Annual Geological Conference 2004, June 4 – 6
Putra Palace, Kangar, Perlis, Malaysia

Geochemistry and petrology of syenite, monzonite and gabbro from the Central Belt of Peninsular Malaysia

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Abstract: The Benom Igneous Complex is situated in the central part of of this belt forms a pear shaped batholith consists of a variety of igneous rocks ranging in composition from granitic to syenitic to monzonitic and gabbroic. The syenitic, monzonitic, gabbroic are found mainly in the western part of the batholith. The range of SiO_2 for each of the gabbro, syenite and monzonite are 46.5 to 49.1%, 52.9 to 56.9% and 56.6 to 64.7% respectively and characterized by high alkali content, shoshonitic with I type characteristics. They have very high LIL elements, i.e. Ba and Sr are nearly 1000 times rock/mantle. The high Ba and Sr values may results from the penetration of the lower lithosphere by a small volume of mantle material that is enriched in those elements.

INTRODUCTION

Despite the extensive research project carried out on the Eastern and Western Belt (e.g. Liew, 1983, Cobbing *et al*., 1992), the Central Belt recieved very little attention from previous workers except some of the work done by Jaafar Ahmad (1979). Peninsular Malaysia has been divided into three distinct belts i.e. Eastern, Central and Western Belt. The division also conveniently divided the granitic and other igneous rocks in the area. The Central Belt which has less published information of their geochemical affinities however is comparable to the Eastern belt (Cobbing *et al*., 1992). The granitic and other igenous rocks of this belt form a narrow and well defined line of single plutons emplaced into Permo-Triassic rocks. The Benom Igneous Complex is situated in the central part of of this belt form a pear shaped batholith consists of a variety of igneous rocks ranging in composition from granitic to syenitic to monzonitic and gabbroic. The latter three rock types occur mainly at the western margin of the Complex characterized by high potash content and can be classify as belonging to an alkali series which is of rare occurrence in Peninsular Malaysia. This paper will discuss the new major, trace and rare earth elements geochemistry of this three rock types from the western part of the Benom Complex (Figure 1). The rocks are found intruding into Middle to Upper Triassic sediments of the Semantan Formation and also thermally metamorphosed the sediments. The various types of metasedimentary rocks are calc-silicate pelitic hornfels with lesser amount of quartzites. The rocks are invariably folded possibly implying a folding phase before the igneous intrusion.

PETROLOGY

Modes were determined for medium and coarse grained rocks by point counting. The data were collected using a Swift Model E point counter fitted with an automated stage. Samples were either normal thin sections (area of rock approximately 30 by 40 mm) or polished thin section that had been prepared for microprobe analyses. Usually the total counts were between 1500 - 2000 on each specimen in such a way that the whole surface of the thin section was covered. Minerals counted were alkali feldspar, plagioclase, quartz, biotite, hornblende, muscovite, sphene, allanite, zircon, epidote, Fe-Ti oxide, flourite and apatite. All Perhentian granite samples plot in the syenite, monzonite and gabbro field on a Q-A-P diagram (Streckeisen, 1976).

Syenite

The syenite is essentially made up of K-feldspar, hornblende, plagioclase, quartz with lesser amount of pyroxene and biotite. The microcline phenocrysts in the syenite are usually pale pink in colour. Carlsbad twinning in these tabular crystals is obvious even in hand specimen. It is observed that the oriented K-feldspar often contain inclusions of plagioclase laths arranged in a zonary manner. The composition of the plagioclase in the syenite varies from sodic andesine to calcic oligoclase. Pyroxene when present is usually rimmed by green hornblende. Quartz occurs as interstitial mineral, occasionally forms micrographic intergrowth with plagioclase. The plagioclase mode in the syenite can reached up to 25% but varies from sample to sample. With an increase in plagioclase, the syenite grades to monzonite. Apatite is quite common, both as accicular aggregates and as equant or prismatic crystals. Sieve texture is commonly seen in hornblende. The green hornblende sometime contains inclusion of apatite and quartz. Opaque mineral probably magnetite is sparsely distributed in the syenite. Sphene and epidote, probably the early crystallisation product is also present. Epidote also occurs as veinlets commonly traverse the syenite. The syenite sometimes show foliated texture defined by the aligned, tabular, simple twinned K-feldspar and lamella twinned plagioclase. The hornblende and biotite are sometimes aligned parallel to K-feldspar and plagioclase which enhance the foliation.

