"GEOLOGY OF THE GONDWANA SYSTEMS WITH SPECIAL REFERENCE TO INDIA AND AUSTRALIA AND WITH A VIEW TO TEST IF THE KNOWN FACTS MA-KE A REASONABLE PALAEOGEOGRAPHIC SYNTHESIS WHEN APPLIED TO CAREY'S RECONSTRUCTI-ON OF GONDWANAL-AND

By

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INTRODUCTION

About a hundred years ago two brothers, W.T. and H.F. Blanford, working in the sub-tropical parts of India declared that the conglomerate they had examined in Talcher was of glacial origin, and consequently there was land ice in the tropical part of India in the late Palaeozoic times. Their observation and reasoning becomes more remarkable when it is realised that they did not find any striated or facetted boulders to back their argument. Ridiculed by their colleagues, and laughed at by geologists, physicists, astronomers, meteorologists, and other naturalists abroad, they had to wait for about two decades before the discovery of a striated pavement decided the issue in their favour. Medlicott in a manuscript report in 1872 suggested the name Gondwana after the ancient Kingdom of the Gonds, an aboriginal tribe which still populates the area, for the formation, and Feistmantel brought it into print in 1876.

Discoveries of similar formations in Australia, S. America, and S. Africa followed in quick succession, and land connections were envisaged to explain the occurrence of identical flora. It was Suess, who in 1885, introduced the term Gondwana-land for the hypothetical continent which comprised all these continents and the "land-bridges", that connected them.

In 1912, Wegener propounded his theory of Continental Drift. The storm it raised has not yet fully subsided. It got some immediate adherents, who, though they recognised the necessity of further research, saw a ray of hope in it. But a large majority of geologists found it wholly inacceptable.

A remarkable part of the theory, however, was the well nigh perfect fitting of S. America to the west of Africa, and the similarities the two continents showed. But by far the most absorbingly interesting feature of this new concept was the solution it offered for the Permo-Carboniferous glaciation, by reducing the size of the ice cap, if not by the very objectionable migration of the poles. There was a hope, but Wegener put his case badly, and Schuchert, Coleman, Willis and other geophysicists showed that the forces required to shift the continents were inconceivable and incomprehensible. Those suggested by Wegener and by Taylor were fallacious and open to serious objections.

While the Atlantic side was easier to demonstrate, the fitting of the major pieces of the "jig saw" puzzle on the other side of Africa, the 'key piece', continued to cause trouble. Du Toit assembled a mass of evidence, but failed to convince. Much work, which has a direct bearing on the geology of the Gondwanas, has since been done but has not been brought together and correlated.

This paper attempts no solution, but studies the palaeogeography of the Gondwanas in the light of modern knowledge of stratigraphy and sedimentation. The epeirogeney in the various basins of deposition, as measured in terms of the thicknesses of sediments in them, is compared from isopach maps for the different periods. Though lack of reliable data stands in the way of specific classifications being adopted, an attempt is made to place these basins in Marshall Kay's geosynclinal types. These areas of deposition with the isopach form lines are then placed on the various reconstructions of Gondwanaland, on the presumption that they should match in tectonic characters etc. on either side of the continents if the continents are to be brought together under the Drift theory, or they should meet the demands of the classical school with fixed continents. For obvious reasons it was not possible to deal with all the various assemblies of the former continent, and reference is made only to those by Schuchert, Wegener, Du Toit and one presented by Prof. Carey at the Pan-Indian Ocean Science Congress, 1951, in Bangalore (India), not yet published. Some other reconstructions are briefly mentioned, while Rode's theory of 'Sheet Movement' which has an Indian background, has been discussed in some detail. Anomalies of fauna, flora,

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The use of such terms as shales, greywackes, and even sandstones etc. has, in the past, not been on any scientific system. As a matter of fact, these were not defined with any mathematical precision, and the field and laboratory classification was a matter purely of opinion. Attempts are being made in different countries, but it would be some years before these bear fruit, while the author had to take the material from published literature now available. No lithofacies maps could, therefore, be attempted, but would provide a good subject for study in the future.

The paper lays special emphasis on the Gondwanas of India and Australia only, but the maps cover the other continents included in Gondwanaland. The isopachs of other countries are only approximate, particularly so is the case with South America. They are being studied and it is proposed to make them the subject of a subsequent paper.

The Author would here like to express his deep gratitude to Prof. S.W. Carey, of the University of Tasmania, under whose direction this work was carried out, for his constant help and encouragement. Without his guidance it would not have been possible to complete this paper in the time available, while Mr. M. R. Banks gave of his time most ungrudingly, and helped with the literature in some foreign languages. They also made numerous valuable suggestions and offered constructive criticism. The author is also grateful to Mr. J.C. Ferguson, Director, South

Rhodesian Geological Survey, Mr. M.A. Condon of Bureau of Mineral Resources, Dr. W.D. Johnston of the U.S. Geological Survey and Messrs. V.P. Sondhi and A.B. Dutt of the Geological Survey of India for the help they rendered.

Last but not the least the author must thank the Commonwealth Government of Australia, a Research Fellowship from whom made his visit to this country and this work possible.

CHAPTER II

PREVIOUS LITERATURE

The title of this paper hardly gives an indication that the subject covers several branches of the science, i.e. stratigraphy, palaeontology, structure, glaciation, origin of coal, and the various theories of the origin of continents and oceans. Added to these is the great difficulty of covering at least four continents, with the result that the available literature is in several different languages. Apart from English one has to know French, Dutch, Portugese, Spanish and German, to be able to do it satisfactorily. The Bibliography at the end will, however, show the author's limitations in the linguistic field. This has obliged him to leave South America out of general discussion. Only a few papers in English are available, and most of these are too old, however, admirable they be.

Yet the amount of published literature in English is very large indeed. The necessity to get reliable measured sections in the various basins made it necessary to go through a very large proportion of this. The Geological Survey of India alone has published scores of papers and summarised them in a series of Memoirs by Fox, and one each by Gee and Jowett, in the thirties of this century. The numerous papers by Blanford and Medlicott are still of interest and importance. In fact Fox appears to borrow most of his ideas from these, and only clothes them in modern language. Thus, following them, he advocated that the

Gondwanas were deposited in Rift valleys or in large fresh water lakes, that the glaciers were descending from the Vindhyan heights, which have been standing as a mountain range since the Pre-Cambrian times, and that the coal is of drift origin. Vredenburg in 1880 pointed out that the deposition was apparently not in rift valleys and Gee repeated the suggestion, but he too agreed with the rest of Fox's hypothesis. Fox's views were, however, adopted by the Survey and got into the text books by Wadia and Krishnan. Both of these are admirable summaries of the geology of India, but the author has a preference for the latter's Geology of India and Burma.

The period between Blanford and Fox is filled by numerous papers, mainly by Ball, Hughes, King and Mallet. Extra-Peninsular India also received early attention, and Wynne, Lydekker and Stoliczka did pioneering work in the Salt Range, Kashmir and the Himalayas. Their work was later revised by Gee, Middlemiss, Hayden and Wadia.

The Australian part has been equally ably treated by David, Sussmilch, Andrews, Maitland, Blatchford and others, and more recently by Raggatt, Clarke, Teichert, Carey, Browne, Voisey, Conditt *et al*. As a result of their efforts the geology of eastern Australia is fairly well known, but the same cannot be said of Western Australia. Only in recent years Teichert has made valuable contributions while Clarke, Raggatt et al. have added materially to the knowledge of this vast area. Their efforts have, however, only been concentrated on the margins and very little is even now known of the interior parts.

The knowledge about the geology of Africa is rather patchy. Of South Africa, Rhodesia etc. a fair amount is known, chiefly through the writings of Du Toit, Dixey, Stockley, Mennel and others, but of the areas not in the British Commonwealth it is difficult to get a reasonable picture. Of the Congo Basin Veatch has given a comprehensive account in the Memoirs of the Geological Society of America, but only little has been published in English about Madagascar and Portuguese East Africa. Du Toit's "Geology of South Africa" is an admirable summary.

"A Geological Comparison of South America with South Africa", Du Toit's well known paper, is by far the most important publication about the former continent which the author could depend upon, though I.C. White's "Report of the Brazilian Coal Commission" was also used. Lisboa, D. White and a few others have a few papers to their credit. Caster has during last few years added materially to the knowledge of S. American geology and his papers are mines of information. The isopachs for South America are, however, largely based on Weeks' paper, and alterations have been made only where information available justified such an action.

Sherlock pleads a cause which, however important or reasonable it may be for Europe, does not seem to apply to Gondwanaland. He wants to do away with the Permian System from the Standard Scale. His book, "The Permo-Triassic Formations", and Reed's "Geology of the British Empire" cover very extensive areas and are very useful and reliable summaries.

On the subject of Gondwanaland, literature by the two sharply divided schools was consulted in some details. On the one side are Wegener with his "The Origin of Continents and Oceans" and Du Toit with his "Our Wandering Continents", Holmes, Caster and others with small but interesting papers and on the other side are ranged such well known names as Schuchert, Bailey Willis, Brookes and many more, who believed in the essential fixity of the continents and explained the faunal and floral distribution by land bridges, that have since disappeared, or by island arcs.

A large amount of work has been done in recent years in Europe and in America on sedimentation and geosynclines, though a uniform system of nomenclature is yet to be adapted. An attempt is, however, made here to make use of this advance in knowledge.

The bibliography at the end is, by no means, exhaustive, and many of the papers consulted have not been included.

CHAPTER III

PRE-GONDWANA FRAMEWORK OF INDIA AND AUSTRALIA

Late in the Carboniferous Period several continents were subjected to very extensive glaciation. The glacial beds and the succeeding deposits formed a "System" which is usually referred to as "Gondwana", though it has different names in different countries - Gondwana System in India, Karroo in S. Africa, Santa Catherina in S. America, and Kamilaroi (now apparently abandoned) in Australia. Though seen today in widely scattered areas these Gondwana formations are, perhaps, unique for the similarity of their sediments and their fossil contents. But before proceeding to study them it is essential to look into the geological framework of the two countries as it existed at the beginning of the Gondwana deposition, as this can give an insight into their origin and mode of deposition.

Each of the two countries may conveniently be divided into two geologically distinct provinces: India into (A) Peninsular and (B) extra-Peninsular and Australia into (C) the Western shield and (D) the Tasman geosyncline. The aim here will be to describe these separately and briefly, making a note of any similarities or affinities that this study brings out.

(A) PENINSULAR INDIA

Rocks of the Gondwana Systems are seen scattered in a number of isolated outcrops, unconformably overlying the older rocks along certain very definite lines, which in some cases follow the courses of the existing rivers. These older rocks, in the main, are assigned to the oldest Archaean System, and if any younger rocks were deposited in these areas, they had been completely eroded away before the Gondwana beds were deposited.

The predominating types of rocks are granites, gneisses and schists. The gneisses vary considerably in mineral composition and are often banded. This banding may be due to a difference in the character of the original sediments which have been metamorphosed. Actinolite schists, epidote rocks, quartz-mica schists, and granulites are common. In many places marble occurs in these rocks.

The gneisses are intruded by quartz and pegmatite veins as well as by dolerite dykes apparently both older and younger than the Permo-Carboniferous sediments.

Though these gneisses are the typical rocks of Peninsular India and are usually seen underlying the Gondwana formations in Bengal, Bihar, Madhya Pradesh and other areas, the latter are occasionally seen to be actually overlying or in close proximity to a very different type, the well known charnockites. These range from acid to ultra-basic in composition and are characterised by the presence of hypersthene, blue coloured quartz and a peculiar waxy look.

Associated with these is often a garnetiferous gneiss or schist which has been variously named as Bezwada or Kailasa gneiss, but is most commonly referred to as khondalite. From the charnockite type area it is described as garnetiferous leptynite. Krishnan (1951: pp.319-320) thinks that "they are "para-schist" derived from aluminous sediments". They consist of quartz, felspars (orthoclase, microcline and acid plagioclase) and iron-garnet as the essential minerals, with frequently fairly large amounts of sillimanite and graphite. "There are, however, parts of exposures of these rocks where neither sillimanite nor graphite may be present .... The differences that may be found in their mineralogical composition are incidental to regional variation in the nature and composition of sediments (though of essentially similar nature) as we are dealing here with comparatively large areas."

There seems to be general agreement with the view expressed above regarding the origin of khondalite, but the origin of charnockites is not yet clear. One school regards it as distinctly intrusive while the other considers that it, too, is a product of metamorphism.

Vindhyans - a system of marine and fresh water sedimentary rocks - were supposed to be of pre-Cambrian age, as no fossil had been found in them till recently. In 1949, however, Misra (1949 : p.438) discovered a specimen of primitive Dasycladaceae in the Rohtas Limestones and this would, if confirmed, place the age of the middle part of the formation as Ordovician. Recent work indicates that the Vindhyan System may be Cambrian in age. It skirts the Gondwana formation in Central India while in the Wardha Valley Lower Gondwana beds are known to overlie the Vindhyan beds with an unconformity.

(B) EXTRA-PENINSULAR INDIA

Outside Peninsular India rocks of Permo-Carboniferous age occur in the Salt Range, Kashmir, Spiti, Simla area, Darjeeling and Assam. Apparently they continue all along the Himalayan region. The basal bed of the Gondwana System in every locality is a tillite which rests with an unconformity of varying magnitude over the older rock, except, perhaps in parts of Kashmir. The presence of the tillite in north-eastern Assam is, moreover, doubtful.

Of all these areas the geology of the Salt Range and parts of the Kashmir, Spiti and Simla areas is fairly satisfactorily known, but knowledge about Darjeeling is small, and very little indeed is known of the Assam Gondwanas. The first four areas will be described briefly here.

<u>SALT RANGE</u>. The beds that underlie the "Speckled Sandstone and Boulder Bed" - the Salt Pseudomorph Beds - are presumably of Cambrian age, and an unconformity separates them.

The early Palaeozoic succession in this area is :

6.	Speckled sandstone and Boulder Bed.		
	- UNCONFORMITY -		
5.	Salt Pseudomorph Shale -	450 ft.	Red to purple and greenish shale with pseudomorphs of salt crystals.
4.	Magnesian Sandstones -	250 ft.	Well bedded, cream coloured dolomite or arenaceous dolomite.
3.	<u>Neobolus</u> Bed-	100 ft.	Fossiliferous grey micaceous shales.
2.	Purple Sandstone -	450 ft.	Fine grained sandstone with shales at the base.
1.	Salt Marl	-1,500 ft.	Bright red calcareous clay or marl with much salt and gypsum.

Though great academic interest exists as to the age of the Salt Marl, the formation that is really of great interest here is the <u>Neobolus</u> Bed, because of its contents of well preserved fossils. These are the primitive brachiopods, the <u>Neobolus warthi</u>, <u>N.wynnei</u>, etc. as well as Trilobites; <u>Ptychoparia richteri</u>, <u>P.sakesarensis</u>, <u>Redlichia noetlingi</u>, <u>Chittidillia plana</u>, <u>Conocephalus warthi</u>

Brachiopods; <u>Lingula warthi</u>, <u>Lingulella wanniecki</u>, <u>Orthis warthi</u>, etc.

Pteropod; <u>Hyolithes wynnei</u>.

This fossil assemblage indicates a Middle Cambrian age.

The succeeding Magnesian Sandstones which overlie these contain some fucoid and annelid markings, also the gastropod, <u>Stenotheca</u>.

The Magnesian Sandstones are conformably succeeded by the Salt Pseudomorph beds and these are, as has been mentioned earlier, unconformably overlain by the tillite over which was deposited the Speckled Sandstone.

<u>KASHMIR and SPITI</u> : A conformable, well developed Palaeozoic succession exists in Kashmir and Spiti. The formations in the two areas are so similar - though different formational names have been given to them - that it would suffice to give descriptions of only one. The succession is as follows:-

Kanawar System	-	Carboniferous -	4,000
Muth Quartzite	-	Devonian)	
	-	Silurian) over	2,500
	-	Ordovician)	
Haimanta System	-	Cambrian "	5,000

Practically all the 2,500 ft. of the Muth quartzites are fossiliferous and consequently the list of species available is very great. They are overlain in Spiti by the rocks of the Kanawar System, which is subdivided as follows:-

Po Series	- 2,000 ft. -	<u>Fenestella</u> shales Thabo Stage:quartzites and shales with plants.
Lipak Series	- 2,000 ft. -	Limestone and shales.

The Lipak Series is very prolific in fossils, characteristic of the Lower Carboniferous, e.g.,

Brachiopods: *Productus cora*; *P. semireticulatus*; *Chonetes hardrensis*; *Syringothyris cuspidata*; *Spirifer kashmiriensis*; *Strophomena analoga*; *Reticularia lineata*; *Athyris roysii*, *A. subtilita*.

Trilobite: *Phillipsia* cf. *cliffordi*.

Lamellibranchs: *Concordium* sp., *Aviculopecten* sp.

Pteropod: *Conularia quadrisulcata*.

Also: Cephalopods, Gastropods, Crustacea, fish teeth, etc.

The Lipak Series is conformably overlain by the Po Series which, on the basis of its fossil contents, is considered to be Lower Carboniferous in the lower portion and Upper Carboniferous in the upper portion. The fossils are:

Thabo Stage (Lower Po series) - *Rhacopteris ovata* *Sphenopteridium furcillatum*.

Fenestella shales (Upper Po series) - Brachiopods: *Productus scabriculus*. *P. undatus*; *Spirifer* cf. *gerardi*, *S. triangularis*, and *Recticularia lineata*.

The lower part, carrying the foregoing plant fossils, is composed of black shales, traversed by intrusive dykes and sheets of dolerite. The upper division is mostly shales and quartzites, the higher parts of which are shales with a preponderance of the polyzoan genus Fenestella. In Kashmir a limestone carrying Syringothyris cuspidata, lies above the Muth Quartzite and below the Fenestella Shales. Volcanic activity is recorded in Kashmir in the form of the Panjal Traps. Middlemiss dated their commencement in Middle Carboniferous though they may be younger, and entirely intrusive.

Further west in the Kashmir - Hazara area an unfossiliferous system of phyllites, quartzites, quartz-schists, conglomerates etc. known as the Tanawal Series underlies the Tanakki Conglomerate which is now regarded as the equivalent of the Talchirs and the Blaini. They, perhaps, fill the gap between the Cambrian and the Upper Carboniferous.

SIMLA AREA: The Blaini Boulder Bed (tillite) unconformably overlies the limestone, slates, grits etc. of the unfossiliferous Jaunsar Series. The Jaunsar Series is, perhaps, of late Pre-Cambrian age.

From the brief resume given above it would be clear that whereas almost the whole of Peninsular India was being subjected to erosion throughout the Palaeozoic period, there was a long geosynclinal basin to the north of it in which deposition was more or less continuous. This basin extended from at least Spiti to Hazara, through Kashmir, and, perhaps further west. Eastward, too, it probably extends into Assam, north of the Shillong plateau, which is a continuation of the Peninsular gneisses. Salt Range, however, might have belonged to the marginal zone, and was oscillating between areas of provenance and the basin.

The stratigraphical position of the Vindhyan Series will be discussed later. The full impact of Misra's discovery has not yet been felt in the circle of the Indian geologists, but it is likely to prove very interesting and may cause a complete revision of the Indian stratigraphy.

(C) AUSTRALIA

WESTERN SHIELD : There are four main areas where Permo-Carboniferous rocks are exposed. In addition there is a fifth area where rocks of the age are reasonably believed to exist. The first four are, from the south, the Collie Basin, the Irwin Basin; the N.W. Basin and the large Kimberley Desert area; while the fifth is to the east of Kimberley on the boundary between Western Australia and Northern Territory.

Important contributions have, however, been made in the last few years and the areas in question are now receiving a great deal of attention.

The Permo-Carboniferous in the Collie Basin, and the Irwin River area are deposited directly on the Pre-Cambrian gneisses and schists. The whole sequence is very like that in India. The gneisses, constituted of a variety of rock types, are intruded by pegmatite veins and occasionally carry beds of marble. The rocks have been assigned to several formations, and a detailed study is yet to be made.

From what little is known, it is clear that the khondalites of India have a very close parallel in the Yilgarn and Jimperding Series here, and they, too, are associated with charnockites. Prider (1945; p.147 et.seq.) has made a detailed study of them and is of the opinion that "This series of metasediments finds its equivalents in the Khondalites of India" - (ibid. page 147). He compares the charnockites from the two countries and considers them to be identical. Carrying the similarities further, he mentions that "where the Indian ultrabasic charnockites are intrusive into khondalites there may be a development of spinel-sapphirine rocks and sillimanite-cordierite - biotite - hypersthene rocks. The unusual contaminated types are represented in the Western Australian province by cordierite - anthophillite rocks of Toodyay, and garnet - biotite - cordierite - hypersthene rocks of Dangia". - (ibid, page 166). And when he finds that he is not able to duplicate any of the types known from India, he makes the very pertinent remark "but it is to be noted that practically none of the country in which these charnockites occur has been geologically surveyed".

The occurrence in these widely separated areas of two rather uncommon rock types, in identical close relationship is, to say the least, most surprising. If both the charnockites and the khondalites are results of metamorphism, they must have required very similar initial sediments in the original geo-synclines followed by similar stages in the high grade meta-morphism. If the charnockite is regarded as intrusive the above argument is by no means weakened. But what is perhaps, most amazing is the presence of these rock types in identical intimate mutual relationship in Madagascar and parts of central Africa, and this makes one to wonder if it is not more than a mere coincidence.

The above, however, does not hold for the N.W. Basin and the Kimberley Division. In the latter area the Permo-Carboniferous are underlain by Middle and Upper Devonian beds which in turn unconformably overlie the Pre-Cambrian schists. The lower parts are generally calcareous, though the basal limestone is only locally developed, and is unfossiliferous. This is overlain by a fossiliferous bed of limestone containing Amphipora ramosa, and the corals Thamnopora and Prismatophyllum, etc. Horizons of coral reefs have been recognised and Wade has called one of them "The Great Devonian Barrier Reef". The total number of species now known is 380, brachipods contributing about half of these. They include Schizophoria, Productella, Atrypa, etc. Productella productoides has, of these, a wide lateral distribution.

In the Margaret River area the Middle Devonian limestones are overlain by a goniatite facies which has been subdivided into four stages, closely corresponding to the subdivisions of the Ammonoid facies of the Upper Devonian in Germany.

The Devonian beds here form a belt 220 miles long running south-east almost from King Sound. The strata are over 2,000 ft. thick.

Further east the Devonian formation is seen again in the Burt Range area but the sequence is slightly different here. Moreover it is, here, underlain by a 100 ft. thick bed of basalt which rests unconformably over older rocks. Casts of Lepidodendron are reported from associated sandstones in these beds.

About 2,600 feet of Carboniferous rocks with Syringothyris and Rhipidomella have recently been reported from the N.W. Basin. Teichert (1952 :119) has given the following section for the carboniferous formation in the N.W. Basin:

Red Hill Sandstone	..	200 ft.
Yindagindi Limestone	..	300 ft.
Williamsbury Sandstone	..	1,200 ft.
Moogooree Limestone	..	900 ft.

He assigns a Tournaisian age to the Moogooree Limestone. The occurrence of Lithostrotion and Syringothyris in the core of a bore hole in the Price's Creek suggests their presence in the

Kimberley Division as well. Guppy et al (1952), however, do not mention these.

THE TASMAN GEOSYNCLINE : Surprising though it may appear on the first look, the pre-Permo-Carboniferous formations of east Australia are as different from those of West Australia discussed above, as the extra-Peninsular are from the Peninsular in India. Further the differeances appear to run in the same channels. Thus, the Kashmir-Spiti formations have their nearest parallel in some of the islands of the East Indies, and have more in common with this area than with the formations in Peninsular India, or in Western Australia which are much closer to it in distance.

The succession here, unfortunately varies from one part to the other and it is not possible to pick any area as typical. A detailed description will, on the other hand, be out of place. It would, therefore, suffice to bring out some salient points in the geology of this region at the commencement of the Permo-Carboniferous period.

