J. Ind. Geophys. Union (November 2016)
v.20, no.6, pp: 551-557

Petrology and geochemistry of the troctolite and ultramafic from the Paleoproterozoic Kandra Ophiolite Complex, Eastern Dharwar Craton, SE India

V.V. Sesha Sai

Geological Survey of India, Southern Region, Bandlaguda, Hyderabad-India-500068
E-mail : seshu1967@gmail.com

ABSTRACT

Field and petrological studies indicate the presence of two spatially associated high Mg lithounits; troctolite and ultramafic within the southern gabbros of the Paleoproterozoic Kandra Ophiolite Complex (KOC), Eastern Dharwar Craton, SE India. Petrographic studies indicated that troctolite is essentially composed of olivine and plagioclase with sub-ordinate augite, while magnetite and ilmenite are noticed as accessory oxides. Mineral chemistry studies by EPMA reveal that olivine in troctolite is forsterite ($Fo_{63.14}$) plagioclase is labrodorite ($An_{69.96}$) and the Fe-Ti oxide ilmenite in troctolite analysed TiO_2-53.08 %, FeO^T-44.22%). Major oxides of troctolite indicated SiO_2 - 43.10%, TiO_2 - 0.29%, Al_2O_3 -15.81%, FeO - 10.44%, Fe_2O_3 - 5.56%, CaO-7.92% and MgO - 13.08%. Petrographically, ultramafic is essentially composed of magnesio hornblende with subordinate chlorite, while ilmenite is the accessory oxide phase. Mineral chemistry studies by EPMA of the ultramafic indicate that the magnesio hornblende analysed SiO_2 – 43.71%, Al_2O_3 -14.61%, FeO – 15.35% and MgO - 9.94%, while chlorite analysed SiO_2 – 27.02%, Al_2O_3 -22.6%, FeO – 19.75% and MgO - 19.7%. Ilmenite in the ultramafic analysed FeO – 45.14%, TiO_2 – 53.44%. Major oxides of ultramafic indicated SiO_2 - 28.6%, TiO_2 - 0.65 %, Al_2O_3 - 17.22 %, FeO – 6.84 %, Fe_2O_3 - 6.88%, CaO – 0.41% and MgO- 26.84%. HFSE depletion is noticed in both these high Mg lithounits; (Zr- 42.17 ppm, Nb-2.65ppm and Y-5.35ppm) in troctolite and (Zr- 40.13ppm, Nb-2.47ppm and Y-3.16 ppm) in ultramafic. Rare Earth Element (REE) geochemical studies indicate that these spatially co-existing troctolite and ultramafic show an overall depleted but contrasting REE patterns. Troctolite exhibits a low magnitude positive Eu anomaly while the ultramafic exhibit a negative Eu anomaly indicating co-magmatic origin of the mafic-ultramafic lithounits in the southern gabbros of KOC.

Key words: Troctolite, ultramafic, Kandra ophiolite, Eastern Dharwar Craton and India.

INTRODUCTION

The extrusive basic igneous rocks at the Kandra area were initially studied by Roy (1944) who designated them as "Kandra volcanics". Subsequently Subramanyam (1966) studied the rocks representing the "Kandra volcanics" and the associated granite intrusives and opined that these rocks were emplaced during the time gap between close of Archaean Dharwar and deposition of Proterozoic Cuddapah rocks. Nagaraja Rao et al., (GSI, 1990) carried out Geological mapping around Kandra area and established the stratigraphy in the area and redesignated the Kandra volcanics as Kandra Igneous Complex (KIC). Rao (1992) during the field studies observed that Kandra area in the Nellore schist belt (NSB) consists of para and ortho metamorphics, basic igneous rocks belonging to two different periods of intrusion migmatites, granites and pegmatites and hence proposed that the term "Kandra volcanics" be restricted to amygdaloidal amphibolites and ortho amphibolites. Leelanandam (1990), based on geological setup of the rocks exposed around Kandra area and their disposition in the regional geological and structural setup was the first to suggest the "possible" ophiolitic nature of Kandra volcanics. Based on the geological setting and available the ages of the granitic rocks around the Kandra area in southern part of NSB, an age of ~1500 Ma was suggested for emplacement of Kandra dolerites (Rao et al., 2004). Extensive field and petrological studies (Sesha Sai, 2005) indicated the presence of parallel sheeted dolerite dykes with profound chilled margins in the area to ENE of Kandra. Further by identifying the presence of veins of oceanic plagiogranite in a sheeted dyke near Gollapalle area to the NE of Kandra the oceanic crust nature of Ultramafic-mafic suite at Kandra was confirmed; hence KIC was designated as Kandra Ophiolite Complex (KOC; Sesha Sai, 2009). Vijaya Kumar (2010) carried out geochronological studies and assigned a U-Pb age of 1.85 Ga to the oceanic crust of Kandra in SE India. Saha (2011) studied the structural aspects and interpreted the dismembered nature of the Paleoproterozoic KOC. The accretionary nature of the Palaeoproterozoic oceanic crust at Kandra along the SE India and its tectonic significance was discussed by Vijaya Kumar et al., (2010); Saha, (2011); Saha and Mazumder, (2012).

