CHAPTER VI.

PETROGENESIS

Introduction:

Sir Thomas Holland (1900) who, for the first time described so lucidly and in such great detail the charnockite series of rocks, gave a number of reasons to consider them as a consanguineous series of rocks and opined that they constitute a definite petrographic province. Subsequent to Holland's description from Madras Presidency, besides the thorough re-investigation of this type locality by a number of authors, these rocks have been identified from various other parts, in and outside India, and are being increasingly recognised in Pre-Cambrian areas in all parts of the world and the subject, which was
once an Indian problem, has now assumed a global significance. The results of these investigations have appeared in numerous research papers in which a large volume of data has been brought to light and a host of problems connected with this series of rocks have been discussed. Excellent summaries of the published works on charnockites and numerous associated problems have been given by Mensel (1951), Pichamuthu (1953), Parras (1958) and more recently by Howie (1964). An attempt is made here to give a very brief resume of the different views that have been expressed on the origin of charnockites in order to indicate how far the postulations of the present investigation tally with them. As the charnockites of the present investigation constitute an important part and parcel of the Mysore Charnockites the summary of the views on the origin of the latter are given in a separate section.

In the following review, the interpretations which are almost similar are grouped together and are arranged more or less in the increasing order of divergence from the original interpretation of Holland.
A review of the views on the origin of the charnockites other than those of Mysore:

As has been stated in the beginning of this Chapter, the discoverer of the charnockite series, Sir Thomas Holland (op.cit), believed that these rocks present a consanguineous suite formed by the differentiation and consolidation of a normal plutonic intrusion. This view was accepted and substantiated by Washington (1916), Adams (1929), Tilley (1936, 1937a), Crookshank (1938), Buddington (1939 & 1948), Pulfrey (1946), Rajagopalan (1947), Srirama Rao (1947), Wilson (1947), Anna Hietnan (1947), Foldervoart and Backstrom (1949), Eskola (1952) and Leelananda Rao (1956). But there are quite a number of investigators who by their detailed research have shown that Holland's petrogenetic interpretation does not adequately explain the peculiarities of charnockites and they have either modified Holland's explanation or offered alternative 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 recrystallisation of which the charnockites are formed and regarding the kind of metamorphism. In the following account, the genetic interpret-
functions which differ from Halland's have been briefly reviewed.

Lebedev (1939) considers the Ukraine charnockites as abnormal igneous rocks formed by 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.

Tyrrell (1926) opines that charnockites are either products of primary igneous crystallisation under conditions of high temperature and great uniform pressure or that they represent usual plutonic igneous rocks which have undergone slow recrystallisation in the solid state on being subjected to plutonic metamorphism. A similar opinion has been expressed by Nöckolds (1940), Fermor (1946) and Turner (1948).

Marker (1909) believes that they resulted from regional metamorphism of plutonic intrusions, Stillwell (1913) from thermal metamorphism of ancient orthoschists, Vredenberg (1918) from thermal metamorphism of Archaean igneous schists (Dharwar volcanics), Groves (1935) from plutonic metamorphism of ancient, foliated biotite granites and
their inclusions and Hewie (1955 and 1965) from the slow recrystallisation in the solid state under plutonic metamorphic conditions of a series of plutonic igneous rocks of the usual characters. Subramaniam (1959) considers only the acid members (vis., charnockites or birkremites, enderbites, hypersthene-quartz syenites and alaskites) as constituting the charnockite suite and opines that these represent igneous suite which has undergone metamorphic reconstitution and recrystallisation. According to him, there is no genetic relation between them and the basic members which he calls as pyroxene-granulites.

Ramberg (1952) is of the opinion that the enderbitic 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 charnockitic rocks 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 recrystallisation, so that the rocks, whatever their ultimate origin, must be regarded as metamorphic.
W. Uusimaa complex of Southern Finland, states "Regarding the mode of origin, some of these rock types may be interpreted as being magmatic, while others are metamorphic. Neither is a metasomatic interpretation impossible in a limited sense" (p.114).

Quensel (1951), in his detailed study of the charnockite series of Verberg 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 plutometamorphic transformation of the surrounding orthogneiss and intermediate members as hybrid-rocks formed by the mixing up of rock components of different chemical composition. According to Rider (1945), who has studied the charnockites from Bangi, Australia, the basic members are formed by the consolidation of basic magma contaminated with aluminous sediments and the acid and intermediate members are derived from them by subsequent granitisation. Naidu (1963), who discards the use of the term "charnockite" and recommends in its place the term "hypersthen-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 migmatisation.
between the potassic granites and the older noritic rocks and the Peninsular gneisses.

