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CHARNOCKITES OF THE TYPE AREA NEAR MADRAS—A REINTERPRETATION

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ABSTRACT. Mutual relationship of the rock units in the type charnockite area near Madras city is described and the terms 'Charnockite' and 'Charnockite Series' redefined. The 'Acid' division of the charnockite series of Holland, composed of alaskites, birkremites, enderbites and hypersthene quartz syenites, is considered to be an igneous suite which has undergone metamorphic reconstitution and recrystallization with concomitant changes in mineralogy, such as, unmixing of perthites and formation of garnet. The rocks of the 'Basic' division of Holland are essentially pyroxene granulites and variants which have no genetic relationship to the charnockites *sensu stricto*. Sporadic exposures of norite with pyroxenite layers and lenses are considered syntectonic lenses, unrelated to the charnockite suite. The rocks of the 'Intermediate' division of Holland grade from homogeneous hypersthene diorites to charnockite-pyroxene granulite migmatites, and are hybrids resulting from partial assimilation and incorporation of pyroxene granulite by the charnockitic magma. Garnetiferous sillimanite gneisses (khondalites) are also developed in force in the area; Holland's leptynites are inferred to be a thoroughly reconstituted and recrystallized facies of khondalite. The above association of charnockites, hybrid rocks, pyroxene granulites and recrystallized khondalites is also found in the larger massifs of Southern India such as those of Nilgiri, Shevroy, and Palni. Mineralogical, petrographic and chemical data are presented to substantiate the reinterpretation.

INTRODUCTION

Since the publication of Sir Thomas Holland's (1900) classic memoir nearly sixty years ago on the charnockite series of Peninsular India, similar rocks have been discovered and studied in many other parts of the world. Some of these studies have advanced our knowledge of their petrology and petrogenesis and excellent reviews of the literature on charnockitic rocks have been presented by Quensel (1951), Pichamuthu (1953), and Wilson (1955). Though charnockitic rocks have been described in India from Mysore by Rama Rao (1945) and Jeypore and Bastar, by Crookshank (1938) and Ghosh (1941), the type charnockite area in the neighbourhood of Madras city has not received any serious attention. The need for a detailed petrological account of the area, with particular reference to the mode of occurrence of charnockites and their mutual relationship to the basement rocks cannot be over-emphasized. Various theories on the origin of charnockites have been adduced without a thorough knowledge of the type area from where these rocks were first recorded and studied. The writer therefore commenced early in 1953 field and laboratory studies of the type area charnockites and related rocks, at the suggestion of Dr. M. S. Krishnan, Director, Geological Survey of India. Preliminary results of the study have been presented in periodical progress reports of the Geological Survey of India, by the writer, which have so far not been published. A brief summary of the author's views on these rocks has however appeared in

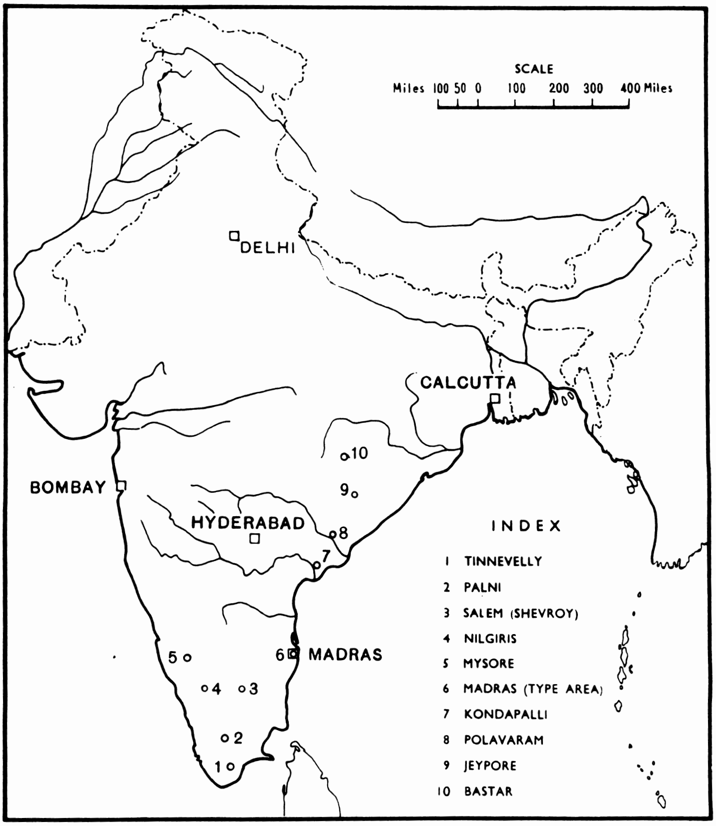


Fig. 1. Map of India showing some localities from which charnockitic rocks are reported.

the recent edition of *Geology of India and Burma*, by Krishnan (1956, p. 108-109). Since the initiation of this study a few papers on charnockites have appeared, the most outstanding being that of Howie (1955) who has made a major contribution to the geochemistry of Madras charnockites. Naidu (1954) has given petrographic description of rocks from Southern India having charnockitic affinities, while Wilson (1957), has dealt with structural features of charnockitic rocks. Eskola (1957) has offered a stimulating discussion on the Mineral Facies of charnockites. The most recent contribution is by Howie and the present writer (1957) on the paragenesis of garnet in charnockite, enderbite and related granulites. The present paper is a preliminary account of the field and laboratory observations made by the writer and some of the resultant ideas. A comprehensive report embodying new data on the petrology, mineralogy and geochemistry of charnockites and related rocks together with their field relations is under preparation.

ACKNOWLEDGMENTS

The writer is most grateful to Prof. C. E. Tilley for providing research facilities in the Department of Mineralogy and Petrology, Cambridge University, discussing several aspects of the problem, critically reading the manuscript, and constant encouragement. Grateful thanks are due to Prof. A. F. Buddington of Princeton University, for kindly reading the manuscript and stimulating discussions during a field trip in the type area in January-February, 1957. Thanks are also due to Dr. R. A. Howie of the Department of Geology, Manchester University, for valuable discussions; to Dr. S. O. Agrell of the Department of Mineralogy and Petrology, Cambridge University, for placing at the disposal of the writer collections of thin sections of charnockites from various parts of the world; to Prof. H. Kuno of the Tokyo University for kindly arranging to have several rocks chemically analyzed by Dr. T. Katsura; to the Royal Society of London for the award of a bursary enabling the writer to work at Cambridge; and to the Director, Geological Survey of India, for according permission to present this paper. Finally, the writer is under a deep dept of gratitude to Dr. M. S. Krishnan for suggesting this study and his encouragement by generously financing the cost of chemical analyses of 12 rocks.

GEOLOGICAL SETTING

An area of over 90 square miles between St. Thomas Mount, 9 miles south of Madras city, and Vandalur 20 miles south of Madras city, was examined in great detail and comprehensive rock collections made for petrographic and

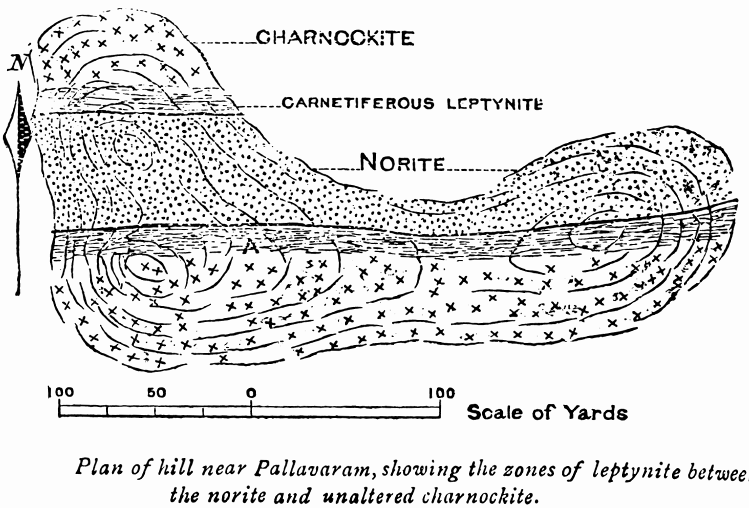


Fig. 2. Holland's sketch showing garnetiferous leptynite-norite-charnockite association at Pallavaram.

According to the writer's interpretation, the sketch represents in plan an interstratified unit of khondalite and pyroxene granulite intruded by charnockite, resulting in the recrystallization of khondalite to leptynite along the contacts with charnockite.

chemical studies. The accompanying map (fig. 3) shows the distribution of rock types in the type area, and the structural elements displayed by them. It must be emphasized here that a map with geological boundaries will be largely inferential, as critical areas are under soil cover, and the intermingling of rock types much too complex.

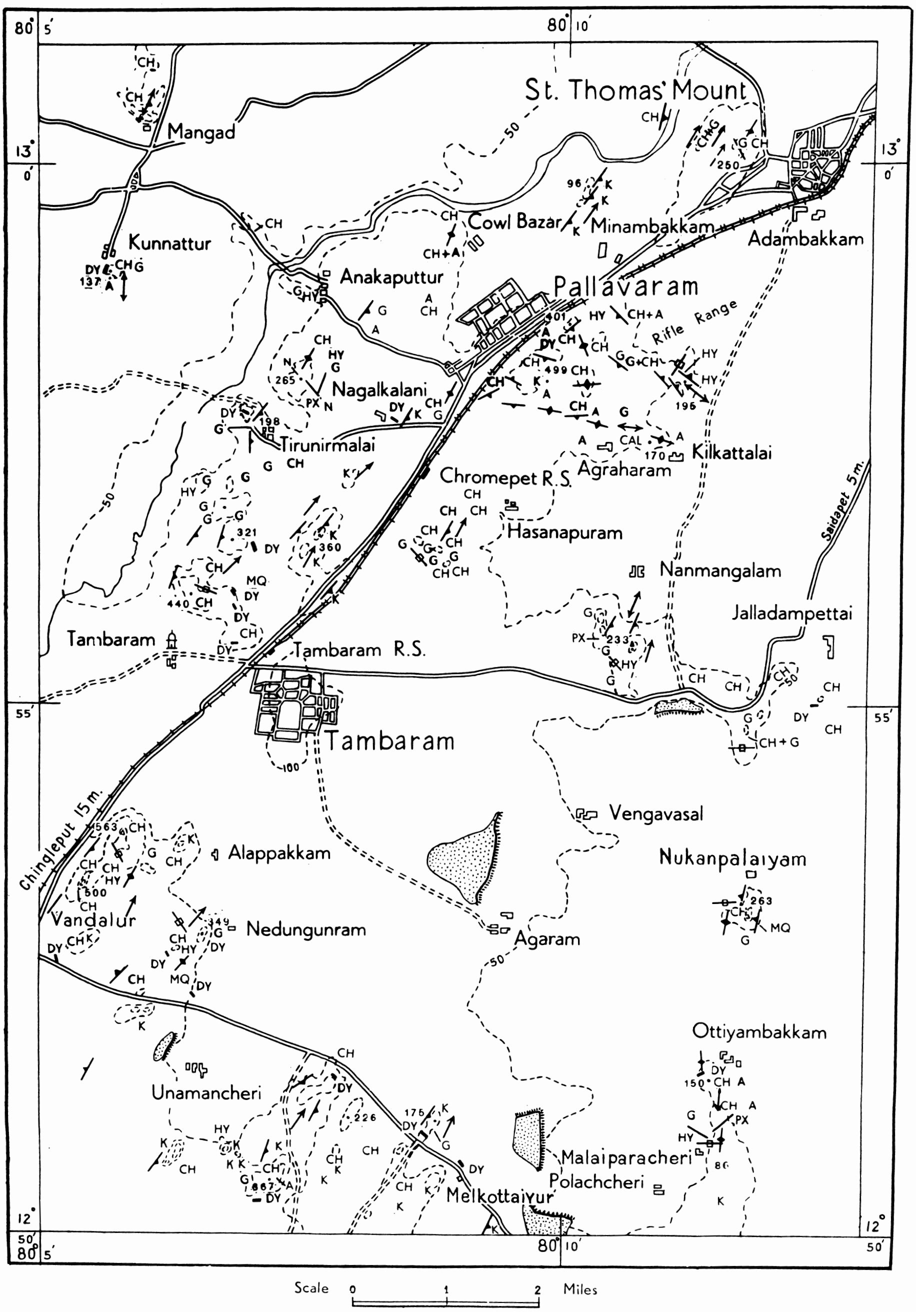


Fig. 3. Sketch map of the type charnockite area near Madras city (portions of Topo sheets 66 $C/_4$, $D/_1$ and $D/_5$) showing structural elements and distribution of rock types.

