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Petrology and Geochemical Study of Calc-Alkaline Lamprophyres from South of Garla Area Bank of Munneru River, Eastern Dharwar Craton, Telangana South India

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ABSTRACT

The Eastern Dharwar Craton (EDC) in southern India frequently features lamprophyre dykes, with the present study identifying two new dykes near South of Garla village. Petrographic and geochemical analyses were conducted on these dykes, which intrude the granitoids of the Peninsular Gneissic Complex-II (PGC-II) within the EDC. Petrographic examination revealed a panidiomorphic texture, with clinopyroxen, biotite, and amphibole as phenocrysts, and k-feldspar, plagioclase feldspar, and biotite in the groundmass. The lamprophyre's composition is characterized by varying levels of SiO2, Fe2O3, MgO, CaO, K2O, TiO2, and Al2O3, alongside elevated concentrations of trace elements such as Ba, Sr, Ni, Zr, V, and Cr. The lamprophyre is classified as minette of the Calc Alkaline Group based on its geochemical and petrological attributes.

Introduction:

India boasts numerous occurrences of lamprophyres, spanning from the Precambrian to the Cretaceous period, with a significant concentration found in the Eastern Dharwar Craton (EDC). The EDC is home to a diverse array of lamprophyres, primarily found in two main regions: (i) along the western margin of the Cuddapah Basin within the EDC, known as the Wajrakarur Kimberlite Field (WKF), where lamprophyres of calc-alkaline and/or shoshonitic compositions are commonly observed (Pandey et al., 2017a, 2017b, 2018a), and (ii) the Prakasam Alkaline Province (PAP) (Leelanandam, 1989) or the 'Cuddapah intrusive province' (CIP) (Madhavan et al. 1995) To the east of the Cuddapah Basin, at the convergence point of the EDC and the Eastern Ghats Mobile Belt (EGMB), lamprophyres are predominantly alkaline in nature, although some exhibit shoshonitic characteristics (Madhavanet al., 1998; Chalapathi Rao, 2008).

The lamprophyres of EDC are known to be associated with greenstone belts, granite gneisses and in particular with Kimberlite clan of rocks (KCR). Lamprophyres in EDC are reported from WKF, Precambrian Penakacherla schist belt, Mudigubba lamprophyre at the western margin of Cuddapah basin, Bayyaram Lamprophyre at the northeastern margin of the EDC in the western margin of Pakhal basin, Khammam district and lamprophyres of Prakasam Alkaline Province (PAP). Some of the lamprophyres are reported in NE margin of EDC to the north of Khammam at Polayapalli. In Nallamalai fold belt of Cuddapah basin, earlier K.Appavadhanulu followed by NMS Rock classified mafic intrusive as lamprophyres but, Scott Smith confirmed these rocks as lamproites (LL).

Dominantly two generations of lamprophyres are found in EDC viz. Neo-Archaean age and Meso-Proterozoic ages.

In Khammam district few isolated lamprophyre are reported which are intruded within the granites (Appavadhanulu1971; Subrahmanyam et al.1987; Meshram et al.2015; Adhikary et al. 2016a and Adhikary et al. 2016c, Adhikary 2024a and Adhikary 2024b). The present correspondence reports the first occurrence and petrographic and geochemistry study of a two lamprophyre dykes near south of Garla Village bank of Munneru River .

Regional Geology:

Lamprophyre dykes are abundant in the cratons of India, with the EDC hosting the greatest variety and quantity of these rocks. Along both the eastern and western margins of the Cuddapah Basin, significant occurrences of lamprophyric rocks are found, collectively referred to as the CIP or PAP (Fig:1A). In the CIP large number of lamprophyre cluster is present which is mainly intruded within the nepheline syanite. In the other side in PAP lamprophyre cluster is found mainly intruded within the gabbro body (Madhavan et al.1998; Ratnakar et al.1980;1992;1994). In the garla area, Khammam district previously one lamprophyre occurrence was reported by earlier worker (Subrahmanyam et al.1987) north of the presently found lamprophyre. Presently found lamprophyres were intruded with the granitoid body (Fig:2). This dyke measures approximately 1 to 1.5

meters in width and has an exposed strike length of around 40 meters. Trend of the lamprophyre is N35°W and its cut the granitoid foliation (Fig:3A&B). These lamprophyre dykes are mesocratic to melanocratic, fine granied in nature. Porphyritic texture present in the rock. Groundmass and phenocryst both the mode is present. Occllar structure is not observed in these dykes.

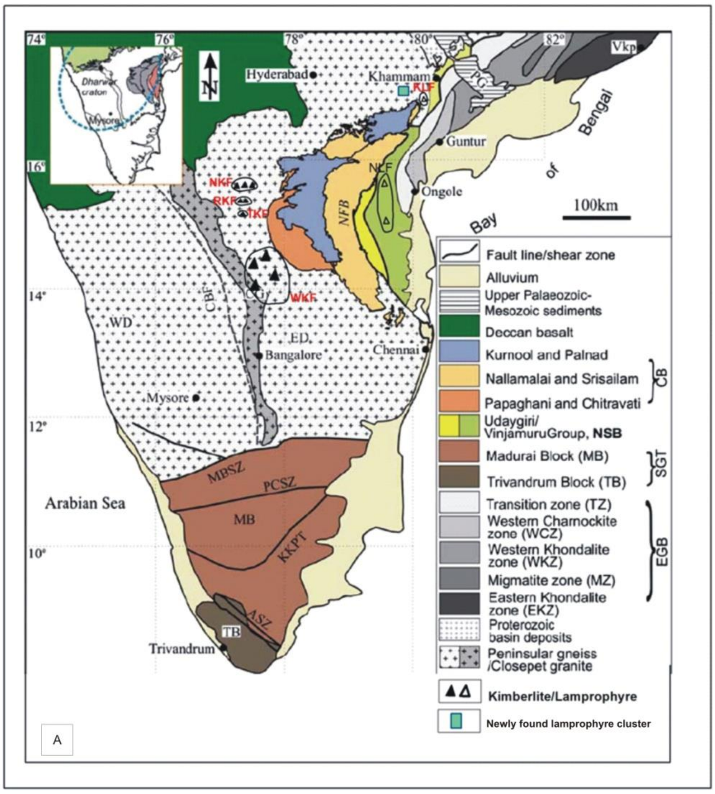

Fig.1A. Location of study area in Khammam district, Telangana (after Naqvi, 2005).

