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High Ba igneous rocks from the Central Belt of Peninsular Malaysia and its implication

AZMAN A. GHANI, RAMESH, V., YONG, B.T., KHOO, T.T. & SHAFARI MUDA

Department of Geology
University of Malaya
50603 Kuala Lumpur

Abstract: Trace element characteristics of gabbro-monzonite-syenite from the Benom Igneous Complex, Sungai Ruan, Raub show that they are very high in large ion lithophile (LIL) elements. The rocks contain: Ba (2,401–10,744 ppm; mean: 4,590 ppm), Rb (257–434 ppm) and Sr (578–2,340 ppm; mean: 1,000 ppm) which is higher compared to the rocks from other areas. The strong enrichment of these elements (Ba and Sr) is probably related to transfer of enriched (hydrous?) fluids from the mantle into the lower crust and possibly initiated melting to form the rocks besides the possibility of being linked to mantle plumes.

INTRODUCTION

Peninsular Malaysia has been divided into three distinct belts namely Eastern, Central and Western Belt. The division also conveniently divided the granitic and other igneous rocks in the area. For example, the granitic rocks from the Western Belt are distinctly different from those of Eastern Belt. Thus the former shows 'S' type characteristics and predominantly monzogranite to granodiorite contrast to the latter which is predominantly 'I' type and has wider spectrum of rock types from monzogranite to granodiorite to diorite and gabbro. 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 igneous rocks of this belt form a narrow and well defined line of single plutons emplaced into Permo-Triassic rocks. The plutons occur very close to the Bentong-Raub line, which may suggest an underlying structural control for their emplacement. This short paper will report some of the trace element characteristics and its implication to the gabbro-syenite-monzonite complex from the central part of the Central belt (Fig. 1) near to the Raub township. The area has been studied by several workers and different interpretations have arisen (Scrivenor, 1931; Richardson, 1939; Khoo, 1968; Hutchison, 1971; Jaafar, 1979; Khoo & Tan, 1983; Shafari Muda, 1992; Tan & Khoo, 1993; Yong, 1998; Ramesh, 1999; Mohd Rozi Umor & Syed Sheikh Almashoor, 2000). The main controversy is either the rock in this area represents a migmatite complex or the product of igneous differentiation. The earliest report of this area was by Scrivenor (1931) who noted the occurrence of hornblende-bearing igneous rocks in the area. Richardson (1939) made the first detailed study of the area, mapping the rocks and proposed that the suite of rocks resulted from granitization of earlier basic and ultrabasic rocks by the later Benom granitic magma. Khoo (1968), however interpreted that all rocks in this region have been metamorphosed and suggested a low facies series but still maintained the term syenite. Hutchison (1971) based on two localities in the Benta area (northern part of the study area) suggested the whole series of rocks represent a migmatite complex (Benta Migmatite Complex) that is unrelated to the Benom granite.

GENERAL GEOLOGY

The study area lies within the Central belt, flanking the western part of the Benom granite. 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 amounts of quartzites. The igneous rocks found in the area are mainly of gabbro, syenite, monzonite, with lesser amounts of doleritic dykes and mafic microgranular enclaves.

The syenite is essentially made up of K-feldspar, hornblende, plagioclase, quartz with lesser amounts 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 zonal manner. The composition of the plagioclase in the syenite varies from andesine to oligoclase. Pyroxene when present is usually rimmed by green hornblende. Quartz occurs as an interstitial mineral, occasionally forming micrographic intergrowths with plagioclase. The plagioclase mode in the syenite can reach up to 25% but varies from sample to sample. Apatite is quite common, both as accicular aggregates and as equant or prismatic crystals. Sieve texture is commonly seen in hornblende. The green hornblende sometimes contain inclusions of apatite and quartz. Opaque minerals probably magnetite are sparsely distributed in the syenite. Sphene and epidote, probably the early crystallisation products are also present. Epidote also occurs as veinlets that 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.

Monzonite is a holocrystalline inequigranular, coarse grained rock comprising of K-feldspar, plagioclase, augite, hornblende and biotite. The K-feldspar is microcline and their perthite varieties. They occur as big crystals showing good Carsbad twinning and sometimes faint zoning outlined by dust inclusions. Plagioclase occur as lath shape crystals showing distinct lamellae twins. Their composition vary from An_{24} to An_{37}. Small lath shape plagioclase crystals are also found in big K feldspar crystals. Some plagioclases are sericitised to fine micas along twin-planes. Individual hornblende crystal is subhedral and twinning is not uncommon. Clinopyroxene mainly augite is commonly twinned and exhibit corona texture made up of hornblende. Biotite occurs as subhedral crystals. Some of the biotite contain 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.

