Description of some important textures and paired host-enclave geochemistry of mafic microgranular enclaves (MME) in the Eastern Belt granite, Peninsular Malaysia: preliminary observations

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Abstract: This paper describes some of the important petrographic characteristics of the mafic microgranular enclaves from the Eastern Belt granite of Peninsular Malaysia as well as their chemical relationship. The enclaves are invariably darker coloured and finer grained than the enclosing granitic rocks. They usually have sharp contact with the granitic host. Occurrence of the acicular apatite in the enclave indicates that the crystals are quenched, probably formed when a globule of relatively mafic (enclave) magma comes into contact with cooler granitic magma (granitic host). Occurrence of the quartz-hornblende ocellar reflected hybridism of the two magmas. The variable geochemical trends in the enclave and their host rocks is probably related to the variable degrees of diffusive exchange between the enclave and their host rock magmas during slow cooling.

INTRODUCTION

The term enclave was proposed by Lacroix (1890) to describe fragments of rocks enclosed in homogeneous igneous rocks. Different types of enclave occur in the igneous rocks have been summarized by Didier (1991). Among the common enclaves in igneous rock are xenolith (piece of country rocks introduced into magmas), schlieren (elongated or lenticular enclave with gradual margins), surmicaceous enclave (melting residues) and mafic microgranular enclave (blob of coeval magma that have sharp contact with their host). Although in most cases, enclaves are scattered in the granitoid plutons, they may be locally associated in swarms. The polygenic swarms contain various types of enclave in contrast to monogenic swarms that group only one type of enclave.

Mafic microgranular enclaves are probably the most common type of enclave in granitic pluton (Vernon, 1983a, 1983b, 1991; Vernon et al., 1988; Barbarin & Didier, 1991, 1992; Fourcade & Javoy, 1991). The enclaves are invariably darker coloured and finer grained than the enclosing granitic rocks (e.g. Barbarin, 1991). They usually have sharp contact with the granitic host. Fine grained margins, if present is, usually considered to represent the chilled margin which resulted from the quenching of hot mafic magma against cooler felsic magma (e.g. Vernon, 1983b).

In Peninsular Malaysia, mafic microgranular enclaves are found abundantly in the Eastern Belt granite. The granite are compositionally expanded calc-alkaline series mainly metaluminous I type characterised by hornblende and sphenie. The batholiths are mainly small and composite ranging from gabbro to granodiorite and monzogranite. The present paper describes the general characteristics of mafic microgranular enclave in the Eastern Belt, with emphasize on the microstructure, geochemistry and their significance.

THE EASTERN BELT GRANITE

The eastern granitoid province which consists of the Central Belt and the Eastern Belt (Cobbing et al., 1992) comprises of an extended compositional spectrum from gabbro to monzogranite. The whole province consists of several batholith such as Boundary Range, Kapal and Stong complex to the north and Blumut Muntakah to the south (Johore). In common with other terrains, narrow sedimentary screens often separate different mapable units. The batholiths are surrounded by narrow contact metamorphism aureoles superimposed on low grade metamorphic country rocks (Hutchison, 1977). A biotite ± hornblende monzogranite-granodiorite of variable texture is the most common rock type. Mafic dykes of continental tholeiite, and similar to the magma formed in a within plate tectonic setting are common (Azman, 2000). The radiometric dating results summarized by Liew (1983) indicate ages of emplacement of the batholiths from Permain to Triassic. He suggested three intrusive episode that are, 255-270 Ma (middle to late Permain), 220-240 (early to middle Triassic) and 200-220 (middle to late Triassic).

