Bulletin of Pure and Applied Sciences.
Geology (Geological Science), Vol.42F, No.1,
January-June 2023: P.10-19
Original Article

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.48165/bpas.2023.42F.1.2
Available online at www.bpasjournals.com

Magma Mingling and Mixing evidence from Kyrdem Granitoids, Meghalaya, India

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(Received on 20.09.2022, Revised on 14.11.2022, Approved on 02.02.2023, Accepted on 11.02.2023, Published on 15.06.2023)

How to cite this article: Devi S.K. and Thomas H. (2023). Magma Mingling and Mixing evidence from Kyrdem Granitoids, Meghalaya, India. *Bulletin of Pure and Applied Sciences- Geology,* 42F(1), 10-19.

Abstract:
The Kyrdem Granitoids (KG) pluton covers an area of about 230 sq. km. in the Ri-Bhoi district of Meghalaya. The KG (479±26 Ma) which intrudes the Shillong Group of metasediments represents one of the granite plutonism episodes of Meghalaya plateau. Mineralogically, KG can be grouped into coarse-grained porphyritic granite with grey and pink K-feldspar phenocrysts and aplite without phenocrysts. The aplite intrudes the porphyritic one as small pulses at several places. KG exhibits textural evidence for magma mixing and mingling during its evolution. Two types of enclaves are hosted in the KG viz. the country rock xenoliths and the microgranular enclaves (ME). Xenoliths which include amphibolites, granite gneiss, and quartzite of the Shillong Group are noticed in the porphyritic granite of KG. Microgranular enclaves (ME) hosted in KG are confined to the porphyritic granites and they are absent in the aplite. They are mesocratic to melanocratic, fine to medium grained and range in size from a few centimeters to a few meters. The ME shows different shapes ranging from subrounded, ovoid, and discoidal to ellipsoidal. The contacts between the host rock KG and the ME are sharp but occasionally diffused contacts are also noticed. In some cases, the ME shows finger-like projections with a convex face towards the host rock. Elongated, tabular, and sub-rounded K-feldspar megacrysts with a corroded margin are observed in the ME. These K-feldspar megacrysts commonlyresemble those that of the host rock. The above features suggest the origin of KG by magma mixing. Furthermore, textures including quartz ocellli, acicular apatite morphology, inclusion zones in feldspars and mafic clots also indicate that magma mingling and mixing plays a significant role in the evolution of KG.

Keywords: *Kyrdem Granitoids; Microgranular Enclaves; Magma Mingling And Mixing; Meghalaya; Quartz Ocelli.*

1. INTRODUCTION

The Kyrdem Granitoids (KG) is one of the several igneous bodies reported from Meghalaya plateau. The study area is about 230sq Km and is located in the Ri-Bhoi district of Meghalaya in the northeast of Shillong the capital city of the state. It falls within the coordinates of (25°38'N to 25°48'N and 92°00'E to 92°10'E). Earlier some geological works had been carried out in Kyrdem Granitoids, but magma mingling and mixing based on the field and petrographic evidence have not been studied especially. In this paper, an attempt has been made from field and petrographic evidence to prove that magma mixing and mingling between the felsic and mafic magmas takes place in KG.

Magmatic interaction processes and the generation of granitic melts have been widely studied by many researchers (Huppert and Sparks, 1988; De Rosa et al., 1996; Poli et al. 1996; Thomas & Tait, 1997; Mazumder, 1986). Magma mixing occurs when different magmas interact chemically and form blended entirely homogeneous hybrid magma, whereas magma mingling indicates the process of physical interaction between different magmas to form a rock product which preserves compositional heterogeneities (Vernon, 1984; Sparks and Marshall, 1986). Homogenization or mixing dominates, where large proportions of mafic magma interact with a relatively small proportion of granitoid melt, whereas mingling prevails where a small amount of mafic magma interacts with a significant proportion of granitoid magma (Frost and Mahood, 1987).

Microgranular enclaves (ME) of diverse nature and origin which appear to be especially prevalent in granitic rocks provide proper evidence of magma mixing and mingling in the field (Vernon, 1983; Furman et al., 1985; Castro et al., 1991, Kumar et al., 2004, 2005).

