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# Petrochemistry of Bang Tha Cham granitoid, Chonburi Province, Central Granite Belt, Thailand

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**ABSTRACT**: Triassic granitoid is exposed in the Bang Tha Cham area of Chonburi Province, Eastern Thailand, along the NW-SE trending Klaeng fault zone located between the Central Granite Belt and Eastern Granite Belt. The geology in the Bang Tha Cham area mainly comprises Carboniferous sandstone and Triassic granite. Twenty representative samples were collected and classified into three groups; based on mineral compositions, petrography, and geochemistry; as Group I quartz monzonite, Group II quartz syenite, and Group III granite. Whole-rock geochemistry of Groups I to III were plotted showing the granite to granodiorite compositions (Group III) and granite to granodiorite compositions (Groups I and II) for $SiO_2$ against $Na_2O$+$K_2O$ of S-type granite, shown in the diagram of Al/(Ca+Na+K) versus Al/(Na+K). These granites originated from a high-K calc-alkaline to a shoshonitic series derived from an upper crustal source. Tectonic discrimination diagrams suggested that these granites were formed during the within-plate Triassic event. Crystallization pressure-temperature (P-T) conditions of the granites were 3.0 to 3.2 kbar and 723 to 732 °C. The granitoid was moderately metamorphosed and recrystallized during the Klaeng tectonic era, with estimated crystallization P-T conditions of 10.4 to 10.9 kbar and 300 to 483 °C. Granites in the Bang Tha Cham area of Chonburi Province are classified as S-type granites belonging to the Central Granite Belt which intruded both syn-collisional and post-collisional after the closure of the Paleothethyan in the Triassic.

**KEYWORDS**: petrochemistry, carboniferous sandstone, tectonic line, S-type granite, Central Granite Belt, Chonburi Province Thailand

## INTRODUCTION

Granitoids in Thailand can be divided into three belts with a north-south trend. The three belts, which are the Eastern Granite Belt (EGB), the Central Granite Belt (CGB), and the Western Granite Belt (WGB), run from Yunnan Province in China through Chiang Rai Province to Chonburi Province in the Thai Peninsula and then onward to Malaysia [1, 2] (Fig. 1(a)). The EGB granites range from Permian to Triassic ages and are intruded into Carboniferous sedimentary rocks, metamorphic rocks, Permian volcanic rocks, and volcanic clastic rocks. The CGB granites range from Triassic to Jurassic ages, while the WGB granites range from the Cretaceous to the Tertiary [1–3]. Granites from the EGB, the CGB, and the WGB belong to the oldest, the younger, and the youngest belts, respectively. The EGB and CGB granites run along the Sukhothai fold belt and the edge of the Indochina Terrane and have been correlated to both subduction and collision events [4, 5]. The EGB consists of a metaluminous (I-type granite), whereas the CGB consists of a I-type granite and peraluminous (S-type granite) [5–8]. The granites in Southeast (SE) Thailand [4] can be separated into Chonburi and Rayong granites (of the CGB) and Chanthaburi granite (of the EGB) [3, 4, 6, 9]. The ages of granites distributed in the Chonburi, Rayong, and Chanthaburi areas range from 238 to 208 [4, 10, 11], while the age of granite in the Chonburi area ranges from 222 to 218 Ma [4], Rayong area ranging from 220 to 238 Ma [4, 10], and Chanthaburi area ranging from 221 to 208 Ma [4, 11]. The Chonburi, Rayong, and Chanthaburi granites are defined as fault-detached [8] or Klaeng fault zone [12, 13], forming Chanthaburi [9], Chonburi, and Rayong granites in the southern portion of the Sukhothai Arc. The batholiths positions were shown in Fig. 1(b). The petrogenesis and geochemical data of the Bang Tha Cham granites were discussed, together with the relationship with the granites in SE Thailand during the Paleothethyan evolution. This study elucidated the petrography and geochemistry of the granitic rocks, with emphasis placed on the evolution of the magmatic crystallization and the tectonic setting.

The geology in the Bang Tha Cham area, Chonburi Province comprises Carboniferous siltstones and sandstones, Triassic granite, and Cretaceous gneiss, which are oriented in a NW–SE direction along the Klaeng fault zone [12–15]. The sediment sequences are Carboniferous siltstone, sandstone and limestone, Permian to Triassic sandstone, shale and limestone interbedded with slate, Triassic mudstone interbedded with siltstone and sandstone, and Jurassic conglomerate [4, 6, 9, 12]. Metamorphic rocks as Nong Yai gneiss

