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Some problems with the classification of the 'S' type granite with particular reference to the Western Belt granite of Peninsular Malaysia

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Abstract: The Peninsular Malaysian granites have been grouped into two granite provinces namely Western and Eastern Belt granites. The Western Belt has been considered as constituting an exclusively 'S' type granite. The 'S' type features in the granites are, (a) high initial $^{87}Sr/^{86}Sr$ isotope ratio > 0.710, (b) low Na_2O content, < 3.2% Na_2O in rocks with ~ 5% K_2O, (c) narrow range of felsic rock (SiO_2: 65.95 to 77.4%), (d) high K_2O/ Na_2O ratio, 1.4 - 2.8 ('S' type: 0.9 - 3.2), (e) usually ilmenite bearing and (f) contain pelitic or quartzose metasedimentary xenoliths. However, detailed study of published and unpublished field and geochemical reports reveal that the Western Belt granite shows mixed 'I' and 'S' type features and thus the batholiths cannot be designated as exclusively 'S' type. The 'I' type features are (a) Al-rich minerals such as sillimanite and cordierite are absent, (b) occurrence of primary wedge sphene and pale green amphibole especially in the northern part of the batholith, (c) occurrence of pinkish K-feldspar crystals (usually as phenocrysts), (d) occurrence of mafic, hornblende bearing enclaves, (e) increasing ACNK values with SiO_2, (f) showing a similar trend to the 'I' type granite in P_2O_5 vs Rb and A-B plots. Implication of this study indicates that the Western Belt granite is not solely derived from metasediments. The study favours a mixed origin of crustal material such as metapelites, greywackes and metaigneous rocks.

Abstrak: Batuan granit Semenanjung Malaysia boleh dibahagikan kepada tiga kumpulan berdasarkan kepada wilayah iaitu granit Jalur Barat, Tengah dan Timur. Granit Jalur Barat dianggap terdiri dari granit jenis 'S' secara ekslusif. Ciri-ciri 'S' dalam granit ini ialah (a) nisbah isotop $^{87}Sr/^{86}Sr$ yang tinggi iaitu > 0.710, (b) kandungan Na_2O yang rendah, iaitu 3.2% Na_2O dalam batuan yang mempunyai ~ 5% K_2O, (c) batuan felsik yang bersela rapat (SiO_2: 65.95 to 77.4%), (d) nisbah K_2O/ Na_2O yang tinggi, 1.4 - 2.8 (Jenis 'S': 0.9 - 3.2), (e) selalunya mengandungi ilmenit dan (f) mengandungi zenolit metasedimen berpelit atau berkuarza. Walaubagaimanapun, kajian terpeinci laporan geokimia yang diterbitkan dan yang belum diterbitkan mencadangkan granit Jalur Barat terdiri dari campuran ciri-ciri 'I' and 'S' dan oleh itu batholith tersebut tidak boleh anggap sebagai jenis 'S' secara ekslusif. Ciri-ciri 'I' adalah (a) mineral yang kaya Al seperti sillimanit dan cordierit tidak hadir, (b) kewujudan sfen primer berbentuk baji dan amfibol hijau muda terutamanya di bahagian utara batolith ini, (c) kewujudan kristal K-feldspar yang berwarna merah jambu (selalunya sebagai fenokris), (d) kewujudan 'enclave' mafik berhornblen, (e) kenaikan nilai ACNK dengan pertambahan nilai SiO_2, (f) menunjukkan trend yang sama dengan granit jenis 'I' type granite dalam plot P_2O_5 vs. Rb and A-B. Implikasi kajian ini menunjukkan granit Jalur Barat tidak keseluruhannya terhasil dari perleburan batuan metasedimen. Kajian ini mencadangkan asalan campuran bahan-bahan kerak seperti batuan metapelit, greywacke dan metaigneus adalah lebih sesuai sebagai batuan punca granite Jalur Barat.

