fortunately I have been, firstly to have had the privilege of working in India, with the wonderful range of geological problems and, secondly, to have had the companionship of so many Indian geologists.'

His writings are models of clear exposition aimed at advancing our knowledge of the subject. Early in his career he attempted a series of review articles which were published in *Current Science* entitled, 'Some recent advances in Indian geology'. They were masterly reviews marked by clearness and insight and revealed his capacity for assimilating a large volume of data and distill from it the very essence for the edification of others.

In his 86th year, he said there was little remaining for him to accomplish except to light the way for the younger generation to become good geologists. This he did sincerely and to the best of his ability. He will be remembered for a long time to come for his classic contributions to Indian geology and the role he has played in geological education in this country.

He apparently remained in good health till the last. He took ill and was shifted to Bhopal where he passed away in the early hours of 23rd May 1994.

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We extract below excerpts of West's earliest writings contributed more than sixty years ago to the newly started journal, 'Current Science'. These are of the nature of review articles entitled 'Recent Advances in Indian Geology'. Although a great deal of new information has been added and vast changes have taken place in our understanding of the geological evolution of the Indian continent, these early observations made prior to the advent of the Plate Tectonic Era which has revolutionized earth science have a charm of their own. It will be seen that West had a prophetic vision and had anticipated many of the modern developments.

– Editor

Some recent advances in Indian geology

W. D. West

Geological Survey of India

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 summarize 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.

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(1)

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

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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.

* * *

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. 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. They are the oldest rocks in Rajputana.

Perhaps the feature of greatest interest which has been brought to light by Heron's 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 paralleled 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. Further south still the injection dies out, and slates are found once more.

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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.

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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.

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 worthwhile 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	Magnetite-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 part 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.

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 composition by abundant veins of aplite. 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.

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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 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. 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.

* * *

South India

In 1886 R. Bruce Foote mapped the rocks around Bellary and Dharwar, south of the great Deccan Trap outcrop. 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·

> '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.

(2)

Deccan trap volcanic activity

In India we have one of the best developments extant of the 'plateau basalt' type of igneous activity, known as the Deccan

Trap. The importance of a thorough study of these rocks will readily be appreciated when it is understood that in the opinion of many geologists the basalt, which is the predominant type in this series of rocks, is probably the primitive rock from which most other rock types have been evolved by some process of differentiation. The remarkable similarity in chemical composition which all plateau basalts throughout the world exhibit suggests that they have been derived directly from some primitive source without the intervention of any process of differentiation, and their study is, therefore, of great importance in relation to several branches of geology. So far, considering the very great area which these lavas cover in India, the extent to which they have been studied in detail is lamentably small. Their study is conveniently divided into two sections. On the one hand, we have the immense thickness of horizontally bedded basalts and dolerites which make up the greater part of the Deccan Trap, and which are typical 'plateau basalts'. These show, even in detail, great uniformity of character, though certain slight differences in chemical composition can be discerned between the earlier and later outpourings. On the other hand, there occur certain areas along the north-west corner of the Deccan Trap outcrop, notably in Gujerat, Kathiawar and Cutch, in which differentiation has proceeded along special lines to an advanced stage giving rise to a great variety of rock types. It is essential for a complete understanding of either of these groups that both should be studied.