Bunge (1943) and Pelovinkina and Palivkina (1964) regard the charnockites of Arendal and Ukraine as products of metasomatism of a pre-existing rock complex respectively. Klimov, et al. (1964) regard the East Antarctic charnockites as products of charnockitisation — granitisation in granulite facies.

Gevers and Dunne (1943) interpret the evidences afforded by the charnockitic rocks of Port Edward in Natal as indicative of their formation by palingenesis and widespread granitisation, varying from place to place, of highly metamorphic ancient rocks comprising granulites, biotite schists and marbles.

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

Ghosh (1941) believes that the basic charnockite members of Bastar, India, are derived by thermal metamorphism of impure calcareous sediments and the intermediate and acid members from later granitisation by alkaline solutions of the basic members. Kuthuswamy (1951) thinks on the basis of the association of scapolite-bearing rocks,
that the charnockites particularly the basic members of the type area i.e. Madras, are products of metamorphism of impure calcareous sediments. Meier (1960) regards the Langoy charnockites as a series of highly metamorphosed geosynclinal sediments. Corray (1962) opines that the charnockites of Ceylon are high-grade metamorphic rocks and at least some basic charnockites of the area afford evidences of having been formed by the metamorphism of sediments. Luts (1964) opines that the charnockites of the Anabar Massive constitute a group of sediments and volcanic rocks which have been thoroughly metamorphosed under the conditions of the granulite facies.
Earlier views on the genesis of Mysore charnockites in general and Satnur-Halaguru charnockites in particular.

The charnockites of Mysore including those of the Satnur-Halaguru area have been investigated by several workers, especially by the officers of the State Geological Department. Detailed descriptions of the 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, (Southern India)" and more recently by Pichamuthu (1953) in his excellent review "The charnockite Problem".

The earlier officers of the State Geological Survey, like Slater (1906), Smeeth (1916), Jayaram (1912 & 1913) Sampat Iyengar believed and subscribed to the view that charnockites are primary igneous rocks, constituting the third of the four epochs of igneous activity of the Mysore Plateau, intrusive into the older Peninsular gneisses and were in turn intruded by Closepet granites. Further, they considered the associated hypersthene-bearing quartz-magnetite rocks as also members belonging to the charnockite series and treated them as products of
local gravitational differentiates of charnockite magma.

It was Vredenberg (1916, pp. 433-44) who first questioned the above view and suggested that the charnockites were only the metamorphosed representatives of the Dharwars and that metamorphism was connected with the intrusion of the younger (Closapet) granites.

Vredenberg's view did not receive any support, and was in fact strongly criticised by Sampat Iyengar (1920). Kama Rao, who has done the largest amount of work on the charnockites of Mysore, by his detailed field and petrographic study, confirmed the suggestion of Vredenberg. He compiled in the year 1945, his work of 25 years on the charnockites of Mysore, in the previously cited publication "The charnockite rocks of Mysore". He opined that the charnockites of Mysore did not represent the differentiated phases of any normal igneous plutonic rock mass, but were formed by repeated metamorphism and granitisation of a complex series of rocks of different modes of origin and age. According to him, the charnockites of Mysore have resulted as described below:

1. From repeated metamorphism of a composite series of ancient, impure sediments which have given rise, by recrystallisation, 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 equi-granular.

2. From recrystallisation differentiation of 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 of the charnockites.

3. From the reaction of alkaline fluids connected with subsequent granitic injections, 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 the younger granites, with the formation of intermediate to acid types of the charnockites. "

He suggested that the acid and intermediate charnockites of the Malaguru and Sivasamudram areas have formed by the "disintegration and incorporation of the norites in the intrusive granites, in which process the hypersthene of the norites is possibly scattered as xenocrysts in the gneissic granites". In his very recent publication "A handbook of the geology of the Mysore State, Southern India" Rama Rae (1962) summarises his earlier discussions on the charnockites of the State and defends his earlier views expressed.
Pichamuthu (1953) in his outstanding review work "The charnockite problem" has quite exhaustively covered the contribution on the charnockites of Mysore. He opines that in Mysore there are charnockites of two different ages: the older granulitic and foliated charnockites formed from the high grade metamorphism of pre-existing peninsular gneisses and Dharwar schists and the younger, granitic and coarse-grained charnockites formed by palingenesis and widespread metamorphism. The two crops of charnockites are separated by a period of basic dyke intrusions which contain clouded plagioclase and olivine and the clouding according to him was caused by thermal metamorphism of the dykes by the later palingenetic charnockites. Based on field, microscopic and chemical study, Pichamuthu (1953, 1959 & 1965), concluded that in quarries of Kabbaldurga there are evidences of "metasomatic transformation of gneisses into charnockites" and called the process as "Charnockitisation". The transformation, according to him, was "nearly isochemical and took place 'in situ'. He does not, however, give the exact reason for this "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 Vredenborg or Rama Rao (p.147) and the "charnockites should be freed from the bondage of Closepet granites" (p.136).