INTRODUCTION

In southeastern Australia the importance of source rock composition and separation of melt and refractory residue in characterizing various suites has led to the 'I' and 'S' type granite classification. In this scheme, the 'I' type granites represent the melt products of igneous source rocks while 'S' types result from melting of sedimentary or metasedimentary source material. In both cases, the source is taken to lie within continental crust. In Peninsular Malaysia the Western and Eastern Belt granites of the Peninsular Malaysia are 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). The Western Belt granites of Peninsular Malaysia (Fig. 1) is characterized by a huge mountain range extending from Malacca in the south to Thailand in the north (Cobbing *et al.*, 1992). The country rocks penetrated by the granites are predominantly isoclinally folded phyllitic Lower Paleozoic metasedimentary rocks including marble, and less strongly folded Upper Paleozoic formations. The granites have been considered as constituting an exclusively 'S' type granites (e.g. Liew, 1983; Hutchison, 1996) However, studies and reviews of granitoid batholiths (Pitcher, 1979; Shaw and Flood, 1981) suggest that 'S' type granitoids may display a wide range of mineralogical and chemical characteristics and that the criteria adopted for identification of granitoid type in one terrain may not strictly hold true in another. The aims of this paper are two fold, firstly to review some aspects of the granite

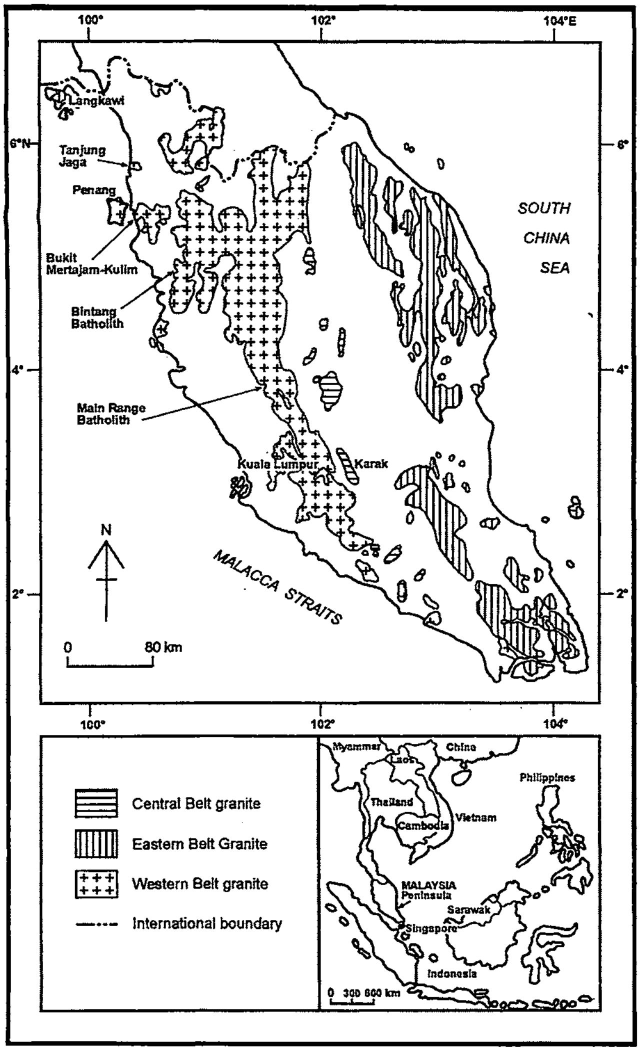

Figure 1. Map of the Peninsular Malaysia showing the Western Belt granite in relation to other granite batholiths.

classification with particular references of the 'I-S' type classification and secondly to compare the criteria of the 'S' type granite classification that has been adopted in the western Belt granite of the Peninsular Malaysia.

REVIEW ON THE GRANITE CLASSIFICATION

Previous granite classification

At least 20 schemes of granite classification have been proposed. Among the criteria that have been used in classifying rocks of granitic composition are petrography (e.g. Orsini 1976), mineralogy (e.g. Lameyre and Bowden 1982), peraluminosity (Shand 1943), zircon morphology (Pupin 1980), major element chemistry (e.g. Debon and Lefort, 1983) and tectonic environment (e.g.Pitcher 1983). One of the most widely used mineralogical classifications in igneous rocks is the quartz - alkali feldspar - plagioclase diagram (QAP) (Streckeisen 1976). In this diagram, granitic rocks show considerable variation in the relative proportion of alkali feldspar (albite, orthoclase and microcline) and plagioclase (An>5) and contain between 20 - 60% quartz. In this diagram, granitic rocks are subdivided into alkali feldspar granite, syenogranite, monzogranite, granodiorite and tonalite. It not only classifies rocks of granitic type but also more basic rocks such as diorite, monzonite, syenite and gabbro.

