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# PETROGRAPHIC EVIDENCE OF MAGMA MIXING IN KYRDEM GRANITOIDS, MEGHALAYA PLATEAU, NORTHEAST INDIA

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## ABSTRACT

*The evidence of magma mixing in Kyrdem Granitoids (KG) is gathered from the field relations and petrographic studies of the rocks collected from the field. Field and petrographic evidences strongly suggest that the microgranular enclaves (ME) represent mafic to hybrid coeval magma globules, which are mingled and undercooled into a partly crystalline, relatively cooler felsic host KG. Some of the ME contains K-feldspar megacrysts and smaller felsic-mafic xenocrysts, which appear more-or-less identical to that observed in felsic host KG except their crystal boundaries. Particularly the K-feldspar megacrysts in ME seem aligned in the direction of ME elongation and correlate well to those of felsic host KG, which must have attained in the semi-solidified conditions of ME and felsic melt. It is therefore suggested that both ME magma globules and partly crystalline felsic melt co-mingled in plutonic setting. The xenocrysts bearing ME in KG should represent hybrid product of felsic-mafic magmas. Ocellar quartz grains rimmed by fine mafic minerals and presence of mafic (biotite) and felsic (K-feldspar and plagioclase) xenocrysts in ME are indication of mechanical mixing forming the hybrid ME magma zone at deeper level. Abundant acicular apatites are ubiquitous in some ME, which can be formed when undercooling (quenching) of ME (hybrid) magma occurred against relatively* *cooler felsic host KG. Elongated ME and alignment of its constituting minerals in the direction of felsic KG magma flowage strongly suggest stretching of ME globules due to its partial molten state in felsic magma. It is more probable that enclave magma derived by melting of mantle or lower crustal rocks intruded into crustal derived felsic (KG) melt, and mixed to form the ME (hybrid) melt which later dispersed into relatively cooler felsic KG. Kyrdem Granitoids and their enclaves have been evaluated in terms of magnetic susceptibility (MS in $10^{-3}$ SI unit) in order to understand the redox condition of comingled mafic and felsic melts. KG (MS=15.56-31.55$\times10^{-3}$SI) and microgranular enclaves (ME) (MS=24.47-32.09$\times10^{-3}$ SI) are moderately to strongly oxidized, magnetite series granites formed in a late- to post-tectonic calk-alkaline, mafic-felsic magma interacting environment.*

**Key words**: Kyrdem granitoids, Magma mixing, magnetic susceptibility, Ocellar quartz.

## Introduction

Magma mixing/mingling implies physical and chemical interaction between melts, leading to obvious disequilibrium conditions. Disequilibrium influences the nucleation and growth rate of crystals. Kyrdem granitoids exhibit excellent evidence for magma mixing and mingling both at outcrop/map scale (magma mingling and mixing zones), and at thin-section/crystal scale (mixing textures). These textures – quartz ocelli, acicular and mixed apatite, K-feldspar megacrysts in microgranular enclaves (ME), and mafic clots – constitute a textural assemblage whose origin can be explained in terms of magma mixing and mingling models. The occurrences of mafic enclaves within granitoid plutons suggest their undoubted magmatic origin. But in some cases, the presence of amphibolite and metasedimentary xenoliths within the granitoid plutons is truly significant. This paper, for the first time, highlights the field occurrence, magnetic susceptibility (MS), petrography, magma-mixing processes of Kyrdem granitoids at and around Kyrdem Village (92°E and 92° 10'E and latitudes 25° 38'N and 25° 50'N), East Khasi Hills, Meghalaya in order to build up a petrogenetic model and to place constraints on tectonic evolution of Kyrdem granitoids and microgranular enclaves.

**Geological setting of the Kyrdem Granitoids**

Meghalaya plateau, erstwhile known as Shillong plateau, is a Precambrian geotectonic shield of northeast India. Medlicott (1869) reported the occurrence of several felsic plutons, named after prime villages, which are located along the Tyrsad-Barapani lineament of the Meghalaya plateau (Fig. 1a, b). Mazumder (1976, 1986) described the geology of Meghalaya plateau and considered these felsic plutons (Mylliem, Nongpoh, Kyrdem and South Khasi) as late- to post-tectonic, fracture-controlled diapirs resulting from episodic thermal events caused by mantle upwelling.

Meghalaya plateau has experienced major magmatic episodes at ca 1800 Ma, ~1600 Ma, ~1400 Ma and ~500 Ma with recycled Neoarchaean (ca. 2560 Ma) crustal component forming the granite gneisses, and later partial contribution of granite gneissic sources producing post-collisional Cambro-Ordovician granite plutons with a small input of mafic to hybrid (enclave) magmas particularly in the evolution of South Khasi, Mylliem, and Kyrdem plutons. Meghalaya plateau thus records Columbia and Gondwana supercontinent affinities during its crustal growth history, similar to as noted elsewhere globally forming integral part of Pan-African-Indian-Prydz-Brasilian. These felsic plutons appear younging in age from southwest to northeast and contain abundant microgranular enclaves (Kumar, 1998). Cambro-Ordovician (512.5±8.7 Ma) felsic magmatism in the Kyrdem region of Meghalaya plateau, herewith referred to as Kyrdem granitoids (KG), intrudes the Shillong Group and Precambrian gneissic complex forming an oval-shaped plutonic body with longer axis almost trending N-S (Fig. 1b). Thermal aureole is poorly developed or covered under the alluvium. KG exhibit very coarse grained porphyritic texture with abundant K-feldspar megacrysts (up to 9cm long) and subordinate amount of amphibole, biotite, plagioclase and quartz. The size of K-feldspar megacrysts increases from margin (Dwarksuid) to the interior (Kyrdem) of the KG pluton. Late felsic pulses as fine grained granite, leucocratic (aplite) and pegmatite veins intrude the KG at several places. Grey and pink varieties of KG can be recognized, but pink colour of KG is the result of post-magmatic fluids, which have not affected the magnetic properties of KG. Modal composition of KG corresponds to quartz monzonite, monzogranite and granodiorite. KG has been geochemically characterized as metaluminous (I-type) to peraluminous (S-type) granitoids (Ghosh *et al.*, 1991). Sikdar and

Rahman (1998) have studied the structural state of K-feldspar megacrysts from KG, and have concluded that the core of KG pluton has cooled slowly as compared to the margin.

