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RESEARCH ARTICLE

Petrochemistry and tectonic evolution of Munnar granite, Idukki district, Kerala

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Several post-tectonic granite bodies, ranging in age from 740±30 to 512±20 Ma, have been reported from the south-western margin of the South Indian shield. The present study of Munnar granite and the associated rocks has brought out two generations of granite—one, a post-tectonic undeformed non-foliated granite and the other a pre-tectonic regionally deformed, well-foliated gneissic granite. The gneissic granite, showing uniform granite chemistry and mineralogy, is suggested to have been formed by progressive deformation of an older granitoid intrusion. The gneissic granite was earlier considered as part of the migmatite country rock. Thus, two granite-forming events are identified, of which the older granite-event has not hitherto been recorded in the southwestern margin of the South Indian shield.

Acid igneous activity in the Precambrian terrain of Kerala is indicated by several granite bodies (Figure 1). All these granites, falling within the time span of 740±30 Ma, and 512±20 Ma[1-7] point to a Late Precambrian–Early Palaeozoic tectonomagmatic event. Among these granites, the Munnar granite, occurring in the high hills of the Western Ghats in the eastern part of Central Kerala (Figure 1), is the subject of the study.

Field relations and petrography

In the study area around Munnar, granite, gneissic granite, sheared gneiss, migmatite and calc-silicate rock are the chief rock types, traversed by minor quartz, pegmatite and aplite veins (Figure 2). The contacts of rocks are mostly not exposed due to thick vegetation and soil cover.

The general trend of migmatite and other rock units is WNW-ESE with dips of 35° to 65° towards north. Foliation trend shows local variations to WSW-ENE and occasionally to NNE-SSW. Local reversals of dip are also noticed (Figure 2). Megascopically, migmatite is a composite rock with alternating quartzo-feldspathic

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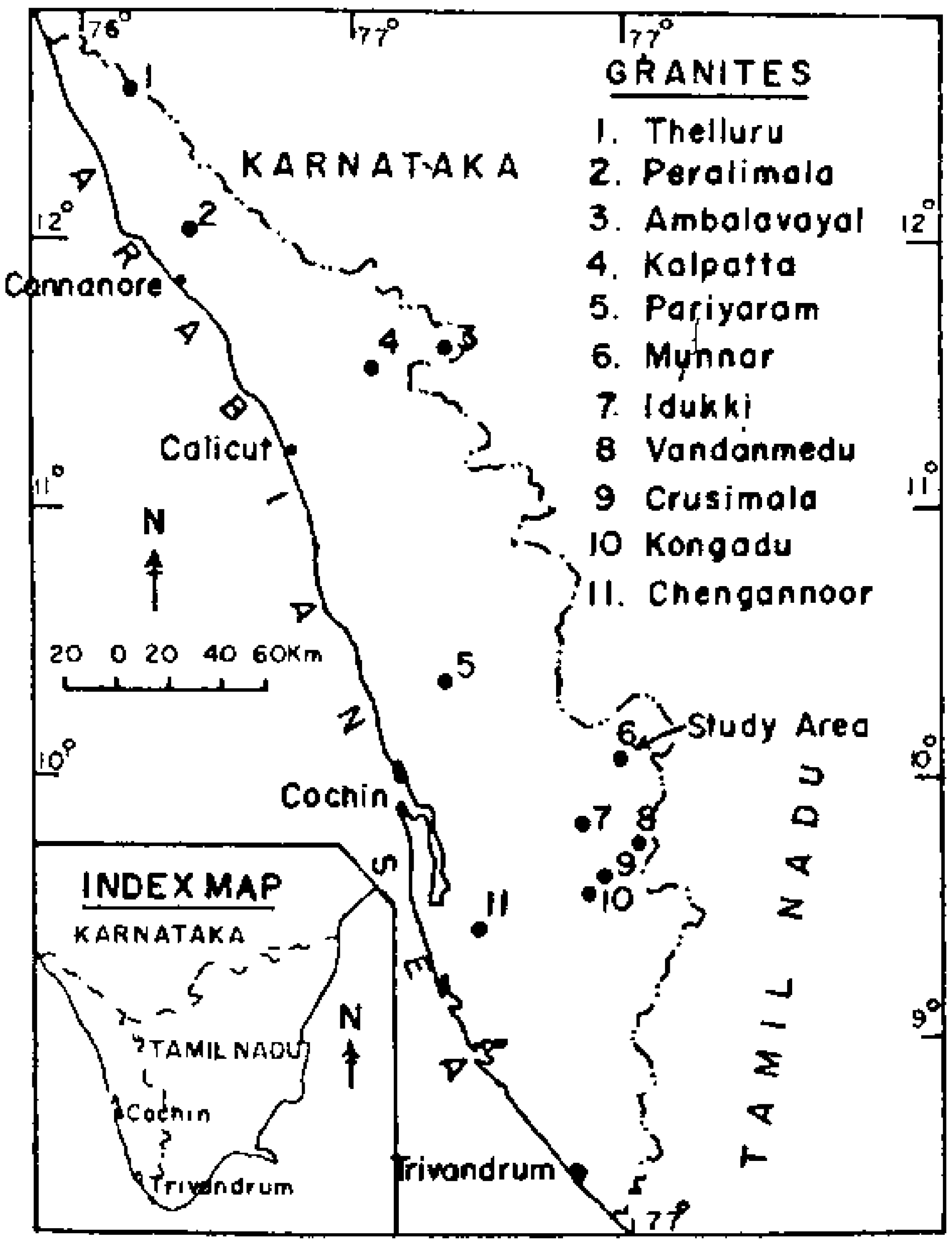

Figure 1. Granite locations in Kerala.

and mafic bands imparting pronounced colour banding with foliation parallel to banding.