The classification by peraluminosity was introduced by Shand (1943) and is based on the molar proportion of Al_2O_3 to CaO, Na_2O and K_2O (e.g. mol $Al_2O_3/CaO + Na_2O + K_2O$ (ACNK)). Thus granitic rocks have been divided into three groups, namely peraluminous granites: A > CNK, metaluminous granites: CNK > A > NK and peralkaline granites: A < NK (Clarke, 1981).

The classification by opaque phases was suggested by Ishihara (1977) and is based on the occurrence of ilmenite and magnetite in granitic rocks. In this classification, *magnetite* and *ilmenite* series rocks can be distinguished by their different magnetic susceptibilities; rocks of the magnetite series showing high values (more than 100 X 10 emu/g) while those of the ilmenite series have lower than 100 X 10 emu/g. Ishihara (1977) emphasized the role of crustal carbon in the generation of the ilmenite - series magmas while deep seated carbon free material and a tensional tectonic setting favoured the generation of magnetite series magmas. He suggested that oxygen fugacity was the most important variable controlling the formation of magnetite and ilmenite series. This suggests that the ilmenite series was generated in the middle to lower continental crust where pelitic rocks containing carbonaceous material may occur and that the magnetite series originated at greater depth i.e. upper mantle or lower crust. Although there were attempts to correlate this classification with the I/S type classification (Chappell and White, 1974), the two classifications are not exactly equivalent (Takahashi *et al.*, 1980).

The idea of using zircon in the characterisation of granitic rocks was developed by Poldervart (1950, 1956). Later, Pupin (1980) divided granitic rocks into three main groups based on the morphology of zircon populations found in rocks. They are:

(a) crustal origin (autochthonous and aluminous granites),
(b) mantle origin (alkaline and tholeiite granites),
(c) mixed origin (calc alkaline and sub-alkaline granites).

Varva (1994) studied the internal morphology of zircon crystals from different types of granites. He observed that the morphological evolution of zircon varies systematically between the different granitic types. He concluded that important factors controlling the zircon morphology in the different types of granitic rocks are high cooling rates, magma mixing, enrichment of H_2O and trace elements in residual liquids and the major element chemistry of the magma (Na and K to Al).

However above all classifications described earlier in this section, the most popular granite classification is the subdivision between those granites derived from a sedimentary ('S' type) or igneous ('I' type) source rock.

Aspects of this classification will be given in detail in next two sections below.

Introduction to 'I' and 'S' type granite classification

The distinction between 'I' and 'S' type granitic rocks is largely genetic. 'I' type granites are considered to have been generated from igneous source materials and 'S' types granite from a sedimentary source (White and Chappell, 1974). The concept was presented by Chappell and White at a meeting of the IGCP Circum-Pacific Plutonism Project in Santiago, in September 1973 and was published as an extended abstract in the following year (Chappell and White, 1974). The concept has been developed by Chappell and White and their co-workers in a series of papers (Chappell and White, 1984; 1992, Chappell and Stephens, 1988, White and Chappell, 1983 ; 1988). A clear spatial distribution of 'I' and 'S' type granites exists in the southeastern Australia batholiths (White and Chappell, 1983). A line separates dominantly 'S' type granites to the west from exclusively 'I' type granites in the east. This so-called I-S line is considered to be a major tectonic line (White and Chappell, 1983).

The geochemical characteristics of the 'S' type granites and their explanation

The 'S' type granite is characterised by restricted SiO_2 content (65 to 75%) which according to Chappell and White (1984) is characteristic of rocks 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 low 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' types, 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.

TECTONIC SETTING AND ROCK DISTRIBUTION

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 (Cobbing *et al.*, 1992). The Western belt granite is characterised by 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 centers 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, in press) (Figure 1).

