



Geochemistry and K/Ar results of the Mesozoic-Cenozoic plutonic and volcanic rocks from the Meratus Range, South Kalimantan

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Abstract: New geochemical and K/Ar data of the plutonic and volcanic rocks from the Meratus Range are presented. The data show that three main periods of magmatic activities occurred in this area, i.e., Lower Cretaceous (131–103 Ma) represented by granitoid rocks, Upper Cretaceous (82–66 Ma) characterised by volcanic/subvolcanic and granitoid rocks, and Upper Paleocene-Lower Miocene (62–19 Ma) represented by volcanic and subvolcanic rocks. Although some samples show plagiogranites, which may have been derived from an oceanic basaltic magma, the Lower Cretaceous granitoid rocks are mostly calc-alkaline, I-type, subducted related volcanic arc granite (VAG). Preliminary geochemical studies on the Upper Cretaceous and Tertiary volcanics and subvolcanics confirm that they were produced in an island arc environment. The Upper Cretaceous volcanics vary from medium-K basalt to medium- and high-K andesite and dacite and the Tertiary volcanics, except one sample of low-K basalt, are medium-K basalt, andesite and dacite. Except the low-K Tertiary basalt, those two volcanics are enriched in LILE (Ba, Rb, Th and K), LREE (La, Ce and Nd) and depleted Nb relative to K and La. However, unlike many other subducted related rocks, part of the Upper Cretaceous andesite and most of the Tertiary volcanics have high MgO concentrations. While the high MgO Upper Cretaceous volcanics may have been produced in an immature island arc, the origin of the Tertiary high MgO volcanics is still open for discussion. Considering the tectonic evolution of the Meratus Range, the Tertiary high MgO volcanics might have resulted from a reaction between ascending melts and hot mantle peridotite.

Abstrak: Data baru geokimia dan K/Ar dari Pegunungan Meratus, Kalimantan Selatan disajikan. Data ini menunjukkan adanya tiga perioda utama kegiatan magma: Kapur Awal (131–103 jtl) diwakili oleh batuan granitan, Kapur Akhir (82–66 jtl) dicirikan oleh batuan vulkanik/dan granitan, dan Paleocene Akhir-Miosen Awal (62–19 jtl) diwakili oleh batuan vulkanik dan subvulkanik. Walaupun sebagian batuan granitan tergolong di dalam plagiogranit, sebagai turunan batuan basalt oseanik, batuan granitan Kapur Awal merupakan batuan busur kepulauan, bersifat kalk-alkali, tipe-I (VAG). Demikian pula ciri geokimia batuan vulkanik/subvulkanik Kapur Akhir dan Tersiernya menunjukkan bahwa mereka terbentuk di lingkungan busur kepulauan. Batuan vulkanik Kapur Akhir bervariasi dari basalt-K sedang, andesit K-sedang dan tinggi sampai dasit, sedangkan Batuan vulkanik Tersier, kecuali satu contoh basalt-K rendah, berupa basalt- dan andesit-K sedang serta dasit. Kecuali satu contoh basalt-K rendah, kedua kelompok batuan itu kaya akan kandungan LILE (Ba, Rb, Th dan K), LREE (La, Ce dan Nd) dan dicirikan oleh deplesi Nb relative terhadap K dan La. Namun demikian tidak seperti layaknya batuan gunungapi busur kepulauan yang lain, sebagian batuan vulkanik/subvulkanik Kapur Akhir dan umumnya batuan yang Tersier mengandung magnesium tinggi. Sementara batuan vulkanik bermagnesium tinggi yang berumur Kapur Akhir barangkali terbentuk di busur kepulauan yang masih "immature", genesa batuan bermagnesium tinggi yang berumur Tersier masih perlu didiskusikan. Dengan mempertimbangkan evolusi tektonik daerah Kalimantan Selatan, Batuan Gunungapi Tersier bermagnesium tinggi ini diduga sebagai hasil reaksi antara magma dan mantel peridotit panas.

INTRODUCTION

The relationship between the geochemistry of volcanic and plutonic rocks and their tectonic settings has long been recognised. Geochemical criteria for identification of the paleotectonic setting of ancient volcanic sequences and plutonic rocks

have been proposed by several workers (e.g., Pearce and Cann, 1973; Pearce *et al.*, 1975, 1977; Mullen, 1983; Pearce *et al.*, 1984; Meschede, 1986). However the overall geological setting, such as, the nature of the basement and the tectonic development are needed to consider. The composition of basaltic magmas is dependent upon their source

composition, the depth and degree of partial melting, the mechanism of partial melting and the various fractionation and contamination processes they may have undergone en route to the surface. One of the most complex problem of magma generation is basalt and related differentiated rocks generated in a subduction zone environment. It is generally agreed that the process of magma generation in this environment is a multistage multisource phenomenon (e.g., Kay, 1984; Arculus and Powell, 1986).

Plutonic and volcanic rocks are widely exposed throughout the Meratus Range of South Kalimantan. They consist of sub-parallel, NE-SW trending of granitoid, volcanic, and ultramafic rocks. A number of geologists (Katili, 1973, 1975; Hamilton, 1979) believed that the Meratus Range is a subduction related complex of Cretaceous age, that extend through Central Java to Sumatra. However detailed data on the subduction complex of South Kalimantan are very poor.

As part of the *Proyek Kajian dan Informasi Geologi Tematik (PKIGT)* undertaken by the Indonesian Geological Research and Development Centre, Department of Mine and Energy, a field study and sampling programme in the Meratus Range (including Pulau Laut) has been done since 1994. The results of K-Ar and geochemical analyses of the plutonic and volcanic rocks are presented here to understand the tectono-magmatic evolution of this area.

SAMPLES AND ANALYTICAL PROCEDURES

Fresh samples are difficult to collect because of the very dense vegetation and highly weathered volcanic formations. In order to get the best samples, most of the sample were taken from road cuts, big boulders or river floats. The samples analysed here are selected samples collected during field work in 1994–1997. Complete results of the analyses are available in the *PKIGT* and the authors.

Geochemical Analyses

Major and trace element analyses were done at the University of Tasmania, Australia and the Tsukuba University, Japan. Weathered surfaces were removed before rock samples were crushed into coarse-grained gravel in a steel jaw crusher. About 50–80 gram of selected fresh grains were then ground in a tungsten-carbide swing mill. Major elements were measured from glass discs, which were prepared with 0.7 gram sample powder, 3.75 gram lithium borate flux, and 0.05 gram lithium

nitrate (Norris and Chappel, 1967), using an automated Phillips PW 1480 X-Ray fluorescence spectrometer. Trace elements were also analysed using this spectrometer, which were measured from pressed powder pills backed by boric acid. Volatile components (loss on ignition) were determined by heating 1–1.5 gram sample powder to 1,000°C overnight. Rare earth elements (REE) were determined using an ion-exchange XRF technique. The detailed procedure followed for determining the REE is presented by Robinson *et al.* (1986). Accuracy and precision were monitored using a variety of national standard and international standard rocks.

K-Ar Analyses

K-Ar mineral datings were done in the K-Ar laboratory, the Indonesian Geological Research and Development Centre in Bandung. Thin section examinations were done before the rock samples were crushed into -72+150 or -100+200 mesh (depending on the grain size of the minerals). The argon was extracted by fusion under vacuum and the isotopic composition was measured by mass spectrometry. The potassium concentration was determined by flame photometry following the method described by Cooper (1963). The constant used in age calculations are from Steiger and Jager (1978).