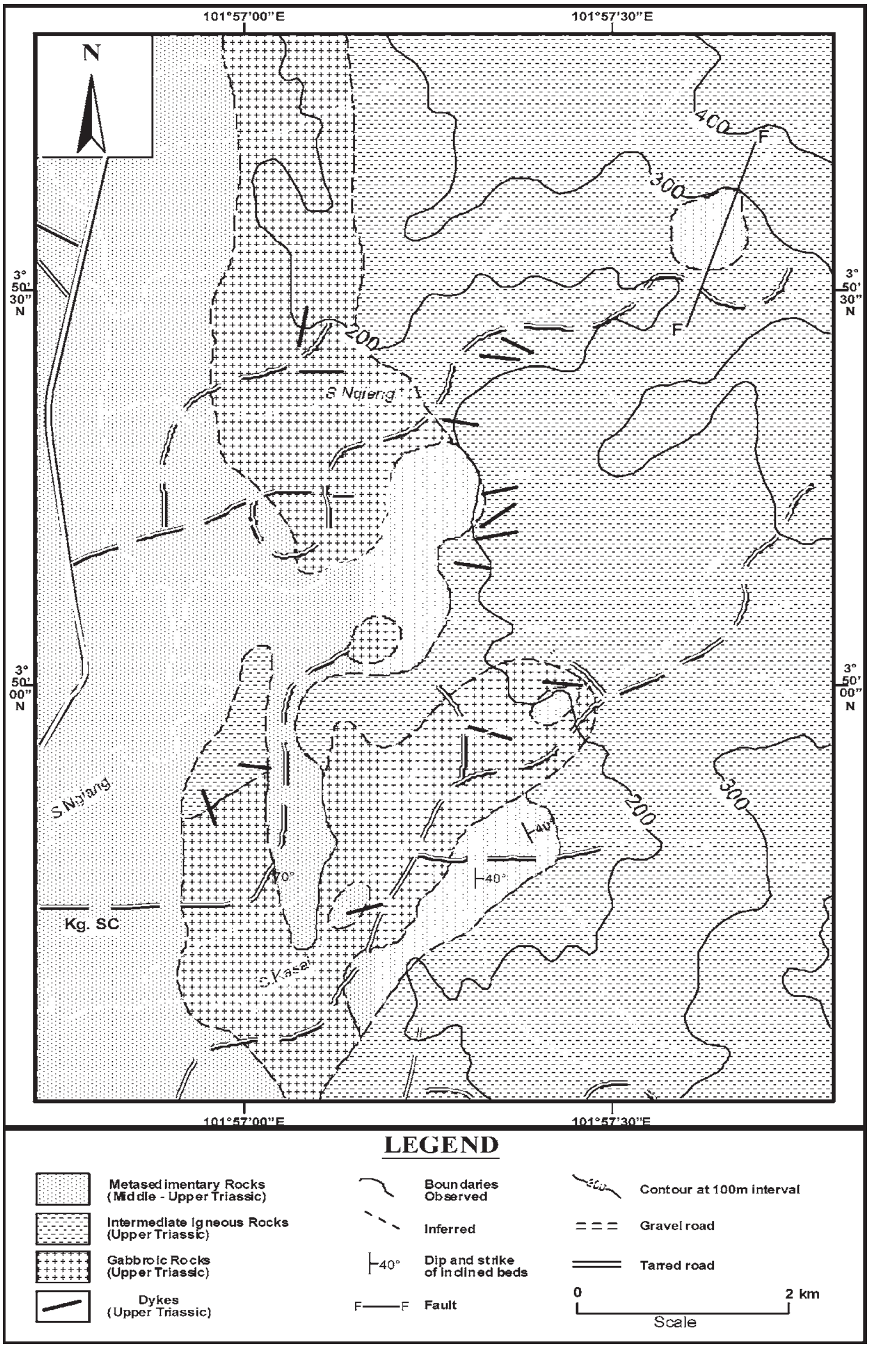

Figure 1. Simplified geological map of the western part of the Benom Complex.

