# Some Recent Advances in Indian Geology.*

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## INTRODUCTION.

THE Editor of *Current Science* has asked me to contribute an article on recent advances in Indian geology. The following notes, dealing with certain aspects of the subject with which I am more familiar, have been put together in the hope that they may prove to be of interest not only to students of geology in India, but also to geologists outside India who have not the time to keep in touch with developments in this country.

Perhaps the most disturbing feature of modern scientific work is the immense output of literature which is continually appearing in every branch of science. So great is this becoming that it is a matter of difficulty for any worker to keep in touch with the progress that is being made, even in his own subject. This difficulty applies with particular force to geology. Modern geology has become so comprehensive, and its various aspects have become so specialised, that it has been said that there are no longer any geologists but only specialists in various branches; while specialists have been defined as those who know more and more about less and less. India is a large place, with a very varied geology and the considerable number of papers on Indian geology that are continually appearing, overburdened as they often are with the details of their subject, make it difficult for anyone not directly interested in them to appreciate fully the progress that is being made. In writing these notes, therefore, I have tried as far as possible to draw attention to the main lines along which our understanding of the geology of India is developing, rather than to summarise every paper that has recently appeared, which would in any case be impossible within the limits of a series of short articles.

I have divided this account into five sections: (1) The Archæan Rocks of Peninsular India, (2) Deccan Trap volcanic activity, (3) The geology of the Himalaya, (4) The geology of Burma, (5) The geology of the Salt Range. A section dealing with recent advances in palæontology by Mr. D. N. Wadia has already appeared in *Current Science* (December, 1933). The section on the geology of Burma is being contributed by my colleague Mr. V. P. Sondhi, to whom I am much indebted.

## THE ARCHÆAN ROCKS OF PENINSULAR INDIA.

The Archæan rocks of India occupy a greater area than any other formation. They are important economically in containing rich deposits of gold, iron, manganese and mica. It is unnecessary to stress the importance of pure scientific research in the bearings which it may have on economic development; and a detailed study of the Archæan rocks in India, such as is being carried on in certain areas, needs no further justification. The problems associated with Indian Archæan geology are so many, and their proper discussion would be so laborious, that in the following notes only a very general account can be given of the main trend of recent work. It is unfortunate that most of this work is yet unpublished, and some indication of the lines along which it is developing may therefore prove to be of value.

The peculiar difficulties that beset the geologist who is endeavouring to interpret the geological history of Archæan times are well known. The metamorphism which these rocks have undergone has in some cases made originally dissimilar rocks appear similar, while in other cases the same rocks have been made to appear profoundly different in different places where they have suffered varying degrees of metamorphism. A further difficulty in the way of correlating these very old rocks is that many of their outcrops have become isolated from one another, either by the denudation of intervening tracts or by the superposition of later rocks; and it is difficult sometimes to be certain whether a difference observed in the rocks of two neighbouring but separated tracts is due to actual difference in the age of the rocks, or to lithological variation, or to the effects of varying metamorphism.

Before referring to the recent advances made in this branch of Indian geology a word may be given about the classification

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of these old rocks. This question of nomenclature is a thorny one, and perhaps the less said the better. But two points call for comment. It is becoming increasingly clear, more especially as the result of Dr. A. M. Heron's researches in Rajputana, that the old metamorphosed rocks of India of undoubted sedimentary origin have to be subdivided into two or three systems, separated from each other by big unconformities. The term Archæan was first introduced by Dana in 1872 to include all rocks older than the Cambrian.[1] But it is the custom in many countries to restrict its use to the more highly metamorphosed rocks older than the Cambrian, and to designate the less metamorphosed rocks as Pre-Cambrian or some such term. As regards India, in 1906 Sir Thomas Holland divided all rocks older than the Cambrian as follows:[2]

| | | |
|---|---|---|
| Purana | .. | Cuddapah to Vindhyan. |
| Archæan | .. | Dharwarian<br>Eruptive gneisses and granites<br>Schistose gneisses<br>Oldest gneisses. |

Such a classification, while it may have served a useful purpose nearly 30 years ago, is clearly inadequate at the present day. It is not proposed here to suggest any alternative. But the work that is gradually being completed in the several Archæan tracts in India, which is referred to in the following notes, should, after the effects of varying metamorphism and of changing lithology have been disentangled, lead in the end to a natural classification based on fuller data than are at present available.

