The Mannapra syenite, Central Kerala, India: Geochemistry, petrogenesis and bearing on anorogenic magmatism

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Abstract. Occurrence of a syenite body near Mannapra, Trichur district, Kerala, is reported. The syenite, emplaced within charnockitic country rocks along the Idamalayar fault-lineament, is exposed over an area of 8 km². The rock, classified as quartz alkali feldspar syenite based on Q-A-P proportions, has alkali feldspar as the dominant mineral constituent which shows variation in perthitic texture from crypto- to micro- and patch-perthites. Both ortho- and clino-pyroxenes are present, with the former showing blebs of plagioclase suggesting Al-unmixing. Clinopyroxene shows subsolidus reequilibration with greenish pleochroic grain margins and local conversion to alkali amphibole. The petrochemical characters indicate that the syenite crystallized from a partial melt which equilibrated from K-rich, Rb-depleted source in the upper mantle, in response to crustal distension and mantle degassing prior to the rifting of the continent. Reaction between early formed minerals and the late peralkaline liquid towards the residual phase resulted in subsolidus reequilibration textures. The syenite is envisaged to be yet another example of the manifestation of anorogenic magmatism in this part of the Indian shield.

Keywords. Syenite; mineralogy; geochemistry; petrogenesis; subsolidus reequilibration; anorogenic magmatism.

1. Introduction

Occurrences of a number of alkali plutons have been recently noted in the Kerala region, showing spatial relationship with regional fault-lineaments (*e.g.* Nair *et al* 1983; Santosh and Nair 1985). As the region occupies a significant portion of the south-western part of the Indian shield and the western continental margin of India, studies on the petrochemistry and tectonics of these intrusives have been taken up to understand their role in the geologic and tectonic evolution of the region. Available geochronologic data suggest a Late Precambrian-Early Paleozoic taphrogenic magmatism with imprints of related metallogeny to which phase the alkaline intrusives and pegmatites of the region are correlated (Santosh and Nair 1983; Santosh 1984a).

The close relationship between alkaline magmatism and rift-tectonics is well known (Bailey 1974; Murthy and Venkataraman 1964). As the plutons, ranging from alkali granites to alkali syenites and carbonatites (Nair *et al* 1984a, b) are spatially related to fault-lineaments which have probable mantle extension, it is presumed that the magmatism which is anorogenic in nature, is a precursor to the rift-tectonics of the continental margin (Santosh and Nair 1985). The occurrence of a syenite pluton near Mannapra, Trichur district, Kerala, is reported here. Based on its geochemical characters, an attempt has been made to evaluate its petrogenetic aspects.

2. Geological setting

The major part of the lithology of the Trichur district comprises charnockite group of rocks made up of hypersthene and/or diopside bearing granulites and hornblende

Figure 1. Generalised geological map of the Mannapra area. The inset shows location of the syenite along the NW-SE trending Idamalayar fault-lineament.

granulites (Mahadevan 1964; Rao 1978). The charnockites show development of a foliation which has a general NNW-SSE to N-S trend with steep dips towards west. In the Mannapra locality, the charnockite is medium to coarse-grained variety with a feeble NW-SE foliation trend. Towards east of the locality, the charnockites show contact with migmatitic gneisses containing hornblende and biotite.

The syenite is exposed as a NW-SE elongated body around 8 km² within the charnockites near the charnockite-migmatite contact. It occurs along the NW-SE trending Idamalayar lineament (figure 1). This lineament is an active fault along which a suite of gabbroic dykes of Tertiary age and the alkaline pluton of Sholayar are emplaced (Tilak 1980; Nair *et al* 1984b; Santosh and Sankar 1984). The syenite shows rather sharp contacts with the charnockitic rocks. From the quartz-hypersthene-feldspar assemblage of the charnockite, there is an abrupt change to interlocking pyroxene-feldspar assemblage of the syenite as discernible in few localities. The syenite is medium-to-coarse grained at its exposed peripheries and tends to be coarse grained towards the centre.

