Patchy charnockites from Jenapore, Eastern Ghats granulite belt, India: Structural and petrochemical evidences attesting to their relict nature

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The charnockite patches that occur within leptynite host, in and around Jenapore, northern sector of the Eastern Ghats granulite belt, are disposed in a linear fashion and generally have sharp lithological contact with the host leptynite. Sometimes the patches and foliations of the host are cofolded. Also, the patches sometimes have the internal S_1 foliation, while the host leptynite records only S_2 foliation. Mineralogically and chemically patchy charnockites and host leptynites are distinct entities, and cannot be related by any prograde and retrograde reactions. Particularly important is the peraluminous granitic composition and high Rb/Sr ratios of the leptynites, presumably resulting from biotite-dehydration melting; as against metaluminous granodioritic to tonalitic composition and low Rb/Sr ratios of the patchy charnockites, presumably resulting from hornblende-dehydration melting. The charnockite patches here can be interpreted as caught up patches or xenolith within granitic melt (leptynite). Mg-rich rims of garnet in the charnockite patch were probably caused by heat from the crystallising melt or decompression during ascent of melt.

1. Introduction

Charnockitic rocks are important constituents of high grade terrains, and could have originated by both igneous and metamorphic processes (Newton 1992a). From its type area, near Pallavaram, Madras (presently Chennai), Holland (1893, 1900) first suggested a plutonic igneous origin of the charnockite. Later on, Howie (1955) elaborated this idea and proposed the concept of plutonic metamorphism, according to which charnockitic magma was emplaced at lower crustal depths. Pichamuthu (1960) first described 'patchy charnockites' within host amphibolite facies gneisses from Kabbaldurga, Karnataka, south India, and interpreted them as arrested growth from the host. Subsequently, many workers suggested that the 'patchy charnockites' from several places in south India are products of *in situ* metamorphic transformation or 'charnockitisation' (Janardhan *et al* 1979; Hansen *et al* 1987a, b; Stahle 1987; Newton 1992b). Some workers even interpreted the larger charnockite bodies as products of 'progressive charnockitisation' (Raith *et al* 1990; Srikantappa *et al* 1992; Janardhan *et al* 1994; Harley and Santosh 1995; Janardhan and Francis 1996).

These diverse petrogenetic interpretations or models for the origin of charnockitic rocks are based primarily on petrological observations; the structural setting of these rocks, are, in many cases, not well documented. In this context it is important to note that from some south Indian localities Naha (1988) and Naha *et al* (1993) described charnockitic rocks that occur in a variety of different structural setting and differ in style and time relation.

Keywords. Patchy charnockite; leptynite; distinct entities; relict.

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Also, in the Eastern Ghats granulite belt, India, the charnockitic rocks occur in different modes, namely, as larger massif-type bodies and as patches in the host leptynitic gneisses (Bhattacharya *et al* 1993a, 1994; Rao *et al* 1995; SubbaRao *et al* 1995; Kar 1995). Several workers have assumed an *in situ* transformation origin for the patchy charnockites (Aftalion *et al* 1988; Paul *et al* 1990), but Bhattacharya *et al* (1993a, 1994) described the relict nature of the patchy charnockites from the Chilka Lake area. Recently, Dobmeier and Raith (2000) presented an alternative interpretation—"arrested growth" for the patchy charnockites of the Chilka Lake area. This is one of the leading controversies, and for a proper resolution of this issue, many more specific examples should be investigated. The present communication deals with a case of patchy charnockite from the northern sector of the Eastern Ghats belt.

The charnockitic rocks here occur in two different modes. One variety occurs as large massif-type bodies associated with minor bands and lenses of enderbite, two-pyroxene granulite and hornblende-bearing mafic granulites. The other variety occurs as patches within leptynitic gneisses. It can be shown on the basis of field-structural and petrological data that, the massif-type charnockite is a product of hornblende-dehydration melting in the protolith of hornblende-bearing mafic granulite and the associated two-pyroxene granulite and enderbite are cumulates of solid peritectic phases, equilibrating with the charnockitic melt (Kar *et al* 2000).

Any scientific discussion of charnockitic rocks should take into account its nomenclature. Holland (1900) first defined the charnockite as orthopyroxene-bearing granite, found abundantly in south India, with the conviction that they are of plutonic igneous origin. Later on, Streckeisen (1976) also subdivided the orthopyroxene bearing quartzo-feldspathic rocks into charnockite, farsundite, charno-enderbite and enderbite, with the assumption that they are plutonic rocks. On the other hand, in his review paper Newton (1992a) noted that many of the south Indian charnockitic rocks are poor in K-feldspar, corresponding to granodiorite or quartz monzonite, rather than granite, in mineralogy. He also pointed out that these rocks are complexly foliated, interlayered with various metasediments, and some contain garnet and even graphite, and are definitely metamorphic in origin. For these reasons, he suggested that it is better to adopt Pichamuthu's (1969) most general and non-genetic definition of charnockite as any quartzo-feldspathic rocks with orthopyroxene. Some Indian workers (Bhattacharya *et al* 1993a; Sen and Bhattacharya 1993) and workers from elsewhere also use the term charnockite in a similar manner (De Waard 1969; Ridley 1992; Kilpatrick and Ellis 1992). It is also important to note that the natural occurrence of charnockitic rocks includes intimately associated varieties that may be termed charnockite, charno-enderbite and enderbite.

2. Geological setting

Besides the presence of the massif-type charnockite suite of rocks in the study area, metapelitic granulites and orthopyroxene-free granites are also important lithologies. Metapelitic granulites are primarily of two types, namely, khondalite and quartzite. Quartzite occur as minor bands within khondalite. On the other hand, orthopyroxene-free granites are principally of three types, namely, leptynite, leucogranite and porphyritic granite-gneiss. The definition of dominant lithologies is presented in table 1.