The other point which must be referred to here concerns the use of the word 'Dharwar'. Until quite recently this name has been used to embrace all the bedded schists of Archæan age, including both metamorphosed sediments and contemporaneous lava flows.[3] But the recent work[4] in Rajputana and Bihar and Orissa has indicated the presence of two or more series within the Archæan, separated from one another by unconformities. The use of the term Dharwar in its original comprehensive sense can thus no longer be maintained. To avoid misunderstanding it will therefore be better in future to refer to the Archæan rocks of each tract by their local names, the term Dharwar being restricted to the rocks of the Dharwar district and adjacent tracts in Mysore. In this way no implication of correlation will be introduced into the nomenclature which is not justified by the known facts.

In the following account attention will be confined to the four tracts in which detailed work has recently been done.

### RAJPUTANA.

In Rajputana Dr. A. M. Heron, who commenced work there in 1908, has now completed the mapping of the crystalline rocks, and the publication of the details of his work is being eagerly awaited. As a result of this work two points are clearly brought out which are of particular interest. First, the necessity of dividing the crystalline rocks of this area into four distinct groups or systems, separated from each other by marked unconformities frequently accompanied by conglomerates. Second, the remarkable way in which some of the oldest rocks in India are in certain places still in the condition of almost unaltered shales and slates.

As regards the former point, the crystalline rocks of Rajputana have to be divided into the following groups, given in order:

Delhi system
— — — — unconformity with conglomerate
*Raialo series*
— — — — unconformity with conglomerate
Aravalli system
— — — — — unconformity with conglomerate
Banded Gneissic Complex

Of these the Raialo series, which includes the well-known Makrana marble, is the smallest and least important, and is often missing.[5] The Banded Gneissic Complex, to be distinguished from the injection gneisses formed by the intrusion of acid magma into the Aravallis and Delhis at a much later date, is thought to be the equivalent of the Bundelkhand gneiss of Eastern Rajputana, though the two are never seen in actual contact. They are mainly of igneous origin, but there do occur amongst them biotite- and chlorite-schists and granulites which may represent metamorphosed sediments greatly injected by both basic and acid rocks.[6] They are the oldest rocks in Rajputana.

Perhaps the feature of greatest interest which has been brought to light by Heron's

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[1] *Amer. Jour. Sci.*, 3rd series, 1872, **3**, 253.

[2] *Trans. Min. Geol. Inst. Ind.*, 1906, **1**, 47.

[3] *E.g.*, L. L. Fermor, *Mem. Geol. Surv. Ind.*, 1909, **37**, 1120; and J. A. Dunn, *op. cit.*, 1929, **54**, 154.

[4] *Rec. Geol. Surv. Ind.*, 1886, **19**, 98.

[5] *Op. cit.*, 1929, **62**, 172.

[6] *Op. cit.*, 1930, **63**, 143.

work is the way in which the Aravallis are in places still in the condition of practically unaltered shales and slates. We have, in fact, in Rajputana one of the largest areas in the world of Archæan rocks which have suffered little or no metamorphism, perhaps only to be parallelled by the little altered Archæan rocks of Finland. The way in which such rocks have escaped metamorphism during Archæan and later times is one of the most interesting problems of Indian Archæan geology. When traced along the strike to the south these Aravalli rocks become injected with acid magma on an immense scale, and the rock becomes a banded gneiss.[7] Further south still the injection dies out, and slates are found once more. These composite gneisses are described by Heron as being exactly similar to the injection gneisses in Sutherlandshire, Scotland, recently described by H. H. Read. In Eastern Rajputana the Aravalli rocks rest unconformably on the eroded surface of the Bundelkhand gneissose granite, and there seems to be no doubt now as to the relative ages of these rocks.

