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Textural Relations of Lamprophyric Mafic Microgranular Enclaves and Petrological Implications for the Genesis of Potassic Syenitic Magmas: the example of Piquiri Syenite, southern Brazil

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Abstract - The Neoproterozoic Piquiri Syenite exhibits a large amount of mafic microgranular enclaves (MME) with elliptical-shape and millimeter to centimeter-size dimensions. These enclaves were originated by co-mingling of minette-type lamprophyre and potassic syenite magmas, producing the typical textural features of quenched magmas. They show elongated crystals of diopside and Mg-biotite, and acicular apatite. Early crystallized phases are represented by the same minerals, which occur as phenocrysts (diopside + Mg-biotite) and euhedral smaller crystals (apatite). The textural relationship and the identification of mineral phases as K-clinopyroxene and pyrope in the MME, suggest that mingling started at mantle conditions, when lamprophyric and syenitic magmas were near crystal-free and close to *liquidus* temperatures. The absence of syenite xenocrysts and chilled-margins in MME, are consistent with the high temperature of co-mingling. Alkali feldspar laths that poikilitically enclose quenched phases, represent late-magmatic mineral phase. The Piquiri Syenite MME represent a quite rare example of co-mingling between lamprophyre and intermediate magmas, and represents important evidence for the genesis of potassic silica-saturated magmas at mantle conditions.

Keywords - lamprophyres, mafic microgranular enclaves, syenite, mingling.

INTRODUCTION

Microgranular enclaves were originally defined by Didier & Roques (1959), as ellipsoidal-shape rocks with few centimeters to some decimeter size and, abrupt and well-defined contacts with host-rock. Mafic microgranular enclaves (MME) as characterized by many authors in Didier & Barbarin (1991) are fine to very fine-grained mafic enclaves, always finer than the host-rock, which are usually granites, although MME were also described in syenitic rocks (Dorais & Floss, 1992). Close to the syenite-MME contact region is observed a finer-grained, mm- to cm-size zone, which is interpreted as chilled margin according to the criteria of Didier (1964) and Barbarin & Didier (1991). Bussy (1987) argued that chemical exchanges between both magmas are restricted to some millimeters of this zone, even though many authors admit that they can be much more effective (Vogel *et al.*1984, Nardi & Lima 2000). MME are fine to medium-grained rocks, with great amounts of elongate and acicular minerals, which are included mainly in plagioclase and amphibole (Reid *et al*, 1983; Vernon, 1990, 1991). Needles of apatite are the commonest of these elongate minerals produced by quenching. Orientation of mineral laths is very common, reflecting the magmatic flow during crystallization of MME and their host magma. Most of MME described in literature, have dioritic composition and are associated to Cordilleran calc-alkaline granitoids (Didier, 1973) as in the Sierra Nevada Batholith (Pabst, 1928; Barbarin, 1989, 1991) and, Peruvian Coastal Batholith (Bussel, 1991). Shoshonite granitoids are also frequent hosts of MME, as characterized by Nardi & Lima (2000) in the Lavras do Sul Shoshonitic Association from southernmost Brazil. MME of alkaline suites are well characterized by Platevoet & Bonin (1991) in the magmatic province from Corsica (France). Granitic rocks of post-collisional settings, except for the peraluminous leucocratic granitoids, are also MME rich (Bitencourt & Nardi 2000).

MME were also described as originated from lamprophyric magmas (Harker & Marr, 1891; Bussy, 1987). Lamprophyric enclaves usually occur associated to appinites in calc-alkaline abnormally K_2O-rich rocks (Ayrton, 1991) and are contemporaneous with calc-alkaline granitoids (O'Connor, 1974). Such geochemical feature is assumed by many petrologists as primary and associated with deep-mantle derived lamproitic magmas (Ayrton,

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1991). In spite of lamprophyric rocks have been considered as typical late intrusions (Rock, 1987), Barnes *et al* (1986) and Ayrton (1991) demonstrated that such mafic magmas may intrude granitic magmatic systems during crystallization, mainly where the melt/crystal fraction is higher. Sabatier (1991) described vaugnerite as MME associated to magnesio-potassic, probably shoshonitic, granites in the Hercynian magmatism from western and central Europe. Such rocks, composed of amphibole, biotite, plagioclase and minor quartz, alkali feldspar and, apatite, were considered as plutonic equivalents of minette or kersantite lamprophyres, with chemical signature of melts produced from K-enriched metasomatised-mantle sources.

The association of syenites and lamprophyres, mainly minettes, were described in the last decades by several authors (Esperança & Holloway, 1987; Thompson et al, 1989; Gibson *et al*, 1993; Stabel *et al*, 2001). Such lamprophyric magmas are associated with potassic syenites, generally as dikes, and probably can evolve to intermediate syenitic liquids through mineral fractionation. The MME of Piquiri Syenite (Stabel *et al*, 2001) are minettic rocks produced by mingling of lamprophyric and syenitic magmas. They present textural features, such as mafic phenocrysts and felsic minerals restrict to the groundmass, where mafic minerals are abundant, a feature typical of lamprophyres. A remarkable feature of these enclaves is the presence of clinopyroxene grains with relatively high K contents, which are interpreted as produced at very high pressures, above 5 GPa (Plá Cid *et al*, 2002). This paper presents the textural aspects of these MME, which represent minette liquids co-mingled with the syenite magma, and discusses the petrological evolution of this system.

