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Geochemistry of Permian Kuantan Granite Peninsular Malaysia: Implication to Highly Fractionated I-Type Granite

(Geokimia Permian Granit Kuantan Semenanjung Malaysia: Implikasi kepada Granit Jenis I Berfraksinasi Tinggi)

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ABSTRACT

The 262.0 ± 1.7 Ma Kuantan granite of the Peninsular Malaysia Eastern Belt comprises coarse-grained biotite monzogranite and syenogranite. The granite marked the earliest subduction-related magmatic intrusion during the collision of the Sibumasu and Indochina blocks. This paper reported whole-rock geochemical data of Kuantan granite to constrain the magma source and petrogenesis of the granite. The Kuantan granite stands out due to its elevated SiO_2 concentration, surpassing 72%. It also exhibits high levels of K_2O, ranging from 4.51% to 6.5%. The A/CNK value falls between 1.01 and 1.08, and there are notable negative Eu anomalies that range from 0.05 to 0.27. Together with other older fractionated I-type granites in the easternmost Peninsular Malaysia, they formed distinct granitic facies from the eastern Belt granite proper. This study suggests that the Permian highly fractionated I-type granites resulted from the partial melting of intra-crustal mafic rocks, while the primitive I-type granitic melts underwent significant fractional crystallization.

Keywords: Eastern belt granite; fractionated I-type granite; Kuantan granite; Peninsular Malaysia granite

ABSTRAK

Granit Kuantan berumur 262.0 ± 1.7 juta tahun terletak di Jaluran Timur Semenanjung Malaysia terdiri daripada monzogranit dan syinogranit butiran saiz pertengahan ke sangat kasar. Granit ini menandai magma penerobos yang terawal terkait dengan subduksi semasa perlanggaran antara blok Sibumasu dan Indochina. Kertas ini melaporkan data geokimia batuan granit Kuantan untuk merungkaikan asalan magma dan proses kejadiannya. Granit Kuantan dibezakan oleh ketinggian kandungan SiO_2nya melebihi 72%. Ia juga menunjukkan aras ketinggian K_2O daripada 4.51% hingga 6.5%. Nilai A/CNK berada antara 1.01 dan 1.08 dan terdapat anomali Eu negatif yang ketara pada julat dari 0.05 ke 0.27. Bersama dengan granit tua jenis I berfraksinasi di bahagian paling timur di Semenanjung Malaysia yang lain, mereka membentuk fasis granit yang berbeza berbanding dengan granit Jaluran Timur berhampiran. Kajian ini mencadangkan bahawa granit Permian jenis I berfraksinasi tinggi ini dihasilkan daripada batuan mafik di dalam kerak yang dicairkan separa dan kemudiannya granit jenis I yang lebih tua ini mengalami perubahan fraksinasi habluran yang ketara.

Kata kunci: Granit jaluran timur; granit jenis-i berfraksinasi; granit Kuantan; granit Semenanjung Malaysia

INTRODUCTION

Highly fractionated granitoid rocks, which include A-, I-, and S-types, often exhibit a tendency to converge towards the composition with the lowest temperature (Chappell 1999). Such felsic granitic rocks have very high SiO_2 content (73-77%), high total alkalis (K_2O + Na_2O), low MgO, P_2O_5, and Fe_2O_3 (Wu et al. 2020). Many highly fractionated granites contain abundant miarolitic cavities associated with aplopegmatite dykes and quartz tourmaline pegmatitic clots, which suggests a shallow levels emplacement (Jamil et al. 2016; Wu et al. 2003). Many S- and I-type fractionated granitoid show overlap characteristics with A-type granite (Pérez-Soba & Villaseca 2010). This is due to the extended fractional crystallization; they both show the same compositional and mineralogical features.The fact that they both I- and S-type granite overlap in composition and mineralogy makes it difficult to distinguish the high fractionated granite from the A-type granite. This paper reports a comprehensive analysis of the composition and age determination of the felsic Kuantan granite, located to the east of Peninsular Malaysia. Thus, the aim of this paper was to present and discuss the possible reasons for the geochemical affinity of the extensive fractionation of Kuantan granite I-type magma, as opposed to A-type magma, which may represent a different granitic facies compared to the Eastern granite proper.

