Petrology and Geochemistry of Lamprophyres from Tirthal Area, in Eastern Margin of the Eastern Dharwar Craton, Khammam, Telangana, India

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Abstract

The presence of lamprophyre dykes is very common in the Eastern Dharwar Craton (EDC), southern India. The present paper reports five new lamprophyre bodies from the Tirthal area near the bank of the Muneru River (80°08′ 13.00″:17°19′ 9.0″), north of Khammam, Telangana. Petrography and geochemistry of the lamprophyre dykes are also discussed in this paper. The study area mainly consists of granitoids of Peninsular Gneissic Complex-II (PGC-II) of the EDC. The lamprophyre intrudes the granitoids of the EDC. Petrographic studies revealed the presence of panidiomorphic texture. Euhedral crystals of clinopyroxene, biotite and amphibole are present as phenocryst in the lamprophyre, while k-feldspar, plagioclase feldspar, biotite and apatite are present in the groundmass. The lamprophyre is characterized by SiO_2 (40.03%-45.23%), Fe_2O_3 (9.09%-13.45%), MgO (9.78%-11.96%), CaO (8.25%-14.78%), K_2O (0.69%-2.37%), TiO_2 (1.3%-1.53%) and Al_2O_3 (9.76%-12.02%) contents. Similarly trace elements analysis gave higher amounts of Ba (2030-10498ppm), Sr (438-925 ppm), Ni (156-225 ppm), Zr (417-590 ppm), V (141-169 ppm) and Cr(388-482 ppm). All the samples gave higher LREE values as compared to HREE with a total REE content within the range of 1108.50-2004.49 ppm. The lamprophyre is classified as minette belonging to Calc Alkaline Group based on geochemical and petrological studies.

Keywords: Titthal Lamprophyre, Eastern Dharwar Craton (EDC), Calc-Alkaline Lamprophyre (CAL)

Introduction

In India, there are number of lamprophyre occurrences ranging in age from Precambrian to Cretaceous, especially in the Eastern Dharwar Craton (EDC) which hosts the maximum number and variety of lamprophyres. The lamprophyres in the Eastern Dharwar Craton (EDC) are exposed in two-broad domains: (1) towards the western margin of the Cuddapah Basin within the Eastern Dharwar Craton mainly known as Wajrakarur Kimberlite Field (WKF) where the lamprophyres of calc–alkaline and/or shoshonitic nature are reported (Pandey et al., 2017a, 2017b), and (2) the Prakasam Alkaline Province (PAP) (Leelanandam, 1989) or the ‘Cuddapah intrusive province’ (Madhavan et al., 1998) towards the east of the Cuddapah Basin at the junction of the EDC and Eastern Ghats Mobile Belt (EGMB) where the lamprophyres are essentially of alkaline variety with a few of them displaying shoshonitic character (Madhavan et 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 the Wajrakarur kimberlite field, 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 the Prakasam Alkaline Province (PAP). Some of the lamprophyres are reported in the NE margin of the 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. Dominantly two generations of lamprophyres are found in EDC viz. Neo-Archaean age and Meso-Proterozoic ages.

In Khammam district few isolated lamprophyres are reported which are intruded within the granites (Appavadhanulu, 1971; Subrahmanyam et al., 1987; Meshram et al., 2015; Adhikary et al. 2022). At Tirthal area single lamprophyre dyke are previously reported by Adhikary et al. 2022. The present correspondence reports the first occurrence of five new dyke bodies and petrographic and geochemistry study of a lamprophyre dykes of Tirthal area.

Regional Geology

Various lamprophyre dykes are present incratons of India. EDC consists of the most number and verity of lamprophyres. In the eastern and the western margins of the Cuddapah basin lot of lamprophyric rocks are present which is recognized as Cuddapah Intrusive Province (CIP)/Prakasham Alkaline Province (PAP) (Figure 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 Tirthal area, Khammam district previously one lamprophyre occurrence was reported by earlier worker (Adhikary et al., 2022) north of the presently found lamprophyre. Presently found lamprophyres were intruded with the granitoid body (Figure 1B). These dykes are ~0.5 to 1 mt wide having ~50 mt exposed strike length on the west bank of Muneru/Pakhal River. Trend of the dyke is N35°W. Thickness and length are not same for all the dykes. Some of the lamprophyre bodies are very small only few cm scale. These small bodies are mainly apophyses of the larger body. And others are long and medium thickness. It has a sharp contact with the host granitoids (Figure 2A & 2B). In the margin of these dykes no chilled margin effect are present. Few xenoliths of the country rock are present within the dykes bodies (Figure 2F). Dykes also cut across the foliation of the granitoids, it also indicates the intrusive relationship between host rock and the lamprophyres (Figure 2E). Megascopically, these lamprophyre dykes are mesocratic to melanocratic, fine grained in nature. Branching nature also observed in these lamprophyres bodies (Figure 2C). Phenocrysts are present in the dykes and also uniformly distributed within matrix. clinopyroxene are present as a phenocryst with in melanocratic matrix component. Pitted structure is also present within the rock due to the removal of mafic phenocrysts (Figure 2D).

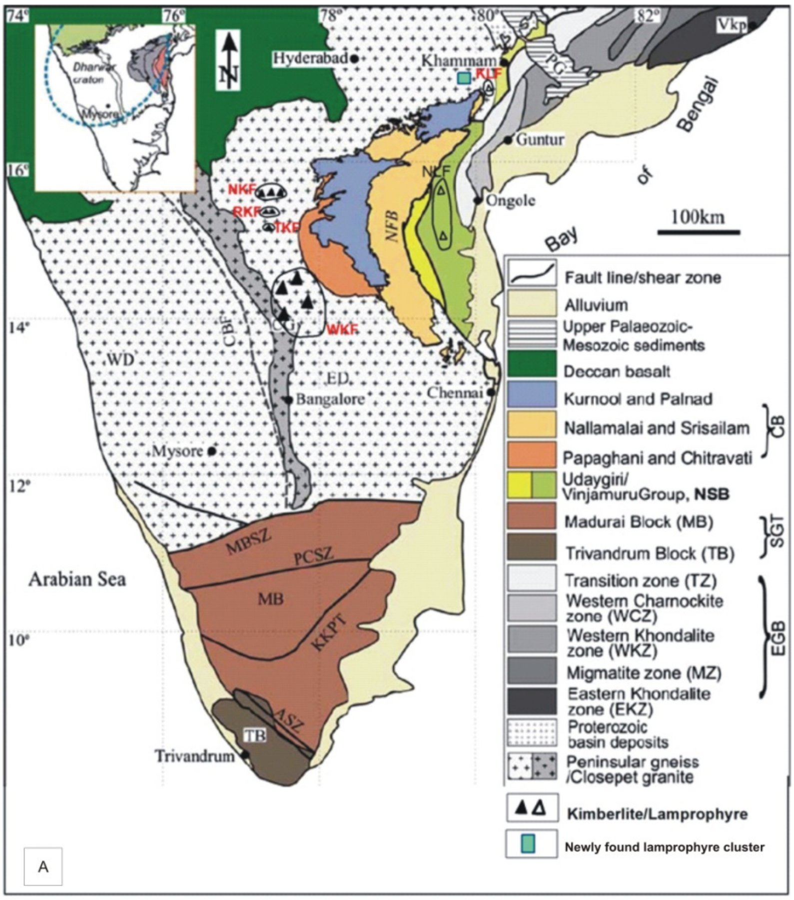

Figure 1A: Location of Study Area in Khammam District, Telangana (after Naqvi, 2005)

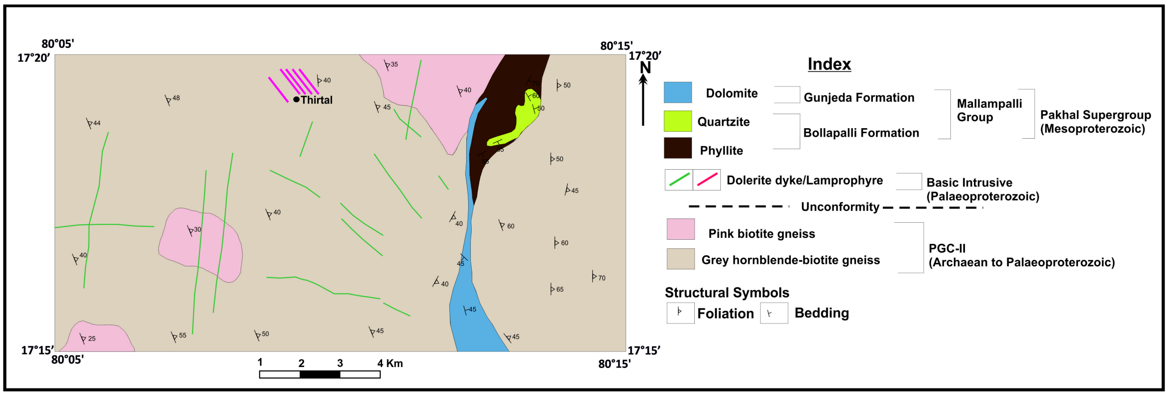

Figure 1B: Geological Map and Location of Lamprophyres in the Study Area (Adhikary, 2022)

