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CHARNOCKITES AS METAMORPHIC ROCKS*

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ABSTRACT. In many areas of the world (for example, Ceylon, South India, northeastern United States, East Africa, West Greenland, Western Australia), charnockites ranging from acid to basic in composition are intimately associated with metasedimentary rocks belonging to the granulite facies of metamorphism. In such areas, charnockites are spoken of as being "interbanded", "interlayered", or even "interbedded" with their associated rocks. Even in the type areas of South India where large charnockite masses were originally thought to be massive and intrusive, recent mapping has revealed the presence of bands of metasediments conformable to the foliation of the surrounding charnockites.

Apart from their close association in the field, however, charnockites and their associated metasediments in areas of granulite facies metamorphism have similar textural features, common mineralogical characteristics, and, in several instances, the same structural pattern. Such similarities along many different lines suggest strongly that the charnockites and metasediments in these areas have had a common metamorphic and tectonic history, and that the charnockites, *as they now occur*, are metamorphic rocks, largely confined to granulite facies areas.

In some environments, charnockites and (more commonly) charnockitic biotite gneisses containing unstable or relic orthopyroxene are found with migmatized and granitized rocks, together with scattered relic metasedimentary bands. Here, later metamorphic events appear to have changed rocks that were originally formed in the granulite facies to those having mineralogical and other characteristics typical of the amphibolite facies. Charnockites of acidic composition may, however, occur as diffuse pegmatites, cross-cutting veins and dikes, and intrusive bodies. Such occurrences are thought to have been formed by palingenesis and antexis of preexisting charnockites.

THE PROBLEM

Fifteen years ago, Pichamuthu reviewed what he called "the charnockite problem" (Pichamuthu, 1953) and came to the conclusion that charnockites had different modes of origin in different parts of the world; these he classed broadly as "igneous" and "metamorphic". Since that time thousands of square miles in several parts of the world, where charnockites are well displayed, have been mapped in some detail, and there is considerable evidence not only that the majority of charnockites are of metamorphic origin, but also that they occur only in particular regional settings. An attempt is made in this paper to examine some of the evidence for such a view. No comprehensive review of charnockites is attempted as this was efficiently done a few years ago (Howie, 1964).

Although the term "metamorphic" was first used by Lyell in 1833 for "altered stratified rocks", for the purpose of this paper Daly's definition (Daly, 1917) is most acceptable. According to it, metamorphic rocks are those in which:

> recrystallization of the original crystalline or amorphous material has taken place, with or without chemical reactions; no general melting of the rock or simultaneous solution of its constituents has accompanied the recrystallization.

In judging the charnockites as metamorphic rocks, therefore, the first and primary question to be answered is "are the charnockites, *as we see*

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them today, rocks whose form or character has been changed; or do we see them as they were originally formed"? Questions relating to the original nature of the rocks or to the conditions under which they formed are necessary corollaries but subsidiary to the primary question.

On what kind of evidence are we to base our answers? Geochemical criteria, though they have been used to a great extent, are really not helpful. There is, as Howie (1955) has remarked, a convergence in the stability fields of plutonic rocks and of high grade metamorphism that makes it almost impossible to distinguish, geochemically, an igneous rock from a metamorphosed igneous rock. Thus, the many reasons for which the "charnockites, alaskites, birkremites" of Madras have been thought of as being of primary igneous origin (Subramaniam, 1959, p. 346) are indicative only of "magmatic" or "high" temperatures—temperatures that are equally common in high grade regional metamorphism.

We must, therefore, rely more and more on evidence that is difficult to dispute, namely, in the mode of occurrence of the charnockites, their relationships to the surrounding rocks, their structural patterns, their mineralogical composition, and their textural features.

Much has been written about the nomenclature of the charnockites. To the field geologist, however, charnockites are dark, greasy-looking rocks, grayish, greenish, or bluish-gray in color and equigranular in texture, in which a pleochroic orthopyroxene, probably hypersthene, is suspected and invariably found to be present, whether the rock is acid, intermediate, or basic in composition. To a person who has worked in charnockite areas for some time, a charnockite can be recognized immediately, whether it occurs in North America, Greenland, Finland, northwest Scotland, Nigeria, Nyasaland, South India, Ceylon, Australia, or Antarctica. That, surely is as critical and valid a test as any of the nomenclature most generally adopted by field geologists, namely, *acid charnockite, intermediate charnockite,* and *basic charnockite* for the acid, intermediate, and basic divisions of Holland's charnockite series (Holland, 1900). As this paper is not concerned with a discussion of nomenclature, the above terminology is used without further definition.