The Western Belt granite occurs to the west of a belt containing ophiolite- melange association which is known as the Bentong –Raub line by Hutchison (1975, 1977). Mitchell (1977) interpreted this ophiolite line to mark a Triassic collision suture separating an eastern Malay Peninsula crustal block and western Malay Peninsula crustal block. He proposed that, in such a tectonic reconstruction, the Western Belt granites were formed in a continent collision setting broadly analogous to that of the Tertiary Himalayan leucogranites.

In term of rock types and mineral associations the whole Western belt granite can be divided into three distinct groups. The first group covers about 90% of the total Western Belt granite volume. The main rock type is a coarse to very coarse-grained megacrystic biotite 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). Aplopegmatite and mesogranites are commonly associated with the individual granitic body. Common features of the aplopegmatite and mesogranites complex is the development of mineral layering; good examples are found in the Kuala Lumpur granites (Pitfield *et al.*, 1990); Tanjung Jaga area (Jerai pluton) and south of Tuba island (contact granite with Setul formation) in the Langkawi group and occurrence of aplo-pegmatite dykes e.g. Kuala Lumpur Granite (Ng, 1997). Distinct mineralogy of this group is high Al biotite, muscovite (may be primary, Miller *et al.*, 1981) and Mn rich garnet (Liew, 1983).

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 complexes are 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). Khoo and Lee (1994) have reported a suite of plutonic rocks consisting of hornblende - biotite quartz monzonite, tonalite, granodiorite and adamellite from northeasternmost Western Belt granite. Amphibole bearing enclaves have also been reported in the Bujang Melaka granite (Singh and Yong, 1982) and Baling granite

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 complex intruded the Selut Schist (Pre Devonian), Gombak Chert (Late Devonian to Early Carboniferous, Sempah Conglomerate (Permian) which were collectively known as the Bentong Group (Alexander, 1968). The complex comprises units of tuff lavas, lavas and a distinctive porphyry subvolcanic unit that contains orthopyroxene phenocrysts (Liew, 1983; Chakraborty, 1995). Two main rock types of the complex are orthopyroxene-lacking rhyodacite and orthopyroxene-bearing rhyodacite (Chakraborty, 1995; Singh and Azman, 2000).

COMPARISON OF THE 'S' TYPE AND THE WESTERN BELT GRANITES

Petrographic differences

This section will compare the petrographic features of the Western Belt granite to the 'S' type rocks from the Lachlan Fold belt. Mafic 'S' type granite from the Lachlan Fold Belt may be very biotite-rich, up to 30% of the rock (Chappell and White, 1992). The biotite content in the Western Belt granite rarely exceeds 12%, even in the amphibole bearing granites, the highest recorded value is 15% (Mohd Imran Idris, 1996). The pleochroism scheme of the biotite in the Western Belt granite is typically pale brown to dark brown and varies to black brown to foxy red in the contact facies compared to those from the 'S' type granite of the Lachlan Fold Belt which is mainly reddish in colour (Chappell and White, 1992). The latter generally contains ilmenite and rarely magnetite and they never contain primary sphene, although secondary sphene, formed by alteration of biotite is common. Primary wedge shaped sphene has been reported in the Western Belt granites by many previous workers (e.g. Liew, 1983 ; Mohd Imran Idris, 1996), especially in the northern part of the batholith. The primary sphene is sometimes associated with pale green amphibole (actinolitic hornblende). The amphibole has been reported to occur either in the Western Belt granite proper and in its enclaves (e.g. Singh and Yong, 1982 ; Mohd Imran Idris, 1996). Both sphene and amphibole are considered to be characteristic of 'I' type granites (Chappell and White, 1974). Although no amphibole has been reported in the 'S' type rocks from the Lachlan Fold Belt, actinolitic hornblende and cummingtonite have been reported in a number of 'S' type plutons of the New England batholith in eastern Australia (Shaw and Flood, 1981). The K-feldspar in the 'S' type granites is always white in colour, never pink, if the rock is fresh (Chappell and White, 1992). On the other hand, pinkish K-feldspar crystals (usually as phenocrysts) are present in the Western Belt granite (e.g. Bukit Mertajam-Kulim granite, Azman *et al.*, 2000). However it is uncommon in the Main Range proper, but is characteristic of the Late Cretaceous granites, e.g. south Johore area. Mafic, hornblende bearing enclaves have been reported in the Baling area (Khoo and Lee. 1994) (northern part of the Western Belt granite) in contrast to the Australian 'S' type granite which contain pelitic or quartzose metasedimentary xenoliths.

