CHAPTER VI

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INTRODUCTION:

Sir Thomas Holland (1900), who for the first time described lucidly and in great detail the charnockite series of rocks, gave a number of reasons to consider them as a consanguineous series and opined that they constitute a definite petrographic province. Subsequent to his description from the Madras Presidency and their thorough reinvestigation by many authors, similar rocks have been identified from various other parts in and out of India and are being recognised in pre-cambrian areas in all parts of the world. This problem has now attained world-wide significance. Outstanding summaries of the important published works on charnockites and numerous associated problems are given by Quensel (1951), Pichamuthu (1953), Parran (1958) and more recently by Howie (1964). An attempt is made here to briefly review the different views expressed on the origin of the charnockites in order to indicate how far the propositions of the present investigations tally with them. As the charnockites of this area (Sivasamudram) constitute a part and parcel of the Mysore charnockites, the summary of the views on their origin are given in a separate section.
A Review of the Views on the origin of the charnockites other than those of Mysore

As stated in the beginning of this chapter, the discoverer of the charnockite series—Sir Thomas Holland (op. cit.)—believed that these rocks are a consanguineous suite formed by differentiation and consolidation during a normal plutonic intrusion. This view was accepted and substantiated by Washington (1916), Adams (1929), Tilley (1936 & 1937), Crookshank (1939), Buddington (1939, 1948), Pulfrey (1946), Rajagopalan (1947), Sri Rama Rao (1947), Wilson (1947), Anna Haitman (1947), Holdervaart and Backstrom (1949), Escola (1952) and Leelananda Rao (1956).

But there are quite a number of investigators, who by detailed research, have shown that Holland's petrographic interpretations do not adequately explain the peculiarities of charnockites and have either modified Holland's explanation or offered alternate interpretations. Most of them consider charnockites in their present state as largely metamorphic rocks and not as a normal igneous suite. They, however, differ considerably in their views regarding the type or types of rocks from the recrystallization of which the charnockites are formed and regarding the kind of metamorphism. In the following account, the genetic interpretations which differ from Holland's have been briefly reviewed.
Lebdev (1939) considers the Ukaranian charnockites as abnormal rocks formed by the reaction of acid or granitic magma with metadolerite or metagabbro under deep seated conditions.

Evans (1921) believes charnockites to be derived from the consolidation of a magma contaminated by argillaceous sediments.

Tyrrel (1926) opines that charnockites are either products of primary igneous recrystallization, under conditions of high temperature and great uniform pressure, or that they represent usual plutonic igneous rocks which have undergone slow recrystallization in the solid state on being subjected to plutonic metamorphism. A similar opinion has been expressed by Nockolds (1940), Ferzor (1948) and Turner (1948).

Harker (1909) believes that they resulted from regional metamorphism of plutonic intrusions, Stillwell (1918) from thermal metamorphism of ancient orthoschists, Vredenburg (1918) from thermal metamorphism of Archaean igneous schists (Dharwar Volcanics), Groves (1935) from plutonic metamorphism of ancient foliated biotite granites and their inclusions and Howie (1955 and 1965) from the slow recrystallization in the solid state under plutonic metamorphic conditions of a series of plutonic igneous rocks of usual characters. Subramaniam (1959) considers
only the acid member (viz., charnockites, birkremites, enderbites, hypersthene-quartz-syenites and alaskites) as constituting the charnockite suite and opines that these have undergone metamorphic reconstitution and recrystallization. According to him there is no genetic relationship between them and the basic members which he calls pyroxene granulites.

Ramberg (1952) is of the opinion that enderbites, gneisses and norites of charnockite affinity of western Greenland are products of high grade regional metamorphism of gneisses belonging to the amphibolite and epidote amphibolite facies and not igneous differentiates.

Sutton and Watson (1951) studied the charnockites of Scourie in Sutherland and opined that although the rocks are chemically and often mineralogically similar to many igneous types, their geometrical relations can only have been produced by intense plastic deformation of an essentially solid complex with concomitant recrystallization, so that the rocks, whatever their ultimate origin, must be regarded as metamorphic.

Parras (1958) by his detailed investigation of the v. Uusima complex of S. Finland, regards the mode of origin of some of these rock types as being magmatic while others as metamorphic. Neither is a metamomatic interpretation impossible.
Quensel (1961), in his detailed study of the charnockite series of Varberg district (SW of Sweden), treated the basic members as metamorphosed primary basic igneous rocks corresponding to dolerite and gabbro, acid members as representing in part plutonic metamorphism of surrounding orthogneiss and intermediate members as hybrid rocks formed by the mixing up of rock components of differing chemical composition.

