

Alkali granite-syenite-carbonatite association in Munnar Kerala, India; implications for rifting, alkaline magmatism and liquid immiscibility

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Abstract. Occurrence of carbonatite is reported from the Munnar area, Kerala, where an alkali granite-syenite-carbonatite association is seen emplaced along the intersection zone of the Attur and Kerala fault-lineaments. The carbonatites are of two varieties, a calcite-rich soelite and a very coarse grained, calcite and dolomite bearing alvikite. Higher levels of SiO_2 , Al_2O_3 and CaO are characteristic of these as compared to the composition of typical carbonatites. The transition element levels are high whereas the incompatible elements show lower values. The low Sr values, lower amount of apatite and absence of rare metal minerals preclude a primary carbonatite magma. The associated syenite and alkali granite have higher K_2O , $\text{K}_2\text{O}/\text{Na}_2\text{O}$, K/Rb , K/Ba and transition element levels. Petrochemical features suggest the rock association to be a result of separation of an immiscible fraction of less viscous carbonate liquid during cooling and ascent from a more viscous polymerized alkali silicate phase. The pre-requisites for melt equilibration and liquid immiscibility were achieved through volatile degassing related to crustal warping and rifting. The unique alkaline association of Munnar, which shows spatial relationships with deep-seated faults as well as a probable triple-point junction, is suggested to be a signature of late Precambrian alkaline magmatism which manifested in the Indian shield as a precursor to the rifting of the continental margin.

Keywords. Alkali granite-syenite-carbonatite; geochemistry; petrogenesis; alkaline silicate magma; liquid immiscibility; rifting.

1. Introduction

Alkaline rock associations, especially carbonatite complexes, have been a topic of interest for geologic, tectonic and experimental petrologic investigations the world over. In India, the Sevathur, Jokipatti, Newania and Bhinder complexes occurring in Precambrian settings and the Amba Dongar complex of Tertiary age have been studied in detail (Deans and Powell 1968; Phadke and Jhingran 1968; Sukheswala and Udas 1964; Udas and Krishnamurthy 1970; Borodin *et al* 1971). The present study reports the occurrence of carbonatite in the Kerala region which shows a unique genetic association with syenite and alkali granite. The study also attempts at petrogenetic considerations based on geochemical data and emphasises a rift-controlled alkaline magmatism in this part of the Indian continent during late Precambrian times as revealed by tectonic and geochronologic considerations.

2. Geologic setting

The alkali granite, syenite and carbonatite are emplaced within Precambrian gneisses of Munnar area in Kottayam district, Kerala (figure 1). The complex is spatially related to

the inter-section zone of the NE-SW trending Attur lineament and the NW-SE trending Kerala lineament (figure 2) and occurs within the Anamalai-Palni-Cardamom massif (Katz 1978).

The alkali granite is exposed as an E-W trending irregular body (figure 1) and is traversed by pegmatites, aplites and quartz veins of varying dimensions (Nair *et al*

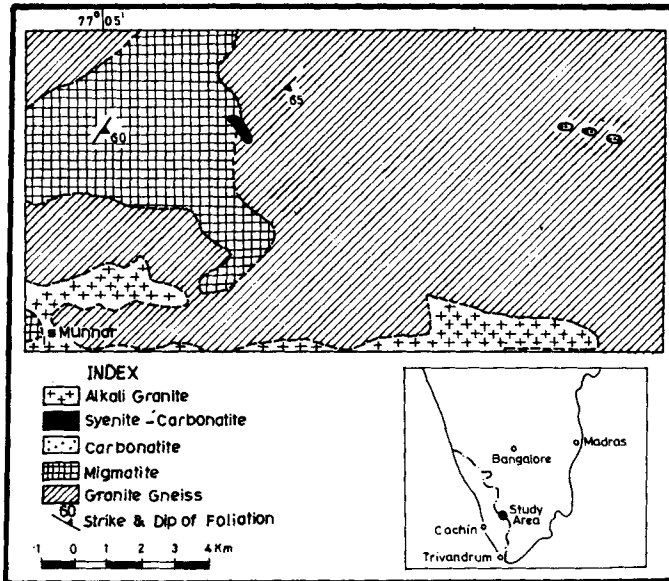


Figure 1. Geological map of Munnar area.