Geochemical differences

The Western belt granites also have an initial $^{87}Sr/^{86}Sr$ isotopic ratio of more than 0.708 (Cobbing *et al.*, 1992) implying source rocks of sedimentary or supracrustal protoliths (Chappell and White, 1974) which is consistent with the 'S' type rocks from the Lachlan Fold Belt, Australia. The 'S' type rocks from the Lachlan Fold belt typically have Na_2O contents below 3% (majority below 2.5%) (Fig. 5, White and Chappell, 1983), whereas half (60 from 127) of the analysed Western Belt rocks have Na_2O of more than 3%. However the potassium content for the Western Belt granites still fall within the 'S' type rocks i.e. less than 3.2% Na_2O in rocks with ~ 5% K_2O. This is evident from the Na_2O vs K_2O plot (Fig. 2) where only 34 out of 127 samples plot in the 'I' type field.

Despite the chemical similarities given above, the Western Belt granites also have some characteristics which are more of 'I' type than those of the 'S' type granite. Compared to the analyses of the 'S' type rocks from the Lachlan Fold Belt, the Western Belt granites are higher in Ca, Na and Sr indicating derivation from a more feldspar-rich source. The latter also display more regular inter-element variations similar to the 'I' type rocks.

Villaseca *et al.* (1998) established the diversity of crustally derived peraluminous series on the A-B diagram of Debon and Lefort (1983). They have divided the peraluminous granitoids into four types namely highly

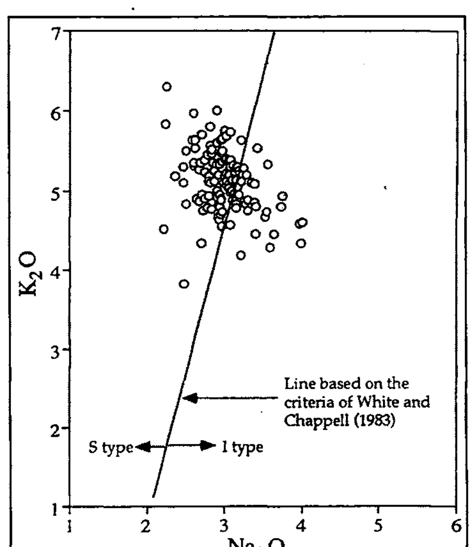

Figure 2. Na_2O vs. K_2O plot of the Western Belt granite. Field of the 'S' and 'I' type granite is after Chappell and White (1983). Note that in general the Western Belt granite contain slightly higher Na_2O content compared to the 'S' type granite at the same K_2O concentration.

peraluminous (h-p), moderately peraluminous (m-p), low peraluminous (l-p) and highly felsic peraluminous (f-p) granitoids. Plots of Western belt granites on this diagram are shown in Figure 3. Trend of the I and S type granite from the Lachlan Fold Belt is also shown in the diagram. The majority of the Western belt granites samples plot in the l-p and some in the m-p and f-p fields. The general trend of the plots is increasing towards the most differentiated sample which is in contrast to most of the Australian 'S' type granites, (e.g Cooma and Bullenbalong suites). In fact the general trend shown by the Western Belt granite is similar to the 'I' type trend of the Australian rocks (e.g. Jindabyne and Moruya suites) (Fig. 3).

The most distinctive difference between the compositions that result from the crystal fractionation of felsic 'I' and 'S' type melts is that P decreases in abundance in the 'I' type and increases in the 'S' type compositions when the rocks become more felsic. This is probably best illustrated on P_2O_5 (Wt %) vs Rb (ppm) diagram (Fig. 4). The 'I' type granite pattern shows that P decreases progressively with increasing Rb whereas a positive correlation of P_2O_5 vs Rb is found in the 'S' type granites (see Chappell and White, 1992, p. 22). They interpreted the positive correlation between Rb and P contents indicate derivation from a sedimentary source rock. However, plots of the Western Belt granites on the P_2O_5 vs Rb diagram produce a trend similar to the 'I' type granite pattern. This is supported by the P_2O_5 vs SiO_2 diagram (Fig 5) which shows that the P_2O_5 of the Western Belt granites decrease with increasing SiO_2. This is comparable to the general trend produced by the 'I' type granites from the Lachlan Fold Belt. The fractionated Western Belt granites (SiO_2 > 75%) have P_2O_5 contents less than 0.1% which is consistent with the decrease of P in more siliceous melts (Harrison and Watson, 1984) (Fig. 4). On the other hand, the analogues plot for the 'S' type granites show a very different trend with the data lying in a triangular area extending from about 0.15% P_2O_5 in the most mafic rocks (Fig. 6 in Chappell, 1999), to both higher and lower values in the felsic granites, ranging from 0.02 to 0.42% (Chappell, 1999).