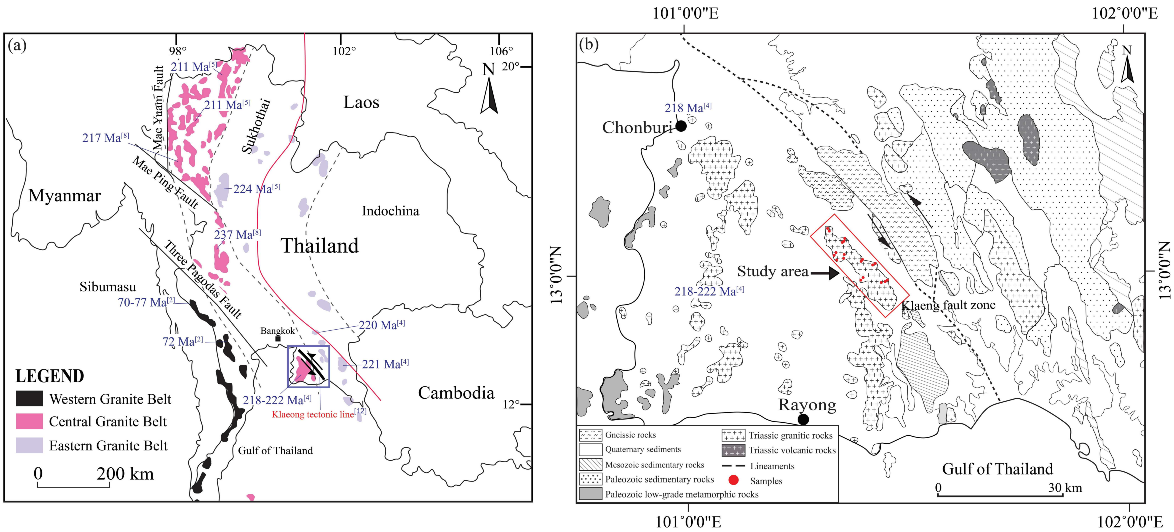


**Fig. 1** (a), Tectonic sketch map showing the distribution of granitoid rocks and granite belts in Thailand (modified after [2, 4]); (b), Geological map of the study area and adjacent area (modified after [4, 10, 14]).

and migmatite distributed along the Klaeng tectonic fault zone were dated at 234 to 235 Ma by U-Pb zircon dating [15, 16]. Cretaceous Khao Chao gneiss is a high-grade metamorphic rock related to the Klaeng fault in the northern part of the Bang Tha Cham area (Fig. 1(b)) [4, 6, 13].

## MATERIALS AND METHODS

Twenty granite samples were collected from the Bang Tha Cham area covering 70 km$^2$, as shown in Fig. 1(b). The samples were prepared, polished for thin sections, and stained at the Department of Earth Sciences, Faculty of Science, Kasetsart University (KU), Thailand for petrography and modal analysis. For staining techniques, 15% sodium hexanitrocobaltate solution and amaranth were used to stain K-feldspar to yellow and plagioclase to white, respectively. The percentages of quartz, K-feldspar, and plagioclase minerals were classified as a QAP diagram [17]. Chemical compositions of whole rocks were analyzed by X-ray fluorescence (XRF, BRUKER S4 Pioneer model, Germany) at the Faculty of Science, Chulalongkorn University (CU), Thailand. Eight oxides, namely $SiO_2$, $TiO_2$, T-FeO, MnO, CaO, $Na_2O$, $K_2O$, and $P_2O_5$ were measured by calibration with rock standards provided by the Geological Survey of Japan (GSJ) and the United States Geological Survey (USGS) including JR-1, JG-1a, JG-2, JA-2, Jb-1b, GSP-2, BHVO-2, AGV-2, and RGM-1. Loss on ignition (LOI) of six granite samples was determined by heating powdered samples at 1,100 °C for 3 h and reweighing. Six granite samples were analyzed for trace elements and rare earth elements using an inductively coupled plasma mass spectrometer (ICP-MS) (Agilent 7700 Series ICP-MS, USA) at the Thailand Institute of Nuclear Technology. The chemical compositions of biotite and muscovite were assessed by an Electron Probe Micro-Analyzer (EPMA, JEOL JXA-8100 model) at the Department of Geology, Faculty of Science, CU. Operating conditions were set at an accelerating voltage of 15.0 kV with 20 nA sample current for biotite.

## RESULTS AND DISCUSSION

### Petrography of granitic rocks in the Bang Tha Cham area

The granitic rocks in the Bang Tha Cham area were separated into three groups as quartz monzonite (Group I), quartz syenite (Group II), and granite (Group III) based on mineral composition and texture. Group I was intruded by Group II in the central and southern parts of the mountain with a width of 5 to 20 m. A later intrusion into the area occurred as the granite of Group III intruded into Group I at the edge of the mountain.