FIELD EVIDENCE

One of the most remarkable features of the occurrence of charnockites that has been brought out by recent mapping in many parts of the world is their close and intimate association with metasediments formed in the granulite facies of regional metamorphism.

In Ceylon, for example, charnockites are extensively developed in the Central Highlands over several thousands of square miles, as part of the Highland series (Cooray, 1962). In this area they are interlayered on all scales with quartzites and quartz schists, marbles and calc granulites, and pelitic to semi-pelitic granulites, schists and gneisses in which sillimanite, almandine, perthitic orthoclase, forsterite, diopsidic pyroxene, phlogopite, rutile, ilmenite-magnetite, spinel, and graphite are critical or common minerals. That this close association between metasediments and charnockites is not accidental is seen in the southeast of the island. Here a small enclave of charnockites and metasediments known as the Kataragama complex is completely surrounded by hundreds of square miles of biotite and hornblende gneisses of almandine amphibolite facies grade in which charnockites and metasediments are absent or very rare (see Cooray, 1967, Geol. Map). A similar type of association is seen in the southwestern sector of the island, though here zones or belts of charnockites and metasediments alternate with belts of non-charnockitic granitized gneisses.

The charnockites of the Highland series lie conformably next to each other and to the associated granulites, there being a striking parallelism of such s-planes as foliation, bedding (in quartzites and marbles), and margins of bands. This interbanding can be seen on all scales, from an inch or less to hundreds and even thousands of feet, but whatever the scale, the appearance of stratification is so remarkable as to resemble a well bedded series. Further, the interbanding is so regular that it can be traced along the strike for distances of 50 or more miles, as in the Rangala-Polonnaruwa area (Cooray, 1962, fig. 3).

That this close association of charnockites with metasediments is almost an essential factor in the occurrence of the former is seen in other parts of the world as well. Many excellent examples are available from Africa, only a few being quoted below. In Malawi (formerly Nyasaland), for example, charnockites are associated with granulite facies metasediments (marbles, pelitic and semi-pelitic granulites) in a clearly defined zone, outside which they are not found (Morel, 1958). In the North Pare region of Tanzania (formerly Tanganyika), the metamorphic rocks assigned to the Usagaran System include metasedimentary granulites and schists as well as charnockites, all of which represent a thick series of metamorphosed sediments (Bagnall, 1963). In fact, in Tanzania generally, where charnockites are widespread, they are interbanded with metasedimentary granulites and, whatever their original nature, are thought to have resulted from high-grade metamorphism, under granulite facies conditions, of preexisting rocks (Sutton, Watson, and James, 1954; Wright and James, 1958). In the Kitgum area of Uganda, where charnockites are associated with granulite facies gneisses, there are no indications of an instrusive relation between the two (Almond, 1962). In the southern West Nile area of Uganda (Hepworth, 1964), charnockites occur as "a component part of the layered Granulite Group which contains a variety of rock types" including leucocratic granulites, diopside-scapolite granulites, kyanite- and sillimanite-bearing garnet quartzites, spinel, andalusite, cordierite, and other granulites; the Granulite Group is said to have been formed in the granulite facies of metamorphism. In the Zomba area of Malawi (Bloomfield, 1965), "paragneisses and charnockitic granulites", which attained granulite facies metamorphic conditions and were folded together along northwest axes, outcrop over about 400 square miles.

Similar examples are found in Europe, North America, and Australia. In Finland, charnockites are confined to two areas of high-grade metamorphism, namely, the West Uusimaa complex in the southwest where they are associated with marbles (Parras, 1958) and in Finnish Lapland where they form an essential part of a succession of metasedimentary granulites (Eskola, 1952). In West Greenland, enderbitic charnockites are found with metasediments in a central granulite facies complex which is surrounded by non-charnockitic amphibolite facies rocks (Ramberg, 1948). A similar relationship exists between the Scourian and Laxfordian complexes in northwestern Scotland (Sutton and Watson, 1951). In the San Gabriel Mountains of California, charnockites of the Aurelia Ridge Group are interbanded and interlayered with metasedimentary granulites, the whole assemblage having been formed under granulite facies conditions during a first phase of metamorphism (Hsu, 1955). Similarly, in the Little Moose Mt. syncline of the Adirondacks, alternating layers of charnockite, marble, and pelitic metasediments constitute a folded supracrustal sequence metamorphosed in the hornblende-granulite facies (de Waard, 1967). In fact, de Waard (1965) has made the general statement that "charnockites of the Adirondacks are commonly grey green, orthopyroxene-bearing *metamorphic* rocks". In the Musgrave block of Central Australia, rocks of the charnockite suite are found associated with metasedimentary rocks and orthogneiss, all of which have been subjected to deep-seated regional metamorphism (Wilson, 1959).