Other differences that may be important between 'I' and 'S' type rocks from the Lachlan Fold Belt is that as the rocks become more mafic, 'I' type always become progressively more peraluminous and 'S' type always progressively peraluminous. In other words the ACNK

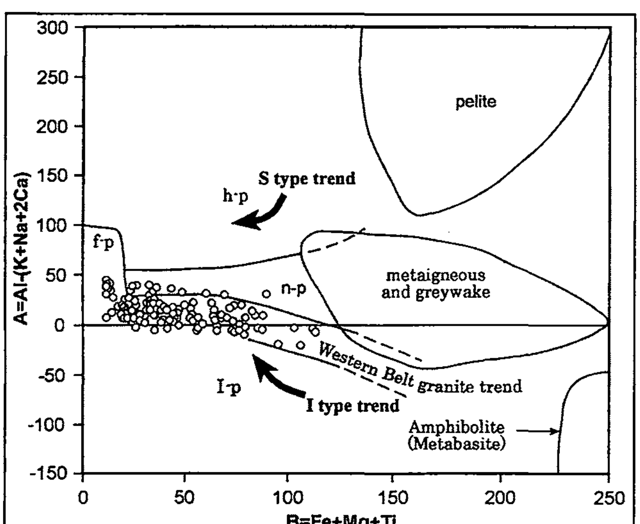

Figure 3. A-B diagram (modified from Debon and Lefort 1983 ; after Villaseca 1998) for the Western belt granite. Also shown in the diagram is the projection of several crustal protoliths. Note: f-p:highly felsic peraluminuous granitoids; m-p: moderately peraluminuous granitoids; h-p: highly peraluminuous granitoids; l-p: low peraluminuous granitoids.