Post-tectonic granite

The granite is exposed as a WNW-ESE-trending linear body with irregular outline, surrounded by gneissic granite, migmatite and calc-silicate rock (Figure 2). Tongue-like projections of granite are seen extending into the surrounding gneissic granite and migmatite. The contacts of granite with other rocks are sharp. The granite is pink, medium-grained and shows isotropic fabric. Though biotite and hornblende are the mafic minerals in both granite and gneissic granite, mafic minerals are less in the former.

The granite lacks preferred orientation of mineral grains. Alkali feldspar is the perthitic variety of microcline. Plagioclase feldspar is myrmekitized and is usually corroded by alkali feldspar. The anorthite content of plagioclase feldspar ranges from 7 to 18 with a mean value of 13. The modal composition of 30 samples, when plotted in the Q.A.P. triangular diagram[8], falls mostly in the granite field (Figure 3). The isotropic nature of the fabric and absence of evidences of strain-induced recrystallization are suggestive of post-tectonic emplacement.

Pre-tectonic granite

Exposure of gneissic granite is seen as a continuous stretch surrounding the younger granite (Figure 2). Gneissic granite is pale pink and medium-grained with foliation expressed by parallel planar alignment of flakes of biotite, prisms of hornblende, lenticular flattened quartz grains and occasionally aggregates of mica and feldspar. Unlike in migmatite and associated gneisses, where foliation is strengthened by colour

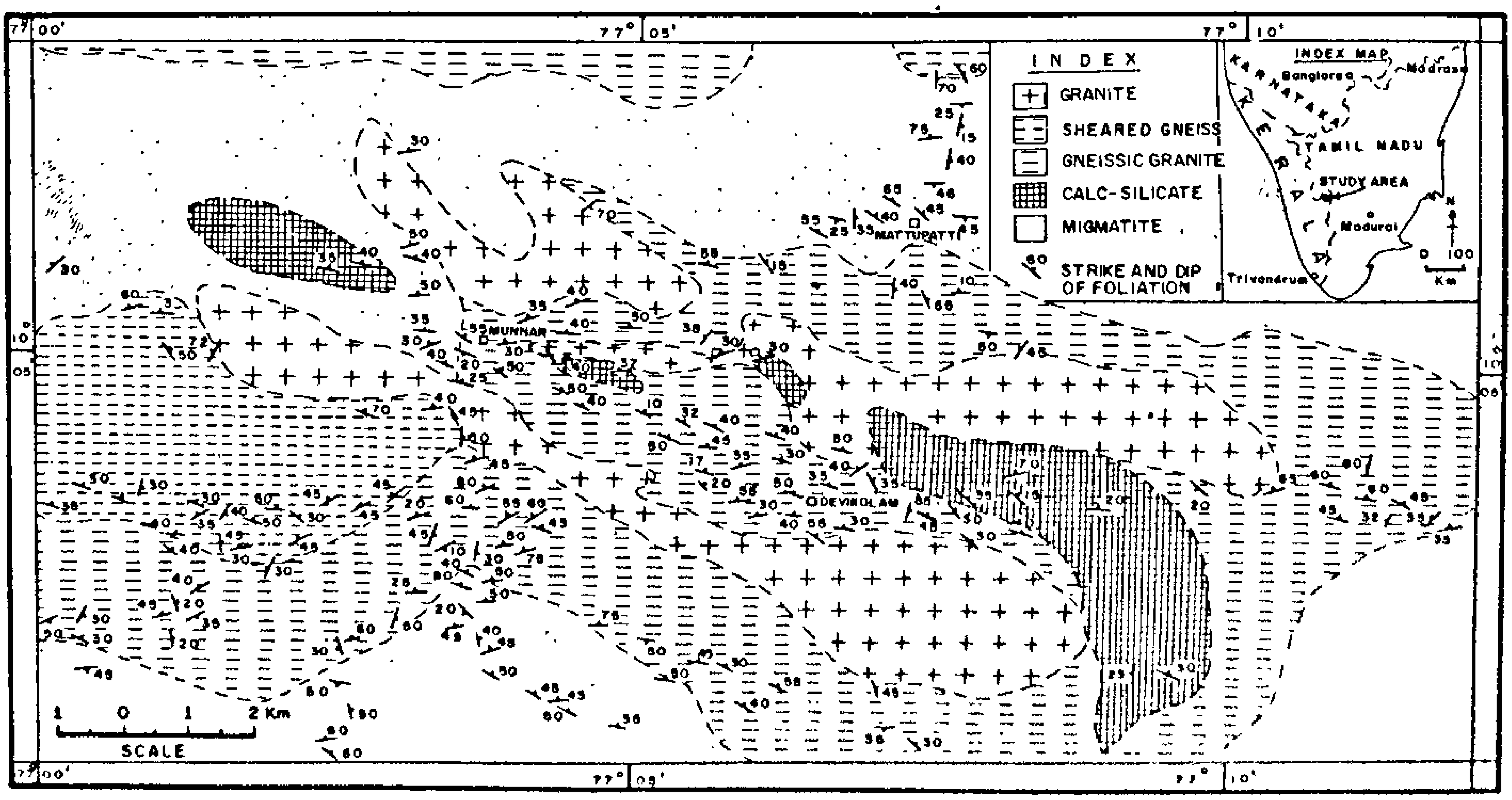

Figure 2. Geological map of Munnar area.

