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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 sphene. 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 Muntahak 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 Permian), 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, chlorite 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 occeli 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). Oglethorpe (1987) also found the same type of apatite in the contact facies of Thorr 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 the 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 knows 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).

Host rock	Guntong Granodiorite	Guntong Granodiorite	Guntong Granodiorite	Peda Granite	Peda Granite
Sample	AX	AX2	AX3	SBX1	SBX2
wt%					
SiO_2	58.36	56.22	53.2	60.31	61.33
Al_2O_3	16.47	17.15	18.49	17.48	16.47
Fe_2O_3	5.8	6.65	7.38	8.34	7.29
MnO	0.12	0.11	0.18	0.23	0.25
MgO	4.87	4.67	4.97	1.65	1.41
CaO	7.15	7.29	8.02	3.82	3.78
Na_2O	4.04	5.42	5.69	4.77	6.43
K_2O	2.14	2.14	1.91	2.93	2.7
Total	98.95	99.58	99.84	99.53	99.66
ppm					
Zn	59	65	81	143	140
Ni	10	9	13	27	26
Co	27	31	34	31	33
Cr	452	277	171	293	386
Ba	794	691	486	452	447
Nb	7	2	1	3	2
Zr	128	120	110	168	173
Sr	467	454	415	86	91
Rb	81	74	61	480	451

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 Guntong 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 Guntong enclaves are more basic (SiO_2 : 53.2 to 58.4%) compare to those from the Peda granite (SiO_2 : 60.3 to 61.3%). Other elements that show significantly different between the enclaves are CaO, Zn, Ni, Ba, Zr, Rb and Sr. CaO in the enclave from Guntong 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)

Figure 1. Mafic microgranular enclave from the Eastern Belt of Peninsular Malaysia. Note the porphyritic texture and darker margin.

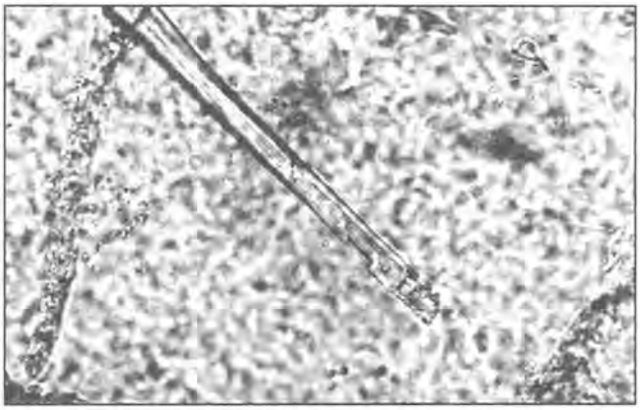

Figure 2. Photomicrograph of the acicular apatite with hollow ribbed cylinder.

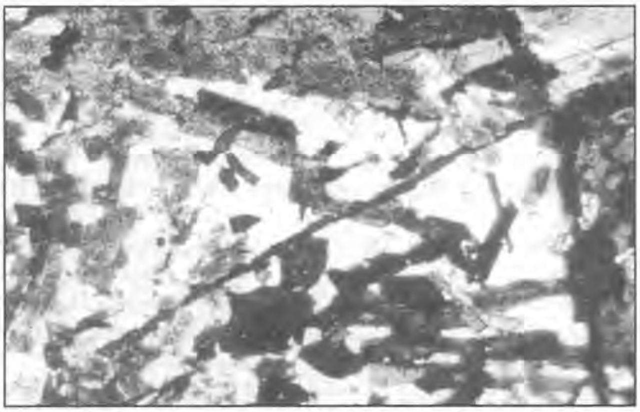

Figure 3. Bladed texture biotite from the Maras Bukit Jong granite.

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 (Waight *et al.*, 2001).

REFRENCES

AHMAD TAJUDDIN IBRAHIM, M. RASHID SALUKI & AZMAN A. GHANI., 2000. Geochemistry of the granitic rocks from north of the Lawit Batholith, Besut, Terengganu. *Proceeding Annual Geological Conference, Geological Society of Malaysia, Shangrila Hotel, Penang*, 73-79,

ANGUS, N. S., 1962. Occelar hybrids from the Tyrone igneous series, Ireland. *Geol.Mag.*, 94:2-27.

AUGUSTITHIS, S.S., 1973. *Atlas of the textural pattern of granites, gneisses and associates rock types.* Elsevier, Amsterdam 378 pp.