Three phases of folding are recorded from the study area (Kar 1995). Large massif-type charnockite and khondalite are characterised by the presence of streaky gneissic foliation and pervasive gneissosity respectively. Minor quartzite bands in the khondalite host and hornblende-bearing mafic granulite bands in the charnockite host define reclined, intrafolial F_1 folds. The gneissic foliations of the hosts are axial planar to these folds, and hence designated as S_1 fabric. F_2 folds, fairly tight, commonly developed on these S_1 fabrics and have axial planar leptynitic foliation in both the khondalite and massif-type charnockite. Hence the leptynitic foliation is designated as S_2 fabric. F_2 folds commonly occur on a mappable scale. Except the mesoscopic F_2 fold hinges, S_1 fabric is parallel to S_2 fabric on a regional scale. The composite $S_1 \| S_2$ fabric defines broad F_3 warps. This three-phase folding history is correlatable to those described from the other areas in the Eastern Ghats (Halden *et al* 1982; Bhattacharya *et al* 1994; Shaw 1996).

Orthopyroxene-free granites generally occur as minor stock-like bodies at the core of the mapable F_2 folds in the charnockite and khondalite host (figure 1, insets A & B). The foliations present in them, i.e., leptynitic foliation in leptynite and leucogranite passes undeviated into adjacent charnockite and khondalite, and is axial planar to F_2 folds, and hence this foliation is designated as S_2. Similarly, the gneissic foliation in porphyritic granite is parallel to the axial plane of the mesoscopic F_2 fold in the host charnockite and/or khondalite, and hence it is also designated as S_2.

On the other hand, dismembered charnockite patches are generally disposed in a linear fashion within the leptynitic host (figure 2). Notably,

Table 1. *Definition of different rock types used in the text.*

Charnockite	Quartzo-feldspathic rock with orthopyroxene as essential mineral phase; minor clinopyroxene and garnet also present.
Khondalite	Quartz-rich rock with alkali feldspar, sillimanite and garnet as essential mineral phases.
Leptynite	Quartzo-feldspathic rock with plattung structure; biotite and garnet are common ferromagnesian phase.
Leucogranite	Quartzo-feldspathic rock with plattung structure, with minor or no ferromagnesian phases.
Porphyritic granite	Granite with common porphyritic texture; alkali feldspar megacrysts and biotite rich foliation swerves around it.

Note: Plattung structure – Platy granoblastic texture, as defined by Mehr (1962) and Sen (1987).

boundaries between them are very sharp. On a closer look, a few significant features can be noted.

- Foliation of the host leptynite swerves around the charnockite patches, with internal foliation (figure 3).
- Foliation of the host leptynite abuts against the charnockite patch.
- The charnockite patches are often folded and the foliation of the host leptynite is parallel to the axial plane of these folds (figure 4).

These features indicate the pre-existing nature of the charnockite patches in the host. In other words, the charnockite patches are enclave in host leptynite.

Porphyritic granite-gneiss also contains enclaves of charnockite with internal foliation, and the foliation of the host swerves around the charnockite patch. Also, the porphyritic granite veins are commonly found to inject the charnockite. These veins are also ptygmatically folded. Furthermore, in the leucogranite host, dismembered charnockite patches are tightly folded with axial planar leptynitic foliation. Sometimes the leptynitic foliation of the host leucogranite is found to also overprint the charnockite patch. All these features collectively suggest the relict nature of the charnockite patches.

The only foliation present in the leptynite, leucogranite and porphyritic granite is designated as S_2, hence the internal foliation of the relict charnockite patches is pre-S_2, and probably S_1. Moreover, the folds defined by the patchy charnockites within leptynite and leucogranite host (figure 4) can be designated as F_2 folds. Additionally, the ptygmatic fold defined by porphyritic granite is also an F_2 fold.