REGIONAL GEOLOGY OF SOUTH KALIMANTAN

The area of study belongs to the mainland of Kalimantan (Meratus Complex) and Pulau Laut (Fig. 1). Geology of the area have been studied by Krol (1920), Sumarsono (1984), Sikumbang (1986), Sikumbang and Heryanto (1994), Heryanto and Sanyoto (1994), Supriatna *et al.* (1994) and Rustandi *et al.* (1995). The following discussions of the regional geology is largely based on these reports.

The oldest rocks in the study area comprises pre-Cretaceous ultramafic and metamorphic basement. The ultramafic rocks consist of harzburgite, peridotite, serpentinite and gabbro. The metamorphic rocks, on the other hand, comprise hornblende schist, mica schist, epidote schist, glaucophane schist and amphibolite. These basement rocks are intruded by Early-Late Cretaceous granitoids and unconformably overlain by Cretaceous clastic (the Pitap Formation) and carbonate (the Batu Nunggal Limestone) sediments, and volcanics (the Haruyan Volcanics).

The Pitap Formation which is made up of sandstone, conglomeratic sandstone, claystone, chert with limestone intercalations containing

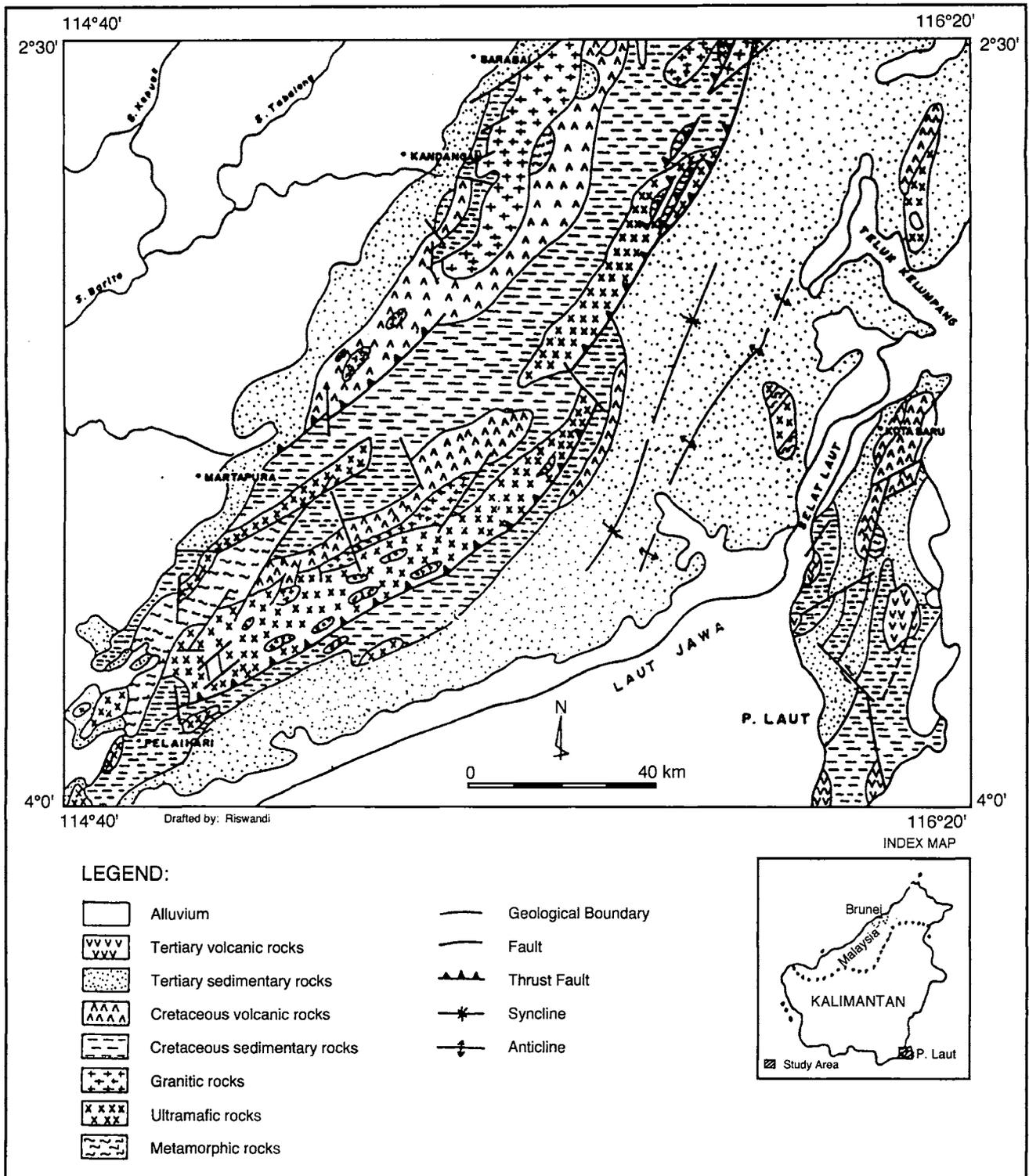


Figure 1. Schematic geological map of the Meratus Range (simplified from Supriatna *et al.*, 1994). Also shown is the location of study area.

fossils of *Radiolaria*, was possibly deposited in a fore-arc region (Heryanto and Sanyoto, 1994). The unit interfingers with the Cretaceous Haruyan arc volcanics, which was deposited in a marine environment. Rocks of this formation have been intensely folded with steeply dipping, faulted resulting NE-SW trending direction and altered (silicified and sulphide minerals). The Batununggal Limestone comprises massive, well-bedded limestone containing fossils of *Orbitolina* of Early Cretaceous and was deposited in a fore-reef environment (Heryanto and Sanyoto, 1994). Tertiary fluviatile to shallow marine sediments of the Tanjung, Berai, Warukin and Dahor Formations unconformably overlay the Cretaceous rocks.

Tertiary Volcanics (or subvolcanics), composed of andesitic to basaltic rocks, occur in spotted areas along strike-slip faults, which might have developed into normal faults. In Pulau Laut the volcanics form a cone-shape as found at G. Jambangan. A K-Ar analysis of hornblende from microdiorite intrusion observed at G. Kukusan (Sunata *et al.*, 1995) resulted in 19.58 Ma. This rock is also associated with a big fault which can be traced from G. Kukusan to the south up to G. Jembangan.

GRANITOID PLUTONISM

Granitoid rocks are well widely exposed at the western flank of the Meratus Range (Fig. 1). The main rock types are holocrystalline hypidiomorphic granite, tonalite, trondjemite and diorite. The granite consists mainly of albite, hornblende, biotite, muscovite and quartz, with accessories of apatite and zircon. The tonalite is composed of plagioclase (oligoclase and andesine), hornblende, pyroxene, biotite and quartz; while magnetite, sphene, zircon and apatite are present as accessories. Trondjemite, petrographically similar to the granite, but lower in mafic mineral concentration. Eleven samples have been dated using a K-Ar method and the result shows seven of them ranging from 131 to 101 Ma (Lower Cretaceous) and the rest ranging from 87 to 70 Ma (Upper Cretaceous) (Hartono and Permanadewi, 1997, *PKIGT*, unpub.).

In terms of overall major element geochemistry the granitoids are a typical subduction-related magmatism. Predominantly they are calc-alkaline (Fig. 2), I-type (Fig. 3) granitoids (Chappell and White, 1974). On Pearce *et al.* (1984) diagrams the volcanic arc character of the granitoids is clear (Fig. 4a, b). In these diagrams most of the granitoids fall in the volcanic arc granite (VAG) area, and only few samples fall in the oceanic ridge granite (ORG) field. The low K_2O concentration of several granitoid (plagiogranite?) might indicate that they developed in an oceanic environment, resulted from

fractionation of an oceanic basaltic magma.

