Proc Indian natn Sci Acad **78** No. 3 September 2012 pp. 431-444
© *Printed in India*.

Status Report

Kimberlites, Lamproites, Lamprophyres, their Entrained Xenoliths, Mafic Dykes and Dyke Swarms: Highlights of Recent Indian Research

N V CHALAPATHI RAO* and RAJESH K SRIVASTAVA
Department of Geology, Centre of Advanced Study, Banaras Hindu University, Varanasi 221 005, India

This paper provides a glimpse of the past five-year research on kimberlites, lamproites, lamprophyres, their entrained mantle as well as lower crustal xenoliths, mafic dykes and dyke swarms from various cratons and mobile belts of the Indian shield. New findings have provided significant insights on the nature, composition and evolution of deep Indian continental lithospheric mantle, resolved important geological controversies and received considerable national and international attention. Two major international conferences – the sixth international dyke conference and tenth international kimberlite conference were also held in the country during this period thereby making it indeed a golden era of researches on deeper mantle petrology in India.

Key Words: Kimberlite; Lamproite; Lamprophyre; Mafic Dyke; Xenoliths; India

Introduction

There has been a considerable spurt, especially during the past five years, involving research on kimberlites, lamproites, lamprophyres, their entrained mantle as well as lower crustal xenoliths, mafic dykes and dyke swarms from various geological domains of the Indian shield. Results obtained from these studies have provided new insights on the nature, composition and evolution of deep Indian continental lithospheric mantle, resolved important geological problems/controversies apart from attracting considerable international attention. Besides, two major international conferences were also held during this period viz., VI International Dyke Conference at Banaras Hindu University, Varanasi (February, 2010) and X International Kimberlite Conference at Bangalore (February, 2012). Highlights of the research findings during 2007-2012 are discussed below under separate headings.

Kimberlites

Geological Society of India has brought out an issue exclusively devoted to "Kimberlites and related rocks of India" (Fareeduddin and Rao, 2007) which contain original as well as review articles providing important information on the diamond exploration in India, distribution of these rocks, new discoveries and petrology, geochemistry and geochronology. In a lead article Radhakrishna (2007a) highlighted the glorious past of the Indian diamond industry and pointed out an urgent need to integrate geological and geophysical information to search for hitherto unknown primary sources that yielded world-famous diamonds from the alluvial gravels from the lower reaches of Krishna Valley. Petrography is an important criterion for distinguishing mafic potassic-ultrapotassic rock types and Fareeduddin *et al.* (2007) brought out an extensive atlas depicting the petrographic characteristics of Indian occurrences. Majhgawan pipe in the Panna area of Bundelkhand craton is the only operational mine in primary source for diamond in India. Rau (2007) critically reviewed the geology of the Majhgawan pipe and the nearby diamondiferous conglomerate horizons such as Itwan, Jhiri and Gahadra and gave an account of the morphology of diamonds recovered from them. Mainkar and Lehmann (2007) reported reconnaissance petrography and geochemistry of the Behradih kimberlite pipe, Mainpur field, Bastar craton and exclude its lamproitic affinity. *In situ* U-Pb dating of titanite from the Tokapal kimberlite, Indravati basin, Bastar craton, gave a Neoproterozoic age of 620±30Ma (Lehmann *et al.*, 2007). New kimberlite occurrences have been reported from the state of Andhra Pradesh (i) on the left bank of Tungabhadra river near Mantralayam in Kurnool district of Andhra (Ravi *et al.*, 2007), (ii) Bommaganapalli area, Kalyandurg, Anantapur district (Mukherjee *et al.*, 2007), (iii) Timmasamudram area, Wajrakarur kimberlite field (WKF), Anantapur district (Srinivas Choudary *et al.*, 2007) and (iv) Chagapuram area, Gadwal schist belt (Ravi and Satyanarayana, 2007). Likewise, in the Mahasamund district of Chhattisgarh, rocks

---

*Author for Correspondence: E-mail: nvcr100@gmail.com with kimberlitic affinity are discovered and microdiamonds have been recovered from them (Chellani, 2007). The utility of kimberlitic calcrete as a viable exploration tool has been demonstrated with case studies from WKF (Roy, 2009). Some new locales for kimberlite exploration were delineated from Bouguer gravity modeling in the Narayanpet kimberlite field (NKF), Eastern Dharwar craton (EDC) (Veeriah *et al.*, 2009). These authors infer that the regional controls for kimberlite emplacement are the margins of upwarps in the deeper layers and five potential zones for kimberlite search near Vinjamur, Amreddypalle, Bijwar-Dhawad, Kadmur and Irladinne are identified. Diamond-facies spinel grains have been reported from Tokapal kimberlite of central India suggesting it to be either diamondiferous or its source regions going through highly oxidizing conditions thereby leading to the destruction of diamond (Chalapathi Rao *et al.*, 2012c).

Based on recent 1.1 Ga U-Pb (perovskite) and Rb-Sr (phlogopite) ages, Anil Kumar *et al.* (2007) linked the emplacement of 1.1 Ga kimberlites in the EDC to the impingement of a short-lived mantle plume at the base of the lithosphere or due to reorganisation of mantle convection regime at that time. K-Ca ages of leached phlogopites from two Proterozoic kimberlites from WKF and NKF in south India are shown to be in good agreement with their previously measured Rb-Sr ages and are considered to be strongly supportive of all of their contemporaneous emplacement at ca.1100 Ma (Gopalan and Anil Kumar, 2008). U-Pb perovskite ages for a number of kimberlites from WKF and NKF indeed confirm their 1.1-Ga emplacement age but their initial Sr and Nd isotopic ratios point out involvement of distinct mantle sources (Chalapathi Rao *et al.*, 2012d).

Precambrian and Phanerozoic potassic-ultrapotassic mafic magmatism in the Indian shield has been reviewed by Chalapathi Rao (2007a,b, 2008) and contrasting mantle sources are inferred for kimberlites and lamproites from the EDC. Petrophysical properties involving density and magnetic susceptibility of Indian kimberlites and lamproites are reported. Whereas their magnetic susceptibility is demonstrated to be directly proportional to the respective ferromagnetic mineral content, their density is mostly controlled by olivine, carbonate and iron and/or titanium oxide minerals (Chalapathi Rao, 2008b). Petrogenetic modeling involving rare earth elements necessitate derivation of WKF and NKF kimberlites of EDC from a dominantly lithospheric, and not asthenospheric, domain (Chalapathi Rao and Srivastava, 2009). However, from a combined bulk geochemical and isotopic (low Hf_i relative to Nd_i) grounds, Paton *et al.* (2009) place the derived depths of the WKF and NKF magmas to an asthenospheric source within or below the transition zone. A mixed Group I- and II-southern African kimberlite source, comprising variable components of earlier subduction related- and later plume related-metasomatism, is inferred for the generation of two of the kimberlites (NK-2 and KK-6) from the NKF (Chalapathi Rao and Dongre, 2009). Several overlapping petrological and geochemical characters of Group I- and II-kimberlites displayed by the kimberlites of southern India can be explained by this model. The Siddanpalli kimberlites occurring in the granite-greenstone terrain of the Gadwal area in the EDC, southern India possess different geochemical signatures compared to the other known kimberlites in the EDC. A combination of factors involving: (i) higher degrees of partial melting; (ii) relatively shallower depths of derivation; (iii) possible involvement of subducted component in their mantle source region; and (iv) previous extraction of boninitic magmas from their geological domain are inferred to have been involved in their genesis (Chalapathi Rao *et al.*, 2010a).

Phanerozoic diamondiferous kimberlite (orangeite) event synchronous with the Deccan Traps is recognised in the Bastar craton (Lehmann *et al.*, 2010). This work demonstrated that the Indian shield had a thickened lithosphere at the end-Cretaceous and that the Cretaceous superfast northward motion of the Indian plate cannot be linked to its lithospheric thinning, as previously thought. First discovery of orangeites (Group-II kimberlites) outside Kaapvaal craton of southern Africa has been made and their genesis is attributed to mantle plume -lithosphere interaction in the Bastar craton during the end-Cretaceous (Chalapathi Rao *et al.*, 2011c). This study has additionally evidenced fertility of the Phanerozoic Indian lithosphere with regard to diamond prospectivity contrary to the proposal made by Griffin *et al.* (2009) wherein the post-Gondwana breakup kimberlites and lamproites were considered unlikely to carry high diamond grades. A compelling link between kimberlites, flood basalts and some mantle plumes has been proposed, with focus on the Deccan Large Igneous Province (LIP), which has an important implication in the global petrogenetic models involving simultaneous eruption of small-volume (kimberlitic) and large-volume (basaltic) magmas (Chalapathi Rao and Lehmann, 2011). The geographical zonation of the kimberlite, lamprophyre, carbonatite and other alkaline rock spectrum in the Deccan LIP is inferred to reflect variable thickness of the pre-Deccan Indian lithosphere with a thinner lithosphere along the rift zones of northwestern and western India and a thickened Bastar craton lithosphere in central India. This heterogeneity is thought to control the volume of melt generation and melt ascent, as well as the ultimate alkaline magma type (Chalapathi Rao and Lehmann, 2011; Fig. 1).