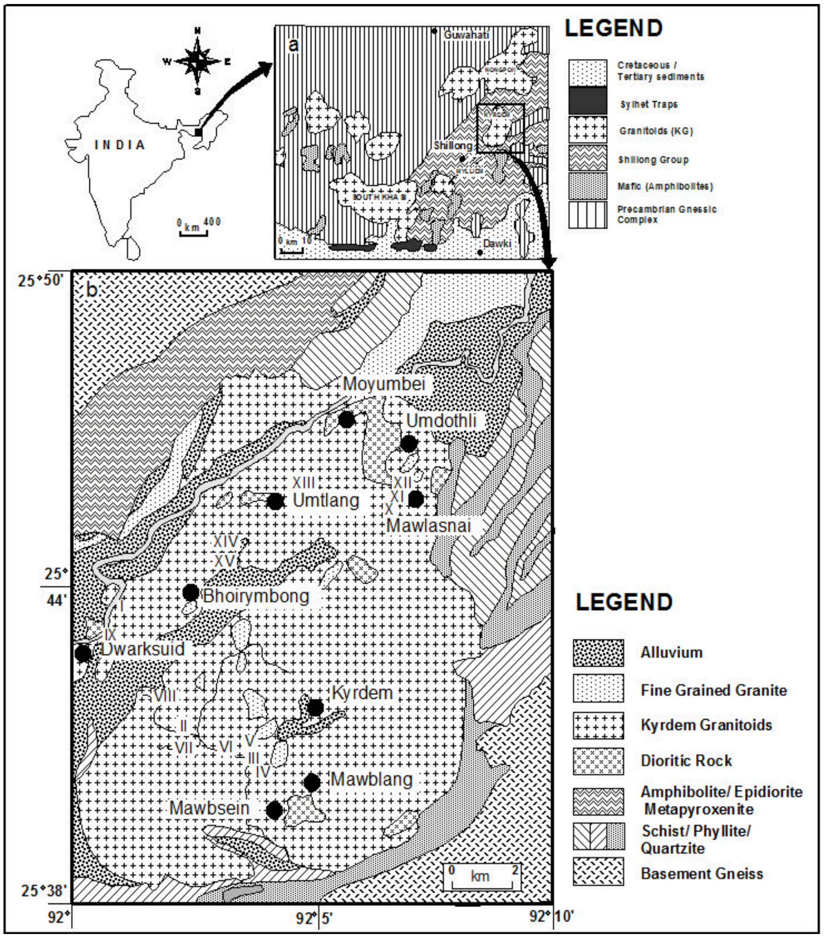


Fig.1: (a) Part of geological map of Khasi hills of Meghalaya plateau showing locations of various felsic plutons including the Kyrdem granitoids (KG), drawn after Mazumder(1976).
(b) Geological map of Kyrdem and surrounding regions of East Khasi Hills district showing exposures of Early Ordovician felsic magmatism as KG, drawn after Chakraborty (1989).

## MATERIAL AND METHOD

The study area was divided into several sectors, and planned traverses across the KG pluton were taken to establish the field relationships of enclaves particularly the microgranular enclaves (ME) and host KG. Fresh outcrops were carefully chosen for the study of ME and felsic host KG. Field data (location, inter-relationships of various lithotypes, magnetic susceptibility, shape and size of enclaves and its contact relations with host KG etc.) were collected with the help of traditional geological tools and adequate number of fresh rock samples was collected for petrography and modal analysis. Thin section of rock samples were studied using Leitz Laborlux 12 polarizing microscope. The microscope is provided with 20V and 6V of 20W tungsten halogen lamp for incident and transmitted light investigations. The microscope is fitted with the Vario Orthomat fully automatic camera system attached with Vario tube microscope binocular phototube. Modal mineral analysis of representative ME and KG samples was carried out using James Swift automatic point counter (Model F 415 C). Minimum of 2500 points was counted for each sample and the volume percentages of the minerals were recalculated.

Xenoliths of amphibolite (greenstone), gneiss and quartzites are found hosted in KG but their occurrences are restricted to the margin of the pluton. Amphibolite xenoliths are at places net-veined by felsic melt and rarely marginal reactions can be observed, which strongly suggest intrusion of KG melt into pre-existing country rocks. Temperature of KG melt was not high enough to melt the mafic xenoliths but reacted marginally, net-veined and fragmented them into angular, platy and rectangular shapes. These xenoliths in KG are morphologically different from microgranular enclaves. Gneissic xenoliths retain original sedimentary fabric but are slightly folded and banded because of its ductile nature probably developed due to thermal rejuvenation by KG melt. Quartzite xenoliths hosted in KG are mostly represented by rocks of Shillong Group, and therefore should have been incorporated into KG melt at emplacement level. Xenoliths in KG occur near the margin and shallow part of the intrusion, which have not been suffered intense thermal metamorphism and therefore could not lead to partial melting process.
Oxidizing nature of bulk KG melt was locally reduced to ilmenite series ($0.26\times10^{-3}$SI) granite near the margin of the KG pluton as a result of reaction with pelitic country rocks at shallow emplacement level.

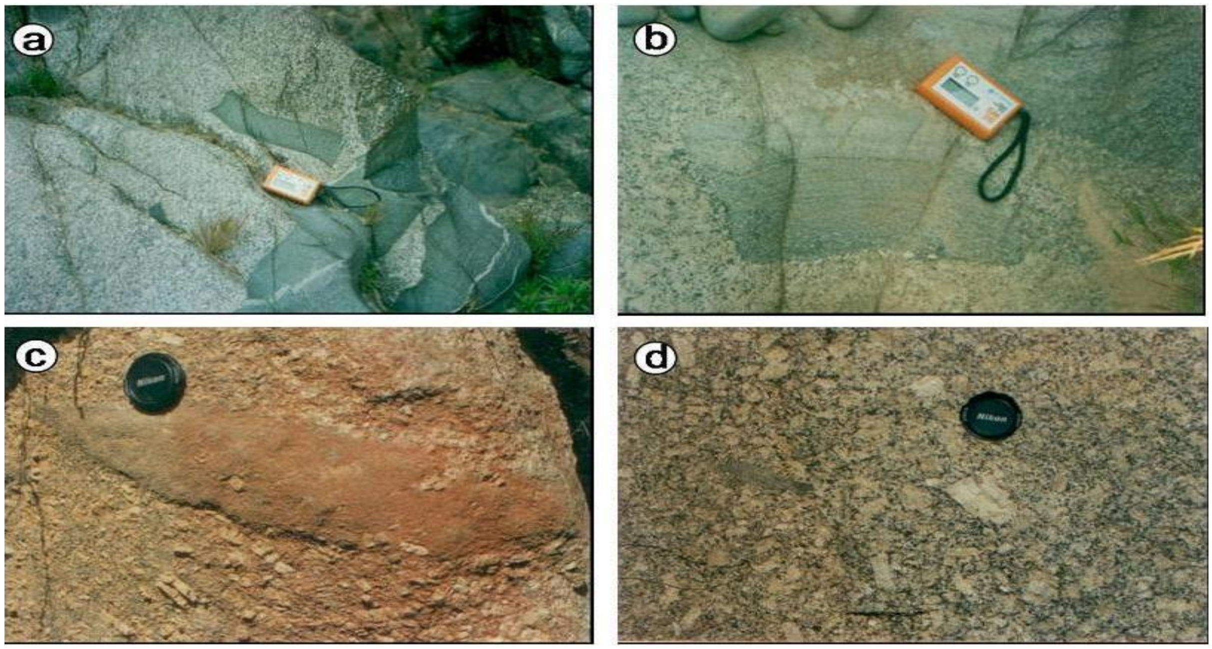


**Fig. 2:** (a) Amphibolite xenoliths of various shapes and size in porphyritic (K-feldspar megacrysts) Kyrdem granitoids (KG). Note the felsic net-veining of xenolith. Length of MS meter equals 9.7 cm. (b) Gneissic xenolith in KG. Scale is the same as in (a). (c) Elongated K-feldspar megacrysts bearing microgranular enclave (ME) in KG.

Alignment of K-feldspar megacrysts in ME correlate with that of host KG. Length of lens' cap equals 5.5 cm. (d) Randomly oriented K-feldspar megacrysts of various shapes and sizes. Note a small, platy, pelitic xenolith in KG. Scale is the same as in (c).