3. Mineralogy

In thin sections, the syenite shows a general hypidiomorphic granular texture. However, the alkali feldspar tends to form megacrysts in some cases. The mineralogical assemblage comprises alkali feldspar, orthopyroxene, clinopyroxene and amphibole with minor plagioclase, biotite and opaques. Accessories include apatite, zircon, sphene, epidote, chlorite and calcite. Point counting with an electrical integrator shows average modal contents of 4.2% quartz, 72.1% alkali feldspar, 5.5% plagioclase, 7.2% pyroxenes, 3.3% amphibole, 2.4% biotite and 2.2% opaques with accessories

Figure 2. Photomicrographs (in crossed nicols, except d) of Mannapra syenite. The length of photographs a, b and d is 6 mm and c is 3 mm. (a)-Perthitic K-feldspar. (b)-Orthopyroxene showing blebs of exsolved plagioclase. (c)-Plagioclase lath showing lamellar twinning in orthopyroxene. (d)-Biotite flakes fringing magnetite grain.

(b)

(d)

(a)

(c)

Figure 3. Major element variations in the Mannapra syenite

Figure 4. $K_2O/(K_2O + Na_2O)$ vs K_2O , $CaO/(CaO + Na_2O)$ vs Al_2O_3 and $FeO/(FeO + MgO)$ vs Al_2O_3 diagrams.

constituting the rest 3.1%. The recalculated Q-A-P proportions (5.13:88.14:6.73) correspond to that of quartz alkali feldspar syenite, following Streckeisen's (1976) scheme.

Alkali feldspar, which forms the dominant mineral constituent, occurs as subhedral to anhedral grains exhibiting varied perthitic textures. The exsolved Na-phase in the host K-feldspar that generally lacks microcline cross-hatching is found as braids to coarser blebs and patches. The perthitic textures could be classified as varying from fine cryptoperthite to coarse braid micropertthite and patch perthite (figure 2a). Plagioclase is relatively rare and occurs as subhedral laths showing lamellar twinning with extinction angles corresponding to a range in composition of $Ab_{90}An_{10}$ to $Ab_{80}An_{20}$. Plagioclase is generally seen as minor discrete grains but also occurs as inclusions in alkali feldspar.

Pyroxene constitute the major mafic silicate in the syenite and occur as large subhedral crystals. In the absence of data on mineral chemistry, estimation of their

Figure 5. A-F-M and K-Na-Ca variations in the syenite. The broken line represents calc-alkaline trend (after Barker and Arth 1976).

Figure 6. Trace element variations in the Mannapra syenite.

precise composition is difficult. But some inferences could be drawn based on their optical characters. Both ortho- and clino-pyroxenes are present in the syenite, with the latter being more dominant. The orthopyroxene shows moderate pleochroism with an absorption as X = pale pink, Y = yellowish green and Z = greenish pink. Basal sections of the orthopyroxene show symmetrical extinction and (001) sections show straight extinction. Elongated patches of plagioclase are observed within the orthopyroxene laths (figures 2b, c). This texture closely resembles that described by Emslie (1975) and suggests Al-unmixing from the pyroxene solid solution as a result of lowering of pressure. Clinopyroxene is pale brownish and non-pleochroic with $Z \wedge c = 40-44^\circ$. In many cases, the grain margins show feeble to moderate pleochroism with X = greenish brown, Y = greenish yellow and Z = green with a slight increase in the $Z \wedge c$ value. The pyroxenes are rarely fresh and unaltered. A moderate degree of subsolidus alterations is common, characterised by the development of greenish amphiboles. Some grains show partial breakdown to an assemblage of magnetite-biotite turquoise chlorite-amphibole.

In addition to the occurrence as a subsolidus reaction product, amphibole is also found as discrete laths exhibiting strong pleochroism as X = greenish yellow, Y = yellowish green and Z = deep green with $Z \wedge c = 13^\circ$, indicative of an alkaline composition.