The trace element abundance of the granitoid rocks is presented in Figure 5a, b. The figures show plots of representative granitoids (Fig. 5a) and plagiogranites (Fig. 5b) and compared them to a mid oceanic ridge basalt (MORB) and an oceanic island basalt (OIB). The trace element concentration of the granite is consistent with their origin in a subduction zone environment. They are enriched in large ion lithophile elements (LILE) (Ba, Rb, Th and K), but depleted in high field strength elements (HFSE) (Nb, Zr and Ti) and Y. In contrast, there is no enrichment in LILE and the depletion of HFSE is not significant in the plagiogranite (Fig. 5b).

The rare earth element (REE) patterns of these two type of granitic rocks are presented in Figure 6. In this plot the granite 95PR 5 and plagiogranite 96MD23A have a similar pattern, with relatively low $(La/Yb)_N$ and flat heavy REE, suggesting a similar process in their origin. The granite 96MD 17B has a different pattern with high $(La/Yb)_N$, concave upward of the medium rare earth and a positive Eu anomaly, suggesting different source/sources from the other two granitoid types.

CRETACEOUS VOLCANICS

The Cretaceous volcanics (the Haruyan Volcanics) are well exposed both in the western and eastern flanks of the Meratus Range and in Pulau Laut (Fig. 1). They are submarine volcanics which consist of lava, volcanic breccias and tuff of mostly andesitic and basaltic composition. Basaltic pillow lavas are exposed in some places, indicating a marine environment. The basalt is porphyritic, with plagioclase, pyroxene and olivine phenocrysts set up in a groundmass of volcanic glass, pyroxene and magnetite. The andesite is porphyritic, with plagioclase, clinopyroxene \pm orthopyroxene \pm hornblende phenocrysts in a groundmass of volcanic glass, microlitic plagioclase and microcrystalline of pyroxene, magnetite \pm hornblende. Seven samples were analysed for age determination using a K-Ar method, and the result shows an age ranging from 82 to 66 Ma (Upper Cretaceous) (Hartono and Permanadewi, 1997, *PKIGT*, unpub.).

Based on the SiO_2 vs $Na_2O + K_2O$ diagram (Le Bas *et al.*, 1986) the rocks from the Cretaceous volcanics are mostly saturated (only few slightly oversaturated) basalt-andesite-dacite with SiO_2 content ranging from 49 wt % to 66 wt % (Fig. 7). On the SiO_2 vs K_2O diagram (Fig. 8) the Cretaceous volcanics fall within medium-K basalt to medium- and high-K andesite-dacite. The volcanics are tholeiitic and calc-alkaline when they are plotted on the diagram SiO_2 vs FeO/MgO (Fig. 9a) and

AMF (Fig. 9b) diagrams, indicating that the rocks resulted from a subduction zone magmatism. The high content of Al_2O_3 (17 wt %) and low TiO_2 (1 wt %) are also characteristics of subduction-related rocks. Other major element characteristics are the high contents of MgO , CaO and Na_2O in some andesites (see also Hartono *et al.*, 1997).

Like in many other island arc rocks, the Cretaceous volcanics are characterised by high concentrations of LILE (Ba, Rb, K and Sr) and depleted in HFSE (Ti and Nb). Compared to MORB these volcanics have higher contents of LILE, but

these element concentrations are similar when they are compared to OIB (Fig. 10a). It can be seen in these diagrams that there is an Nb depletion relative to K and La, which is typical of the arc signatures.

Rare earth element characteristics of the Cretaceous andesites are presented in spidergram (Fig. 11a). The diagrams show a strong light REE enrichment with $(\text{La}/\text{Yb})_N$ varying from 4.4 to 7.8 and $(\text{La}/\text{Sm})_N$ from 1.9 to 2.5, consistent with the evolved nature of the andesites. The negative Eu anomaly is also characteristics of the basaltic andesite and andesite indicating plagioclase

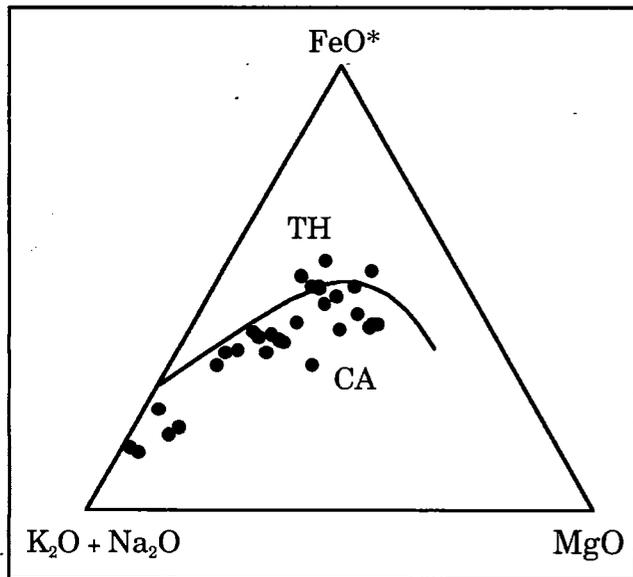


Figure 2. AMF plot for the Meratus Range granitoids.

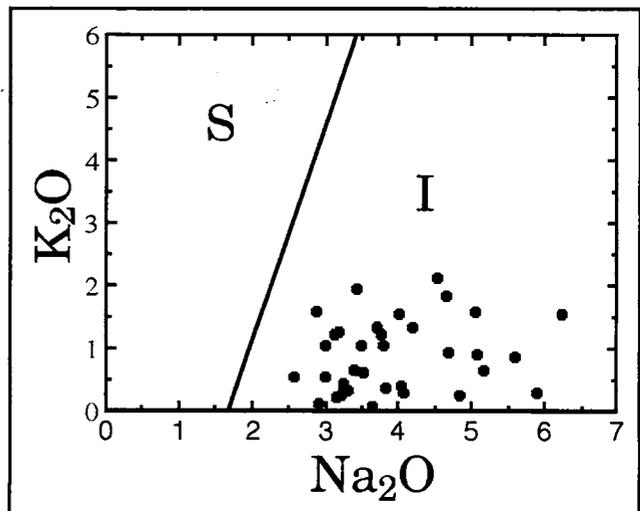


Figure 3. Alkali variation diagram for the Meratus Range granitoids. Line separate the field of I- and S-type granites of Chappell and White (1974).

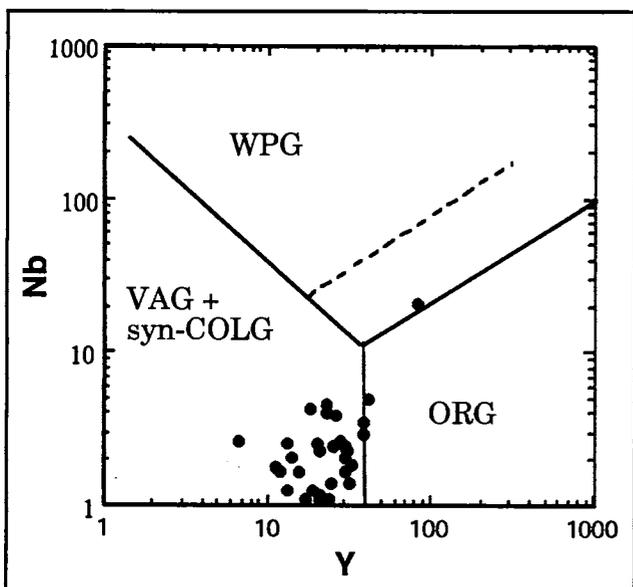


Figure 4a. Tectonic setting-classification plots for the Meratus Range granitoids based on Y vs Nb (Pearce *et al.*, 1984). VAG: volcanic arc granite; syn-COLG: syn-collisional granite; WPG: within-plate granite and ORG: oceanic ridge granite.