The most important contribution to our understanding of the petrography of the rocks of the former category has been provided by Dr. L. L. Fermor, whose study of the lavas penetrated by a deep boring at Bhusawal, some 250 miles north-east of Bombay, has provided us with an accurate statement of the petrography of these rocks. In a study of the 29 flows penetrated, it is shown that the predominant type of rock is a basalt or dolerite of specific gravity 2.91, consisting essentially of labradorite felspar (Ab_1 An_2), enstatite-augite (pigeonite), iron ore and glass, while olivine, always completely altered, occurs in 18 out of 29 flows. This description may be regarded as typical of the greater portion of the flows of the Deccan Trap of India. In this paper, particular attention is paid to the minerals of late crystallisation, occurring either as linings and infillings to the amygdales of the flows, or as alteration products of the glassy base and of some of the minerals. To the former group belong the minerals chlorophæite, delessite, chalcedony, opal, quartz and lussatite, and the zeolites heulandite, apophylite and ptilolite, with calcite; while to the other group belong palagonite, chlorophæite, celadonite, chabazite, together with iddingsite, delessite and serpentine which are pseudomorphous after the olivine. The conclusion is reached that, with the possible exception of the calcite, these minerals have been formed during a late stage in the final consolidation of the lavas, and have not been deposited by meteoric waters. This is the first time these minerals of late crystallisation have been adequately described. Both in this and in subsequent papers the process known as 'palagonitisation' is discussed in detail, a subject which also receives attention in a paper by D. N. Wadia. Finally, a further point brought out by Dr Fermor is that in a number of the flows the olivine, and sometimes the labradorite, phenocrysts have sunk to the base of flows which were apparently more fluid than the rest at the time of eruption. This observation of the sinking of the crystals leads the author to suggest that the ultrabasic rocks found occasionally in the Deccan Trap, such as in Baluchistan, may have originated by some such mode of gravity differentiation.

In 1916 Drs. L. L. Fermor and C. S. Fox published an account of the Deccan Trap lava flows near Linga in the Chhindwara district, Central Provinces, with a map showing the distribution of five separate flows. Specimens representing four of these flows have now been analysed and the results discussed by Dr. Fermor. Although of the four specimens analysed two are basalts and two are dolerites, the analyses are all very similar. It is only when the norms are calculated that slight differences are brought out. These show that from the lowest to the highest flow the direction of change is increasing alkaline felspars, increasing total felspars, and increasing total pyroxenes, with decreasing total iron ores. When compared with the norm of the eleven analyses of Deccan Trap made by Washington, after arranging these latter into their probable order of extrusion, it is found that the differences in composition as one ascends in the Traps is similar in direction but much larger in degree than that shown by the four specimens. From this it is deduced that the tendency to differentiation illustrated by the lavas of Linga on a small scale is an epitome of that generally applicable to the lavas of the Deccan Trap series as a whole.

* * *

Coming now to the second portion of our subject, we have to deal with a large variety of rock types, some very basic, some very acid, and others markedly alkaline, which are found mainly in the peninsula of Kathiawar and the adjacent country. These rocks are definitely part of the Deccan Trap volcanic episode, but represent the results of advanced differentiation localised about certain areas or along certain lines. Ever since the days of F. Fedden it has been realised that the peninsula of Kathiawar was exceptional in containing several foci of eruption in which differentiation had proceeded to yield a large variety of rocks. So long ago as 1893 Dr. J. W. Evans made a collection of rocks from Junagarh State, and subsequently published a paper describing one of them, a monchiquite containing primary analcite, which he found on the margin of a nepheline-syenite. Recently one or two of his students have re-examined this collection and shown it to be very varied. M. S. Krishnan has made a detailed petrographical study of those collected from the Girnar and Osham hills. Of these the majority are nepheline-syenites and dolerites, but other less common types include quartz-porphyry, syenite porphyry, syeno-diorite, diorite-gabbro, porphyrite, andesite, olivine-gabbro, lamprophyre, limburgite, obsidian, rhyolite and pitchstone. In this paper six new analyses are given, which the author considers indicate a petrographical province of the 'Atlantic' type. At about the same time K. K. Mathur, V. S. Dubey and N. L. Sharma published a small-scale map of the rocks of Mount Girnar, representing the first attempt to map this focus of eruption. In the accompanying papers intrusions of olivine-gabbro, diorite and monzonite, granophyre, and nepheline-syenite are described. These are intruded into typical Deccan Trap lavas which they have domed up forming Mount Girnar. Although there is apparently no direct evidence of the mode of origin of these rocks, reasons are given for supposing them to have been derived by differentiation *in situ* through progressive crystallisation, estimates being given to show that the parental magma was of intermediate or dioritic composition. It is thought that crystal settling through gravity has not been operative. More recently, other rocks of Dr Evans's collection, from the West Gir forest, have been described by S K. Chatterjee. These are mostly basic dykes, chiefly olivine-dolerites, but mention is also made of irregular intrusions of acid rocks consisting of spherulitic granophyre, pitchstone, rhyolite and other types. Seven new analyses by the author are given. Other more general papers which include references to the Deccan Trap of Kathiawar, and which are not generally known, are E. Howard Adye's two memoirs on the 'Economic Geology of Navanagar State' and on the 'Economic Geology of the Porbandar State', which are illustrated by a large number of photomicrographs; and a paper by K. P. Sinor on the 'Igneous and Sedimentary Rocks of Bhavnagar Territory,' also illustrated.