Group I was composed of quartz (10 to 15%), alkali feldspar (40 to 55%), plagioclase (30 to 50%), biotite and muscovite (3 to 5%), and accessory minerals including apatite, zircon, and ilmenite (1 to 2%) (Fig. 2(a) and Fig. 3(a)). Alkali feldspar phenocrysts ranged in size from 0.2 to 0.5 mm as subhedral to anhedral crystals with perthitic texture. Quartz commonly occurred as subhedral to anhedral crystals, ranging in size from 0.1 to 0.3 mm and exhibiting well-defined recrystallization. Plagioclase was characterized by subhedral to euhedral crystals from 0.2 to 0.5 mm in diameter. Biotite was lamellar shaped, reddish brown to greenish brown, with pleochroism from medium brown to dark brown and occasional foliation (Fig. 2(b) and 2(c)).

Group II consisted of quartz (10 to 20%), alkali

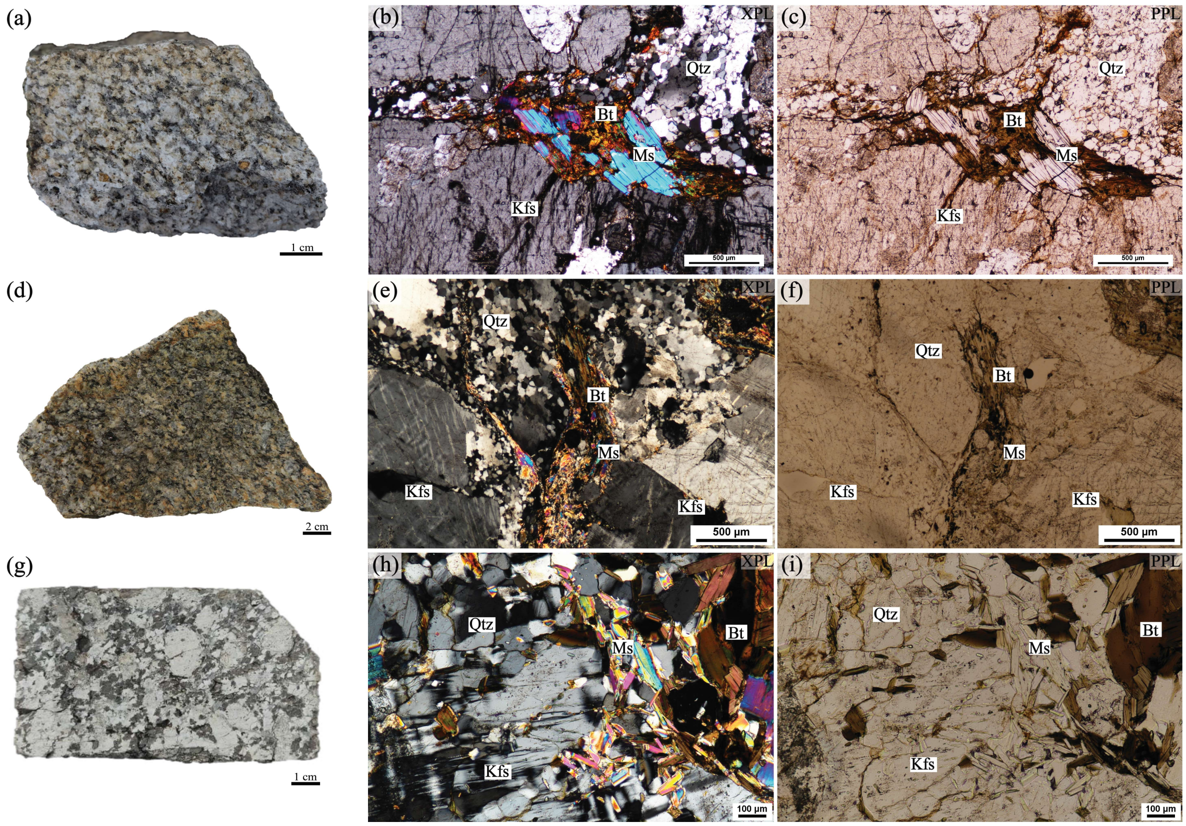


**Fig. 2** (a), Quartz monzonite (Group I) showing medium-grained and equigranular texture; (b,c), Photomicrographs under plane-polarized light (PPL) and cross-polarized light (XPL) showing the mineral assemblages and texture, quartz, alkali feldspar, and foliation of biotite and muscovite; (d), Quartz syenite (Group II) showing the medium-grained and foliated texture of biotite; (e,f), Photomicrographs under PPL and XPL showing the mineral assemblages and texture, quartz, alkali feldspar, and foliation of biotite and muscovite; (g), Porphyritic K-feldspar texture of Group III granite; (h,i), Mineral assemblages and texture, quartz, coarse-grained alkali feldspar, biotite, and muscovite. Abbreviations: Qtz, quartz; Kfs, alkali feldspar; Bt, biotite; Pl, plagioclase; Ms, muscovite.

feldspar (60 to 85%), plagioclase (20 to 30%), and micaceous minerals (biotite and muscovite at 3 to 5%) with trace amounts of accessory minerals such as apatite, zircon, and ilmenite (1 to 2%) (Fig. 2(d) and Fig. 3(a)). Alkali feldspar phenocrysts ranged in size from 0.5 to 1.0 cm as subhedral to anhedral crystals with a perthitic texture. Quartz ranged from 0.2 to 0.5 mm and infrequently showed myrmekite and recrystallization textures. Plagioclase was fine-grained, lath shaped, and elongate with fine-grained alkali feldspar and quartz. Biotite displayed foliation and was always associated with muscovite (Fig. 2(e) and 2(f)).