Lamproites

Chelima dykes intruding the Nallamalai Group of

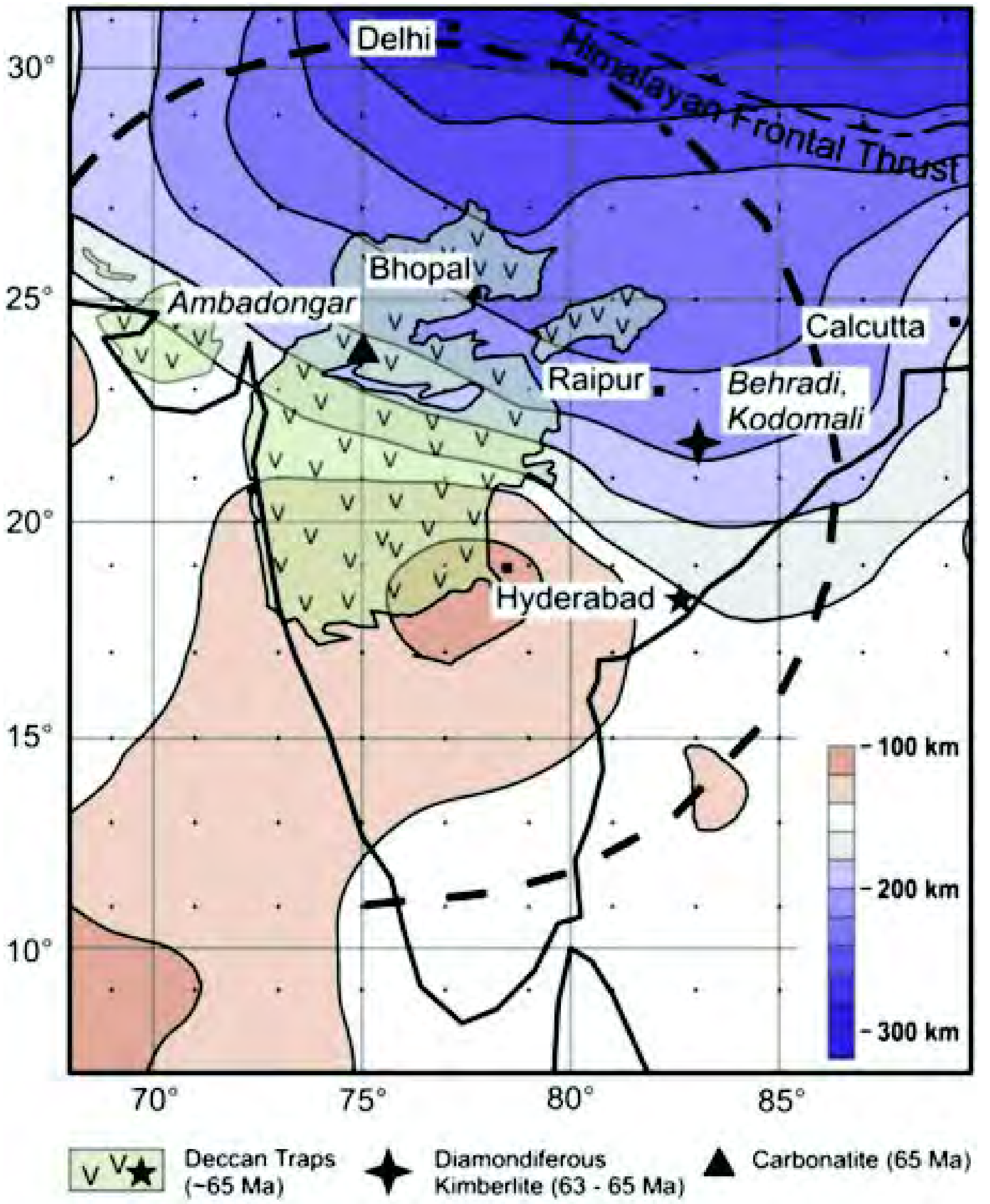

Fig. 1: **Regional variations in lithospheric thickness, calculated by converting the seismic shear-wave velocities into temperature profiles and then fitting geotherms. Dashed circle is the postulated Deccan plume. Presently exposed Deccan Traps, Ambadongar carbonatite in NW India and diamondiferous orangeites from the Bastar craton are also plotted (see Chalapathi Rao and Lehmann, 2011 for relevant references)**

Cuddapah rocks, southern India, are shown to be consistent with their nomenclature as lamproites and crustal contamination is demonstrated to have little effect on their geochemistry (Chalapathi Rao, 2007b). Chelima lamproites are also shown to be genetically unrelated to the other igneous activities in the Cuddapah sedimentaries and adjoining kimberlites in the Wajrakarur area (Chalapathi Rao, 2007b). Sr-rich apatite and Nb-rutile are reported from the Chelima lamproites and the paucity of these trace elements in respective minerals from the nearby Krishna lamproites is suggested to reflect either the difference in the nature of their metasomatized mantle source regions or varying melt fraction of their magmas, or both (Chalapathi Rao, 2011). Workable geochemical models for prognostication of the diamond prospectivity of the lamproites have been brought out which demonstrate the non-diamondiferous nature of the Krishna lamproites of southern India (Chalapathi Rao *et al*., 2011a). Based on Sr-Nd-Hf-Pb isotopic compositions, generation of the Krishna lamproites from a carbonate-metasomatised Archaean subducted source has been favoured and involvement of sub-continental lithospheric source is ruled out (Chakrabarti *et al*., 2007). On the contrary, from low K/Na and HREE abundances, Paul *et al*. (2007) opined that the Krishna lamproites were derived from depths shallower than the garnet stabiliy field and their source regions are less deeper than those of kimberlites from the EDC. Based on incompatible trace element ratios, Chalapathi Rao *et al*. (2010b) altogether exclude Krishna lamproites to be products of direct plume- (asthenospheric) derived mantle as well as subduction-related components and infer their derivation from sources similar to those of the co-spatial Cuddapah basin lamproites and WKF and NKF kimberlites from the EDC. A *vein-plus-wall-rock* model involving phlogopite + amphibole + rutile + clinopyroxene + apatite + titanite occurring as metasomatic veins in a depleted lithospheric mantle, within the garnet stability field, is suggested to be a plausible source (Chalapathi Rao *et al*., 2010b).

One of the Krishna lamproites *viz*. Pochampalle dyke has been dated by Ar-Ar method to be of 1500 Ma, which makes it roughly 250 Ma older than the other Krishna lamproites (Osborne *et al*., 2011). These authors further demonstrate that the Pochampalle lamproite was derived from an isotopically distinct source region with a lower ^{143}Nd/^{144}Nd ratio than the other lamproites in the Krishna field. Eight new occurrences of diamondiferous lamproites (termed as Saptarshi lamproites) are reported by multi national company Rio Tinto in Bunder area, Bundelkhand craton (Masun *et al*., 2009). Rb-Sr (phlogopite and whole-rock) dating of one of these lamproites gave an age of 1100Ma similar to that of the nearby Majhgawan and Hinota pipes (Masun *et al*., 2009). New occurrences of lamproite dykes intruding the basement granite at Khadka area near the northern margin of the Indravati basin are recorded (Yellappa *et al*., 2010). These lamproites are hydrothermally altered and also possibly metamorphosed but relics of their original textures are well-preserved thereby providing clues as to the nature of the protolith. Groundmass spinel compositions and HFSE contents firmly evidence their lamproitic nature.

Lamprophyres

Widespread occurrences of lamprophyric rocks are known since more than a century from the various Gondwana coal fields such as Jharia, Ranigunj, Karanpura, Daltongunj, etc. in the Damodar valley at the northern margin of the Singhbhum craton, eastern India. However, their nomenclature is not straight forward and they have been differently termed as kimberlites, lamproites, orangeites, lamprophyres by different workers at different times. Based on mineral-genetic classification, Mitchell (2007) recommends them to be termed as lamproites *var*. Damodar and excludes their comparision with Kaapvaal craton-type orangeites and Kimberley craton-type lamproites. Detailed petrological and geochemical work on the Cretaceous ultrapotassics in the Jharia area reveal the presence of a thinned and metasomatically veined lithosphere that inherited an ancient (Archaean) subducted component at the margin of the Singhbhum craton (Srivastava *et al*., 2009a). The diverging petrological and geochemical characters of kimberlites and lamproites (cratonic signature) and those of aillikites (rift-related signatures) portrayed by these rocks is shown to be a direct outcome of such a unique lithosphere. The melt contribution of the Kerguelen plume in their genesis is also shown to be minimal (Srivastava *et al*., 2009a). On the other hand, from a detailed mineralogical study of ultrapotassic rocks from the nearby Ranigunj coal field Mitchell and Fareeduddin (2009) conclude them to be peralkaline lamproites and rule out their affinities to kimberlite or orangeite or aillikite or minette. Early Cretaceous lamprophyre dykes of the Meghalaya plateau of eastern India intrude the Archaean Gneissic Complex and their emplacement is shown to be structurally controlled by Nongchram fault and their genesis related to Kerguelen hotspot magmatism (Nambiar, 2007). Petrological and geochemical studies on lamprophyres from the Mahakoshal schist belt, central India have led to the identification of role of extension and metasomatised mantle in their genesis (Srivastava and Chalapathi Rao, 2007). Likewise, petrogenetic studies on lamprophyres from Chhotaudepur area, western India, demonstrated their Deccan linkages and highlighted the role of highly fusible mantle leading to the generation of small-volume potassic magmas during the large-scale flood basalt generation (Chalapathi Rao *et al*., 2012a).

Crustal and Mantle Xenoliths

On the basis of mineral chemistry and texture, a cumulate origin is proposed for the eclogitic xenoliths from the southern Indian kimberlites (Patel *et al*., 2009). Carbonate and limestone xenoliths, hosted in 1.1-Ga kimberlites from Siddanpalli, EDC, are reported and their derivation has been demonstrated to be from the Kurnool and Bhima sedimentaries (Dongre *et al*., 2008). This work provides first evidence for the physical continuity of the Purana Proterozoic basins of peninsular India and recognize a Mesoproterozoic age of these basins contrary to the existing belief that they are Neoproterozoic and resolved an important chronological issue and controversy in Indian Geology (Chalapathi Rao *et al*., 2010b). Incidence of micro-diamonds in the Kanyakumari beach, southern most tip of India, reported by Rau (2006), could not be confirmed by subsequent studies by Dinesh *et al.* (2010) who conclude that grains with brilliant luster are in fact zircons.