AZMAN A GHANI, 2000. Mesozoic mafic dykes from EasternBelt (Part 2): Geochemistry of the younger dykes. *Proceeding Dynamic Stratigraphy and Tectonics of Peninsular Malaysia, 3rd seminar, The Mesozoic of Peninsular Malaysia 2000*, p. 96-105

AZMAN A GHANI, AZLAN MOHAMAD & A.TAJUDDIN IBRAHIM, 1999. Description and implication of microstructure in mafic microgranular enclave from the Bukit Labohan granite, Terengganu. *Warta Geologi 25(1) (in press).*

AZMAN A. GHANI, M. RASHID SALUKI & A.TAJUDDIN IBRAHIM, 2001. Contrasting textural and geochemical composition of mafic microgranular enclave in granodiorite and syenogranite from Lawit batholith, Terengganu. *Warta Geologi 27(1) (in press).*

BARBARIN, B., 1986. Comparison of mineralogy of mafic microgranular enclaves and host granitoids, Central Sierra Nevada, California (Cordilleran Section). *Geol. Soc. Am., Loa Angeles California, Abstract Programs., 18*, 83.

BARBARIN, B., 1991. Enclave of the Mesozoic calc-alkaline granitoid of the Sierra Nevada batholith, California. *In:* J. Didier and B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, p. 135 -153.

BARBARIN, B. & DIDIER, J., 1991. Microscopic features of mafic microgranular enclaves. *In:* J. Didier and B. Barbarin (eds) *Enclaves and granite petrology.* Elsevier, p. 253-262

BARBARIN, B. & DIDIER, J., 1992. Genesis and evolution of mafic micro- granular enclaves through various types of interaction between co- existing felsic and mafic magmas. *Trans. Roy. Soc. Edinb. : Earth Sciences,* 83:145-153.

BARBARIN, B., DODGE, F.C.W., KISLER, R.W. & BATEMAN, P.C., 1989. Mafic inclusion and associates aggregates and dikes in granitoid rocks, Central Sierra Nevada. Analytical Data. *U. S. Geol. Surv. Bull.*, 1899: 1-28.

BATEMAN, P.C., 1983. A summary of critical in the central part of the Sierra Nevada batholith, California, USA. *Geol. Soc. Am. Mem.*, 159:241-254.

BATEMAN, P.C., CVLARKE, L.D., HUBER, N., MOORE, J.G., & RINEHART, C.D., 1963. The Sierra Nevada batholith, a synthesis of recent work across the central part. *Geol. Surv. Prof. Paper 414D*, 46 pp.

CANTAGREL, J. M., DIDIER, J. & GOURGAUD, A., 1984. Magma mixing : origin of intermediate rocks and "enclaves" from volcanism and plutonism. *Phys. Earth Planet. Inter.*, 35:63-76.

COBBING, E. J., PITFIELD, P. E. J., DARBYSHIRE, D. P. F., & MALLICK, D. I. J., 1992, The granites of the South-East Asian tin belt. *British Geological Survey Overseas Memoir* 10.

DEBON, F., 1975. Les massifs granitoides a structure concentrique de Cauterets-Panticosa (Pyrenees occdentales) et leurs enclaves. Ute etude petrographique et geochemique. *Mem. Sci. Terre*, Nancy, 33, 420 pp .

DEBON, F., 1991. Comparative major element chemistry in various " microgranular enclave-plutonic host" pairs. *In*: J. Didier & B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, p. 293-312.

DIDIER, J., 1973. Granites and their enclaves: the bearing of enclaves on the origin of granites. *Dèvelop. Petrol. Ser.*, Vol. 3, Elsevier: New York, 393p.

DIDIER, J., 1991. The various types of enclaves in the Hercynian granitoids of the Massif Central, France. *In*: J. Didier & B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, p. 47-61.

EBERZ, G.W., NICHOLLS, I. A., MASS, R,. MCCULLOCH, M. T & WHITFORD, D.J., 1990. The Nd- and Sr- isotopic composition of I-type microgranitoid enclaves and their host rock from the Swift Creek pluton, southeast Australia. *Chem. Geol.* 85:119-134

FOURCADE, S. & JAVOY, M., 1991. Sr-Nd-O isotopic features of mafic micro-granular enclaves and host granitoids from Pyrenees, France: Evidence for their hybrid nature and inference on their origin.*In*: J. Didier & B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, 345-364.

Frost, T. P. & Mahood, G. A., 1987. Field, chemical and physical constraints on mafic-felsic magma interaction in the Lamark Granodiorite, Sierra Nevada, California. *Geol. Soc. Am. Bull.*, 99:272-291.

FURMAN, T. AND SPERA, F. J., 1985. Co-mingling of acid and basic magma with implication for the origin of mafic 'I' type xenoliths, field and petrochemical relations of an usual dike complex at Eagle Peak Lake, Sequoia National Park, California, USA. *Jour. Volc. Geotherm. Res.*, 24:151- 178.

GARDNER, P. M., 1972. Hallow apatites in a layered basic intrusion, Norway. *Geol.Mag.*, 109(5):385-392.

HAYATI TURIMAN, 2000. *Kajian tekstur batuan, kaitan lapangan* *dan geokimia granit Maras bukit Jong kawasan Batu Rakit, Kuala Terengganu, Terengganu Darul Iman.* Unpubl. B Sc thesis, Univ. of Malaya.