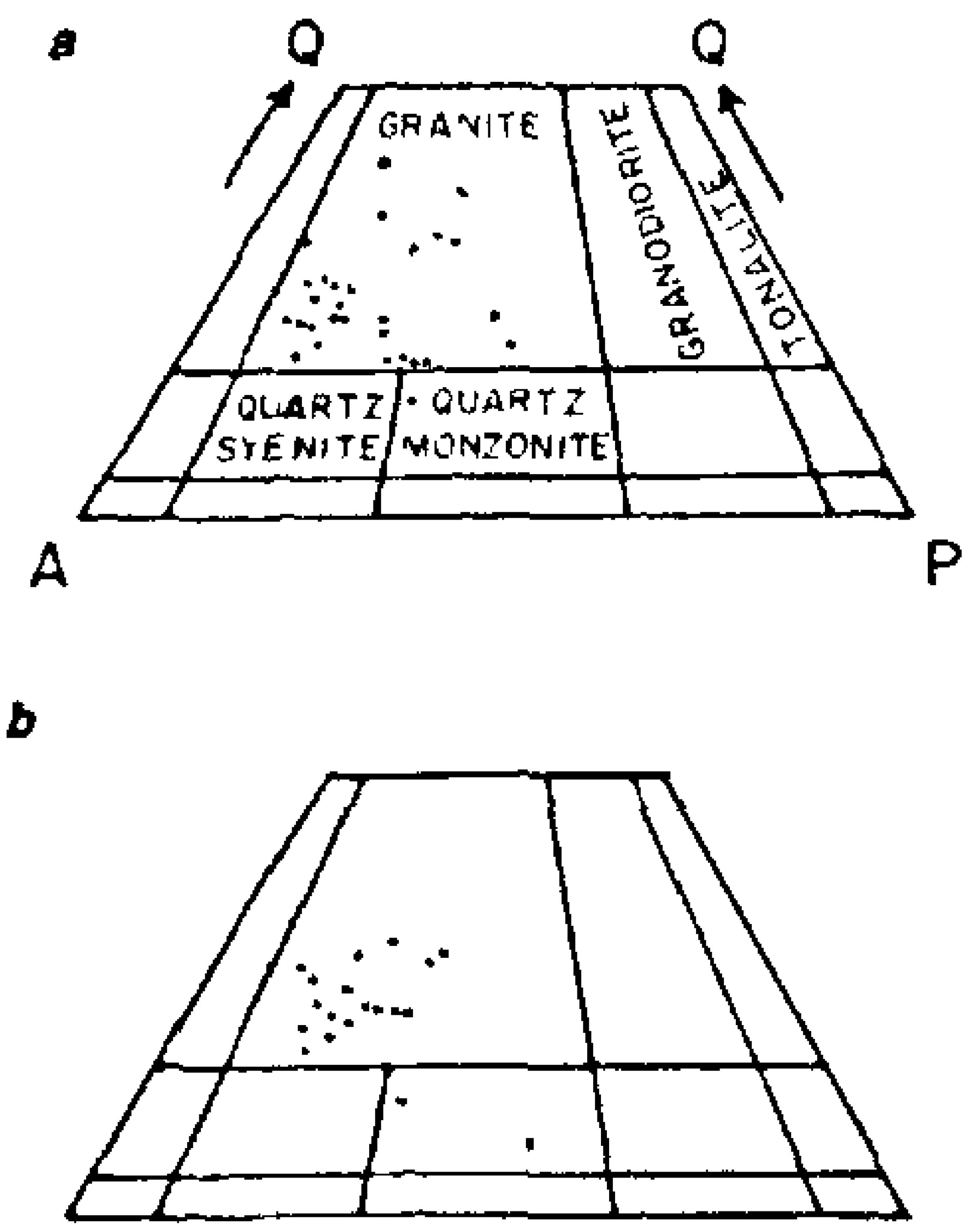

Figure 3. Q–A–P diagram. a, Granite; b, Gneissic granite.

banding, foliation in gneissic granite is after parallel alignment of mineral grains.

In medium to coarse-grained-gneissic granite, which is essentially a quartz-feldspar rock, predominating alkali feldspar is the perthitic variety of microcline. Plagioclase feldspar, often corroded by alkali-feldspar, shows intense sericitization. Anorthite content ranges from 17 to 27, the mean being 22.5. The modal composition of 19 samples, when plotted in the Q-A-P triangular diagram[8], falls in the granite field (Figure 3). The texture of the rock indicates its involvement in deformation. Higher anorthite content of plagioclase feldspar compared to post-tectonic granite is a feature commonly noted in syn-kinematic granites[9].

Sheared gneiss, exposed in the central part of the western portion of the area (Figure 2), is leucocratic, highly weathered and breaks along closely-spaced foliation planes. Micro-banding of alternate quartz-rich and feldspar-rich layers that have suffered intense kaolinization of feldspars imparts fissility resembling mylonitic foliation. This rock is the sheared equivalent of the gneissic granite.

In mineral composition the sheared gneiss is comparable with the gneissic granite. Quartz occurs mostly as ribbons alternating with layers of finer grained feldspar and quartz. Mortar texture, with large undulose quartz grain set in a fine-grained aggregate of quartz and feldspar, is noticed. Quartz grains often show marginal granulation and occasional crenulated margins. Alkali feldspar, due to its brittle nature, has suffered granulation along margins and is also altered to chlorite. Plagioclase has developed cracks. Biotite is often transformed into the fibrous variety. Ribbon type quartz, mortar texture and marginal granulation of mineral grains point to shearing. Sutured borders of quartz may be on account of partial recrystallization. Foliation due to shearing has been superposed on the pre-existing gneissic foliation.

Geochemistry

Analytical data on major, minor and trace elements of granite and gneissic granite are presented in Table 1. Pulverized (−200 mesh) and homogenized samples were analysed for major elements by the conventional wet chemical method, and trace elements, Na and K by AAS at the laboratories of Centre for Earth Science Studies, Thiruvananthapuram. Georeference standards Sy_2, Sy_3 and MRG_1 were used to check precision. The analytical uncertainties are, for SiO_2 about 1%, Al_2O_3 and FeO about 2% and for the rest of major elements about 5% of the amount present. Regarding trace elements, the analytical uncertainty for concentrations more than 100 ppm is better than 4% and for lesser concentrations about 10% of the amount present.