FIELD OCCURRENCE AND PETROGRAPHY OF THE MAFIC MICRO­GRANULAR ENCLAVES

The mafic microgranular enclaves found in the Eastern Belt granite are usually from 1 cm to 50 cm in size. The enclaves are finer grained and darker coloured than their host and usually have a well defined, sharp contact with the surrounding host granite. Sometimes they show porphyritic texture (Fig. 1). Their distribution, however is not restricted to any particular part of the granite as observed in other granites (e.g. Didier, 1991). Microscopically the enclaves are holocrystalline and consist
of K-feldspar, quartz, plagioclase, biotite, hornblende, clinopyroxene, apatite, zircon, magnetite, chloride and epidote. The mafic mineral constitutes about 30 to 70% of the enclaves and are mainly of biotite, hornblende and clinopyroxene. Hornblende sometimes rimmed a quartz crystal, forming a quartz-hornblende ocelli texture (detailed description is given below). Biotite occurs as euhedral to subhedral crystals with the colour range from reddish brown to green. Plagioclase crystal is usually zoned and the composition ranges from An$_{27}$ to An$_{32}$. Apatite crystals of accicular and equant shape are found as accessory minerals. The significance of the accicular type of apatite is given below.

**DETAIL DISCRIPTION AND SIGNIFICANCE OF ENCLAVE TEXTURE**

**Rapid quenched apatite**

Apatite occurs in two habits in the mafic microgranular enclave. The first type of apatite are large equant free crystals inclusion with hexagonal cross section up to 0.2 mm across, which occur most commonly along grain boundaries of biotite crystals. The second type are small prismatic to acicular crystal up to 0.4 mm long (Fig. 2). The smaller acicular apatite has an average length to breadth ratio of 10:1. The ratio decreases with increasing crystal size. These acicular apatites are usually associated with biotite clots. When examined in detail, the cores are seen to be hollow ribbed cylinders (Fig. 2). Example of the second type of apatite is found in the Maras Bukit Jong granite (Hayati Turiman, 2000). Ogglethorpe (1987) also found the same type of apatite in the contact facies of Thor granite, Donegal and suggested that the cylinders consist of solid + gas.

**Quartz ocelli**

Quartz-hornblende ocellar texture consists of relatively large quartz crystal with small hornblende crystals included in its rim zone (e.g. Angus, 1962; Sabatier, 1980; Vernon, 1990; Hibbard, 1991). In the Eastern Belt granite, the texture has been found in the enclave from Bukit Labohan pluton, Terengganu (Azman et al., 1999, in press). The ocellar can occur up to 6.5 mm across in the mafic microgranular enclave (Fig. 3). The rim consists of subhedral to euhedral hornblende with sizes less than 0.5 mm across. The thickness of the hornblende rim ranges from 0.5 to 1 mm. Inner quartz crystal can be up to 4 mm across. The texture suggests that a more felsic system (represent by inner quartz crystal) has mixed with a more mafic system containing undercooling generated small hornblende crystals, juxtaposes quartz with hornblende. Loose surfacial attachment of hornblende to quartz surface set the stage for their fixation into the quartz (Hibbard, 1991).

**Bladed biotite crystal**

The biotite crystal is relatively small (up to 0.25 mm across) sometimes show bladed texture which according to Hibbard (1991) is an unusual morphology of biotite that is prone to form in a heterogenous juxtaposition of melt and crystalline phase characterizing mixing system. The texture has been found in the Maras Bukit Jong granite, Terengganu (Hayati Turiman, 2000).

**PAIR HOST-ENCLAVE GEOCHEMISTRY**

Understanding the genesis of mafic microgranular enclave is essential to understand the origin of granitic rocks and vice versa. Didier (1973) pointed out that 'it would be useful if further studies were directed towards discovering whether a connection exist between overall chemical compositions of the enclave and their enclosing igneous rocks'. Since then, numerous comparative studies have been done on enclave-host pairs from various plutons (e.g. Otto & Wimmenauer, 1973; Debon, 1975; Maury et al., 1978; Orsini, 1979; Reid et al., 1983; Zopri, 1988; Eberz et al., 1990; Pin et al., 1990; Debon, 1991). Many of them show the existence of chemical and/or mineralogical relationship between the members of such pairs, thus demonstrating their present cognate character. In this section, geochemical relationship between mafic microgranular enclave and their host rock will be discussed using some example of granitic pluton from the Eastern Belt granite.