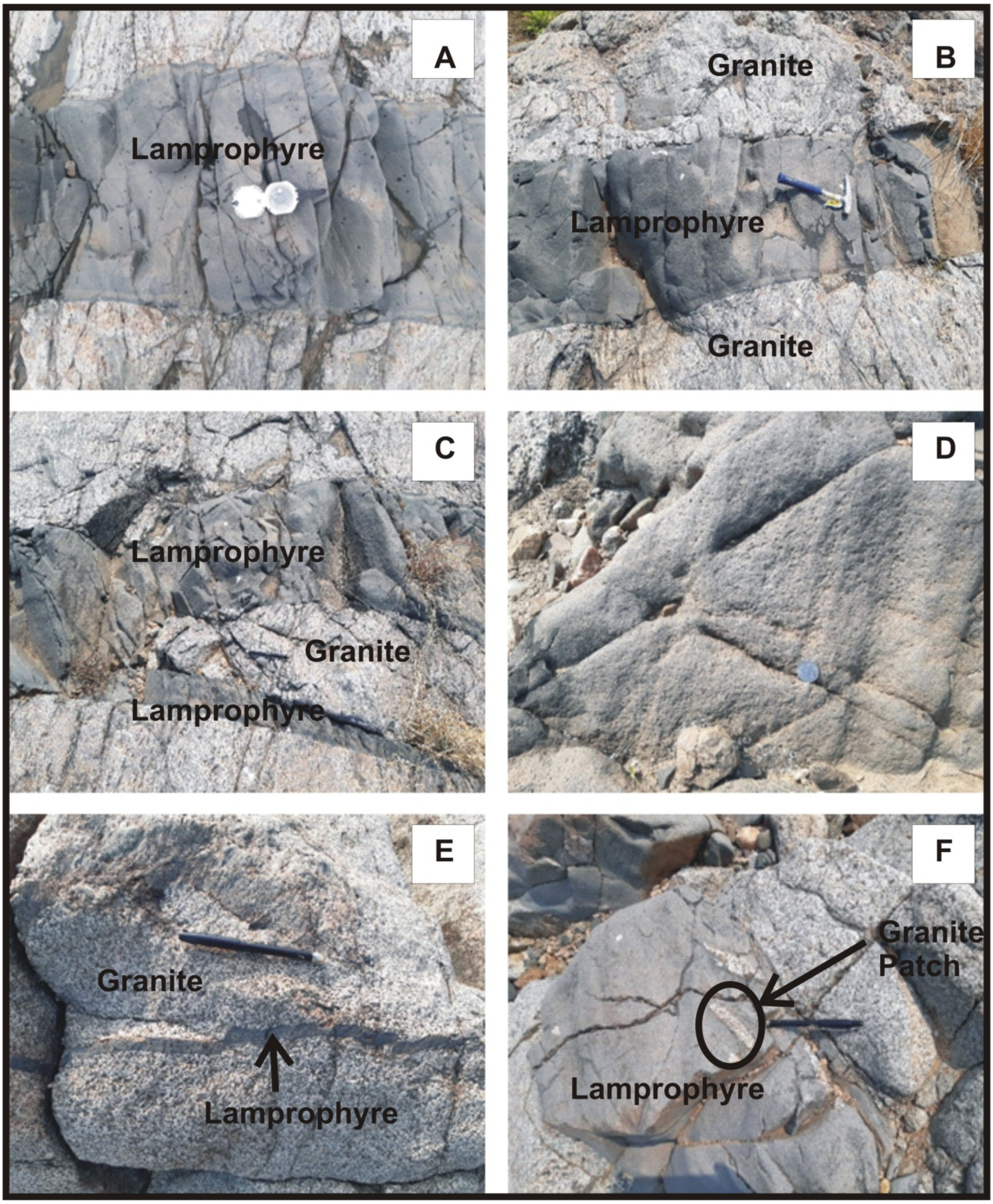

Figure 2A: Field photograph of Tirthal Lamprophyre. **Figure 2B:** Sharp contact nature of the Tirthal Lamprophyre along with granitoids. **Figure 2C:** Branching nature of the Tirthal Lamprophyre. **Figure 2D:** Pitted structure of the Tirthal Lamprophyre. **Figure 2E:** Very thin lamprophyre in the Bank of Muneru River at Tirthal area. **Figure 2F:** Patches of granitoids within Lamprophyre in Tirthal area.

Analytical Techniques

The mineral chemistry of various phases of Tirthal lamprophyres has been analysed by the CAMECA SX100 Electron Probe Micro Analyzer (EPMA) housed at GSI, Kolkata. 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 were used. The microprobe was calibrated using (Na, Al) on Albite, (Mn) on Rhodonite (Ca, Mg) on Diopside (Ti) on

TiO2, (K, Si) on Orthoclase (Cr) on Chromium (Fe) on Almandine. Analyses of the selected and representative mineral phases are given in Table 1, 2, 3, 4 & 5.

Petrography and Mineral Chemistry

Petrographical studies show that, these dykes have a porphyritic-panidiomorphic texture. Clinopyroxene, biotite and amphibole are present as phenocrysts in Tirthal lamprophyres (Figures 3A, 3B & 3C). In these dykes k-feldspar, plagioclase feldspar and biotite are present as a groundmass portion. Carbonate is also present in the rock, which replaces clinopyroxene. Clinopyroxenes are mostly elongated in shape in the rock (Figures 3E, 3F, 3G & 3H). In the ground mass portion, carbonate is also present. The size of the phenocrysts is 1500 micron × 900 micron for diopside, 820 × 600 micron for augite, 400 micron for biotite laths and up to 400 microns for plagioclase. Magnetite and apatite are present as accessory minerals in the groundmass part. Cpx appears pale brown to greenish in color. Petrographical studies also show that, ocelli structures are present within these rocks. In some portions, carbonate completely replaces the original minerals like clinopyroxene. From the modal study, dominance of biotite over amphibole, k-feldspars over plagioclase feldspars and the presence of diopside indicate that this lamprophyre is classified as minette (Le Maitre, 2002).

