

## 'I' type features in the so-called 'S' type Western Belt granites, Peninsular Malaysia

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**Abstract:** The Western Belt granites of Peninsular Malaysia have been considered as constituting exclusively 'S' type granites. The 'S' type features in the granites are, (a) high initial  $^{87}\text{Sr}/^{86}\text{Sr}$  isotope ratio,  $> 0.710$ , (b) low  $\text{Na}_2\text{O}$  content,  $< 3.2\%$   $\text{Na}_2\text{O}$  in rocks with  $\sim 5\%$   $\text{K}_2\text{O}$ , (c) narrow range of felsic rock ( $\text{SiO}_2$ : 65.95 to 77.4%), (d) high  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  ratio, 1.4–2.8 (S type: 0.9–3.2), (e) usually ilmenite-bearing and (f) contain pelitic or quartzose metasedimentary xenoliths. Despite the similarities above, the Western Belt granites also have some characteristics which are more characteristic of 'I' type than those of the 'S' type granites, namely (a) Al-rich minerals such as sillimanite and cordierite are absent except some andalusite, (b) occurrence of primary wedge sphene and pale green amphibole especially in the northern part of the batholith, (c) pinkish K-feldspar crystals (usually as phenocrysts) present, (d) occurrence of mafic, hornblende-bearing enclaves, (e) increasing ACNK value with  $\text{SiO}_2$ , (f) increasing peraluminosity towards the most differentiated rocks ('S' type granite: increasing peraluminosity towards the most mafic varieties) and (g)  $\text{P}_2\text{O}_5$  vs Rb trend is similar to the 'I' type granite. The aspects of the Western Belt granites highlighted in this paper warrants more serious and in-depth study in order to understand the nature of the granite source rock(s) (cf. Chakraborty, 1994). They are clearly some differences between the Western Belt protolith compared to those of the southern Australian rocks.

### INTRODUCTION

The Western Belt granites of Peninsular Malaysia (Fig. 1) are characterised by the 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 exclusively 'S' type granites (e.g. Liew, 1983; Hutchison, 1996). However, recent 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. This short paper will compare some of the petrographic and geochemical features of the Western Belt granites with the original 'I'-'S' type rocks from the Lachlan Fold Belt, Australia.

Table 1 shows a summary of the distinctive features of the 'I' and 'S' type granites of the Lachlan Fold Belt as originally proposed by Chappell and White (1974). The classification highlighted the importance of source rock composition, that is igneous ('I' type) and sedimentary ('S' type) origin in granite petrogenesis. The concept was presented

at a meeting of the IGCP Circum-Pacific Plutonism Project in Santiago, in September 1973 and was published as an extended abstract the following year (Chappell and White, 1974). The concept has been further 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).

