RETROGRESSION OF CHARNOCKITES FROM MADUKKARAI, TAMIL NADU—EVIDENCE FROM GEOCHEMISTRY AND FLUID INCLUSIONS

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ABSTRACT

Effect of shearing and retrogression of charnockites is commonly noticed in the area around Madukkarai. Petrographic and geochemical studies suggest uralitization of orthopyroxene and relative elemental mobility during retrogressive stage. Fluid inclusion studies suggest a change in the early carbonic stage to CO_2-H_2O to the late aqueous stage during retrogression of charnockites.

INTRODUCTION

Charnockites are the widespread granulite facies rocks in southern Peninsular India. The massive charnockites exposed in many parts of Tamil Nadu have been traversed by major shear belts termed as Moyar-Bhavani and Noyal-Cauvery shear zones[1]. Within these shear zones, extensive retrogression of charnockites is noticed resulting in the development of epidote-amphibolite facies assemblages[2]. Very little information is available on the process of charnockite in the breaking in southern India.

This study presents field, petrographic and geochemical data on the process of retrogression of charnockites around Madukkarai. The nature of changes in the composition of intergranular fluids during retrogression is also documented by the study of fluid inclusions.

GEOLOGICAL SETTING

The Precambrian terrain around Madukkarai is predominantly composed of calc-gneisses, marbles, calc-granulites, ironstones and garnet-sillimanite-biotite gneisses (khondalites). These supracrustal rocks now occur as huge enclaves within the vast country of charnockites. The various metasedimentary units and the charnockites have been thrown into a series of folds culminating in an anticlinorium trending NNE-SSW. Numerous amphibolites and norites occur as dyke-like bodies within the charnockites. Development of garnet-clinopyroxene-plagioclase-scapolite ± calcite; garnet-sillimainite-biotite-K-feldspar-quartz; and garnet-orthopyroxene-clinopyroxene-plagioclase-quartz assemblages in various lithological units of Madukkarai suggest that they have suffered high-grade regional metamorphism. Based on garnet-biotite and garnet-biotite-sillimanite-plagioclase-quartz assemblages, regional metamorphic pressure and temperatures of 6–7 kbars and 650–700°C are obtained.

Subsequent to granulite facies metamorphism, the area has been dissected by several shear belts during which period retrogressive mineral assemblages have been developed. This is connected with the development of N 80° E – S 80°W to E-W trending major Bhavani and Noyal-Cauvery shear belts probably of Proterozoic age[3]. Emplacement of numerous pink porphyritic granites has been recorded in the area, often filling the fractures developed during shearing.

FIELD OCCURRENCE AND PETROGRAPHY OF CHARNOCKITES

Charnockites around Madukkarai are mainly restricted to low-lying areas, bordering the main mass of supracrustal unit exposed in the central part. Charnockites are greasy, dark-looking, medium to coarse-grained rocks of greenish grey colour. Their general N 80°E to E-W trending foliation conforms to similar trends observed in the metasedimentary units. They exhibit granoblastic mosaic texture indicating thorough recrystallization during granulite facies metamorphism. In coarse-grained rocks, orthopyroxene measuring 1–3 cm is noticed. Based on the mineral assemblages, the charnockites of Madukkarai area can be classified into two types: (i) Plagioclase-orthopyroxene-biotite-K-feldspar ± quartz, and (ii) garnet-plagioclase-orthopyroxene-biotite ± quartz ± sphene.

In thin section, tabular hypersthene ($2V_\alpha$ 53–66°) exhibits strong pleochroism from pink, yellowish green to green. Plagioclase varies in composition from andesine to labradorite. They exhibit well-

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developed twinning often bent and broken lamellae indicating the effect of later deformation. K-feldspar is sub-hedral and is generally microperthitic. Reddish brown biotite is commonly seen. Garnets when present occurs as euhedral to sub-hedral light pink-coloured grains. They show sieved texture with inclusions of quartz and biotite. Quartz occurs as rounded to sub-rounded grains with serrated margins. In more deformed and sheared zones, quartz grains are generally flattened and appear ribbon-like. Recrystallization of quartz, results in the development of neo-blasts all along the grain boundaries.

The effect of shearing and retrogression of charnockitic assemblages appears to be widespread in the area around Madukkarai. Development of two sets of sub-parallel shear planes trending N 45°W to N 50–60°E, cross-cutting the regional foliation is noticed in most of the exposures and quarries examined in the region. Some of these shear planes are filled by quartz + plagioclase + K-feldspar ± biotite bearing pegmatites. As a result of shearing and associated pegmatitic activity, the greasy colour of the charnockite is lost along the shear planes, leaving behind bleached gneissic patches. The width of this bleached zone is highly irregular, varies from a few centimeters to 2–3 m and is mainly related to the intensity of shearing. Serial samples were collected across one such sheared and bleached zone to study any changes that occurred during retrogression. Thin section study reveals almost complete breakdown of hypersthene to bluish green hornblende (uralite). In some of the sections studied, a thorough rehydration resulted in the formation of yellowish brown coloured material, probably smectite, with relic of orthopyroxene. There is a gradual increase in modal amounts of biotite as one approaches from charnockite to bleached zones, with the concomitant decrease in hypersthene. Further, the original biotites present in the charnockites show alteration to chlorite. Presence of all these mineral assemblages indicates a thorough rehydration of charnockitic assemblage resulting in the development of retrogressive minerals.