FIELD RELATION BETWEEN SYENITE AND MME

The Piquiri syenite is an intrusion with a crescent shape and diameter of about 12 km. This intrusive body, composed dominantly by syenites with minor co-magmatic granites and quartz monzonites, is situated in southernmost Brazil, in a post-collisional setting. It has a Pb-Pb zircon age of 612 Ma (Phillip *et al*, 2002), and presents a potassic nature. The central part of this intrusion presents a large amount of mafic rocks as enclaves and, at least, three petrographic types were identified: (i) Type I - microgranular rocks with dioritic composition and mafic mineralogy constituted by mica, with minor amounts of amphibole, which were interpreted as emplaced into the syenitic intrusion under crustal conditions; (ii) Type II - mesocratic, fine to medium-grained inequigranular rocks, with pargasite and aluminous-diopside plus potassium-bearing augite. Only two enclaves of this type were found, and more data are necessary to determine its role in the syenite origin. The alkaline and potassium-rich character of these enclaves suggest that they may be related to the syenite origin, although the absence of chilling textures and the presence of high-pressure minerals do not preclude a xenolithic origin. They are chemically distinguished of type-III by lower K_2O/Na_2O ratio, MgO and REE, and higher Al_2O_3, Nb, and U contents; (iii) Type III - mafic microgranular enclaves (MME) formed by pyroxene and mica phenocrysts This enclave-type is largely dominant (> 90%) in the host syenite, and its characterization is the aim of this paper. Their textures indicate that mme are rocks that have the original mineralogy mostly preserved, and the local presence of amphibole rims around clinopyroxene is due to late to post-magmatic transformation by reaction with interstitial water-rich fluid.

The lamprophyre enclaves generally have oval shape, although rounded and irregular forms were also observed. Most MME have diameter of about a few centimeters (< 5 cm), reaching up to half meter. They are fine- to very fine-grained ultramafic rocks, and macroscopically it is possible to observe mafic phenocrysts, as well as alkali feldspar xenocrysts from the host syenite. Chilled margins are very rare. In some parts of the intrusion, the MME constitute swarms and bands which are oriented according to the magmatic flow observed in the host syenite. The isolated enclaves are usually oriented by magmatic flow, and show internal orientation of mafic minerals. Along the zones where the magmatic flow was more intense, MME are elongated and are frequently associated with schlieren and cumulatic concentrations of early-crystallized pyroxenes.

Cumulates formed by biotite, clinopyroxene, and apatite occur as layers and irregular masses with generally gradational contacts with the host syenite. They are medium grained and equigranular and show the same magmatic-flow orientation of host syenite. They are interpreted as formed by magmatic-flow segregation of syenitic and lamprophyric magmas after mingling and local mixing, and are probably composed mostly of the lamprophyric magma early-crystallized phases.

TEXTURAL FEATURES

The mineralogy of Piquiri Syenite MME was identified by optical microscope followed by electron microprobe determinations, referred and discussed by Plá Cid *et al* (2002).

The lamprophyre mafic microgranular enclaves of Piquiri Syenite are porphyritic, with diopside and Mg-biotite phenocrysts, which are surrounded by a fine-grained groundmass composed of Mg-biotite/phlogopite, diopside and augite, apatite, alkali feldspar, and Fe-Ti-oxides. The main accessory phases are amphibole (Mg-hornblende and actinolite), zircon, plagioclase, sulfides, fluorite, and titanite. Some samples exhibit strong mineral orientation, particularly of mica and acicular apatite in the groundmass, controlled by magmatic flow. Most grains are elongated, acicular and euhedral (Fig. 1). Mafic globular aggregates (clots), composed of mica, pyroxene, and euhedral apatite were observed in some MME. These clots show diopside, partially transformed to actinolite, which is surrounded by reddish anhedral Mg-biotite grains.

Early-magmatic phenocrysts

Diopside and Mg-biotite are the only phenocrysts observed in the MME (Fig. 1). Diopside phenocrysts are larger than those of Mg-biotite, frequently reaching up to 4 mm, with mean size between 2 and 3 mm (Figs. 1A, 1B, and 1C). Mg-biotite phenocrysts are euhedral grains, with mean size between 1 and 2 mm (Fig. 1D).