Behaviour of elements with respect to SiO_2 in terms of correlation co-efficient of the components is given in Table 2. The behaviour of major elements in granite and gneissic granite agrees with the expected pattern of

Table 1. Chemical composition

	Granite*	Gneissic granite**
SiO_2	70.91%	69.29%
Al_2O_3	14.11%	14 63%
FeO	01.12%	01.48%
Fe_2O_3	02.43%	02.50%
CaO	02.23%	03.14%
MgO	00.55%	00.77%
Na_2O	02.51%	02.35%
K_2O	04.63%	04.29%
TiO_2	00.33%	00.33%
MnO	00.04%	00.05%
P_2O_5	00.12%	00 09%
LOI	00.29%	00.29%
Moist.	00.14%	00 17%
Rb	108 ppm	109 ppm
Ba	746 ppm	864 ppm
Sr	202 ppm	196 ppm

*Average of 30 nos. of analyses; **Average of 19 nos. of analyses.

Table 2. Correlation coefficients—SiO_2 vs major elements

Element	Granite	Gneissic granite
Al_2O_3	−0.5624	−0.3242
FeO	−0.5587	−0.6466
Fe_2O_3	−0 4096	−0.3888
CaO	−0 6197	−0 6128
MgO	−0 5574	−0 6454
Na_2O	−0 1719	−0.2422
K_2O	+0.5315	+0.5071
TiO_2	−0 4679	−0 4258

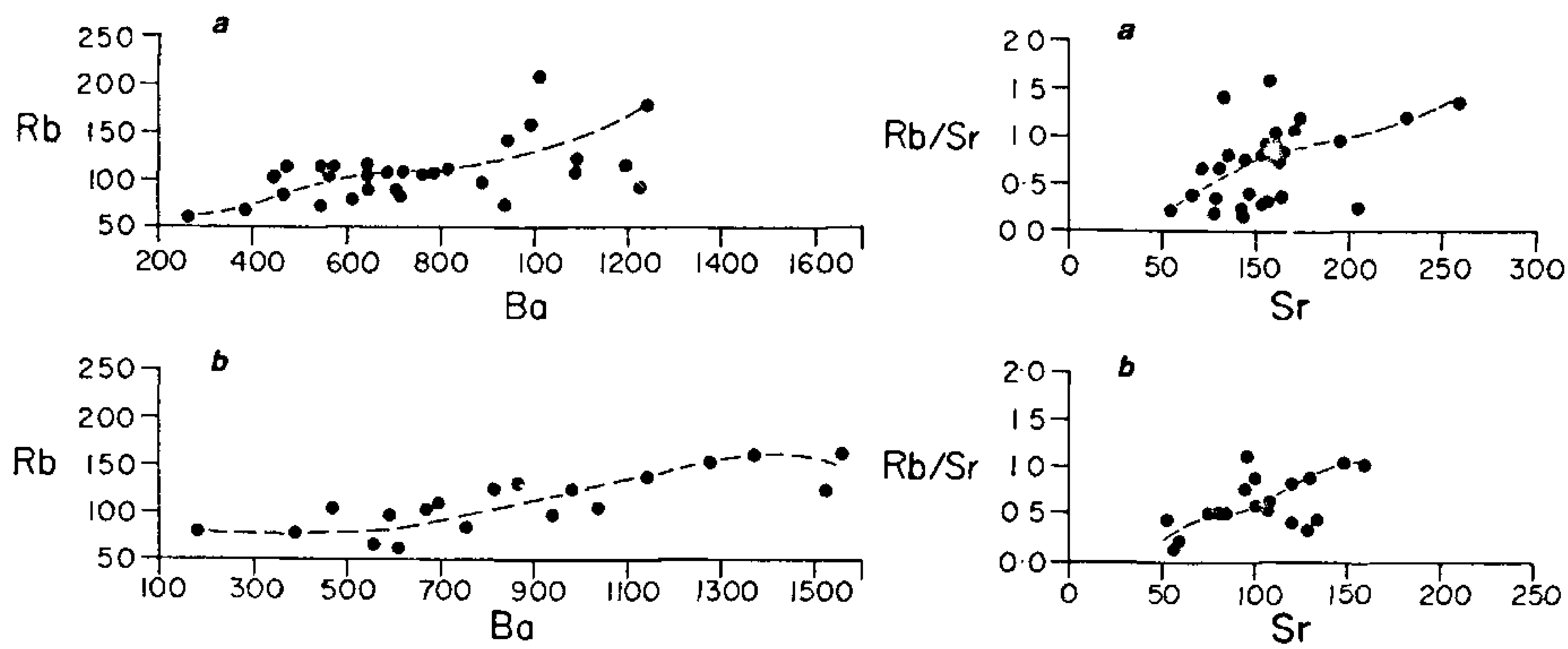

Figure 4. Rb vs Ba and Rb/Sr vs Sr plots. *a*, Granite; *b*, Gneissic granite.

magmatic differentiation. The K/Rb ratio ranges from 169 to 663 in granite and 218 to 477 in gneissic granite. There is positive correlation between K/Rb and potash with correlation coefficient of +0.62 for granite and +0.73 for gneissic granite which could be expected when the distribution of K and Rb is related to igneous fractionation[10]. Critical trace element variations such as colinear increase of Rb and Rb/Sr with Ba and Sr respectively (Figure 4) indicates crystal fractionation as an inherent process in the evolution of these rocks[11]. In order to assess the elemental distribution pattern in relation to petrogenetic trends, the analytical data were plotted in Na_2O+K_2O (A)–FeO^t (F)–MgO and K–Na–Ca diagram (Figure 5). Both granite and gneissic granite closely follow a calc-alkaline trend[12]. The plots fall close to and almost parallel to the A-F tie-line, indicating an alkali-enrichment trend. K-Na-Ca plots of granite and gneissic granite show pronounced enrichment of K relative to Na and Ca.