The Delhi system provides a problem of correlation which makes the geology of Rajputana of such intriguing interest. For the rocks of this system, although belonging to a late period of Archæan geology, are considerably folded and highly metamorphosed. They are in fact in many parts of Rajputana more highly metamorphosed than the older Aravalli rocks. To understand how this has come about it is necessary to state that structurally Rajputana is dominated by the great Delhi synclinorium, which runs in a N.E.–S.W. direction in north-east Rajputana, swinging round to a N.–S. direction in southern Rajputana and Bombay. Heron describes it as having roughly the shape of an hour glass, being narrowest in the centre and splaying out in the north-east and in the south. This is due to the fact that in the centre the syncline is a simple fold, but to the north-east and to the south it becomes complicated by the appearance of many secondary folds, and the outcrop becomes much wider. The fact that the Delhi rocks in the centre of the synclinorium are more highly metamorphosed than the older Aravalli rocks, is thought by Heron to be due to the fact that they were more deeply buried and more greatly intruded by igneous rocks than the underlying Aravalli rocks which are only seen in the outer parts of the synclinorium.[8] This anomaly of metamorphic grade leads C. S. Middlemiss to adopt a reversed order of superposition for the Aravallis and Delhis in Idar State, at the south-west end of the synclinorium.[9] But Middlemiss, in investigating only a small area, was handicapped in being confined in his work to a comparatively short distance along the strike; and moreover the Delhi-Aravalli unconformity is not recognisable as such within Idar, while inversion and overfolding are general. The later work of Heron, carried on over a greater area, and including the tracing of the Delhi-Aravalli unconformity for something like 500 miles, and the mapping of the lower unconformity of the Aravallis upon the Bundelkhand gneiss and the banded gneisses, has settled definitely the age relations between the major rock groups of Rajputana.

In post-Delhi times the south-western side of the synclinorium was swamped with great intrusions of granite at two different periods. These igneous rocks, together with four different sets of basic intrusions and extrusions, have been described in detail by A. L. Coulson in his account of the geology of Sirohi State.[10] The first acid phase includes the Erinpura granite and its associated aplites and pegmatites, intrusive into both Aravalli and Delhi rocks. No volcanic rocks are found associated with this phase. The second phase of acid intrusion is known as the Malani system. It includes the Idar granite as the plutonic phase, a variety of quartz-porphyries, felspar-porphyries, granophyres and similar rocks as the hypabyssal phase, and rhyolites and dellenites as the volcanic phase, including the well-known Malani rhyolites. Of considerable petrographical interest is the suite of igneous rocks intruded into the Erinpura granite near the village of Mundwara, on the western border of the State. These include picrites, gabbros and dolerites, basalts and pyroxenites, sodalite-syenites, and agglomerates. The memoir is accompanied by a large number of chemical analyses, which add to the interest of the petrographical descriptions.

On the eastern side of the Delhi synclinorium, B. C. Gupta has described the geology

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[7] *Op. cit.*, 1929, **62**, 171-172.

[8] *Op. cit.*, 1931, **65**, 143-144.

[9] *Mem. Geol. Surv. Ind.*, 1921, **44**, pt. 1.

[10] *Op. cit.*, 1933, **63**, pt. 1.

of Central Mewar in a memoir which is now in the press.[11] The paper is of value in giving a detailed description of the Banded Gneissic Complex and of the Bundelkhand gneiss. Although the two are everywhere separated by a belt of Aravalli rocks, and although where seen on either side of the belt they are markedly different, Gupta agrees with Heron in regarding them as roughly the same. He looks upon the Bundelkhand gneiss as having crystallised under very deep-seated conditions, while the gneissic complex with its heterogeneous structure is thought to have been formed in a higher zone of the earth's crust, where there was more opportunity for the incidence of directed pressure, as well as a fairly high temperature. The Aravallis rest on both with an erosion unconformity, sometimes accompanied by conglomerates.