Group III as granite “sensu stricto” consisted largely of quartz (25 to 55%), alkali feldspar (30 to 60%), and plagioclase (10 to 30%) with small amounts of biotite, muscovite, apatite, and zircon (3 to 5%) (Fig. 2(g) and Fig. 3(a)). The granite was coarse-grained with porphyritic texture of alkali feldspar phenocrysts (1.0 to 2.0 cm) and a groundmass of plagioclase, quartz, and biotite. The alkali feldspar phenocrysts were subhedral to anhedral crystals with perthitic and poikilitic textures and were always replaced by sericite. The plagioclases were subhedral to euhedral (0.25 to 0.50 mm). The biotite was flaky, exhibited a lamellar shape of brown to medium brown, and had moderately marked pleochroism from brown to dark brown consisting of zircon and apatite. Muscovite formed with biotite (Fig. 2(h) and 2(i)). The quartz was always anhedral and was formed later in the crystallization path among alkali feldspar, plagioclase, and biotite.

The Groups I quartz monzonite and the Group II quartz syenite displayed well-defined foliations of plagioclase, alkali feldspar, quartz, and biotite. The foliation texture of these rocks formed as a result of movement along the Klaeng fault zone. The granites of Group III intruded into granitic rocks in Groups I and II.

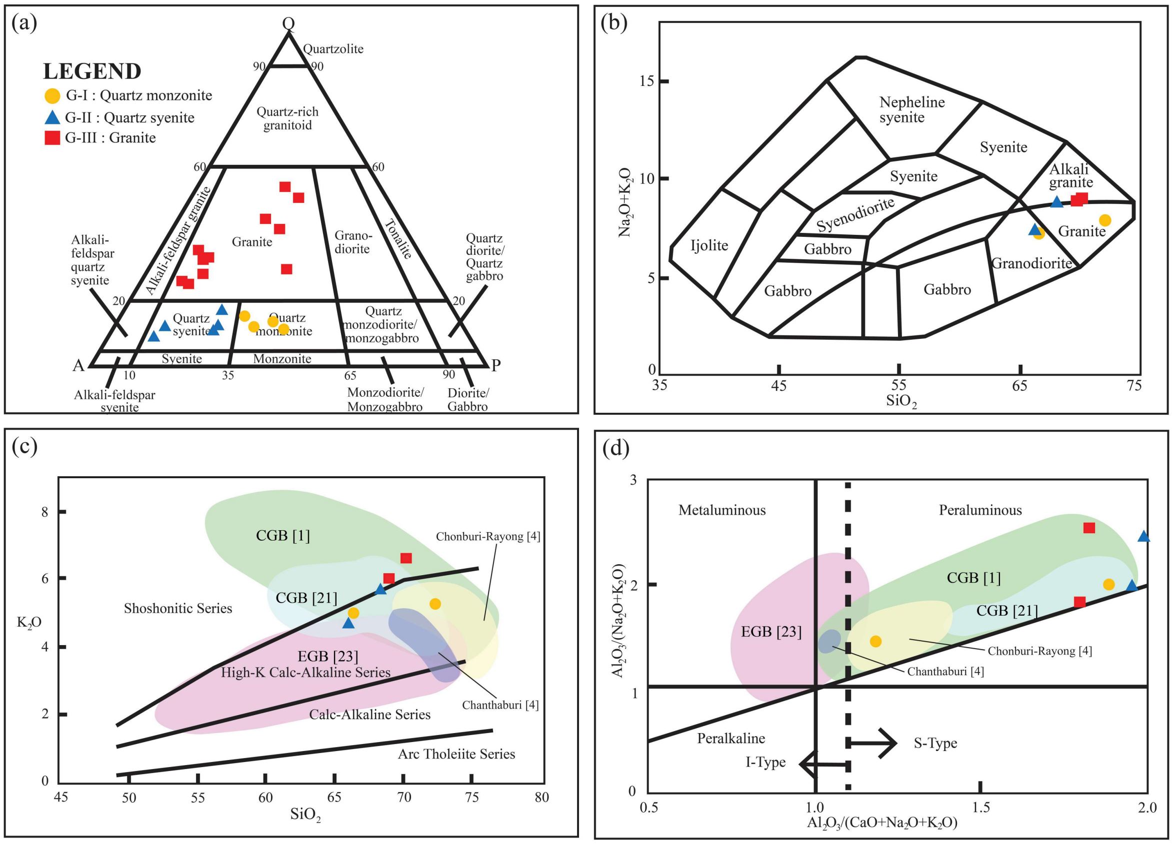


**Fig. 3** (a), Granitic samples in the study area separated into three groups: G I quartz monzogranite, G II quartz syenite, and G III granite; (b), Discrimination diagram of plutonic rocks from whole-rock geochemical data from the three granite groups; (c), Diagram plots of $SiO_2$ against $K_2O$; (d), Diagram plots of Al/(Ca+Na+K) against Al/(Na+K). The yellow shade, light blue shade, and green shade of the CGB were from data reported by [1, 4, 21], while the red shade and blue shade of the EGB were from data reported by [4, 23].