**Example of enclave-host pairs geochemistry in the Eastern Belt of Peninsular Malaysia-northern part of the Lawit Batholith,**

Brief comparison between enclave-host pairs for the northern part of Lawit batholith has been given by Azman et al. (2001, in press). The Lawit batholith consists of a central core of a very coarse, inequigranular, biotite granite known as the Peda granite, bordered to the east and west by the earlier hornblende bearing Guntong granodiorite (Ahmad Tajuddin et al., 2000). The main petrological differences between these two rocks are that the granodiorite contains hornblende and biotite whereas the granite only contains biotite as main mafic phases. The mafic microgranular enclaves from Peda and Guntong plutons contain the same minerals as their granitoid host but in totally different proportion (Azman et al., 2001; c.f. Bateman et al., 1963; Bateman, 1983; Barbarin, 1986; 1991). They are broadly composed of plagioclase (40-50%) and mafic mineral (35 to 45%), whereas the granitoid host contain fewer of these phases and much more quartz and K-feldspar (Barbarin et al., 1989). The enclaves from Peda granite contain biotite whereas those from Guntong granodiorite contain both hornblende and biotite as a main mafic phase.
Table 1. Major and trace elements analyses of the enclave from the Lawit granite (Ahmad et al., 2000).

<table>
<thead>
<tr>
<th>Host rock</th>
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<td></td>
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<td>Granodiorite</td>
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<tr>
<td></td>
<td>AX</td>
<td>AX2</td>
<td>AX3</td>
<td>SBXI</td>
<td>SBX2</td>
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<tr>
<td>SiO₂ (%)</td>
<td>58.36</td>
<td>56.22</td>
<td>53.2</td>
<td>60.31</td>
<td>61.33</td>
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<tr>
<td>Al₂O₃ (%)</td>
<td>16.47</td>
<td>17.15</td>
<td>18.49</td>
<td>17.48</td>
<td>16.47</td>
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<tr>
<td>Fe₂O₃ (%)</td>
<td>5.8</td>
<td>6.65</td>
<td>7.38</td>
<td>8.34</td>
<td>7.29</td>
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<tr>
<td>MnO (%)</td>
<td>0.12</td>
<td>0.11</td>
<td>0.18</td>
<td>0.23</td>
<td>0.25</td>
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<tr>
<td>MgO (%)</td>
<td>4.87</td>
<td>4.67</td>
<td>4.97</td>
<td>1.65</td>
<td>1.41</td>
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<tr>
<td>CaO (%)</td>
<td>7.15</td>
<td>7.29</td>
<td>8.02</td>
<td>3.82</td>
<td>3.78</td>
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<td>Na₂O (%)</td>
<td>2.14</td>
<td>2.14</td>
<td>1.91</td>
<td>2.93</td>
<td>2.7</td>
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<td>Total wt%</td>
<td>98.95</td>
<td>99.58</td>
<td>99.84</td>
<td>99.53</td>
<td>99.66</td>
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<td>Zn ppm</td>
<td>59</td>
<td>65</td>
<td>81</td>
<td>143</td>
<td>140</td>
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<td>Ni ppm</td>
<td>10</td>
<td>9</td>
<td>13</td>
<td>27</td>
<td>26</td>
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<td>Co ppm</td>
<td>27</td>
<td>31</td>
<td>34</td>
<td>31</td>
<td>33</td>
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<td>Cr ppm</td>
<td>452</td>
<td>277</td>
<td>171</td>
<td>293</td>
<td>386</td>
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<tr>
<td>Ba ppm</td>
<td>794</td>
<td>691</td>
<td>486</td>
<td>452</td>
<td>447</td>
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<td>Np ppm</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Zr ppm</td>
<td>128</td>
<td>120</td>
<td>110</td>
<td>168</td>
<td>173</td>
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<tr>
<td>Sr ppm</td>
<td>467</td>
<td>454</td>
<td>415</td>
<td>85</td>
<td>91</td>
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<tr>
<td>Rb ppm</td>
<td>81</td>
<td>74</td>
<td>61</td>
<td>480</td>
<td>451</td>
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</table>