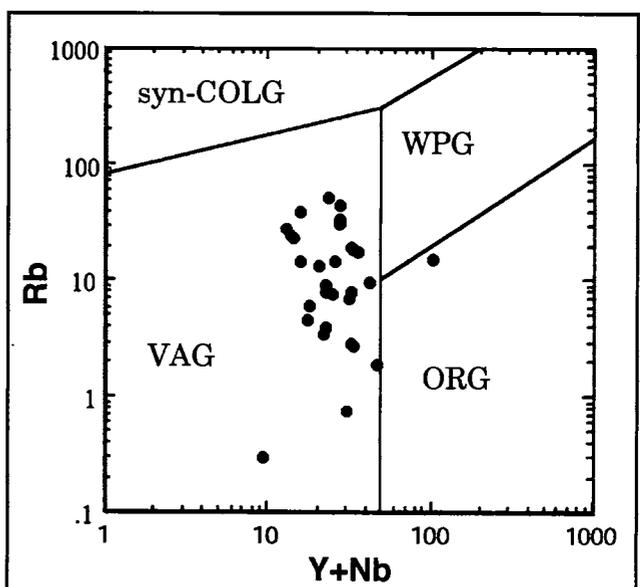


Figure 4b. Tectonic setting-classification plots for the Meratus Range granitoids based on Y + Nb vs Rb (Pearce *et al.*, 1984). VAG: volcanic arc granite; syn-COLG: syn-collisional granite; WPG: within-plate granite and ORG: oceanic ridge granite.

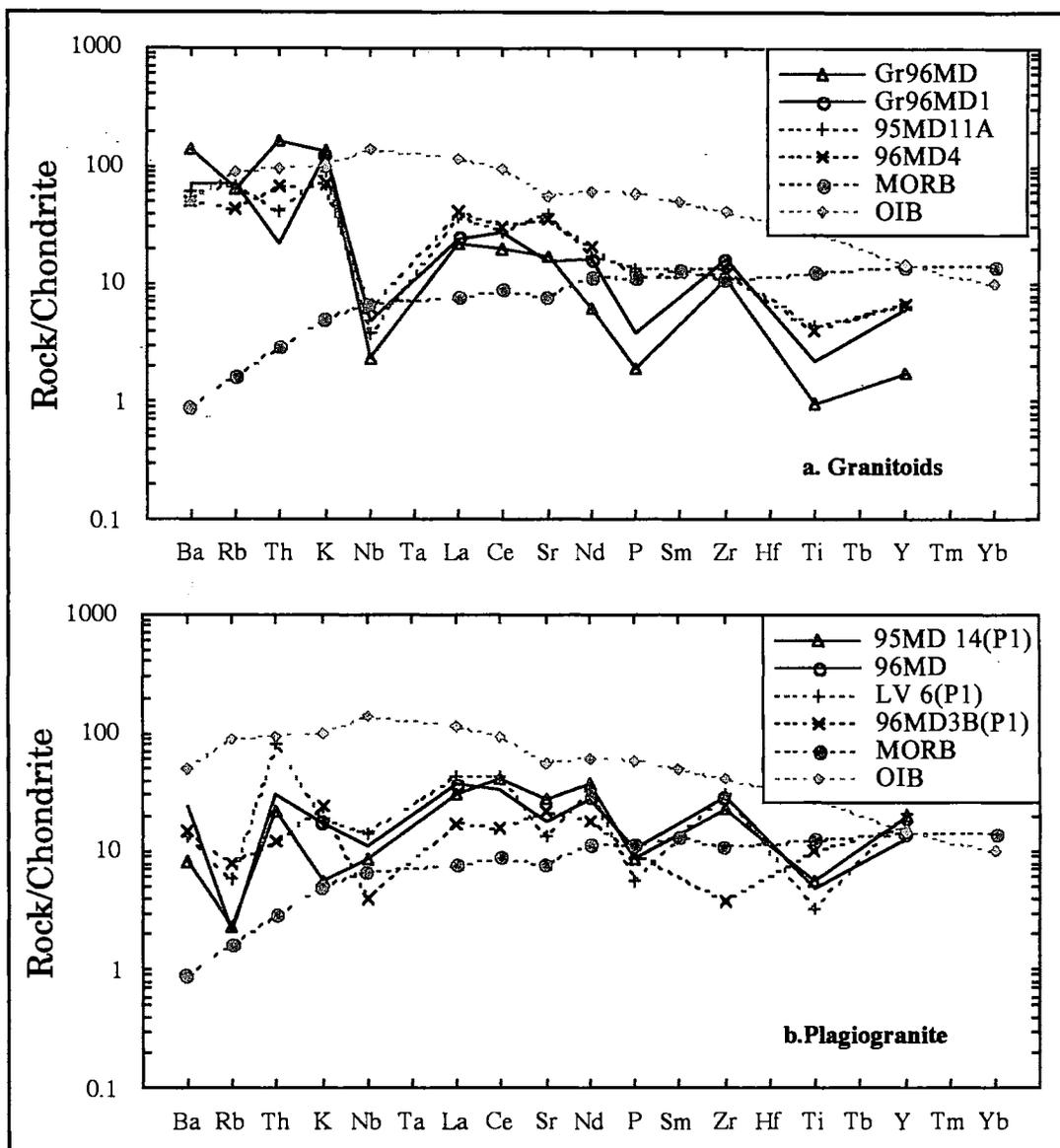


Figure 5. Chondrite-normalised trace element abundances for representative granitoids (a) and plagiogranites (b) from the Meratus Range.

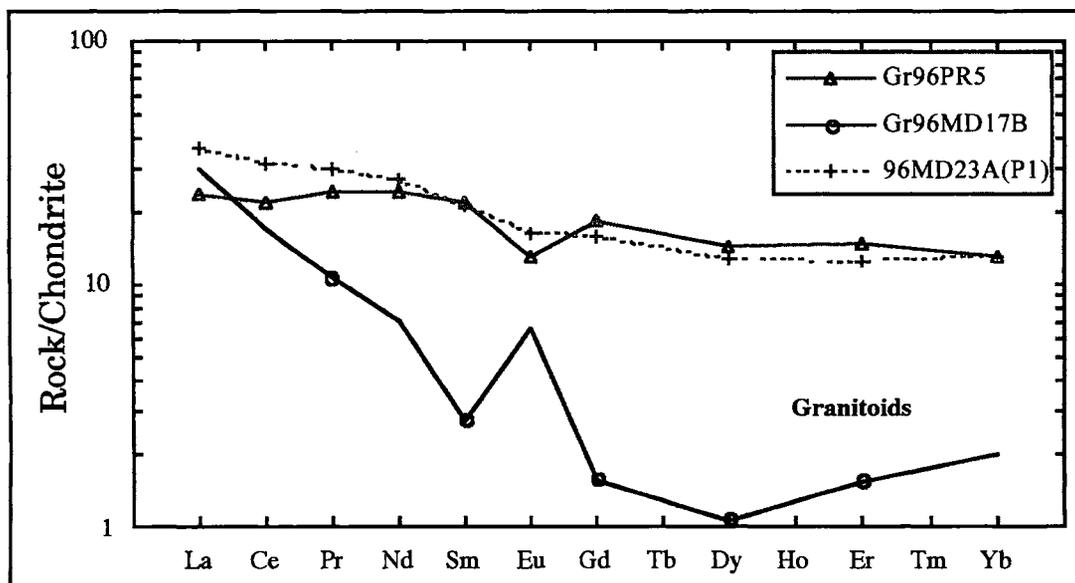


Figure 6. Chondrite-normalised REE abundances for the granitoids from the Meratus Range.