A very important feature, and one to which there will be occasion to refer again, is the perfect conformity of the strata in the eastern part of the region. The boundary between the Permian and the Carboniferous here has been only arbitrarily fixed where the first marine fauna with Eurydesma hobartense appears. Apparently there was no break in sedimentation at least since the Middle Devonian time. In the western part of the belt, however, the Permian formations transgress on to older rocks and are, consequently, unconformable. The Carboniferous System is represented by both marine and fresh water sediments, in which two distinct types of flora, Lepidodendron and Rhacopteris occur. Walkom (1944) points out that the affinities of both these floras are with the Lower Carboniferous and hence considers that the U.Carboniferous are not represented. But, not all geologists are agreed on this point. The fact that the Permian beds are conformable over these does indicate that there was no break in sedimentation. Brachiopods are the commonest element in the fauna. Volcanic activity was, apparently, wide-spread, particularly in N.S.Wales, and andesites and rhyolites predominate over the more basic types.

Another peculiar feature of the Carboniferous deposits of eastern Australia is the onset of glacial conditions in the latter part of the Lower Carboniferous times. Thus, igneous activity went on concurrently with the glaciation, a condition obtained to-day in Greenland. The Carboniferous Period is supposed to end with the deposition of the tillites of the Lochinvar Shales in N.S.Wales. Table I, adapted from David and Browne (1950; 330) sums up the position satisfactorily.

It might also be pointed out that the Lower Carboniferous of the east Australian fauna and flora are cosmopolitan and show close affinities to the Tethyan and Chinese fauna and flora.

This difference between the Tasman geosyncline and the Western Shield area was noticeable even in the Devonian period. David remarks (ibid; p.260) that "The Middle and Upper Devonian faunas of Kimberley bear no marked resemblance to any of those of eastern Australia .... It is noteworthy that in contrast to those of eastern Australia the Upper Devonian beds contain about 66% of the total known Devonian fauna. In view of their presence in the east, the absence of Calceola and Stringocephalus is rather unexpected". Stringocephalus has recently been reported from the Devonian formation of Kimberley.

The above is a brief review of the Pre-Gondwana geological formations in India and Australia. Though there is not enough of palaeontological evidence to correlate eastern Australia with any precision with extra-Peninsular India, there does appear to be a certain affinity between these two regions. In character the two basins might have been almost identical. David (ibid; 309) acknowledged it when he envisaged the extension of the Tethys to this region. Curiously enough there was volcanic activity in Kashmir beginning in Middle Carboniferous while similar outpourings were going on in east Australia. On the other hand, Western Australia seems to have somewhat closer affinities with

Peninsular India. The Devonian and the Carboniferous beds there have, however, no counterpart in India. But if Misra's identification of the fossils in the Rohtas Limestone is accepted, there would be reason to suspect that the Upper Vindhyan formations might well have ranged into the Devonian and Carboniferous periods. On the other hand, formations of these ages might have been removed from the more stable parts of Peninsular India.

CHAPTER IV

PERMO - CARBONIFEROUS PERIOD

Late in the Palaeozoic Era the unique group of rocks, often referred to as the Gondwana System, was deposited. The most remarkable feature of this, obviously, was that it was ushered in by a glacial epoch which has left its mark in the form of tillites, faceted and striated boulders, varves and striated platforms. These tillites lie usually with a profound unconformity on the older rocks. As the ice cap receded and took the deposition of tillites further and further towards its centre, the released areas were naturally covered by vast fresh water lakes and marshes, or were transgressed by sea. Sedimentation continued, more or less uninterrupted in most areas throughout the Permian and the greater part of the Mesozoic, and almost everywhere the facies is mixed. The term "Gondwana System" was originally applied to the fresh water sediments, but has since been extended to include all the Permian - Jurassic formations of Gondwanaland. In fact the presence of the characteristic flora is also not being insisted upon. In India the L. Cretaceous beds of Cutch are included. A detailed correlation is given in Table II.

As has been mentioned in the last chapter, India and Australia can each be divided into two geological provinces, and these will here be treated separately:

T A B L E I

TENTATIVE CLASSIFICATION AND CORRELATION OF THE CARBONIFEROUS ROCKS OF THE COMMONWEALTH OF AUSTRALIA

(Adapted from David & Browne)

		NEW SOUTH WALES		QUEENSLAND		VICTORIA, ETC.	WESTERN AUSTRALIA
		MARINE	TERRESTRIAL	MARINE	TERRESTRIAL		
UPPER	Namurian (Muscovian & Stephanian)	(a) Emu Creek Series of Drake (= Neerkol Series (b) Kullatine Series of North Coast, with Tait's Ck. glacial beds at the top.	Upper Kuttung Series with Lochinvar Shales at top; Rhacopteris flora predominant	Neerkol Series with Pustula, Choristites aff. mosquensis etc., in lower parts.	(a) Silver Valley Series with Rhacopteris Flora. (b) Freshwater beds in Mackay - Proserpine area.		(a) Grant Range and Kungangie beds of West Kimberley. (b) Lyons Series (in part) of North-West Basin. (c) Irwin R. glacial beds.
LOWER	Visean	Upper Burindi Series with coral-lime-stones near the top = D_2 of Avonian. Lepidodendron veltheimianum present.	Lower Kuttung Series with Lepidodendron flora pre-dominant.	Rockhampton Series (upper part) with Riverleigh and Lion Creek Lime-stone at top = D_2 of Avonian.	(a) Upper Drummond Series with L. veltheimianum and Aneimites austrina. (b) Pascoe River beds with Cordaites, etc.	(a) Mansfield fish-beds with L. veltheimianum (b) Mudstones, con-glomerates, etc. overlain by rhyolites and dacites at head of Barkly and other rivers. (c) Upper beds in Macallister - Mitchell River (d) Upper part of Grampian Series.	(a) Marine beds in Burt Range East Kimberley. (b) Lithostrotion lime-stone of Price's Creek bore, West Kimberley. (c) ? Plant-beds of Yarrada Hill, West Kimberley. (d) Moogooree Limiestone etc. of N.W. Basin.
-Avonian -Dinantion	Tournaisian	Lower Burindi Series with Protocanites lyoni in lower part L. veltheimianum present.		(a) Rockhampton Series (lower part) with Protocanites near the base. (b) Upper Star Series with Phillipsia, L. veltheimianum and L. australe (?).			

C A R B O N I F E R O U S

(A) PENINSULAR INDIA

Though they occur in isolated patches, most of the exposures of the Gondwana System lie in four river valleys, leaving only a few unimportant basins outside. These four river valleys are :-

(1) the classical Damodar Valley, including the Son Valley

(2) the Mahanadi Valley

(3) the Narbada Valley, which may be extended to include the higher Gondwanas of Kutch.

Table III is adapted from Fox (1930-a,Plate 9) and Krishnan (1949; pp.246-7) and gives the standard subdivisions of the Gondwana, as well as the correlation of the formations in different parts of the country:

TALCHIR SERIES

From the foregoing table it would be seen that the basal glacial beds in all the areas are known as Talchir. They vary in thickness from place to place, as is to be expected of a deposit made by a receding ice-cap on an uneven surface, and the maximum is over 900 ft. in Raniganj. Only the lower beds carry the boulders, while the upper are usually variegated shales and varves. The boulders consist mostly of granite gneisses which are often similar to the older rocks around, though no detailed investigation has, perhaps, been carried out to establish this. But, in addition, there are other types, chief of these being quartzites. In the Son Valley (Singrauli) area, the author noted that the striations were carried almost exclusively by a maroon red quartzite boulders, which were never more than 8-10 inches in diameter, whereas the gneiss boulders were often as much as four feet or more across. Boulders over fifteen feet in diameter have been recorded from other areas. It is not known with certainty where these quartzite boulders came from. Some are said to be similar to some Vindhyan quartzites, but none has so far been proved to be of that origin. The boulder bed itself is never more than 100 ft. in thickness. Working in the Talcher Coalfield Mr. K.K. Dutta (personal communication) noticed khondalite boulders in the tillite, while the known exposures of khondalite are only to the south of the area. In Singrauli the author noted gabbro boulders over four feet in diameter. No gabbro is known from the area to the north.

Overlying these are thinly bedded, fine grained, variegated shales which break up into long, narrow pieces, and are, consequently, referred to as "needle shales". In modern terminology these should perhaps, be classed as typical fine graywackes. Specimens from Singrauli showed that a good proportion of the quartz in the shales was not rounded and there was considerable amount of garnet present. None of the gneisses in the neighbourhood are, however, rich in garnet. Some sandstones

TABLE II

	P. INDIA	KASHMIR	SALT RANGE	N.S. WAIES	Q'LAND	IRWIN BASIN	N.W. BASIN	KIMBERLEY DIV.	TASMANIA	S. AFRICA	S. AMERICA
CRETACEOUS	Umia Stage	Cretaceous Limestone	Belemnite Beds	-	Stanwell Beds	-	-	-	-	Uitenhage Series	-
JURASSIC	Jabalpur Series Rajmahal Series	- Megalodon Limestone	- Variegated Series	Clarence Series	Walloon Series Marburg & Bundamba Series	JURASSICS OF WESTERN AUSTRALIA			-	- Drakensburg Volcanics	- Serra Geral Eruptives
TRIASSIC	Mahadeva Series Panchet Series	Trias Beds	Dolomite Stage Bivalve Beds Ceratite Beds	Wianamatta Stage Hawkesbury Series Narrabeen Series	Ipswich & Esk Series	-	-	-	Felspathic Sandstone Ross Sandstone	Cave Sandstone Red Beds Molteno Beds (Stormberg Series) M.& U. Beaufort Series	Sao Bento Beds Rio De Rasto Beds Upper Estrada Nove
PERMIAN	Raniganj Coal Measures		Upper Productus Limestone	U. Coal Measures	U. Bowen Coal Measures	-	Mungaden Sandstone Coolkilya Sandstone Nalbia Ss.		Cygnet Coal Measures Ferntree Mudstone		-
			M.Products Limestone			Wagina Sandstone	Wandagee Formation Quinannee Shales	Liveringa Gr.	Woodbridge Glacial Formation	L.Beaufort Series	
	Barren Measures	Zewan Bed	L.Productus Limestone	U. Marine Series	- M. Bowen Series	Carynginia Shales	Cundlego Sandstone Bulgaloo Shales	Noonkanbah Formation	Grange Mudstone	-	-
	Barakar Coal Meas.	Gangamopteria Bed	Speckled Sandstone	Greata Coal Measures		Irwin River Coal Meas. High Cliff Sandstone	Wooramel Sandstone	Poole Sandstone	- Porter's Hill Ms.	-	- Lower Estrada Nova
	Umaria-Karharbari	Agglomeratic Slate	Conularia Bed	L.Marine Series	L. Bowen Series	Fossil Cliff Formation		Nura Nura Member	Granton Limestone	Ecca Series	
CARBONIFEROUS	Talchir Shales Talchir Series	Agglomeratic Slates	Glacial Bulder Bed	Lochinvar Stage	L. Bowen Series	Holmwood Shales Nangetty Formation	Lyons Gr.	Grant Formation	Boulder Bed L. Shales	U. Shales Dwyka Conglomerate	Iratzy Shales Rio Bonite Beds

are present near the top and in places there are small pockets and lenses of limestone. Fermor has reported thinly bedded limestone from the former Korea State. No fossils are reported from these.

Plant fossils have been reported from a number of areas, the most important of these being Rikba in Karanpura Coalfield, which have been described in Palaeontologia Indica, Series XII, Vol. IV, page 2 (1886). They include:

Pteridospermae	*Glossopteris indica*, *G.communis*, *Gangamopteris cyclopteroides*, *G.angustifolia*, *G.buriadica*.
Cordaitales	*Noeggerathiopsis hislopi* etc.

DAMUDA SERIES.

The Damuda Series overlies the Talchir Series with a distinct unconformity in many places, though they are apparently conformable in Raniganj. In addition, there is a change in lithology, from the coloured shales to white, felspathic sandstone and shales, carbonaceous shales, coal seams, clay bands, etc. The Damuda Series is divided into four stages :

(4) Raniganj Coal Measures
(3) Barren Measures (Iron Stone Shales)
(2) Barakar Coal Measures
(1) Karharbari Stage.

The Karharbari Stage consists of pebbly grits and sandstones, with a maximum thickness of about 400 ft. and carrying a few coal seams, two of which are being worked.

The Barakar beds are the most important coal measures of the country, and carry in the Jharia coalfield, no less than 24 seams over three feet in thickness, and at least 21 of these are over five feet. The thickest, the Kargali seam, in the Bokaro coalfield, is well over 100 ft. thick. The Barakar Stage has been recognised in practically every major coalfield and its maximum estimated thickness is over 2,000 ft.

The plant fossils contained in it include :-

Equisetales :	Schizoneura gondwanensis, S.wardi, Phyllotheca griesbachi.
Pteridospermae :	Glossopteris indica, G.communis, G.ampla, G.retifera, Gangamopteris cyclopteroides Sphenopteris polymorpha.
Cycadophyta :	Taeniopteris danocoides, T.feddeni.,
Cordaitales :	Noeggerathiopsis hislopi, N.whittiana Dadoxylon indica.

The Barakar Stage passes into the Barren Measures without any visible break. In places the Barren Measures are so highly ferruginous that they have been described as 'Iron-Stone Shales' and worked, not only on a cottage industry scale, but also for a modern blast furnace. Their thickness varies from about 1,400 ft. to 2,000 ft. and as the name indicates, they are completely devoid of any workable coal seam . Outside the

TABLE III

CORRELATION OF THE GONDWANA STRATA

Adapted from C.S. Fox.

	STANDARD SCALE			GONDWANA DIVISIONS	DAMODAR VALLEY	RAJMAHAL	SON-MAHANADI VALLEYS	SATPURA	GODAVARI VALLEY	GODAVARI
UPPER GONDWANAS	Cretaceous	Lower		Umia						
	Jurassic	Upper		Jabalpur			Bansa Beds	Jabalpur	Chikiala	Tirupati
		Middle		Kota						
		Lower		Rajmahal	Rajmahal	Rajmahal with traps	Athgarh sst	Chaugan	Kota	Raghavapuram
										Golapilli
	Triassic	Rhaetic		Maleri		Dubrajpur	Tiki	Bagra	Maleri	
		Keuper		Pachmarhi	Supra-Panchet Durgapur?		Chicharia Parsora	Denwa Pachmarhi (Mahadeva)		
		Muschel-kalk								
		[illegible]								
LOWER GONDWANAS		Bunter		Panchet	Panchet			Almod	Mangli	Chintalpudi Sandstones
			Damuda Series	Raniganj	Raniganj		Himgir Pali	Bijori	Kamthi	
			Damuda Series	Barren Measures	Barren Measures (Ironstone sh.)			Motur		
	Permo-Carboniferous		Damuda Series	Barakar Karharbari	Barakar Karharbari	Barakar	Barakar	Barakar	Barakar	
				Rikba Beds Talchir	Talchir	Talchir	Talchir	Talchir	Talchir	
				Boulder-Bed	Boulder-Bed		Boulder-Bed	Boulder-Bed	Boulder-Bed	

limits of the Damodar Valley, the Barren Measures are not recognisable as such, since the overlying Raniganj Stage also does not carry any coal. In the Satpura region beds equivalent in age are known as Motur Stage.

The Raniganj Coal Measures are typically developed in the Raniganj coalfield where they have a thickness of over 3,000 ft. They are composed of sandstone, shales, and coal-seams. The sandstones are distinctly finer grained, harder, and perhaps carry a smaller proportion of felspars than those of the Barakar Stage. Workable seams occur in the Raniganj field alone.

The fossil flora they carry is rich and varied, and includes:-

Equisetales :	*Schizoneura gondwanensis*, *Phyllotheca indica*.
Sphenophyllales :	*Sphenophyllum speciosum*.
Pteridospermae :	*Glossopteria indica*, *G.communis*, *G.browniana*, *G.retifera*, *G.angustifolia*, *G.stricta*, *G.tortuosa*, *G.formosa*, *G.divergens*, *G.conspicua*, *Gangamopteris whittania*, *Sphenopteris hughesi*, *S.polymorpha* etc.
Cordaitales :	*Noeggerathiopsis hislopi*.
Coniferales :	*Buriadia sewardi*.

Also Incertae, Ginkgoales, Filicales, etc.

Extremely interesting, however, is the so-called Umaria Marine bed, comprising four two-inch thick limestone bands, contained in ten feet of shales, and carrying marine fossils, which is exposed in a railway cutting in Umaria over a length of only a few feet. It is said to be distinctly unconformable over the Talchir beds but is conformably overlain by typical Barakar Coal Measures. Its fauna was considered by Cowper Reed to be quite distinct, but recent work in Australia indicates that it may have fairly close affinities with that of Western Australia. Reed gave it a Permo-Carboniferous age. It includes several Brachiopods, Gastropods, some crinoid stems and fish teeth.

The occurrence of this isolated marine bed in the heart of the country has puzzled the Indian geologists ever since its discovery in 1921. Fox (1931; pp.234-5, also Plate X) on Fermor's suggestion, envisaged an arm of the sea running to the north, right across the Vindhyan Ranges which he, elsewhere, mentioned were high mountains at the time. Krishnan, (1949; pp.284-5) consequently, thinks that a connection to the west is more probable. The fossils are said to have some affinities to the east, (Assam and Burma) rather than to those of Salt Range, (Coggin Brown; 1912; 238-240, Tschernyschew: 1904; 186-187, Diener: 1905; 189). The question will be taken up in detail in a later chapter when the palaeogeographic map of India is discussed.

(B) EXTRA-PENINSULAR INDIA

The record of extra-Peninsular India reveals an altogether different geological history from that given in the section above. The deposits are mostly of marine origin which, perhaps, carry one of the best known records of the evolution of life. In fact, part of it is considered to be the best record of the Middle Permian fauna in the world, and is often referred to as the "Punjabian Age". The Salt Range, the Spiti-Kashmir and the Simla-Garhwal areas are again the preservers of this record.

SALT RANGE :

This area has received a great deal of attention from both Indian and foreign geologists, not only because of the intrinsic interest in its fossils and the age of the Saline Series underneath, but also because the Productus Limestone was the first fossiliferous bed to be discovered in India. The succession is as follows :-

Productus Limestone 700'	Upper 200 ft.	Chideru Stage :	Marl and Sandstones	
		Jabi " :	Sandstones and marls with Cephalopods.	-Kungurian
		Kundghat " :	Sandstones with <u>Bellerophons</u>.	
	Middle 200-400 ft.	Kalabagh " :	Crinoidal limestones, with marl and dolomites.	
		Virgal " :	Cherty limestone.	-Punjabian
	Lower 200 ft.	Katta " :	Brown, sandy limestone and calcareous sandstones.	
		Amb " :	Limestones with <u>Fusulina</u> and calcareous sandstone.	Artinskian.

Speckled sandstone 300'-500'	(Speckled Sandstone Stage: (300'	Clays, gray and blue. Mottled sandstone, with *Gangamopteris* etc.
	(*Conularia* Beds : (200' (Boulder Beds (10'-200' : Glaciated (boulders in fine matrix.	Olive shales and sandstones with *Conularia* and *Eurydesma* - Sakmarian to Uralian

As has been mentioned in the last chapter, the lowest bed of the formation is a glacial tillite which rests unconformably over the Salt Pseudomorph Bed, supposed to be of Cambrian Age.

The tillite carries boulders which are said to have their source in the Aravallis and the Kirana hills, and a striated pavement* in west Rajputana indicates that ice did move in that direction. These tillites are overlain by Olive Shales, Speckled Sandstones, Lavender Shales etc. These may be greywackes and sub-greywackes, though no detailed work has been attempted. They carry a rich, varied, fauna, in which *Conularia* is the most abundant genus. The fossils include :-

Gastropoda : *Conularia laevigata*, *C. warthi*, *C. punjabica*, *C. salaria*, *Pleurotomaria nuda*, *Bucania warthi*.

Lamellibranchia : *Pseudomonotis subradialis*, *Eurydesma cordatum*, *E. hobartense*, *E. subovatum*, *Sanguinolites tenisoni*.

* This may, however, be older.

Brachiopoda : *Spirifer vespertilio*, *Martiniopsis darwini*, *Chonetes cracowensis* *C.prath*.

Near Kathwai *Glossopteris* and *Gangamopteris* occur a few feet above the marine horizon carrying *Conularia*. This *Conularia* fauna, along with *Eurydesma hobertense*, and *E.cordatum* is also recorded from the Lower Marine Series in New South Wales, where again it is associated with *Gangamopteris*, and a correlation is reasonably well established.

Overlying the Speckled Sandstones is the classical Productus Limestone Series which has been subdivided into several stages, as in the table given above. It is very rich in fossils, particularly in brachiopods. Space would not permit a complete list of the fossils, but the following is representative:

Brachiopoda : *Productus indicus*, *P.spiralis*, *P.transversalis*, *P.lineatus*, *P.cora* *Spirifer marconi*, *S.kinsari*, *S.niger*, *S.wynnei*, *S.warchaensis*, *Orthis indica*, *Athyris sub-expansa*, *A.ryossii*, *A.capillata*, *Marginifera typica*, *Dielasma trimuense*, *D.elongatum*, *D.truncatum*.

Lamellibranchia : *Aviculopecten regularis*, *A.morahensis*, *Schizodus emerginatus*, *S.dubiformis*, *Solemya biarmica*.

Gastropoda	:	*Pleurotomaria durga*, *P.punjabica*, *Bellerophon equivocalis*, *B.jonesianus*.
Cephalopoda	:	*Metacoceras goliathus*, *Waagenoceras oldhami*, *Xenodiscus plicatus*, *Xenaspis carbonaria*.

This fauna is almost identical with that of Kashmir and it has been suggested that the two areas represent the two shores of the geosyncline. It is, however, more probable that the eugeosyncline lay further to the north and both Kashmir and the Salt Range lay on the same shore. Differences in ecology would explain the slight differences in fauna.

KASHMIR :

The Permo-Carboniferous succession in Kashmir is summarised below :-

Zewan Bed 500'	Fossiliferous shales and limestones with *Protoretepora ampla* at the base.
Gangamopteris Bed 200'	Cherts, siliceous shales, carbonaceous shales and flaggy quartzites.
Agglomeratic Slates ?	Typical greywackes and beds of trap and thin limestone bands.

The volcanic activity which started in Middle Carboniferous Period is believed to have continued throughout the

Permian Period. The basalt is amygdaloidal, olivine free and does not contain any well formed augite crystals. The flows form distinct lenses, and there are beds of inter-trappean fossiliferous limestone. The lavas are occasionally inter-bedded with the slates, but generally they occupy separate areas, as the traps are not very extensive and vary in thickness from place to place. It is, however, by no means certain that these, so called, "traps" are not intrusive and belong to a much later period of igneous activity.

The slate is a typical graywacke, and "the embedded fragments are quite angular and often become very large in size at random. They are pieces of quartzites, slate, porphyry, granite etc., irregularly dispersed in a fine grained martrix. The rock is generally unfossiliferous throughout .... That such a rock could not have been the product of any simple process of sedimentation, whether subaerial or submarine, is quite clear, and the origin of the deposit so widespread and of such uniform character is a problem" (Wadia - 1949; 411). As has been mentioned earlier, the succession in this area is conformable and sedimentation was more or less continuous from at least the Ordovician Period, till, perhaps, after the Jurassic, and well over 15,000 ft. of strata were deposited. The Agglomeratic Slates, therefore, are not likely to be a simple sedimentary breccia similar to what are known to have accumulated in front of a moving geanticline in the Alpine region. Even though striated boulders have not been found in this, the author considers that there cannot be any doubt that this is a tillite. Conformably overlying the Agglomeratic Slates and similarly underlying the Zewan Beds is a series of shales and quartzites which has yielded a typically Gondwana flora.

