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## RESEARCH ARTICLE

# FIELD RELATIONSHIP AND GEOCHEMISTRY OF MICROGRANULAR ENCLAVES IN HOST ROCK GRANITES IN AND AROUND NALGONDA DISTRICT, INDIA

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**ABSTRACT**

The microgranular enclaves are mesocratic to melanocratic, fine to medium grained, porphyritic, and sub rounded to elliptical shaped showing typical magmatic signatures into the host rock granite/gneisses of the Peninsular Gneissic Complex of the Eastern Dharwar Craton (EDC) part of Nalgonda district. The macro and micro granular enclaves are either/or partially dissolved due to mixing of magma. Geochemically, the enclaves is rich in $K_2O$+$Na_2O$, suggesting it is an alkali granite derived from calc-alkaline magma. The REE pattern shows strong Eu negative anomaly, suggesting early separation of plagioclase. The enhance level of LILE relative to HFS element point to the subduction zone enrichment and/or crustal comtamination of the source region.



## INTRODUCTION

Understanding the evolution of granitic magmas and the dynamics of magma chambers has benefited significantly from the study of enclaves, particularly since the widespread recognition that most mafic microgranular enclaves correspond to blobs of new magma that intruded and were trapped in the host granite (Didier, 1973; Wiebe, 1974; Vernon, 1984; Frost & Mahood, 1987; Didier & Barbarin, 1991). Mafic magmatic enclaves (MME) and synplutonic mafic dykes provide much insight in understanding the magma chamber processes, chemical diversity and accretinary history of calc-alkaline batholiths.The field, petrographic, elemental and isotopic data on MME and synplutonic mafic dykes have been presented for characterizing magma chamber process of phanerozoic batholiths in the plate margin settings (Hibbard,1981;Frost and Mahood,1987;Castro *et al*,1990,1991; Arculus,1994;Tamura and Tatsumi,2002; Barbarin,2005;Kumar,2010;Tamura *et al*,2009; Shukuno *et al*,2006;Turnbull *et al*.,2010;Perugini and Poli,2012;Jayananda *et al*.,2014). Archean cratons all over the world contains voluminous Tonalite-Tronjhemite-Granodiorite, calc-alkaline to potassic plutons (Jayananda *et al*.,2014).The late Neoproterozoic calc-alkaline to potassic plutons are the most voluminous lithologies in the Eastern Dharwar Craton and form a wide window for magma chamber processes at different crustal levels (Jayananda *et al*.,2014). In this paper, we present the field relationship and geochemical behavior of the enclaves occurring within the leocogranite in and around Suryapet town, part of Nalgonda district.

### Geological field setting

Enclaves are important constituents of the plutons in the EDC (Chadwick *et al*.,2000; Moyen *et al*.,2003b; Jayananda *et al*.,2009; Prabhakar *et al*.,2009; Ahmad,2011; Gireesh,2002). Mesocratic to melanocratic, rounded to elliptical, fine to medium grained, mafic to hybrid microgranular enclaves (ME) are ubiquitous in medium to coarse-grained Leucogranite and granite gneiss (Santosh Kumar,2010). In the study the mafic enclaves are irregularly distributed in each pluton and includes the hornblende biotite gneiss, hornblende gneiss, quartzo-felspathic gneiss, amphibolites. The geological map of the study area with location map is shown in Fig 1a,1b). Synplutonic mafic dykes are less common in the core but more common along the periphery of the plutons. They range in composition from gabbro to diorite and align parallel to the magmatic foliation of the host granitoids(M. Jayananda *et al*,2014).These enclaves are older when compared to the country rock. At location Kudakuda they are found to alligned themselves in an oriented direction trending N20°W to S20°E (Field photo 1). The enclaves within the pink granite show a particular direction which implies that the flow direction of the magma varies from

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N25°W to S25°E ,East of Undrakonda (Field photo 2).At some places, the almost digested enclave is observed within the quartzo-feldspathic gneiss (Field photo 3).Remnants of PGC observed as enclaves having sharp contacts with the pink granite and reaction rims is conspicuously observed(Field photo 4) where its contact is chilled. In one location an ellipsoidal micro mafic enclave occur as residue in grey granite ( length=20 cm,width=5 cm, Field Photo 5) .Micro fold is observed within the fine grained enclave biotite gneiss.