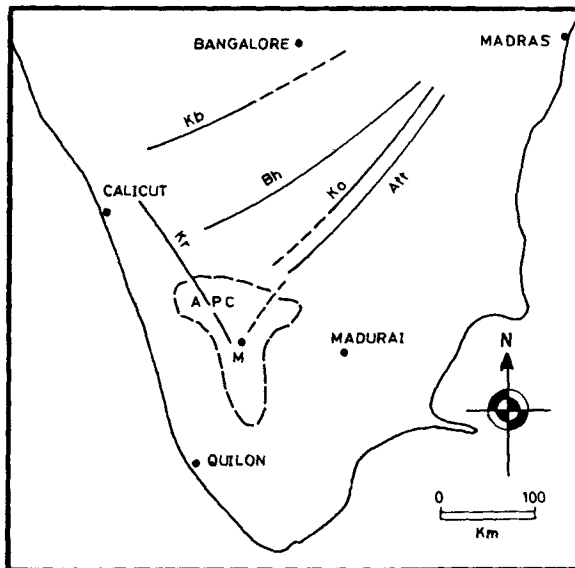


Figure 2. Relationship of the study area with regional fault-lineaments of South India (Kb—Kabbani lineament; Bh—Bhavani lineament; Ko—Koratti lineament; Att—Attur lineament; Kr—Kerala lineament; APC—Anamalai-Palni-Cardamom massif (after Katz 1978); M—Munnar area).

1983). The associated gneisses are of pink and grey varieties, the former bearing porphyroblastic pink feldspar and the latter having dominance of biotite. Regional foliation trends vary from WNW-ESE to E-W with northerly dips of 50 to 70°. The migmatites of the area incorporate minor lenses of pyroxene granulite and biotite-rich 'restite'. Recent geochronologic data (Odom 1982) assign an age of 740 ± 30 m.y. for the granite.

Carbonatites are exposed as two minor patches. The one which occurs towards north of the study area (figure 1) is seen as patches, lenses and veins of 0.3 to 1 m thickness, cutting coarse grained syenite which occurs as a NW-SE elongate body. Exposures are found very near the 15 km point of the road from Munnar to Udumalpet. The second exposure is towards east of the area, near Ellapatty estate 24 km from Munnar on the road to top station where coarse-grained carbonatite occurs as lenticular bodies up to 1.5 m thickness within gneissic rocks. In both the localities, the carbonatite bodies show sharp and discordant margins with absence of any pseudomorphs or corroded relicts within them. Fenitisation is characterised by the development of pink K-feldspar megacrysts and coarse pyroxene laths in the country rock at the contact.

3. Mineralogy

The alkali granite is a massive medium-to-coarse grained rock with pink feldspar and quartz. The K-feldspar (microcline) exhibits development of perthitic stringers. Plagioclase occurs as subhedral laths showing lamellar twinning and corresponds to albite-oligoclase in composition. Quartz is generally anhedral. Biotite, sphene, apatite and zircon are the major accessories. The opaque is represented by magnetite. Modal analyses show an average of 21.5 % quartz, 60.3 % alkali feldspar and 12.1 % plagioclase (Nair *et al* 1983).

The syenite is leucocratic and coarse-grained with feldspar and pyroxene as the principal minerals. In thin section, an assemblage of micropertthitic K-feldspar, augite and minor aegirine augite, subordinate sodic plagioclase, alkali amphibole and biotite is seen. Primary calcite occurs commonly filling interstices or as veins. Apatite, sphene and zircon occur in accessory amounts.

The carbonatites are fresh and homogeneous and represent two varieties. A coarse-grained holocrystalline type having yellowish calcite crystals constituting 90 % of the rock, with pyroxene, apatite and magnetite correspond to sovite (Streckeisen 1979). The second variety which contains highly coarse calcite crystals (up to 1 cm) and associated dolomite with mafic minerals constituting 30 % of the rock corresponds to alvikite. The sovite exhibits an interlocking crystals mosaic of calcite in thin-section and the individual crystals exhibit polysynthetic twinning. The calcite crystals of alvikite show exsolution blebs of dolomite. The major mafic component in both the varieties is aegirine augite which forms euhedral to subhedral laths. The opaque phase is dominantly magnetite. Rarely, phlogopite, biotite and minor laths of albite are also noted. Small crystals of euhedral apatite are found occluded in the calcite grains.