HIBBARD, M. J., 1991. Textural anatomy of twelve magma-mixedgranitoid systems. *In*: J. Didier & B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, 431-443

HUTCHISON, C. S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Bull. Geol. Soc. Malaysia,* 9:187-207.

LACROIX, A. 1890. Sur les enclavess acidesdes roches volcaniquesd'Auvergne. *Bull. Serv. Carte Geol. Fr.,* 2:25-56.

LE BAS, M. J., 1982. The Caledonian granites and diorites of England and Wales. *In:* D.S. Sutherland (ed) *Igneous Rocks of the British Isles.* Wiley, Chichester, pp 191-201.

LIEW, T.C., 1983. *Petrogenesis of the Peninsular Malaysia granitoid batholiths.* Unpubl. PhD thesis, Australia National University.

MAURY, R.C., DIDIER, J. & LAMEYRE, J., 1978. Comparative magma/ xenolith relationships in some volcanic and plutonic rocks from the French Massif Central. *Contrib. Mineral. Petrol.* , 66:401-408.

MOHD RASHID SALUKI, 1995. *Geologi kawasan Gunung Tebu, Besut Terengganu dengan penekanan kepada batuan granitoid.* Unpubl. B Sc thesis, Univ. of Malaya.

OGLETHORPE, R.D.J., 1987. *A mineralogical and chemical study of the interaction between granite magma and pelitic country rock, Thorr pluton, Co. Donegal, Eire.* Unpubl. PhD thesis, Univ. of Liverpool.

ORSINI, J.B., 1979. Contribution a la connaissance des granitoides tardi-orogeniques du batholite corsosarde. Les enclaves sombres de l'association plutonique calco-alkaline. *Trav. Lab. Sci. Terre, Univ. Marseille-Saint Jerome, C, 3,* 104 pp.

OTTO, J. & WIMMENAUER, W., 1973. Les enclaves des granites de la Foret Noire. *Bull. Soc. Geol. Fr.,* 7, XV:199- 208.

PIN, C., BINON, M., BELIN, J. M., BARBARIN, B, & CLEMENS, J. D., 1990. Origin of Microgranular enclaves in granitoids : equivocal Sr-Nd evidence from Hercynian rocks of Massif Central (France). *Jour. Geophys. Res.,* 95:17821-17828.

PITCHER, W.S. & BERGER, A.R., 1972. *The geology of Donegal: A study of granite emplacement and unroofing.* Wiley Interscience, London. 435 pp.

REID, J.B., EVANS, O.C. & FATES, D.G., 1983. Magma mixing in granitic rocks of the Central Sierra Nevada, California. *Earth Planet Sci. Lett.,* 66:243-261.

SABATIER, H., 1980. Vaugnerites et granites: une association particuliere de roches grenues acides et basiques. *Bull. Mineral.,* 103:507-522.

STONE, M. & AUSTIN, G.C., 1961. The metasomatic origin of potash feldspar megacrysts in the granites of Southwest England. *Jour. Geol.,* 69:464-472.

VERNON, R.H., 1983a. Restite, xenoliths and microgranitoid enclaves: *Jour. Proc. Royal Soc. New South Wales,* 116:77 - 103.

VERNON, R.H., 1983b. Microgranitoid enclaves in granite-globules of hybrid magma quenched in a plutonic environment. *Nature,* 309:438-439.

VERNON, R.H., 1986. K-feldspar magacrysts in granite-phenocrysts, not porphyroblasts. *Earth Sci. Rev.,* 23:1-63.

VERNON, R.H., 1990. Crystallisation and hybridism in microgranitoid enclave magmas: microstrutural evidence. *Jour. Geophys. Res.,* 95:17849-17859.

VERNON, R.H., 1991. Interpretation of microstructure of microgranitoid enclaves. *In*: J. Didier & B. Barbarin (eds) *Enclaves and Granite Petrology.* Elsevier, p. 277 -291.

VERNON, R.H., ETHERIDGE, M.A. & WALL, V.J., 1988. Shape and micro-structure of microgranitoid enclaves : indicators of magma mingling and flow. *Lithos.,* 22:1-11.

WAIGHT, T.E, MASS, R & NICHOLLS, I.A. 2001. Geochemical investigation of microgranitoid enclaves in the S-type Cowra Granodiorite, Lachlan Fold Belt, SE Australia. *Lithos,* 56:165-186

WYLLIE, P.J., COX, K.G. & BIGGAR, G. M., 1962. The habit of apatite in synthetic systems and igneous rocks. *Jour. Petrol.,* 3:238-243.

ZOPRI, M.J., 1988. *Melanges magmatiques dans les granitoides de Sardaigne septentrionale: implications sur l'hybridation, la zonationet la mise en place des plutons calco-alkalins.* Unpublished thesis, Univ. Aix-Marseille III, Marseille, 364 p.