The charnockite suite and associated rocks stand out as a series of small ridges and hillocks in plain country, and roughly trend NE-SW to NNE-SSW paralleling the coast line. Prominent among these hillocks are:

Hills	.500 and .563	— East of Vandalur.
Hill	.349	— Near Nedungunram.
Hills	.367 and .226	— East of Unamancheri.
Hill	.263	— South of Nukanpalaiyam.
Hillocks	.150 and .86	— West of Ottiyambakkam.
Hill	.233	— In the Nanmangalam R. F. area.
Hill	.440	— Comprising Tambaram R. F.
Hill	.321	— Comprising Mullumalai and Pulikkaradu, north of Tambaram R. F.
Hill	.360	— Pachchai Malai.
Hill	.198	— At Tirunirmalai.
Hillock	.137	— At Kunnattur.
Hill	.265	— NE of Tirunirmalai (Pammal hill of Holland).
Hill	.499	— Mosque hill of Pallavaram.
Hill	.401	— Tirusulam hill, Pallavaram.
Hill	.195	— Panchapandava hill, Pallavaram.
Hill	.170	— WNW of Kilkattalai.
Hill	.250	— St. Thomas Mount and adjacent Magazine hill.

Besides the above, there are several small knolls and rock outcrops in the plains between above hillocks. Most of these hillocks are almost devoid of any vegetation, being largely composed of weathered boulders of rocks with a very thin soil cover on which thorny shrubs thrive. Hills .500 and .563 near Vandalur, however, are well vegetated in contrast to the others. There are extensive stone quarries on hills .499, .401 and adjacent hillocks exposing excellent sections. The sequence of rocks in the area as interpreted by the writer, together with Holland's original classification, is tabulated below:

LEGEND

DY	Dolerite dykes	
A	Alaskites and reconstituted facies	Charnockite Suite
CH	Hypersthene granites, Hypersthene quartz syenites, Enderbites and reconstituted facies	Charnockite Suite
N	Norite	Syntectonic lenses of basic rock
PX	Pyroxenite	Syntectonic lenses of basic rock
HY	Hypersthene Diorites and variants	Hybrid rocks
G	Pyroxene granulites and variants	Basement rocks
K	Garnetiferous sillimanite gneisses (Khondalite) and recrystallized facies	Basement rocks
MQ	Magnetite quartzites	Basement rocks
CAL	Calc-silicate rock lenses	Basement rocks

Regional lineation

Vertical foliation

Foliation with steep dip

Horizontal lineation

Vertical joints

SEQUENCE OF ROCKS IN TYPE AREA

Subramaniam		*Holland*
Dolerite dykes		Dolerite dykes
Charnockite suite	Alaskites, charnockites (hypersthene granites or birkremites), enderbites, and hypersthene quartz syenites. All rocks have undergone varying degrees of metamorphism resulting in development of garnet, unmixing of microperthites, etc. Xenoliths of pyroxene granulites occur in most types.	'Acid' division of charnockite series and leptynites
Syntectonic lenses of basic rock	Norite with layers and schlieren of pyroxenite.	'Ultra-basic' division of charnockite series, pyroxenites composed of hypersthene, augite hornblende, sometimes with olivine, green spinel and magnetite
Hybrid Rocks	Homogeneous granodioritic rocks; hybrid rocks with xenoliths of basic granulites, and charnockite-pyroxene granulite migmatites composed of alternating layers of pyroxene granulite and coarse charnockitic material. Coarse veins of charnockitic material are noticed in profusion, traversing these hybrid granodioritic rocks.	'Intermediate' division of charnockite series with contemporaneous veins and basic fine grained schlieren.
Basement Rocks	Pyroxene granulites and variants containing hornblende, garnet, biotite, etc. They appear to be reconstituted sheets of norite or gabbro associated with the metasedimentary basement; some of them may be reconstituted calcareous rocks. Occur as lenticular bodies and as xenoliths in the hybrid and charnockitic rocks; form the mafic component in the migmatitic facies. Some granulites carry nodules of calc silicate rock.	'Basic' division of charnockite series equivalent to norite.
Basement Rocks	Schistose gneisses composed of quartz, felspar, biotite, garnet, sillimanite and infrequently graphite (khondalites); leptynite appears to be a thoroughly reconstituted and recrystallized facies of above. Thin bands of magnetite quartzite are interstratified with the khondalites.	Not reported.

STRUCTURE

The rocks of the area have a NNE-SSW strike of foliation occasionally veering to NE-SW, with steep easterly dips varying from 60°-80°; at several points the various rock units display vertical foliation. The charnockites (hypersthene granites and variants) occasionally display a distinct linear element due to stretching of the quartz grains and to a lesser extent the dimensional orientation of the mafic minerals. The linear structure is conspicuous on weathered surfaces, where differential weathering of felspars and quartz brings out the structure clearly. In fresh specimens, however, the general greasy lustre of the quartz and felspars which are both colored, masks the same. This lineation is generally parallel to the foliation, but occasionally plunges at low angles to the NE. The lineation in the charnockite suite of rocks is conformable to the lineation in the pyroxene granulites and garnetiferous sillimanite gneisses with which they are interstratified. This is a 'b' lineation and consequently indicates the general trend of the regional fold axes. Horizontal lineation of this type is generally suggestive of slightly overturned isoclinal folds. Wilson (1957, p. 4) has described such isoclinal structures in charnockites and related granulites near Simon Hill ,Western Australia. Holland (1900, p. 125, 176, 219) has referred to the linear arrangement of minerals and inclusions in these rocks, attributing it to be a magmatic feature accentuated by later deformation. The almost uniform and steep easterly dip of all the rock units of the area is indicative of the slight overturning of the isoclinally folded rocks to the west. It is considered that the rocks of the area were tightly folded isoclinally, after the emplacement of the charnockite suite as interstratified sheets in a basement of khondalites and pyroxene granulites.

The rocks in the Tirusulam hill .401 and Mosque hill .499, Pallavaram, show a sharp swing in their strike of foliation, resulting in a WNW-ESE trend. They, however, swing back to their original trend near Issapallavaram. This large bend in the structural trend in which all the rocks are involved, is interpreted to be a local flexure in the regional fold structure.

There are distinct vertical tensional joints across the foliation in all rock units, more particularly in the charnockite suite of rocks which also display almost horizontal primary flat joints. In addition, sheeting parallel to the topography generally at intervals of 10-15 inches and sometimes as much as 2-5 feet is noticed in several quarries. The dolerite dykes in the area appear to be emplaced along these joints, as many of them trend WNW-ESE or E-W which is the principal direction of the major joints in these rocks.

A mylonitic rock is observed at the contacts of charnockitic rocks with the khondalites, in the Nedungunram hill .349 and Vandalur hill .563, but in general, sharp contacts between the various rock units in the area cannot be deciphered. The rocks in the area, appear to have undergone a series of deformations culminating in the emplacement of the charnockite suite of rocks with subsequent plastic deformation. The textures indicated by these rocks support this contention. The intermingling of zones of highly recrystallized rocks simulating a quartzite with zones of coarsely crystalline undeformed rocks within a short distance of 3 or 4 feet is a feature noticed throughout the area. It is likely that such zones of intense recrystallization represent annealed primary fissures and fractures along which movements have taken place during the consolidation period. The overall structure in the area is interpreted to be a series of tight isoclinal folds overturned to the west plunging at low angles to the NE.

NOMENCLATURE

Holland (1893, p. 162) suggested the name charnockite for a hypersthene granite, in honor of Job Charnock, whose tombstone was made of this rock. He later (1900, p. 130) defined charnockite as a hypersthene granite composed of quartz, microcline, hypersthene and accessory iron ores. He states (1900, p. 131):

> Charnockite is a convenient name for a quartz-felspar-hypersthene-iron ore rock in the charnockite series, and not a name for *any* hypersthene-granite occurring in other petrographical provinces. The much complained of burdens of petrographical nomeclature are not due to the creation of specific names for local

> types, but to irresponsible and unwarranted extension of such names to include unrelated members of different and widely separated petrographic provinces, in which the accidents of differentiation and segregative consolidation may have produced by chance similar mineral aggregates.

Holland (p. 125, 128) suggested the term "Charnockite series" for a group of rocks genetically related to charnockite, which vary from acid charnockite to ultra basic pyroxenite, characterized by even grained granulitic (panidiomorphic) texture and the constant presence of highly pleochroic orthorhombic pyroxene approaching hypersthene. In spite of Holland's warning, both the above terms have been indiscriminately used both in India and other countries, with the result that we have in the literature descriptions of charnockitic rocks which, in the opinion of the writer, bear little resemblance to the rocks of the type area. Holland's classification of the charnockite series into 'Acid', 'Intermediate', 'Basic' and 'Ultrabasic' divisions, restricting charnockite to the acid members has been misunderstood, and rocks described as 'Acid', 'Intermediate' and 'Basic' charnockites. The term charnockite has therefore lost its original significance and is applied more or less to any dark-colored granulitic rock occurring in the Archaean of India and elsewhere. The writer has seen collections of amphibolites, pyroxene granulites, pyroxene gneisses, pyroxene syenites, norites, gabbros, diorites, granodiorites and dark colored granites, all of which are referred to as charnockites!

A small chip of rock from Job Charnock's tombstone was re-examined by the writer and found to carry grains of red garnet[1] in addition to hypersthene, quartz, felspar (microperthite) and ores. Field examination has also shown that garnet is present in most rocks of the charnockite suite in variable amounts. In fact, a large specimen which megascopically did not reveal any garnet, when powdered for separation of zircons, showed a fair amount of the mineral. In view of this, the writer would redefine Charnockite as a *hypersthene quartz felspar rock with or without garnet, characterised by greenish blue feldspars, and greyish blue quartz, the dominant felspar being a microperthite.* The hypersthene granites of Madras are similar to birkremites of Ekersund, and Holland (1900, p. 135) has mentioned that Vogt's (1893, p. 4) description of bronzite granite is applicable to the South Indian charnockite. Tilley (1936, p. 315) has discussed the merits of the terms 'Charnockite' and 'birkremite' and is inclined to consider them synonymous.

Granulitic texture has been emphasized as a uniform feature of charnockites, but the writer considers this untenable, as field examination has shown these rocks to vary from coarsely crystalline types (grain size varying from 1 mm to 2 cm), to thoroughly recrystallized dense types simulating a quartzite.

Charnockite suite

Petrographic examination of rocks in the type area has shown that rocks generally grouped as acid charnockites can be classified into the following distinct types:

1. Charnockite (hypersthene granite or birkremite).
2. Enderbite.

[1] Holland (1893, p. 163) has recorded the presence of garnet of the almandine variety in the rock from Charnock's tombstone. Unfortunately this has not been mentioned in his famous memoir.

3. Hypersthene quartz syenite.
4. Alaskite (quartz-felspar rocks of Holland, 1900, p. 144).

Types 1, 2 and 3 invariably carry orthopyroxene, which in some cases is partially or completely reconstituted to garnet, so that we have rocks carrying only hypersthene, both hypersthene and garnet and only garnet. Type 4 is a binary granite devoid of any mafic mineral, but grades to garnetiferous and non-garnetiferous charnockite the passage types carrying pink garnets. Charnockite *sensu stricto* with wide textural and mineralogical variation, and in part garnetiferous, is wide-spread in the type area and freely grades into the other types mentioned above. The presence of enderbite in the Pallavaram area has been indicated by Tilley (1936, p. 314), and recent chemical analysis of some rocks from the type area (Howie, 1955, p. 732) and Howie and Subramaniam (1957, p. 572) show a dominance of soda over potash, confirming Tilley's suggestion. The writer's field and laboratory studies have indicated that garnetiferous and non-garnetiferous enderbites are more prevalent in the type area than charnockite *sensu stricto*. Tilley (1932, p. 314) defines enderbite as an acid member of the charnockite series characterized by rhombic pyroxene, in which plagioclase (antiperthite) is the essential felspar. He has also drawn attention to the association of enderbites with typical charnockites.