4. Geochemistry

The analytical results of four carbonatite samples are given in table 1 and those of two syenite samples and the average data of seven alkali granite samples in table 2.

Table 1. Major and trace elements data of carbonatites from Munnar.

	M-15	M-18	M-39	M-40
Major elements wt %				
SiO ₂	17.21	9.99	17.33	16.68
Al ₂ O ₃	2.60	2.55	3.06	3.57
TiO ₂	0.11	0.08	0.17	0.09
Fe ₂ O ₃	0.08	0.04	0.03	0.04
FeO	0.72	1.08	0.93	1.08
MnO	0.03	0.04	0.04	0.04
MgO	0.80	0.80	1.60	1.20
CaO	49.28	50.40	43.69	44.80
Na ₂ O	0.50	0.23	0.25	0.31
K ₂ O	0.58	0.01	0.57	0.02
P ₂ O ₅	0.09	0.09	0.04	0.02
Moisture	0.09	0.13	0.21	0.09
L.O.I.	27.87	34.41	31.61	31.70
Trace Elements, ppm.				
Ag	5	4	3	11
B	160	190	90	100
Ba	164	78	233	16
Bi	50	62	43	51
Co	23	22	19	19
Cr	57	83	120	94
Cu	8	10	8	6
Li	4	4	4	3
Ni	33	64	59	61
Pb	68	62	43	51
Rb	10	11	37	38
Sr	107	553	105	307
Y	17	17	19	19
Zn	26	26	22	21
Zr	30	37	21	29

Samples M-15 and M-18 from carbonatite associated with syenite; Samples M-39 and M-40 from lenticular carbonatite in gneisses.

The major elements were analysed by wet chemical methods. Na and K were determined by flame photometer. Trace elements were analysed by atomic absorption spectrophotometer (Perkin-Elmer 4000). Y and Zr were determined by XRF.

General geochemical features of the carbonatites include high levels of SiO₂ (av. 15.3), Al₂O₃ (av. 2.95) and CaO (av. 47.04) and low levels of TiO₂ (av. 0.11), Fe₂O₃ (0.06), MgO (av. 1.10) and P₂O₅ (0.06). Based on the chemical classification recently proposed by Woolley (1982), the plots of the carbonatites in the ternary, CaO-MgO-Fe₂O₃ + FeO + MnO (figure 3) fall in the field of sovite/alvikite.

A comparison of the mean content of some oxides and elements in the Munnar carbonatite with those of sovite, alvikite, typical carbonatite (mean as well as range) and sedimentary carbonate rocks is presented in table 3. Overall, the element concentrations are comparable with those of sovite and alvikite and fall within the spectrum of typical carbonatites. Higher contents of trace elements like Co (av. 20.8 ppm), Cr (av. 88.5 ppm), Ni (av. 54.3 ppm) and Pb (av. 56 ppm) than that of sedimentary carbonates (0.1, 11, 20 and 9 ppm respectively) are characteristic. However, the Ba (av. 122.8 ppm) and Sr (av. 268 ppm) values are low, compared to similar values

Table 2. Major and trace elements data of syenite and alkali granite of Munnar.