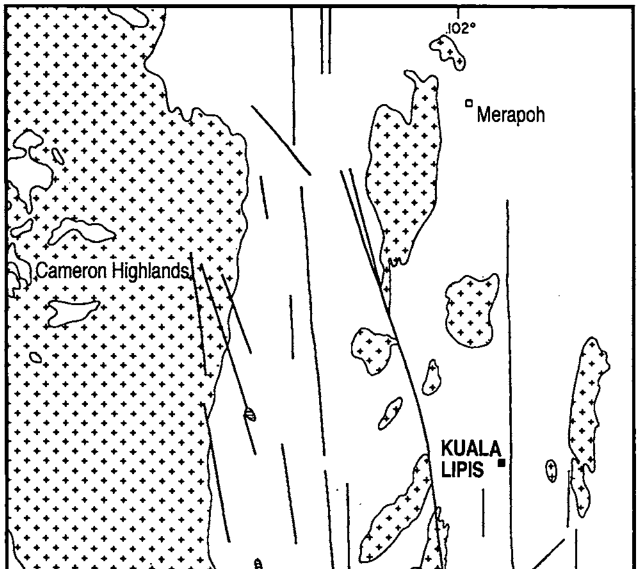

Figure 1. Map of the central part of Peninsular Malaysia showing the igneous rocks from the Raub and Kuala Lipis area (after Khoo & Tan, 1983)

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 grains and parallel intergrowths with augite. They are usually pleochroic from green to pale green. Biotite occurs as flakes with distinct cleavages can occur up to 35% in some gabbroic samples. Inclusions of ilmenite and sphene are common along cleavage traces and ragged edges of biotite.

TRACE ELEMENT GEOCHEMISTRY

Representative analyses of the gabbro, syenite and monzonite from the study area are presented in Table 1. Detailed geochemistry and petrogenesis of this complex will be presented elsewhere (Azman *et al.*, in prep.). This paper will only emphasize on particular trace elements especially the large ion lithophile elements (Ba, Sr and Rb). Trace elements of the rocks is presented in a multi-element spider diagram (Fig. 2). Four representative samples from the study area with increasing SiO_2 were plotted on this diagram. Normalizing values used in this diagram is after McDonough *et al.* (1991). The profile generally does not show any systematic trend with decreasing SiO_2. Rb, Ba, U, K, Nb, P and Ti are depleted or show 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 rock 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 (2,401–10,744 ppm; mean: 4,590 ppm), Rb (257–434 ppm) and Sr (578–2,340 ppm; mean: 1,000 ppm). The former 2 elements are nearly 1,000 times rock/mantle (Fig. 2). Literature survey shows that there is no/little published data on the rock with similar LIL elements content. The rock that has high LIL element values (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 Oceanic Island basalt cannot match the Ba content found in the rocks from the study area (Tarney and Jones, 1994) (Fig. 3). The rocks from North Atlantic high grade craton and Oceanic Island basalt usually have up 2,500 ppm Ba and 1,800 ppm Sr. Another rock that has high Ba and Sr is the late Archean syenitic Murdock Creek pluton, Ontario which is related to extensional tectonic setting (Rowins *et al.*, 1993). The range of Sr and