The Zewan Beds are an important stratigraphic horizon as they have yielded fossils which permit easy correlation with other parts of the world. The fauna, as has been mentioned, is very closely allied to that of the Salt Range, and includes :-

Brachiopoda	:	*Productus cora*, *P.indicus*, *P.spiralis*, *P.abichi*, *Spirifer rajah*, (abundant), *S.fasciger*, *Marginifera himalayensis* (abundant), *M.vihiana*, *Chonetes lissarensis*, *C.laevis*, etc.
Bryozoa	:	*Protoretepora ampla*, *Fenestella* aff. *fossula*.

SPITI :

The Permo-Carboniferous Kuling System of Spiti unconformably overlies the Po Series or earlier rocks. The lowest beds are grits and quartzites overlain by calcareous sandstones and these, in turn are overlain by the brown or black, carbonaceous and siliceous shales known as Productus Shales. These Productus Shales have been identified in Kashmir, Kumaon and Nepal, and in spite of their vicinity to the Salt Range, the fauna they exhibit is considered to be of different facies. Amongst the species present are :-

Brachiopoda	:	Productus purdoni, P.abichi, P.gangeticus, Spirifer rajah, S.fasciger, Marginifera himalayensis, Chonetes lissarensis.
Cephalopoda	:	Xenaspis carbonaria, Cyclolobus oldhami C.kraffti, C.haydeni.

SIMLA-GARHWAL :

The Permo-Carboniferous of this area begins with the Blaini Tillites lying unconformably over older rocks. The Blainis, unlike their counterpart in Peninsular India, contain some limestones and slates. They are overlain by a 2,000 ft. thick formation known as the Krol Series, which varies in lithology from place to place. The following table gives some idea of this change:-

		SIMLA AREA	GARHWAL
Upper Krol	:	Limestone	Massive limestone
Middle "	:	Red Shales	Purple Shales
Lower "	:	Limestones	Slates

The whole area has been involved in complicated thrusting and faulting.

OTHER AREAS.

Permo-Carboniferous rocks are reported from Hazara, where a bed of conglomerates is overlain by a series of purple and speckled sandstones, shales and dolomitic limestones with a total thickness of over 2,000 ft.

Rocks of the same age also occur in Darjeeling, Bhutan, Assam, etc., but their geology is only meagerly known. Tillites and coal seams have been recorded from eastern Nepal and Darjeeling and coal seams and marine beds from further east. In Mt. Everest area the Carboniferous Mt. Everest Limestone is overlain by about 2,000 ft. of Lachi Series which, in its calcareous sandstone, carries an Upper Permian fauna. It is overlain by the Tso Lhamo Series of Triassic Age.

(C) WESTERN SHIELD (AUSTRALIA)

The areas where Upper Palaeozoic rocks occur in Western Australia have been mentioned in the last chapter. Though the more accessible areas on the west have received considerable attention during the last few years, not much is known about the interior. The following review, however, gives a satisfactory idea of the geology of this region.

COLLIE, MUJA AND WILGA BASINS

The Collie Basin in the south is only about a hundred square miles in area. The strata consist of micaceous shales, and current bedded sandstone. It is divided into (Fairbridge: 1952):-

Cardiff Formation	..	300 ft.
Collieburn Formation	..	1,220 ft.
Collie Formation with tillite (70 ft.)	..	1,400 ft.
		2,920 ft.

The Permians strata here are covered by Tertiary deposits, though further west Jurassic beds are known to occur. The succession is known only from bore records. The entire formation is of fresh water origin and recent work indicates isolated basins with rounded basin contours, in each of the three areas. Fairbridge (ibid:144) points out that "analysis of plant spores .... shows a clear correlation between the two upper formations, Collieburn and Cardiff, with the Upper Permian (Tomago and New Castle) Coal Measures of N.S.Wales ..... with the Lower Permian Greta Coal measures of N.S.W..... there is no close tie up with the Collie" (lowest) Formation. He further mentions that, "at least the Collieburn and Cardiff stages are younger than and not equivalent to the Irwin River Coal Measures as has often been assumed in the past".

This would, perhaps, suggest a correlation of the tillite below the Collie Formation with the erraties in Caryngina Shales of the Irwin Basin.

IRWIN AND N.W. BASIN

The sediments in these two areas have much in common though they have been described under different names. Thus the Callytharra Limestone in the N.W. Basin has a fauna very similar to that of the Fossil Cliff Formation of the Irwin Basin, stated to be of the lowest Artinskian age. Eustatic oscillations seem to have affected both the areas simultaneously and facilitate correlation even though the N.W. Basin had marine deposition throughout. The sections for the N.W. Basin given in Table IV below are after Teichert (1952: 120) and from a personal communication from Mr. M.A. Condon, Bureau of Mineral Resources, to whom the author is grateful, while that for Irwin River is after Fairbridge (1952: 140). The correlation is derived from their descriptions.

......Table IV

TABLE IV

N.W. BASIN		IRWIN BASIN
Condon's Section	Teichert's Section	
UNCONFORMITY		UNCONFORMITY
Kennedy Group - 1,650'	Mungaden Sandstone .. 700 Coolkilya Sandstone-1,000 Nalbia Sandstone - ?	
Wandagee Formation 600'	Wandagee Formation - 600	Wagina Sandstone - 300'
Quinannie Shale 450'	Quinannee Shales - 560	
Cundlego Formation 1,000'	Cundlego Sandstone - ?	
Bulgadoo Shale 850' Mallens Sandstone 1,000' Coyrie Formation 725'	Bulgadoo Shales - 2,650	Carynginia Shales- 800'
Wooramel Sandstone 200'	Wooramel Sandstone - 150	Irwin River Coal Measures - 160'
Callytharra Formation 760'	Callytharra Limestone - 650	High Cliff Sandstone - 110' Fossil Cliff Formation - 180' Holmwood Shales - 1,650'
Lyons Group 4,300'	Lyons Group - 2,000 to 2,500	Nangetty Formation - 800'
12,135'		4,000'

North of Gascoyne R. the Callytharra Limestone increases in thickness and limestone becomes more important. Its fauna has some affinities with Timor.

The Callytharra Limestone has yielded a fossil fauna which contains the following :-

Fenestella spinulifera, F.pectinis, F.fossula, Protoretepora ampla, Chonetes pratti, Reticularia lineata, Productus semireticulatus, P.punctatus, P.undatus, P.spiralis, P.indicus, Spirifer hardmani, S.fasciger, S.dubia, S.convolutus, Conularia warthi, Bellerophon costatus, Pleurotomaria sp. etc.

The Wooramel Sandstones are mainly current bedded micaceous sandstones in which some brochiopods, pelecypods and bryozoa occur. The transition is very sudden and a distinct shallowing of the basin is said to be indicated.

The Bulgadoo Shales appear to be a continuation of the shallow basin conditions that characterise the Wooramel Sandstone. They are composed of carbonaceous siltstone and quartz greywacke and contain a fauna that is very distinct from that of the Callytharra Limestone. It is here correlated with the Irwin River Coal Measures in the lower part and the Caryngina Shales in the upper part.

The Irwin River Coal Measures carry several seams, and one of them is reported to be 12 ft. thick, but is of inferior quality. D. Carroll (1945: 91) examined the heavy mineral assemblage in these Coal Measures, and came to the conclusion that the garnets must have been derived from a western source.

The Carynginia Shales are jarositic and carry dumps of erraties, not probably known from the equivalent horizon in the N.W. Basin. It is probable that these shales are also to be correlated with the Cundlego Sandstones and the Quinannee Shales of the N.W. Basin.

With the deposition of the Wandagee Formation began a period of general shallowing of the basin, also reflected in the Wagina Sandstone. They are composed of siltstones, quartz greywackes, calcareous sandstones with some limestones and is highly fossiliferous. The list given by Raggatt and Fletcher (1937) contains :-

Spirifer rostalinus, S.marconi, S.byroensis, S. fasciger, S.convolutus, Aulosteges ingens, A.baracoodensis, Taeniothaerus subquadratus, etc. Teichert (1952: 128) remarks that "One of the most remarkable development in the Wandagee Formation is the explosive evolution of the crinoid Calceolispongia". He has added many species to the list of fossils which now totals over 150 species and includes Strophalosia kimberleyensis, Cleothyridina royssii, Euryphyllum reidi, Verbeekiella mersa and Cardiomorpha blatchfordi, Fistulipora compacta, F. conica, Polypora multiporifera, and P. retificus.

The Wagina Sandstones appear rather abruptly, though perfectly conformably, above the jarositic shales. They consist of red and white mottled sandstones and in the higher parts have intercalations of carbonaceous shales and creamy white clay shales. There are bands of conglomerate and grit through the entire formation. There are plant fossils in these.

The fossil assemblage in the Nalbia Sandstone appears to be different from that underneath. Most prominent are a new species of Schizodus and Oriocrassatella stokesi, also present in the Desert Basin and in the Permian beds of the Northern Territory. Close to the top of the formation occur Thomnopora immensa, and Strophalosia kimberleyensis.

The Coolkilya Sandstone carries Helicoprion davisii, Paragastrioceras wandageense, and Calceolispongia robusta. Verbeekiella mersa and Propinacoceras australe persist from the Quinannee Shales.

The Mungadan Sandstone are medium to coarse grained rocks which vary between quartz sandstone and sub-greywackes, mostly highly ferruginised. It is poorly fossiliferous, but a rich bed, 150 ft. above the base, carries Chonetes and

Streptorhynchus. At 380 ft. there is a Neospirifer horizon, and close by silicified wood is found. It is separated from the Jurassic Curdamuda Sandstone by an angular unconformity.

Thus the sections though very thick, are incomplete, and Teichert considers all the beds upto the top of the Wandagee Formation as of Artinskian age, with the possible exception of the glaciogene beds at the base. He stated (1947: 28) that "Even the thickest section known in W. Australia represents only part, almost certainly not more than half, of Permian time".

DESERT BASIN

Very little of the geology of this vast area, supposed to be 140,000 square miles, is really known. Wade alone did some detailed work in the N.W. corner, and later Guppy examined a small area.

The following succession is from a recent paper by Guppy and others (1952: 108) :-

TABLE V

UNCONFORMITY

Liveringa Group	Impure sandstone, sedimentary iron ore, sandstone, siltstone — Mainly estuarine.	1,200 Approx.
Noonkanbah Formation	Sandstone, siltstone, shale and claystones — Marine and brackish water.	1,200
Poole Sandstone	Sandstone, arkosic sandstone, conglomerate — Estuarine	200-1,200
Nura Nura Member	Limestone, sandstone, bands of conglomerate — Marine	25 - 50
EROSIONAL UNCONFORMITY		
Grant Formation	Sandstone, conglomerates, arkosic sandstone, tillite, siltstone, shale and limestone — Glacial and aqueo-glacial	0-3,500

UNCONFORMITY

Devonian Limestone.

The Grant Formation includes all the glacial sediments above the Devonian Limestone. There were apparently two distinct phases of glaciation and an interglacial period. The flora in the upper glacial beds is said to have some affinities with that of Karharbari Stage in India, but fossils are not common.

The Nura Nura Member carries a rich fauna, including Metalegoceras clarkei, and Thalassoceras wadei, which, according to Miller, (Teichert: 1941; p.303) are Artinskian. The lower beds may then be Sakmarian, or older.

There is, apparently, a disconformity below the Nura Nura Member. The Poole Sandstone consists of well bedded, white weathering to light brown, fine, micaceous sandstones with plant remains. Outcrops of low elevation are commonly highly ferruginised. Cross-bedding, ripple-marks and worm tracks are characteristic.

The thickness of the formation increases in a north-westerly direction from approximately 200 ft. in the Poole Range, to approximately 600 ft. in western St.George Range and to atleast 1,200 ft. in the Nerrima Bore and Grant Range. The flora which includes :

Glossopteris cf. browniana, G. cf. indica, Noeggerathiopsis hislopi, Samaropsis milleri, etc. is considered to be Middle to Lower Permian, (Teichert; 1941).

Nooncanbah Formation carries a rich fauna. Appriximately 170 species have been recognised which include: Spirifer rostalinus, Taeniothaerus sub-quadratus "Chonetes pratti", Strophalosia kimberleyensis etc. with many bryozoa and corals. Some of the beds are gypseous and saliferous, indicating that the basin was, on occasions, barred.

The Liveringa Group is highly ferruginised. The lower parts are marine and contain alternating calcareous, sandy sediments, gray-green arkosic sandstone and intercalated limonite. Overlying these are estuarine beds with plant remains and finally about 600 ft. of shales.

It is very remarkable that no Gangamopteris has so far been found in this basin, and though a very large area remains to be surveyed, this agrees with eastern Australia, where none occurs north of Lat. 22° S. Teichert (1943) thinks that this was, perhaps, because the plant was better adapted to colder climate than Glossopteris. It would, however, be difficult to explain the Indian and African occurrences of the genus on this supposition. In the latter country it is found from very near the equator. The matter will be discussed in a later chapter.

A distinct rhythm in sedimentation is again very noticeable and very tempting to use in correlation.

The Permian formation is known from an area within two parallel fault, the Pinnacle and the Mt. Fenton Faults. They tend approximately N. 37° W. and to the N.E. of the former older formations are known. The area to the S.W. of Mt.Fenton Fault is dune covered, but the available information is said to indicate the presence of Mesozoic beds in this region. The area between these faults may, therefore, be either a trough in which the thickest section of the Palaeozoic sediments had been deposited, or a step with a thicker section of Palaeozoic sediments south-west of the Mt. Fenton Fault, [illegible] (Guppy et al: 1952).

On the other hand, faulting might have occurred late in the Mesozoic Era, and erosion might, since, have removed the younger beds from the area between the faults, and completely stripped that to the N.E. of Pinnacle Fault. In Chapter VI it will be shown that this has extensively taken place in India.

This area too, like the N.W. Basin, had been subjected to erosion before the succeeding formation came to be deposited, and so originally the sediments might have been thicker.

BONAPARTE GULF BASIN

There are several small isolated basins in this area, each showing a distinct fauna. Exact correlation has, therefore, not been possible. Port Keats Group is the best known section.

It is composed of 1,500 to 2,000 ft. of sediments and exhibits a fresh-water facies in the lower part, correlated with the Poole Sandstone, mentioned above, and a marine facies which may be the equivalent of parts of Noonkanbah Formation and Liveringa Group.

It is, consequently, considered to be entirely Artinskian.

The sediments rest on pre-Cambrian granites and sediments and it is remarkable that no glaciogene beds have, so far, been found.

(D) TASMAN GEOSYNCLINE

The Permian was a period of constant disturbances in the Tasman Geosyncline. Apparently several small basins of deposition existed at the same time. These were more or less separated from one another, and were fed by separate sources. It is, therefore, not surprising that successions differ from part to part. Nevertheless it is remarkable to note several points of similarity between this region as a whole and, for instance, Kashmir, with which it was only indirectly connected, or South Africa and even S. America.

For the same reason no section is altogether representative of the whole area. The Hunter River Basin of New South Wales, however, remains the classical and by far the most important area. David, Sussmilch, and others, have published a large number of papers on this area, and its geology is fairly well known. Another important area is the Bowen Basin in Queensland, and a third is that of Tasmania. These will be taken up separately.

NEW SOUTH WALES :

In the preceding chapter it was pointed out that the sedimentation in this area was continuous, and the boundary is only arbitrarily fixed making the lowest beds of the Lochinvar Stage the beginning of the Permian. The succession, therefore, in this area is as follows, the younger series becoming progressively transgressive :

Upper Coal Measures		
Newcastle Stage		1,500 ft.
Tomago Stage	?	3,000 ft.
Upper Marine Series		
Mulbring or Crinoidal Stage		3,000 ft.
Muree Stage		400 ft.
Branxton Stage		3,000 ft.
Lower or Greta Coal Measures		
		300 ft.
Lower Marine Series		
Farley Stage		985 ft.
Rutherford Stage		1,170 ft.
Allandale Stage		1,000 ft.
Lochinvar Stage		2,740 ft.
		16,095 ft.

David (1950; 330), considers that the marine fossiliferous horizon with erratics and containing Eurydesma should be the base of the system, and thinks that beds above the E.hobartense Zone are Permian (Artinskian). Higher up, the stage consists of shales, shaly sandstone, tuff and lava flows. The Allandale Stage consists of tillites, andesitic tuff and tuffaceous sandstones, etc. The Rutherford Stage exhibits a lateral change in facies between West Maitland and Pokolbin. In the latter locality it is thickest and consists of shales, limestones, sandstones and lava flows; whereas at West Maitland the rocks are mainly shales, sandstones and mudstones. The Farley Stage is formed of fossiliferous sandstones, grit and tuff etc. and rare erratics. The bottom bed is known as the Ravensfield Sandstone and because of its persistency, is a valuable marker horizon in fieldwork.

The Lower Marine Series have yielded a rich fossil fauna, which includes the following :-

Bryozoa	:	Stenopora tasmaniensis, Protoretepora ampla.
Brachiopoda	:	Dielasma hastata, Taeniothaerus subquadratus, Terrakea brachythaerus.
Pelecypoda	:	Aviculopecten tenuicollis, A.sprenti, Deltopecten subquinquelineatus, D. illawarensis, Eurydesma hobartense, E.cordatum.
Gastropoda	:	Bellerophon (warthia) costatus, Conularia sp.

Gangamopteris occurs about 1,250 ft. above the base of the series at Lochinvar.

Reed (1932) compared this fauna with the Upper Carboniferous fauna of Bren Spur, Kashmir, and found ten species to be definitely common, and another sixteen to be closely allied, leaving, thus, only eighteen out of 59 species as not recorded in Australia, while the remaining are too poorly preserved for specific comparision, or their allied forms from Australia are poorly described.

The most important outcrop of the Greta Coal Measures is near the Lochinvar dome, and consists of conglomerates, shales, sandstones, and coal seams, They contain the typical Permian plant fossils. West of the dome they disappear, to re-emerge in the core of the dome near Muswellbrook. Here they rest on rhyolites, and tuffs which carry Glossopteris, Gangamopteris and Dadoxylon. The coal measures include seven coal seams, aggregating 90 feet.

The overlying Branxton Stage consists of sandstones, conglomerates, tuffs and shales. At about 200 ft. above the base erratics appear and continue till the base of the Mulbring Stage. They are considered to have been dropped by floating ice. The presence of glendonites, pseudomorphs in calcite after glauberite, which have been reported from various localities from Queensland to Tasmania, provide a useful horizon for correlation. The calcareous shales and sandstones of the

Muree Stage carry a large number of erratics and numerous fossils. The Mulbring Stage is composed of soft shales, though near the top are a hundred feet of cherty shales and tuffs. The Upper Marine Series thins out between Maitland and the coast. The fossil fauna of the Upper Marine Series includes:-

Coelenterata	:	Plerophyllum gregoriana
Bryozoa	:	Protoretepora ampla, Stenopora. tasmaniensis, Fenestella propinqua, F.fossula, Polypora sp.
Brachiopoda	:	Dielasma hastata, Strophalosia clarkei, Terrakea brachythaerus.
Pelecypoda	:	Aviculopecten tenuicollis, A.sprenti, Deltopecten subquinquelineatus, D.illawarensis.
Gastropoda	:	Bellerophon (Warthia) costatus.

Many of the species are common with Lower Marine Series, the Callytharra Limestone of Western Australia, Kashmir, and the Salt Range.

The Upper Coal Measures carry a rich flora, which includes Glossopteris of many species, Gangamopteris, Noeggerathiopsis, etc. The Tomago Stage is mainly sandstones, shales and coal, whereas the Newcastle Stage is composed of sandstones, shales, cherts and conglomerates. Much of the sandstones is tuffaceous.

It is interesting to note that the flora of the two Coal Measures is almost identical. Walkom (1944: 7) stressed the point when he stated, "I have not attempted to divide the flora according to the species present in the Lower and Upper Coal Measures. Indeed I am not quite certain that it would be possible to do so with any great degree of accuracy." Considering the rapid rise and fall of the various species of the Glossopteris - Gangamopteris flora, this appears to be rather surprising, and, in fact, suggests that the difference in age between these Coal Measures was, perhaps, not material. Teichert places both the Lower and the Upper Marine Series in the Artinskian, and the absence of any difference in their fauna supports the above conclusion.

It, therefore, seems reasonable that the begining of the Upper Coal Measures should also be placed in the Artinkian period.

It would also be seen from the above that there were at least three distinct periods of glaciation in New South Wales, i.e. the basal, recorded by the Lochinvar Shales and tillites, the second indicated by the erratics in the Allandale-Rutherford Stages, and finally, there was the one that started in the Branxton time and finished early in Mulbring time. Apparently glaciation had started in the Middle Carboniferous Epoch. Refrigeration, however, ended before the close of the Artinskian period.

QUEENSLAND :

Though the general sequence of events appears to be the same as in New South Wales, local differences in the form of the basins of deposition are reflected in differences in lithology and sediments in Queensland. No description would really be representative unless at least the formations in central and coastal districts are separately described. Space here, however, will not permit that, and as a choice had to be made, the classical Bowen Basin has been selected. The succession, according to David, is :-

Upper Bowen Coal Measures	9,600 ft.
Middle Bowen Coal Measures	
Marine Stage	2,400 ft.
Collinsville Coal Measures	700 ft.
Lower Bowen Coal Measures	
Mt.Delvin volcanic Stage	2,000 ft.
Mt.Delvin Coal Measures	400 ft.
Mt.Toussaint Volcanic Stage	3,000 ft.
	18,100 ft.

The volcanic activity at the base of the formation was certainly more intense than in New South Wales. In Cracow, for instance, the lavas alone are almost 10,000 ft. thick. In the

Bowen Coalfield the rocks are mostly andesitic agglomerates and interbedded sandstones which pass into the Mt.Delvin conglomerates, sandstones and coal seams, with *Glossopteris* flora. The igneous activity was repeated later. In the area between Lotus Creek and Dawson there are some limestones and calcareous shales which are rich in fossils including *Eurydesma cordatum*. In the Dawson-Mackenzie coalfield erratics occur in shales, tuffs and limestones below the *E.cordatum* horizon, but there are no basal tillites north of Bowen R. The fossils recorded from the series include :
Taeniothaerus subquadratus, *Linoproductus springsurensis*, *Aviculopecten mitchelli*, *A.tenuicollis*, *Dielesma hastata*, *D.cymbaeformis*, *Plerophyllum gregoriana*, *Monilopora nicholsoni*, *Fenestella fossula*, *Protoretepora ampla*, *Chonetes cracowensis*, *Strophalosia clarkei*, *Terrakea brachythaerus*.

The flora includes :-
Phyllotheca australis, *P.robusta*, *Sphenophyllum speciosum*, *Cladophlebis roylei*, *Sphenopteris polymorpha*, *S.lobifolia*, *Glossopteris browniana**, *G.indica**, *G.ampla**, *G.tortuosa**, *G.jonesi*, *Vertebraria indica**, *Gangamopteris cyclopteroides**, *G.angustifolia**, *Noeggerathiopsis hislopi**, *Samaropsis dawsoni*, *Dictyopteridium sporiferum**.
Species marked * also occur in the Barakar Coal Measures and in the Talchir Series in India, while many others are common

with New South Wales. Many of these continue in the Upper Series, but others disappear.

The lower part of the Middle Bowen Series in the Bowen Coalfield is often regarded as a separate stage, under the name of Collinsville Coal Measures. It is, essentially, a fresh water deposit, beginning with a basal conglomerate and including five coal seams. It has yielded _Glossopteris indica_, _G.ampla_, _G.jonesi_, _Noeggerathiopsis hislopi_, etc. _Gangamopteris_ has not been found north of latitude 22°S. The beds above this stage are of marine origin, consisting of sandstones and shales and carrying eratics. This record of glaciation is, apparently, the equivalent of the Upper Marine Series of New South Wales. The beds are remarkably rich in fossils, which include :

Coelenterata	:	_Plerophyllum gregoriana_.
Bryozoa	:	_Fenestella fossula_, _Stenopora_ sp., _Protoretepora ampla_.
Brachiopoda	:	_Dielesma hastata_, _D.cymbaeformis_, _Strophalosia clarkei_, _Taeniothaerus subquadratus_, _Terrakea brachythaerus_, _Spirifer convolutus_.
Peleeypoda	:	_Aviculopecten tenuicollis_, _A.sprenti_.