Radhakrishna (1956), in his account on 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 Khushnuma that Closepet granites played no role 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 charnockite types 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 main study was on Closepet granites.

In his "recent contribution on the Archaean's of Mysore" Sadashivaiah (1962) recalls his 1943 work on the charnockites of the Halaguru area wherein he had concluded "that the bulk of the 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" (1962, p.65).

Concluding remarks of the author:

It is evident from the foregoing resume that the genesis of charnockites has been interpreted in more than one way. This may be due to the fact, as has been opined by some of the authors, that there are 'charnockites and charnockites' and charnockites can form by more than one way. And now disregarding Holland's appeal many investigators (e.g., Parras, 1958) opine that 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 evidences adduced and a personal bias for a particular evidence. This is further complicated by the fact that one and the same set of evidences could be interpreted in more than one way. Realising the above, it is sometimes remarked that we should give more importance for the 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 of rocks are restricted in their occurrence to the deeply eroded Pre-Cambrian terrains, their mineral assemblage, texture and other distinctive characters have been determined by their crystallization (either magmatic or metamorphic) under the granulite facies conditions.

With a background of the foregoing account on the genesis of the charnockites, the author of this thesis has endeavoured to discuss the genesis of the Satnur-Halaguru charnockites.
Discussion of the mode of formation of Satnur-Halaguru charnockites.

In any attempt to reconstruct satisfactorily the mode of formation of the charnockites of the Satnur-Halaguru area, it is essential to take into consideration their field and petrological characters. So, in the following pages the significance of the field, petrographic, mineralogical and chemical characters of the rocks is critically discussed.

A. Field characters :

1. The occurrence of charnockites within the Archaean formation, which has been subjected to long continued denudation, exposing rocks of very deep-seated origin and characterized as a whole by plutonic metamorphism — This is also true of charnockites occurring all the world-over, without exception. In fact, this feature is now being considered as one of the peculiarities of charnockites. Realizing this, Bowis (1955) remarks that charnockites may be probably of Pre-Cambrian age.

2. Absence of transgressive and intrusive relationships and contact aureoles.

From the magmatist point of view, it may be argued that this character of charnockites is due to their
formation by the consolidation of deep-seated intrusion which prevented chilling and other intrusive effects. But this argument cannot satisfactorily explain the other characters of charnockites described below.

4. Lack of regularity in the distribution of charnockite varieties.

It is already pointed out (see Chapter IX), that the different charnockite varieties of the area vis., acid, intermediate, basic and ultrabasic, do not show regular sequence characteristic of differentiated rocks of magmatic origin. Neither is there anything like an intrusive relationship of one member with the other. Added to this the radiometric age data (see also Chapter XIV) shows that the different charnockite varieties are essentially of the same age. All these observations favour the formation of charnockites under metamorphic conditions rather than by magmatic differentiation.

5. Occurrence of metasedimentary intercalations like pelitic gneisses (with sillimanite, cordierite, garnet etc.), calc-silicate granulites (with scapolite, basic plagioclase, garnet, hedenbergite etc.), pyroxene-quartz-magnetite rocks and quartzites.

The metasediments and charnockites lie conformably to each other, their foliation planes, banding and margins being parallel to each other in nearly every exposure.
Occurrence of metasedimentary intercalations like those in the Satnur-Halaguru charnockites is not unusual. They have been recorded in many of the charnockite localities the world-over, including the type area viz., Madras. The significance of the association of the two rocks has been differingly interpreted. Holland (1900) also noted the occurrence of metasedimentary inclusions consisting principally of microperthite, corundum, sillimanite, rutile, hercynite and biotite but treated them as altered inclusions of some foreign rock and reckoned them to be evidences in favour of the magmatic origin of charnockites. Some, like Prider (op.cit) and Rama Rao (1945), have observed evidences of assimilation of metasediments (especially pelitic) by charnockites and argued that charnockites have acquired their mineral composition and other characters through assimilation. But others, like Muthuswamy (op.cit), Cooray (op.cit), Heier (op.cit), think that the very intimate association of metasediments with charnockites is in itself 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.

Evidences presented in Chapters VII and IX of this thesis make it clear that in the Satnur-Halaguru area,
except for their intimate association, the various meta-
sediments have not played any role in the formation of
charnockites. The field relationship, petrological and
mineralogical data, however suggest, that the charnockites
were formed from rocks that were laid down contempor-
aneously with the associated metasediments and the two have
had much the same metamorphic history.