As regards the more acid types of rock, which have been known to occur in the Deccan Trap ever since W. T Blanford published his observations on the geology of the Tapti and Lower Narbada valleys, K. K. Mathur and P. R. J. Naidu have recently described some acid intrusions and lavas on the coast north of Bombay comprising trachytes, granophyres and rhyolites These include the 'granophyric trachyte' of Kharodivadi described by M. S Krishnan. Associated with these rocks are glassy gabbros and dolerites. As a result of calculating the silica percentage of the glassy base of these rocks, shown to be about 68%, the authors are led to believe that the acid intrusions represent the same glassy base after it had separated from the partly crystallised magma and solidified away from it. They further conclude that these acid intrusions are a very recent phenomenon. Subsequently, in his presidential address to the geology section of the Indian Science Congress, 1934, Mathur brought together all known occurrences of both acid and very basic rocks of Deccan Trap age, and discussed briefly their origin and age. He suggests that the acid types occur mainly along two lines, one running north and south, from Pavagad hill in the Panch Mahals in the north, to Bombay Island in the south, and one running east and west, along the Narbada valley to as far as Barda hill in Porbandar State in Kathiawar. He further suggests that their origin may be due to the assimilation of acid rocks by the molten basalt, basing his conclusions on certain observations made by W. T. Blanford and P N. Bose. His view, however, that the rhyolite on Pavagad hill is an intrusion has now been shown to be incorrect, A. M. Heron having confirmed the original view of Dr Fermor that it is a flow capping the hill and part of the general succession of lavas. As regards the age of these rocks, while recognising the possibility that in certain cases both the acid and the very basic types were extruded at the beginning of the Deccan Trap period, he inclines to the view that for the most part they are very recent in age, attributing their age in some cases to a period subsequent to the establishment of the present topography, a conclusion which perhaps some geologists will find it difficult to accept.

It was mentioned above that Dr. Fermor had suggested means whereby the ultra-basic rocks of Deccan Trap age, such as those in Baluchistan, might have been derived from the normal basaltic magma by the sinking of some of the phenocrysts. Further light has been thrown on this problem by W. D. West, who has examined the cores of rock brought up by deep borings put down through Deccan Trap lava flows in different parts of Kathiawar. These rocks include very basic types such as limburgite and ankaramite, interbedded with the more normal Deccan Trap type of basalt A study of the phenocrysts of olivine, augite and felspar found in these very basic lavas shows that in each type of rock the composition of the phenocrysts is closely related to the composition of the rock in which they occur. Thus the felspar phenocrysts in the more basic types are bytownite-anorthite as compared with the medium labradorite which occurs in the normal Deccan Trap basalt, while the olivines are more magnesian and the pyroxenes more calcic than those found in the normal basalt. These facts are thought by West to show that the different rock types did not originate during the Deccan Trap volcanic period by the sinking of phenocrysts as they crystallised from the basalt, since the phenocrysts differ markedly in composition from those found in the basalt; but that differentiation of the basalt took place long before Cretaceous times, and that the various rock types so formed were already available for extrusion when remelting took place during Upper Cretaceous times.

