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Geochemical characteristics of S- and I-Type Granites: Example from Peninsular Malaysia granites

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Abstract: The Peninsular Malaysian granites are distributed into three parallel belts, i.e. Western, Central and Eastern belts. They have been grouped into two granite provinces; a Western province consisting of granites confined to the Western Belt with an age range from 200 to 230 Ma and the Eastern province consisting of granites from both the Eastern and Central belt and aged from 200 to 264 Ma. A first order difference between the Western and Eastern Belt Granites of Peninsular Malaysia is the S type nature of the former. This is contrast with the expanded compositional nature of the Eastern Belt rocks where I type; S type granitoids and mafic rocks are all recognized. Among the other geochemical difference between these two granitoids province are expanded nature of the Eastern Belt Granite, low Na2O and high Th, U, Sn, Pb and Cs of Western Belt Granite compared to the Eastern Belt Granite. Both Western and Eastern belt granitic magmas are controlled by different mineral proportion (Western Belt Granite: K-feldspar, plagioclase and biotite and Eastern Belt granite: hornblende, K-feldspar, plagioclase, biotite)

INTRODUCTION

S- and I-type granites from the Tasman Orogenic Zone of Eastern Australia were studied in detail by Chappell and White (1974). The granites, which are of widespread occurrence, may be distinguished by chemical, mineralogical, field and other criteria. White, Chappell and their coworkers (1974, 1978, Hine et al, 1978) have carried out a complete study of magma provenance in this area, particularly in the Lachlan Fold Belt. They recognized a group of early, metamorphically harmonious plutons largely composed of S-type granites, which probably originated from the remelting of metasediments, and a younger group of mostly I-type granites with aureoles derived from remelting of deep-seated igneous material. Classification of granites according their magmatic origin results in the formation of two contrasting groups, S-types and I-types. S-types result from the partial melting of metasedimentary source rocks, a process called anatexis or ultra metamorphism. In many Mesozoic-Cenozoic regions, the 'S' type batholith has been identified to occur inboard from 'I' type along continental margins (e.g. western North America, the Himalayas and eastern Asia, Pitcher, 1983). This 'I-S' duality is believed to reflect the progressive remobilization of continental crust in granitoid genesis with time as the locus of magmatism migrated landwards, away from the trench in subduction system. Similar features also occur in the Peninsular Malaysia granites. The Western and Eastern Belt granites of the Peninsular Malaysian also separated by a line, which is parallel to the Bentong-Raub suture (Hutchison, 1975). The Western Belt granite of Peninsular Malaysia has been regarded to be constituted by exclusively 'S' type granites (e.g. Liew, 1983; Hutchison, 1996) in contrast to the Eastern Belt granite which is dominated by 'I' type with subordinate 'S' type granites (Liew, 1983). In this paper the characteristic of I and S type granite will be compared with particular reference to the Western (Main Range Granite) and Eastern Belt granite of Peninsular Malaysia.

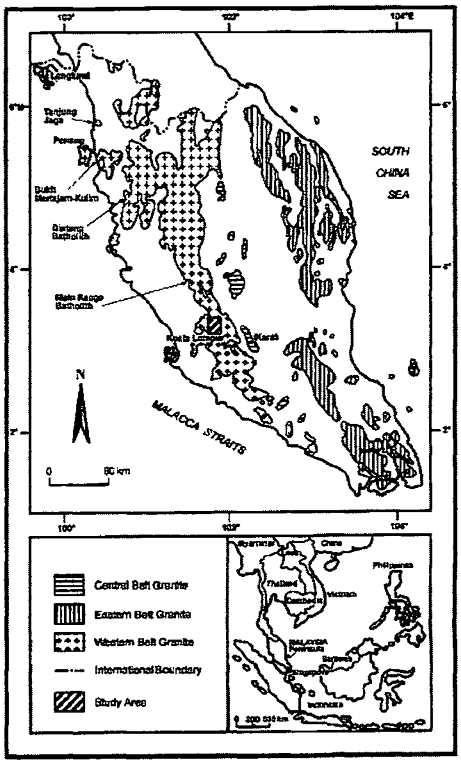

Figure 1: Map of the Peninsular Malaysia show the Western Belt granite in relation to other granites batholith. Square inset map shows the location of Peninsular Malaysia.