3. Petrography

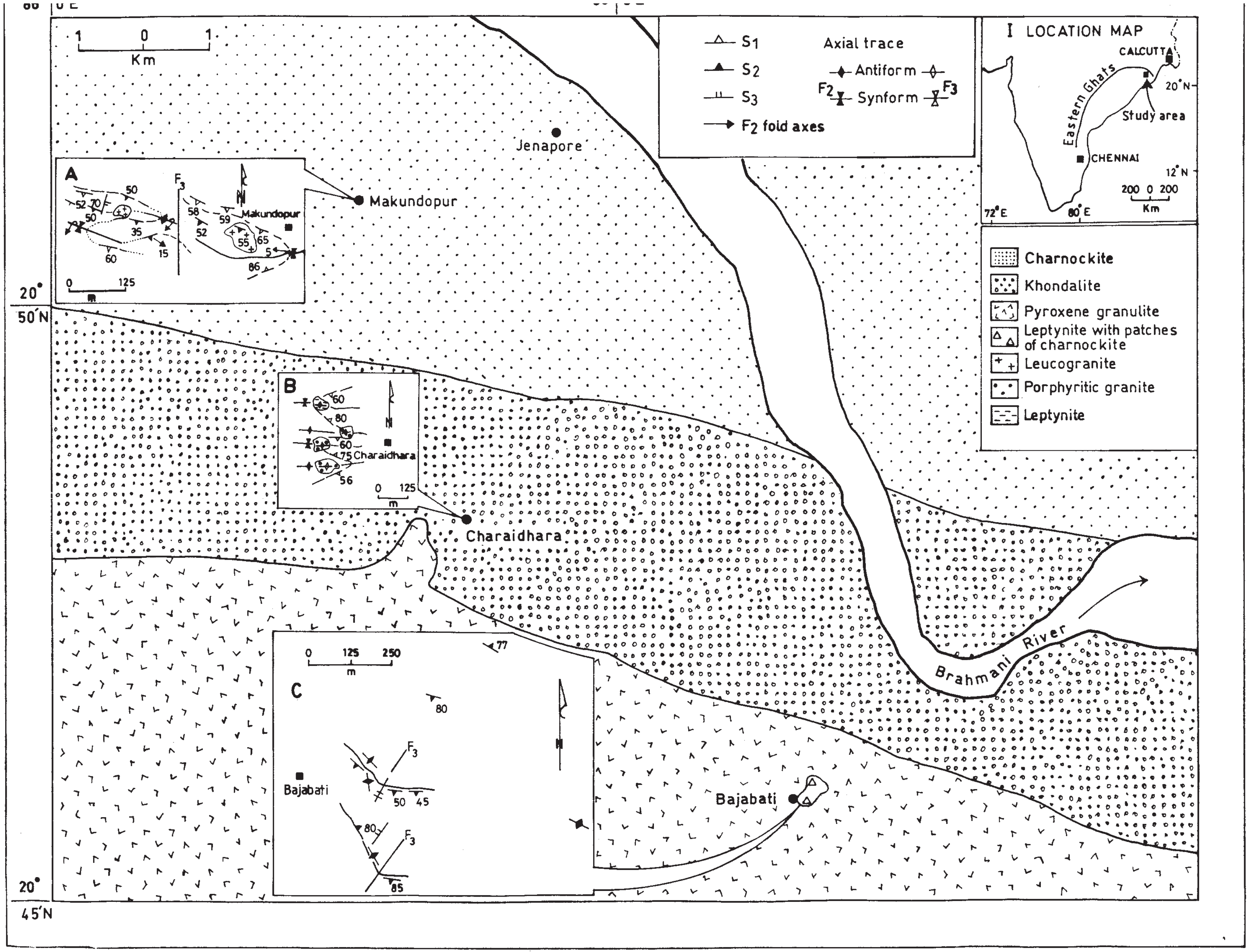
3.1 *Orthopyroxene-free granite*

The orthopyroxene-free granites are mainly composed of quartz, alkali feldspar and plagioclase feldspar (table 2). Alkali feldspar largely dominates over plagioclase feldspar. Hence, they are plotted in field 3 (granite) in the modal Q-A-P diagram (figure 5), after Streckeisen (1976). Perthite is very common. Biotite, ilmenite and garnet are common mafic minerals. Occasionally sillimanite trails are present as included phases within garnet. Traces of hornblende have also been noticed. Mafic minerals never exceed 10% by volume. Zircon is the common accessory.

Quartzo-feldspathic matrix in leptynite and leucogranite are also characterised by relatively fine-grained, polycrystalline, elongate quartz and feldspar with irregular grain boundaries. Occasionally, reduction of grain boundary area to minimize surface free energy resulted in a typical platy granoblastic texture, plattung structure (Mehr 1962 and Sen 1987). Macroscopically, this foliation is manifested as typical leptynitic foliation. On the other hand, in the porphyritic granite, large megacrysts of K-feldspar are embedded in a groundmass of relatively fine-grained quartz and feldspar. Occasionally, in the biotite rich domains, swerving of foliation, defined by biotite flakes, around the K-feldspar megacrysts, is noticed. In overall appearance it looks like a magmatic foliation.

3.2 *Patchy charnockite*

Patchy charnockites of the present area are mainly composed of quartz, plagioclase feldspar and alkali feldspar (table 3). Orthopyroxene is the principal ferromagnesian phase, although garnet is also common. Clinopyroxene and hornblende are present in minor quantities. Plagioclase largely dominates over alkali feldspar in most of the patches (figure 5). Notably, the present samples of patchy charnockites are mafic rich (>15%) and are distinct from the host, which contains less than 10% by volume of mafic minerals (figure 6).


1 0 1
Km
Jenapore
Makundopur
Charaidhara
Bajabati
Brahmani River
S1
S2
S3
F2 fold axes
Axial trace
Antiform
F2 Synform F3
I LOCATION MAP
CALCUTTA
Eastern Ghats
Study area
CHENNAI
20° N
12° N
72° E
80° E
200 0 200
Km
Charnockite
Khondalite
Pyroxene granulite
Leptynite with patches of charnockite
Leucogranite
Porphyritic granite
Leptynite
A
B
C
F3
0 125
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0 125 250
m
20° 50′N
20° 45′N

Figure 1.

Sharp grain-grain contact with common triple junction (typical granoblastic texture) is the frequently observed texture in the charnockite patches. However, in some samples, microscale gneissic banding, defined by alternate layers of mafic and felsic minerals, was noticed. In fact, this gneissosity defines the internal foliation of the charnockite patches on a mesoscopic scale.

3.3 *Host leptynite*

The host leptynites are strictly granitic in composition, with a high alkali feldspar/plagioclase ratio (table 3). Perthite is also common. Garnet and biotite are the common mafic minerals. A notable feature is the variable proportion of garnet and biotite. Zircon is the common accessory. Garnet xenoblasts commonly contain sillimanite inclusion trails. Biotite occurs in two different modes. One is commonly found to corrode the garnet margin. Occasionally this mode of biotites is found to separate garnet xenoblast and alkali feldspar, and can be interpreted as retrograde phase, after garnet. The other mode of biotite grains is an included phase within garnet xenoblasts.

Similar to the other granites, the host leptynites are also characterised by the presence of plattung structure, as manifested by the preferred alignment of relatively fine-grained, polycrystalline elongate quartz and feldspar with irregular grain boundaries. In biotite rich domains a typical gneissic foliation results, which enhances the plattung structure.

4. Geochemistry

4.1 *Bulk chemistry*

Two pairs of charnockite patches and host leptynite (as given in table 3) were selected for bulk chemical analysis. The chemical analyses for whole rock compositions was done by X-ray Fluorescence Spectrometry at the Wadia Institute of Himalayan Geology, Dehradun. The bulk chemical data are presented in table 4.

Host leptynites are characterised by high normative orthoclase (34.11, 32.70) and low normative anorthite (7.60, 8.90), which is reflected in the high modal abundance of alkali feldspar (table 3). In terms of normative Ab-An-Or proportions (figure 7), after Le Maitre (1989), the compositions of the leptynites can be described as granite sensostricto. Additionally, the leptynites are peraluminous granites with a little normative corundum (1.28, 0.95) and an alumina saturation index (A/CNK) greater than unity (1.08, 1.04). This marginally peraluminous character is reflected in the presence of aluminous garnet and/or biotite in addition to feldspars. In trace element chemistry, the leptynites are depleted in transitional trace elements (Cr, Ni) and base metals (Zn, Cu) and are enriched in Y, Th, Ba and Pb. Also, they are depleted in Ti. It is important to note that the leptynites have a high Rb/Sr ratio (1.17, 1.45).