Biotite is found as two textural varieties. It generally occurs as thin laths fringing magnetite grains (figure 2d). Biotite is also found as an interstitial phase along with amphibole and quartz. In both cases, it shows moderate pleochroism from brownish yellow to reddish brown. Euhedral crystals of zircon and apatite are generally found as inclusions within pyroxenes. Calcite is apparently primary as it is not found as an alteration product along with other ferromagnesium minerals, but frequently occurs as an interstitial phase between the grain boundaries of alkali feldspars, comparable with similar occurrences in other alkaline rocks of the region (Nair and Santosh 1984a). The opaques are mainly represented by magnetite and subordinate ilmenite. Minor pyrite and chalcopyrite are also found.

4. Geochemistry

Eight representative samples of the Mannapra syenite were analysed for major and selected trace elements. The samples for analyses were collected from working quarries around Mannapra area. Major elements were analysed by wet chemical methods and trace elements by atomic absorption spectrophotometer (Perkin-Elmer 4000). The precision and accuracy were checked by performing duplicate analyses. The analytical data summarised in table 1, shows comparison with average values of the Sholayar syenite (SH), an alkali feldspar syenite in central Kerala (Nair *et al* 1984b) and with those averaged for alkali syenite (AS) by Nockolds (1954). All the analyses show quartz-normative character with significant amount of normative diopside implying alkaline nature (table 2).

The SiO_2 content shows a moderate variation from 58.94 to 62.62 with a mean at 60.45, comparable with AS (61.86) and SH (64.14). Al_2O_3 values are fairly consistent with a mean at 16.76. The variations in the levels of Fe_2O_3 (1.53–5.21), FeO (1.02–2.79), CaO (2.46–6.94) and MgO (0.80–1.76) are significant and show mean values (2.81, 1.88, 3.86 and 1.34 respectively) which are comparable with those of SH and AS, except in the

Table 1. Major and trace element analyses of Mannapra syenite compared with those of similar syenites

	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-8	MP-10	Mean (MP)	Mean (AS)	Mean (SH)
Major elements, wt. %											
SiO ₂	61.39	60.69	60.83	62.26	62.62	56.72	60.14	58.94	60.45	61.86	64.14
Al ₂ O ₃	16.82	16.82	17.33	16.82	17.33	15.29	17.33	16.31	16.76	16.91	16.82
TiO ₂	0.32	0.10	0.39	0.52	0.23	0.14	0.16	0.44	0.29	0.58	0.49
Fe ₂ O ₃	2.22	1.53	3.46	1.93	1.38	5.21	3.54	3.18	2.81	2.32	2.62
FeO	1.02	1.78	2.28	2.79	1.10	2.14	1.38	2.53	1.88	2.63	0.82
MnO	0.04	0.07	0.05	0.06	0.03	0.12	0.03	0.06	0.06	0.11	0.02
MgO	1.12	1.76	1.12	1.28	0.96	1.92	0.80	1.76	1.34	0.96	0.64
CaO	3.14	3.81	3.81	3.58	2.46	6.94	3.36	3.81	3.86	2.54	2.64
Na ₂ O	3.37	3.24	4.04	3.65	3.39	2.84	3.20	3.21	3.37	5.46	2.59
K ₂ O	8.34	8.53	5.46	4.82	8.50	6.90	8.44	7.75	7.34	5.91	7.87
P ₂ O ₅	0.16	0.18	0.15	0.21	0.12	0.23	0.34	0.41	0.23	0.19	0.05
Moisture	0.21	0.39	0.26	0.12	0.14	0.24	0.27	0.17	0.23	—	0.23
L.O.I.	0.28	0.34	0.33	0.63	0.27	0.63	0.39	0.43	0.41	—	0.33
K ₂ O/Na ₂ O	2.47	3.14	1.35	1.32	2.50	2.43	2.64	2.41	2.28	—	3.04
Fe ₂ O ₃ /FeO	2.18	0.86	1.52	0.69	1.44	2.43	2.57	1.26	1.62	—	3.20
Mg/Mg + Fe ⁺	0.22	0.30	0.14	0.18	0.23	0.18	0.12	0.20	0.20	—	—
Agpatite index	0.87	0.87	0.73	0.67	0.85	0.80	0.83	0.84	0.81	—	—
Trace elements, ppm.											
Ba	844	440	918	1704	530	608	416	494	744	—	445.2
Bi	94	90	78	112	60	70	58	66	78.5	—	—
Co	64	60	62	56	58	70	54	64	61	—	—
Cr	48	—	22	24	48	60	54	56	44.5	—	25.2
Cu	—	40	22	6	6	36	6	8	12.5	—	43.6
Ni	98	60	82	50	100	124	84	102	87.5	—	32.0
Pb	50	38	10	16	38	40	54	38	35.5	—	20.6
Rb	98	106	70	54	110	84	116	98	92	—	170
Sr	272	320	328	196	382	278	70	292	267	—	8.8
V	—	40	60	60	—	60	—	40	52	—	—
Zn	40	88	78	124	26	56	30	60	62.75	—	29.8
Zr	60	100	100	140	160	160	40	40	97.5	—	108.2
K/Ba	82.3	160.93	49.37	23.48	133.13	94.21	168.41	130.23	105.22	—	—
Ba/Sr	3.10	1.38	2.80	8.69	1.39	2.19	5.94	1.69	3.4	—	57.2
K/Rb	706.43	668.00	647.47	740.94	641.45	681.87	603.97	656.46	668.3	—	408
Rb/Sr	0.36	0.33	0.21	0.28	0.29	0.30	1.66	0.34	0.47	—	—