The mafic microgranular enclave from Peda granite constitutes up to 40% modal biotite together with plagioclase, K-feldspar, quartz, apatite, zircon and opaque phase. Compared to the enclaves from granodiorite, the Peda granite enclaves have more felsic mineralogy. In mafic microgranular enclave from Gunton granodiorite, biotite usually exceed hornblende in a single thin section. Plagioclase zonation is more obvious compared to those from the Peda granite. Accicular apatite in the enclave indicates the magma have undergone rapid quenching. Major and trace elements analyses of the enclaves from both granites (s.l.) is given in Table 1 (data from Rashid Saluki, 1995). In general the Gunton enclaves are more basic (SiO₂ : 53.2 to 58.4%) compare to those from the Peda granite (SiO₂ : 60.3 to 61.3%). Other elements that show significantly different between the enclaves are CuO, Zn, Ni, Ba, Zr, Rb and Sr. CaO in the enclave from Gunton rock is about 2 times more compared to CaO content in the Peda enclave. Large ion lithophile element (Rb, Sr and Ba) also show contrasting behaviour between the enclaves. As expected the more felsic mafic microgranular enclave from the granitic rocks have an elevated Rb content (451 to 480 ppm) compared to the enclave from the granodiorites (61 to 81 ppm). On the other hand the former has low Ba and Sr (447 to 452 ppm and 86 to 91 ppm respectively) compared to the latter (486 to 794 ppm and 415 to 467 ppm respectively).

**CONCLUDING REMARKS**

The relative fine grained size of the enclaves is consistent with a high nucleation rate and low growth rate, which apply when the degree undercooling of magma is relatively large. This can occur when a globule of relatively mafic magma comes into contact with the granitic magma. This implies that magma of the globule is much more undercooled than the granitic magma with respect to its liquidus (Vernon, 1983b). Occurrence of large K-feldspar crystals in enclave has been interpreted in various ways, this include as phenocryst/megacrysts (Furman & Spera, 1985; Vernon, 1986; Frost & Mahood, 1987), porphyroblast (Pitcher & Berger, 1972; Augustithis, 1973; Le Bas, 1982).
and foreign crystals (Cantagrel et al., 1984). Occurrence of igneous microstructural such as inclusion of biotite in the K-feldspar large crystals (cf. Stone & Austin, 1961) and gleomeroporphyritic texture formed by the large crystals may suggest that they are phenocryst or megacrysts. Vernon (1986) suggests that the large size of the megacrysts is evidently due to nucleation difficulties for K-feldspar in granitic melts.

Occurrence of the acicular apatite indicates that the crystals are quenched, probably formed when a globule of relatively mafic magma comes into contact with cooler granitic magma (cf. Wyllie et al., 1962). Gardner (1972) reported similar quenched apatites from the super-cooled roof zone of basic magma chamber. The presence of quenched apatite in the mafic microgranular enclave is significant since apatite is judged to be an early crystallising phase. This implies that the basic magma must have been virtually crystal free when it was injected into the felsic granitic magmas. Both magmas are probably mixed. This is evident from the occurrence of the quartz-hornblende ocellar which reflected hybridism of two magmas (Vernon, 1991). He suggested that the texture probably form in response to the instability of quartz in the mafic magma.

The variable geochemical trends in the enclave and their host rocks is probably related to the variable degrees of diffusive exchange between the enclave and their host rock magmas during slow cooling (Waite et al., 2001).

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