Geological Set Up

KOC occurs as a discordant mafic-ultramafic Complex in the southern part of NSB in Eastern Dharwar Craton (EDC). Situated close to the eastern margin of the Proterozoic Cuddapah Basin at its southern end (Figure 1a), the WNW-ESE trending KOC is exposed over a length of 18 kms with a maximum width of 5 km in its central portion around Kandra (Figure 1). Field studies indicate the "discordant relationship" of KOC with the amphibolite and mica schist of NSB (Sesha Sai, 2005). KOC is made predominantly of two magmatic components (i) the northern dolerite and diabase dykes that represent the hypabyssal part and (ii) the southern cumulus gabbro and olivine gabbronorite that represent the plutonic part of KOC. KOC is charecterised by absence of a significant volcanic component. Caught up patches of quartz arenites and conglomerate are widely noticed in northern dykes, while field studies indicate that at the westernmost part of KOC the dolerite dykes are intrusive into the conglomerate-quartzite sequence (Sesha Sai, 2005). N-S to NNE-SSW trending younger dolerites are noticed as intrusive into the northern dykes that are charecterised by enclaves of conglomerate and quartz arenite. The sheared southern contact of the KOC and its disposition of KOC along a major fault indicate the tectonic contact of the KOC with NSB (Leelanandam, 1990; Sesha Sai, 2009). Through this communication the petrological, mineral chemistry and geochemical details of the spatially associated troctolite and ultramafic are presented in a succinct manner. Both the troctolite and ultramafic rocks are spatially associated with the southern gabbros of KOC. EPMA analyses of samples from the troctolite and ultramafic was carried out by CEMECA Sx100 Electron Probe Micro Analyzer at the EPMA Laboratory, Geological Survey of India, Hyderabad. The operating conditions were 15 kV accelerating voltage, 1–2 micron beam diameter and 12 nA current.

Troctolite

Petrographic studies indicate that troctolite is essentially composed of olivine and plagioclase with sub-ordinate augite, while magnetite and ilmenite are noticed as accessory oxide phases. Plagioclase is unaltered and exhibits characteristic lamellar twinning. Olivine in plane polarized light is colorless with high relief. In crossed nicols olivine exhibit high birefringence. The interspaces between the euhedral plagioclase laths are occupied by subhedral to anhedral grains of olivine. Development of cumulus texture; a magmatic texture indicating fractional crystallisation is noticed in troctolite. Reaction coronas between olivine and plagioclase are observed in troctolite (Figure 2a). Mineral chemistry studies by EPMA reveal that the olivine in troctolite is forsterite ($Fo_{63.14}$) plagioclase is labrodorite ($An_{69.96}$), close to the bytownite field. The Fe-Ti oxide ilmenite analysed TiO_2-53.08 %, FeO^T-44.22%. Olivine-plagioclase rich troctolite has been reported from the Sikhote-Alin ophiolite from the terrain located at the southern far east of Russia (Vysotskiy and Khanchuk, 2016). Geochemical studies reveal that the troctolite of KOC analysed (in %); SiO_2-43.10, TiO_2-0.29, Al_2O_3 -15.81, FeO-10.44, Fe_2O_3 - 5.56, CaO-7.92 and MgO-13.08 (Table-1). Trace element geochemistry (ppm) indicate depleted HFSE in troctolite; Zr- 42.17, Nb-2.65 and Y-5.35. Rare Earth Element (REE) geochemical studies indicate that the troctolite exhibits an overall depleted REE pattern with a positive Eu anomaly (Figure 3) indicating fractionation of the plagioclase from the melt. EPMA analyses of the mineral phases from the troctolite of KOC is furnished in Table-2.