Diopside: It is generally present as light green euhedral and subhedral crystals, forming homogeneous crystals occasionally forming glomerous-porphyritic texture. Occasionally, it exhibits concentric zones, with two types of arrangement: (i) a core, with green color, composed of Mg-hornblende and actinolite lamellae plus Fe-oxide grains, surrounded by a clean rim of colorless or pale-green zone (Fig. 1C); (ii) light green euhedral phenocrysts with a narrow rim of green pyroxene. Near to the contact of enclave with syenitic rock, diopside phenocrysts with multiple zones formed by amphibole plus Fe-oxide and pale-green diopside are observed. The contact between diopside phenocrysts and groundmass minerals is normally sharp and straight, sometimes curved between diopside and Mg-biotite phenocrysts, suggesting a high temperature of crystallization. Diopside phenocrysts contains mineral inclusions, such as: (i) euhedral apatite (Fig. 1B); (ii) lamella of colorless or light-green amphibole; (iii) euhedral light-brown mica grains (1A); (iv) euhedral Fe-oxides associated to amphibole lamella; (v) acicular apatite inclusions in the outer rim of zoned pyroxene. Inclusions of pyrope-rich garnet with extremely high #mg (up to 71) within diopside phenocrysts are described in the mica-clinopyroxene-apatite cumulate. The homogeneous diopside phenocrysts of MME revealed the presence of up to 0.6 wt% of K_2O in their cores.

Mg-biotite: it occurs as euhedral phenocrysts with light brown to deep-brown pleochroism. Generally they present straight and non-reactive contacts with groundmass minerals, and include euhedral (Fig. 1D) and acicular apatite along their borders, in addition to zircon, and euhedral diopside crystals. Sometimes they include alkali feldspar crystals, mostly in their borders.

Late-magmatic phenocrysts

These pheno-crysts include the groundmass minerals, and crystallized after co-mingling, when temperature between mafic and intermediate magmas attains equilibrium. The late-magmatic phenocrysts are represented by poikilitic grains of alkali feldspar (Figs. 1A, 1B, 1C, 3, and 4) and reddish-brown mica (Figs. 2 A and 2B). Poikilitic alkali feldspar crystals form large (< 5 mm-size) plates, sometimes with fine-perthites, and with no-reactive contacts with the groundmass crystals. Reddish-brown mica phenocrysts frequently are observed with inclusions of alkali feldspar and acicular apatite (Fig. 2A and 2B), and the contact between phenocrysts and inclusions is normally curved and lobated. In the cumulative rocks, alkali feldspar grains constitute oikocrysts including diopside, biotite, and apatite cumulate minerals.

Groundmass

The groundmass of MME is made of diopside, Mg-biotite, apatite, Fe-Ti-oxides, sulfides. Groundmass minerals usually range from 0.1 to 0.7 mm in size. As is noted mainly in figures 3 and 4 alkali feldspar poikilitic phenocrysts include all groundmass mineral phases. Anisotropy in the MME is registered by strong orientation of elongated Mg-biotite, sometimes of diopside, as well as by acicular apatite.

Diopside: Euhedral, subhedral, and elongated crystals are found in the MME groundmass, with green to light-green color, sometimes with colorless cores, and measuring in average 0.3 mm. The elongate crystals, which are dominant among the groundmass mafic phases, have in average 10:1 (length: width) ratios (Figs. 3A and 3B), reaching up to 25:1. The contacts with other mineral are straight and non-reactive. The diopside crystals include euhedral phlogopitic mica, acicular apatite, acicular iron oxides, and rare ex-solution lamellae of amphibole. Some of these elongated crystals