In India itself there are numerous examples of charnockites being associated with high-grade metamorphic rocks, as for example in the Salem district (Narayanan, 1955), Cape Comorin district (Paulose, 1956), Guntur and Krishna districts (Narasinga Rao, 1963), Srikakulam district (Sriramadas, 1963), and in the Tinnevelly district (Narayanaswamy and Lakshmi, 1967). As the most recent example, one may quote the current work of M. V. R. Rau in the Anantagiri metamorphic complex, 75 km northwest of Visakhpatam (M. V. R. Rau, personal commun.). Here, hypersthene–diopside–hornblende assemblages (that is, charnockites) are interbedded with garnet–biotite–sillimanite assemblages, garnetiferous quartzites, and calcite-diopside granulites and gneisses. The rocks in the complex have been formed in hornblende-granulite to pyroxene-granulite facies of metamorphism. Further, what have always been regarded as "massive" charnockite bodies such as the Shevaroy, Nilgiri, and Palni Hills are now known to have metasediments occurring within them (Subramaniam, 1959). In Ceylon, too, the so-called charnockite "massifs" of Haputale and Rakwana (Adams, 1929) are known to contain interlayered metasedimentary bands and to be folded into rather flat-lying folds.

One cannot leave the field evidence without referring to the type area near Madras. Recent work has shown that the charnockites of the Pallavaram area are interbanded with calc granulites and pelitic to semi-pelitic granulites and gneisses, as in Ceylon (see Muthuswami, 1951;

Howie and Subramaniam, 1957; Subramaniam, 1959; Leelananda Rao, 1960a, b). (Further discussion of the type area is made below.)

The examples quoted above should be sufficient to show that charnockites from many parts of the world are interlayered or interbanded with metasedimentary rocks that have been formed in the highest grades of regional metamorphism. In all these instances, the charnockites are perfectly conformable with the surrounding rocks, and it is more than likely that their antecedents, whether sedimentary or igneous, formed an integral part of the original successions.

STRUCTURAL EVIDENCE

One of the main features that led Holland to suggest a magmatic origin for the charnockites of Madras was the supposed homogeneity of large masses of these rocks and the difficulty of finding evidence of folding in them (Holland, 1900). This view cannot now be upheld, and although modern methods of structural mapping and petrofabric analysis have still not been extensively applied in charnockite areas, there is sufficient evidence to show that many charnockites, even the "massive" ones, have been folded and deformed with the rocks with which they are interbanded.

The first suggestion that the Madras charnockites had a structural pattern was made by Narayanan, Ramachandran, and Sankaran (1955) who, on the initial results of petrofabric studies, showed that the charnockites were b-tectonites. A similar conclusion regarding the charnockites of Salem was reached by Ramanathan (1956). A little later Wilson (1957) pointed out that the elongation of mineral grains in the charnockites, when viewed "down structure", was parallel to the plunge of the axes of tight folds in the interstratified khondalites (for example, garnet-sillimanite schists). Subramaniam (1959) also showed that a marked b-lineation exists in the acid charnockites, basic charnockites, and metasediments at Madras, all of which are conformable to each other. The rocks in the type area belong to a tightly-folded isoclinal pattern, overfolded to the west, and the sketch map that accompanies Subramaniam's paper shows that several small folds, whose closures can be seen, are also present. In the Pallavaram area of Madras, Merh (1963) has found that metamorphic charnockites formed during or after an early deformation were retrogressively altered during a later one.