## Geochemistry of granitic rocks in the Bang Tha Cham area

Geochemical data of major, trace, and rare earth elements of the granites from Groups I, II, and III are shown in Tables 1 and 2. Group I (quartz monzonite), Group II (quartz syenite), and Group III (granite) showed $SiO_2$ compositions ranging from 69.34 to 70.63 wt%, 65.87 to 68.13 wt%, and 66.28 to 72.60 wt%, respectively. The granites of Group I and Group II had a lower $Na_2O+K_2O$ contents than the granite of Group III. By contrast, the quartz monzonite of Group I and the quartz syenite of Group II showed higher CaO contents than the granite of Group III which had lower MgO (0.83 to 1.20 wt%), $TiO_2$ (0.23 to 0.35 wt%), and $Fe_2O_3$ (2.52 to 3.52 wt%) than the quartz syenite of Group II (1.46 to 2.84 wt% of MgO, 0.35 to 0.72 wt% of $TiO_2$, and 3.93 to 5.50 wt% of $Fe_2O_3$) and the quartz monzonite of Group I (0.34 to 2.70 wt% MgO, 0.18 to 0.60 wt% TiO2, and 2.07 to 4.19 wt% Fe2O3). These major and minor compositions showed clear mineral assemblages as quartz, K-feldspar, plagioclase, and biotite. The TAS diagram plot of $SiO_2$ against alkali ($Na_2O+K_2O$) of these granitic rocks (Fig. 3(b)) showed that the studied rocks fell within the granite field with some granodiorite compositions. The plot of $K_2O$ against the $SiO_2$ diagram revealed that the granitic rocks were mainly high-K calc-alkaline to shoshonitic series (Fig. 3(c)), while the plot of Al/(Ca+Na+K) versus Al/(Na+K) demonstrated that the rocks could be classified as peraluminous S-type granite (Fig. 3(d)). Harker variation diagrams of Zr versus major oxides and other elements showed negative correlations of $SiO_2$, $K_2O$, $Na_2O$, $Al_2O_3$, and $P_2O_5$; but positive correlations of $Fe_2O_3$, $TiO_2$, Sr, and Ba were observed between the granite, quartz syenite, and quartz monzonite (Fig. 4). The diagrams illustrated similar trends in individual groups, probably reflecting some relationship of the magmatic sources. The chondrite-normalized REE pattern with chondrite-normalized La/Yb ratios (9.28 to 20.44) exhibited slight enrichment from LREE and depleted

**Table 1** Representative whole-rock geochemical analyses of granitic rocks in the Bang Tha Cham area, Chonburi Province, Thailand (major and minor oxides).

| Rocks | G-I : Quartz monzonite | | G-II : Quartz syenite | | G-III : Granite | |
|---|---|---|---|---|---|---|
| Sample No. | CGH-05 | CGH-08 | CGH-01 | CGH-06 | CGH-09 | CGH-11 |
| Major and minor oxides (wt%) | | | | | | |
| $SiO_2$ | 72.60 | 66.43 | 68.13 | 65.87 | 69.34 | 70.63 |
| $Al_2O_3$ | 16.04 | 16.11 | 16.99 | 16.47 | 16.30 | 16.33 |
| $Fe_2O_3$ | 2.07 | 5.34 | 3.93 | 5.50 | 3.52 | 2.52 |
| CaO | 0.47 | 1.12 | 0.53 | 1.30 | 0.47 | 0.41 |
| MgO | 0.34 | 2.70 | 1.46 | 2.84 | 1.20 | 0.83 |
| $Na_2O$ | 2.72 | 2.35 | 2.58 | 2.25 | 2.34 | 2.16 |
| $K_2O$ | 5.25 | 4.89 | 5.59 | 4.58 | 6.08 | 6.54 |
| $P_2O_5$ | 0.15 | 0.14 | 0.16 | 0.15 | 0.16 | 0.14 |
| $TiO_2$ | 0.18 | 0.60 | 0.35 | 0.72 | 0.35 | 0.23 |
| LOI | 1.44 | 2.33 | 1.89 | 2.20 | 1.69 | 1.60 |
| Total | 99.82 | 99.68 | 99.72 | 99.68 | 99.76 | 99.79 |

