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Kimberlites, Lamproites and Lamprophyres from The Indian Shield: Highlights of Researches During 2016-2019

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Highlights of researches on kimberlites, lamproites and lamprophyres (and their entrained xenoliths) during 2016-2019 from the Indian context are presented. A few previously unknown occurrences have been brought to light, and a wealth of petrological, geochemical and isotopic data on these rocks became available. All these studies provided new insights into the nomenclatural as well as geodynamic aspects such as subduction-tectonics, mantle metasomatism, lithospheric thickness, supercontinent amalgamation, and break-up and nature of the sub-continental lithospheric mantle from the Indian shield.

Keywords: Kimberlite; Lamprophyre; Lamproite; Xenoliths; India

Introduction

Last half-a-decade has witnessed a significant output pertaining to the research contributions on deep mantle derived alkaline rocks, such as kimberlites, lamproites, lamprophyres and their entrapped xenoliths from the Indian shield. A number of new occurrences have been discovered, precise age data became available, and high quality mineral-chemistry, bulk-rock and radiogenic isotope data have been generated - all of which contributed immensely to our understanding of the nature and evolution of the sub-continental lithospheric mantle (SCLM), through geological time, beneath the Indian cratons and mobile belts. This review essentially provides a snapshot of researches on these rocks which have been published essentially in peer-reviewed journals. Each of these rock types are treated separately in the subsequent sections below.

Kimberlites

All the previously dated kimberlites from the Eastern Dharwar Craton (EDC), southern India, are of Mesoproterozoic age viz., ca. 1100 Ma. However, Chalapathi Rao *et al.* (2016a) reported a much younger (Late Cretaceous ca. 90 Ma) macrocrystic

kimberlite intrusion in the Mesoproterozoic macrocrystic kimberlites from the Timmasamudram cluster, Wajrakarur kimberlite field, EDC. These authors reported groundmass perovskite SIMS U-Pb age, Nd isotopes (LA-ICP-MS) composition and bulk rock geochemical data for these kimberlites. The Nd isotope composition of the perovskites from the Mesoproterozoic (~1100 Ma) intrusion show a depleted ϵ_{Nd} value of 2.1 ± 0.6 to 6.7 ± 0.3 , whereas those from the Late Cretaceous (~90 Ma) intrusion show an enriched ϵ_{Nd} value of -6.3 ± 1.3 . Since, the ages for these younger intrusions are indistinguishable from the igneous activity related to the Marion hotspot-generated Madagascar large igneous province, Chalapathi Rao *et al.* (2016a) related this youngest kimberlite activity in the southern India to be spatially and temporally related to the Madagascar LIP. Two of the macrocrystic kimberlites from the Timmasamudram cluster of the Wajrakarur kimberlite field (TK-1 and TK-4 pipes) were shown to be geochemically similar to the Group II kimberlites (orangeites) from the Kaapvaal Craton, South Africa and end-Cretaceous kimberlites from the Bastar Craton (Dongre *et al.*, 2017). An important implication of the study is that it suggests that the thick lithosphere beneath the Dharwar Craton was preserved till the

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Late Cretaceous when the ca. 90 Ma kimberlite intruded the craton.

Titanium rich garnets, which are common in the alkaline igneous rocks and rarely observed in the kimberlites, were reported from the groundmass of the P-15 and KL-3 Wajrakarur kimberlites (Dongre *et al.*, 2016). These garnets range in composition from andradite to schorlomite, with some proportions of grossular, in P-15 and are essentially schorlomite in KL-3. As these Ti-rich garnets are closely associated with the chromian spinels they are inferred to be the products of spinel replacement, which is further corroborated by the Raman spectroscopy (Dongre *et al.*, 2016). The authors concluded that these Ti-rich garnets to be the products of reaction between spinels and late stage residual fluid.