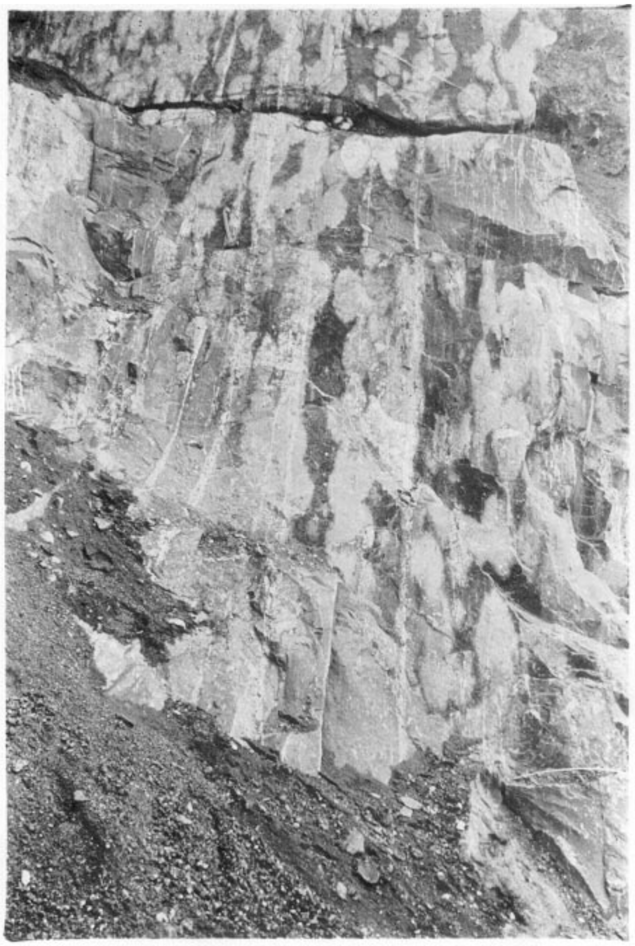

Figure 2. Patches of charnockitic rocks in leptynitic host, disposed in a linear fashion.

Figure 1 caption.

Lithological map of the area in and around Jenapore. Insets depict some important field relations. **Inset A:** Minor stocks of leucogranite are emplaced along the core of the F_2 folds in massif-type charnockite. Note the foliation in leucogranite (S_2) passes undeviated into the host charnockite massif and parallel to the S_2 foliation of the host. **Inset B:** Minor stocks of porphyritic granite and leptynite are emplaced along the core of the F_2 folds in khondalite. **Inset C:** S_2 foliation of the leptynite with patches of charnockite shows F_3 fold. **Inset I:** Location of the study area.

Figure 3. Charnockite patch, with internal foliation (S_1) in leptynitic host; foliation of the host (S_2) swerves around the patch.

Figure 4. Folded charnockite patch in leptynitic host. Leptynitic foliation (S_2) of the host (marked by arrow), roughly E-W, is axial planar to the fold.

The chemical composition of the patchy charnockites (table 4) can be described as granodioritic to tonalitic in a normative Ab-An-Or diagram (figure 7). They are metaluminous in character, as evidenced by their moderate A/CNK values (0.89, 0.72). Moreover, the charnockite patches are rich in Niggli fm than the host leptynite (figure 8). In trace element composition, these charnockites are relatively depleted in Rb, Pb contents and enriched in Cu, Ni, Zn, Sr than the host leptynites (figure 9). Also, the patchy charnockites have a low Rb/Sr ratio (0.35, 0.18), just opposite to the host leptynite. Additionally, the patchy charnockites are characterised by high Ba contents.

4.2 *Mineral chemistry*

The mineral chemical data are obtained by Electron Probe Micro Analysis. EPMA work was carried out at the University Science Instrumentation Center of the Roorkee University,

Table 2. *Modal mineralogy of different varieties of orthopyroxene-free granites.*

Sample no.	Quartz	Alkali feldspar	Plagioclase	Garnet	Biotite	Hornblende	Opaque	Accessory
JN138	33.6	50.8	12.8	–	0.8	0.2	1.6	0.2(Zr)
JN126B	30	43.6	20.8	–	0.8	2	2.4	0.4(Zr)
2.J.65A	31.6	58.4	8.8	–	0.4	–	0.8	–
Jen 318A	30.4	56.8	12	–	–	–	0.4	0.4(Zr)
Jen 303	26.8	56.4	16	–	–	–	0.8	–
Jen 354A	26.4	53.6	18.2	–	0.2	–	1.6	–
JN58D/2	29.6	50.8	17.6	–	1.6	–	0.4	–
JN135	31.2	49.4	16.8	–	2.4	–	0.2	–
Jen 348A	27.2	42	25.6	3.2	1.6	–	0.4	–
JN 114D/2	33.6	52.4	12.4	–	0.8	–	0.8	–
JN 50C	25.6	51.6	16.8	3.2	1.2	–	1.6	–
JN 48D	34.8	45.2	20	–	–	–	–	–
Jen 306	37.6	39.6	21.6	0.8	0.4	–	–	–
JN 139	36.4	43.2	16.4	–	1.2	0.8	2	–
JN 91	28	41.2	26.4	–	1.6	–	2.8	–
2.J.60L	32.4	53.2	12	–	0.8	–	1.2	0.4(Zr)

Zr: Zircon.