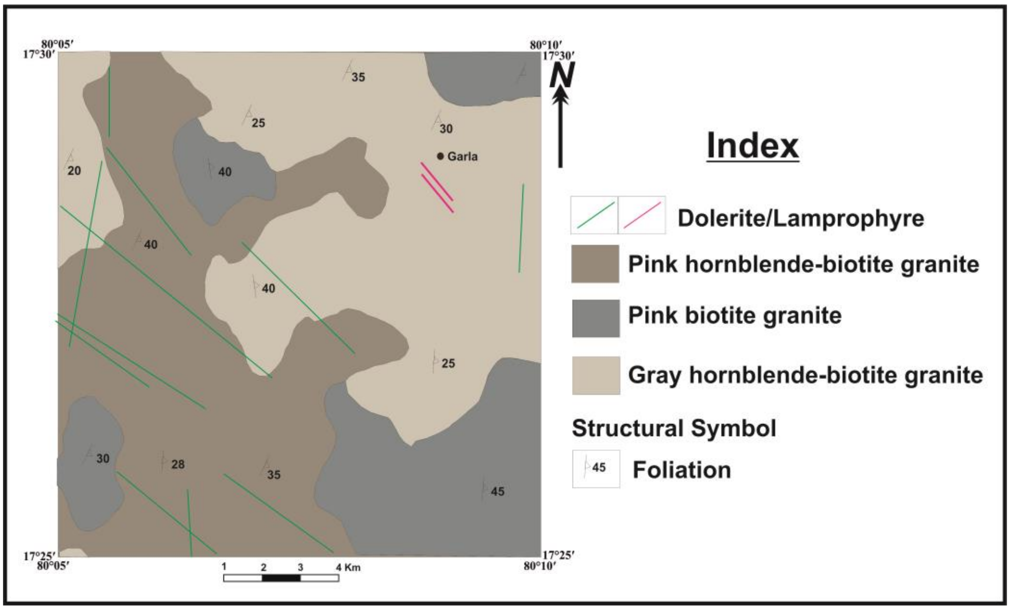

Fig. 2. Geological map of the study area (Adhikary,2022).

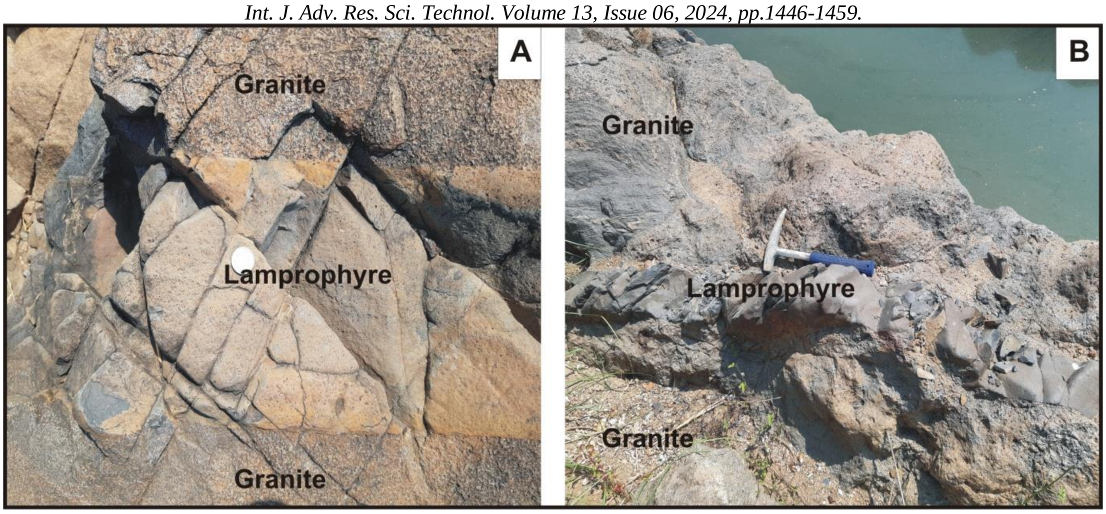

Fig. 3. A. Intrusive Lamprophyre dyke in and around Garla area,
B. Field photo show that sharp contact between Granite and Lamprophyre.

Methods of analysis:

Mineral chemistry analysis of various phases within the lamprophyres south of Garla was conducted using the CAMECA SX100 Electron Probe Micro Analyzer (EPMA) available at GSI facilities in Kolkata and Faridabad. Operating parameters included an acceleration voltage of 15 kV, a beam current of 20 nA, a beam diameter of 1 µm, and a counting time of 10 s. Calibration of the microprobe was performed using standard minerals such as albite for (Na, Al), rhodonite for (Mn), diopside for (Ca, Mg), TiO2 for (Ti), orthoclase for (K, Si), chromium for (Cr), and almandine for (Fe). The analysis results for selected and representative mineral phases are presented in Tables 1, 2, 3, and 4.

At the Chemical Laboratory of the Geological Survey of India (GSI) in Kolkata, India, both major and trace element analyses of whole rock samples were conducted. Major oxides were analyzed using X-ray fluorescence spectrometry, while trace and rare earth element (REE) concentrations were determined using ICP-MS. The precision of the analyses was ensured to be <2% for all elements when reported at 100X detection limit. To verify accuracy and precision, several standards were run alongside the samples. The data for major oxides, trace elements, and REEs are presented in Tables 5, 6, and 7, respectively. Standardized CIPW norms for all samples were automatically calculated using the IgROCS computer program (Verma et al.2013).

Petrography and mineral chemistry:

Under microscope, the rock consists of biotite, K feldspar, plagioclase, sphene, calcite, pyrite, chalcopyrite. The rock shows porphyritic texture. The phenocrysts are mainly dark mica and rarely Cpx and Cpx is altered to amphiboles and then to biotite. The ground mass consists of mainly biotite, K-feldspar, plagioclase, calcite and sphene . The mica phenocrysts having a size of up to 0.8mm and the altered Cpx is upto1.2mm. The ground mass is very fine grained. The Cpx is altered to serpentine (Fig:4A&B). The altered phyllosilicate minerals give a turbid appearance to the rock. Apatite is present as a major accessory phase exhibiting two distinct grain size and at places elongated crystals are also noticed. Pyrite and chalcopyrite is seen within the rock.