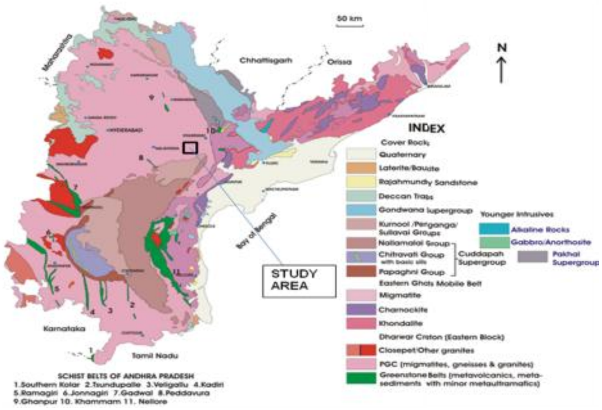



Figure 1 a: Geological map indicating the study area.

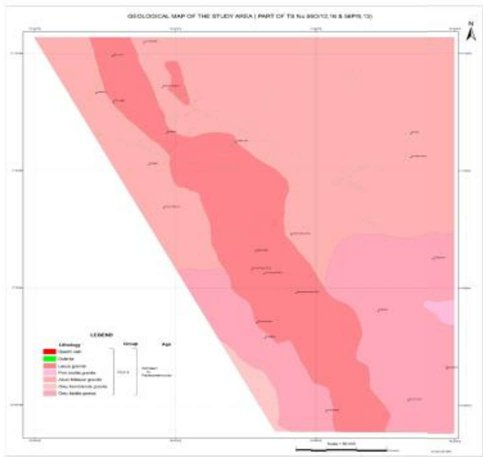


Figure 1b : Geological map of part of Nalgonda district,Telangana,India.

Field photo 1: The mafic rock trending N20°W to S20°E at Kudakuda.

Field photo 2: The enclaves within the pink granite show a particular direction which implies that the flow direction of the magma is from N25°W to S25°E at 4 Km East of Undrakonda.

Field photo 3: Assimilation assemblage of biotite gneiss seen is almost digested with the host rock at Kondalraogudem.

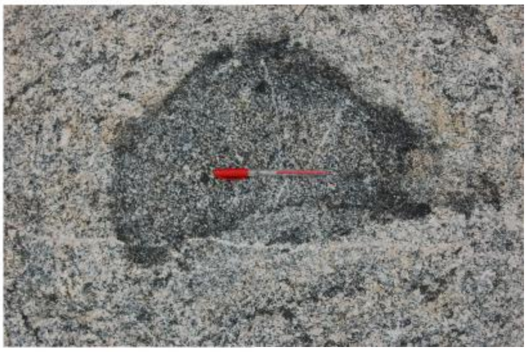
Field photo 4: Remnants of PGC observed as enclaves having sharp contacts with the pink granite and reaction rims is conspicuously observed at 1 ½ Km NE of Suryapet.

Field Photo 5: Ellipsoidal micro mafic enclave occur as residue in grey granite ( length=20 cm,width=5 cm) at 1 Km North of Durajpalli.

Field photo 6: Enclave of biotite gneiss(PGC) showing Ptygmatic fold within the Leuco granite at 1 Km West of Kondalraogudem

Field photo 7: Synplutonic mafic enclave with quartz veins along the foliation plane and fracture zone at 1 Km West of Kondalraogudem

Field photo 8: Micro fold is observed within the fine grained enclave biotite gneiss at Ramasamudram



Field photo 9 :The almost digested enclave observed within the quartzo-feldspathic gneiss.Its contact is chilled at Ramasamudram.

Field photo 10: Mafic dyke intrusion at 1km North of Durajpali

**Sampling and analytical techniques**

A total 0f 10 samples from the enclaves and dyke were collected. Sample weights were 1-1.5 kg before crushing and powdering. Major, minor and trace element abundances were determined by X'UNIQUE II (PHILIPS) X-ray spectrometry System at PPOD Lab, AMSE Wing, Geological Survey of India, Bangalore and Chemical Division, Geological Survey of India ,Southern Region, Hyderabad .Whereas the minor, trace and rare earth elements (REE) were carried out by ICP-MS Sciex Elan Model 6100 at Chemical Division, Geological Survey of India ,Southern Region, Hyderabad. The elements include $SiO_2$,$Al_2O_3$,$Fe_2O_3$,Mno,MgO, MnO,$K_2O$, $Na_2O$, $TiO_2$,$P_2O_5$,Be,Ge, As, Mo, As, Hf, Ta, W, Bi, U, La, Ce, Pr, Nd, Eu, Sm, Tb, Gd, Dy, Ho, Er, Tm, Yb, Lu. The contents of $SiO_2$,$Al_2O_3$,$Fe_2O_3$,Mno,MgO, MnO,$K_2O$, $Na_2O$,$TiO_2$, $P_2O_5$ are presented at Table 1.