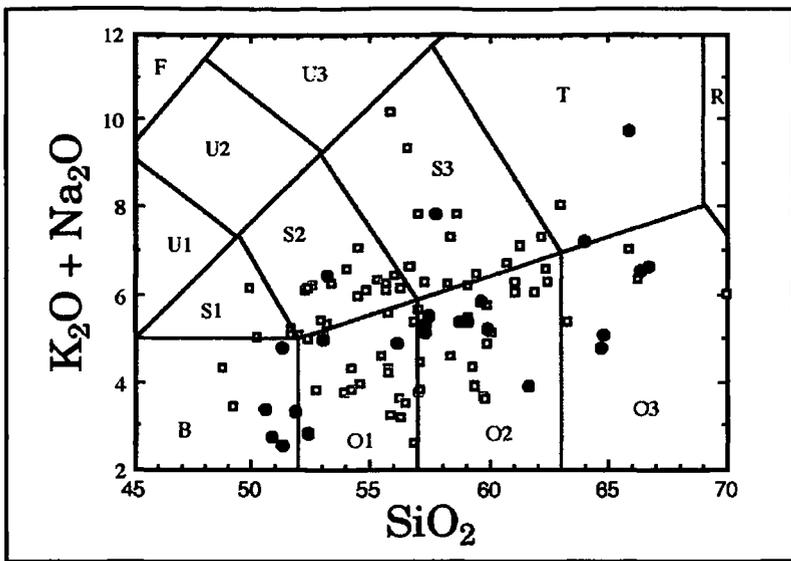


Figure 7. Nomenclature of volcanic rocks from the Meratus Range (square: Cretaceous and circle: Tertiary volcanics) based on TAS diagram (LeBas *et al.*, 1986). Pc: microbasalt, B: basalt, O1: basaltic andesite, O2: andesite, O3: dacite, S1: trachybasalt, S2: basaltic trachyandesite, S3: trachyandesite, T: trachyte, trachydacite, U1: basanite, tephrite, U3: tephritephonolite, Ph: phonolite, F: foidite and R: rhyolite.

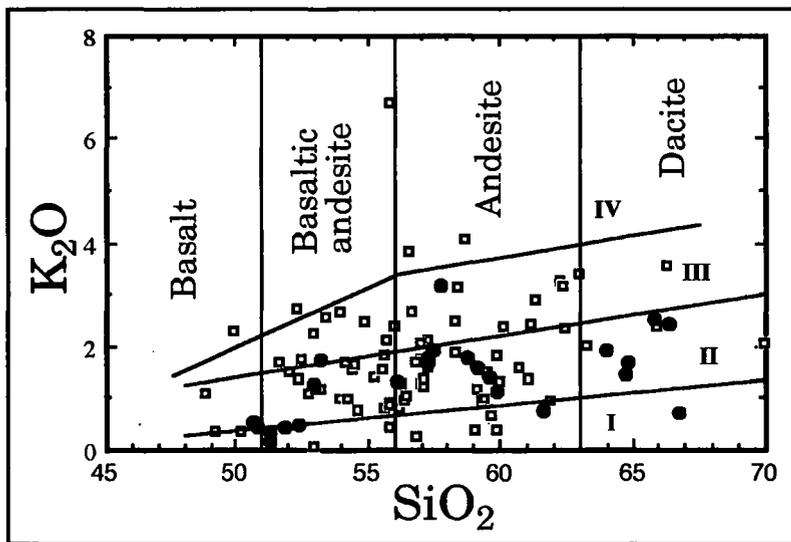


Figure 8. Classification of volcanic rocks from the Meratus Range based on SiO_2 - K_2O diagram. Symbols as for Figure 7.

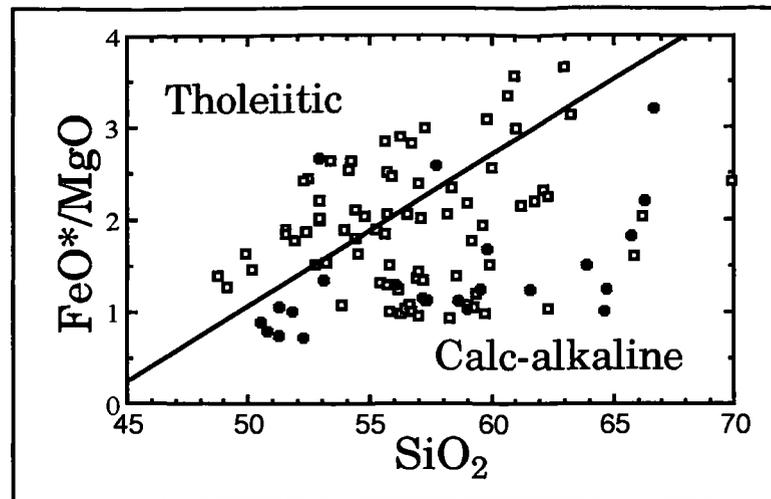


Figure 9a. Tholeiitic and calc-alkaline fields for the volcanic rocks from the Meratus Range based on SiO_2 vs FeO^*/MgO diagram. Symbols as for Figure 7.

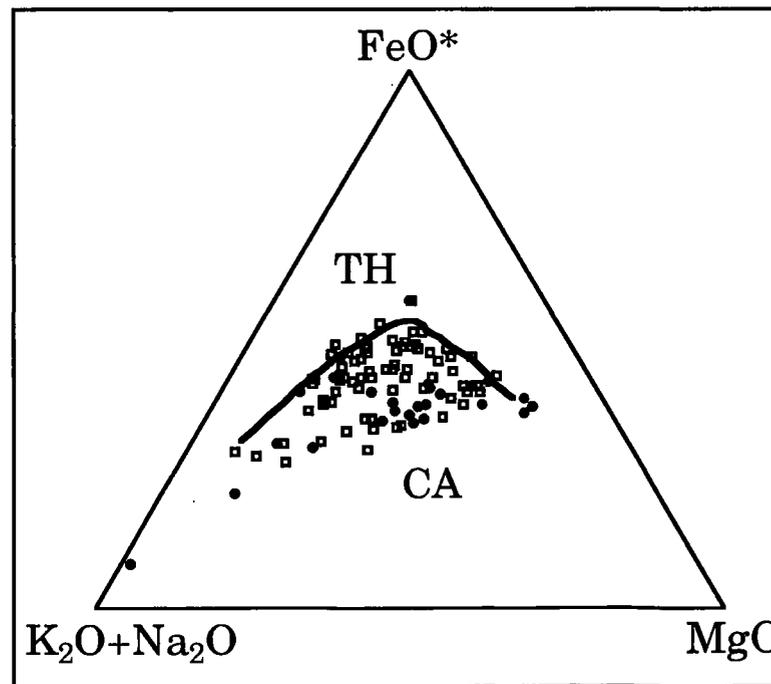


Figure 9b. Tholeiitic and calc-alkaline fields for the volcanic rocks from the Meratus Range based on AMF diagram. Symbols as for Figure 7.