### CENTRAL PROVINCES.

In the Central Provinces, what is undoubtedly the most detailed mapping that has so far been attempted in Indian Archæan geology has been carried out by Dr. L. L. Fermor and his co-workers in the Nagpur, Chhindwara and Bhandara districts. It is a matter for regret that the full details of this work are unlikely to be published for some time to come, though summaries are to be found in the Director's annual reports.[12]

This series of Archæan rocks, named the Sausar series, are economically important for the rich deposits of manganese ore that they contain. They have been divided up into a number of stages which have a remarkable constancy over the area in which they have so far been mapped. These stages are so distinct, and their order now so well established, that it is worth while giving them in detail here, for comparison with other areas.

| | |
|---|---|
| Sitapar stage .. | Hornblende-schists. |
| Bichua stage .. | *Pure facies:* white dolomitic marbles, with serpentine, tremolite, and diopside. *Impure facies:* diopsidites, actinolite schists, and schists with wollastonite, grossularite, tremolite, and anthophyllite. |
| Junewani stage .. | Muscovite-biotite-schists with autoclastic conglomerates. |
| Chorbaoli stage (?=Ramtek stage) | Quartzites and muscovite-quartz-schists. |
| Mansar stage .. | Muscovite-biotite-sillimanite-schists, with lenticular beds of manganese ore. |
| Lohangi stage .. | Pink calcitic marbles and calciphyres. |
| Utekata stage .. | Banded calc-granulites. |
| Kadbikhera stage | Megnetite-biotite-granulites. |

The Ramtek stage was originally given a separate position, but it is probably identical with the Chorbaoli stage. All these stages with the exception of the Sitapar stage, the hornblende-schists of which probably represent metamorphosed lava flows, are now regarded as of sedimentary origin.

In the Sausar tahsil and in the northern part of the Ramtek tahsil these rocks display a very high grade of metamorphism, the characteristic pelitic rock being a garnet-sillimanite-biotite-schist, while in the dolomitic rocks the mineral wollastonite occurs. But traced to the south and to the east the grade of metamorphism decreases, so that while in the northern and western parts of the area the manganese ore occurs in a muscovite-biotite-sillimanite-schist, with or without garnet, in the southern part of the area, around the manganese mines of *Kandri and Mansar, the country rock is* a muscovite-phyllite or schist, in which biotite is very subordinate. In both cases the stage is the same, being overlain and underlain by the same rocks in both areas. Accompanying the increasing metamorphism in the north there is a great abundance of pegmatite intrusions.

The complexity of the folding in these rocks is very great, and W. D. West has brought forward evidence for the existence of a 'nappe' in the vicinity of Deolapar, in the Ramtek tahsil, whereby slightly different lithological facies of the Sausar series, originally deposited far apart, have been brought into juxtaposition with one another.[13]

In addition to these metamorphosed sedimentary rocks, there are a variety of porphyritic and fine grained granites, pegmatites and ortho-gneisses which are younger than the Sausar series. There is also a gneiss which has gone by the general name of 'streaky gneiss'. In places this occupies as great an area as the Sausar series. It has been shown by West that much of this rock is really a composite or injection gneiss, formed by the intimate penetration of an igneous granulite of granodioritic

[11] *Op. cit.*, 1934, **65**, pt. 2.

[12] See especially, *Rec. Geol. Surv. Ind.*, 1931, **59**, 143-44 and *op. cit.*, 1931, **65**, 100-101.

[13] *Rec. Geol. Surv. Ind.*, 1931, **65**, 102-104.

composition by abundant veins of aplite.[14] Similar injection has affected the more schistose members of the Sausar series, especially the Mansar stage. All these gneisses are definitely younger than the Sausar series, and there seems to be nothing in this area comparable to the banded gneissic complex of Rajputana, upon which the Sausar series might have been laid down.