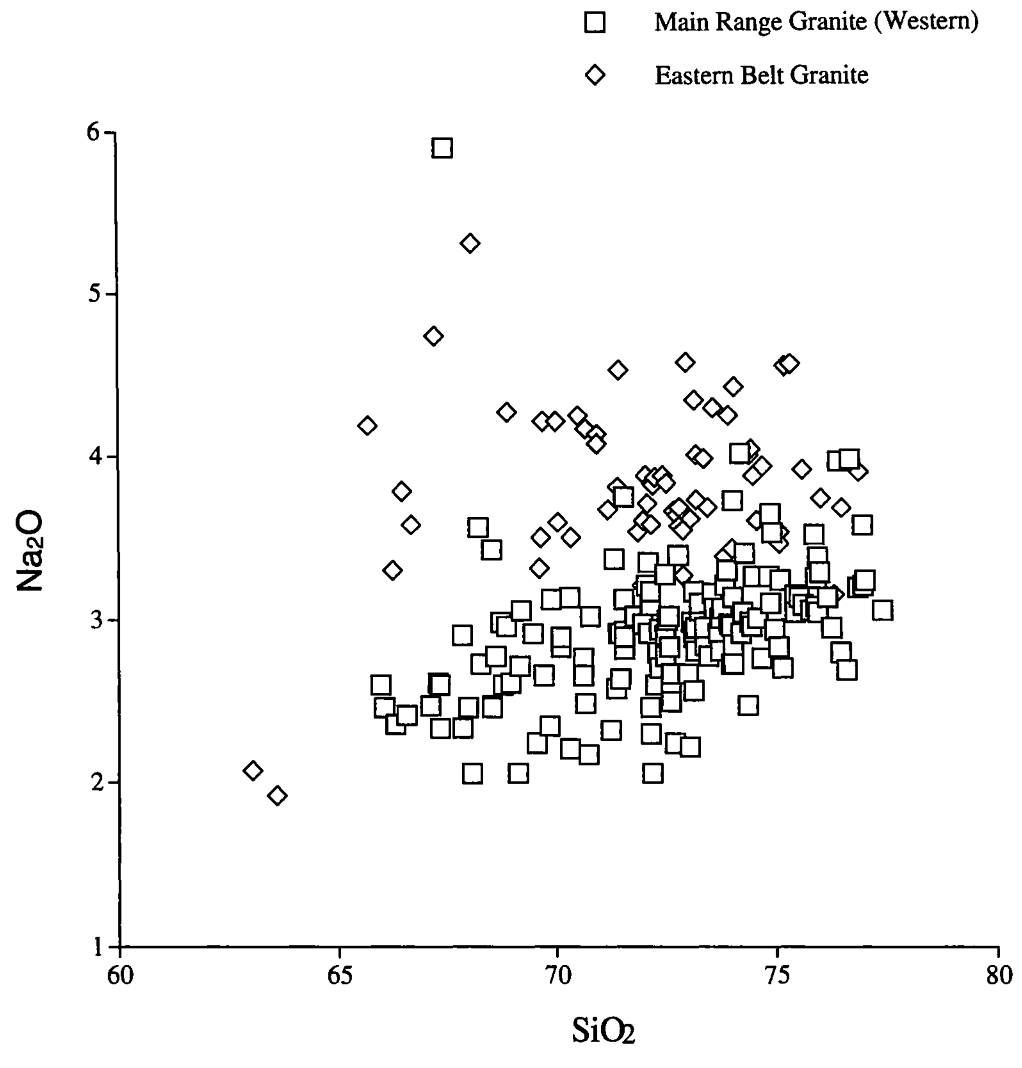

Figure 2: Na_2O vs K_2O plot of the Eastern & Western Belt granites. Field of the 'S' and 'I' type granite is after Cahappell and White (1983). Note that in general the Western Belt granite contain slightly higher Na_2O content compared to the 'S' type granite at the same K2O concentration.

PENINSULAR MALAYSIA GRANITES

The Peninsular Malaysian granites are distributed into three parallel belts, i.e. Western, Central and Eastern belts (Fig 1). They have been grouped into two granite provinces; a Western province consisting of granites confined to the Western Belt with an age range from 200 to 230 Ma and the Eastern province consisting of granites from both the Eastern and Central belt and aged from 200 to 264 Ma (Cobbing et al. 1992). The Western belt granites is characterised large batholith or complex plutons of restricted compositional range comprise of a suite of tin bearing S type granite. It forms a huge mountain range extending from Malacca in the south to Thailand in the north, which covers the area exceeding 15000 km^2. Two main batholith masses can be distinguished in the Western Belt Granite. These are the Main Range batholith on the eastern flank and the adjacent Bintang batholith immediately to the west. Small intrusive centres are found further to the west. These are called Bukit Mertajam-Kulim, Penang, and Langkawi complexes. Each granitic batholith and complex consists of individual plutons (Liew, 1983; Azman et al., 2000). The main rock type is a coarse to very coarse-grained megacrystic biotite muscovite granite. Two-phase variants, however, developed almost everywhere and may be volumetrically important (Pitfield et al., 1990; Cobbing et al., 1992; Mursyidah and Azman, 1999). The second group corresponds to the amphibole bearing granite found in several granitic bodies at the northern part of the Western belt granite. The Bintang granite complex is the best example. Common mineralogical assemblages of this complex is low Al-biotite + sphene ± actinolitic hornblende (Liew, 1983; Borhan Doya, 1995; Azman et al., 2000). The third group is the felsic volcanic rocks associated with the Western Belt granite. The best-known volcanic complex is the Genting Sempah volcanic complex, that is related, both temporally and spatially, to the granite. The Sempah volcanic complex occupies the central part of the Western Belt Batholith to the east of Kuala Lumpur city.

The Eastern Belt granite consists of smaller batholiths consisting of zoned and unzoned plutons of compositionally expanded, but dominantly monzogranite with I type affinities which lies to the east of the Bentong Raub line. Mineralization in the Eastern Province consists of mainly of base metal deposits located within and in the marginal zone of certain plutons. Throughout the belt the granitoids develop very narrow thermal aureoles and some have miarolitic cavities indicating high level emplacement. Rock types ranging from monzogranite to granodiorite to diorite to gabbro are found in composite batholiths characterised by hornblende and biotite as the main mafic phases. The dioritic and gabbroic rocks sometimes form single plutons (Pemanggil & Aur Islands) or forms the margins of granitoid bodies (Bukit Kemuning gabbro & Linden Gabbroic stock Johore). Rare occurrences of rocks belonging to the alkalic series are found at Perhentian Kecil Island (Azman & Khoo 1998, Azman 2000, 2001) consisting of the Perhentian Kecil Syenite, rimmed by the more evolved Perhentian Granite. The Syenite consists of a variety of igneous rocks ranging in composition from syenitic to monzonitic and even gabbroic, characterised by high-K shoshonite affinities. Geochemically the granitic rocks from the Eastern Belt Granite belong to an expanded Calc alkaline series. Zircon inheritance ages for of the eastern Belt Granite give a range from 900 to 1400 Ma younger than the Western Belt Granite dated between 1500 to 1700 Ma (Liew 1983).