A comparative study of the mafic-ultramafic xenoliths hosted by the Proterozoic kimberlites of Dharwar craton and alkali basalts derived from the late Cretaceous Deccan volcanic province reveal elevated geotherm beneath NW India (Karmalkar *et al*., 2009). Furthermore, the nature and style of metasomatism in the sub-continental lithospheric mantle in the two domains is inferred to be different and probably reflects the influence of the Reunion mantle plume on the Deccan-related xenoliths (Karmalkar *et al*., 2009). Significant differences in the composition and structure of the sub-continental lithospheric mantle (SCLM) along an 80-km traverse across the eastern margin of the Closepet granite have been brought out from the compositions of garnet xenocrysts and eclogitic xenoliths sampled by the kimberlites (Griffin *et al*., 2009). The SCLM beneath the SW end of the traverse was found to be more depleted than that at the NE end whereas the middle-portion of the traverse is characterised by a highly refertilised (metasomatised) SCLM which is likely to correspond to a cratonic suture between eastern and western Dharwar cratons (Griffin *et al*., 2009). Sapphirine-bearing Mg-Al (spinel + phlogopite bearing) crustal xenolith that has undergone peak metamorphism in the amphibolite-granulite transitional facies has been reported from the Pipe-3 (Lattavaram) kimberlite, WKF, EDC (Patel *et al*., 2010a). This constitutes the first record of sapphirine-bearing rocks from the central part of the Dharwar craton.

Major-element concentration of garnet concentrates from WKF and NKF kimberlites from EDC reveal that diamond in the WKF to have been derived from both lherzolitic and harzburgitic varieties whereas its rarity in the NKF is inferred to be due to shallower depth of origin of kimberlite magma (Patel *et al*., 2010b). On the other hand, based on the groundmass perovskite oxybarometry and paucity of olivine macrocrysts from the NKF kimberlites, Chalapathi Rao *et al.* (2012b) conclude that redox conditions were favourable for diamond prospectivity but magmatic emplacement could, instead, have played a major role in their low diamond potential. A rare occurrence of glimmeritic (mica-rich) enclave – composed of abundant modal biotite, subordinate proportions of clinopyroxene and apatite, and minor amounts of feldspar, carbonate and sphene – is reported from the lamprophyre of Settupalle alkaline pluton, Eastern Ghats mobile belt (EGMB), India (Chalapathi Rao, 2010). Glimmeritic enclave is construed to be an autolith of the proto-lamprophyre magma which failed to reach the surface, and lined the wall-rock along the conduit of the lamprophyric intrusion. This provides evidence for multi-stage modification of the lithospheric mantle due to the infiltration of the potassium-rich melts such as lamprophyres (Chalapathi Rao, 2010).

Mafic Dykes and Dyke Swarms

History of dyke swarm research in India has been comprehensively reviewed by Srivastava *et al.* (2008a). Geological Society of India has also published two special issues on Precambrian Mafic Magmatism in the Indian Shield which incorporates almost complete updated information on dykes from various cratons and mobile belts (Srivastava and Ahmad, 2008 and 2009 and the references therein). The 6th International Dyke Conference has been organized by the Department of Geology, Banaras Hindu University under the convenorship of Rajesh K. Srivastava. Proceeding volume of this conference is now available and contains many recent works on dykes of India (Srivastava, 2011). Subsequent paragraphs will provide glimpses of recent work, since 2007, on mafic dykes and dyke swarms emplaced within the Indian shield.

Ernst and Srivastava (2008) reviewed the record of Indian LIPs and LIP-'fragments' from the Dharwar craton, Bastar craton, Singhbhum craton, Eastern Ghats alkaline province and Aravalli craton. They recognized 2370-2180- and 1890-Ma mantle plume centres which need to be firmly established by additional data (see Fig. 1). The Proterozoic mafic dyke swarms exposed in the Dharwar craton are of special interest because this craton has been a principal constituent of several ancient supercontinents (Radhakrishna *et al*., 2007; Heaman, 2008; Srivastava *et al*., 2008b; Pradhan *et al*., 2010; Srivastava, 2011; Mohanty, 2011a, b). Some recent U-Pb ages reported for the mafic dykes (and sills) of EDC includes 1.88-Ga mafic sill from the Cuddapah basin (French *et al*., 2008), 2.37-Ga WNW trending dolerite dyke the Bangalore dyke swarm (Halls *et al*., 2007; Anil Kumar *et al*., 2012), 2.37-Ga E-W-trending Harohalli-Penukonda-Chennekottapalle mafic dykes, 2.22 Ga N-S trending Kandlamadugu dyke, 2.21 Ga NW-SE trending Somala dyke, 2.18-Ga E-W trending Bandepalem mafic dyke, 2.18-Ga NW-SE Dandeli dyke (all ages from French and Heaman, 2010), 2.21-Ga N-S trending mafic dykes emplaced very close to, and parallel to the western margin of, the Closepet granite batholith (Srivastava *et al*., 2011a), and 1.19-Ga N-S trending Harohalli alkaline dyke swarm (Pradhan *et al*., 2008). French *et al*. (2008) have recognized remnant of a Palaeoproterozoic (1891-1883) LIP covering the southern Bastar craton and nearby Cuddapah basin from the adjacent Dharwar craton, India. This inference is based on high-precision U-Pb dates of NW-SE-trending mafic dykes from the southern Bastar craton, and a mafic sill from the Cuddapah basin, and indicate mafic magmatic episode that spans an area of at least ~90,000 km^2 in the south Indian shield. This is well-supported by recent report on the palaeomagnetism of 1.88-Ga dykes from the Bastar and Dharwar cratons by Meert *et al*. (2011). The robust palaeomagnetic data reported by them questioned the existing reconstruction of the Columbia supercontinent. Meert *et al*. (op.cit) recommended that either the Columbia supercontinent did not exist at 1.9 Ga or requires major modification and concluded that the Columbia supercontinent remains a viable possibility although relationships between individual elements should be re-evaluated as more data becomes available.

Ratre *et al*. (2010) dated N-S-trending dyke from the northern Bastar craton by SHRIMP method and reported 1.45-Ga age. They inferred this age as a lower time constraint on the sedimentary sequences of the Purana basin (Khariar basin) that have been deposited unconformably over the Bastar craton. Similar age (1.42 Ga; Sm-Nd systematics) is reported for a diabasic intrusive within the Mesoproterozoic Singhora Group of Chhattisgarh Supergroup (Das *et al*., 2011). Same diabasic intrusives within the Mesoproterozoic Singhora Group are also studied by Sinha *et al*., (2011). Their observations confirm the existence of igneous/hydrothermal activity in the Chhattisgarh basin which is consistent with the Rb/Sr age of sill. A concomitant thermal event in the basin at ~1100 Ma with related hydrothermal activity is thus proved by them. Recently, Srivastava *et al*. (2011b) have presented evidence for a Paleoproterozic event of metamorphism in the Bastar craton on the basis of mineral chemistry and U-Pb geochronology of mafic dykes. These new data indicate the metamorphic grade in this region belongs to medium amphibolite facies. U-Pb age results for metamorphic rutile from a boninite-norite (BN) dyke yielded a Palaeoproterozoic date of 2118±2 Ma, interpreted to indicate the time of exsolution of retrograde rutile from Ti-rich actinolite. This represents a robust minimum age constraint for the timing of emplacement of the BN dyke swarm.

An integrated study (palaeomagnetic, geochronological and geochemical) of Proterozoic dykes from Dharwar craton, southern India supports the presence of at least two different E-W-trending dyke swarms (~2370 and ~1890 Ma) in the Dharwar craton (Piispa *et al*., 2011). Numerous palaeomagnetic sites in the east-west-trending Bangalore dyke swarm of the Dharwar craton carry a consistently steep remanence which has been interpreted as primary (Halls *et al*., 2007). Yellappa and Chetty (2008) identified three dyke trends e.g. NW-SE, E-W and NE-SW, based on Remote Sensing studies of LANDSAT images, aerial photographs and field observations around the Ramagiri schist belt, EDC, whose emplacement has been attributed to variable Palaeostress regimes prevailing during the Proterozoic. Krishnamacharyulu *et al*. (2008) studied dyke swarms surrounding the SW portion of the Cuddapah basin for their gravity and magnetic profiles. They suggested that such results can be used to decipher the presence of radial dykes. Multi-channel analysis of surface waves (MASW) technique is applied to the dolerite dykes to delineate weathered and fractured zones that can be potential groundwater reservoirs (Seshunarayana *et al*., 2008). Mesoproterozoic mafic dykes from the Prakasam Alkaline Province of EGMB have been studied for their geochemical characteristics (Vijaya Kumar and Rathna, 2008). Metamorphosed mafic dykes exposed around Chilka Lake granulites, in the EGMB have been studied by Bose *et al*. (2011). They suggested that these mafic bodies were metamorphosed and deformed by tectonothermal events at ca. 800-500 Ma.

A number of publications have also appeared dwelling on the petrology and and geochemistry of the mafic dykes and dyke swarms. E-W-trending mafic dykes of picrite basalt to basaltic andesite compositions are reported from Kalyadi, Dharwar craton, which display at least two different petrogenetic affinities: (i) a low Ti-affinity and (ii) a transitional-type MORB affinity (Chandrasekharam *et al*., 2008). Likewise, Devaraju *et al*. (2008) recognised mafic dykes displaying volcanic arc, ocean floor and N-MORB affinity with destructive plate margin emplacement feature from WDC. Jayananda *et al*. (2008) reported Paleoproterozoic high-magnesian norite dykes from the Halagur-Satnur areas of EDC and suggested their derivation from a metasomatised refractory mantle source corresponding to the composition of a boninitic magma. Similar tholeiite-boninite associations are reported globally in space and time that suggest a large-scale mantle heterogeneity during the Palaeoproterozoic (Srivastava, 2008).