The silica content of microgranular enclaves ranges from 64.86 wt % to 70.86 wt % where as the dyke silica content varies from 44 wt % to 49.01 wt %. Alkali content is high in both mafic enclaves and granites but $Na_2O$ is in excess of $K_2O$.(fig 2)

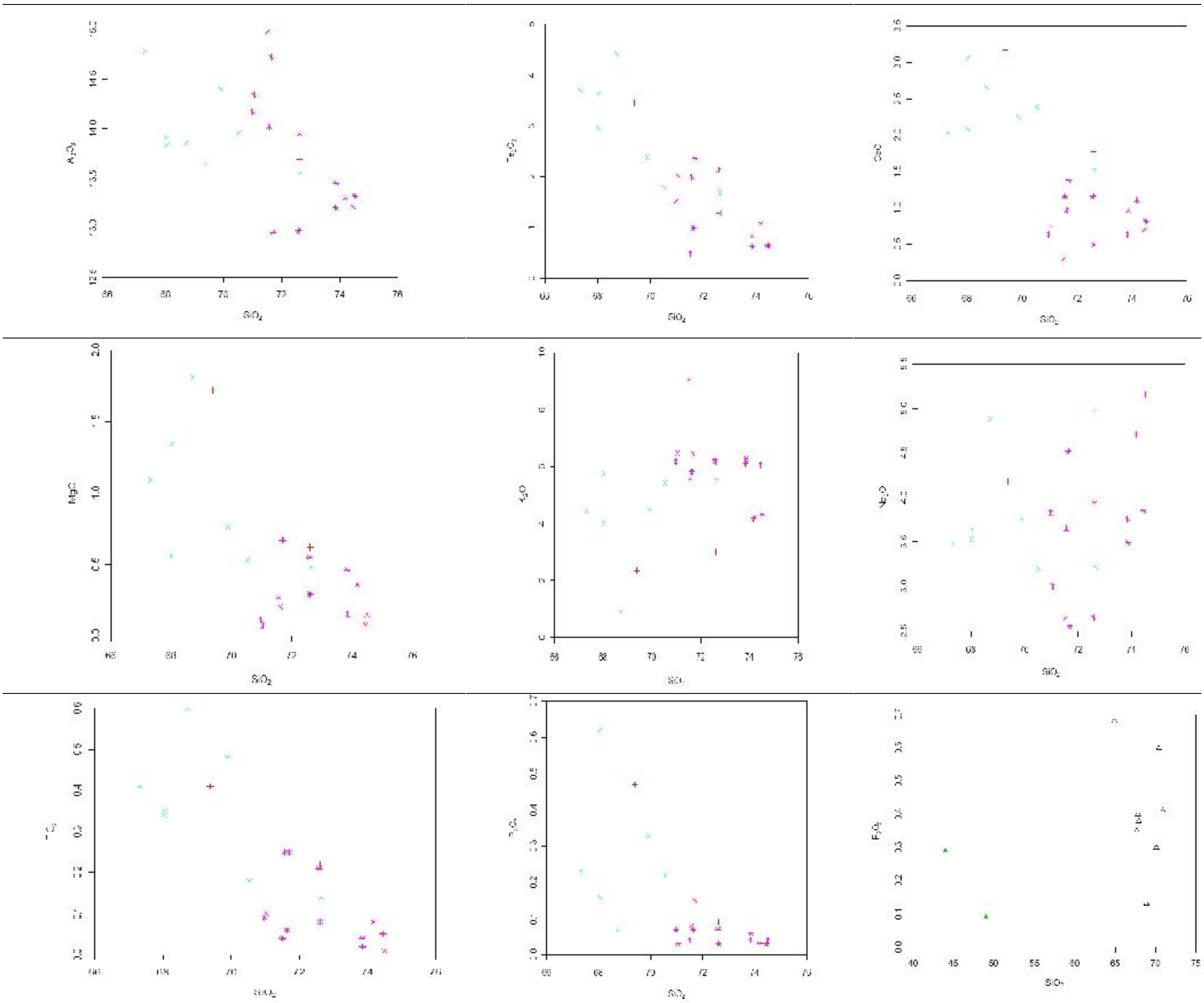


**Fig 2** Harker variation diagram for the granite,part of Nalgonda district, a marked variation in the abundance of some major elements mostly in ranges of $SiO_2$,$Fe_2O_3$, $Al_2O_3$, CaO, $TiO_2$ and MnO.This variation suggest diverse protolith is directly corelated with the modal abundance of the main mineral phase.