According to Prider (1945), who has studied the charnockites from Dangin, W.Australia, the basic members are formed by the consolidation of a basic magma contaminated with aluminous sediment and the acid and intermediate members are derived from them by subsequent granitization. Naidu (1963), who discards the term charnockite and recommends in its place the term hypersthene bearing rock, believes that the basic and ultrabasic members are differentiated products of a parental noritic magma and the intermediate and acid charnockites are the result of migmatization between the potassic and the older noritic rocks and the Peninsular gneiss.

Bugge (1943) and Polovinkina and Nalivikina (1964) regard the charnockites of Arendal and Ukrainian as products of metasomatism of pre-existing rock complex respectively.

Klimov (1964) et al., regard the East Antarctic charnockites as products of charnockitization and granitization in granulite facies.
Gevers and Dunne (1943) interpret the evidence afforded by the charnockite rocks of Port Edward in Natal as indicative of their formation by Palingenesis and widespread granitization, varying from place to place, of highly metamorphic ancient rocks comprising of granulites, biotite schists and marble.

Legoux (1939) considers the charnockite series of Massif of Man (Ivory coast of W. Africa) as representing granitized products of deep roots of mountains during period of orogeny.

Ghosh (1941) believes that the basic charnockites of Bastar (India) are derived by thermal metamorphism of impure calcareous sediments and the intermediate acid members from later granitization by alkaline solutions of basic members. Muthuswamy (1951) thinks, on the basis of association of scapolite-bearing rocks, that the charnockites, particularly the basic members of the type area (Madras), are products of metamorphism of impure calcareous sediments. Meier (1960) regards the Langoy charnockites as a series of highly metamorphosed geosynclinal sediments. Cooray (1962) opines that the charnockites of Ceylon are high grade metamorphic rocks and at least some basic charnockites there afford evidences of having been formed by the metamorphism of sediments.
Lutz (1964) opines that the charnockites of the Anabar massif constitute a group of sediments and volcanic rocks which have been thoroughly metamorphosed under granulite facies conditions.

Wilson (1964), while describing the petrological features and structural setting of Australian granulites and charnockites, states that the magmatic charnockites have developed in a high temperature and low oxygen environment. Searle (1964), investigating the charnockite series of Ceylon, considers them to be originally volcanic rocks of basic composition which have undergone later metamorphism.

Mahadevan (1964), investigating the charnockite suite of rocks forming part of Western Ghats in Kerala, opines that basic charnockite is not genetically related to the acid members and believes that the latter are products of replacement of the country rocks by alkaline fluids of varying composition under conditions of high mobility. He considers intermediate charnockites to be the products of partial replacement of basic granulites.

Viswanathan et al., (1964) on the basis of the morphology of zircons from charnockites and associated rocks of the Pallavaram, Kanyakumari and parts of Puri, suggest a magmatic origin for the basic and acid charnockites and think that they are not differentiated members of the same magma.
Rode (1964), from his studies in South India and more intimately in Bihar and Rajasthan, where he discovered these rock types for the first time, suggests that they owe their origin not purely to magmatic processes nor to simple metamorphism, but to additive metamorphism induced by deep seated hornblendic intrusives on igneous and sedimentary, granulitised and granitised rock masses in the shield regions.

McIver et al. (1964), investigating the charnockites and associated hypersthene-bearing rocks in Southern Natal, South Africa, suggest two processes for the formation of the more acid hypersthene-bearing rocks. 1) large scale incorporation by a hypersthene-quartz-dioritic magma of alkali felspar rich, siliceous granulites, and 2) probably on a more subordinate scale, an assimilative reaction between the more basic hypersthene-bearing rocks and intrusive leucogranite melts with possibly also local mixing of such magmas.

Dirk De Waard (1964), while investigating the charnockite terrain of the Adirondack Highlands, U.S.A., has recognised charnockites, occurring both in the basement complex and in the supracrustal sequence which are foliated grey green perthitic rocks with metamorphic mineral assemblages and textures. He opines that they developed by high grade metamorphism during the Grenville orogenesis from pre-existing quartzo-felspathic rocks of
diverse origin and of low water content--basement charnockites being derived from norites and anorthosites and supracrustal charnockites from acid volcanic flows.

Hepworth (1964), in his detailed study of the charnockites of Southern West Nile, Uganda, considered them as components of a regionally layered series of highly metamorphosed rocks and stated that "the existing mineral assemblages in the southern west Nile charnockites area, as a result, related to at least two phases of metamorphism—one granulite facies metamorphism superimposed by extensive retrogressive metamorphism."

