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SOME PROBLEMS PERTAINING TO THE PENINSULAR GNEISSIC COMPLEX

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Abstract

Since the terms Peninsular gneiss and Dharwar schist have recently been used by some writers without reference to the original meaning ascribed to them by the geologists who first coined those terms, attention is drawn here to their exact scope and significance. In Karnataka, 'Peninsular gneiss' comprised *all granites and gneisses except those* of Closepet, Chitaldrug, Hosdurga, Arsikere, Banavar, and Saulanga; and 'Dharwar schist' included all the crystalline schists (metavolcanics and metasediments) as opposed to the felsic gneisses. Peninsular gneiss was considered to be intrusive into the Dharwars. No early geologist in India was entirely of the opinion that the Dharwars were younger than the gneisses.

The Bababudan Syncline contains the oldest Dharwar sequence composed of mafic and ultramafic volcanics and intrusives (some of komatiitic affinity) intercalated with iron formations. Limestones are entirely absent.

The actual base of the Dharwars has nowhere been definitely proved. Vertical shafts more than 3 km deep in the Kolar Gold Fields have not touched the bottom. The fact that in some places the schists are seen 'resting on gneiss' does not mean that they constitute the lowest Dharwars.

A general progressive metamorphism in the schist belts in southern Karnataka can be noticed from north to south, culminating in high grade granulite facies rocks. There is no field evidence which lends support to the presumption that the charnockites are overthrust on the Dharwars.

Numerous examples are available throughout Karnataka to prove the intrusive relationship between Peninsular gneiss and Dharwars. There are probably some schistose rocks which are older than the Dharwars, but, so far, they have not been definitely identified. The suggestion that the Sargur schists of southern Karnataka are pre-Dharwars is not based on precise stratigraphical, petrological, geochemical, or geochronological data. These highly metamorphosed isolated strips of schists could well be constituents of the lowest Dharwar sequence.

The problem of the nature of the primordial crust, as elsewhere in the world, has not been satisfactorily resolved in southern India. The occurrence of very old migmatitic gneisses suggest a probable primitive simatic crust.

As in many Precambrian shield areas, the granites and gneisses of Karnataka can be generally grouped into three types which were formed at different times in varying tectonic environments.

While the granulite facies rocks in the most ancient rock complexes are probably related to a higher thermal regime of the earth in early Precambrian time, it must be realised that the existence of pyroxene granulite facies assemblages alone is insufficient evidence to infer that such rocks have had an exclusive origin in the lower crust. It is now known not only in south India but in many parts of the world that gneisses have been transformed into charnockites. There are charnockites of different geological ages and of different modes of formation. The prevalence of enderbites in southern India is probably due to the conversion of early tonalitic rocks in the high grade metamorphic terrains.

INTRODUCTION

Just as in human affairs where the so-called 'eternal triangle' poses grave problems, Precambrian geology also has its eternal triangle to cope with—the relationship of Greenstone, Gneiss, and Granulite, which in southern India are represented by Dharwar Schist, Peninsular Gneiss, and Charnockite, respectively. Since there has recently been a tendency on the part of some workers to re-define the scope and limits of these terms to suit their particular views, it is necessary, at the outset, to consider what the authors of these terms had in mind when they proposed them.

PENINSULAR GNEISS

The original term 'Fundamental gneiss' implied that it was the oldest basement rock, and since the Mysore geologists found evidences that the gneissic rocks were not the oldest, H. H. Hayden, Director of the Geological Survey of India, suggested to W. F. Smeeth who was then the Director of the Mysore Geological Department, that the term might be changed to something else. Smeeth (1916, pp. 16-17) then proposed the name 'Peninsular gneiss' since it is 'probably the most extensive formation of Peninsular India.' He described it as 'a complex of various granites but so protean that no adequate description can be given. The various granites give evidence of successive intrusion, and the fact that the earlier forms contain their own pegmatites which are truncated by subsequent forms, points to a long continued period of plutonic activity. Frequently, the various members mingle either by repeated injection or absorption or crushing and shearing, and we get zones or areas which are highly banded or crushed or with complex flow structure. Other portions are more homogeneous and appear as granite masses. Amongst these latter are some which may be definitely later in age than the gneiss as a whole'. If the excellent geological map produced by the Mysore Geological Department in 1915 is examined, it will be seen that except for the Closepet, Chitaldrug, Hosdurga, Arsikere, Banavar, and Saulanga granites, all the other granites and gneisses are grouped under Peninsular gneiss. The composite and migmatitic nature of this gneiss was recognised nearly four decades ago (Pichamuthu, 1936; 1938).