The structural patterns of the charnockites of Ceylon support this evidence. It is clear, in areas that have been mapped on the scale of 2 inches to 1 mile, that the major and minor structures in the charnockites are identical to those in the surrounding metasediments, and that such structures were formed at the same time or very soon after the metamorphism that produced the rocks. In the Highland series of Rangala, for example, the s-planes of both charnockites and metasediments have a common orientation, and elongate quartz leaves in charnockites and quartzo-feldspathic gneisses are parallel to the major fold axes (Cooray, 1961). Further, both rock groups are folded into a regular structural pattern—a regularity that extends over several thousand square miles (see Cooray, 1967, Geol. Map). In the Polonnaruwa area, north of Rangala, quartzites, marbles, and charnockites are described as being folded into a series of isoclinal structures (Vitanage, 1959, p. 49). In the central part of the Alutgama area, southwestern Ceylon, charnockites are interbanded with garnet–biotite–cordierite gneisses in the eastern limb of an overturned dome structure; further east is a large symmetrical antiform plunging to the north, its shape being defined by a narrow charnockite band in granulite facies metasediments (Cooray, 1965; 1967, fig. 43). A plot of the poles to the foliation planes over the Alutgama sheet indicates that there is a marked statistical homogeneity with respect to the strike of the bedding/foliation planes of all the rocks in the area (Cooray, 1965, fig. 26). These π-poles are arranged in a girdle about a regional fold axis that is very near the maximum orientation of lineations and minor folds, namely, 335° with a plunge of about 15°. Elsewhere in southwestern Ceylon, charnockites, metasediments, and gneisses have been folded along axes that can be traced for 50 or more miles (see Cooray, 1967, Geol. Map). The structural elements in the charnockites and associated metamorphic rocks were clearly developed at the same time.

Within the charnockite bands of Alutgama area are narrow bands and ribs of calc granulite, cordierite granulite, quartzite, quartz schist, and amphibolite. They form isolated bodies whose s-planes are parallel to those of the containing charnockites, and it is hardly likely that they could have remained in place after the intrusion of large amounts of charnockite "magma" and after considerable deformation. On the contrary, the structural evidence indicates that the charnockites formed a part of the original supracrustal succession which was subjected to granulite facies metamorphism and orogenic deformation at about the same time. The same features are seen in the Kurunegala sheet, where charnockites and quartzites are folded into a succession of antiforms, and where granitization along certain bands has produced retrograde biotite gneisses from charnockites (Cooray, 1967, fig. 42).

Two examples from outside India and Ceylon may be quoted. In an exploratory study of charnockite granulites from the Musgrave Range of central Australia, Wilson (1959) has shown that the quartz fabric has a symmetry close to monoclinic, giving reasonable confirmation of the field evidence that the observed lineation is the axial direction of the folds. From West Greenland (Berthelsen, 1960) comes a detailed structural study of a high-grade metamorphic area in which it is shown quite clearly that the charnockites were formed with other granulites during progressive metamorphism to granulite facies conditions and that they suffered the same tectonic history as the associated rocks.

MICROSCOPIC EVIDENCE

The most conspicuous textural feature of the charnockites, whatever the degree of acidity, is the even grain size of the constituent minerals and the marked absence of euhedral forms. This feature is so common that it sometimes tends to be overlooked. What is important, however, is that the identical textural feature is common in the associated metasediments. Even in rocks that possess some degree of gneissosity, the even grain size is characteristic of individual foliae, and it is present in the apparently "massive" charnockites. No igneous textures have been seen in the charnockites of the Highland series of Ceylon. The persistent equigranular texture and the rounded and embayed outlines of the hypersthene crystals in the Madras charnockites have been remarked on by Howie (1955), and it was these features rather than the inconclusive geochemical evidence that led him to believe that the Madras charnockites are metamorphic in origin.

Other textures of charnockites that are typical of metamorphic rocks are the gradational boundaries and interdigital contacts between them and adjacent metasediments, as well as the absence of chilled margins.

Several mineralogical characteristics stamp the charnockites as metamorphic and not magmatic rocks. There is, for example, no evidence anywhere in the Highland series of Ceylon of the *normal igneous sequence* of mineral crystallization. Instead, orthopyroxene can repeatedly be seen to be derived from clinopyroxene, sometimes forming complete or partial rims round it; a similar mineral relationship was noted in the charnockites of Bastar (Ghosh, 1941) and of southwestern Sweden (Quensel, 1951).