Robert Macdonald (1964), working on the charnockites of West Nile district of Uganda (Grove's type area), agrees with Grove's thesis on their origin from plutonic metamorphism of igneous and sedimentary assemblage but disagrees with Grove's thesis of a sequence of progressive metamorphism in the Mount Wati region. On the contrary, he has observed general retrogressive metamorphism associated with tectonic reworking, granitization and metasomatism.

Bertolani (1964) is of the opinion that "the little Piemont granulitic charnockitic complex is determined mainly by retrogressive metamorphism due to Hercynic and Alpine metamorphisms which have transformed catazonal rocks in episone schists west of the Insurbric line."
Earlier Views on the genesis of Mysore Charnockites in general and 'Sivasamudram area in particular

The charnockites of Mysore, including those of the Sivasamudram area, have been investigated by many workers, especially by the officers of the Mysore Geological Department. Detailed description of various charnockite exposures, as found in the different parts of the state with particular reference to their mineral assemblages, the transformations they have undergone and their mode of origin in general have been given by Rama Rao (1945) in his important contribution "The charnockite rocks of Mysore, South India" and more recently by Pichamuthu (1953) in his excellent review the "Charnockite Problem".

The earlier officers of the Mysore Geological Department like Slater (1908), Smeeth (1916), Jayaram (1912 & 1913), Sampat Iyengar (1923) believed and subscribed to the view that charnockites are primary igneous rocks, constituting the third and fourth epochs of igneous activity of the Mysore plateau, intrusive into older Peninsular gneiss and in turn intruded by Closepet granites. Further they considered the hypersthene-bearing quartz-magnetite rocks also as members belonging to the charnockite series and treated them as products of local gravitative differentiates of a charnockite magma.
It was Vredenberg (1918) who first questioned the above view and suggested that the charnockites were only the metamorphosed representatives of the Phanerites and that metamorphism was connected with the intrusion of younger (Closepet) granites.

Vredenberg's view did not receive any support and was in fact strongly criticized by Sampat Iyengar (1920). Rama Rao's (1945) work on the charnockites of Mysore by detailed field and petrographic study, confirmed the suggestion of Vredenberg. He compiled 25 years of his work on the charnockites in the above mentioned publication the "Charnockites of Mysore". He opined that they did not represent the differentiated phases of any normal igneous plutonic rock but were formed by repeated metamorphism and granitization of a complex series of rocks of different modes of origin and age. His views on the origin of Mysore charnockites are given below:

1) From repeated metamorphism of composite series of ancient, impure sediments which have given rise by recrystallization to hypersthene granulites with varying silica percentage corresponding to the acid, intermediate or basic divisions of the charnockites depending upon the original composition of the type altered. These are usually fine grained and equigranular.
2) From recrystallization differentiation of the contaminated portions of sheets and sills of basic rocks intruding such sediments giving rise to granulitic norites, hypersthene gabbros and pyroxenites, corresponding to the basic and ultrabasic divisions.

3) From the reaction of alkaline fluids connected with subsequent granitic injection on the basic rocks of the above two series and also from the varied phases of incorporation, digestion, and assimilation of those basic rocks in younger granites, with the formation of intermediate to acid types of charnockites.

He suggested that the acid and intermediate charnockites of the Sivasamudram and Halaguru areas have formed by the digestion and incorporation of norites in the intrusive granites, in which process the hypersthene of norites is possibly scattered as xenocrysts in the gneissic granites. In his very recent publication "A handbook of the Geology of the Mysore State, South India", S. R. Rao (1982) summarises his earlier discussion on the charnockites of the state and defends those views.

Pichamuthu (1953) in his outstanding review "The charnockite Problem" has quite exhaustively covered the contributions on the charnockites of Mysore. He opines that in Mysore there are charnockites of two different ages, the older foliated charnockites formed from high
grade metamorphism of pre-existing Peninsular gneisses and Dharwar schists, and the younger granitic coarse grained charnockites formed by palingenesia and widespread metamorphism. The two crops of charnockites are separated by a period of basic dyke intrusion which contain clouded plagioclase and olivine and the clouding according to him was caused by thermal metamorphism of the dykes associated with the formation of the later palingenetic charnockites. Based on field, microscopic and chemical study (1953, 1959, 1965) he concluded that in quarries of Kabbaldurga there are evidences of metasomatic transformation of gneisses into charnockites and called the process as "Charnockitization." The transformation, according to him, was merely 'isochemical' and took place 'in situ'. He does not however, give the exact reason for the reactivation but states that it was probably associated with epirogenic movements. As regards the role of the younger Closepet granite in the formation of Mysore Charnockites, he states that the Closepet granite has not played as much part in the formation of charnockites as postulated by Vredenberg or Sama Rao and the "Charnockites should be freed from the bondage of Closepet granites."