Ultramafic

Petrographic studies indicate that the ultramafic is essentially composed of greenish amphibole with subordinate chlorite and accessory ilmenite. Amphibole exhibits optical characters of magnesio-hornblende and is pleochroic in shades of pale green. Minor displacement is noticed at places along the cleavage planes of the amphibole (Figure 2b). Chlorite is pale greenish in color and occurs as randomly oriented grains. Ilmenite under reflected light is grayish and anisotropic. Geochemically ultramafic analysed SiO_2 - 28.6, TiO_2 –0.65, Al_2O_3 -17.22, FeO – 6.84, Fe_2O_3 - 6.88, CaO – 0.41 and MgO- 26.84. (Table-1). Mineral chemistry studies by EPMA indicated that the amphibole analysed SiO_2 – 43.71, Al_2O_3 -14.61, FeO – 15.35 and MgO - 9.94 indicating tschermakite composition, while chlorite analysed SiO_2 -27.02, Al_2O_3 -22.6, FeO-9.75, MgO - 19.7. Ilmenite analysed FeO-44.22 and TiO_2 -53.08. Rare Earth Element (REE) geochemical studies indicate that the ultramafic exhibits a depleted REE pattern with a significant negative Eu anomaly (Figure 3). EPMA analyses of the mineral phases from the ultramafic of KOC is furnished in Table-2.

DISCUSSION

Recent field studies indicated that the troctolite and ultramafic bands occur as N35°W-S35°E bands near to the vicinity of Δ 183 (14°24':79°47'10") to the north of Arimanapadu in southern high ground of KOC. It is observed that both these spatially associated high Mg lithounits are confined to the southern gabbros; the plutonic part of the KOC. Ultramafic slivers have been reported at Kandra in the form of talc-chlorite schists (Leelanandam, 2006). Reaction coronas between olivine and plagioclase are noticed in some gabbroic rocks wherein the low pressure conditions during corona formation is well constrained by the conditions during

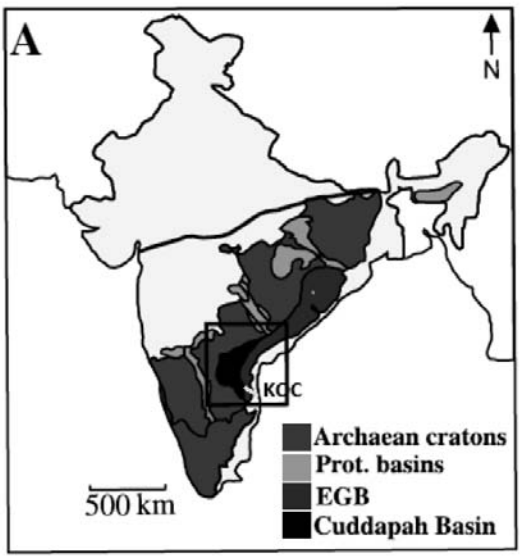

Figure 1a. Simplified Geological Map of India showing the Precambrian terrane in SE India. Note the location of KOC to the east of southern end of eastern margin of Proterozoic Cuddapah basin.