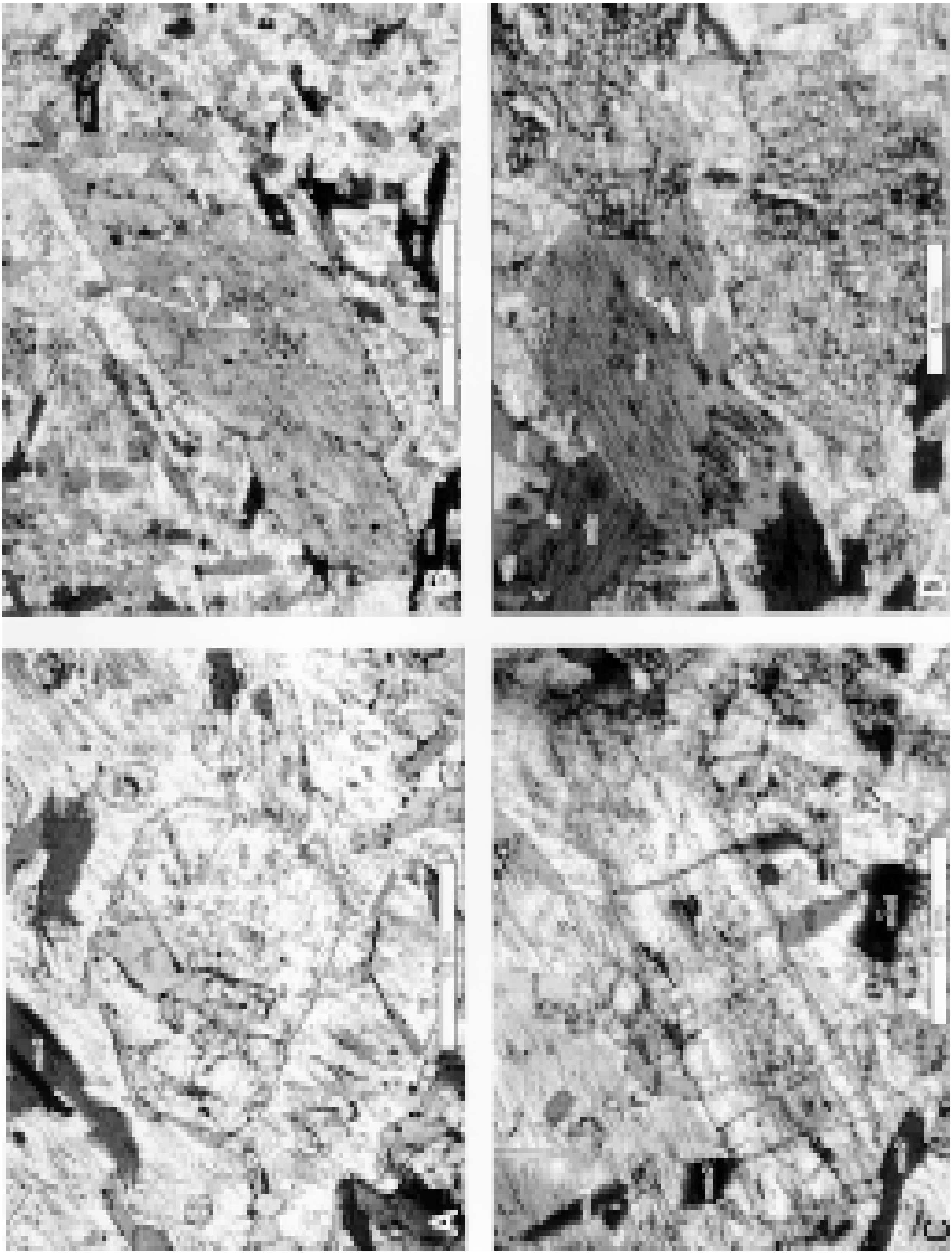

Figure 1 - Digital images obtained under light transmitted optical microscope. Pyroxene phenocryst including euhedral grain of mica. Note groundmass minerals included in poikilitic plates of alkali feldspar (A). Similar to figure 1A, but the inclusions in pyroxene phenocrysts are euhedral apatite grains. The strongly elongate shape of groundmass minerals is also observed (B). Zoned pyroxene phenocryst with central region composed of pyroxene plus amphibole lamellae and oxide crystals (C). Sample with low rate quenching, as noted by higher amounts of pyroxene and mica phenocrysts, and lower proportion of groundmass minerals (D). Symbols legend of all figures: cpx - clinopyroxene; mic - mica; ap - apatite; af - alkali feldspar; amph - amphibole; ox - oxides; mic2 - anhedral mica.

