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Rb-Sr Geochronology, Nd-Sr Isotopes and Whole Rock Geochemistry of Yelagiri and Sevattur Syenites, Tamil Nadu, South India

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Abstract

Alkaline magmatism during the late Proterozoic is an important event in the northern part of the South Indian granulite terrain. A number of alkaline plutons comprising saturated syenite and ultramafic rocks often associated with carbonatite are found localized along NE-SW trending lineaments, which are considered as deep crustal fractures. Along one such lineament, the alkaline complexes of Yelagiri, Sevattur and Samalpatti have intruded into the country rocks comprising epidote hornblende gneiss. The isotope characteristics and geochemistry of Yelagiri and Sevattur plutons are examined in this paper. Whole rock Rb-Sr isochron ages of the Yelagiri and Sevattur syenites are 757± 32 Ma and 756± 11 Ma respectively. The close spatial relationship, similarities in age, mineralogical and geochemical characteristics of these plutons strongly suggest their close genetic relationship. The initial Sr and Nd isotope ratios of the Sevattur carbonatites suggest their derivation from an alkali metal and LREE enriched mantle source. However, the silicate rocks of the Yelagiri and Sevattur plutons have distinctly different isotopic characteristics from this enriched mantle source. Combined geochemical and isotopic characteristics of these silicate rocks indicate that silicate rocks of both plutons are derived independently from isotopically different sources from those of carbonatites. Moreover, comparison with the isotopic characteristics of Archean crustal rocks in South India indicates that the source regions of both silicate rocks are lower-crustal portions, which are deeper than any other crustal portion exposed in South India, or isotopically metasomatized crustal portions by volatile influx from carbonatite.

Key words: Rb-Sr age, Nd-Sr isotopes, Yelagiri and Sevattur syenites, carbonatite, lower-crust.

Introduction

In the northern part of the south Indian granulite terrain in the Vellore and Dharmapuri districts of Tamil Nadu, lying just south of the amphibolite facies - granulite facies transition zone, a number of alkaline plutons comprising saturated syenite, pyroxenite and carbonatite have been reported (Udas and Krishnamurthy, 1970; Borodin et al., 1971; Krishnamurthy, 1977; Subramanian et al., 1978; Viladkar and Subramanian, 1995; Miyazaki et al., 1999; etc.). These complexes are located along a major NE-SW trending lineament (Grady, 1971) in a gneissic terrain.

Sr and Nd isotope data from carbonatites have now been shown to be effective in monitoring the nature of the subcontinental mantle (e.g. Bell and Blenkinsop, 1989), even though the relationships between carbonatites and their associated silicate rocks are complex and still not completely understood. Comprehensive isotopic studies of carbonatites and their associated silicate rocks reveal that there are several alkaline-carbonatite complexes with wide isotopic variation in the associated silicate rocks, which require the involvement of other mantle components and/or continental crust. Therefore, open-system behaviour such as assimilation or mixing either with other mantle melt or sources, or with continental crust is considered to influence the petrogenesis of these alkali- carbonatite complexes (e.g. Bell and Peterson, 1991; Simonetti and Bell, 1994; Bell, 1998). Although several alkaline plutons in Tamil Nadu are not associated with carbonatite, comprehensive Sr and Nd isotopic investigation of alkali-carbonatite complexes provides important information about petrogenesis and source characteristics not only of alkaline-carbonatite complexes but also of associated alkaline plutons.

The Yelagiri pluton is located at the northernmost part, Sevattur pluton is in the middle and Samalpatti pluton is situated further southwest (Fig. 1). The Sevattur and Samalpatti are associated with carbonatite and form alkali-carbonatite complexes. The age of the alkaline magmatism reported from Sevattur and Samalpatti includes a K-Ar age of 700± 30 Ma for phlogopite from the Samalpatti carbonatites (Moralev et al., 1975), a Rb-Sr whole rock isochron age of 767± 8 Ma for the Sevattur syenites (Kumar et al., 1998), Rb-Sr whole rock-mineral isochron

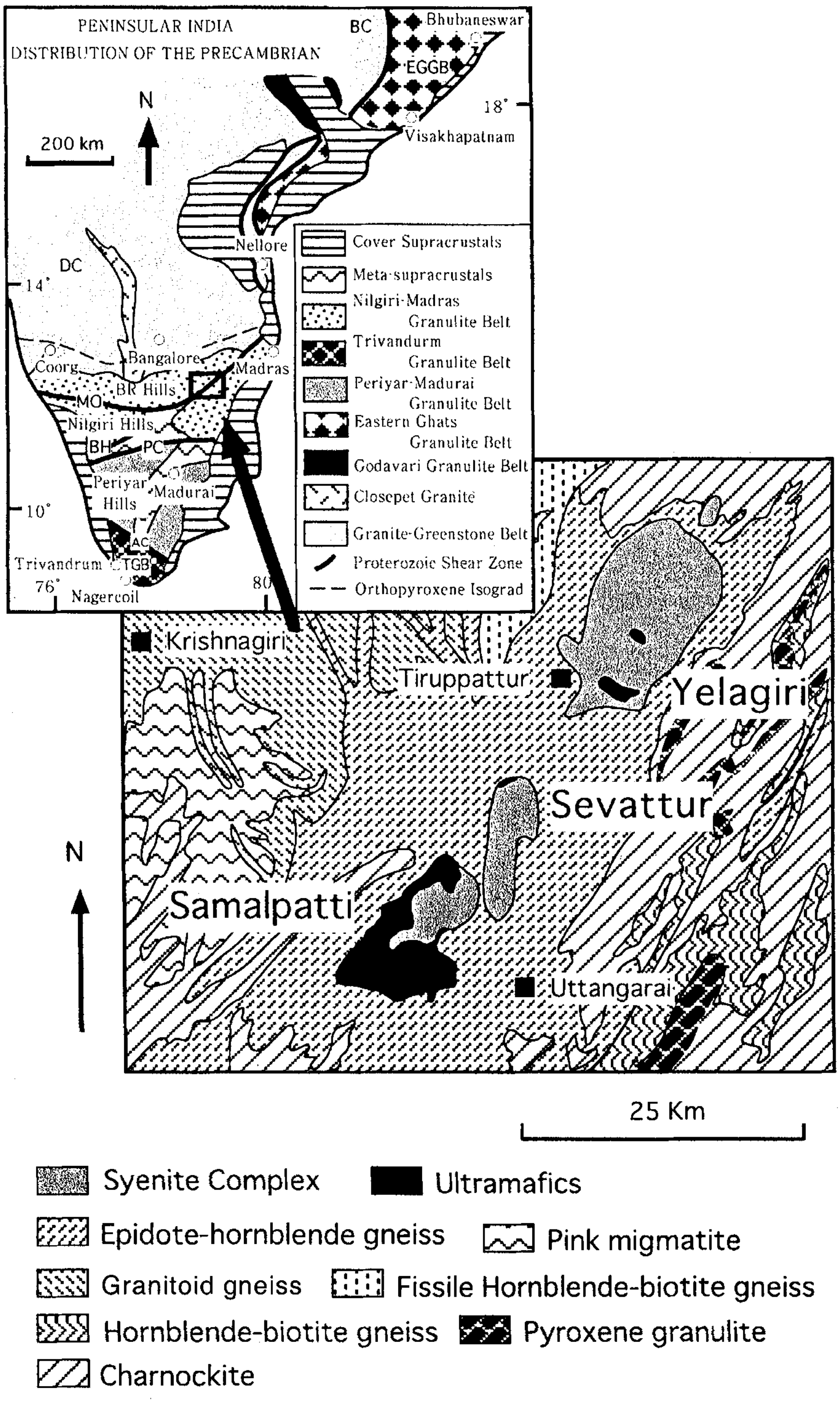

Fig. 1. Simplified geological map of northern Tamil Nadu area. The Yelagiri, Sevattur and Samalpatti plutons are emplaced in this region (modified from Geological Survey of India, 1995). Upper left shows the generalized geology of South India (modified from Yoshida, 1995).

ages of 771± 18 Ma and 773± 18 Ma for the Sevattur carbonatites and pyroxenites respectively (Kumar and Gopalan, 1991) and a whole rock lead/lead age of 801± 11 Ma for the Sevattur carbonatites (Schleicher et al., 1997). These age data of the plutons indicate late Proterozoic alkaline magmatic activity in the region. The available data pertain to the carbonatites and few pyroxenites and the isotopic data on syenites are totally lacking. Further, precise age determination of the Yelagiri pluton has not been presented.

The existence of alkali metal and LREE enriched subcontinental upper mantle (hereinafter "enriched mantle") are recognized under this region (e.g., Kumar and Gopalan, 1991; Wickham et al., 1994; Reddy et al., 1995; Kumar et al., 1998; Schleicher et al., 1998). However, Kumar et al. (1998) reported that the initial Sr isotope ratio of the Sevattur syenites is somewhat lower than that of the Sevattur carbonatites. They presumed that this isotopic gap reflected some differences in the source for these magmas. So far detailed Sr and Nd isotopic studies of the Yelagiri and Sevattur syenites have not been carried out. Therefore, petrogenesis and source characteristics of these syenites are not clearly elucidated. Comprehensive geochemical studies including Sr and Nd isotopes are desirable to solve this problem.

In this paper, we present whole-rock Rb-Sr isochron ages of the Yelagiri and Sevattur plutons, their Sr and Nd isotopic characteristics and whole rock geochemistry, so as to place constraints on their petrogenesis and location of their source regions.