Antiperthitic plagioclase, very commonly in the sodic andesine range An_{35}, and mesoperthitic microcline or orthoclase are the characteristic *feldspars* of charnockites, suggesting that exsolution of subsolidus components took place during fluctuations of temperature and pressure during metamorphism. The same factors may have been responsible for the symplectic intergrowths of pyroxene and plagioclase seen in many intermediate charnockites from Ceylon. Although Howie (1964) has noted the prevalence of plagioclase twinning on the albite-ala law, plagioclase twinning in the Ceylon charnockites is often absent or vaguely defined. Zoning, where present, generally takes the form of a continuous variation in extinction position from rim to core, the rims being more calcic than the cores (Cooray, 1961). The *pyroxenes* of the Madras charnockites are not typical of an igneous differentiation series, either in the variation of the Fe/Mg ratio (Howie and Subramaniam, 1957) or in the iron-magnesium distribution coefficient (Kretz, 1961, quoted by Howie, 1964). *Garnet,* a common constituent of charnockites, is nearly always an almandine-pyrope variety. Rounded *monazite* grains are present in several of the acid to intermediate charnockites of southwestern Ceylon, and they are markedly different from the euhedral monazite grains in granitic pegmatites near Colombo. Pichamuthu (1959) has drawn the same distinction between rounded monazite grains in charnockites and metasediments from Cape Comorin and Travancore and euhedral monazites in granites and gneisses of the same area. *Zircons* from the charnockites of Polonnaruwa are notably rounded in form and very similar to the zircons in adjacent quartzites (Vitanage, 1957). Finally, *graphite* is a common accessory mineral in charnockites of Ceylon where it occurs in the same form and manner as in quartzites, calc granulites, garnet-sillimanite gneisses, garnet-cordierite gneisses, and hornblende-garnet granulites.

The predominantly metamorphic minerals and the striking freshness of these minerals in most charnockites strongly support the field and structural evidence that the charnockites of most areas, *as seen today*, are metamorphic in origin. Further, the evidence is overwhelming that the mineral assemblages recorded as being present in charnockites from most parts of the world are confined to the restricted field of the granulite facies, though they may persist as unstable associations or relics into the upper portions of the almandine-amphibolite facies field (see below).

CONCLUSIONS

The metamorphic facies of charnockites.—It has been shown above that in many parts of the world, charnockites are associated with rocks of high-grade regional metamorphism. That this association is not accidental has been recognized by the grouping together of charnockites and their associated metasediments, as in the "layered Granulite Group" of the southern West Nile district (Hepworth, 1964) and in the Highland series of Ceylon (Cooray, 1961, 1962). Highland series rocks for example, are characterized by:

A. sillimanite and potassium feldspar in pelitic rocks,
B. hypersthene as the typical ferromagnesian mineral,
C. pyroxenes in basic rocks of amphibolitic composition,
D. the presence of hornblende and biotite in certain areas,
E. rutile as the typical titanium mineral and the absence of sphene except in impure calcareous rocks,
F. antiperthitic plagioclase and untwinned, mesoperthitic potassium feldspar.

These mineralogical characteristics as well as the mineral assemblages (see Cooray, 1961, p. 126) place the Highland series in the granulite facies of regional metamorphism, rocks of both the pyroxene granulite and hornblende granulite sub-facies (Fyfe, Turner, and Verhoogen, 1958) being present. The presence of hornblende and biotite in charnockites of the Highland series is thought to be due either to retrogressive metamorphism affecting pyroxene granulite facies rocks (Cooray, 1961, 1962) or to hornblende granulite sub-facies metamorphism following pyroxene granulite/sub-facies metamorphism (Hapuarachchi, 1967). In the magmatitic and granitic gneisses of the Vijayan series, which adjoin the Highland series on two sides, charnockites are absent (Cooray, 1962). Further, biotite, hornblende, microcline, and sphene are typical Vijayan minerals, hypersthene, sillimanite, and rutile being extremely rare. Vijayan series rocks are thought to represent Highland series rocks altered during later metamorphic episodes under almandine-amphibolite facies conditions (Cooray, 1962).

The charnockites of many other areas have been shown to belong to the granulite facies. Among them might be mentioned the charnockites of Malawi (Morel, 1958), Uganda (Hepworth, 1964), southwestern Finland (Parras, 1958), Finnish Lapland (Eskola, 1952), California (Hsu, 1955), West Greenland (Berthelsen, 1960), Vavato, Madagascar (Delbos, 1958), the Salem district of India (Narayanan, 1955), and the Anantagiri complex of the Eastern Ghats (M.V.R. Rau, personal commun.). Though not specifying facies conditions, Howie's work on the Madras charnockites led him to the conclusion that they were formed by recrystallization in the solid state under conditions of "plutonic metamorphism" (Howie, 1955). Similarly, enderbites and charnockites in the Congo are considered to be the products of "katazonal metamorphism" of an old gneissic basement (Delhal, 1963).