T-MORB or T-OIB type tholeiitic late Phanerozoic dykes are particularly predominant in coastal Kerala. The temporal variations and mantle sources of these dykes was recently reviewed by Radhakrishna (2007b). Radhakrishna and Joseph (2012) studied late Cretaceous mafic dykes exposed around southwest coast of Kerala for their geochemistry and paleomagnetism and discussed about role of plume in the Indian Ocean region. Pratheesh *et al*. (2011) also studied Cretaceous mafic dykes in the Moyar Shear Zone (MSZ) area, north Kerala, India for their petrology, geochemistry and anisotropy of magnetic susceptibility (AMS). They suggested their derivation from a N-MORB type magma. AMS data on these dykes suggests normal magnetic fabrics.

Mafic dyke swarms are well exposed and documented from the Bastar craton and have been studied extensively by several workers in recent years (Srivastava and Gautam, 2008, 2009; Gautam and Srivastava, 2011 for reviews). A Neoarchaean–Palaeoproterozoic intracratonic boninite-norite dyke swarm is reported from the southern Bastar craton (Srivastava, 2008). These dykes are classified as high-Ca and low-Ca boninites which are supposed to be derived from a metasomatized, highly refractory mantle. PGE geochemistry of these boninite-norite dykes is presented by Srivastava *et al*. (2010). PGE variations in these rocks together with those of major - and other trace elements are consistent with a model involving olivine fractionation along with chromite as a cotectic phase. Boninite dykes are also documented from the central (Gautam and Srivastava, 2011; Srivastava and Gautam, 2012) and northern (Subba Rao *et al*., 2007, 2008a, b;

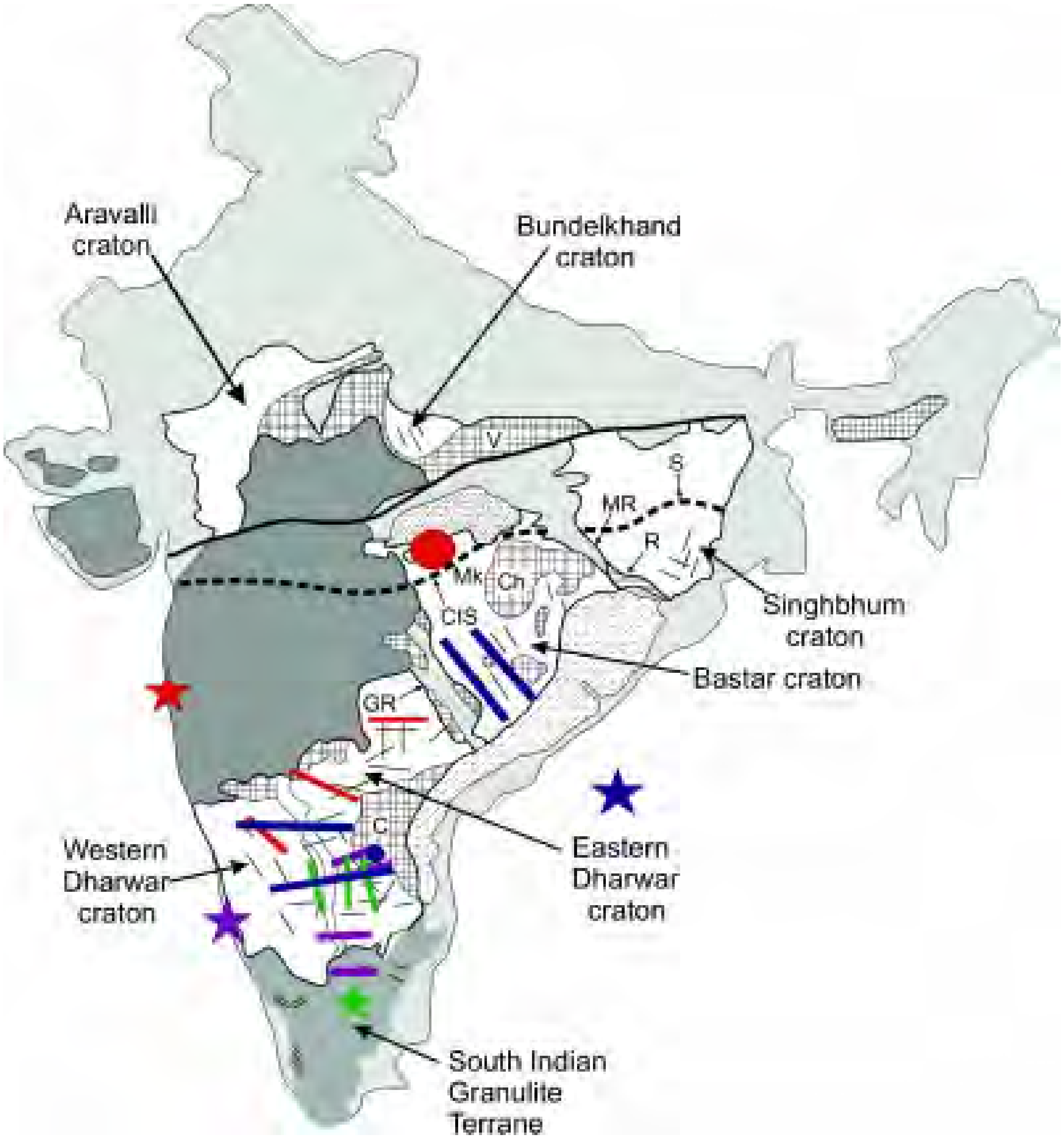

Fig. 2: Distribution of various Proterozoic mafic units. Filled star shows locations of inferred mantle plume. Violet: 2.37-Ga Bangalore swarm; Red: 2.18-Ga Mahbubnagar swarm; Green: 2.21-Ga Southern Dharwar swarm; Blue: 1.88-1.89-Ga Southern Bastar – Cuddapah LIP (Ernst and Srivastava, 2008; Srivastava *et al*., 2011)

Chalapathi Rao and Srivastava, 2009) parts of the Bastar craton. Chalapathi Rao and Srivastava (2009) suggested petrogenesis of boninite dyke, exposed near Dongargarh area, through interaction of a refractory and fluids derived from subducted sediments, which ultimately hint a fossil subduction zone in this region during Palaeoproterozoic. Hussain *et al*. (2008) presented geochemical data on mafic dyke swarms of the central and NE parts of the Bastar craton. Sr-Nd isotope data are reported for the early Precambrian sub-alkaline BD_1 and BD_2 mafic dykes of the southern Bastar craton (Srivastava *et al*., 2009). These dykes display a limited range of initial $^{143}Nd/^{144}Nd$ but a wide range of apparent initial $^{87}Sr/^{86}Sr$. All samples have positive εNd values. Presented isotopic data do not suggest severe crustal contamination during the emplacement of these dykes. Overlapping positive εNd values for BD_1 and BD_2 dykes suggest a similar mantle source tapped by variable melt fractions at different times was responsible for the genesis of these two mafic dyke swarms of southern Bastar craton.

"$^{40}Ar/^{39}Ar$ whole-rock ages of 63.7 ± 2.7 Ma and 66.6 ± 2.2 Ma for two samples of sub-surface mafic dykes intrusive into the sedimentary rocks of the Mesoproterozoic Chhattisgarh basin, Bastar craton, central India have been reported (Chalapathi Rao *et al*., 2011b). The obtained ages are synchronous with those of the Deccan Traps whose nearest exposures are at a distance of ~200 km to the west, and the recently dated diamondiferous orangeites (Group-II kimberlites) of the Mainpur area (located ~100 km SE within the Bastar craton). The chemical composition of the Chhattisgarh mafic dykes is indistinguishable from the chemostratigraphic horizons of the upper Deccan lavas of the Wai Subgroup (Ambenali and Poladpur Formations) and confirms them to be a part of the Deccan Large Igneous Province (LIP) (Chalapathi Rao *et al*., 2011b) as also opined earlier by Subba Rao *et al*. (2007). The Deccan-age of the Chhattisgarh dykes and the Mainpur orangeites permits a substantial increase of at least 8.5×10^4 km^2 in the spatial extent of the Deccan IP (Chalapathi Rao *et al*., 2011b). Petrology and geochemistry of the sills and dyke swarms from various domains of the Deccan Traps are studied and their correlations with chemo-stratigraphic horizons of the lava flows attempted (Ray *et al*., 2007; Sheth *et al*., 2009; Vanderkluysen *et al*., 2011). Nature of the Precambrian basement beneath the Deccan Traps has been deciphered from the felsic xenoliths in dolerite dykes emplaced within the Deccan Traps (Ray *et al*., 2008).

Chakraborty *et al*. (2011) studied mafic dykes that intrude the tremolite-zone siliceous dolomites of Palaeoproterozoic Mahakoshal Group of rocks of central India. They conclude that mineralogical transformation augmented by metasomatic alteration has considerably changed the physical properties of mafic dykes and allowed strain concentration preferentially along the dyke margins which in turn developed a pervasive foliation that is missing in the central part of the dyke. Mishra *et al*. (2011) infer the genesis of the mafic-ultramafic intrusives and extrusives in relation to the basement gneiss of the Central Indian Tectonic Zone *vis-a-vis* rift tectonics.