Mean (MP)—Mean of Mannapra syenite analyses; Mean (AS) Average of alkali syenite from Nockolds (1954); Mean (SH) Average analysis of Sholayar syenite from Nair *et al* (1984a).

slightly higher levels of CaO. In the absence of Ca-rich plagioclase, this component must reflect the compositional variation of the pyroxenes. The unusually higher Fe_2O_3 and CaO contents in one sample (MP-6) is reflected in the high modal contents of ferromagnesium minerals. Na_2O (av. 3.37) and K_2O (av. 7.34) are comparable with those of SH (av. 2.59 and 7.87 respectively) but differ from AS in having higher K_2O and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios (av. 2.28). Higher K_2O content is, however, noted to be a general feature of all alkaline plutons of the Kerala region (Nair and Santosh 1984a). $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (av. 10.71) is less than Al_2O_3 (av. 16.76) and in most cases is less than $1/6 \text{ SiO}_2$, classifying the syenite and plumbitic (Polanski 1949). With respect to total alkalis, there is a pronounced deficiency in alumina, expressed in the occurrence of up to 14.89% normative diopside (table 2). Agpaite indices calculated for the syenite show an average of 0.81, being close to unity. $\text{Fe}_2\text{O}_3/\text{FeO}$ levels (av. 1.62) are slightly lower than those of SH (av. 3.20). $\text{Mg}/\text{Mg} + \text{Fe}'$ ratios show a variation from 0.30 to 0.12, consistent with a moderate degree of fractionation.