Radhakrishna (1956) in his account "The Closepet Granites", discusses the relation between the charnockites and closepet granites and has made some useful remarks on the Mysore charnockites. He agrees with Pichamuthu
that Closepet granites have not played any part in the formation of charnockites. "The charnockites represent an older series of metamorphic rocks, which have been affected by closepet granites in a manner quite different to that postulated by Rama Rao. The granites instead of being responsible for the production of charnockites by denoting a higher degree of metamorphism have had the reverse effect of degrading the charnockites to amphibolites." He does not, however, go deep into the problem of origin and evolution of the charnockites as his study was on closepet granites.

In his recent contribution on the Archeans of Mysore, Sadashivaiah (1982) recalls his 1943 work on the charnockites of the Halguru area wherein he had concluded "that the bulk of charnockites in Mysore have been formed due to the assimilation of aluminous sediments by the basic magma giving rise to the norites, wherever these norites have been subjected to injection metamorphism at different energy levels acid and intermediate charnockites have originated."

Recently Devaraju (1967), who has done extensive work on the charnockites of Satnur-Halguru area, has shown that charnockites are older than the associated gneisses and granites and include acid, intermediate, basic and ultrabasic members all of which are essentially of the same age viz., about 2900 m.y. This conclusion
was drawn by him on the basis of field, petrographic, mineralogical, petrochemical and radiometric evidences. According to him the charnockites of the Satnur-Halaguru area, as seen in their present state, are largely metamorphic rocks formed by metamorphism and migmatization of a more uniform rock under the pyroxene-granulite facies. The different members of the series do not represent separate intrusions or differentiates of a common parent magma but are products of metamorphic differentiation and migmatization under the pyroxene-granulite facies. He also states that the gneisses of the area were formed by the complete diabascation of the charnockites, granitization and migmatization under middle or low almandine amphibolite facies conditions, where, apart from still lower temperature and pressure, water was widely prevalent. He opines that the formation of granite, which took place almost in continuity with the formation of gneisses, represents the final episode of the complex plutonic history of the area. Available evidences suggest that the granites did not form by large scale magmatic intrusion but by piecemeal transformation of pre-existing rocks. According to him, they are very much younger than the charnockites and have played no role in the formation of the latter.
CONCLUDING REMARKS

It is evident from the foregoing resume that the genesis of charnockites has been interpreted in more than one way. This may be because, as has been opined by some, there are charnockites formed by more than one process. Disregarding Holland's appeal many investigators (e.g. Parras, 1958) think that the mode of origin is not an essential criterion for the definition of charnockites. The differing opinions, sometimes expressed by different investigators on the charnockites of one and the same locality, appear to be dependent upon several factors like the difference in the nature of evidence adduced and personal bias for some particular evidence. This is further complicated by the fact that the same evidence could be interpreted in more than one way. Realising the above it is sometimes remarked that more importance should be given for accurate description of the regional setting and not to the manner in which the genesis is interpreted.

It is now generally agreed that the charnockite series are restricted in their occurrence to the deeply eroded Precambrian terrains, their mineral assemblage, texture and other distinctive characters having been determined by their recrystallization (either metamorphic or magmatic) under the granulite facies conditions.
With the background of the foregoing account on the genesis of the charnockites, the author has endeavoured to discuss the genesis of the Sivasamudram charnockites.

**Discussion of the mode of formation of Sivasamudram Charnockites**

In order to give a satisfactory explanation of the mode of formation of the Sivasamudram charnockites it is necessary to consider the petrographic, field, mineralogical and chemical characters. So, in the following pages a critical discussion of the significance of these aspects is carried out.

A. **FIELD CHARACTERS**

1. The occurrence of charnockites within the Archaean terrain, subjected to long and continuous denudation exposing rocks of very deep seated origin and characterized as a whole by plutonic metamorphism.

   This is true all over the world without exception and has been considered as one of their peculiarities. Noting this, Howie (1955) remarks that charnockites may be probably of pre cambrian age.

2. Absence of an intrusive and transgressive relationship and contact aureoles.
This character may be argued from the magmatist point of view as due to their formation by the consolidation of a deep-seated intrusion which excluded chilling and other intrusive effects. The above statement cannot satisfactorily explain the characters cited below.