	M-14	M-17	Mean (1)	MRG
Major elements, wt. %				
SiO ₂	60.32	60.94	60.63	71.34
Al ₂ O ₃	14.79	15.81	15.30	13.84
TiO ₂	1.07	1.01	1.04	0.24
Fe ₂ O ₃	0.91	1.24	1.08	1.68
FeO	2.77	2.19	2.48	0.84
MnO	0.05	0.09	0.07	0.02
MgO	1.44	1.28	1.36	0.66
CaO	7.84	6.27	7.06	1.70
Na ₂ O	2.15	2.70	2.43	2.56
K ₂ O	7.14	6.10	6.62	5.66
P ₂ O ₅	0.08	0.09	0.09	0.02
Moisture	0.14	0.19	0.17	0.14
L.O.I.	0.60	1.37	0.99	0.50
K ₂ O/Na ₂ O	3.32	2.26	2.79	2.21
K ₂ O/CaO	0.91	0.97	0.94	3.33
K ₂ O/MgO	4.96	4.77	4.87	8.58
Fe ₂ O ₃ /FeO	0.34	0.57	0.45	1.97
Trace elements, ppm.				
Ag	2	2	2	..
B	160	120	140	110
Ba	1383	655	1119	233
Bi	28	61	445	41
Co	21	24	235	15
Cr	334	432	383	288
Cu	13	9	11	10
Li	5	6	5.5	7
Ni	110	115	112.5	99
Pb	51	45	48	53
Rb	173	216	194.5	..
Sr	385	339	362	233
Y	22	23	22.5	..
Zn	55	25	40	45
Zr	76	78	77	..
K/Ba	37.5	77.3	57.4	201.7
K/Rb	342.8	234.3	288.6	..
Ba/Sr	4.1	1.9	3	1.0
Rb/Sr	0.45	0.64	0.55	..

Mean (1)—Average of two syenite analyses of present study. MRG—Mean analysis of seven samples of the alkali granite (after Nair *et al* 1983).

reported for carbonatites of the Nellore schist belt, (Vasudevan *et al* 1977). Considerable variability in geochemical features among the carbonatite complexes in different localities of south-west Asia has been observed (e.g. Deans and Powell 1968). In the present case, the contrast in geochemistry, especially the trace element characters like low Ba and Sr levels and high Ni and Cr levels are assumed to result from peculiar petrogenetic history as discussed later.

The mean SiO₂ (60.63) and Al₂O₃ (15.3) levels of the associated syenite (table 2) are comparable with those of other alkali syenites of Kerala. The higher K₂O/MgO (av. 4.87) are also similar. The high CaO values (av. 7.06) are however, unique and

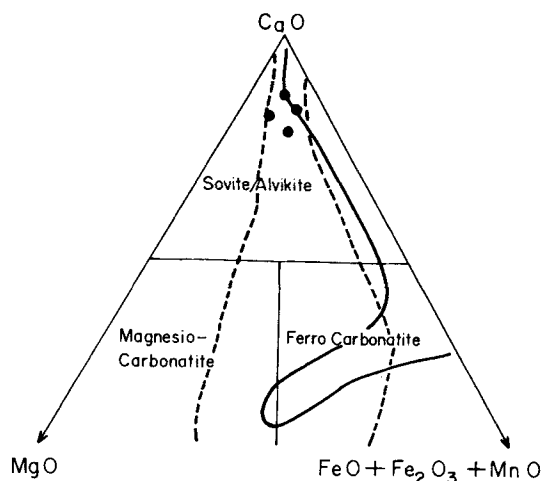


Figure 3. CaO–MgO–FeO + Fe₂O₃ + MnO plots of the carbonatites. The thick line represents the field of Thundulu carbonatites and the broken line represents the field of Alno carbonatites (after Woolley 1982).

Table 3. Salient geochemical features of Munnar carbonatite compared with data on other carbonatites (oxides in weight per cent and elements in ppm).

	Mean (1)	Sovite	Alvikite	Mean (2)	Range	Mean (3)
Fe ₂ O ₃	0.06	0.4–2.7	0.8–5.9	3.12	tr–38.88	0.54
MnO	0.04	0.1–0.82	0.54–1.9	0.61	tr–8.60	0.14
MgO	1.10	<0.1–0.4	<0.1–0.4	5.64	tr–42.68	7.79
TiO ₂	0.11	<0.1–0.1	<0.1–1.0	0.80	tr–5.20	0.07
Ba	122.8	360–3280	465–3280	2600	tr–69000	8.9
Co	20.8	<5	<5	17	0–130	0.1
Cr	88.5	5–12	5–20	48	0–1360	11
Cu	8	<5	<5–10	2.5	0–1461	4
Li	3.8	20–55	5–55	—	0–100	5
Ni	54.3	<5–35	<5–55	8	0–280	20
Pb	56	<10	<10–61	—	0–700	9
Sr	268	745–1860	560–1145	4000	tr–154000	592.3
Y	18	<10–110	<10–118	96	0–1000	30