CHAMPION GNEISS

Reference should be made here to some granites and gneisses which were considered to be the oldest, and named after the Champion lode in the Kolar Gold Field. This is how Smeeth (1916, pp. 15-16) describes it: 'The earliest of these is a comparatively fine-grained micaceous gneiss with bands and veins of coarser granite, pegmatite and quartz. It is usually highly crushed . . . . It intrudes in tongues (into the Kolar hornblendic schists) . . . . The gneiss is often characterised by the presence of grains or blebs of opalescent quartz, the colour varying from a slight bluish milkiness to brown or dark grey . . . . The Champion gneiss represents a very early period of granitic intrusion into the Dharwar schists . . . . There is evidence of their having been intruded and cut off by the next succeeding formation (Peninsular Gneiss)'.

Attention may be drawn here to the fact that certain features of the Champion gneiss such as greasy appearance, brown or dark grey colour of the quartz grains and acicular inclusions in them, all these are characteristic of the quartzes in charnockites.

M. Ziauddin has recently put forward the view that they are only felsic lavas, pyroclastics, and porphyries forming part of the volcanic sequences in schist belts. Are there in the Kolar region both volcanic as well as intrusive rocks which could be considered as Champion gneisses? If so, can they be identified and demarcated in the field? Along with a consideration of these questions it is also necessary to determine what exactly is the relationship between the Champion and Peninsular gneisses.

THE DHARWARS

The term 'Dharwar' coined by Bruce Foote (1886, p. 98) was applied by him to designate all the crystalline schists comprising both metavolcanics and metasediments as opposed to the felsic gneisses. He was of the opinion that the Dharwars were younger than the Peninsular gneisses and rested on them, whereas the Mysore geologists considered the Dharwars as older rock formations into which the gneisses were intrusive. This relative relationship need not concern us at this stage when we are trying to define and describe what is meant by the Dharwars, especially what their lower and upper limits could be. For the specific purpose of this Seminar, it is the lower limit that is more important. Such a discussion leads naturally to a consideration of Dharwar stratigraphy.

The suggestion has already been put forward that the Bababudan Syncline in Karnataka contains the oldest Dharwar formations comparable in some respects with the Barberton type of southern Africa (Pichamuthu, 1974, p. 342). The Dharwars in this region are composed of mafic and ultramafic volcanics and intrusives, intercalated with banded iron formations. There are no limestones, and it is possible that rocks of komatiitic affinity could be present. Deposition probably started in the Bababudan basin and spread very much beyond it resulting in younger beds successively overlapping the older ones. The fault on the Arabian Sea coast of India appears to have abruptly cut off the western part of the Dharwar craton. The Barberton type need not be the only model for Precambrian sequences but the craton in Karnataka has certain resemblances to it.

It is interesting to speculate on how deep the schist belts extend downwards. In the Kolar Gold Field the shafts have gone down to more than 3 km and still not reached the base of the Dharwars. Probably, as we go northwards in Karnataka and as younger beds are met with, the formations are shallower, but we have no data regarding their thickness. Everywhere else in the world the existing schist belts are considered as 'remnants' of a formation which was once continuous, but in Karnataka some think of each strip of schist as a geosyncline or minigeosyncline, though there is no basis for such a conclusion..

In working out Precambrian stratigraphy it should be remembered that the degree of metamorphism can never be used as a criterion of age especially in regions affected by polyphase metamorphism, for in such conditions, no valid subdivision or correlation can be based on the local metamorphic state of different parts of a crystalline complex.

PROGRESSIVE METAMORPHISM

In a series of papers commencing from 1951, I have been suggesting that as one proceeds southwards in southern Karnataka one comes across progressively lower levels of the crust and, therefore, more metamorphosed rocks, till at deeper regions granulites and charnockites are more prevalent (Pichamuthu, 1951; 1953a, b; 1959, 1962, 1965). The magnetite-quartzites often containing garnet and hypersthene, as in the granulite zone rocks of Sivasamudram and Biligirirangans in Karnataka, could well be the more highly metamorphosed hematitic quartzites occurring further north in the greenschist and amphibolite facies Dharwar rocks. It could be not only the same formations at deeper levels of the crust but also of older sequences. Belts of recognisable supracrustal rocks which have passed through the same general high-grade metamorphism as the surrounding gneisses are a common constituent of nearly all high-grade Archaean terrains (Windley and Bridgwater, 1971, p. 38).

The view has sometimes been expressed that in the greenstone belts of Karnataka there is a break between the low-grade schists (greenschist facies) and the high-grade rocks (granulite facies); and that the high-grade granulites are overthrust on the Dharwars (Nautiyal, 1966; Iyengar, 1971, p. 53). There is, however, no field evidence to support this. Crushed or mylonitised zones do not occur between the schists or gneisses and the charnockites to prove the existence of such an overthrust. The break is between the Dharwars (amphibolite and granulite facies) and the high-grade rocks belonging to the Eastern Ghats orogeny (Pichamuthu, 1974, p. 345), and there is charnockite on either side of it.