Enclaves hosted in KG can be classified as xenoliths of country rocks (amphibolite and metasedimentary rocks) mostly confined to margin of the KG pluton (Fig 2a, b) and fine to medium grained, mesocratic to melanocratic, mafic-felsic phenocryst-bearing (Fig. 2c) or phenocryst-free microgranular enclaves commonly ubiquitous in porphyritic KG (Fig. 2d), exposed in and around Sohliya, Mawbsein and Mawblang regions. The shape of ME is rounded to elliptical on 2D outcrop, and size varies from a few cm to about one meter across commonly having sharp contacts with felsic host KG.

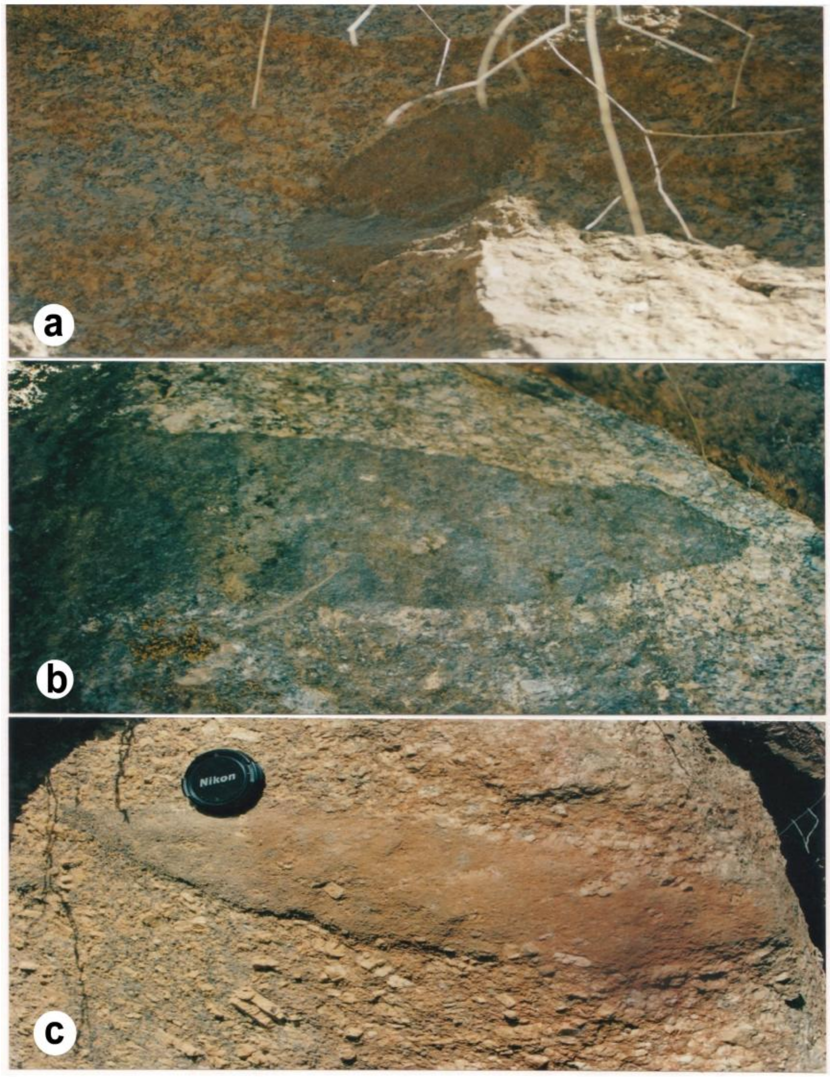


**Fig. 3a:**Fine-grained, melanocratic, ellipsoidal ME showing sharp contact with felsic host KG. The length of ME equals12cms.**b:** Dark-colored elongated, mafic-felsic xenocrysts bearing ME showing sharp contacts with KG. Base of the photograph equals 30cms. **c:** Elongated K-feldspar megacrysts bearing ME hosted in KG. Note the alignment of K-feldspar megacrysts in ME and its megacrysts elongation correlate with that of host KG. Length of lens' cap equals 5.5 cms.

The KG show porphyritic texture when megacrysts of K-feldspars (orthoclase and microcline) are present. The KG are medium- to coarse-grained, inequigranular and hypidiomorphic. Perthitic texture is common in K-feldspar. The major constituting minerals are hornblende (~2mm), biotite (~4mm), plagioclase (~6mm), K-feldspar (~10mm, groundmass) and quartz (~8mm). Epidote, sphene, apatite and magnetite are the main accessories present in KG. Sphene occurs as anhedral to euhedral crystals showing two-sets of cleavages. The ME are composed of K-feldspar as megacrysts and microphenocrysts, subhedral to anhedral plagioclase phenocrysts and anhedral quartz grains. Anhedral microphenocrysts of mafic (biotite and hornblende) are also present in ME. The ME therefore exhibits fine- to medium-grained, hypidiomorphic and porphyritic textures. Some of the ME show cummulate-like texture commonly developed near the margin, and are composed of closely spaced cumulus phases such as hornblende, biotite and plagioclases without much intercumulus phases(Fig. 4c). Even at microscopic level the ME-KG contact is generally sharp, wavy (irregular, pillow-like) and devoid of reaction rim but elongated, prismatic biotite flakes and hornblendes are oriented almost parallel to the contact boundaries (Fig.4 a, b, c). Myrmekitic intergrowth (sub-solidus) texture is occasionally observed at the grain boundary interface of K-feldspar (of host KG) and plagioclase (of ME) along the ME-KG contacts. In ME the felsic minerals are relatively larger in size than the mafic minerals. The average grain sizes of the minerals excluding the phenocrystic phases in ME vary from about 0.1 to 1mm. Accessories include apatite, sphene, epidote, and magnetite, which are commonly found associated with major rock-forming minerals, mostly with mafic (biotite and hornblende) minerals. Among the accessories sphene and acicular apatite are abundant phases and are widely distributed. Sphene occurs as anhedral to euhedral crystals showing two-sets of cleavages.