Mean (1)—Average of 4 carbonatite analyses of present study; Sovite and alvikite analyses from Barber (1974); Mean (2)—Typical carbonatite composition from Gold (1963); Range—Range of abundances in carbonatites (after Gold 1966); Mean (3)—Average of sedimentary carbonates (after Turekian and Wedepohl 1961).

correspond to the ubiquitous association of primary calcite in the syenite. Fe₂O₃/FeO rates are rather low (av. 0.45) indicative of low oxygen fugacities during crystallization. As the syenite crystallized from an alkali silicate melt enriched with CO₂ (as discussed later), CO₂-partial pressure seems to have been dominant.

The granite shows an average of 73.34 SiO₂ and 13.84 Al₂O₃·K₂O values are high (av. 5.66) yielding higher K₂O/Na₂O (av. 2.21), K₂O/CaO (av. 333) and K₂O/MgO (av. 8.58) ratio. Plots of log₁₀ (K₂O/MgO) vs SiO₂ (after Rogers and Greenberg 1981)

fall in the alkali granite field (figure 4). $\text{Fe}_2\text{O}_3/\text{FeO}$ ratios are high (av. 1.94) and comparable with those of I-type granites (Chapell and White 1974). Detailed geochemical studies of the alkali granite were reported earlier (Nair *et al* 1983) based on which a mantle-derivation is suggested.

5. Petrogenesis

Although alkaline complexes with carbonatite and syenite (Maravic and Morteani 1980) occurring in the Archean granulite facies of shield areas and genetically related to rifting (Hansen 1980) are widely recognised, the association alkali granite-syenite-carbonatite of Munnar devoid of related mafic differentiates like gabbros or lamprophyres may be considered unique. As the carbonatite bodies are homogeneous with complete absence of pseudomorphs or corroded relicts (Heinrich 1966), a metasomatic origin is not suggested. Moreover, the veins and lenses are sharp and discordant and the mineral assemblage is suggestive of a magmatic parentage.

The lack of enrichment in P, Ba, Sr, Zr and Y and the absence of rare metals in the carbonatite imply that the rock was probably not derived from a primary carbonatite magma. The less evolved nature as depicted by relatively higher contents of transition elements (*e.g.* Ni-av. 54.3 ppm, Cr-av. 88.5 ppm) and the lower levels of incompatible elements (*e.g.* Rb-av. 24 ppm; Y-av. 18 ppm) also substantiate this. Moreover, the volume of carbonatite and syenite is relatively low to account for an exclusive carbonate magmatism. Detailed petrochemical studies of the associated alkali granite showed that it was derived from an alkali-silicate magma generated at mantle depths (Nair *et al* 1983).

Liquid immiscibility between CO_2 rich and silicate liquid is well established from investigations of the $\text{Ab-An-Na}_2\text{CO}_3\text{-H}_2\text{O}$ system (Koster van Groos and Wyllie

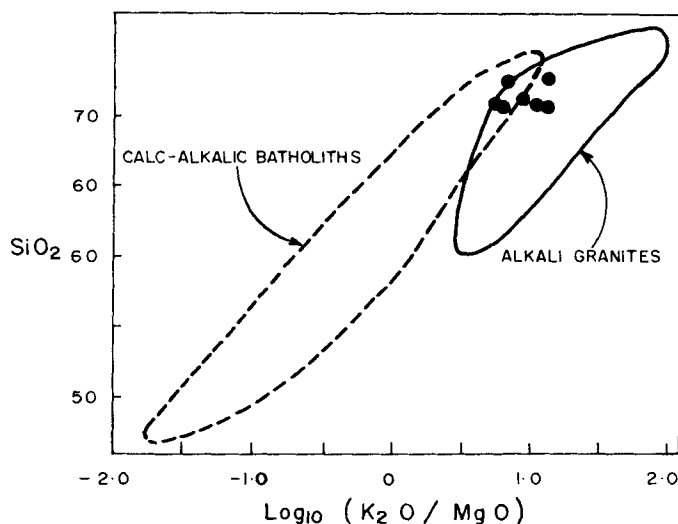
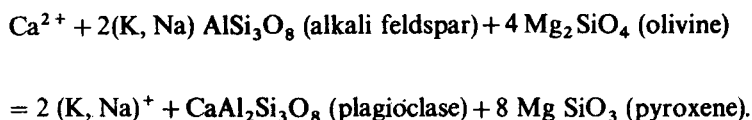


Figure 4. SiO_2 vs $\log_{10} (\text{K}_2\text{O}/\text{MgO})$ plots (after Rogers and Greenberg 1981) of the Munnar alkali granite.