Due to progressive metamorphism, before the massive charnockites of Biligirirangan and Nilgiris are met with, there are the 'pseudo-charnockites' and 'quasi-charnockites' of Jayaram (1906, pp. 50-51; 1908, pp. 117-119). Further south there are very clear examples, as at Kabbaldurga, of the charnockitisation of Peninsular gneiss (Pichamuthu, 1961, pp. 46-49).

PENINSULAR GNEISS-DHARWAR SCHIST RELATIONSHIP

The controversy as to whether the schists or the gneisses are older has been going on for several decades. The main arguments for and against have been adequately summarised in many recent publications (Radhakrishna, 1974, pp. 442-445) and it is not necessary, therefore, to repeat them here.

It is a significant fact that Newbold (1844) who was the earliest to differentiate the schists from the gneisses, pointed out several instances where the gneisses were intrusive into the schists. It was Foote, however, who was firmly of the opinion that the Dharwar Schists were younger. He considered that the Kolar Gold Field schists rested with 'marked unconformity' on granite gneiss (Foote, 1886, p. 98). No one at present would support this view. Later, while geologically surveying the Bellary district, now in Karnataka, he mentioned several localities where he believed that the schists were younger than the Bellary granitoids (which is equivalent to the Closepet granite), a view again which would be unacceptable to modern workers. It is interesting to note that he recognised 'gneissoid' rocks that differed from the typical granitoids, and which he considered as stratigraphically part of the 'Dharwar Series,' or as part of a 'younger gneissic system' conformable to the Dharwars (Foote, 1895, p. 147). The views expressed by Oldham (1893, pp. 35, 48) on this question are not his own but based entirely on the work done by Foote in the Bellary district, and hence, have no independent value.

According to Holland (1900, p. 194), the lower limit of the Dharwars is not sufficiently defined to warrant the assumption that all the Dharwars are younger than all the Archaean gneisses.

Hatch (1902, p. 4), Walker (1902, pp. 3-4) Maclaren (1906, p. 107), Middlemiss (1917, p. 197), Jones (1922, p. 207), Heron (1935, pp. 9, 11), and Crookshank (1948, pp. 108-109), found evidences of gneissic intrusion into schists, but have explained it away as due to local re-fusion, plastic deformation and penetration. Among those who have given unqualified support to the view that the Peninsular gneiss is intrusive into Dharwar schists, mention may be made of Fermor, Pascoe, Rama Rao, Smeeth and other officers of the Mysore Geological Department.

In summary, it may be stated that no early geologist in India was entirely of the opinion that the Dharwars were younger than the gneisses.

Recently, however, some have advocated the view that Peninsular gneiss forms the basement for the Dharwars, but it should be pointed out that they have not used these terms in their original sense.

EVIDENCES OF PENINSULAR GNEISS INTRUSION INTO SCHIST

A careful study of the geological map of southern Karnataka produced by the Mysore Geological Department sixty years ago, will reveal several examples of Peninsular gneisses intruding into Dharwar Schists. Some of them will be enumerated below:

(1) The Dharwarian north-south trends are in many places abruptly cut off by granites and gneisses as in the schist belt south east of Davangere, or in the Tarikere valley where the Ajjampur-Kaldurga conglomerate beds are cut across by gneisses (Pichamuthu, 1970b, p. 87). The foliation trends of the gneiss in this valley is east-west (Srinivasan and Sreenivas, 1972, p. 77) which is at right angles to the general run of Dharwars in this region;

(2) Slivers of steeply dipping schists interdigitated by gneiss indicate intrusion rather than erosion;

(3) Separate patches of schist of varying sizes adjoining schist belts suggest isolation by gneissic intrusion;

(4) There are several occurrences of 'mantled gneiss domes' in the schist belts. In the Sirankatte dome in the Chitaldrug schist belt, Sambasiva Iyer as long ago as 1901 reported that the texture of the granite near the borders is finer-grained than in the middle indicating that the gneisses were intrusive into the schists. A recent study by Srinivasan and Sreenivas (1968, p. 54) has confirmed this observation, and they consider that the Sirankatte gneisses were emplaced in a pre- to early-tectonic period;

(5) The gneisses swerve round and often deflect the schist trends;

(6) The Peninsular gneisses are physically in contact with Dharwar schists of different ages. This could be due either to intrusion of the gneiss or overlap by successively younger Dharwar beds. The fact that schists 'overlie' gneisses does not mean that the gneiss is not intrusive. Smeeth has clearly defined Peninsular gneiss as intrusive into schists but also underlying them in many places. There is no contradiction in this;

(7) There are contact effects along the borders of the schist belts which could have been caused by the intrusion of the Peninsular gneiss. This difference in the metamorphic grade was the basis on which the early Mysore geologists classified the Dharwars into a lower Hornblendic division and an upper Chloritic division. Such metamorphic effects on the borders of Precambrian greenstone belts have been considered by Anhaeusser *et al,* (1969, p. 2196) as caused by heat from the intruding granites, but proximity of the belt to mantle heat sources because of the relatively thin crust, and the frictional heat generated during deformation may also have been important;