Plots of K_2O vs Na_2O for granite and gneissic granite fall mostly in the granite field[13] (Figure 6). One common feature is the narrow Na_2O range compared to that of K_2O. Calc-alkali batholiths and alkali granites are differentiated based on the proportion of SiO_2 and Log_{10} (K_2O/MgO)[14]. Almost all the plots of granite and gneissic granite fall in the field of alkali granite (Figure 7). In the Ab–An–Or normative ternary diagram[15] the plots fall in the granite-adamellite fields (Figure 8). In investigating Precambrian granites from the Indian shield Niggli values were used for distinguishing magmatic granites from replacement granites[16]. The magmatic granites not only fall within the igneous field on Niggli's al-alk-c/fm diagram, but also show systematic variation when al, c, and c/fm values are plotted against alk values. The Niggli

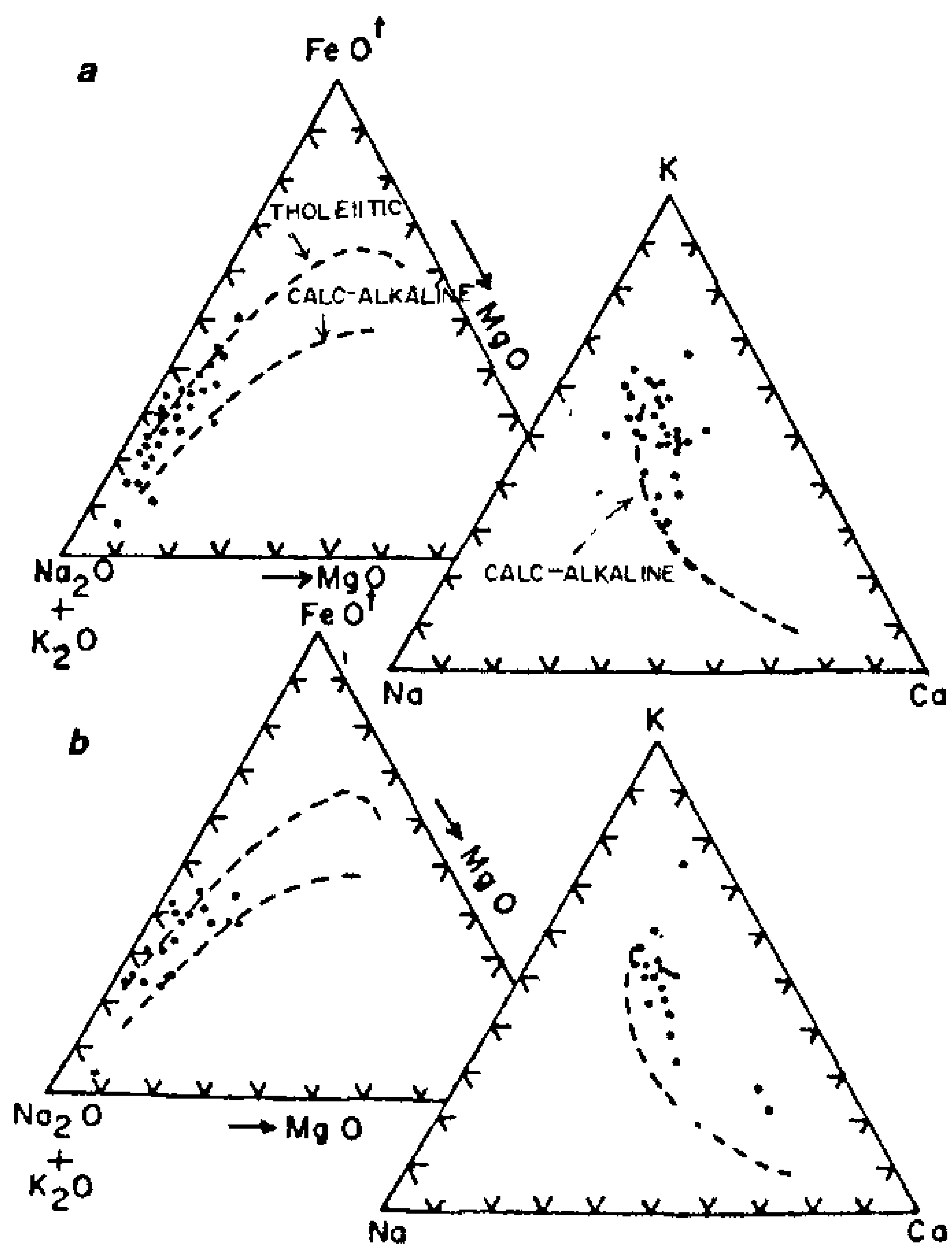

Figure 5. Ternary A F M and K Na Ca projections. *a*, Granite; *b*, Gneissic granite.

variation diagrams also show a similar behaviour. c and c/fm, when plotted against alk, show a systematic decrease, while al values, after an initial increase, decrease (Figure 9).