1973) and through various studies on natural examples (Roedder and Coombs 1967; Roedder 1979; Philpotts 1982). In an alkali-rich system, an immiscible carbonate-rich magma develops at some stage (Hamilton *et al* 1979). The immiscibility of carbonatitic and alkalic silicate liquids can be physically explained as the separation of a less viscous carbonate liquid from a more viscous polymerized silicate phase. The carbonate liquid would be lower in density because of higher content of H₂O and this contrast in density could cause phase separation due to the earth's gravitational field alone (Moller *et al* 1980). The pre-requisite to establish separation of immiscible silicate-saturated carbonatite liquid and the associated carbonate-saturated silicate melt is achieved as follows:

Large-scale volatile outgassing occurs during crustal warping and distension prior to rifting which trigger mantle degassing (Bailey 1974). Imprints of such large-scale volatile influx is recognised in the Kerala region (cf. Nair and Santosh 1984). Rapid ascent of volatiles enriched in CO₂ liberated from the mantle cause partial melting at shallower levels of the mantle, resulting in the following ion-exchange reaction (Moller *et al* 1980):



Alkali metals are subsequently introduced into the carbonate liquid. This fixes the CO₂ partial pressure, thus preventing Ca²⁺ ions from crystallizing as plagioclase and polymerizes the ortho-silicate ions. The high potassic nature and other geochemical characters of the associated syenites imply melt equilibration from a phlogopite bearing peridotite at depths exceeding 120 km as the peridotite solidus crosses the continental geotherm at these depths (Harris *et al* 1983). Phlogopite-rich pockets have been proposed for the origin of other similar syenites from Kerala (Nair and Santosh 1984). The concentration of alkalis and CO₂ in the alkali silicate melt increased and subsequent cooling and ascent of the magma led to the separation of an immiscible fraction (Mysen 1975). A fingerprint of this carbonate and silicate-liquid immiscibility is preserved in the form of primary calcite in both the alkali granite and the syenite.

From the same liquid composition, calcite is precipitated at lower pressures and dolomite, ankerite and siderite at higher pressures (Wyllie and Biggar 1966). The alvikite carbonatite occurring as lenses and patches within the syenite has an association of calcite and dolomite. This variety crystallized at slightly elevated pressures together with the associated syenite. The sovite carbonatite, occurring within gneisses, however, represents the ultimate fraction which crystallized at lower pressures, presumably due to the higher level of emplacement controlled by the lineament.

The perpotassic nature of the associated syenites, with ubiquitous association of primary carbonate and aegirine is comparable with the orthoclase fenite described from Sudan (Harris *et al* 1983). In the second locality, fenitisation is restricted to the development of K-feldspar megacrysts and laths of aegirine. Similar phenomena are reported by Verwoerd (1967) from the fenitised aureoles of South African carbonatites. Concentration of K in K-feldspar and their recrystallization is a general mineralogical tendency of fenitisation (Heinrich 1966).

6. Tectonic significance

Carbonatites and other alkaline complexes are, in general absent in orogenic belts and are confined to stable continental platforms. They are mostly related to vertical movements in the earth's crust and occur in regions of lithospheric rifting. Examples include the East African carbonatites which are confined to narrow zones of rift faults (De Kun 1971) and the carbonatite complexes of India which occur along deep-seated faults (Katz 1978; Sethna 1974).