The mafic dykes of doleritic composition termed 'Newer Dolerites', which are intrusive within the Singhbhum granite pluton, are inferred to have been emplaced in at least three pulses of magmatic activity ranging from Early Proterozoic to Mesoproterozoic. Bose (2008, 2009) have presented comprehensive reviews on these dykes and presented detailed petrological and geochemical investigations. He negates any genetic link between these diverse magmatic suites. Mineral chemistry on the Newer dolerite dyke swarm around Bisoi is presented by Maity *et al*. (2008). Hypabyssal igneous activity in the form of mafic-ultramafic dykes and sills is widespread in the Damodar valley (Kumar and Ahmad, 2007; Srivastava, 2012). Mafic dykes of different compositions are reported from the Proterozoic Chotanagpur Gneissic Complex (CGC) (Ghose and Chatterjee, 2008). Patil and Arora (2008) presented palaeomagnetic and rock magnetic investigation results from mafic dykes from Raniganj coal fields and unambiguously relate them to the Rajmahal traps of 117 Ma. Ray *et al*. (2011) have explored the petrological controls on rheological inversion of a suite of deformed mafic dykes from parts of the Chhotanagpur Granite Gneiss Complex. They propose a viable mechanism for the development of fish-head boudins. Formation of the dyke swarms in this area is correlated with the ca.1.5-Ga extension of their gneissic basement.

Mondal *et al*. (2008 a,b) have reviewed the Precambrian mafic magmatism, mostly represented by mafic dyke swarms, occurring in the Bundelkhand craton. Very recently Pradhan *et al*. (2012) provided robust age control on the Bundelkhand dykes. They report U-Pb age of 1979 ± 8 Ma for the NW–SE trending dykes and $^{207}Pb/^{206}Pb$ age of 1113 ± 7 Ma for the Mahoba suite of ENE–WSW-trending dykes. Mineral chemistry and geochemistry on these mafic dykes is presented by Pati *et al*. (2008). Dykes and dyke swarms of different ages and nature are also well-documented from the Aravalli craton. Ahmad *et al*. (2008) have presented comprehensive review on these Precambrian mafic magmatisms.

A number of mafic intrusive bodies in the form of dykes and sills are documented from the whole Himalayan range (Ahmad, 2008). Mafic dykes of doleritic composition intrude the Lower Cambrian Krol and Tal Formations in the Nainital region (Kumar *et al*., 2008). It is inferred that these dykes are derived from a slightly crustally contaminated tholeiitic basaltic magma derived from nonpyrolite enriched mantle source. In the central and NW Shillong plateau widespread dolerite, basalt and ultrabasic dykes have intruded the basement rocks in NW-SE, NE-SW and N-S direction (Mallikharjuna Rao *et al*., 2009). Mallikharjuna Rao and Poornachandra Rao (2008) presented geochemical data on Cretaceous mafic dykes of the West Garo Hills region and suggest their derivation from a picritic magma that underwent extensive low-pressure olivine fractionation. Srivastava *et al*. (2009b) studied Proterozoic olivine tholeiite intrusive from the Central Crystallines of the western Arunachal Himalaya for their petrological and geochemical characteristics and suggested their derivation from a olivine tholeiite melt generated from a depleted lherzolite mantle source. These mafic rocks show very close geochemical similarities with mafic rocks reported from the western Himalaya.

Future Perspectives

From the above presentation it is clear that a huge data base has now become available on kimberlites and related rocks and their entrained xenoliths as well as on mafic dykes from the Indian shield. Past half-a-decade can well be regarded as a golden era of deeper mantle petrology studies in India. Generation of high precision mineral ages using the state-of-the-art techniques (SHRIMP, LA-ICP-MS) and application of multi-element isotope systematics (involving Hf-Os-Pb-Nd) on these rocks have the potential to shed further insights on the evolution of the SCLM beneath the Indian shield and thus constitute some of the important thrust areas of future research.

Acknowledgements

We thank Profs D.M.Banerjee (Delhi University) and A.K. Singhvi (Physical Research Laboratory) for their kind invitation and for providing us a wonderful opportunity to write this article. We tried our best to incorporate and discuss as many references as possible in this review. However, if we inadvertently overlooked any reference we offer our sincere apologies to the concerned colleagues.

References

Ahmad, T., 2008. Precambrian mafic magmatism in the Himalayan mountain range. Jour. Geol. Soc. India, v. 72, p. 85-92.

Ahmad, T., Deb, M., Tarney, J. and Raza, M., 2008. Proterozoic mafic volcanism in the Aravalli–Delhi orogen, northwestern India: geochemistry and tectonic framework. Jour. Geol. Soc. India, v. 72, p. 93-111.

Anil Kumar, Hamilton, M.A. and Halls, H.A., 1012. A Palaeoproterozoic giant radiating dyke swarm in the Iharwar craton, southern India. Geochem. Geophys. Geosyst., v. 13, Q02011,doi:10.1029/2011GC003926.

Anil Kumar, Heaman, L.A. and Manikyamba, C., 2007. Mesoproterozoic kimberlites in south India: A possible link to ~1.1 Ga global magmatism. Precam. Res., v. 15, p. 192-204 .

Bose, M. K., 2008. Petrology and geochemistry of Proterozoic 'Newer Dolerite' and associated ultramafic dykes within Singhbhum granite pluton, eastern India. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 413-445.

Bose, M. K., 2009. Precambrian mafic magmatism in the Singhbhum craton, eastern India. Jour. Geol. Soc. India, v. 73, p. 13-35.

Bose, S., Das, K., Chakraborty, S. and Miura, H., 2011. Petrology and geochemistry of metamorphosed basic intrusives from Chilka Lake Granulites, Eastern Ghats Belt, India: Implications for Rodinia breakup. In: Dyke Swarms: Keys for geodynamic interpretation, R. K. Srivastava (Ed.), Springer-Verlag, Berlin Heidelberg, p. 241-261.

Chakrabarti, R., Basu, A.R. and Paul, D.K., 2007. Nd-Hf-Sr-Pb isotopes and trace element geochemistry of Proterozoic lamproites from southern India: Subducted komatiite in the source. Chem. Geol., v. 236, p. 291-302.

Chakraborty, K., Sanyal, S. and Sengupta, P., 2011. Fluid induced metamorphism in a suite of mafic dykes from Palaeoproterozoic Mahakoshal Group, central India. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (ed.), Springer-Verlag, Berlin, Heidelberg, p. 219-240.

Chalapathi Rao, N.V., 2007a. Contribution of kimberlites and lamproites in understanding sub-continental lithospheric mantle: an Indian perspective. In: C. Leelanandam, I.B.Ramaprasada Rao, Ch.Sivaji and M. Santosh (Eds.), The evolution of the Indian continental crust and upper mantle. International Association of Gondwana Research (IAGR) Special volume (T.M.Mahadevan volume),v.10, p. 123-134.

Chalapathi Rao, N.V., 2007b. Chelima dykes, Cuddapah Basin, southern India: A review of the age, petrology, geochemistry and petrogenesis of the worlds' oldest lamproites. Jour. Geol. Soc. India, v.69, p. 523-538.

Chalapathi Rao, N.V., 2008a. Precambrian alkaline potassic-ultrapotassic, mafic-ultramafic magmatism in Peninisular India. Jour. Geol. Soc. India, v. 72, p. 57-82.

Chalapathi Rao, N.V., 2008b. Petrophysical properties of Indian kimberlites, lamproites and lamprophyres. In: Indian Dykes:, Geochemistry, Geochronology & Geophysics. R.K. Srivastava, Ch. Sivaji and N.V. Chalapathi Rao (Eds.). Narosa Publishers, New Delhi, p. 309-318.

Chalapathi Rao, N.V., 2010. Glimmeritic enclave in a lamprophyre from the Settupalle alkaline pluton, Eastern Ghats Mobile belt. J. Geol. Soc. India, v. 75, p. 783-790.

Chalapathi Rao, N.V., 2011. Sr-rich apatite and Nb-rutile from the Chelima lamproite dykes, Cuddapah basin, southern India and their petrological significance. Curr. Sci., v. 100, p. 207-1210.

Chalapathi Rao, N.V., Anand, M., Dongre, A. and Osborne, I., 2010a. Carbonate xenoliths hosted by the Mesoproterozoic Siddanpalli kimberlite cluster (Eastern Dharwar craton): implications for the geodynamic evolution of southern India and its diamond and uranium metallogenesis. Int. Jour. Earth Sci., v. 99, p. 1791-1804.

Chalapathi Rao, N.V., Burgess, R., Lehmann, B., Mainkar, D., Pande, S.K., Hari, K.R. and Bodhankar, N. 2011b. ^{40}Ar/^{39}Ar ages of mafic dykes from the Mesoproterozoic Chhattisgarh basin, Bastar craton, central India: Implication for the origin and spatial extent of the Deccan Large Igneous Province. Lithos, v. 125, p. 995-1005.

Chalapathi Rao, N.V., Dharma Rao, C.V. and Sanjay Das., 2012a. Petrogenesis of lamprophyres from the Chhotaudepur area, Narmada rift zone, and its relation to Deccan magmatism. Jour. Asian Earth Sci., v. 45, p. 24-39.

Chalapathi Rao, N.V. and Dongre, A., 2009. Mineralogy and geochemistry of the kimberlites NK-2 and KK-6, Narayanpet kimberlite field, Eastern Dharwar craton, southern India: evidence for a transitional kimberlite signature. Canad. Mineral., v. 47, p. 1117-1135.

Chalapathi Rao,N.V., Dongre, A., Kamde, G., Srivastava, R.K., Sridhar, M. and Kaminsky, F. E., 2010a. Petrology, geochemistry and genesis of newly discovered Mesoproterozoic highly magnesian, calcite-rich kimberlites from Siddanpalli, Eastern Dharwar craton, southern India: Products of subduction-related magmatic sources? Mineral. Petrol., v. 98, p. 313-328.