In certain areas, charnockites occur with hornblende granulite subfacies or even almandine amphibolite facies rocks (for example, Muthuswami, 1953). This appears to be so in a transitional zone between Highland series and Vijayan series rocks in Ceylon and also in much of the southwestern sector of the island. In the latter area, charnockites are associated with wollastonite–scapolite–diopside granulites, garnet–cordierite–sillimanite granulites and gneisses, and quartz-feldspar granulites, and invariably contain biotite and hornblende. They can, however, be traced into charnockitic biotite gneisses in which garnet is usually present, hypersthene exists as relics in highly uralitized meshes, biotite and hornblende appear as late minerals, and the presence of water is evident. The same phenomenon can be seen on a small scale in parts of southwestern Ceylon where late granitic pegmatites which cut across charnockites have "decharnockitised" border zones on either side (Cooray, 1965). These charnockitic biotite- and hornblende-bearing gneisses, of which there are a large variety, are derived from normal charnockites by retrogressive metamorphism, the reactions *diopside* → *hypersthene* → *hornblende* → *biotite* and *hypersthene* → *biotite* being typical of the transformation (Cooray, 1965). Furthermore, charnockitic rocks are often found in association with leucocratic biotite-garnet granitic gneisses, some of which contain diffuse patches of grayish-green charnockite looking material which, in thin section, are seen to have small relics of hypersthene enmeshed in uralite. The conversion of charnockites into charnockitic rocks and ultimately into non-charnockitic biotite-hornblende gneisses of the almandine amphibolite facies, probably in the presence of water, can be clearly demonstrated in Ceylon. (A similar transformation has been seen by the writer near Dindigul in South India).

In the Ipernat Dome of West Greenland (Lauerma, 1964), hypersthene gneisses are converted by retrogressive metamorphism into granodiorites and quartz dioritic gneiss through a wide transitional zone, while pyroxene amphibolites of the granulite facies are altered to amphibolites without hypersthene. It may thus be that what at first sight appear to be almandine amphibolite facies charnockites or even hornblende granulite sub-facies charnockites may, on closer examination, turn out to be polymetamorphic rocks derived from pyroxene granulite sub-facies charnockites by diaphthoretic changes.

The transition from charnockite to biotite gneiss has, however, been explained by quite the opposite process. Near the village of Kabbal, Bangalore, in South India, coarse-grained patches of charnockite have been formed by in situ transformation of hornblende-biotite gneiss (Pichamuthu, 1961). At Bauchi in northern Nigeria, charnockite has been derived from biotite gneiss by the introduction of some ferrous-iron rich juvenile solution (Oyawoye, 1964). Both examples represent what may be termed "charnockitiszation" near the amphibolite facies/granulite facies boundary. The reactions that are typical of the process, namely *hornblende* → *diopside* → *hypersthene* (Hietanen, 1967) are the reverse to those operating in "decharnockitization".

The parent materials of charnockites.—The evidence set forth in the preceding sections should be sufficient to show that many, if not most, of the charnockites of the world are metamorphic rocks formed by the complete recrystallization of preexisting rocks. The latter may have been sedimentary, volcanic extrusive, or magmatic intrusive, but their original textural and mineralogical characters have been completely destroyed in the process.

Charnockites of certain areas appear to have some geochemical similarity to igneous rocks, and it is possible that they represent a volcanic series in a sedimentary geosynclinal succession. Basic charnockites may even have originated from intrusive magmatic rocks such as dolerites. Such antecedents are, however, relatively restricted.

On the other hand, there is widespread evidence that the antecedents of charnockites were sediments. Attention has already been drawn to rounded zircons, rounded monazites, and grapite as accessory minerals. Narrow bands of quartzite, calc granulite, sillimanite-cordierite granulite, and garnet-sillimanite granulite from a few feet to a few inches in thickness have been recorded within charnockites from several areas, and they may retain their relative positions for long distances. If the charnockites were originally igneous intrusives, then almost insurmountable problems of space arise. There are, at least in Ceylon, hardly any instances of assimilation and hybridization such as one would expect if charnockites were intrusive. What instances there are of apparent assimilation, for example, lenses and patches of calc rock with variable orientation, are due to deformation processes. Thermal contact effects have hardly ever been seen.