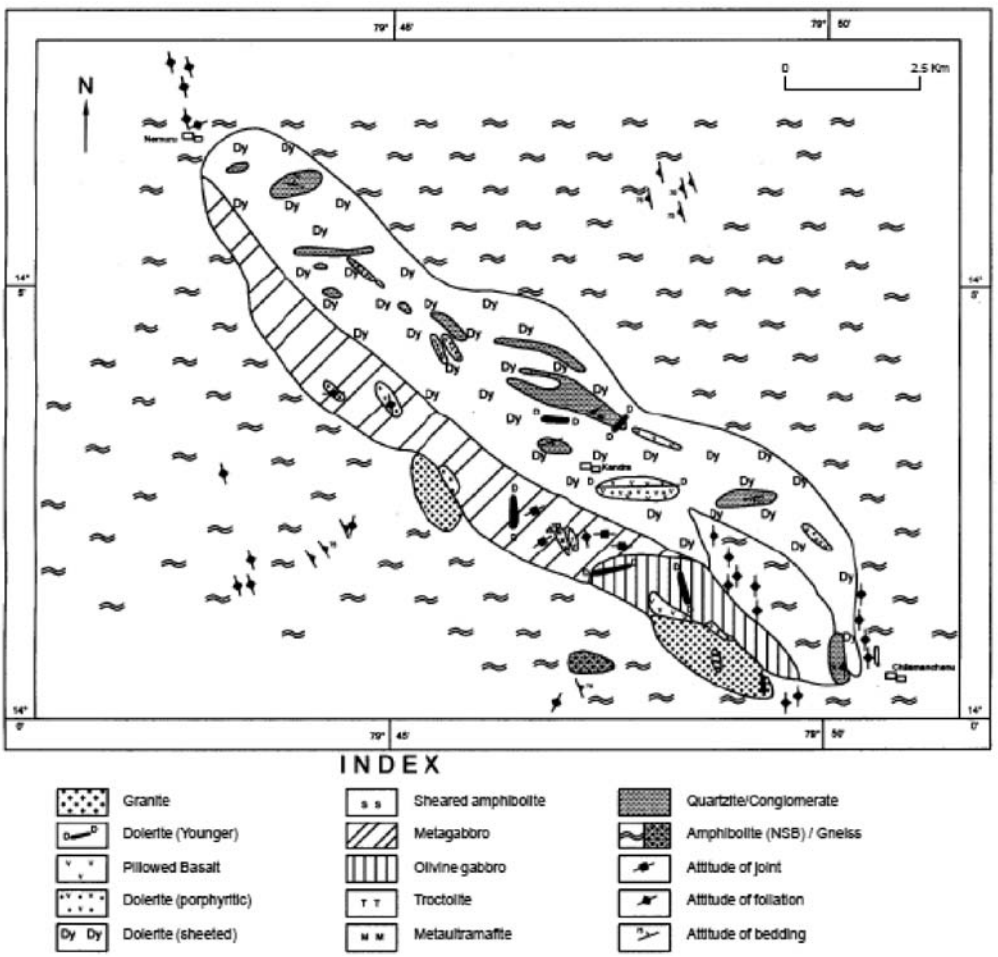

Figure 1b. Geological map of Kandra ophiolite complex, Nellore schist belt (Sesha Sai, 2009; modified after Nagaraja Rao et al., 1990)

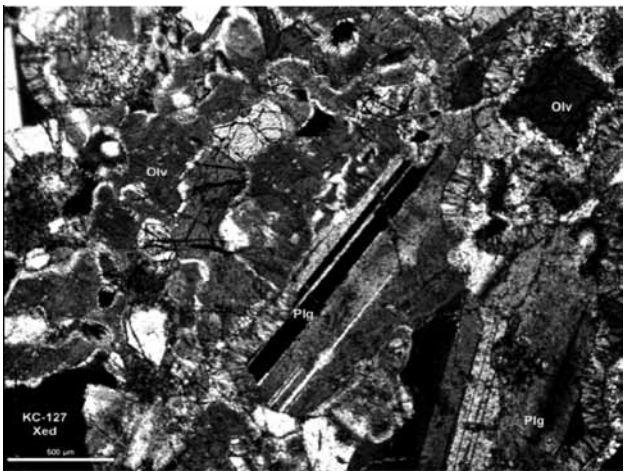

Figure 2a. Photomicrograph of olivine and plagioclase in the troctolite.