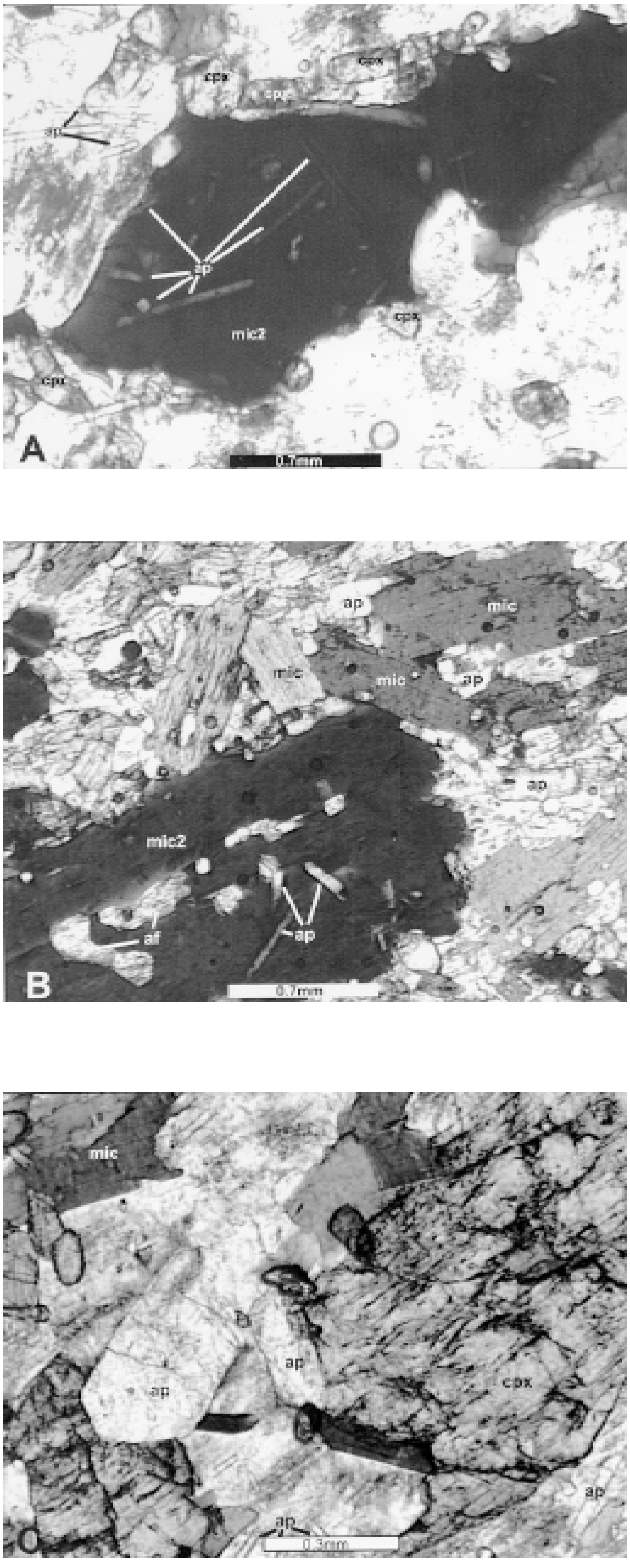

Figure 2 - Digital images obtained under light transmitted optical microscope. Anhedral late mica phenocryst including several aciculate apatites (A). Subhedral late mica phenocrysts enclosing poikilitically alkali feldspar and aciculate apatites, contrasting with the earlier crystallized euhedral grains. Note the straight contacts of euhedral crystals, and the sinuous contours of poikilitic phenocryst (B). Detail of euhedral early-crystallized apatite crystals (C).

Figure 3 - Digital images obtained under light transmitted optical microscope. Elongate crystals of mica and pyroxene crystallized by quenching of hotter mafic magma against cooler felsic ones. The axial ratio of pyroxene is estimated around 12 (length:width), and slightly lower for mica crystals (A). Note the poikilitic character of alkali feldspar plates, corroborating its late-magmatic crystallization after co-mingling event (B). Two generations of groundmass mica crystals. Elongate grains crystallized during undercooling of mafic magma, and dark anhedral grains probably formed during a later magmatic stage (C).

present, in the core, K_2O concentrations of up to 0.44wt%; in one sample, acicular inclusions of K-augite in the core of elongated diopside crystals were observed.

Mg-biotite: both types described as phenocrysts, were observed in the groundmass, with size around 0.2 mm, and rare grains with 0.01 mm. Grains with brown color form elongated crystals, with 5:1 to 10:1 (length:width) ratio (Fig. 3A and 3C). Phlogopite euhedral crystals are also present, but only as inclusions in diopside groundmass grains.

Apatite: two generations of apatite were observed in MME: (i) euhedral equidimensional grains (Figs. 2C and 4B) and (ii) acicular grains (Fig. 4). Euhedral apatite grains are 0.01 to 0.05 mm long, generally occur as isolated grains in the groundmass, but sometimes form aggregates. Rare crystals with more than 0.05 mm were observed. These euhedral grains were also observed as inclusions in pyroxene phenocrysts, rarely in mica phenocrysts and in the groundmass pyroxene. Early crystallized, mafic-rich clots also contain euhedral apatite. Acicular crystals show variable and high length:width ratios (Fig. 4). The common ratio between the axes of acicular apatite ranges from 5:1 to 20:1. The samples with higher modal proportions of euhedral apatites are richer in acicular crystals. Furthermore, the samples with diopside and Mg-biotite crystals more elongated have the acicular apatite with the higher length:width ratio. Acicular apatite is observed as inclusions in groundmass mafic minerals. Where the mafic minerals are less abundant, apatite crystals are strongly oriented and sometimes occur as aggregates of needle-shape grains (Fig. 4C).

Contact relation of MME and host syenite

MME and host syenite generally have curved contacts and more rarely straight contours. Normally, these contacts are marked by absence of chilled margins. In some MME are observed greater amounts of anhedral poikilitic mica megacrysts. Magnetite produced by late-magmatic transformation of diopside to actinolite is greater in these MME. Sometimes, near to the contact zone, diopside and alkali feldspar xenocrysts of syenitic magma are observed in the MME. The enclaves with high modal proportion of xenocrysts present discrete chilled margins, marked by grain size decrease of Mg-biotite and diopside groundmass grains; the contacts of such enclaves are sharp.

Xenocrysts

Rare xenocrysts of alkali feldspar and diopside were observed in MME. The alkali feldspar xenocrysts are strongly perthitic millimeter-size tabular grains, as in the host syenite, with overgrowth rims including elongate and acicular minerals (Fig. 5B). The groundmass minerals included in the rims are smaller than those present in MME. The borders are normally corroded, with albite and microcline surrounding the alkali feldspar. Inclusions of early-crystallized host-syenite minerals, such as diopside, apatite, and titanite, were observed inside the alkali feldspar xenocrysts. Ocelli texture is occasionally present, with rims of elongated Mg-biotite and diopside crystals surrounding these xenocrysts (Fig. 5A).

Alkali feldspar xenocrysts are restrict to a few MME samples, suggesting that at least one magmatic pulse of mafic magma mingled with the partially crystallized intermediate syenitic one under crustal pressures.

The diopside xenocrysts of MME are not easily distinguished from pyroxene phenocrysts, but some characteristics are particularly diagnostic. Diopside xenocrysts are tabular grains, and occur in samples with abundant alkali feldspar xenocrysts. They are strongly fractured, crashed, and include Mg-biotite, alkali feldspar, euhedral apatite, and greenish-blue amphibole belonging to the actinolite series. Some amphibole phenocrysts of syenitic rocks have the same inclusions as the diopside xenocrysts of MME, suggesting that some amphibole phenocrysts crystallized from syenitic magma were assimilated from the mafic magma during co-mingling and probably transformed to diopside.