Chalapathi Rao, N.V., Kamde, G., Kale, H.S. and Dongre, A., 2010b. Petrogenesis of the Mesoproterozoic lamproites from the Krishna Valley, Eastern Dharwar craton, southern India. Precamb. Res., v. 177, p. 103-130.

Chalapathi Rao, N.V., Kamde, G., Kale, H.S. and Dongre, A., 2011a. Diamond prospectivity of Mesoproterozoic lamproites from the Krishna valley, eastern Dharwar craton, southern India: Insights from whole-rock geochemistry. Geochem. Jour. v. 45, p.79-85.

Chalapathi Rao, N.V. and Lehmann, B., 2011. Kimberlites, flood basalts and mantle plumes: New insights from the Deccan Large Igneous Province. Earth-Sci. Rev., v. 107, p. 315-324.

Chalapathi Rao, N.V., Lehmann, B., Belyatsky, B. and Mainkar, D., 2011c. Petrogenesis of the end-Cretaceous diamondiferous Behradih kimberlite pipe, Bastar craton: Implication for mantle-plume lithosphere interaction in Central India. Contrib. Mineral. Petrol., v. 161, p. 721-742.

Chalapathi Rao, N.V., Lehmann, B. and Mainkar, D., 2012 c. Diamond facies chrome spinel from the Tokapal kimberlite, central India and its petrological significance. Mineral. Petrol., doi: 10.1007/s00710-012-0199-5.

Chalapathi Rao, N.V., Paton, C. and Lehmann, B., 2012b. Origin and diamond prospectivity of Mesoproterozoic kimberlites from the Narayanpet field, Eastern Dharwar craton, southern India: insights from groundmass mineralogy, bulk-chemistry and perovskite oxybarometry. Geol. J., v. 47, p. 186-212.

Chalapathi Rao, N. V. and Srivastava, Rajesh K., 2009. A new find of boninite dyke from the Paleoproterozoic Dongargarh Supergroup: Inference for a fossil subduction zone in the Archaean of the Bastar Craton, Central India. N. Jahrb. Mineral., v. 186/3, p. 271-282.

Chalapathi Rao, N.V. and Srivastava, R.K., 2009. Petrology and geochemistry of Mesoproterozoic diamondiferous kimberlites from the Wajrakarur kimberlite field, Eastern Dharwar craton, southern India: Constraints on their genesis and mantle source regions. Contrib. Mineral. Petrol., v. 157, p. 245-265.

Chalapathi Rao, N.V., Wu, F.Y., Mitchell, R.H., Li, Q.L. and Lehmann, B., 2012d. Mesoproterozoic U–Pb ages, trace element and Sr–Nd isotopic composition of perovskite from kimberlites of the Eastern Dharwar craton, southern India: Distinct mantle sources and a widespread 1.1 Ga tectonomagmatic event. Chem. Geol., doi:10.1016/j.chemgeo.2012.04.023.

Chandrasekharam, D., Melluso, L., Cucciniello, C., Mathew, B. and Perini, G., 2008. Petrogenesis of E-W trending dykes from Kalyadi, Dharwar Craton, southwestern India. In: Indian Dykes: Geochemistry, Geophysics and Geochronology. R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 199-214.

Chellani, S.K., 2007. New find of diamonds in Basna kimberlite field, District Mahasamund, Chattisgarh. Jour. Geol. Soc. India, v. 69, p. 619-624.

Das, P., Das, K., Chakraborty, P. P. and Balakrishnan, S., 2011. 1420 Ma diabasic intrusives from the Mesoproterozoic Singhora Group, Chhattisgarh Supergroup, India: Implications towards non-plume intrusive activity. Jour. Earth Syst. Sci. v.120, p. 223-236.

Devaraju, T. C., Alapieti, T. T., Sudhakara, T. L. and Kaukonen, R. J., 2008. Mafic Dyke Swarms of Volcanic Arc, Ocean Floor and N-MOR Basalt Affinity with Destructive Plate Margin emplacement features in the northern segment of Western Dharwar Craton. In: Indian Dykes: Geochemistry, Geophysics and Geochronology R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 215-238.

Dinesh, A.C., Maran, N., Shareef, N.M., Chandrasekhariah, K.C. and Jayaprakash, C., 2010. Observations on the reported incidence of micro-diamonds in the beach sands of the Kanyakumari coast, Tamil Nadu. Jour. Geol. Soc. India, v. 76, p. 587-588.

Dongre, A., Chalapathi Rao, N.V. and Kamde, G., 2008. Limestone xenolith from the Siddanpalli kimberlite, Gadwal Granite-Greenstone terrane, Eastern Dharwar craton, southern India: Remnant of Proterozoic platformal cover sequence of Bhima/Kurnool age? Jour. Geol., v. 116, p. 184-191.

Ernst, R. E. and Srivastava, Rajesh K., 2008. India's place in the Proterozoic world: constraints from the Large Igneous Province (LIP) record. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 41-56.

Fareeduddin, Mishra, V.P. and Basu, S.K., 2007. Kimberlites, lamproites and lamprophyres: A petrographic atlas. Jour. Geol. Soc. India, v. 69, p. 467-504.

Fareeduddin and Rao, M.S. (Ed.), 2007. Kimberlites and related rocks in India. Jour. Geol. Soc. India, v. 69, p.413-672.

French, J. E., Heaman, L. M., Chacko, T. and Srivastava, Rajesh K., 2008. 1891-1883 Ma southern Bastar-Cuddapah mafic igneous events, India: A newly recognized Large Igneous Province. Precamb. Res., v. 160, p. 308-322.

French, J.E. and Heaman L.M., 2010. Precise U–Pb dating of Paleoproterozoic mafic dyke swarms of the Dharwar craton, India:

Implications for the existence of the Neoarchean supercraton Sclavia. Precamb. Res, v. 183, p. 416-441.

Gautam, G. C. and Srivastava, Rajesh K., 2011. Petrology, geochemistry and petrogenesis of early Precambrian mafic dyke swarm from Dondi-Bhanupratappur-Keshkal, central Bastar craton, India. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (ed.), Springer-Verlag, Berlin, Heidelberg, p. 203-218.

Ghose, N. C. and Chatterjee, N., 2008. Petrology, tectonic setting and source of dykes and related magmatic bodies in the Chotanagpur Gniessic Complex, Eastern India. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao, (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 471-493.

Gopalan, K. and Anil Kumar, 2008. Phlogopite K-Ca dating of Narayanpet kimberlites, South India: Implications to the discordance between their Rb-Sr, Ar/Ar ages. Precamb. Res., v. 167, p. 377-382.

Griffin, W.L., Kobussen, A.F., Babu, E.V.S.S.K., O'Reilly, S.Y., Norris, R. and Sengupta, P., 2009. A translithospheric suture in the vanished 1-Ga lithospheric root of South India: Evidence from contrasting lithosphere sections in the Dharwar Craton. Lithos, v.112, p.1109-1119.

Halls, H. C., Kumar, A., Srinivasan, R. and Hamilton, M. A., 2007. Paleomagnetism and U-Pb geochronology of eastern trending dykes in the Dharwar craton, India: Feldspar clouding, radiating dyke swarms and the position of India at 2.37 Ga. Precamb. Res., 155, p. 47-68.

Heaman, L. M., 2008. Precambrian Large Igneous Provinces: An overview of geochronology, origins and impact on earth evolution. Jour. Geol. Soc. India, v.72, p.15-34.

Hussain, M. F., Ahmad, T. and Mondal, M. E. A., 2008. Geochemistry of the Precambrian mafic dyke swarms of the central and northeastern parts of Bastar craton, central India: constraints on their enrichment processes. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R.K. Srivastava, Ch. Sivaji and N.V. Chalapathi Rao (eds.), Narosa Pub. House Pvt. Ltd., New Delhi, p. 397-412.

Jayananda, M., Mahesha, N., Srivastava, Rajesh K., Mahabaleswar, B. and Blais, S., 2008. Petrology and geochemistry of Paleoproterozoic high-magnesian norite and dolerite dyke swarms from the Halagur-Satnur areas, Eastern Dharwar Craton, Southern India. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 239-260.

Karmalkar, N.R.,Duraiswami, R.A., Chalapathi Rao N.V. and Paul, D.K., 2009. Mantle-derived mafic-ultramafic xenoliths and the nature of Indian sub-continental lithosphere. Jour. Geol. Soc. India, v.73, p.657-679.

Krishnamacharyulu, S. G. K., Vijaya Kumar, K. and Sivaji, Ch., 2008. Gravity and magnetic anomalies over a system of multiple dykes. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 319-329.

Kumar, A. and Ahmad, T., 2007. Geochemistry of the mafic dykes in parts of Chotanagpur gneissic complex: Petrogenetic and tectonic implications. Geochem. Jour., v. 41, p.173–186.

Kumar, S., Singh, B., Pandey, A. and Singh, V. K., 2008. Mineralogy and geochemistry of mafic dyke at Nainital, Kumaun Lesser Himalaya. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 609-624.

Lehmann, B., Storey, C., Mainkar, D. and Jeffries, T., 2007. In-situ U-Pb dating of titanite in the Tokapal-Bhejripadar kimberlite system, Central India. Jour. Geol. Soc. India, v. 69, p. 553-556.

Lehmann, B., Burgess, R., Frei. D., Belyatsky, B., Mainkar, D., Chalapathi Rao, N.V. and Heaman, L.M., 2010. Diamondiferous kimberlites in Central India synchronous with the Deccan flood basalts. Earth Planet. Sci. Lett., v.290, p. 142-149.