Geological Setting of the Area

Several Geologists (Medlicott, 1869; Mazumdar 1976; Acharyya *et al.,* 1986; Ghosh *et al.,* 1994) reported emplacements of granitoid plutons in the Meghalaya plateau. The KG represents one of the granite plutonic episodes of Meghalaya plateau and intrudes the Shillong group of metasediments and Precambrian Gneissic Complex. Geological map of the study area (modified from Chakraborty (1989) is shown in (Fig.1). Geochronological and geochemical studies carried out by (Ghosh et al., 1991) of this KG to be metaluminous (I-type) to peraluminous (S-type) granitoids and an age of 479±26 Ma. From the study of magnetic susceptibility and whole rock composition, (Kumar and Mohan, 2008) concluded that KG and the microgranular enclaves (ME) are moderate to strongly oxidised, magnetite series granites formed in a late to post-tectonic calc-alkaline, mafic-felsic magma interaction environment.

Field observation

Based on the mineral content and textures, the rocks of Kyrdem Granitoids can be grouped into a) coarse-grained porphyritic granite of grey and pink varieties with K-feldspar phenocrysts and b) aplite granite without K-feldspar phenocrysts. The aplite intrudes the porphyritic one as small pulses at several places. The intrusive nature is seen in Figure 2a near the Nongshiong village. Two types of enclaves are hosted in the KG viz. the country rock xenoliths and the microgranular enclaves (ME). The contacts between the host rock KG and the ME are sharp and are observed clearly in (Fig. 2b) but occasionally diffused contacts are also noticed. In some cases, the ME shows finger liked projections are marked in (Fig. 2e) with a convex face towards the host rock.

The grey porphyritic granite is the major rock type of the area. The size of the phenocrysts varies from a few mm to 10 cm in length and a few mm to 6 cm in width. But a few giant phenocryst of K-feldspar up to 28cm in length are also noticed very rarely and are spotted in Figure-3b.The concentration of K-feldspar megacrysts showing local imbrications is observed in grey porphyritic granite. They show no evidence of moulding of one megacryst around another thereby suggesting that they are formed by crystal accumulation not *in situ* growth (Paterson *et al*., 2005). The cumulates of K-feldspar megacryst are shown in (Fig.3d). The grey and pink porphyritic granites are similar except the colour of their K-feldspar phenocryst. The fine-grained granite as late felsic pulses intrudes the porphyritic one at several places.

The enclaves hosted in the KG can be grouped into the country rock xenoliths and the microgranular enclaves (ME). Xenoliths which include amphibolites are observed in (Fig. 3f), granite gneiss and quartzite as in (Fig. 3e) of the Shillong Group are noticed in the porphyritic granite of KG and also mostly in the marginal parts of the pluton. ME hosted in KG are also confined to the porphyritic granites, and they are absent in the aplite granite.