To the south and south-east of this tract of the Sausar series there occurs an area of very much less metamorphosed rocks, known as the Sakoli series. These have been studied by D. S. Bhattacharji and S. K. Chatterjee, who have shown them to consist of phyllites and slates, hæmatite-sericite-quartzites, chlorite-schists and jaspilites.[15] They are mostly separated from the Sausar series by alluvium; but where the two series are seen adjacent to one another the evidence suggests that the Sakoli series are but the upward continuation of the Sausar series. The much lower grade of metamorphism is due, according to Chatterjee, to their having suffered retrograde metamorphism. They will be referred to again below.

### BIHAR AND ORISSA.

Turning now to the third area in northern India where detailed work has been done, Bihar and Orissa, we find that, excluding younger pre-Cambrian rocks which are perhaps of Cuddapah age, there are three distinct lithological series of Archæan age, as follows:

Iron-ore series, with Dalma volcanic flows and tuffs at the top.

— — — — — — — — — — — —

Gangpur series, limestones and schists with manganese ore.

— — — — — — — — — — — —

Older Metamorphic series.

The oldest, composed mainly of hornblende-schists and quartzites, resemble lithologically the Dharwars of South India. The Gangpur series, recently mapped by M. S. Krishnan, show a considerable resemblance to the Sausar series.[16] Dr. Fermor has always maintained that the manganese ores of India very probably occupy a single horizon within the Archæan, and in Gangpur State the presence of manganese ore and of both calcitic and dolomitic limestones suggests a correlation with the Sausar series. These rocks are separated from the Iron-ore series by a belt of crushing, so that the relation between the two is obscure. They bear, however, no lithological resemblance to one another, although found in adjacent tracts. The Iron-ore series are found resting with a strong unconformity upon the Older Metamorphic rocks, as first shown by H. C. Jones.[17] They are too well known to need description, but J. A. Dunn's recent memoir brings out well the way in which a single series of rocks may show very different grades of metamorphism in different places.[18] In South Singhbhum the Iron-ore series is little metamorphosed or disturbed; but northwards both the metamorphism and the folding increase, until in North Singhbhum the rocks are highly metamorphosed and severely folded. Previously the Iron-ore series, partly on account of its little metamorphism in South Singhbhum and partly on account of the fact that it rests unconformably on older metamorphic rocks, had been regarded by Jones as likely to be of Cuddapah age, the underlying metamorphic rocks being referred to as Dharwar. Both these series are now included by Dunn within the Dharwar system, using the term Dharwar as synonymous with metamorphosed Archæan sediments and including all the schists below the Eparchæan unconformity. The chief reason he puts forward for supposing them to be older than Cuddapah age is that they are intruded by gneissic granites which are themselves intruded by dolerites (in places metamorphosed to epidiorites). And since no intrusions of dolerites have been known in Peninsular India between Cuddapah and Rajmahal (Jurassic) times, it is deduced that the Iron-ore series, the granites, the dolerites, and the folding and metamorphism are all older than Cuddapah, and therefore Archæan in age.

The Chota Nagpur granite-gneiss, and the Singhbhum and other granites, have been studied in detail by Dunn and by L. A. N. Iyer.[19] They are intruded into the Iron-ore series, but are all regarded as Archæan in age. The reaction between these granites and the country rocks, which has given rise to hybrid rocks and synantetic minerals, is discussed by Iyer, who has also

[14] *Op. cit.*, 1933, **67**, 304.

[15] *Op. cit.*, 1929, **62**, 132-133 and *op. cit.*, **65**.

[16] *Op. cit.*, 1933, **67**, 63-65.

[17] *Op. cit.*, 1922, **54**, 41.

[18] *Mem. Geol. Surv. Ind.*, 1929, **54**.

[19] *Ibid.*, chaps. X and XI; and *Rec. Geol. Surv. Ind.*, 1932, **65**, 490.

furnished a number of chemical analyses of the various granites.