Under microscope, these lamprophyre from Garla shows panidiomorphic porphyritic texture (Fig:4C), the phenocrysts are mainly dark mica and Cpx and the ground mass consists of biotite, K-feldspar, plagioclase, calcite, chlorite and minor amphiboles. With in the Cpx grain compositional difference is recorded . Other than these, apatite, zircon, epidote and opaque minerals seen as accessory phases. Pyrite, chalcopyrite, REE mineral phase is also noticed. The dark mica are subhedral to euhedral in phenocryst, which having a length of 6.1mm. The Cpx is mainly subhedral to euhedral shape in phenocrysts and varies in size from 0.8 x 0.8mm to 2 x 3.7mm (Fig:4D). Some of the small sized phenocrytsare altered to serpentine, talc and chlorite. Muscovite is seen in a small amount. Some of the feldspars shows lath shaped. Some of the Cpx is fractured and carbonates are seen along the fracture. Inclusions of apatite in mica imply their earliest crystallization in the magma. Biotite and plagioclase are also seen within the groundmass.

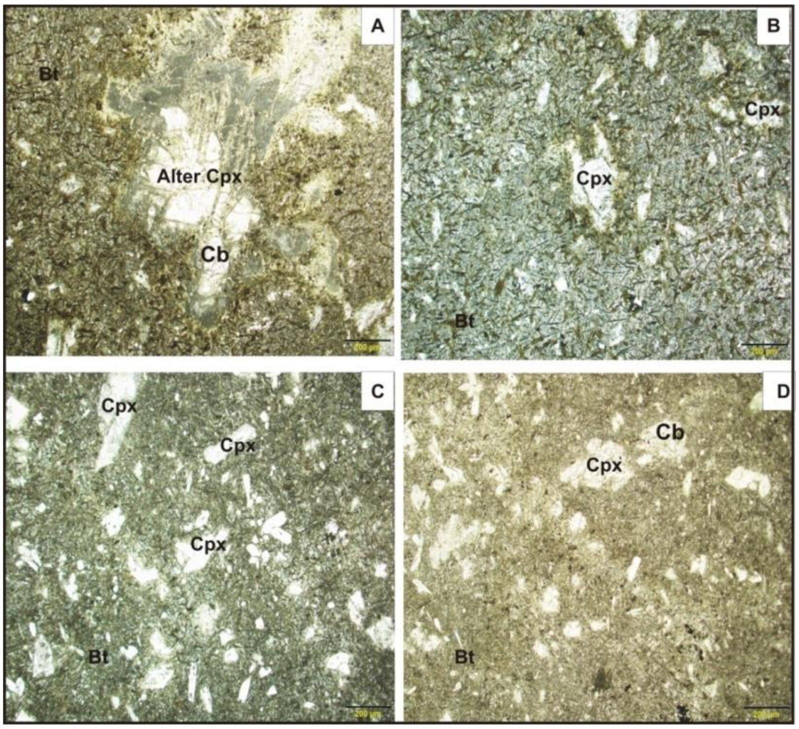

Fig:4A Carbonate altered mafic minerals in Garla Lamprophyres.
Fig:4B Presence of Clinopyroxene phenocryst in Garla Lamprophyres.
Fig:4C Garla lamprophyres shows panidiomorphic porphyritic texture in thin section.
Fig:4D Subhedral to euhedral shape Cpx in Garla Lamprophyres.

Clinopyroxene: In the lamprophyre sample (DA 61 and 62) under study, clinopyroxenes are mainly diopsidic (Fig:5A &B) (Wo47-51 En46-51 Fs9-09) in nature (Fig:6A). Al and Ti values for clinopyroxene when plotted onCa (a.p.f.u) vs. Ti (a.p.f.u) diagram (Fig:6C), show orogenic nature of the lamprophyre.

Amphibole: The majority of the amphiboles present are of the actinolite variety (see Fig:6B). Actinolite is typically not found in igneous rocks, indicating that its presence likely results from the metamorphism of pre-existing amphiboles in the presence of a hydrous melt. (Leake et. al 1997) These samples exhibit depletion in Al2O3, K2O, and TiO2, indicating a calc-alkaline magma nature (see Fig:6D). This is further supported by the TiO2 (wt%) versus SiO2 (wt%) plot (see Fig:6D) (after Rock, 1991) for the amphibole suggesting calc-alkaline nature of the studied lamprophyres.

Feldspar: In the Garla lamprophyre feldspars are present essentially as groundmass (Fig:5C&D). The feldspars are of albitic composition. The average composition range of the feldspar is Or0 Ab85-92 An 6-14.It is depleted in FeO.

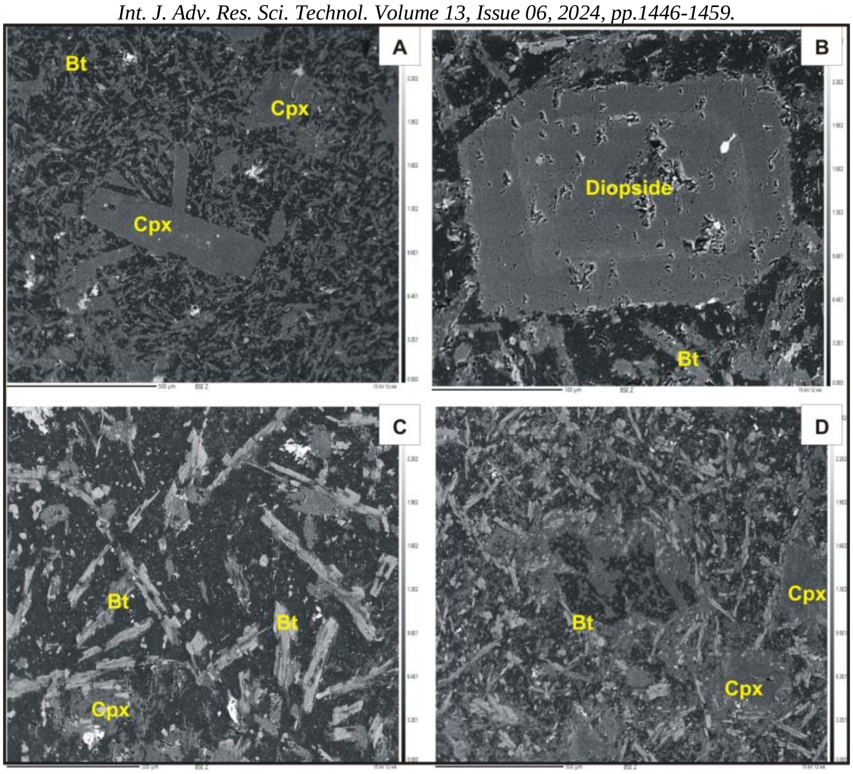

Fig:5A BSE image of elongated CPX present in the Garla lamprophyres.
Fig:5B BSE image of presence of compositional difference in Clinopyroxene (Diopside) phenocryst in Garla Lamprophyres.
Fig:5C BSE image of groundmass portion of the Garla Lamprophyres.
Fig:5D BSE image of biotite,Cpx and ground mass portion of the Garla Lamprophyres.