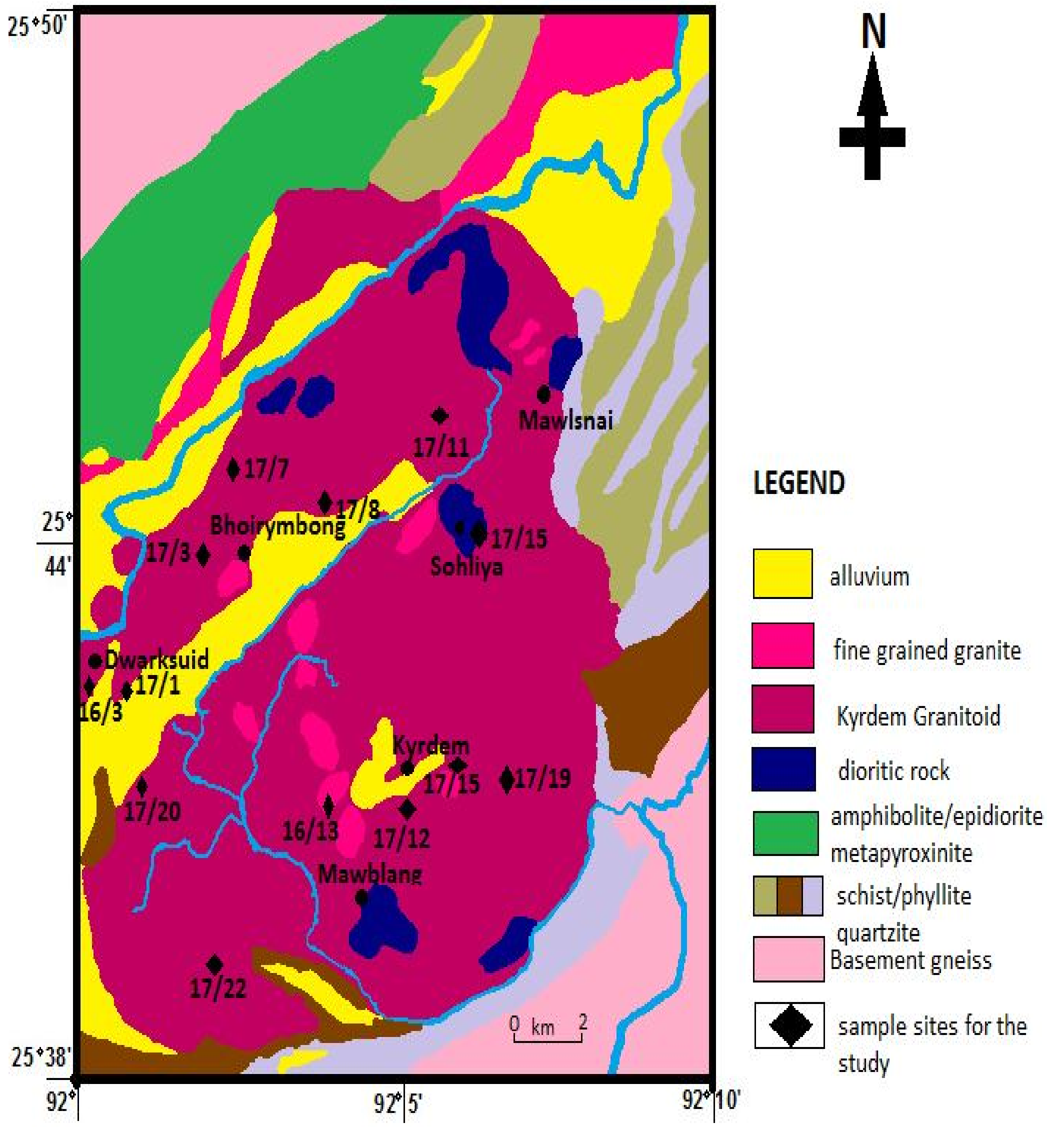

Figure 1: Geological map of Kyrdem granitoid (modified from Chakraborty, 1989)

They are mesocratic to melanocratic, fine to medium grained and range in size from a few centimetresto a few metres. Their size and number increases in and around Sohliya and Mawblang regions. They show a wide range of shapes from subrounded, ovoid, angular as seen in (Fig. 3c), discoidal to ellipsoidal (2D) as observed in (Fig. 2c), and in some locations lenticular and elongated shapes are also noticed in Figure 3a. In some areas ME hoisting K-feldspar phenocryst are also observed as in (Fig. 2d).

Elongated, tabular, and sub-rounded K-feldspar megacrysts with a corroded margin are observed in the ME. These K-felspar megacrysts are very resembled with that of the host rock. Quartz crystals surrounded by mafic minerals giving rise to ocelli textures are also found in the ME and (Fig. 2f) clearly shows ocelli texture.