Phani and Raju (2017) and the Geological Survey of India (2018) have discovered a new kimberlite pipe (Ahobil) in the Lattavaram cluster of the Wajrakarur kimberlite field in the Eastern Dharwar Craton. These authors presented preliminary petrography and geochemistry of this pipe and have discussed its diamond prospect. Detailed mineralogy, bulk-rock geochemistry, and Sr-Nd isotope studies on this occurrence were subsequently carried out by Sharma *et al.* (2019; Fig. 1). Olivines of two generations, Ti-poor phlogopite, spinel, perovskite, Ti-rich hydrogarnet, calcite and serpentine are the mineral constituents of this pipe. Sharma *et al.* (2019) brought out that the Ahobil kimberlite has depleted mantle model age (T_{DM}) significantly older than the rest of the kimberlites from the Dharwar Craton and geochemical behaviour similar to Group I kimberlites. Wide variation in oxygen fugacity, as inferred from the perovskite oxybarometry, suggests a non-diamond prospective nature of the pipe.

Shaikh *et al.* (2017) have presented detailed mineral chemistry of the Late Cretaceous macrocrystic kimberlite and Mesoproterozoic aphanitic kimberlite pulse in the TK-4 pipe of the Timmasamudram cluster, Wajrakarur kimberlite field. They showed that these kimberlites are rich in Al-Na-poor diopside and phlogopite set in the groundmass of diopside, phlogopite, spinel, perovskite and apatite. Four compositional zones were identified in the phlogopite and two xenocrystic core and one magmatic rim population of the olivine were identified. Given

the high Fe^{3+} in phlogopite, spinel, and perovskite from the TK-1 pipe, the authors have suggested the high oxygen fugacity prevalent during magma crystallization unlike those observed in TK-4. Complicated zoning patterns have been attributed to the complex evolutionary history of the magma and based on mineralogical evidences, they concluded that the TK-1 and TK-4 pipes are not the archetypical kimberlites, but can be classified as diopside-phlogopite lamproite.

Major and minor element compositions of olivines from the P3 kimberlite and P4 lamproite (Wajrakarur field) have been studied in detail by Shaikh *et al.* (2018). Based on textural and compositional variations, three distinct populations of olivine, phlogopite, and clinopyroxene have been identified. The first population includes glimmerite, phlogopite-clinopyroxene nodules and Mg-rich olivine – all of which are to be the disaggregated mantle xenoliths. The second generation grains are macrocrystic and have genetic links to the proto-kimberlite/lamproite. The third generation of olivine is phenocrystic as deduced from euhedral nature that crystallized at mantle depths and is essentially of magmatic in origin. Shaikh *et al.* (2018) concluded that the metasomatized wall-rock for the lamproite contained abundant MARID-type as well as phlogopite-rich metasomatic veins, however, the source for kimberlites was relatively refractory.

Lamproites

Detailed mineralogy of the P-12 “para-kimberlite” from the Wajrakarur kimberlite field of the Eastern Dharwar Craton has been presented by Kaur and Mitchell (2016). They reported the occurrence of olivine, Al-Na poor diopside, Al poor and Fe-Ti rich phlogopite and K-Ti richterite as the major minerals present in this rock. Five parageneses of clinopyroxene and three parageneses of K-rich richterite amphibole are described besides bimodal size distribution of perovskite and spinel exhibiting atoll texture. Rarely found minerals like cymrite, gittinsite, witherite, strontianite and hydrogrossular are also reported from this pipe. Based on the texture and mineral chemistry, these authors concluded that this pipe is essentially an olivine lamproite and not a kimberlite. They also suggested that the relict subducted oceanic slab in the sub-continental lithospheric mantle of the Dharwar Craton at depths of 160-220 km (Das Sharma and

Fig. 1: (A) BSE images displaying garlanding texture where central olivine grain in Ahobil kimberlite is circumscribed by perovskites with spinel overgrowth. Abbreviations: Ol- olivine, Spl- spinel and Pv- perovskite. (B) Si elemental X-ray map showing that major silicates are olivine and phlogopite; (C) Fe elemental X-ray map displaying spinel is the main iron bearing phase; (D) Ca elemental X-ray map reflecting perovskite is the main carrier of calcium; (E) Mg elemental X-ray map demonstrating that olivine is the major Mg-bearing minerals and (F) Ti elemental X-ray map indicating perovskite as a major Ti-hosting phase. Image source: Sharma *et al.* (2019)

Ramesh, 2013) was responsible for the metasomatism of the mantle and generated lamproite magmatism.