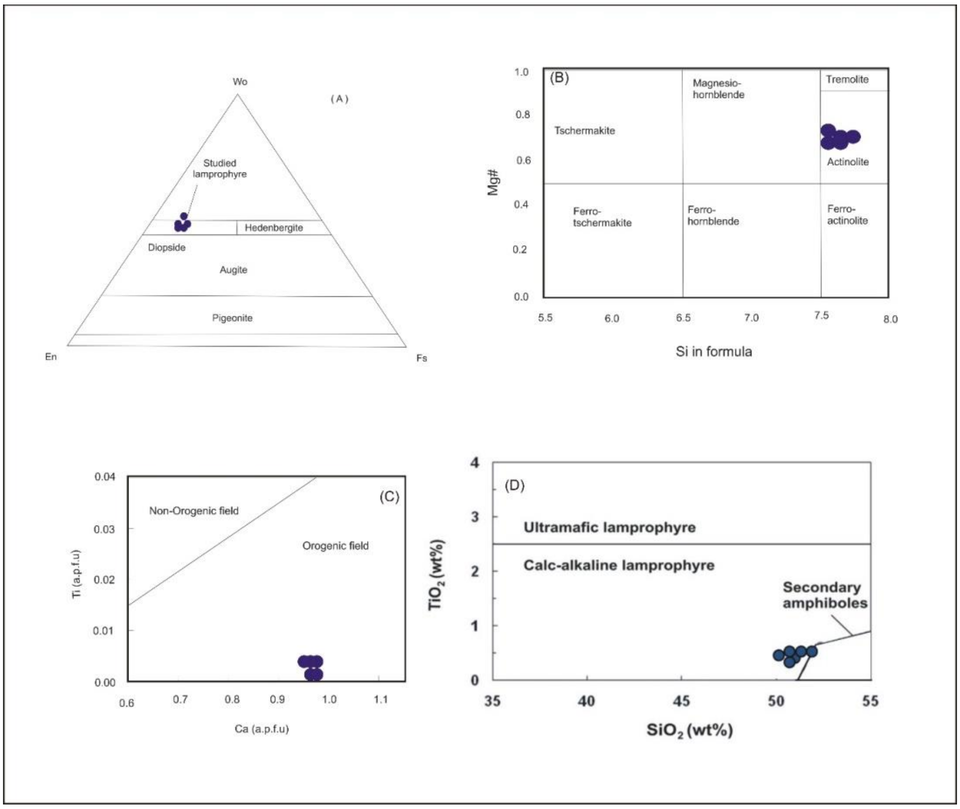

Fig. 6. **A**. The pyroxene classification diagram illustrates the diopsidic nature of the clinopyroxenes found in the Garla lamprophyre (see Fig. B). The Si vs. Mg# plot, adapted from Leake et al. (1997), aids in the classification of amphiboles from the Garla lamprophyre (see Fig. C). Additionally, the Ti (a.p.f.u) versus Ca (a.p.f.u) plot, based on Sun and Bertrand (1991), demonstrates the orogenic affinity of the clinopyroxenes (see Fig. D). Lastly, the TiO2 (wt%) versus SiO2 (wt%) plot, following Rock (1991), suggests the calc-alkaline nature of the studied Garla lamprophyre.

Table 1: The typical clinopyroxene assays (wt%) from the southern Garla lamprophyres

Oxide Wt%	1	2	3	4	5	6	7	8	9	10
	CPX1	CPX2	CPX3	CPX4	CPX5	CPX6	CPX7	CPX8	CPX9	CPX10
SiO2	51.06	50.47	52.51	50.8	49.38	48.38	51.32	48.94	51.46	48.52
TiO2	0.7	0.93	0.49	0.62	1.29	1.55	0.7	1.67	0.61	1.62
Al2O3	3.11	3.54	1.83	3.15	4.31	5.17	2.92	5.17	2.86	4.96
Cr2O3	0.79	0.15	0.34	0.88	0.13	0	0.46	0.09	0.77	0.29
FeO	4.82	6.07	4.76	4.89	6.94	8.75	4.8	7.48	4.87	6.57
MnO	0.01	0.23	0.16	0.13	0.24	0.1	0.12	0.25	0	0.05
MgO	15.93	15.26	16.77	15.82	14.88	11.58	15.93	13.73	16.19	14.16
CaO	22.05	21.66	22.12	22.01	21.05	22.75	22.05	21.29	21.52	22.43
Na2O	0.38	0.43	0.3	0.35	0.44	0.46	0.34	0.48	0.36	0.37
K2O	0.01	0.02	0	0	0.02	0	0	0	0	0.01
Total	98.86	98.76	99.28	98.65	98.68	98.74	98.64	99.1	98.64	98.98
Cations for 6 oxygen atoms										
Si	1.89	1.88	1.93	1.89	1.84	1.83	1.90	1.83	1.91	1.81
Ti	0.02	0.03	0.01	0.02	0.04	0.04	0.02	0.05	0.02	0.05
Al	0.14	0.16	0.08	0.14	0.19	0.23	0.13	0.23	0.13	0.22
Cr	0.02	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.02	0.01
Fe3+	0.05	0.07	0.04	0.05	0.08	0.05	0.04	0.05	0.03	0.09
Fe2+	0.10	0.12	0.11	0.10	0.14	0.23	0.11	0.18	0.12	0.12
Mn	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Mg	0.88	0.85	0.92	0.88	0.83	0.65	0.88	0.76	0.90	0.79
Ca	0.87	0.86	0.87	0.88	0.84	0.92	0.88	0.85	0.86	0.90
Na	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	4	4.01	3.99	4.02	4	3.98	3.99	3.99	4.02	4.02
En	0.47	0.46	0.48	0.47	0.46	0.36	0.47	0.43	0.48	0.44
Fs	0.05	0.07	0.06	0.05	0.08	0.13	0.06	0.10	0.07	0.06
Wo	0.47	0.47	0.46	0.47	0.47	0.51	0.47	0.47	0.46	0.50

Table 2: Analyses (wt%) of amphiboles from the Sooth of Garla lamprophyres that are representative