GENERAL GEOLOGY

The original subdivision of the granitic rocks from Malaysia Peninsular, Thailand, and Myanmar (Hutchison 1983, 1973; Mitchell 1977) consists of four granite provinces: (i) Eastern (granite in the Eastern Belt of the Malay Peninsula), (ii) Main Range (tin granite from the western Malay Peninsula and southern Thailand), (iii) Northern (granite from the north of Thailand), and (iv) Western (granite from the southwest of Thailand and Eastern Myanmar) (Figure 1). The (i) and (ii) granites exposed in Eastern and Western Malay Peninsular. The U-Pb zircon dates of the Eastern province granitoid range from 289 to 220 Ma, compared to the Western granitoid (Western of Bentong Raub line) being entirely Late Triassic, spanning 227-198 Ma (Cao et al. 2020; Du et al. 2020; Jamil et al. 2016; Liew & McCulloch 1985; Liew & Page 1985; Liu et al. 2020; Ng et al. 2015b; Quek et al. 2021; Wang et al. 2021; Yu et al. 2022).

The Western Belt granite extends from the north in southern Thailand to Melaka in the south, as well as Bangka and Belitung in Indonesia (Ng et al. 2017). Ghani et al. (2013) and Quek et al. (2015) have shown that the granite, previously considered to be exclusively S-type collisional granite, also contains I-type granite. The Eastern province granite of Malay Peninsular, forming small batholiths and plutons, mainly granodiorite-granite and associated syenite-gabbro intrusions (Cobbing et al. 1992). The Eastern granite province has been interpreted to represent a Permo-Triassic pre-collisional arc-type magmatism and shows a magmatic trend younging towards the west of Malay Peninsular (Liew 1983; Ng et al. 2015a). The older granite (mainly Permian) occurs as a coastal outcrop (Maras Jong and Kuantan granites) or island off the east coast (Besar and Perhentian granites) of Peninsular Malaysia. The eastern Belt has a different kind of granite known as A-type granite, which can be found in the Besar Island group (Ghani et al. 2014). The A-type granite U-Pb zircon age is 280-282 Ma, among the oldest granite magmatisms in Peninsular Malaysia. The presence of shallow magma emplacement, a high Fe_T/MgO ratio and Ga, low CaO, Sr, P, Nb, and Ti, and high predicted zircon saturation temperatures indicate that the Besar granite may be categorized as an A-type granite.

The size of Kuantan granite is less than 30 km^2. The geometry of the Kuantan granite consists of two lobes, the eastern and western lobes (Figure 1), which are partly separated by younger basaltic lavas. The main Kuantan granite pluton creates a ridge in a north-northwest direction, stretching from Teluk Chempedak to Bukit Kecil. Additionally, it shapes the circular hills of Bukit Ubi in the southern region (Yap 1986). The granite intruded into the Late Palaeozoic strata of sandstone, conglomerate, and shale interbedded with ash-flow tuffs and rhyolitic. The granites have been intruded by younger lamprophyric and basaltic dykes ranging from a few cm to a few meters thick (Ghani, Lo & Chung 2013). The youngest formation in the Kuantan area is the Late Cenozoic basalt lava, which extends over the low-lying areas and surrounds the granite hills (Haile et al. 1983) (Figure 1). Chakraborty (1977) divided the Kuantan basalt to three main types that is olivine basalt, limburgite, and olivine nephelinite. Ghani and Taib (2007) suggested that young Kuantan basaltic rocks is a plume related rather than wrench tectonics-induced extension.