Mainkar, D. and Lehmann, B., 2007. The diamondiferous Behradih Kimberlite pipe, Mainpur kimberlite field, Chhattisgarh, India: reconnaissance petrography and geochemistry. Jour. Geol. Soc. India, v. 69, p.547-552.

Maity, B. K., Ray, J. S., Chattopadhyay, B., Sengupta, S., Nandy, S. and Saha, A., 2008. Contrasting petrological variants in newer dolerite dyke swarm around Bisoi, Eastern Indian Shield: Insights from petrography and mineral chemistry. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 447-470.

Mallikharjuna Rao, J. and Poornachandra Rao, G. V. S., 2008. Geology, geochemistry and palaeomagnetic study of Cretaceous mafic dykes of Shillong Plateau and their evolutionary history. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 589-607.

Mallikharjuna Rao, J., Poornachandra Rao, G. V. S. and Sarma, K. P., 2009. Precambrian mafic magmatism of Shillong Plateau, Meghalaya and their evolutionary history. Jour. Geol. Soc. India, v.73, p. 143-152.

Masun, K., Sthapak, A.V., Singh, A., Vaidya, A. and Krishna, C., 2009. Exploration history and geology of the diamondiferous ultramafic Saptarshi intrusions, Madhya Pradesh, India. Lithos, v.112, p.142-154.

Meert, J. G., Pandit, M. K., Pradhan, V. R. and Kamenov, G., 2011. Preliminary report on the paleomagnetism of 1.88 Ga dykes from the Bastar and Dharwar cratons, Peninsular India. Gond. Res., v. 20, p. 335-343.

Mishra, M. K., Devi, S. J., Kaulina, T., Dass, K. S., Kumar, S. and Ahmad, T., 2011. Petrogenesis and tectonic setting of the Proterozoic mafic magmatic rocks of the central Indian Tectonic Zone, Betul area: geochemical constraints. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (Ed.), Springer-Verlag, Berlin, Heidelberg, p.189-201.

Mitchell, R.H., 2007. Potassic rocks from Gondwana coal fields of India: Closing pandroa's box of petrological confusion? Jour. Geol. Soc. India, v. 69, p. 505-512.

Mitchell, R.H. and Fareeduddin, 2009. Mineralogy of peralkaline lamproites from the Raniganj Coalfield, India. Mineral. Mag., v. 73, p. 457-477.

Mohanty, S. 2011a. Palaeoproterozoic assembly of the Napier Complex, Southern India and Western Australia: Implications for the evolution of the Cuddapah basin. Gond. Res., v.20, p.344-361.

Mohanty, S., 2011b. Palaeoproterozoic dykes and event stratigraphy of the South Indian and Western Australian Cratons: Implications for assembly of an Archaean Supercontinent "SIWA" and its breaking. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (ed.), Springer-Verlag, Berlin, Heidelberg, p. 95-113.

Mondal, M. E. A., Chandra, R. and Ahmad, T., 2008a. Precambrian mafic magmatism in Bundelkhand Craton. Jour. Geol. Soc. India, v. 72, p. 113-122.

Mondal, M. E. A., Raza, M. and Ahmad, T., 2008b. Geochemistry of the mafic dykes of the Aravalli-Bundelkhand proto-continent: implications for sub-continental lithosphere evolution of north Indian shield. In : Indian Dykes: Geochemistry, Geophysics and Geochronology, R.K. Srivastava, Ch. Sivaji and N.V. Chalapathi Rao (Eds.), Narosa Pub. House Pvt. Ltd., New Delhi, p. 527-545.

Mukherjee, A., Sravan Kumar, Ch., Krishna Reddy, K. , Siddique, S.N. and Chaturvedi, L., 2007. Two new kimberlites in Bommaganapalli area, Anantapur district, Andhra Pradesh based on systematic stream sediment sampling and ground magnetic survey. Jour. Geol. Soc. India, v. 69, p. 625-640.

Nambiar, A.R., 2007. Early Cretaceous lamprophyre dykes from Nongchram fault zone, Meghalaya, Northeastern India. Jour. Geol. Soc. India, v. 69, p. 641-652.

Osborne, I., Sherlock, S., Anand, M. and Argles, T., 2011. New Ar-Ar ages of southern Indian kimberlites and a lamproite and their geochemical evolution. Precamb. Res., v. 189, p. 91-103.

Patel, S.C., Ravi, S., Anilkumar, Y., Naik, A., Thakur, S.S., Pati, J.K., and Nayak, S.S., 2009. Mafic xenoliths in Proterozoic kimberlites from Eastern Dharwar Craton, India: Minerology and P-T regime. Jour. Asian Earth Sci., v. 34, p. 336-346.

Patel, S.C., Ravi, S., Anilkumar, Y., and Pati, J.K., 2010a. Sapphirine-bearing Mg-Al xenolith in Proterozoic kimberlite from Dharwar craton, southern India. Curr. Sci., v. 98, p. 547-550.

Patel, S.C., Ravi, S., Anilkumar, Y. and Pati, J.K., 2010b. Major element composition of concentrate garnets in Proterozoic kimberlites from the Eastern Dharwar Craton, India: Implications on sub-continental lithospheric mantle. Jour. Asian Earth Sci., v. 39, p. 578-588.

Pati, J. K., Raju, S., Malviya, V. P., Bhusan, R., Prakash, K. and Patel, S. C., 2008. Mafic dykes of Bundelkhand Craton, Central India: field, petrological and geochemical characteristics. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 547-569.

Patil, S. K. and Arora, B. R., 2008. Palaeomagnetic and rock magnetic studies on the intrusives from Raniganj Basin, Damodar valley: linkage to the Rajmahal volcanic. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 511-526.

Paton, C., Hergt, J.M., Woodhead, J.D., Phillips, D. and Shee, S.R., 2009. Identifying the asthenospheric component of kimberlite magmas from the Dharwar craton, India. Lithos v. 112, p. 296-310.

Paul, D.K., Crocket, J.H., Reddy, T.A.K. and Pant, N.C., 2007. Petrology and geochemistry including platinum group element abundances of the Mesoproterozoic ultramafic (lamproite) rocks of Krishna district, southern India: Implications for source rock characteristics and petrogenesis. Jour. Geol. Soc. India, v. 69, p. 577-596.

Piispa, E. J., Smirnov, A. V., Pesonen, L. J., Lingadevaru, M., Anantha Murthy, K. S. and Devaraju, T. C., 2011. An integrated study of Proterozoic dykes, Dharwar Craton, Southern India. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (Ed.), Springer-Verlag, Berlin, Heidelberg, p. 33-45.

Pradhan, V. R., Pandit, M. K., Meert, J. G., 2008. A cautionary note on the age of the Paleomagnetic pole obtained from the Harohalli Dyke swarms, Dharwar Craton, Southern India. In: R.K. Srivastava, C. Sivaji and N.V. Chalapathi Rao (Eds.), Indian Dykes: Geochemistry, Geophysics and Geochronology. Narosa Publishing House, India, p. 339-351.

Pradhan, V. R., Meert, J. G., Pandit, M. K., Kamenova, G., Gregorya, L. C. and Malone, S. J., 2010. India's changing place in global Proterozoic reconstructions: A review of geochronologic constraints and paleomagnetic poles from the Dharwar, Bundelkhand and Marwar cratons. Jour. Geodynamics, v. 50, p. 224-242.

Pradhan, V. R., Meert, J. G., Pandit, M. K., Kamenova, G. and Mondal, M. E. A., 2012. Paleomagnetic and geochronological studies of the mafic dyke swarms of Bundelkhnad craton, central India: Implications for the tectonic evolution and paleogeographic reconstructions. Precamb. Res., v. 198-199, p. 51-76.

Pratheesh, P., Prasannakumar, V. and Praveen, K. R., 2011. Mafic dykes of Moyar Shear Zone, North Kerala, India: Emplacement history and petrogenetic interpretation based on structure, geochemistry and magnetic fabric. Iranian Jour. Earth Sci., v. 3, p. 185-193.

Radhakrishna, B.P., 2007. Diamond exploration in India: Retrospect and Prospect. Jour. Geol. Soc. India, v. 69, p. 419-442.

Radhakrishna, T., 2007b. Temporal variations and mantle sources of the mafic dyke swarms in south India. Deep Continental Studies News Letter, v. 17, p. 2-7.

Radhakrishna, T. and Joseph, M., 2012. Geochemistry and paleomagnetism of late Cretaceous mafic dykes in Kerala, southwest coast of India, in relation to large igneous provinces and mantle plumes in the Indian Ocean region. Geol. Soc. Amer. Bull., v. 124, p. 240-255.

Radhakrishana, T., Krishnendu. N. R. and Balasubramonian, G., 2007. Mafic magmatism around Cuddapah Basin: Age constraints, petrological characteristics and geochemical inference for a possible magma chamber on the south western margin of the basin. Jour. Geol. Soc. India, v. 70, p. 194-206.

Ratre, K., De Waele, B., Biswal, T. K. and Sinha, S., 2010. SHRIMP geochronology for the 1450 Ma Lakhna dyke swarm: Its implication for the presence of Eoarchaean crust in the Bastar Craton and 1450-517 Ma depositional age for Purana basin (Khariar), Eastern Indian Peninsula. Jour. Asian Earth Sci., v. 39, p. 565-577.

Rau, T.K., 2006. Incidence of diamonds in the beach sands of the Kanyakumari coast, Tamil Nadu. Jour. Geol. Soc. India, v. 67, 11-16.

Rau, T.K., 2007. Panna diamond belt, Madhya Pradesh - A Critical Review. Jour. Geol. Soc. India, v. 69, p. 513-522.