There is clearly still a large field for research into problems of Deccan Trap volcanic activity, and it is a field which is admirably suited to research by those unattached to official surveys. It must, however, be controlled by detailed and accurate field work, aided by chemical analyses, if it is to be of any real value.

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The Geology of the Himalaya

During the past ten years or so considerable progress has been made in our knowledge of the geology of the Himalaya, which has only served to show how complicated is the geology of this great range and how great is our ignorance of its real structure. During this period work by the Geological Survey of India has mainly been concentrated in two areas, the North-West Himalaya in Hazara and Kashmir, and the Simla hills around Simla and Chakrata; while in addition there have been several foreign expeditions to the Karakoram and neighbouring tracts beyond the Himalaya which have added something to our knowledge of the geology of those parts. Thus, in spite of large blanks still existing on the geological map of the Himalaya, largely accounted for by the inaccessibility of Nepal, the accumulating results of steady mapping are gradually providing a sure foundation on which may ultimately be built a complete synthesis of Himalayan geology. Theories of mountain structure based on our present incomplete knowledge of even one section of the Himalaya must necessarily be largely speculative. They arrive almost by every mail, and are frequently advanced by those whose acquaintance with Himalayan geology is by no means extensive. Perhaps of no part of Indian geology can one more truly say that the more one knows of it the more one realises how little one knows. The present policy of the Geological Survey is to concentrate its small available resources on two sections of the Himalaya, as stated above, in the belief that a sustained attack on these two selected areas will yield more valuable knowledge of the geological structure of the Himalaya as a whole than a larger number of smaller investigations spread over a wider area. The summary that follows, therefore, deals mostly with these two areas. In compiling it the writer is indebted to his colleague Mr. J. B.

Auden for many fruitful discussions on the problems raised therein.

The North-West Himalaya

The most striking feature in the orogeny of the North-West Himalaya is the way the strike of the mountains, after following an arcuate S.E.–N.W. direction for over 1,200 miles from Assam to Kashmir, makes a great bend in Hazara, rapidly curving round through an E.–W. to a N.–S. direction, and producing thereby a great re-entrant angle in the alignment of the mountains between Abbottabad on the South-West and the Kashmir valley on the North-East. This bend is seen not only in the frontal ranges bordering the Indo-Gangetic alluvium, but is repeated in each successive range northwards, culminating in the Pamir massif. Even this great mass shows the same trend lines, which are south–west on the west, equatorial through the Pamirs, and south-east on the east side, as first determined by D. L. Ivanow and subsequently confirmed by Sir Henry Hayden. As regards the origin of this feature, it had previously been supposed by E. Suess in his great work 'Das Antlitz der Erde' that the rapid change in the strike of the mountains was due to the meeting at an oblique angle of two mountain systems, the Himalaya and the Hindu Kush. For this line of meeting Suess used the term 'schaarung', which was translated by Sollas as 'syntaxis'. The following quotation from the English edition gives his conclusions:

> 'Like two shallow streams of lava, or two flows of slag running side by side, the waves of which as they cool come into syntaxis against a long line, now fusing completely together, now encroaching on one another, so the chains of the Himalaya meet those of the Hindu Kush '

