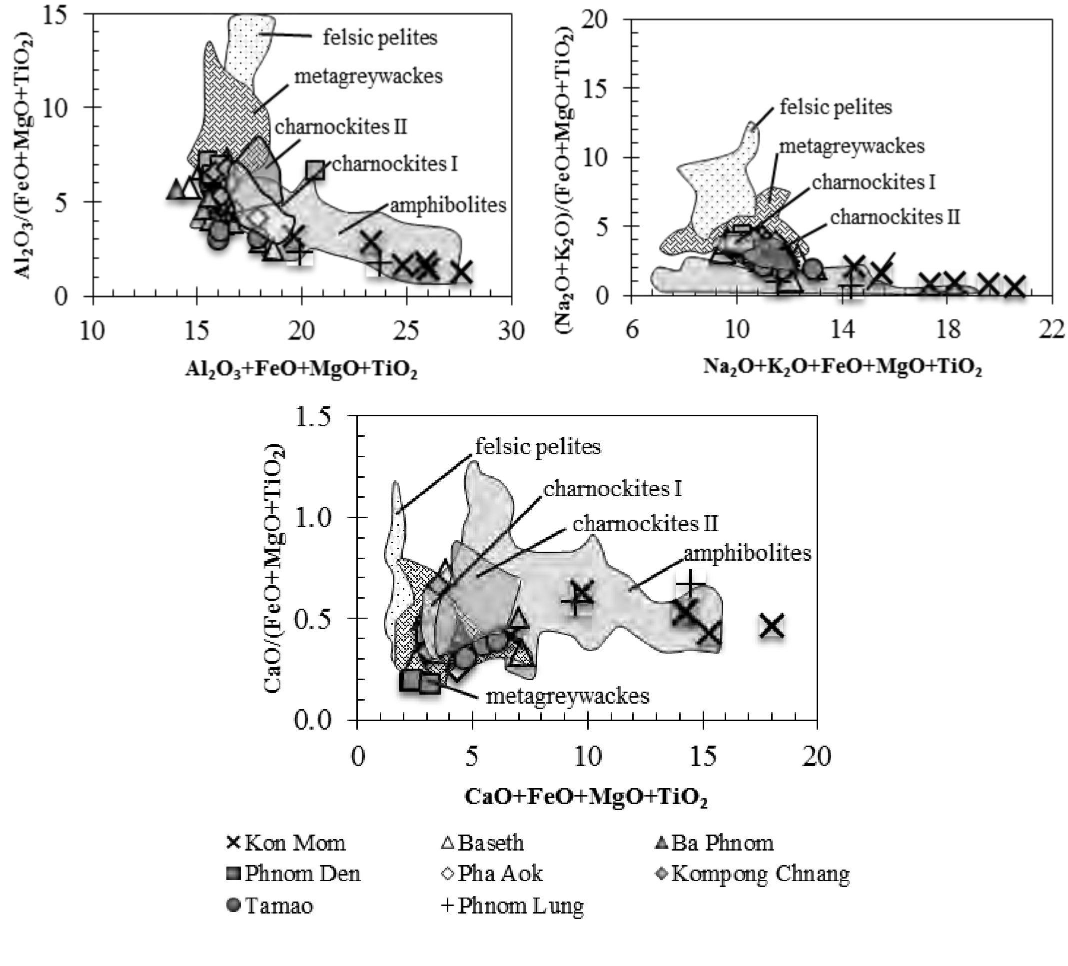

Figure 8. Plots showing compositional fields of experimental melts derived from partial melting of felsic pelites, metagreywackes, amphibolites [26], and charnockite I [28] & charnockite II [27] and composition of granitic rocks of Cambodia.

In contrast, the ilmenite-series granites with high SiO_2 contents exhibit strong depletion of Sr (Figure 5) and Eu (Figure 6) that reflects melting of rocks with intermediate SiO_2 content where plagioclase was present as residual phase and/or as a major fractionating phase.