Geological Setting and Petrography

The Yelagiri and Sevattur plutons (Fig. 1) intrude into the epidote-hornblende gneisses, which constitute the country rocks of the region. These gneisses are highly sheared and rarely contain relic patches of charnockite indicating that they are retrogressive in origin. The Yelagiri pluton is an elliptical body of about 20x12 km, elongated in NE-SW direction. It is almost entirely composed of syenite with pyroxenite and biotite pyroxenite forming elongated masses measuring up to 50m. Pyroxenite also occurs as xenolithic blocks with sharp contacts in the syenite. Although geological information on the Yelagiri pluton is not sufficient, almost all the constituent rocks of this pluton do not show strong deformation and metamorphism shown by the country rocks. Hence, this pluton is considered to keep the initial intrusive character.

The Sevattur pluton, located 10 km southwest of Yelagiri pluton, has an oval shape elongated in N-S direction and measures about 12 x 5 km. Syenite forms the major lithounit here and is rimmed on the north by carbonatite and subsequently by pyroxenite. The carbonatite body, which is about 3 km in length with a maximum width of 200 m in the central part, is mostly dolomitic carbonatite with dykelets of sövite and lesser ankeritic carbonatite. Pyroxenite is dominated by clinopyroxene with rare olivine grains and due to metasomatism consequent to the intrusion of carbonatite, has been transformed into phlogopite pyroxenite in the contact zone. Subsequent hydration of the phlogopite has resulted in the formation of vermiculite, which is being mined. Fenitization has affected the gneisses as well as the syenite. Pyroxenite also occurs as xenolithic blocks in syenite and carbonatite. The detailed mineralogy of the Sevattur carbonatite and associated rocks has been described by Viladkar and Subramanian (1995). There is no evidence that the Sevattur pluton suffered strong deformation and metamorphism. Hence, this pluton is also considered to keep the initial intrusive nature.

Syenites of both plutons exhibit similarity in petrography. They are medium to coarse grained typified by hypidiomorphic texture and occasionally are porphyritic with tabular K-feldspar. The constituent minerals are mainly K-feldspar (microcline or perthite), sodic plagioclase, clinopyroxene and occasional hornblende. Sphene, quartz, magnetite, apatite and zircon are the common accessory minerals. Due to variation in modal clinopyroxene, color index varies from leucocratic through mesocratic to melanocratic. The modal Q-A-P content indicates a range from syenite to quartz monzonite through monzonite in the narrow sense, according to the classification scheme of Streckeisen (1976). For lucid understanding, these rocks are described as syenite in this paper. However, two samples, which represent the most leucocratic part in the Sevattur syenite, are classified as adamellite, because of high modal quartz content.

Analytical Techniques

Whole rock major and trace elements of syenites were measured by X-ray fluorescence spectrometry (RIGAKU, RIX3000) in the Department of Geology, Niigata University, following the method described by Takahashi and Shuto (1997). FeO was determined by volumetric analysis.

Rb-Sr and Sm-Nd isotopic analysis of whole rocks was done at Niigata University on a Finnigan MAT262 mass spectrometer following the standard mass-spectrometric isotopic-dilution procedures (Kagami et al., 1987,1989; Miyazaki and Shuto, 1998). Total errors are less than 0.25

ng of Rb, 0.52 ng of Sr, 0.04 ng of Sm and 0.34 ng of Nd. Measured $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr$= 0.1194 and $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd$= 0.7219. The measured values were corrected using values of 0.710251 for the $^{87}Sr/^{86}Sr$ ratio of NBS-987 and 0.512106 for the $^{143}Nd/^{144}Nd$ ratio of JNdi-1 which is a new standard provided by the Geological Survey of Japan. The $^{143}Nd/^{144}Nd$ ratio of 0.512106 for the JNdi-1 corresponds to the $^{143}Nd/^{144}Nd$ ratio of 0.511851 for the La Jolla (Miyazaki and Shuto, 1998). The precision for $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ are 0.5% and 0.15% respectively. Isochron age was calculated by a computer program of Kawano (1994) using the equation of York (1966). We used the following CHUR values (=0 Ma) for calculation of initial εSr and ε Nd values : $^{87}Sr/^{86}Sr$= 0.7045, $^{87}Rb/^{86}Sr$= 0.0827, $\lambda\,^{87}Rb = 1.42 \times 10^{-11} y^{-1}$, $^{143}Nd/^{144}Nd$= 0.512638, $^{147}Sm/^{144}Nd$= 0.1966, $\lambda\,^{147}Sm = 6.54 \times 10^{-12} y^{-1}$.

C and O isotope ratios were analyzed at Shinshu University on a MAT250 mass spectrometer. The extraction of CO_2 from rock samples was performed after McCrea (1950) and Epstein et al. (1964).

Whole Rock Geochemistry

Major and trace elements

The results are listed in Table 1 and plotted on variation diagram shown in Fig. 2. SiO_2 contents vary from 53.56 to 60.79 wt. % in the Yelagiri syenites and vary from 51.13 to 59.25 wt. % in the Sevattur syenites. (Because of limited data, it is difficult to identify whether two high silica rock (adamellite) samples of the Sevattur pluton are differentiated from the Sevattur syenites. Therefore, two high silica rock samples of the Sevattur pluton are excluded from following descriptions of major and trace elements.)

Syenites of both plutons have similar contents of alkalis (K_2O+Na_2O ranging from 7.34 to 11.84 wt. % in Yelagiri and ranging from 7.77 to 11.70 wt. % in Sevattur), K_2O/Na_2O ratios (0.62-1.47 in Yelagiri and 0.78-1.55 in Sevattur) and agpaitic index ([(K+Na)/Al, atomic] ranging from 0.75 to 1.02 in Yelagiri and ranging from 0.69 to 0.98 in Sevattur). However, Fe_2O_3/FeO ratios of the Yelagiri syenites (1.42-2.60) are relatively higher than the ratios of the Sevattur syenites (1.07-1.76).

Table 1. Major and trace element compositions of Yelagiri and Sevattur syenites and high silica rocks.

	Yelagiri Syenite												
Sample No.	Ye-1	Ye-2	Ye-3	Ye-4	Ye-5	Ye-6	Ye-7	Ye-8	Ye-9	Ye-10	Ye-11	Ye-12	Ye-13
Major elements (wt%):													
SiO_2	60.73	56.06	56.82	60.31	60.71	60.79	60.34	59.72	57.41	57.24	56.05	60.76	53.56
TiO_2	0.50	0.71	0.56	0.51	0.48	0.50	0.45	0.49	0.66	0.58	0.58	0.47	1.13
Al_2O_3	17.67	16.22	16.95	17.40	17.57	16.43	17.11	17.25	16.79	16.69	16.72	16.62	14.25
Fe_2O_3	3.27	4.61	4.13	3.40	3.28	3.20	3.09	4.27	4.36	3.84	4.26	3.28	6.59
FeO	1.44	2.82	2.58	1.41	1.33	1.83	1.49	1.64	2.07	2.52	2.66	1.62	4.63
MnO	0.11	0.15	0.16	0.12	0.11	0.11	0.13	0.12	0.15	0.14	0.15	0.12	0.26
MgO	1.03	2.36	2.03	1.09	1.00	1.38	1.33	1.56	1.88	1.93	1.99	1.37	3.15
CaO	2.98	4.59	4.43	3.03	2.99	3.88	3.38	4.13	4.65	4.85	5.26	3.95	7.12
Na_2O	5.11	4.36	5.33	4.97	5.17	4.46	5.32	5.87	4.28	4.33	4.35	4.80	4.54
K_2O	6.62	5.42	4.69	6.87	6.54	5.47	6.08	4.31	6.28	6.20	5.97	5.18	2.80
P_2O_5	0.20	0.49	0.37	0.21	0.20	0.26	0.24	0.25	0.45	0.44	0.45	0.25	0.55
L.O.I.	0.29	0.57	0.58	0.31	0.41	0.38	0.35	0.34	0.44	0.34	0.40	0.46	0.77
Total	99.95	98.36	98.62	99.62	99.78	98.70	99.30	99.95	99.44	99.10	98.86	98.87	99.34
K_2O/Na_2O	1.29	1.24	0.88	1.38	1.27	1.23	1.14	0.73	1.47	1.43	1.37	1.08	0.62
Fe_2O_3/FeO	2.27	1.63	1.60	2.41	2.47	1.75	2.07	2.60	2.11	1.52	1.60	2.03	1.42
(Na+K)/Al	0.99	0.90	0.87	1.02	1.00	0.90	0.99	0.87	0.94	0.95	0.92	0.89	0.75
Trace elements (ppm):													
Ba	1602	1745	1578	1767	1563	1797	1753	1788	2764	2683	3044	1698	742
Cr	7	18	18	8	6	9	13	27	9	10	10	7	15
Nb	19	15	12	18	14	13	13	13	16	6	3	10	20
Ni	n.d.	3	6	n.d.	n.d.	3	3	6	3	1	1	2	6
Rb	167	139	118	169	162	173	130	97	151	144	114	116	47
Sr	1342	1372	1457	1370	1307	1384	1364	1516	1768	1685	1944	1333	1120
V	86	137	109	84	82	83	84	101	128	131	133	85	189
Y	27	25	23	27	23	24	24	25	36	19	19	22	48
Zr	293	236	235	298	279	200	257	215	214	129	80	178	389
Nd	-	57	48	56	49	-	52	-	70	43	42	-	109
Sm	-	9.7	7.5	9.3	8.4	-	8.0	-	13.4	8.0	8.1	-	18.8

L.O.I., Loss on ignition; n.d., not detected; -, not analyzed.