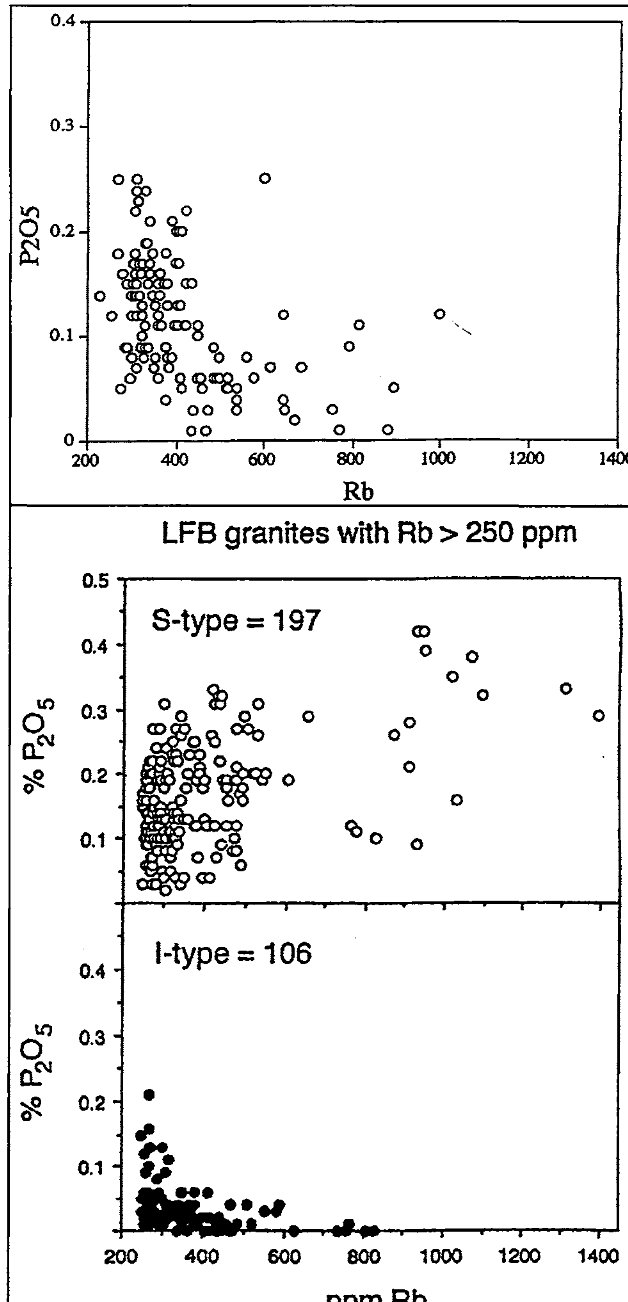

Figure 4. P_2O_5 vs Rb plot of the Western Province granites.The smaller diagram is the P_2O_5 vs Rb plot of the 'I' type granites from the Lachlan Fold Belt (Chappell and White 1992).

values in the 'I' type granite increase and those from the 'S' type granite decrease with SiO_2. Thus the increasing ACNK values with SiO_2 in the Western Belt granite is consistent with the 'I' type feature (Fig. 6). Chappell and White (1992) suggested that this is because more mafic rocks will always be closer to the composition of their source rocks. The majority of the lower ACNK values (ACNK<1) of the Western Belt granites are the amphibole bearing samples. We can assume that the amphibole bearing rocks in the Western Belt granites are closer to the source composition (Chappell, 1999). The hornblende bearing enclaves reported in the northern part of the Western Belt (Khoo and Lee, 1994) can be regarded as cumulates consistent with the presence of basaltic component in the rock.

CONCLUDING REMARKS

This paper highlighted some of the problems with binary classifications of granites. Other binary classifications that have been proposed are given in the earlier part of this paper. Although all these classifications may be very helpful in initially understanding the differences in granites, they also lead to a pigeon-holing which is contrary to the expressed natural diversity of granites on a world scale.

The 'S' type rocks with many 'I' type characteristics is not uncommon.The Tertiary volcanic complex of the Isle of Mull, NW Scotland (in Beckinsale, 1979) consists of three centres, and it has been established that the early (centre 1) granites consists of crustal melts which show some of the characteristics of 'S' type granites (high Sr ratio and low Na_2O content). The latter two centres (centres 2 and 3) on the other hand, show many 'I' type characteristics (low Sr ratio and high Na_2O content).

In contrast to the findings of Liew (1983), this study shows that the Western Belt granite consists of mixed 'I' and 'S' type features and thus the batholiths cannot be designated as exclusively 'S' type. The 'I' type characteristics of the Western Belt granite of Peninsular Malaysia are (a) Al-rich mineral such as sillimanite and cordierite are absent except for some andalusite, (b) occurrence of primary wedge sphene and pale green amphibole especially in the northern part of the batholith, (c) occurrence of pinkish K-feldspar crystal (usually as phenocrysts), (d) occurrence of mafic, hornblende bearing enclaves, (e) increasing ACNK values with SiO_2, (f) increasing peraluminosity towards the most differentiated rocks which is in contrast to the 'S' type granite (increasing peraluminosity towards the most mafic varieties) and (g) showing a similar trend to the 'I' type granite in P_2O_5 vs. Rb and A-B plots. In fact, in detail, the granites probably consist of more 'I' type than those of 'S' type features.

The only true 'S' type features in the granites are (a) high initial $^{87}Sr/^{86}Sr$ isotope ratio - > 0.710, (b) low Na_2O content, < 3.2% Na_2O in rocks with ~ 5% K_2O, (c) high K_2O / Na_2O ratio, 1.4 - 2.8 ('S' type: 0.9 - 3.2). Although all the 'S' type features are consistent with the melt derived from pelitic rocks (Liew, 1983, Hutchison, 1996) the fact that the Western Belt granite produce a similar trend to the 'I' type rock, e.g. figures 3, 4 and 5 and 'I' type characteristics as described above suggest that other source(s) cannot be ruled out.