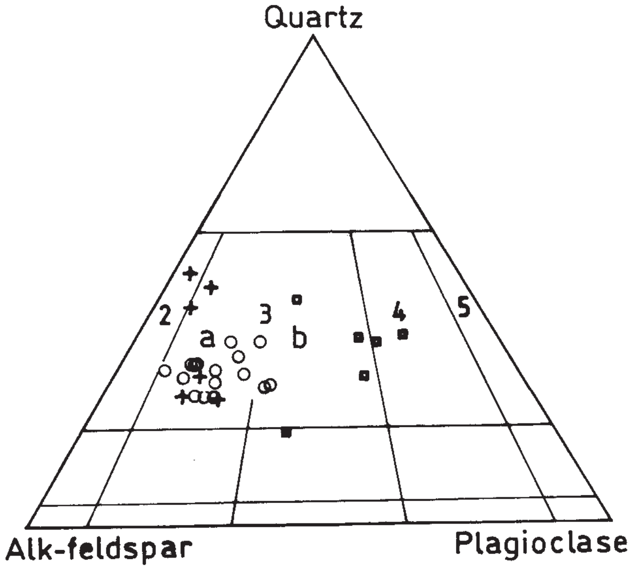

Figure 5. Modal Q-A-P plots, after Streckeisen (1976) of the orthopyroxene-free granites (circle), patchy charnockites (box) and host leptynites (plus).

using Jeol Jxa-8600M microprobe machine. 15 kV accelerating voltage, 2×10^{-8} ampere sample current and 3mm beam diameter were used. Mineral chemical data are presented in table 5.

The plagioclases of the host granite are mostly andesine, Ab: 63–68%, (table 5). However, a little variation in X_{An}/X_{Ab} proportion is noticed in different microdomains (figure 10). Notably, all of them have very low molar X_{Or} content (2–3%). Similarly plagioclases of the patchy charnockites are also andesine, Ab: 60–65% (table 5). They are also poor in orthoclase (1–3%). A little variation in X_{An}/X_{Ab} proportions in different microdomains is also a notable feature (figure 10).

Garnet compositions in patchy charnockite are variable in different microdomains ($Alm_{58}Py_{21}$ and $Alm_{55}Py_{25}$, see table 5). One important feature is that garnet shows subtle magnesium enrichment from core to rim, Py_{21} to Py_{23}, indicating heating and/or decompression.

5. P-T estimates

P-T values are estimated from the coexisting garnet-clinopyroxene-plagioclase in the charnockite patches. The values are estimated by using the TWEEQU computer programme. Thermodynamic parameters of different minerals are taken from the internally consistent data set of Berman (1988 and updated database of 1992). Berman (1991) has shown that with the proper choice of solution models, this technique may estimate temperature and pressure with uncertainties less than ±40° C and less than ±0.5 kbar respectively. For garnet, the solution model of Berman (1990) for quaternary garnet solid solutions is used. For plagioclase ($X_{An} > 0.30$), the alumina-avoidance model of Newton *et al* (1980) is not applicable and hence the model of Fuhrman and Lindsley (1988) is adopted. For pyroxenes an ideal solution model is adopted here, because this model fits well with the internally consistent database (Bhattacharya *et al* 1993b).

The pressure estimate is 7.75 kbar at 660° C (table 5). Slightly higher temperature is also obtained from a separate microdomain (700° C). This variation is consistent with the compositional variation of garnet and clinopyroxene. Notably, the high temperature domain has a higher $K_D^{Grt-Cpx}$ value and has relatively less magnesian pyroxene and more magnesian garnet than the low temper-

Table 3. *Modal mineralogy of patchy charnockite and host granite.*

Sample No.	Rock type	Quartz	Alkali feldspar	Plagioclase	Orthopyroxene	Clinopyroxene	Garnet	Biotite	Hornblende	Opaque	Accessory
2. J 154	Charnockite	21	12.9	21.4	20.1	5.3	13.6	2.2	–	3.5	–
2. J 156	Granite	24.8	50.8	17.6	–	–	3.2	2	–	0.8	0.8 (Zr)
1. J 45B	Charnockite	24.2	13.7	26.7	22.7	3	–	6.8	0.5	2.9	–
1. J 45D	Granite	50	42.8	2.6	–	–	–	4.4	–	0.2	–
2. J 90A	Charnockite	18.8	16	26.2	30.6	1.6	–	5.2	–	1.6	–
2. J 95	Granite	41.9	44.2	5.3	–	–	4.4	1.6	–	2.6	–
2. J 82	Charnockite	22.6	8.6	25.8	21.6	2.4	12.8	2.8	1	2.4	–
JN 192C	Granite	48	40.7	7.1	–	–	–	3.2	–	1	–
JN 206A	Charnockite	14.8	33.6	26.4	6.4	2	11.6	0.4	0.4	4	0.4 (Zr)
JN 206C	Granite	24.8	54.4	12.8	–	–	4.8	0.8	–	1.6	0.8 (Zr)
JN 205A	Charnockite	39.2	24.8	20	10	3.2	2	–	–	0.4	0.4 (Zr)
JN 205B	Granite	29.2	49.2	12.8	–	–	7.2	0.4	–	1.2	trace

Zr: Zircon.

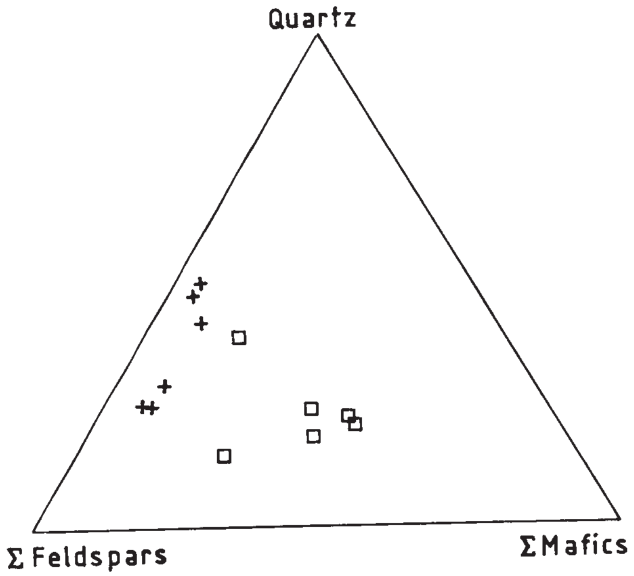

Figure 6. Modal quartz-feldspar-mafic proportions of patchy charnockites (box) and host leptynites (plus).

ature domain (table 5). These two domains probably represent two different frozen-in conditions, as proposed by Frost and Chacko (1989).