Fig 1

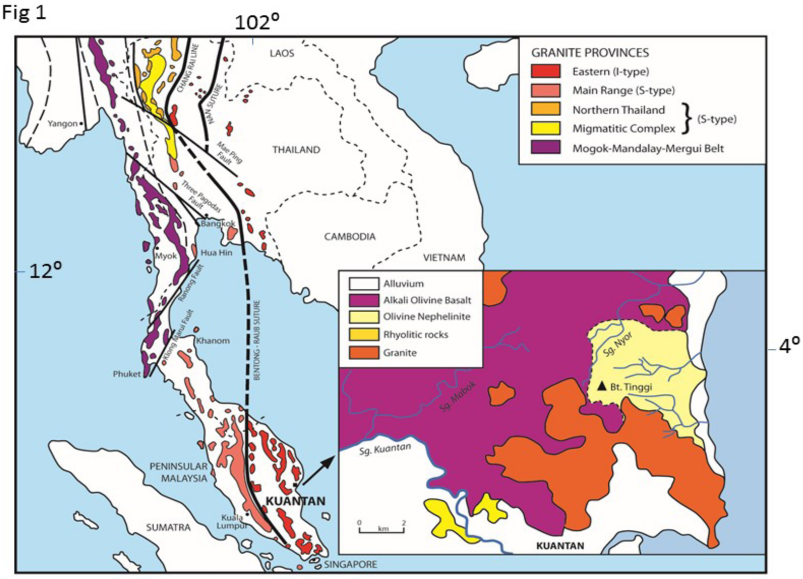


FIGURE 1. Map showing the location and geology of the study area. Subdivision of granitoids from the Southeast Asian Tin Belt (modified from Cobbing et al. 1992)

PETROGRAPHY

The Kuantan granite is typically medium- to very coarse-grained biotite monzogranite and syenogranite. The mineral composition of the Kuantan granite is quartz (~31%), K-feldspar (~33%), plagioclase (~30%), biotite (~up to 10%), and hornblende (~1%). Opaque minerals, zircon, sphene, fluorite, and apatite are among the accessory minerals found in the granite. Quartz is anhedral and interstitial to plagioclase and K-feldspar. Plagioclase occurs as subhedral to crystals with sometimes have zoning and twinning. Alkali feldspars are microcline-microperthite, usually similar in size to quartz and plagioclase. However, in certain parts of the granite, large alkali feldspar crystals (up to 3 cm across) are also present. Biotite is mainly subhedral and the main components of the mafic clot. The pleochroic scheme is Y = straw yellow and X = dark brown. It sometimes associated with sphene, apatite, and zircon. Biotite soletime altered to chlorite which developed along the crystal rims or. Secondary muscovite occurs as tiny crystals present in heavily sericitised parts of plagioclase.

ANALYTICAL METHODS

Ten samples of Kuantan granite were collected and analyzed for major, trace, and rare elements. Each sample was cleaned, dried and crushed using jaw crusher and tema-mill located at the Geology Department, Universiti Malaya. The rocks ware analysed for major, trace and REE elements using ICP-MS and X-Ray Fluorescence (XRF) spectroscopy at the Acme Labs of Bureau Veritas Commodities Canada Ltd.

Analyzed for U-Pb zircon ages was one sample (KN6). The analysis was conducted at NTU Taiwan. Prior to manual selection under a binocular microscope, zircons were extracted using magnetic and density-based separation methods from the host granite. The zircon then were mounted in epoxy resin and polished. The Agilent 7500s quadrupole inductively coupled plasma mass spectrometer, in conjunction with the New Wave UP213 laser ablation system, is used for zircon U-Pb analysis.

RESULTS

ZIRCON U-Pb AGE DATING

The result of U Pb zircon ages for the sample KN6 is plotted in Figure 2. 17 zircons and 20 spots were analyzed for KN6, and 17 spots defined a weighted mean $^{206}Pb/^{238}U$ ages of 262.0 ± 1.7 Ma (MSWD = 1.6), which represents the emplacement age of the granite in the study area. We have excluded the other two spots (11c, 18c) from the weighted average age calculations due to their low Concordia values. They provide an age of 303 Ma, which could potentially indicate a xenocryst or an inherited zircon.

GEOCHEMISTRY

Figure 3 displays the complete rock analysis of the Kuantan granite, along with other granite types found in the Malay Peninsula, such as the Eastern Province and Main Range granites, including the Besar A-type granite (Cobbing et al. 1992; Ghani et al. 2014; Ng et al. 2015a). We included the Besar granite for comparison and discussion, given its unique status as the only A-type granite in Peninsular Malaysia (Ghani et al. 2014). These form a combined data set (n = 103 and n = 71) for both Eastern Belt and Main Range granites, respectively.