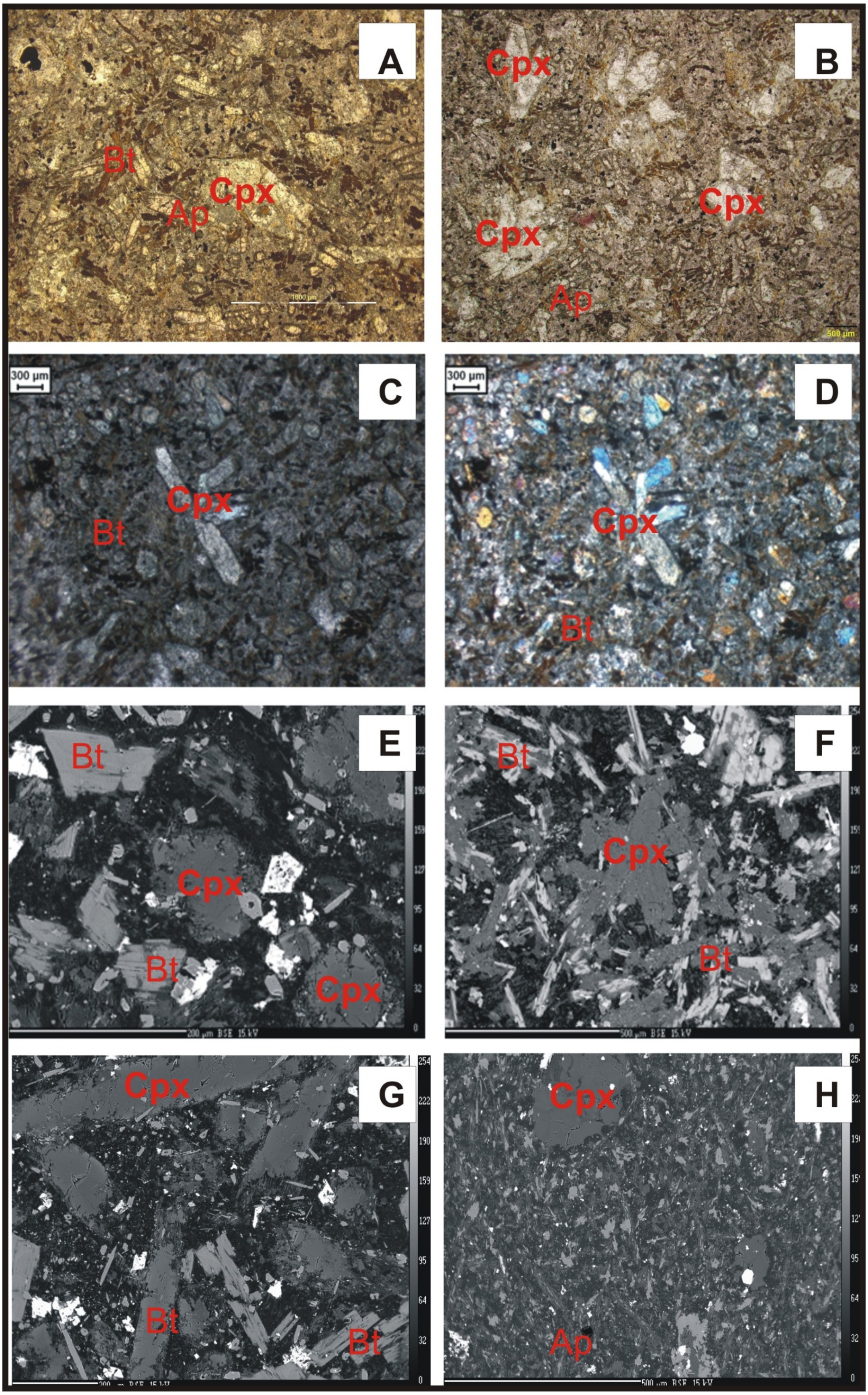

Figure 3A: Clinopyroxene-Mica phenocryst within ground mass in Tirthal lamprophyre (PPL). **Figure 3B:** Clinopyroxene-biotite phenocryst within ground mass in Tirthal lamprophyre (CPL). **Figure 3C:** Elongated Clino pyroxene within Tirthal lamprophyre (PPL). **Figure 3D:** Elongated Clino pyroxene within Tirthal lamprophyre(CPL). **Figure 3E:** BSE image of Clinopyroxene-Mica phenocryst within ground mass in Tirthal lamprophyre. **Figure 3F:** BSE image of elongated Clino pyroxene within Tirthal lamprophyre. **Figure 3G:** BSE image of elongated Clino pyroxene and biotite within Tirthal lamprophyre. **Figure 3H:** BSE image of apatite present in the groundmass part of the Tirthal lamprophyres.

Clinopyroxene: In the lamprophyre samples under study, clinopyroxenes are mainly diopsidic (Wo48-50 En40-41 Fs9-10) in nature (FIG:4A). Al and Ti values for clinopyroxene when plotted on Ca (a.p.f.u) vs. Ti (a.p.f.u) diagram (Figure 4C), show orogenic nature of the lamprophyres.

Amphibole: Most of the amphiboles are of actinolite variety (Figure 4B). Actinolite is usually absent in the igneous rocks and hence its formation suggests auto metamorphism of existing amphiboles with the hydrous melt (Leake et al., 1997). They are depleted in Al2O3, K2O and TiO2 revealing a calc-alkaline nature of the magma (Figure 4D). TiO2 (wt%) versus SiO2 (wt%) plot (Figure 4D) (after Rock, 1991) for the amphibole suggesting calc-alkaline nature of the studied lamprophyres.

Feldspar: In the Tirthal lamprophyres feldspars are present essentially as groundmass. 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.

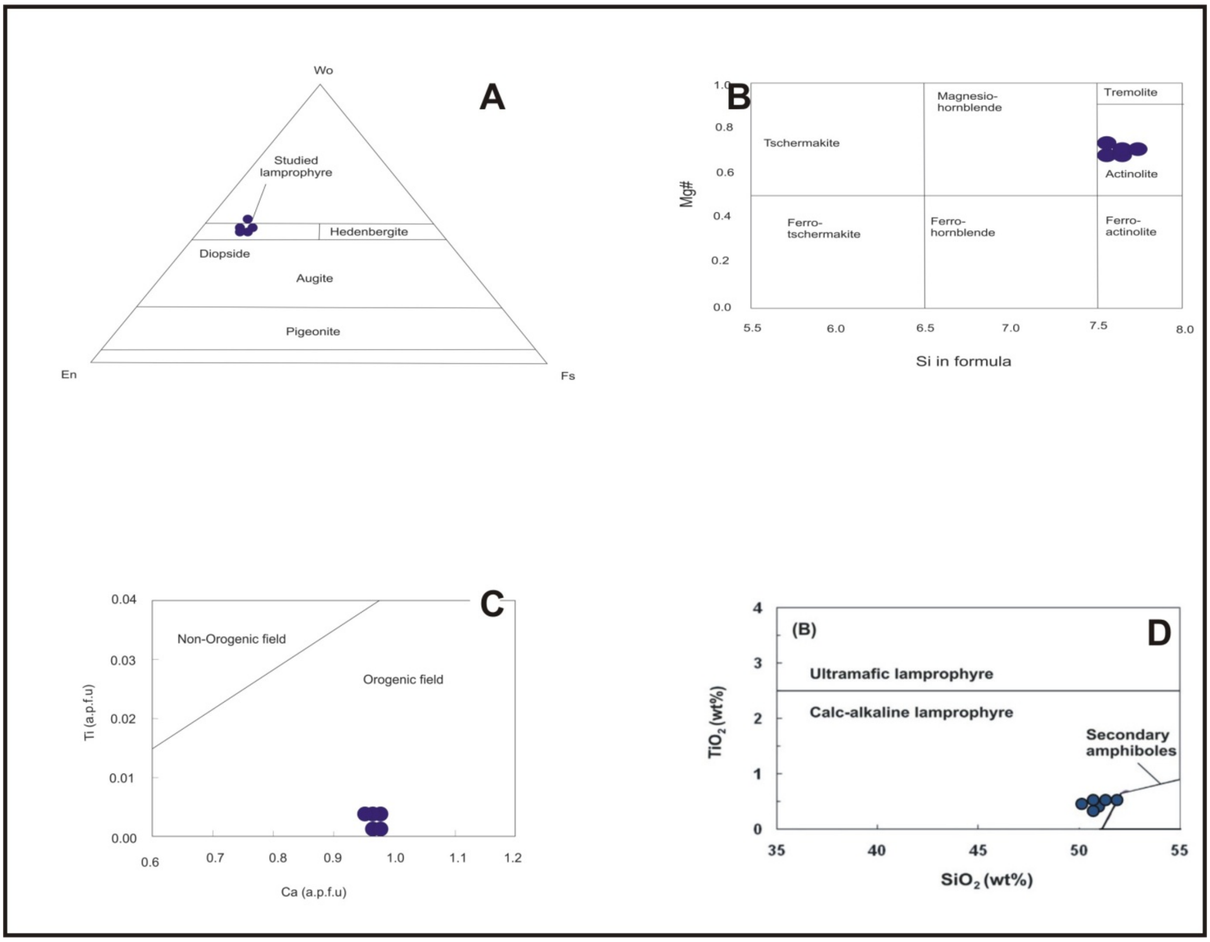

Figure 4A: Pyroxene classification diagram showing diopsidic nature of the clinopyroxenes from the lamprophyre. **Figure 4B:** Si vs. Mg# plot for the classification of amphiboles (after Leake et al., 1997) from the lamprophyre. **Figure 4C:** Ti (a.p.f.u) versus Ca (a.p.f.u) plot (after Sun and Bertrad, 1991) of clinopyroxene showing their orogenic affinity. **Figure 4D:** TiO_2 (wt%) versus SiO_2 (wt%) plot (after Rock, 1991) for the amphibole suggesting calc-alkaline nature of the studied lamprophyre.

Geochemistry

Whole rock major and trace element analyses were carried out at the Chemical laboratory, Geological Survey of India (GSI), Kolkata, India. X-ray fluorescence spectrometry was utilized for major oxide analysis, while ICP-MS was used to determine trace and rare earth element (REE) concentration. The precision is < 5% for all analyzed elements when reported at 100X detection limit. Several standards were run along with the studied samples to check accuracy and precision. Table 6, 7 and 8 presented the data of major oxide, trace elements and REE. Standardized CIPW norms for all samples were automatically computed using the IgROCS computer program (S.P. Verma et al., 2013).

Tirthal lamprophyres are characterized (Table 6) by SiO_2 (40.03%-45.23%), Fe_2O_3 (9.09%-13.45%), MgO (9.53%-12.16%), CaO (8.25%-14.78%), K_2O (0.69%-2.37%), TiO_2 (1.3%-1.52%) and Al_2O_3 (9.76%-12.02%) contents. Similarly, trace elements analysis (Table 7) of the lamprophyres shows that they contain higher amount of Ba (2030-10498 ppm), Sr (438-925 ppm), Ni (156-225 ppm), Zr (417-590 ppm), V (141-169 ppm) and Cr (355-482 ppm). REE analysis of the samples indicates that the total REE content (Table 8) of the rock is more than 1000 ppm. All the samples show higher LREE values compared to HREE with a total REE content within the range of 1108.50-2004.49 ppm.