6. Discussion

Arrested charnockite formation is generally thought to be the product of subsolidus dehydration. The dehydration reaction vis-a-vis charnockite paragenesis can only form by decrease of water activity which could be either externally or internally controlled (cf. Hansen *et al* 1984; Srikantappa *et al* 1985). The external control of incipient charnockite formation assumes that the subsolidus dehydration of the gneiss assemblage was caused by decrease of H_2O activity as a result of channelled influx of 'CO_2-wave' from a deep mantle source (Janardhan *et al* 1982; Ravindrakumar and Chacko 1986; Santosh 1986, Hansen *et al* 1987a; Newton 1992b). On the other hand, Srikantappa *et al* (1985) envisaged that incipient charnockitization, i.e., dehydration could happen due to a decrease of fluid pressure with the onset of near-isothermal uplift following the peak stage of regional metamorphism.

It is noteworthy here that at P-T conditions (~6–7 kbar, 700°–800° C) and oxygen fugacity (f_{O_2}) below Q-F-M buffer, commonly recorded from the Eastern Ghats (Bhattacharya and Sen 1991; Sengupta *et al* 1991; Bhattacharya 1996; Dasgupta and Sengupta 1998 and this study, table 5), pervasive CO_2 flooding sufficient to grow 10 volume% orthopyroxene require 1.5 volume% graphite to precipitate (Lamb and Valley 1984). The charnockite-leptynite association of the present area does not contain graphite. Hence, it is unlikely that CO_2-flooding could be the causative mechanism of charnockite formation here.

On the other hand, the disposition of incipient charnockite along some structural weak zone, could be compatible with the internally controlled mechanism of charnockite formation, proposed by Srikantappa *et al* (1985) and modified by Raith and Srikantappa (1993). In the Eastern Ghats granulite belt, the incipient charnockites are thought to be produced along a near horizontal stretching lineation related to F_3 folding (Halden *et al* 1982; Dobmeier and Raith 2000). The charnockite patches described here are also disposed in a linear fashion (figure 2). However, they show the evidence of both F_3 folding and F_2 folding (figure 4). Also, they preserve the imprints of S_1 foliation. These field-structural features are not compatible with the hypothesis of arrested growth by an internally controlled mechanism.

On the other hand, arrested type charnockite formation, described from the Eastern Ghats granulite belt and elsewhere commonly indicate that the lithoboundary between the charnockite patch and host gneisses is diffused (Pichamuthu 1961; Janardhan *et al* 1979, 1982; Halden *et al* 1982; Ravindrakumar *et al* 1985; Srikantappa *et al* 1985; Ravindrakumar and Chacko 1986; Hansen *et al* 1987b; Newton 1992b; Raith and Srikantappa 1993; Dobmeier and Raith 2000). Whatever may be the mechanism for metamorphic transformation, this field relation is said to be critical. In contrast, the lithoboundary between charnockite patches and host gneiss is very sharp here (figures 2, 3 and 4), and this argues against the arrested growth hypothesis.

In modal mineralogy and bulk chemistry the leptynites are granitic in composition with high normative orthoclase, while the patchy charnockites are mostly granodioritic in composition with much less normative orthoclase (figure 7). Moreover, the patchy charnockites are metaluminous while the host leptynites are peraluminous in character (table 4). Hence, it can be suggested from these observations that patchy charnockites and host leptynites are mineralogically and chemically distinct entities.

The patchy charnockites have comparatively lower Rb/Sr ratios than the host leptynites. It should be noted here that leptynite from other parts of the Eastern Ghats has been described as product of biotite-dehydration melting (Sen and Bhattacharya 1997), and they are characterised by high Rb/Sr ratio. On the other hand, the

Table 4. *Bulk chemistry of patchy charnockite and host leptynite.*

Rock type	Charnockite		Leptynite	
Sample no	JN 205A	JN 206A	JN 205B	JN 206C
SiO_2	60.58	51.65	70.55	73.66
TiO_2	2.42	1.28	0.57	0.4
Al_2O_3	14.04	16.83	14.85	14.14
Fe_2O_3	11.3	9.1	4.28	2.86
MnO	0.23	0.13	0.06	0.04
MgO	1.53	7.06	0.39	0.26
CaO	4.6	8.71	2	1.65
Na_2O	2.54	3.15	2.36	2.35
K_2O	2.93	2.11	5.52	5.76
P_2O_5	0.71	0.5	0.22	0.15
Total	100.88	100.52	100.00	101.26
LOI	1.78	0.78	0.4	0.47
A/CNK	0.89	0.72	1.04	1.08
Normative values				
Q	18.04	0	28.64	32.53
C	0	0	0.95	1.28
Or	17.35	12.5	32.7	34.11
Ab	21.49	26.65	19.97	19.88
An	18.37	25.62	8.9	7.6
Ol	0	13.55	0	0
Niggli values				
c	17.28	22.69	10.67	9.49
alk	15.19	10.69	28.92	31.96
fm	38.5	42.49	19.17	13.79
Trace elements				
Cr	25	187	28	43
Ni	24	37	8	13
Cu	10	23	5	3
Pb	21	18	33	48
Zn	129	91	58	36
K	24323	17516	45823	47815
Rb	91	77	202	178
Ba	2138	1528	1393	1287
Sr	260	436	139	152
Ga	24	16	20	17
Nb	63	15	23	12
Zr	483	182	298	267
Ti	14507	7673	3417	2398
Y	70	20	23	25
Th	21	3	11	102
Rb/Sr	0.35	0.18	1.45	1.17

massif-type charnockites in the study area has been described as a product of hornblende-dehydration melting (Kar *et al* 2000), and they are characterised by low Rb/Sr ratio. Hence, in the study area, the patchy charnockites could be the product of hornblende-dehydration melting while the host leptynites could be the product of biotite-dehydration melting. However, the relatively higher Ba contents in the patchy charnockites than the host leptynites is the most unusual feature. Large amounts of fractional crystallization could produce this feature, so that early separated K-feldspar might have incorporated Rb, while Ba entered into the late crystallizing K-feldspar.