Mineral chemistry and whole-rock geochemistry of Mesoproterozoic (~1.4 Ga) lamproite dyke from the Garledinne (Banganapalle) cluster, south-western part of the Paleo-Mesoproterozoic Cuddapah Basin, Eastern Dharwar Craton was presented by Chalapathi Rao *et al.* (2016b). These lamproite dykes trends in WNW-ESE direction and show signs of silicification and carbonate alteration (Joy *et al.*, 2012). The lamproites display porphyritic texture composed of pseudomorphed olivine macrocrysts and phenocrysts and titanian-phlogopite in the groundmass rich in spinel, apatite, rutile, barite and carbonates. Alteration of phlogopite to chlorite and serpentine is common in these dykes. The spinels are classified as chromite or magnesio-chromite. Based on major oxide geochemistry, these lamproites are chemically similar to the Roman Province potassic-ultrapotassic rocks and show variation in chemistry as expected when an olivine+clinopyroxene assemblage fractionates. However, based on the trace element geochemistry these rocks are similar to the global anorogenic lamproites. Sub-chondritic Nb/Ta and super-chondritic Zr/Hf ratio is consistent with the interaction between sub-continental lithospheric mantle and sub-lithospheric mantle leading to the carbonate metasomatism of the mantle source region. Emplacement of these Mesoproterozoic dykes has been suggested to be related to the extensional setting during the break-up of the Columbia supercontinent.

An ultrapotassic dyke from Sakri (Nuapada lamproite field) at the margin of the Bastar Craton and the Eastern Ghats Mobile Belt is shown to have affinities to the kamafugites and is classified essentially as a lamproite on the basis of presence of Ti-phlogopite, Na-poor diopside, Fe-rich sanidine, ulvospinel and Sr-rich apatite (Chalapathi Rao *et al.* 2016c). The $^{40}\text{Ar}/^{39}\text{Ar}$ dating yielded an emplacement age of 1045 ± 9 Ma, similar to the other Mesoproterozoic lamproites from the Bastar and Bundelkhand Cratons and kimberlites from the Eastern Dharwar Craton. Initial ϵNd values range between -3.9 and -4.4 while the initial $^{87}\text{Sr}/^{86}\text{Sr}$ ranges between 0.705865 and 0.709024 . Such large variation in Sr isotopes with nearly constant and negative ϵNd value is consistent with their derivation from a phlogopite

rich enriched lithospheric mantle, which is responsible for the ultrapotassic character of the dyke. Trace element modelling suggested derivation of the melt from low degrees partial melting of a spinel-garnet transition zone lherzolite.

Mineralogy of the nine lamproite dykes from Vattikod cluster, Ramadugu lamproite field in Eastern Dharwar Craton has been reported by Kaur and Mitchell (2017). Presence of Ti-rich and Al-poor phlogopite, tetraferriphlogopite, K-Ti-rich amphiboles, Al-poor clinopyroxene, K-feldspar and spinels classify these rocks as *bona fide* lamproites. The amphiboles have diverse chemistry and classified as potassic-arfvedsonite, potassic-richterite, potassic-ferro-richterite, potassic-katophorite, Ti-rich potassic-katophorite, Ti-rich potassic-magnesio-katophorite. Feldspar also has diverse compositions and includes K-feldspar, Ba-K-feldspar and Na-feldspar. Spinels are chromite-magnetite and qandilite-ulvospinel-franklinite. Secondary phases such as titanite, allanite, zircon, calcite, chlorite and quartz are also present. The paper concludes with the classification of different dykes as pseudoleucite-amphibole-lamproite, pseudoleucite-phlogopite-lamproite, and pseudoleucite-phlogopite-amphibole lamproite. One dyke consisting of a high modal percentage of apatite is classified as pseudoleucite-apatite-phlogopite-lamproite. Comprehensive mineralogy and geochemical study including Sr-Nd isotopes of the lamproites from the Vattikod lamproite field is described by Talukdar *et al.* (2018). High K_2O along with F-rich hydrous mineralogy highlight the role of metasomatic phlogopite and apatite in the mantle source regions. The authors have shown that geochemically these lamproites along with those from the Ramadugu and Krishna lamproite fields show mixed affinity to the orogenic and anorogenic lamproites (Fig. 2). Elevated Ti/Eu and Zr/Hf ratios are compatible with the carbonate metasomatism of the lithospheric mantle previously enriched by ancient subduction process. Extremely enriched Nd isotopes (-10.6 to -9.3) and radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7037 – 0.7087) suggest the phlogopite rich enriched lithospheric mantle as the source region for these lamproites. It is concluded that these lamproites are generated from a two stage metasomatized mantle- (i) initial metasomatic event related to the subduction process during the amalgamation of the Columbia supercontinent, and (ii) latest metasomatic episode