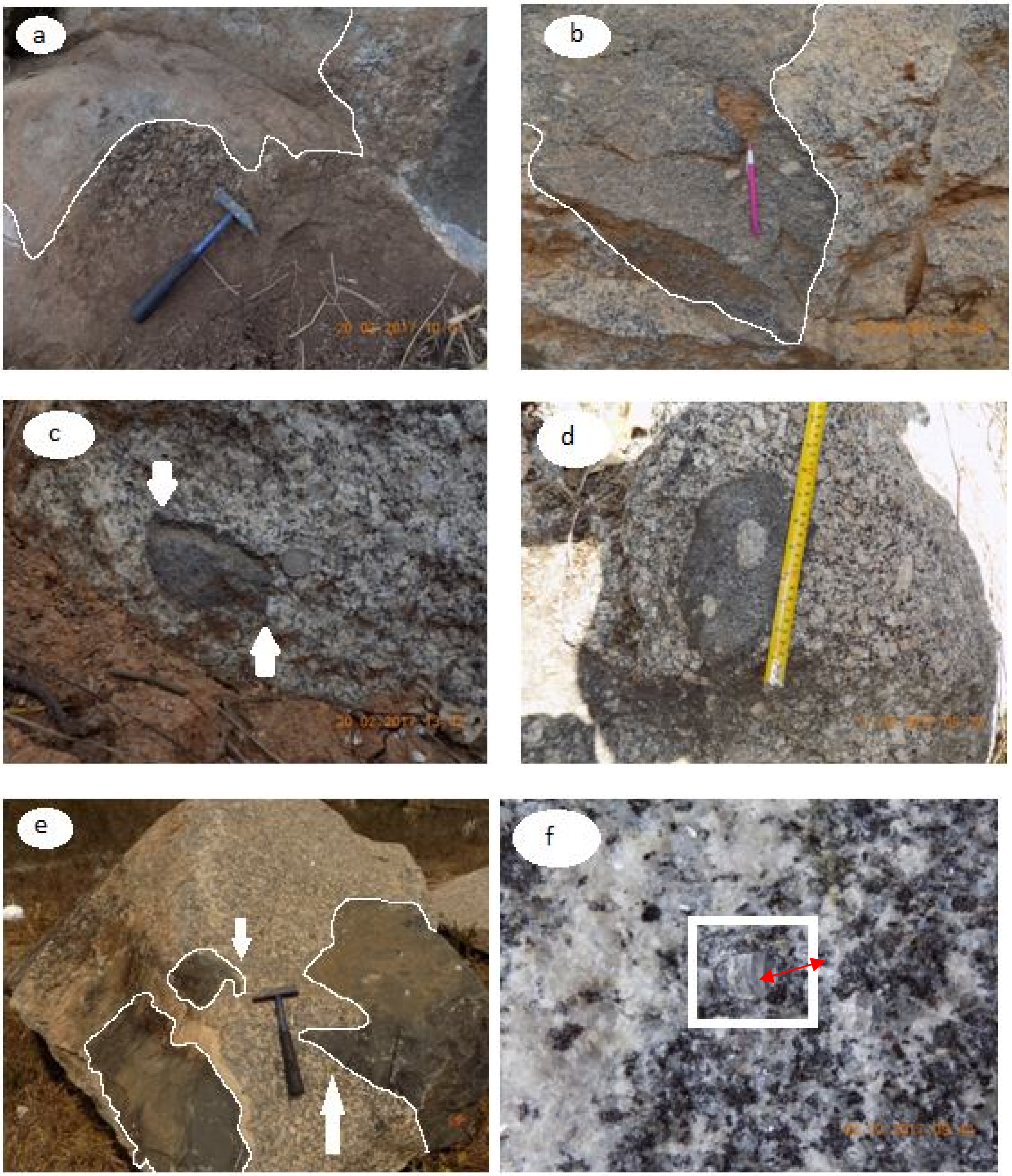

Figure 2: (a) Intrusive contact between the fine-grained and coarse-grained porpyritic granite (b) sharp contact between ME and KG (c) ellipsoidal ME with fingering structures at both end (d) ME hosting K-feldspar phenocryst (e) ME with fingerlike projections towards the host rock (f) quartz ocelli (~1 cm in length) in the ME from KG.

Figure 3: (a) elongated ME in porphyritic KG (b) giant plagioclase crystal with length of 28cm (c) angular ME with sharp contact with KG (d) cumulation textures in KG (e) & (f) xenoliths of quartzite and amphibolites in KG respectively.

Petrography

The porphyritic KG contains phenocrysts of K-feldspar in a groundmass of quartz, plagioclase, K-feldspar, and biotite. It contains titanite, apatite, opaque iron minerals, and zircon as accessory minerals. Chlorite and sericitere present the secondary minerals formed by the alteration of biotite and plagioclase. It exhibits coarse-grained, inequigranular and hypidiomorphic texture. Microcline predominantly represents K-feldspars, and many of them show microperthitic textures. The contact between the plagioclase and microcline is characterized by the development of myrmekitic intergrowth and albitic rims. Inclusions of biotite and plagioclase in K-feldspars are also observed. Further, growth of acicular apatite as noted in (Fig. 4a) is also encountered particularly in plagioclase and microcline minerals. The fine-grained KG is composed of K-feldspar, quartz, plagioclase and biotite with sphene, apatite, zircon, and iron minerals as accessory minerals.