(8) The comparatively large volume of gneiss to schist has sometimes been interpreted to mean that the former served as the basement for the latter. It may be pointed out that there is nothing unusual in a 'sea' of granite surrounding 'islands' of schist; this is a common feature of greenstone belts all over the world. Intrusive granite batholiths are generally very large, sometimes as much as 1800 km long and

200 km wide. In the north Atlantic region formation of large amounts of granitic material around 3000 m.y. occurred throughout the craton;

(9) In Karnataka, there is abundant evidence that the Chitaldrug granite has intruded the Jogimardi traps, that the Jampalnaikankote gneissic granite is intrusive into the Maradihalli pillow lavas, and that the Shimoga gneissic granite has invaded the ultramafics near Devarnarsipur. All these 'gneissic granites' belong to Smeeth's Peninsular gneiss;

(10) An important evidence of intrusion of Peninsular gneiss is the occurrence in it of felsic and mafic xenoliths—the felsic derived from earlier granites and gneisses, the mafic being fragments of Dharwar schists. There are no striking differences between the mafic xenoliths in Bangalore gneisses and the hornblende schists in Dharwar belts. In fact the mafic xenoliths correspond to the grade of metamorphism which has affected the schist-gneiss complex. This has been noticed by Radhakrishna (1956, p. 46) in the north-south run of Closepet granites. There is a progressive change from biotite and hornblende schists near Pavagada and Maddagiri, to hornblende granulites near Tumkur, Magadi and Kunigal, while further south the xenolithic inclusions are pyroxene granulites with close affinities to charnockites. Srinivasan and Sreenivas (1972, p. 77) have also observed that the mineral assemblages in the gneisses are typical of the same grade as that of the adjoining schist belt. There are soapstone enclaves near the ultramafic belt of Nuggihalli, quartzite xenoliths west of Talya and Neralkatte, and amphibolite inclusions along the margin of the Kolar schist belt. The 'tarurite' xenoliths are metamorphosed impure limestones;

(11) In the Bababudan area which contains some Early Precambrian rocks, there is no direct evidence of intrusion as granites or gneisses have not been recognised in the Jagar valley basin. But the mafic flows, sills, and dykes, as well as the banded ironstones in many places contain crystals of tourmaline which probably indicates the proximity of a granitic intrusive not far below.

SIGNIFICANCE OF XENOLITHS

The Peninsular gneisses abound in mafic xenoliths of various shapes and sizes. These were believed to be fragments of Dharwar schists which were caught up during the time of the gneissic intrusion. This constituted one of the important evidences for considering the Dharwars as older than the gneisses.

Very similar arguments and interpretations have also been put forward in the schist belts of other parts of the world. Viljoen and Viljoen (1969a, b), Anhaeusser (1973, p. 369), Glikson (1972, p. 3334), Wilson (1973, p. 389), and others consider such mafic xenoliths as remnants of supracrustal rocks corresponding to the lowest assemblage found in the main greenstone belts (lowermost members of the greenstone belt stratigraphy), and the gneisses as younger. They are remnants of similar earlier structures eroded to a much deeper level. Ferruginous, mafic, and ultramafic types are common, which are the 'resister' rocks in any granitisation process. Such relics which occur scattered within the granites and gneisses range in size from schist belts to smaller xenolithic rafts, shredded schistose slivers, pods and patches.

There is no difficulty in explaining the presence of xenoliths far away from the boundaries or borders of schist belts. Extensive invasion by granites is responsible for the migmatisation of the xenoliths and for the complex metamorphic history of such areas. Glikson (1972, p. 3334) states that tonalites and granodiorites which have intruded schist belts commonly abound in mafic xenoliths which points to the origin of the melts below a mafic crust.

According to Anhaeusser (1973, p. 377), the real ages of such lower volcanic assemblages are unknown because of the geochronological difficulties in dating rocks of this type; all that can be said is that 'they are older than the granites intruding them. Nowhere can it be demonstrated that they overlie granitic crust.'

ARE THERE PRE-DHARWAR ROCKS?

Among the schistose rocks of south India there are probably some which are older than the Dharwars but, so far, they have not been definitely identified. The rocks of the Bababudan Syncline, Kolar Schist Belt, and sundry other patches in southern Karnataka can be considered as older than the quartzite-phyllite-limestone-ironstone formation of the major schist belts, but there is no proof as yet to consider only the latter as Dharwars and the former as pre-Dharwars. The Mercara Group which was proposed last year (Swaminath, *et al*, 1974, pp. 38-39) for the lowest members of the Dharwars in Karnataka is now sought to be raised to the rank of a Supergroup, somewhat equal to the status of the Dharwars, and renamed after Sargur (Viswanatha, 1975, pp. 4-7). Till more definite evidences—stratigraphical, petrological, geochemical, and geochronological—are provided to justify its separatism from the Dharwars, it would be prudent to make a slower and firmer approach. In the words of Beloussov which he wrote in some other connection, 'I think we are all in a hurry . . . . Elementary knowledge of the history of our science advises us of the necessity to reserve for the future different ways until the factual data will make the most likely choice.' Till such time, therefore, we could consider the Sargur Group as belonging to the lowest Dharwar sequence, analogous to the position of the Onverwacht Group in the Swaziland Sequence of the Barberton region.