MINGLING AND MME CRYSTALLIZATION

Based upon textural evidences, three different groups of minerals were recognized in the MME: (i) a pre-mingling group, dominated by early phases crystallized directly from a mafic magma before mingling; (ii) groundmass minerals of MME quickly crystallized by quenching of mafic magma against the syenitic host magma; (iii) mineral overgrowths representing the later crystallization event after the thermal equilibration between both magmas.

Pre-mingling phases

Euhedral crystals of apatite, pyrope, potassian-rich pyroxene, and euhedral phlogopite represent such minerals. Phenocrysts also crystallized before

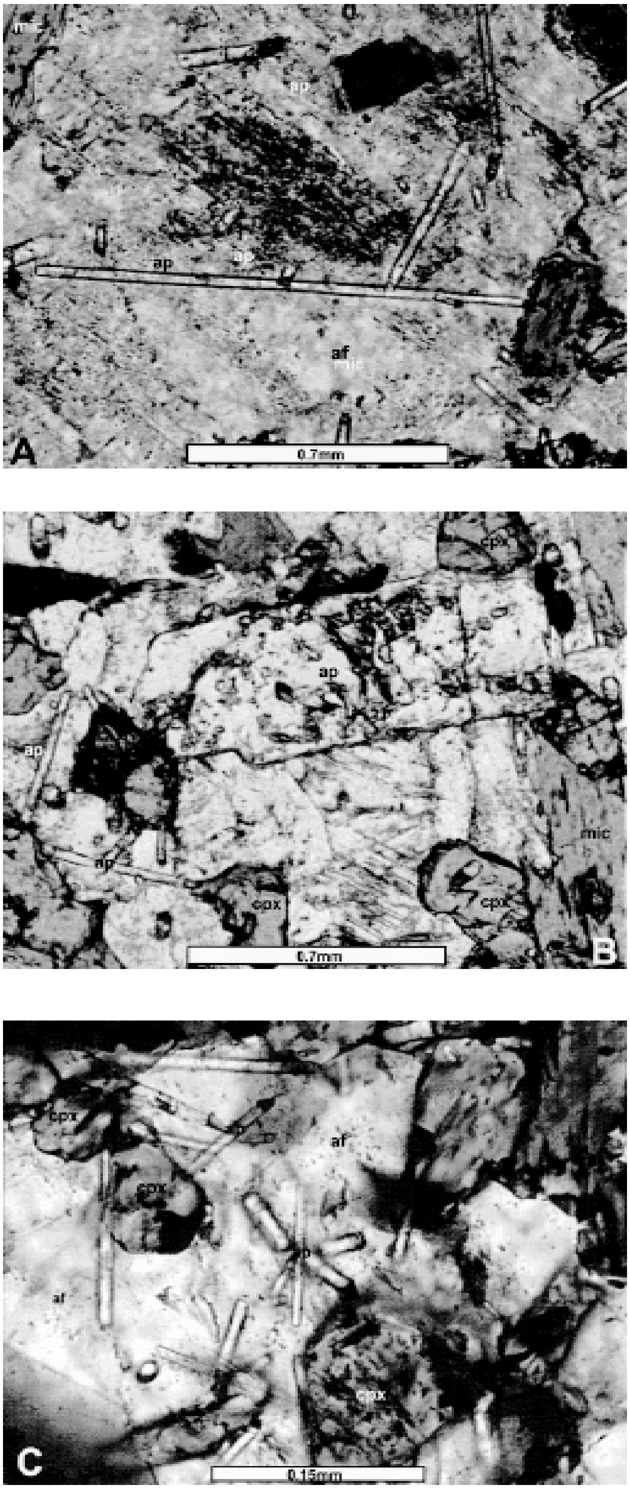

Figure 4 - Digital images obtained under light transmitted optical microscope. Aciculate apatite crystals enclosed poikilitically in alkali feldspar plates (A). Comparison between early-crystallized euhedral apatite, and aciculate grains originated during co-mingling (B). Detail of apatite needles included in alkali feldspar. It is also observed the occurrence of basal sections of elongate pyroxene crystals (C).