Major oxide data are plotted in the MgO (wt%) versus SiO_2 (wt%) diagram (Lefebvre et al., 2005) (Figure 5A) showing that these lamprophyres belong to the calc-alkaline group. The SiO_2 (wt%) vs TiO_2 (wt%) plot (Rock, N. M. S., 1991) also suggest that these lamprophyres are of the calc-alkaline variety (Figure 5C). CIPW norm calculation data also support these lamprophyres as calc-alkaline in nature (Rock, N. M. S., 1977) (Figure 5D). Major oxide data are used to identify the source region of the lamprophyre rock. Al_2O_3 vs TiO_2 diagram (Muller D. et al., 1993) (Figure 6A) and K_2O vs TiO_2 diagram (Thorpe R.S., 1987) (Figure 6B) confirm that these lamprophyres magma have been generated from a subduction related source. All the samples are plotted in the overlapping field between subduction zone and the within plate field with more affinity towards the subduction zone. Trace elements and the REE data have been plotted in different diagrams to understand the character of the Tirthal lamprophyres. Discrimination diagram (Pearce et al., 1973) based on trace elements Nb/Pb vs V/Cr also supports the calc-alkaline nature (Figure 7A). These lamprophyres are crystallized from the LREE enriched magma revealed from the chondrite normalized REE pattern (Nakamura, 1974) (Figure 7B). Discrimination diagram (Pearce et al., 1973) based on trace elements Sm vs Ce/Yb also supports the calc-alkaline nature (Figure 5B). In multi element plots, these lamprophyres show negative Ta-Nb anomalies, indicating a subduction related setting of this rock (Foley 1984; Peacock 1990; Saunders 1992 and Kent 1995). Plagioclase fractionation is indicated by the presence of negative Sr and Eu anomalies (Wood et al., 1979) in these rocks. Chondrite normalized multi element diagrams (Thompson, R.N. et al, 1984) show Tirthal lamprophyres considerably enriched in incompatible elements and a negative anomaly in K and Sr suggests the presence of phlogopite mica in the source.

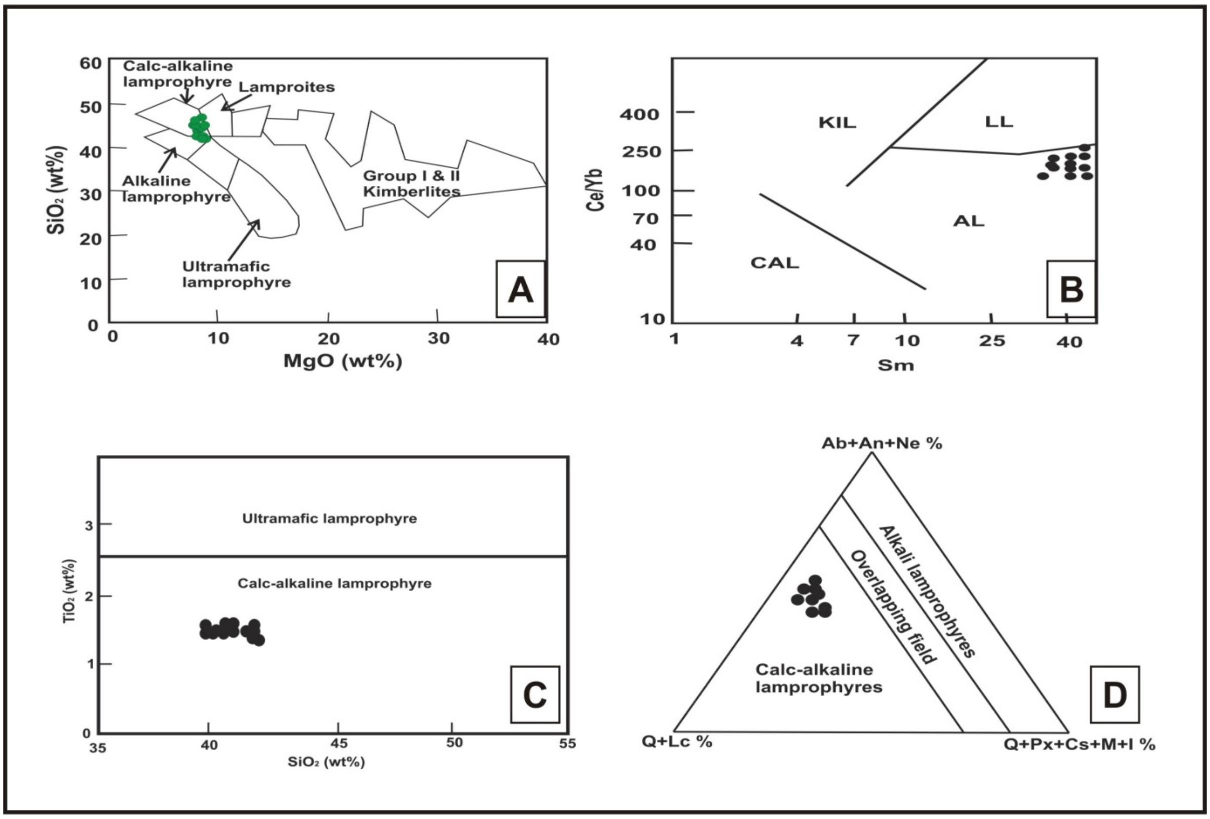

Figure 5A: MgO vs SiO2 discrimination plot for various alkaline mafic potassic ultrabasic rocks, **Figure 5B:** Plot of SiO2 versus (Na2O + K2O) for lamprophyres. **CAL,** Calc-alkaline lamprophyres; **AL**, Alkaline lamprophyres; **UML**, Ultrabasic lamprophyres; **LL**, Lamproites, **Figure 5C:** TiO2 vs SiO2 plot suggesting calc-alkaline nature of the Tirthal lamprophyre, **Figure 5D:** Diagram for distinguishing calc-alkaline and alkaline lamprophyres using the normative parameters.

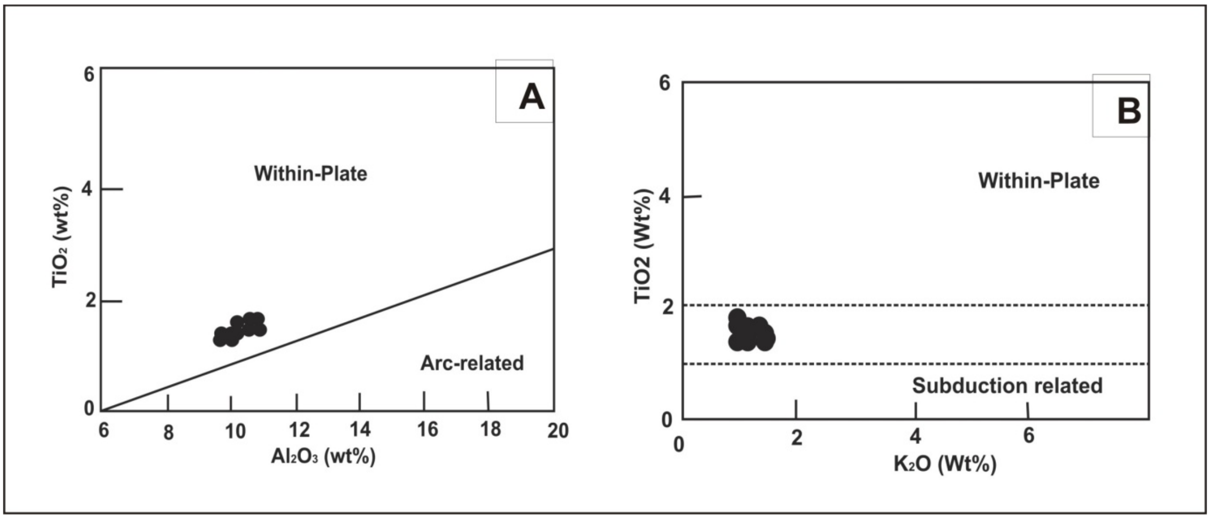

Figure 6A: Al2O3 vs TiO2 discrimination plot for distinguishing within-plate and arc related basalt, **Figure 6B:** K2O vs TiO2 plot for distinguishing within-plate and subduction related K-rich mafic lavas.

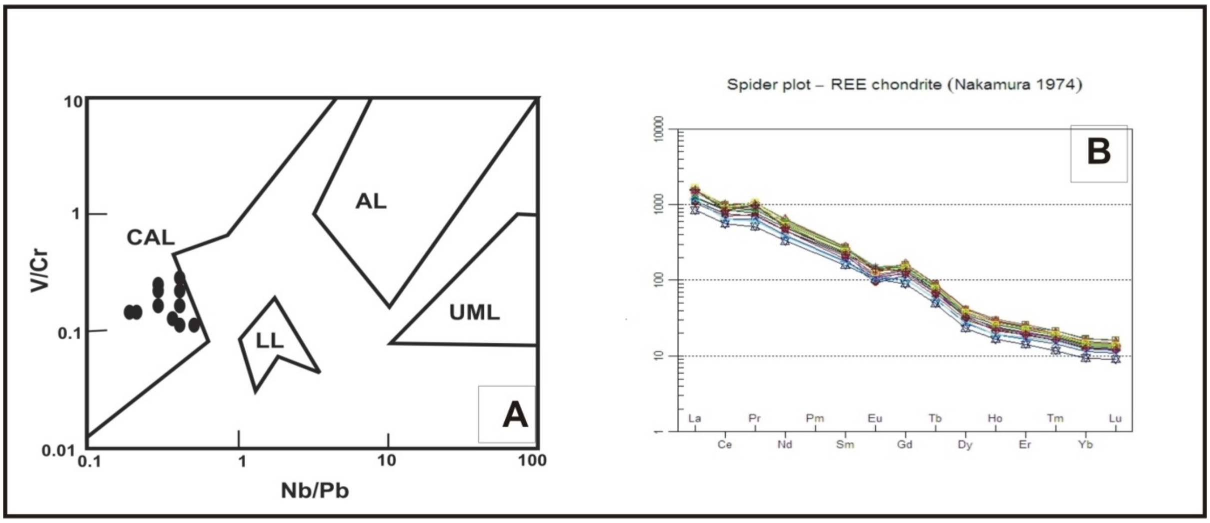

Figure 7A: Simple discrimination between the lamprophyre branches using trace elements ratios of Nb/Pb vs V/Cr, Chondrite normalization rare earth pattern for Tirthal lamprophyre.