### SOUTH INDIA.

In 1886 R. Bruce Foote mapped the rocks around Bellary and Dharwar, south of the great Deccan Trap outcrop.[20] The belts of schistose rocks which overlie the main gneissic foundation, consisting of hornblende schists, chlorite-schists, quartzites, banded hæmatite-quartzites, limestones and conglomerates, were named by him the Dharwar system, and were thought to overlie the gneisses unconformably, which were therefore regarded as the older. Subsequent work, however, has shown that these gneisses frequently show intrusive relations towards the Dharwars, and they are now regarded as younger. As regards the nature of the Dharwars, it was formerly assumed that, apart from the hornblende schists and epidiorites, the majority were metamorphosed sediments. Of late, however, the Mysore Geological Department have concluded that nearly all the rocks of the Dharwar system are of igneous origin, while the conglomerates are regarded as autoclastic. This point of view is summarised by W. F. Smeeth in 'An Outline of the Geological History of Mysore', in Bulletin No. 6. Department of Mines and Geology, Mysore State. With reference to this change of view, C. S. Middlemiss in 1919 wrote as follows:[21]

> 'So far I think I am right in saying that no graphic representation of these extraordinary wholesale transformations of granites, quartz-porphyries and other igneous rock types, into schists, conglomerates, limestones and quartzites, has as yet appeared from the pencil of any of those responsible for the statements.'

So far as I am aware this detailed information is still not forthcoming, though it may probably safely be assumed that some at any rate of the rocks formerly regarded as sedimentary are of igneous origin, and that some of the conglomerates are autoclastic. It appears, however, that not all the geologists of the Mysore Geological Department are in agreement over the origin of these rocks, B. Rama Rao in particular suggesting that some of the crystalline schists may be metamorphosed sediments.[22]

In the above-mentioned paper Smeeth describes the Dharwars as being broadly divisible into an upper group consisting mainly of chlorite-schists, and a lower group consisting mainly of hornblende-schists. The granites and gneisses, now regarded as younger than the Dharwars, cover by far the greater part of the area. They include various types, of which the more important are the Champion gneiss, the peninsular gneiss, the Charnockite series, and the Closepet granite, in order of age. An account of these is given by Sampat Iyengar in his presidential address before the Indian Science Congress.[23]

Compared with the Archæan rocks of other parts of India, the true Dharwars of the Dharwar district are lithologically similar to the Champaner series in Bombay, which have now been shown by Heron to be identical with the Aravalli system of Rajputana.[24] It is possible that the Aravalli rocks are continued southwards beneath the Deccan Trap to emerge in Dharwar and Mysore as Dharwar rocks. Recently considerable attention has been paid to some manganiferous marbles, spessartite-rocks and *tarurites* (*veined hornblende*-schists with secondary pyroxene) which occur near a place called Sakarsanhalli, in the Kolar district of Mysore State. Dr. Fermor considered these rocks similar to the manganiferous rocks in the Sausar series.[25] They were thought by B. Jayaram of the Mysore Geological Department to belong to a low horizon in the Dharwars, or even to an older series.[26] Later they were examined and mapped by P. Sampat Iyengar, who concluded that these varied rocks are not metamorphosed sediments or in any way comparable to the gondite series of the Central Provinces, but are altered phases of the hornblendic rocks, the alterations being brought about by the contact metamorphism of acidic intrusions and subsequent metasomatic or meteoric changes.[27] As, however, he applied a similar origin to the calc-granulites of the Sausar series which he saw at Utekata, about the sedimentary origin of which there is now not the slightest doubt, his conclusions regarding the rocks at Sakarsanhalli may be questioned. However,

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[20] *Rec. Geol. Surv. Ind.*, 1886, **19**, 98.

[21] *Proc. As. Soc. Beng.*, 1917, **13**, cxcviii.

[22] *Rec. Mysore Geol. Dep.*, 1922, **21**, 186; *op. cit.*, 1924, **23**, 128; and *op. cit.*, 1925, **24**, 144-147.

[23] *Proc. Seventh Ind. Sci. Congr.*, 1921, cxv.