The subtle magnesium enrichment in the rim of a garnet from patchy charnockite can be interpreted as a result of heating; the heat being released from crystallisation of the host leptynite (granite). More magnesian rim could also be related to decompression accompanying emplacement of the leptynite (granite). In this context it is important to note that Sen *et al* (1995) recorded lower pressure (∼ 6 kbar) from patchy charnockites as compared to larger bodies of charnockites (∼ 8 kbar) from the Chilka Lake area.

7. Conclusion and implication

The charnockite patches preserve the imprints of early deformational structures, which are char-

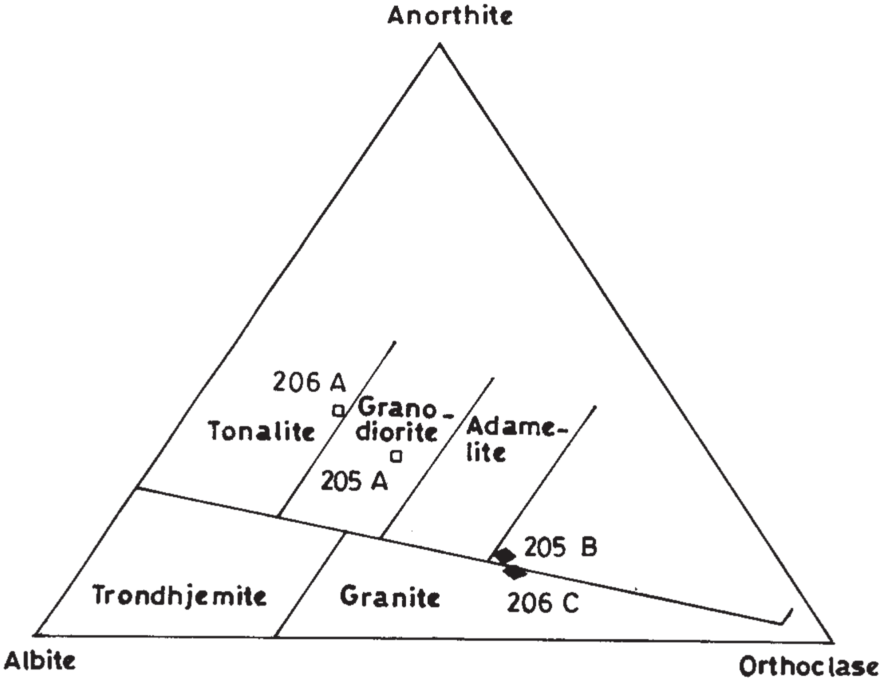

Figure 7. Normative Ab-An-Or proportions of patchy charnockites (box) and adjacent host leptynite (solid rhomb), after Le Maitre (1989); sample numbers are given.

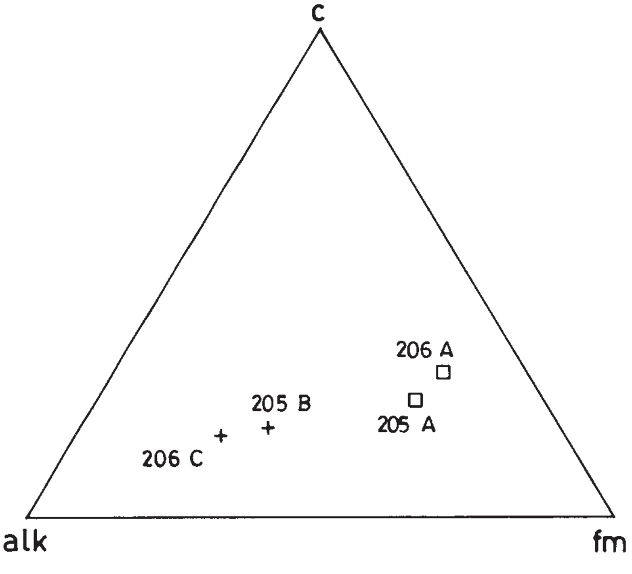

Figure 8. Niggli *c-fm-alk* proportions of patchy charnockites (box) and adjacent host leptynite (plus); sample numbers are given.

acteristically absent in the leptynitic host. Also, the charnockite patches are mineralogically and chemically distinct from the host. The distinctive mineralogy and chemistry, and especially the Rb/Sr ratio, clearly suggests different source rocks for patchy charnockites and leptynites; hornblende and biotite dominated respectively. Hence, it can be concluded that (1) the charnockitic patches are relict and (2) the patchy charnockite and host leptynite are genetically unrelated.

The leptynite is commonly thought to be the product of crustal melting of a pelitic source (Sen 1987; Karmakar and Fukuoka 1992; Sen and Bhattacharya 1997). In the Eastern Ghats, this melting event is correlated to regional F_2 deformation (Sen and Bhattacharya 1997). Notably, the leptynite here also contain only S_2 fabric. On the other hand, the charnockitic patches frequently record F_2 folding and preserve the imprint of S_1 foliation on mesoscopic and microscopic scale. These lead me to suggest that the charnockitic patches originated during or prior to regional F_1 folding event in the Eastern Ghats. Later on, they are caught up within the host leptynite (granitic melt) during F_2 folding.

Finally, the massif-type charnockite body in the adjoining area, which has been interpreted as the product of hornblende-dehydration melting, synkinematic with F_1 deformation (Kar *et al* 2000) and relict charnockite patches with both the structural imprints of F_1 and chemical signature of hornblende-dehydration melting, are most likely cogenetic. An important idea emerges from the present study: charnockitic rocks of different modes of occurrence, if found in adjoining areas, both should be investigated before proposing a petrogenetic model or hypothesis for any one of them.