Oxide Wt%	1	2	3	4	5	6	7
	AMP1	AMP2	AMP3	AMP4	AMP5	AMP6	AMP7
SiO2	50.14	53.71	55.76	54.54	55.37	54.25	56.8
TiO2	0.23	0.06	0.03	0.11	0.05	0.04	0
Al2O3	6.43	1.76	1.08	1.81	1.26	2.05	0.77
Cr2O3	0.21	0	0.09	0.22	0.08	0.05	0.1
FeO	9.47	7.53	6.24	8.36	7.73	7.9	5.42
MnO	0.12	0.35	0.27	0.24	0.2	0.15	0.13
MgO	16.1	18.81	20.11	17.96	18.95	18.59	19.92
CaO	12.68	13.25	12.78	12.39	12.57	12.59	12.73
Na2O	0.86	0.23	0.33	0.27	0.29	0.41	0.24
K2O	0.36	0.13	0.08	0.21	0.1	0.15	0.09
Total	98.85	98.013	99.32	98.35	98.91	98.46	98.35
Cations for 23 oxygen atoms							
Si	7.24	7.72	7.82	7.80	7.84	7.73	8.00
Ti	0.02	0.01	0.00	0.01	0.01	0.00	0.00
Al	1.09	0.30	0.18	0.31	0.21	0.34	0.13

Cr	0.02	0.00	0.01	0.02	0.01	0.01	0.01
Fe3+	0.13	0.08	0.22	0.13	0.18	0.19	0.00
Fe2+	1.02	0.82	0.51	0.87	0.73	0.76	0.64
Mn	0.01	0.04	0.03	0.03	0.02	0.02	0.02
Mg	3.46	4.03	4.20	3.83	4.00	3.95	4.18
Ca	1.96	2.04	1.92	1.90	1.91	1.92	1.92
Na	0.24	0.06	0.09	0.07	0.08	0.11	0.07
K	0.07	0.02	0.01	0.04	0.02	0.03	0.02
Total	15.26	15.12	14.99	15.01	15.01	15.06	14.99

Table 3: Representative mineral chemistry data (wt%) for feldspar from the lamprophyre south of Garla.

Oxide Wt%	1	2	3	4	5	6
	FELDS1	FELDS2	FELDS3	FELDS4	FELDS5	FELDS6
SiO2	67.58	67.17	66.52	68.21	64.94	67.81
Al2O3	19.25	19.77	20.13	19.45	20.9	19.5
FeO	0.28	0.48	0.34	0.18	0.1	0.15
CaO	0.72	0.91	1.15	0.22	2.52	0.37
Na2O	11.41	10.76	10.14	11.01	9.49	11.44
K2O	0.07	0.09	0.1	0.24	0.35	0.03
BaO	0.06	0.03	0.1	0.04	0.14	0.03
TOTAL	99.37	99.21	98.48	99.35	98.44	99.33
Cations for 8 oxygen atoms						
Si	2.975863	2.96339	2.948632	2.993939	2.89842	2.984426
Al	0.999134	1.028059	1.051745	1.006265	1.099495	1.011579
Ti	0.002318	0	0.001	0	0	0
Fe	0.010312	0.01771	0.012604	0.006608	0.003733	0.005521
Ca	0.033972	0.043018	0.054621	0.010347	0.120516	0.017449
Na	0.974229	0.920463	0.871539	0.93705	0.821289	0.976278
K	0.003932	0.005065	0.005654	0.013437	0.019925	0.001684
Ba	0.001035	0.000519	0.001737	0.000688	0.002448	0.000517
Total	5.000795	4.978224	4.947532	4.968334	4.965826	4.997454
Or	0.388458	0.522908	0.606776	1.39845	2.071825	0.16919
Ab	96.25506	95.0356	93.53142	97.52468	85.39703	98.0779
An	3.35648	4.441493	5.8618	1.07687	12.53114	1.752913

Table 4: Representative mineral chemistry data (wt%) for biotite from the lamprophyre south of Garla.

Oxide Wt%	1	2	3	4	5	6
	Bt 1	Bt 2	Bt 3	Bt 4	Bt 5	Bt 6
SiO2	31.96	35.42	34.78	33.53	33.98	33.03
TiO2	4.1	3.13	3.8	3.75	3.68	4.36
Al2O3	14.26	15	13.88	15.16	13.84	13.96
FeO	18.9	17.48	17.98	19.89	17.55	18.39
MnO	0.24	0.25	0.19	0.16	0.28	0.25
MgO	10.23	11.22	11.93	10.42	11.63	10.53

CaO	0.4	0.7	0.07	0.05	0.11	0.19
Na2O	0.12	0.79	0.17	0.06	0.06	0.18
K2O	7.87	6.51	8.18	8.14	8.27	8.14
Cr2O3	0	0	0	0	0	0.06
Total	88.08	90.05	90.98	91.16	89.4	89.09
Cations for 22 oxygen atoms						
Si	5.259626	5.552403	5.490686	5.328127	5.464028	5.364865
Al iv	2.740374	2.447597	2.509314	2.671873	2.535972	2.635135
Al vi	0.025736	0.323972	0.073472	0.167629	0.087205	0.037487
Ti	0.507443	0.369005	0.451166	0.448154	0.445034	0.532589
Fe	2.601269	2.291655	2.373899	2.643329	2.360164	2.498086
Mn	0.033456	0.033196	0.025407	0.021536	0.038138	0.034395
Ca	0.070535	0.117578	0.011841	0.008513	0.018953	0.033067
Na	0.038292	0.240127	0.052039	0.018487	0.018708	0.05669
K	1.652007	1.301675	1.647174	1.649888	1.696228	1.686412
Cr	0	0	0	0	0	0.007705
OH*	4	4	4	4	4	4
Ba	0.256638	0.16461	0.173817	0.212317	0.184607	0.197925
TOTAL	17.18538	16.84182	16.80882	17.16985	16.84904	17.08436

Geochemistry

Whole rock major and trace element analyses were conducted at the Chemical Laboratory of the GSI in Hyderabad. Major oxides were analyzed using X-ray fluorescence spectrometry, while ICP-MS was employed to determine trace and REE concentrations. The precision for all analyzed elements is maintained at less than 5% when reported at 100X detection limit. To ensure accuracy and precision, several standards were analyzed alongside the samples. The data for major oxides, trace elements, and REEs are presented in Tables 4, 5, and 6. Standardized CIPW norms for all samples were computed automatically using the IgROCS computer program (Verma et al.2013).

Garla lamprophyres are characterized (Table:5) by SiO_2 (45.95%-47.83%), Fe_2O_3 (9.78%-11.39%), MgO (8.91%-10.87%), CaO (7.91%-11.49%), K_2O (0.15%-2.58%), TiO_2 (1.20%-1.35%) and Al_2O_3 (11.14%-12.16%) contents. Similarly trace elements analysis (Table:6) of the lamprophyre show that, its contain higher amount of Ba (3279-3844 ppm), Sr (535-884 ppm), Ni (198-237 ppm), Zr (423-740 ppm),V(163-181 ppm) and Cr(285-388 ppm). REE analysis of the samples indicates that, total REE contain (Table: 7) of the rock is more than 1500 ppm (1588-1983 ppm). All the samples show this rock is enriched in LREE.