## Classification/tectonic environment

The classification of the rock with total alkali silica (TAS) $SiO_2$ vrs($K_2O$+$Na_2O$) geochemical rock classification diagram of Cox *et al* (1979) fig-3, adapted by Wilson (1989) for plutonnic rocks shows the enclaves falling in the acid field or to be more specific , they fall in granodiorite field and 2 dykes are falling in the gabbro field. After plotting the, mostly the plots TAS vrs Silica by Middlemost(1985) (fig 4) fall in the granodiorite field but 2 dykes are in the gabbro field. The AFM plot after Irvine and Baragar(1971) (fig 5),suggests the magma to be of Calc-alkaline in nature and the dykes are of tholeiitic Series. As per the FeO-$K_2O$+$Na_2O$-MgO plot (fig 6), it is clear that the rock is moderately rich in $K_2O$+$Na_2O$ which means it is an alkali granite. Also,when the major Oxides data were plotted in the R1-R2 diagram of De La Roche *et al* (1980) (fig 7) which is based upon the cation proportions expressed as millications .On an X-Y bivariate graph using the plotting parameters R1& R2 where R1 is plotted along the X-axis and is defined by R1=4Si-11(Na+K)-2(Fe+Ti) and Fe represents the total Fe while the R2 is plotted along the Y-axis and is defined as R2=(Al+2Mg+6Ca), the plots fall in the granodiorite field and 2 dykes are in the gabbro field.

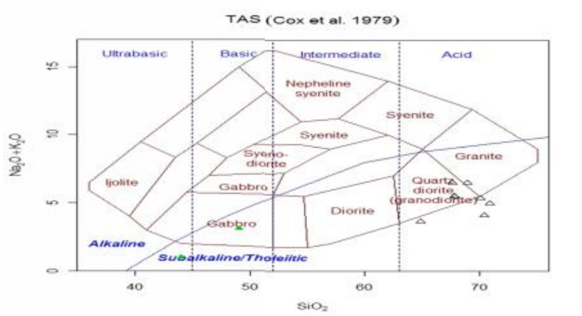



Fig 3:$SiO_2$ vrs $K_2O$+$Na_2O$ geochemical rock classification diagram of Cox et al (1979)

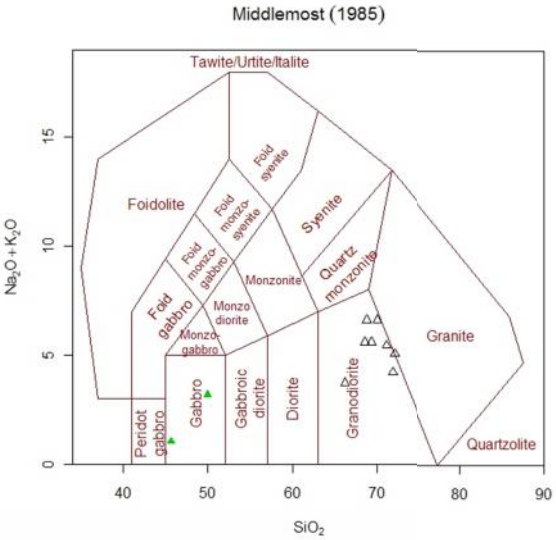



Fig 4: $SiO_2$ vrs $K_2O+Na_2O$ geochemical rock classification diagram of Middlemost (1985)

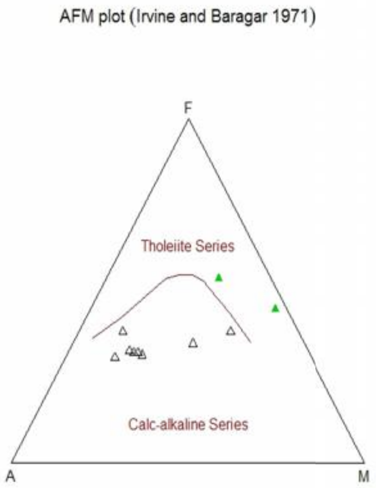



Fig 5: AFM plot after Irvine and Baragar,1971.