[24] *Rec. Geol. Surv. Ind.*, 1934, **68**, pp. 24-25.

[25] *Op. cit.*, 1926, **59**, 92.

[26] *Rec. Mysore Geol. Dep.*, 1923, **22**, pt. 2, 35.

[27] *Op. cit.*, 1931, **30**, 14-18.

in a very recent paper by M. B. Ramachandra Rao and K. Sripada Rao on the origin and correlation of these rocks, the same conclusion is reached that they are altered phases of the hornblende-schists of the lower division of the Dharwars and not metamorphosed sediments.[28] For the time being, then, the origin of these rocks must remain uncertain, though it is evident that they are very similar lithologically to parts of the Sausar series.

## CORRELATION.

A condensed statement of the Archæan rocks in different parts of India has been given by J. A. Dunn.[29] This is of value in drawing attention to the difficulties of the problem, but his final table of correlation probably requires modification. For reasons given at the beginning of this article, it is impossible at present to correlate the Archæan rocks of the various tracts in India. But certain lines along which this may ultimately be accomplished are becoming clearer, and may be referred to briefly here.

Dr. Fermor has advanced the view that the manganese ores in the Archæan rocks of India are likely to be all of one age, and he has accordingly suggested that all Archæan rocks which contain syngenetic manganese should be taken to be of the same age, especially if they are associated with crystalline marbles, as in the Central Provinces.[30] The correlation of the Sausar series in the Central Provinces with the Gangpur series in Bihar and Orissa is a natural consequence of this hypothesis. Further, he has suggested that the Iron-ore series of Bihar and Orissa may be the same as the Sakoli series in the Central Provinces, both containing hæmatite rocks, and both being devoid of marbles.[31] At any rate it seems safe to suggest that the Sausar series and Sakoli series are together equivalent to the Gangpur series and Iron-ore series.

As regards the other Archæan tracts in India, it has already been indicated that the Aravallis of Rajputana and the Champaners of Bombay are lithologically similar to the Dharwars of South India, and it is possible that the two are continuous beneath the Deccan Trap of the Bombay Presidency. Thus, viewed broadly, we seem to have two belts of Archæan sedimentary rocks in India, within each of which the rocks can be roughly correlated; the Aravalli-Champaner-Dharwar belt, with a meridional extension, and the Central Provinces-Bihar and Orissa belt, with an equatorial extension. The difficulty arises when we try to find some common factor between these two belts which may be of correlative value. If we try to correlate the Sausar series of the Central Provinces with one of the three metamorphosed sedimentary systems in Rajputana on lithological grounds, it seems clear that they bear most resemblance to the Delhi system, with its calc-gneisses, mica-schists and quartzites. But the fact that manganese occurs in the Champaner series, which is the same as the Aravalli system, suggests, as Dr. Fermor has pointed out, a correlation of the Sausar series with the Aravallis, though the two are not particularly alike lithologically.[32] This separation of the Archæan tracts into two belts on structural and lithological grounds should not be allowed to obscure the probability of the Aravalli strike in south-east Rajputana curving round so as to join up with the E.-W. strike of the Central Provinces. The completed mapping of the older rocks of Rajputana shows that in the south the strike splays out to the south and to south-east before it plunges beneath the later Deccan Trap, as a glance at the new geological map of India will show. And it is quite possible that the south-eastern wing continues on beneath the Deccan Trap towards the Archæan rocks of the Central Provinces. It is true that some of the manganese in the Champaners may not be of syngenetic origin; but the occurrence of manganese ore of true gonditic affinities in Aravalli phyllites in Jhabua State certainly suggests an affinity between the Sausar series and the Aravalli system. The only alternative is the possibility that there are two horizons of manganese in the Archæan rocks of India, which Dr. Fermor thinks unlikely. As a possible means of correlation between the Central Provinces and South India, the manganiferous rocks at Sakarsanhalli, in Mysore State, have already been referred to. But the present uncertainty as to their origin makes their value for purposes of correlation rather doubtful. The only other similarity that one can point to between the rocks of the two belts is the lithological resemblance between the Older

[28] *Bull. Mysore Geol. Dep.*, 1934, No. 14.
[29] *Aust. Assn. Adv. Sci.*, 1926, **18**, 291.
[30] *Rec. Geol. Surv. Ind.*, 1926, **59**, 80.
[31] *Op. cit.*, 1933, **67**, 65.
[32] *Op. cit.*, 1934, **68**, 26.