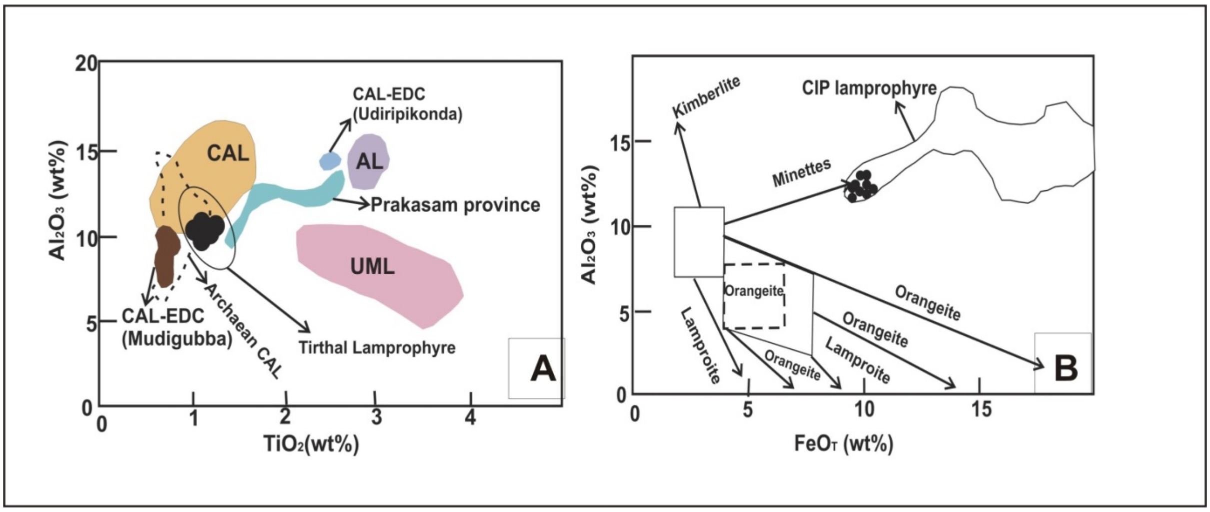

Figure 8A: FeO_T vs Al2O3 variation diagram of the Tirthal lamprophyre showing fractionation trends of minnett type, **Figure 8B:** Al2O3 vs. TiO2 classification plots for the Tirthal lamprophyres. Fields for CAL (calc-alkaline lamprophyres), AL (alkaline lamprophyres), UML (ultramafic lamprophyres) and Archaean CAL from different cratons are taken from Lefebvre et al. (2005) and references there in. The field taken: Prakasam Province lamprophyres at eastern margin of the Cuddapah basin (Madhavan et al., 1998; Kumar and Rathna, 2008; Meshram et al., 2015); Eastern Dharwar Craton CAL-Mudigubba (Pandey et al., 2017a; Pandey et al., 2017b).

Discussion

FeO_T vs Al2O3 diagram (Mitchell 1995) shows that these Tirthal lamprophyres belong to the minette variety (Figure 8B). The Al2O3 vs TiO2 diagram shows that the present lamprophyre data are plotted well within Calc-Alkaline Lamprophyre field (Figure 8A). In this diagram, a comparative study was conducted between Tirthal lamprophyres and other CIP/PAP lamprophyres, as well as Mudigubba lamprophyre. This comparison shows that this rock's characteristics are slightly different from the Prakasam Province field (Madhavan et al., 1998; Kumar et al., 2008; Meshram et al., 2015) as well as the Mudigubba field (Pandey et al., 2017a; Pandey et al., 2017b). This lamprophyre is quite similar to the 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. Tirthal lamprophyre samples exhibit relatively higher values of Sc, Cr, Ni, and Co, suggesting that these lamprophyres' magma can be generated from a primary magma source. Tirthal lamprophyre samples contain higher concentrations of LREE and compatible elements (Sun et al., 1989) (i.e. Ni, Cr) indicating that Tirthal lamprophyres magma is generated from a small degree of partial melting of peridotite mantle at greater depths in the garnet stability fields (Ferguson et al., 1971, Hirschman et al., 1999). A strong Hf negative anomaly in the samples suggests that Tirthal lamprophyre magma is generated from the garnet stability field. Tirthal lamprophyres show a negative Sr anomaly, indicating either residual clinopyroxene in the source melt or depletion of the mantle source in Sr during a previous phase of melt extraction (Chalapati Rao, 2004).

Conclusion

Based on the combined study of petrography and geochemistry, it is clear that these lamprophyres belong to the Calc-alkaline group as a minette variety. This rock crystallized from LREE-enriched magma, as shown by the chondrite normalized REE pattern. The multi-element spider diagram shows that, these rocks source region is related to subduction-related characteristics. In the diagram, samples are plotted in the overlapping field between subduction zone and within plate field with more affinity towards a subduction-related source. These lamprophyres in the Tirthal area provide a good opportunity to study one such lamprophyre-granitoids relationships and the evolution of ancient cratonic lithosphere. In this view, new findings of calc-alkaline lamprophyres are very crucial for the regional geology and tectonic setting of the EDC.

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References

[1] Adhikary, D., Mukherjee, S. and Sahoo, R. (2022): Lamprophyre cluster within the granite terrain adjoining the western margin of Proterozoic Pakhal basin, Southern India. Indian Journal of Geosciences, 76(1), pp. 1-12.

[2] Appavadhanulu, K. (1971): A short note on the lamprophyre dykes in parts of Khammam district, Andhra Pradesh. Indian Minerals, 25, pp. 387-398.

[3] Chalapathi Rao, N. V. (2008): Precambrian alkaline potassic-ultrapotassic, mafic-ultramafic magmatism in Peninsular India. J. Geol. Soc. India, 72, pp. 57-84.

[4] Chalapathi Rao, N. V., Gibson, S. A., Pyle, D.M. and Dickin, A. P. (2004): Petrogenesis of Proterozoic lamproites and kimberlites from the Cuddapah Basin and Dharwarcraton, southern India. Journal of Petrology, 45, pp. 907–948.

[5] Ferguson, J., and Currie, K L. (1971): Evidence of Liquid Immiscibility in Alkaline ultrabasic dyke at Callander Bay, Ontario. Journal of Petrology, 12, pp. 561–585.

[6] Foley, S. F. (1984): Liquid immiscibility and melt segregation in alkaline lamprophyres from Labrador. Lithos, 17, pp. 127–137.

[7] Hirschman, M. M., Ghiorso, M. S. and Stolper, E. M. (1999b): Calculation of peridotite partial melting from thermodynamic models of minerals and melts.II. Isobaric variations in the melt near the solidus and owing to variable source composition. Journal of Petrology, 40, pp. 297–313.

[8] Kent, R. (1995): Continental and oceanic flood basalt provinces: Current and future perspective: In R.K. Srivastava & Chandra (eds) Magmatism in Relation to Diverse Tectonic Settings. A. A. Balkema: Rotterdam. pp. 17-42.

[9] Kumar, K. V. and Rathna, K. (2008): Geochemistry of the mafic dykes in the Prakasam Alkaline Province of Eastern Ghats Belt, India: Implications for the genesis of continental rift-zone magmatism. Lithos, 104, pp. 306–326.

[10] Leake, B. E. et al. (1997): Nomenclature of amphiboles : Report of the subcommittee on amphiboles of the international mineralogical association, commission on new minerals and mineral names. Am. Mineral., 82, pp. 1019–1037.

[11] Leelanandam, C., (1989): The Prakasam Alkaline Province in Andhra Pradesh, India. Journal of Geological Society of India, 34, pp. 25-45.

[12] Lefebvre, N., Kopylova, M. and Kivi, K. (2005): Archaean calc alkaline lamprophyres of Wawa, Ontario, Canada: Unconventional diamondiferous volcaniclastic rocks. Precambrian Research, 138, pp. 57–87.

[13] Le Maitre, R. W. (2002): Igneous Rocks: A Classification and Glossary of Terms, Cambridge University Press, Cambridge.

[14] Madhavan, V., David, K., Mallikharjunarao, J., Chalapathirao, N. V. and Srinivas, M. (1998): Comparative study of lamprophyres from the Cuddapah Intrusive Province (CIP) of Andhra Pradesh, India. Geological Society of India, 52, pp. 621–642**.**

[15] Meshram, T. M., Shukla, D. and Behera, K. K. (2015): Alkaline lamprophyre (camptonite) from Bayyaram area, NE margin of the Eastern Dharwar Craton, southern India. Current Science, 109 (10–11), pp. 1931–1934.