The ME is fine to medium grained and showed hypidiomorphic textures. They are mainly composed of K-feldspar, plagioclase, quartz, biotite and hornblende with titanite, apatite, zircon and Fe-minerals as accessory minerals. Inclusions of biotite in the K-feldspar may be formed due to the interaction of K-feldspar minerals from the felsic magma and the mafic magma whereby lock-in of the mafic minerals by feldspar lead to the formation of this texture. Formation of a cluster of mafic minerals in the form of mafic clots shown in (Fig. 4d) in which hornblende occurs along with biotite, titanite, opaque Fe-minerals and apatite is very common in the ME. In some cases, titanite shows an ophitic relationship with laths of plagioclase in the presence of K-feldspar and quartz giving the titanite-plagioclase ocelli as observed in Figure-4b. The zone of titanite-plagioclase ocelli is devoid of mafic minerals, but they are further again surrounded with mafic minerals mainly biotite and hornblende. Typically, the ME shows a sharp crenulated contact margin with the host porphyritic granite showing clearly in (Fig.4f) without giving any notable reaction features.

2. DISCUSSION AND CONCLUSION

Enclaves of various shapes and sizes are common in calc alkaline plutons and are good indications of mafic-felsic magma mixing, mingling and flowage texture (Dorais et al., 1990; Didier and Barbarin, 1991; Barbarin, 2005).

Mafic enclaves are particularly abundant and large around massive mafic intrusions of Sohliya and Mawblang and their size and abundance decreasing with distance from the contact between the mafic and granitoid rocks. The shape of the enclaves, rounded to ovoid, sub angular and more rarely to angularin (Fig. 3c) having serrated or cuspate margins with lobes convex towards the host granitoids indicates quenching of the ME against the cooler felsic host (Kumar, 2004). The enclaves with rounding to ellipsoidal shape as noticed in (Fig. 2c) are a strong indication of magma mingling and flow whereas lenticular or elongated shapes as in Figure-3a indicate either plane or linear deformation (Vernon et al., 1988). Didier (1987) again, also emphasised that ME with irregular shape and crenulated to cuspate contacts, generally are closed to the place where mixing process was active, whereas the granitic magma transported ME which have rounded shape and sharp contacts during the emplacement. Crenulated to cuspate contacts occur especially between two liquids that have a high temperature, composition, and rheology contrasts.