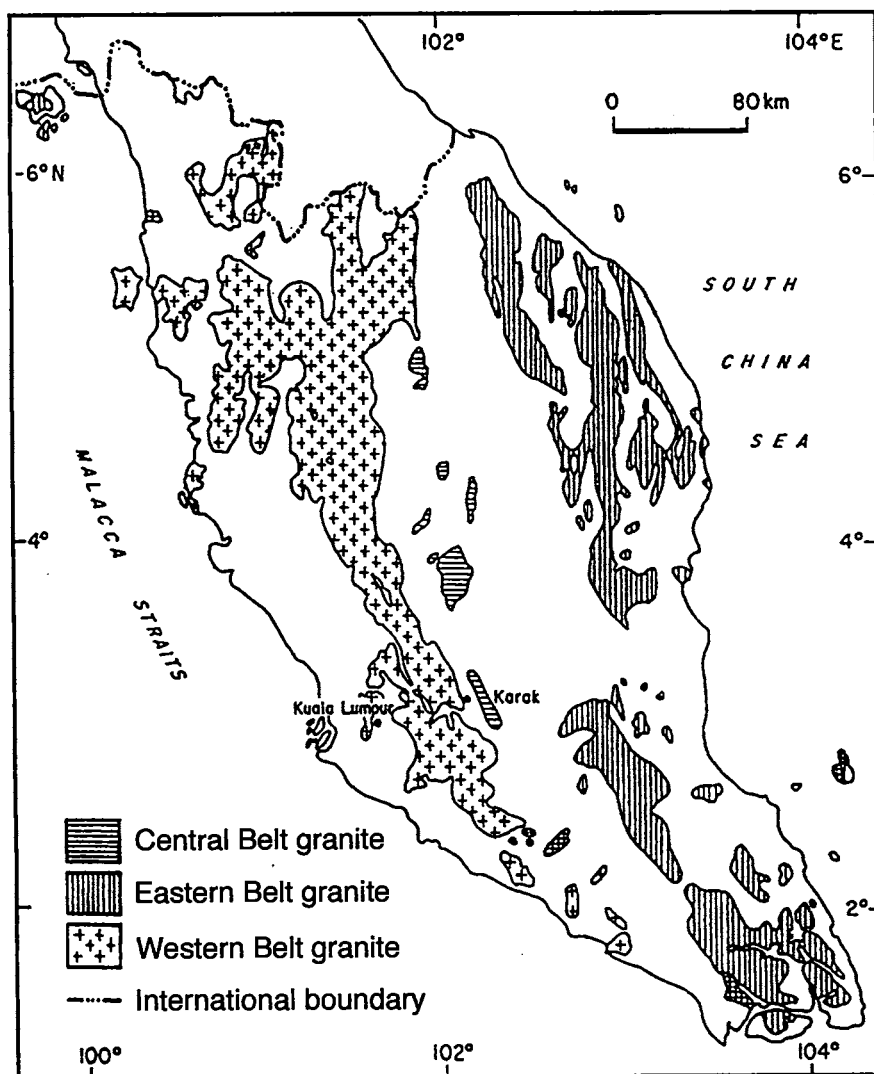
### PETROGRAPHIC ASPECT

The mineralogy of the 'S' types reflects their different chemical compositions. The strongly peraluminous 'S' type magma (ACNK  $> 1.1$ ; Table 1) will precipitate Al-rich minerals such as andalusite, cordierite, sillimanite, muscovite and almandine. Such Al-rich minerals are widespread in the 'S' type granites of the Lachlan Fold Belt Australia (Chappell, 1984). In the Western Belt granites, the Al-rich minerals such as sillimanite and cordierite are absent except some andalusite has been reported in the Sungei Ara granite Penang (Chakraborty and Amerizal, 1984). Almandine garnet is abundant in the late stage aplopegmatite rocks and rarely found in the Western Belt granite proper.

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

**Table 1.** Summary of the distinctive features of the 'I' and 'S' type granites of the Lachlan Fold Belt as originally proposed by Chappell and White (1974).

I-types	S-types
1. Metaluminous mineralogy; hornblende common and more abundant than biotite in mafic samples; accessory sphene common.	1. Peraluminous mineralogy: biotite and muscovite predominate; no hornblende; some cordierite and/or aluminosilicates; monazite may be accessory.
2. Hornblende-rich igneous-appearing xenoliths.	2. Pelitic or quartzose metasedimentary xenoliths.
3. Relatively high Na <sub>2</sub> O.	3. Relatively low Na <sub>2</sub> O.
4. Molecular Al <sub>2</sub> O <sub>3</sub> /(Na <sub>2</sub> O + K <sub>2</sub> O + CaO) < 1.1.	4. Molecular Al <sub>2</sub> O <sub>3</sub> /(Na <sub>2</sub> O + K <sub>2</sub> O + CaO) > 1.1.
5. Normative diopside or small amounts of normative corundum.	5. Normative corundum > 1%.
6. Broad spectrum of compositions from mafic to felsic.	6. Narrow range of more felsic rocks.
7. Regular inter-element variations within plutons; linear or near linear variation diagrams.	7. More irregular variation diagrams.
8. Mafic hornblende-bearing enclaves.	8. Metasedimentary enclaves.
9. Initial <sup>87</sup> Sr/ <sup>86</sup> Sr 0.704–0.706.	9. Initial <sup>87</sup> Sr/ <sup>86</sup> Sr > 0.708.
10. Usually unfoliated; contacts strongly discordant; well developed contact aureoles.	10. Often foliated; sometimes surrounded by high grade metamorphic rocks.