Petrographic examination by the writer has shown the presence of a syenitic facies of charnockite in which the modal quartz varies from 5-20 percent. These rocks can be called hypersthene quartz syenites and appear to be very similar in character to similar rocks described by Buddington (1939, p. 127; 1952, p. 58). This type is also partly garnetiferous.

Beside the above, coarse pegmatites facies of all the above types are seen traversing the rocks. The writer suggests that the term "Charnockite suite" be restricted to this assemblage of rocks consisting of charnockites, enderbites, quartz syenites and alaskites, which appears to be initially of magmatic origin. Later metamorphism has presumably resulted in mineralogical changes, such as formation of garnet and unmixing of perthitic felspars, with wide textural changes. Charnockite suite in this paper therefore refers only to rocks of the acid division of Holland.

Other rock units in the type area

Hybrid rocks.—The intermediate division of Holland is largely composed of homogeneous and inhomogeneous hybrid rocks resulting from inter-action of the magma which gave rise to the charnockite suite referred above, with pyroxene granulites prevalent in the area. A migmatitic phase in which pyroxene granulite carries parallel bands of charnockitic material is also developed at several points, and even in hand specimens the two types can be readily distinguished. Holland (1900, p. 147) himself has recognized such composite types and states:

> Even in a hand specimen, the composite nature of these 'intermediate' rocks is generally very noticeable, the basic and the acid portions being either distributed in irregular patches or arranged in parallel bands. This fact makes it very difficult to place any one specimen in the commonly employed system of rock classification.

The situation described above is, in the opinion of the writer, inconceivable in rocks which are products of differentiation, but perfectly consistent with their being products of incorporation and assimilation of pre-existing rocks by an igneous intrusion of later age. The hybrid rocks in the type area show at several points relicts of pyroxene granulites which have been called "autoliths" by Holland (1900, p. 217), but these appear to be xenoliths. Holland (1900, p. 219) has described what he calls a primary breccia in which some scores of angular fragments of dark-colored, basic, fine grained rock are seen to be in a matrix of lighter colored more quartzose and coarser charnockite. Holland (1900, p. 149) has stated:

> It seems evident that these intermediate forms are composed of half norite and half charnockite.

Indeed, re-examination of a specimen 9.660 described by Holland (1900, p. 156) as augite norite shows it to be a pyroxene granulite veined by charnockite, it being possible to differentiate the felspars and pyroxenes in the two portions, by optics. It therefore seems clear that the intermediate division of Holland, represents a group of hybrid rocks, which can be expected to occur in association with charnockitic rocks in most Precambrian terrain. The writer would group these rocks separately, and not classify them with charnockites, though they owe their genesis to influx of charnockitic material on basic rocks.

Syntectonic lenses of basic rock.—There are small exposures of norites which do not show any marked recrystallization and which are very different from the pyroxene granulites described below, the most conspicuous being on the Pammal hill .265, NE of Tirunirmalai. These norites which carry schlieren of pyroxenite have been described by Holland (1900, p. 164). The writer considers these small masses of norite with related pyroxenitic layers as syntectonic lenses, unrelated to the pyroxene granulites or to the charnockites. Such masses of gabbro and norite are scattered all over the Archaean of South India and appear to have been emplaced as small lenses during a particular orogenic epoch.

Basement rocks.—The basic division of Holland is largely composed of pyroxene granulites and variants which are developed in force in the type area. They are easily distinguished from the rocks of the "Charnockite suite", as they are homogeneous, granulitic, and tend to weather to bouldery runs. Inclusions of such granulites are seen in the hybrid rocks, and in the charnockite suite of rocks, where they tend to become rich in biotite. At one point in the type area, the granulites are garnetiferous and carry nodules of calc-silicate rock (Howie and Subramaniam, 1957, p. 569).

Foliated schistose rocks with an assemblage of minerals similar to khondalites are developed in force in the type area where they form a definite horizon. These are largely quartzo-felspathic gneisses with variable proportions of garnet, biotite, sillimanite and occasionally graphite. These rocks have a variable composition across the foliation (bedding) and contain intercalations of pelitic, psammatic and cafemic material, as also layers of pyroxene microgranulite and magnetite quartzite. The garnets in these rocks are leached out on weathered surfaces. Sillimanite sheafs are aligned parallel to the foliation. At contacts with charnockites these rocks are thoroughly recrystallized with development in force of sillimanite and diablastic garnets; where metamorphic reconstitution is complete, the resultant rock is a garnetiferous granulite described by Holland

(1900, p. 142) as garnetiferous leptynite. Leptynites may therefore be regarded as reconstituted facies of khondalites.

MUTUAL RELATIONSHIP OF ROCK UNITS

Charnockite suite

The distribution of the various rock units encountered in the type area is shown in the map (fig. 3) and it is not intended to go into the details of their distribution. The rocks of the charnockite suite vary in texture from very fine grained brownish or bluish-gray types simulating a dense quartzite to coarse grained types with an abundance of bluish-green or gray felspar, blue quartz and visible grains of pyroxene. These rocks on weathering, display conspicuously the linear arrangement of stretched quartz grains parallel to the prevalent foliation. The association of dense, fine grained rocks with coarsely crystalline types is suggestive of these rocks having suffered active deformation in the plastic stage. Very coarse veins composed largely of blue quartz and greenish grey felspars traverse these rocks and can seen in all the exposures in the area. The Alaskitic variant of the charnockite is found at several points, and appears to be a border facies. The following field relationships have been observed:

1. Alaskite composed of blue quartz and pink felspar passing to typical charnockite (Hillock .150, south-west of Ottiyambakkam).
2. Garnetiferous alaskite passing to typical charnockite containing garnet which in turn passes to a type devoid of garnet (Hill .440 in Tambaram R. F. area and Hillock .170 WNW of Kilkattalai).

The rocks of the charnockite suite carry at several points inclusions of basic rocks which vary from biotite pyroxenites to pyroxene granulites. Such inclusions are seen in all the larger exposures of charnockitic rocks. Enderbites, quartz syenites, hypersthene granites and alaskites are so intimately associated that it would be difficult to demarcate them separately in a map. Of these, enderbites are most prevalent in the hills .563 and .500 near Vandalur, the hillocks near Melkottaiyur, and in portions of the larger hills .499 and .401 near Pallavaram.

Hybrid rocks

Exposures of these rocks are seen at the following points:

1. 3 furlongs west of Unamancheri
2. Southern slope .86 east of Malaiparacheri
3. Knoll west of .367
4. On .367 west of Unamancheri
5. On hill .349 near Nedungunram
6. Hills .499 and .401 near Pallavaram
7. .250 at St. Thomas Mount

They carry basic inclusions which have a linear arrangement and at some places as at St. Thomas Mount, develop into a charnockite-pyroxene granulite migmatite (pl. 3). As these rocks represent a hybrid facies, no clear cut contacts between them and rocks of the charnockite suite can be established. The occurrence of coarse charnockitic pegmatite across the foliation and the presence of innumerable xenoliths. present unequivocal evidence as to their hybrid nature. Holland (1900, p. 218-219) has described some rocks as primary breccia, in which fine grained basic fragments are scattered in a matrix of coarse charnockite. Such rocks are common in the type area and are clearly hybrids. Holland's (1900, p. 221) 'autoliths' and 'contemporaneous veins' appear to the writer to be 'xenoliths' and 'acid' late phase pegmatites respectively.

Syntectonic lenses

At Pammal hill .265 NE of Tirunirmalai, Nanmangalam hill .233 and the hillock .86 near Malaiparacheri, norites with layers and lenses of pyroxenite are seen. These norites appear to be intrusive into pyroxene granulites as at Pammal hill, where small cross cutting layers of pyroxenite are also seen. These have been described by Holland (1900, p. 164-165). He has, however, grouped this norite in the basic division of his charnockite series. The rocks at Pammal hill and elsewhere with associated pyroxenite layers. differ from the pyroxene granulites of the area in their mineralogy and texture and do not appear to have undergone any significant metamorphic changes. The writer would consider these to be syntectonic lenses, emplaced during an orogenic period preceding the emplacement of the rocks of the charnockite suite which cut these norites at Pammal hill and elsewhere.

Basement rocks.—Pyroxene granulites and variants represent the most important group of basement rocks in the type area, the other being the quartzo- felspathic garnet sillimanite gneisses (khondalites) and their recrystallized facies. They occur as bouldery runs, small hillocks, as layers interstratified with khondalites, and as xenoliths in the charnockite suite of rocks and related hybrid types. They are noticed at the following points:

1. Thin layers in khondalites. SE of Vandalur.
2. Thin layer in khondalites. 1 mile SE of above north-west of Unamancheri.
3. As inclusions in charnockitic rocks at hill .349 near Nedungunram.
4. As inclusions in the charnockitic rocks of hills .563 and .500 at Vandalur.
5. As inclusions in charnockitic rocks in the hill rise south of Ottiyambakkam.
6. As inclusions in the charnockitic knolls south of Jalladampettai.
7. In charnockitic rocks at .233 south of Nanmangalam, as inclusion and layers.
8. In the small hills north of Tambaram forming a broad band northwards towards Tirunirmalai.
9. As inclusions in charnockitic rocks of .440. .360 and other hills. W and NE of Tambaram.
10. As inclusions in the charnockite suite of rocks west of Hasanapuram.
11. As bands and layers in charnocktic rocks of hills .499 and .401 near Pallavaram.
12. As layers and inclusions in charnockitic rocks of the St. Thomas Mount hill .265.

These rocks have a linear structure conformable to that in the charnockite suite of rocks with which they are inter-banded. A garnetiferous facies of these granulites with nodular lenses of calc-silicate rock occurs near Kilkattalai and has been described (Howie and Subramaniam, 1957, p. 569). At St. Thomas Mount, these granulites have been injected by charnockite resulting in a migmatitic facies. That these pyroxene granulites are much older than the charnockite suite of rocks is brought out by the fact that they occur as interstratified layers in the khondalites, have a uniform granulitic texture, display thorough recrystallization, contain cross cutting veins of coarse charnockite, and occur as inclusions in the hybrid rocks and in rocks of the charnockite suite. The following description of the St. Thomas Mount hill by Holland (1900, p. 172) is significant.

> The main mass of St. Thomas Mount itself is augite-norite which, however, is so cut through by acid veins, that in places the rock becomes an irregular mixture of charnockite and norite such as, characterises the varieties described as 'intermediate.'

This, in the writer's opinion, offers a clear example of the intrusive nature of the charnockite suite, into pyroxene granulites (norite of Holland).

The garnetiferous sillimanite gneisses or khondalites form a distinct zone west of the Madras road extending over 6 miles and forming the group of knolls and the hillock .360, ending up a little north of Minambakkam. These rocks get compact near contact with the charnockites, forming a thoroughly recrystallized garnetiferous granulite. Holland (1900, p. 173) regarded these as metamorphosed charnockites, but his description quoted below lends support to the writer's belief that they are metamorphosed khondalites.

> The garnetiferous leptynite is dirty white in color, is more distinctly foliated and crushed easily under the hammer.

Holland has sketched the relationship of charnockite, leptynite and norite (1900, p. 173, fig. 4) and states (1900, p. 142) that leptynites are found at the contacts of charnockites and norites, considering them to have formed due to dynamo-metamorphism of charnockite. It appears to the writer that the plan sketched by Holland (fig. 2) represents an interstratified unit of khondalite and pyroxene granulite (Holland's leptynite and norite) which has been intruded by charnockite. The resulting situation would be the recrystallization and reconstitution of the khondalites along their contacts with charnockite and consequent formation of leptynite, a relationship found in the Pallavaram area. Holland (1900, p. 174, fig. 5) has sketched and described a specimen showing the gradual passage of charnockite into leptynite. In this case, the charnockite is grading into a garnetiferous alaskite, which is quite distinct from a leptynite. Such passage types have been referred to earlier.