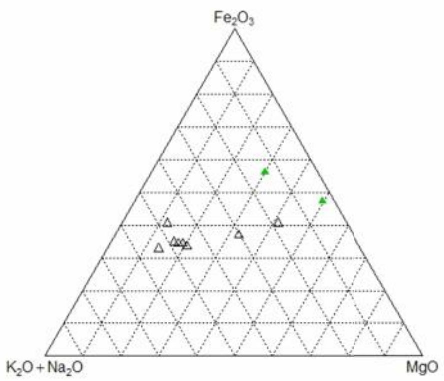



Fig 6: FeO-K2O+Na2O-MgO plot

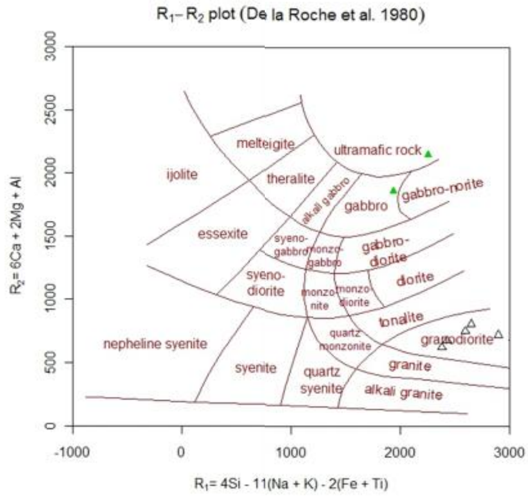



Fig 7: R1-R2 diagram of De La Roche et al (1980)

The major Oxides data were again plotted in the R1-R2 diagram of Batchelor and Bowden (1985) (fig 8) which is based upon the cation proportions expressed as millications on an X-Y bivariate graph using the plotting parameters R1& R2 where R1 is plotted along the X-axis and is defined by R1=4Si-11(Na+K)-2(Fe+Ti) and Fe represents the total Fe while the R2 is plotted along the Y-axis and is defined as R2=(Al+2Mg+6Ca), which is primarily a major element based on geotectonic classification, it shows that the enclaves are syncollision to mantle fractionates.

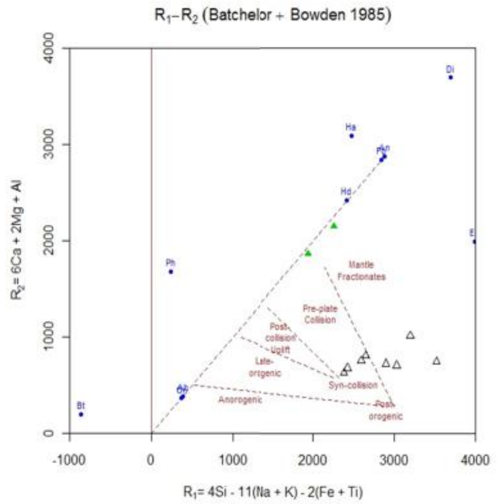



Fig 8: R1-R2 diagram of Batchelor and Bowden,1985 where R1=4Si-11(Na+K)-2(Fe+Ti) & R2=(Al+2Mg+6Ca)

### *Rare earth elements (REE)*

The REE pattern of the igneous rock is controlled by the REE chemistry of its source and the crystal melt equilibrium which have taken place during its evaluation.Characteristic chondrite normalised REE pattern of granite shows strong negative Eu anomaly suggesting early separation of plagioclase by Nakamura (1974) (fig 9)