A bed 93 feet in thickness is almost packed with _Strophalosia clarkei_.

The Upper Bowen Series consists mostly of tuffaceous grey-green sandstones, and grey shales. There are some coal seams and some basalt flows. The flora still contains Glossoptoris. The fauna includes a great variety of brachiopods, bryozoa, lammellibranchs, and gastropods, mostly the same species as those of the Middle Bowen Series.

In the Coastal part of Queensland as well as N.S. Wales, it appears, the deposition was entirely marine in character. There is no unconformity underneath and there was no break in sedimentation since at least the Lower Carboniferous time. There seems to be no faunal break either. In central Queensland, on the other hand, there is an angular unconformity below the Lower Bowen Series which overlies the Lower Carboniferous Star Formation.

TASMANIA:

Though the author became personally familiar with the Permian System in Tasmania, the following description is based on a paper by Hills and Carey (1949), and another by Banks (1952).

Permian formation is estimated to have a thickness of over 3,270 ft. and overlies unconformably rocks of the Eldon Group (Silurian and Devonian) and older rocks. It begins, as elsewhere, with a tillite. The succession is given below :-

Triassic System		
Disconformity		
Cygnet Coal Measures		200 ft.
Ferntree Mudstone		300 ft.
Woodbridge Glacial Formation		400 ft.
Grange Mudstone	)	
Porter's Hill Mudstone	)	1,150 ft.
Granton Limestone and Marl	)	
Basal Glacial Formation		1,220 ft.
Unconformity.		3,270 ft.

The basal tillites vary in thickness and character in different areas. Near Wynyard a striated platform indicates that the movement of the ice was from the south-west. Some of the erratics are reported to have their origin in the western part of the island (Florence Quartzite), and this goes to confirm the general direction of ice movement.

The lower part of the Granton Limestone and Marl is composed of mudstones and sandstones with thin beds of limestones, calcareous shales, etc. The higher beds are largely sandstones and mudstones. Erratics are present throughout, though they are not common.

The Porter's Hill Mudstone, yellowish in colour, is also of marine origin, though imperfect fragments of Gangamopteris are preserved in it.

The Grange Mudstone is composed of mudstones, marls, and limestones while erratics are common in it. The rocks are generally yellow to brown, laminated, and rich in fossils. The fauna resembles that of Granton Limestones.

Wyndhamia dalwoodensis is characteristic and allows a correlation with the Branxton Stage of the Upper Marine Series.

About 400 ft. of sandstones and mudstones with erratics up to six feet in diameter in the Woodbridge Glacial Formation indicate a return of the glaciation. The sandstones are mainly quartzitic, and the grains are angular. Western Tasmania, again, appears to be a part of the terrain from which the sediments were derived. Rarely, there are thin bands of limestone too. Fossils are generally rare, but sometimes entire bands appear to have been formed of them.

It would be noticed from the above that glaciation hardly ever ceased till the end of the Ferntree Mudstone. The ice cap was sometimes situated very near and sometimes it receded away, perhaps, to the south west. It will be endeavoured later to show that this interpretation fits into the palaegeographic picture presented in this paper.

CORRELATION

The correlation of the Gondwana Systems may thus be split up into three separate problems:-

(1) Correlation within the Gondwana formations.

(2) Correlation of the Gondwana succession with the European time scale, the Artinskian-Sakmarian ages.

(3) Decision where the Permo-Carboniferous boundary should fall within the latter.

For the purpose of the present paper it does not appear to be necessary to go into any detailed discussion of nos.2 and 3 above, which really are palaeontological problems. It might, nevertheless, be mentioned that the author is inclined to regard the Sakmarian as the uppermost part of the Carboniferous. This was the view held by Fox (1930; A) in India and by David and Browne (1950) in Australia.

The usual method of correlation is to select a fossil with a short vertical, but wide horizontal distribution. The difficulty, however, is that there are often not enough dependable species available, and they vary in favour. Thus, only a few years ago the world of palaeontologists and the stratigraphers was divided over the Paralegoceras-Metalegoceras controversy, and the age of the Gondwana formations in Australia was supposed to hang by the narrow thread of its determination. Now that there is agreement on it, it has receded in importance. Teichert has in the meantime stressed the importance of Helicoprion for the purpose of correlation, particularly with the European time scale. But it is to be remembered that correlation on the basis of a single species is never very reliable. A solid correlation has got to be established on a complete faunal or floral assemblage and proved on statistical ground - the type of work done by Cowper Reed (1932), or Raggatt and Fletcher (1937), quoted earlier.

The correlation given in Table II above is based mainly on those of Fox (1931), David (1950) and Teichert (1941). It thus represents the more orthodox view, and is widely supported. A slightly different correlation is provisionally suggested in the following pages. It is based on the rhythm in sedimentation, mentioned earlier, that has long been recognised in Australia, and seems to have affected the character of sediments in India too. Later in this paper it is suggested that the correlation of the S. African formations may have to be revised in future. It has not been used here for the simple reason that the author does not think that there is enough evidence yet.

This rhythm in sedimentation above the tillites, as Teichert has stressed, is present on either side of the continent. Thus, everywhere, with the possible exception of parts of Queensland, there are marine deposits in the lowest part followed by fresh water sediments. There is, then, a reversion to marine conditions, but the fresh water conditions return later. This might have been due to simple eustatic changes in sea level, and connected to the waxing and waning of the ice cap, which must inevitably have been playing a very important part. Most of the basins were of intracratonic type in which the rate of sedimentation was usually able to keep pace with subsidence. Only rarely the sagging was more rapid and marine invasion took place. In this state of near approximation to balance between subsidence and sedimentation a superimposed eustatic oscillation with an amplitude of, say, 500 ft., might be expected to top the balance in many areas, causing an oscillation between much more widespread seas and much more restricted seas.

In any case, this allows a rough correlation of the sediments involved, while the contemporaenity of Nura Nura, Callytharra, and Fossil Cliff has been discussed earlier, and Cowper Reed's correlation of the Agglomeratic Slates/Speckled Sandstones of India with the Lower Marine Series of New South Wales has already been mentioned. Raggatt and Fletcher have, on the other hand, listed many species which are common to the Agglomeratic Slates on the one hand, and the Callytharra-Fossil Cliff limestone on the other and have established their comtemporaenity. Cowper Reed also considered the Umaria fauna to be of Permo-Carboniferous affinities, though altogether distinct, with every species new in itself. The Grant Range flora is allied to that of Karharbari. Taking all this into account, it should be satisfactory to consider the following as, more or less, of the same age.

Part of the Lower Marine Series - New South Wales.

Part of the Lower Bowen Series - Queensland.

Callytharra Limestone.	N.W. Basin.
Fossil Cliff Formation.	Irwin Basin.
Nura Nura Member.	Desert Basin.
Umaria Marine Bed.	Peninsular India.
Conularia - Eurydesma bed.	Salt Range.
Agglomeratic Slate.	Kashmir.
L. Krol Limestone.	Simla/Garhwal.

Perhaps they were really contemporaneous, but it would be difficult to prove it unless more work is done and some definite evidence is available. As to whether they were Permian or Carboniferous in aged, Teichert's view is, apparently, the most adaptable, to consider the Artinskian/Sakmarian boundary and leave the reader to decide for himself whether he regards the latter as part of Permian or of Carboniferous. He places this boundary below the beds listed above, and there appears to be a fair amount of agreement over it.

But whereas in eastern Australia the sequence represents the entire Permian Period, in W. Australia the preserved sediments end very soon after the Artinskian period and represent only about half the Period, during which the double facies

TABLE VI

FACIES	N.S. Wales	Irwin Basin	Salt Range	Kashmir	Simla - Garhwal	Penin. India
ESTUARINE	U. Coal M.	Wagina Sandstone	(Marine)	(Marine)	(Marine)	Raniganj Coal M.
MARINE	U. Marine Ser.	Carynginia Shales	Productus Limestone	Zewan Bed	U. Krol Limestone	Barren Measures (Fresh water)
SHALLOW SEA-ESTUARINE	Greta Coal M.	Irwin River Coal M.	Speckled Sandstone	Gangamopteris Bed	M. Krol Purple & red shales	Barakar Coal M.
MARINE	L. Marine Series	High Cliff Sandstone. Fossil Cliff Form.	Conularia Bed		L. Krol Limestone	Umaria Marine Bed
GLACIOGENE	Lochinvar tillite	Holmwood Shales Nangetty Form.	Boulder Bed	Agglomeratic Slate	Blaini Boulder Bed	Talchir Ser.

change had already taken place. Thus, if a correlation of the eastern and Western Australian formations on the basis of facies changes is regarded as satisfactory, it follows as a corollary that the deposition of the U. Coal Measures of N.S. Wales, as has been suggested from another line of evidence earlier, started late in the Artinskian period and covers the rest of the Permian Period. The rate of sedimentation, therefore, was considerably slower than the rate of deposition of the lower formations.

It appears to be very interesting and may be significant to note that crustal condition much more stable than what prevailed in the Barakar times may be concluded for the Raniganj Coal Measure, which might have been contemporaneous. The sediments in these are much finer, less felspathic, often pinkish and "the coal seams are much more constant than in the case of the Barakar strata" (Gee: 1932: 49). This might mean that the rate of sedimentation was slower there, too.

In Table VI, below, is given the correlation based on these eustatic changes.

.... TABLE VI

The return of the U.Coal Measure fresh water condition is, however, not noticeable in extra-Peninsular India where marine sediments continue in each area. On the other hand, Barren Measures, considered to be of fresh water origin, bridge the period between the two Coal Measures. The Barren Measures are highly ferruginous in Raniganj Coalfield, and might have been contemporaneous with the Liveringa Group, parts of which are also highly ferruginous.

In India, the top of the Damuda Series is, usually, regarded as the end of the Permian formation, though the Lower Gondwana System is supposed to run into the Lower Triassic Age, ending only with the Panchet Series. In Australia there is in places a clear break above the Permian beds. The appearance, however, of Thinnfeldia flora marks the boundary in both the countries.

CHAPTER V

THE MESOZOIC ERA

Though there was, apparently, some upheaval at the end of the Permian Period in eastern Australia, S. Africa, etc., sedimentation continued altogether unhampered in parts of India. The Damuda Series passes into the overlying Panchet Series without any break, and the same is the case in Kashmir and Spiti. In the Salt Range a slight unconformity is, however, reported. Fox has put the lowest beds of the Triassic formations of Peninsular India in the Lower Gondwana System mainly on floral continuity and this lack of any break. (Fox: 1931; p.80 et.seq. also Ibid - 176-178). The author is of the opinion that there is not enough of justification for this Scheme of two-fold division. It was, moreover, considered convenient to treat the Gondwana System by the geological ages. This would be more in line with the treatment in Australia, it would also provide reasonably well defined periods for more palaeogeographic maps, and thus lead to a closer scrutiny of the condition of deposition.

TRIASSICS

(A) PENINSULAR INDIA

The Panchet Series consists in general of "Talchir-like" greenish-buff to yellowish-brown sediments, both sa-

sandstones and shales, and a mild glaciation has some-times been suspected. The higher beds near Hirapur are yellowish-grey, micaceous sandstones, and red clays. Conglomerates are quite common in the higher beds in Raniganj. These may really be grey-wackes and sub-greywackes, and may indicate slightly more disturbed conditions, though there is need for detailed work.

One of the main reasons for its inclusion in the Lower Gondwana System is the continuation of some species of the Glossopteris flora. But at the same time a number of vertebrates and Estheria mangliensis are reported from a few localities. They are given below:-

Labyrinthodonta	:	Gonioglyptus longirostris, G.huxleyi, Glyptognathus fragilis, Pachygonia incurvata, Pachygnathus orientale.
Reptilla	:	Dicynodon orientalis, Epicampodon indicus.

The Panchet Series attain a total thickness of about 1,500 to 2,000 feet. Above these is an unconformity, and the Parsora beds are regarded as the lowest beds of the Upper Gondwana System. Glossopteris suddenly disappears, though Noeggerathiopsis persists. Thinnfeldia flora shows a remarkable development and T.odontopteroides is abundant.

The Parsora Beds are medium grained, ferruginous and micaceous sandstones.

The Mahadeva Series, too, is wholly of Triassic age and is divided into several stages. It is entirely devoid of any carbonaceous matter. The lowest, the Pachmarhi Stage, is composed of hard, red and buff, ferruginous shales and sandstones. The higher, Maleric Stage, is still red but the sandstones are often calcareous. In Rewa they are known as Tiki Beds, and carry vertebrate fossils, including Labyrinthodonts, reptiles, Saurischia, Thecodonts and fishes, which indicate an Upper Triassic age. The Denwa and Bagra Stages, found elsewhere, correspond to the Maleri State.

(B) EXTRA-PENINSULAR INDIA

Marine Triassics are extensively developed in this region. The succession in Spiti, where it attains a thickness of 4,000 feet, is very important indeed, and can easily be subdivided into stages corresponding to Bunter, Muschelkalk and Keuper. They are also exposed in Baluchistan. Space here, however, will not permit of their detailed description.

SPITI

The Triassic rocks here are composed of dark coloured limestones and dolomites with intercalations of blue coloured shales. The formation is very persistent in its colour and character, and can be traced over wide areas. Hayden worked out the following sequence (Krishnan: 1949; p.329).

TABLE VII

LIAS		Kioto Limestone	Massive limestone and dolomite with *Stephanoceras* 300' from the top.	1,600'
UPPER TRIASSIC.	Noric.		Massive limestone and dolomite with *Spirifera noetlingi*	800'
		Quartzite Series	White and brown quartzites with grey limestone with *Spirifera maniensis*.	300'
		Monotis Shales	Sandy and shaly limestone with *Monotis salinaria* .	300'
		Coral Limestone	Limestone with *Spiriferina greisbachi*, corals and crinoids.	100'
		Juvavites Beds	Brown weathering slates with *Juvavites angulatus*.	500'
	Carnic.	Tropite Beds	Dolomite limestone with *Dielasma julicum* and ammonites	900'
		Grey Beds	Grey shales and shaly limestone with *Spiriferina shalshalensis*	500'
		Halobia Beds	Dark splintery limestone with *Halobia* cf. *comata*	140'
TRIAS	Ladinic	Daonella Limestone.	Hard, Dark limestone with *Daonella indica*.	150'
		Daonella Shales	Black limestone and shales with *Daonella lommeli*.	160'

MIDDLE TRIASSIC	Muschelkalk	U.Muschel-kalk.	Concretionary limestone with shale bands and Ptychites rugifer.	20'
		L.Muschel-kalk.	Dark shales and grey limestone with Keyserlingites dieneri.	6'
		Nodular Limestone	Hard nodular limestone with few fossils.	60'
		Basal Muschelkalk	Shaly limestone with Rhynchonella griesbachi.	3'
LOWER TRIASSIC	Bunter	Hedenstr-oemia Beds	Limestone with Pseudomonotis himaica. Shaly limestone and shales.	27'
		Meekoceras Zone.	Thin bedded limestone and shales with Hedenstroemia mojsisovicsi.	7'
		Ophiceras Zone.	Thin bedded limestone and shales with Meekoceras varaha.	3'
			Grey limestone with Ophiceras sakuntala, etc.	1'
		Otoceras Zone.	Brown limestone with Otoceras woodwardi.	2'
Permian			Productus shales, etc.	

The Triassic beds overlie the Permian Productus shales conformably and pass in turn, conformably into the Jurassic. The lithology suggests that conditions remained fairly uniform, and the eugeosyncline apparently changed into miogeosyncline. Communication with the Alpine area had distinctly improved and several fossil species are common.

The succession in Kumaon (Painkhanda-Byans) area, is very similar and has been mapped in fair detail.

KASHMIR.

The succession here, though apparently thicker, is similar to that in Spiti, and this renders separate treatment unnecessary.

Krishnan (1949; 351-354), compares the Triassic formations of the Western Himalayas and points out that these distinctly peter out between Spiti and Byans in Kumaon or become progressively sandy.

SALT RANGE.

Compared to the Triassic formation of Kashmir and Spiti, those of Salt Range are much thinner, and attain a total thickness not exceeding 500 feet in the Trans-Indus area. The sections are, however, incomplete, for the Upper Triassic beds are missing. There is an unconformity between them and the Permian, as well, as has been mentioned earlier.

On account of their predominance the Ceratites have lent their name to the lower part of this formation, which is composed of thin-bedded light grey limestone, shales, sandstones, and green marls. The Middle Triassic sandstones are often referred to as Bivalve Beds. It also includes beds of limestones and dolomites.

HAZARA.

Bedded grey limestone, 500-1,200 feet in thickness, represents the Triassic formation here, while in Attock Dist. it, apparently, overlies the Pre-Cambrian formations directly.

BALUCHISTAN.

This new area now appears on the map with inliers of Triassic beds apparently several thousands of feet in thickness, and fairly rich in fossils which include Monotis salinaria. In places, these unconformably overlie Productus bearing limestones of Permian age.

(C) AUSTRALIA - WESTERN SHIELD

Information regarding the Triassic rocks from Western Australia is meagre. The Derby Series is, however, considered to be Triassic in age, and from bore hole records rocks of the age have been reported in the south. Detailed information is, however, not available.

(D) AUSTRALIA - TASMAN GEOSYNCLINE

NEW SOUTH WALES :

While the eugeosyncline had changed, perhaps, to miogeosyncline in extra-Peninsular India, it had almost died out in east Australia, and the small exposures there are mostly thin fresh-water deposits. Even these sediments were marked by a general tranquility of the basin, though there is evidence of some volcanic activity in Queensland.

The most important of these areas is in New South Wales where a large outcrop occurs around Sydney and for 200 miles N.N.W. of it. Three series are recognised, as below :

Wianamatta Series - 800'	-	Shales and sandstones with plant and fish remains.
Hawkesbury Series - 900'	-	Coarse to medium grained sandstones.
Narrabeen Series -1,246'	-	Red and green shales and sandstones with <u>Taeniopteris</u> and <u>Thinnfeldia</u>.
2,946 feet		

They thin out rapidly inland but each series in turn, occupies a smaller area than the lower one,

The Narrabeen Series consists of chocolate shales and red sandstonex with some fine-grained conglomerates, and beds of tuff. Raggatt has worked out in detail the stratigraphy of these and divided them into three stages. The flora indicates close affinities to that of the Panchet Series of India.

The Hawkesbury Series carries bands of conglomerates in sandstones and the pebbles in it are of a great variety. There are some bands of shale which carry large blocks with vertical bedding. It has been suggested that they are formed by undercutting of the shale-beds by suddenly flooded torrential streams. Sometimes the sandstone forms the matrix for a breccia of shale fragments.

The lower part of the Wianamatta Series, some 350 feet thick, is composed almost entirely of shales and is followed by calcareous and siliceous sandstones. In the shales are included some impure seams of coal as well.

QUEENSLAND

In Queensland the Esk and Ipswich Series are two different facies of the same formation and pass into one another horizontally. The Ipswich is at least 4,000 feet thick. The former, in the type locality, is composed primarily of andesitic agglomerates of some thousands of feet in thickness. There are tuffs, grits and shales, carrying Nilssonia cf. princeps and Thinnfeldia. There are also layers of calcareous shales and carbonaceous matter in the upper part of grey sandy shales and sandstones with Thinnfeldia.

It is remarkable that in the Queensland Triassic succession there are no red beds. In the entire formation there is no evidence of dessiccation otherwise, and workable coal seams were deposited. This is a very unusual feature for the Triassic formations, particularly those of fresh water origin, for almost any part of the world. A reasonable explanation has, however, not yet been offered.

TASMANIA

The Triassic formation in Tasmania overlies the Permians with a distinct disconformity. The Glossopteris flora is, at this stage replaced by the Thinnfeldia flora and the vertebrates appear for the first time. The sequence, according to Banks (1952) is:-

Unconformity
Felspathic Sandstones
Ross Sandstones and Shales
Disconformity.

He considers that in many places the thickness may be more than 2,000 feet.

The Ross Sandstones and Shales are composed primarily, of quartz, some of which has a sparkling appearance due to the development of crystal faces around the original rounded grains. It is remarkable that this rather unusual character is also developed in the Molteno Beds of S.Africa and the

Hawkesbury Series of N.S. Wales (Plate IX), both of which are considered to be of the same age. Certain beds of the Ross Sandstones carry abundant muscovite which lend them a distinct fissility. Often the beds have small flakes of graphite too. Some evaporites are also associated with these sandstones. The sandstones are massive, even textured and often current bedded. The fossils include the labyrinthodonts of the family Captorhinidae, fish, Acrolepis hamiltoni, and A.tasmanicus. Plant fossils are common and include : Phyllotheca australis, Thinnfeldia odontopteroides, Phoenicopsis elongatus, etc.

The Felspathic Sandstones overlie the Ross beds and includes the Coal Measures. Some of the beds are distinctly arkosic and there may be up to 80% felspar in the sediments. Shales and siltstones are associated with the sandstone. Plant fossils are very abundant, and of the 27 species described, 18 are common with the Ipswich Series of Queensland. This would indicate a Lower to Upper Triassic Age for this Formation. The fossils include :

Phyllotheca australis, Neocalamites carrerei, Cladophlebis australis, C.johnstoni, C.tasmanica, Thinnfeldia odontopteroides, T.acuta, T.feistmanteli, Pterophyllum strahani, Taeniopteris carruthersi, Gingko digitata, etc.

OTHER AREAS

In addition to the areas described above there are some restricted lake deposits in Victoria and South Australia.

JURASSICS

Just as the Triassic was a period of regression, the Jurassic was one of world wide transgression. Wide areas in Australia were covered by water. In India a large part of Baluchistan, Rajputana and Cutch was also covered by sea in the Middle Jurassic Epoch. On the east coast marine limestones are reported though further inland fresh water deposits continued to be formed. The Jurassic deposits are, thus, widespread, and well preserved by fossils are abundant. Thin beds of coal, too, were deposited in Peninsular India, as well as in the Punjab.

(A) PENINSULAR INDIA

The Rajmahal and Jabalpur Series cover the Jurassic Period and beds belonging to these are scattered all over the Peninsula.

The Rajmahal Series is composed of about 2,000 feet of trap including about 100 feet of intertrappean sediments. The crater or fissure from which these traps were errupted is not known, but a distinct increase in their thickness to the north indicates that it was in that direction. This might place the source in the miogeosynclinal zone of the Tethys. Fossils are contained only in the lower intertrappeans, the lowest carrying <u>Unio</u>, and the two higher ones, a large variety of plant remains. Their age was regarded as Liassic by Feistmantel, but Sahni considered them to be Upper Jurassic.

In the coastal tract between the Eastern Ghat and the Bay of Bengal there are outliers in Cuttack, Ellore and Ongole, which are assigned a Rajmahal age on the basis of their flora.

The type area for the Kota Stage, an equivalent of the Rajmahal Series, is in the Pranhita-Godavari Valley, where it is 2,000 feet thick, and is composed of brown sandstones and grits with red clay bands, an occasional bed of limestone, carbonaceous shales and rarely a thin seam of coal. It overlies the Maleri rocks and there is some difference of opinion about the age of the latter. A variety of fossils, including the Crustacean, <u>Estheria</u>, fish and plant remains have been found in the Kota Beds, and indicate an age not younger than Lias.

Strata belonging to the Jabalpur Series had been recognised at intervals from near Umaria in S. Rewa westward along the southern side of the Narbada Valley. Characteristically they are formed of white sandstone and clays and carbonaceous shale and an occasional thin seam of coal. It is divided into two stages, the lower Chavgan Stage has a flora more allied to that of Kota, whereas the plants of the upper Jabalpur Stage have their nearest relatives in the plant beds of Kachch (Cutch). R.D. Oldham, (Fox 1931; 114) was inclined to think that the Jabalpur flora was formed in a botanical region different from that of the east coast. The Jabalpur Series unconformably overlies beds of Maleri Stage and progressively overlaps on to older Gondwana rocks.