He especially emphasised, however, the essential unity of the movements, and the unity of structure of the whole. Quite recently D. N. Wadia's work in the more southern portion of this syntaxial area has shown that both from a structural as well as from a stratigraphical point of view there is a complete continuity of Himalayan geology around this re-entrant, at any rate on its southern border, the structure and stratigraphy on the Hazara side of the syntaxis being the mirror image of the structure and stratigraphy on the Kashmir side, as originally pointed out by Middlemiss. Instead, therefore, of two directions of mountain movement having converged upon Hazara, the Hindu Kush from the north-west and the Himalaya from the north-east, as envisaged by Suess, Wadia concludes that there has been a single Himalayan movement from the north which has come up against some underground obstacle around which it has been forced to diverge. It is suggested by him that a tongue of the ancient and stable peninsular rocks extends upto the north-west beneath a covering of Kainozoic rocks, and that this has formed the obstacle to the folding movement coming from the north, so that the original north and south direction of movement has been resolved into a N.E.–S.W. direction in Kashmir, and a N W.–S E. direction in Hazara. There still, however, remains the difficulty of explaining how the W.S.W. to E.N.E. direction of overthrust which is found on the south-west side of the syntaxis, in the neighbourhood of Garhi Habibulla, can have originated in a movement coming from the north. This latter problem was discussed briefly by J. W. Gregory, who suggested that the older supposed 'Altaid' mass of the Safed Koh in the country west of Peshawar may have been responsible for this backward movement. Recently D. Muschketoff has suggested that this 'Jhelum wedge', as he calls the underground obstacle, has been a tectonic feature of importance since Caledonian times, and has been responsible for a number of abnormalities such as the N.N.W.–S.S.E. direction of the Ferghana range, which although of Kainozoic age runs at right angles to the main Himalayan trend lines on either side. A complete understanding of the origin of this great orogenic feature will probably have to await further information concerning the structure of the Hindu Kush, the Karakoram, the Pamirs, and the country north of the Pamirs.

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The Himalayan arc

In all these discussions it is generally assumed that Gondwanaland played a passive role, and that it was the southward move of the rest of Asia against Gondwanaland which buckled up the soft marine deposits of the Tethys, and caused them to be thrust over the edge of Gondwanaland, which to some extent broke along its northern border. But it is of course equally conceivable that it was Gondwanaland which moved against Asia, crumpling up the rocks of the Tethys, and underthrusting itself beneath them. The writer has always failed to understand how one can expect to decide whether Asia moved south and over Gondwanaland, or whether Gondwanaland moved north and under Asia, by observing the structure of the country along the line of thrusting, though others appear to think it possible. There is, however, one line of reasoning which seems to throw light on this problem, and that involves a consideration of the position of Asia with respect to the rest of the world before and after the movement. This point of view has been developed by P. Lake, who, in a paper on island arcs and mountain building, has drawn attention to the fact that the well-known arcs off the Pacific coast of Asia, the East Indian arc through Sumatra and Java, the Himalayan arc, and the Iranian arc of Persia, which are all of Kainozoic age, all have their convex side facing away from Asia, the Pacific arcs facing east, and the others facing south or south-west. We are thus required to explain how a single Asiatic mass can have moved along its eastern border towards the Pacific and at the same time along its southern border towards the Indian Ocean As Lake points out, a movement of the mass as a whole in both directions does not seem possible, but underthrusting of the ocean-floor from both sides is conceivable, and is, in fact, a necessary consequence of the contraction theory or of Joly's theory. This view receives additional support from a consideration of the central Asian mass itself. Had the earth's crust spread outwards radially from central Asia, we should expect to find a deficiency of matter at the centre of the continent, as Burrard has pointed out. But in fact the reverse is the case, and there is an excess of mass protruding above the spheroidal surface which has nothing to equal it elsewhere on the globe. Consequently the alternative hypothesis, that there has been a general pressure acting towards central Asia, seems to be the more acceptable.

The further suggestion developed by Lake in this same paper, that all mountain arcs which have the shape of an arc of a circle, have been formed by movement of a slice of the