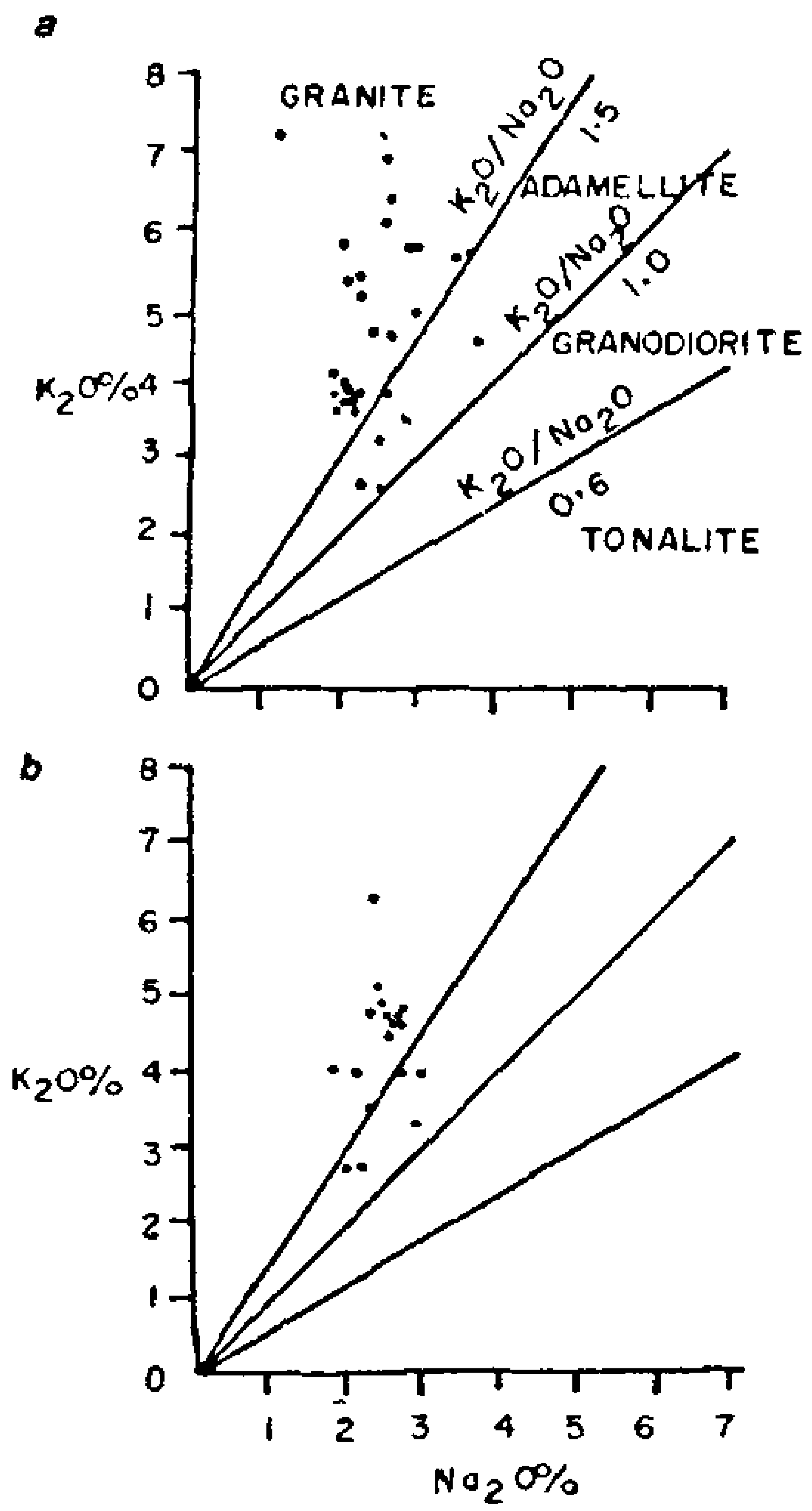

Figure 6. Na_2O vs K_2O plots. a, Granite; b, Gneissic granite.

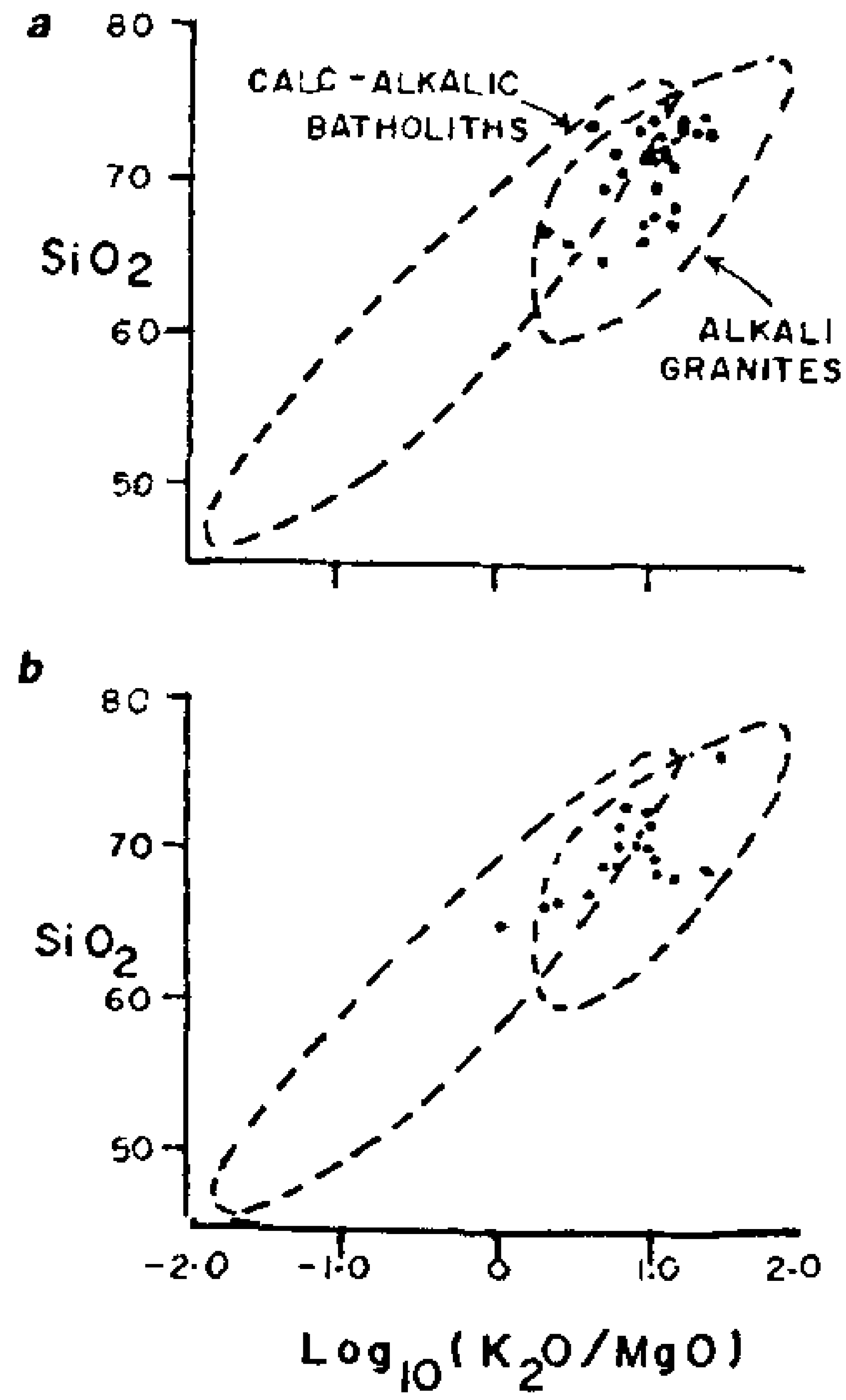

Figure 7. $Log_{10}(K_2O/MgO)$ vs SiO_2 plots. a, Granite; b, Gneissic granite.