A somewhat similar situation as in Karnataka appears to exist in Rhodesia where, according to Wilson (1973, p. 393), the simplest explanation of this lowest assemblage (Sebakwian) is that it forms an early but integral part of the main greenstone belt succession, and that the gneisses are essentially younger than the greenstone belts which they surround, a view also shared by Viljoen and Viljoen.

From the existing geochronological data available for the Karnataka region, it is not possible to treat the Dharwars as entirely Proterozoic in age as has been done by Nautiyal (1966), and Srinivasan and Sreenivas (1972). Some Dharwar rocks have given much older dates (Pichamuthu, 1971, p. 262).

Windley and Bridgwater (1971, p. 44) consider with Salop (1968, p. 61) that it is inadvisable to erect a division around 3000 m.y. separating Katarchaean from Archaean (Dearnley and Dunning, 1968; Sutton, 1967) since greenstone belts were apparently forming from as early as 3400 m.y. in Barberton Mountain Land to as late as 2700-2900 m.y. in Canada. I have similarly pointed out that the arbitrary fixation of the upper limit of Archaean at 2500 or 2600 m.y. (the supposed boundary between the Archaean and Proterozoic), leads to irreconcilable anomalies in the Karnataka Precambrians since such an age demarcation cuts across all the three chief components—the Dharwars, Peninsular Gneisses, and Charnockites (Pichamuthu, 1970a, p. 528).

DHARWAR BASEMENT AND THE PRIMORDIAL CRUST

The question as to what is the base on which the Dharwars rest has been debated now for well over 100 years. Practically all the Indian geologists who were engaged in the study of Precambrian rocks were brought up in the belief of a sialic basement. This was at the back of Pascoe's mind when he made that often quoted statement about 'the picture with no wall to support it', or when Smeeth (1924, p. 40) stated, 'Dr. Fermor shares with me an intense repugnance to any suggestion that the Dharwars might once have been suspended in mid-air with no visible means of support.'

While discussing this problem of the Dharwar basement in my Presidential address to the Geology Section of the Indian Science Congress in 1947, I stated:

'A most intriguing question that arises whenever we deal with this ancient formation is regarding the basement rock. Are the Dharwars the oldest or were they laid down on some pre-Dharwar rocks? Do the Lower Dharwars which are composed of acid and basic volcanic flows, represent the first-formed rocks of the pre-aquatic period of earth's history, or, were they extravasated on a very ancient gneiss which represents the primeval crust? In the earliest basic volcanic rocks pillow structures have been recognised and this indicates that these flows are of submarine origin. Associated with these oldest volcanic rocks there are also thin bands of ferruginous cherts and dark siliceous schists which represent the earliest formed sediments. The lower Dharwars cannot therefore be the earth's 'foundation stones'. It is extremely doubtful also, whether any accessible rock can be referred to the original crust, for repeated fusion and metamorphism must have changed their original characters. The veil of time hangs heavily over this period and it is problematical whether we shall ever be able to pierce this and wrest its hidden secrets. It seems to be as stated by Hutton, that 'in the economy of the earth, there is no trace of a beginning'.

The position is not very different at present, for, while there have been several speculations and surmises, no definitive evidences have so far been produced regarding what could be considered as the lowermost member of the Dharwar sequence, the basement on which it rests, and the nature of the primordial crust if it still can be identified.

I visualised in 1947 not the Peninsular gneiss as the basement, but a 'pre-Dharwar gneiss', pebbles of which in the oldest Dharwar conglomerates were 'probably the only fragmentary evidence we have of the basement' (Pichamuthu, 1947, p. 3). I had already reported 10 years earlier that the felsic pebbles in the Kaldurga conglomerates were largely of tonalite and tonalitic gneiss (Pichamuthu, 1935, pp. 265-267). It is interesting to note that one of these pebbles has now given a very old age of 3250 ± 150 m.y. (Venkatasubramanian and Narayanaswamy, 1974, pp. 318-319). Even so, these may not be fragments of the original crust.

There are two opposing schools of thought regarding the nature of the primordial crust: (1) That continental material was formed very early in the history of the earth by rapid separation into core, mantle, and crust; and (2) that continents have grown throughout geological time as derivations of the mantle as it undergoes partial melting, differentiation, and degassing processes. According to the first view, the primordial crust is originally of sialic composition. According to the second, it is of basaltic or more mafic composition. No agreement has, however, been so far reached on this fundamental question. Isotopic studies of lead indicate that a proto-crust existed at least 4000 m.y. ago in the Tanzanian, Rhodesian, and Canadian cratons (Robertson, 1970, p. 63).