Ravi, S. and Satyanarayana, S.V., 2007. Discovery of kimberlites in Chagapuram area, Mahaboobnagar district, Andhra Pradesh. Jour. Geol. Soc. India, v. 70, p. 689-692.

Ravi, S., Rau, T.K., Reddy, N.S. and Nayak, S.S., 2007. Tungabhadra kimberlite field, Kurnool district, Andhra Pradesh. Jour. Geol. Soc. India, v. 69, p. 611-618.

Ray, R., Sheth, H.C. and Mallik, J. 2007. Structure and emplacement of the Nandurbar-Dhule mafic dyke swarm, Deccan Traps, and the tectonomagmatic evolution of flood basalts. Bull. Volcan., v. 69, p. 537-551.

Ray, R., Shukla, A.D., Sheth, H.C., Ray, J.S., Duraiswami, R.A., Vanderkluysen, L., Rautela, C.M. and Mallik, J., 2008. Highly heterogeneous Precambrian basement under the central Deccan Traps, India: Direct evidence from xenoliths in dykes. Gond. Res., v. 13, p. 375-385.

Ray, S., Sanyal, S. and Sengupta, P., 2011. Mineralogical control on rheological inversion of a suite of deformed mafic dykes from parts of the Chottanagpur Granite Gneiss Complex of Eastern India. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (Ed.), Springer-Verlag, Berlin, Heidelberg, p. 263-276.

Roy, A., 2009. Calcrete to kimberlite: A prospector’s hunt for “kimberlite traits” in calcretes. Jour. Geol. Soc. India, v. 73, p. 320-324.

Seshunarayana, T., Satish Kumar, K., Deenanadh, S., Rama Mohan Rao, Y. and Senthil Kumar, P., 2008. Subsurface imaging of dolerite dykes in Hyderabad granite terrain using multichannel analysis of surface waves. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 331-338.

Sheth, H.C., Ray, J.S., Ray, R., Vanderkluysen, L., Mahoney, J.J., Kumar, A., Shukla, A.D., Das, P., Adhikari, S. and Jana, B., 2009. Geology and geochemistry of Pachmarhi dykes and sills, Satpura Gondwana Basin, central India: Problems of dyke-sill-flow correlations in the Deccan Traps. Contrib. Mineral Petrol., v. 158, p. 357-380.

Sinha, D. K., Jain, S. K. and Naganath, K. P., 2011. Tectonic significance and age of doleritic sill near Bandhalimal in the Singhora protobasin of Chhattisgarh Basin, Central India. In: Dyke Swarms: Keys for Geodynamic Interpretation, R. K. Srivastava (Ed.), Springer-Verlag, Berlin, Heidelberg, p. 167-187.

Srinivas Choudary, V.S., Rau, T.K., Reddy, N.S. and Nayak, S.S., 2007. Timmasamudram kimberlite cluster, Wajrakarur kimberlite field, Anantapur distirct, Andhra Pradesh. Jour. Geol. Soc. India, v. 69, p. 597-610.

Srivastava, Rajesh K., 2008. Global intracratonic boninite-norite magmatism during the Neoarchean-Paleoproterozoic: Evidence from the central Indian Bastar craton, Int. Geol. Rev., v. 50, p. 61-74.

Srivastava, Rajesh K., 2011. Dyke Swarms: Keys for Geodynamic Interpretation. Springer-Verlag, Heidelburg, 605p.

Srivastava, Rajesh K. and Ahmad, T., 2008. Precambrian Mafic Magmatism in the Indian Shield – Part I. Special Issue, Jour. Geol. Soc. of India, v. 72(1), p. 1-140.

Srivastava, Rajesh K. and Ahmad, T., 2009. Precambrian Mafic Magmatism in the Indian Shield – Part II. Special Issue, Jour. Geol. Soc. of India, v. 73, p. 1-152.

Srivastava, Rajesh K. and Chalapathi Rao, N.V., 2007. Petrology, geochemistry and tectonic significance of Palaeoproterozoic alkaline lamprophyres from the Jungel Valley, Mahakoshal supracrustal belt, Central India. Mineral. Petrol., v. 89, p. 189-215.

Srivastava, M.K., Chalapathi Rao, N.V. and Sinha, A., 2009. Cretaceous potassic intrusives with affinities from Jharia area: Magmatic expression of metasomatically veined and thinned lithospheric mantle beneath Singhbhum craton, Eastern India. Lithos, v. 112, p. 407-418.

Srivastava, Rajesh K., Ellam, Rob M. and Gautam, G. C., 2009. Sr-Nd isotope geochemistry of the early Precambrian sub-alkaline mafic igneous rocks from the southern Bastar craton, Central India. Mineral. Petrol., v. 96, p. 71-79.

Srivastava, Rajesh K. and Gautam, G. C., 2008. Precambrian Mafic Dyke Swarms from the Southern Bastar Central India Craton: Present and Future Perspectives. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 367-376.

Srivastava, Rajesh K. and Gautam, G. C., 2009. Precambrian mafic magmatism in the Bastar Craton, Central India. Jour. Geol. Soc. India, v. 73, p. 52-72.

Srivastava, Rajesh K. and Gautam, G. C., 2012. Early Precambrian mafic dyke swarms from the Central Archaean Bastar craton, India: geochemistry, petrogenesis and tectonic implications. Geol. Jour. (In Press; DOI: 10.1002/gj.1302).

Srivastava, Rajesh K., Mondal, S. K., Balaram, V. and Gautam, G. C,. 2010. PGE geochemistry of low-Ti high-Mg siliceous mafic rocks within the Archaean Central Indian Bastar Craton: Implications for magma fractionation. Mineral. Petrol., v. 98, p. 329-345.

Srivastava, Rajesh K., Hamilton, M. A. and Jayananda, M., 2011a. 2.21 Ga Large igneous province in the Dharwar Craton, India. International Symposium on Large Igneous Provinces of Asia, Mantle Plumes and Metallogeny, Irkutsk, Russia, Extended Abstract, p. 263-266.

Srivastava, Rajesh K., Heaman, L. M., French, J. E. and Filho, C. F. F., 2011b. Evidence for a Paleoproterozic event of metamorphism in the Bastar Craton, Central India: P-T-t constraints from mineral chemistry and U-Pb geochronology of mafic dykes. Episodes, v. 34, p. 13-24.

Srivastava, Rajesh K., Sivaji, Ch. and Chalapathi Rao, N. V., 2008a. Dyke swarms of Indian Shield in space and time. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 1-18.

Srivastava, Rajesh K., Ch. Sivaji and Chalapathi Rao, N. V., 2008b. Indian Dykes: Geochemistry, geophysics, and geochronology. Narosa Publishing House Pvt. Ltd., New Delhi, 650p.

Srivastava, Rajesh K., Srivastava, H. B. and Srivastava, V., 2009b. Petrology and geochemistry of Proterozoic olivine tholeiite mafic intrusive rocks from the Central Crystallines of the western Arunachal Himalaya, India: Evidence for a depleted mantle. Curr. Sci., v. 97, p. 1355-1361.

Srivastava, Rajesh K., Sinha, A.K. and Kumar, S., 2012. Geochemical characteristics of Mesoproterozoic metabasite dykes from the

Chhotanagpur Gneissic Terrain, eastern India: Implications for their emplacement in a plate margin tectonic environment. J. Earth Syst. Sci., v. 121, p. 509-523.

Subba Rao, D. V., Khan, M. W. Y., Sridhar, D. N. and Naga Raju, K., 2007. A new find of younger dolerite dykes with Continental Flood Basalt affinity from the Meso-Neoproterozoic Chhattisgarh Basin, Bastar Craton, Central India. Jour. Geol. Soc. India, v. 69, p. 80-84.

Subba Rao D. V., Sridhar, D.N., Balaram, V., Naga Raju, K., Gnaneshwara Rao, T., Keshavakrishna, A. and Singh, U.P. 2008a. Proterozoic mafic-ultramafic dyke swarms in the vicinity of Chhattisgarh-Khariar-Singhora basins in northern Bastar craton, central India. In: R.K. Srivastava, Ch. Sivaji and N.V.Chalapati Rao (Eds.), Indian Dykes Geochemistry, Geophysics and Geochronology, Narosa Publishing House, New Delhi, p. 377-396.

Subba Rao, D.V., Balaram, V., Naga Raju, K. and Sridhar, D.N., 2008b. Paleoproterozoic boninite-like rocks in an Intracratonic setting from Northern Bastar craton, Central India. Jour. Geol. Soc. India, v. 72, p. 373-380.

Vanderkluysen, L., Mahoney, J.J., Hooper, p.R., Seth, H.C. and Ray, R. 2011. The feeder system of the Deccan Traps (India): Insights from dike geochemistry. Jour. Petrol., v. 52, p. 315-343.

Veeriah, B., Ramadass, G. and Himabindu, D., 2009. A subsurface criterion for predictive exploration of kimberlites from Bougeur gravity in the Eastern Dharwar craton, India. Jour. Geol. Soc. India, v. 74, p. 69-77.

Vijaya Kumar, K. 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, v. 104, p. 306-326.

Yellappa, T., Chalapathi Rao, N.V. and Chetty, T.R.K., 2010. Occurrence of lamproitic dykes at the northern margin of the Indravati basin, Bastar craton, Central India. Jour. Geol. Soc. India, v. 75, p. 632-643.

Yellappa, T. and Chetty, T. R. K., 2008. Mafic Dykes around Ramagiri Schist Belt, East Dharwar Craton, South India: Possible palaeo stress regimes. In: Indian Dykes: Geochemistry, Geophysics and Geochronology, R. K. Srivastava, C. Sivaji and N. V. Chalapathi Rao (Eds.), Narosa Publishing House Pvt. Ltd., New Delhi, p. 261-279.