Major element variations are shown in figure 3, where they are plotted against SiO_2 . All the elements show overall smooth trends of variations consistent with the empirical laws governing magmatic crystallization. Al_2O_3 , K_2O and Na_2O show increasing trends with increasing SiO_2 . The sympathetic behaviour of these oxides is in accordance with the petrographic observation of alkali feldspar being the major liquidus phase towards the late stages of crystallization. MgO , FeO' and CaO show sharp decrease with increasing silica saturation, consistent with early crystallization of ferromagnesium minerals. The inter-element variations are shown in figure 4, where $\text{K}_2\text{O}/\text{K}_2\text{O} + \text{Na}_2\text{O}$ vs K_2O plots show smooth increase supporting the evidence of alkali feldspar fractionation. The $\text{CaO}/\text{CaO} + \text{Na}_2\text{O}$ vs Al_2O_3 plots show a sharp decline. Since plagioclase occurs only as a minor constituent, this variation records the change in pyroxene and amphibole compositions towards more sodic end members, which in turn is a reflection of the increasing peralkalinity of the liquid. Mitchell and Platt (1978) and Stephenson and Upton (1982) suggest that peralkalinity has a direct control over Na-enrichment whereas silica saturation is rather unimportant. In this regard, the bulk rock analyses need not show peralkalinity (av. mol% $\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{Al}_2\text{O}_3 = 0.81$ in the present case) as exemplified by a majority of rock suites of the Gardar Province of Greenland. $\text{FeO}'/\text{FeO}' + \text{MgO}$ vs Al_2O_3 plots do not show much variation, testifying to the above view that alkalis played the determining role, as exemplified in the A-F-M and K-Na-Ca diagrams (figure 5), where the plots of the syenite closely follow an alkali enrichment trend relative to the F-M join, with a specific increase in K and Na relative to Ca.

Among trace elements, the mean levels of Co (61 ppm), Cr (44.5 ppm), Ni (87.5 ppm) and Zn (62.8 ppm) are higher than those of Sholayar syenite (30.4, 25.2, 32 and 29.8 ppm respectively). This correlates well with their entry in ferromagnesium minerals, the modal content of which is almost double (18.2%) than that of Sholayar (av. 9.7%). Ba (av. 744 ppm), Sr (av. 267 ppm) and Zr (av. 97.5 ppm) show higher levels where as Rb (av. 92 ppm) is rather low. The range is as follows: Ba 416–1704 ppm, Sr 70–382 ppm, Rb 54–116 ppm and Zr 40–160 ppm.

The K/Rb ratio is high (668.3) compared to SH (av. 408) and that reported for syenites of the Eastern Ghat belt (333, Bose *et al* 1982). Ba/Sr (av. 34) and Rb/Sr (av. 0.47) values are rather low. K/Ba shows an average of 105.2.

Variation of trace elements with respect to SiO_2 is shown in figure 6. Ba shows an overall increase which can be correlated with its partitioning in late crystallizing K-

Table 2. Normative composition of Mannapra syenite

	MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-8	MP-10	Mean
Q	3.9	0.66	7.86	12.36	4.92	2.04	2.88	2.34	4.62
or	49.48	50.60	32.25	28.36	50.04	40.59	50.04	45.59	43.37
ab	28.30	27.25	34.06	30.92	28.82	24.10	27.25	27.25	28.49
an	6.12	6.12	13.07	15.01	6.95	8.62	7.78	7.23	8.86
wo	3.25	4.64	2.09	0.81	1.86	10.09	3.02	3.83	3.70
di	2.80	3.00	1.50	0.40	1.50	4.80	2.00	2.70	2.34
fs	—	1.32	0.40	0.40	0.13	—	—	0.79	0.61
en	—	0.66	1.72	3.70	1.19	—	—	2.24	1.90
hy	—	1.40	0.20	2.20	0.10	—	—	0.40	0.86
fs	—	—	—	—	—	—	—	—	—
mt	2.32	2.32	5.10	1.86	2.32	6.96	3.94	4.64	3.68
he	0.64	—	—	—	—	0.48	2.72	—	1.28
il	0.61	0.15	0.76	1.06	0.46	0.30	0.30	0.91	0.57
ap	0.67	0.67	0.34	0.34	0.34	0.67	0.67	1.01	0.59
Ab	33.73	32.45	42.91	41.62	33.56	32.88	32.03	34.03	35.40
An	7.29	7.28	16.46	20.21	8.10	11.76	9.15	9.03	11.16
Or	58.98	60.27	40.63	38.17	58.34	55.36	58.82	56.94	53.44

bearing phases. This increase in Ba with silica saturation supports the deduction that alkali feldspar constitutes the dominant fractionating phase in the syenite. Sr shows a slight increase initially, to be followed by a decrease with higher SiO₂ levels, marking early precipitation of Ca-bearing minerals, mainly apatite and pyroxene. Cr, Ni and Rb show scatter. However, K/K + Na *vs* Rb shows a positive correlation. Interelement correlations show that Ba and Sr contents of the syenite maintain a reciprocal relationship whereas Sr *vs* Rb and Sr *vs* Ca plots yield overall positive correlations. Zr concentrates towards the residual phase.