**Table 2** Trace elements and REE of granitic rocks in the Bang Tha Cham area, Chonburi Province, Thailand.

| Rocks | G-I : Quartz monzonite | | G-II : Quartz syenite | | G-III : Granite | |
|---|---|---|---|---|---|---|
| Sample No. | CGH-05 | CGH-08 | CGH-01 | CGH-06 | CGH-09 | CGH-11 |
| Trace elements (ppm) | | | | | | |
| Rb | 372.10 | 485.00 | 362.20 | 351.40 | 343.20 | 430.40 |
| Y | 71.80 | 76.10 | 72.10 | 71.80 | 71.30 | 73.80 |
| Zr | 234.30 | 226.50 | 310.80 | 321.20 | 276.30 | 174.70 |
| Nb | 14.40 | 15.00 | 14.40 | 14.30 | 14.70 | 150.00 |
| La | 5.38 | 6.92 | 17.68 | 8.62 | 3.46 | 0.64 |
| Ce | 13.61 | 13.80 | 37.04 | 16.32 | 5.86 | 1.47 |
| Pr | 1.51 | 1.62 | 4.65 | 1.94 | 0.71 | 0.20 |
| Nd | 5.54 | 5.93 | 17.22 | 7.13 | 2.60 | 0.75 |
| Sm | 1.25 | 1.19 | 3.77 | 1.44 | 0.54 | 0.20 |
| Eu | 0.06 | 0.14 | 0.24 | 0.15 | 0.04 | 0.01 |
| Gd | 1.21 | 1.64 | 3.89 | 1.85 | 0.76 | 0.27 |
| Tb | 0.15 | 0.18 | 0.45 | 0.21 | 0.08 | 0.03 |
| Dy | 0.76 | 0.76 | 1.86 | 0.89 | 0.36 | 0.13 |
| Ho | 0.14 | 0.13 | 0.31 | 0.15 | 0.06 | 0.02 |
| Er | 0.44 | 0.38 | 0.86 | 0.42 | 0.19 | 0.06 |
| Tm | 0.06 | 0.04 | 0.10 | 0.05 | 0.02 | 0.01 |
| Yb | 0.39 | 0.28 | 0.58 | 0.29 | 0.14 | 0.04 |
| Lu | 0.05 | 0.04 | 0.07 | 0.04 | 0.02 | 0.01 |
| Sc | 0.66 | 0.67 | 1.37 | 0.94 | 0.18 | 0.06 |