GEOCHEMISTRY

Major and trace element data for two charnockites and for five serial samples collected in the shear zone are presented in table 1. The samples were analysed using an atomic absorption spectrometer.

Garnetiferous charnockites of Madukkarai show lower Al_2O_3 (13–15 wt.%) and CaO (3–4 wt.%) and higher FeO^t (3–5 wt.%) and MgO (4–6 wt.%) contents when compared to higher Al_2O_3 (16–17 wt.%), CaO (5–8 wt.%) and lower FeO (1.3–3.4 wt.%) and MgO (2.8–4.2 wt.%) content in non-garnetiferous charnockites. To determine whether the precursors for charnockites were para or ortho in nature, the chemical analyses were plotted on various discriminant diagrams like Niggli al-alk vs c, mg vs c and 100 mg-c-(al-alk). In all these diagrams (figures not given) the charnockites fall in the dolomite and pelite field suggesting their para nature. This was also confirmed in the mg vs Cr and mg vs Ni plots where they show negative correlation. The spatial association of charnockites with other meta-sedimentary units like pelites (garnet-sillimanite-biotite-K-feldspar) and carbonates in Madukkarai area further supports their para nature.

Major and trace element studies of rock samples collected across the shear zone suggest the following. There is a general increase in SiO_2, TiO_2 and Na_2O contents with the decrease in MgO (table 1), where progressive stages of retrogression of charnockite are observed. The content of Cr and Ni decreases with the increase in Sr. These features suggest that selective metasomatism occurred during retrogression of charnockites. Such elemental mobility has also been recorded along shearzones elsewhere[4].

FLUID INCLUSIONS

Fluid inclusion study was carried out on serial samples collected across the shear zone using CHAIXMECA microthermometry apparatus. The precision and accuracy of the values reported are within the errors of ±0.2°C. Doubly-polished thin section studies of charnockites and bleached zones indicate presence of three types of inclusions viz: (i) CO_2-rich inclusions, (ii) CO_2-H_2O inclusions, and (iii) H_2O-rich inclusions.

