MICROGRANULAR ENCLAVES IN NEOPROTEROZOIC GRANITOIDS OF SOUTH KHASI HILLS, MEGHALAYA PLATEAU, NORTHEAST INDIA: FIELD EVIDENCE OF INTERACTING COEVAL MAFIC AND FELSIC MAGMAS

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The microgranular enclaves (ME) in south Khasi granitoids (SKG) are mesocratic to melanocratic, fine- to medium-grained and porphyritic, and occur abundantly between Mawthaphdah and Jashiar villages. The ME are 3 to 30 cm across, and their shapes vary from subrounded, ovoid, to ellipsoidal and show sharp and crenulate contacts with the SKG without deformational and/or reaction signatures. The megascopic features of ME and their relationships with SKG reveal that mafic and felsic (SKG) magmas having some initial crystallinities co-existed, mixed and generated a hybrid (ME) magma. Minerals such as K-feldspar megacrysts, mafic and felsic xenocrysts were transferred and disequilibrated, and became corroded in the new hybrid magma. The hybrid magma further evolved as ME globules mingled and undercooled into relatively cooler SKG magma.

Introduction

Medlicott (1869) had described granitoid masses within Shillong Group. Mazumder (1986) discussed the Precambrian geology of the Khasi hills, and observed numerous enclaves sometimes occurring parallel to the foliation in the granitoids defined by the elongation of K-feldspar megacrysts. Ghosh et al. (1991) carried out geochronological and geochemical studies of granitoids including the Neoproterozoic south Khasi granitoids (690±19 Ma, with an initial $^{87}Sr/^{86}Sr=0.71074\pm0.00029$), and have mentioned the presence of enclaves of amphibolite, granite gneiss and diorite. The French term enclaves include xenoliths, surmicaceous enclaves (mica-rich restite from metasedimentary source region), cognate or autolith (cogenetic affiliation with host rocks), and microgranular (fine grained, mafic magmatic) enclaves (Didier, 1984). In this communication, we report the field relations and types of microgranular enclaves (ME) hosted in south Khasi granitoids and discuss their implication for mafic and felsic magma mixing and mingling processes.

Geological Framework

The Neoproterozoic felsic magmatism in the southern Khasi hills (West Khasi Hill district), referred to as south Khasi granitoids (SKG), intrudes a gneissic complex and the rocks of the Shillong Group of Meghalaya plateau (Fig.1c). The SKG cover an area of about 600 sq km, and are overlain by Cretaceous-Tertiary sediments. The SKG and other granitoids of Mylliem, Kyrdem, and Nongpoh regions of Meghalaya plateau (Fig.1b) are considered to be late- to post-tectonic, fracture controlled diapirs (Mazumder, 1986) that most likely evolved as a result of a protracted Pan-African thermal event during Neoproterozoic-Early Palaeozoic that was related to mantle upwelling (Ghosh et al. 1991). The granitoids in the southern part of the SKG pluton have a foliation, defined by the elongation of K-feldspar megacrysts (phenocrysts), and are oriented parallel to the contact of the granitoids with the gneissic country-rocks. The foliation has formed during flow of the SKG magma during emplacement. The granitoids in the central part are dominated by very coarse-grained and porphyritic granitoids, in which tabular, rounded to subrounded and elongated K-feldspar megacrysts are randomly distributed, but locally show a crude alignment. Some megacrysts of K-feldspar reach a size of 7 cm. However, fine to medium grained equigranular granitoids do occur amidst the porphyritic granitoids. Quartz-aplite and micropegmatite veins cut across the granitoids at several places.