There are 4000 m.y. old granites in west Greenland, and a very ancient gneiss complex in Swaziland. Anhaeusser (1973, p. 380) considers that the existence of an ancient granitic relic as in West Greenland does not necessarily implicate the entire earth's crust in a similar set of circumstances during this period of time, for, just as at present there are continents and oceans, so too might this have been the case in the past.

Some of the oldest granitic gneisses in N. America (3550 m.y.) are believed (Anhaeusser, 1973, p. 374) to have formed by synkinematic intrusions of trondhjemitic and granitic magmas into country rocks consisting of layered basaltic lavas, possible sills of dolerite or gabbro, peridotite, and mica schist of sedimentary origin. This is considered as support for the existence of an early mafic or ultramafic crust.

The granitic assemblage of the shields is, according to Anhaeusser *et al*, (1969, p. 2177), probably largely of a secondary origin, having been derived from the mantle and from reworked primitive crust. The addition of younger granitic material has resulted in appreciable thickening, and reconstitution or obliteration of an earlier more primitive crust. It thus seems unlikely that unaltered remains of early crustal material will be found although it is possible that parts of the migmatite of the shields might represent altered and granitised vestiges of an early crust.

There is evidence in southern Africa that the greenstone belts were formed on a sialic crust, however thin it might have been, with the development of early sediments which must have been derived from a granitic source (Anhaeusser *et al*, 1969, p. 2178). There is a possibility, however, that it was more mafic than the present sial (Ramberg, 1964).

Bridgwater, Watson, and Windley (1973, p. 503) regard rocks such as those of the lower parts of the Barberton Mountain Land as models for crust of ocean type which originated some 1000 m.y. after the formation of the earth, and perhaps approaching primordial basalts in chemical character, and the Amitsoq gneisses as models for early (but not necessarily primitive) granitic crust of continental type. The oldest rocks likely to be preserved would be granitic since in unstable environments the denser rocks might be rapidly returned to the mantle and recycled, but this does not mean, according to these authors, that any granitic rocks we see now are primordial. For a type of crust which could predate differentiation into oceanic and continental regimes, they point to the agmatitic gneisses which are common in both the north Atlantic craton and the granitic gneisses surrounding the major greenstone belts; even these are not primordial nor necessarily contain older crustal elements.

Glikson (1972, p. 3336) has observed that unlike the late potassic granites, the early sodic batholiths nowhere intrude the detrital sedimentary units occurring at higher stratigraphical levels in greenstone belts, and, therefore, concludes that the intrusion of these early sodic batholiths into the oceanic crust took place earlier than the commencement of detrital sedimentation.

I have referred to these several and often divergent views to show that the question of the nature of the primordial crust has not yet been satisfactorily solved. Can we in Karnataka, which contains one of the most typical greenstone belts in the world, make any significant contribution towards the solution of this problem? It must be realised that the Peninsular gneiss as we find it today cannot be such a crust as there are enclaves in them of older felsic and mafic rocks. It is probable that not all of the primordial crust has necessarily vanished, and may remain as vestiges in some of the deeply infolded schist belts of the Dharwar craton.

Migmatisation of amphibolites result in banded rocks in which the amphiboles are transformed to biotite. The banded gneisses and migmatites (Peninsular gneiss) could have been produced thus. One of the implications of such an interpretation would be that such gneisses have developed by the progressive transformation of an early simatic crust.

Basal conglomerates: If the Peninsular gneiss everywhere formed the basement on which the Dharwars were deposited, basal conglomerates should be found more commonly in all the schist belts wherever the gneiss and schist were in contact, but this is not so. This prompted Fermor (1936, pp. 69-70) long ago to ask the question, 'If the interpretation be correct that the gneisses (though not yet foliated according to Maclaren, 1906, p. 109) provided the floor on which the Dharwars were laid down, and at the same time the junctions between the Dharwars and the gneisses are not faulted, why are basal conglomerates so rare in the Dharwars?' He answered it himself by stating that the assumption that the granite-gneisses are post-Dharwar and, therefore, intrusive, would explain the general absence of such basal conglomerates.

GRANITES

Just as in many Precambrian shields, the granites and gneisses of Karnataka can be generally grouped into three types which were formed at different times in different tectonic environments:

1) An early basement consisting of gneisses that migmatise conformable schist belts (Peninsular gneiss).

2) Intermediate stage—massive to highly foliated granites, probably derived by local melting of the basement; have both intrusive and gradational contacts with surrounding rocks (Mantled gneiss domes and other granitic bodies completely surrounded by schists).

3) Late stage—massive, post-orogenic granites; intrude adjacent schists and gneiss with sharp transgressive contacts (Younger granites).

In Karnataka there are very few occurrences of typical granites; they are generally either gneissic granites or granitic gneisses.