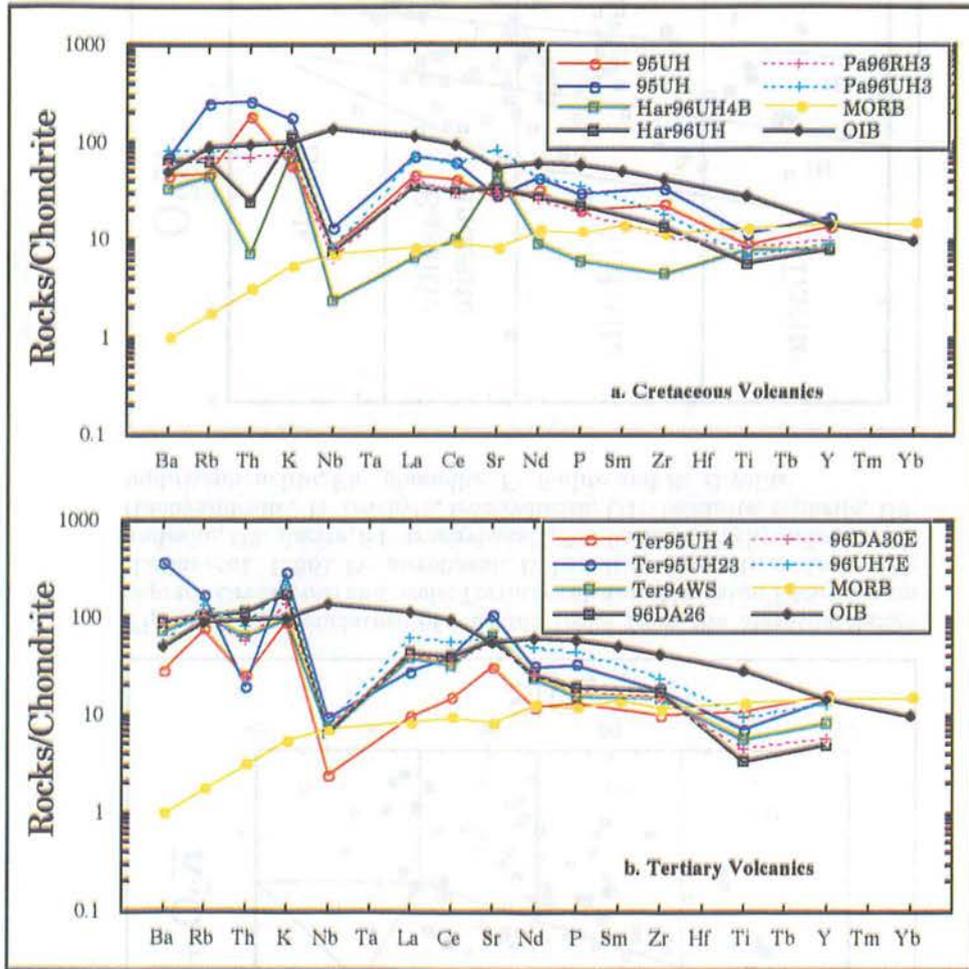


Figure 10. Chondrite-normalised trace element concentration for the Cretaceous volcanics (a) and Tertiary volcanics (b) from the Meratus Range.

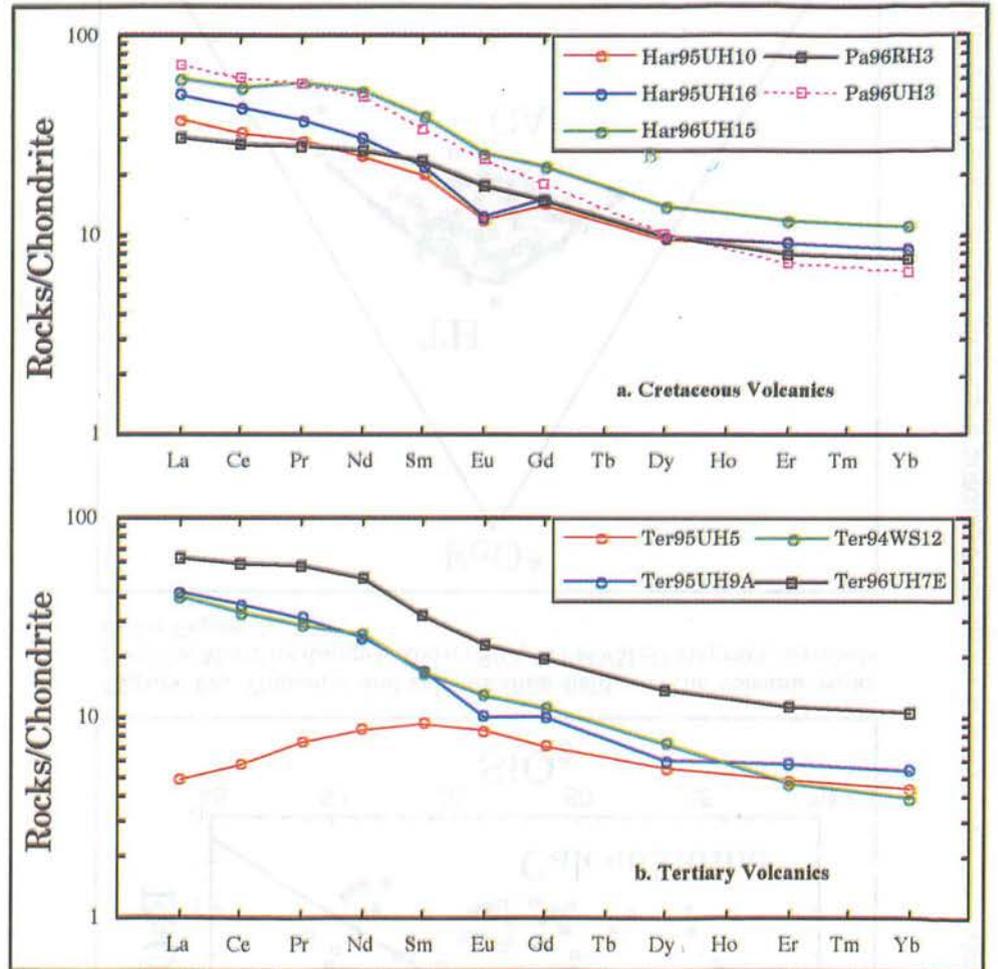


Figure 11. Chondrite-normalised REE abundance for the Cretaceous volcanics (a) and Tertiary volcanics (b) from the Meratus Range.

fractionation. However, for the more evolved andesite the Eu anomaly is not evident due to the plagioclase phenocryst abundance.

TERTIARY VOLCANICS

The Tertiary volcanics and subvolcanics are exposed only in very limited areas. In Pulau Laut, the rocks are exposed in association with strike-slip faults (Hartono *et al.*, 1997) and in Kalimantan as small dykes in the Cretaceous volcanics. Lithologically they consist of basalt, andesite and few dacite and their associate intrusives. Seven samples were determined for K-Ar dating, and the results give an age ranging from 62.5 to 19.5 Ma (Lower Paleocene-Lower Miocene) (Hartono and Permanadewi, 1997, *PKIGT*, unpub.). The microgabbro and basaltic andesite from Pulau Laut give an age 62.5 Ma and 57.5 Ma respectively, while the rest is ranging from 52.5 to 19.5 Ma.