Alkaline magmatism is established as a precursor to rift tectonics and is especially important in the early stages of tensional tectonics (Bailey 1974). The Munnar alkaline complex occur along the intersection zone of the Madurai and Kerala aulacogenes made up of the NE Palni arm, NS Cardamom arm and the NW Anamalai arm. Katz (1978) considered a triple point junction at the aulacogene stage probably manifesting a hot-spot formed as a resultant tensional wedge due to NE dextral/NW sinistral interaction. The alkaline complex is thus obviously related to a distensional tectonic regime.

The alkali granite has recently been dated to be of 740 ± 30 my (Odom 1982). Interestingly, the carbonatites of the adjacent terrane, namely the Sevathur and Jokipatti in Tamil Nadu are dated to be of 720 ± 30 m.y. (Udas 1971). It is thus revealed that the southern part of the Indian shield evidenced an episode of alkaline magmatism during the late Precambrian times related to the pre-rift tectonics of the continent.

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References

- Bailey D K 1974 in *The alkaline rocks* (ed) H Sorenson (New York: John Wiley) 148
 Barber C 1974 *Lithos* 7 53
 Borodin L S, Gopal V, Moralev V M, Subramonian V and Ponikarov V 1971 *J. Geol. Soc. India* 12 101
 Chappell B W and White A J R 1974 *Pac. Geol.* 8 173
 Deans T and Powell J L 1968 *Nature (London)* 218 750
 De Kun N 1961 *Neues Jahrb. Mineral Monatsh.* 6 124
 Eckermann H 1961 *Bull. Geol. Inst. Univ. Uppsala* 11 1
 Gold D P 1963 *Econ. Geol.* 58 988
 Gold D P 1966 *Miner. Soc. India, IMA volume*, 83
 Hamilton D L, Freestone I C, Dowson J B and Donaldson C J 1979 *Nature (London)* 279 52
 Hansen K 1980 *Lithos* 13 145
 Harris N B W, Mohammed A E R O and Shaddad M Z 1983 *Geol. Mag.* 120 115
 Heinrich E W 1966 *The geology of carbonatites* (Chicago: Rand McNally) 555 p.
 Heinrich E W and Dahlem D H 1966 *Miner. Soc. India, IMA Vol.* 37
 Katz M B 1978 *J. Geol. Soc. India* 19 185
 Koster van Groos A G and Wyllie P J 1973 *Am. J. Sci.* 273 465
 Maravic H and Morteani G 1980 *Lithos* 13 159
 Moller P, Morteani G and Schley F 1980 *Lithos* 3 171
 Mysen B O 1975 *Yb. Carnegie Instn. Wash.* 74 454
 Nair N G K and Santosh M 1984 *J. Geol. Soc. India* 25 35
 Nair N G K, Santosh M and Thampi P K 1983 *Neues Jahrb. Mineral. Abh.* 148 223-232
 Odom A L 1982 Final Rep. U.N. Case 81-10084

- Phadke A V and Jhingran A G 1968 *Geol. Soc. India* **9** 165
Philpotts A R 1982 *Contrib. Mineral. Petrol.* **80** 201
Roedder E 1979 in *The evolution of the igneous rocks* (ed.) H S Yoder Jr. (Princeton: University Press) 15
Roedder E and Coombs D S 1967 *J. Petrol.* **8** 417
Rogers J J W and Greenberg J K 1981 *Geol. Soc. Am. Bull.* **92** 57
Sethna 1974 *J. Geol. Soc. India* **15** 429
Streckeisen A L 1979 *Neues Jahrb. Mineral. Abh.* **134** 1
Sukheswala R N and Udas G R 1964 *Rep XII Int. Geol. Cong. Sec. 7* 1
Turekian K K and Wedepohl K H 1961 *Bull. Geol. Soc. Am.* **72** 175
Udas G R 1971 *Bull. Volcan.* **35** 799
Udas G R and Krishnamurthy P 1970 *Proc. Indian Natl. Sci. Acad.* **A36** 331
Vasudevan D, Rao T M and Kota Reddy 1977 *J. Geol. Soc. India* **18** 515
Verwoerd W J 1967 *Geol. Surv. S. Africa Dep. Mines Handb.* **6** 452
Woolley A R 1982 *Mineral. Mag.* **46** 13
Wyllie P J and Biggar G M 1966 *Miner. Soc. India, IMA Vol.* **92**