Wilson (1973, p. 400) classifies the granites in the following manner:

1) The 2900 m.y. old granites are largely tonalites with some granodiorites and adamellites, some of which probably originated by partial melting of downsagged crust. The Peninsular gneisses correspond fairly closely to this category.

2) The 2600 m.y. old granites, according to the same author, may be the remobilised and melted 'basement gneiss'; they display some thermal metamorphism with development of andalusite and cordierite in rocks of suitable composition. This is reminiscent of the Closepet granites of Karnataka;

3) The continuing processes of rheomorphism, anatexis, granitisation and metasomatism has favoured the development of progressively K-enriched granite phases (granodiorites, adamellites, granites). The Chamundi granites could be cited as an illustration of this phase.

While there are obvious metamorphic aureoles around the younger K-rich granites, such aureoles may be absent around bodies of the older tonalitic gneisses (Talbot, 1973, p. 416). This may explain why there are not very clear effects of metamorphism around the 'mantled gneiss domes' in Karnataka.

The development of granites and gneisses of different ages in different tectonic environments probably holds the clue for the understanding of the relationship of the Peninsular gneissic complex and the Dharwar schists. Both these were formed during a long period of geological time, and the felsic intrusions must have punctuated the course of sedimentation and volcanism comprising Dharwar stratigraphy. The identification of such episodes should have top priority in the investigation of Precambrian rocks of southern India.

GRANULITES AND CHARNOCKITES

The confinement of granulite facies rocks to the most ancient complex is probably related to a higher thermal regime of the earth in early Precambrian time, caused by the heat generated by radioactive elements of U^{235} and K^{40}. Owing to the much higher geothermal gradient in these times, sedimentary and igneous rocks were subject to dehydration and recrystallisation. According to Salop (1968, p. 64), these processes probably took place in the lower part of the thick sedimentary series at the time when sediments were accumulating on the surface; such metamorphism took place under conditions of lack of water in relatively dry rocks, that is, under conditions which were favourable for the development of granulite facies.

It has been shown in recent years that certain lithophile elements including K, Rb, Th, and U, are depleted in varying degree in parts of the earth's lower crust. Orogenic activity involving high grade regional-thermal metamorphism, repeated anatectic melting, and progressive dehydration in deep crustal zones, have often resulted in pyroxene granulite facies rocks which are lower in the heat-producing elements, and are higher in Ca, Mg, Fe, Ti, and Mn relative to rocks of lower grade assemblages (Lambert and Heier, 1967; 1968). However, as pointed out by Lewis and Spooner (1973, p. 1111), the existence of pyroxene granulite facies assemblages alone is insufficient evidence to infer that such rocks have had an exclusive origin in the lower crust, since close association with more hydrated lower grade amphibolite facies assemblages have been recognised in many parts of southern India. Where complexes of granulites have been regenerated, the initial dry mineral assemblages are frequently replaced by assemblages carrying hornblende, biotite, and other minerals appropriate to the amphibolite facies (Watson, 1973, p. 445). These changes are noticeable in the Nilgiri hills and in some other parts of the charnockite terrain of southern India.

The transformation of Peninsular gneisses into charnockite has been recorded from some parts of Karnataka (Pichamuthu, 1960, pp. 135-136; 1961, pp. 46-49; Ziauddin, 1975, pp. 215-219), and Tamil Nadu (Holland, 1900, p. 225; Narasimha Rao, 1969, p. 74). In the high grade Precambrian terrains of Greenland, Scotland, Kola Peninsula, and the Aldan and Ukrainian massifs, the granulites are products of high grade metamorphism of supracrustal assemblages (Sheraton, 1970; Bowes *et al,* 1971; Glikson, 1972, p. 3339). Similar transformation has also been noticed in Antarctica (McLeod, 1964, p. 240; Klimov, Ravich and Soloviev, 1964, pp. 455-457). That schist beds have also been transformed into charnockites is indicated by the fact that in Sivasamudram, Halagur, and Biligirirangans in Karnataka, and in the Nilgiris (Tamil Nadu), they are interbanded with beds of ironstones. The charnockites of Sri Lanka (Highland Series) contain bands of limestone and thick beds of quartzite, and in the Eastern Ghats they are associated with quartzites.

I have long ago drawn attention to the fact that in Karnataka enderbites are the common variety of charnockites (Pichamuthu, 1953b, pp. 135-136, 147). According to Ravich (1968, p. 209), enderbites are the products of the initial granitisation stage when soda metasomatism was prevailing. They are products of incomplete granitisation of basic schists and similar rocks. The prevalence of enderbites has since been reported from many parts of south India. This is very likely due to the possibility of the early tonalites having been converted into enderbites in the high grade metamorphic terrains.

The charnockites of southern India like the Peninsular gneisses, contain mafic xenoliths, the 'basic schlieren' of Holland. Except for the dark colour and the presence of hypersthene in them, the Biligirirangan charnockites in the extreme south of Karnataka, bear an extraordinary resemblance to outcrops of Peninsular gneisses. Here, the process of charnockitisation of the gneisses which began further north in the region of Closepet and Kabbal, appears to have advanced much further.