CUTCH

A formation which rivals that of Spiti in importance and fossil contents and exceeds it in thickness is developed in Cutch. As these are the oldest rocks outcropping in the region, the base is not exposed and the top is eroded away, and yet the total known thickness is estimated to be over 6,000 feet. The succession is as follows:-

Umia. (3,000 feet)	(Marine sandstones with Crioceras etc. (and sandstones with plants. (Marine sandstone and conglomerates (with Trigonia etc. (Sandstones and shales with Perisphinctes and Oppelia.

Katrol. (1,000 feet)	(Ferruginous red and yellow sandstones with Aspidoceras. (Dhosa oolite, and oolitic limestones with Peltoceras, etc.
Chari. (1,100 feet)	(White limestone with Peltoceras, Oppelia, etc. (Shales with "golden oolites" (Grey limestones and marls with Oppelia, corals, etc. (Yellow sandstones and limestones with Trigonia, Corbula, etc.
Patcham (1,000 feet)	

The fossils from this area were studied by L.F. Spath, who distinguished 114 genera, fiftyone of which are new to India, and nearly 600 species. No resemblances were detected with the Mediterranean, the N.W. European or the Boreal privinces, but a revision of the work is called for. There is close affinity with Madagascar.

Large parts of Rajputana were also submerged by this Jurassic sea and the deposits show up in Jaisalmer and Bikaner from underneath the all pervading sand.

The highest beds of Umia carry a flora which is considered to be Upper Gondwana in character. Their upper portion contains an ammonite bed described as Lower Cretaceous in age.

MADRAS

In the Godavari-Kistna-Guntur tract some marine beds occur in association with the Upper Gondwana plant beds.

The ammonites are badly preserved, but the plant fossils indicate an Upper Jurassic age.

(B) EXTRA-PENINSULAR INDIA

SPITI

The Megalodon or Kioto Limestone bridges over the Trias-Jura boundary, with 200 feet of Triassic and 1,500-1,600 feet of Jurassic beds. The Jurassic part of the Kioto Limestone is called the Tagling Stage and can be followed right across from the western border of Nepal to Kashmir, underlying the easily recognisable beds of Spiti Shales, about 500 feet thick. Thus the total thickness of the Jurassic formation here is about 2,000 feet. The Spiti Shales are splintery, black, micaceous with an abundance of well preserved fossils, especially ammonities. There are a few thin intercalations of limestone in the upper part. The fossils are often enclosed in calcareous nodules. There, apparently, is an unconformity between the Spiti Shales and the Kioto Limestone, but the former pass upwards into the Giumal Sandstones of Neocomian age without any break.

The Jurassic formation can also be traced to the east of Nepal, and probably continues right through it. In Mt. Everest area it still retains the characteristic lithology described above.

KASHMIR

Jurassic beds, almost identical in many features with those of Spiti, are developed in the Zanskar Range, which is a direct continuation of the Spiti basin. There is, however, appears to be no unconformity in many of the localities, between the shales and the underlying limestone, and the strata, if anything, may be thicker.

SALT RANGE

Jurassic rocks, very different from the above, are developed in the western part of the Salt Range. The section is 100-200 feet thick near Amb, 500 feet near Kalabagh and over 2,200 feet in the Surghar Range further south-west. The facies is dominantly coastal and in some respects resembles that of Cutch, described earlier. Apparently only the Middle and Upper Jurassics are present.

The lower beds are known as Variegated Sandstones, and are succeeded by Yellow Limestone, Alum Shales and gypseous beds. In these beds are bands of haematite and, locally, thin layers of "golden oolite" resembling those of Cutch.

The Crinoidal Limestone below the Variegated Sandstones in the Trans-Indus area may be Lower Jurassic, and it is here that the Upper Jurassic is developed. Near

Kalabagh some poor quality coal seams are also present, which sometimes carry fossil plants of the Jabalpur Stage.

This distinct change in lithology and the increase in thickness towards the south-west suggest that the Salt Range basin at this stage, as also perhaps during the Triassic Period, was, apparently, not directly connected with the Spiti basin to the east. On the other hand, it was, probably, connected to the south along its western end.

BALUCHISTAN

A Jurassic facies, in some ways like that of Spiti is developed here and attains a thickness of 3,000 to 4,000 feet near Quetta. There are crinoidal and oolitic limestones, and calcareous shales. The fossils allow an easy correlation with the European Lias. Triassic rocks are also well developed on the Makran coast. It was, apparently, a gulf or bay of the Tethys, and might have continued into Cutch. The faunal differences, in that case, would be ecological.

In Attock and Hazara districts Jurassic beds similar to those of Spiti are developed.

(C) AUSTRALIA - WESTERN SHIELD

The widespread Middle Jurassic transgression which affected such large areas in India seems to have brought large parts of West Australia also under water. The deposits are of fresh water origin in the south, and marine in the north.

An exposure near Perth has yielded some typical Jurassic plant fossils, including Cladophlebis australis, Thinnfeldia talbragarensis, Taeniopteris spathulata, Ptilophyllum pecten, etc.

In the Irwin River area the Jurassic formation rests unconformably on Permian beds, and has been affected by faulting. The rocks of the series include ferruginous and light-coloured sandstones, with argillaceous sandstones, shales and lignites. Near Geraldton marine fossils are included in some clays and oolitic limestones which are associated with terrestrial beds containing Otozamites. Somewhat similar marine fossiliferous beds occur on the Minilya River in the North-West district. Here, too, they appear to be bounded on both sides by faults. The bed here is only about 25 ft. thick, but appears to be extensive.

In West Kimberley area Teichert (1947 : 1793) assigns about 550 feet of beds to Jurassic age in some bore holes. Marine fossils were obtained from parts of these which he thinks to be very closely allied to those of Timor, Spiti and New Zealand, (Teichert 1939; 85).

(D) <u>AUSTRALIA - TASMAN GEOSYNCLINE</u>

<u>QUEENSLAND</u>

The Queensland succession is regarded as standard for the eastern part of Australia and the type area is that between the Brisbane River and the Main Divide and Macpherson Ranges. However, the system covers a wide area with its terrestrial and fresh water deposits, and is divided into Bundamba, Marburg and Walloon Series. The junction with the underlying Triassic beds is conformable in places, and disconformable in others.

The Bundamba Series begins with a conglomerate which passes into siliceous or felspathic sandstones, grits, and shales. It rests on gently folded Ipswich beds at Bundamba but further north-west transgresses on to the Esk Series. The overlying Marburg Series is seen in the Helidon-Gatton area and is composed of felspathic and micaceous flaggy and current bedded sandstones, grits, coarse ferruginous sandstones, clay-shales and conglomerates. Even a coal seam was encountered in a bore near Laidley. The fossils include <u>Cladophlebis australis</u>, <u>Taeniopteris spathulata</u>.

The Walloon Series is divided into two stages. The lower, Rosewood Stage - 1,100 feet thick - is developed to the west of Ipswich. More than half the beds are said to be exceedingly soft and are a somewhat calcareous sandstones. The remaining part is of calcareous and carbonaceous shales with lenses and concretionary nodules of ferruginous material. To the south and south-east of Gatton the higher stage is developed and is made up of about 700 feet of felspathic sandstones.

Jurassic beds with a total thickness of over 3,100 feet are exposed in the Great Artesian Basin and the three series mentioned above have been recognised there. They extend to Natal Downs and further north and perhaps are continuous with the Jurassic rocks north of the Pasco river.

NEW SOUTH WALES

Jurassic rocks here are exposed in two areas, the first a continuation of the Brisbane-Ipswich exposure, and the second that of the Great Artesian Basin, and are known as the Clarence Series and Artesian Series respectively.

The Clarence Seines is divided into four stages, as below:-

Grafton Stage	Soft sandstones, shales, etc., with coal.	1,450'
Kangaroo Creek Stage	Massive siliceous sandstones and conglomerates.	410'
Mallanganee Coal Measures	Shales with thin coal bands.	489'
Tabulam Stage	Sandstones and shales and rarely some lavas.	1,017'
		3,366'

The Coal Measures in this series carry a rich flora which includes Taeniopteris spathulata, Thinnfeldia odontopteroides, etc. and is correlated with the Lower Walloon Stage.

The Artesian Series appears on the other side of the Main Divide and stretches for about 300 miles in a south-south-west direction. The general sequence is :-

Pilliga Beds	:	Massive, coarse, porous sandstones and grits, etc.	750'
Gowen Beds	:	Ferruginous and calcareous shales with plant remains.	200'
Garravilla Lavas	:	Basic amygdaloidal lavas.	600'
Pottinger Beds	:	Fine grained sandstones and shales, often calcareous and carbonaceous.	700'
			2,250'

The Artesian Series directly overlies beds of the Triassic System in some areas but overlaps it in others.

OTHER AREAS

Jurassic rocks occur scattered over a large area in the Northern Territory, and were presumably part of one extensive formation. They are composed of sandstones, interbedded conglomerates etc. and contain plant remains in which

Otozamites bengalensis - a species characteristic of the Rajmahal Series and its equivalent beds on the east coast of India - occurs to confirm the age. Their total thickness is supposed to be a few hundred feet.

Though they outcrop only in the extreme south, bore records indicate that Jurassics are fairly extensive in the southern part of Victoria. They are thick too, for at Kitcunda they exceed 4,000 feet and David thinks that they might originally have been over 5,000 feet.

These Victorian Jurassic formations are, as in other parts of eastern Australia, entirely terrestrial or fresh water in origin, and consist of mudstones, felspathic sandstones, grits, conglomerates and shales. Coal seams occur interbedded in these.

This depositional basin can be traced intermittently to South Australia, where at Robe, it is still almost 2,500 feet thick, indicating that the area affected was very extensive indeed. Extensive areas of Queensland, New South Wales, Victoria, Northern Territory and South Australia were receiving sediments. Tasmania, might have been a land area, where igneous activity resulted in extensive dykes and vast sills.

CRETACEOUS

The Umia Series of Cutch, the highest formation of the Gondwana System, just extends into the Cretaceous and it would, therefore, not be necessary to deal with the formations of this age in great detail. Mention should, however, be made of the beds near Trichinopoly which preserve a fauna very closely allied to that of the N.W. Basin (Teichert : 1939; 86). The sea appears to have extensively transgressed at this period and marine sediments are scattered all over Central India and Rajputana.

The basin in Uttattur, however, appears to have been occasionally isolated - barred, presumably. Apart from evaporites, phosphatic nodules and chalk were deposited in this area. The sediments here are thicker than elsewhere and include marine fossils, some of which are of wide areal distribution, and have been recorded from S. Africa, New Zealand, New Guinea etc.

Barred basin conditions, apparently, prevailed on the west coast of Australia as well, and it is remarkable that evaporites, phosphatic nodules and chalk feature in the sediments in this area too.

Three maps cover the Jurassic - Cretaceous Periods. The first, Plate X, represents the Palaeogeography of the

Jurassic Period, excluding the Tithonian. Plate XII... covers the Tithonian - Neocomian Period, while Plate XIII. is for the rest of the Cretaceous Period. It was considered that this would be an advantage, even though the lack of exact correlation has prevented the use of many measured sections, particularly so on Plate XII.. The two major transgressions of the Cretaceous Era have been separated and this facilitates the study and comparison, specially in the Indo-Australian Basin.

CHAPTER VI.

RECONSTRUCTIONS OF PALAEOGEOGRAPHY

In the past several attempts have been made at reconstructing the palaeogeographic maps of the different geological periods, notable amongst these were the works of Schuchert, while Fox in India (for the Gondwana System only), and David and Browne in Australia attempted to produce local maps. Recent advances in knowledge and the new conceptions of stratigraphy and the environmental control of sediments demand a revision of the work. There has, also, been the development of the technique of statistical representation of sedimentary data on maps. These are the isopach and lithofacies maps, and the former have been extensively used in this paper. Unfortunately, almost the entire published information available on the Permian formations of India and Australia would be regarded as antiquated when measured by the yardstick of modern standards of sedimentary terminology, and it would not be possible to present lithofacies maps. The interesting patterns produced by the isopach maps are, however, a worth while beginning.

PALAEOGEOGRAPHY OF INDIA - PERMIAN.

Fig. I gives a map of the present distribution of the Damuda Series along with the thicknesses recorded. In Peninsular India these are represented by :

3. Raniganj Series
2. Barren Measures
1. Barakar Series

of the standard scale and their equivalents in other areas. Karharbari Stage is some times added below the Barakar Series.

Figures for the sections given have been taken from the various published Records and Memoirs of the Geological Survey of India, and can be considered reliable. It is significant that the thicknesses generally decrease as one proceeds towards the west or the north-west in Peninsular India. Thus the total thickness of the Damuda Series is 8,700 ft. in Raniganj, 5,900 ft. in Jharia, 3,200 ft. in Aurunga, 2,700 ft. in Hutar, and about 1,500 ft. in Singrauli. Ramkola lying between Hutar and Singrauli, has 3,700 ft. of the Damuda beds, and apparently represents a local embayment of the basin. For the other two east coast basins unfortunately, measured sections are not available from abundant localities. In the Godavari basin, apparently, the Barakar Stage is thinner, but the overlying Kamthi Stage is thick instead. Thus in Gandikamaram the total thickness is of the order of 7,300 ft., though in Kasipur it is only 3,500 ft., and decreases to 3,200 ft. some fifty miles further to the north-west. For the Mahanadi Valley only two authentic sections are available and both are incomplete. They are, however, used in the maps. In the Satpura basin the trend is slightly disturbed and the thicknesses increase towards the west (2,350 ft. in Pench Valley and 4,500 ft. in Tawa Valley).

Fox was of the opinion that the Gondwana System in India was deposited in block-faulted basins and that "the main faults seem to have been formed simultaneously with the deposition in the basin" (Krishnan: 1949: 282). Fox's palaeogeographic map is given as Inset in Plate I. The impossibility of drawing isopach form-lines in the valleys shown by him needs no demonstration, but there is considerable evidence, both positive and negative, to show that the sediments were not deposited in faulted basins. This has been discussed here in considerable detail.

CONTRADICTION OF "RIFT VALLEY" CONCEPT.

If the deposits were formed in narrow faulted basins, one would normally expect to have these basins deeper in the middle, and as a consequence, the deposits would be thickest in a narrow belt running all along the length of the valley. The isopach form-lines would, then, be oval or concentric.

There is no record of any such increase of thickness, and certainly there is no decrease in the thickness of the strata as one proceeds east.

Over and above this, with the type of valley imagined by Fox, there would be land surfaces on both sides of this basin, with their own drainage systems. Such rivers would discharge into the basin more or less at right angles. The immediate effect of such a drainage system would be that the sediments would be coarser on the two sides and would gradually increase in fineness towards the centre. Far from this being the case every observer in the area has remarked about the uniformity in the character of the deposits across the width of the basin. On the other hand Fox was arguing against his own case when he remarked (1931: 39), that "the conglomeratic bands become thicker, more frequent, and contain larger sized pebbles the further west one goes from Raniganj to the Karanpura coalfield. This is especially true of the lower part of the Barakar Series ...... In general the coal seams in the Damuda Valley field also deteriorate in quality in a westward direction ...... It also seems, speaking generally, that coal seams grade into shale more frequently in a westerly direction ...... and the seams appear to split up towards the west". Not only this, but each movement of the fault would rejuvenate the tributary streams, and at the same time, take the main stream towards maturity, thereby making it more sluggish, and less able to deal with the coarse material brought down by the former. This coarse, often poorly rounded and often ill sorted, material would deposit "fanglomerates" where the streams debauched into the main valley. There is no reason why such "deltas" should not have been preserved, or should have gone undetected in an area so intensively mined and geologically mapped in such detail.

One has also to take into account the impact of contemporaneous faulting along the margin on the lithology of the deposits. In order to account for the thickness and uniformity of the sediments, fault subsidence would need to have continued pari passu with the sedimentation. Thus, with each renewal of the movement along the marginal faults, the deposits would become coarser, and conglomerates and breccias would be likely to occur. These, however, would be confined to a comparatively narrow marginal belt.

The dips in the Damodar Valley coalfield are generally to the south, and the explanation is that the movement along the southern fault line was greater than along the northern. While there is no doubt that this is correct, the result of contemporaneous faulting of this nature would be that the sediments on the south would be coarser on the whole, and conglomerates would be more common, the boulders in them bigger, and less rounded. If the renewal of the movement was oft-repeated, there would, perhaps, be no clays at all on this side of the basin, and perhaps no coal either. Field evidence, however, does not show this.

Again it has been recorded by various observers in the field that the faults that cut across the beds die out on either end, and have been described as contemporaneous sag-faults. With such faults developing while the deposition was going on actively, the sediments would again tend to sort out, the fines shifting to the down-throw side of the basin. Not only this but such a fault is bound to result in local unconformities on either side of the fault line, though for different reasons and consequently showing different features. On the downthrow side the faulting would inevitably result in some tilting of the beds with dips generally away from the fault. When such beds are overlain by younger deposits there would be an unconformity. On the other, comparatively stable side, this faulting would, perhaps, start a cycle of contemporaneous erosion. This sub-aqueous or aerial erosion would result in a disconformity. The many eminent geologists who have worked in the area have not recorded any of these features.

Then again, it is common practice in the mining areas, on coming across a fault underground, to trace the continuation of the seam by merely working out the direction of throw. The thickness and quality of the seam are always identical on the two sides of the fault. Where more than one seam is being worked the entire sections on either side of the fault remain the same, and there is, generally, no increase or decrease in the intervening beds.

All this may be negative evidence, but the cumulative effect of so many different lines of argument should be regarded as sufficient and it may be conceded that the Indian geologists who examined the area have shown an undue reverence for the views of the past giants of the Geological Survey of India, like Blanford and Medlicott. Gee (1932: 84) was one of the few who did not agree with the above view and he remarked that "there is, however, no reason to suggest that this area of gradual subsidence and accompanying sedimentation was limited by any tectonic structure - either rift faults or pronounced folds - as has been previously suggested. On the contrary, there is little doubt that the present tract of Gondwanas ..... represents only a small portion of the original area of Gondwana sedimentation and owes its preservation to the fact that it has been subsequently faulted down within the Archaean land mass". He thought that "The major displacements, affecting as they do the Lower Gondwanas and Supra-Panchets alike, took place at a later date, probably during

Jurassic time" (ibid: 85). Mallet, (1874: 327), was, perhaps, nearer the truth when he envisaged the Gondwana deposits as extending from Darjeeling to Peninsular India, beneath the Ganges Valley alluvium.

What has been said above would, perhaps, have been sufficient to show that the faulting observed in the Indian coalfields was not contemporaneous, but Krishnan (1949: 282) has stated that "It is often seen that the stages or beds which appear to be perfectly conformable in the centre of the basin become unconformable near the faulted boundary". This, if correctly interpreted, would be sufficient to prove that the faulting was contemporaneous, and this has necessitated a more detailed examination of the available information.

With a sinking basin on one side and a rising ridge on the other, an occasional disturbance between the negative and positive areas is quite possible, and might bring about an unconformity away from the centre. Later, if the basin is block-faulted, and the sediments on the upthrow side are eroded away, it would be suspected that the unconformity was produced by contemporaneous faulting. This would, however, be rare. The possibility of some local contemporaneous faulting, too, is not denied and it might have produced the phenomena in some places.

On the other hand there are features observed by every geologist in the field which rule out any possibility of contemporaneous faulting having been the main controlling factor in these basins. In this category is the fact that in innumerable localities unfaulted, natural boundaries, even in the type area of the Damuda coalfield, are seen, and these have no place in a basin controlled by faulting. Griesbach (1880: 13), Ball (1878: 69), Jowett (1925: 143) and Gee (1932: 101) have pointed them out. The last named of these authors has shown that the greater part of the northern boundary of the Raniganj coalfield is not faulted at all, although the southern boundary has been faulted down by over 9,000 feet. Yet - and this appears inexplicable - there is no decrease in the thickness or the character of the sediments.

Moreover, instances of gneisses occurring on the downthrow side, (Fox: 1930; p.149) and Gondwana beds occurring on the upthrow side of the boundary faults are by no means rare. Finally, it might be pointed out that block faulting is always a more or less vertical movement resulting in a clear cut, single extensive fault, but here, "many of the faults are not clean dislocations indicative of definite up and down movement by the rocks, but rather suggest a kind of twisting and skewing effect which has led to a more or less horizontal movement as well" (Jowett ibid:141). Fox (ibid: 150) arrived at identical conclusions in Jharia, and added, "Along the north the Barakar coal seams appear as though the gneiss had been driven into them from the east .... To the west the gneisses again appear to have been forced into the Barakars".

The evidence produced earlier was admittedly largely negative in character, but what has been shown here is positive, and should rule out any doubts about the structural control of the Gondwana basins in India.

Fox, has, moreover, never tried to explain the occurrence of Gondwana outliers outside his rift-valleys. The thickness in some of them is quite considerable and yet there is no evidence of large scale faulting as observed in the type area. The boundary faults, naturally, result in high dips close to them, which with the sediments on the downthrow side, are always away from the fault. This rule does not hold for Singrauli, an area with which the author is very familiar. There is, in this area, a gentle dip in the Barakar beds which is always towards the north, and the dips increase moderately close to the boundary. Sometimes a local anticline is noted, but even here the dips nearest the fault continue to be towards it. No distinct faulting was noted either, though one was presumed by analogy. Even drilling to the depth of over 300 ft. failed to reveal any in an area of at least 15 square miles. Well over 1,500 ft. of beds belonging to the Gondwana System are exposed here, and the thickness must have been more. The area this field covers is quite considerable too, and the above features should be regarded as a strong evidence for the refutation of the 'rift valley-lake theory', as advocated by Fox. What would, perhaps, be more unaccountable, if modern conceptions about the tectonic control of sediments are correct, is the character of the sediments. It is almost identical with that of the type area, the Damodar Valley, which is supposed to have been contemporaneously faulted down by several thousand feet. And Singrauli is not an isolated instance.

Summing up the above lines of argument one finds that the evidence against the 'rift valley' theory falls under the following heads:

(1) Facies of sediments: No change of facies towards the fault-lines, lack of marginal deltas, etc.

(2) Structural evidence: A large part of the northern boundary of the Raniganj trough is not faulted, whereas the throw of the southern fault is over 9,000 ft. Yet the thickness of the beds and the character of the sediments do not change towards this fault, in fact the thickening is at right angles to this - i.e. towards the east.

(3) Absence of clean-cut single faults.

(4) Presence of identical sections on either side of a fault in coal mines.

(5) The presence of extensive outliers outside the rift valleys.

(6) The general agreement of the facies between the sediments in these outliers and the exposures in the faulted valleys.

ISOPACH FORM-LINE MAP OF INDIA

Fig.II, is an attempt to reconstruct isopachs consistent with the available recorded thicknesses, and not confined by the fault basin theory. In some places there is a good deal latitude as to how the lines should be drawn - especially in the marginal areas where the basin is supposed to have been shallow. However, such areas are of relatively little tectonic significance, for quite minor differential warping may appreciably alter the extent of the basin. But it is the area of the rapid and great subsidence and steep gradients across the isopachs which are tectonically significant. The author has found that these areas stand out clearly and it is difficult to juggle the form-lines to give a significantly different picture than that presented in Fig.II. The only possible alternative is given as an inset and the reason why the former has been preferred is that it shows a positive area in Orissa. Fox had recognised the presence of a ridge there in the Damuda Period as he found younger Gondwana sediments lying directly on the gneisses in this area. In his honour, the author suggests, that it be called the "Fox Ridge".

THE VINDHYAN RANGE

A very important point which the isopach form-lines, shown above, raise concerns the Vindhyan Range. The opinion of the Indian geologists, as expressed by Wadia (1949; 93-4) is that they have remained a mountain range ever since their uplift in the Pre-Cambrian times. Elsewhere (ibid; 128 see also: 153), he gives a hypothetical section of the Gondwana formation with the Vindhyans standing as high mountains on one side. Krishnan (1949: 283-4) concurs. Both Fermor and Fox appear, in some way, to be in two minds about them. On the one hand they seem to believe in their existence as high mountain ranges, and picture glaciers coming down these heights, and on the other, they bring a narrow arm of the Tethys across them to explain the Umaria fossil bed. Krishnan (ibid: 284) rejects the idea only on the ground that this would mean that the arm of the sea came right across the top of the Vindhyan mountain "which remain as elevated land to this day".