Monzonite

Monzonite is a holocrystalline inequigranular, coarse grained comprising of K-feldspar, plagioclase, augite, hornblende and biotite. The K-feldspar is microcline and their perthite varieties. They occur as big crystal showing good Carlsbad twinning and sometimes faint zoning outlined by dust inclusions. Plagioclase occurs as lath shape crystal showing distinct lamellae twin. Their compositions vary from An24 to An37. Small lath shape plagioclase crystals are also found in big K feldspar crystals. Some plagioclase is sericitised to fine mica along twin-plane. Individual hornblende crystal is subhedral and twinning is not uncommon. Clinopyroxene mainly augite commonly twinned and exhibit corona texture made up of hornblende. Biotite occurs as subhedral crystals. Some of the biotite contains inclusions of equant apatite and some are chloritised. Granophyric intergrowth between quartz and K-feldspar occurs both in the interstices and inside K-feldspar phenocrysts.

Gabbro

The gabbro is essentially made up of augite, hornblende, biotite and plagioclase. The augite is commonly twinned and rimmed by hornblende and hornblende in turn is rimmed by biotite. In fact the occurrence of successive rims made up of augite, hornblende and biotite is not uncommon. Some augite crystals are weakly pleochroic from yellowish brown to pale brown. Primary hornblende usually forms subhedral grain and parallel intergrowth with augite. They are usually pleochroic from green to pale green. Biotite occurs as flakes with distinct cleavage can occur up to 35% in some gabbroic samples. Inclusions of ilmenite and sphene are common along cleavage traces and ragged edges of biotite.

GEOCHEMISTRY

Analytical Procedure

Wherever possible, 2 kg samples of the freshest available material were collected. The samples were firstly trimmed in order to remove any altered / weathered material. Some of the removed sawn slabs were used for photograph. The clean and freshest samples were split into 1 cm cubes using a hydraulic jaw-splitter and an automatic jaw-crusher and washed to remove dust.

The chips were then reduced to powder by grinding in a "Tema" laboratory disc mill using a tungsten-carbide barrel. W, Co and Ta are known contaminants that could be introduced at this stage. Milling time was 30 seconds (150 micron) and another 15 seconds to reduce the size to 53 microns. The sample powder was not sieved as it is believed that this procedure introduces unnecessary inhomogenity into the sample. The samples powder was then shaken and dried at 105°C ± 5 for 1-2 hours.

Glass fusion disc were used in the analysis of major elements. Each disc was prepared by using a mixture of approximately 0.5 g (weighed to 4 decimal places) of 153 microns of rock powder with 3.3 g of lithium borate flux in a ratio of 5.4321 : 1 flux : rock, at 1150^{o}C and casting the melt onto 4 cm diameter aluminium platterns. The resultant glass disc was then mounted on a backing disc for analysis. Powder pellets used in trace elements analysis, were prepared by mixing 7 g of 53 microns powder with 12 to 15 drops moviol binder solution (4 g Moviol + 10ml ethanol + 50 ml distilled water). The resultant mixture was pressed into a 4 cm disc under 5 tons pressure and left dried before analysis.

Major oxide elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3 (expressed as Fetot in data tables), MgO, MnO, CaO, Na_2O, K_2O, P_2O_5) and trace elements (Ba, Ce, La, Cr, Nd, Nb, Ni, Pb, Rb, Sc, Sr, Th, V, Y, Zn and Zr) were analysed by X-Ray fluorescence Spectrometer 3080E of Japanese Rigaku Industrial Corporation with RSD (Relative Standard Deviation)=3% at the National Research Center of Geoanalysis of China.

For FeO, the $K_2Cr_2O_7$ Titration is used with RSD=5%; for CO_2, Coulometry is used with RSD=10%; and for H_2O^+ the gravimetry is used with RSD=5%.

For Rare earth element, 0.25 g of rock samples was mix with 2 g of Na_2O_2 in graphite crucible, at 700°C. The mixture then was extract with water. The precipitation of hydrated oxide is dissolved with HNO_3 and analysed using Inductive Coupled Plasma Mass Spectrometer located at the National Research Center of Geoanalysis of China (RSD =3%).

