

Sr-rich apatite and Nb-rutile from the Chelima lamproite dykes, Cuddapah Basin, southern India and their petrological significance

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The Chelima dykes intrude the Nallamalai Group of sedimentary rocks in the Cuddapah Basin, southern India, and constitute some of the world's oldest (1.38 Ga) known lamproites. Electron probe micro-analysis reveals that the Chelima apatite is Sr-rich (SrO: 2.01–7.72 wt%) and LREE-poor (Σ LREE = <1 wt%), whereas the Chelima rutile is Nb-bearing (Nb₂O₅: 0.58–1.91 wt%) and Fe-poor (FeO: <0.79 wt%). Even though apatite and rutile are present, albeit in much lesser modal proportions, in the co-spatial and broadly coeval (1.25–1.56 Ga) Krishna lamproites at the NE margin of the Cuddapah Basin, these minerals are relatively much impoverished in their respective Sr (SrO: up to 0.11 wt%) and Nb (Nb₂O₅: up to 0.13 wt%) contents. Recent geochemical (isotopic) studies showed the existence of an ancient (2–2.5 Ga) and anomalously enriched (metasomatized) subcontinental lithospheric mantle beneath the Cuddapah Basin and its environs. The contrasting distribution of two highly incompatible trace elements (viz. Sr and Nb) in apatite and rutile from the Chelima and Krishna lamproites reflects either the difference in the nature of their metasomatized mantle source regions or varying melt fraction of their magmas, or both. The present study shows distinct petrogenesis of the co-spatial Cuddapah (Chelima) and Krishna lamproites and highlights the utility of trace element chemistry of accessory phases in unravelling the nature and evolution of the underlying subcontinental lithospheric mantle.

Keywords: Apatite, lamproite, niobium, rutile, strontium.

LAMPROITES are extremely rare, Mg-rich (MgO > 5 wt%), peralkaline perpotassic and ultrapotassic igneous rocks characterized by one or more of essential minerals such as leucite, K-richterite, Ti-phlogopite, diopsidic clinopyroxene, wadeite and priderite¹. Although petrological and geochemical studies on lamproite were initiated² in the 1940s, the discovery of diamondiferous lamproites in Western Australia³ stimulated resurgence in the research on lamproites, which has continued ever since. Lamproites are currently thought to represent the most extreme, incompatible, element-enriched products of the ancient and anomalously metasomatized (enriched) mantle⁴. This, coupled with great depths (>150 km) of derivation render

their mineralogical and geochemical studies significant to our understanding of the processes taking place in the lower part of the Earth's continental plates.

The Eastern Dharwar craton of southern India is characterized by voluminous Mesoproterozoic alkaline mafic potassic–ultrapotassic magmatism⁵. This rare and exotic magmatism (Figure 1) is manifested in the form of several fields of: (i) kimberlites (Wajrakarur kimberlite field, Narayanpet kimberlite field and Raichur kimberlite field) towards the western side of the Cuddapah Basin; (ii) lamproites within the Cuddapah Basin (at Chelima and Zangamarajupalle; termed as Cuddapah lamproites) and at its northeastern (Krishna lamproite field) and northwestern (Ramadugu lamproite field) margins, and (iii) a plethora of lamprophyres towards the eastern margin of the basin, within the Eastern Ghats Mobile Belt (EGMB). The present study concerns the mineral chemistry of apatite and rutile – two of the dominant accessory minerals – in the Chelima lamproite dykes.

The Chelima dykes intrude the slates and phyllites of the Nallamalai Group of sedimentary rocks of the Cuddapah Basin, and constitute some of the world's oldest (1.38 Ga) known lamproites⁶. The Chelima dykes have been exhaustively and extensively mined since antiquity, presumably for diamond⁷, leaving only dumped and processed dyke material as a testimony of the old workings.