The Kuantan granite has a very high SiO_2 content ranging between 72.91 and 76.63 wt% and plots at the felsic end of both Main Range and Eastern Belt granites (Figure 3). The SiO_2 content, however, is slightly lower than that of Besar granite, which consistently has more than 75% SiO_2. On a Y vs. Rb plot (Figure 3(e)), the Kuantan sample plot follow the I type trend. This diagram also discriminates

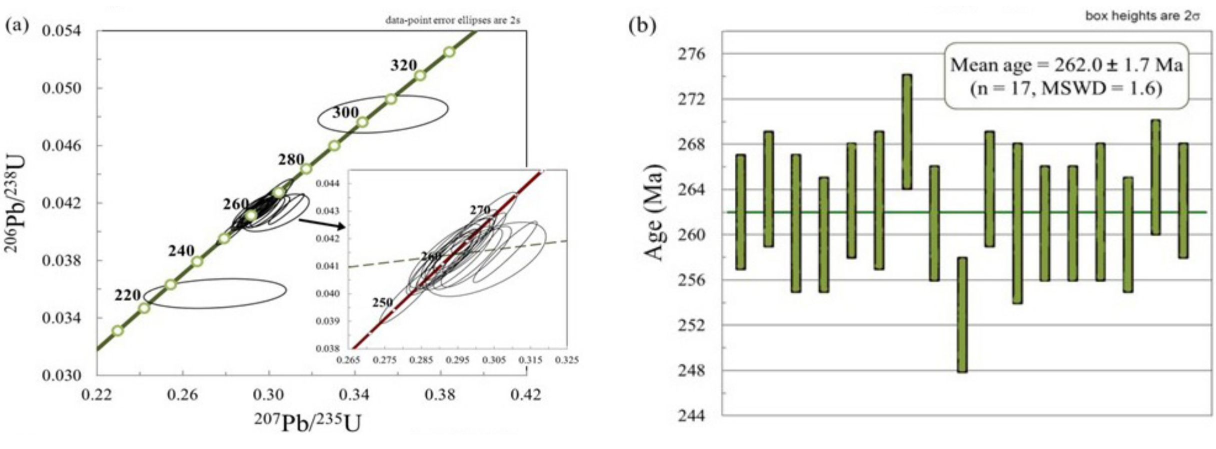


FIGURE 2. Zircon U-Pb concordia and weighted average diagram for sample KN6 from the Kuantan granite

between the Eastern Belt and Main Range granites also have a clear affinities of I-type and S-type, respectively (Figure 4). The Kuantan granite also has very low P_2O_5 (0.006-0.02%), CaO (0.4-1.05%), TiO_2 (0.03-0.12%), and MgO contents (0.03-0.15%). Al_2O_3 contents of the granite range from 12.62-14.05 wt% and ACNK ratios of 1.01 to 1.08 (Figure 4(a)). When comparing Na_2O and K_2O, both the Kuantan and Besar granite samples are located inside the I-type field (Figure 4(b)).

Figure 5(a) and 5(b) shows the REE pattern and trace elements Chondrite-normalized pattern for the Kuantan granite, respectively (Sun & McDonough 1989). The Kuantan granites show variable REE patterns (Figure 5(a)), from the enrichment of light REEs to a typical flat HREE and LREE with a large negative anomaly. This type of REE pattern is similar to other highly evolved granites (Ludington 1981; Whalen 1983). The Kuantan granite samples exhibit significant variations in their $(Gd/Yb)_N$ and $(La/Yb)_N$ ratios, which range from 0.79 to 16.37 and 1.24 to 2.89, respectively. Additionally, these samples show negative Eu anomalies, having Eu/Eu* ratios that vary from 0.05 to 0.27 (Figure 5(a)). The Kuantan granite patterns on the primitive mantle-normalized diagram exhibit an abundance of LILE elements (Th, Rb, U, and K) and a scarcity of HFSE elements (Ti and Nb), along with negative anomalies in Sr and P (Figure 5(b)). The pattern as a whole is alike and well comparable to the Besar A type granite (Ghani et al. 2014).

On Figure 6(a) and 6(b), both samples from Besar granite (A-type granite) and Kuantan granite plot in a clearly different field. Both Kuantan and Besar granites have high SiO_2 (>72%) content and overlap in some major and trace elements. On a Na_2O+K_2O/CaO vs. Zr+Nb+Ce+Y plot, the Besar and Kuantan granites plot in the A-type granite and fractionated granite fields, respectively (Figure 6(a)). All Kuantan samples are located inside the volcanic arc and within plate fields in the comparisons of Rb vs. Nb+Y (Figure 6(b)). The LIL modelling shows that the evolution of the Kuantan magma is controlled by K-feldspar, plagioclase and biotite (Figure 6(c)).