PETROGRAPHY

Some of the geochemical aspects of S- and I-type granitoids are reflected in the mineralogy. Modal distribution of the felsic end members shows that the composition of the Western Belt Granite is similar to Eastern Belt Granite, both falling in the monzogranite and syenogranite range. Minerals occurring in Western Belt Granite, in decreasing abundance, are K-feldspar, quartz, plagioclase, biotite, muscovite, allanite, zircon, sphene, apatite, secondary epidote, tourmaline, ilmenite, amphibole, andalusite and garnet. Amphibole found in the northern part of the Western Belt granite (Cobbing et al., 1992; Khoo and Lee, 1994; Singh and Yong 1982) is mainly actinolitic hornblende in composition with an atomic Mg/(Mg+Fe) range from 0.5 to 0.6 (Liew, 1983). Compared to the Australian S-type Granite, hornblende is absent, but muscovite is common, while in the mafic S-types, biotite is often very abundant. Monazite is the usual accessory in the S-types and apatite inclusions are common in biotite. The Eastern Belt granitoids range in composition from diorite to granite but are mainly of granodioritic composition. The mineralogy assemblage is K-feldspar, quartz, plagioclase, low Al biotite, hornblende, sphene, magnetite and ilmenite

GEOCHEMICAL DIFFERENCES

300 geochemical analyses of the Western Belt and Eastern Belt Granites have been collected from published and unpublished data (e.g. Liew 1983, Cobbing et al. 1992; Azman 2000, 2001, 2003 and unpublished data; Azman et al. 2000). All data represent the granites (Main Range) and hornblende granite (Taiping granitic complexes) from the Western Belt and Granite to granodiorite and mafic association (Pemanggil Diorite and Perhentian Kecil Syenite) of the Eastern Belt.

On major element classification plots such as Na_2O vs K_2O (Fig 2), majority of the rocks from Eastern Belt Granite plot in the I type field of White and Chappell (1983). In contrast, those from the Western Belt Granite plot in the S type field. The high Na_2O content of the Eastern Belt Granite is shown in the SiO_2 vs Na_2O diagram (Fig 2). The Eastern Belt Granite rarely contain less than 3 % Na_2O, while the Western Belt granites rarely exceed 3 % Na_2O. This is comparable to the Australian I-types Granite, which have relatively high sodium (Na_2O greater than 3.2%), in felsic varieties, decreasing to more than 2.2% in mafic types. Australian S-types Granite has relatively low sodium, Na_2O normally less than 3.2% in rocks with approximately 5% K_2O, decreasing to less than 2.2% in rocks with approximately 2% K_2O. In general, major element data from rocks of both Western and Eastern Belt Granite (s.s.) of Peninsular Malaysia show well-developed trends typical of high –K calc –alkali suites (Fig 3 K_2O vs SiO_2). The only difference is that the the Eastern Belt Granite shows an extended range of SiO_2