6. The banded and foliated nature of the charnockites.

This is one of the common features of charnockites.
Holland (op.cit) also noted this and considered it not as
due to dynamometamorphism but because of the arrangement
of crystals at right angles to the direction of maximum
pressure before consolidation.

Banding in rocks has been explained in different
ways but in rocks like charnockites it should be regarded
as one of the features suggestive of their metamorphic
origin.

As has already been pointed out (Chapter II,
p. 39), the acid and intermediate charnockites of Satnur-
Malaguru very commonly exhibit perfect banding and folia-
tion, which is due to the occurrence of darker layers
(usually less than a few mm. in width) enriched in dark
components, corresponding to the intermediate to basic
(dioritic type) members alternating with those of the
lighter, corresponding to the acid members, while the basic charnockites are generally characterised by the linear parallelism of their components rendering the rocks foliated and schistose. The perfect and fine bending and foliation displayed by the charnockites of the Satnur-Halaguru area, in the opinion of the author of this thesis, cannot be satisfactorily explained from the magmatic point of view and is more suggestive of their development under metamorphic conditions.

On the whole, the various field characters of the Satnur-Halaguru charnockites discussed in the foregoing section strongly suggest that they are one of the oldest (much older than the associated gneiss (Peninsular) metamorphic rocks of the area with much the same metamorphic history as those of the associated metasediments.

B. Petrographic characters:

1. The remarkable freshness of the charnockites, both in hand specimen and in sections.

This character of the charnockites is yet to receive a satisfactory interpretation. Fermor (1936) considered this preservation of the hypometamorphic impress in toto or in part in charnockites as an evidence of relative upliftment of the charnockite region by faulting after the isogeotherms in the earth's crust had fallen
sufficiently, prior to the fall of pressure. Radhakrishna
(1952, pp.36-44) attributes this peculiarity of the char-
nockites to their exposure at the surface in relatively
recent times and is connected with selective upliftment
along faults of only the isolated masses of charnockites
like the Milgiris, the Shevaroys and the Biligirirangan's,
probably during the post-Miocene period. Pichamuthu (1953,
p.148) also remarks that "the comparatively recent uplift
of these rocks is probably the reason why many observers
have remarked on the "fresh appearance" of the charno-
ckites". Howie (1955) regards the fresh appearance of
these rocks as a possible evidence of deep-seated meta-
orphic origin. The author of this thesis is of the opi-
nion that the freshness of the charnockites is more sug-
gestive of the fact that these rocks, whether brought to
the present position quite recently or otherwise, did not
experience any hydrothermal alteration and cataclasis,
subsequent to their formation under plutonic conditions.

2. Irregular and rapid variation in the grain size
and relative proportion of the minerals, even within the
limits of a small outcrop — This is also a feature which
cannot be satisfactorily explained by the magmatic origin
of the charnockites.

3. The xenomorphic granular texture (or granulitic
texture of Holland) and the almost constant absence of pronounced porphyritic crystals.

Though Holland explained this feature of charnockites from the magmatic point of view, he also could recognize that these characters are "unusual" in an igneous rock to demand a special explanation. The advocates of the metamorphic origin of charnockites believe that this character is one of the important evidences of a metamorphic origin. The author of this thesis also regards this feature as an evidence of metamorphic origin of charnockites.

4. The rounded and embayed outline of the pyroxenes — This character is also suggestive of a metamorphic origin for charnockites. Howie (op.cit) also looks upon this character as an evidence of metamorphic origin.

5. The frequent occurrence of one mineral as an inclusion in another — This is also not a common feature of igneous rock and is generally seen in rocks of metamorphic origin.

6. Evidences of strain like undulose extinction (shown invariably by quartz and sometimes by felspar), slight but sufficiently distinct elongation of minerals parallel to banding and foliation, peripheral granulation, fracturing and bending of twin lamellae and cleavages and
the frequent occurrence of thin fracture planes — These are again features of rocks of metamorphic origin.

7. Presence of myrmekitic borders around the potash felspars.

Holland (op. cit.) explained quartz de-corrosion (or 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 due to replacement of one felspar by the other. In the Satnur-Halaguru charnockites there are also sufficient evidences in favour of considering myrmekite as a metamorphic feature representing a case of replacement of one felspar by the other due to soda metasomatism followed by potash metasomatism.

8. The occurrence of quartz of two generations (in quartz-bearing members), an older generation occurring mostly as rounded inclusions in the felspar and pyriboles and a later generation occurring as larger sized patches invariably showing distinct undulose extinction and often carrying randomly arranged hair- and dust-like dark grey and opaque inclusions. This is also difficult to explain
by a magmatic hypothesis and it is a feature connected with the metamorphic origin of the charnockites.