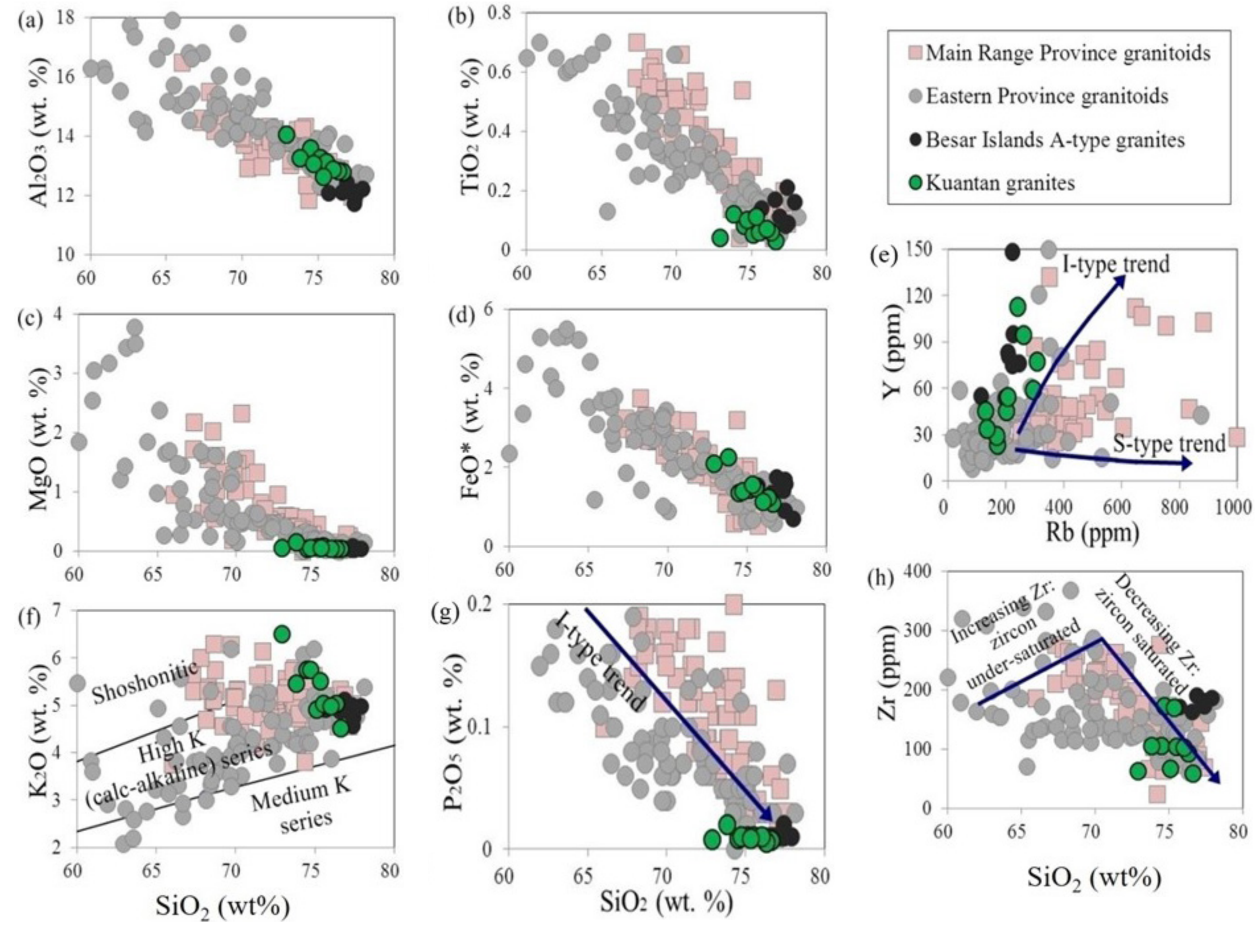
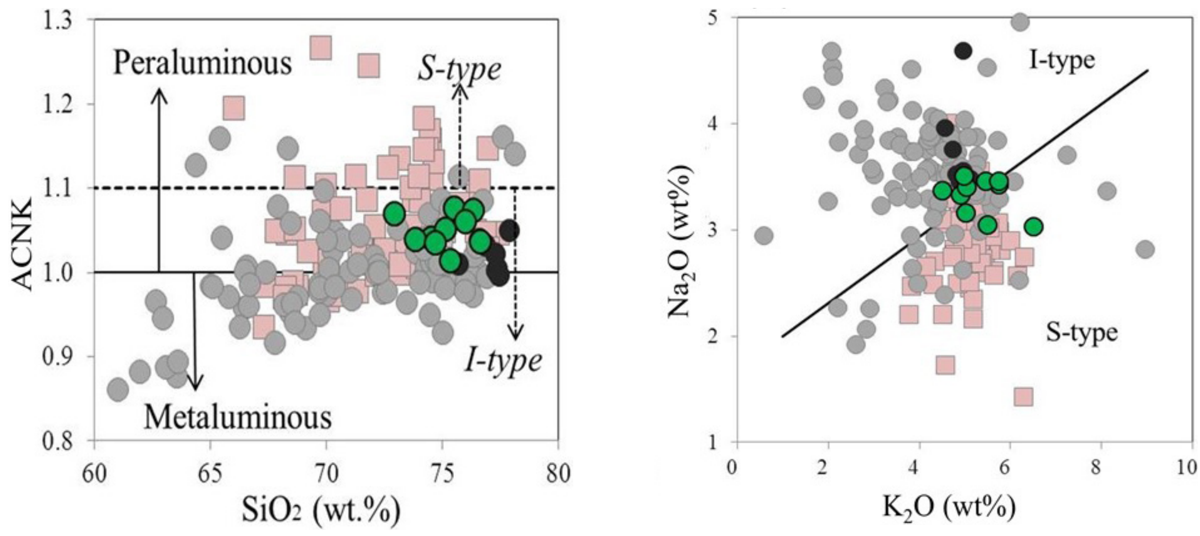