Fig. 2: Major oxide and trace element discrimination diagram for the EDC lamproites. (A) CaO (wt%) vs. Al_2O_3 (wt%) variation in the EDC lamproites compared to worldwide orogenic and anorogenic lamproites. (B) $100 \cdot \text{Nb}/\text{Zr}$ vs. $100 \cdot \text{Th}/\text{Zr}$ plot and (C) Hf-Th-Nb/2 ternary plot discriminating orogenic and anorogenic affinities for the lamproites at the Vattikod, Krishna and Ramadugu Fields (collectively shown as EDC lamproites). Please refer Talukdar *et al.* (2018) for further details and relevant references

related to the extension related carbonate metasomatism caused by asthenospheric upwelling associated with the fragmentation of Columbia.

Kaur and Mitchell (2019) further describe the mineralogical aspects of lamproite from Gundrapalli, Ramadugu lamproite field of the Eastern Dharwar Craton. The authors report the presence of baotite,

rutile, titanite, barite, and hydro-zircons compensating the absence of wadeite and priderite. Presence of baotite is reported for the first time in any lamproite from India and it is analogous to the baotite-bearing Kvaløya lamproite from Troms, Norway.

Trace element studies of olivine from the diamondiferous pipes from the Mesoproterozoic

(~1100 Ma) Wajrakarur kimberlite field, Eastern Dharwar Craton, and the end-Cretaceous (~65 Ma) Kodomali and Behradih orangeites from the Mainpur kimberlite field, Bastar Craton, are reported (Shaikh *et al.*, 2019). Mineralogically, the authors classify these rocks as olivine lamproites that were previously reported as kimberlites or orangeites. Olivine macrocrysts which are Mg-rich (Fo content ranging between 89 and 93%), are inferred to have been derived from disaggregated mantle peridotite. Olivine macrocrysts that are Fe-rich comparatively with Fo content ranging between 82 and 89%, are considered to be metasomatic products of the mantle wall-rock by a precursor lamproite magma. The olivine phenocrysts are suggested to be of magmatic origin with Fo content ranging between 83 and 92%. The authors use Al-in-olivine thermometry approach to model the paleogeotherm of the sub-continental lithospheric mantle beneath the Dharwar and Bastar Cratons. Their modelling results in 41–43 mW/m² and 38–41 mW/m² paleogeotherm at ~1100 Ma and ~65 Ma, respectively beneath the Dharwar and Bastar Cratons.

Satyanarayanan *et al.* (2018) have presented petrography, mineralogy and geochemistry of two lamproite dykes from the Sidhi Gneissic Complex, Mahakoshal belt, central India. Embayed phlogopite grains with sieve texture showing conspicuous zoning reveal dynamic mixing in the lamproite magma chamber. The phlogopites hosts apatite and barite showing their primary and early crystallization. Clinopyroxene and carbonates are also common. Whereas one dyke shows phlogopite compositions following the trend of lamproite, another phlogopite from the other dyke follows the trend of minette, a variety of calc-alkaline lamprophyre. Both the dykes are ultrapotassic and show conspicuous Nb-Ta and positive Pb anomaly on the primitive mantle-normalized multielement diagram. Trace element abundances are similar to those of the anorogenic lamproites worldwide and elevated large ion lithophile elements (LILE) mimic those observed in the arc magmas. Very high Nb/Ta ratio is consistent with the rutile-rich metasomatism consistent with negative Nb-Ta anomaly. The authors conclude that diverse chemical evolution of the magma that assimilated a deep-seated carbonatite led to the carbonatitic character of the dyke.