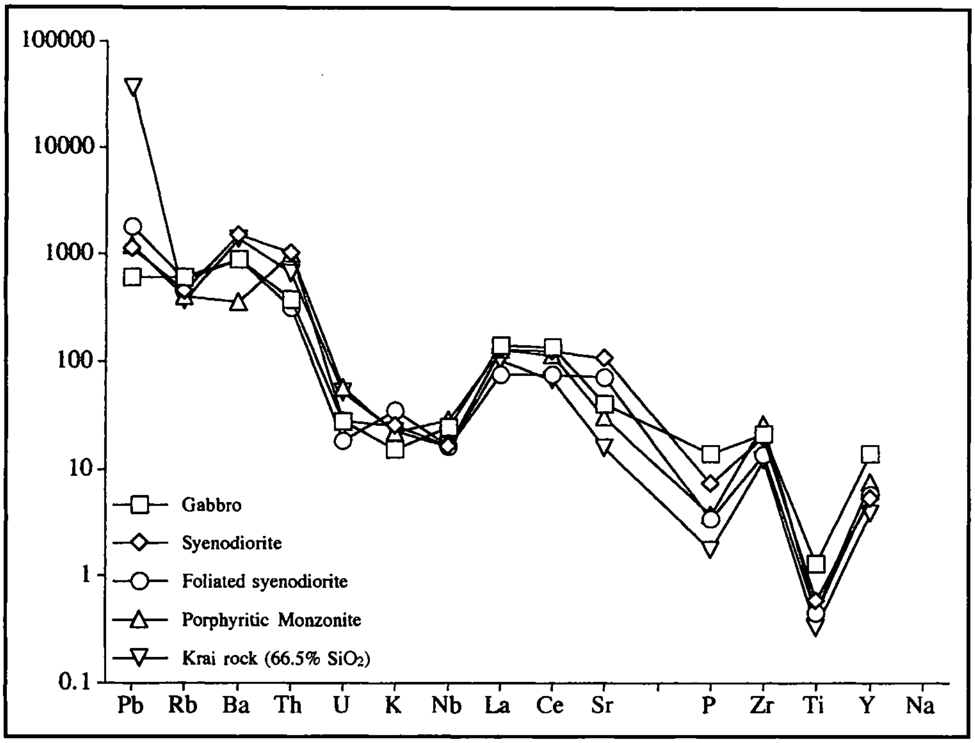

Figure 2. Multi-element variation diagram of gabbro, syenite and monzonite from the study area. Profile of a sample from Krai area (Lata Rek, Cobbing *et al.*, 1992) is also shown for comparison.

Ba in these rocks are 227–2,881 ppm and 1,660–4,302 ppm respectively (Kerrich and Watson, 1984; Rowins *et al.*, 1993). In Peninsular Malaysia, Cobbing *et al.* (1992) recorded a sample from Boundary Range batholith (near Kuala Krai area) with 9,836 ppm Ba and 344 ppm Sr, (Sr content, however is much less than the Raub rocks). The multi-element spider diagram profile of this sample has been compared to the Raub rocks (Fig. 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 (2,590 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 (cf. Tarney and Jones, 1994).

IMPLICATION

The strong enrichment of these elements (Ba and 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

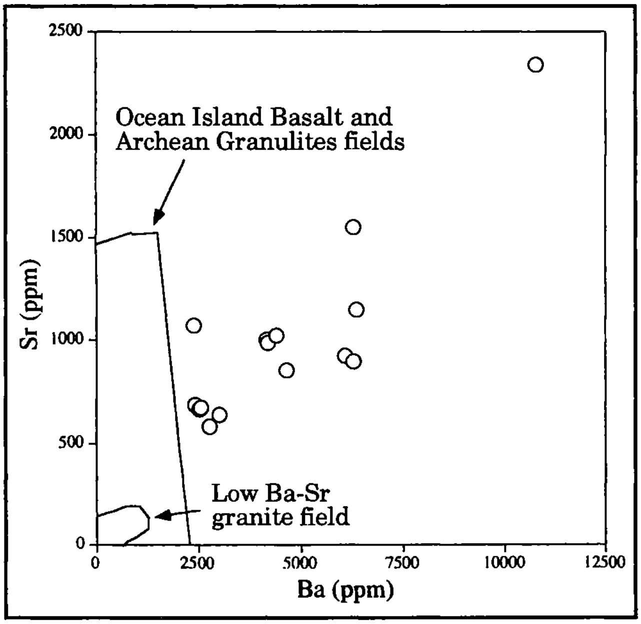

Figure 3. Ba vs Sr of gabbro, syenite and monzonite from the study area. Note that the Ba values is much higher compared to the rocks from Ocean Island Basalt and Archean granulites fields.

Table 1. Representative chemical composition of major and trace elements of syenite, gabbro and monzonite from the Raub area (after Ramesh, 1999 and Azman unpublished data).