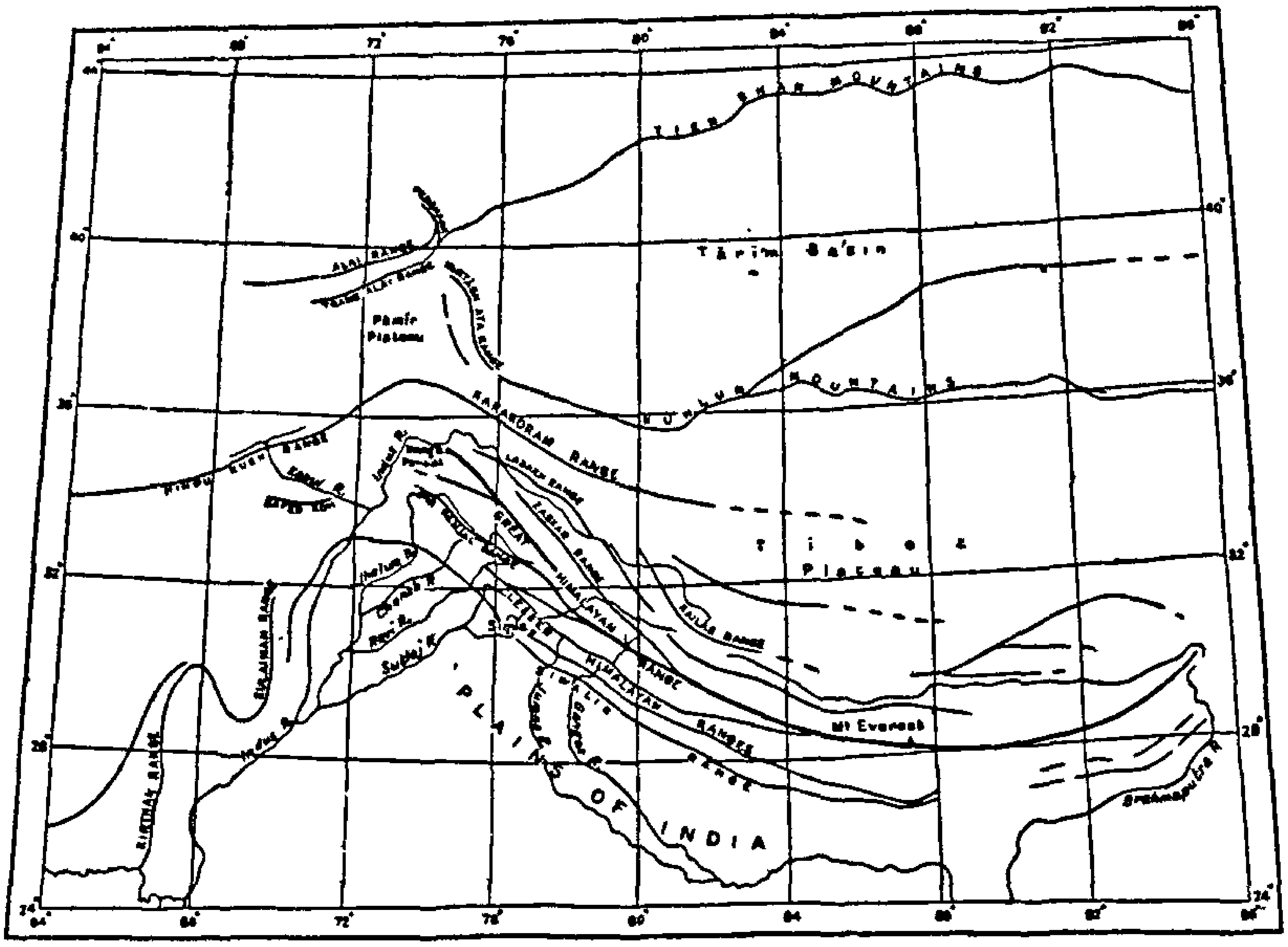

Figure 1. Trend lines of the mountain ranges of the Himalayas and Tibet (mainly after Burrard)