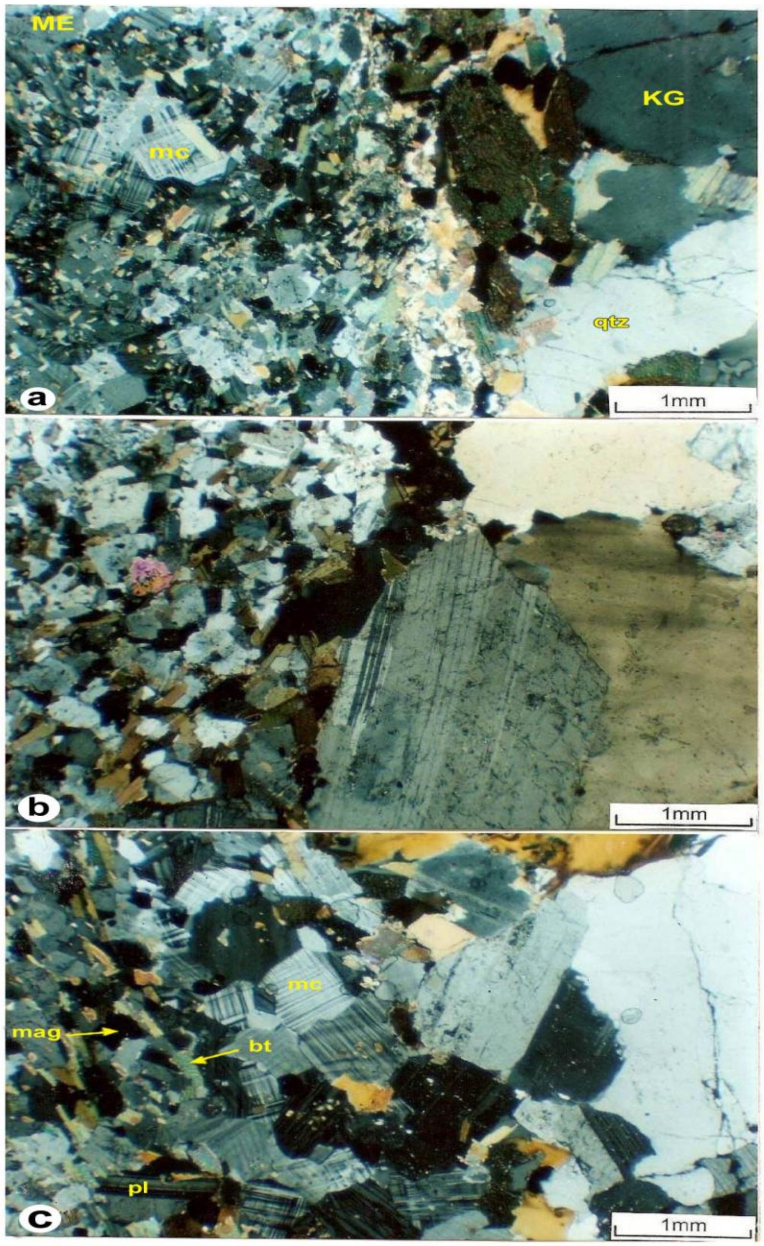


**Fig.4a:** Microphenocrysts of microcline (mc) embedded in fine-grained ME (left) having sharp contact with felsic host KG (right). Note the accumulation of sub-idiomorphic mafic crystals along the ME-KG contact. **b:** Sharp contact between ME and KG. Note the plagioclase crystal face in KG marks the ME-KG contact. **c:** Cumulate-like (pl-bt-mag-mc) texture with relatively

fine-grained interior (left), developed at ME-KG contact, which is further surrounded by felsic (quartz) minerals of KG.

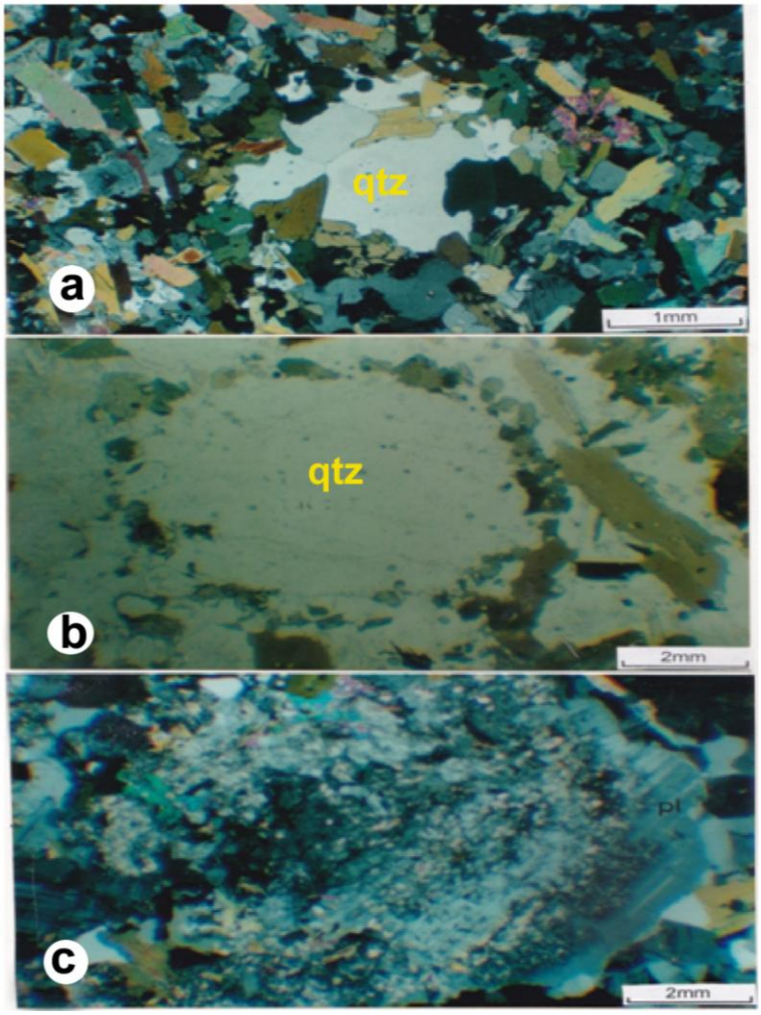


**Fig. 5a:** Quartz (qtz) xenocrysts surrounded by amphiboles and biotite in ME. 25x, Crossed Polars. b: Ocellar quartz (qtz) surrounded by fine grains of mafic(amphibole and biotite) minerals in ME. 10x, Plane Polarized. c: Sericitized, patchy zoned plagioclase (pl) xenocryst in ME. Note the corroded interior and outer growth in plagioclase. 10x, Crossed Polars.

K-feldspar megacrysts and felsic-mafic phenocrysts remain as phenocrysts (equilibrium) phases in felsic host but became xenocrysts (corroded, disequilibrated) because of their mechanical transfer into mafic (enclave) magma, and therefore corrosion or dissolution of these phases occurred just below the mafic melt liquidus (e.g. Anderson and Eklund, 1994; Kumar et al., 2004a, b). In the present and many other studies K-feldspar megacrysts in ME are found identical (in zoning pattern, twin plane, size and distribution of poikilitic inclusions except the small difference in their outer shapes) to that observed in granitoids, which suggest that K-feldspar megacrysts in granitoids are phenocrysts (not the porphyroblast) whereas in ME they are xenocrysts (Vernon, 1986; Didier, 1987; Elberg and Nicholls, 1995; Kumar et al., 2005a)