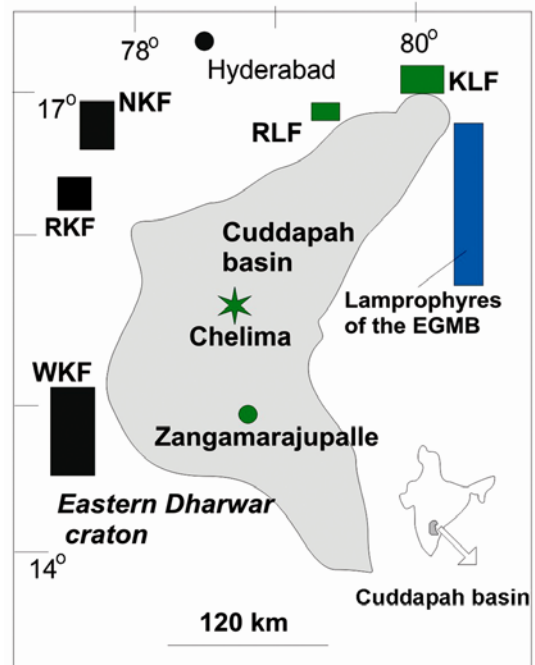


Figure 1. Location map of the Cuddapah Basin in the Eastern Dharwar craton, southern India. Various Mesoproterozoic kimberlite, lamproite and lamprophyre fields representing alkaline potassic magmatism are also depicted. NKF, Narayanpet kimberlite field; RKF, Raichur kimberlite field; WKF, Wajrakarur kimberlite field; KLF, Krishna lamproite field; RLF, Ramadugu lamproite field; Chelima and Zangamarajupalle, Cuddapah Basin lamproites and EGMB, Eastern Ghats Mobile Belt.

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Petrographic studies^{8,9} (Figure 2) reveal that olivine is completely altered, but two generations can be distinguished from pseudomorphs. Ferroan dolomite and more rarely serpentine has replaced the olivine macrocrysts as well as most of the groundmass olivines. The rock shows abundant (10–15 modal %) and highly pleochroic and strongly zoned phlogopite phenocrysts. At places, alteration of phlogopite to talc and chlorite is noticed. Apatite, rutile, serpentine and opaque oxides such as magnetite occur as accessory phases in a dirty-brown clayey matrix. Apatite occurs mostly as acicular laths and rarely as stubby prisms, whereas rutile is present as reddish-brown, rounded to subhedral crystals (Figure 2). Textural studies suggest crystallization of apatite and rutile as late-stage groundmass phases and negate their derivation as disaggregated constituents from the host/basement rocks.

Recent studies^{10,11} have shown that compositional data of the accessory minerals in potassium-rich alkaline rocks, such as kimberlites, orangeites and lamproites, are important in their textural–genetic classification and in distinguishing between rocks of similar petrography but which are genetically unrelated. Based on this premise, electron probe microanalysis (EPMA) was carried out on apatite and rutile in the Chelima lamproites. EPMA was carried out on a CAMECA SX100 microprobe at the Mineral Resources, Technical University of Clausthal, Germany. An accelerating voltage of 20 kV, a beam current of 50 nA and a beam diameter of 2 μm were used. The analyses were carried out using wavelength dispersive spectrometers employing TAP, PET and LLIF crystals and a PAP on-line correction program. Several in-house natural and synthetic standards were used for calibration. After repeated analyses, it was found that the error on major element concentrations was <1%, whereas the error on

trace elements varied from 5% to 10%. Details of the standards analysed and the spectral lines used for each element calibration have been provided by Torab and Lehmann¹². The chemical composition of the Chelima apatite and rutile is presented in Tables 1 and 2 respectively.

The CaO content of the Chelima apatite varies from 50.01 to 54.91 wt%, whereas its P₂O₅ content displays a limited range of 39.47–41.42 wt% (Table 1). Significant proportion of strontium (SrO: up to 7.72 wt%; Figure 3) is a characteristic feature of the Chelima apatite. Other substituting elements include iron (FeO*: up to 0.24 wt%), silicon (SiO₂: up to 1.14 wt%) and light rare earths (ΣLREE : up to 0.82 wt%) all of which are, however, in much lesser proportions. The Chelima rutile has a high titanium (TiO₂: 96.04–98.01 wt%) and low iron content (FeO*: 0.20–0.79 wt%), but substitution of niobium (Nb₂O₅: up to 1.91 wt%) is a conspicuous feature in all the analysed grains.