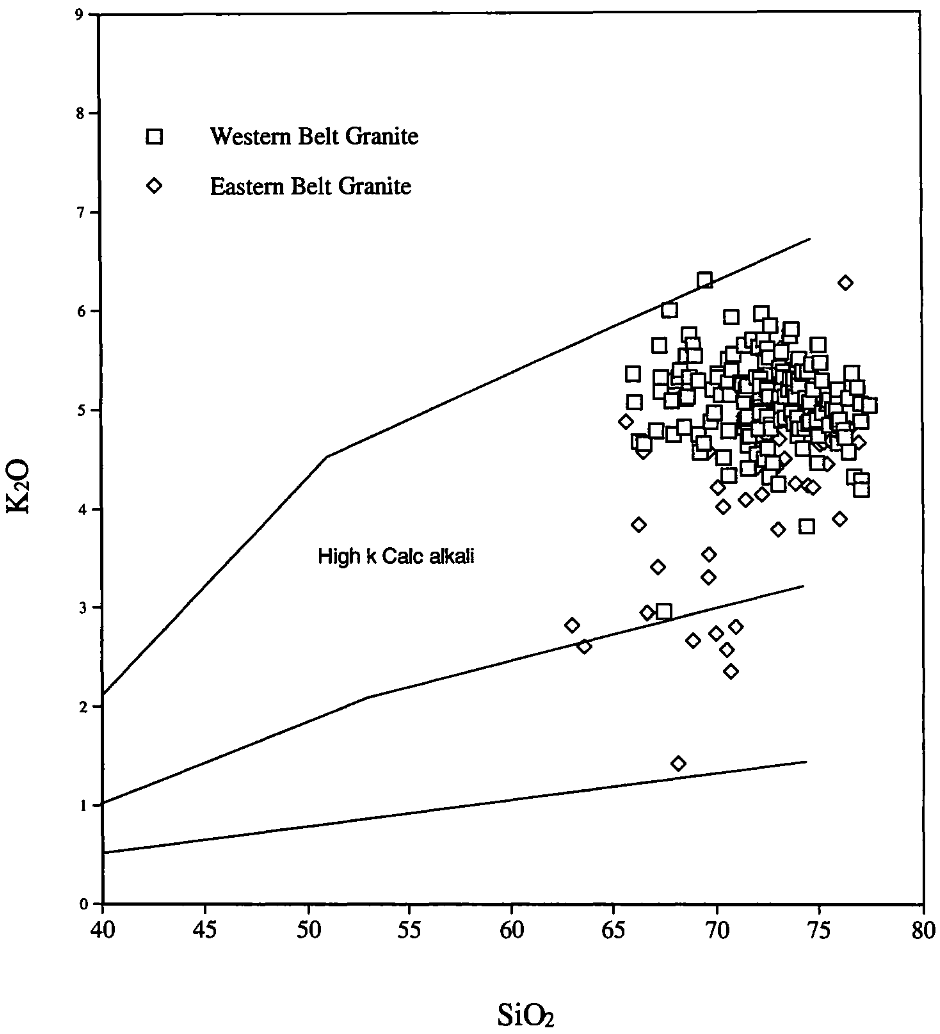

Figure 3: K_2O vs SiO_2 of the Eastern & Western Belt granites. Most of the Eastern & Western Belt granite samples fall in the high k calc alkali filed of Peccerillo & Taylor (1976)