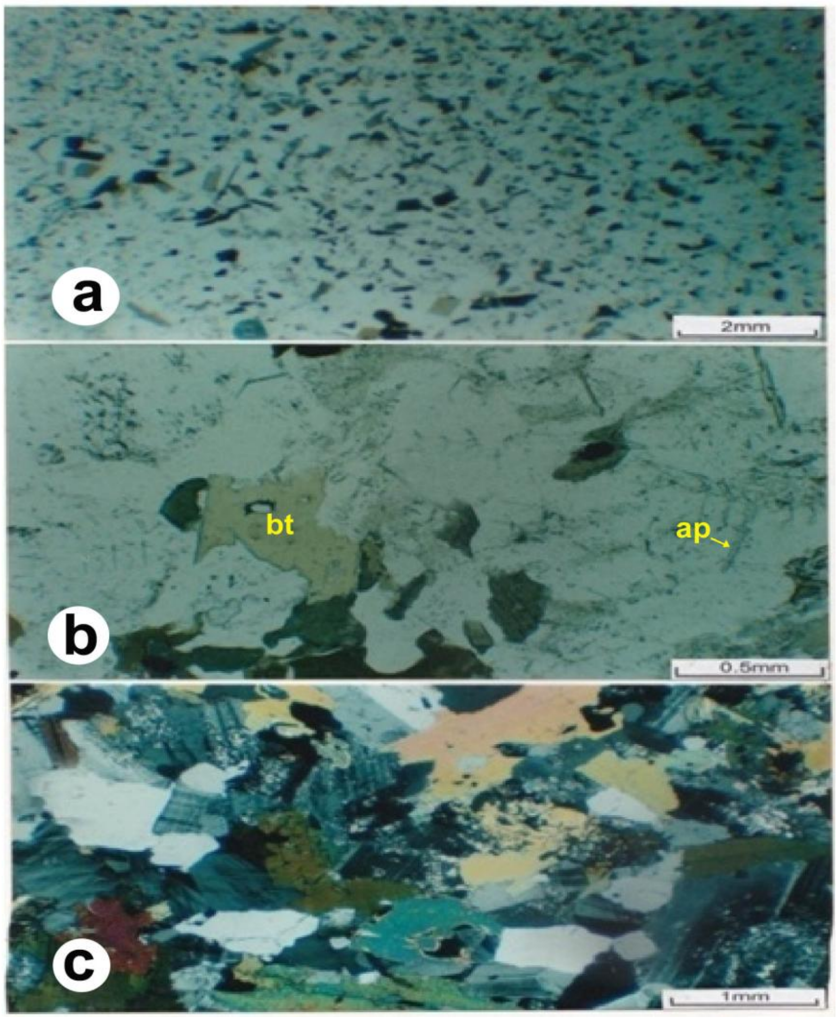


**Fig.6a:** Fine grained, hypidiomorphic texture of ME containing abundant elongated, platy and granular biotites. 10x, Plane Polarized. b: Abundant acicular apatite (ap) poikilitically hosted in quartz and K-feldspar of ME. Note also some elongated crystals of biotite (bt). 63x, Plane

Polarized. c: Medium-grained, equigranular hypidiomorphic textures of ME containing plagioclase, biotite, microcline, K-feldspar, and quartz. 25x, Crossed Polars.

The fine-grained margin and relatively coarser core of ME, sharp and crenulate (irregular, pillow-like without reaction rim) ME-KG contacts are indication of ME magma mingling and undercooling into partly crystalline felsic host KG in plutonic setting. Mafic (amphibole and biotite) and felsic (plagioclase, K-feldspar, quartz) microxenocrysts, apart from conspicuous megacrysts, can also be observed in some ME , which might have mechanically transferred from felsic to mafic magma, and hence disequilibrated in new (hybrid) magma environment (Barbarin and Didier, 1992; Barbarin, 2005). Some of the ME in KG contain patchy zoned (highly sericitized) plagioclase xenocrysts, which must have formed in hybrid environment (Fig.5c). At places quartz in ME occurs as silicic blebs surrounded by biotite grains, which might have incorporated incidentally into hybrid (ME) zone during mafic-felsic magma mixing event. Ocellar (rounded) quartz surrounded by fine mafic grains observed in some ME is strong indication of hybrid nature of ME (Fig. 5a, b). Presence of patchy zonation in plagioclase and mafic-felsic xenocrystic phases in ME has been interpreted as representative of partial melting textures (e.g. Tindle and Pearce, 1983; Chappell et al., 1987; Chen et al., 1989) but proponents of magma mixing hypothesis interpret these features as resorption and dissolution in a new hybrid magma environment where mechanically transferred phases are dissolved (corroded), and stabilized by nucleating fine-grained mafic phases over the partly dissolved xenocrysts (Kumar et al., 2004a).

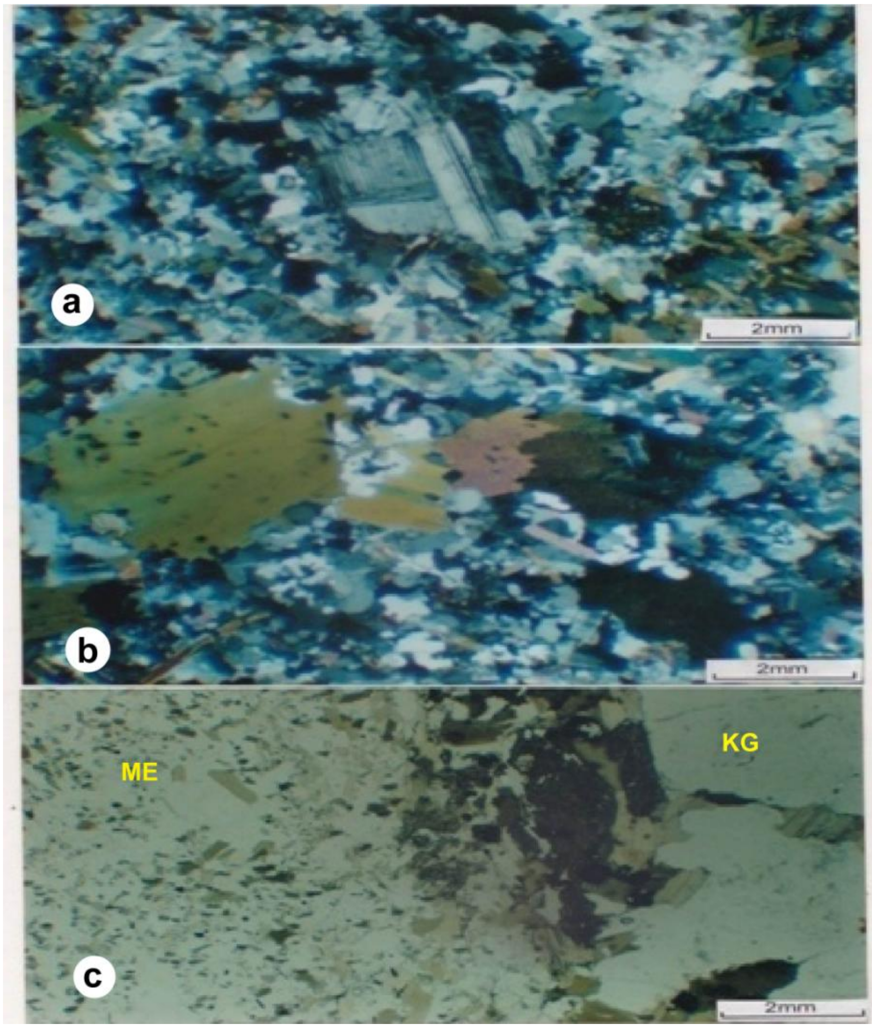


**Fig.7a:** Small, anhedral plagioclase xenocryst showing albite-pericline twinning embedded in fine-grained ME. 10x, Crossed Polars. b: Poikilitic, anhedral (xenocrysts) biotites embedded in fine-grained ME. 10x,Crossed Polars. c: Fine-grained, chilled margin of ME (left) against coarse felsic KG (right). Note the accumulation of coarse mafic phases at the ME-KG contact without any deformational or reaction signature. Some of the elongated, prismatic mafic crystals are aligned parallel to contact outline. 10x, Plane Polarized.