Table 1. Contd.

	Sevattur Syenite									High silica rocks	
Sample No.	Se-1	Se-2	Se-3	Se-4	Se-5	Se-6	Se-7	Se-8	Se-9	Se-h1	Se-h2
Major elements (wt%):											
SiO_2	51.27	59.25	51.13	56.17	56.39	52.57	52.28	52.77	54.08	70.88	71.01
TiO_2	1.13	0.63	1.07	0.80	0.75	1.15	1.21	1.10	0.87	0.14	0.14
Al_2O_3	16.85	17.85	16.28	17.26	17.26	15.97	16.80	15.88	16.69	15.36	14.93
Fe_2O_3	5.49	2.27	5.77	3.92	3.78	5.03	5.28	4.25	4.19	1.14	0.95
FeO	3.14	1.80	4.00	2.26	2.15	3.99	3.78	3.96	3.17	0.32	0.39
MnO	0.19	0.13	0.19	0.16	0.21	0.21	0.21	0.18	0.17	0.14	0.12
MgO	3.07	1.09	3.61	1.66	1.59	3.22	3.01	3.04	2.29	0.15	0.16
CaO	7.81	3.38	7.83	5.39	5.18	7.35	8.30	6.88	5.92	1.57	1.61
Na_2O	4.37	5.53	4.16	4.73	4.82	3.89	4.40	4.00	3.81	5.28	5.28
K_2O	4.06	6.17	3.61	5.63	5.32	4.36	3.41	5.07	5.90	4.10	4.01
P_2O_5	0.59	0.18	0.69	0.33	0.37	0.63	0.56	0.62	0.43	0.04	0.04
L.O.I.	0.57	0.62	0.62	0.75	0.67	0.46	0.67	0.57	0.52	0.21	0.25
Total	98.54	98.90	98.97	99.06	98.48	98.84	99.91	98.33	98.03	99.33	98.90
K_2O/Na_2O	0.93	1.12	0.87	1.19	1.10	1.12	0.78	1.27	1.55	0.78	0.76
Fe_2O_3/FeO	1.75	1.26	1.44	1.73	1.76	1.26	1.40	1.07	1.32	3.56	2.45
(Na+K)/Al	0.74	0.98	0.71	0.90	0.88	0.77	0.69	0.85	0.87	0.90	0.92
Trace elements (ppm):											
Ba	3055	1733	2765	2102	2694	3624	2982	2742	5014	1515	1456
Cr	18	10	18	9	5	11	21	14	18	3	3
Nb	24	39	7	17	21	24	29	26	22	47	45
Ni	5	5	8	4	1	5	7	6	6	n.d.	n.d.
Rb	76	207	74	139	133	117	57	89	109	107	103
Sr	2323	976	1958	1400	1346	2064	2321	1971	2291	565	560
V	201	83	221	136	133	229	205	201	164	16	11
Y	28	25	19	21	28	25	33	26	24	13	13
Zr	145	272	101	184	112	136	143	142	136	133	143
Nd	55	41	43	35	45	48	64	51	47	14	14
Sm	10.1	6.8	7.8	6.1	7.9	8.4	11.8	9.4	8.5	2.2	2.1

L.O.I., Loss on ignition; n.d., not detected.

Major elements of both syenites show similar behaviours, when they are plotted against SiO_2 (Fig. 2a). TiO_2, Fe_2O_3, FeO, MnO, MgO, CaO and P_2O_5 contents of syenites of both plutons show a decrease with increase in SiO_2, whereas Al_2O_3, Na_2O and K_2O contents of both plutons show an increase with increase in SiO_2. These major elements against SiO_2 trends are generally fairly smooth, implying that the main process of magmatic evolution may be crystal fractionation.

Although the major element characteristics of the Yelagiri and Sevattur syenites are similar, non-overlapped trends are identified in several major elements (Fig. 2a). Fe_2O_3, FeO, MgO and P_2O_5 trends of the Yelagiri syenites are higher than those of the Sevattur syenites, whereas Al_2O_3 and K_2O trends of the Yelagiri syenites are lower than those of the Sevattur syenites. However, TiO_2, MnO, CaO and Na_2O trends of the Yelagiri and Sevattur syenites overlap each other.

In trace elements, scattered data points make difficult to identify variation trends of some trace elements. However, the general behaviour of some trace elements are identified in Fig.2b. In the Sevattur syenites, Ba, Sr, V, Cr, Ni, Sm and Nd generally behave as compatible elements, whereas Rb and Zr behave as incompatible elements. Y is stable and Nb is scattered. In the Yelagiri syenites, V and Rb behave as compatible and incompatible elements, which are similar to the Sevattur syenites, whereas Cr, Nb, Ni, Y, Zr, Sm and Nd have large dispersion. Ba and Sr (excluding Ye-13) generally behave as compatible elements. Several trace element variations support the inferences drawn from the major elemental variations.

The general coherence of Cr and MgO for the Yelagiri and Sevattur syenites (Fig. 3a) indicates pyroxene and hornblende fractionation in syenites. However, the distributions of Ni against MgO show poor coherence, because of low Ni concentrations. TiO_2 and V are positively correlated in the Yelagiri and Sevattur syenites (Fig. 3b). These trends mainly reflect the amount of accessory Fe-Ti oxide and sphene, although hornblende must also be Ti carrier in both syenites. A plot of Sr against CaO shows a linear co-variation for the Yelagiri syenites (excluding Ye-13) and the Sevattur syenites (Fig. 3c). This co-variation implies that Sr substituted Ca possibly in plagioclase and hornblende by admittance. A plot of Ba against Sr also shows a linear co-variation implying that some amount

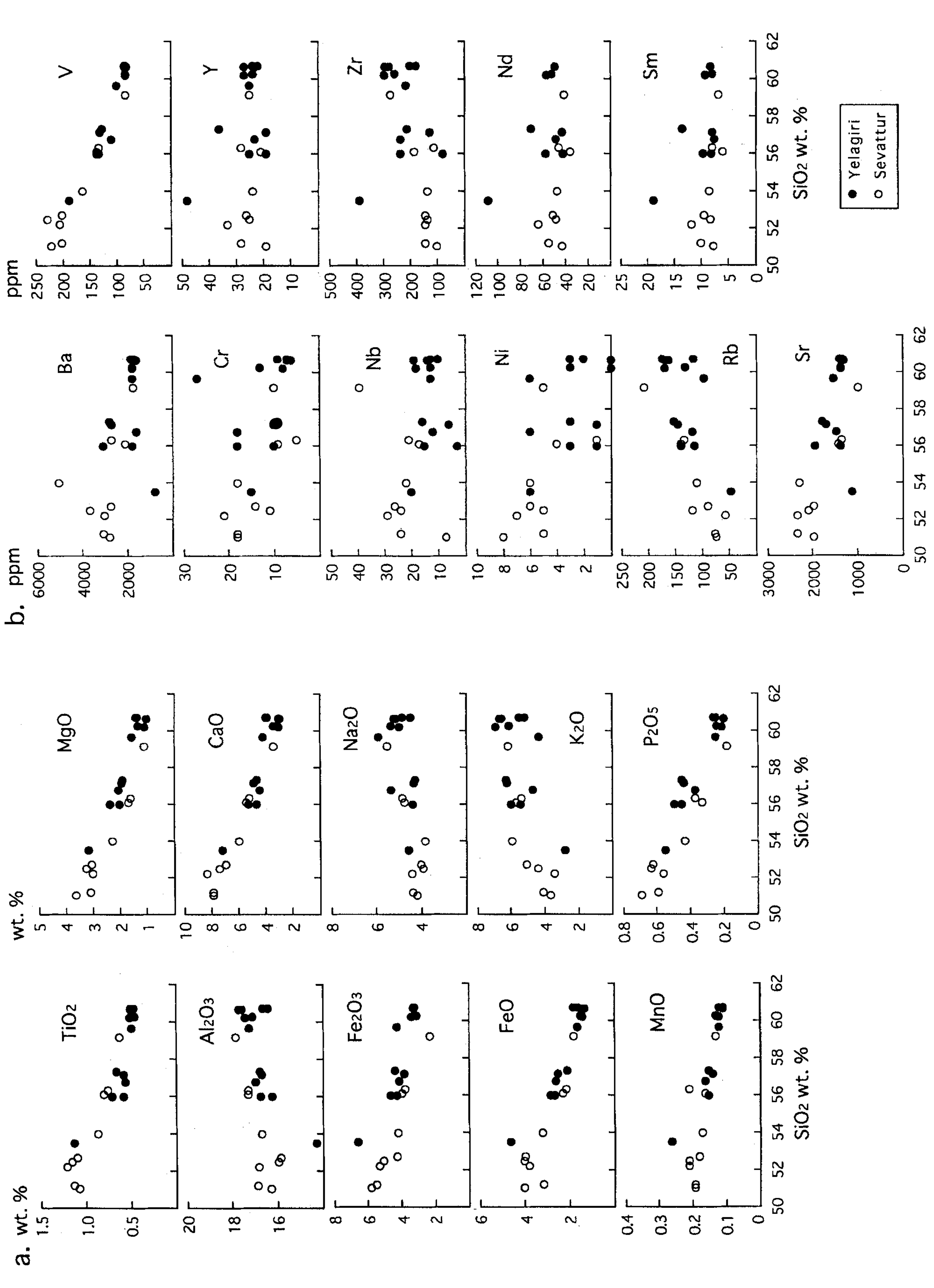

Fig. 2. a. SiO_2 vs. major element variation diagrams of Yelagiri and Sevattur syenites. b. SiO_2 vs. trace element variation diagrams of Yelagiri and Sevattur syenites.