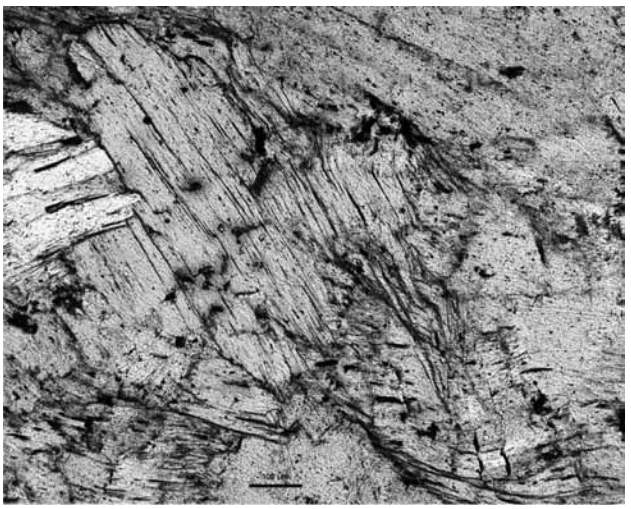

Figure 2b. Photomicrograph showing cleavage with minor displacement in magnesio hornblende.

Table 1. Geochemical analyses of Troctolite and ultramafic from KOC, EDC, India.

Major oxide (%)	**KC-127** Troctolite	**KC-125B** Ultramafic	**Trace Element (ppm)**	**KC-127** Troctolite	**KC-125B** Ultramafic
SiO_2	43.10	28.6	Th	0.95	2.17
TiO_2	0.29	0.65	U	<0.5	<0.5
Al_2O_2	15.81	17.22	Zr	42.17	40.13
Fe_2O_3	5.56	6.88	Nb	2.65	2.47
FeO	10.44	6.84	Be	<0.3	<0.3
MnO	0.19	0.1	Y	5.65	3.16
CaO	7.92	0.41	Cs	<0.2	<0.2
MgO	13.08	26.84	Hf	1.09	1.06
Na_2O	1.65	0.01	La	4.48	2.02
K_2O	0.20	0.01	Ce	9.07	5.66
P_2O_5	0.04	0.08	Nd	4.61	2.55
Cr_2O_3	0.1	0.01	Sm	1.08	0.65
LOI	0.37	11.34	Eu	0.65	0.09
TOTAL	98.66	98.99	Gd	1.01	0.68
Mg. No.	55.61	80.62	Dy	1.02	0.63

Table 2. EPMA analyses of the mineral phases from the troctolite and ultramafic of KOC.

Oxide	Mineral chemistry of the olivine, plagioclase and ilmenite from the troctolite of KOC						Mineral chemistry of the amphibole, chlorite and ilmenite from the ultramafic of KOC			
SiO_2	36.32	53.38	50.17	51.02	0.02	0.02	43.71	44.29	0.01	0.02
Al_2O_3	0.005	0.80	31.72	31.02	0.01	0.00	14.61	14.77	0.02	0.00
TiO_2	0.00	0.00	0.06	0.03	52.74	53.08	0.45	0.32	53.44	54.12
MnO	0.37	0.39	0.00	0.00	0.55	0.57	0.17	0.19	0.92	0.92
MgO	31.14	25.44	0.00	0.00	1.81	1.74	9.94	10.01	0.38	0.36
FeO	32.04	19.72	0.12	0.04	43.86	44.22	15.35	15.81	45.14	44.51
Na_2O	0.03	0.05	3.56	3.82	0.18	0.27	1.84	2.01	0.01	0.02
K_2O	0.00	0.02	0.01	0.02	0.00	0.00	0.27	0.31	0.00	0.00
CaO	0.01	0.07	14.34	14.02	0.01	0.00	11.16	11.21	0.00	0.00
Cr_2O_3	0.02	0.00	0.00	0.00	0.08	0.05	0.07	0.07	0.05	0.02
P_2O_5	0.01	0.02	0.01	0.01	0.01	0.00	0.06	0.00	0.00	0.01
Total	99.84	99.89	99.99	99.98	99.27	99.95	97.63	98.99	99.97	99.98
Si	0.994	1.311	9.156	9.295	0.001	0.001	6.456	6.459	0.001	0.001
Ti	0.000	0.000	0.000	0.000	1.995	1.997	0.050	0.035	2.017	2.036
Al	0.000	0.023	6.823	6.660	0.001	0.000	2.543	2.538	0.001	0.000
Cr	0.000	0.000	0.000	0.000	0.003	0.002	0.008	0.008	0.002	0.000
Fe(ii)	0.733	0.405	0.018	0.006	1.845	1.849	1.896	1.928	1.894	1.861
Mn	0.009	0.008	0.000	0.000	0.023	0.024	0.021	0.023	0.039	0.039
Mg	1.270	0.931	0.000	0.000	0.136	0.130	2.189	2.176	0.028	0.027
Ni	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Ca	0.000	0.002	2.804	2.736	0.000	0.000	1.766	1.751	0.000	0.001
Na	0.000	0.000	1.260	1.349	0.000	0.000	0.527	0.568	0.000	0.000
K	0.000	0.000	0.002	0.005	0.000	0.000	0.051	0.051	0.000	0.000
TOTAL	3.006	2.680	20.063	20.052	4.003	4.002	15.507	15.546	3.982	3.964
	Core	Rim	Core	Rim	Ilmenite (6 oxygens)		(Amphibole) Tschermakite (23 oxygens)		Ilmenite (6 oxygens)	
	Olivine (4 oxygens)		Plagioclase (8 oxygens)							