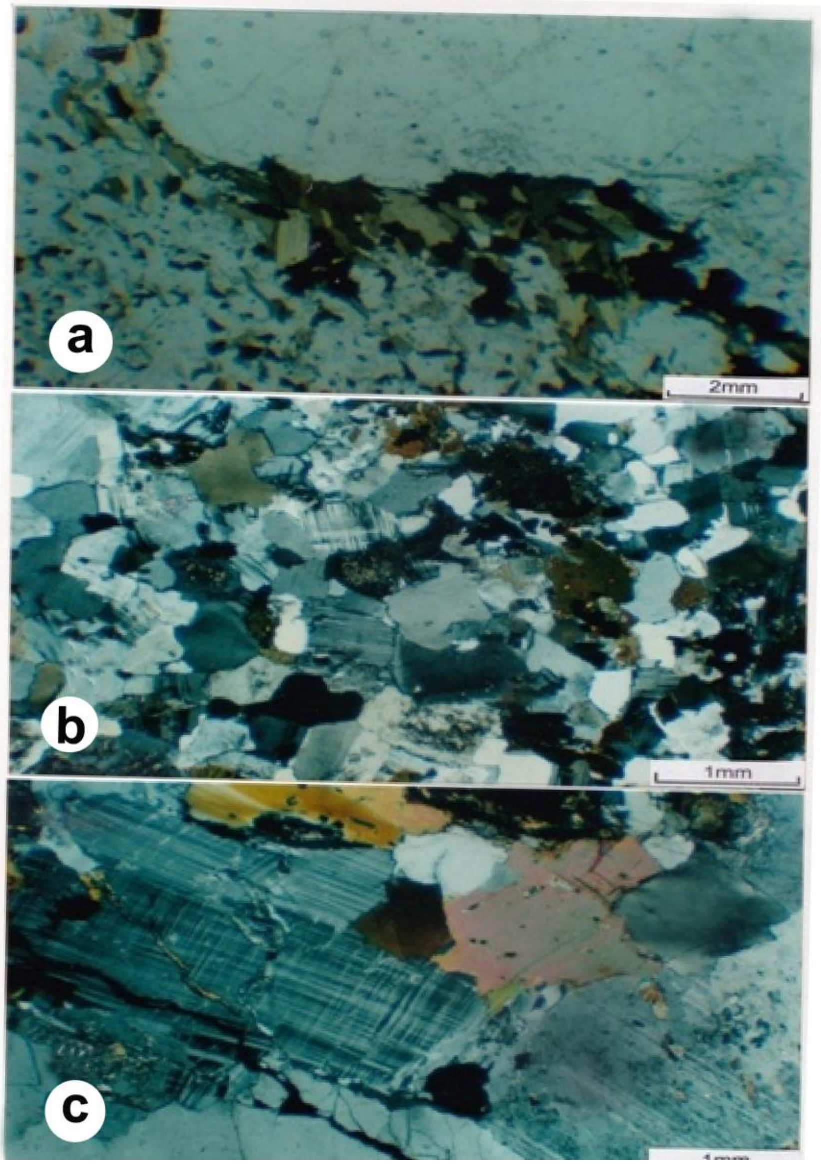


**Fig. 8 a:** Sharp to wavy ME-KG contact. Note the accumulation of abundant biotite crystals aligned parallel to contact outline. 10x, Plane Polarized. b: Medium-grained, equigranular, leucocratic KG showing hypidiomorphic texture. 25x, Crossed Polars. c: Coarse-grained KG showing hypidiomorphic texture containing plagioclase, K-feldspar (+ perthite) and biotite crystals. 25x, Crossed Polars.

Undercooling of ME globules is evident by sharp, crenulate (irregular), pillow-like (wavy) ME-KG contacts observed even at microscopic level. But abundant mafic (biotite) minerals grown at the interface of some ME-KG contacts (Fig.8a) must have precipitated due to rapid drop in ME temperature and selective diffusion of potassium and water needed for the growth of hydrous mafic phases, which were supplied from the adjacent felsic melt (Johnston and Wyllie, 1988; Wiebe, 1993, 1994; Kumar et al., 2004a). This process may also be responsible for $K_2O$ enrichment of some ME.

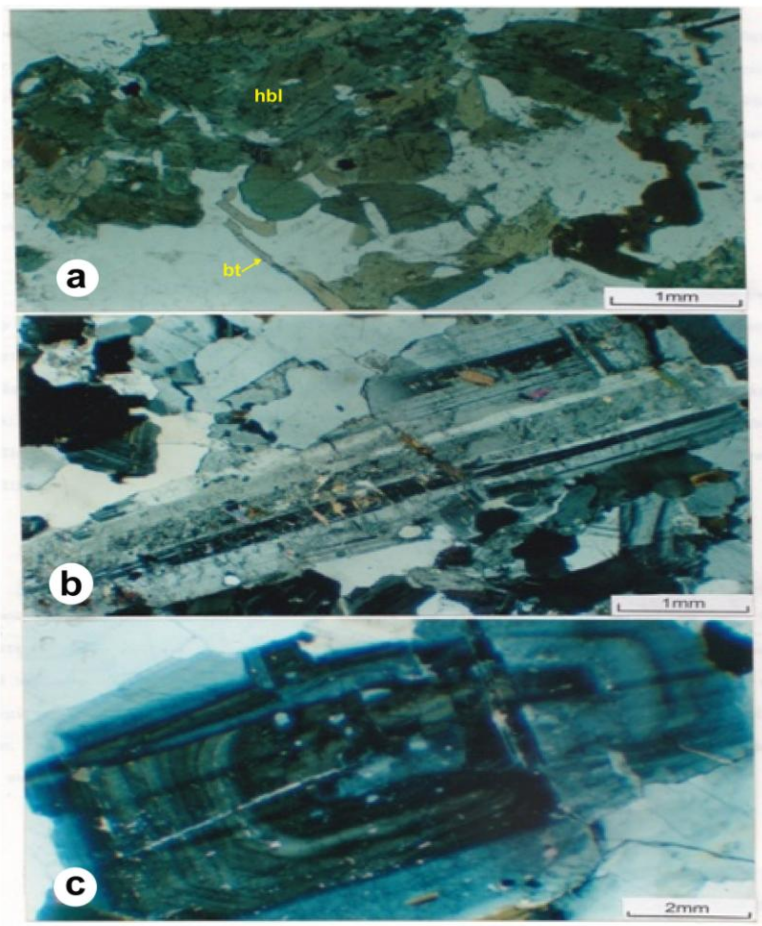

**Fig. 9 a:** Aggregates of subidiomorphic to idiomorphic hornblendes (hbl) and biotite (bt) in KG. Note that some amphiboles are partially replaced by biotite. 25x. Plane Polarized. b: Sub-idiomorphic plagioclase phenocryst in porphyritic KG. Note the albite and pericline twinning in plagioclase. 25x, Crossed Polars. c: Oscillatory to normal zoned, truncated plagioclase phenocryst in porphyritic KG. 10x,Crossed Polars.