FIGURE 3. Major and trace Harker diagrams of the Kuantan granite and the Besar Island A-type granite. For regional comparison, the Main Range and Eastern Belt granite samples are also plotted in each diagram



(a) (b)

FIGURE 4. (a) ACNK vs. SiO_2 plot; (b) Na_2O vs. SiO_2 plot for the Kuantan granite and Besar Island A-type granite. For regional comparison, the Main Range and Eastern Belt granite samples are also plotted in the diagram

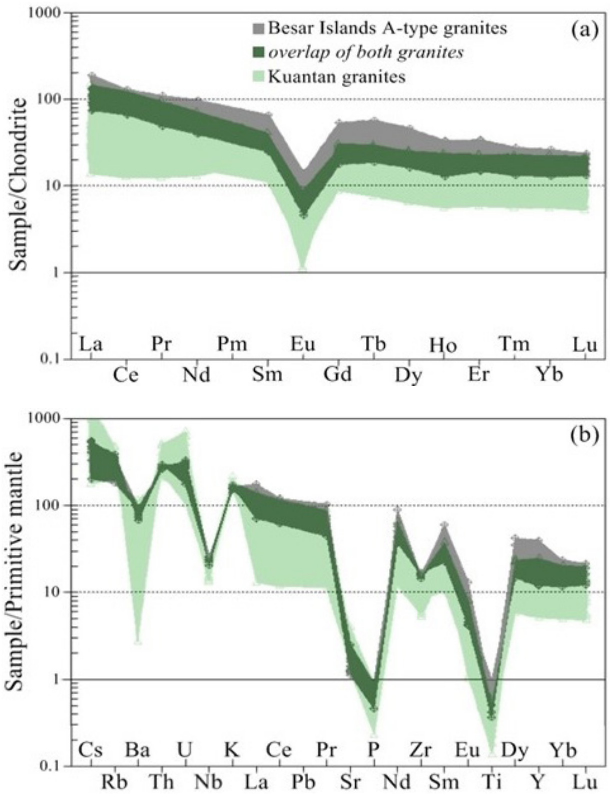


FIGURE 5. REE diagram and Primitive-mantle normalized spidergrams for the Kuantan granite. Elements are arranged in the order of decreasing incompatibility from left to right. The Primitive-mantle values are from Sun and McDonough (1989)