crystallisation of the magma as the coronas must have formed during initial igneous cooling (Turnet and Stuwe, 1992). However, presence of primary igneous texture is noticed in the troctolite in the form of development of cumulus plagioclase. Studies from the Ligurian Ophiolites of Italy (Renna and Tribuzio, 2011) indicated that the troctolite rich in olivine is crystallised from the infiltring melts showing the geochemical signatures of mid oceanic rich basalt (MORB). REE geochemical studies indicate that spatially co-existing troctolite and ultramafic show depleted REE patterns. However, troctolite exhibits a low magnitudes positive Eu anomaly indicating plagioclase fractionation from the melt giving rise to the troctolite, while in contrast the ultramafic exhibit negative Eu anomaly (Figure 3) indicating subsequent crystallisation and co-magmatic relationship with the troctolite (Sesha Sai, 2015). The observation that the Fe-Ti oxide nature of the troctolite in the southern gabbro complex of the KOC through the present study attains significance since it corroborates with the occurrence of the Fe-Ti oxide of the gabbros associated with the oceanic crust (Robinson, et al., 2000).

Eastern Gondwana Correlations

KOC is situated in the southern part of the Neoarchaean NSB (Ravikant, 2010). Magmatic evolution of some Archean greenstone belts may be related subduction-related Proterozoic ophiolites (Furnes et al., 2014). 1.85 Ga KOC of eastern Gondwana signifies events of arc–continent collisions resulting in assembly of Paleoproterozoic supercontinent Columbia (Vijay Kumar et.al.2010). Island arc basalt-type geochemical signatures are characteristic of mafic rocks of Palaeoproterozoic Kandra (Vijay Kumar et al., 2015). A significant cluster of Paleoproterozoic ophiolites has been inferred to occur along the margins of Australia, Antarctica and India (Moores, 2002, Vijay Kumar et al., 2010, Santosh, 2012). Palaeoproterozoic perhaps witnessed the Nuna supercontinent assembly 1.9–1.8 Ga (Reddy and