Field Relations of Enclaves and their Types

The enclaves hosted in SKG can be broadly classified into two types: country rock xenoliths and microgranular enclaves (ME). The former are confined to the margin of the SKG pluton whereas ME ubiquitously occur in equigranular and porphyritic varieties of SKG but are more frequent in porphyritic SKG. Mafic aggregates and quartz pods are locally present in SKG. The ME hosted in SKG are mesocratic to melanocratic, fine- to medium-grained and phenocryst-bearing or phenocryst-free. Based on

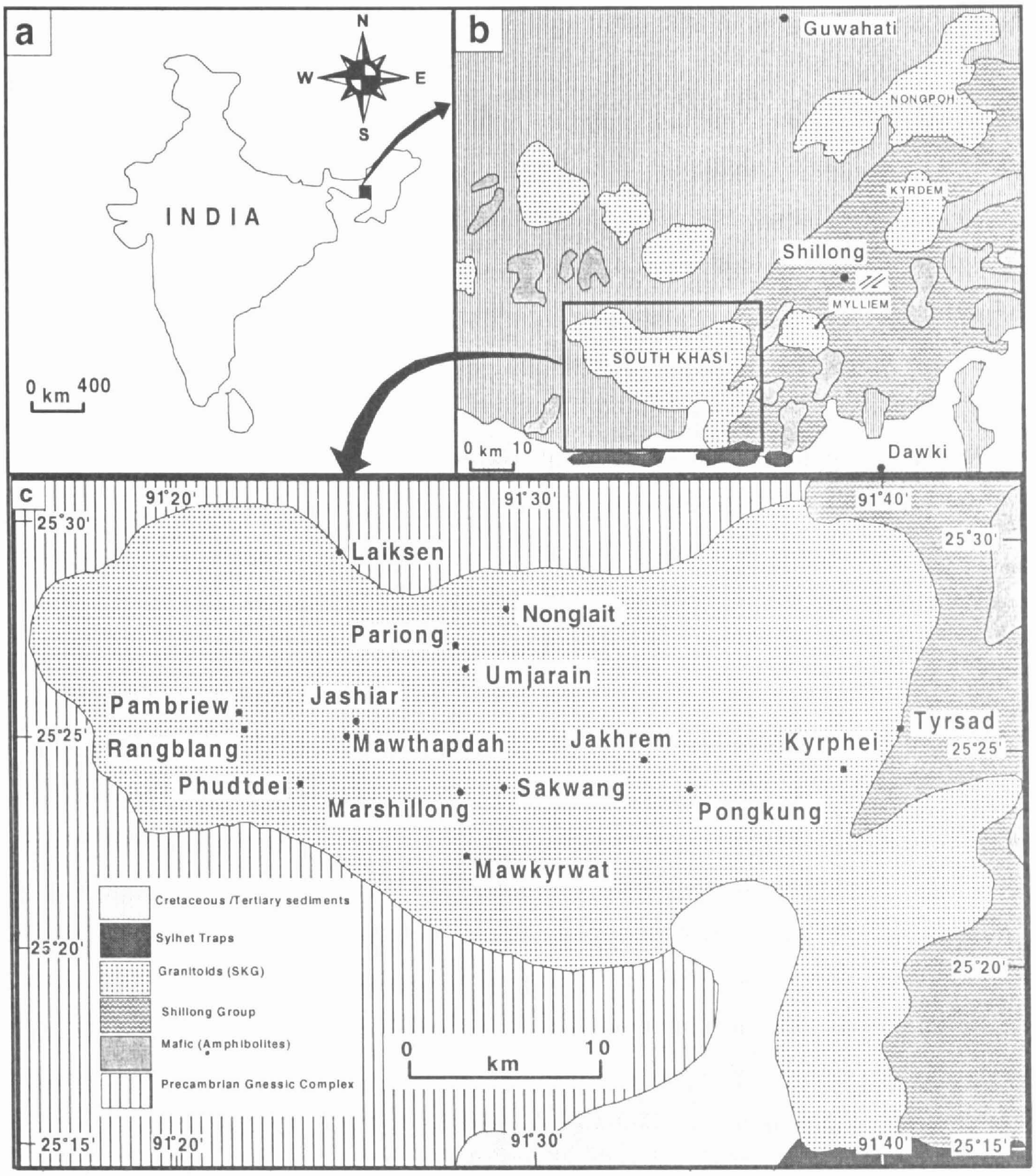

Fig.1. (**a**) Location of study area in northeast India. (**b**) Part of geological map of northeast India showing various granitoid plutons. (**c**) Geological map of south Khasi region of west Khasi Hill district showing Neoproterozoic granitoids (SKG) and its relationship with adjacent lithotypes (simplified and digitized after Mazumder, 1976).