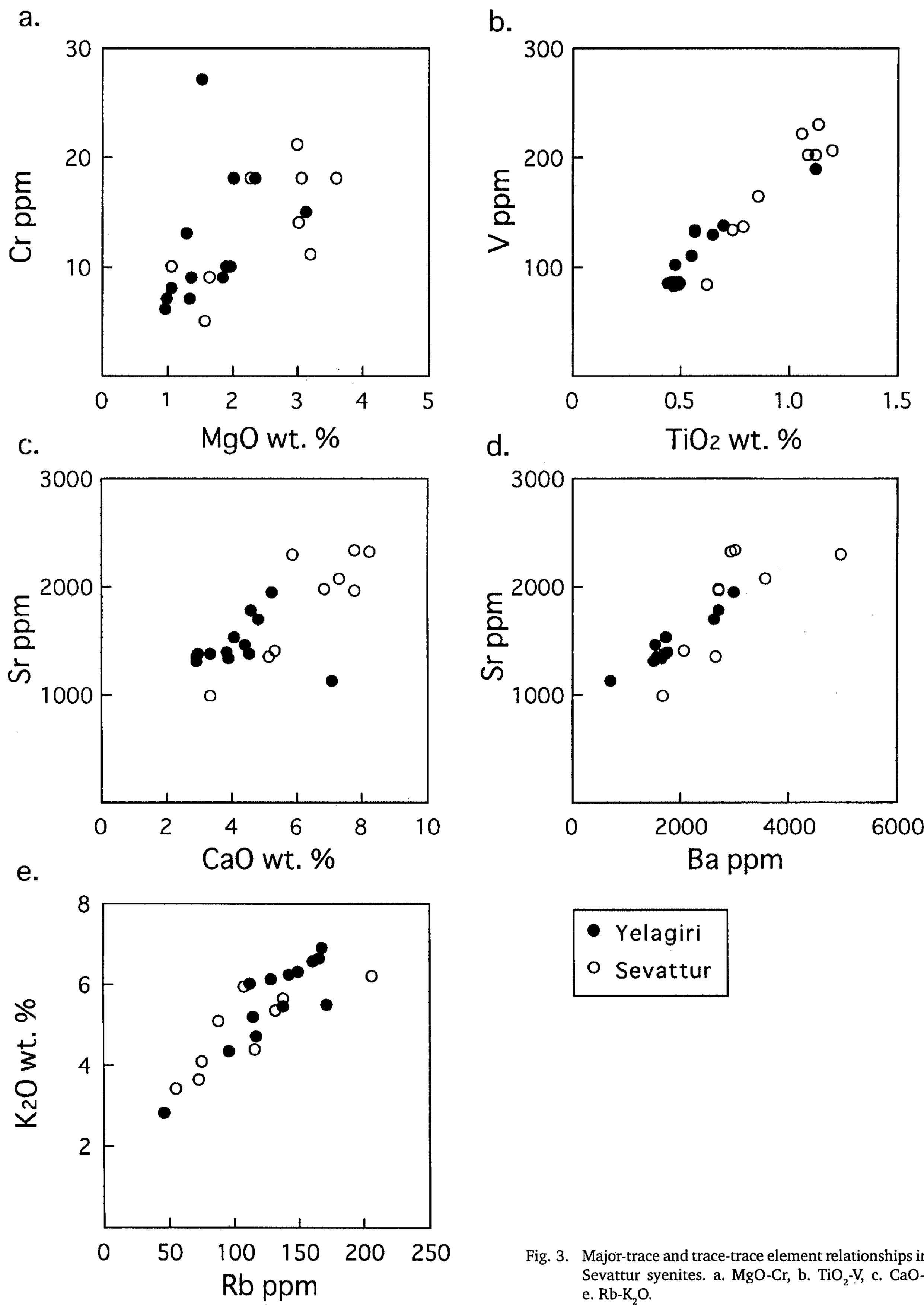

Fig. 3. Major-trace and trace-trace element relationships in Yelagiri and Sevattur syenites. a. MgO-Cr, b. TiO_2-V, c. CaO-Sr, d. Ba-Sr, e. Rb-K_2O.

of Sr may be occupying the sites of Ba in the feldspars (Fig. 3d). Poor positive correlation of K_2O and Ba indicates that Ba may be mainly controlling plagioclase fractionation. The conspicuous geochemical coherence between Rb and K_2O is depicted in the Yelagiri and Sevattur syenites (Fig. 3e), which are most dependent on K-feldspar amounts. However, the K/Rb ratios of the Yelagiri and Sevattur syenites generally decrease with increasing differentiation, implying the role of hornblende fractionation. Apatite, zircon and sphene are generally known to strongly concentrate Sm and Nd. In the Yelagiri syenites, sphene and zircon are anticipated to be the major carriers of these REE, because of generally positive correlations of REE-TiO_2 and REE-Zr. Meanwhile in the Sevattur syenite, sphene and apatite are anticipated as major carriers of these REE, because of generally positive correlation of REE-TiO_2 and REE-P_2O_5.

From major and trace element characteristics described above, the Yelagiri and Sevattur syenites may show magmatic evolution, which are mainly controlled by fractional crystallization. Different characteristics of major and trace elements may reflect the somewhat different chemical and physical conditions between the Yelagiri and Sevattur syenites. However, wide dispersions shown in many trace elements of the Yelagiri syenites may indicate that slightly open system behaviours influenced the Yelagiri syenites.

The notable feature of the Yelagiri and Sevattur syenites is their high concentrations of Ba (742-3044 ppm in Yelagiri; 1456-5014 in Sevattur) and Sr (1120-1944 in Yelagiri; 560-2323 ppm in Sevattur). Although the concentrations of these elements are mainly controlled by plagioclase fractionation, this feature may reflect their source characteristics. The Yelagiri and Sevattur syenites have high Sr/Y ratios (23-101 in Yelagiri, 39-101 in Sevattur), which may be attributable to garnet in their source region. Such high concentrations of Ba and Sr and high Sr/Y ratios are reported from other syenite and alkaline granites in South India. Syenite in Pakkanadu pluton (Sukumaran and Ramanathan, 1996), syenite in Salem alkaline and ultramafic complex (Reddy et al., 1995) and several alkaline granites from Kerala (Santosh

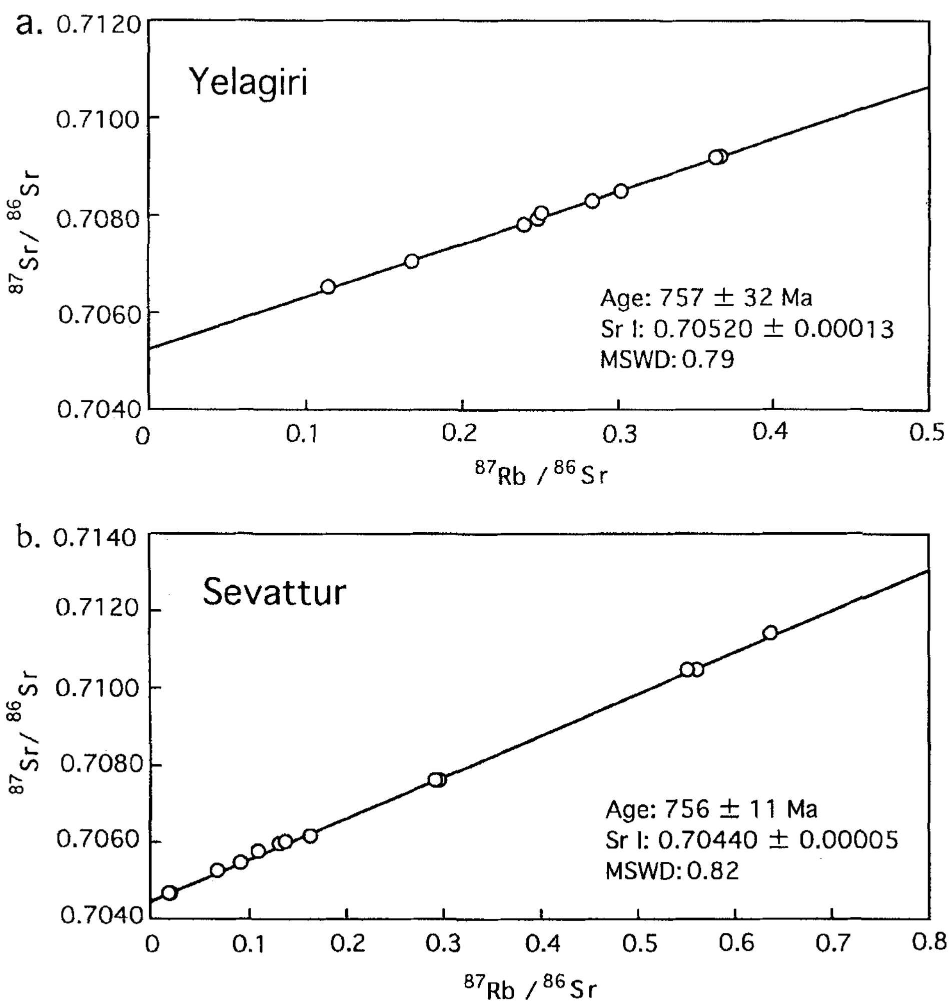

Fig. 4. a. Whole rock Rb-Sr isochron diagram of Yelagiri syenites. b. Whole rock Rb-Sr isochron diagram of Sevattur syenites including pyroxenites and high silica rocks.