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

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 later generally contain 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; Borhan Doya, 1995; 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 amphiboles have been reported to occur either in the Western Belt granite proper and in their enclaves (Singh and Yong, 1982; Liew, 1983; Cobbing *et al.*, 1992; Mohd Imran Idris, 1996). Both sphene and amphibole are considered to be characteristic of 'I' type granites (Chappell and White, 1974; Table 1). Although no amphibole has been reported in the 'S' type rock 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, Borhan Doya, 1995). 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.

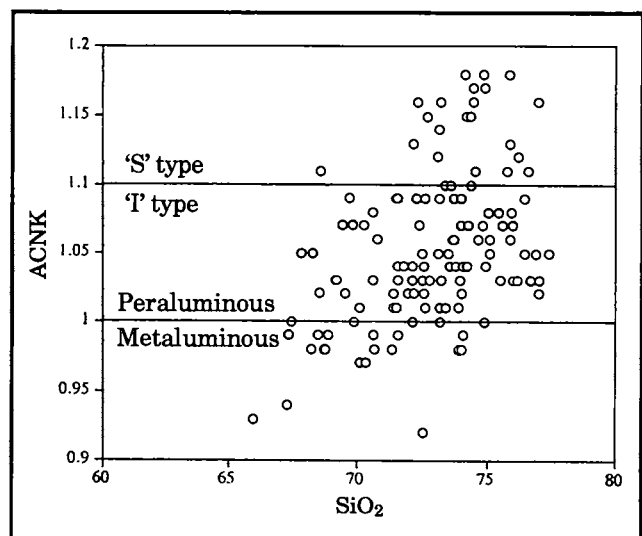
### Geochemical aspect

The Western belt granite is characterised by highly evolved rocks with  $\text{SiO}_2$  ranging from 65.95 to 77.4% which is comparable to the 'S' type rocks from the Lachlan Fold Belt, Australia. The narrow range of felsic rock imply that there is no basic intrusion associated with the Western granites batholith. The Western belt granites also have an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic ratio of more than 0.708 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.

Despite the chemical similarities given above, the Western Belt granites also have some characteristics which are more characteristic of 'I' type than those of the 'S' type granites. 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 later also display more regular inter-element variations similar to the 'I' type rocks.

The increasing ACNK values with  $\text{SiO}_2$  (Fig. 2) in the Western Belt granite is in contrast to the trend observed in the 'S' type granites from Lachlan Fold Belt which increase as the rocks becomes more mafic (White and Chappell, 1983). Furthermore on the diagram, most of the Western Belt granites plot in the 'I' type field (ACNK < 1.1) of Chappell and White (1974). Only 19 samples out of 127 samples analysed fall in the 'S' type field.

Villaseca *et al.* (1998) established the diversity of crustally derived peraluminous series on a A-B diagram of Debon and Lefort (1983). They have divided the peraluminous granitoids into four types namely highly peraluminous (h-p), moderately peraluminous (m-p), low peraluminous (l-p) and highly felsic peraluminous (f-p) granitoids. Plot of Western belt granites on this diagram is shown in Figure 3. Majority of the samples plot in the l-p and some in the m-p and f-p fields. The general trend of the plot is increasing peraluminosity towards the most differentiated sample which is in contrast to most of the Australian 'S' type granites, with increasing peraluminosity towards the most



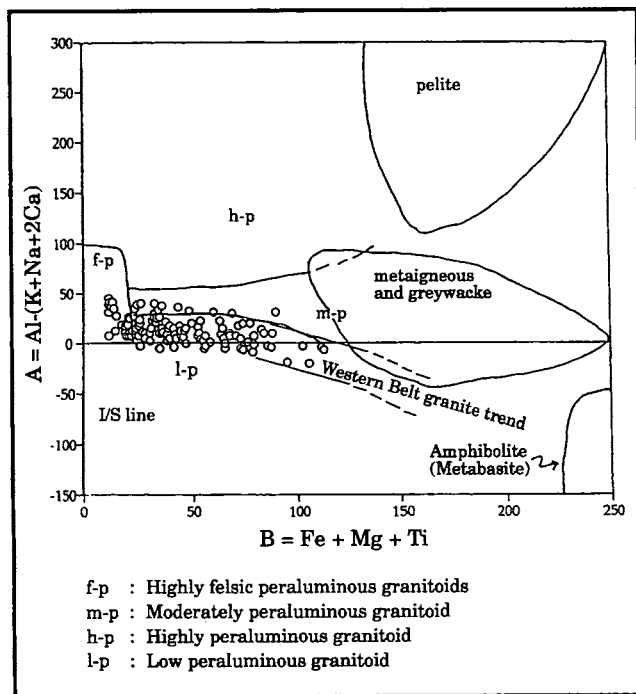
**Figure 2.**  $\text{Al}_2\text{O}_3/\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$  vs  $\text{SiO}_2$  (ACNK) diagram for the Western Belt granite. Line at ACNK = 1 divided between peraluminous and metaluminous and line at ACNK = 1.1 divided between 'I' and 'S' type granite.