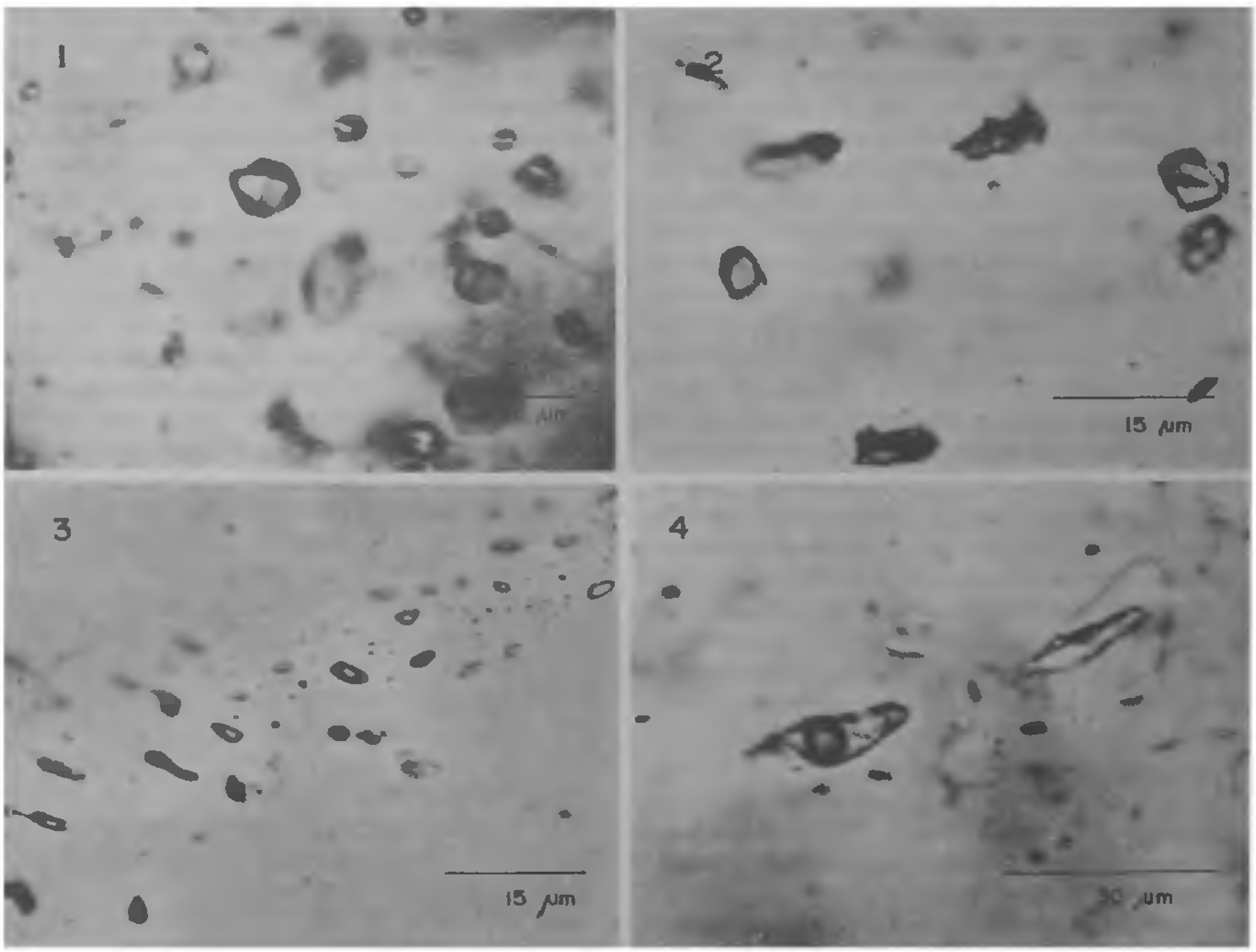
Monophase carbonic inclusions characteristically occur in charnockites. They vary in size from 8 to 10 μm to less than 4 to 5 μm and characterized by a well-developed negative crystal shape (figure 1). The inclusions are generally aligned along healed fractures within quartz grains. Temperature of melting (T_m) of these inclusions varies from −56.6 to −57.7°C indicating them to be almost pure CO_2 inclusions. Temperature of homogenization (T_h) ranges from 5 to 20°C with a density[5] of 0.71–0.91 g/cm^3.

Fluid inclusion studies on samples collected across the sheared/bleached zone show interesting results. Monophase carbonic inclusions are the characteristic types recorded in charnockite samples collected away from the shear plane (JM 62/6) with high density of 0.77 g/cm^3 (table 2). As one approaches the shear plane, there is significant change in the density (0.62 g/cm^3, JM 62/2) as well as the composition of fluids. There is a gradual change in fluid composition from CO_2-rich to H_2O–CO_2 to H_2O-rich inclusions from charnockite to sheared and bleached zones. Some of the CO_2-H_2O inclusions appear bi-phase at room temperature. They show an average degree of filling of 0.1 to 0.2 (H_2O = 10 to 20%; CO_2 = 90 to 80%). These inclusions range in size from 10 to 20 μm and generally appear oval or elongated (figures 2 and 3). T_h of these inclusions varies from 14 to 25°C and final homogenization of CO_2-H_2O takes place at higher temperatures of 112–336°C (table 2). Swanenberg[6] based on Redlich-Kwang equation (MRK) calculated the volumetric properties of the CO_2-H_2O system and constructed combined isochores for CO_2-H_2O fluids for varying degrees of filling and densities. Based on the degree of filling of 0.2, the CO_2-H_2O inclusion shows a density of 0.8 g/cm^3.

H_2O-rich inclusions (figure 4) characteristically occur in samples collected adjacent to pegmatites. They generally cross-cut the early carbonic inclusions and often occur associated with carbonic inclusions in an array. T_m of these inclusions varies from −3 to −6°C indicating their low salinity of 5–8 wt.% NaCl equivalent[7]. T_h varies from 187 to 268°C indicating a density of 0.949–0.888 g/cm^3.

CONCLUSIONS

Field and petrographic study of charnockites around Madukkarai indicates that retrogression of these high grade metamorphic rocks proceeded along a set of shear planes formed during the



Figures 1–4. 1. Isolated negative crystal shape of inclusions in quartz grains; **2,3.** Arrayed CO_2-H_2O inclusions in quartz grains; **4.** H_2O-rich bi-phase inclusions in quartz grains.