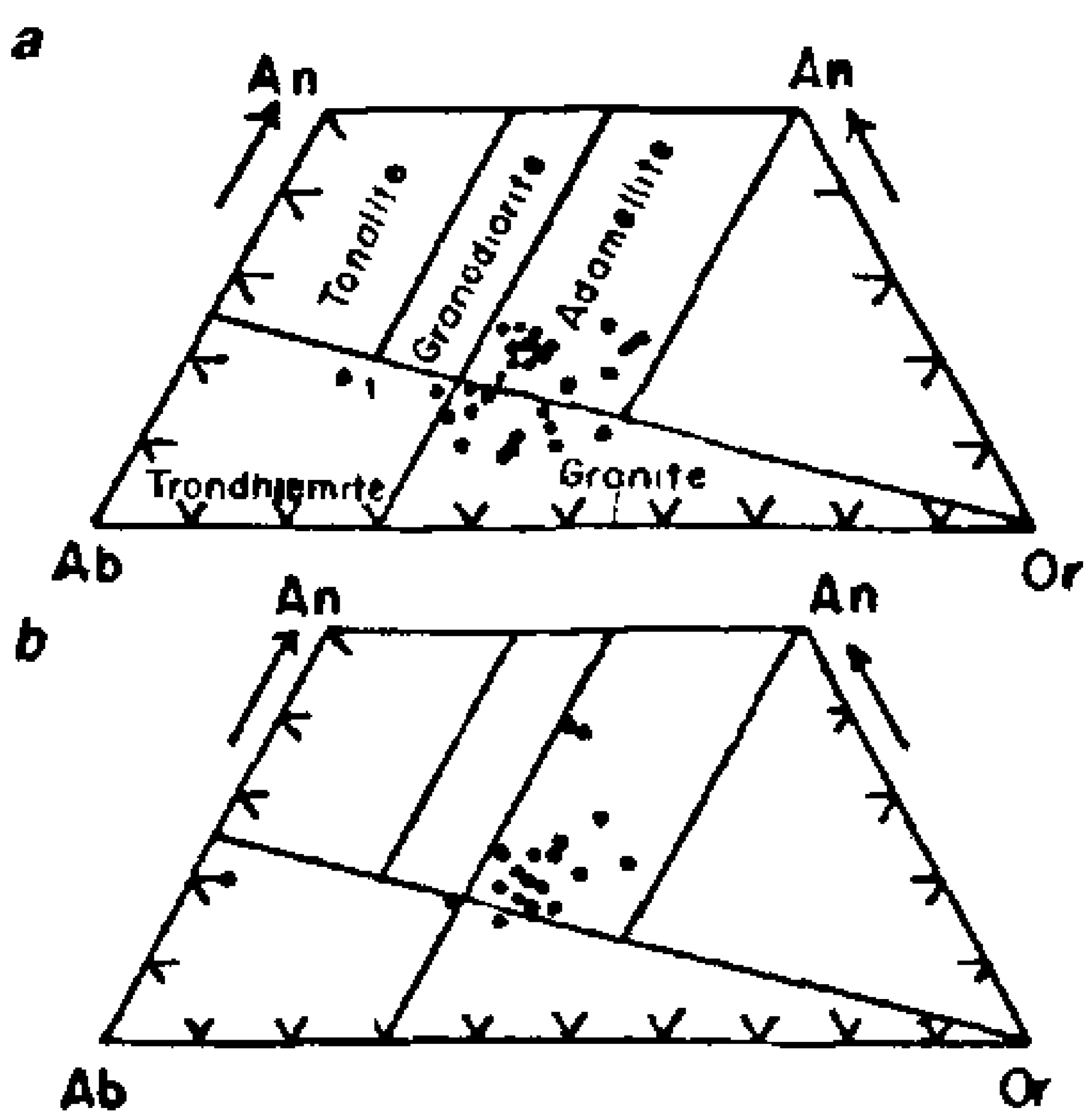

Figure 8. Normative Ab–An–Or ternary plots. a, Granite; b, Gneissic granite.

Discussion

Average content, range and behaviour of major and trace elements, and geochemical classification schemes indicate that there is close resemblance among granite and gneissic granite, their differences being mainly in physical characters. In examining details of granite and gneissic granite in terms of the most widely used criteria for distinguishing 'I' and 'S' granites[17–19], it can be seen that while mineralogical criteria favour 'I' type characterization, some of the chemical characters point to both 'I' and 'S' types. K_2O/Na_2O ratio and average normative corundum suggest 'S' type affinity. However, the values fall close to the boundary, separating 'S' from 'I'. The slight variation in K_2O/Na_2O ratio and normative–corundum average may be due to crustal contamination. $Al_2O_3/CaO + Na_2O + K_2O$ average has 'I' affinity. Rock type variation, indicated in chemical and mineralogical schemes, points to 'I' type affinity. However, the imprints of deformation and metamorphism in gneissic granite suggest similarity with 'S' type. On the whole, the granitic rocks of the area resemble 'I' type more than 'S' type. In terms of high SiO_2, $Na_2O + K_2O$ and Fe/Mg ratio the granite shows chemical similarity to A type[20,21]. But CaO along with Sr and Ba are on the high side. This may be due to contamination from the surrounding calc-silicate rocks.