3. The inclusion like occurrence of charnockites in gneisses suggests that charnockites are older which has been confirmed by radiometric evidence. The contacts of the inclusion, particularly of acid charnockites, are gradational and there are sufficient evidences suggesting the breakdown and transformation of charnockites into gneisses by granitization and migmatization.

4. It is already pointed out that there is no regular sequence between the different charnockite varieties namely acid, intermediate, basic and ultrabasic as observed in the differentiated mafic igneous complexes. Neither there is an intrusive relationship of one member with the other. In addition to this, the radiometric age data shows that the different charnockite varieties are essentially of the same age.

5. Occurrence of metasedimentary intercalations like calc-silicate rocks, pyroxene-quartz-magnetite rocks and quartzites.

Metasediments and charnockites bear conformable relationship; the foliation planes, banding and margins
of each other are nearly parallel in every outcrop.

Occurrence of metasedimentary intercalations in charnockites is not a rare feature. It has been reported from all over the world including the type area, Madras. The association of the two rocks has been interpreted in many ways. Holland (1900) also noted the occurrence of metasedimentary inclusions, consisting principally of microperthite, corundum, sillimanite, rutile, hercynite and biotite considered it to be an evidence in favour of a magmatic origin. Like Prider (op. cit.) and Rama Rao (1945), some have observed evidences of assimilation of metasediments by charnockites and argued that they have acquired their mineral composition and other characters through assimilation. But others believe that the very association of metasediments with charnockites itself is an important indication of their formation by the metamorphism of sediments. They give conformable field and occasional gradational relations between the two rocks as evidences in support of their conclusions.

From his own observations the author of this thesis has come to the conclusion that except for their intimate association the various metasediments have not played any role in the formation of charnockites.

6. The Banded and foliated nature of the charnockites:

The banded and foliated nature of the charnockites is a common feature. Holland (1900) also observed such a
feature and considered it not as due to dynamothermal metamorphism, but due to the arrangement of crystals perpendicular to the direction of maximum pressure before consolidation.

As already described earlier (chapter II) banding and foliation are prominent in acid and intermediate varieties, which are due to the alternation of basic and acid bands, basic bands of the composition intermediate to basic and acid bands of acid charnockite composition. In basic charnockites linear parallelism of components is characteristic rendering the rocks foliated and schistose. This perfect banding which is seen commonly though explained in different ways, the authors of this thesis feels that in charnockites it should be regarded as one of the feature suggestive of their metamorphic origin.

B. Petrographic Characters:

1. Charnockites are remarkably fresh both in hand specimen and in sections. This character has not been satisfactorily interpreted. Formor (1936) attributed it to the preservation of the hypometamorphic impress in toto or in charnockites and regarded it as an evidence of relative upliftment of the charnockite region by faulting after the isothermals in the earth's crust had fallen sufficiently, prior to the fall of pressure. Radhakrishna (1952 pp. 36-44) thinks that this peculiarity is due to exposure at the surface.
in relatively recent times and is connected with selective uplift along faults of only the isolated masses of charnockites like the Nilgiris, the Shevaroys and the Billigirirangan hills, during the past Miocene period. Pichamuthu (1953 p. 148) also remarks that the comparatively recent uplift of these rocks is probably the reason for their freshness. Howie (1955) regards their fresh appearance as an evidence of deep-seated metamorphism. The author of this thesis is of the opinion that the freshness of these rocks is possibly due to the absence of hydrothermal alteration and cataclasis, subsequent to their formation under plutonic condition irrespective of its time of upliftment (recent or otherwise).

2. Irregular and rapid variation of grain size, as well as the relative proportion of the minerals within a small outcrop is a factor that cannot be satisfactorily explained by magmatic origin.

3. Their xenomorphic granular texture and absence of pronounced porphyritic crystals.

Though Holland (1900) was able to explain this character as magmatic he was not satisfied as he felt it was an unusual character in an igneous rock. Those who advocate a metamorphic origin for charnockites, consider this character as an important evidence of a metamorphic origin. The author of this thesis endorses the view.
4. The rounded and embayed margins of the pyroxenes is also suggestive of a metamorphic origin as advocated by Howie (op. cit.).

5. The frequent occurrence of one mineral in another is also not a common feature in igneous rocks.

6. Evidences of strain like undulose extinction, elongation of minerals parallel to bending and foliation, passing of fracture plane through all the minerals, fracturing and bending of twin lamellae, cleavages and peripheral granulation are again features of metamorphic origin.