Oldest lamproite from the Indian shield, as old as 2.2 Ga and correlating with the global records of LIPs, has been reported from the Nuapada lamproite field, Bastar Craton (Santosh *et al.*, 2018). Zircon Lu-Hf isotope results reveal derivation of the magma from a refertilized Paleo-Mesoarchean sub-continental lithospheric mantle or OIB-type source, which is also consistent with the trace element geochemistry in these lamproites. Authors have linked the origin of these lamproites to the voluminous Paleoproterozoic (2.2 Ga) mafic dyke swarms in the Bastar and Dharwar Cratons that form part of a major global rifting event. They concluded that the related mantle plume originated from the subducted slabs associated with the Archean subduction-accretion event related to the Neoarchean cratonization as well as the thermal blanket effect of the oldest supercontinent.

Lamprophyres

Petrology, bulk rock geochemistry and isotope geochemistry (Sr-Nd) studies of Mudigubba, Udiripikonda, Kadiri, Sivarampeta and Korakkodu lamprophyre dykes intruding the Peninsular Gneissic Complex, towards the western margin of the Cuddapah basin, have been reported from the Eastern Dharwar craton (Phani *et al.* 2019, Raghuvanshi *et al.* 2019, Pandey *et al.* 2017a,b,c, 2018 and Khan *et al.* 2018). These lamprophyres, based on mineral chemistry and geochemistry, can be broadly grouped into belonging to two domains: (i) calc-alkaline lamprophyres (CALs) e.g., Mudigubba, Kadiri and Korakkodu and (ii) Shoshonitic lamprophytes e.g., Udiripikonda and Sivarampeta. Petrology and geochemistry studies on Mudigubba and Kadiri lamprophyre suggest them to be calc-alkaline lamprophyres (Pandey *et al.* 2017a, 2018). High Mg#, Ni and Cr support primary nature of magma, whereas conspicuous negative anomalies at Nb, Ta and Ti multielement spider diagram suggest their derivation from subduction derived mafic magmas, which is further corroborated by depleted Nb/U, Ce/Pb ratios and elevated Th/Yb ratios and U and Pb contents. Hf/Sm, Ta/La, ratios further suggest that the source enrichment was caused by fluid-related metasomatism. These links the source enrichment to the accretion related growth of the Dharwar craton during Neoarchean which leads to the occurrence of subduction modified mantle wedge in the SCLM

Fig. 3: Photomicrographs of lamprophyres from the Deccan Large Igneous Province. (a) Radiating prismatic clinopyroxene grains displaying cumulo porphyritic texture with feldspar and plenty of dispersed spinel confined to the groundmass (Kanthari lamprophyre dykes). (b) Large amphibole grains (>3 mm) in feldspathic groundmass, a typical in equigranular, porphyritic texture of lamprophyre (Jeetnagar lamprophyre dykes). (c) Oscillatory zoned clinopyroxene in feldspathic groundmass with inclusions of spinel and apatite (Moradungari lamprophyre dykes). (d) Megacryst of olivine with a reaction rim around it (Kanthari lamprophyre dykes). (e) Amphibole and clinopyroxene as dominant phenocryst phases in Chhota udepur lamprophyres; spinels sporadically occur in groundmass and also present as inclusions. (f) Carbonate ocelli in the groundmass (Seraphalia lamprophyre dykes). (g) An amphibole phenocryst in equilibrium with clinopyroxene, with the inclusions of apatite suggesting prior crystallization of the later (Chhota udepur lamprophyre dykes). (h) Euhedral amphibole having needle shaped inclusions of apatite; lath shaped phlogopite and spinel are also present in feldspathic groundmass (Moradungari lamprophyre dykes). (i) Sieved clinopyroxene with spinels as inclusions in feldspathic groundmass (Seraphalia lamprophyre dykes). Abbreviations: Am- amphibole, Ap- apatite, Carb- carbonate, Cpx-clinopyroxene, Fsp- feldspars, Ol- olivine, Spl- spinel and Ph-phlogopite. Image source: Pandey *et al.* (2019)