Affinity of the source materials for partial melting of the crustal rocks such as amphibolites, metagraywackes, and metapelites could be visualized by experimental studies based on the ratios of major oxides (e.g. [26]). For example, partial melts derived from mafic source rocks such as amphibolites have low Al_2O_3/(FeO+MgO+TiO_2) and high CaO+FeO+ MgO+TiO_2. This feature is applicable with the magnetite-series granitic rocks of Cambodia, i.e. Kon Mom and Phnom Lung of high Mg# (32-47) (Figure 8). On the other hand, the ilmenite-series granites have high CaO+FeO+MgO+TiO_2 of field of amphibolite-derived melts but intermediate Al_2O_3/(FeO+ MgO+TiO_2) between majorly amphibolite with slight extension to metagraywackes (Figure 8). Furthermore, these granites share similar composition to dehydration melting experiments of charnockites making Sr-depleted, Y-undepleted, LREE-enriched characters ([27]&[28]). The presences of plagioclase with low abundance or absence of garnet in the source further support charnockite as one of the major sources for these granitic rocks. Similar condition have been report for high K-, highly fractionated I-type granites such as Chengannoor granite, southern India [29], Kontum massif [21] and Dalat zone [15]. It is also consistent with crustal evolution of central Vietnam which was stated that Indochina was subjected to high metamorphism in the lower crust associated with charnockite during Indosinian Orogeny [21]. The I-type affinity of these granites precludes melt derived from metagreywackes. Thus, the transitional range between I- and S- type compared to the Lachlan Fold Belt granites and Malay Peninsula from some studied granitic rocks and slight extension to metagreywacke field suggest involvement of immature sediments in the magma chamber during magma ascent to the upper crust. A plausible petrogenetic model for high-K I type granitic rocks was proposed by [29]. There was first a period of underplating of basaltic crust with ponding of mafic magmas in the lower crust, and then a partial melting of this basaltic lower crust formed charnockitic magma. The partial melting of the latter produces high-K I-type granitic rocks. This scenario is plausible for the petrogenesis of the ilmenite-series granitic rocks of Cambodia.

Tectonic Affinity

All granitic rocks in this study show the high-K and calc-alkaline characters with the enrichment of LILEs such Cs, K, Rb, U, and Th with respect to HSF elements, especially Nb and Ti (Figure 5), which are the typical features of subduction-related environment (e.g. [30], [31], [32]). The low $(La/Yb)_N$ (<20) in addition classifies these granitic rocks as post-Archean subduction-related environment (Figure 9A) [17]. It is agreed with the conclusion of [33] which assumed that the Southeast Asian margin was an Andean-type volcanic arc from mid-Jurassic through to mid-Cretaceous. Based on trace element tectonic discrimination of [20], the granitic rocks of Kompong Chnang, Ba Phnom, Kon Mom, and Phnom Lung fall into the volcanic arc field while those of Phnom Den and Pha Aok, and Baseth and Tamao are classified as syn-collsion, and late and post-collision environments respectively (Figure 9B). The magnetite-series granitic rocks were formed in volcanic arc setting while the tectonic setting during the emplacement of ilmenite-series granites varies from volcanic arc to syn-collision and post-collision.

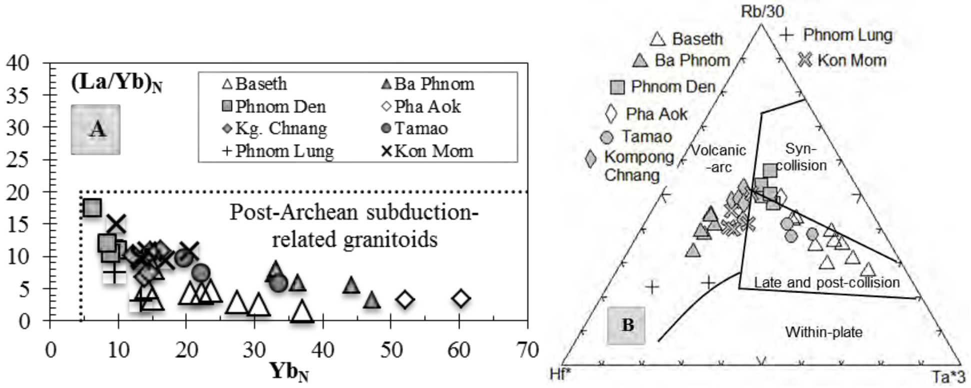

Figure 9. A. Plot of (La/Yb)N vs YbN showing post Archean subduction-related magmatism [17]; B. Tectonic discrimination for the granitic rocks of Cambodia [20].

Conclusions

There are obviously ilmenite-series granites in southern Cambodia and magnetite-series granitic rocks in northern Cambodia. The ilmenite-series granites are rich in SiO_2, LREE and LILE with no strong negative anomalies of Eu, Ba, Sr, Ti and Nb while the magnetite-series granitic rocks have intermediate SiO_2 compared to the former with less negative anomalies of Eu, Ba, Sr, Ti, and Nb. The ilmenite-series granites have high K I-type affinity and are derived from partial of melting of igneous rocks within the crust. The magnetite-series granitic rocks have high K I-type characteristic and have similar geochemical affinity to amphibolite-derived melt. The ilmenite-series granites range from volcanic-arc granites to syn- and post-collision granites while the magnetite-series granitic rocks belong to volcanic arc granites.

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