7. Presence of myrmekitic borders around potash felspar:

Holland (op. cit.) explained myrmekite from the magmatic point of view, considering it as a feature resulting from the action of residual alkali fluids derived from the charnockite magma. After the publication of Holland's memoir in 1900 a lot of work has been done on myrmekites and myrmekitization and it is now generally agreed that it is a metamorphic feature developed essentially in the solid state by the replacement of one felspar by another. In the case of Sivasamudram charnockites, there are numerous evidences to consider myrmekite as metamorphic caused by the replacement of sodalime felspar by the potash felspar metasomatically.
3. The occurrence of two generations of quartz, the quartz of an earlier generation occurring as inclusions within the pyriboles and felspars and the later generation as patches, invariably showing undulose extinction and carrying random hair like inclusions. It is difficult to explain this feature by a magmatic hypothesis.

Mineralogical Characters:

1. There is no regularity in the appearance and disappearance of minerals from ultrabasic to acid members as seen in a definite consanguineous series of igneous rocks. Pyroxene and plagioclase of almost the same composition occur in all the members of the charnockite series. Holland (op. cit.) stated that this abnormality makes them different from normal igneous rocks.

2. Nature of Plagioclase:

a) Narrow range of compositional variation

Plagioclase which is a dominant felspar in the enderbitic, intermediate and basic members, has an unusually narrow range of variation in the anorthite content from 25 to 50%, which cannot be explained by a magmatic hypothesis.

b) Antiperthitic Nature:

The plagioclase that occurs in acid, intermediate and basic varieties is very commonly antiperthitic.
According to Ramberg (1952), the antiporphitic nature of plagioclase is rarely seen in the plagioclase of igneous rocks, but is characteristic of those occurring in rocks formed under the granulite facies conditions of metamorphism.

c) Absence of zoning:

The plagioclase of charnockites are unzoned which is characteristic of rocks of deep seated origin. This feature along with the other characters can be taken into consideration as an evidence of their formation by metamorphism.

d) The nature of Twinning:

The plagioclases of charnockites are both twinned and untwinned. The untwinned plagioclases are more common than the twinned, showing evidences of strain. Even among the twinned grains, twinning is faint, patchy, discontinuous and distorted. Donnay (1943) regards discontinuous and distorted twin lamellae as characteristic of metamorphic and hybrid rocks and Kohler (1948) considers the poor development of twin lamellae as characteristic of plagioclase felspar formed at low temperatures.

A study of the twin laws of plagioclase reveals that they are more frequently twinned after the albite law. Twinning according to the mansbach-ala and albite-ala
laws are not uncommon while manebach and pericline laws are less observed. Twinning after the albite-carlsbad and carlsbad laws which is characteristic of plagioclase occurring in igneous rocks is absent. These twin laws thus indicate the formation of fivaseumudram charnockites under plutonic conditions (Naidu, 1963) by metamorphism (Turner, 1951; Goral, 1951 and others).

3. Nature of Orthopyroxene:

a) Strong pleochroism

Unlike the orthopyroxenes of igneous rocks, which are almost non-pleochroic, the orthopyroxenes of charnockites are strongly pleochroic. According to Bowie (1755), it is common in rocks of deep-seated origin and can well be considered as a criterion of their formation under metamorphic conditions.

b) The occurrence of orthopyroxene of almost the same composition from acid to ultrabasic members:

Though the orthopyroxenes of charnockites range in composition from bronzite to ferrohypersthene they do not exhibit a systematic variation in their composition with the basicity of the rocks. It is a feature which cannot be satisfactorily explained by magmatic hypothesis.
4. **Nature of Clinopyroxene**

The clinopyroxenes of the charnockites have almost the same optical characters thereby the composition too, which is again a feature that contradicts the idea of charnockites being a consanguineous series of igneous rocks.

5. Zircons which are common accessory minerals are rounded and ovoidal suggesting a metamorphic and metasomatic origin (Poldervaart, 1954).

6. The typical metamorphic minerals like scapolite and sillimanite, which are common in metasediments are absent in charnockites. Even garnet which is abundant in metasediments is scarce in charnockites. Moreover field evidence shows that the two have neither gradational relationship nor show any intermixing.

**Chemical Characters:**

It has already been pointed out while discussing the petrochemistry of the rocks, that the charnockites of the area do not have any exceptional chemical composition. In terms of the main elements chemical composition, as Parras (1958) puts it, "may be interpreted as being members of the calc-alkaline suite of plutonic rocks."