earth's crust along a single basal thrust plane, and in particular its application to the Himalaya, is one which, in spite of (or because of) its simplicity, is not in accord with the observed facts. Although the Himalayan arc can be shown to be part of a circle, with its pole in Central Asia, it must be remembered that, geologically considered, the Himalaya are but a part of a much more extensive mountain system, which continues to the south-west through Baluchistan and Persia, and to the south-east through Burma. And since they have been formed on the site of a long geosyncline by the crushing of its deposits through the movement of Eurasia and Gondwanaland towards one another, the shape of the mountain system so produced must be determined partly by the original disposition of the geosyncline, and partly by the shape of the two impinging masses. Further, as shown by Wadia in the Punjab re-entrant, there is a continuity of geological structure around this feature which forbids one to bring the Himalaya (geologically considered) to an end at Nanga Parbat, the point at which Lake has to end his Himalayan arc. Moreover, as recently pointed out by Auden, our increasing knowledge of the structure of the Himalaya shows that not only are there a number of thrust planes of paramount importance within the Himalaya, but also that the angle of these thrusts is extremely variable and does not conform to the low angle required by Lake's hypothesis. As he says, it would appear impossible to regard any single *dislocation or nappe as having borne the whole burden of the* advance upon the foreland.

On the other hand, Burrard, as a geographer, considers that there is no Himalayan arc at all, for in his opinion the Himalaya cannot be considered independently of the mountains further north, including the Kun Lun, the Tien Shan, the Karakoram and the Hindu Kush, ranges which either show no curvature at all, or curve northwards. But this view ignores the important geological fact that while the Himalaya and its immediately associated mountain ranges are, at any rate mainly, of Kainozoic age, the Kun Lun, the Tien Shan, and possibly the others also, are much older having been formed most probably at the end of the Palæozoic (Hercynian). It does, however, contain a germ of truth. It is a well-established principle that older structures frequently play an important part in influencing the formation of later structures. And although the great Himalayan arc is no doubt to be regarded as essentially Kainozoic in origin, it is yet a *moot point as to the extent to which an older 'grain' may still* be preserved within the main Kainozoic superstructure.

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The Geology of the Himalaya

The Simla-Chakrata hills. We may now consider the second area within the Himalaya which has of late received attention from the Geological Survey of India. In 1925 G. E. Pilgrim and W. D. West began a resurvey of the country between Simla and Chakrata, and were later joined by J. B Auden. This area had first received attention from H. B. Medlicott so long ago as 1860, and was subsequently the subject of several papers by R D. Oldham and others. It was Medlicott, however, who laid the foundations of our knowledge of this part of the Himalaya.

A feature of the geology of much of this country, which puzzled Medlicott and subsequent observers, is the occurrence of highly metamorphosed rocks, such as garnetiferous mica-schists and amphibolites, resting on top of practically unaltered rocks, such as the Simla slates

According to Pilgrim and West, these rock groups are not now in their original position relative to one another. Detailed mapping and metamorphic considerations have led them to conclude that the metamorphic rocks, which are really part of the belt of rocks forming the central axis of the Himalaya, have been forced southward for many miles along a nearly horizontal thrust plane, so as to lie now on top of the unaltered rocks. These metamorphic rocks, named the Jutogh series, are seen forming the upper part of the ridge on which Simla is built, the small hill station of Chail, and the greater part of the Chaur mountain south-east of Simla. At the two former localities they occur as true 'klippe', since the effects of denudation have left them as isolated outliers capping the two hills. But the outcrop that forms the greater part of the Chaur mountain continues northwards along a high ridge, and so joins up directly with the main mass of crystalline schists and granites north of the Sutlej river. The Chaur outcrop is thus a direct southward extension of the rocks of the central axis of the Himalaya, and the way in which these metamorphosed rocks extend so far south as a nearly horizontal sheet, overlying the less metamorphosed slate-limestone group of rocks, is one of the most striking features of the geology. In addition to the major thrust plane along which the Jutogh series have travelled, there are other thrust planes in the rocks below, of which the Chail thrust is the most important. The crush phenomena found along the line of this thrust afford evidence of considerable horizontal movement here also. It is possible that the oncoming of the uppermost Jutogh beds like a gigantic wave from the north, induced the formation of the underlying thrusts, the rocks being piled up one on top of the other as a result of great horizontal compression.

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