At places observed cumulate-like (bt-pl-mc) texture in some ME adjacent to ME-KG contacts should have been formed either by gas-driven filter pressing process (Sisson and Bacon, 1999) or excavated from base of the mafic magma chamber (Wiebe et al., 1997; Kumar et al., 2004a) but cannot be considered cumulate products of felsic magma because grain size of ME is observed 10 to 15 times smaller than the same mineral phases in felsic host (Didier, 1984; Kumar et al., 2004a). The felsic (quartz) envelop observed around some ME should have been driven out from the evolved interior of ME enriched in residual liquid (Bacon, 1986; Sisson and Bacon, 1999). The cumulate of ME lack intercumulus phases. Some amphiboles in KG cluster closely forming mafic aggregates are partially being replaced by biotite suggesting that biotites formed at the expense of amphiboles as a result of biotitization (Fig 9a). The occurrence of ME is higher in and around Sohliya and Mawblang regions, it is therefore more probable that these regions represent the locus of ME magma intrusion, however distribution of ME throughout the KG pluton should be related to whole-body convective system and amount of ME (hybrid) magma below the felsic melt. Abundant acicular apatites are ubiquitous in some ME, which can be formed when undercooling (quenching) of ME (hybrid) magma occurred against relatively cooler felsic host KG(Fig 6b).

## RESULTS AND DISCUSSION

Field and petrographic evidences suggest that low fraction of mafic (enclave) magma having some initial crystals coeval with partly crystalline felsic (KG) magma have formed a narrow hybrid (ME) magma zone after thermal equilibration, and later another pulse of mafic magma injected and pooled below felsic and/or hybrid magmas. Convective forces disaggregated the hybrid zone and some parts of lower mafic (± cumulate) zones as hot, crystal-charged ME globules which dispersed, mingled and undercooled into relatively cooler host KG (Fig.11). Some of the elements continued to diffuse between ME and KG during mingling before complete solidification of interacting felsic-mafic system. Some of the elemental diffusion between ME and KG also occurred during mingling regime. The ME can represent remnants of the mafic-end member or hybrid magma globules. Homogenization or mixing dominates where large proportion of mafic magma interacts with relatively small proportion of felsic melts, whereas mingling occurs where small fraction of mafic magma interacts with large amount of felsic magma.

Modal volume percentages of 32 (sixteen pairs) of representative ME and KG samples were estimated. The obtained results are summarized in tables 1a and 1b respectively for ME and KG. . Recalculated Q(quartz)-A(alkali feldspar)-P(plagioclase) modal volume percentages of ME and KG were then plotted in International Union of Geological Sciences (IUGS) recommended triangular diagram (Streckeisen, 1973; Le Maitre, 2002) to name the individual rock type and further to identify the igneous series in the same Q-A-P space (Lameyre and Bowden, 1982).

**Microgranular enclaves (ME)**

The ME hosted in KG solely corresponds to the quartz monzodiorite composition belonging to calc-alkaline granodiorite (medium potassium) igneous series (Fig. 10). The ME mostly contain relatively higher modal abundance of mafic minerals (hornblende, biotite and magnetite) compared to those of KG. However some of the ME have higher modal quartz compared to their respective host KG, even though the ME appear melanocratic (dark coloured) due to fine-grained texture and mafic mineral dominance.

**Kyrdem granitoids (KG)**

As per IUGS recommendation (Le Maitre, 2002) the modal compositions of KG are mostly quartz monzonite and monzogranite but some are granodiorite and monzogranite showing affinity with calc-alkaline granodiorite to monzonite (medium to high potassium) igneous series (Fig. 10).

Based on modal mineralogy, colour index and the mineral assemblage (in order of abundance), IUGS nomenclatures of ME and KG are given in tables 1a and 1b respectively.

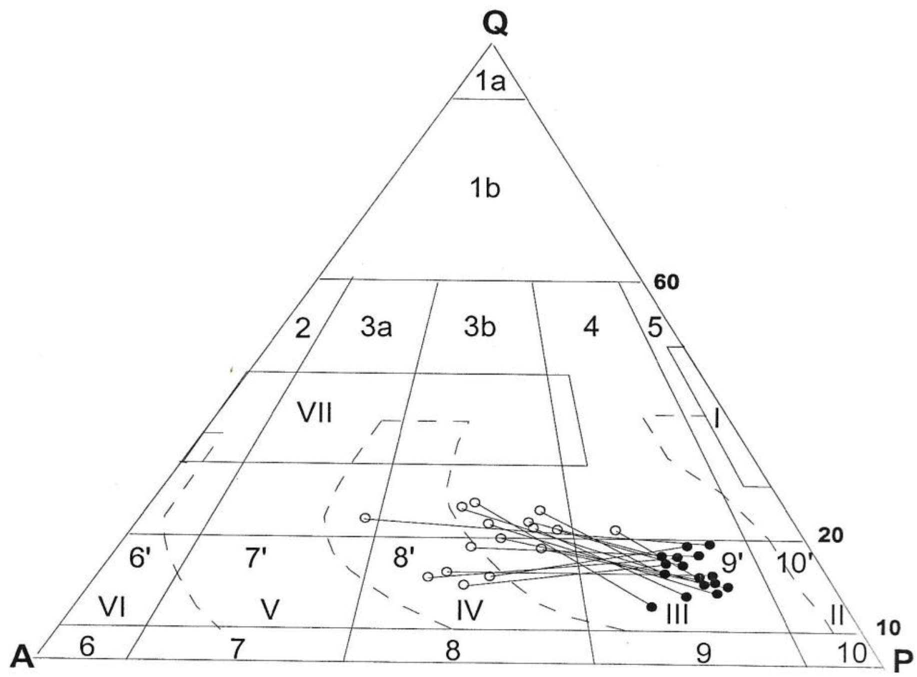


**Fig. 10 :** QAP modal volume percent of ME (•) and KG(°) showing classification of individual rocks and igneous series formed by rocks in association (Streckeisen,1973;Le Maitre, 2002).ME and respective KG are joined by the tie lines. Fields of igneous series of granitoids are shown after Laymere and Bowden (1982).Fields I- tholeiitic series, II-calc-alkaline trondhjemite (low-K) series, III-calc-alkaline granodiorite (medium-K) series, IV-calc-alkaline monzonite (high-K) series, and-aluminous granitoids of alkaline province, VI-alkalic and peralkalic series and VII-fields of granitoids generated by crustal fusion.

Table 1a: Modal mineral abundance (volume percentage) of representative microgranular enclaves (ME) hosted in Kyrdem granitoids (KG)

| Sample No. | B3E | B4E | B9E | B11E | K16E | K19E | K20E | K21E | K23E | K25E | K26E | K29E | K31E | K34E | K35E | K50E | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| Plagioclase | 44.5 | 54.1 | 41.6 | 36.8 | 41.9 | 48.4 | 49.9 | 46.7 | 50.3 | 47.5 | 47.5 | 57.7 | 43.9 | 42.2 | 40.4 | 54.2 | 46.66 |
| K-feldspar | 12.9 | 12.2 | 12.3 | 13.2 | 10.8 | 9.8 | 8.7 | 10.5 | 10.2 | 9.8 | 10.5 | 11.2 | 13.1 | 11.2 | 10.3 | 10.2 | 11.06 |
| Quartz | 11.6 | 10.1 | 10.4 | 5.0 | 11.0 | 9.5 | 8.9 | 13.2 | 9.5 | 12.3 | 10.0 | 10.1 | 10.4 | 6.8 | 9.5 | 13.7 | 10.13 |
| Hornblende | 2.0 | 3.3 | 13.8 | 12.0 | trace | trace | 0.3 | trace | trace | trace | trace | trace | trace | trace | trace | trace | trace |
| Biotite | 26.7 | 18.5 | 19.9 | 32.0 | 34.2 | 30.0 | 29.8 | 26.8 | 28.0 | 28.9 | 30.0 | 20.5 | 29.8 | 37.0 | 37.8 | 19.2 | 30.55 |
| Accessories | 2.3 | 1.8 | 2.0 | 1.0 | 2.1 | 2.3 | 2.4 | 2.8 | 2.0 | 1.5 | 2.0 | 0.5 | 2.8 | 2.8 | 2.0 | 2.7 | 2.06 |