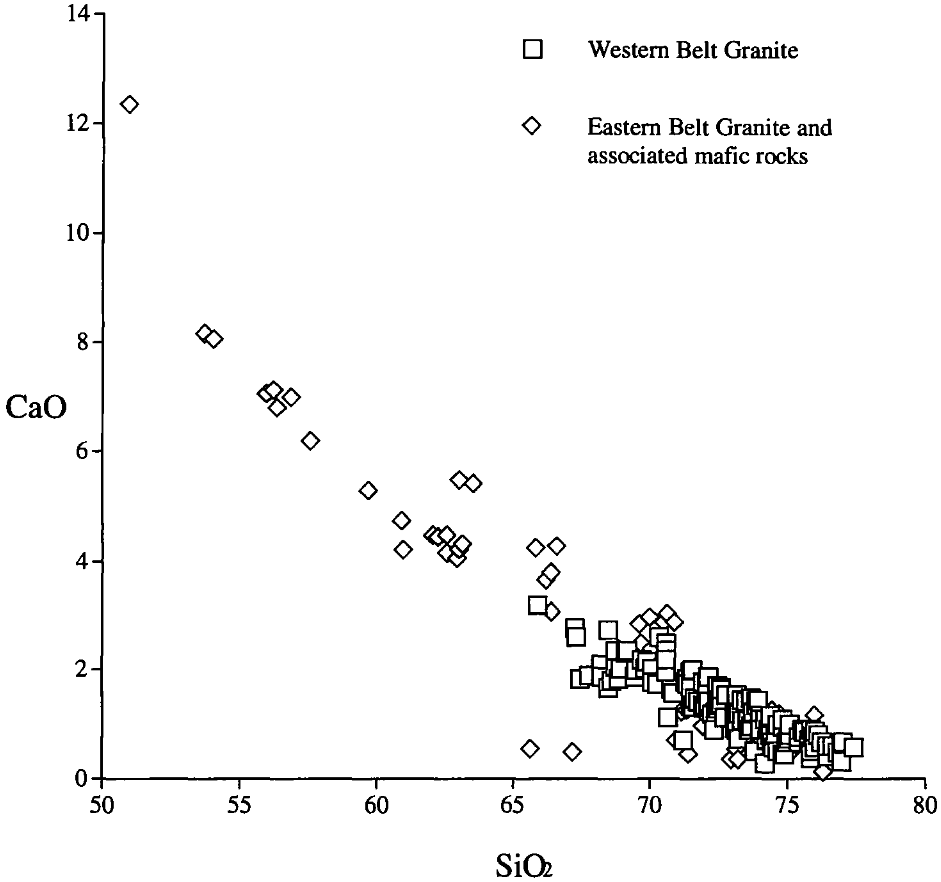

Figure 4: CaO vs Sr diagram for the Eastern & Western Belt granites

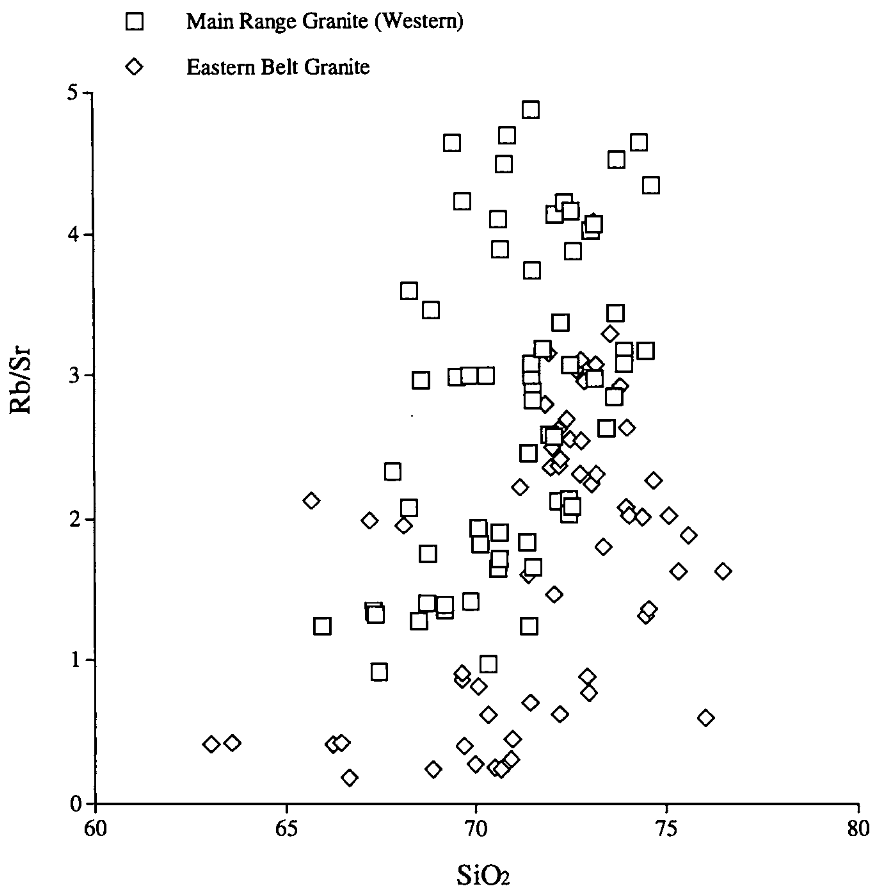

Figure 5: Rb/Sr vs SiO_2 diagram for the Eastern & Western Belt granites

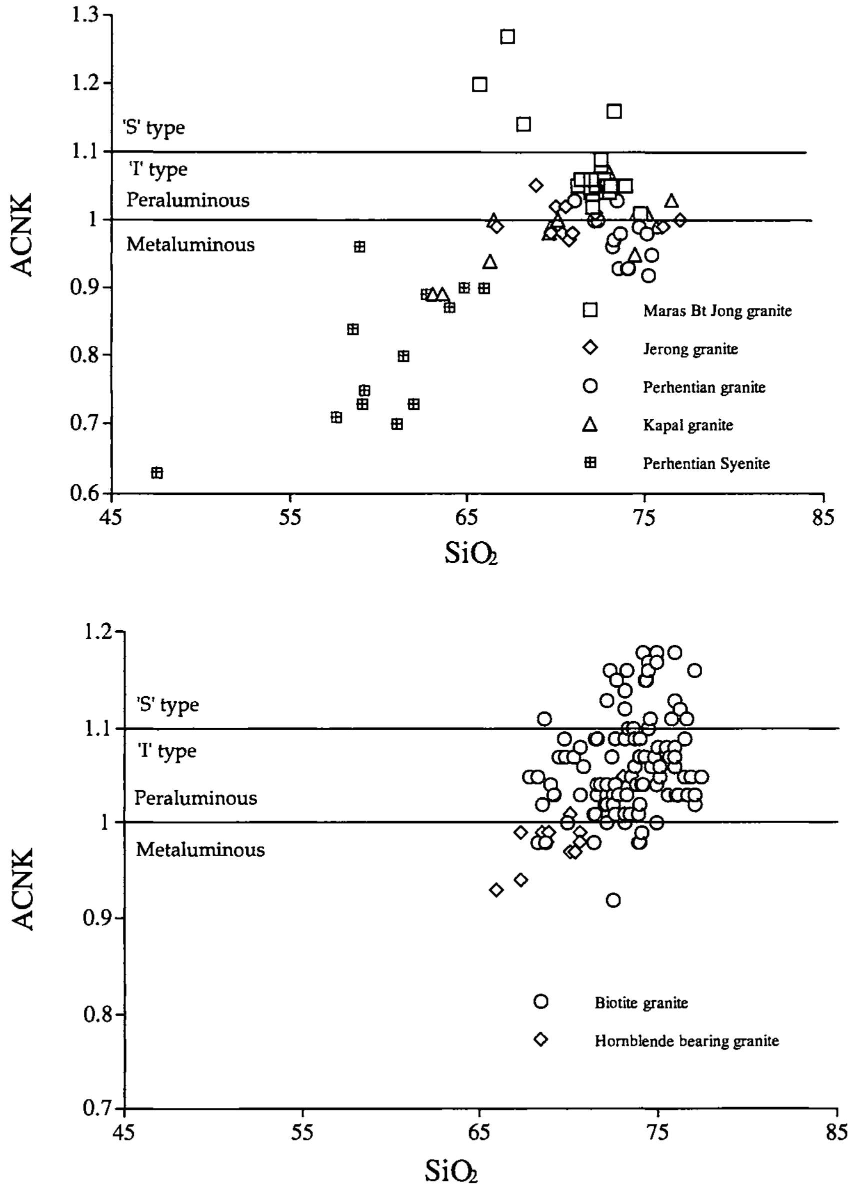

Figure 6: $Al_2O_3/CaO+Na_2O+K_2O$ vs SiO_2 (ACNK) diagram for the Eastern & Western Belt granites.