mode of occurrence and megascopic features, the ME hosted in SKG can be classified into three main types: (1) Fine-grained, melanocratic ME without phenocrysts; (2) fine-grained, melanocratic, porphyritic ME, enclosing K-feldspar megacrysts (~3 cm) and/or mafic (biotite and hornblende) phenocrysts (~5 mm) and, (3) medium-grained, mesocratic, porphyritic ME, with felsic (quartz, K-feldspar and plagioclase) and mafic (biotite and hornblende) phenocrysts (~5 mm). All varieties of ME described here can be noted in single outcrop of SKG pluton.

Shape and Size of Enclaves

The xenoliths are light or dark coloured and range in size from about 5 to 12 cm. They show a range of shapes from angular to subangular, and have metamorphic (gneissic) microstructures (Fig. 2a). Most of the xenoliths match the country-rocks lithounits, whereas the ME do not. In the central parts of the SKG pluton, the ME are widespread varying in shapes from subrounded, ovoid, discoidal to ellipsoidal (Figs. 2b,d and f). The ME contain felsic and mafic mineral assemblages similar to those noted in their

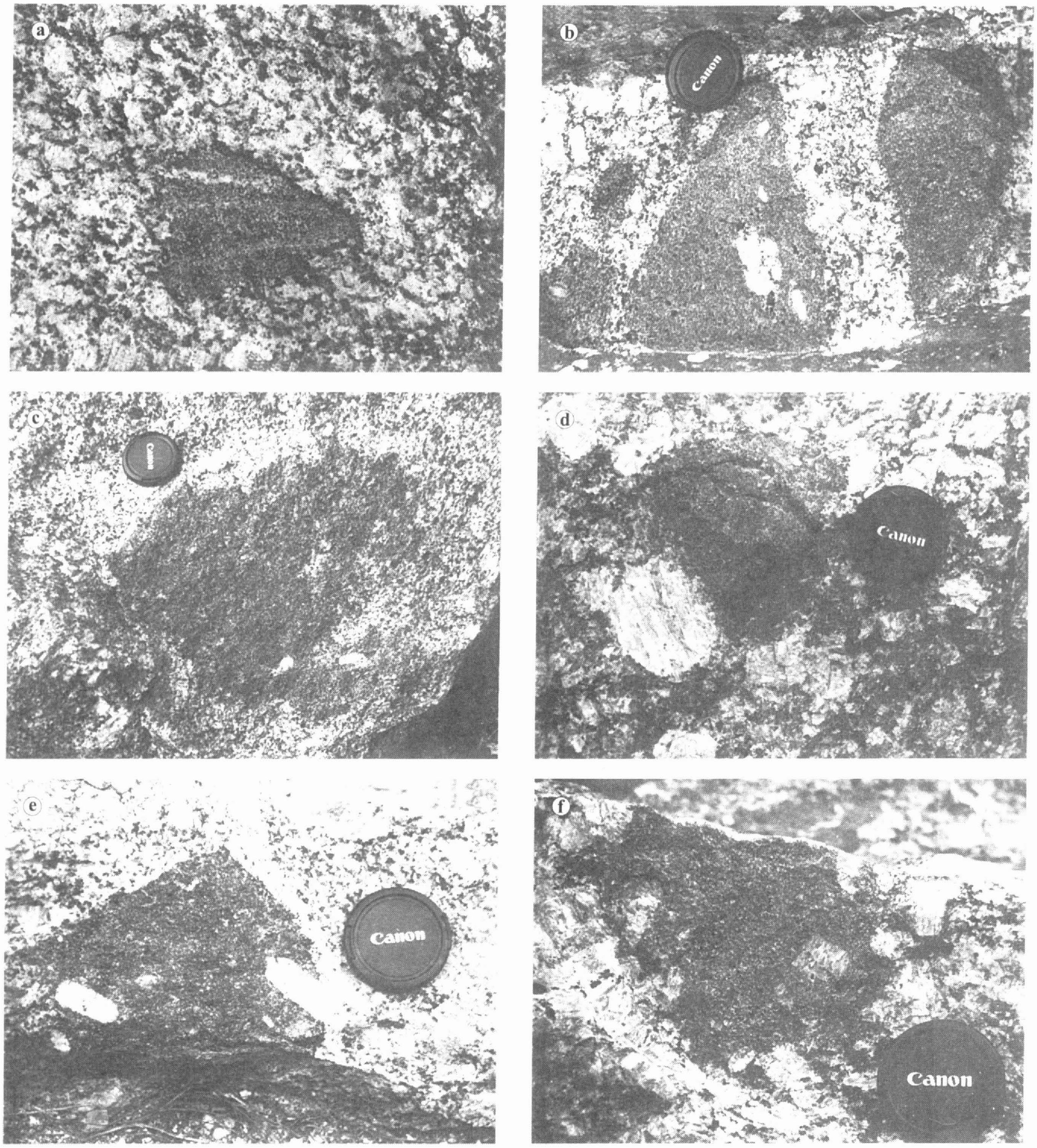

Fig.2. (**a**) Subangular xenolith (6 cm across) of country rock showing metamorphic (gneissic) texture with reaction rim of fine-grained mafic minerals. (**b**) Angular, subrounded and ellipsoidal ME of variable sizes with and without felsic phenocrysts. The felsic phenocrysts (xenocrysts) in ME resemble with those of the granitoids. Note that a small near circular ME (lower left) contains armoured quartz xenocrysts giving rise to occellar texture. (**c**) Phenocryst-free ellipsoidal ME showing crenulate contact with host granitoids. Note the prominent felsic rim around the ME. (**d**) Fine-grained, subrounded ME devoid of K-feldspar megacrysts but found associated with rounded megacryst of K-feldspar. The K-feldspar megacrysts show poikilitic habit enclosing mafic minerals. (**e**) Fine-grained ME, which partly and fully encloses subhedral to elongated K-feldspar megacrysts. The ME-host granitoid contact is sharp. (**f**) Fine-grained ME, partly and fully enclosing K-feldspar megacrysts confined mostly near the contact. The ME-host granitoid contact is crenulated. Scale: Diameter of lens' cap is 4 cm.