beneath the EDC. On the other hand, the Udiripikonda, Sivarampeta and Korakkodu lamprophyre dykes are exposed in the Mesoproterozoic diamondiferous Wajrakarur kimberlite fields. Petrology and geochemistry suggest them to be originated through a low degree of partial melting of enriched mantle source (see Pandey *et al.*, 2018, Khan *et al.*, 2018).

Geochemistry displays overlapping features of both AL and CAL, however, high K_2O/Na_2O ratio of Udiripikonda (1.49-2.79) and Sivarampeta (1.59-1.89) displays their shoshonitic nature. Bulk rock geochemistry and isotopic (Sr-Nd) geochemistry suggest modification of sub-continental lithospheric mantle by subduction and asthenospheric upwelling

and a shallower mantle source region of the lamprophyres with respect to coeval kimberlites.

Lanjewar and Randive (2018) reported petrology and geochemistry of lamprophyres of the Harohalli dyke swarms occurring in the Halaguru and Mysore area in the Eastern Dharwar craton. These lamprophyres are classified as calc-alkaline with shoshonitic affinity. Bulk rock geochemistry and trace elements show primitive character and reveal their primary source falling within fields of primitive-MORB and enriched -MORB. Trace elements ratios Ba/Nb, Nb/Yb, Ba/Th, Th/Nb indicate back-arc basin magmas with inputs of shallow subducted components.

Recently, Giri *et al.* (2018) have reported cobaltoan pyrite in a lamprophyre dyke exposed in Banjari village of central India, intruding the Archean Sidhi Gneissic Complex (2.5 Ga) and highlighted the ore potential of lamprophyre magma for Co metal. This study reveals that in a pyrite-chalcopryrite association Co can be preferentially sequestered into the structure of pyrite. Petrology and geochemistry of biotite-rich lamprophyre dyke from the Thanewasna area, western Bastar craton have been reported for the first time (Meshram *et al.* 2018). Based on petrography, mineral chemistry and bulk rock, this dyke can be classified as calc-alkaline lamprophyre in general and minette in particular. The Thanewasna lamprophyre, when compared with the worldwide data, show a comparatively lower Ti content, but matches well with that of the Mudigubba calc-alkaline lamprophyre in the Dharwar craton (Pandey *et al.* 2017 b).

The Kutch volcanics and associated other igneous rocks in NW India are some of the oldest components of the Deccan Large Igneous Province. Four new $^{40}\text{Ar}/^{39}\text{Ar}$ ages of igneous intrusions from the Kutch were reported by Sen *et al.* (2016), which includes that of a lamprophyre dyke from the Island belt, with an age of ca. 67 Ma. Sharma *et al.* (2018) studied a chrome diopside megacryst from a lamprophyre from the Late Cretaceous Mundwara alkaline complex, NW India. Single mineral thermobarometry revealed that megacryst was derived from a relatively depth ~100 km than that of already reported for chrome diopside (~50 km) in the spinel-lherzolite xenoliths from the alkali basalts of Deccan age (ca. 66-67 Ma) from the Kutch area, NW India. Sharma *et al.* (2018) inferred that the

lithospheric thickness beneath the Mundwara complex was approximate ~100 km during Late Cretaceous and its composition was similar to that of the cratonic lithosphere. A new occurrence of lamprophyre has been recorded from Saurashtra peninsula of NW India (Naushad *et al.* 2019) and it shares petrological and geochemical similarities with other Deccan-related lamprophyres.