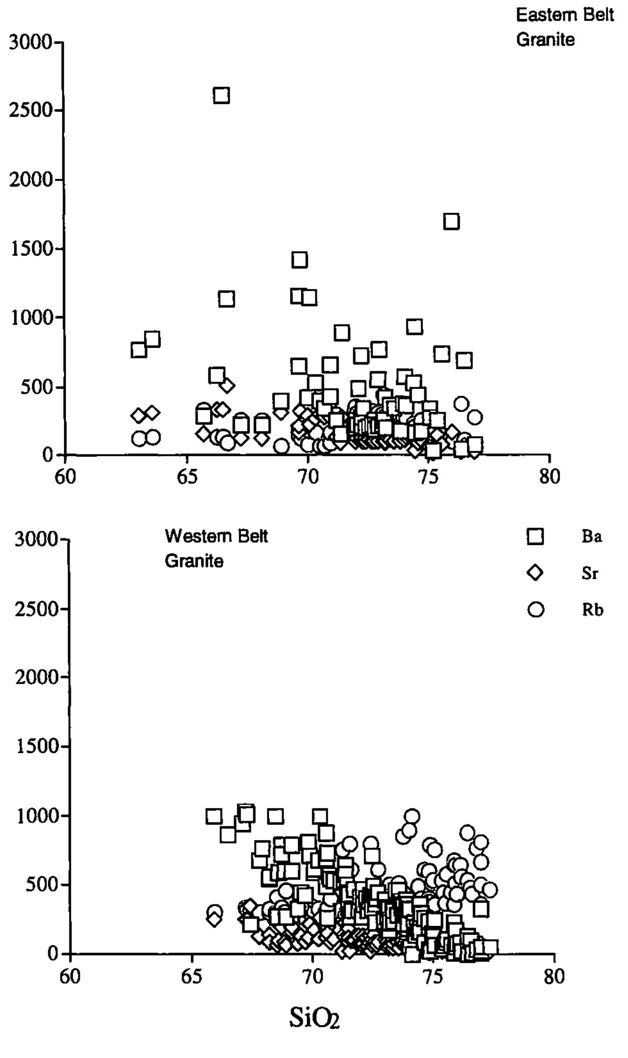

Figure 7: Large ion Lithophile elements (Rb, Sr, Ba) plot for the Eastern and Western Belt Granites.

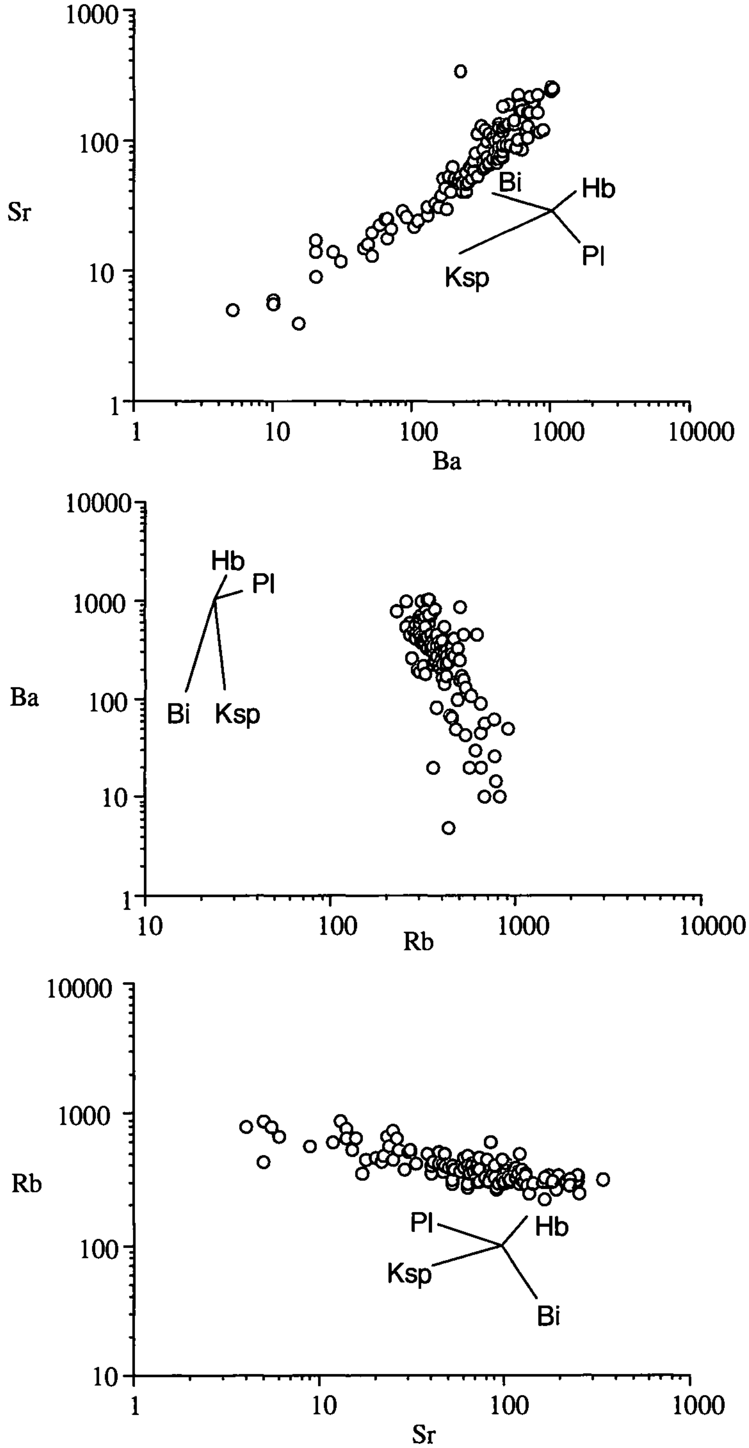

Figure 8: Large ion lithophile elements modeling of the Eastern & Western Belt granites. Mineral vector indicate path-evolved liquids for 20% of mineral precipitating. Ksp= K-feldspar; Pl = Plagioclase; Bi = Biotite and Hb = Hornblende.