When the chemical analyses of charnockites are plotted on Larsen and Miggli type of variation diagrams,
they fall on smooth curves. Howie (1955) also observed such a feature in his geochemical study of the Madras charnockites and commented that this feature "could hardly be the case for any random series of sediments."

The above mentioned characters of charnockites have made many investigators to look upon them as some of the incredible reasons for considering them as normal igneous rocks, which acquired the characters of a charnockite either by consolidation of the magma under deep-seated conditions, as opined by Holland (op. cit.), Rajagopalan (1947) and Leelananda Rao (1956), or by slow recrystallization of such normal igneous rocks under plutonic metamorphic conditions, as opined by Groves (1935) and Howie (1955, 1965). On the contrary, Heier (1960), who by his detailed investigation of both the main and trace elements of Langoy charnockites, has concluded that "the chemistry of these rocks, prevents the use of this kind of data a proof of their origin." He also obtained smooth curves identical to those of Howie (1959), for the Madras charnockites, by plotting the major elements of the rocks on the "Larsen type" variation diagram. He argued that "the fact that the major elements of the diversely originated rocks of Langoy, all plot on relatively smooth curves on the variation diagram of the Larsen type shows especially well the futility of using them as indicators of the origin of these highly metamorphosed rocks."
The author of this thesis after considering his own evidences and those of others interprets the chemical data in the following manner.

The chemical data suggests that the parent rocks of charnockites had a composition comparable with the calc-alkaline series of plutonic rocks, which by metamorphism under the granulite facies gave rise to charnockites. It neither suggests that they are igneous nor does it prove that they were igneous before they acquired the present character through metamorphism. Such an interpretation looks feasible, when it is known that the chemical composition of any common igneous rock can be compared to known sediments. So it suggests, as Heier puts it, that chemical data is not useful in interpreting their origin and is not opposed to considering charnockites as metamorphic rocks as is clearly indicated by their field, petrographic and mineralogical characters.

Critical Examination of the earlier postulations on the origin of the Mysore Charnockites in general and the Sivagamudram charnockites in particular in the light of the present observations:

The various field, petrographic and mineralogical evidences suggest that charnockites are not intrusives (no evidence of intrusion in field) and differentiated phases of crystallisation of an intrusive magma as opined
by the earlier officers of the State Geological Survey viz., Slater (1908), Smeeth (1916), Jayaram (1912 and 1917) and Sampat Iyengar (1920) but are metamorphic rocks. Evidences enumerated earlier (page 137) make it clear that the hypersthene bearing quartz-magnetite rocks which were regarded by the earlier officers of the Survey as one of the members of the charnockite series are an entirely different unit with no genetic relation whatsoever with the charnockites except for their development under the same metamorphic conditions, as those of the associated charnockites.

Based on the present observations it can be said that Vredenberg (1918) and Rama Rao (1945) are correct to the extent of interpreting charnockites as metamorphic rocks but their idea of how and when the metamorphosis took place and the mode of evolution of charnockites is not acceptable. The very fact that charnockites are much older than granites and that they received a metamorphic impress long before the formation of the Closepet granites rules out the view of Vredenberg (1918) and Rama Rao (op. cit.) that the formation of charnockite was intimately connected with the injection of granite. Further, Rama Rao's (1945) view that the acid and intermediate charnockites were formed by the disintegration, assimilation and incorporation of norites in the younger Closepet granite and the activity of the alkaline fluids connected with
their intrusion, becomes unacceptable. This has also been pointed out by Pichamuthu (1953) and Radhakrishna (1956). Evidences are lacking to support Rama Rao's (1945) view that the basic and ultrabasic members are products of crystallisation differentiation of a contaminated basic magma and that the hypersthene of charnockites is always secondary after various minerals like hornblende and biotite. It is actually the other way viz., hornblende and biotite are secondary after pyroxenes.

Pichamuthu (1953, 1959, 1961 and 1963), on the basis of field, microscopic and chemical study demonstrated that there are evidences of transformation of gneisses to charnockites ("charnockitization"). This view of Pichamuthu is not substantiated by the present petrological study and radiometric age data which have revealed that the charnockites are the oldest rocks and show evidences of conversion to gneisses ("gneissification"). Likewise Pichamuthu's view (1959b), that there are charnockites belonging to two generations - older ones formed from regional and thermal metamorphism of Peninsular gneiss and Dharwars and younger charnockites formed by palingenetic fusion and widespread metasomatism - separated from each other by a period of basic dyke intrusion, also finds no support from the present investigation. As has been shown recently by Devaraju and Sadasivaiah (1966) the basic dykes of the area are the youngest rocks bearing intrusive
relationship and chilling against granites, gneisses and charnockites and the clouding of plagioclase occurring in them is due to the action of diuteric solutions and not due to thermal metamorphism.