The overall picture of mutual relationship of rock units in the type area can be summarized as below. Rocks of the charnockite suite were emplaced as sheets and lenses in a gently folded basement sequence of khondalites with interstratified pyroxene granulites. There was a certain amount of hybridization with formation of mixed types and migmatites. The whole sequence of rocks was subsequently involved in regional deformation, resulting in tight isoclinal folding of the rock units and their subsequent overturning to the west. The norites and related pyroxenites are thought to be syntectonic lenses, emplaced during a minor orogeny of pre-charnockite age. As these lenses have been enclosed by other rocks, they have not been markedly affected by subsequent deformation.

The writer was fortunate to visit with Professor Buddington certain sections of the Shevroy in Salem district and the Nilgiri section between Mysore and Ooty (see fig. 1) described previously by Holland (1900, p. 179, 186, 187). In the Shevroys, khondalites and their recrystallized facies (leptynites) were found interbanded with charnockitic rocks and pyroxene granulites. The intermediate members of Holland (1900, p. 180), called by him eruptive breccias, were found to be hybrid rocks carrying inclusions of basic material in a charnockitic matrix. The meta-sedimentary nature of the leptynites was evident from the high quartz content of these rocks. A similar situation was found in the Nilgiri section along the Ooty-Mysore Road. The writer has also seen a similar field association of rocks in the northern slopes of the Palni massif. Dr. Krishnan (personal communication) has observed charnockitic rocks having an intrusive relationship with leptynitic and khondalitic rocks, near Tinnevelly, Kondapalli and Polavaram, while Crookshank (1938, p. 402) has reported the intrusive nature of the charnockites of Jeypore. Adams (1929, p. 467-511) has described the association of charnockite with pyroxene granulites, khondalites, and leptynites in Ceylon.

MINERALOGY

Valuable data on the mineralogy of 'Charnockites' and associated rocks of the type area have been presented by Howie (1955) and Howie and Subramaniam (1957). These together with additional data based on the writer's laboratory work will be briefly discussed, as the mineralogy of these rocks offers valuable clues to their origin and mutual relationship.

Charnockite suite

As stated earlier, this suite is composed of alaskites, enderbites, hypersthene quartz syenites and charnockites (hypersthene granite or birkremite); their mineralogy is as follows:

Essential minerals —Blue quartz, bluish green felspars which include plagioclase, antiperthite, microperthite and microcline; orthopyroxene ranging in composition from eulite to hypersthene.

Varietal minerals — Clinopyroxene, garnet, hornblende and biotite.

Accessory minerals — Apatite, zircon, ilmenite, titanomagnetite and pyrrhotite.

The nomenclature of the rock types in the suite is based on the relative proportions of the essential minerals, and to a lesser extent those of the varietal minerals. Orthopyroxene, which is the typomorphic mineral, is present in all types except in the alaskites and in rocks which have suffered extreme reconstitution, where it has been reconstituted to garnet.

Quartz.—Quartz in these rocks is bluish-gray or blue in color and in thin sections show marked wavy extinction. This is due to rewelding of small grains into leaves or plates of quartz and it seems to the writer that the blue color of the mineral may be attributed to an optical effect caused by dispersion of incident light on such rewelded grains.

Felspars.—Plagioclase felspars in these rocks have a range in composition of An_{20} to An_{35}, but generally are around An_{30}. In the enderbitic rocks they are strongly antiperthitic, but subordinate amounts of plagioclase plates devoid of antiperthitic structure displaying simple and complex twinning are present in most rocks except the alaskites. Antiperthite. similar to "Hair antiperthite" described by Eskola (1952, p. 148) are found in the enderbitic rocks. The prevalence of the unusual twin law "Albite-Ala" in the plagioclase of these rocks recorded earlier by Rajagopalan (1946, p. 329), Naidu (1954, p. 208) and Howie (1955, p. 744) has also been observed by the writer, and is in consonance with their host rocks having an igneous parentage. The strong development of antiperthites in enderbite is considered by Tilley (1936, p. 315) as indicative of high temperature of consolidation of magmas connected with their low water content. The plagioclase in these rocks does not show zoning.

The potash felspars in these rocks range from microperthites to microcline perthites and microcline. "Hair perthites" and "Flame perthites" similar to those described by Eskola (1952, p. 149) are fairly common (plate 2, fig. 6). Some of the felspar grains which appear to have no perthitic structure under ordinary magnifications, are found on high magnification to be perthites and may be considered as cryptoperthites. These cryptoperthites are found in relatively undeformed rocks and on unmixing induced by deformation, become strongly perthitic as in the rocks which are recrystallized. The composition of these perthites deduced from optics range from Or_{52} to Or_{83} (± 5 percent) and the majority of rocks, particularly the enderbites, carry perthites of the compositional range Or_{52} to Or_{65}. Michot (1951, p. 270) has suggested the name "mesoperthite" for microperthites which carry equal amounts of orthoclase and plagioclase, and considers them to have formed under high temperature environments. A reference to Bowen and Tuttle's diagram (1950, p. 49, fig. 3(1)) will show that such mesoperthitic felspars as are found in the charnockite suite of rocks would indicate a temperature of unmixing of over 600°C. suggesting thereby that these rocks have consolidated at much higher temperatures. Tuttle (1952, p. 116) has also stated that:

> . . . perthites when composed of nearly equal amounts of albite and microcline is evidence per se of high temperature and suggests a magmatic history for the rocks concerned.

Eskola (1957, p. 107) has also considered the mesoperthitic hair perthites, found in charnockites as indicative of highest temperatures.

The color of these rocks is largely governed by the color of the prevalent felspars, and all the members of this suite carrying orthopyroxenes have a bluish color, while the alaskites are pinkish or grey. Buddington and Leonard (1953, p. 893) have recorded this peculiarity in the rocks of the Diana Quartz Syenitic Complex in the Adirondacks in which pyroxenic facies are green in color, whereas the hornblendic facies are pink. It seems to the writer that rocks consolidated under exceptionally dry conditions would have this bluish color as oxidation of iron oxide present in a diffused state in the felspars would be at a minimum. Chips of blue charnockite heated at 600-700°C for a few hours turned pink, simulating typical flesh colored granites.

Orthopyroxene.—Orthopyroxene is the essential mafic constituent of the charnockites, enderbites and quartz syenites, being absent only in some highly reconstituted facies, where they are totally trasnformed to garnet. The orthopyroxene is not merely a hypersthene as hitherto believed, but ranges in composition from eulite En_{25} to hypersthene En_{64} as deduced from optics following

Hess (1952), and from chemical analyses (Howie, 1955; Howie and Subramaniam, 1957; and unpublished data). The orthopyroxenes in the enderbitic rocks are ferrohypersthenes and eulites and occasionally show lamellae of clionopyroxene. In the syenites and charnockites, however, they are typical hypersthenes, with pleochroic inclusions. Pleochroism is in greens and salmon pink and does not appear to be related to the tenor of iron in the mineral. The presence of exsolution lamellae of clinopyroxene and schiller inclusions are suggestive of the igneous nature of these orthopyroxenes. The occurrences of pyroxene to the exclusion of hornblende in these rocks, is suggestive of a relatively dry magma devoid of "hydroxyls", which would consequently require a higher melting temperature.

Garnet and other varietal minerals.—Garnet rich in almandine and pyrope molecules occurs in many of the rocks of the charnockite suite and its paragenesis has been discussed in detail (Howie and Subramaniam, 1957, p. 581-582).

Clinopyroxene approaching diopsidic augite in composition (deduced from optics) is present in small amounts in some rocks of this suite, while hornblende and biotite which are clearly secondary, occur in minor amounts in some rocks.

Accessory minerals.—Apatite, zircon, titanomagnetite, ilmenite and pyrrhotite are the accessory minerals in these rocks. All these occur as euhedral and subhedral individuals, though some zircons are rounded. The rounding of some of the zircons may perhaps be attributed to early crystallization with subsequent corrosion during consolidation and plastic deformation of the rocks. The magnetites in these rocks are being isolated to determine their TiO_2 content, which in turn well help in evaluating their temperature of formation (Buddington, et al., 1955). During preparation of magnetite concentrates, a considerable amount of pyrrhotite was identified in fractions isolated with a hand magnet. The occurrence of pyrrhotite in these rocks as an accessory mineral is a noteworthy feature, and is suggestive of the consolidation of the host rock at elevated temperatures.

Hybrid rocks

These rocks contain minerals found in the charnockite suite described above and those found in the pyroxene granulites which will be described below. The following statement of Holland (1900, p. 147) is of interest in this connection:

> In fact in nearly all sections of these intermediate rocks all the minerals characteristic of charnockite are found mixed irregularly with all the minerals of the norite.

While describing the rocks of the intermediate division from Shevroy, Holland (1900, p. 180) states that in one thin section, patches as basic as norite are mixed with portions as acid as charnockite.

Syntectonic lenses of norite with pyroxenite layers

These rocks have a simple mineralogy being composed of sub-calcic plagioclase An_{50-65}, orthopyroxene En_{55-82}, clinopyroxene (augite), olive green hornblende, spinel and opaque ores. The plagioclase felspar and pyroxenes do not show any recrystallization. The pyroxenite is composed of almost equal proportions of orthopyroxene En_{82} and augite showing salite structure, both the pyroxenes showing paramorphic alteration to green hornblende.

Basement rocks

Pyroxene granulites.—These rocks carry sub-calcic plagioclase varying in composition from An_{35} to An_{70}, orthopyroxenes of the compositional range En_{38} to En_{55}, and light green clinopyroxenes (diopsidic augites and ferroaugites), as essential minerals, quartz, garnet, strongly pleochroic secondary hornblende and biotite as varietal minerals, and apatite, calcite and ores and occasionally sphene as accessories.

Khondalites.—These are composed predominantly of quartz, microperthite, subordinate plagioclase, garnet, sillimanite, green spinel, ores and occasionally an iron rich amphibole.

DISCUSSION

If as Holland assumed, the intermediate and basic rocks were genetically related to the charnockites, this would be reflected in the mineralogy of the various rocks, and brought out clearly by the compositional variations in the orthopyroxenes and plagioclases. The pyroxene granulites carry orthopyroxenes ranging in composition from En_{38} to En_{55} while the rocks of the charnockite suite are En_{25} to En_{64}. Such a situation is not consistent with the granulites and charnockites being members of a differentiation series, and clearly shows that they are genetically unrelated. A specific case has been cited in an earlier paper (Howie and Subramaniam, 1957, p. 584) in which we have stated:

> In the present instance, however, for rocks around Pallavaram, the basic granulite Ch. 199 carries an orthopyroxene of composition $En_{40.5}$, while the acid garnetiferous enderbite Ch. 113 has an orthopyroxene of composition $En_{50.5}$, which is inconsistent with the accepted facts of mineral variation in a differentiation series where the basic members carry a magnesian orthopyroxene and the more acid members a progressively more iron rich orthopyroxene. The garnets from these two rocks behave in the same way, the more basic rocks having the more iron rich garnet.

The variation in composition En_{25} to En_{64} in orthopyroxenes of the charnockite suite of rocks is consistent with their being a differentiation series; in fact the more acid members carry progressively iron rich orthopyroxene, while the syenitic rocks carry magnesian orthopyroxenes (see table 1). The lamellar nature of the orthopyroxenes in the charnockite suite has already been referred to. The orthopyroxenes in the granulites are recrystallized and are clearly metamorphic; Hess (1952, p. 180) has classified an orthopyroxene in a granulite from the Pallavaram area as metamorphic.

PETROGRAPHY

Petrographic descriptions of rocks from the type area have been given by Holland (1900), Washington (1916, p. 324-333), Naidu (1954, p. 266-267), Howie (1955, p. 726-730), and Howie and Subramaniam (1957, p. 567-571). The writer's petrographic studies of rocks of the type area suggest the following classification:

Charnockite suite.—Alaskite, charnockite (birkremite), enderbite and hypersthene-quartz syenite (all above types are partly garnetiferous).

Hybrid rocks.—Homogeneous hypersthene diorites and variants grading to hybrid types where basic and acid portions are readily discernable in hand specimens and thin sections; charnockite-pyroxene granulite migmatites.