Table 2. Rb, Sr, Sm and Nd concentrations and Sr and Nd isotopic data of Yelagiri and Sevattur plutons and their host gneisses.

Sample No.	Rb(ppm)	Sr(ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Sr I (757Ma)	εSr	Sm(ppm)	Nd(ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	Nd I (757Ma)	εNd
Yelagiri syenite												
Ye-2	152	1440	0.3045	0.708452(06)	0.705161	22.1	9.65	56.7	0.1028	0.511681(14)	0.511171	-9.6
Ye-3	124	1480	0.2424	0.707768(06)	0.705148	21.9	7.52	48.0	0.0948	0.511686(14)	0.511215	-8.7
Ye-4	181	1422	0.3677	0.709185(10)	0.705211	22.8	9.32	56.0	0.1006	0.511701(14)	0.511202	-9.0
Ye-5	172	1357	0.3666	0.709189(07)	0.705227	23.0	8.43	49.4	0.1032	0.511707(18)	0.511195	-9.1
Ye-7	140	1419	0.2851	0.708253(07)	0.705172	22.3	8.03	52.4	0.0926	0.511704(14)	0.511244	-8.2
Ye-9	163	1885	0.2503	0.707946(06)	0.705241	23.2	13.4	69.9	0.1162	0.511722(12)	0.511145	-10.1
Ye-10	156	1791	0.2525	0.708004(07)	0.705275	23.7	8.02	42.6	0.1139	0.511682(12)	0.511117	-10.7
Ye-11	123	2083	0.1703	0.707039(06)	0.705198	22.6	8.09	42.3	0.1156	0.511697(12)	0.511123	-10.5
Ye-13	47.4	1169	0.1174	0.706487(13)	0.705218	22.9	18.8	109	0.1045	0.511601(09)	0.511082	-11.3
Sevattur syenite												
Se-1	80.0	2447	0.0946	0.705416(12)	0.704394	11.2	10.1	54.9	0.1109	0.511732(14)	0.511181	-9.4
Se-2	219	989	0.6402	0.711374(12)	0.704455	12.1	6.75	41.1	0.0992	0.511663(14)	0.511171	-9.6
Se-3	81.9	2091	0.1134	0.705706(12)	0.704481	12.4	7.82	43.4	0.1090	0.511698(14)	0.511157	-9.9
Se-4	148	1434	0.2986	0.707578(10)	0.704351	10.6	6.12	34.8	0.1063	0.511708(14)	0.511181	-9.4
Se-5	142	1391	0.2943	0.707561(14)	0.704380	11.0	7.90	44.6	0.1070	0.511685(12)	0.511154	-9.9
Se-6	127	2209	0.1665	0.706112(10)	0.704313	10.0	8.44	47.8	0.1068	0.511686(14)	0.511156	-9.9
Se-7	60.1	2427	0.0717	0.705207(14)	0.704433	11.7	11.8	63.8	0.1119	0.511726(14)	0.511171	-9.6
Se-8	97.9	2091	0.1354	0.705946(14)	0.704483	12.5	9.38	50.9	0.1115	0.511721(10)	0.511168	-9.7
Se-9	119	2442	0.1406	0.705981(09)	0.704462	12.2	8.48	47.2	0.1087	0.511708(14)	0.511168	-9.7
Sevattur high silica rock												
Se-h1	109	558	0.5642	0.710450(11)	0.704353	10.6	2.21	14.3	0.0931	0.511694(14)	0.511232	-8.4
Se-h2	107	556	0.5552	0.710422(11)	0.704421	11.6	2.12	14.0	0.0913	0.511664(11)	0.511211	-8.8
Sevattur pyroxenite												
SePx-1	5.80	705	0.0238	0.704632(12)	0.704375	10.9	19.3	96.2	0.1211	0.511733(14)	0.511132	-10.4
SePx-2	7.15	986	0.0210	0.704622(11)	0.704395	11.2	20.9	111	0.1138	0.511719(11)	0.511154	-9.9
Sevattur carbonatite												
SeCa01A	0.08	7212	0.00003	0.705281(12)	0.705281	23.8	45.7	227	0.1217	0.511954(10)	0.511350	-6.1
SeCa04A	0.05	8292	0.00002	0.705192(13)	0.705192	22.5	50.6	232	0.1320	0.512017(13)	0.511362	-5.9
SeCa04B	0.05	8304	0.00002	0.705313(14)	0.705313	24.3	52.9	272	0.1176	0.511973(14)	0.511389	-5.3
SeCa04D	0.07	8173	0.00002	0.705251(11)	0.705251	23.4	51.3	265	0.1169	0.511905(12)	0.511325	-6.6
SeCa05A	0.24	8806	0.00008	0.705103(10)	0.705102	21.3	9.80	66.3	0.0894	0.511877(14)	0.511434	-4.5
SeCa05B	0.57	8779	0.00019	0.705107(08)	0.705105	21.3	7.70	49.7	0.0937	0.511853(14)	0.511388	-5.4
SeCa05C	0.53	8571	0.00018	0.705108(11)	0.705106	21.3	9.75	63.1	0.0935	0.511840(10)	0.511376	-5.6
SeCa05D	1.15	8353	0.00040	0.705085(09)	0.705081	21.0	11.4	71.7	0.0959	0.511879(14)	0.511403	-5.1
SeCa06A	0.39	9609	0.00012	0.705146(14)	0.705145	21.9	25.5	159	0.0972	0.511854(14)	0.511371	-5.7
Hornblende gneiss nearby Sevattur pluton												
2205B	39.6	427	0.2684	0.711280(12)	0.708379	67.8	6.66	56.4	0.0714	0.510527(14)	0.510173	-29.1
2304A	8.05	364	0.0640	0.704043(14)	0.703352	-3.6	4.66	24.5	0.1148	0.511299(14)	0.510729	-18.2

and Drury, 1988; Santosh et al., 1989) have high concentrations of Ba and Sr and high Sr/Y ratios (excluding syenites in Pakkanadu due to absence of Y data). These similar geochemical characteristics allow us to consider that the Yelagiri and Sevattur syenites also have sources similar to the syenites and alkaline granites, which are largely distributed in South India.

Rb-Sr isochron ages of Yelagiri and Sevattur plutons

Rb-Sr and Sm-Nd isotopic compositions and ratios of the analyzed samples are given in Table 2. Nine syenite samples from the Yelagiri pluton define an isochron corresponding to an age of 757± 32Ma and an initial ratio of 0.70520± 0.00013 (2σ) (Fig. 4a). Although it is considered that the Yelagiri syenites are influenced by slightly open system behaviours, there is no correlation between initial $^{87}Sr/^{86}Sr$ ratios and Sr concentrations. Therefore, the Rb-Sr isochron age of the Yelagiri syenites is expected to be rarely disturbed. Nine syenite samples from the Sevattur pluton give Rb-Sr isochron age of 755± 21Ma and an initial ratio of 0.70441± 0.00007 (2σ). Two pyroxenite samples and two high silica rock samples of the Sevattur pluton also harmonize this isochron. Thirteen whole rock samples including syenites, pyroxenites and high silica rocks give Rb-Sr isochron age of 756± 11Ma and an initial ratio of 0.70440± 0.00005 (2σ) (Fig. 4b). These similar data indicate that the pyroxenites and high silica rocks are co-genetic with the syenites.

Rb-Sr isochron ages of the Yelagiri and Sevattur plutons are in agreement with the Rb-Sr whole rock isochron age of 767± 8 Ma and initial Sr isotope ratio for the Sevattur syenites determined by Kumar et al. (1998). These ages are also within the analytical errors of the Rb-Sr whole rock-mineral isochron ages of 771± 18 Ma and 773± 18 Ma for the Sevattur carbonatites and pyroxenites determined by Kumar and Gopalan (1991). As the rocks of the Yelagiri and Sevattur plutons have no evidence of metamorphism, their Rb-Sr whole rock isochron age indicates the timing of magmatic emplacement of these