Sr-rich apatite is widely reported from carbonatites¹³, minettes¹⁴, peralkaline potassic rocks such as lamproites^{15,16} and orangeites (Group II kimberlites)¹⁷, including the 117 Ma lamproitic/lamprophyric rocks in the Damodar valley coal fields of the eastern Indian shield¹⁸. High Sr contents in the Chelima apatite are different from those reported from granitoid rocks (up to 0.09 wt% SrO)¹⁹ and additionally rule out a xenocrystic origin via basement granitoids. Sr contents in the Chelima apatite are indistinguishable from those in diamondiferous lamproites from West Kimberley, Western Australia²⁰ (Figure 3). Rutile is generally considered to be an uncommon mineral in lamproites¹⁷, but nevertheless has been reported¹⁷. In India, apart from the Chelima lamproite, rutile has also been reported from the Krishna lamproites²¹ and Ranigunj and Jharia lamproites^{11,18}. Amongst the potassic alkaline rocks in various Indian cratons, the niobian rutile is so far reported only from the lamproites/lamprophyres of the Damodar valley^{11,18}.

Even though apatite and rutile are present, albeit in much lesser modal proportions, in the co-spatial and broadly coeval (1.25–1.56 Ga) Krishna lamproites^{22,23} at the NE margin of the Cuddapah Basin (Figure 1), these two minerals are strongly impoverished in Sr (SrO: 0.05 to 0.11 wt%; Figure 3) and Nb (Nb₂O₅: up to 0.13 wt%) content²¹ respectively, relative to those from the Chelima lamproites. Recent geochemical (isotopic) studies showed the existence of an ancient (2–2.5 Ga) and anomalously enriched (metasomatized) lithospheric mantle beneath the Cuddapah Basin and its environs^{9,24}. The genesis of the Krishna and Chelima lamproites has also been recently explained²¹ by the 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. The contrasting distribution of Sr and Nb, two highly incompatible trace elements, in apatite and rutile from the co-spatial Chelima and Krishna lamproites could thus

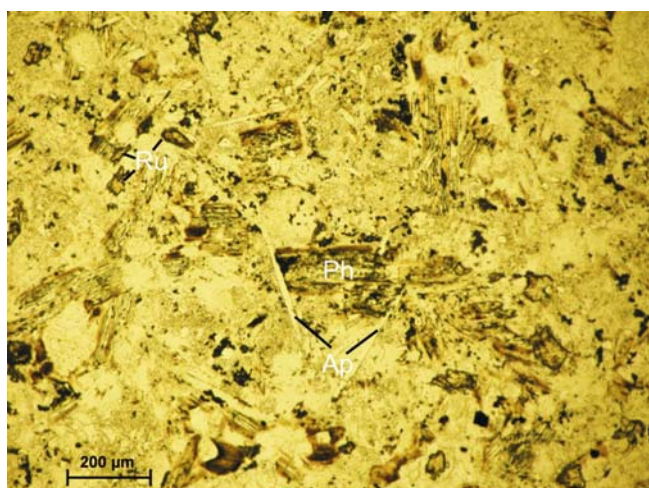


Figure 2. Photomicrograph depicting the acicular and prismatic habit of apatite (Ap) and subrounded to subhedral nature of rutile (Ru) in groundmass of the Chelima dyke. Phlogopite (Ph; chloritized at places) is the dominant phenocrystic phase (plane polarized light; uncrossed nicols).

Table 1. Mineral chemistry (wt%) of apatite in the Chelima lamproite (C1-C sample)

Oxide wt%	1	2	3	4	5	6	7	8
CaO	54.60	51.47	52.77	53.03	50.01	50.99	51.27	54.91
Na ₂ O	0.34	0.14	0.10	0.07	0.14	0.15	0.13	0.15
SrO	2.76	5.75	5.86	2.78	7.72	7.13	6.14	2.01
FeO*	0.07	0.09	0.15	0.24	0.09	0.22	0.32	0.20
La ₂ O ₃	0.11	0.26	0.12	0.22	0.27	0.15	0.15	0.11
Ce ₂ O ₃	0.37	0.42	0.33	0.41	0.43	0.26	0.21	0.15
Pr ₂ O ₃	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nd ₂ O ₃	0.07	0.14	0.09	0.12	0.10	0.08	0.09	0.04
ThO ₂	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00
P ₂ O ₅	40.66	41.33	41.21	41.01	40.37	40.53	39.47	41.42
SiO ₂	0.07	0.26	0.03	1.14	0.52	0.39	0.92	1.08
Total	99.08	99.87	100.66	99.04	99.66	99.89	98.69	100.06
Cations based on 25 oxygens								
Ca	9.949	9.369	9.568	9.584	9.225	9.359	9.504	9.786
Na	0.113	0.046	0.033	0.024	0.046	0.051	0.044	0.048
Sr	0.272	0.566	0.575	0.272	0.771	0.709	0.616	0.194
Fe	0.010	0.013	0.021	0.034	0.013	0.031	0.046	0.027
La	0.007	0.017	0.007	0.014	0.017	0.010	0.010	0.006
Ce	0.023	0.026	0.021	0.025	0.027	0.016	0.013	0.009
Pr	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nd	0.004	0.008	0.005	0.007	0.006	0.005	0.006	0.002
Th	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
P	5.854	5.945	5.904	5.857	5.885	5.879	5.781	5.833
Si	0.012	0.045	0.005	0.192	0.090	0.066	0.159	0.180
Total	16.246	16.035	16.139	16.011	16.081	16.126	16.178	16.086