Syntectonic lenses.—Norite. hornblende norite, pyroxenite, and hornblende-hypersthenite.

Basement rocks (pyroxene granulites and khondalites).—Pyroxene granulite. biotite pyroxene granulite. hornblende-hypersthene-biotite-andesine granoblastic gneiss, hypersthene-hornblende-labradorite gneiss. garnetiferous-ferrohypersthene. clinopyroxene-granulite with lenses of calc-silicate rock. garnetiferous sillimanite gneiss (khondalite) and recrystallized facies of same (leptynite).

Charnockite suite

The charnockite suite of rocks shows marked textural and mineralogical variation. in spite of a megascopic similarity in the greenish blue color. Thin sections display a holocrystalline texture indicative of apparently continuous crystallization. with the major constituents displaying a xenomorphic relationship. The quartz in these rocks shows wavy extinctions and is composed of smaller individuals welded together. The potash felspar is primarily a microperthite with incipient microcline hatching, while plagioclase which is subordinate is an oligoclase An_{20-30}. Myrmekite is present and occurs along contacts of quartz and microperthite. Orthopyroxenes present. vary in composition from hypersthenes to eulite and are occasionally lamellar. Other minerals present are occasional grains of clinopyroxene. biotite. and secondary hornblende. with apatite. zircon. and ores. Garnet is developed in many rocks sometimes to the exclusion of orthopyroxene. The feldspars in enderbites are antiperthitic plagioclases and mesoperthites, denoting a higher content of soda; the orthopyroxenes in them are ferrohypersthenes and eulites. The quartz syenites carry only about 10-15 percent of modal quartz and simulate charnockite *sensu stricto* in other respects. The alaskites have been described as quartz felspar rocks associated with charnockite by Holland (1900, p. 145) who states:

> They differ from the normal charnockite merely in the complete suppression of the hypersthene and concomitant increase in the size of the two remaining constituents, quartz and felspar, which present precisely the same microscopic peculiarities as the constituents of the normal charnockite.

The writer has found these rocks to be composed essentially of microcline microperthite, and rutilated quartz with myrmekitic intergrowths of felspar. Zircon and ores are present as accessories while garnet is developed in the border facies near contacts with khondalites.

Thin sections of recrystallized facies of rocks of the charnockite suite display typical granulitic texture with polygonal grains of felspars and quartz forming a mosaic in which grains of orthopyroxene and accessory minerals are scattered. In some strongly deformed rocks the quartz leaves display a pronounced preferred orientation (plate 1, fig. 6). The absence of turbidity and inclusions in the felspars (perthites) and quartz. as also their polygonal outline and sutured margins are suggestive of recrystallization. The formation of perthite from sub-microscopic cryptoperthites has been considered by Chayes

(1952, p. 293) to be a feature of granitic rocks showing intense granulation of quartz. The potash felspars in the coarse undeformed rocks are cryptoperthites and microperthites which tend to become perthitic in slightly deformed types containing highly granulated quartz (plate 1, fig. 5). In some instances, the process is carried to a farther stage resulting in the formation of plagioclase and microcline (plate 1, figs. 1-2). Buddington (1939, p. 329) has shown that under appropriate temperature conditions "non-uniform pressure" favors the complete dissociation of perthitic felspar of quartz syenite rocks of the Adirondack region with resultant formation of albite or oligoclase, and microcline. Unmixing of cryptoperthites and perthites in the rocks of the charnockite suite, may be attributed to post crystallization deformation. The modal and chemical compositions of the recrystallized types do not differ much from those of coarse grained undeformed types.

Hybrid rocks

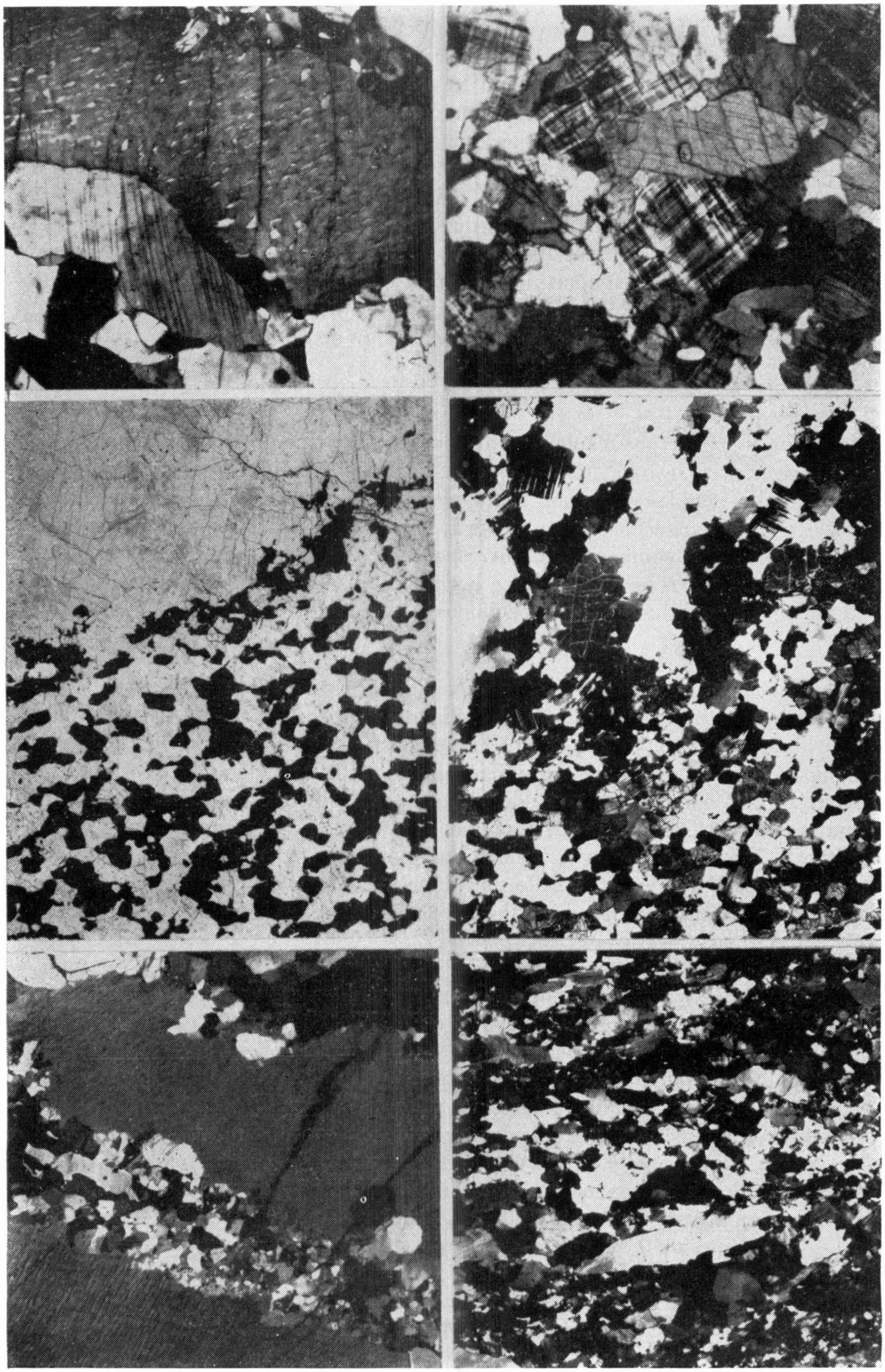
The hybrid types display granulitic texture where they are homogeneous, and are uneven in other cases (plate 2, figs. 4-5). As stated earlier, they have a mineral assemblage common to the pyroxene granulites of the basement, and rocks of the charnockitic suite (plate 1, figs. 3-4). Plagioclase and orthopyroxene of differing compositions, corresponding to those in pyroxene granulite and charnockite respectively, have been recognized and their composition determined from optics, in some specimens of these hybrid rocks.

Syntectonic lenses

The norites and associated pyroxenites are considered to be syntectonic lense and have been dscribed by Holland (1900, p. 157-159, 164-169) and Washington (1916, p. 328-333). These rocks are fairly coarse in texture as compared to the pyroxene granulites, and show little evidence of recrystallization (plate 2, fig. 3). They are devoid of quartz which is invariably present in the granulites. The norites carry plagioclase An_{50-65} and orthopyroxene En_{55-68}, while the pyroxenite carries an orthopyroxene En_{82}. For the purpose of our discussion, it is sufficient to state that these rocks bear little resemblance to the pyroxene granulites with which they are associated.

Basement rocks

Pyroxene granulites.—The pyroxene granulites are characterized by their uniform granulitic texture and readily distinguished from the norites referred to above by the ample evidence of recrystallization displayed by thin sections. Unforunately, Holland has grouped these granulites with the norites. Thin sections display a granulitic texture with the plagioclase felspars (An_{35-70}) showing polygonal outlines, displaying an equal proportion of twinned and untwinned plates (plate 2, fig. 2). Orthopyroxenes occur as rounded grains together with clinopyroxenes, and in plain light they are hardly distinguishable from one another when both exhibit a similar absorption tint. Orthopyroxenes are hypersthenes or ferrohypersthenes, while the clinopyroxenes are augites and ferroaugites pleochroic in pale green. Strongly pleochroic secondary amphibole is present in many types sometime predominating over the pyroxenes. Garnets are present in some types, while biotite, ores, calcite, apatite, and



sometimes sphene are present in varying amounts as accessory minerals. Quartz is present interstitially and is often in intergrowth with plagioclase. Various types have been recognized among these granulites on the basis of their textural and mineralogical variations. Some of these granulites which occur as layers in the khondalites are extremely fine-grained and can be called microgranulites, and perhaps represent metamorphosed and recrystallized basic sills. On the whole, these pyroxene granulites differ from norites in their displaying a characteristic metamorphic texture, containing plagioclase and orthopyroxenes with wide compositional variation, carrying minor amounts of quartz and developing a garnetiferous or biotite rich facies. If they are the genetic relatives of the charnockites, we would expect them to carry magnesian orthopyroxenes and sub-calcic plagioclase of limited compositional range, but this is not the case. Holland's (1900, p. 154) description of these rocks is significant. He writes:

> The norites are almost always granulitic (panidiomorphic) in structure, neither the ferromagnesian silicates nor the plagioclase showing any noticeable approach to idiomorphic outlines, *but when quartz occurs as it sometimes does in small quantities* it is irregularly developed around the minerals as if it were the last of the constituents to crystallize.

Khondalites.—The khondalites and their recrystallized facies have been described in an earlier paper (Howie and Subramaniam, 1957, p. 570). Khondalite proper is a buff-colored schistose rock with abundant garnet (altered to brownish aggregates) and visible sheafs of sillimanite. Thin sections show a high proportion of quartz characterized by wavy extinction, acicular inclusions, and sutured margins, and minor amounts of perthitic potash felspar (plate 2, fig. 1). Garnets occur as subhedral crystals and rugged grains which develop "atolls" and carry inclusions of spinel, ores, quartz, plagioclase, biotite and sillimanite. The recrystallized facies of above is a medium grained rock with porphyroblasts of pink or rose colored garnets, and in thin sections display a mosaic of granulated quartz with subordinate potash felspar, in which garnets are scattered. Sillimanite occurs as prismatic crystals, while minerals of undeformed khondalite described earlier are also present in varying amounts. The writer considers leptynite described by Holland (1900, p. 173) to be a completely recrystallized and reconstituted facies of khondalite. The high proportion of normative and modal quartz in leptynite (see table 1) is significant, and suggestive of its affinity to khondalite.

It will be seen from the above brief review of the petrography of these

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PLATE 1

Photomicrographs of charnockites

Fig. 1 upper left. Ch 60—Enderbite showing large plate of microperthite and adjacent plagioclase, crossed Nicols × 45.