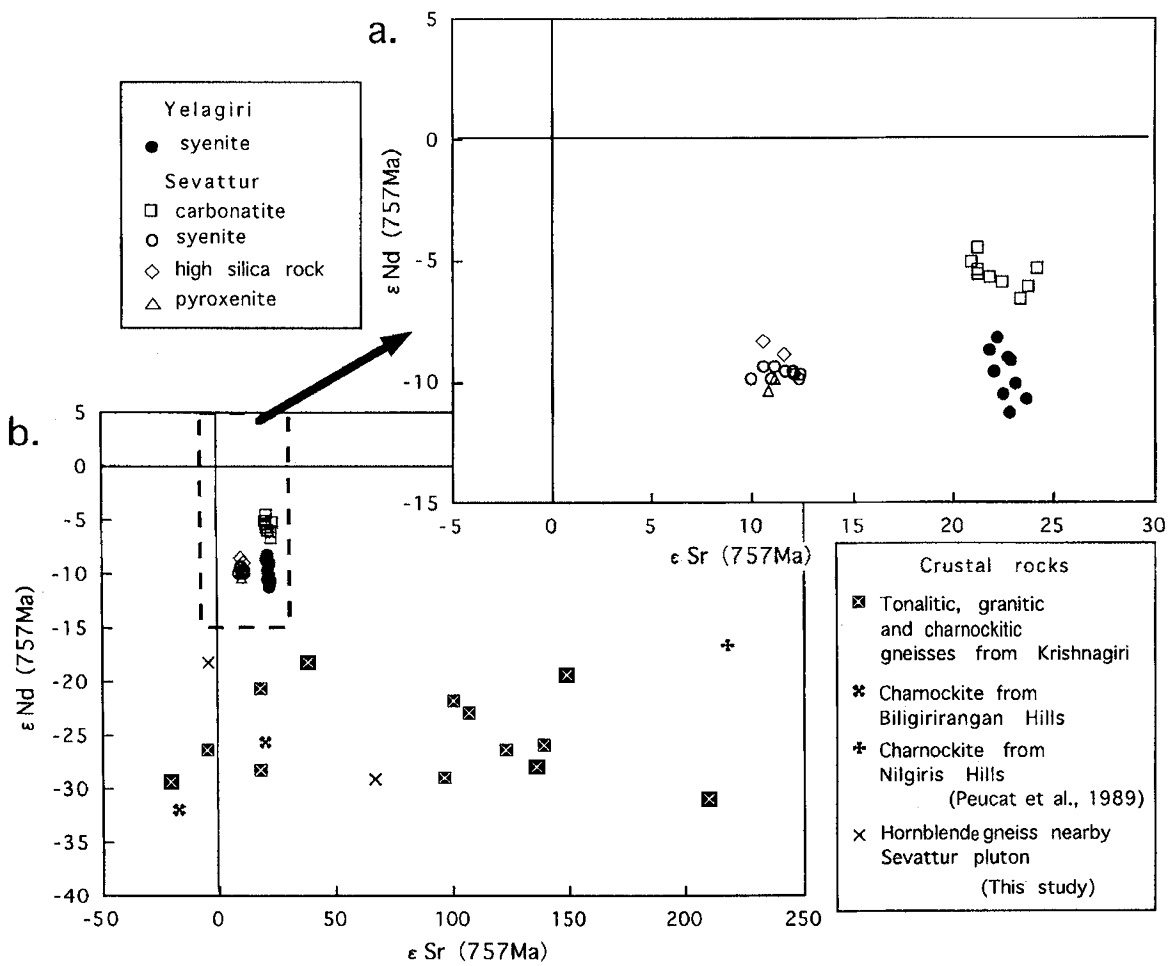

Fig. 5. a. εSr(T) vs. εNd(T) diagram for Sevattur and Yelagiri rocks. b. Comparison of εSr and εNd values between Sevattur and Yelagiri rocks and crustal rocks at 757 Ma.

plutons. The similarity in age and close spatial relationship between the Yelagiri and Sevattur plutons strongly suggest their close genetic relationship.

Samples of the Yelagiri and Sevattur plutons show restricted variation in their $^{147}Sm/^{144}Nd$ ratios. Therefore, Sm-Nd whole rock isochron age of these plutons could not be obtained.

Nd-Sr isotopes

Using whole rock Rb-Sr isochron age of Yelagiri syenites, initial Sr and Nd isotope ratios and σ values were calculated and presented in Table 2. For comparison we have also determined initial Sr and Nd isotope ratios and ε values of Sevattur carbonatites, pyroxenites, high silica rocks and syenites using the same age. The Yelagiri syenites show a range of ε Sr(T=757Ma) between 21.9 to 23.7 and of ε Nd(T=757Ma) between -11.3 to -8.2. They fall in the lower right-hand quadrant on ε Sr(T) vs. ε Nd(T) diagram (Fig. 5a). While Sevattur syenites exhibit a range of ε Nd(T) between -9.9 to -9.4 within the range of the Yelagiri syenites. The ε Sr(T) of the Sevattur syenites is lower, ranging between 10.0 to 12.5. Pyroxenites and high silica rocks of the Sevattur pluton have similar or closer Sr and Nd isotope characteristics to the Sevattur syenites. But, the carbonatites from the Sevattur show ε Sr(T) range between 21.0 to 24.3, as in the case of the Yelagiri syenites. However, ε Nd(T) range of the Sevattur carbonatites (ε Nd(T)= -6.6 to -4.5) is somewhat higher than the ranges of syenites of both plutons. The oxygen and carbon isotopic compositions of calcites and dolomites from the Sevattur carbonatite samples show very little variation, with average values of $\delta^{18}O$= +7.1‰ and $\delta^{13}C$= -5.1‰ from calcites and $\delta^{18}O$=+7.2‰ and $\delta^{13}C$= -4.8‰ from dolomites (Table 3, Fig. 6). All carbonatite samples analyzed plot within the field for 'primary igneous carbonatites' (Keller and Hoefs, 1995).

Table 3. C and O isotopic data of Sevattur carbonatites.

Sample No.	calcite $\delta^{13}C$ PDB (‰)	$\delta^{18}O$ SMOW (‰)	dolomite $\delta^{13}C$ PDB (‰)	$\delta^{18}O$ SMOW (‰)
SeCa01A	-5.2	7.6	-5.0	7.5
SeCa04A	-5.2	7.5	-5.3	6.9
SeCa04B	-5.1	6.8	-5.1	6.5
SeCa04D	-5.1	6.6	-5.1	6.6
SeCa05A			-4.6	7.8
SeCa05B			-4.5	7.7
SeCa05C			-4.7	7.4
SeCa05D			-4.3	7.7

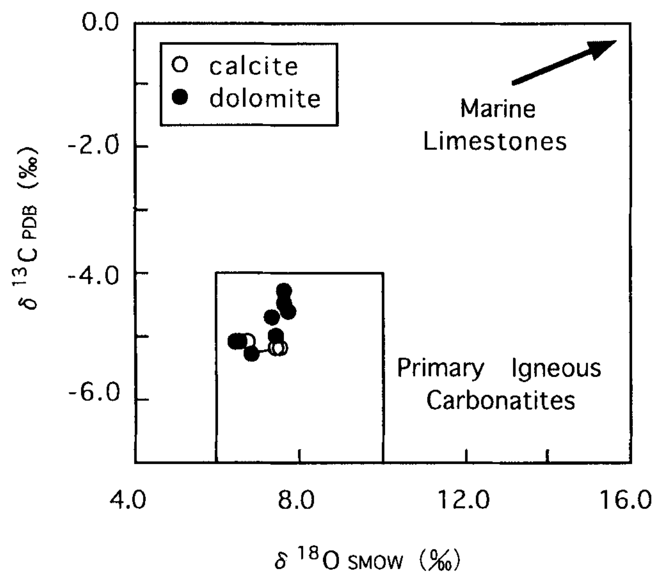

Fig. 6. Plot of $\delta^{13}C_{PDB}$ vs. $\delta^{18}O_{SMOW}$ for Sevattur carbonatites. Tie-line joins calcite-dolomite pairs from identical sample. Part of the primary igneous carbonatite field as defined by Keller and Hoefs (1995).

Discussion and Conclusion

The $\delta^{18}O$ and $\delta^{13}C$ data of the Sevattur carbonatites (Fig. 6) indicate that they originated from mantle-derived melts. Because of the very high concentrations of Sr and Nd in carbonatite magmas, their low melting temperatures and probable rapid transport through the crust, crustal contamination for these elements is minimum in comparison to most other mantle-derived magma types (Bell and Blenkinsop, 1989; Kumar et al., 1998). Thus the initial Sr and Nd isotope ratios for the Sevattur carbonatites are likely to be representative of their mantle source. They have high initial $^{87}Sr/^{86}Sr$ ratios and low initial $^{143}Nd/^{144}Nd$ ratios relative to the bulk earth and CHUR (Fig. 5a). Thus, these isotope ratios imply an alkali metal and LREE enriched mantle as the source. Several authors also described the existence of enriched subcontinental mantle source in this region (e.g., Kumar and Gopalan, 1991; Wickham et al., 1994; Reddy et al., 1995; Kumar et al., 1998; Schleicher et al., 1998).

However, syenites and pyroxenites of the Sevattur pluton show low initial εSr and εNd values compared to the values of carbonatites (Fig. 5a). The Yelagiri syenites also show low initial εNd values compared to the values of Sevattur carbonatites, even though initial εSr values are similar to the values of carbonatites. It is noticeable that silicate rocks of both plutons have low initial εNd values compared to the values of Sevattur carbonatites. These isotopic diversities between carbonatites and silicate rocks may be caused by differences in their source or different influences from other materials.

Isotopic differences of silicate rocks are also observed between the Yelagiri and Sevattur plutons. Their contemporary activity, close spatial relationship and generally similar petrographical and geochemical characteristics lead us to expect genetic relationship between the Yelagiri and Sevattur syenites. Moreover, common notable geochemical features such as high Ba and Sr concentrations and high Sr/Y ratios lead us to consider that the syenites of both plutons were derived from common or similar source. However, initial εSr values of silicate rocks are significantly different between the Yelagiri and Sevattur plutons (Fig. 5a).

The possible reasons for isotopic diversity of silicate rocks are:

A. The silicate magma for the two plutons were derived independently from isotopically different sources from carbonatites.
B. The silicate magmas for the two plutons were derived from a common or isotopically similar source to carbonatites then independently changed their isotopic characteristics due to crustal contamination.