mafic varieties (e.g. Cooma and Bullenbalong suites). In fact the general trend shown by the Western Belt granites is similar to the 'I' type trend of the Australian rocks (e.g. Jindabyne and Moruya suites).

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. This is probably best illustrated on the  $P_2O_5$  (wt%) vs Rb (ppm) diagram (Fig. 4) The 'I' type granite pattern show 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 similar trend to the 'I' type granite pattern.

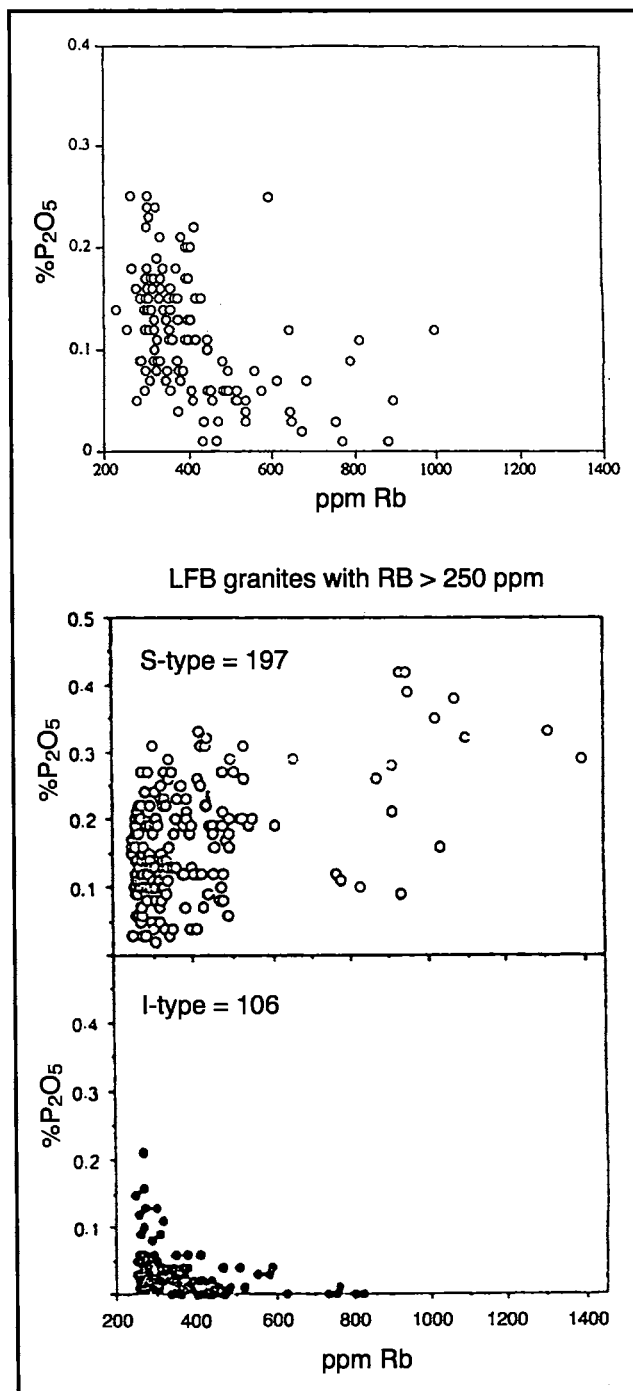
### CONCLUDING REMARKS

This short note highlighted some of the problems with binary classifications of granites. Other binary classifications that have been proposed (apart from 'I' and 'S' classification) are intrusive vs autochthonous granitoids (Ranguin, 1957),



**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.

leucogranites vs monzogranites-granodiorites (Didier and Lameyre, 1969) and magnetite and ilmenite series (Ishihara, 1977). Although all these classifications may be very helpful in initially understanding the differences in granites, they also lead to pigeon-holing which is contrary to the expressed natural diversity of granites on a world scale.