Major and Trace element Geochemistry

24 samples, (syenite : 8; Monzonite : 7; Gabbro : 9), were analyzed for major and trace elements. Selected major elements Harker variation diagrams have been plotted for gabbro, syenite and monzonite and are shown in Figure 2. The range of SiO_2 for each of the gabbro, syenite and monzonite are 46.5 to 49.1%, 52.9 to 56.9% and 56.6 to 64.7% respectively. In general, the plots show clear trends of decreasing TiO_2, MgO, CaO, and P_2O_5 with increasing SiO_2. All rocks from the three units generally have high alkali content (Na_2O + K_2O) ranging between 8.05 to 11.05% for syenite, 8.16 to 9.72% for monzonite and 5 to 8.85% for gabbro. The Western Benom Plutonic Complex are predominantly shoshonitic (Figure 3) with I type characteristics. On the K_2O versus SiO_2 plot the whole dataset of gabbro, syenite and monzonite lies in the shoshonite field.

Trace elements Harker variation diagrams have been plotted for gabbro, syenite and monzonite and are shown in Figure 4. Most of the plot show that the syenite and gabbro overlap. In general Ni, Sc, V and to a lesser extent Cr decrease with increasing SiO_2. Rb, Sc, V and to a lesser extent Cr increase with increasing SiO_2. Interestingly in many plots (Cr, Pb, Rb. Sc, Th, and Zn) the trend is confined to syenite and gabbro only. In this plots the monzonitic rock form a different trend or cluster. A gap between gabbro-syenite and monzonitic rocks is clearly shown in nearly all plot i.e between 57 to 63% SiO_2. The only monzonitic samples which contain 56% SiO_2 may represent a cumulate part of the monzonitic magma. The monzonitic rocks contain restricted content in all trace elements compared to both syenite and gabbro (e.g. Ba, Cr, Rb, Pb, Sr, Th, V and Zr). In Rb and Pb versus SiO_2, a different trend shown by the syenite-gabbro and monzonitic rocks, The former increase whereas contrast to the monzonitic rock which is decrease with increasing SiO_2. The data may imply that the syenite-gabbro and monzonitic magmas are different. However the fact that, these three rock type occurs in close association in the field may ruled out the hyphotesis.

The trace element data also show that the studied rocks contain very high LIL elements. The rocks contain barium from 2401 to 10744 ppm with a mean of 4590 ppm and Sr from 578 to 2340 ppm with a mean of 1,000 ppm. Mohd Rozi Umor & Syed Sheikh Almashoor (2000) found that the intermediate and basic plutonic igneous rocks near Benta (northern part of the study area) contain barium from 2826 to 4333 ppm with a mean of 4342 ppm and Sr from 644 to 958 ppm with a mean of 829 ppm. Cobbing *et. al*. (1992), recorded a sample from the Boundary Range batholith near Kuala Krai with 9836 ppm Ba and 344 ppm Sr.

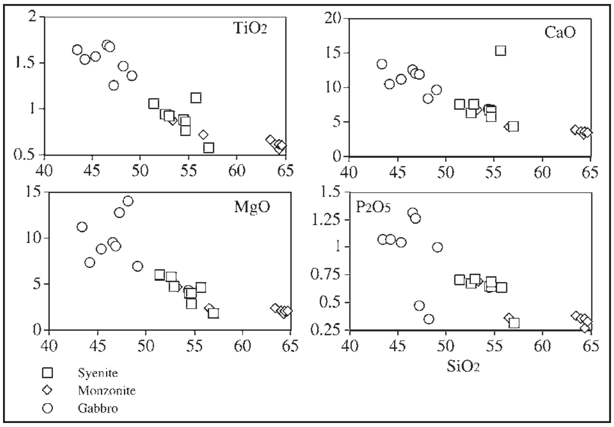

Figure 2. Selected Major element Harker diagram for the basic and intermediate rocks from Western part of the Benom Complex. All values in %.