Major oxide data is plotted in the MgO(wt%) versus SiO_2 (wt%) diagram (Lefebvre et al.2005) (Fig:7A) and it shows that these lamprophyres belongs to Calc-alkaline group. SiO_2 vs Na_2O+k_2O diagram (Rock, N .M .S 1987) (Fig: 7B) and SiO_2 (wt %) vs TiO_2 (wt%) plot (Rock, N .M .S 1991)also suggest that these lamprophyres are calc-alkaline verity (Fig:7C) .CIPW norm calculation data also support these lamprophyres as a calc-alkaline in nature (Rock, N .M .S 1977) (Fig: 7D).Major oxide data is used for the identifying the source region of the lamprophyres rock.Al_2O_3 vs TiO_2 diagram(Muller D et al.1993 (Fig:8A) and K_2O vs TiO_2 diagram(Thorpe R.S1987) (Fig:8B) confirmed that these lamprophyres magma have been generated subduction related source. All samples have been plotted in the overlapping area between the subduction zone and within-plate fields, showing a greater affinity towards the subduction zone. Trace elements and the REE data have been plotted in different diagrams for understanding the character of the south of garla lamprophyres. Discrimination diagram (Pearce et al.1973) based on trace elements Nb/Pb vs V/Cr also support the calc-alkaline nature (Fig:9A).These rocks are crystallized from the LREE enriched magma revealed from the chondrite-normalized REE pattern(Nakamura 1974) (Fig;9B). In multi element plots, these lamprophyres show negative Ta-Nb anomalies which also indicates subduction related setting of these rocks (Foley 1987; Peacock 1990; Saunders 1992 and Kent 1995).Plagioclase fractionation is indicated by presence of negative Sr and Eu anomalies (Wood et al.1979) (Fig:9C) in these rocks. Chondrite normalized multi element diagrams (Thompson,R.N et.al 1984)(Fig:9D) indicates that the lamprophyres south of Garla are significantly enriched in incompatible elements and exhibit a negative anomaly in K and Sr, suggesting the presence of phlogopite mica in their source.

Table 5: Representative major oxide analysis of South of Garla lamprophyres

Sample No	PCS-61/1	PCS-61/2	PCS-61/3	PCS-62/1	PCS-62/2	PCS-62/3
SiO2	47.83	47.7	46.12	46.48	45.95	46.25
Al2O3	11.57	11.56	11.79	11.14	12.16	11.27
Fe2O3	10.49	10.53	9.78	11.18	11.39	10.24
MnO	0.13	0.14	0.12	0.17	0.21	0.15
CaO	11.41	11.49	11.01	8.31	8.61	7.91
MgO	9.76	9.76	9.77	10.87	8.91	10.71
Na2O	3.31	3.27	3.71	2.34	2.39	2.53
K2O	0.18	0.21	0.15	2.45	2.31	2.58
TiO2	1.32	1.34	1.24	1.22	1.35	1.2
P2O5	1.51	1.48	1.51	1.4	1.43	1.46
VAL_MG	68.50	68.42	70.02	70.98	66.31	72.46
OR_NORM	1.10	1.28	0.94	15.29	14.55	16.31
AB_NORM	28.99	28.65	28.95	20.91	21.56	22.90
AN_NORM	16.75	16.82	15.97	13.37	16.66	12.59
NE_NORM	0.00	0.00	2.34	0.00	0.00	0.00
LC_NORM	0.00	0.00	0.00	0.00	0.00	0.00
DI_NORM	25.56	26.02	25.37	16.51	15.31	15.40
OL_NORM	14.78	15.25	17.93	20.03	15.85	21.28
MT_NORM	2.40	2.41	2.29	3.64	3.74	3.38
IL_NORM	2.59	2.64	2.50	2.45	2.73	2.44
AP_NORM	3.62	3.55	3.71	3.43	3.53	3.62

Table 6: Representative trace element analysis of South of Garla lamprophyre (ppm)

Sample No	PCS-61/1	PCS-61/2	PCS-61/3	PCS-62/1	PCS-62/2	PCS-62/3
Ba	3752	3279	3844	3544	3315	3736
Co	41	41	36	38	39	31
Cr	316	313	285	323	388	292
Cu	66	65	59	51	67	39
Ga	24	23	15	23	26	14
Nb	29	30	7	34	36	6
Ni	237	232	218	222	219	198
Pb	171	174	51	121	110	33
Sc	21	22	20	21	25	20
Sr	724	685	543	738	884	535
V	168	170	165	163	181	164
Y	37	38	29	37	42	26
Zn	109	112	95	154	111	131
Zr	625	609	423	670	740	407
Th	175	170	163	143	164	128
Rb	5	5	2	116	81	83

Table 7: Representative analysis of REEs (ppm) from the lamprophyre south of Garla.

Sample No	PCS-61/1	PCS-61/2	PCS-61/3	PCS-62/1	PCS-62/2	PCS-62/3
La	475.40	467.13	404.40	515.45	478.95	407.49
Ce	808.14	783.32	710.33	870.07	811.24	725.27
Pr	102.67	98.84	86.48	110.44	102.66	87.43

Nd	341.60	334.55	287.06	368.63	338.03	294.37
Sm	43.96	42.26	39.43	46.74	42.79	40.03
Eu	8.87	8.40	7.94	8.94	8.75	8.06
Gd	36.45	34.72	32.85	38.60	35.53	33.19
Tb	3.08	2.88	2.76	3.20	2.97	2.78
Dy	10.21	9.35	9.13	10.60	9.66	9.17
Ho	1.51	1.38	1.33	1.59	1.41	1.35
Er	4.44	4.08	3.75	4.65	4.23	3.82
Tm	0.51	0.45	0.43	0.53	0.47	0.45
Yb	3.04	2.74	2.57	3.14	2.80	2.62
Lu	0.45	0.40	0.38	0.47	0.41	0.39
Total	1840.31	1790.51	1588.84	1983.06	1839.90	1616.40