C. Mineralogical characters.

1. The mineral sequence of the charnockite rocks of Satnur-Malaguru displayed in table 22 reveals that the appearance and disappearance of minerals in a regular order from ultrabasic to acid members is not clearly defined as seen in a definite consanguineous series of igneous rocks. Pyroxenes, hornblende and even plagioclase of more or less the same composition occur in all the members of the charnockites. Holland (op.cit) also noted the occurrence of hypersthene among all the members of the charnockite series and remarked that the charnockite series differ from normal igneous rocks in not exhibiting a more or less definite order of successive appearance among the constituent minerals.

2. The microperthitic nature of K-felspars.

The microperthitic K-felspar has been considered by some investigators (e.g., Ramberg 1952, Feserl, 1952) as one of the characteristic minerals of granulite facies rocks like acid charnockites. It is now generally agreed that perthites with regularly oriented perthitic bodies are the result of the exsolution of the sodic component under falling temperature conditions. An exsolution origin
of this kind has already been proposed for the micro-perthites occurring in the charnockites of Satnur-Halaguru by Sadashivaiah (1943) from his detailed investigation of them on the lines indicated by Alling (1936).

3. The nature of the plagioclase.

(a) Narrow range of compositional variation: Plagioclase, the most abundant felspar in the enderbite, intermediate and basic charnockites has an unusually narrow range of variation in composition (being generally lying between An% 27 to 45) when compared with the large variation in the bulk composition of the charnockite members. Also plagioclase of almost the same composition (i.e. with an An content of 27-35 %) occurs in the acid, intermediate and dioritic basic members. Even the plagioclase occurring as a subordinate constituent in some of the ultrabasic members is unusually acidic (viz., An% 26-40%). Such an occurrence cannot be explained by the magmatic origin of the charnockites.

(b) Antiperthitic nature: The acidic plagioclase with An% 29-38 %, occurring in the acid, intermediate and dioritic charnockites, is very commonly antiperthitic. According to Ramberg (1952), the antiperthitic nature of plagioclase is a feature rarely seen in the plagioclase of igneous rocks but is characteristic of those occurring in
the rocks formed under the granulite facies conditions of metamorphism.

(c) Absence of zoning: The plagioclase of charnockites is without exception unzoned. This feature may be considered as a common character of plagioclase occurring in rocks of deep seated origin. In rocks like charnockite the unzoned nature of the plagioclase may be considered as one of the supporting evidences in favour of metamorphic origin.

(d) The nature of twinning: The plagioclase of the charnockite series of Satmuk-Halaguru is both twinned and untwinned. The untwinned plagioclase is more common in many slices of the acid charnockite and other members showing conspicuous evidences of strain. Even among the twinned plagioclases twinning is often faint, patchy, discontinuous and distorted, especially when the An. content is less than about 35%. In thin sections of some of the acid charnockites the plagioclase twinning is so fine and faint as to be noticeable with difficulty under high magnification. 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 laws of twinning of the plagioclase (table 9, Chapter III) of charnockites has brought to light that while they are most frequently twinned after the albite law the twinning after the manebach-ala and albite-ala laws are not uncommon and on manebach and pericline laws it is less observed. Besides, the study has revealed the absence of twinning according to the carlsbad and albite-carlsbad laws which is so characteristic of plagioclases occurring in igneous rocks formed either under volcanic conditions or at shallow depths. The plagioclases thus exhibit twin laws indicative of the formation of the Satnur-Kalaguru charnockites under plutonic conditions (Naidu, 1963) and by process of metamorphism (Turner, 1951; Gorai, 1951 and others).

4. The nature of orthopyroxene:
(a) The strong pleochroism: The orthopyroxenes of charnockite rocks are often strongly pleochroic. Such strong pleochroism is almost unknown in the orthopyroxenes of igneous rocks but is commonly observed in rocks of deep-seated origin like charnockites and it might well be considered as a criterion of their metamorphic formation as suggested by Howie (1955).

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

Although the composition of the orthopyroxene of charnockites of Satnur-Malaguru ranges from bronzite to ferrohypersthene, it mostly lies in the range of hypersthene. Bronzite is restricted in its occurrence to some of the ultrabasic members but hypersthene and ferrohypersthene are found in all the members and a systematic variation in their composition is lacking. The mineralogical characters of the orthopyroxenes described above do not favour the magmatic origin of the charnockite group of rocks.

5. The nature of clinopyroxene:

The clinopyroxene occurring in different members of the charnockite series varies only slightly in its optical characters and thereby composition. This feature is again inconsistent with the view that the charnockites are a consanguineous series of igneous rocks but supports the metamorphic origin.