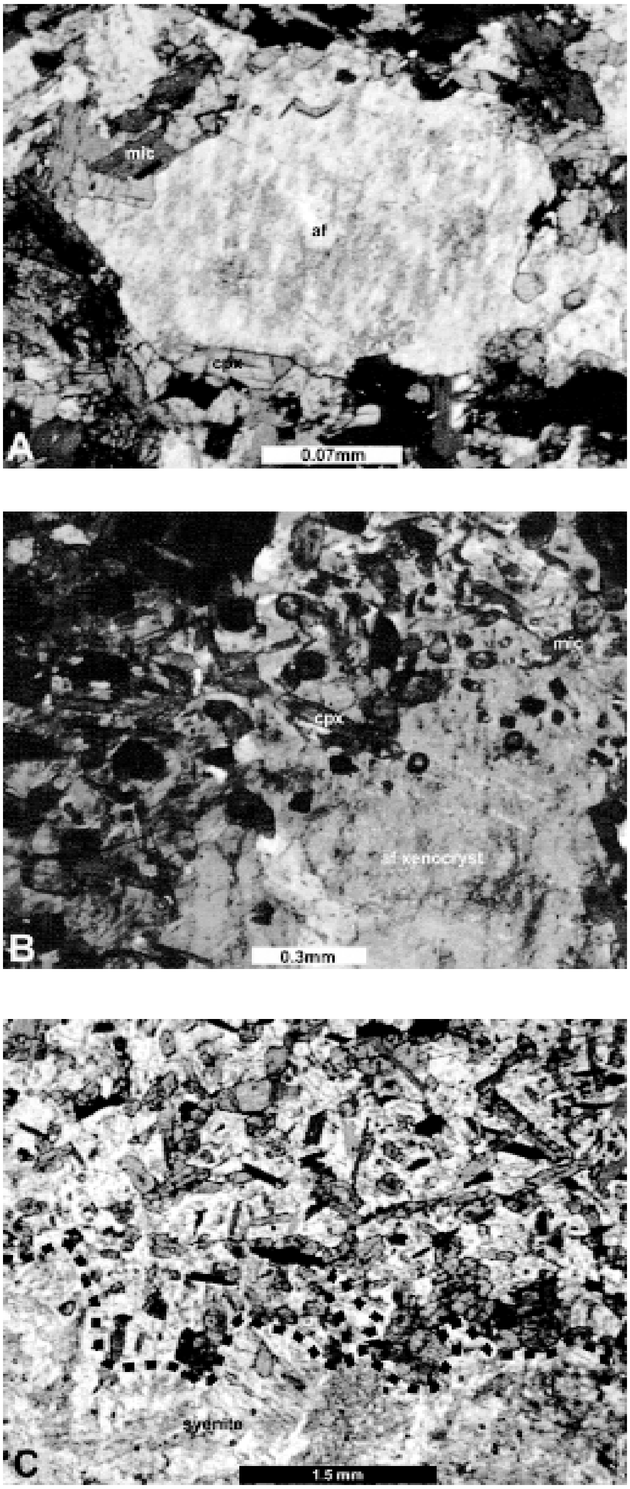

Figure 5 - Digital images obtained under light transmitted optical microscope. Alkali feldspar xenocrysts surrounded by groundmass mafic minerals constituting ocelli texture (A). Overgrowth after co-mingling of alkali feldspar xenocrysts that include poikilitically groundmass minerals (B). Contact between the syenite and MME showing absence of chilled margin and a sinuous contour, suggesting high-temperature interaction. Note the elongate shape of groundmass minerals.

mingling, and the textural relations suggest that diopside and apatite started to crystallize before mica. The presence of lamella ex-solutions of Mg-hornblende in most diopside phenocrysts (Fig. 1C) suggests that amphibole is an early mineral phase. The outer zones of pyroxene phenocrysts without amphibole lamellae certainly were crystallized during co-mingling with the syenitic magma. Several MME have significant amount of large apatite euhedral crystals, with minor proportion of elongate minerals, which indicates that such enclaves contained a higher proportion of crystals when mingling occurred. The presence of different proportions of xenocrysts in the studied samples is additional evidence that suggests that mingling involved magmas with contrasting crystallization rates.

Crystallization due to quenching

Groundmass mineral assemblage was formed during this second phase by underccoling of mafic magma, which also involved transformations of the early-crystallized minerals. The textural relations exhibited by groundmass apatite, diopside, and Mg-biotite suggest their fast and simultaneous crystallization.

During this phase, the undercooling suffered by the mafic magma is registered by the growing of acicular apatite, and elongated crystals of Mg-biotite and diopside (Figs. 3, 4, 5B, and 5C). The elongation ratio of these phases is related to the amount of early euhedral minerals: the most elongated mineral phases formed at this stage are in the samples with lower proportions of pre-mingling minerals. Samples that represent magmas with higher liquid proportions, which have higher temperature at the time of mingling, yielded more elongated crystals, reflecting the higher temperature gradient in the contact with the lower temperature host syenite magma. Such temperature gradient causes some undercooling in the mafic magma, and prevented a large-scale exchange of crystals between mafic and intermediate magmas, as suggested by the very low xenocrysts content recognized in MME.

Post-mingling crystallization

This stage developed when mafic and felsic magma attained thermal equilibrium. Alkali feldspar grew as poikilitic crystals that include all quenched minerals (Fig. 5B). During mingling and post-mingling phases, the crystallization of diopside phenocrysts continued at its margins, and do not present lamellae amphibole ex-solutions. Anhedral mica phenocrysts are developed and included mainly acicular groundmass apatite. Corrosion and re-crystallization of rims around alkali feldspar xenocryst and late formation of actinolite rims around diopside grains took place during this stage. Amphibole rims were mainly observed in some mafic aggregates (diopside + Mg-biotite).

CONCLUDING REMARKS

The magmatic origin of MME is supported by their microstructures similar to those described by Vernon (1991) and many other authors. The clear evidence of magmatic flow during quenching is indicative that at least 35% of melt was present (Arzi, 1978) at the time of mingling. Such value is coherent with the estimated amount of phenocrysts before mingling, which was around 15%.