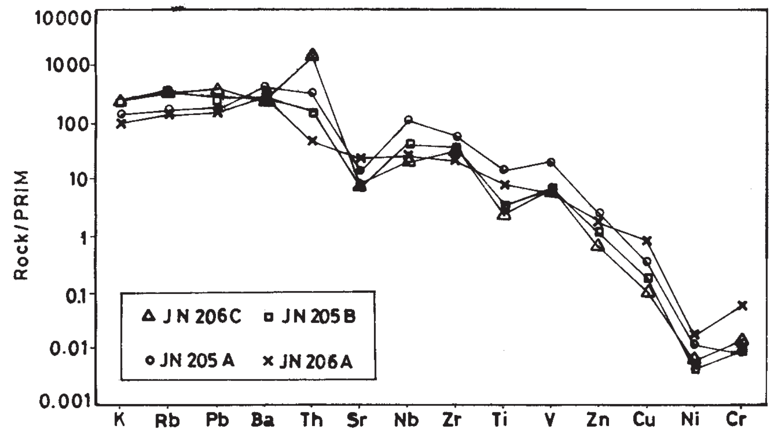

Figure 9. Primitive mantle (PRIM of Taylor and McLennan 1985) normalised multi-element plots of patchy charnockites and host leptynites; sample numbers are given in inset box.

Table 5. *Representative mineral chemistry from patchy charnockite and host orthopyroxene-free granite.*

Sample no.	JN 205A (charnockite patch)								Jen 303 (leucogranite)		
Microdomain	1			2			3		1	2	3
Mineral phases	Garnet		Plag	Garnet	Cpx	Plag	Garnet	Cpx	Plag		
Locations	Core	Rim	Core	Core	Core	Core	Core	Core	Core	Core	Core
Reference no.	5/1	5/2	5/3	5/4	5/5	5/6	5/7	5/8	5/9	5/10	5/11
SiO_2	38.46	40.34	59.74	39.32	53.37	59.81	40.53	52.92	61.19	61.21	60.84
Al_2O_3	21.82	22.37	25.05	22.02	1.93	25.53	22.14	1.79	24.94	25.11	25.25
FeO	26.64	25.15	0	26.69	8.56	0	24.91	9.88	0	0	0
MnO	1.03	0.82	0	0.75	0.05	0	0.68	0.07	0	0	0
MgO	5.65	5.96	0	5.63	15.33	0	6.51	15.09	0	0	0
CaO	6.67	6.72	6.91	6.73	21.59	6.82	6.65	21.31	6.47	6.68	6.31
Na_2O	0	0	6.2	0	0.57	7.22	0	0.59	6.57	6.65	7.85
K_2O	0	0	0.38	0	0.02	0.18	0	0.06	0.39	0.37	0.36
TiO_2	0.07	0.03	0	0.03	0.26	0	0.05	0.27	0	0	0
Summation	100.72	101.39	98.28	101.17	101.68	99.56	101.47	101.98	99.56	100.02	100.61
Oxygen	12	12	8	12	6	8	12	6	8	8	8
Si	2.99	3.09	2.74	3.03	1.94	2.68	3.08	1.92	2.76	2.75	2.69
Al	1.99	2.02	1.35	1.99	0.08	1.35	1.99	0.08	1.33	1.33	1.32
Fe_2	1.74	1.64	-	1.73	0.26	-	1.61	0.29	-	-	-
Fe_3	-	-	-	-	-	-	-	0.01	-	-	-
Mn	0.06	0.04	-	0.04	-	-	0.04	-	-	-	-
Mg	0.65	0.68	-	0.65	0.83	-	0.74	0.82	-	-	-
Ca	0.55	0.55	0.34	0.57	0.84	0.33	0.54	0.83	0.31	0.32	0.29
Na	-	-	0.55	-	0.04	0.63	-	0.04	0.58	0.58	0.67
K	-	-	0.02	-	-	0.01	-	-	0.02	0.02	0.02
Ti	-	-	-	-	-	-	-	0.01	-	-	-
Sum cation	7.98	8.02	5	8.01	3.99	5	8	4	5	5	4.99
X alm	0.58	0.56	NA	0.58	NA	NA	0.55	NA	NA	NA	NA
X py	0.21	0.23	NA	0.22	NA	NA	0.25	NA	NA	NA	NA
X gr	0.18	0.19	NA	0.19	NA	NA	0.19	NA	NA	NA	NA
X sp	0.03	0.02	NA	0.01	NA	NA	0.01	NA	NA	NA	NA
X fsl	NA	NA	NA	NA	0.13	NA	NA	0.15	NA	NA	NA
X en	NA	NA	NA	NA	0.43	NA	NA	0.42	NA	NA	NA
X wo	NA	NA	NA	NA	0.44	NA	NA	0.43	NA	NA	NA
X an	NA	NA	0.37	NA	NA	0.34	NA	NA	0.34	0.35	0.3
X ab	NA	NA	0.6	NA	NA	0.65	NA	NA	0.63	0.63	0.68
X or	NA	NA	0.03	NA	NA	0.01	NA	NA	0.03	0.02	0.02
K_D grt-cpx	NA			0.357			0.428		NA		
T° C	NA			660° C			700° C		NA		
P (kbar)	NA			7.75 kbar			NA		NA		

Note: Plag – Plagioclase; Cpx – Clinopyroxene.

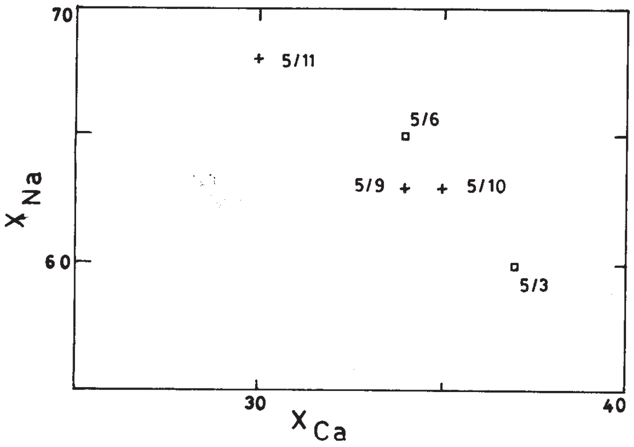

Figure 10. X_{Ca} vs. X_{Na} plots of plagioclase. Box: patchy charnockite. Plus: leucogranite host. Reference numbers follow table 5.

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