**Table 1**Major oxides in wt % and REE and trace elements in ppm

| Sample | S03 | S3A | Avg4 | RS10A | RS7B | RS8 | Avg1 | S14A | S46A | S4A | Avg2 | S35 | S44A | Avg3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lithology | basic dyke | basic dyke | basic dyke | Mafic enclave | Mafic enclave | Mafic enclave | Mafic enclave | Mafic enclave | Mafic enclave | mafic enclave | mafic enclave | Mafic Micro dyke | Mafic Micro dyke | Mafic Micro dyke |
| SiO2 | 49.01 | 44 | 46.51 | 67.63 | 70.86 | 70.08 | 69.52 | 70.37 | 67.88 | 67.77 | 68.67 | 64.86 | 68.90 | 66.88 |
| Al2O3 | 13.86 | 8.4 | 11.13 | 13.48 | 12.46 | 12.66 | 12.87 | 9.94 | 13.51 | 14.75 | 12.73 | 7.53 | 14.22 | 10.88 |
| Fe2O3 | 12.51 | 14.84 | 13.68 | 4.66 | 3.67 | 3.92 | 4.08 | 5.03 | 3.93 | 4.72 | 4.56 | 8.08 | 3.97 | 6.03 |
| MnO | 0.18 | 0.43 | 0.31 | 0.09 | 0.06 | 0.05 | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.19 | 0.07 | 0.13 |
| MgO | 6.69 | 15.59 | 11.14 | 2.23 | 2.05 | 2.41 | 2.23 | 4.44 | 2.06 | 1.41 | 2.64 | 8.23 | 1.64 | 4.94 |
| CaO | 11.77 | 11.32 | 11.55 | 2.83 | 3.33 | 3.31 | 3.16 | 3.06 | 4.12 | 3.68 | 3.62 | 4.28 | 2.49 | 3.39 |
| Na2O | 2.15 | 0.46 | 1.31 | 3.53 | 3.49 | 3.39 | 3.47 | 0.59 | 3.99 | 4.09 | 2.89 | 0.48 | 4.77 | 2.63 |
| K2O | 0.96 | 0.52 | 0.74 | 2.97 | 1.49 | 1.97 | 2.14 | 3.53 | 1.48 | 1.44 | 2.15 | 3.17 | 1.73 | 2.45 |
| TiO2 | 0.96 | 0.65 | 0.81 | 0.52 | 0.37 | 0.37 | 0.42 | 0.27 | 0.44 | 0.51 | 0.41 | 0.48 | 0.42 | 0.45 |
| P2O5 | 0.09 | 0.29 | 0.19 | 0.35 | 0.41 | 0.30 | 0.35 | 0.60 | 0.38 | 0.4 | 0.46 | 0.68 | 0.13 | 0.41 |
| LOI | 1.05 | 2.83 | 1.94 | 1.03 | 1.19 | 0.95 | 1.06 | 1.48 | 1.50 | 0.27 | 1.08 | 1.37 | 1.13 | 1.25 |
| La | 8.92 | 6.73 | 7.82 | 64.84 | 62.97 | 53.16 | 60.33 | 82.17 | 68.23 | 13.98 | 54.79 | 62.67 | 70.75 | 66.71 |
| Ce | 19.45 | 16.92 | 18.19 | 135.44 | 110.29 | 94.03 | 113.26 | 152.63 | 117.30 | 26.67 | 98.87 | 118.11 | 126.87 | 122.49 |
| Pr | 2.45 | 2.55 | 2.50 | 16.13 | 12.11 | 10.11 | 12.79 | 17.47 | 12.72 | 3.35 | 11.18 | 13.60 | 13.20 | 13.40 |
| Nd | 11.05 | 13.09 | 12.07 | 62.27 | 43.30 | 35.07 | 46.88 | 65.43 | 46.06 | 14.80 | 42.10 | 51.74 | 43.67 | 47.70 |
| Eu | 1.00 | 1.17 | 1.08 | 1.88 | 1.52 | 1.26 | 1.55 | 2.45 | 1.77 | 1.34 | 1.85 | 1.86 | 1.18 | 1.52 |
| Sm | 3.03 | 3.82 | 3.43 | 14.41 | 7.78 | 6.54 | 9.58 | 12.29 | 8.20 | 3.87 | 8.12 | 9.47 | 8.76 | 9.12 |
| Tb | 0.63 | 0.84 | 0.73 | 1.55 | 0.95 | 0.79 | 1.10 | 1.37 | 1.03 | 0.79 | 1.06 | 1.00 | 1.34 | 1.17 |
| Gd | 3.35 | 4.71 | 4.03 | 11.45 | 6.13 | 5.16 | 7.58 | 9.61 | 6.77 | 4.51 | 6.96 | 7.24 | 6.97 | 7.10 |
| Dy | 4.12 | 5.02 | 4.57 | 6.87 | 5.03 | 4.46 | 5.45 | 6.68 | 5.50 | 4.86 | 5.68 | 5.07 | 7.98 | 6.53 |
| Ho | 0.88 | 1.09 | 0.98 | 1.18 | 1.01 | 0.89 | 1.03 | 1.30 | 1.12 | 1.01 | 1.14 | 0.95 | 1.71 | 1.33 |
| Er | 2.39 | 2.81 | 2.60 | 2.70 | 2.68 | 2.39 | 2.59 | 3.24 | 2.90 | 2.63 | 2.92 | 2.37 | 4.89 | 3.63 |
| Tm | 0.42 | 0.46 | 0.44 | 0.39 | 0.49 | 0.42 | 0.44 | 0.57 | 0.50 | 0.44 | 0.50 | 0.43 | 1.06 | 0.74 |
| Yb | 2.47 | 2.67 | 2.57 | 2.17 | 2.93 | 2.22 | 2.44 | 3.32 | 3.03 | 2.53 | 2.96 | 2.40 | 7.28 | 4.84 |
| Lu | 0.36 | 0.39 | 0.37 | 0.30 | 0.42 | 0.33 | 0.35 | 0.48 | 0.45 | 0.38 | 0.44 | 0.37 | 1.12 | 0.74 |
| Be | 0.79 | 0.51 | 0.65 | 4.50 | 4.35 | 3.11 | 3.99 | 4.49 | 5.85 | 0.79 | 3.71 | 4.20 | 4.69 | 4.45 |
| Ge | 1.25 | 1.21 | 1.23 | 1.15 | 1.14 | 1.15 | 1.15 | 1.26 | 1.14 | 1.15 | 1.18 | 1.46 | 1.11 | 1.29 |
| Hf | 2.15 | 2.37 | 2.26 | 8.77 | 7.79 | 6.68 | 7.74 | 6.15 | 6.01 | 3.01 | 5.06 | 4.62 | 6.75 | 5.69 |
| Ta | 0.33 | 0.23 | 0.28 | 1.24 | 0.99 | 0.85 | 1.02 | 0.76 | 2.59 | 0.31 | 1.22 | 0.80 | 1.90 | 1.35 |
| Bi | 0.10 | 0.10 | 0.10 | 0.17 | 0.25 | 0.34 | 0.26 | 0.16 | 0.55 | 0.10 | 0.27 | 0.26 | 0.87 | 0.56 |
| U | 1.00 | 0.50 | 0.75 | 23.36 | 63.33 | 13.15 | 33.28 | 10.80 | 16.20 | 1.50 | 9.50 | 7.10 | 8.28 | 7.69 |