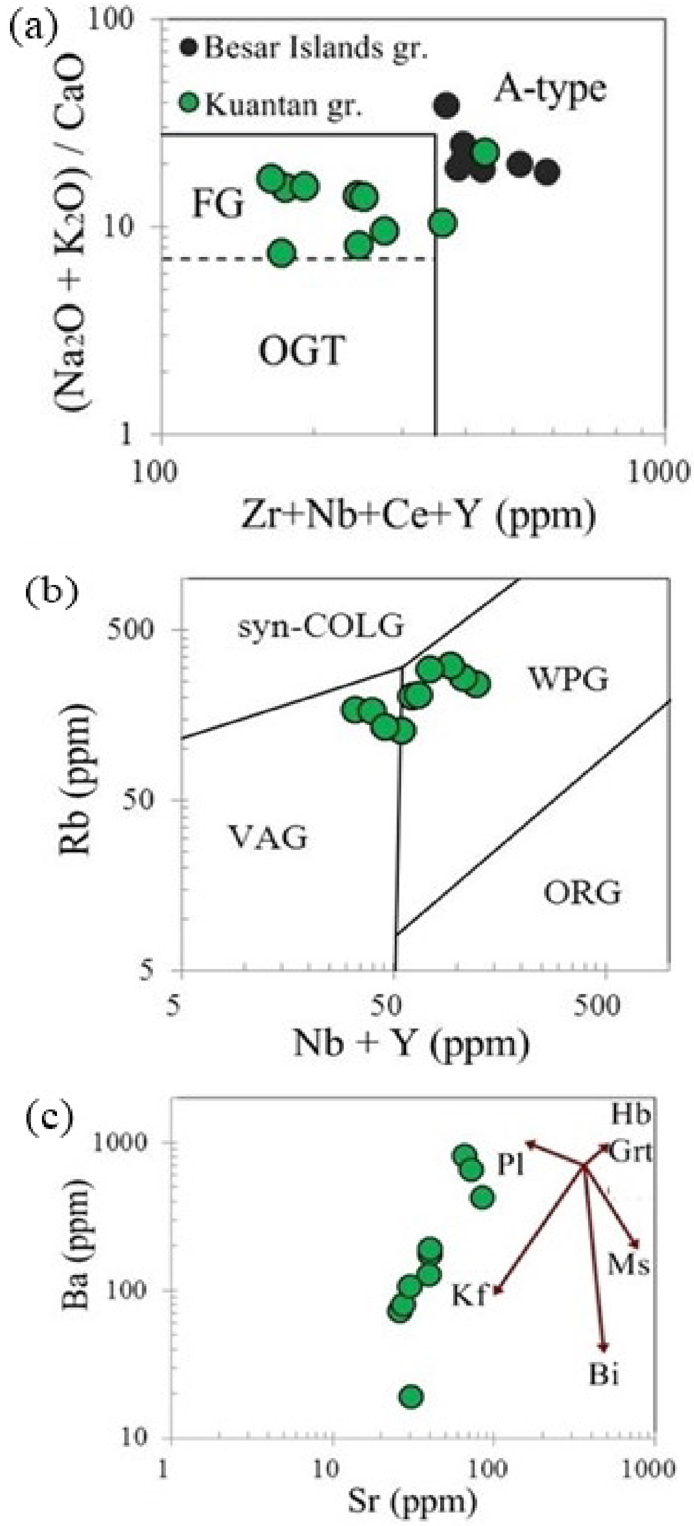


FIGURE 6. Various plots of the Kuantan granite samples (a) Nb vs. 10000*Ga/Al, (b) Rb vs. Nb+Y and (c) Ba vs. Sr log plot

DISCUSSION

The rocks of the Kuantan Granite located in the Permian Eastern Belt Province Suite of Malay Peninsular and have high-K calc-alkaline affinity. The age of the granite is 262.0 ± 1.7 Ma (MSWD = 1.6). It is among the earliest granitic plutons of the Peninsular Malaysian Eastern Belt. In general, the compositions of the Kuantan granites fall within the felsic end-members of the Eastern Province granite, with the SiO_2 composition generally exceeding 72.9%. Another granite that can be grouped in the felsic Eastern Belt is Maras Jong granite (299 Ma), Perhentian Kecil Syenite, and Besar granite (280 Ma) (Ghani et al. 2014; Ng et al. 2015b). Thus, this group represents different granitic facies from the Eastern Belt granite proper, as they have a high SiO_2 content; most of them are Permian in age and located in the easternmost part of Peninsular Malaysia. They are mainly syeno-monzogranite (Streckeisen 1976). The granitic texture and field occurrence similar to the Main Range granite, Malay Peninsular. Among the similar features are occurrence of tourmaline-feldspar pods, biotite-rich enclaves, dark grey microgranite, and porphyritic microgranite enclaves in the Maras Jong granite. Tourmaline-feldspar pods are very common throughout the Western Belt granite, often surrounded by felsic leucogranite rims made up of feldspar and quartz crystals up to 2 to 3 cm thick (Jamil et al. 2016).