[16] Mitchell, R. H. (1995): Kimberlites, orangeites and related rocks. Plenum Press, 1995, New York, pp. 410.

[17] Muller, D., Morris, B. J. and Ferrand, M. J. (1993): Potassic alkaline lamprophyres with affinities to lamproites from the Kerinya Syncline, South Australia. Lithos, 30, pp. 123-137**.**

[18] Nakamura (1974): Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochimica et Cosmochimica Acta, 38(5), pp. 757-775**.**

[19] Naqvi, S. M., (2005): Geology and Evolution of the Indian Plate (From Hadean to Holocene – 4 Ga to 4 Ka). Capital Publishing Company, New Delhi, pp. 450.

[20] Pandey, A., Chalapathirao, N. V., Chakrabarti, R., Pandit, D., Pankaj, P., Kumar, A. and Sahoo, S. (2017b): Petrogenesis of a Mesoproterozoic shoshonitic lamprophyre dyke from the Wajrakarur kimberlite field, eastern Dharwar craton, southern India: Geochemical and Sr–Nd isotopic evidence for a modified sub-continental lithospheric mantle source. Lithos, pp. 292–293.

[21] Pandey, A., Chalapathirao, N. V., Pandit, D., Pankaj, P., Pandey, R., Sahoo, S. and Kumar, A. (2017a): Subduction – Tectonics in the evolution of the eastern Dharwar craton, southern India: Insights from the post-collisional calc-alkaline lamprophyres at the western margin of the Cuddapah basin. Precambrian Research, 298, pp. 235–251.

[22] Peacock, S. M. (1990): Fluid processes in subduction zone. Science, 248, pp. 329–337.

[23] Pearce, J. A. and Cann, J. R. (1973): Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters, 19(2), pp. 290–300.

[24] Ratnakar, J., Madhavan, V., Srinivasan, T. P. and Narsimhareddy, M. (1980): Some preliminary observations on the Purimetla alkaline pluton, Prakasam district, Andhra Pradesh. Geoviews, 8, pp. 93-98.

[25] Ratnakar, J., Ramakrishna, D. V., Vijayakumar, K., Nagsaisarma, V. and Babu, E. V. S. S. K. (1992): A new occurrence of alkaline lamprophyre near Kellampalle, Prakasam district, Andhra Pradesh, India. Current Science, 63, pp. 569-570.

[26] Ratnakar, J. and Vijayakumar, K. (1994): The Ravipadu gabbros, Prakasam province, Andhra Pradesh (Abstract). Workshop on Eastern Ghat Mobile Belt, Visakhapatnam, India, 1994, pp. 80-81.

[27] Rock, N. M. S. (1977): The nature and origin of lamprophyres some definitions, distinctions, and derivations. Earth Science. Review, 13, pp. 123-169**.**

[28] Rock, N. M. S. (1987): The nature and origin of lamprophyres. Geological Society Special Publication, 30, pp. 191-226.

[29] Rock, N. M. S. (1991): Lamprophyres. Blackie**,** Glassgow, pp. 285**.**

[30] Saunders, A. D., Storey, M., Kent, R., Wandnorry, M. J. (1992): Consequences of Plume-lithosphere interactions In: Magmatism and the causes of continental Break-up, Geological Society London, Special Publication, 68, pp. 41–60. Storey, Alabaster, and Pankhurst (eds).

[31] Subrahmanyam, K., Mallikharjunarao, J. and Leelanandam, C. (1987): Occurrence lamprophyre dykes near Khammam, Andhra Pradesh. Indian Journal of Geosciences, 59, pp. 65–70.

[32] Sun, C. M., Bertrad, J. (1991): Geochemistry of clinopyroxenes in plutonic and volcanic sequences from the Yanbian Proterozoic ophiolites (Sichuan Province, China): Petrogenetic and geotectonic implications. Schweiz. Mineral. Petrog. Mitt., 71, pp. 243–259.

[33] Sun, S. S. and Mcdonough, W. F. (1989): Chemical and isotopic systematic of oceanic basalts: implications for mantle composition and processes. Geological Society London, Special Publication, 42, pp. 313–345.

[34] Thompson, R. N., Morrison, M. A., Hendry, G. L. and Parry, S. J. (1984): An assessment of the relative roles of crust and mantle in magma genesis; an elemental approach. Philosophical Transactions Royal Society London Series, A310, pp. 549-590.

[35] Thorpe, R. S. (1987): Permian K-rich volcanic rocks of Devon: Petrogenesis, tectonic setting and geological significance. Earth Science, 77, pp. 361-366.

[36] Verma, S. P. and Gómez, M. A. (2013): Computer programs for the classification and nomenclature of igneous rock. Episodes, 36, pp. 115–124.

[37] Wood, D. A., Joron, J. L., Treuil, M., Norry, M. and Tarney, J. (1979): Elemental and Sr isotope variations in basic lavas from Iceland and the surrounding ocean floor. Contributions to Mineralogy and Petrology, 70, pp. 319-339.

Table 1: Representative Analyses (wt%) of Clinopyroxene from the Tirthal Lamprophyres

Sample Nos.	**27 / 1**	**28 / 1**	**30 / 1**	**31 / 1**	**40 / 1**	**1 / 1**	**2 / 1**	**3 / 1**	**4 / 1**	**13 / 1**	**14 / 1**	**15 / 1**	**16 / 1**	**23 / 1**	**30 / 1**	**35 / 1**
SiO2	47.555	48.073	51.662	51.276	49.984	50.49	50.36	50.33	47.25	45.25	49.79	50.29	49.22	48.77	49.46	49.55
Al2O3	5.936	5.401	2.313	2.426	4.182	3.83	3.79	4.25	6.11	6.69	3.92	4.01	4.39	4.02	4.38	4.43
TiO2	1.37	1.163	0.602	0.57	0.807	1.12	1.49	1.29	1.92	2.16	1.35	1.25	1.46	1.02	1.3	1.51
MgO	14.487	14.852	16.401	16.47	15.65	15.35	14.93	15.01	13.48	11.42	15.17	15.08	14.47	14.92	14.88	15.02
FeO	6.611	6.938	5.282	4.825	4.859	5.52	5.9	5.8	8.19	10.04	5.66	5.77	6.72	5.47	6.36	5.71
MnO	0.146	0.118	0.108	0.032	0.075	0.13	0.22	0.03	0.11	0.11	0.05	0.12	0.07	0.1	0.05	0.13
CaO	21.331	21.038	21.35	22.12	21.774	23.42	23.5	23.18	22.73	22.64	23.5	23.44	23.1	23.27	23.28	23.6
Na2O	0.406	0.317	0.304	0.306	0.367	0.39	0.33	0.37	0.48	0.66	0.42	0.41	0.38	0.43	0.41	0.36
K2O	0	0.003	0	0.028	0	0.02	0.01	0.02	0.03	0.02	-0.01	0	0	0	0.01	-0.04
Cr2O3	0.495	0.123	0.253	0.436	1.062	0.49	0.29	0.16	0.08	0.16	0.47	0.08	-0.03	1.07	0.37	0.57
Total	98.34	98.03	98.28	98.49	98.76	100.76	100.82	100.44	100.38	99.15	100.32	100.45	99.78	99.07	100.50	100.84
Cation calculations on the basis of 6 Oxygen																
Si	1.780	1.804	1.923	1.902	1.854	1.841	1.842	1.842	1.745	1.708	1.824	1.840	1.819	1.810	1.812	1.809
Al	0.262	0.239	0.101	0.106	0.183	0.165	0.163	0.183	0.266	0.298	0.169	0.173	0.191	0.176	0.189	0.191
Ti	0.039	0.033	0.017	0.016	0.023	0.031	0.041	0.036	0.053	0.061	0.037	0.034	0.041	0.028	0.036	0.041
Mg	0.808	0.831	0.910	0.911	0.865	0.834	0.814	0.819	0.742	0.643	0.829	0.822	0.797	0.825	0.813	0.817
Fe3+	0.116	0.108	0.033	0.069	0.060	0.107	0.087	0.083	0.171	0.208	0.123	0.105	0.117	0.147	0.134	0.116
Fe2+	0.091	0.110	0.131	0.080	0.091	0.061	0.093	0.094	0.082	0.109	0.050	0.071	0.091	0.023	0.061	0.059
Mn	0.005	0.004	0.003	0.001	0.002	0.004	0.007	0.001	0.003	0.004	0.002	0.004	0.002	0.003	0.002	0.004
Ca	0.855	0.846	0.851	0.879	0.865	0.915	0.921	0.909	0.899	0.916	0.923	0.919	0.915	0.925	0.914	0.923
Na	0.029	0.023	0.022	0.022	0.026	0.028	0.023	0.026	0.034	0.048	0.030	0.029	0.027	0.031	0.029	0.025
K	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	-0.002
Cr	0.015	0.004	0.007	0.013	0.031	0.014	0.008	0.005	0.002	0.005	0.014	0.002	-0.001	0.031	0.011	0.016

Table 2: Representative Analyses (wt%) of Amphiboles from the Tirthal Lamprophyres