DISCUSSION ON THE PARENTAGE, PREMETAMORPHIC HISTORY AND MUTUAL RELATIONSHIP OF CHARNOCKITES

Parentage and Premetamorphic history

When a metamorphic origin is ascribed to any rock, the problem of parentage and premetamorphic history of the rock also inevitably arises. Nothing can be told very definitely about this aspect of charnockites or for that matter many other rocks of similar deep seated origin. It may be due to the fact that at depths both metamorphic and igneous activities merge into one another and yield an end product of identical character within a given range of temperature and pressure (Turner and Verhoogen, 1960).

Recent investigations have revealed that charnockites are high grade metamorphic rocks formed under the granulite facies conditions of metamorphism, but they fail to give any definite idea about the parentage. Authors like Groves (op. cit.), Nockolds (op. cit.) and Howie (1955) believe that charnockites were originally calc-alkaline igneous rocks (i.e. before they acquired the present charnockite), impress). Ghosh (op. cit.), Muthuswamy (op.cit.),
Heier (1960) and Cooray (1962) on the basis of the field association of charnockites with metasediments think that they represent completely or partially reconstructed sediments. Heier (op. cit.) in particular who has done a detailed investigation of their chemistry opines that the use of such data as a proof of their origin is not possible as their chemistry closely resembles calc-alkaline igneous rocks and considers them on the basis of field evidences and association with metasedimentary rocks as highly metamorphosed geosynclinal sediments and lavas. He defends further by stating that there is hardly any igneous rocks whose compositions are not comparable to known sediments.

The Sivasamudram charnockites as already stated are intimately associated with metasediments and bear a conformable relation with them. They both possess mineral assemblages indicative of their formation under identical metamorphic conditions (pyroxene–granulite facies) but there is hardly any gradational relationship between the two. The metasediments which have altogether a different chemical composition provide ample petrological and mineral evidences to consider them as metamorphosed sediments, whereas the charnockite possess a normal chemical composition comparable to any calc-alkaline igneous rocks.

In the present state of knowledge it may be said that the charnockites and metasediments are contemporaneous.
and acquired the present characters by their thorough recrystallization under the pyroxene-granulite facies conditions. The two may represent inter-banded rocks before metamorphism. With the available evidences it is difficult to decide whether the parent rocks were completely igneous or sedimentary or partly igneous and partly sedimentary.

The mutual relationship of the different charnockite members:

Holland (op. cit.) considered that charnockites are magmatic and its different members are consanguineous and result from magmatic differentiation. Such an idea still prevails among some investigators. But Groves (1935), Howie (1955) and others who by their detailed chemical study attribute a metamorphic origin to charnockites think that the present variation in composition from acid to ultrabasic is due to a similar variation in the parent rock. Quite a few think that ultrabasic and basic members are magmatic products of a normal basic magma (Naidu, 1963) or contaminated basic magma (Prider, 1945, Rama Rao 1945), while the intermediate and acid members are the result of migmatization and granitization of basic charnockite, there is no consanguinity between the basic and acid members.

Rama Rao (op. cit.), observing the occurrence of basic charnockite inclusions in acid members in various stages of digestion, concluded that the basic members
constitute older noritic rocks and the acid and intermediate as having been forward by assimilation and migmatization brought about by the Closepet granite intrusion.

The occurrence of basic and ultrabasic charnockites as inclusions within acid members no doubt suggests beyond doubt that the former are older. But the radiometric dating has indicated the same age for all the members, pointing out their contemporaneous formation. With the available evidences it is possible to interpret the relationship between the different charnockite members in one of the ways given below.

1. It is possible that different charnockite members were derived from an original more uniform parent rock by metamorphic differentiation under the granulite facies conditions.

2. They may represent original granitic rocks with basic inclusions, which by metamorphism and migmatization under the granulite facies have given rise to the charnockites. In this way, the basic and ultrabasic members represent recrystallized original basic inclusions while the acid and intermediate represent the recrystallized original granitic portions. This can explain the inclusion like occurrence of basic members in the acid members adequately.
3. They may also represent a series of recrystallized sediments in which case the different members result from the variation in the composition of original sediments or from metamorphic differentiation. It is also possible that the basic members represent original basic sills and dykes, while the acid members represent the sediments.

The evolution of charnockites and associated rocks of the area are dealt with in a separate chapter (XIV) at the end of the thesis.