On a spider diagram multi element profiles normalised to primitive mantle (Sun & Macdonough 1989) (figure 10), the micrgranular enclaves has patterns showing enrichment of Large Ion Lithophile Element (LILE) Ce relative to Hgh Field Strength Elements(HFSE) and Heavy Rare Earth elements(HREE) Nb,Zr,Ti,Y and Yb. This is similar to typical patterns for volcanic arc granites.They point to the enrichment of Ce and Sm in Calc-alkaline and Shonshonitic Series and also to low value of Yb relative to the normalising composition in the volcanic arc granites.The enhanced level of LL element relative to HFS element in enclaves points to the subduction zone enrichment and/or crustal contamination of the source region (Pearce *et al* 1984) (figure 11).The chondrite normalised Rare Earth Element(REE) diagrams of Nakamura (1984) fig 9 show everall moderately steep patterns characterised by a negative slope with overall enrichment in the LREE relative to HREE with negative Eu anomaly.The patterns indicate mantle fractionated LREE and poorly fractionated HREE.

## SUMMARY AND CONCLUSIONS

From field evidences, a flow texture of the fabric, where syntectonic movement is noticed. Enrichment of biotite at places occurs and migmatisation of magma is evidenced. Different models have been proposed for mechanisms of mixing and hybridization in plutonic environment. Vernon (1983) and Castro *et al.* (1990) attributed mixing and hybridization through a single step intrusion of mafic magma into felsic magma chamber while other workers (Dorais *et al*., 1990; Kumar, 2010) explained hybrid nature of enclaves by two stage process involving in-situ mixing of two end members to produce hybrid magmas which subsequently generated enclaves. Perguni and Poli (2000) and Perguni *et al*. (2003) have argued that interaction of mafic and felsic magmas is a chaotic process depending largely on rheological behaviour of two magmas. Initially when mafic magma is introduced into crystallizing felsic host, strong rheological difference between two magmas do not allow large scale interaction. Temperature of hotter mafic magma rapidly decreases as a consequence of injection into slightly colder felsic host which results in heating of crystallizing host. This process narrows down thermal and rheological differences of two magmas leading to physical interaction including introduction of crystals from host into mafic magma as well as dispersal of mafic magma into felsic host as enclaves (Perguni *et al*., 2003).From the TAS classification of Cox *et al* (1979) and Middlemost,(1994) shows the enclaves to fall in the acidic field i.e granodiorite field and 2 dykes are falling in the gabbro field. As per the FeO-$K_2O$+$Na_2O$-MgO plot (fig 5), it is clear that the rock is moderately rich in $K_2O$+$Na_2O$ which means it is an alkali granite. The AFM plot after Irvine and Baragar(1971) (fig 5),suggests the magma to be of Calc-alkaline in nature and for the dykes the magma is of tholeiitic series. The major Oxides plotted in the R1-R2 diagram of De La Roche *et al* (1980) (fig 7), falls in the granodiorite field except for the dykes they are within the gabbro/ultramafic.The major Oxides data plotted in the R1-R2 diagram of Batchelor and Bowden,1985 (fig 8) which is primarily a major element based on geotectonic classification has classified the enclaves as syncollision to mantle fractionates.