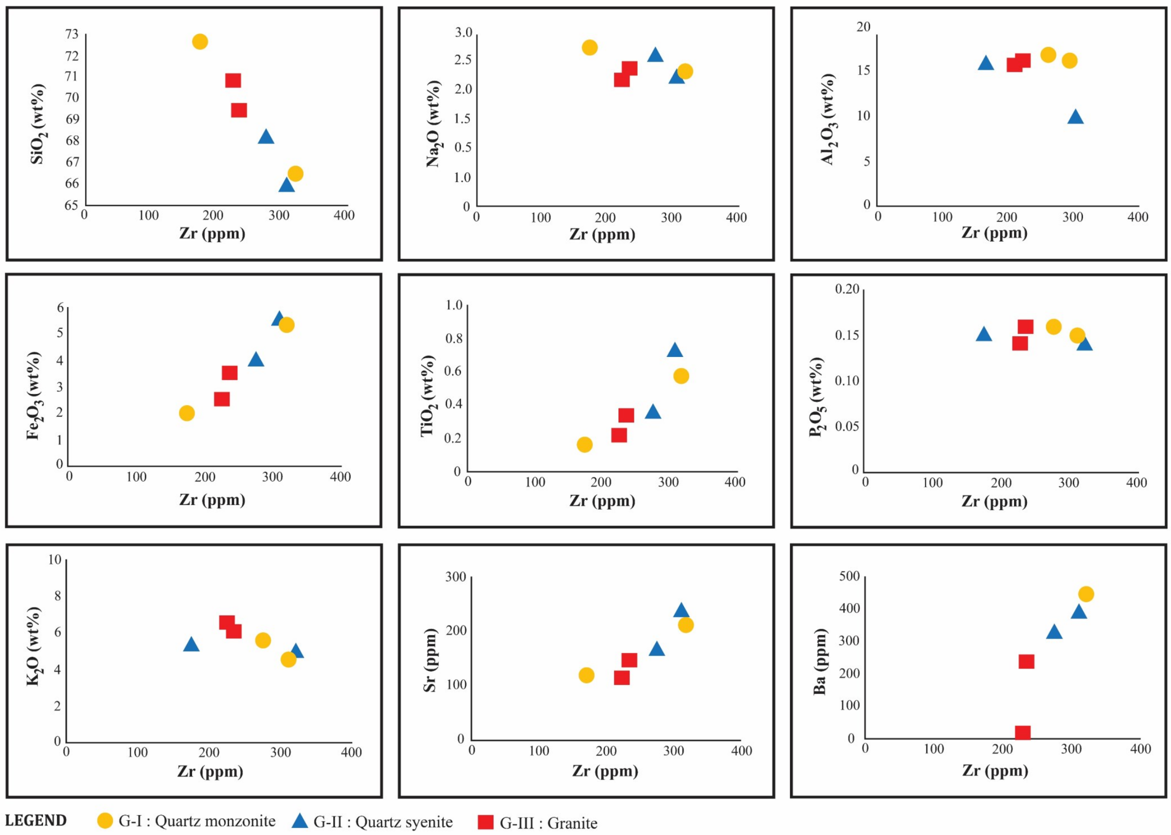


**Fig. 4** Harker variation diagram plots of Zr against other major and minor oxides of the studied granitic rocks from Bang Tha Cham area, Chonburi Province, Thailand.

HREE with negative Eu in chondrite-normalized REE patterns, similar to the pattern of the Central Granite Belt (Fig. 5(d)).

### Crystallization P-T conditions and intrusion depths

The equilibration pressure and temperature (P-T) of plutonic rocks can be measured by numerous geothermobarometers. The P-T conditions of granitic rocks in the Bang Tha Cham area were calculated using the Al-in biotite geobarometer and Ti-in biotite geothermometer [18, 19], respectively. Crystallization pressure was calculated using the Al-in biotite geobarometer pressure (P) of the granitic rocks. Following the equation from [18], the calculated pressures of Groups I and III ranged from 10.4 to 10.9 kbar ($P_{avg}$ = 10.6 kbar), with Group II ranging from 3.0 to 3.2 kbar ($P_{avg}$ = 3.1 kbar). In terms of crystallization temperature, the Ti-in biotite geothermometer of [19] was used to calculate the crystallization temperature (T) of the granitic rocks. The calculated temperatures of granitic rocks of Groups I and III ranged from 300 to 483 °C and 723 to 732 °C for Group II. Results differed among the groups, with granitic rocks showing moderate metamorphism and recrystallization along the Klaeng tectonic line. The intrusion depth of the granitic rocks in the study area was estimated based on the calculated crystallization pressures ($P$) using the equation: $P = \rho g h$, where $P$ = pressure (GPa), $\rho$ = continental crust density (2.73 kg/m$^3$), $g$ = specific gravity (10.0 m/s$^2$), and $h$ = depth (km) [20, 21]. The intrusion depths were determined from the calculated pressures using Al-in biotite geobarometry of the granites, with mean depths of the plutons estimated at 10.8 to 12.8 km for the granitic rocks in the study area. These intrusion depths were also consistent with the calculated temperatures of the granitic rocks which were compatible with the temperature range of the middle to upper crust, conforming to the general continental crust.

### Tectonic implications

The petrographic characteristics of Group I and Group II granites were shown by the foliation textures, suggesting that the igneous rocks were metamorphosed and recrystallized along the Klaeng tectonic fault line [4, 6, 12]. The Group III granite was characterized by the porphyritic textures of alkali feldspar and megacrystic biotite granite with the appearance of