To elucidate this problem, initial εSr and εNd values (calculated at 757 Ma) of granulite gneisses of neighbouring Krishnagiri area (Peucat et al., 1989) are compared with those of the Sevattur and Yelagiri plutons (Fig. 5b). These gneisses are tonalitic, granitic and charnockitic gneisses with paleopressures from 5 to 6 kb (Peucat et al., 1989). Two hornblende gneisses, which are the country rocks of the Sevattur and Yelagiri plutons, are also plotted on Fig. 5b. These crustal rocks have initial εSr (757 Ma) values from -20 to 211 and initial εNd (757 Ma) values from -31 to -18. The range of initial εSr values is very wide and includes the values for the Sevattur and Yelagiri plutons. On the other hand, the initial εNd values are low compared with the Yelagiri and Sevattur syenites. This fact suggests that the sources of these syenites are not crustal rocks distributed around the Yelagiri and Sevattur plutons.

More high-grade crustal rocks are believed to occur in the deeper part of the crust. These high-grade crustal rocks are supposed to be high pressure charnockites such as those exposed in the Nilgiri Hills, Shevaroy and Biligirirangan Hills and Harur Hills (Peucat et al., 1989). The highest pressures are recorded in the Shevaroy and Biligirirangan Hills (7.5-8 kb), and along the northern slope of the Nilgiri Hills (9kb) (Janardhan et al., 1982; Raith et al., 1983). These high-pressure charnockites have initial εSr (757Ma) values from -24 to 218. Although only three high-pressure charnockite data of Biligirirangan and Nilgiri Hills are available, their initial εNd (757Ma) values range from -32 to -17. These initial εSr and εNd values are similar to those of Krishnagiri gneisses (Fig. 5b). Therefore, these high-pressure charnockites are excluded from the candidates of the sources of the Yelagiri and Sevattur syenites.

However, Newton and Hansen (1986) argue that Archean crustal section in south India is only the upper half of a thickened crust and is not representative of all or most of the lower continental crust. They also insist that lowermost crust is dominantly mafic, which is not represented by the exposed Precambrian plutonic and granulite-facies complexes. Therefore, there is still possibility that crustal rocks of lower part have close or similar initial εSr and εNd values contributing to the source of the Yelagiri and Sevattur syenites.

The idea that carbonatite and associated alkaline-silicate rocks specially silica-undersaturated rocks are derived from common or isotopically similar mantle source, is expressed by many authors based on Sr and Nd isotope evidence. Simonetti and Bell (1994) studied the Chilwa Island carbonatite complex and expressed the relationship between carbonatites and silica-undersaturated rocks by liquid immiscibility. Kumar et al. (1998) revealed the similar initial $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios between syenites of the Pikkili pluton (consisting mainly of nepheline-syenite) and carbonatites and pyroxenites from the Hogenakal pluton. Taking their similarity in age and close spatial relationship into consideration, they suggested the genetic relationship of these plutons and the derivation from common mantle source.

On the other hand, silica-saturated or -oversaturated rocks are thought to have incorporated some crustal material. Foland et al. (1993) compared Sr and Nd isotope results of coexisting quartz-syenites and nepheline-syenites of Marangudzi complex in southwest Zimbabwe and Mt. Brome complex in southern Quebec. They demonstrated that quartz-syenites coexisting with nepheline syenites were generated from common silica-undersaturated magma by assimilation of granitic crust coupled with fractional crystallization. Simonetti and Bell (1994) expressed the possibility of lower-crustal effect on silica-saturated rocks of the Chilwa Island carbonatite complex. Bell (1998) expressed in his review that wide isotopic variation of silicate rocks associated with carbonatites requires the involvement of other mantle components and/or continental crust.

To elucidate influences of crustal materials during the formation of the Yelagiri and Sevattur syenites, relationships between initial $^{143}Nd/^{144}Nd$ ratio and SiO_2 are shown in Fig. 7. If AFC or binary mixing process involving mantle derived magma and crustal materials is effectively operated, the decreasing initial $^{143}Nd/^{144}Nd$ ratio with increasing SiO_2 is expected to be observed. However, the Yelagiri and Sevattur syenites do not show such trend supporting AFC or binary mixing process. The Sevattur syenites have relatively constant initial $^{143}Nd/^{144}Nd$ ratios, whereas the Yelagiri syenites show increasing initial $^{143}Nd/^{144}Nd$ ratio with increasing SiO_2. Other chemical parameters (e.g., Na_2O+K_2O, Zr, Nb) of the

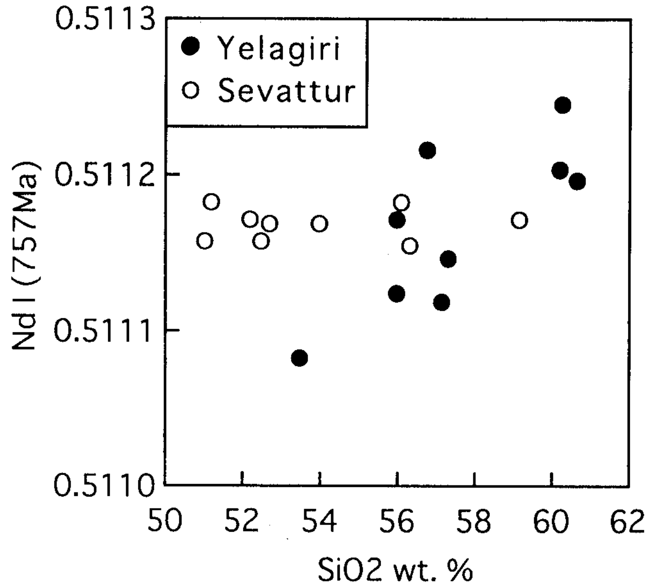

Fig. 7. Nd I (757Ma)-SiO_2 relationship in Yelagiri and Sevattur syenites.

Yelagiri syenites also show similar trends of $^{143}Nd/^{144}Nd$ ratio with increasing evolution. According to relationship between initial $^{143}Nd/^{144}Nd$ ratios and SiO_2 of the Yelagiri and Sevattur syenites, AFC or binary mixing is not a probable process in the Yelagiri and Sevattur syenites. Therefore, the Sr and Nd isotopic characteristics of the Yelagiri and Sevattur silicate rocks are not result of isotopic change caused by crustal materials after magma derivation, but generally reflect their source characteristics. At the present time, the meaning of "opposite" correlation indicated by the Yelagiri syenites is not clear. However, this unique trend is not observed between initial $^{87}Sr/^{86}Sr$ ratios and any major and trace element.

The Yelagiri and Sevattur plutons are spatially related to major lineaments like many alkaline plutons in South India (Rajesh and Santosh, 1996). Most of the lineaments in South India are deep-seated faults or shears and are rift-related in nature (Grady, 1971; Katz, 1978; Drury et al., 1984). The petrogenesis of silica saturated and over saturated alkaline plutons in Kerala are linked to deep crustal anatexis within continental plate induced by decompression melting (Santosh and Drury, 1988; Santosh et al., 1989). Crustal fractures act as conduits for heat and volatile transfer from the underlying mantle. The volatile influx brings with it mobile elements, especially alkalies (Santosh et al., 1989). Similar petrogenetic model is expected for the Yelagiri and Sevattur syenites, because of their tectonically similar emplacements. Several common trace element characteristics and the large volume of syenites compared to the exposed volume of mafic rocks also support this idea. The Sevattur carbonatite may represent such heat and volatile supplying magmas. Similar volatile related lower-crust melting model was proposed to explain the voluminous syenites and A-type granites of Transbaikalian Siberia (Litvinovsky and Podladchivkov, 1993) and of Northern Transvaal South Africa (Lubala et al., 1994).

According to the several views mentioned above, the silicate magma for the two plutons may be derived from sources isotopically different with those of carbonatites (possibility A is more probable). Several geochemical and tectonic features lead to the possibility that the silicate rocks of the two plutons were generated by lower-crust melting induced by volatile influx from carbonatite magma. In both plutons, fractional crystallization may act as main evolution process after magma generation. Although slight Nd isotope modification is observed in the Yelagiri syenites, Sr and Nd isotope characteristics of silicate rocks may generally show the isotope characteristics of their crustal sources. The different initial εSr values of silicate rocks between the Yelagiri and Sevattur plutons may indicate isotopic heterogeneity of their crustal sources. However, it is not clear whether volatile influx modified the initial Sr and Nd isotope ratios of source protolith or not. Therefore, it is difficult to clarify whether the source regions of silicate rocks are lower-crustal portions, which are deeper than any other crustal portion exposed in South India, or crustal segments isotopically metasomatized by volatile influx from carbonatite. Further Sr and Nd isotopic studies of alkaline plutons in South India and comprehensive isotopic comparison are desired to solve this problem.

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References

Bell, K. (1998) Radiogenic isotope constraints on relationships between carbonatites and associated silicate rocks - a brief review. J. Petrol., v. 39, pp. 1987-1996.

Bell, K. and Blenkinsop, J. (1989) Neodymium and strontium isotope geochemistry ofcarbonatites. In: Bell, K. (Ed.) Carbonatites-Genesis and Evolution. Unwin Hyman, London, pp. 278-300.