This conception of the Vindhyans remaining a system of mountains since the Pre-Cambrian time is not tenable. For Pre-Cambrian rocks to exist as mountains for such a long time, they would have to have a mantle of incomprehensible thickness. This mantle, too, would have to be Pre-Cambrian, if Wadia has correctly stated his case. Some boulders in Talchir beds of the Peninsula are compared to in situ rocks in the Vindhyan System, but these observations have been based on examination of hand specimens only. One wonders what have the agents of erosion been doing if they have not succeeded in removing these few thousand feet of sediments, that are exposed in the Vindhyans, since the Permian time? It is, moreover, difficult to understand how these boulders came to be deposited in the Peninsula when all evidence goes to show that the movement of the ice was in exactly the opposite direction. Only two striated platforms have been discovered and both contradict the possibility of any movement of the ice from the Vindhyans to the south. Fox expresses a belief in such a direction but omits to give any reason for his contention.

This idea of the existence of the Vindhyans as high mountains was born in the days of Blanford and Medlicott, when it was difficult otherwise to explain the existence of tillites, and the Talchirs were supposed to have been deposited by glaciers. No one today, however, believes that these tillites all over Gondwanaland were formed by valley glaciers. The evidence of Pleistocene ice cap has convinced every one who has given a thought to the problem that these Carboniferous tillites were also deposited by a similar ice cap. The extent and location of this ice cap is discussed later.

The author considers that there is no evidence to show that the Vindhyans existed as mountains in the Damuda Period, though he will concede the possibility of their having been a land surface in the preceding glacial period. The Carboniferous Ice Age was sufficient to peneplane them. Not only this, but if the rocks exposed there today are really Pre-Cambrian - and doubt is being expressed in certain quarters (Misra: 1949: 438) - what the Carboniferous glaciation removed from above them must have been much younger. It may have been anything up to Denonian or even Lower Carboniferous, and this suggests the possibility that the Vindhyans were not uplifted in the Pre-Cambrian times at all.

Considered in the light of above arguments, there are only two possibilities for the Vindhyan Ranges. Either there was an ortho-geosyncline in the area in which the deposition was taking place more or less continuously, as in the Spiti and Kashmir area further north, or that they were raised some time early in the Palaeozoic Era, (this might have been the activity which raised the Salt Range too) and thoroughly peneplaned by the Carboniferous glaciation. The area now occupied by most of the Vindhyan formation later formed a part of the basin in which the Gondwana sediments were being deposited.

The Pengunga striated platform is marked on Vindhyan limestones. Its preservation shows that the area remained a part of the Gondwana basin for a fairly long time and received thick deposits. These are just being removed, exposing the platform. Thus, atleast in this area there is definite evidence that the Vindhyans were not standing as high mountains and, instead, formed part of the basin more or less continuously from the glacial period till, perhaps, the U. Gondwana time. In the Wardha Valley they are again overlain by the Gondwana beds and Hughes (1877: 12) thought that between them and the Kamthis there was no physical break !! They were undoubtedly raised in the post-Gondwana period, perhaps by the orogenic movement which lifted the Himalayas, perhaps somewhat earlier, and have since been subjected to agents of denudation. In view of their greater height they lost more of their thickness than the lower area further south, and this is estimated to have lost over 12,000 feet at least. The waterfalls, gorges and rapids in the Narbada and other Peninsular rivers as well as on the Vindhyan plateau itself stand as a contradiction to Wadia's (ibid. 1949: 93-94) concept that Peninsular India has never suffered an upheaval since the Vindhyan times in Pre-Cambrian. The Son flows through a valley faulted by several hundred feet along its north. The tributaries all join the main stream with waterfalls, and have not had time to cut a deep valley for themselves. In fact this young, extensive fault is responsible for much of the Vindhyan topography. The uplift which resulted in these waterfalls and gorges must have been very recent indeed, but there must have been more, and there is no reason to believe otherwise.

Though the isopachs in Figure II, could have been crowded against the Vindhyan Range, these theoretical considerations have persuaded the author to let them cut right across the region. They do have a natural trend across the area, but only a moderate thickness is presumed over them, on the supposition that they were peneplaned. On emerging from this area the isopachs run along the southern coast of the Tethys, and enclosing the Salt Range, go on to the west.

THE CUTCH AREA

Returning to Peninsular India, it would be noticed that some of the isopachs are shown as running into the Cutch area. The trend for these was shown by the increase in the thickness of the sediments towards the west in the Narbada Valley, and it is presumed that the respective beds are not exposed. One arm of these then turns to the north to join the Salt Range arm, while other, apparently, ran southwards. Thus, of Peninsular India only the western part was left as a structural high, while the other area of provenance comprised central India and Rajputa.

THE MARINE BASIN ON THE EAST COAST OF INDIA

The map shows increasing thicknesses on the east coast where no Gondwana beds are known to occur to-day. This is, admittedly, more or less pure induction. It would, perhaps, have been possible to retain this as a structural high and connect the Umaria bed to the west or the north. But a look at the geological map of Umaria (Gee: 193) will show that this was, probably, not the case. The Talchir-Barakar boundary is exposed, about a mile away, in each of these directions, and the marine beds are not present. Moreover the affinities of the Umaria fauna, and the increasing thicknesses in this direction in every individual basin have induced the author to adopt this. If Umaria was connected to the west, through the Cutch, its fauna would have shown more affinities to that of Jabal-i-Biadh and Onilahy or to that of the Salt Range, and not to that of Assam. This will be discussed in detail later in this paper.

FRESH WATER BASIN

The extensive and thick ice cap of the Permo-Carboniferous age must have peneplaned the whole of Peninsular India. When the ice receded, the Permian transgression occurred. At the same time a wide flat area became the flood plain of the numerous newly born streams, and was covered with fresh water sediments..To begin with there might have been glacial lakes all over the area, but such lakes are likely to last for a comparatively short period. The epeirogenic movement that followed was apparently of a very moderate nature, and the sagging only just managed to keep pace with the deposition. That the difference in depth from one extreme to the other was never very great is evident by the general uniformity of the deposits from Raniganj at one end to Umaria and Singrauli at the other, the increasing thicknesses in the east signifying only a slight increase in the rate of sagging. That such sagging might have been accompanied by some faulting is not denied, but the great majority of the faults occurred much later, when also the major boundary faults were produced to preserve the sediments. Unfortunate has been the inclusion of all the faults in the category of contemporaneous faults and has resulted in a neglect to look for the evidence to differentiate them. Later it would be shown that there are two classes of faults, one pre-Jurassic, the other post-Jurassic, with the latter class over-whelmingly predominant.

PALAEOGEOGRAPHY OF AUSTRALIA - PERMIAN

For the Permian System of Western Australia the paucity of data does not permit a close study, but the form assumed by the isopachs is, in a general way, very similar to that in India, except that more marine sediments appear to have been formed in the area. As has been mentioned earlier there are four separate areas of these deposits, but there is general agreement that the

N.W. Basin and the Irwin Basins have much in common. The Desert Basin, from what little is known of it, shows a general similarity to these two. But the Collie Basin was, perhaps, an isolated area, and has only fresh water sediments. Fig.III shows the isopachs for the area. That the general trend of the isopachs is essentially right is confirmed by the work of Condit et al (Condit, Raggatt and Rudd 1936: 1036), which demonstrates that the thickness in the N.W. Basin increased gradually towards the north-west.

Above the Permian beds there is an unconformity in each area, and the preserved sections represent only the lower half of the Permian Period. Consequently, though the thickest reliable section for the N.W. Basin is 12,135 feet, the figure shows additional isopachs up to 15,000 feet. For the Desert Basin, the only dependable section is, at its thickest, over 7,000 feet (Guppy et al: 1952: 108) with an unconformity on the top. If the original thickness of the sediments was more, it would, perhaps, be covered by the additional isopachs shown, and one could add a few more or remove one or two without affecting the general pattern.

Similar isopach form-line maps are also produced for other areas, i.e. Eastern Australia, South and Central Africa, and South America, though for the last mentioned area much help was taken from Weeks' (1948) paper. It would, perhaps, be pertinent to add that, as in the case of India, attempts were made to exhaust all possible alternatives and the forms retained here are those that appeared to fit best the available information.

These isopach form lines of the different Continents were then transferred on to the various reconstructions of Gondwanaland. It was presumed that if the Continents were together at the time, these lines should continue from one to the other and the basins should show an essential similarity. Whereas if the Continents were not together, these isopachs should not cut across the "land bridges". In neither case should they contradict any of the established facts of local geology. This line of evidence to the author's mind, is more definite than that based on faunal and floral similarities, hitherto put forward and violently debated upon as to the route of the migration of life.

Fig. IV is a Palaeogeographic Map for the whole of the Permian Period on the reconstruction thus selected. It is after Carey (Paper read at the Pan-Indian Ocean Science Congress, Bangalore, India, 1951: Ms.). It was also considered essential that if similar isopach form lines for any other geological period were drawn on these Continents, the reconstruction chosen should again stand the tests mentioned above, and there should be no need to make any changes in the positions of the Continents

SAGGING OF THE BASIN

On this new map of Gondwanaland the basin between India and Australia runs in the form of a gulf from the Tethys. Apparently, the Fox Ridge in India continued further east, perhaps, through smaller islands, and only occasionally acted as an effective barrier. On the Indian side the floor of the basin would have an average slope of about 1/225 when fully loaded with the Talchir and Damuda sediments at the end of the Permian Period. This slope is so very moderate that if it were possible to strip the land of all the sediments, one could walk over it from Calcutta to Umaria without even feeling that one was rising all the time. A railway engineer would not need to improve the gradient. The slopes might have been slightly greater on the Australian side. Teichert (1952: p.134) has shown that in the N.W. Basin the average uplift between the M. Devonian to M. Permian was of the order of 0.02 m.m. per year, "not too much even for a stable shield" (ibid).

It is consequently not necessary to presume any faulting to explain the increase in thickness of sediments towards the centre of this basin, and there is nothing to show that contemporaneous faulting did take place. The author believes that it was a mere sagging of the floor, simple epeirogenic movement, positive on one side, and negative on the other. That the rate of this movement was not very slow is shown by the lithofacies, which has preserved many unstable minerals in the sediments. On the other hand, an overall uniformity of the sediments demands a fairly uniform movement. It was during occasional lags in the sag that the coal cyclothems developed.

MODERN EXAMPLES

With a peneplaned area on either side the slope of the basin would be very negligible. A distinct shore line would, nevertheless, be established on three sides of the gulf or bay. If conditions permitted, fresh water sediments would be deposited on one side of this shore line and marine sediments on the other. Such conditions exist today on the north coast of Sumatra, in the lower Indus-Ganges basin as well as in the Digul-Fly rivers basin of south New Guinea. In the latter area the slope of the land over an area of more than 50,000 square miles, is extremely small and an eustatic rise of the sea level of the order of eight or ten feet only, would submerge the land over scores of miles inland, and cause marine deposits to lie on top of fresh water sediments. In a section these would appear as tongues. One one side of this transitional zone there would be fresh water deposits over the entire thickness of the formation, on the other side it would all be marine in character. Examples of such deposition during the Permian Period of Russia and America are quoted later.

MINERAL OCCURRENCES

Though it does not in itself constitute an evidence, it appears to be an interesting coincidence that the iron ore deposits of Yampi Sound (Australia) lie opposite those of Singhbhum (India) and both are composed of banded hematite-quartzite. While the occurrence of charnockite-khondalite has been discussed earlier, it is very likely that detailed work would bring out many more such similarities. Gold deposits offer distinct possibilities.

TYPES OF GEOSYNCLINES

While the basin was sinking, the cratonic area was rising, partly as a result of the removal of the load of the ice, such as has been going on in Scandinavia since the Pleistocene time, and partly as a result of the epeirogenic movement itself. Thus was, apparently, developed a basin which can be put in the 'autogeosynclinal class' of Marshal Kay (1947: 1289 et.seq.). Without, perhaps, essentially differing from him, Dapples, et al (1948: 1924 et.seq.), would regard the Indian part of the basin as, from time to time, varying between 'stable shelf' and 'mildly unstable shelf', passing, on the Australian side through 'intracratonic basin'. They envisage such a variation themselves when they state that, (ibid: 1934) "Unstable shelf associations grade imperceptibly into those of the stable shelf on the one hand, and into ..

associations of the intra-cratonic basin on the other". The deposits observed in the areas discussed confirm this classification in all respects, with mildly unstable conditions prevailing most of the time. Arkosic sandstones, coal cyclothems, subgreywackes (quartz-muscovite sandstones), sandstone, siltstones and argillaceous limestones characterise this class. "Fossils are not common and are particularly deficient in benthonic forms" (ibid: 1936). In the 'intra-cratonic basin' such as has been identified on the Australian side, these authors consider the sandstones and shales to be generally of the same type as in unstable shelf areas discussed above, but limestones gain in importance, with evaporites developing if the basin becomes barred at any stage. The 'stable shelf' deposits, though of less importance in the present case, are described by them as consisting of a few hundred feet at the maximum, and comprising predominantly pure sandstones with grains well winnowed and rounded, glauconite sandstones, quartz-muscovite sandstones and claystones, etc.

BARRED BASIN

Woolnough, working in the Irwin River area came to the conclusion that the basin was, apparently, periodically barred to the west during the Permian Period. More recently Clarke et al (1948: 76-80) as a result of their detailed work, supported the above general conclusion, but suggested that

"The intermittent bar was, thus, probably not to the west of the present Irwin River Basin, but to the north[4]. They thought that it was "via the southern part of the N.W. Basin". Map figure IV shows the Fox Ridge running across the gulf, and the author suggests this to have been responsible for the occasional barring of the basin, although it is to the north of the Desert Basin. This would explain the occurrence of evaporites in parts of the succession in the last mentioned basin, particularly in the Nooncanbah Series.

It is likely that this ridge was continued towards Australia, through small islands. As the basin sank the ridge either did not sink, or was even isostatically raised, thus barring the basin. Erosion would reduce the ridge, and the bar would, temporarily become ineffective, when incursions of new types of fauna would take place. Then, perhaps, movement would occur again and the whole cycle would be repeated. An intermittent sinking of the basin is indicated in the Indian coalfield as well, where it allowed the coal cyclothems to be developed.

Clarke *et al* recognised nine or ten marine invasions, and "each brought in varying numbers of pelagic animals. *Metalegoceras jacksoni* accompanied only one of these. Others were characterised by other goniatites, nautiloids, the pelagic *Conularia* and more eurytopic types of gastropod" (*ibid*). Except for the beds which carry the remains of these invading animals, others carry very few fossils. Apparently conditions in the gulf were not very suitable for marine life to abound.

ORIGIN OF COAL IN INDIA

Though it would be seen from the above that coal cyclothems are quite normal in the tectotops envisaged, it is essential to discuss the occurrence of coal in detail here on account of some common misconception about its origin in India. Fox (1930.A.:196 et.seq.) and others (e.g. Gee: 1932: 50) have regarded them as allochthonous because of (a) the stratification of the seams, (b) partings in and splitting of the seams, (c) absence of the tree stems in floor in situ, (d) the terrestrial character of the plants, (e) the cyclical nature of the deposits, and finally, (f) conformability of the strata above and below them.

From the very nature of the problem it is difficult to come to any definite conclusions, for as Fox himself recognises (ibid.: 198-9), "it is evident that totally opposite modes of accumulation for the original plant material have been deduced from the same facts". The author, however, is convinced that most of the coal seams in India are autochthonous, and would here endeavour to point out the fallacies in Fox's lines of argument given above, and to give his own reasons.

(a) Perhaps the most forceful argument in Fox's armoury is the stratification of the seams. However, stratification in rocks occurs as a result of the seasonal nature of the deposits and other longer rhythms, and there appears to be no reason to believe that the same process could not operate in the case of autochthonous coal seams, as a result of the seasonal nature of the foliage, - if the plants were not evergreens - and its heavy deposition during the autumn. It does not necessarily imply a dry and wet season, and even marsh-plants have their annual periods of growth, flowering and fructification, etc. Longer climatic rythms are probable and might easily have produced the stratification. H.Potonie has shown that even peat often shows a bedded, or, rather, sheety structure.

(b) The parting, splitting and passage of the seam laterally into shales would, much more readily, be the result of changes in environments. Thus the facies change on the well drained margins of a basin sloping gradually to the centre would naturally be sandstones, followed by shales, carbonaceous shales, and coal as one proceeded to the centre, occupied by the swamp forests. Coal, in this environment, is one of the facies, merging gradually into appropriate facies on either side. If, however, this ideal condition was ever so slightly disturbed by a more rapid sinking of the basin, a more rapid rising of the source areas of the sediments or an eustatic or climatic change, it might cause shales or even sandstones to encroach along the margin of this bed of coal, or even to wholly cover it. If this sinking of the basin occurs rather suddenly even conglomerates may come to rest directly on top of the coal. In epeirogenic movements such changes are quite normal, and explain all observed phenomena.

Fox's view that coal is always formed under tropical conditions is not borne out by recent researches either. Apparently rain forests develop wherever rainfall considerably exceeds 100" in the year, particularly if it is evenly distributed. Thus, they exist today in Assam, East Indies, etc. in the tropical parts of the world, and in Tasmania, in the temperate. Though it would be admitted that rainfall is, perhaps, not the only controlling factor, coal seams do appear to have been restricted to these areas of high rain, tropical as well as temperate.

(c) The absence of tree stems <u>in situ</u> is at best, a negative evidence. Moreover, not all coal seams elsewhere in the world, believed to be autochthonous, have stems in the floor. Apart from other factors, one would imagine that, their preservation would depend upon the type of root system the trees developed. If the stems were not very thick and if the roots were not very deep, perhaps, the trees would topple over soon after they died.

But one wonders if the stems are really absent when Fox admits (1931: 42) that "there are many instances of Vertebraria extending upward irregularly across these planes. If Vertebraria are in the position of growth they have slowly become embedded in the settling sediments". Further, the occurrence of ferruginised tree stems are commonly reported, some of them from within the coal seams (Geo: 1932, 50). It would be unusual that, if all the wood that went into the constitution of the coal was of the same nature, only these small pieces were selected for replacement by iron, while the rest was converted into coal. It seems more reasonable to presume that it was because these were foreign, of a different texture and material and for some reason more prone to being replaced by iron bearing solutions.

(d) Fox's conclusion that since the flora preserved in the associated sediments is of a terrestrial character, coal was also formed out of wood grown on land is, obviously, not based on sound argument or evidence. Stopes and Watson (quoted by Raistrick and Marshall 1939: 170, et.seq.), conducted researches in England on the flora that went into the constitution of the coal and came to the conclusion that it was different from that preserved as fossils in the overlying shales. More significant was their conclusion that whereas the former was aquatic in origin, the latter was terrestrial, though some of it naturally got into the coal. Their work was facilitated by the occurrence of coal balls, which have not been found in India, and perhaps no comparable work has been done there. This is a very strong point in favour of the autochthonous origin of coal in England, for if the flora was transported this difference would be difficult to explain.. (ibid.: 173).

Large fossil trees have been found in the Gondwana sandstones, but this does not mean that the coal was formed of them. The coal forming flora in India is yet to be worked out.

(c) The failure of Fox to arrive at a correct interpretation of the cyclic nature of the deposits is hardly to be wondered at, for the importance of the tectonic control of basin in determing the type of sediments was not as well understood twentyfive years ago. But in the light of modern knowledge and researches in the oilfields of America, as well as in the Alps, it can confidently be stated that with an intermittently subsiding basin - and Fox agrees on this point - the deposits could not be otherwise in character. The coal cyclothems of America exhibit similar characteristcs. The point has been discussed above and need not be further elaborated.

(f) The conformability of the strata above and below is quite normal under the hypothesis postulated here. On the other hand the occurrence of fire clays underlying many of the coal seams in Bihar is a definite evidence that the coal there is autochthonous in origin (Raistrick and Marshall, ibid: 38). Fox (1934: 18) points out that "many of the shales of the Barakars have been found suitable for fire-clays, but this has so far not been proved true for the likely looking shales of the Raniganj series". He produces this as an evidence against their autochthonous origin. Admittedly clays of suitable quality do not occur under every seam, but this is only due to the fact that they fail to meet the rigid demands of the modern ceramic industry. Perhaps the leaching out process was not completed in these "likely looking shales". Moreover, it is difficult to imagine that about 125 feet of good quality coal would accumulate in a single seam - Kargali seam - out of drift wood. It is estimated that peat is compressed to a fifteenth part of its original thickness in being converted to coal. This would place the thickness of the peat required at over 1,800 feet, though with lower beds under increasing pressure it never, perhaps, stood at that thickness. Drifted wood to form 1,800 feet of peat over an extensive area cannot be produced even by repeated major catastrophies like the Assam Earthquake of 1950 which stripped vast areas of hill sides of their entire vegetation. The absence of mineral impurities from these coal deposits would, moreover, be inexplicable.

One has only to peruse recent works on the orgin of coal to be convinced that although coal may be formed by drift wood, such deposits are typically "of limited extent, varying thickness, and high ash content", (Stutzer and Nee 1940: 151, see also Moore 1940: 136, et.seq. and Raistrick and Marshal ibid.:46-62). This, perhaps, the thickest seam of good quality coal in the world, with the probable exception of the Manchurian seam, was certainly not formed of wood growing elsewhere, and Kargali seam is not an exception in the Indian Coalfields. Karo and many others are over 50 feet in thickness. The Raniganj coalfield alone has an aggregate of over 400 feet of coal.

THE INDO-AUSTRALIAN GULF.

The isopach maps of India and Australia bear strong similarities to the isopach map of the English Coalfields (North, 1931: 99). The maximum thickness of the sediments, indicating the tectonically most active part of the basin, was perhaps in the region between the two opposing coasts as they stood at the time. It might very well have been the shadow of the event that was yet to come, the splitting of the land along that line. The subsidence, and accordingly the thickness of the sediments preserved, decreased, more rapidly on the Australian side. The lithotope favoured the deposition of limestones, and not so much of coal, not at least in the present coastal region. It occurs only in the Collie Basin and the Irwin River Area, perhaps allochthonous in both.

D.Carroll, working on the heavy mineral assemblage in the Irwin Basin arrived at the conclusion that the garnet, etc. in the upper part of the Coal Measures came from a western source (1945: 91). She suggested a ridge of garnetiferous gneisses, a continuation of the Northampton-Greenouch region. In his palaeogeographic map of the Permian period, David (1950 : 393) shows the area to be a part of the "Westralian" geosyncline. Even though this was not so, the region, apparently, is too small to yield a significant amount of heavy minerals. The author suggests that the detrital material concerned came from the Khondalites of India or Ceylon, perhaps more from the latter, and the Greenough area was continuous with it.

THE UMARIA MARINE BED

The occurrence of a marine bed in the heart of India without any apparent connections with the sea area outside has puzzled the Indian geologists for a long time. The suggestion by Fermor, accepted by Fox, that an arm of the sea ran across the top of the Vindhyans has been referred to earlier. Krishnan (1949: 284 -5) suggested a connection to the west. This, however, does not take into account the affinities of the fauna which are distinctly with the Anthracolithic assemblage in Assam. A look at the isopach map of India, with a structural low running into the Cutch area, will show that this, however, was not altogether impossible.

On the other hand, it is very likely that the connection of this fossil bed was to the south east, where, marine conditions might have prevailed over a fairly extensive area.* Its records are found only in Australia now, and it appears that even the last vestige of it has been removed from the coastal areas of Madras, and Orissa, as well as from Madhya Pradesh. That the geological map of Umaria area suggests this to have been the most probable direction of marine transgression has been mentioned earlier.