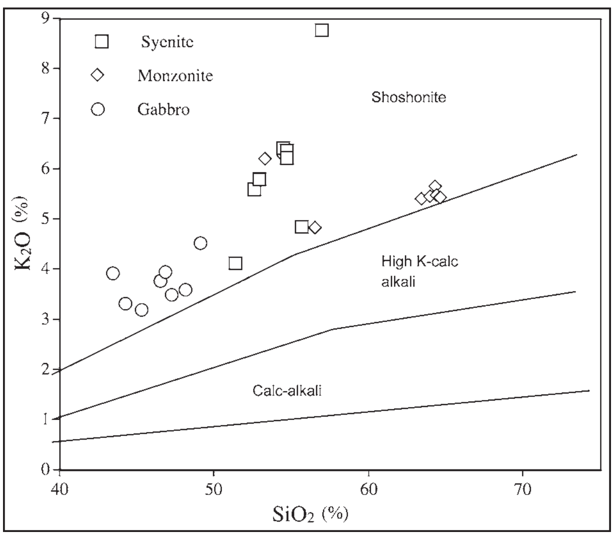

Figure 3. K_2O versus SiO2 diagram of the basic and intermediate rocks from Western part of the Benom Complex. Compositional field after Peccerillo and Taylor (1976).

Trace elements (+K_2O, P_2O_5 and TiO_2) of the rocks is presented in a multi-elements spider diagram (Figure 5). Normalizing value used in this diagram is after Mc Donough *et al*. (1991). The Ba and Sr content in these rocks are very high compared to other rocks elsewhere, i.e. Ba and Sr are nearly 1000 time rock/mantle. The profile generally does not show any systematic trend with decreasing SiO_2. Rb, Ba, U, K, Nb, P and Ti are depleted or negative anomalies against mantle composition. Gabbroic rock has higher Ce, La, P and Y and lower K compared to the monzonitic and syenitic rocks. Foliated syenite is lower in most of the elements i.e. Th, U, Nb, La, Ce, P, Zr and Ti compared to other rocks. In general, the pattern produced by these rocks is difficult to match to other rocks from elsewhere.

Compared to other rocks elsewhere, the rocks from studied area have very high LIL elements i.e. Ba (2401-10744 ppm ; mean : 4590 ppm), Rb (257 - 434 ppm) and Sr (578 - 2340 ppm ; mean : 1000 ppm). The former 2 elements are nearly 1000 times rock/mantle (Figure 2). Literature survey shows that there is no/little published data on the rock with similar LIL elements content. Other rock that has high LIL elements value (to our knowledge) is the monzodioritic rocks from the Fanad pluton, Donegal (Azman, 1997). The rocks from this pluton have up to 4367 ppm Ba and 2094 ppm Sr. Even the rocks from North Atlantic high grade craton and Ocean island basalt cannot match Ba content found in the rocks from the study area (Tarney & Jones 1994) (Figure 6). Those rocks from North Atlantic high grade craton and Ocean island basalt usually have up 2500 ppm Ba and 1800 ppm Sr. Other rock that have high Ba and Sr is the late Archean syenitic Murdock creek pluton, Ontario which related to extensional tectonic setting (Rowins *et al*., 1993). The range of Sr and Ba in this rocks are 227 - 2881 ppm and 1660 - 4302 ppm respectively (Kerrich & Watson, 1984; Rowins *et al*., 1993). In Peninsular Malaysia, Cobbing *et al*. (1992) recorded a sample from Boundary Range batholith (Near Kuala Krai area) has 9836 ppm Ba and 344 ppm Sr (Sr content, however much less than the Raub rocks). The multi-elements spider diagram profile of this sample has been compared to the Raub rocks (Figure 2). From the diagram, it is obvious that the Krai rock has the same profile to the Raub rocks. The former, however, has very high Pb (2590 ppm) and low Ce, Sr, P, Ti and Y. However, since they are well separated in space there is no way this can be anything to do with petrogenetic relationship during emplacement (Tarney & Jones 1994).