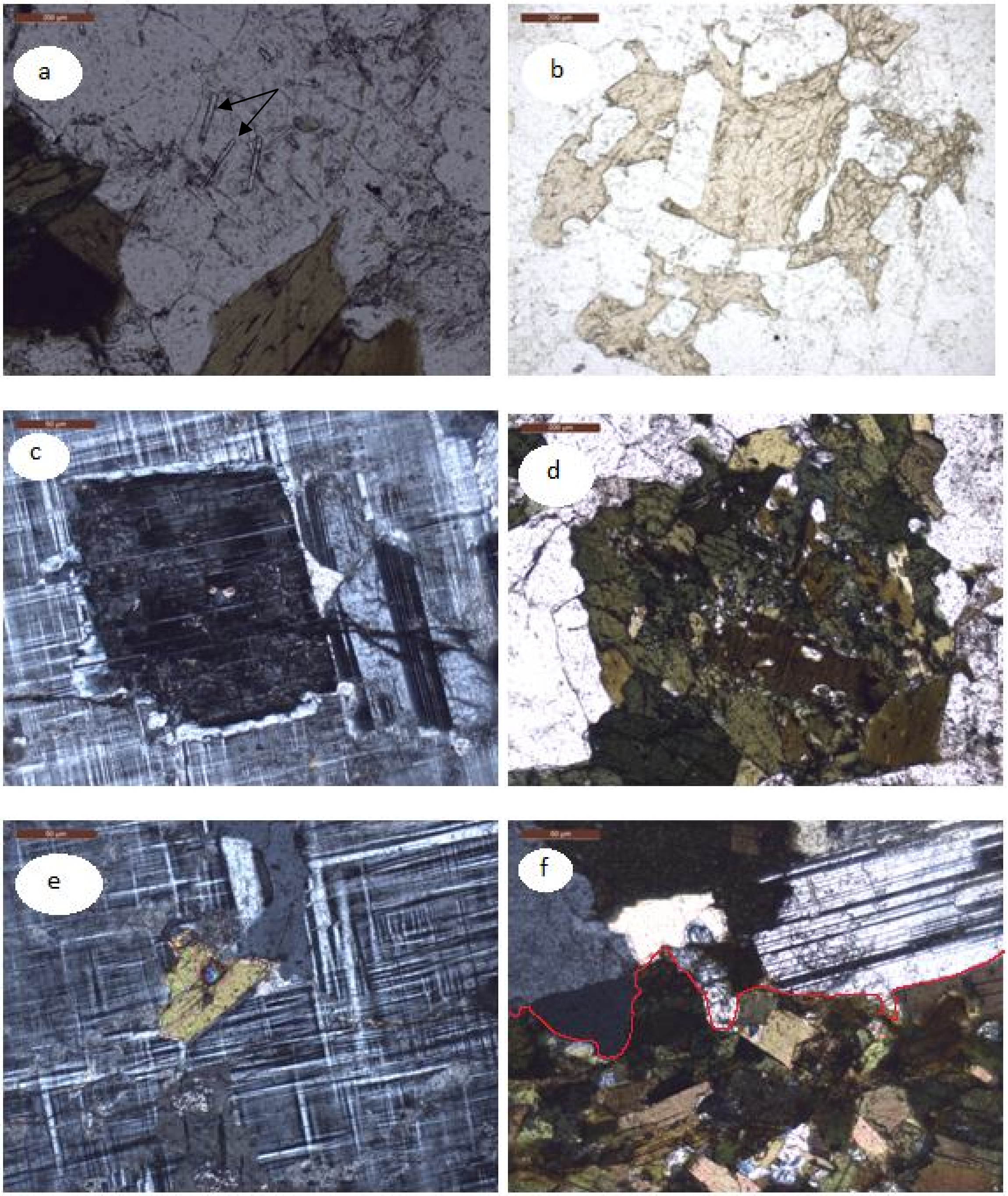

Figure 4: (a) Acicular apatite crystals in KG (b) titanite-plagioclase ocelli with ophitic relationship (c) plagioclase inclusion in microcline from KG (d) mafic clots in ME (e) biotite inclusion in K-feldspar in KG (f) sharp crenulated contact between the ME and KG in thin section.

The K-feldspar megacrysts present in the ME as noted in (Fig. 2d) are defined to be formed by mechanical transfer of K-feldspar megacrysts from a more felsic magma into the more mafic magma during magma mixing in the early stages of crystallisation (Vernon, 1991). MEhosted K-feldspar megacrysts in KG show signs of resorption resulting in rounded morphology due to reheating by a hotter mafic or hybrid magma system probably at the initial stage of mixing (Hibbard, 1965; Kumar, 2010).

When the felsic and mafic magmas interact the quartz crystals from the felsic magma has become unstable in that new environment and causes undercooling of it (Vernon, 1990,1991; Hibbard, 1991, Baxter and Feely, 2002). This promotes the nucleation of fine-grained mafic minerals leading to the growth of fine-grained aggregates which use the quartz xenocrysts as a substrate. Subsequent precipitation may lead to an outer rim of mafic minerals around the quartz crystal preserving as in Figure 2f in ocellar texture (Palivcova et al., 1995).

The presence of acicular apatite in Figure 4a as a quench texture represents a rapid cooling of the hot mafic magma when incorporated with the relatively cooler felsic rock mass supporting the magma mingling and mixing (Hibbard, 1991).

The titanite-plagioclase ocelli as in (Fig. 4b) which is having an ophitic relationship in the presence of K-feldspar and quartz has been cited as evidence of two-stage mixing of the magma by (Hibbard, 1991). In this texture, the titanite-plagioclase ocelli were mantled with K-feldspar and quartz after their crystallisation during the first stage of mixing. The crystallisation of the mafic minerals took place during the second stage of mixing.