6. Zircon, which is a common accessory mineral of the acid and intermediate charnockites, is very commonly characterised by its rounded and ovoidal outline — a feature suggestive of metamorphic and metasomatic origin.

7. Typical metamorphic minerals like cordierite,
sillimanite and scapolite, which occur so commonly in the intimately associated metasediments, are absent in the charnockites proper. Even the common metamorphic mineral garnet which is so abundant in the associated metasediments, occurs very rarely in the charnockites. Moreover, in the field, no gradational relationship between the two rocks viz. charnockites and metasediments, has been observed. This fact suggests that there was neither gradational relationship between the parent rocks of metasediments and charnockites nor was there an intermigration of components across the boundaries of the two rocks during their metamorphism to obliterate the original boundaries.

The various mineralogical characters discussed in the foregoing like those of the petrographic characters, indicate that the charnockites of Satnur-Halaguru are metamorphic rocks formed under F.T. conditions of the pyroxene-granulite facies.

D. Chemical characters:

It has been pointed out in Chapter V (pp. 143), that in their chemical composition the charnockites of Satnur-Halaguru area are not exceptional rocks. In their chemical composition, expressed in terms of the main elements, as Parras (1958) puts it, "may be interpreted as being members of the calc-alkaline suite of the plutonic rocks".
When the chemical analyses of the charnockites are plotted in Larsen-type and Niggli variation diagrams, they fall on reasonably smooth curves. Howie (1955) also noted such a feature in his geochemical study of the Madras charnockites and remarked that this feature "could hardly be the case for any random series of sediments".

The above mentioned chemical characteristics of charnockites viz. the composition (expressed in terms of both main and trace elements) comparable with those of the normal calc-alkaline series of rocks and the smooth curves on the Larsen-type and other variation diagrams have been looked upon by many investigators of charnockites as one of the very valuable reasons for considering them as normal igneous rocks, which acquired their charnockite characters either just by the consolidation of the magma under deep-seated conditions, as opined by Holland (op.cit), Rajagopalan (1947), Leelananda Rao (1956) or as rocks formed by the slow recrystallisation of such normal igneous rocks under plutonic metamorphic conditions as opined by Groves (1935) and Howie (1955, 1965). But, contrary to this, Heier (1960) who also found by his detailed chemical investigation (of both the main and trace elements) of Langoy charnockites the same features as those noted by Howie (op.cit) and others, concluded that "the chemistry of these rocks, which is comparable to the chemistry
of calc-alkali plutonic rocks, prevents the use of this kind of data as a proof of their origin. He obtained smooth curves, almost identical to those obtained by Howie for the Madras charnockites, by plotting the major elements of the diversely originated rocks on the variation diagram of the "Larsen-type" and argued, "the fact that the major elements of the diversely originated rocks of larn" all plot on relatively smooth curves on the variation diagrams 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, considering the field, petrographic and mineralogical data, all of which favour the metamorphic mode of formation and bearing in mind the interpretations and conclusions of other investigators, thinks it best to interpret the chemical data of the Satmura-Halaguru charnockites as follows:

The chemical data suggests that the parent rocks, which by metamorphism under granulite facies gave rise to charnockites, had a composition comparable with the calc-alkali series of plutonic rocks or acquired both the composition and other individualities of charnockites through metamorphism. That apart, it neither proves that the charnockites are igneous nor it proves that they were
igneous before they acquired the present characters through metamorphism. Such an interpretation looks quite feasible when it is known that there are hardly any common igneous rocks with chemical composition not comparable to known sediments (Heier, 1960, pp. 209). It suggests, as Heier puts it, that the chemical data of charnockites is not a useful criterion in interpreting the origin. It also shows that the chemical data is not opposed to considering charnockites as metamorphic rocks as clearly indicated by their field, petrographic and mineralogical characters.

Conclusion:

The author of this thesis is of the opinion that the field, petrographic and mineralogical characters discussed in the foregoing afford strong confirmation of the view that the charnockites of the Satnur-Halaguru area, as they are seen at present, are metamorphic rocks, older than the associated gneisses (Peninsular type) and granites (Closepet type) but contemporaries of the associated metasediments, formed under granulite facies conditions of regional metamorphism. The petrochemistry of the charnockites is also not opposed to such an interpretation.
Critical examination of the earlier postulations on the origin of the Mysore charnockites in general and the Satnur-Halaguru charnockites in particular in the light of the present observations.