Table 1 *Chemical analyses of charnockites and gneisses (ιetrogressed charnockite)*

	1	2	3	4	5	6	7
SiO_2	67.59	69.35	62.92	61.80	65.79	58.60	62.94
Al_2O_3	14.87	13.04	17.59	16.79	16.75	16.96	16.86
TiO_2	0.49	0.30	0.87	0.68	0.49	0.68	0.68
FeO^t	3.20	5.31	2.98	1.33	3.44	3.17	2.70
MgO	5.68	4.04	3.47	2.83	2.77	3.84	4.20
CaO	3.39	4.00	6.58	9.86	5.60	7.25	8.23
Na_2O	4.40	3.43	4.86	5.32	4.21	7.56	3.59
K_2O	0.37	0.24	0.27	0.27	0.19	0.24	0.28
MnO	0.03	0.05	0.03	0.03	0.03	0.02	0.02
P_2O_5	0.17	0.08	0.20	0.17	0.17	0.14	0.12
FeO^t/MgO	0.56	1.31	0.86	0.47	1.24	0.83	0.64
Total	100.19	99.84	99.77	99.08	99.44	99.46	99.62
Trace elements (ppm)							
Cr	116	96	57	41	31	23	24
Ni	54	62	29	24	20	17	17
Rb	24	14	15	13	12	13	14
Sr	196	143	187	196	185	193	198

JM 92–Garnetiferous charnockite; qz 34%, plg 31%, bio 8%, opx 19%, gar, 5%, 1 km south of Kovipudur; JM 92– Garnetiferous charnockite; qz 44%, plg 25%, bio 10%, opx 2%, gar 19%, 2 km south west of Madukkarai; JM 62/2 to JM 62/6 – serial samples collected across the shear plane-Marapalam quarry; JM 62/2 – Gneiss; qz 38%, plg 42%, bio 19%, opx 2%, opa 2%, 6 inches away from pegmatite; JM 62/3 – Geiss; qz 43%, plg 43%, bio 14%, opx 0.15%, 4 ft away from pegmatite and 1 ft away from charnockite patch; JM 62/4 – Charnockite; qz 52%, plg 35%, bio 11%, opx 1%, opx 2%, 6 ft away from pegmatite; JM 62/5 – Charnockite; qz 49%, plg 44%, ortho 0.31%, bio 7%, 9 ft away from pegmatite; JM 62/6 – Charnockite; qz 29%, plg 49%, orth 0.14%, bio 17%, opx 4%, apa 1%, 11 ft away from pegmatite.

Table 2 *Microthermometric results (°C)*

	CO_2 inclusions			CO_2-H_2O inclusions				H_2O inclusions			
Sample number	T_m	T_h	∂(g/cm³)	$T_m CO_2$	$T_h CO_2$	∂(g/cm³)	T_h CO_2-H_2O	T_m	Salanity Wt.% NaCl eqvi.	T_h	∂(g/cm³)
JM 81	−57.2	18–20	0.78	−57.8	9–24	0.87–0.74	204–310	−2 to −3	4	216	0.944
JM 92	−56.6	5–8	0.88					−8.5	12	98–331	0.990–0.743
JM 62/2	−56.8	13–29	0.84–0.64	−56.9	16–22	0.82–0.75	115–298	−3 to −6	8	183–269	0.967–0.879
JM 62/3	−57.7	16–21	0.81–0.77	−57.7	24–25	0.72	236–311				
JM 62/4	−56.6	18–19	0.79	−56.6	19–23	0.85–0.72	298–336				
JM 62/5	−56.7	19–20	0.78	−56.7	19–20	0.78	112				
JM 62/6	−57.4	18–19	0.79	−57.2	14–19	0.82–0.77	28–30				

development of major shear belts in the area. As a result of shearing and pegmatitic activity, the original dark, greenish-grey colour of the charnockites is lost with the concomitant breakdown of pyroxene to give rise to hornblende. Geochemical studies suggest enrichment of certain elements like SiO_2, TiO_2 and K_2O and Sr, and depletion of MgO, Cr and Ni suggesting mobility of elements during retrogression of charnockites. A change in the fluid regime from the early carbonic stage during charnockite formation to CO_2-H_2O to late aqueous inclusions was recorded from the study of fluid inclusions. The early carbonic inclusions show higher density of 0.91 g/cm^3, indicating a pressure of entrapment at the order of 4–5 kb at 700°C. The change from this high density to very low density (0.6 g/cm^3) CO_2-rich inclusions along sheared and retrogressed areas around Madukkarai suggest a drop in fluid pressure at the order of 1.5–2 Kb. Similar observations have been made in the northern part of the area, for e.g. in Nilgiri granulite terrain. High density (1.076 g/gcm^3) CO_2-rich inclusions which predominate in Nilgiris[8] show a change in density to 0.700 g/cm^3 during shearing and retrogression along Bhavani shear belt. Such features may be related to the shearing, upliftment and erosion of the granulite terrain probably during Proterozoic times. Thus, during retrogression, apart from the substantial decrease in the density of CO_2-rich inclusion, the composition of the fluids also changed. The source for these aqueous fluids is the numerous pegmatites which cross-cut charnockites.

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ANNOUNCEMENT

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