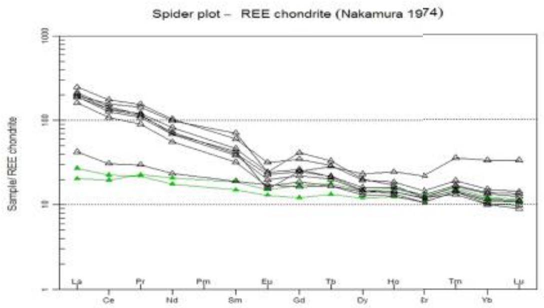



Fig 10:Chondrite normalized rare earth element patterns of the enclaves,part of Nalgonda district,after Nakamura,1974

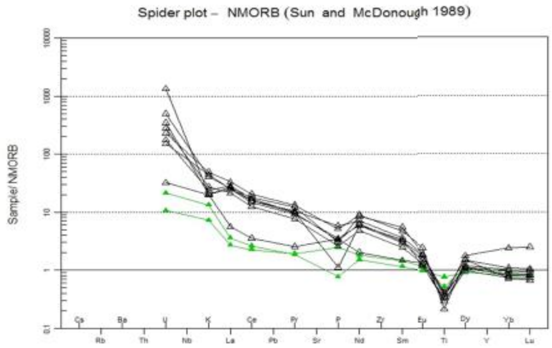



Fig 11 :Normalized primitive mantle rare earth element patterns of the enclaves,part of Nalgonda district,after Sun and Mcdonough,1989.

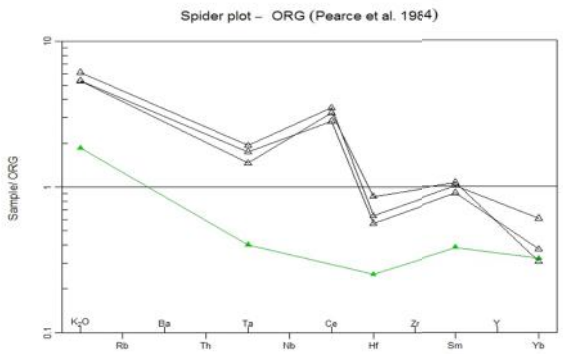



Fig 11:Granite discrimination element patterns of the enclaves,part of Nalgonda district,after Pearce et al,1984

The characteristic chondrite normalised REE pattern of granite shows strong negative Eu anomaly suggesting early separation of plagioclase (Nakamura 1974). And with normalised to primitive mantle (Sun & Macdonough 1989 ) (figure 10), the enhanced level of LL element relative to HFS element in microgranular enclaves points to the subduction zone enrichment and/or crustal contamination of the source region (Pearce *et al* 1984) (figure 11). The eastern Dharwar province contains only younger basement (2.7-2.6 Ga) and 2.57-2.53 Ga juvenile plutons and diatexites (Krogstad *et al*., 1995; Peucat *et al*., 1993; Rogers *et al*., 2007). The mafic magma may form blobs and be scattered in the felsic host to form mafic magmtic enclaves (MME). Mingling increases surface contact of mafic and felsic components in magma chamber leading to chemical transfer between MME and granitoid host (Barbarin, 2005) which is documented in field photo 2. The injection and rapid cooling of successive pulses of mafic magma into granodioritic-granitic magma resulted in the formation of the observed enclaves. (Torkian, Ashraf; Furman,Tanya, 2015)

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