The absence of evidences of an intrusion and the various field, petrographic and mineralogical observations of the present investigation, enumerated earlier, indicate that the charnockites of Satnur-Halaguru are not differentiated phases of crystallisation of an intrusive magma as opined by the earlier officers of the State Geological Survey viz. Slater, Smeeth, Jayaram and Sampat Iyengar, but are metamorphic rocks. Evidences given on pages 308-310 of Chapter X make it fairly 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 actually a separate entity and have no genetic relation whatsoever with the charnockites except for their development under the same metamorphic conditions (viz. pyroxene granulite facies) as those of the associated charnockites.

Based on the observations of the present investigation, it can be said that Vredenberg and Rama Rao are correct to the extent of interpreting the charnockites as metamorphic rocks, but their opinion of how and when the
metamorphism took place and how the charnockites evolved is inadequate and not acceptable. The fact that the charnockites are much older than the granites and that they received their charnockitic impress much earlier than the formation of the associated Closepet granites makes the view of Vredenberg (1918) and Rama Rao (op.cit), viz. that the charnockite formation was intimately connected with the injection of granite, untenable. For the same reason the view of Rama Rao (1945), viz. that the acid and intermediate charnockites of Halaguru and round about 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. Further, it should also be noted that the charnockite exposures near Satnur-Halaguru, including the localities that provided evidences for the above mentioned view of Rama Rao are not found in the granites (of Closepet type) but are present in biotite- and hornblende-gneisses (Peninsular). This fact has also been pointed out by Pichamuthu (1943, p.138) and Radhakrishna (1956, p.58). There are also no evidences in support of Rama Rao's view that the basic and the ultrabasic charnockites were formed from the crystallisation differentiation of contaminated basic magma or in support of his interpretation that the hypersthene of charnockites
is always secondary after various minerals like hornblende, biotite etc. — it is actually the other way — hornblende and biotite are secondary after the pyroxenes.

Pichamuthu's (1953, 1959, 1961 and 1965) demonstration based on field, microscopic and chemical study, that in the Kabbal quarry there are evidences of "charnockitisation" or transformation & of gneisses (Peninsular) into charnockites, becomes unacceptable when it is understood from the radiometric age determination that the charnockites are older than the gneisses. The situation is actually the reverse. There are ample evidences of "gneissification" of charnockites or the formation of gneisses from charnockites by "decharnockitisation". Besides there are no evidences in support of Pichamuthu's view that there are charnockites belonging to two periods (of ages) — the older charnockites formed from regional thermal metamorphism of Peninsular gneiss and Dharwars and the younger charnockites formed by palingenetic fusion and widespread metasomatism — separated from each other by a period of dyke intrusion. The recent detailed investigation of the dolerite dykes (Devaraju and Sadasivaiah, 1966) of Satnur-Halaguru has shown that they are very much younger than the charnockites, gneisses and granites as they bear intrusive relationship and show chilling effects.
against them. Besides it is also found, that the dykes have not suffered from thermal or any other kind of metamorphism and the clouding of the plagioclase occurring in these dykes is due to exsolution and to the action of deuteric solutions containing iron and not due to the thermal metamorphism associated with the palingenetically formed younger charnockites as postulated by Pichamuthu. In addition to this, in the charnockite region itself there are basic dykes in which the plagioclases are clouded as well as the basic dykes in which they are not clouded. Further, there are a number of recorded occurrences of basic dykes in noncharnockitic region containing clouded plagioclase.

It is true that charnockites of Satnur-Halaguru are intimately associated with metapelites but there are no definite evidences of assimilation of these to give rise to basic charnockites as opined by Sadashivaiah (1943). Evidences are also not available to demonstrate that the acid and intermediate charnockites originated by the injection, metamorphism and granitisation of noritic rocks at different energy levels, as opined by him.
Discussion on the parentage, pre-metamorphic history and mutual relationships of charnockites:

(i) **Parentage and pre-metamorphic study**:

The problem of parentage and pre-metamorphic history are matters of immediate concern when a metamorphic origin is assigned to the charnockites. This is rather an intricate problem about which nothing very definite could be said. It appears to be mostly so, with not only the charnockites but also with other rocks of similar deep-seated origin. It is probably because at depths of a few kilometers, igneous and metamorphic processes merge into one another and apparently may yield identical end products within a given range of temperature and pressure (Turner and Verhoogen, 1960, p.329). Most of the recent investigators agree that the charnockites, as they appear, are high grade metamorphic rocks formed under granulite facies conditions but they either differ in their views or express uncertainty regarding the parentage. Investigators like Groves (op.cit), Mocoldz (op.cit), Howie (1955) opine, considering the similarity of the composition of the charnockites with those of the calc-alkaline series of igneous rocks, that the charnockites originally (i.e., before they acquired the present characters of charnockites) represented a normal calc-alkali series of
igneous rocks. But, based on other evidences like field relation, association and occasional gradation into the often intimately associated metasediments, petrology and mineralogy, authors like Ghosh (op.cit), Muthuswamy (op. cit), Heier (1960), and Cooray (1962) think that the charnockites represent essentially or at least in part reconstructed products of sediments. Heier (op.cit) in particular, who has also investigated in detail the chemistry of the charnockites, opines, as indicated earlier, that the chemistry of these rocks, which is comparable to the chemistry of calc-alkali plutonic rocks, prevents the use of this kind of data as a proof of their origin and considers, on the basis of field appearance and association with the metasedimentary rocks, as representing highly metamorphosed geosynclinal sediments and lavas. He further defends his above mentioned view by stating that there is hardly any common igneous rock with the chemical composition not comparable to known sediments.