**Figure 4.**  $P_2O_5$  vs Rb plot for the Western Belt granite. The smaller diagram is the  $P_2O_5$  vs Rb plot for the I and S type granite of the Lachlan Fold Belt, Australia (after Chappell and White, 1992).

**Table 2.** Summary of the contrasting petrographic features of the Western Belt granite and the 'S' type granite from the Lachlan Fold Belt, Australia.

Western Belt Granite, Peninsular Malaysia	'S' Type Granite (Lachlan Fold Belt, Australia)
Both peraluminous and metaluminous mineralogy present. Biotite predominate, hornblende and sphene occur especially in the northern part of the batholith. Andalusite present, no cordierite. Muscovite and garnet in the evolved part of the granite.	Peraluminous mineralogy. Biotite and muscovite predominate. No hornblende and primary sphene. Al-silicate and cordierite present.
Modal biotite up to 15%.	Mafic 'S' type can contain up to 30% modal biotite.
Pink K-feldspar present.	No pink K-feldspar.
Biotite colour mainly brown. Reddish biotite occurs in the contact facies.	Mainly reddish biotite.
Increasing ACNK value with SiO <sub>2</sub> . Peraluminous to metaluminous magma.	Decreasing ACNK value with SiO <sub>2</sub> . Peraluminous magma.
Pelitic metasedimentary and hornblende-rich igneous appearing enclaves.	Pelitic or quartzose metasedimentary inclusion.
Regular interelements variation diagram.	Irregular interelements variation diagram.

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 consist of crustal melts which show some of the characteristics of 'S' type granites (high Sr ratio and low Na<sub>2</sub>O content). The latter two centres (centres 2 and 3) on the other hand, show many 'I' type characteristics (low Sr ratio and high Na<sub>2</sub>O content). The 'I' type characteristics of the so-called 'S' type Western Belt granite of Peninsular Malaysia is shown in Table 2. 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

1. high initial <sup>87</sup>Sr/<sup>86</sup>Sr isotope ratio, > 0.710 (Liew and Mc Culloch, 1985),
2. low Na<sub>2</sub>O content, < 3.2% Na<sub>2</sub>O in rocks with ~ 5% K<sub>2</sub>O
3. narrow range of felsic rock (SiO<sub>2</sub>: 65.95 to 77.4%) and
4. high K<sub>2</sub>O/Na<sub>2</sub>O ratio, 1.4–2.8 (S type: 0.9–3.2).

Features 1 and 2 may suggest that the Western Belt granites represent a metasedimentary melt (metapelite?). However, the fact that the granites produce a similar trend to the 'I' type rocks in Figures 2, 3 and 4 suggest that other type of source cannot be ruled out. In Figure 3, the trend is increasing peraluminosity towards the most differentiated sample. Projection of this trend

backwards shows the possible protoliths of the rocks are either metabasite or quartz feldspathic metaigneous rocks. One other interesting point shown in this diagram is that all the samples, even the amphibole-bearing granites at the northern part of the batholith, are confined to a common trend which suggests a restricted granite source.

Other differences that may be important between 'I' and 'S' type rocks from the Lachlan Fold Belt is that the rocks become more mafic, 'I' type always become progressively more peraluminous and 'S' type always progressively peraluminous. In other words the ACNK values in the 'I' type granite increase and those from the 'S' type granite is decrease with SiO<sub>2</sub>. Thus the increasing ACNK values with SiO<sub>2</sub> in the Western Belt granite is consistent with the 'I' type feature. Chappell and White (1992) suggested that this is because more mafic rocks will always be closer to the composition of their source rocks. Majority of the lower ACNK values (ACNK < 1) of the Western Belt granites are the amphibole-bearing samples. Therefore, the amphibole-bearing granites of the Western Belt is closely related to their source rock.

The aspects of the Western Belt granites highlighted in this paper warrant more serious and in-depth study in order to understand the nature of the granite source rock(s) (cf. Chakraborty, 1994). There are clearly some differences between the Western Belt protolith compared to those of the southern Australian rocks.

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Manuscript received 7 December 1999