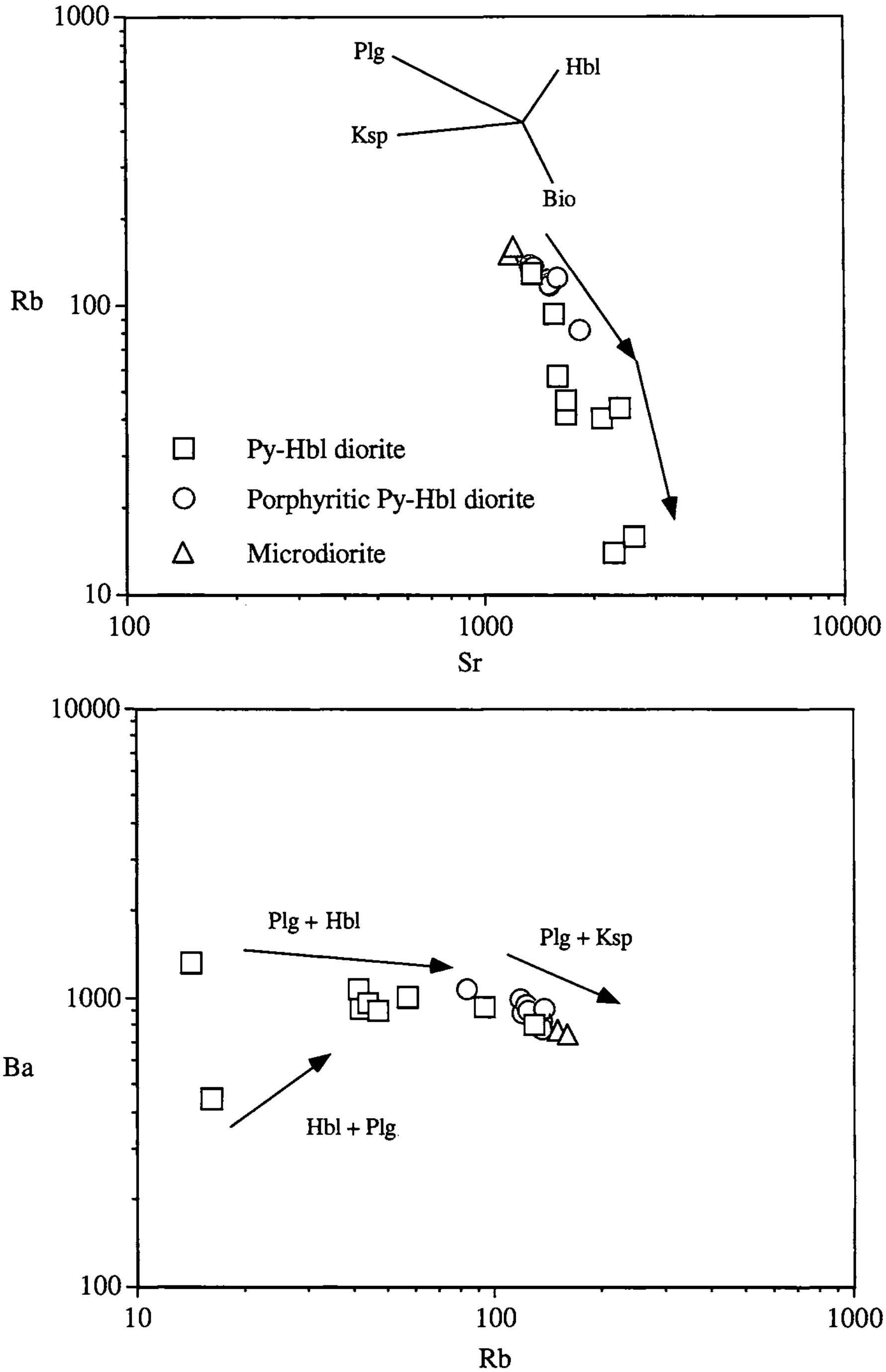

Figure 9: Large ion lithophile elements modelling of the Pemanggil island igneous rocks (e.g. Eastern Belt granite). Mineral vector indicate path evolved liquids for 20% of mineral precipitating. Ksp= K-feldspar ; Pl = Plagioclase ; Bi = Biotite and Hb = Hornblende

and K_2O contents compared to the Western Belt Granites. Thus the Eastern Belt Granitic suite (including Syenitic, dioritic and gabbroic composition) grade from calc alkali to high –K calc –alkali to shoshonite. However Eastern Belt granite proper (SiO_2 > 65%) is confined to high– K calc–alkali affinities. This expanded nature of the Eastern Belt granite is clearly shown in the CaO vs SiO_2 diagram (Figure 4) where the granitic and associated mafic and intermediate rocks for both Eastern and Western Belt granites were plotted together. The SiO_2 content of the Eastern Belt Granite and associated mafic and intermediate rocks range between 50 to 78% SiO_2, in contrast to the Western Belt granites which are confined to SiO_2 > 65%.