The typology of the Kuantan Granite suggest that they are 'I' type granitoid (Chappell & White 1992, 1974). Among the 'I' type features of the Kuantan granite are: (i) hornblende and biotite are present; (ii) muscovite, garnet, monazite, and cordierite are not present; (iii) sphene is present with hornblende; (iv) sedimentary xenoliths are not common; (v) show the typical evolutionary pattern of I-type granites, such as the Rb vs. Y diagram (Figure 3(e)); (vi) the ACNK value is less than 1.1 (Figure 4(a)); and (vii) rocks should have more than 3.2% Na_2O with about 5% K_2O (Figure 4(b)). Points (i) to (vii) confirm that the Kuantan granite is I-type. The I-type fractionated type of Kuantan magma is also supported by very low P_2O_5 contents (0.006-0.02 %) (Figure 3(g)).

High SiO_2 (> 72.9%), Na_2O+K_2O contents, high Rb/Sr (1.86 to 10.10) ratios, high Rb content (129 ppm to 308 ppm) and significant negative anomalies of Ba, Ti, P, and Sr suggest significant fractional crystallization processes operate in the magma (Zhu et al. 2009). The Kuantan granite's composition, which is rich in silica (SiO_2), indicates that it may have originated from a source that is also rich in SiO_2 or it might be the first stage of melting that occurs when a solid containing plagioclase, feldspar, and quartz starts to melt. Evidence of large-scale magma mixing in the Kuantan granite is absent. The occurrence of mafic enclaves and schlieren is only on a local scale, and a large part of the granite is homogeneous which suggest that the magma mixing is not the important mechanism in the granite petrogenesis.

Regionally, the Kuantan and other Permian felsic granites of eastern Peninsular Malaysia can be correlated to Tachileik Granite in eastern Myanmar, which also same U-Pb zircon ages ~ 266 Ma (Gardiner et al. 2018). They suggested that the Tachileik Granite is part of the magmatism in the Peninsular Malaysian Eastern Belt. Nevertheless, the granite's Hf isotope data, with an εHf value of −9.6, indicates significant crustal enrichment. The Permian granite in Peninsular Malaysia, including the Kuantan granite, exhibits a range of zircon εHf(t) values from +0.62 to -5.25. These values suggest that an ancient crustal component with an enriched isotopic signature has mixed with either newly formed material or a depleted mantle source (Ng et al. 2015a). They proposed that the I-type Eastern granitoids exhibit around 20% of sedimentary sources melting, which was assimilated into the parental magma. The tectonic setting of the Permian magmatism of Peninsular Malaysia was linked to plate-margin magmatism. The initiation of the melting of the oceanic plate via a dehydration process occurred during the Early Permian due to the subduction of the Paleotethys oceanic plate under the Indochina block. The parental I-type granitic magma resulting from this process had significant fractional crystallization, leading to the formation of high SiO_2 granite.

CONCLUSIONS

The Kuantan pluton shows an age of 262.0 ± 1.7 Ma. This age ranks among the earliest granitic plutons in the Permo-Triassic Eastern Province granitoids. The Kuantan granites have traits that are common in highly fractionated I-type granites, such as being calc-alkaline, peraluminous, and having high SiO_2 and K_2O levels. Moreover, the notable negative Eu anomalies, are the result of the fractional crystallization of K-feldspar, plagioclase, and biotite. Despite the compositional overlap between the Kuantan and Besar A-type granites, it is suggested that the Kuantan granites originated through significant fractional crystallization of crustal magma. The Permian Kuantan granite can be correlated with the initiation of the early felsic magma melting by the subduction of the Paleotethys oceanic plate under the Indochina block. However, the Kuantan granite lacks several characteristics often associated with the I type, such as a shallow depth of magma placement, high levels of Ga and FeT/MgO ratio, low levels of CaO, Sr, P, Ti, Nb, and high calculated zircon saturation temperatures remains to be resolved.

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