Bell, K. and Peterson, T. (1991) Nd and Sr isotope systematics of Shombole volcano, East Africa, and the links between nephelinites, phonolites, and carbonatites. Geology, v. 19, pp. 582-585.

Borodin, L.S., Gopal, V., Moralev, V.M. and Subramanian, V. (1971) Precambrian carbonatites of Tamil Nadu, South India. J. Geol. Soc. India, v. 12, pp. 101-112.

Drury, S. A., Harris, N. B. W., Holt, R. W., Reeves-Smith, G. J. and Wightman, R.T. (1984) Precambrian tectonics and crustal evolution in South India. J. Geol., v. 92, pp. 3-20.

Epstein, S., Graf, D. L. and Degens, E. T. (1964) Oxygen isotope studies on the origin of dolomites. In: Craig, H., Wasserburg, G. J. and Miller, S. L. (Eds.) Isotopic and Cosmic Chemistry. North-Holland, Amsterdam, pp. 169-180.

Foland, K. A., Landoll, J. D., Henderson, C. M. B. and Jiangfeng, C. (1993) Formation of cogenetic quartz and nepheline syenites. Geochim. Cosmochim. Acta, v. 57, pp. 697-704.

Geological Survey of India (1995) Geological and Mineral map of Tamil Nadu and Pondicherry, Scale 1: 500,000. Geological Survey of India.

Grady, J.C. (1971) Deep main faults in South India. J. Geol. Soc. India, v. 12, pp. 56-62.

Janardhan, A. S., Newton, R. C. and Hansen, E. C. (1982) The transformation of amphibolite facies gneiss to charnockite in southern Karnataka and northern Tamil Nadu, India. Contrib. Mineral. Petrol., v. 79, pp. 130-149.

Kagami, H., Iwata, M., Sano, S. and Honma, H. (1987) Sr and Nd isotopic compositions and Rb, Sr, Sm and Nd concentrations of standard samples. Tech. Rep. ISEI, Okayama Univ., Series B 4, pp. 165-177.

Kagami, H., Yokose, H. and Honma, H. (1989) $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios of GSJ rock reference samples; JB-1a, JA-1 and JG-1a. Geochem. J., v. 23, pp. 209-214.

Kawano, Y. (1994) Calculation program for isochron ages of Rb-Sr and Sm-Nd systems using personal computer. Joho Chishitsu (Geoinformatics), v. 5, pp. 13-19 (in Japanese with English abstract).

Katz, M. B. (1978) Tectonic evolution of the Archean granulite facies belt of Sri Lanka-South India. J. Geol. Soc. India, v. 19, pp. 185-205.

Keller, J. and Hoefs, J. (1995) Stable isotope characteristics of recent natrocarbonatites from Oldoinyo Lengai. In: Bell, K. and Keller, J. (Eds.) Carbonatite Volcanism: Oldoinyo Lengai and Petrogenesis of Natrocarbonatites. IAVCEL Proceeding of Volcanology. IAVCEL, pp. 113-123.

Krishnamurthy, P. (1977) On some geochemical aspects of Sevattur carbonatite complex, North Arcot district, Tamil Nadu. J. Geol. Soc. India, v. 18, pp. 265-274.

Kumar, A. and Gopalan, K. (1991) Precise Rb-Sr age and enriched mantle source of the Sevattur carbonatites, Tamil Nadu, South India. Curr. Sci., v. 60, pp. 653-655.

Kumar, A., Charan, S.N., Gopalan, K. and Macdougall, J.D. (1998) A long-lived enriched mantle source for two Proterozoic carbonatite complexes from Tamil Nadu, southern India. Geochim. Cosmochim. Acta, v. 62, pp. 515-523.

Litvinovsky, B. A. and Podladchikov, Y. Y. (1993) Crustal anatexis during the influx of mantle volatiles. Lithos, v. 30, pp. 93-107.

Lubala, R. T., Frick, C., Rogers, J. H. and Walraven, F. (1994) Petrogenesis of syenites and granites of the Schiel alkaline complex, Northern Transvaal, South Africa. J. Geol., v. 102, pp. 307-316.

McCrea, J. M. (1950) On the isotopic chemistry of carbonates and a paleotemperature scale. J. Chem. Phys., v. 18, pp. 849-857.

Miyazaki, T. and Shuto, K. (1998) Sr and Nd isotope ratios of twelve GSJ rock reference samples. Geochem. J., v. 32, pp. 345-350.

Miyazaki, T., Rajesh, H. M., Ram Mohan, V., Rajasekaran, K. C., Kalaiselvan, A., Rao, A. T. and Srinivasa Rao, K. (1999) Field study of alkaline plutons in Tamil Nadu and Andhra Pradesh, South India, 1997-1998. J. Geosci., Osaka City Univ., v. 42, pp.205-214.

Moralev, V.M., Voronovski, S.N. and Borodin, L.S. (1975) New findings about the age of carbonatites and syenites from Southern India. USSR Acad. Sci., v. 222, pp. 46-48.

Newton, R.C. and Hansen, E.C. (1986) The South India-Sri Lanka high-grade terrain as a possible deep-crust section. In: Dawson, J.B., Carswell, D.A., Hall, J. and Wedepohl, K.H. (Eds.) The Nature of the Lower Continental Crust. Geological Society Spe. Publ. No. 24, London: Blackwell, pp. 297-307.

Peucat, J.J., Vidal, P., Bernard-Griffiths, J. and Condie, K.C. (1989) Sr, Nd and Pb isotopic systematics in the Archean low- to high-grade transition zone of southern India: syn-accretion versus post-accretion granulites. J. Geol., v. 97, pp. 537-550.

Raith, M., Raase, P. and Ackermand, D. (1983) Regional geothermobarometry in the granulite facies terrane of south India. Royal Soc. (Edinburgh) Earth Sci. Trans., v. 73, pp. 221-244.

Rajesh, H. M. and Santosh, M. (1996) Alkaline magmatism in Peninsular India. In: Santosh, M and Yoshida M. (Eds.) The Archaean and Proterozoic terrains in Southern India within East Gondwana. Gondwana Res. Group Mem. No.3, Field Sci. Publ., Osaka, pp. 91-115.

Reddy, B.M., Janardhan, A.S. and Peucat, J.J. (1995) Geochemistry, age and origin of alkaline and ultramafic rocks of Salem, Tamil Nadu, South India. J. Geol. Soc. India, v. 45, pp. 251-262.

Santosh, M. and Drury, S. A. (1988) Alkali granites with Pan-African affinities from Kerala, S. India. J. Geol., v. 96, pp. 616-626.

Santosh, M., Iyer, S. S., Vasconcellos, M. B. A. and Enzweiler, J. (1989) Late Precambrian alkaline plutons in southwest India: geochronologic and rare-earth element constraints on Pan-African magmatism. Lithos, v. 24, pp. 65-79.

Schleicher, H., Todt , W., Viladkar, S.G. and Schmidt, F. (1997) Pb/Pb age determinations on Newania and Sevattur carbonatites of India: evidence for multi-stage histories. Chem. Geol., v. 140, pp. 261-273.

Schleicher, H., Kramm, U., Pernicka, E., Schidlowski, M., Schmidt, F., Subramanian, V., Todt, W. and Viladkar, S.G. (1998) Enriched subcontinental upper mantle beneath southern India: evidence from Pb, Nd, Sr and C-O isotopic studies on Tamil Nadu carbonatites. J. Petrol., v. 39, pp. 1765-1785.

Simonetti, A. and Bell, K. (1994) Isotopic and geochemical investigation of the Chilwa island carbonatite complex, Malawi: evidence for a depleted mantle source region, liquid immiscibility, and open-system behaviour. J. Petrol., v. 35, pp. 1597-1621.

Streckeisen, A. (1976) To each plutonic rock its proper name. Earth-Sci. Rev., v. 12, pp. 1-33.

Subramanian, V., Viladkar, S.G. and Upendran, R. (1978) Carbonatite alkaline complex of Samalpatti, Dharampuri district, Tamil Nadu. J. Geol. Soc. India, v. 19, pp. 206-216.

Sukumaran, G. B. and Ramanathan, S. (1996) Fenitisation around Mulakkadu and Pakkanadu alkaline complex - Salem district, Tamil Nadu. Proc. of IX Conv. of Indian Geological Congress, v. 1996, pp. 169-175.

Takahashi, T. and Shuto, K. (1997) Major and trace element analysis of silicate rocks using X-ray fluorescence spectrometer RIX3000. The Rigaku-Denki J.,v. 28, pp. 25-37 (in Japanese).

Udas, G.R. and Krishnamurthy, P. (1970) Carbonatites of Sevattur and Jogipatti, Madras State, India. Proc. Indian National Sci. Acad., v. 36, pp. 331-343.

Viladkar, S.G. and Subramanian, V. (1995) Mineralogy and geochemistry of the carbonatites of the Sevattur and Samalpatti complexes, Tamil Nadu. J. Geol. Soc. India, v. 45, pp. 505-517.

Wickham, S.M., Janardhan, A.S. and Stern, R.J. (1994) Regional carbonate alteration of the crust by mantle-derived magmatic fluids, Tamil Nadu, South India. J. Geol., v. 102, pp. 379-398.

York, D. (1966) Least-square fitting of a straight line. Can. J. Phys., v. 44, pp. 1079-1086.

Yoshida, M. (1995) Assembly of East Gondwana during the Proterozoic and its rejuvenation during the Pan-African period. Mem. Geol. Soc. India, v. 34, pp. 25-45.