Sample Nos.	24 / 1	34 / 1	18 / 1	19 / 1	20 / 1	26 / 1
SiO2	53.1	50.349	52.62	56.13	56.0	54.52
Al2O3	0.56	0.738	0.99	0.43	1.3	1.88
TiO2	0.001	5.411	0.01	0.04	0.09	-0.01
MgO	17.498	12.437	17.51	16.71	18.34	18.07
FeO	9.442	11.934	8.95	10.82	9.24	10.22
MnO	0.191	0.3	0.18	0.51	0.13	0.51
CaO	13.477	14.945	15.78	12.99	13.12	12.73
Na2O	0.198	0.351	0.33	0.5	0.45	0.37
K2O	0.022	0.097	0.13	0.04	0.11	0.09
Cr2O3	0.029	0.016	0	-0.02	0	-0.03
Cations on the basis of 23 Oxygens						
Si	7.828	7.454	7.656	7.974	7.847	7.652
Al	0.000	0.000	0.000	0.000	0.000	0.000
Ti	0.000	0.603	0.001	0.004	0.009	-0.001
Mg	3.846	2.745	3.798	3.539	3.831	3.781
Fe	0.000	0.000	0.000	0.000	0.000	0.000
Mn	0.024	0.038	0.022	0.061	0.015	0.061
Ca	2.129	2.371	2.460	1.977	1.969	1.914
Na	0.057	0.101	0.093	0.138	0.122	0.101
K	0.004	0.018	0.024	0.007	0.020	0.016
Cr	0.003	0.002	0.000	-0.002	0.000	-0.003

Table 3: Representative Mineral Chemistry Data (wt%) from Feldspar in the Tirthal Lamprophyres

Sample Nos.	**10 / 1**	**14 / 1**	**15 / 1**	**24 / 1**	**44 / 1**	**47 / 1**	**12 / 1**	**31 / 1**
SiO2	68.67	62.93	69.38	67.98	64.6	63.76	67.06	66.48
Al2O3	19.83	17.43	20.6	19.91	18.38	18.22	20.19	21.13
TiO2	-0.01	-0.04	-0.04	-0.03	-0.05	-0.05	-0.03	-0.02
MgO	0.01	0.21	-0.02	0.04	0.02	0.03	0.08	0.1
FeO	0.37	0.32	0.25	0.38	0.12	0.17	0.21	0.25
MnO	-0.05	-0.01	-0.12	0.05	0.01	-0.03	0.09	-0.12
CaO	0.16	3.7	0.49	0.11	0	0	1.27	1.55
Na2O	12.09	11.46	9.75	12.11	0.35	0.36	11.28	10.97
K2O	0.05	0.12	0.1	-0.01	17.36	17.27	0.19	0.34
Cr2O3	-0.01	-0.07	0.05	0.03	0.06	-0.03	-0.03	0.01
P2O5	0.04	2.65	-0.02	-0.04	-0.03	-0.04	0.05	0.05
Total	**101.17**	**98.7**	**100.42**	**100.58**	**100.69**	**99.98**	**100.52**	**100.59**
	Cations on the basis of 8 Oxygen							
Si	2.975	2.829	2.996	2.966	2.986	2.978	2.935	2.905
Al	1.012	0.924	1.049	1.024	1.001	1.003	1.042	1.088
Ti	0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001
Mg	0.001	0.014	-0.001	0.003	0.001	0.002	0.005	0.007
Fe	0.013	0.012	0.009	0.014	0.005	0.007	0.008	0.009
Mn	-0.002	0.000	-0.004	0.002	0.000	-0.001	0.003	-0.004
Ca	0.007	0.178	0.023	0.005	0.000	0.000	0.060	0.073
Na	1.015	0.999	0.816	1.024	0.031	0.033	0.957	0.930
K	0.003	0.007	0.006	-0.001	1.023	1.029	0.011	0.019
Cr	0.000	-0.002	0.002	0.001	0.002	-0.001	-0.001	0.000

Table 4: Representative Mineral Chemistry Data (wt%) from Biotite in the Tirthal Lamprophyres

Sample Nos.	29 / 1	32 / 1	33 / 1	5 / 1	9 / 1	25 / 1	26 / 1	27 / 1	29 / 1	30 / 1	7 / 1	8 / 1	10 / 1	21 / 1	24 / 1	36 / 1
SiO2	33.558	33.32	36.811	32.93	34.22	35.64	35.14	35.94	37.75	37.9	33.77	33.76	37.35	34.5	34.98	36.39
Al2O3	14.7	14.719	14.546	14.82	13.43	14.49	14.18	14.25	13.95	14.34	13.51	13.65	13.76	14.36	14.51	13.33
TiO2	5.708	6.001	3.833	4.99	5.19	2.27	2.17	2.97	3.79	3.85	5.9	5.46	1.96	5.69	5.42	2.71
MgO	11.923	11.71	10.351	11.03	11.72	14.38	14.66	13.33	15.64	15.34	11.47	12.21	18.35	12.73	12.72	15.17
FeO	16.646	16.763	17.993	18.93	18.09	17.5	15.93	15.87	13.27	13.35	17.66	18.05	14.86	16.46	17.08	16.1
MnO	0.201	0.211	0.167	0.09	0.23	0.28	0.18	0.19	0.15	-0.03	0.17	0.19	0.21	0.33	0.1	0.09
CaO	0.045	0.037	0.131	0.83	0.15	0.34	2.35	0.41	0.05	0.06	1.55	1.05	0.11	0.05	0.09	0.4
Na2O	0.267	0.34	0.277	0.17	0.21	0.07	0.07	0.1	0.14	0.07	0.18	0.2	0.03	0.22	0.28	0.31
K2O	8.136	7.507	9.056	8.22	8.47	8.52	8.28	9.01	10.31	10.28	8.32	7.67	7.47	8.79	8.76	8.94
Cr2O3			-0.04	0.05	0.14	-0.08	0.03	-0.01	-0.07	0.13	0.12	0.01	-0.06	-0.08	0.02	
Total	**91.184**	**90.608**	**93.165**	**92.010**	**91.710**	**93.490**	**92.960**	**92.070**	**95.050**	**95.160**	**92.530**	**92.240**	**94.100**	**93.130**	**93.940**	**93.440**
Cations on the Basis of 6 Oxygens																
Si	5.303	5.292	5.626	5.250	5.400	5.446	5.427	5.534	5.539	5.539	5.313	5.304	5.507	5.328	5.349	5.534
Al	2.738	2.755	2.620	2.785	2.498	2.610	2.581	2.586	2.412	2.470	2.505	2.528	2.391	2.614	2.615	2.389
Ti	0.678	0.717	0.441	0.598	0.616	0.261	0.252	0.344	0.418	0.423	0.698	0.645	0.217	0.661	0.623	0.310
Mg	2.809	2.772	2.358	2.622	2.757	3.275	3.375	3.060	3.421	3.342	2.690	2.860	4.033	2.931	2.899	3.439
Fe	2.200	2.227	2.300	2.524	2.388	2.236	2.057	2.044	1.628	1.632	2.324	2.372	1.832	2.126	2.184	2.048
Mn	0.027	0.028	0.022	0.012	0.031	0.036	0.024	0.025	0.019	-0.004	0.023	0.025	0.026	0.043	0.013	0.012
Ca	0.008	0.006	0.021	0.142	0.025	0.056	0.389	0.068	0.008	0.009	0.261	0.177	0.017	0.008	0.015	0.065
Na	0.082	0.105	0.082	0.053	0.064	0.021	0.021	0.030	0.040	0.020	0.055	0.061	0.009	0.066	0.083	0.091
K	1.640	1.521	1.765	1.672	1.705	1.661	1.631	1.770	1.929	1.916	1.670	1.537	1.405	1.731	1.709	1.734
Cr	0.000	0.000	0.000	-0.005	0.006	0.017	-0.010	0.004	-0.001	-0.008	0.016	0.015	0.001	-0.007	-0.010	0.002

Table 5: Representative Mineral Chemistry Data (wt%) from Apatite in the Tirthal Lamprophyres

Sample Nos.	**5 / 1**	**9 / 1**	**11 / 1**	**22 / 1**	**25 / 1**	**27 / 1**	**29 / 1**	**3 / 1**	**16 / 1**
SiO2	1.09	1.06	1.56	1.19	2.92	1.32	1.45	1.81	0.83
Al2O3	0.02	-0.02	0.06	0.01	0.47	-0.01	0.05	0.41	0.01
TiO2	0.04	0.02	0.01	0	0.07	0.04	0.19	-0.06	-0.02
MgO	0.38	0.27	0.22	0.35	1.16	0.44	0.27	0.35	0.34
FeO	0.3	0.32	0.48	0.32	1.13	0.47	0.41	0.78	0.2
MnO	0.04	0.06	-0.01	-0.07	-0.03	-0.17	-0.06	-0.05	0.09
CaO	55.17	54.84	54.05	54.66	53.11	56.19	55.14	54.93	55.77
Na2O	0.16	0.15	0.16	0.14	0.25	0.16	0.18	0.23	0.18
K2O	0	0	0.01	0	0.33	0.01	0.04	-0.01	0.04
P2O5	40.97	41.68	40.37	41.43	38.84	41.35	41.39	40.19	41.67
Cr2O3	-0.08	0.12	0.1	-0.07	0.1	0.06	-0.08	-0.01	-0.05
Total	**98.09**	**98.5**	**97.01**	**97.96**	**98.35**	**99.86**	**98.98**	**98.57**	**99.06**