Classification based on the total alkali-silica (TAS) diagram (Fig. 7) shows that most of the Tertiary volcanics fall within oversaturated basalt to dacite (andesite is predominant) and only few in saturated field. On the SiO_2 vs K_2O diagram (Fig. 8) most of the rocks are medium-K andesites, few low-K basalt and few high-K andesite. Compared to the Cretaceous volcanics, the Tertiary volcanics are more calc-alkaline (Fig. 9a, b). These basaltic rocks are also characterised by high MgO contents (8.4–11.1 wt %) with the $\text{Mg}^\#$ ($\text{Mg}^\# = 100 \text{ Mg/Mg} + \text{Fe}^{+2}$) varies from 64 to 71, high CaO (10.3–10.9 wt %) and low Al_2O_3 (14.8–15.9 wt %), Na_2O (2.5–3.5 wt %) and low K_2O (0.2–0.5 wt %) concentrations (Hartono and Permanadewi, 1997, *PKIGT*, unpub.). Although the basaltic rocks are low Al_2O_3 and K_2O contents, they are calc-alkaline when plotted in the SiO_2 vs FeO/MgO (Fig. 9a) and AMF (Fig. 9b) diagrams.

Consistent with the major element chemistry, which shows calc-alkaline characteristics, the trace element composition of the Tertiary volcanics also indicates a typical subduction-related magmatism. They are enriched in LILE (Ba, Rb, K and Sr) and depleted in HFSE (Ti and Nb) (Fig. 10b). Compared to MORB, these volcanics have higher contents of LILE, but these element concentrations are similar when they are compared to OIB.

Representative REE analyses of the Tertiary volcanics are presented in Figure 11b. The basalt is characterised by a strong LREE- and HREE depletion and an upward bend in the moderate REE, suggesting the primitive nature of this rock. The absence of the Eu anomaly in this rock suggests no plagioclase fractionation or plagioclase was not in the magmatic source. In contrast, the andesites show LREE enrichment and the Eu negative

anomaly, consistent with the evolved nature of these rocks with plagioclase involved in the fractionation.

DISCUSSION

Magmatic activities in the Meratus Range may have been started in the Lower Cretaceous, which are characterised by the formation of granitoid rocks. This granitoid rock has been previously reported (Heryanto, in prep., 1994; Heryanto and Sanyoto, 1994; Supriatna *et al.*, 1994) as the Batangalai Granite and they suggested that the granite has a continental affinity. On the contrary Sanyoto *et al.* (1994) and Hartono *et al.* (1996) believed that, based on only few samples, the granite is plagiogranite. Robinson *et al.* (1986) proposed that the plagiogranite was produced by fractionation of an oceanic magma over a "hot line" by rising mantle plumes.

The geochemical characteristics and K-Ar results reported here, however, suggest that most of the granite were produced in an island arc environment in the Lower Cretaceous. This granitoid rocks may have been caused by a subduction of the early Jurassic or Triassic oceanic crust beneath the oceanic crust of the Sundaland margin. As reported by Wakita *et al.* (1998) the age of the ultramafic rocks in Pulau Laut is not younger than early Middle Jurassic, possibly early Jurassic or Triassic.

Most of the granitoids have low-Al type (< 15 wt % Al_2O_3), low Sr concentration, slightly enriched in LREE, a negative Eu anomaly and a flat HREE pattern. The geochemical characteristics suggest that these type of granitoids were generated by either low pressure fractionation or partial melting where plagioclase + pyroxene differentiation was important and garnet + hornblende were not involved in the petrogenesis. The plagiogranite has a similar geochemical characteristics, in terms of Al and Sr contents and a REE pattern, suggesting that they were generated from differentiation of basaltic magmas in ophiolite suites. In addition, there may be some granites, for example granite 96MD17B with low concentration of HREE and positive Eu anomaly (Fig. 6), have a different origin (more specifically different source) from these two types of granites.

In the Upper Cretaceous the magmatic activity in South Kalimantan was controlled by a subduction process and resulted in the Haruyan Volcanics (the Haruyan Formation or Pitanak Group of Sikumbang and Heryanto, 1994), which are composed mainly of basalt and andesite. The volcanics were formed in a submarine environment, that is characterised by the presence of basaltic pillow lavas. The

submarine volcanics is also characterised by the presence of radiolarian chert fragments in the tuff breccia (Wakita *et al.*, 1998).

The metamorphic rocks in the Meratus Range could be produced in association with this subduction. The rocks are exposed in the southwestern part of the Meratus Range as a tectonic block in fault contacts with ultramafics and Cretaceous formations (Fig. 1). These metamorphic rocks are mainly products of a high-pressure low temperature metamorphism. They consist of green schists, blue schists and slates (Djumhana, 1997, unpub., Wakita *et al.*, 1998.). The green schist consists of quartz-muscovite-biotite schists, muscovite-biotite schists and epidote tremolite schists, while the blue schist is composed of glaucophane-hornblende schists and glaucophane tremolite schists. Wakita *et al.* (1998.) reported that K-Ar age data of micas of the schists range from 180 to 110 Ma. They claimed that the older ages (180 and 165 Ma, Middle Jurassic) were obtained from the northern edge of the metamorphic distribution and the age of the main part of the metamorphic body were 110–119 Ma (Lower Cretaceous). They further suggested that the northern part of the metamorphic rocks probably belongs to a different tectonic block from the main part. It might be suggested that the older metamorphic rocks are related to the Lower Cretaceous subduction and the younger one are related to the Upper Cretaceous subduction.

However unlike in many other island arc volcanics, some of the Upper Cretaceous Haruyan Volcanics are magnesian andesites (Fig. 12). The figure shows the MgO concentration of the volcanics

compared to this of the island arc Wilis and Lawu volcanics. Compared to these two volcanics, the Upper Cretaceous volcanics of the Meratus Range are higher in MgO contents with similar SiO₂ concentrations. These magnesian andesites are also characterised by high CaO and low Na₂O abundances, and more FeO* enrichment than the Tertiary Volcanics. A number of petrologists (Defant and Drummond, 1990; Peacock *et al.*, 1994) proposed that such andesite may developed in thin crust. Defant and Drummond (1990) also suggested that arcs built on thin crust have a tendency to be more tholeiitic (higher FeO, lower SiO₂). Zr/Nb and Y/Nb ratios (Fig. 13) also support the sub-oceanic mantle source for the Cretaceous Volcanics. This interpretation, however, would conflict with the high K concentration of some andesites from the Haruyan Volcanics (Fig. 8), as it is generally believed that the high-K rocks were produced in a relatively thick crust. It could be possible that K-rich materials (such as sediments) may have involved in the magmatic source. Alternatively the more potassic rocks may be originated from the mantle beneath the granitoid (see the discussion below).