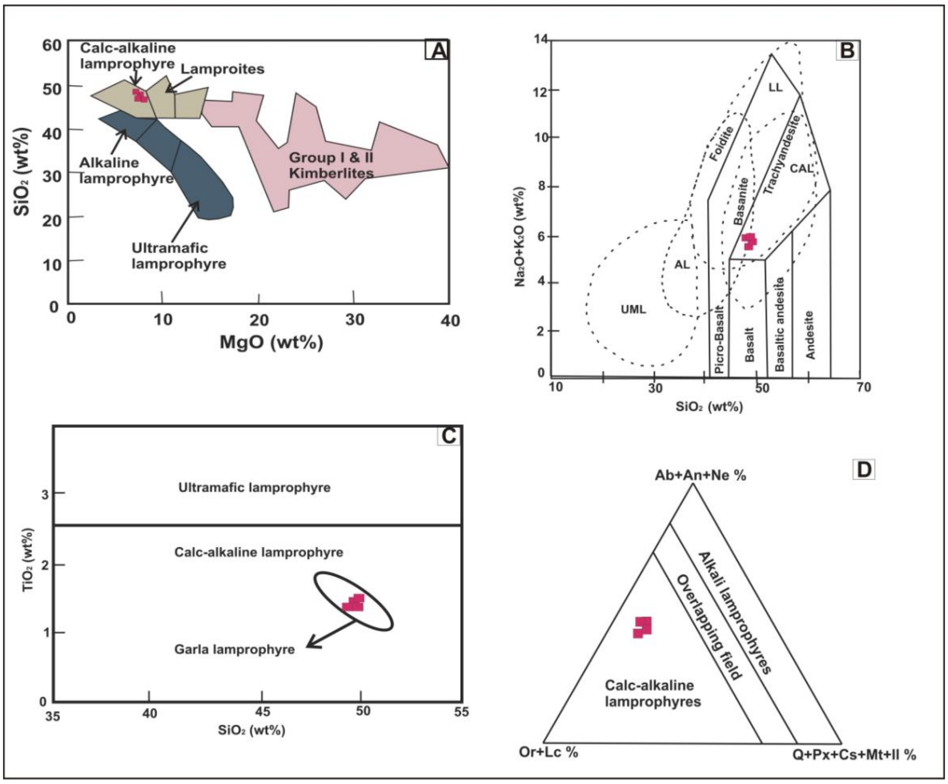

Fig. 7. **A.** MgO vs SiO2 discrimination plot for various alkaline mafic potassic and ultrapotassic rocks. **B.** Plot of SiO2 versus (Na2O + K2O) for lamprophyres, including categories such as CAL, AL (Alkaline lamprophyres), UML (Ultrabasic lamprophyres), and LL. **C.** TiO2 vs SiO2 plot indicating the calc-alkaline nature of the Garla lamprophyre. **D.** Diagram distinguishing calc-alkaline from AL using normative parameters.

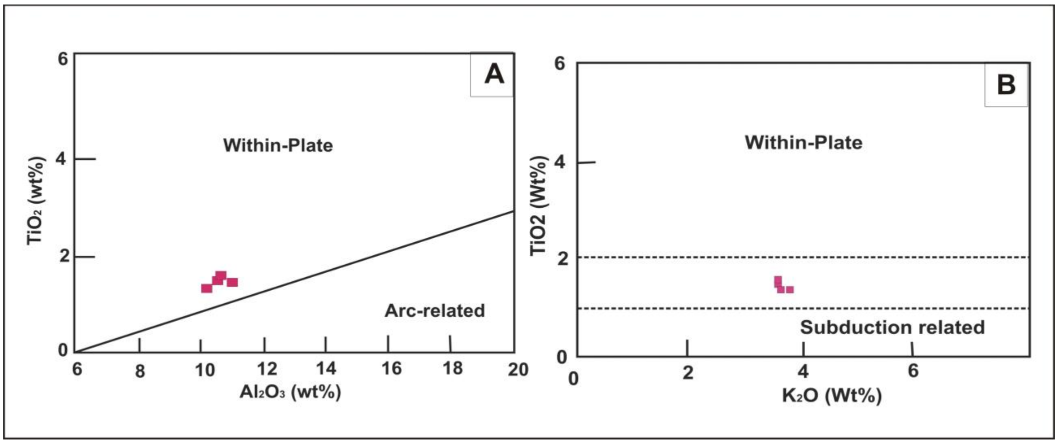

Fig. 8. **A.** Al2O3 vs TiO2 discrimination plot to differentiate within-plate and arc-related basalts. **B.** K2O vs TiO2 plot to distinguish between within-plate and subduction-related K-rich mafic **lavas.**

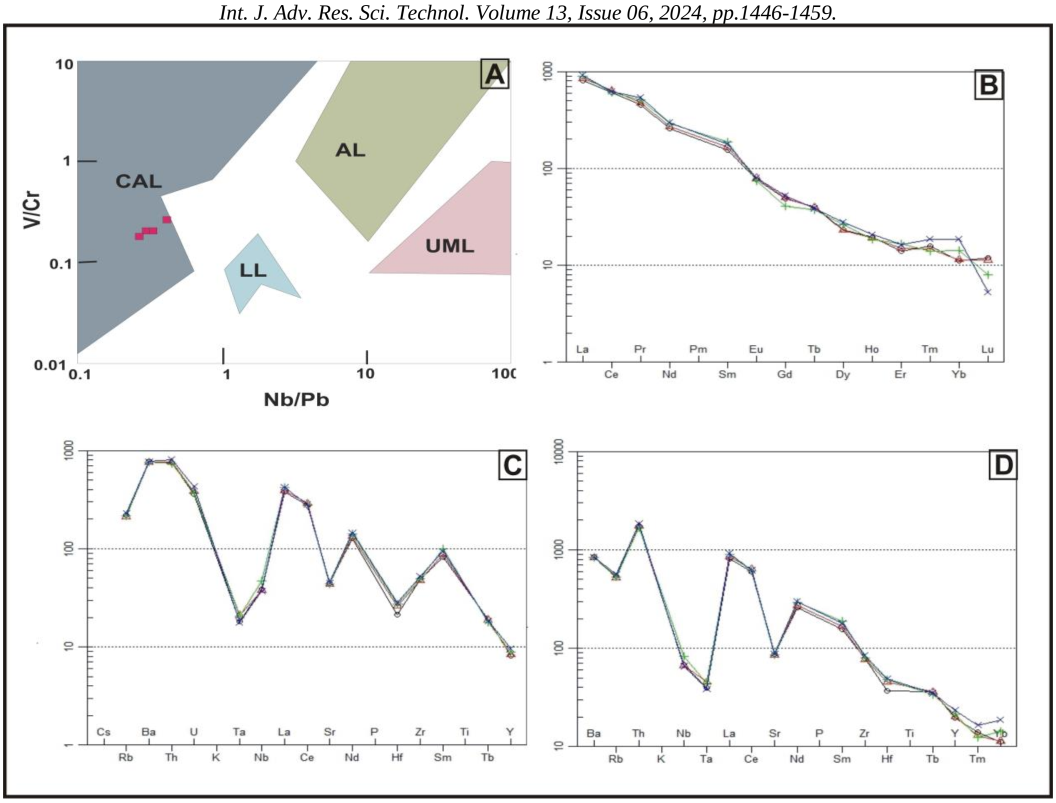

Fig. 9. **A.** Simple discrimination of lamprophyre types using trace element ratios of Nb/Pb vs V/Cr. **B.** Chondrite-normalized REE pattern for the Garla lamprophyre. **C.** Primordial mantle-normalized multi-element pattern for the Garla lamprophyre. **D.** Chondrite-normalized multi-element diagrams of the Garla lamprophyre.