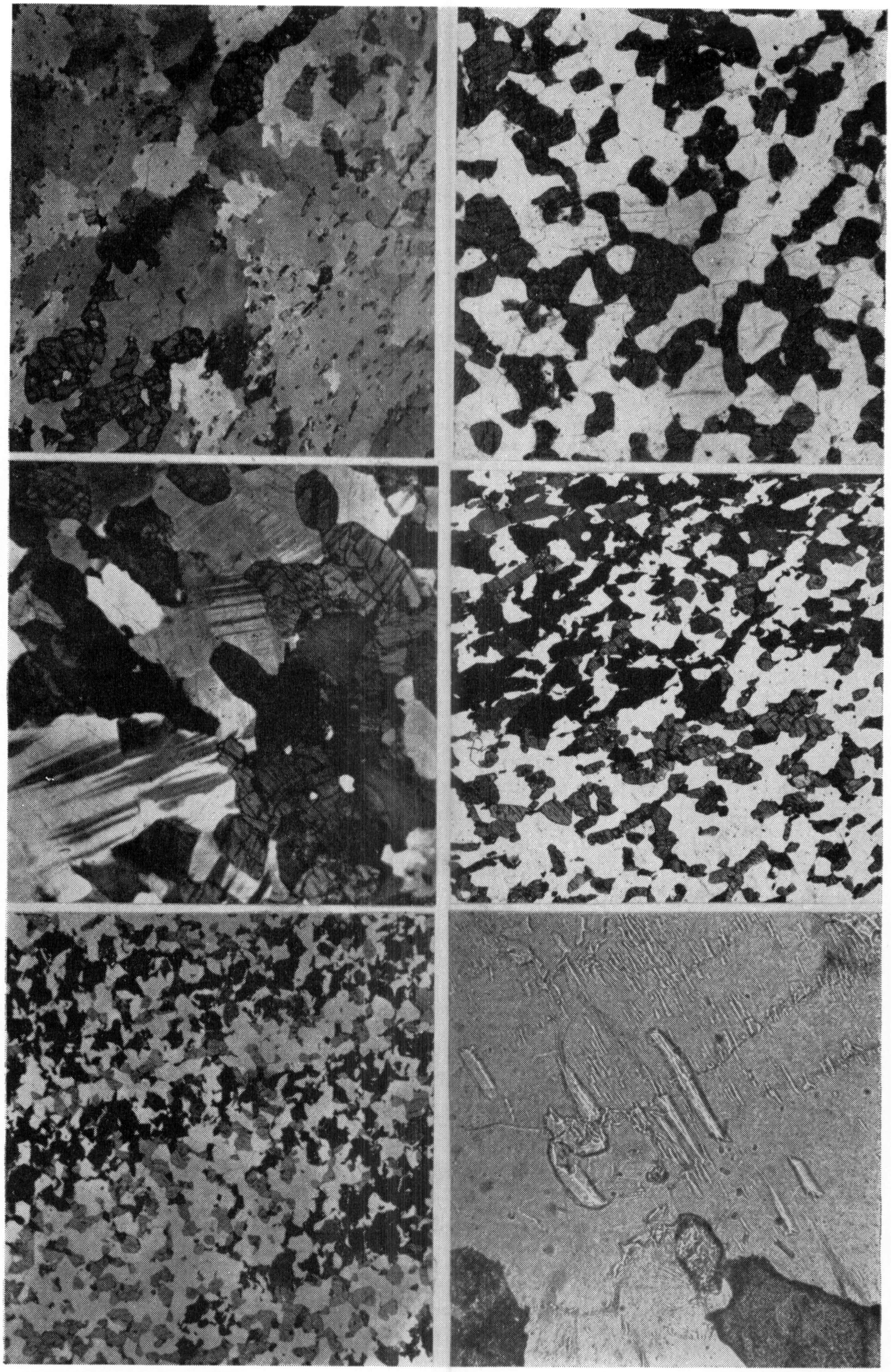
Fig. 2 upper right. Ch 60—Enderbite showing microcline and plagioclase developed due to unmixing of perthite, crossed Nicols × 45.

Fig. 3 center left. Pyroxene granulite-charnockite migmatite, plain light × 13.

Fig. 4 center right. Ch 273—Pyroxene granulite charnockite migmatite, crossed nicols × 13.

Fig. 5 lower left. Ch 110—Slightly deformed charnockite showing large plates of microperthite with peripheral quartz and myrmekite, plain light × 11.

Fig. 6 lower right. Ch 268—Strongly deformed charnockite showing preferred orientation of quartz, crossed nicols × 9.



rocks that we are dealing with genetically unrelated units. The modal compositions of these rocks and the compositions of significant mineral phases present in them determined from optics, are given in table 1.

CHEMISTRY OF ROCKS AND MINERALS

Chemical, normative and modal compositions of 24 rocks from the type area are presented in table 1 and the distribution of trace elements in some minerals and rocks are shown in table 2. Analyses 1 to 13 in table 1 are of rocks of the charnockite suite, 14 to 17 of hybrid rocks, 18 and 19 of basic granulities, 20 and 21 of syntectonic lenses of basic rock, and 22 to 24 of khondalites and leptynite.

The silica percentage in rocks of the charnockite suite ranges from 55.08 in a quartz syenite to 78.53 in an enderbite. In the rocks classified as charnockites (hypersthene granite) and hypersthene quartz syenites, the Na_2O content varies from 1.94 percent in a charnockite (No. 1) to 3.67 percent in a syenite (No. 6), the values for K_2O in the same rocks being 3.87 percent and 6.97 percent respectively. In the enderbites Na_2O percentage ranges from 3.13 to 4.00, with values for K_2O ranging from 1.27 to 3.99. Analysis No. 9 is of an enderbite, and contains almost equal proportions of Na_2O and K_2O.

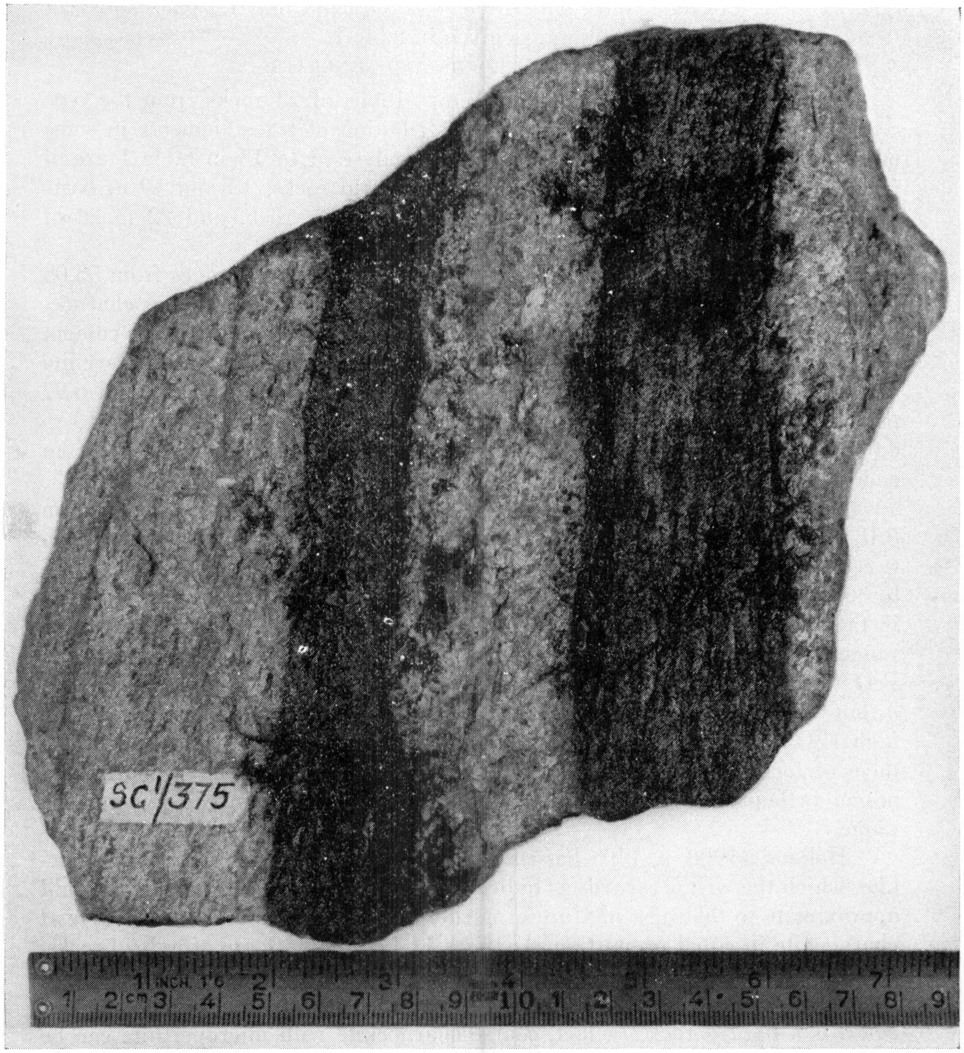
The normative quartz in the rocks of the charnockite suite varies from 6.18 percent in a syenite to 45.78 percent in an enderbite, but is generally between 20 and 30 percent. The modal values for quartz varies generally from 17 to 30 percent, being higher in very acid charnockites and enderbites, and low in the quartz syenites. The MgO content of the rocks of the charnockite suite ranges from 0.26 to 3.99 percent, and these when considered with the values of FeO (after formation of normative magnetite) reflect the composition of the orthopyroxene present. The enderbitic rocks (No. 8 to 13) will be seen to have high FeO values in relation to MgO, which is consistent with the presence in them of ferrohypersthenes and eulites, while in the other rocks, a more magnesian orthopyroxene is indicated, most of them falling in the hypersthene range.

Holland (1900, p. 149) has stated that the intermediate forms of charnockite, which the writer regards as hybrid rocks, have a composition which would approximate to that of a mixture of norite (pyroxene granulite of writer) and charnockite in equal proportion. Analyses 14-17 in table 1 are of hybrid rocks. Analyses 17 is of a hornblende norite from St. Thomas Mount. Examination of thin sections and the hand specimen (9.660) has convinced the writer that this again is a hybrid rock. In fact, coarse charnockite with microperthite can be seen veining the pyroxene granulite in this specimen (plate 2, figs. 4, 5, 6).

PLATE 2

Fig. 1 upper left. Ch 119—Garnetiferous sillimanite gneiss, crossed nicols × 9.
Fig. 2 upper right. Ch 209—Pyroxene granulite, plain light × 9.
Fig. 3 center left. Ch 172—Norite, crossed nicols × 50.
Fig. 4 center right. 9.660—Hornblende Norite (?), Note pyroxene granulite (more mafic) and charnockite (less mafic) portions plain light × 9.
Fig. 5 lower left. 9.660—Do—Note the banded nature of rock due to intermingling of charnockite and pyroxene granulite plain light × 6.
Fig. 6 lower right. Microperthite (hair perthite) vein in pyroxene granulite (Specimen 9.660) plain light × 60.

PLATE 3



Large hand specimen from St. Thomas' Mount showing alternating layers of charnockite and pyroxene granulite.

Analyses 18 and 19 are of typical pyroxene granulites, while 20 and 21 are of norite and pyroxenite. Analysis 22 is that of khondalite, 23 that of a recrystallized facies of the same and 24 that of a leptynite. All the three rocks are characterized by very high silica, and consequent very high normative and modal quartz. Progressive increase in the alkalies can be noticed; the percentages K_2O and Na_2O in No. 22 are 0.59 and 0.11, which increase to 1.26 and 2.22 in No. 23, and 2.19 and 4.54 in leptynite. In the opinion of the writer this indicates the recrystallization and reconstitution of khondalite during the emplacement of rocks of the charnockite suite, which contributed the alkalies.

The trace element contents of some rocks, garnets and potash feldspars from the type area (Howie, 1955, p. 737, 747; Howie and Subramaniam, 1957, p. 576) are of interest, and are given in table 2. The garnets from the rocks of the charnockite suite (Nos. 5 and 6 of table 2) have identical assemblage of trace elements with close similarity in composition, while garnet from a pyroxene granulite (No. 7) has an entirely different trace element composition, the values for yttrium and cobalt being markedly different. The trace element distributions in garnets of leptynite khondalite, and recrystallized khondalite (Nos. 8, 9 and 10) are remarkably similar. The trace element distribution in rocks of the charnockite suite, hypersthene granites and enderbites (Nos. 12, 13, 14 and 15 of table 2) is fairly similar, and differs from the trace element composition of leptynite (No. 11). It may be seen that the distribution of minor elements in these rocks lends support to the writer's interpretations, but much additional data will be needed to draw any definite conclusions.