host SKG, but their modal proportions and grain size differ significantly. The fine-grained melanocratic ME contain K-feldspar megacrysts (~3 cm), which are partly or wholly enclosed within the ME (Figs. 2b, d, e, and f). The shape of the K-feldspar megacrysts is often elongate (2D) and tabular in 3D (Figs. 2e, b). Rounded to sub-rounded K-feldspar megacrysts also occur (Fig. 2f). K-feldspar megacrysts in the ME closely resemble with those in the host SKG. Most of the crystal boundaries of mafic and felsic phenocrysts including K-feldspar megacrysts within the ME appear more as xenocrysts. The rounded felsic (quartz) xenocrysts in ME are in a few cases armoured by fine mafic grains giving rise to ocellar texture. The ME swarms of various dimensions are abundant (Fig. 2b) in the central part of the pluton, between Mawthaphdah and Jashiar villages, which may therefore represents the region of ME (hybrid) magma intrusion into, and their mingling with the SKG magma. The size of ME in the central part of the SKG is relatively larger than those occurring towards the marginal parts of the SKG. The most common size of ME is between 3 and 30 cm, but some attain sizes up to 1.5 m across, although the ME larger than 30 cm are not common.

Enclave and Granitoid Contact

The contacts between the ME and host SKG are generally sharp (Fig. 2b) but in some cases crenulated or serrated (Figs. 2c, f), which are sometimes rimmed by felsic minerals towards the granitoids (Fig. 2c). The ME commonly have sharp contacts, but diffuse contact with their host granitoids occurs in places. Some tabular, elongate K-feldspar megacrysts are embedded within fine-grained discoidal ME in a pattern that is concentric to the ME-SKG contact.