FeO*, Total iron.

Table 2. Mineral chemistry (wt%) of rutile in the Chelima lamproite (C1-C sample)

Oxide wt %	1	2	3	4	5	6	7	8	9
TiO ₂	97.42	96.89	98.01	96.04	96.11	96.46	96.82	97.17	97.03
FeO*	0.38	0.65	0.20	0.79	0.37	0.48	0.31	0.42	0.45
Nb ₂ O ₅	1.03	0.58	1.91	1.43	1.70	1.69	1.47	0.95	0.64
MnO	0.24	0.33	0.23	0.23	0.13	0.07	0.23	0.21	0.43
Ta ₂ O ₅	bd	bd	0.03	0.02	0.01	bd	bd	bd	0.03
Total	99.06	98.45	100.37	98.51	98.31	98.70	98.83	98.76	98.58

FeO*, Total iron; bd, Below detection limit.

directly reflect the difference in the modal mineralogy of the source.

Geochemical studies also suggest²¹ source regions of the Krishna lamproites to have undergone much greater degrees of melting than those of kimberlites of the Eastern Dharwar craton and the Cuddapah (Chelima and Zangamarajupalle) lamproites. This has been attributed²¹ to the location of the Krishna lamproite field at the margin of the craton where the lithosphere is relatively thin compared to its 'core'. Additional support for this inference comes from the Ti-poor nature of the Krishna lamproite micas compared to those from the Cuddapah lamproites^{21,25}. Experimental studies²⁶ suggest that the

increasing Ti contents can be related to increasing pressure (depth of melting), thereby implying that Krishna lamproites were derived from a relatively shallower (more thinned) region than the Cuddapah lamproites. Therefore, the differing Sr and Nb contents in apatite and rutile respectively, in the Chelima and Krishna lamproites can also be accounted for by the difference in the degrees of partial melting of their source regions, with the Krishna lamproites being products of larger melt fraction than those from the Chelima.

Irrespective of the preferred choice between the above two explanations or their combination, the present study shows the contrasting petrogenesis of the co-spatial

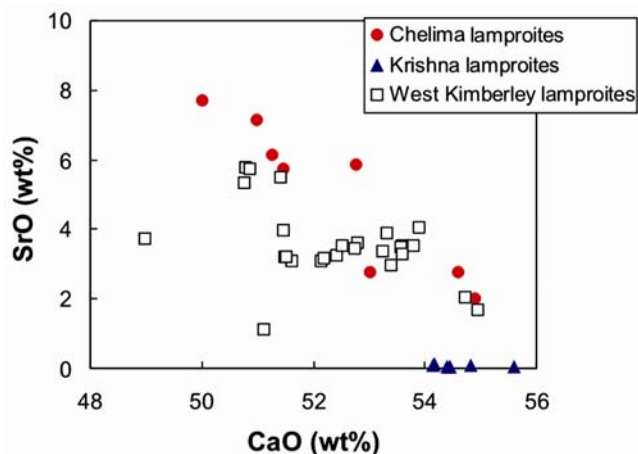


Figure 3. CaO (wt%) versus SrO (wt%) binary plot for the Chelima apatite compared with that of the Krishna lamproites²¹ and West Kimberley diamondiferous lamproites²⁰. Note the conspicuously lower Sr content in the Krishna lamproites and the indistinguishable Sr composition between Chelima and West Kimberley apatites.

Cuddapah (Chelima) and Krishna lamproites and highlights the potential of trace element chemistry of accessory minerals, such as apatite and rutile, in unravelling the nature and evolution of the underlying subcontinental lithospheric mantle.

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