There is an unconformity in the middle Cretaceous, which is indicated by the presence of granitic and ultramafic fragments in the Upper Cretaceous Pitap sediments (Heryanto, in prep.). This unconformity suggests that the Lower Cretaceous subduction which produced granitoids did not continue to the Upper Cretaceous subduction that resulted in the Haruyan Volcanics. A speculative interpretation is that the Lower

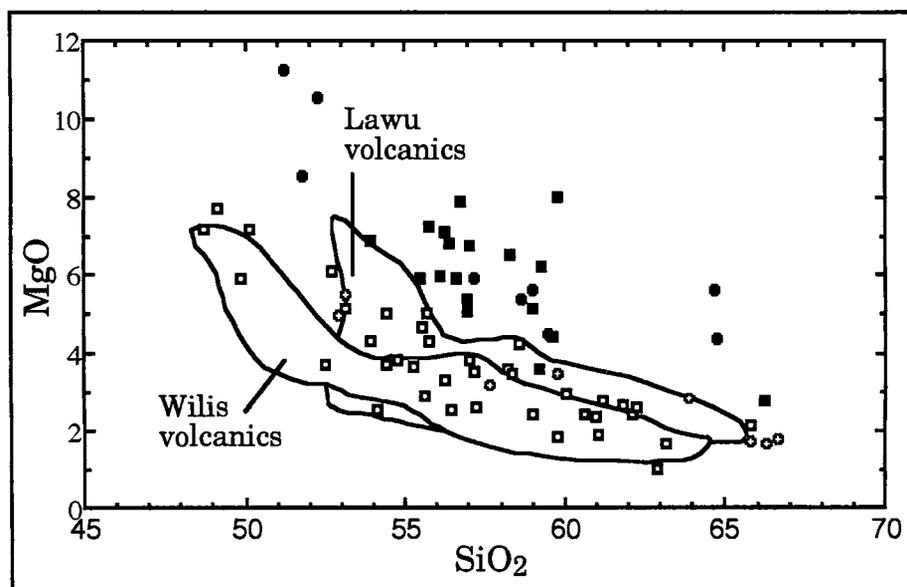


Figure 12. Plot of the Cretaceous (squares) and Tertiary volcanics (circles) from South Kalimantan. Shown for comparison are the area of island arc volcanics of the Wilis and Lawu Mountains, Jawa. Filled symbols are magnesian basalts and andesites and open symbols are the "normal" basalts and andesites.

Cretaceous subduction was ceased when the granitoid accreted to the Sundaland, then was followed by the Upper Cretaceous subduction to produce the Haruyan Volcanics. This oceanic subduction may be partly under oceanic crust which produced the more magnesian andesite and partly under granitoid rocks that resulted in the more potassic rocks (Fig. 13). A more detailed study, however, is needed to solve this problem.

Although the geochemical characteristics of the Tertiary Volcanics show arc related magmatism, based on geological structure investigations, Sanyoto *et al.* (1996) believed that there was no subduction during Tertiary, and the Meratus Range is "a positive flower structure" produced by a collision, which began in the Eocene. This controversy is discussed. Unlike many other island arc volcanic rocks with "normal" concentration of MgO, most of the Tertiary Volcanics are magnesian-rich basaltic and andesitic rocks (Fig. 12) with the Mg[#] up to 74, generally between 67 and 58 (Hartono and Permanadewi, 1997, 1998). There are many ways to produce magnesian rocks in island arcs. However, here the model that the Tertiary magnesian rocks from south Kalimantan might have been produced by a reaction between ascending melts and hot mantle peridotite is proposed. K-Ar analyses on plagioclase crystals of the microgabbro and basaltic andesite from Pulau Laut resulted in 62.5 Ma and 57.5 Ma (Lower Paleocene). It is suggested therefore, that the Upper Cretaceous subduction may have ceased in this time, possibly when the collision began. This collision causes a

primitive basaltic melt to pool immediately below the arc crust, possibly during Paleocene-early Eocene, where it interacts with the mantle peridotite resulted in magnesian basalts.

As mentioned the Tertiary basalts are low Al₂O₃ and K₂O contents, they are not plotted on the tholeiitic field. It is proposed, however, that originally the basalts were tholeiitic, characterised by low Al₂O₃ concentration and high FeO/MgO ratios (medium MgO contents). Because of a reaction with a hot mantle peridotite the MgO concentration of the basalts increases and in consequence lower the FeO/MgO ratios. A primitive melt which trapped in the uppermost mantle may react with residual peridotite to produce a calc-alkaline magma (Yogodzinski *et al.*, 1994). If this interpretation is true the basalts could be tholeiitic with low Al₂O₃ and K₂O contents, and might be interpreted to be a derivative liquid which compositionally closed to an island arc tholeiitic primary magma. The melt would rise up and differentiate to produce magnesian andesites when the compressional stress ceased (possible after 52 Ma equivalent to Upper Eocene).

In addition, it is noted that several samples of Tertiary volcanics have low Y (13–14 ppm) and high Al₂O₃ (> 16 wt %) and Sr (533 ppm–748 ppm), termed as "adakite" and indicating a slab-derived melt (Defant and Drummond, 1990; Peacock *et al.*, 1994). Kay (1984) proposed a model that magnesian adakites in Aleutian could be produced by a reaction between dacitic magmas generated by melting of a subducted slab and hot overlying peridotitic mantle wedge under hydrous condition.

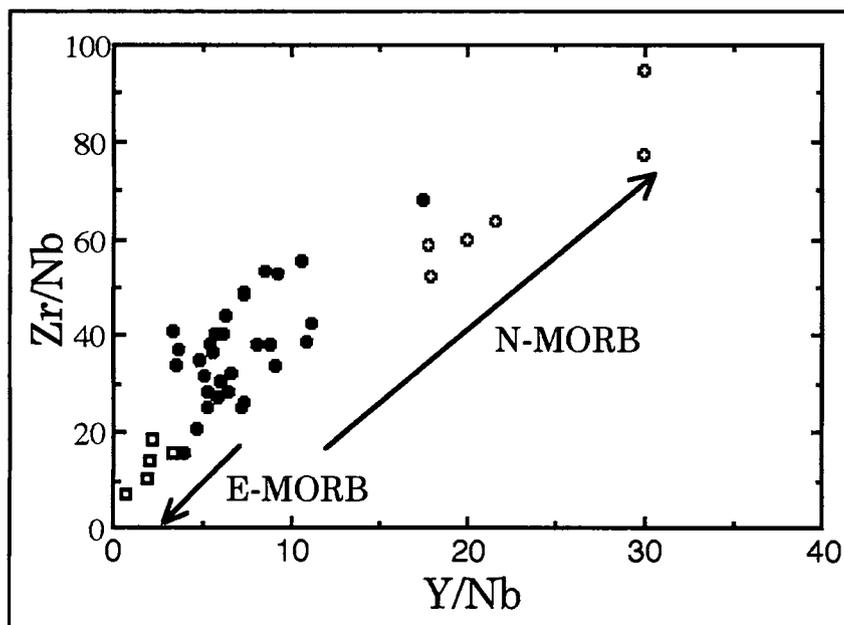


Figure 13. Zr/Nb vs Y/Nb plot for the Cretaceous volcanics from the Meratus Range. Shown for comparison are the field of the Andean (open squares) and Mariana arcs (open circles).

SUMMARY

1. The Lower Cretaceous granitoid rocks from the Meratus Range characterise the first magmatic activity in this area. These rocks might have resulted from the early Jurassic or Triassic oceanic crust subduction beneath the oceanic crust of the Sundaland margin during Jurassic-Lower Cretaceous time. The metamorphic rocks of 180–165 Ma might have a result of this subduction process.
2. The Upper Cretaceous volcanics in South Kalimantan resulted from a subduction process. The magmatic source is probably a sub-oceanic mantle above the subducted slab, resulted in andesitic (including the magnesian andesite) magma with high CaO, low Na₂O contents and more FeO* enrichments. The origin of the more potassic rocks is still open for discussion. This rocks might have been originated from a sub-arc mantle beneath the Lower Cretaceous granite, which have been accreted into the Sundaland margin in the middle Cretaceous. The high P-low T metamorphic rocks of 110–119 Ma might be caused by this subduction.
3. The Tertiary volcanics might have been a result of a previously subduction, which was active during Cretaceous-Lower Paleocene. The early Tertiary (? Paleocene-early Eocene) collision would cause the magma produced to pool in upper mantle, before it rise to the surface in the Upper Eocene-Miocene. Reaction between this magma and the hot upper mantle peridotite would result in magnesian basalts and andesites.

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