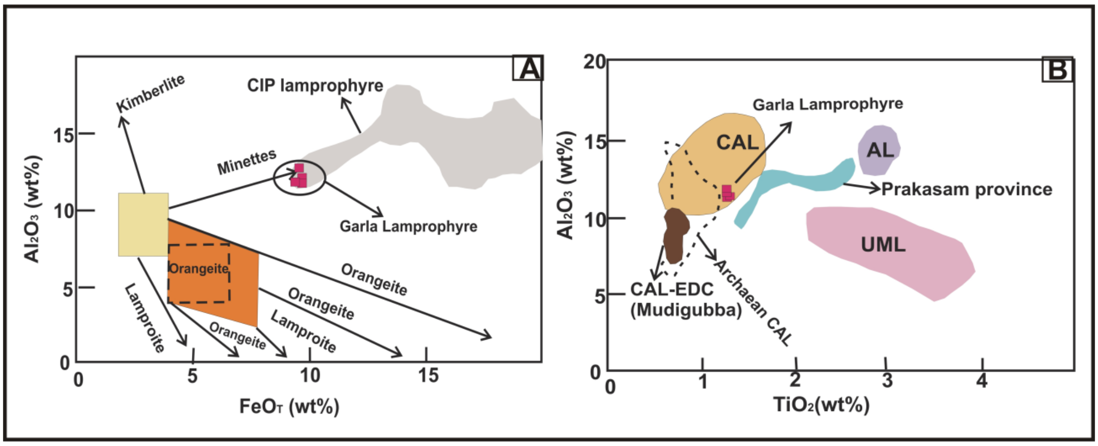

Fig. 10. **A.** FeOT vs Al2O3 variation diagram for the Garla lamprophyre illustrating fractionation trends of minette-type lamprophyres. **B.** Al2O3 vs TiO2 classification plots for the Garla lamprophyres, with fields for CAL, AL, UML, and Archaean CAL from various cratons, as referenced from Lefebvre et al. (2005). The field includes lamprophyres from the Prakasam Province at the eastern margin of the Cuddapah basin. (Madhavan et al. 1998; Kumar and Rathna2008; Meshram et al. 2015); Eastern DharwarCraton CAL- Mudigubba (Pandey et al.2017a; Pandey et al.2017b).

Discussion

FeO_Tvs Al_2O_3diagram (Mitchell 1995) show that these south of Garla lamprophyres belongs minette variety (Fig:10A).Al_2O_3 vs TiO_2 diagram show present lamprophyres data plotted well within CAL field (Fig:10B).In this diagram comparative study was done between south of Garla lamprophyres and other CIP/PAP lamprophyre and Mudigubba lamprophyre. This comparative show that, this rock character slightly different from the Prakasam Province field (Madhavan et al.1998; Kumar et al. 2008 and Meshram et al. 2015) as well as Mudigubba field (Pandey et al. 2017a; Pandey et al. 2017b). This lamprophyre are quite similar like Polayapalle lamprophyre of Khammam (Madhavan et al.1998).

Lamprophyre which is generated from the primary magma normally gave higher value (Rock, N .M .S 1987) of Sc,Cr,Ni and Co .South of Garla lamprophyres samples are given the relatively higher value of Sc,Cr,Ni and Co which is also suggested that this lamprophyre magma can be generated from the primary magma source. South of Garla lamprophyres samples contain higher concentration of LREE and compatible elements (Sun et al. 1989) (i.eNi,Cr) This suggests that the magma of the lamprophyres south of Garla originated from a minor degree of partial melting of peridotite mantle at considerable depths within the garnet stability zone (Ferguson et al. 1971, Hirschman et al.1999). Strong Hf negative anomaly in the samples suggests South of Garla lamprophyres magma generated from garnet stability field. The negative Sr anomaly observed in the lamprophyres south of Garla suggests either the presence of residual clinopyroxene in the source melt or depletion of Sr in the mantle source during a prior phase of melt extraction (Chalapati Rao 2004).

Possible emplacement timing of lamprophyre:

The present work studies the lamprophyres in and around south of Garla area. Direct no dating has been done in this lamprophyre. But some indirect dating phenomena can give an idea Possible emplacement timing of lamprophyres. The lamprophyres in the study area have intruded into the granitoids of the EDC but have not intruded into the Pakhal sediments. Lithopackage in the southeastern fringe of the Pakhal Basin provides evidence of low to moderate grade multi-stage deformation and greenschist to amphibolite facies metamorphism besides a prominent ~1450 Ma metamorphism event. A 1450 Ma EPMA date, obtained from a monazite grain developed at the margin of garnet possibly relates to the earliest phase of metamorphism (M_1) in the Pakhal sediments (Adhikary et al 2020). The Tonalite-Granodiorite-Monzogranite (TGM) gneiss of the EDC is found in and around Khammam area, Telangana, India. Studied lamprophyre are intruded with the TGM suite rocks. Age of the TGM suite of rocks is demarked from the zircon grain is 1629 ± 370Ma (Adhikary et al,2016c). The above TGM rock and the Pakhal sediment age data indicates that, this lamprophyre intruded after 1629 Ma and before 1450 Ma.

Conclusion:

On the combined study of petrography and the geochemistry it is clear that these two newly found lamprophyres belongs to Calc-alkaline group as a minette variety. This rock is crystallized from the LREE enriched magma show from the chondrite-normalized REE pattern. The multi-element spider diagram shows that, this rock source region related to subduction-related characteristics. In the diagram, the samples are situated in the overlapping zone between the subduction zone and within-plate field, showing a stronger association with a subduction-related source. The lamprophyres found in the south of the Garla area offer an excellent opportunity to examine the relationship between lamprophyres and granitoids, as well as to investigate the evolution of the ancient cratonic lithosphere. Therefore, the discovery of these new CALs is highly significant for understanding the regional geology and tectonic framework of the EDC.

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