In continental crustal setting, three main protoliths which can produce important volume of acid peraluminous magmas include metasediments (metapelites), quartzo-feldspathic sedimentary (greywacke) or quartzo-feldspathic metaigneous rocks (orthogneiss) and basic metaigneous rocks (amphibolites) (Beard and Lofgren, 1991; Wolf and Willey, 1994; Rapp and Watson, 1995). On Figure 3 all the three protolith compositional fields are represented (Villaseca *et al.*, 1998). On this diagram, backward projection of the trend produced by the Western belt rocks indicates that the possible protolith is likely to be quartzo-

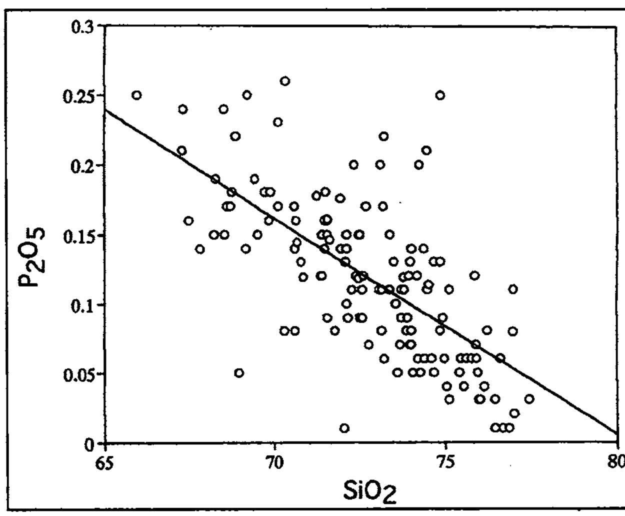

Figure 5. P_2O_5 vs SiO_2 plot for the Western Belt granite. Note that the trend is P_2O_5 decreasing with increasing SiO_2.

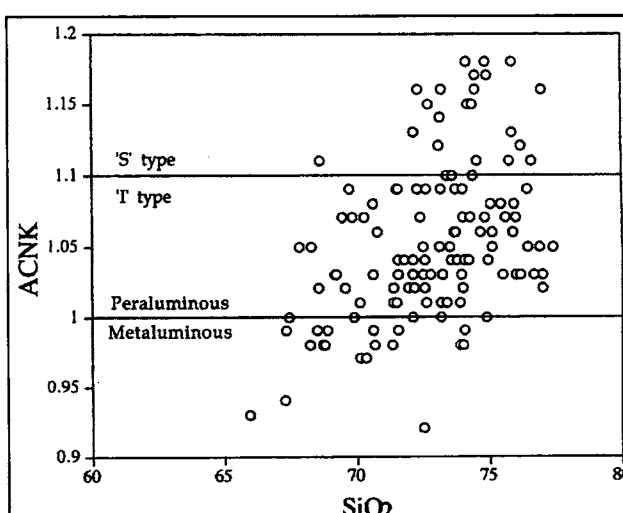

Figure 6. $Al_2O_3/CaO + Na_2O + K_2O$ vs. SiO_2 (ACNK) diagram for the Western Province granites. Line at ACNK = divided between peraluminous and metaluminous and line at ACNK = 1.1 divided between 'I' and 'S' type granite.

feldspathic and amphibolitic rocks. The diagram does not support the melting of metapelite as melting of this material will result a compositional path plot in the h-P field (Villaseca *et al.*, 1998). Thus this diagram suggests that other source rocks (amphibolite and quartzo-feldspathic) apart from pelite, could be possible for the Western Belt granites. Implication of this study indicates that the Main Range granite is not solely derived from metasediments. The study favours a mixed origin of crustal material such as metapelites, greywackes and metaigneous rocks. The aspects of Western Belt granite highlighted in this paper warrants more serious and indepth study in order to understand the nature of the granite source(s) (cf. Chakraborty, 1994). There are clearly some differences between the Western Belt protolith compared to those of the Australian rocks.

ACKNOWLEDGEMENTS

The data reproduced from BGS overseas Memoir (10), the granites of the the SE Asian tin belt by Cobbing *et al.*, (1992) by permission of the British Geological Survey.

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