Intrusive charnockites.—That there are, in some parts of the world, charnockite bodies that are intrusive into the surrounding rocks cannot be doubted. In central Australia, for example, non-foliated orthopyroxene granites are said to be "magmatically emplaced masses of palingenetic origin" (Wilson, 1960). In California, a charnockitic pluton has been described as intruding amphibolite facies country rocks (Compton, 1960).

In southwestern Ceylon, cross-cutting charnockitic dikes sometimes several feet in thickness, have been noted (Cooray, 1965); they are essentially coarse-grained, dark greenish-gray acid rocks, some of which contain large hypersthene crystals surrounded by hornblendic rims. Coarse-grained, diffuse patches of pegmatitic charnockite within medium-grained charnockites are also common, both here and in the Highland series. Still more striking are the "porphyritic" intrusive charnockites seen in southwestern Ceylon (Cooray, 1965). These are medium-grained, fresh-looking rocks with porphyritic feldspars and typical charnockitic appearance. In thin section such rocks have, besides hypersthene, euhedral orthoclase crystals with Carlsbad twinning, a phenomenon not seen in many hundreds of thin sections of metamorphic charnockites studied by the writer. Unlike the latter, these porphyritic charnockites appear to have a directionless fabric. It is also significant that the pegmatitic and porphyritic charnockites are, in all instances, acidic in composition. Basic intrusive charnockites, which might be expected to accompany the acid types if they were differentiates of a charnockite magma, are rare or non-existent.

Phenomena such as the presence of orthoclase augen in metamorphic charnockites (Cooray, 1954), the "permeation" of basic charnockites by acid charnockite to give some intermediate, gneissic varieties, and the existence of isolated patches of pegmatitic charnockite may all be explained by local remelting and slow recrystallization of the quartzo-feldspathic components of charnockites, these components having lower melting points than the rest of the constituent minerals. Partial melting and mobilization of preexisting charnockites have also been postulated for certain South Indian examples (see, for example, Paulose, 1956). Such phenomena can be expected when PT conditions in charnockite terrains reach the vicinity of the melting curve for granite. Further, in polymetamorphic areas like southwestern Ceylon, where changes in P_{H_2O}, even slight, repeated deformations, and fluctuations in pressure and temperature may be expected, palingenesis may easily result. Thus, by refusion, mobilization, and recrystallization, acid charnockites of metamorphic origin could be transformed into dikes and intrusive bodies of pegmatitic and porphyritic character.

The "charnockite problem".—The statement has often been made that a final judgment on the charnockites must be based on Holland's original occurrence (see Howie, 1955; Pichamuthu, 1953). Having seen the outcrops and degree of exposure in the type locality, however, the writer would rather suggest (even at the risk of being thought heretical!) that it is a most unsuitable place to study the regional association of charnockites. Holland himself, because he was a keen observer and recorded what he saw without bias, noticed such features as the absence of chilled edges, lack of contact effects, and absence of porphyritic charnockites. These, he realized, were unusual in igneous rocks. Such features are, however, critical, being common in metamorphic rocks, and it is much simpler to fit the apparent "igneous" features of the Madras charnockites to a metamorphic origin than to explain metamorphic features by stretching the igneous frame in several directions at the same time. To give just one example, the so-called "leptynites" (a term the writer would like to see completely dropped) are simply quartzo-feldspathic gneisses that could be metamorphosed semi-pelites. To say that they are a "reconstituted facies of khondalites" (Subramaniam, 1959) or, in other words, contact phenomena of magmatic charnockites only begs the question.

The "charnockite problem"—if in fact there is one— can never be satisfactorily solved by chemical analyses, important though these are. The charnockites are not just petrological curiosities. On the contrary—and as has been shown above—they are predominant rock types, almost always metamorphic in origin, in thousands of square miles of "basement areas" of the world. Charnockites are thus primarily a problem for the field geologist, and what is needed more than anything else is careful, detailed mapping on a sufficiently large scale of adequate areas so that the regional and local associations of these rocks, their variations, and their structural relationships can be clearly determined.

It is very necessary to view the charnockites in their proper perspective, namely, as forming important members of regional associations. As has been remarked before (for example, Parras, 1958) the regional setting of charnockites is of much greater petrological importance than the exact details of origin. If, in conclusion, one might be allowed a prediction, it is that the detailed mapping just called for will reveal increasingly that charnockites are to be found almost exclusively in high-grade metamorphic terrains as integral members of metamorphic complexes, formed synchronously with their associated metasediments.

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