Sample Rock Type	1sy Syenite	6sy Syenite	10syd Syeno-diorite	B21sy Syenite	P1sy Syenite	24Mz Monzonite	28Mz Monzonite	B2Mz Monzonite	MJ2Mz Monzonite	B1Mz Monzonite	GrMz Monzonite	2G Gabbro	15G Gabbro	16G Gabbro	G1G Gabbro
wt%															
SiO_2	54.41	54.64	54.64	56.97	52.9	63.97	64.37	63.41	64.67	56.55	64.29	54.4	46.82	46.5	49.05
TiO_2	0.88	0.86	0.77	0.58	0.93	0.61	0.61	0.67	0.6	0.72	0.56	0.87	1.68	1.7	1.36
Al_2O_3	16.48	16.52	20.18	18.34	16.61	15.61	15.58	15.4	15.23	20.59	16.2	16.18	12.81	12.16	14.88
Fe_2O_3	8.5	6.46	4.56	5.42	6.94	4.33	4.21	4.8	4.27	4.43	3.54	6.8	9.55	9.66	9.26
MnO	0.11	0.11	0.04	0.08	0.11	0.07	0.06	0.07	0.07	0.06	0.05	0.12	0.14	0.15	0.14
MgO	4.13	4.05	2.9	1.93	4.81	2.13	2.08	2.41	2.06	2.38	1.79	4.39	9.17	9.58	6.96
CaO	6.78	6.65	5.66	4.36	7.55	3.54	3.53	3.85	3.44	4.34	3.24	6.94	12.1	12.62	9.67
Na_2O	2.58	2.73	2.98	2.33	2.27	2.85	2.85	2.86	2.75	4.9	3.22	2.53	1.37	1.19	2.04
K_2O	6.42	6.37	6.21	8.76	5.8	5.45	5.46	5.39	5.41	4.82	5.63	6.32	3.93	3.76	4.51
P_2O_5	0.65	0.65	0.89	0.32	0.72	0.35	0.35	0.38	0.33	0.36	0.27	0.64	1.26	1.32	1.00
LOI	1.29	1.21	1.41	1.41	1.65	0.88	0.87	1.33	1.34	1.31	1.08	1.18	1.59	1.61	1.68
Total	100.23	100.25	100.24	100.5	100.29	99.79	99.97	100.39	100.17	100.46	99.67	100.37	100.42	100.25	100.55
ppm															
Ba	4394	4175	10744	8289	6334	2577	2354	3019	2761	2401	2420	4200	6085	6290	4639
Ca	295	313	239	142	247	210	216	213	219	274	206	305	248	256	305
La	124	135	93	55	103	92	93	88	90	118	64	134	96	102	128
Nb	30	31	12	12	28	24	21	23	22	29	23	53	20	18	38
Ni	48	47	49	18	51	25	26	28	26	32	23	51	138	137	75
Pb	145	157	82	130	139	88	85	103	95	50	74	139	61	43	99
Rb	389	370	269	371	326	268	256	256	262	290	257	434	420	387	317
Sr	1016	996	2340	1547	1145	667	664	635	576	1068	682	984	919	890	854
Th	74	80	88	27	93	83	84	80	91	113	64	75	31	32	42
V	191	195	121	96	163	110	115	103	67	122	95	186	352	372	285
Y	50	50	25	27	48	38	35	38	35	44	34	54	82	65	56
Zn	71	73	41	57	65	56	54	59	50	80	95	77	80	80	86
Zr	412	471	231	156	402	310	302	302	317	398	600	530	220	246	713

fractionation (Halliday and 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-element variation pattern (Tarney and Jones, 1994). However, the Raub rocks have negative anomalies for P which imply that it is unlikely to have garnet residual in the source. Halliday and Stephen (1984) also suggested that the high Sr magmas in the British Caledonian granite are the product of a particular province maintained by a particular process.

CONCLUSION

Occurrence of high Ba and Sr rocks from Raub area may indicate the influence of mantle plume. The high Ba and Sr character probably result from penetration of the lower lithosphere by a small volume of the mantle material that is enriched in these elements (cf. Green and Wallace, 1988; *Ionov et al.*, 1993; Rudnick, 1993). Evidence of the interactions with mantle material are provided by the occurrence of mafic enclaves and mafic synplutonic dykes everywhere in this area (Shafari Muda, 1992; Yong, 1998; Ramesh, 1999). More work has to be done in order to support the existence of mantle plume beneath this region during Permo-Triassic time. Some of the problems related with mantle plume is highlighted below:

1. There are no picrites and komatiites in Peninsular Malaysia which can be related to plume activity.
2. Magmatic provinces associated with mantle plumes are predicted to be equant and have a diameter of 2,000 km whereas the Peninsular Malaysia granites are of elongated batholiths.

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