The so-called 'charnockite dykes', which have been misinterpreted by some as the hypabyssal phase of a charnockite magma, are only mafic dykes intrusive into Peninsular gneiss which have been charnockitised under granulite facies conditions. Commenting on such dykes in granulite terrains which exhibit anomalous metamorphic assemblages characterised by pyroxenes, garnets, or hornblendes, Watson (1973, p. 452) states that 'their interest lies in the demonstration they provide that temperatures sufficiently high to bring about recrystallisation of the dykes had no apparent effect on the granulite country rocks.'

In the Archaean craton of the north Atlantic region also, some dykes show partial or complete recrystallisation to assemblages of amphibolite or even granulite facies which has been variously attributed to emplacement in hot country rocks (O'Hara, 1961; Moorbath and Park, 1972), and to subsequent reheating (Dearnley, 1962). Such local development of granulite facies metamorphism has been noticed in the vicinity of small intrusions of tonalites, diorites, and granites, with minor carbonatites and appinites (Bridgwater, Watson, and Windley, 1973, p. 510).

SUMMARY AND CONCLUSIONS

Peninsular gneiss; The Peninsular gneiss, as defined by Smeeth who coined the term, is intrusive not only into the lower Dharwars but also into the younger members in the Shimoga and Chitaldrug schist belts in Karnataka. No early geologist in India was of the opinion that the Dharwars as a whole were younger than the gneisses.

The Peninsular gneiss is a complex formed of different types of granites and gneisses, and of different ages. Similarly, the Dharwars comprise a sequence of volcanic and sedimentary rocks which was forming practically throughout Precambrian time.

Because of the long period of time during which both the gneisses and schists formed, some constituents of the gneissic complex have intruded into certain members of the Dharwars. An attempt should be made to identify and separate these episodes.

The Peninsular gneissic complex as we see it today is not the primordial crust, but may contain vestiges of it.

Dharwar schists: The Dharwars as defined by Bruce Foote who was the originator of this term, comprise all the crystalline metavolcanics and metasediments, thus excluding the gneisses and granites.

The Dharwar stratigraphy has not as yet been satisfactorily worked out. Great care has to be taken in its elucidation since the relative order of superposition is not always conclusive in a polymetamorphic set-up. There is still considerable difference of opinion as to what constitutes the base of the Dharwar sequence. The Dharwars are supposed to rest unconformably on Bellary gneiss (Closepet granite) by Bruce Foote, Chikmagalur granitic gneiss by Swaminath *et al*, and on other gneisses by some workers. According to Foote, the lowest member of the Dharwars in Bellary is a thin trap overlapped by the 'lowest hematite quartzite' resting directly on a highly porphyritic granite. Srinivasan and Sreenivas consider an orthoquartzite-carbonate as the base of the Dharwars, while according to others it is a current-bedded quartzite.

That an outcrop of schist 'rests on gneiss' is no evidence of the relative ages of the Dharwars and Peninsular gneiss unless it is quite certain that the contact is between the very base of the sequence and the gneiss. Intrusion of gneiss or overlap of sedimentary beds can bring about such a relationship. There is no doubt that the Dharwars must have had a floor; the problem is to recognise it. If anatexis and migmatisation are prevalent, as no doubt it has been in the Precambrian, the boundary between the floor and the fill of former geosynclines will hardly be recognisable.

The rarity of undoubted basal conglomerates in the schist belts is a feature which requires explanation.

Xenoliths: The Peninsular gneisses abound in xenoliths. They may be felsic or mafic, coarse-grained or fine, angular or oval, with sharp or gradational contacts, sometimes boudinaged with pinch and swell structures, and often drawn out. It is very unlikely that they are all of the same age; they could represent several older cover sequences completely disrupted by subsequent mobility and tectonism. They need not also be considered as necessarily pre-Dharwar, for they vary greatly in size, from small pods and patches to large islands of schists.

There are mafic xenoliths in the charnockites which greatly resemble those in Peninsular gneisses.

Metamorphism: A progressive increase in the grade of metamorphism as a function of depth of burial can generally be noticed especially in southern Karnataka. There is no field evidence to suggest that the charnockites have been thrust upon the Dharwars.

Granites: There are very few occurrences of typical granites. They are mostly gneissic granites which could be classified generally into three categories, and which were formed at different times in different tectonic environments. This affords an explanation for the intrusion of gneisses into Dharwar formations of different ages.

Charnockites: It would be incorrect to consider all occurrences of charnockites in southern India as forming the basement and as having an exclusive origin in the lower crust, as they are of different geological ages and of different modes of formation. The charnockites are mostly enderbitic and are probably the high-grade modifications of tonalites. The Peninsular gneisses in some cases have been transformed into charnockites.

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