Table 6: Representative Major Oxide Analysis of Tirthal Lamprophyres

Sample No	PCS-29/1	PCS-29/3	PCS-35/2	PCS-35/3	PCS-35/4	PCS-35/2	PCS-35/3	PCS-35/4	PCS-35/5	PCS-L 8/1	PCS-L 8/2	PCS-L 9/1	PCS-L 9/2	PCS-L 10/1	PCS-L 10/2
SiO2	42.69	43.81	42.1	41.01	40.03	45.23	44.72	41.26	40.87	42.97	43.79	41.11	40.37	44.58	43.26
Al2O3	11.16	10.26	11.84	11.09	10.91	12.02	11.54	11.48	10.66	10.43	10.58	9.95	9.85	9.98	9.76
Fe2O3	10.82	9.74	13.45	11.4	11.48	11.86	10.25	10.75	10.58	10.14	10.57	10.37	11.05	9.09	9.76
MnO	0.17	0.19	0.2	0.2	0.26	0.18	0.17	0.22	0.21	0.16	0.18	0.23	0.21	0.17	0.18
CaO	11.01	11.62	8.25	13.02	12.63	8.75	12.52	12.26	12.45	11.04	10.48	14.78	14.39	10.97	11.55
MgO	11.79	11.33	12.16	10.85	11.13	11.4	9.78	11.28	11.96	10.8	10.75	9.53	10.17	10.33	10.99
Na2O	2.69	2.41	2.14	2.89	2.35	2.5	3.47	2.8	2.36	2.94	2.71	2.64	2.62	2.61	2.29
K2O	1.23	2.25	1.36	1.03	0.79	1.35	1.01	0.91	1.8	1.64	1.61	0.7	0.69	2.37	1.92
TiO2	1.52	1.38	1.42	1.53	1.39	1.4	1.45	1.47	1.46	1.43	1.35	1.37	1.38	1.3	1.3
P2O5	1.83	2.02	1.59	1.93	1.85	1.52	2.06	2.01	2.23	1.91	1.62	1.69	1.86	1.75	1.67
ORTHOCLASE_NORM	7.73	14.12	8.61	6.48	5.08	8.38	6.21	5.75	11.35	10.47	10.26	4.52	4.45	15.15	12.35
ALBITE_NORM	13.76	9.63	19.39	5.06	7.20	22.22	16.30	9.56	2.72	13.30	16.52	4.80	4.02	14.14	11.12
ANORTHITE_NORM	15.69	11.18	20.01	15.16	18.39	18.47	13.45	17.18	14.07	11.25	12.88	14.46	14.27	9.21	11.63
NEPHELINE_NORM	5.67	6.51	0.00	11.35	7.83	0.00	7.72	8.55	10.07	7.35	4.45	10.63	10.92	5.28	5.41
LEUCITE_NORM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIOPSIDE_NORM	23.90	28.93	10.28	32.43	29.63	13.48	30.01	27.24	29.20	27.71	25.62	43.36	40.73	29.87	31.27
OL_NORM	23.13	19.59	31.61	18.99	21.57	23.30	16.11	21.22	21.61	19.79	20.94	12.60	15.37	16.25	18.98
MT_NORM	2.55	2.29	3.19	2.68	2.76	2.75	2.36	2.54	2.50	2.42	2.52	2.51	2.67	3.03	2.35
IL_NORM	3.07	2.78	2.89	3.09	2.87	2.79	2.87	2.99	2.96	2.93	2.76	2.84	2.86	2.67	2.69
AP_NORM	4.51	4.97	3.95	4.76	4.67	3.70	4.97	4.98	5.52	4.78	4.05	4.28	4.70	4.39	4.21

Table 7: Representative Trace Elements Analysis of Tirthal Lamprophyres

Sample No	PCS-29/1	PCS-29/3	PCS-35/2	PCS-35/3	PCS-35/4	PCS-35/2	PCS-35/3	PCS-35/4	PCS-35/5	PCS-L 8/1	PCS-L 8/2	PCS-L 9/1	PCS-L 9/2	PCS-L 10/1	PCS-L 10/2
Ba	4026	9675	2030	3080	2150	2272	2902	2294	5660	6502	5287	2311	2277	10498	9475
Co	42	40	51	47	52	42	43	49	50	43	41	43	46	35	40
Cr	466	388	481	482	465	425	419	439	401	444	397	465	451	355	377
Cu	70	58	67	77	73	40	60	58	56	63	58	58	54	51	50
Ga	22	18	35	19	23	18	13	18	15	14	15	15	16	13	14
Nb	54	30	69	50	33	31	30	24	22	23	23	12	10	14	13
Ni	211	188	180	220	220	156	183	199	225	222	182	207	210	164	215
Pb	105	184	58	44	118	23	30	70	59	23	17	17	16	45	33
Sc	21	23	20	19	25	24	19	26	23	18	19	24	22	17	17
Sr	570	925	445	466	575	438	480	608	723	530	510	497	468	873	783
V	167	168	169	160	149	158	145	152	148	162	163	144	141	156	154
Y	41	45	44	41	53	38	41	54	51	40	41	49	51	44	43
Zn	128	114	261	155	157	224	133	144	148	106	131	154	138	103	137
Zr	506	519	526	457	580	477	459	590	533	417	436	464	436	464	461
Th	104	122	73	106	138	87	120	152	149	118	108	185	163	134	144
Rb	64	124	82	50	28	71	40	29	70	89	85	33	27	126	95

Table 8: Representative REE Analysis of Tirthal Lamprophyres

Sample No	**PCS-29/1**	**PCS-29/3**	**PCS-35/2**	**PCS-35/3**	**PCS-35/4**	**PCS-35/5**	**PCS-35/2**	**PCS-35/3**	**PCS-35/4**	**PCS-8/1**	**PCS-8/2**	**PCS-9/1**	**PCS-9/2**	**PCS-10/1**	**PCS-10/2**
La	417.23	278.11	360.42	370.07	502.06	474.91	346.80	411.99	503.13	392.95	390.15	524.21	564.97	523.41	513.41
Ce	731.64	481.74	650.52	653.06	874.51	824.08	604.70	712.73	871.26	557.70	555.73	739.65	795.08	736.30	719.97
Pr	86.61	57.40	78.65	78.43	104.87	98.71	81.90	96.26	117.15	72.31	69.40	113.33	121.69	113.10	110.24
Nd	314.43	208.74	286.08	285.14	379.41	360.19	282.93	339.50	406.44	246.36	240.92	319.44	342.26	320.58	310.06
Sm	47.96	32.30	44.63	42.80	56.45	53.12	38.75	45.32	56.12	35.94	34.89	46.08	49.80	46.27	44.67
Eu	10.25	7.98	7.66	8.63	10.32	11.40	7.17	9.20	10.46	8.39	8.02	8.77	9.74	11.40	10.76
Gd	38.50	24.86	36.03	33.72	45.15	42.37	31.80	36.79	45.60	28.73	28.31	37.10	40.83	36.81	35.83
Tb	3.54	2.32	3.55	3.19	4.22	3.92	2.90	3.31	4.14	2.64	2.65	3.36	3.72	3.31	3.20
Dy	12.06	7.97	13.10	11.22	14.48	13.38	10.30	11.34	14.22	9.42	9.63	11.71	13.26	11.57	11.15
Ho	1.81	1.16	2.01	1.68	2.14	1.95	1.57	1.65	2.06	1.33	1.35	1.60	1.84	1.60	1.52
Er	5.03	3.21	5.49	4.67	5.89	5.38	4.25	4.56	5.62	3.78	3.91	4.52	5.13	4.48	4.28
Tm	0.58	0.35	0.65	0.54	0.65	0.59	0.49	0.52	0.60	0.44	0.47	0.51	0.59	0.52	0.49
Yb	3.40	2.07	3.69	3.15	3.77	3.43	2.86	3.06	3.45	2.51	2.70	2.92	3.26	2.91	2.76
Lu	0.51	0.31	0.56	0.47	0.56	0.51	0.41	0.44	0.50	0.37	0.40	0.42	0.47	0.42	0.41
LREE	1646.60	1091.12	1464.00	1471.85	1972.77	1864.78	1394.04	1651.79	2010.16	1342.39	1327.43	1788.57	1924.36	1787.88	1744.94
HREE	26.91	17.39	29.04	24.93	31.72	29.17	22.79	24.89	30.58	20.49	21.12	25.05	28.28	24.82	23.81
Total REE	**1673.51**	**1108.50**	**1493.04**	**1496.78**	**2004.49**	**1893.95**	**1416.82**	**1676.69**	**2040.75**	**1362.88**	**1348.55**	**1813.62**	**1952.64**	**1812.70**	**1768.74**