CONCLUDING REMARKS

The strong enrichment of these elements (Ba abd Sr) is probably related to transfer of enriched (hydrous ?) fluids from the mantle into the lower crust (and possibly initiated) melting to form the granites (Stephens and Halliday 1984). It is also possible for this to be linked with mantle plumes (e.g Hill *et al*.,1992). Not all deep mantle plumes are able to break through thick lithosphere, and may just underplate it, but at the same time provide energy for melting of the lower crust. Mantle derived liquid are enriched in Ba and Sr as a result of partial melting of (probably metasomatised) peridotite without plagioclase as a stable phase possibly followed by high pressure fractionation (Halliday & Stephen, 1984). If such, magma interacted with the lower crust, this only serves to maintain Ba and Sr at high levels and lower the Rb/Sr ratios. The enrichment of Sr in the high Ba rock probably indicates the formation of a plagioclase cumulate. Other possibilities to create magma composition with high Ba and Sr with positive anomalies for Sr and P is simply by having garnet residual in the source to sequester the heavy REE and depress the multi-elements variation pattern (Tarney & Jones, 1994). However, the Raub rocks have negative anomalies for P which implies that it is unlikely to have garnet residual in the source. Halliday & Stephen (1984) also suggested that the high Sr magmas in the British

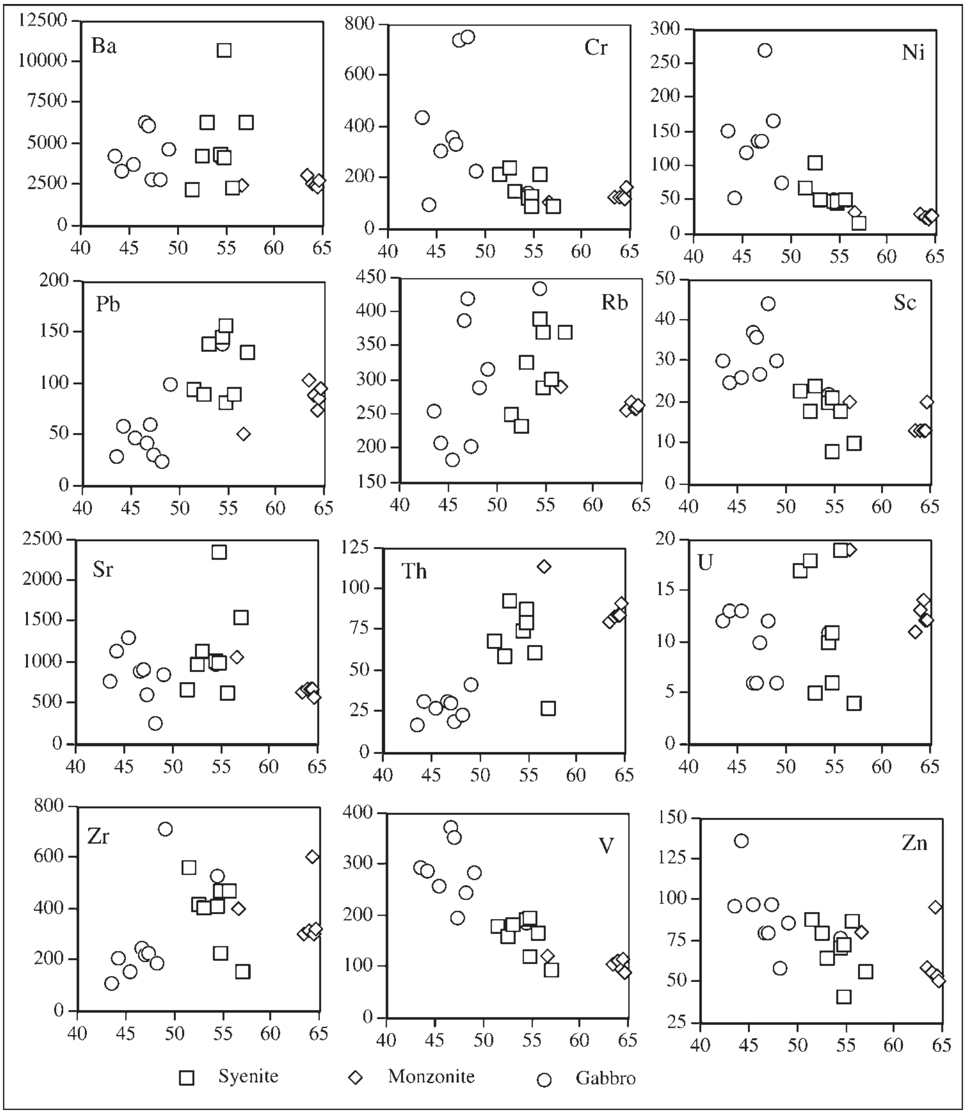

Figure 4. Trace element Harker diagram for the basic and intermediate rocks from Western part of the Benom Complex. Trace element values in ppm.