Mineral chemistry study of a mantle derived ultramafic xenoliths entrained in an Eocene (ca. 55 Ma) lamprophyre dyke exposed in the Dongargarh area along with the first time direct petrographical evidences for the modal metasomatism in the post-Deccan sub-continental lithospheric mantle have been recently reported (R. Pandey *et al.* 2017). Xenolith comprises of olivine, clinopyroxene, mica and numerous inclusions of apatite, interstitial pyrite. Olivine is forsteritic ($\text{Fo}_{85.34}$), whereas clinopyroxene is diopside ($\text{Wo}_{48.36}$, $\text{En}_{43.83}$, $\text{Fs}_{6.53}$ and $\text{Ac}_{1.27}$) and both show compositional similarity with worldwide enriched (metasomatized) mantle peridotite xenoliths. Geothermobarometer applied on the clinopyroxene show temperature (~1200°C) and pressure (~12 kb) comparable to those of other Deccan related xenoliths. However preserved phlogopite and apatite in xenoliths are interpreted as some of the readily fusible metasomatized portions which escaped wholesale melting possibly due to the variable thickness of the underlying SCLM, during the eruption of Deccan Traps.

Based on detailed petrological and geochemical investigations some of the previously reported mid-Cretaceous (ca. 125 Ma) 'anorogenic lamproite' (see Karmalkar *et al.* 2014) dyke from the palampur area in the Kutch region are re-interpreted to be a damtjernite (ultramafic lamprophyre: UML) by R. Pandey *et al.* (2018). These lamprophyres are comprised of olivine, phlogopite and clinopyroxenes phenocryst in the groundmass of perovskite, nepheline and magnetite. Major oxide and trace elements suggest them to be silica undersaturated, potassic to sodic, primitive lamprophyres which shows striking similarity with the ~69 Ma UML and sills of the Tethyan Indus suture zone, which are considered as the earliest known manifestation of the Deccan Large Igneous Province (LIP). Trace element ratios such as Ce/Pb, Nb/U, Th/Yb, Nb/Yb, Nb/La and the isotopic ratios $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70460 - 0.70461), ϵ_{Nd} values (+2.56 to -

0.69) reflects their OIB-type affinity and suggest them to be derived from a slightly depleted mantle source. Trace element ratios such as higher Rb/Sr, Nb and lower La/Sm suggest phlogopite as the residual phase and involvement of carbonatite metasomatism. Palanpur lamprophyre displays temporal similarity with the Kerguelen plume derived Rajmahal basalts and associated alkaline rocks from the eastern India. Whereas, what triggered the Kutch UML magmatism is still debatable, R. Pandey *et al.* (2018) suggested three models which can highlight the geodynamic setting of the Palanpur UML - (i) it could represent the earliest magmatic manifestation of Deccan-Reunion plume event, (ii) it could represent a less known alkaline event spanning between eruption of Rajmahal and Deccan traps, (iii) it could be result of prolonged (Triassic to Paleogene) multiple rifting in the Kutch.

Detailed petrological studies (R. Pandey *et al.*, 2019) on thirteen post-Deccan lamprophyre dykes in the Narmada rift zone from the Chhota udepur alkaline province of the Deccan Large Igneous Province show affinity towards calc-alkaline (kersantite, minette and vogesite), alkaline (sannaite and camptonite) as well as ultramafic (alnöite and damtjernite) varieties of lamprophyres (Fig. 3). Their magmas highlight the strong influence of fractionation processes and their Nb/U and Ce/Pb ratios are similar to the mantle array defined by MORBs and OIBs and suggests an uncontaminated nature. R. Pandey *et al.* (2019) proposed that enriched lithospheric mantle developed during the Neoproterozoic was metasomatized by small-volume CO₂-rich melts imparting a HIMU-type geochemical character during Late Cretaceous, when the mantle plume (*viz.*, Réunion) responsible for the

flood basalt eruption, impinged at the base of the NW Indian lithosphere. From the presence of F-rich apatite and high K/Rb in mica, the depth of post-Deccan lithosphere-asthenosphere boundary (LAB) beneath NW India was inferred to be at least ~100 km at ca. 65 Ma.

Epilogue

Besides the above publications, a review article on these rock types (Ray and Parthasarathy, 2019) and a book on 'Diamond fields of south India' (GSI, 2018) have also been published. A remarkable increase in output of research on these rock types in the last decade from various Indian cratons and mobile belts, is very likely a reflection of the petrological and geochemical significance as well as the economic importance attached to them.

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