The fossils in Umaria are preserved in four separate beds of limestone each hardly more than two inches thick, and separated by thin beds of shale which also contain an occasional fossil. In one of the beds the Productids are lying so thickly packed that the impression of a sudden death overtaking them is almost inescapable. The circumstances in which *Metalegoceras jacksoni* occur on the west coast of Australia in the Irwin Basin are said to be identical. Clarke *et al* have shown that there

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* The recent discovery of marine fossils from a locality some 90 m. to the E.S.E. adds considerably force to this interpretation. See post-script on page 204.

were nine or ten invasions of the Irwin River area by marine fauna, and one of them brought M. Jacksoni. The Productids of Umaria, probably, came in one of these, or a similar invasion. Thin plates of gypsum in the Umaria bed indicate barred basin conditions in that area too.

Cowper Reed (1928: 367-98), who studied this Umaria fauna, thought that it had no affinities with the West Australian fauna. But then, he based his opinion purely on external characters, a technique that was already regarded as unreliable when he adopted it. Moreover, many important discoveries have since been made in Australia, and recent research has tended to change the entire nomenclature of the Productids. The identification of the Umaria fauna, therefore, stands in urgent need of revision, particularly by a person who is familiar with the Australian species. In any case, Cowper Reed's identification provided only negative evidence. It is, in this connection, remarkable to note that Teichert (1949: 4), following Gerth, considers that what Reed described as fish scales (or teeth) may really be parts of the genus Calceolispongia, which has so far been reported only from Western Australia, Timor and Tasmania. Dr. Thomas, Palaeontologist to the Australian Bureau of Mineral Resources, who has been revising the West Australian Permian fauna, is of the opinion (personal communication conveyed through Prof. Carey) that several of Reed's Umaria figures closely resemble W. Australian forms, e.g. his Pleurotomaria umariaensis is very like Ptychomphalia, and his K 21-424 may be Derbya. Actual comparison of specimens may reveal closer affinities.*

It has been pointed out earlier that fresh water deposits pass laterally into marine deposits, and vice versa. This has been quite a common feature in other parts of the world, though originally it sometimes resulted in mistaken correlations everywhere . In the type area of the Permians, the deposits near Perm are typically of fresh water origin. Plant fossils, red beds, ripple marks, sun cracks and every other evidence of their being so are present. But at Kazan the deposits are as typically of marine origin. The passage is very gradual and starts by tongues of limestone appearing between fresh water sediments. Further on the interfingering is more marked and gradually marine lithofacies predominate. Studied separately it would be impossible to infer the relationship between them, and no wonder that altogether different ages were assigned to these beds originally. This change has taken place in a matter of a couple of hundred miles. Dunbar (1941: 315, et.seq.) has described it in great detail. He also cites the very similar example of the Phosphoria Formation in Wyoming (U.S.A.) which too is considered to be Permian in age. In Australia itself a distinct lateral change in facies is recorded from the Kuttung Series in New South Wales. The author considers that similar conditions prevailed in India at the time,

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* See Postscript page 204

and that the Umaria marine beds are remnants of these tongues that came out of the marine deposits further south-east. Fermor (1913: 167) has reported thin beds of limestone from the Talchir shales in the former Korea State, not very far to the southeast of Umaria. Though he did not find any fossils, these may be of marine origin, formed as tongues coming out of the same basin, though at a somewhat earlier stage. These limestones are worthy of a second look and deserve a thorough search for fossils. In any case, fresh water animals did not, then, exist in Peninsular India. Even Fox seems to admit the possibility of such lithofacies changes in his palaeogeographic maps (1932), Plate 10.

The absence of large marine deposits in India, as envisaged above, is probably due to the fact that the area where these were laid down was subjected to erosion during the Triassic period, as a comparison of maps figures IV and VIII will suggest. Though this area was, apparently, again covered by water during the Jurassic period, the Permian deposits might already have been removed. The Jurassic and Cretaceous deposits were, then, alone to be removed in the long period that began at the end of the latter period, and has not yet ended, and no wonder that the job has been thoroughly done. The absence of Panchet and a part of the Raniganj beds from the intervening belt of Johilla Kurasia, Bisrampur and Sohagpur indicates a zone that probably oscillated between and continously negative Umaria area, and the rapidly rising area to the south east.

EXTRA-PENINSULAR INDIA

The environments then prevailing in extra-Peninsular India were very different indeed. The presence of traps of considerable thickness, and the association of typical greywackes, etc. in Kashmir indicate that the region was apparently nearer to the eugeosyncline - if not a part of it - than the Salt Range area further south, which collected only a very moderate thickness of sediments with no volcanics, and was in an equally typical miogeosynclinal belt. Conditions more disturbed than in Peninsular India are portrayed in the distinct differences in sediments in adjacent areas as described in Chapter IV, and apparently all the parts were not in perfect communication all the time. The entire belt, from west of Spiti to Assam, is apparently miogeosynclinal, and the eugeosyncline was further to the north. A detailed study of this area will be very interesting indeed, but it appears that lack of information is going to stand in the way for a long time to come. Tibet lies in the crucial area, but is still the terra incognita.

THE TASMAN GEOSYNCLINE

More like this extra-Peninsular India in genesis, but including in parts the eugeosynclinal belt itself, is the eastern part of Australia. Like the Kashmir area, the sequence is complete here since the Devonian period, and it also continued till the Jurassic. The total thickness and character of the deposits during the period of its existence as a geosyncline was much more than in India. In parts the preserved Permo-Carboniferous sediments are over 23,000 feet thick, as at Cracow. There was intermittent igneous activity throughout tho Permian period and even later, and lava flows are frequent in any section.

Like extra-Peninsular India, there is distinct evidence of basins, separated by structural highs. Since the area has been geologically investigated in more detail than its counterpart in India, D. Hill, in Queensland, as already mentioned, has been successful in identifying these basins. Similar work in New South Wales and the Himalayan region is only waiting for some research worker.

Most of the time these basins were not even in direct communication with each other, and the structural highs that separated them, also supplied them with material. Such was, apparently, the New England Ridge.

THE BASAL TILLITES AND THE GLACIATION

Nothing has so far been said about the tillites that occur under the Permians, almost everywhere. Map, figure VII, shows their distribution and their thicknesses at various localities in India, Australia, as well as in other continents comprising Gondwanaland. It is not surprising that their thicknesses appear to be rather erratic and it has not been found possible to draw isopach lines for them. They were not deposited on an even surface, and were perhaps laid down by a receding ice cap, which must have had an oscillating front. It is, however, remarkable that an isopach map for the entire Permo-Carboniferous Period retains the general pattern produced in figure IV.

The map shows the limits of the glaciation which lie in the form of an oval. Outside this there are no reported tillites, and red beds predominate in the sediments as in north west S. America and Africa. Though red beds, admittedly, do not always indicate a warm dry climate, their occurrence under the present circumstances appears to be significant. The map also indicates the direction of movement of the ice as inferred from the known striated pavements. Only two such localities* are known in India and four have been recorded from Australia. Du Toit, map figure XV, has shown several arrows on Peninsular India, but the author has failed to find any reference of these in the Indian literature. The directions of ice movement in S. Africa and S. America have, however, been taken from Du Toit's books (1937: 76, also 1939: 245). The inevitable conclusion from the map is that the centre of the glaciation covered the area which now forms parts of Rhodesia, Mozambique, Tanganyika, Madagascar and, perhaps, a part of Australia. It apparently extended in the direction of the longer axis of the ellipse.

* One of these may be older.

It does not follow automatically that the South Pole of the peried lay in this area, but it is more than probable. The centre of the Pleistocene glaciation did not coincide with the North Ple. Nor will it be logical to expect the ice cap to be circular. The Pleistocene ice cap was not, the much reduced ice cap today is not. But a geometrical figure appears to be much more reasonable than the one shown on Du Toit's map, and tilts the balance, ever so slightly, in favour of Carey's assembly, if for no other reason, then simply because it reduces the glaciated area very considerably. The directions of striations on the platform shown on the map go to confirm this conclusion. Clarke et al (1948: 43) state that they noticed three huge 'White Horse' type cherty quartzite boulders lying in a straight line. Extended this line passes through the striated platform in India only with a slight change in direction. They also give the source of this quartzite to be in the south, the Yandanooka-Coorow area, which also lies in the same straight line. Though it would be conceded that this in itself does not constitute an evidence, it appears to be an interesting coincidence, and might indicate the direction of the ice-movement from somewhere in the eastern part of Africa to Simla and the Salt Range.

Only such a direction of ice movement would account for the presence of abundant angular garnets in the Talchir shales of Singrauli area, these having been derived from the khondalites to the south east. It would be difficult to account for them if the glaciers are imagined to have descended from the Vindhyan Ranges, for their angularity rules out any possibility of re-deposition from sedimentary rocks, and they are not known from the invervening isoclinally folded Bijawar shales. Neither is it possible to presume their source to be in the Aravalli Ranges for that would not account for their abundance, as the "Vindhyan glaciers" would supply by far the larger part of the sediments. The occurrence of khondalite boulders in the tillites of Talcher - the type area for the Talchirs - has already been mentioned, and no khondalites are known from the north of this field. It is of interest, in this connection, to note that Du Toit (1948: 113-126) from a totally different line of evidence, arrived at the conclusion that the axis of climatic zones from Permian to Rhaetic was NE-SW in Africa.

DISTRIBUTION OF COAL ETC.

Plate V shows the distribution of Permian coal deposits. These have been classified into autochthonous, and allochthonous coals wherever it could be determined with a reasonable degree of certainty. On the east coast of Australia the coal is autochthonous, but in Tasmania it is allochthonous. On the east coast of Africa, too, the coal is considered to be of similar origin. Even more remarkable is the continuation of oil shales from N.S. Wales, through Tasmania, to east Africa. Again a conformable sequence from the Devonian to the Permian occurs in Argentina, S. Africa and eastern Australia, which, on the reconstruction used here, fall in a continuous belt. The continuation of this belt to join a similar conformable sequence in Kashmir is, of course, hypothetical. On Du Toit's reconstruction these belts would not show up unless they are supposed to run through Antarctica. On Schuchert's reconstruction with separate basins, it seems difficult to imagine the existence of identical conditions simultaneously on the different continents, though it is, by no means, impossible. On this map, the post-Permian orogenic movement in east Australia, South Africa and Argentine falls in a narrow compact belt. With each such feature the odds multiply to make a fairly convincing case for the assembly used here.

It may not be out of place here to draw attention to the occurrence of stichtite, a by no means common mineral, even though it is from older rocks. It was originally described from west coast of Tasmania and has been reported from Barberton district in eastern S. Africa (Hall: 1922). These two localities lie almost opposite each other on the maps. The only other locality in the world from which stichtite has, perhaps, been reported is in Canada.

TRIASSIC

Figure VIII gives a map of the Triassic period compiled by the same technique. In Peninsular India the Triassic System is in most places, the highest formation exposed today, and it is not known what proportion of its original thickness is preserved. This part of the map is, therefore, admittedly, imperfect and hypothetical. Yet, it brings out the general character of the Triassic period - the general regression of the sea - surprisingly well. Apparently, the deposition was, for once, in more or less isolated basins, though it does not mean that these basins were faulted as imagined by Fox. Isopach form lines, consequently, do not pass directly from one continent to the other, and this does not allow the test of their continuity to be applied any convincingly. Carey's reconstruction was, however, used again, and it would, presently, be shown that it proved satisfactory. An extensive area on the east coast of India, apparently formed a structural high and was subjected to denudation. There will be reason to refer to this later.

Again the appropriate beds are not exposed in Cutch, but it is presumed that the area did receive sediments and the Triassic System lies under the Jurassic seen there. This Indo-African gulf retained its general form and covered the area up to Madagascar. The east Australian geosyncline, - the Samfrau - too, was very much reduced in extent and changed its character to auto- or exogeosyncline. There was considerable volcanic activity just to the east of Australia (David: 1950:411) during this period !!

DU TOIT 1937.

PLATE VII.

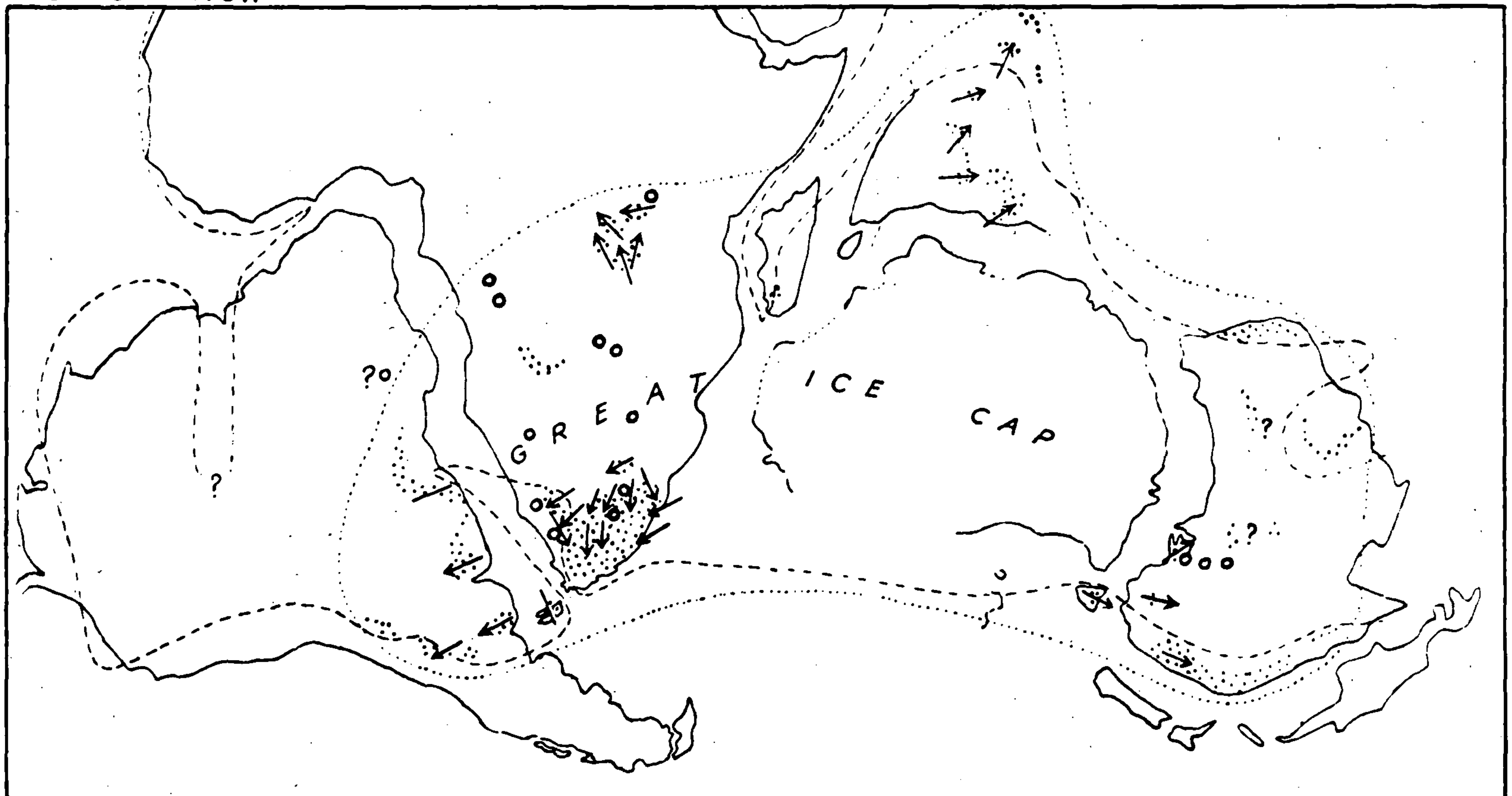

FIG. 9. Showing by stippling the distribution of the late Carboniferous Glacials in Gondwana. Arrows mark deduced ice-flow; lines indicate that precise direction is uncertain; dotted lines mark limit of ice; broken lines indicate edge of continent; circles denote occurrences of Ancient Tillites.

Generally speaking, the deposits are of fresh water origin and vertebrates have been found in many areas. Mostly the sandstones are red. Marine deposition, however, took place in Timor and in extra-Peninsular India, which were in more direct communication. On the other side the geosyncline extended to New Zealand. Coal was formed in east Australia, Tasmania, Abyssinia, etc.

As in the case of Permian System, the deposits of coal were plotted on the map, (see Plate IX). Though the coal formations of N.S Wales, Tasmania and South Africa do appear to be continuous, they would, alone, not constitute an argument in favour of the assembly of Gondwanaland. But when the distribution of the rather unusual glistening sandstones, that extend from Africa to N.S. Wales, through Tasmania, is also taken into consideration, the distribution of coal also becomes significant. No red beds are reported from the Triassic System in Queensland, but in the Broken Bay - Tasmania - Orange Free State triangle they accompany the coal and the glistening sandstones. On Du Toit's or Schuchert's map this would not appear as a single, extensive belt.

JURASSIC

The regression and desiccation that characterised the Triassic Period did not last very long, and the Jurassic Period brought a general transgression of the sea again, map figure X.

All the continents were more or less affected. Practically all of them were more extensively covered than in the Permian Period, even though the land had been thoroughly peneplaned then. The Indo-Australian gulf was widened. Even Ceylon now became a structural low and sediments were deposited there. Marine fauna left its mark in Madras, but the most important record of these marine conditions comes from Cutch. The sea here covered practically the whole of Rajputana, which came in more direct contact with the Salt Range area. A narrow Peninsula, perhaps, separated the latter from the Spiti belt. Southward from Cutch the gulf persisted to include Madagascar and Tanganyika, where the marine fauna has distinct Cutch affinities.

A change in the facies between the north and south of Lake Nayasa, and a sudden disappearance of the Cutch fauna south of Madagascar, along with the absence of any preserved sediments older than the Cretaceous, indicate that the isthmus still connected Australia with East Africa. Large parts of eastern Australia were covered by fresh water, the Permian "island" - the New England Ridge - reappeared. This structural high might have been continuous with the land that existed in New Guinea at the time.

Igneous activity (figure XI) was very pronounced at this period, particularly so in a belt that embraced eastern Australia and Tasmania, South Africa, Brazil and the adjacent parts of Antarctica. Outside this single, extensive area there was sporadic activity only in India. The Rajmahal traps were presumably erupted by some fissures to the north, as their increasing thickness in that direction indicates, and the centre was perhaps in the Tethyan geosynclinal belt. The Abor and the Sylhet traps might originally have been continuous with this, but so little is known about them that it is difficult to form any opinion. The basalts of Aden and Oman are of doubtful age, but those of British Somaliland have been confirmed to be Jurassic. It is likely that the great belt of igneous activity which ran from Brazil to eastern Australia had a branch running through north eastern Africa and embraced the whole area up to British Somaliland and presumably Aden, perhaps even Oman. It is admitted that the African basalt was formerly much more extensive than the present outcrops indicate. "Forming sills and dykes these Dolerites significantly avoid the Gondwanide fold-belt, though occupying a wide region parallel thereto in Uruguay, Brazil, Southern Africa, Antarctica and Tasmania, and just touching New South Wales ..... Their co-genetic nature is borne out by their wonderfully uniform petrological composition and character." (Du Toit: 1937: 94).

The dolerite sills of South Victorialand (Antarctica) were studied by Edwards, and he describes them as a 'perfect match' to those of Karroo. Browne also studied them and he remarks (1923: 251), "This rock is strikingly similar in texture and constitution to a coarse phase of the Tasmanian dolerite from Domain, Hobart, similarity extending even to the curvature of the flattened and elongated pyroxene prisms". He further shows that they give almost identical chemical analyses. In any reconstruction of Gondwanaland on the Drift Hypothesis one is, consequently, strongly tempted to bring the two areas together, even though so little is known of the geology of Antarctica, and more detailed comparison is not possible.

CRETACEOUS

A look at the map figure XII, will show that something very remarkable had suddenly happened. For the first time in its history the entire coast line of Africa from Somaliland to Gold Coast was, apparently, defined and the shape of the continent was determined. Sediments of this age are known as the Coastal System in South Africa, and the name is very apt for they really form a narrow ribbon running all round the southern part of the continent. In South America the sea had almost left the east coast altogether. For the first time, too, the tiny island of Socotra was cut off from the Indian shield and was submerged, while the "land bridge", if one can use that term without causing confusion, between Australia and Africa was broken. Completely different floras appeared in the two continents. For the first time now an identifiable marine fauna is found on the east coast of India, and, surprisingly, it has more in common with the West Australian fauna, than even with West Indian fauna, with which, too, it was, apparently, in direct communication. The Trichinopoly fauna is duplicated in the North West Basin, which also shows great affinities to the Madagascar fauna, thereby indicating that there was free passage during the Upper Cretaceous Period. Sea was, however, more extensively covering India north of R. Narbada. Remarkable is the fact that while the occurrence of evaporites in Uttatur indicates a barred basin on the Indian side, "barred basins .... in the Perth 'Sunkland' during the Lower Cretaceous and Eocene" existed on the opposite side of the basin as well, as is pointed out by Clarke et al (1948: 78). In addition to gypsum and salt, chalk and phosphatic nodules occur in both the areas.

Marine sediments are extensive, and though in places fresh water conditions prevailed temporarily, the only extensive area of fresh water sedimentation was in Sudan, apparently a shallow basin connecting the sea in Egypt with that in Somaliland.

The suggestion is strong that, perhaps, by the end of the Jurassic period S. America on the west started drifting apart, while India-Australia separated from Africa on the east.

CONCLUDING REMARKS

Before closing this chapter it might be pointed out that it is not claimed that the maps presented here are the final word. As more work is done and more authentic measured sections are available, it would be found necessary to make alterations. The author is, however, of the opinion that it is not likely that the overall picture here presented would be materially altered. All such information would go to add to the details. The entire evidence goes to justify the selection of the Gondwanaland reconstruction used.

CHAPTER VII.

SOME OTHER ASPECTS OF PALAEOGEOGRAPHY

Perhaps the best test for a theory is to base its enunciation on as few and broad principles as possible and then to test it on the details. In the preceding chapter the new palaeogeographic map, based on Carey's assembly of Gondwanaland has been presented. It has been built up on the basis of isopach maps and epeirogeny as reflected in the sediments. In this chapter an endeavour will be made to see if the known facts about structure, palaeontology, climate, etc. fit into this new picture any better than in the old. In the next chapter the relative merits of some of the better known reconstructions of Gondwnaland will be briefly reviewed.

Reference has, in the previous chapters, been made to the affinities in rocks, fossils, strikes, etc. some of which suggest consanguinity of the two main countries that are primarily the subject of study here. It has also been shown that the faulting in Peninsular India was not contemporaneous. Jowett was apparently right when he said (1925: 143) "It seems very clear that the whole system of faults and folds is quite independent of the existence of coalfields, and that the latter, which are only remnants of coalfields that originally existed, owe their preservation to the former". To take the point to its natural conclusion it is essential to examine the evidence, if any, for the approximate time of this folding and faulting, though it may be noted that there is only an insignificant amount of the former, while the faulting is all of normal block type.

UPLIFTS IN PENINSULAR INDIA

The circle of Indian geologists has held that Peninsular India has not been subjected to any uplift or movement since the pre-Cambrian times, when the Vindhyans were folded and uplifted. It has been mentioned earlier that this view is a legacy of the time when the glaciers were believed to have come down from these snow capped mountains. Though most Indian geologists of consequence today believe in the Drift Hypothesis they have not given serious thought to the problems that the movements of such a large land mass naturally involve. The author has failed to find any evidence of such long quiescence and has suggested that, perhaps, the Vindhyans were uplifted since the Permian times. The Jurassic map suggests the same for the Aravallis.

GEOFLEXURE AND FAULTING

It is suggested by Carey (1951, MS.) that the drifting of the Indian shield has been about a 'hinge' west of Baluchistan. Similar drifts about hinges are postulated in other parts of the world, e.g., in the Pyrenees, Italy, Mexico, Alaska, etc. This bending and folding of the strata in Baluchistan, through an angle of almost 90°, referred to as a "geoflex" compressed the strata within the two arms, and resulted in a tension on the obtuse side. This tension, Carey suggests, not only opened the Arabian Sea but also brought about the rift faulting on the Peninsula, exactly as the Pyrenees geoflexure opened up the Bay of Biscay while creating the heavily folded and overthrust ranges of Pyrenees Orientales. Fox (1930) writing about the Jharia coal-field points out that gneisses appear to be forced into the Gondwanas along the northern boundary fault, and says "These features have a subtle significance; they clearly indicate tensional forces due to an extension of the strata" And one is almost tempted to add 'followed by a movement in the horizontal direction'.