The mafic clots shown in (Fig. 4d) present in the ME may be formed due to the reaction between pyroxene minerals and the magma there by precipitating calcic amphiboles (Baxter & Feely, 2002). The occurrence of this mafic clot in adjoining KG suggests that that might be distributed due to the interaction of the mafic magma and the felsic host rock. Further, the presence of inclusions of biotite and plagioclase in K-feldspar support the interaction of two magma bodies. All this evidence has proved that KG has undergone magma mingling and mixing between the felsic and mafic magma.

3. ACKNOWLEDGEMENTS

We are thankful to Head, Department of Geology, Mizoram University, Mizoram for his support.

4. AUTHOR'SCONTRIBUTIONS

This research was conceptualized and interpreted by both S. Kavita Devi & Harel Thomas, and Kavita Devi has carriedout the field work, collected the data, complied, and framed the figures and the manuscript text.

5. REFERENCES

1. Acharyya, S. K., Mitra, N. D. and Nandy, D. R. (1986). Regional geology and tectonic setting of North-East India and adjoining region. *Mem. Geol. Surv. India, 119, 6–12.*

2. Barbarin, B. (1988a). Field evidence for successive mixing and mingling between the Piolard diorite and Saint-Julien-la-Vêtre Monzogranite (Nord-Forez, Massif Central France). *Can. J. Earth. Sci. 25, 49-59.*

3. Barbarin, B. (2005). Mafic magmatic enclaves and mafic rocks associated with some granitoids of central Sierra Nevada batholiths, California: nature, origin and relations with the host. *Lithos, 80, 155-177.*

4. Baxter, S. and Feely, M. (2002). Magma mixing and mingling textures in granitoids: examples from the Galway granite, Connemara, Ireland. *Mineral. Petrol., 76, 63-74*.

5. Chakraborty, S., (1989). Report on systematic geological mapping of Kyrdem pluton in East Khasi Hills district. Unpublished GSI report (*Geological map published in Ghosh et al., 1991*).

6. Castro, A. Moreno-Ventas, I. and Dela Rosa, J.D. (1991). Multistage crystallization of tonalitic enclaves in granitoid rocks (Hercynian belt, Spain): implication for magma mixing. *Geol. Runds., 80, 109-120.*

7. DE Rosa, R. Mazzuoli and Ventura, G. (1996). Relationship between deformation and mixing processes in lava flows: a case study from Salina (Aeolian Islands, Tyrrhenian Sea), bull. Volcano, *58, 286-297*.

8. Didier, J. and Barbarin, B. (1991). Enclaves and granite petrology. *Developments in petrology. 13, Elsevier, Amsterdam, 625p.*

9. Didier, J. (1987). Contribution of enclave study to the understanding of origin and evolution of granitic magmas. *Geol. Rundsh., 76, 41-50*.