X = Average; Accessories include apatite, sphene, epidote and Fe-oxides; IUGS nomenclature: All microgranular enclaves are quartz monzodiorite

Table 1b: Modal mineral abundance (volume percentage) of representative Kyrdem granitoids (KG)

| Sample No. | B3G | B4G | B9G | B11G | K16G | K19G | K20G | K21G | K23G | K25G | K26G | K29G | K31G | K34GE | K35G | K50G | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| Plagioclase | 38.4 | 32.5 | 36.3 | 30.8 | 30.0 | 30.9 | 35.5 | 35.0 | 38.2 | 33.6 | 50.2 | 34.9 | 39.0 | 38.2 | 21.4 | 23.7 | 34.29 |
| K-feldspar | 27.4 | 34.7 | 37.8 | 31.0 | 38.2 | 35.5 | 31.3 | 32.0 | 25.0 | 34.0 | 20.0 | 30.9 | 25.5 | 26.7 | 35.7 | 45.7 | 31.96 |
| Quartz | 18.6 | 20.8 | 10.2 | 21.0 | 10.5 | 10.5 | 16.8 | 10.5 | 13.8 | 15.1 | 18.6 | 18.6 | 20.0 | 18.0 | 15.2 | 19.2 | 16.09 |
| Hornblende | 1.6 | 0.9 | 4.2 | 3.4 | - | - | - | 0.1 | - | - | - | - | - | - | | - | - |
| Biotite | 12.0 | 9.2 | 10.2 | 12.0 | 17.2 | 18.3 | 15.4 | 18.4 | 19.1 | 14.8 | 10.2 | 12.8 | 13.6 | 14.0 | 23.1 | 10.0 | 15.06 |
| Accessories | 2.1 | 1.3 | 1.5 | 1.8 | 4.1 | 4.8 | 1.0 | 4.0 | 3.9 | 2.5 | 1.0 | 2.8 | 1.9 | 3.1 | 4.6 | 1.4 | 2.62 |

X = Average; Accessories include apatite, sphene, epidote and Fe-oxides; JUGS nomenclature: KG corresponds to quartz monzonite, syenogranite, granodiorite and monzogranite.

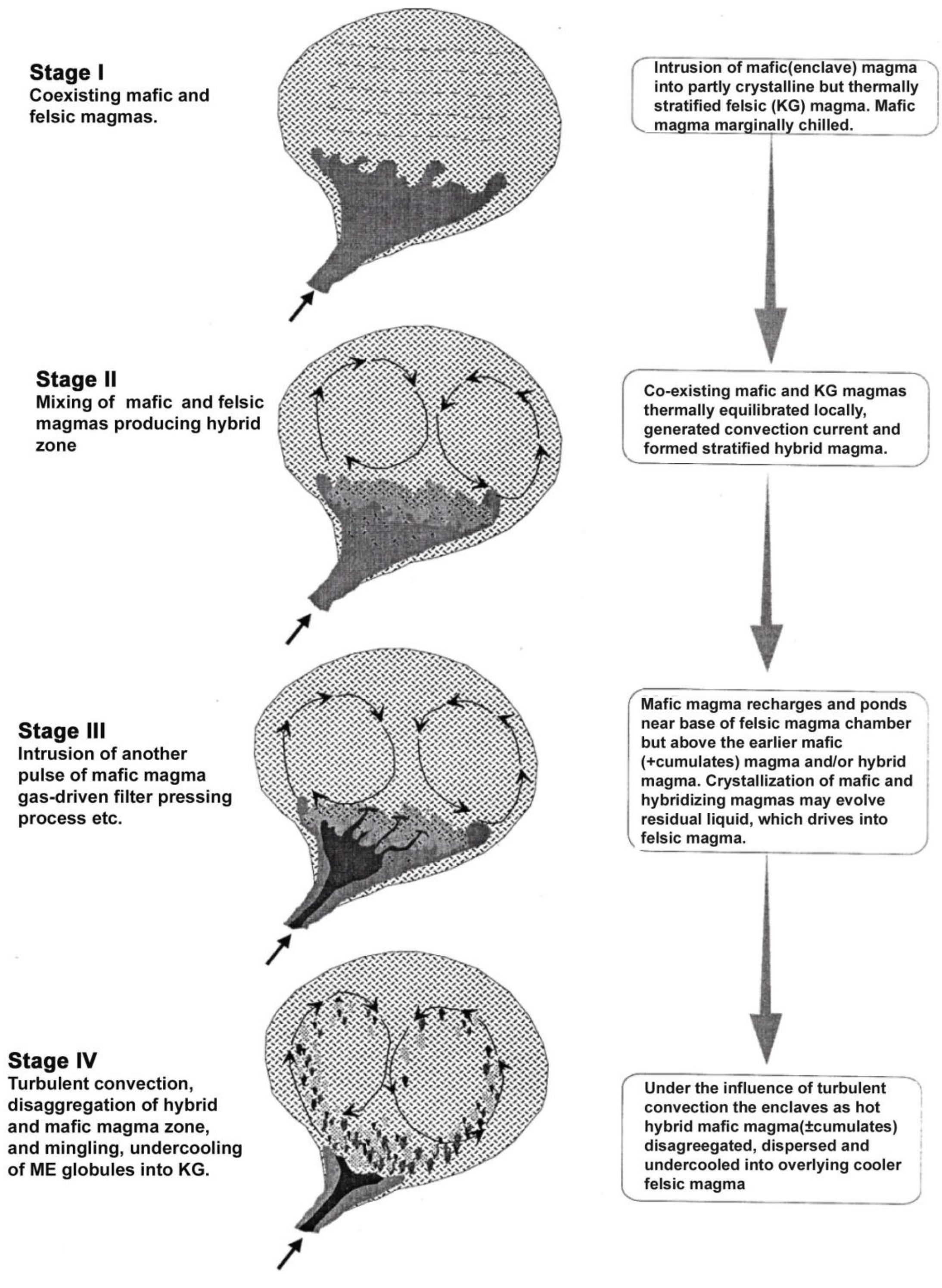


**Fig 11- Schematic cartoon (not to the scale) illustrating the evolution of ME in KG.**

## Conclusions

Most ME in KG are hybrid (mixed) product of mafic (enclave) and felsic (KG) magmas in various proportions. The xenocrysts bearing ME in KG should represent hybrid product of felsic-mafic magmas. Ocellar quartz grains rimmed by fine mafic minerals and presence of mafic (biotite) and felsic (K-feldspar and plagioclase) xenocrysts in ME are indication of mechanical mixing forming the hybrid ME magma zone at deeper level. Abundant acicular apatites are ubiquitous in some ME, which can be formed when undercooling (quenching) of ME (hybrid) magma occurred against relatively cooler felsic host KG.

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