The Satnur-Halaguru charnockites, as has already been noted, are also intimately associated with a variety of metasediments and the two bear a conformable relation. The mineral assemblages of both the rocks indicate their formation under identical metamorphic conditions, namely, pyroxene-granulite facies, but there is hardly any gradational relationship between the two rocks. While the
metasediments have strikingly different composition and provide ample petrographic and mineralogical evidences to consider them as metamorphosed sediments, the charnockites are not having any such exceptional composition and their petrochemistry, as has been pointed already, is comparable with those of the calc-alkali series of plutonic rocks. In the fitness of the present set of conditions, we can only presume that the charnockites are contemporaneous with the associated metasediments and the two acquired their present characteristics by their thorough recrystallisation under the pyroxene-granulite facies conditions. The two rocks might have constituted interbedded or interbanded rocks before metamorphism. From the present chemical composition of the charnockites, we can presume that the parent rocks had essentially a composition comparable with those of the calc-alkali series of plutonic rocks but it is difficult to decide definitely with the available evidences whether the parent rocks were igneous or sedimentary or partly igneous and partly sedimentary — a purely sedimentary parentage is not impossible.

(ii) The mutual relationship of the different charnockite members:

Holland (op.cit) opined that the different charnockites members constitute a consanguineous series of rocks.
and are the result of magmatic differentiation. Such a type of consanguineous relationship of the charnockite members has also been thought over by the investigators who had similar igneous views. Groves (1935), Howie (1955) and others, who believe that the charnockites in their present state are metamorphic rocks, have established by their chemical study that the parent rocks of charnockites constituted a consanguineous calc-alkali series of igneous rocks, and so according to them the present variation in composition of charnockites from ultrabasic to acid corresponds to the similar variation in the parent rocks.

Quite a few investigators however think that ultrabasic and basic members are of a magmatic origin, being just products of consolidation of normal basic magma (i.e., Naidu, 1963) or contaminated basic magma (e.g., Frider, 1945, Rama Rao, 1945) while the intermediate and acid members are the result of migmatisation and granitisation of basic charnockites and so there is no consanguineous relation between the basic and acid members.

Based on the occurrence of basic members as inclusions in various stages of digestion in the acid members, Rama Rao (op.cit) assumed that the former (i.e., basic members) constituted an older noritic rock and the latter (i.e., intermediate and acid members) as having been formed
by assimilation and migmatisation. This interaction according to him was brought about by the action of Closepet granite on the noritic basic charnockites.

The occurrence of basic and ultrabasic charnockites in acid and intermediate charnockites as inclusions is no doubt suggestive of the older age of the former but radiometric dating has shown that the basic as well as the acid members are essentially of the same age. It means that the members of the charnockite series have all formed almost contemporaneously with practically very little difference in time relationship. Besides, on pages 176-179 of this Chapter V, where the significance of the smooth curves of the variation diagrams drawn from the chemical analyses has been discussed, it is concluded that they neither prove igneous nor consanguineous relation nor are they useful in interpreting the genesis of charnockites. With whatever evidences are available, it is possible to interpret the relation between the different charnockite members in any one of the following ways:

1. It may be that the different charnockite members were derived from an original more uniform parent rock by metamorphic differentiation under granulite facies of metamorphism.

2. They might have represented originally granitic
rock with basic inclusions which by metamorphism and migmatisation under pyroxene-granulite facies have given rise to the charnockites. According to this assumption, the basic and ultrabasic charnockites represent essentially recrystallised original basic inclusions while the acid members and intermediate/recrystallised original granitic portion. This adequately explains the inclusions like occurrences of basic members.

3. Charnockites may represent a series of recrystallised sediments in which case the different charnockite members correspond to the variation in the composition of the original sediments and/or in migmatise, the result of metamorphic differentiation. It is also possible, that the basic members constituted basic sills and dykes while the acid charnockite sediments.

The evolution of the charnockites and the associated rock types of the Satnur-Halaguru area, as visualised by the author of this thesis, is given in section II of Chapter XIV.