10. Dorais, M. J., Whitney, J. A., and Roden, M. F. (1990). Origin of mafic enclaves in the Dinkey Creek pluton, Central Sierra Nevada batholiths, California. *Jour. Petro., **31**, 853-881.*
11. Frost, T. P., and Mahood, G. A., (1987). Field, chemical and physical constraints on mafic-felsic interaction in Lamarck granodiorite, Sierra Nevada, California. *Geo. Soc. Amer. Bull. 99, 272-291*.
12. Furman, T., and Sepra, F.J. (1985). Co-mingling of acid and basic magma with implication for the origin of mafic I-type xenoliths, field and petrological relations of an usual dyke complex at Eagle Peak Lake, Sequoia National Park, California, USA. *Jour. Volcano. Geotherm. Res., 24, 151-178.*
13. Ghosh, S., Chakraborty, S., Bhalla, J.K., Paul, D.K., Sarkar, A. Bishui, P.K., and Gupta, S.N. (1991). Geochronology and geochemistry of granite plutons East Khasi Hill, Meghalaya. *Jour. Geol. Soc. India, 37, 331-342.*
14. Ghosh, S., Chakraborty, S., Paul, D.K., Bhalla, J.K., Bishui, P.K., and Gupta, S.N. (1994). New Rb-Sr isotopic ages and geochemistry of granatoids from Meghalaya and their significance in middle to late Proterozoic crustal evolution. *Indian Minerals, 48, 33-44.*
15. Hibbard, M. J. (1965). Origin of some alkali feldspar phenocrysts and their bearing on petrogenesis. *Am. J. Sci. 263, 245-261.*
16. Hibbard, M. J. (1991). Textural anatomy of twelve magma-mixed granitoid systems. . In: J. Didier and B. Barbarin (Eds.), Enclaves and granite petrology. *Development in petrology, 13, Elsevier, Amsterdam, 431-444.*
17. Huppert, H.E., Sparks, R.J.S. (1988). The generation of granitic magmas by intrusion of basalt into continental crust. *Jour. Petrol., 29, 599-624.*
18. Kumar Santosh, Rino, V. and Pal, A. B. (2004). Field evidences of magma mixing from microgranular enclaves hosted in Palaeoproterozoic Malanjkh and granitoids, Central India. *Gondwana Res., 7, 539-548*.
19. Kumar Santosh, Pieru, T., Rino, V., and Lyngdoh, B. C. (2005). Microgranular enclaves in Neoproterozoic granitoids of south Khasi Hills, Meghalya plateau, Northeast India: field evidences of interacting coeval mafic and felsic magmas. *Jour. Geol. Soc. India., 65, 629-633.*
20. Kumar, S. and Mohan Singh, Kh. (2008). Granite series evaluation of Early Ordovician Kyrdem Granitoids and enclaves, Meghalaya Plateau, northeast India: implication on oxidation condition of interacting Mafic-Felsic magma system. *e-Jour. Ear. Sc. Ind., 1(3, 148-159.*
21. Kumar, S. (2010). Mafic to hybrid microgranular enclaves in the Ladakh batholiths, northwest Himalaya: implications on calc-alkaline magma chamber processes. *Jour. Geo. Soc. India., 76, 5-25.*
22. Mazumder, S.K., (1976). A summary of the Precambrian geology of the Khasi Hills, Meghalaya. *Geol. Surv. India, Misc. Pub. No. 23, 311-324.*
23. Mazumder, S.K. (1986). The Precambrian framework of part of the Khasi Hills, Meghalaya. *Rec. Geol. Surv. Ind., 117 (2), 1-59.*
24. Medlicott, H.B. (1869). Geological sketch of Shillong plateau in North Eastern Bengal. *Mem. Geol. Surv. India. 7 Pt. 1.*
25. Palivcova, M. Waldhausrova, J. and Ledvinkova, V. (1995). Ocelli in mafic rocks of granitic complexes. *Krystalinikum, 22, 149-186.*
26. Paterson, S. R., Vrnon, R. H., and Zák, J., (2005). Mechanical instabilities and accumulations of K-feldspar megacrysts in granitic magma, Toulumne Intrusive Suite, California, USA. In köhn d. (ed) General Contributions 2005. *Journal of the Virtual Explorer, 18, paper1*.
27. Thomas, N., and Tait, S. R. (1997). The dimensions of magmatic inclusions as a constraint on the the physical mechanism of mixing. Jour. Volcano. *Geotherm. Res., 75, 176-178*.
28. Sparks, R. S. J., and Marshall, L. A. (1986). Thermal and mechanical constraints on mixing between mafic and silicic magmas. Jour. Volcano. *Geotherm. Res. 29, 99-124.*
29. Vernon, R. H. (1983). Restite, xenoliths and microgranitoid enclaves in granites. Clarke Memorial Lecture, *Jour. Proc. Royal Soc. N. S. W., 116, 77-103.*
30. Vernon, R. H. (1984). Microgranitoid enclaves in granites- globules of hybrid

magma quenched in a plutonic environment. *Nature. 309, 438-139.*

31. Vernon, R. H., Etheridge, M. A., and Wall, V. J. (1988). Shape and microstructures of microgranitoid enclaves: indicators of magma mingling and flow*. Lithos, 22, 1-11.*

32. Vernon, R. H. (1990). Crystallization and hybridism in microgranitoid enclave magma: microstructural evidence. *Jour. Geophys. Res, 95, 17849-17859*

33. Vernon, R. H. (1991). Interpretation of microgranitoid enclaves. In: J. Didier and B. Barbarin (Eds.), Enclaves and granite petrology. Development in petrology, *Elsevier, Amsterdam, 13, 277-291.*