5. Discussion

The absence of highly coarse mesoperthites in contrast to the Sholayar syenite and of microcline cross-hatching in the host K-feldspar imply higher equilibration temperatures for the Mannapra syenite. The variation in the perthitic texture from fine cryptoperthite to coarser braid and patch perthites is indicative of increasing degree of fractionation aided by slow cooling rate and presence of fluids (Parsons 1978; Santosh and Nair 1985). Build-up of a fluid phase towards later stages of crystallization is best exemplified by the texture of ferromagnesian minerals. Clinopyroxenes exhibit pronounced subsolidus reaction resulting in the development of greenish pleochroic grain margins reflecting interaction between the early crystallized pyroxene and late peralkaline fluid (Mitchell and Platt 1978; Stephenson and Upton 1982). Biotite fringes around magnetite are consistent with the reaction:

The magnetite-biotite-chlorite-amphibole assemblage also indicates subsolidus reactions (Mitchell and Platt 1982).

The presence of plagioclase laths in orthopyroxene is significant. Such textures are reported by Philpotts (1966) and Emslie (1975), largely from pyroxenes in anorthositic rocks. Experimental data on synthetic systems and natural rock compositions demonstrate that pyroxenes with high Al_2O_3 contents are stable at high pressures and temperatures (Green and Ringwood 1967). It is recognised that aluminous pyroxenes in subalkaline and some alkaline rocks have crystallized at moderate to high pressures. The presence of exsolved Al in the form of a silica saturated phase (plagioclase) denotes that the original pyroxene did not crystallize from silica-deficient magmas. The pyroxene contained the plagioclase components in solid solution. Decompression of an initially homogeneous orthopyroxene solid solution resulted in the exsolution of a $\text{NaAlSi}_2\text{O}_6$ -rich component (Kushiro 1969). The probability of the plagioclase laths being inclusions is not favoured since, as deduced from petrochemical features, pyroxene crystallized much earlier than plagioclase and hence the latter will not be poikilitically included in the former under normal crystallization-fractionation processes.

6. Petrogenesis

Based on the available petrochemical data, some inferences could be drawn regarding the petrogenesis of the syenite. Four main aspects have to be considered: (i) composition of source material, (ii) mode of melting including depth, (iii) the extent of melting and (iv) the changes in magma prior to solidification.

To start with, we assume that the source is lower crust or upper mantle. This assumption is based on the general geochemical characters of the syenite including high transition element levels and K/Rb ratios. This assumption is substantiated by observations made on similar alkalic plutons of Kerala region (Nair and Santosh 1984a, b; Santosh and Nair 1985) as well as from the adjacent terrains (Bose *et al* 1982). Moreover, the syenite is emplaced along an active fault-lineament which has probable extension to mantle-depths (Nair *et al* 1984b) like other fault-lineaments of the region (Santosh and Sankar 1984).