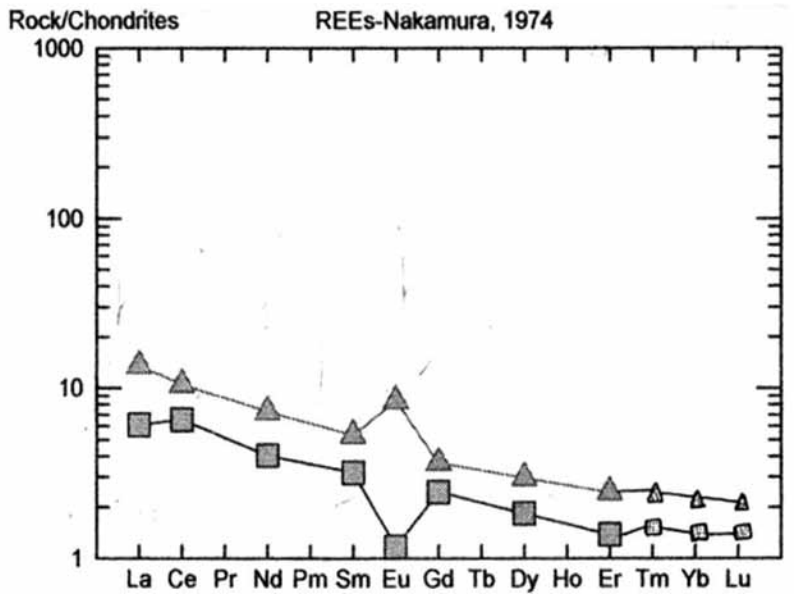

Figure 3. Chondrite normalised REE pattern for troctolite (▲) and ultramafic (■) of KOC.

Evans, 2009). In this context KOC in SE India attains geological significance to correlate the Paleoproterozoic subduction related processes in eastern Gondwana.

CONCLUSIONS

Field studies revealed the existence of two mafic-ultramafic lithounits; troctolite and ultramafic in southern part of KOC. Field disposition attains significance since both these lithounits are confined to the southern gabbros of the KOC; that represent the plutonic component of the Kandra oceanic crust. Incidentally it is observed that the conglomerate-arenite caught patches are confined to the northern dyke Complex, the hypabyssal part of the KOC. Petrographic studies indicate cumulus plagioclase in the troctolite, a feature indicating fractionation of the Ca rich plagioclase from the melt. The high Mg nature of troctolite (13.08 % MgO) and ultramafic (26.84 % MgO) along with the HFSE depletion in both these lithounits indicate the mantle source. REE geochemical studies reveal a depleted but contrasting chondrite normalised REE patterns; a positive Eu anomaly in troctolite and a negative Eu anomaly in ultramafic, indicating a magmatic origin for the mafic-ultramafic suite of rocks from the Paleoproterozoic Kandra Ophiolite Complex, EDC, SE India.

ACKNOWLEDGEMENTS

Shri.S.Kannan, ADG (Retd.), GSI, is profusely thanked for according permission to publish the work. Prof. C. Leelanandam and Dr. T.R.K. Chetty are gratefully acknowledged for helpful discussion and encouragement to publish this paper. Shri. S.T.Narahari, GSI, Hyderabad is thanked for EPMA facility while Dr. S. Bhattacharjee and Dr. Vikash Tripathy are thanked for constructive suggestions. Dr.P.R.Reddy, Chief Editor, IGU is thankfully acknowledged for valuable support.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

Furnes Herald, Maarten de Wit and Yildirim Dilek., 2014. Four billion years of ophiolites reveal secular trends in oceanic crust formation. Geoscience Frontiers, v.5, no.4, pp: 571–603.

Leelanandam, C., 1990. The Kandra volcanic in Andhra Pradesh: A possible ophoilite, Current Science, v.59, pp: 785-888.

Leelanandam C., Burke K., Ashwal L. D., Webb S. J., 2006. Proterozoic mountain building in Peninsular India: an analysis based primarily on alkaline rock distribution. Geological Magazine, v.43, pp: 195-212.

Moores, E.M., 2002. Pre - 1 Ga (pre-Rodinian) ophiolites; their tectonic and environmental implications, Geological Society of America Bulletin, v.114, pp: 80-95.

Nagaraja Rao, B. K., Katti, P.M., and Roop Kumar, D., 1990. Geology of Kandra Igneous Complex, Nellore district, A.P. Unpub. Prog. Rep. G.S.I. FS 1989-90.

Nakamura N., 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochim. Cosmochim. Acta v.38, pp: 757-775.

Rao, A.T., 1992. The Kandra Igneous Complex from the Precambrian Nellore schist belt, Andhra Pradesh. Jour. Appl. Geochem., v.6, no.1, pp: 1-14.

Rao, A.T., Chalamiah, K., Srinivasa Rao, D., Devavarma, D., and Dhananjaya Rao, E.N., 2004. Dolerites from Kandra Volcanic Region, Nellore schist belt, A.P. Jour. Appl. Geochem., v.6 no.1 pp: 1-14.