In terms of magma tectonic grouping[22], the granite

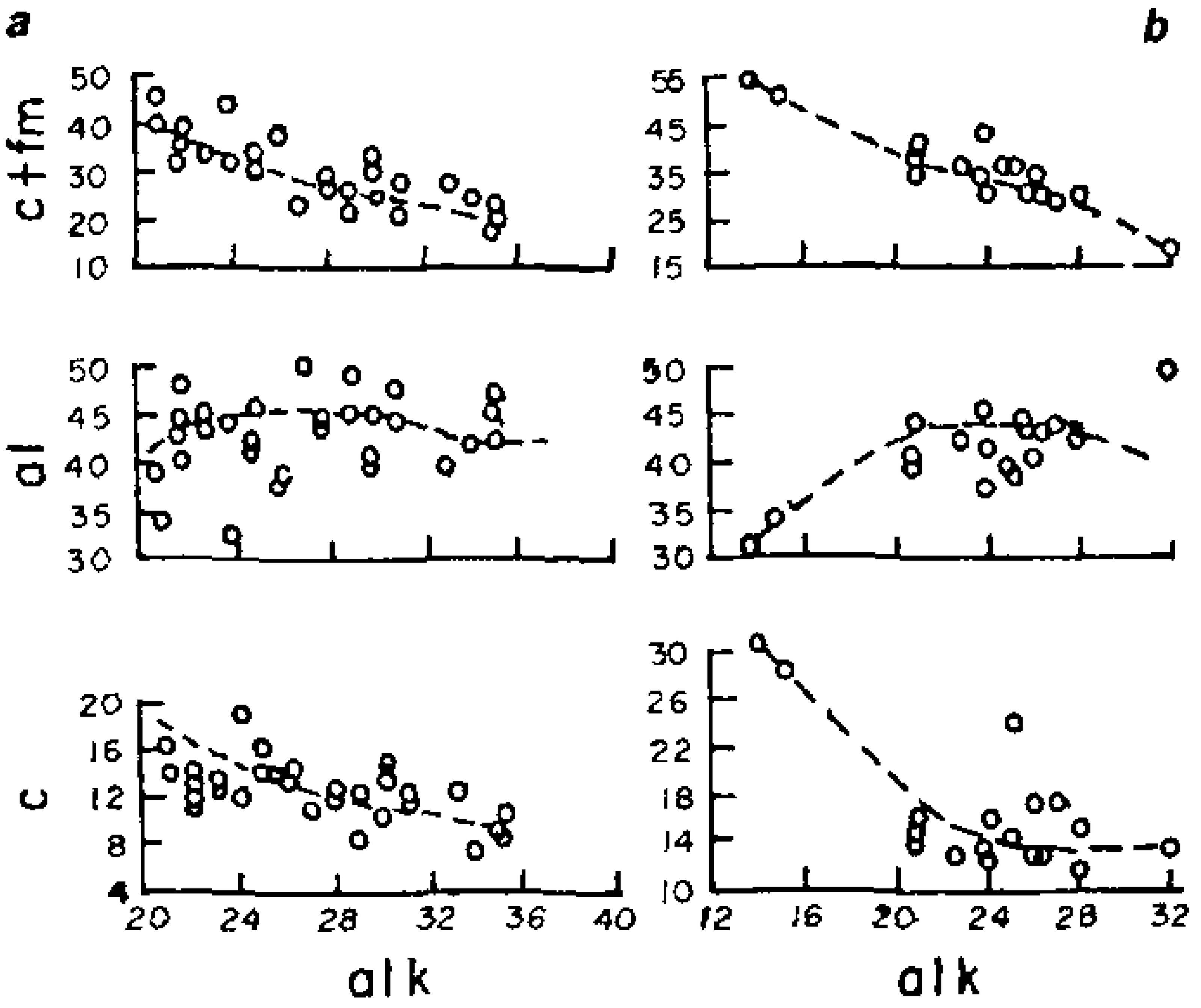

Figure 9. Niggli variation diagrams. *a*, Granite; *b*, Gneissic granite.

of the study area resembles post-kinematic granite as it does not carry evidences of deformation. It is a microcline-albite granite with considerable homogeneity in composition. Gneissic granite is indistinguishable from the granite geochemically and mineralogically, but unlike the granite, these were involved in deformation and have developed foliation. However, the migmatite, the country rock of the area, stands out as a distinct unit. Further, the gneissic granite was involved in deformation and hence is comparable with syn-kinematic granite. Development of similar finely layered gneisses by progressive deformation of granitoid intrusions has been reported[24]. Obviously, the two units, namely the granite and gneissic granite, were formed not together, but belong to two different granite-forming events. The first event, broadly synchronous with tight folding and amphibolite-facies metamorphism, characteristic of this part of the Peninsular shield[24], led to the emplacement, metamorphism, and deformation of the gneissic granite and its sheared equivalent—the sheared gneiss, while the second event that occurred much later around 700–800 Ma as indicated by U–Pb dating of the Munnar granite[25], resulted in the emplacement of the non-foliated Munnar granite. As several granites of comparable age are present in Kerala, this was a major granite-forming event in the south-western margin of the South Indian shield.

The isotope ages of granites from the south-western margin of the South Indian shield, fall within the span of 740 ± 30 and 512 ± Ma[1–7]. Further, these granites are undeformed and hence considered as post-tectonic. However, older granites have been reported from other parts of the high-grade and granite-greenstone terrains of South India. These older granites, in contrast to the younger granites of the south-western margin, carry imprints of metamorphism and deformation and are therefore pre-tectonic. Though some earlier workers[1,27], have hinted at the possibility of such older granites, synchronous with right folding and amphibolite-facies metamorphism characteristic of this part of the peninsular shield, so far these have not been recorded. Thus, for the first time, a granite, consisting of both pre-tectonic and post-tectonic elements, is recognized in the south-western margin of the South Indian shield. The pre-tectonic part of the Munnar granite, represented by the gneissic granite, till now has been mapped as migmatite. Similar pre-tectonic granites are likely to be present in other parts of the south-western margin of the high-grade terrain amidst vast stretches that are shown as migmatites.

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