Howie (1955, p. 748) has drawn attention to the high barium content of the potash felspars of charnockites, and the potash felspars in these rocks carry as much as 4,500 p.p.m. of barium, in an enderbite (see table 2, 1-4). Engelhardt (1936, p. 187) has recorded the high BaO content of microperthitic charnockites, and correlated it with preferential enrichment in barium of potash felspar crystallized at high temperature. The mesoperthitic nature of potash felspars in enderbites of the charnockite suite, and their high barium content may be considered symptomatic of high temperature of crystallization of the magma which gave rise to the charnockite suite.

CONCLUSIONS

1. Charnockite is redefined as a hypersthene quartz felspar rock with or without garnet, characterized by greenish blue felspars and grayish blue quartz, the dominant feldspar being a microperthite. This redefinition is justified as the para type (Charnock's tombstone) is found to be garnetiferous, and this facies is prevalent in the type area.

2. The term "charnockite suite" is suggested for a group of genetically related alaskites, charnockites (birkremite), enderbites and hypersthene-quartz syenites, all of which are partly garnetiferous. This will correspond to the 'Acid' division of Holland's Charnockite Series. If it be considered desirable to retain the term Charnockite Series, it should be restricted to mean only the above suite of rocks.

3. The 'Intermediate' division of Holland consists of an assemblage of hybrid rocks, derived by interaction of charnockite magma on pyroxene granulites of the basement.

4. The occurrences of norite with related pyroxenitic layers and schlieren at Pammal hill and at a few other points in the type area are considered syntectonic lenses, unrelated to the charnockite suite.

5. The 'Basic' division of Holland is largely made of pyroxene granulites and variants, which are interstratified with quartzo-felspathic garnetiferous sillimanite gneisses (khondalite).

6. The 'Ultrabasic' division of Holland is represented by the pyroxenitic schlieren referred in paragraph 4 above.

7. Holland's leptynite is considered a highly metamorphosed and reconstituted facies of khondalite, referred in paragraph 5 above.

8. The charnockite suite of rocks is thought to have been emplaced as thick sheets and lenses in gently folded basement rocks: all the rock units have subsequently suffered intense regional deformation.

9. The charnockite suite of rocks and hybrid types are, as exposed at present, interstratified with the basement rocks with which they are structurally conformable. The rock units in the type area represent a series of tight isoclinal folds plunging gently to the north, and overturned to the west.

10. The charnockite suite of rocks is considered of primary igneous origin based on the following lines of evidence:

(i) The rocks carry mesoperthitic felspars which indicate their having consolidated at magmatic temperatures.

(ii) The high barium content of the potash felspars in these rocks indicates high temperatures of formation.

(iii) The occurrence of pyrrhotite as an accessory mineral also points to high temperatures of consolidation.

(iv) The orthopyroxenes in these rocks show a systematic variation in composition. Some of them show lamellar structure while others show schiller inclusions, both of which are regarded as characteristic of igneous orthopyroxenes.

(v) The plagioclases in these rocks exhibit a rare complex twin law, which may be regarded as suggestive of a magmatic origin for these rocks.

(vi) The rocks of the charnockite suite carry inclusions of older pyroxene granulites.

(vii) The absence of amphiboles in these rocks point to their consolidation at elevated temperatures.

The writer feels that the reinterpretation presented will offer a satisfactory explanation for the almost universal association of charnockites with pyroxene granulites and leptynites. How far these ideas are applicable to charnockite rocks described from other Precambrian shield areas remains to be seen and will be discussed in a future communication.

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Table 1

Chemical, Normative and Modal Compositions of Charnockites and Associated Rocks from the Type Area Near Madras

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	77.32	77.47	71.97	70.65	71.32	64.73	55.08	78.53	71.98	64.24	67.49	65.95
TiO_2	0.56	0.26	0.40	0.46	0.27	0.40	0.72	0.09	0.74	1.51	0.54	0.99
Al_2O_3	9.81	11.00	13.30	15.09	14.31	15.16	20.46	12.49	12.49	13.57	16.13	15.27
Fe_2O_3	0.41	1.04	1.29	0.80	0.88	1.36	1.42	0.53	1.43	0.97	1.14	1.12
FeO	3.33	2.02	2.30	1.53	1.18	2.99	7.02	0.61	2.84	7.10	4.47	4.86
MnO	0.03	—	0.04	0.02	0.07	0.12	0.27	0.01	0.07	0.24	0.12	0.22
MgO	1.21	0.43	0.58	0.53	0.52	2.14	3.99	0.26	0.30	1.36	1.60	2.70
CaO	1.14	1.02	2.10	2.66	1.05	1.92	2.41	2.38	1.53	5.16	3.44	2.95
Na_2O	1.94	2.86	2.78	2.99	2.61	3.67	2.58	3.78	3.94	4.00	3.13	3.74
K_2O	3.87	4.14	4.24	4.69	6.87	6.97	4.69	1.33	3.99	1.27	1.47	2.06
H_2O+	0.25	0.20	—	0.43	0.65	0.58	0.78	0.04	0.58	0.43	0.27	0.25
H_2O-	0.07	0.05	0.27	0.22	0.15	0.30	0.20	0.05	0.30	0.13	0.40	0.20
P_2O_5	0.11	—	0.14	0.08	0.03	0.19	0.10	0.03	0.05	0.17	0.04	Tr.
S	—	—	0.05	—	—	—	—	—	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—	—	—	—	—	—
S =	—	—	0.03	—	—	—	—	—	—	—	—	—
Totals	100.05	100.49	99.43	100.15	99.91	100.53	99.72	100.13	100.24	100.15	100.24	100.31
Density	2.70	2.67	2.72	2.65	2.71	2.58	2.79	2.68	2.71	2.83	2.77	2.84
NORMS												
Quartz	45.06	41.22	33.60	28.50	26.22	8.82	6.18	45.78	29.28	20.64	30.97	22.92
Corundum	0.55	—	0.61	0.46	0.51	—	6.94	0.41	—	—	3.24	1.53
Nepheline	—	—	—	—	—	—	—	—	—	—	—	—
Albite	16.40	24.10	23.58	25.15	22.01	31.44	22.01	31.96	33.54	34.06	26.46	3.44
Anorthite	4.92	5.00	9.45	12.64	5.56	4.17	11.12	11.95	4.45	15.01	16.76	14.73
Orthoclase	22.90	24.46	25.02	27.80	40.49	41.14	27.80	7.78	23.91	7.78	8.67	12.23
Diopside	—	—	—	—	—	3.37	—	—	2.26	8.11	—	—
Hypersthene	7.90	3.34	3.91	2.75	2.49	7.60	20.96	1.13	2.35	9.40	10.60	13.53
Olivine	—	—	—	—	—	—	—	—	—	—	—	—
Magnetite	0.46	1.62	1.86	1.16	1.39	2.09	2.09	0.70	2.09	1.39	1.64	1.62
Ilmenite	1.06	0.61	0.76	0.87	0.46	0.76	1.37	0.15	1.52	2.59	1.03	1.98
Apatite	0.27	—	0.34	0.20	—	0.44	0.27	0.07	0.13	0.40	0.10	—
Pyrite	—	—	0.12	—	—	—	—	—	—	—	—	—
Salic	90.3	94.4	92.2	95.0	95.6	85.8	74.9	97.9	91.6	78.0	86.6	82.9
Femic	9.7	5.6	7.8	5.0	4.4	14.2	25.1	2.1	8.4	22.0	13.4	17.1

TABLE 1 (Continued)

	13	14	15	16	17	18	19	20	21	22	23	24
SiO_2	64.18	58.85	51.55	50.73	50.04	49.64	47.71	47.44	46.30	75.88	81.08	77.93
TiO_2	1.12	1.06	1.12	1.38	1.93	1.91	0.97	1.29	0.83	0.58	0.52	0.31
Al_2O_3	16.40	13.37	13.86	13.33	11.65	11.38	15.57	5.36	16.24	11.03	9.88	10.65
Fe_2O_3	0.95	4.58	1.51	4.99	2.63	1.19	2.31	3.13	2.54	2.46	0.57	0.99
FeO	5.21	7.78	11.63	11.80	15.76	9.48	10.85	12.42	9.42	6.27	2.33	2.50
MnO	0.07	0.18	0.23	0.44	—	0.31	0.38	0.15	0.33	0.11	0.00	0.04
MgO	2.41	2.96	5.80	4.50	5.58	12.24	7.24	19.96	7.83	1.51	1.16	0.18
CaO	3.26	7.15	10.28	8.79	7.89	10.44	11.52	7.60	12.24	0.18	0.42	0.40
Na_2O	3.64	2.83	3.08	2.94	3.08	1.68	2.07	0.48	2.50	0.59	1.26	2.19
K_2O	2.52	0.22	0.54	0.51	0.89	0.70	0.42	0.10	0.15	0.11	2.22	4.54
H_2O+	0.14	0.70	0.25	0.72	0.19	0.80	1.11	0.08	1.26	0.85	0.49	0.08
H_2O-	0.28	0.10	0.12	0.15		0.19	0.07		0.07	0.17	0.14	0.16
P_2O_5	0.08	0.19	0.23	0.17	0.20	0.32	0.12	0.27	0.10	0.03	0.03	Tr.
S	—	—	—	—	—	—	—	0.34	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—	0.07	—	—	—	—
S =	—	—	—	—	—	—	—	—	—	—	—	—
Totals	100.26	99.97	100.20	100.45	99.84	100.28	100.34	98.69	99.81	99.77	100.10	99.97
Density	2.66	3.10	3.10	3.10	3.02	3.14	3.10	3.33	3.02	2.87	2.77	2.67
					NORMS							
Quartz	19.74	20.94	—	4.14	—	—	—	—	—	65.28	61.68	45.48
Corundum	1.92	—	—	—	—	—	—	—	—	9.38	4.79	1.43
Nepheline	—	—	—	—	—	—	—	—	0.85	—	—	—
Albite	30.79	23.58	26.00	24.63	26.20	14.15	17.82	4.19	19.39	5.24	10.48	18.34
Anorthite	15.71	23.35	22.41	21.68	15.29	21.68	31.97	12.23	33.08	1.11	1.95	1.95
Orthoclase	14.85	1.11	3.02	2.78	5.00	3.89	2.22	0.56	0.56	0.56	12.79	26.69
Diopside	—	9.25	22.72	17.45	19.43	23.08	21.00	18.97	21.80	—	—	—
Hypersthene	13.05	11.77	17.94	18.52	20.27	22.86	8.89	42.35	—	12.38	5.80	4.28
Olivine	—	—	2.92	—	5.63	7.63	12.89	13.01	17.13	—	—	—
Magnetite	1.37	6.73	2.09	7.19	3.71	1.86	3.25	4.41	3.71	3.71	0.93	1.39
Ilmenite	2.14	2.13	2.16	2.74	3.65	3.65	1.98	2.43	1.52	1.22	0.91	0.61
Apatite	0.19	0.43	0.54	0.40	0.34	0.67	0.29	0.67	0.34	0.07	0.07	—
Pyrite	—	—	—	—	—	—	—	—	—	—	—	—
Salic	83.2	69.5	51.3	53.5	46.7	39.9	51.8	17.2	54.8	82.4	92.3	93.7
Femic	16.8	30.5	48.7	46.5	53.3	60.1	48.2	82.8	45.2	17.6	7.7	6.3

TABLE 1 (Continued)