Rb/Sr ratios (Fig 5) are higher in the Western Belt Granites (1 to 200) compared to those from the Eastern Belt Granites (0.1 to 3.1). However there are some overlaps between 70 to 75% SiO_2. The high Rb/Sr ratio of the Western Belt Granite reflects the highly evolved nature of the magma compared to the Eastern Belt Granite magma. The Eastern Belt Granite has wider ACNK ratios ranging 0.62 to 1.29 compared to the Western Belt Granites (0.9 to 1.19) (Fig 6). 95% of the samples from the Eastern Belt and 70 % of the Western Belt samples fall into the I type granite field of Chappell and White (1974). The four Eastern Belt samples that fall above ACNK 1.1 are highly evolved granites from the Maras Jong Pluton (Azman 2003). Both Eastern and Western Belt Granites show increasing trends with increasing SiO_2. The Eastern Belt Granite is less enriched in uranium (5-10 ppm) and thorium (18 to 40 ppm) than the Western Belt Granite (Liew 1983). However Cobbing et al. (1992) indicate a wider uranium range for the Eastern Belt rocks (2 – 15 ppm). On modified ACF plots (Liew 1983), the field of the Western Belt granites lie above the plagioclase-biotite tie line whereas bulk of the Eastern Belt Granites plot in the metaluminous region below the plagioclase-biotite tie line. The former also high in incompatible element like Th, U, Sn, Pb and Cs.

Large ion lithophile content of the Eastern Belt is more irregular compared to the Western Belt Granite. This is evident from Ba, Sr and Rb vs. SiO_2 plots (Fig 7).Generally the rocks from the Western Belt have low Rb Sr and Ba (< 1000 ppm). However in detail Rb content in the Eastern Belt (< 500 ppm) is lower compared to the Western Belt granites (< 1000 ppm). LIL modeling (Fig 8) of the Western Belt show that the magmatic evolution is controlled by K-Feldspar, plagioclase and biotite, while in the Eastern Belt Granites hornblende also plays an important role in the magmatic evolution. An example shown in Figure 9, large ion Lithophile of the dioritic rock from Pemanggil Island, Eastern Belt Granites.

CONCLUDING REMARKS

A first order difference between the Western and Eastern Belt Granites of Peninsular Malaysia is the S type nature of the former (Liew 1983; Cobbing et al.1992). This contrasts with the expanded compositional nature of the Eastern Belt rocks where I type; S type granitoids and mafic rocks are all recognized. The scarcity of volcanic rocks associated with the Western Belt Granite contrasts with the abundance of volcanic rocks with an expanded compositional range similar to the associated plutonic rocks in the Eastern Belt. This paper outlines some of the geochemical differences between the Western and Eastern Belt granites. Liew (1983) suggested that the geochemical difference between the granitiods of both provinces largely reflects the S type nature of the West Coast and the predominantly I type nature of the East Coast granitoids. Among the geochemical difference between these two granitoids provinces are:

(i) The expanded range of compositions of the Eastern Belt Granite (SiO_2: 50 to 78% SiO_2) compared to that of the Western Belt granites (SiO_2 > 65%).

(ii) The Western Belt Granites have lower Na_2O contents and high Th, U, Sn, Pb and Cs contents compared to the Eastern Belt Granite

(iii) Magmatic evolution of the Western Belt Granites were controlled by K-feldspar, plagioclase and biotite whereas in the Eastern Belt granite, hornblende, K-feldspar, plagioclase and biotite was the important mineral assemblage in the magmatic evolution.

The 'S' type Western Belt granite is characterised by restricted SiO_2 content (65 to 75%), which according to Chappell and White (1984) is characteristic of rocks were derived from SiO_2 rich sources. The granites are low in Na, Ca and Sr, which are lost during the conversion of feldspar to clay minerals by weathering, and are therefore depleted in pelitic rocks. High K_2O/Na_2O in the 'S' type rocks is explained by the fact that potassium is incorporated into clay during chemical weathering to produce sedimentary rocks, whereas sodium is removed in solution along with Ca, Sr and Pb. The 'S' types are higher in Pb, Cr and Ni. The Fe^{3+}/Fe^{2+} ratios of the 'S' type rocks are significantly lower than those of 'I' type, a feature, which is thought to result from the presence of graphite in the source rocks (Flood and Shaw, 1975). As a result of the lower Na and Ca, 'S' types are always corundum normative or peraluminous and become more strongly so as the rocks become more primitive (Chappell, 1984). This feature is not, however, necessarily a diagnostic property of 'S' type since felsic 'I' types may also have this character. The high incompatible element (Th, U, Sn, Pb and Cs) abundance is a consequence of both derivations from metasediments with high content of these elements and extended crystals fractionation.

On the other hand the Eastern Belt Granitic magmas were derived from a more heterogeneous lower crustal source. This is evident from the wide variation of igneous rocks found in the Eastern Belt. Mafic compositions represent magmas derived from the mantle. Liew (1983) showed that the mineralogical and chemical features of the mafic rocks are similar to those of orogenic basalt and andesite with broad tholeiitic to high K tholeiitic affinities. The Eastern Belt granite proper may derive from source rocks of igneous composition located within the lower to upper crust. Minor occurrences of S type granite in the Eastern Belt suggest that some of the magmas were derived from old metasedimentary crust. Thus, minor hybridation with mantle derived magmas, and hybridation–assimilation of the metasedimentary components are likely to be important.

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