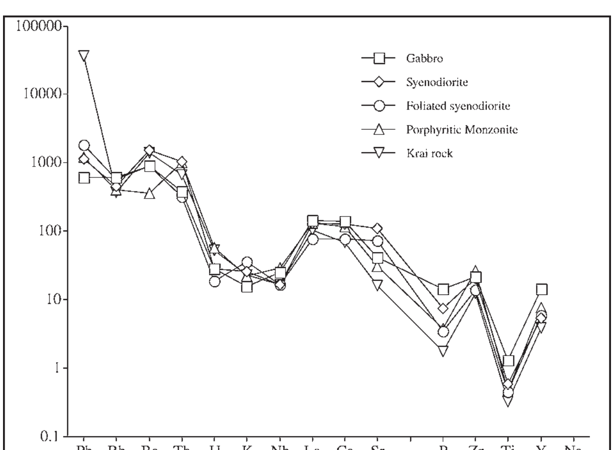

Figure 5. Multi elements plot for the basic and intermediate rocks from Western part of the Benom Complex. Also plotted in this diagram is a sample from Krai area (northern part of Central Belt) which also has high Ba content (~9000 ppm).

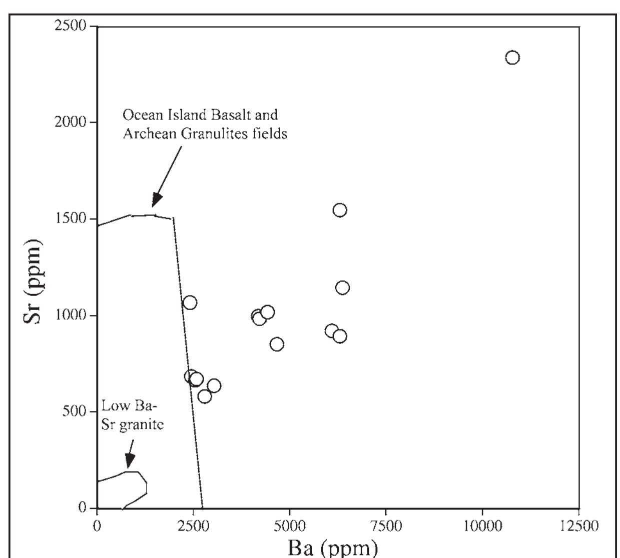

Figure 6. Sr versus Ba diagram of the basic and intermediate rocks from Western part of the Benom Complex.

Caledonian granite are product of a particular province maintained by a particular process.

Azman A Ghani & Mustaffa (2002), considered that the high Ba and Sr values may result from the penetration of the lower lithosphere by a small volume of mantle material that is enriched in those elements. Mohd Rozi Umor & Syed Sheikh Almashoor (2000) considered that the same rock types from the northern part of the study area (Benta Complex) were derived from the melting of eclogite from the mantle and could not have derived from the continental crust. The interaction with mantle material is supported by the occurrences of mafic enclaves and synplutonic dykes in the studied rocks (Yong *et al*., 2004). The Benom granite has yielded an initial $^{87}Sr/^{86}Sr$ ratio of 0.7079 (Cobbing *et al.*, 1992), which points to an origin in highly enriched lithospheric mantle. The long line of Central Belt Plutons and the geochemical data are consistent with 'mantle plume' type magmatism (Davies & von Blanckenburg, 1995, Atherton & Azman, 2002). The granitoids were derived from the melting of cooler, thickened, metasomatized mantle lithosphere when a hot plume-like asthenosheric linear diapir impinged against a mafic lower crust. Some of this magma stalled and crystallized at the base of the crust and subsequently partial melting formed the granitic magma as the asthenospheric upwelling increased. A similar scenario had been used to explain the genesis of the Late Granites of Scotland (Atherton & Azman, 2002).

ACKNOWLEDGEMENT

This project was funded by a University of Malaya research grant F 0705/2004A. Encik Mohd Azrai Ibrahim is thanked for drafting some of the figures.

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Manuscript received 7 May 2004
Revised manuscript received 2 May 2005