Ravikant, V., 2010. Palaeoproterozoic (1.9 Ga) extension and breakup along the eastern margin of the Eastern Dharwar Craton, SE India: New Sm–Nd isochorn age constraints from anorogenic mafic magmatism in the Neoarchean Nellore greenstone belt. Jour. Asian Earth Sci., v.12, pp: 67-81.

Reddy S. M., and Evans D. A. D., 2009. Palaeoproterozoic supercontinents and global evolution: correlations from core to atmosphere. In S. M., Mazumder R., Evans, D. A. D. And Collins, A. S edited Geological Society Special Publication, Palaeoproterozoic Supercontinents and Global Evolution., no.323, pp: 1-26.

Renna M.R., and Tribuzio, R., 2011. Olivine-rich Troctolites from Ligurian Ophiolites (Italy): Evidence for Impregnation of Replacive Mantle Conduits by MORB-type Melts. Journal of Petrology. doi: 10.1093/petrology/egr029

Robinson, P.T., Dick, H.J.B., and Narlad, J.H., 2000. ODP Leg Shipboard part. Lower oceanic crust formed an ultra-slow. spreading ridge, Oceanic Drilling Program Hole 735 B, South west Indian Ridge, Geological Society of America, Special paper, pp: 75-86.

Roy, B.C., 1944. The Nellore mica belt, Geol. Surv. India. Bull. Econ. Geologist., no.11 pp: 156.

Saha Dilip, 2011. Dismembered ophiolites in Paleoproterozoic nappe complexes of Kandra and Gurramkonda, South India. Journal of Asian Earth Sciences, 10 August , v.42, no.3, pp: 158–175.

Saha, D., and Mazumder, R., 2012. An overview of the Palaeoproterozoic geology of Peninsular India, and key stratigraphic and tectonic Geological Society of London, Special Publications, v-365, pp: 5-29.

Santosh M., 2012. India's Palaeoproterozoic legacy. Mazumder, R. & Saha, D. (eds) 2012. Palaeoproterozoic of India. Geological Society, London, Special Publications, v.365, pp: 263–288.

Sesha Sai, V.V., 2005. Petrographic, petrochemical and mineral chemistry studies of Kandra Igneous Complex, Nellore schist belt, Andhra Pradesh. Rec. GSI, v.138, Part-5, pp: 229-233.

Sesha Sai, V.V., 2009. Sheeted dykes in Kandra Ophiolite Complex, Nellore schist belt, Andhra Pradesh-Vestiges of Precambrian Oceanic crust. Jour.Geol.Soc.Ind., v.74, pp: 509-514.

Sesha Sai, V.V., 2015. Geochemical evidence for magmatic origin of the Paleoproterozoic Kandra mafic-ultramafic suite, SE India - Implications from REE studies of troctolite and ultramafic. 25th Goldschmidt conference, Abstract 1769.

Turnet and Stuwe Kurt, 1992. Low-pressure corona textures between olivine and plagioclase in unmetamorphosed gabbros from Black Hill, South Australia. Mineralogical Magazine, December 1992, v.56, pp: 503-509.

Subramanyam, P., 1966. Studies on Kandra volcanics of Nellore district, A.P. (Abstract). Seminar on mafic and ultramafic rocks of India, Osmania University, Hyderabad. pp: 45-46.

Vijaya Kumar, K., Ernst, W.G., Leelanandam, C., Wooden, J.L., Grove, M.J., 2010. First Paleoproterozoic ophiolite from Gondwana: geochronologic–geochemical documentation of ancient oceanic crust from Kandra, SE India.Tectonophysics. v.487, pp: 22-32.

Vijaya Kumar, K., Rathna, K., and Leelanandam, C., 2015. Proterozoic subduction-related and continental rift-zone mafic magmas from the Eastern Ghats Belt, SE India: geochemical characteristics and mantle sources. Current Science, v.108, no.2, pp: 1-14.

Vysotskiy, S.V., and Khanchuk, A.I., 2016. Different-depth gabbro–ultrabasite associations in the Sikhote-Alin ophiolites (Russian Far East). Russian Geology and Geophysics v.57, no.1, pp: 1-14.