MODES

	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	41.8	40.0	34.6	26.6	31.8	14.1	9.1	48.6	32.8	18.5	39.4	23.8
K-Feldspar	28.5	48.0	26.5	37.3	49.1	50.2	26.7	3.5	34.2	26.2	16.5	16.3
Plagioclase	19.5	6.0	31.8	28.0	16.0*	21.2*	32.0	41.2	22.2	32.0	25.5	32.2
Orthopyroxene	7.9	3.0	4.8	6.9	1.9	11.7	0.9	4.7	8.0	19.7	—	12.3
Clinopyroxene	—	—	—	—	—	—	—	—	—	—	—	Tr.
Garnet	—	—	—	—	—	—	18.0	—	—	—	16.1	12.6
Hornblende	—	—	—	—	—	—	—	—	—	1.0	—	—
Biotite	—	1.0	—	0.1	—	Tr.	12.6	0.9	—	—	1.1	1.0
Sillimanite	—	—	—	—	—	—	—	—	—	—	—	—
Apatite & Zircon	0.1	—	0.2	0.3	0.6	0.8	0.4	0.1	0.8	1.2	0.3	0.7
Ores	2.2	2.0	2.1	0.8	0.6	2.0	0.3	1.0	2.0	1.4	1.1	1.1
Green Spinel	—	—	—	—	—	—	—	—	—	—	—	—
Felsic	89.8	94.0	92.9	91.9	96.9	85.5	67.8	93.3	89.2	76.7	81.4	74.3
Mafic	10.2	6.0	7.1	8.1	3.1	14.5	32.2	6.7	10.8	23.3	18.6	25.7

* Includes small percentage of myrmekite

COMPOSITION OF MINERALS

	1	2	3	4	5	6	7	8	9	10	11	12
K-Feldspar	Or 71	Or 85	Or 83	Or 85	Or 83	Or 75	Or 75	—	Or 58	Or 55	Or 65	Or 55
Plagioclase	—	An 33	An 33	An 33	—	An 30	An 35	—	An 35	An 35	—	An 30
Orthopyroxene	En 44	En 39	En 39	En 38	En 52	En 55	En 64	—	En 25	En 27	—	En 49

TABLE 1 (Continued)

MODES

	13	14	15	16	17	18	19	20	21	22	23	24
Quartz	20.6	17.2	—	5.0	1.3**	1.2	—	—	—	53.7	52.9	53.4
K-Feldspar	20.8	1.5	—	9.2	6.9	2.3	—	—	—	7.4	24.3	40.5
Plagioclase	40.2	43.5	45.0	46.3	44.5	34.9	37.5	46.0	46.0	—	—	2.1
Orthopyroxene	9.7	18.0	25.2	10.4	6.2	20.9	6.4	5.0	15.3	—	—	—
Clinopyroxene	—	10.4	24.8	19.2	17.6	24.0	24.8	—	12.4	—	—	—
Garnet	5.8	—	—	—	—	—	8.6	40.7	—	27.6	13.5	2.9
Hornblende	—	0.9	0.9	0.6	18.9	Tr.	20.0	—	24.1	—	—	—
Biotite	0.9	—	—	—	—	13.5	—	—	—	—	4.6	—
Sillimanite	—	—	—	—	—	—	—	—	—	8.9	4.2	—
Apatite & Zircon	0.3	0.5	0.4	0.5	Tr.	0.5	—	}	—	—	—	—
Ores	1.7	8.0	3.7	8.8	4.6	2.7	2.7	} 8.3	2.1	0.6	0.5	1.1
Green Spinel	—	—	—	—	—	—	—	}	0.1	1.8	—	—

** Redetermined by writer on thin sections of rock No. 9.660 from the registered collections of the Geological Survey of India, by Point Count Analysis.

	13	14	15	16	17	18	19	20	21	22	23	24
Felsic	81.6	62.2	45.0	60.5	52.7	61.6	37.5	51.0	61.3	61.1	77.2	93.9
Mafic	18.4	37.8	55.0	39.5	47.3	38.4	62.5	49.0	38.7	38.9	22.8	6.1

COMPOSITION OF MINERALS

	13	14	15	16	17	18	19	20	21	22	23	24
K-Feldspar	Or 55	—	—	—	—	—	—	—	—	—	Or 80	Or 81
Plagioclase	An 30	An62	An 38	An 45	An 50	An 64	An 65-70	—	An 52	—	—	—
Orthopyroxene	—	En 44	En 43	En 40	En 48	En 62	En 41	En 61	En 58	—	—	—

Rocks of the Charnockite Suite

1. 4639 Charnockite, Pallavaram, Madras; Anal. J. H. Scoon, (R. A. Howie, 1955, page: 732).
2. 9.658 Charnockite, Magazine Hill St. Thomas Mount, Madras; Anal. H. S. Washington, (1916, page: 325).
3. 6435 Charnockite, Tirusulam Hill, Minambakkam, Madras; Anal. J. H. Scoon, (R. A. Howie, 1955, page: 732).
4. 3705 Charnockite, (G. S. I. 9.658) Anal. J. H. Scoon, (R. A. Howie, 1955, page: 732).
5. Ch 182 Charnockite, from quarry NW of Cowl Bazaar, Pallavaram, Madras; Anal. T. Katsura, Tokyo.
6. Ch 112 Charnockite, (Hypersthene Quartz Syenite),—West of Hasanapuram quarry south of Pallavaram, Madras; Anal. T. Katsura, Tokyo.
7. Ch 217 Charnockite (Hypersthene, biotite quartz syenite), Tattankunnu quarry between the two rifle ranges south of Minambakkam Rly Station, Anal. T. Katsura, Tokyo.
8. 36218 Enderbite, Pallavaram, Madras; Anal. R. A. Howie (1955, page: 732).
9. Ch 60 Enderbite, small knoll south of mile 24.6, ½ mile WNW of Melkottaiyur; Anal. T. Katsura, Tokyo.
10. Ch 29 Enderbite, northern slopes of Vandalur hill .563, in quarry East of Standard Motors factory; Anal. T. Katsura, Tokyo.
11. Ch 219 Garnetiferous granulite (Reconstituted Enderbite), Tattan Kunnu quarry between the two rifle ranges, south of Minambakkam Rly Station, Anal. R. A. Howie (Howie and Subramaniam, 1957, page: 572).
12. Ch 113 Garnetiferous Enderbite, west of Hasanapuram quarry, south of Pallavaram, Madras: Anal. T. Katsura, Tokyo. K_2O, Na_2O, H_2O+ and H_2O- by R. A. Howie, (Howie and Subramaniam 1957, page: 572).
13. 56 Garnetiferous Enderbite, Pallavaram; Anal. R. A. Howie (Howie and Subramaniam, 1957, page: 572).

Hybrid Rocks

14. Ch 132 Hypersthene Quartz diorite (Hybrid rock), from hillock ¼ mile NW of .321 and ¾ mile SSW of Tirunirmalai; Anal. T. Katsura, Tokyo.
15. 4642A Hypersthene Diorite of the Charnockite Series, Pallavaram, Madras; Anal. J. H. Scoon, (R. A. Howie, 1955, page: 733).
16. Ch 207 Hypersthene Diorite (Hybrid rock), mid point along ridge, W of Muvarasanpattu, and ½ mile E of Tirusulam village, near Pallavaram, Madras; Anal. T. Katsura, Tokyo.
17. 9.660 Hornblende Norite (Hybrid rock ? re-examination of specimen 9.660 shows it to be a pyroxene hornblende granulite veined by charnockite) NE of Magazine Hill St. Thomas Mount, Madras; Anal. H. S. Washington (1916, page: 328).

Basic Granulites

18. Ch 114 Basic granulite inclusion in Ch 112 west of Hasanapuram quarry, south of Pallavaram; Anal. T. Katsura, Tokyo.
19. Ch 199 Basic granulite, (Norite ?) Summit of Paravatta Hill, south of Mosque hill, Pallavaram, Madras; Anal. T. Katsura, Tokyo (Howie and Subramaniam 1957, page: 572).

Pyroxenite and Norite

20. 9.672 "Bahiaite", (Hornblende hypersthenite), "Pammal Hill, Pallavaram, Madras; Anal. H. S. Washington (1916, page: 332).
21. Ch 172 Norite from SE flanks of .265 Pammal Hill ½ mile WSW of Pammal village, Madras; Anal. T. Katsura, Tokyo.

Khonalites and leptynite

22. Ch 119 Khondalite, northern end of Pachaimalai Hill .360; Anal. T. Katsura, Tokyo (Howie and Subramaniam, 1957, page: 572).
23. Ch 121 Recrystallized Khondalite, near contact with charnockite, south of Oddapalaiyam; Anal. T. Katsura, Tokyo (Howie and Subramaniam 1957, page: 572).
24. 3708 Garnetiferous Leptynite (G. S. I. 9.665, Holland 1900, p. 173) Pallavaram, Madras; Anal. R. A. Howie, 1955, page: 732).

TABLE 2

Distribution of Trace Elements in Some Minerals and Rocks of the Type Area

(in parts per million)

(Taken from published data by Howie, & Howie and Subramaniam)

Determinations by: Dr. S. R. Nockolds and R. S. Allen of Cambridge University

			Potash Feldspars				Garnets						Rocks				
	r	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P	0.34	(100)	—	—	—	—	—	—	—	—	—	—	*	350	600	480	130
Ga	0.62	1	10	12	10	10	10	15	10	40	15	10	15	15	15	15	10
Cu	0.63	2	*	*	*	*	450	450	450	*	*	*	*	10	3	*	3
Li	0.68	5	3	3	2	Tr.	1	3	*	12	3	3	5	15	12	10	25
Ni	0.69	2	—	—	—	—	—	—	—	—	—	—	3	2	5	5	*
Mo	0.70	2	—	—	—	—	*	*	*	25	*	*	*	*	—	Tr.	*
Co	0.72	5	—	—	—	—	30	30	45	5	5	5	*	5	3	2	*
V	0.74	5	*	*	*	*	140	220	220	*	*	*	*	50	20	8	10
Zr	0.79	10	5	30	*	—	60	50	50	120	120	120	350	150	250	500	25
Mn	0.80	(80)	80	*	—	—	—	—	—	—	—	—	400	150	300	200	*
Sc	0.81	10	—	—	—	—	100	150	40	*	*	*	*	*	—	—	*
Y	0.92	15	—	—	—	—	1000	1000	150	600	350	450	50	5	20	40	*
Sn	1.12	10	250	250	400	650	—	—	—	—	—	—	50	400	160	125	400
La	1.14	50	*	*	*	*	—	—	—	—	—	—	*	*	65	100	*
Pb	1.20	10	20	20	30	20	*	*	*	40	*	*	10	15	20	25	*
Ba	1.34	10	1750	3500	4500	3000	*	*	*	*	*	*	900	2000	1200	2500	500
Rb	1.47	5	500	550	100	800	—	—	—	—	—	—	125	150	100	100	*

* Element present in amount below the limit of sensitivity.
r = ionic radius of the element
S = limit of sensitivity

1. K-feldspar from rock 6436, Charnockite from Tirusulam Hill (Howie 1955, p. 747)
2. K-feldspar from rock 4639, Charnockite from Pallavaram (Howie 1955, p. 747)
3. K-feldspar from rock 36218, Enderbite from Pallavaram Hill (Howie 1955, p. 747)
4. K-feldspar from rock 3705, Charnockite (G.S.I. 9.658) from St. Thomas Mount (Howie 1955, p. 747)
5. Garnet from Ch. 113, Garnetiferous Enderbite from Pallavaram (Howie and Subramaniam, 1957, p. 576)
6. Garnet from Ch. 219, Garnetiferous granulite from Pallavaram (Howie and Subramaniam, 1957, p. 576)
7. Garnet from Ch. 199, Basic granulite from Pallavaram (Howie and Subramaniam, 1957, p. 576)
8. Garnet from 3708, Garniterous Leptynite from Pallavaram (Howie and Subramaniam, 1957, p. 576)
9. Garnet from Ch. 119, Khondalite, northern end of Pachaimalai Hill .360 (Howie and Subramaniam, 1957, p. 576)
10. Garnet from Ch. 121, Recrystallized khondalite from south of Oddapalaiyam (Howie and Subramaniam, 1957, p. 576)
11. Rock 3708, Garnetiferous Leptynite from Pallavaram (Howie 1955, p. 737)
12. Rock 3705, Charnockite from St. Thomas Mount (Howie 1955, p. 737)
13. Rock 6436, Charnockite from Tirusulam Hill, Minambakkam (Howie 1955, p. 737)
14. Rock 4639, Charnockite from Pallavaram (Howie 1955, p. 737)
15. Rock 36218, Enderbite from Pallavaram (Howie 1955, p. 737)