The term MME is employed in this paper, in the sense of mafic microgranitoid enclaves (Philips, 1880; Vernon, 1983). The restrict occurrence of mafic phenocrysts and the presence of alkali feldspar as a late-magmatic phase characterize them as produced from lamprophyre magma, although the studied rocks are not sub volcanic as lamprophyres are usually defined. Lamprophyre magma is here employed in the sense of magma with high volatile content enough to prevent the early crystallization of feldspars; if its crystallization occurs under sub volcanic conditions a typical lamprophyre will be produced. The existence of lamprophyre magmas, represented by MME associated to syenites, has probably been underestimated because of this conceptual constraint.

Since the Piquiri Syenite show mingling with a minette-type magma (Stabel *et al,* 2001), and minettes are undoubtedly produced from mantle sources (Bachinski & Scott, 1979; Esperança & Holloway, 1987; Thompson *et al*, 1989), it is then probable that mingling started still in the mantle. The generally sinuous contacts between MME and syenite host, and the normal absence of host phenocrysts along the contacts, are evidences that both magmas were very close to liquidus temperatures when mingling occurred. Furthermore, the low amount of phenocrysts in the lamprophyric magma is certainly an additional evidence for source proximity when co-mingling started. The occurrence of minerals such as K-clinopyroxene (Edgar & Vukadinovic, 1993; Harlow, 1997), sometimes as elongated euhedral inclusions, and pyrope-rich garnet (Irifune & Ohtani, 1986; Konzett, 1997) supports that co-mingling occurred still at mantle-conditions. According to Plá Cid *et al* (2002), and based on mineralogical and experimental studies of high-pressure rocks it is estimated a pressure around 5 GPa for pyrope and K-rich clinopyroxene crystallization from lampro-phyric magma. It is difficult to estimate when co-mingling started, however it was certainly still under mantle-pressures (> 3 GPa), since K was preserved in diopside structure. The temperature contrast between both magmas was sufficient only to accelerate the crystallization rate of mafic magma, and prevent the chemical diffusion. The chemical similarity between both magmas also aided to prevent such chemical ex changing. The K-clinopyroxene, found in the core of elongated groundmass crystals and crystallized by quenching of mafic magma against the intermediate syenitic one, rules out the hypothesis that these high-P minerals could be mantle xenocrysts.

Two main hypotheses can explain the evolution of the Piquiri Syenite and MME: (i) the MME are volatile-rich mafic lamprophyric rocks, which probably generated an intermediate liquid with a syenitic composition by segregation of low amounts of mafic minerals. In a later stage occurred co-mingling between parent and daughter magmas. If the intrusion of mafic magma occurred after cooling of syenites, the mafic magma most likely would crystallize as dykes with typical field characteristics of lamprophyric rocks, because of its very high volatile content. The major problem with this hypothesis is to expect sufficient mineral fractionation at mantle pressures to promote the changing of magma composition, however the chemical similarity would explain the very limited diffusion between both magmas. (ii) A second, but no less important possibility is the generation of both, syenitic and lamprophyric magmas at different portions of a veined-mantle (Foley, 1992) with a posterior mingling between them.

The uprising of partially crystallized intermediate syenitic magma in the crust, intruded by a second pulse of mafic magma, explains the occurrence of alkali feldspar xenocrysts in some MME. The presence of MME with dioritic composition supports the idea that other magmatic pulses were mingled with the intermediate syenitic magma at crustal pressures.

The crystallization of MME started with high-pressure minerals, potassian clinopyroxene, pyrope-rich garnet, and phlogopite. Such mineralogy demands a potassium-enriched magma, with high activity of volatile components, particularly water, as expected for a lamprophyric liquid. On the other hand, the principal pre-mingling mineralogy of MME is the same found in the groundmass, mostly crystallized during co-mingling. This fact indicates that co-mingling with syenitic magma did not promote significant chemical changes in the lamprophyric magma. This is confirmed by the different mineralogy of MME and syenitic rocks, the latter contain higher modal proportions of amphibo-le, plagioclase and titanite, and much lower amounts of mica and pyroxene when compared with the MME. In similar co-mingling systems, Vernon (1983) and Dorais & Floss (1992) described MME in syenitic rocks, with amphibole and biotite as the dominant mafic phases, and discrete cores of pyro-xene in amphibole phenocrysts.

The identification of the original composition of mafic magmas in mingling systems is a complex problem (Orsini *et al*, 1991; Nardi & Lima, 2000). As described above, in the Piquiri Syenite lamprophyric MME, the contamination was probably reduced because both magmas were practically crystal-free during, at least, one event of mingling, and cooling was fast, as indicated by quench textures.

The transformation of early amphibole to pyroxene is suggested by the occurrence of lamellae of Mg-hornblende within diopside phenocrysts. Probably, the continuous growth of diopside phenocrysts during and after mingling blocked its total re-equilibration for elements such as K, Al, F, Cl, and H_2O, which were ex solved along the diopside structure, mainly cleavages.

The MME without or with low amounts of phenocrysts contains the more elongate minerals, and the acicular apatite with larger axial ratio. These MME represent portions of hotter mafic lamprophyric magma, where the thermal contrast with the syenitic magma was more pronounced.

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