Discussion and Conclusions

Coeval mafic and felsic magma association with its implication for magma mixing and mingling is widely discussed for many calc-alkaline suites (e.g. Vernon, 1984; Frost and Mahood, 1987; Didier and Barbarin, 1991; Kumar, 1995; Wiebe et al. 2002). The ME are up to 1.5 m across in the Neoproterozoic SKG and display characteristics indicative of mafic and felsic magma interaction. The shapes of the ME, on two-dimensional surfaces, are discoidal, ovoid and ellipsoidal and are morphologically different from angular and gneissic xenoliths of the country-rocks. The xenoliths show marginal reaction signatures and preserve the original sedimentary structures and metamorphic foliation of the country-rocks. Therefore, xenoliths do not represent residua from the source region. Moreover, xenoliths are commonly identifiable as country rocks typical of high-level plutons. The SKG are devoid of surmicaceous enclaves, which commonly represent the residua from the source region (Montel et al. 1991).

The ME hosted in SKG show magmatic features of two-liquid (mafic and felsic) interactions. Mazumder (1986) had suggested on the basis of textural analogousness that the ME could have originally been basic igneous rocks, re-equilibrated within the granitoid melts. The sharp and crenulated ME-SKG contacts and also irregular shapes (rounded to ellipsoidal) of ME can be interpreted as a result of undercooling of hotter mafic ME magma within cooler felsic SKG melts before the entire system was frozen (Vernon, 1984). Thus, all ME globules were emplaced before the SKG solidified. The grain size is ten to twenty times smaller in ME than their host granitoids (Didier, 1984). If the ME represent *cumulates* or *autoliths* then the difference in grain size of mafics (hornblende and biotite) in ME and SKG should not be large, provided they do not represent the chilled marginal facies of pluton itself or as to when they crystallized with felsic minerals. The boundaries between interacting magmas are usually marked by differences in colour index and textures as similarly noted between the ME and SKG.

The presence of K-feldspar megacrysts in granitoids was believed to have resulted from metasomatism (feldspathization), but these are now more commonly described as phenocrysts (Vernon, 1986; Didier, 1987; and references therein). K-feldspar megacrysts remain phenocrysts as long as hosted in SKG, but once transferred into mafic (enclave) magma they become xenocrysts, and may be partly corroded (dissolved) and disequilibrated just below the liquidus temperature (Andersson and Eklund, 1994). The process of mafic and felsic magma mixing occurred at depth where a hybrid (ME) magma zone developed, remnants of this are now represented by xenocrysts bearing ME. Some of the K-feldspar megacrysts in the felsic magma were partially, or completely, engulfed into the ME (hybrid) globules during mingling, as the ME magma was experiencing undercooling. This interpretation differs from that offered by Mazumder (1986) that much of the ferromagnesian minerals in SKG were derived by progressive dissolution of mafic rocks by K-rich melt.

Dissolution of megacrysts and/or phenocrysts is more common in the larger sized ME, possibly because their cores remained in liquid longer whereas smaller ME undercooled more rapidly to a temperature close to the solidus of ME (hybrid) magma globule, which curtailed or prevented the dissolution. The leucocratic (felsic) rim around the cuspate margins of ME could be the result of partial refusion of the felsic host magma induced by ME (hybrid) magma (Pesquera and Pons, 1989) and/or due to latent heat liberated by crystallization of the ME globules. Differences in rheology between interacting felsic and mafic magmas can play an important role in effecting compositional and textural changes (Kouchi and Sunagawa, 1983). Thermal differences between mafic and felsic magmas may be of the order of 100-300°C, and therefore quenching and/or undercooling of hotter mafic magma should occur (Vernon, 1984; Kumar, 1995). If the rheological and thermal differences are small between mafic and felsic magmas a hybrid magma zone may be generated (Sparks and Marshall, 1986) from where ME, as the hotter magma globules, are ejected, mingled and undercooled into partly crystallized SKG magma.

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