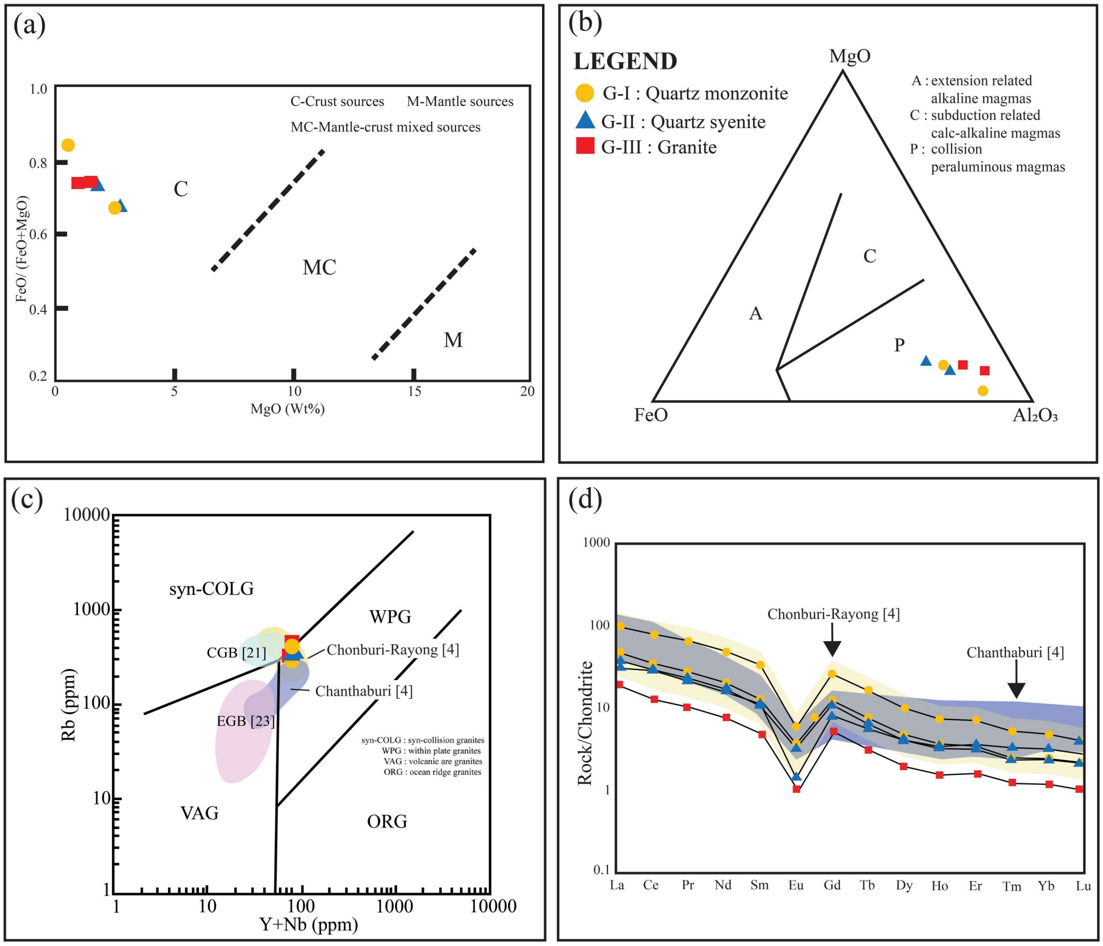


**Fig. 5** (a), MgO against FeO/(FeO+MgO) showing G-I, G-II and G-III plotted in crust source; (b), Ternary of FeO-MgO-$Al_2O_3$ showing G-I, G-II and G-III plotted in collision peraluminous magmas using trace-element based geotectonic classification of granitoids; (c), Y+Nb against Rb showing G-I, G-II and G-III plotted in syn-collision granites to within plate granites; (d), Chondrite normalized REE patterns of granitic rocks from G-I, G-II and G-III showing patterns similar to granites in the CGB [4].

ilmenite in the rocks. The granites were classified as ilmenite series [2, 22] with contents of rare earth minerals (monazite and xenotime) and were consistent with the classification of granites in the CGB [2, 8, 21]. The tectonic setting for the magmato-tectonic environment in the Bang Tha Cham area was inferred from the geochemical result of whole rocks and the previous study reports of CGB and EGB [1, 4, 21, 23]. The TAS diagram (Fig. 3(b)) indicated that these rocks had subalkali compositions, comparable to the CGB field. The $SiO_2$ and $K_2O$ plot (Fig. 3(c)) indicated that these granitic rocks corresponded to high-K calc-alkaline series to shoshonitic series. Ternary plots of Al/(Ca+Na+K) against Al/(Na+K) suggested that the granitic rocks were peraluminous magmas and related to collision (Fig. 3(d) and Fig. 5), while plots of immobile elements (Fig. 5(b) and 5(c)) suggested that these granitic rocks resulted from syn-collision to within-plate granites. The chondrite-normalized REE pattern (Fig. 5(d)) in the study area was comparable to Triassic granites in Chonburi and Rayong Provinces with REE fractionation and relative enrichment of light REEs comparable to syn- and post-collision granites [4]. Based on the tectonic discrimination diagrams (Fig. 3 to Fig. 5), the granitic rocks in the Bang Tha Cham area were comparable to the CGB [4], which originated from syn-collision crustal and subsequent post-collision orogenic events after the closure of the Paleotethyan during the Late to Middle Triassic age (200 to 237 Ma) [4, 5, 13].

## CONCLUSION

Based on our field investigations, the data obtained from petrography and modal analyses suggested that granitic rocks in the Bang Tha Cham area belonged to the CGB and could be classified into three groups as quartz monzonite (Group I), quartz syenite (Group II), and granite (Group III). Group I and Group II showed foliation textures, corresponding to the almost northwest-southeast trending Klaeng Fault zone. The granite of Group III intruded into the quartz monzonite of Group I and the quartz syenite of Group II. Crystallization pressure-temperature (P-T) conditions of the granitoid in the Bang Tha Cham area were estimated at 10.4 to 10.9 kbar and 300 to 483 °C. Moreover, the granitoid was moderately metamorphosed and recrystallized during the Klaeng tectonic era, with estimated crystallization pressure-temperature (P-T) conditions of 3.0 to 3.2 kbar and 723 to 732 °C. The granitoids in Bang Tha Cham area, Chonburi Province could be classified as peraluminous S-type granites and were formed by high K-calc alkaline magmas of the Central Granite Belt which intruded as both syn-collisional and post-collisional after the closure of the Paleothethyan in Triassic times.

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