In order to produce melting in the mantle, a geotherm is required to intersect the appropriate melting curve. The general processes of heating within the earth, radioactivity, thermal radiation and thermal conduction would be too diffuse to cause heat focussing (Bailey 1977). In the absence of sufficient evidences to invoke a 'mantle plume' theory, other methods of raising the temperature could be considered, namely, frictional heating or heating of the overlying rocks by a body of rising magma. The most probable mechanism of melting in stable plate interiors is mantle upwarping, producing rapid decompression melting, resulting in anorogenic magmatism. Bailey (1974, 1977) showed that crustal distension can cause large-scale mantle degassing leading to the addition of volatiles to the overlying rocks causing localised melting. At higher temperatures, gas fluxing can cause heat focussing which function as a doubly efficacious mechanism of melting. The intrinsic association of CO_2 with metamorphic (Newton *et al* 1980; Harris *et al* 1982; Santosh 1984b) and magmatic (Nair *et al* 1984a; Santosh 1984a) regimes of the region is significant. We presume that the NW-SE and NNW-SSE sets of fault-lineaments of the Kerala region served as conduits for considerable volatile-influx resulting in the emplacement of a number of alkali plutons along them, including the syenite of present study. This Late Precambrian-Early

Figure 7. Part of Ab-An-Or ternary diagram with isotherms (after Yoder *et al* 1957) showing the plots of the Mannapra syenite.

Figure 8. $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-Na}_2\text{O} + \text{K}_2\text{O}$ (mol %) plots of the Mannapra syenite. The broken line represents the field of syenites of the Nile Province (after Harris 1982) and the continuous line represents the field of Sholayar syenite (after Nair *et al* 1984b).

Paleozoic taphrogenic magmatism (Santosh and Nair 1983, 1985) serves as a keynote to the pre-rift tectonics of the Indian continental margin, as the genetic link between alkaline magmatism and rift-tectonics is well known (Bailey 1974; Murthy, and Venkataraman 1964). Anorogenic magmatism of similar age has been reported from other shield areas also (Greenberg 1981; Harris 1982).

The data presented here are insufficient to make precise estimates of the nature of source rock. However, some general deductions could be made. Melting of mica-rich

mantle will generate potash-rich magmas whereas more sodic magmas result when amphibole-rich mantle is melted (Lloyd and Bailey 1975). Higher K and K/Rb levels indicate a K-rich, but Rb-depleted source. Low Mg/Mg + Fe' levels and higher Sr-content together with the absence of associated mafic differentiates eliminate derivation by differentiation from a basic magma and suggest partial melting. Experimental studies show that as a consequence of the incongruent melting of orthopyroxene, silica-saturated alkaline magmas can be generated from olivine-rich parent rocks (Reay and Harris 1964). The investigations of Yoder and Tilley (1962) and O'Hara (1968) indicate that at higher pressures, the mineral stabilities change, resulting in the change of position of the thermal divide in the fosterite-silica-nepheline-diopside system, leading to the formation of alkaline magmas directly by fusion and indirectly by fractionation from hypersthene-normative liquids.

Subsequent change in the magma is marked by the development of peralkalinity. Geochemical characters suggest that alkali feldspar was the dominant fractionating phase. Fractionation of feldspar ultimately leads to the development of a peralkaline residuum in any suite, especially when there is a deficiency of alumina with respect to the total alkalis (Bailey and Macdonald 1969). Feldspar being the major liquidus phase, the Ab-An-Or system has been chosen to evaluate the present data. Plots in the system (figure 7) mainly fall in the alkali feldspar solid solution field and within the bounds of 800°C isotherm, with a general trend towards the Or-apex. Log Sr vs log Rb plots (Condie 1973) indicate that the pressures were largely of the order of 8 Kb. In the system relevant to peralkaline rocks, namely, the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-Na}_2\text{O} + \text{K}_2\text{O}$, the plots of syenite fall within the field of similar syenites belonging to phase 2 magmatism in the Nile Province (Harris 1982) and close to the field of the Sholayar syenite (figure 8). Interestingly, the plots define a fractionation trend away from the SiO_2 -apex towards the region of alkalis, similar to the trend of the syenites of the Illimaussaq complex in Greenland (Macdonald 1974), consistent with the view of development of a late-stage peralkaline character, supplemented by the occurrence of up to 14.39% normative diopside. This peralkaline liquid brought about such textures as the coarsening of perthites and the subsolidus reactions of pyroxenes.

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