Metamorphic series of Bihar and Orissa and the Dharwars of South India. This correlation. however, introduces several difficulties.

Finally, considering broadly the ancient metamorphic rocks of Rajputana, it will be found that they differ from those in other parts of India in two main respects. (1) They include a basal gneissic complex, upon which the metamorphosed sedimentary rocks rest unconformably, in contrast to other Archæan tracts in India where the ortho-gneisses have in every case been proved to be younger than the sedimentary schists. (2) They include three or four distinct systems of rocks separated by marked unconformities. This fact has led Heron to believe that the Delhi system is a post-Archæan formation.[33] The high degree of metamorphism and folding to which the Delhi rocks have been subjected is regarded as a phenomenon which was peculiar to Rajputana at so late a stage in pre-Cambrian times. On this assumption there are two alternatives.

(1) That the Delhis were roughly contemporaneous with the Cuddapahs, and that, as Heron has put it:

> 'They owe their folding and the related intrusion of granite batholiths to a special local upheaval in Rajputana which did not affect the rest of India, or to local persistence of disturbance in Rajputana after it had almost died out elsewhere.'

(2) That the Delhis are older than the Cuddapahs, but have no equivalents in other parts of India.

This is probably about as far as one can safely go at present with regard to correlation. But the advances which have been made in our knowledge of the Archæan rocks of India during the past ten or twelve years have been so considerable, that one may be fairly hopeful as to the eventual solution of many of the problems which to-day seem so puzzling. Dr. Fermor is believed to be reviewing the Archæan rocks of India in a comprehensive manner. The publication of his conclusions, based as they are upon an exceptional experience of the Archæan rocks of most parts of India, will be looked forward to with great interest.

In the accompanying table, summarising the classification of the older rocks in the four chief tracts in India that have so far been studied in detail, no correlation is intended between one area and another.

| Rajputana | Central Provinces |
|---|---|
| Delhi system | Ortho-gneisses |
| Raialo series | Sakoli series |
| Aravalli system | Sausar series |
| Bundelkhand gneiss and Gneissic complex | |

| Bihar and Orissa | South India |
|---|---|
| Granitic rocks | Cuddapah system |
| Iron-ore series | Ortho-gneisses |
| Gangpur series | Dharwar system |
| Older metamorphics | |

[33] *Mem. Geol. Surv. Ind.*, 1917, **45**, pt. 1, pp. 110-116.

## Technological Researches at the University of the Punjab.

IN recognition of the valuable researches of basic importance to the Petroleum Industry conducted by Dr. S. S. Bhatnagar, Director, Punjab University Chemical Laboratories, Messrs. Steel Brothers Company Ltd., Agents, Indo-Burma and the Attock Oil Company, Ltd., have placed at the disposal of Prof. Bhatnagar, a sum of 1½ lakhs of rupees for research work on Petroleum and Allied subjects which will be paid in equal instalments over a period of five years. Messrs. Millar and Ward, Agents of Messrs. Steel Brothers, made a lumpsum grant to Prof. Bhatnagar as a personal gift, but the Professor offered to place the money at the disposal of the Punjab University, an offer which was thankfully accepted, with a view to inaugurating a department of Petroleum Research under his guidance.

One of the features of the scheme is that all results of a patentable nature will be exploited jointly by Messrs. Steel Brothers and Prof. Bhatnagar and/or his chemists and the profits will be shared equally between the Company and the parties concerned. Dr. Bhatnagar proposes to give the University a large share of his profits for the furtherance of scientific, industrial and medical research in the University.