The major faults have been plotted on the map, figure XIV and they all appear to run into one another and then towards the "Baluchistan geoflexure". This is certainly remarkable. Those shown in Australia have been taken from Fairbridge's published map and other recent literature and the effect of the geoflex appears to have been felt. Exceedingly interesting is the continuation of the Godavari valley system of faults into the Darling fault of Irwin River-Collie Basin area. The major directions of faulting in the N.W. Basin is N.15.W. and N.75.W. (Condit et al 1936; 1060) and the latter runs into this just outside the present shore of Australia. The continuation of the Mahanadi system of faults might similarly run directly into the Desert Basin, where the Pinnacle and Mt. Fenton faults run parallel in a direction approximately N 53° W.

The nearly east-west faults of the Damodar Valley would run mainly to the north of Australia. The southern boundary fault of this area, if it reached Arnhem Land, is yet to be discovered. Perhaps it did not, and died out in the intervening area. The northern boundary fault had almost died out even in Raniganj. Raggatt (1937: 166) agreed that the Urella fault in Irwin River area is post Jurassic, and thought that some of the faults in the N.W. Basin are post Lower Cretaceous. Teichert (1952: 119) points out that in Wandagee area faulting has affected L. Cretaceous rocks.

Many in Australia believe that the fault pattern in Western Australia was determined in pre-Cambrian times. It may very well be so for India too, only that there is no evidence available here.

THE BEGINNING OF THE DRIFT

This interpretation, if correct, would indicate that Australia had not drifted apart when this faulting occurred. It has apparently been presumed that the drifting of all the continents started simultaneously. The author, however, considers that this need not be the case. The date of each break has to be fixed on independent data, and the evidence that Australia and India were together when the faulting occurred need not convey that India and Africa were also joined together as during the Permian period. It has been demonstrated above that Africa had already taken shape at the beginning of the Cretaceous.

More important than the evidence furnished above is that of the fossil flora. The remarkable uniformity in affinities, genus and species that had marked the flora of Australia, India and Africa from the beginning of the Permian period, was suddenly broken at the beginning of the Cretaceous. While India and Australia continued to have similar flora throughout the Cretaceous, and the east coast marine fauna and barred basin conditions were duplicated in West Australia, the African flora was absolutely different from that of Australia. (Walkom: 1929; 161).

Large scale outpouring of basalt is always associated with tensional faulting, which invariably preceds it. The age of the Deccan Trap is not definitely fixed, but is believed to be either the uppermost Cretaceous, or the lowest Eocene (Palaeocene). This suggests that the age of the faulting is from Middle to Upper Cretaceous, at the latest.

It is more difficult to determine the date when India and Australia parted company, but it would not be very much after this faulting. It might very well have been started by this. The trap that covered Peninsular India almost from one end to the other and flowed out into the Arabian Sea, apparently did not reach Australia. It is seen in Rajahmundry, but not in the North West Basin where marine Eocene Giralian Series overlie the Cretaceous Cardabia Series with only a slight disconformity. The few scattered volcanic outcrops recorded from Western Australia seem to be of different type and of doubtful age. The Kimberley leucites are probably Neocomian. While all this may mean that the trap solidified before reaching the Northwest Basin, or that for some reason the flows were directed more to the west, it may also mean that the countries were not together when the outpouring occurred. Obviously, this is not very direct or convincing evidence but this is as far as the author would go on the available evidence.

AGE OF FAULTING

Striking confirmation of the age of faulting as suggested above is available from a slightly different line of evidence. The dolerite dykes that cut through beds of the Gondwana System in India are admittedly, of two periods of igneous activity, the Jurassic to which the Rajmahal Traps belong, and the Cretaceous-Eocene, when the Deccan Traps were erupted. On the above hypothesis the former is older than the faults, the latter younger. In the Damodar Valley most of the faults are older than the dolerites, (Krishnan: 1949; 282), whereas "the traps in Rajmahal area are affected by the faults" (*ibid*). Dolerite dykes are not reported from Western Australia, but they are not known from Godavari Valley either, and only one has been recorded from Mahanadi Valley.

It has been conceded that the broad down warping movement envisaged here, does not exclude faulting altogether. The argument has primarily been against the major boundary faults, as original boundaries of sedimentary troughs, and most of the other faults seem to have been associated with these. Some local, contemporaneous faulting, however, probably, did take place here and there. Some might have been associated with the movement that brought about the slight unconformity above the Panchet Series. The amount of the unconformity itself does not signify a major convulsion of the earth. Jowett (1925: 141), neverthe-less, assigned the main folding and faulting to this period, but the palaeogeographic maps do not suggest this.

ABSENCE OF VERTEBRATES

A factor that puzzled Indian geologists completely is the total absence of vertebrate and fresh water fauna from the Lower Permian sediments in India. Fox (1932; 207-208), thought that "The absence of land animals (vertebrates) may be explained by the destruction of their bodies in the turbulent floods. It is, however, difficult to account for the absence of fresh-water fauna unless the water of the lake was poisoned by organic acids of the vegetable matter or gaseous emanations from the fault planes". This escape may be ingenious but it is not convincing and Fox himself realised it. The rarity of the conglomerates very difinitely shows that "turbulent floods" were few and far between. The abundance of vertebrate fossils in the Siwalik beds, which are admittedly flood deposited, militates against the hypothesis. One, moreover, wonders why the same factors were not operative in other parts of Gondwanaland where under apparently similar conditions vertebrates are preserved extensively, as for instance, in S. Africa and S. America.

A look at the map, figure VII, will, however, explain the position very satisfactorily. At the height of the glaciation practically the whole of India was covered by the ice. The fauna, as well as the flora, was either destroyed or had migrated. The same was the condition in practically the whole of Australia (with the exception of Cape York Peninsula and Arnhem Land), the whole central and south Africa, and the major part of South America. To the north and west of India was the Tethys. The only considerable areas where land and fresh-water animals could take refuge was the Sahara-Northern Brazil area on the one hand and the Antarctica area on the other. The intensely cold climate was, perhaps, more inimical to animal life than to plants and the former did not survive in northern Australia, though the flora did. It has been pointed out earlier that as the ice receded the sea took over. India was effectively cut off from these vertebrate reservoirs. It was easy for the flora, with its 'winged-pollen' and wave borne transport, to re-establish itself quickly, but neither fish nor vertebrate could return. The only 'land bridge' open was very tortuous indeed and even this was effectively closed in Africa for the ice there persisted much longer, as is shown by the Woodbridge Tillites and the ubiquitous erratics in Tasmania. It is, therefore, not surprising that though vertebrates are recorded from S. America and Africa in the

Lower Permian, they do not appear in India and Australia till the Upper Permian period, and even then are very rare. The forests that grew the Dadoxylon and the Gangamopteris were practically uninhabited for a long time and so, too, was the area over which the fresh water conditions prevailed. The only specimen known from the L. Gondwana beds - the Actinodent is from Kashmir and indicates that perhaps a few survived in the northern part of India, perhaps on the "island" there. Then, sometime after the Middle Permian period a few vertebrates appear to have entered these continents, perhaps, during a very short inter-glacial period, and there is record of Bothriceps from the Upper Coal Measures in New South Wales; and Gondwanosaurus from the topmost Permian beds in Peninsular India.

This conception of an Upper Carboniferous refuge receives additional support from the occurrence of Lepidodendron and Sigillaria from S. Africa and S. America only. It is very significant that Lepidodendron alone is reported from the Permian of Queensland and the Desert Basin only, though it was widespread in the Carboniferous period over the whole of Australia. Apparently, it survived on the Cape York Peninsula and Arnhem Land. Sahni (1926, 243), considers these occurrences as remnants of the Carboniferous flora, and it has been reported from the fresh water Carboniferous of Sudan. It apparently, died out before it could reach N.S. Wales or India. The change of the flora, then, was not due to the "Striking biological changes that involved the wiping out of most of the plant life and by the rise of Gangamopteris-Glossopteris flora" as stated by Du Toit, but due to extermination by ice cap. The Glossopteris flora might have evolved in Antarctica, as suggested by Seward, and spread therefrom, and Du Toit's suggestion that it evolved in S. America, does not appear to be borne out by evidence. From Antarctica it is likely to have reached Australia and Argentina more or less simultaneously, as it presumably did and there got associated with the Lepidodendron.

AGE OF DWYKAS

If the centre of the ice cap was located in east Africa, then it follows as a corrolary that the top of the Dwyka tillites is, probably, younger than what has usually been supposed. It, presumably, ended with the Woodbridge Formation of Tasmania. This is also indicated by the occurrence of Gangamopteris, Eurydesma and Conularia in them, whereas these fossils occur much above the basal tillites in India and Australia. Mesosaurus which occurs in the 'white band' just above the tillites in South Africa, is also known from the Iraty Shales in Brazil. It is significant that recent opinion in S.America (Barbosa: 1952: 317) considers that there exists a disconformity between the latter and the L. Permian Tubarao series, which carry the tillite and the Glossopteris flora. The Iraty Shales are overlain by the marine Passa Dois beds which pass upwards into Middle Triassic beds. A supra-Lower Permian age may, thus, safely be concluded for the Mesosaurus bed in the Parana Basin, and should apply to the White Band as well.

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Oppenheim (1935) considered the Iraty Shales to be distinctly Upper Permian in age

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age, conforming more to the uppermost Raniganj in India. The decline of the genus Gangamopteris in the U. Permian is a well established fact and both in India and Australia its disappearance synchronised with the end the Permian Period.

The presence of Gondwanidium validum a species restricted to the Karharbari beds in India, however, militates against such a conclusion. Yet it may be pointed out that in Australia it occurs even in the U. Coal Measures, and, therefore, appears to be valueless for correlation. Recent work in India has demonstrated that the number of species of Glossopteris and Gangamopteris present and the actual proportion of their leaf impressions in the composition of the flora are more reliable guides of the age of the beds, than the presence or absence of, perhaps, any individual species. Judged by this principle a Permo-Carboniferous age for the Dwyka Series is, apparently, untenable. For the Wankie Sandstones in South Rhodesia, Maufe suggested a are overlain by the marine Passa Dois beds which pass upwards into Middle Triassic beds. A supra-Lower Permian age may, thus, safely be concluded for the Mesosaurus bed in the Parana Basin, and should apply to the White Band as well.

The presence of only one species of Gangamopteris, the ubiquitous G. Cyclopteroides, its complete absence even from the Ecca beds and the occurrence of Glossopteris retifera only in the lowest beds of the Lower Beaufort do indicate a higher age, conforming more to the uppermost Raniganj in India. The decline of the genus Gangamopteris in the U. Permian is a well established fact and both in India and Australia its disappearance synchronised with the end the Permian Period.

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Beaufort rather than on Ecca age (1929; xxx), and these have been found to overlie a tillite (Bond: 1952: 211)!! This flora, certainly, has more affinities with that of Raniganj Coal Measures than the lower formations.

Du Toit has pointed out (1929; 95), the composite nature of the Dwykas in Lainsburg, on the Sundays River and in Natal. He considers the breaks to be due to interglacial recessions. If these interglacial periods were long enough to be recorded so very near the centre of the glaciation, they would naturally be represented by much thicker sediments in Australia, where they must have started earlier and ended later. These were then the periods during which the greater part of the Lower Marine Series, the Greta Coal Measures, and a large part of the Upper Marine Series were deposited in New South Wales. In Natal "a double and sometimes a triple tillite is found" (Du Toit; 1929; 95). In the Hunter River Valley there are the tillites of the Lochinvar Shales, the Allandale-Rutherford Stages and the Branxton-Muree Stages. It would appear, then that the top of the Dwyka tillites is, if anything, slightly younger than the top of the Muree Stage tillites, and considerably younger than the top of the Talchir tillite in India, where these later glaciations do not seem to have reached.

Dwykas are one of the thickest of the tillites at the base of the Gondwana formations and this may indicate their longer duration. The deposition was, apparently, very slow and just sufficient to maintain the conformity of the beds as is found in South Africa. These Dwyka beds may, then, represent a period which presumably started sometime before the deposition of the tillites started in India, for instance, but ended much later. It has, in the past, been taken for granted that the basal tillite everywhere was coeval. This presumption is fundamentally wrong and has resulted in the faulty correlation. It could be true only if the tillites were deposited by local valley glaciers and not by an ice cap - so extensive both in time and area - with its centre in East Africa.

The only reason why this correlation has not been adopted in this paper is that though the stratigraphic evidence is strong and very convincing and there is considerable supporting palaeontological evidence, as pointed out above, the author considers that the point requires more confirmation. It is, for instance, for the palaeontologist to say if there is any thing so primitive in the characters of the Mesosaurus to militate fundamentally against a younger age being assigned to it.

Caster (1952: 141) has pointed out that, "Despite floral affinities with the underlying Permian, the Middle Beaufort reptiles are judged by vertebrate palaeontologists as

Lower Triassic", and this is, perhaps, not without significance. If there was a single ice cap, as the directions of the striations on pavements indicate, the tillites nearest to the centre of this ice cap have get to be younger than those further away. Only those along the margin of the ellipse in figure VII are likely to be contemporaneous. This is independent of any other consideration. Du Toit's inference of the age of the Dwyka based on the evidence of the ages of the tillites in South America and India is founded on fallacious arguments. But then he believed in several different centres of ice, though in his map (figure 9) Du Toit (1937; 76), he has shown a single ice cap.

This new concept of the age of the Dwyka Series does not, on the other hand, cut across the correlation of the Triassic of Africa with those of Australia, which appear to be based on fairly sound grounds. The Ecca Formation, however, becomes the equivalent of the Raniganj Coal Measures of India, and the Upper Coal Measures of New South Wales, and thus contemporaneous with the second period of coal formation instead of the first.

It need not, however, be emphasised that this view is not the same as that expressed by Schuchert, for he imagined the glaciation to begin in Middle Permian time, separately in all the different continents. Here it is supposed to begin well down in the Upper Carboniferous, if not earlier, and end in Upper Carboniferous in India and West Australia, and also perhaps, in South America. Only in South Africa and east Australia it continued till much later in the Permian.

ABSENCE OF TILLITES FROM ZAMBEZI AREA

The absence of the tillites from the Zambezi area was for Du Toit difficult to explain. But it remains no more a mystery when the centre of the ice cap is placed there. Once the acme of the glaciation was passed, and the ice cap had started to retreat areally, it would also reduce in thickness. Towards the end it would lose its power of erosion, and finally would break up, more or less suddenly, over an extensive area. Thereafter, it would probably return during the winter, occupying smaller and smaller areas from year to year, and tending to become more a protective cover than an eroding agent, though its melting during the summer would cause a havoc in the lower regions. This central area, then, would never have any tillites deposited and a considerable belt around it, would, presumably lose it to the floods, if it was not immediately covered up by water. The occurrence of tillites in Uganda, Congo, Madagascar, etc. to the north and west of this central cap area, goes to confirm this view.

The agency of floating trees has been suggested to explain the occurrence of occasional large boulders in the Barakar Stage, sometimes even resting directly on a bed of coal. Swampy conditions do not exclude the possibility of such an origin, but it is not clear how the sphericity and roundness of these boulders are to be explained, unless it be presumed that conglomerate beds were being eroded everywhere. On the other hand these may simply be erratics brought in by floating ice - this explanation has been made for a similar phenomenon in the Irwin River Coal Measure (Clarke, et.al. 1948-49, 65), and the dumped erratics of the overlying Carynginia Shales lend very strong support. This would, perhaps, indicate a local ice cap to the west of Umaria from where valley glaciers descended.

The Carynginia Shales are correlated with the U. Marine Series of N.S. Wales, and a deterioration of climate is, therefore, established. On the other hand, the absence of any sign of this glaciation from N.W. Basin (Teichert: 1952: 128) and the Desert Basin suggests that in this area the cap was situated to the south of the Irwin Basin. It might have been this cap that, after removing the earlier sediments, deposited the tillite now known from below the Collie Formation and initiated the sedimentation in that area.

Similar local glacial conditions, perhaps, appeared in the Panchet period in India. Some of the shales are again "Talchir-like", and very suggestive of varves, but more important than this is the evidence of erratics reported by Crookshank from the Denwa Stage. Fox, however, did not agree, though only on the general ground that the Triassic was a period of widespread desiccation, and rising temperatures, and not of refrigeration. But this was only history repeating itself, for on these very general grounds Blanford brothers were ridiculed when they suggested that Talchirs were of glacial origin. A Triassic glaciation is also inferred for Bolivia and a glaciation has been debated for parts of the Lubilash Beds of Congo. All these areas invite critical and detailed field work. And a cold, moist climate is distinctly inferred for the Queensland Triassic beds.

These lines of evidence would suggest that, apparently, a ridge high enough to carry perpetual snow and glaciers existed in Middle Permian times somewhere in West Australia, and there might have been one in S. India till the Triassic Period. This latter, might have earlier been a low, growing range and showed some signs of having been glaciated during the Barren Measures times, when temperatures were generally lower. It must have attained very considerable height, at least temporarily, to be glaciated in the Triassic Period.

THICKER TILLITES OF DESERT BASIN

The tillites in the Desert Basin are much thicker than further south. Teichert (1941: 393), has suggested that this may be due either to an earlier beginning of the glaciation or a quicker accumulation of the sediments. He, however, does not explain how, with the continents in their present position, an area nearer to the equator could be glaciated before an area in the temperate region. Even with an ice cap, as imagined in this paper, an earlier start of glaciation in the Desert Basin, lying near the margin of the ice cap at its maximum, is not tenable. On the other hand, it should have reached there later and ended earlier than, say, the N.W. Basin.

It may, however, be pointed out that on land the till preserved is usually the deposit formed during the retreat of the ice cap, but over a sea area the deposits formed during the growth of the ice cap are also likely to be preserved. The advance and retreat of the cap about the acme of the glaciation was -and this is very likely - perhaps, very slow. There were, presumably, more spells during which it even halted temporarily, while the basin containued to sink fairly rapidly, and collected thicker deposits than those further south.

DISTRIBUTION OF GANGAMOPTERIS

Teichert (1943), has also pointed out the absence of *Gangamopteris* from the Desert Basin though *Glossopteris* is present in the Poole Sandstones and in younger beds. It is generally not safe to base an argument on the absence of a fossil from an area about which really so very little is known. He mentions that "Du Toit (1930) seems to have been the first to point out that the distribution of *Gangamopteris* is generally more restricted than that of *Glossopteris*. In South Africa it does not range north of Union Territory". Du Toit himself reported it from the Entebbe Series of Uganda in 1931, and this shows the extreme vulnerability of such conclusions. Stockley had, already, reported Gangamopteris from Tanganyika in 1922, and then Rennier in 1933 discovered it in Walikale, Belgian Congo. In fact he found no Glossopteris in his collection, and "more recently Gangamopteris has been found in great abundance in the glacial beds at Walikale" (Veatch: 1935: 152). It also occurs in the Wankie Coal Series of Rhodesia.

After pointing out the absence of the genus from Queensland, which is geologically well explored and should have yielded it, from north of 22°S latitude, Teichert concluded, "that the Gangamopteris plant was better adapted to a colder climate than Glossopteris. Such an assumption would account for its early appearance and its limited northerly distribution". But such an assumption would create the much greater difficulty of explaining its distribution in India and Africa if the present latitude had any significance at the relevant period, as he appears to take for granted. It occurs in India in practically every area from which Lower Gondwana beds have been reported, and this means to about 17° N. latitude. It reached much nearer to the Equator in Africa. Teichert's conclusion about its better adaption to colder climate may still be correct, for in Queensland it appears to have been, for some reason, restricted to the area that had been glaciated a short while earlier. It might, thus, be expected to turn up from the Desert Basin too. If it is really proved that it did not exist in the Basin it would be necessary to look for the absence of some other ecological factor which made the area uninhabitable for the genus. There are obviously many possibilities.

UNIFORMITY OF FLORA

On the other hand, the great uniformity of flora from Argentina to Queensland and from Kashmir to Antarctica indicates, as Du Tóit has pointed out (1937: 83), the absence of any effective barrier in the form of high mountains or, perhaps, wide oceans, as well as a fair uniformity of climate. Knowlton (1919: 501) was right when he pointed out "that plants inherently possess the qualities which permit them to exhibit the more reliable criteria as to the climatic conditions". So that if climate had been different in the various areas, it would have been reflected in the flora.

FOREIGN ORIGIN OF SEDIMENTS

A peculiar feature of the deposits on the east coast of Australia is that the sediments appear to have had their origin further to the east. It has been known for a long time and was re-established when Culey (1938: 103), examining the heavy mineral assemblages in the Permian and Triassic sediments of New South Wales came to the conclusion that the sediments had their source in the east. Du Toit came to the same conclusion for the Karroo beds of southern part of the Cape (1939: 250), Veatch has pointed out the case of the Lubilash sediments of the

Congo basin which appear to have their source in the Atlantic (1935: 61). Krishnan mentions it for the Cretaceous Uttatur Beds of South India and the phenomenon has been noted on the east coast of S. America. The case of Western Australia has already been mentioned in some detail, while Bray (quoted by A Holmes : 1929: 209), has convincingly demonstrated that the source of the Gold Coast Banket deposits lay in the area to the south west, in the region that is now sea. "Thus where the Atlantic now lies there must formerly have been a great river, possibly transporting gold from a continent that has since subsided far beneath the waves, or drifted away to the west where, perhaps, part of it is still recognised in the auriforous tracts of Guiana and Brazil" (ibid). And the diamonds now won from the sediments from the west coast of Africa are said to be identical with those of Brazil and are not akin to those of Africa.

Currently, because of the inherent difficulty of getting rid of large land masses without leaving any trace, the tendency has been to believe that chains of islands existed beyond the coasts. This hypothesis of "island arcs", however, appears to be applicable only to the orthogeosynclinal basin, whereas the instances quoted above - and the list is by no means exhaustive - do not seem to have been restricted to these earth features. Moreover, it seems hard to believe that every major continent in the past had chains of islands all round it, nor is the feature restricted to Gondwanaland for Schuchert had to presume the former existence of Appalachia to explain the source of sediments on the east coast of N. America.

On the other hand, in any reconstruction of the land form on the Drift Hypothesis, Australia had extensive land areas on both sides, S. America had it on the east, and Africa had land areas to the south, as well as to the east and the west. Does it suggest that the sediments came from across the sea? Du Toit has suggested that the source of the red jaspers in certain S. American conglomerates might have been the in situ beds in Africa. Though he has not been able to establish a case, the possibility is, perhaps, there. The only supposition this suggestion demands is the existence of large rivers, like the Amazon and the Ganges, to bring down large quantities of debris during the flood season. The author submits this as a possible explanation, on the assumption of the Drift Hypothesis, for the consideration of geologists working in the critical areas.

"WESTRALIAN GEOSYNCLINE"

Every one who has worked on the west coast of Australia has been struck by the occurrence of *Metalogoceras jacksoni* in the Holmwood Shales of the Irwin Basin. The impression they all got is that *Metalogoceras jacksoni* appear to have been driven into the region and then caught by sudden death. The identical case of the Productids in the Umaria bed has been mentioned earlier. Teichert imagined a warm current moving southward in his 'Westralian Geosyncline' (1951: 88). The geosyncline suggested by him is open to the south but the author suggests that a basin closed to the south, as shown in map figure IV., is more likely to form the death bed of faunas accustomed to more open seas. This inland sea was probably not habitable by Eurydesma,* and this would explain their extreme rarity - if not their absence - from the west coast of Australia, a fact that has puzzled every one to date (ibid) even if it turns up some day from the Permians of Timor, for that island was obviously more favourably situated at the time, in this reconstruction of Gondwanaland.

THE SHIRE-ZAMBEZI AREA

Though this paper deals with Africa only in a general way it seems necessary to mention the anomalous thickness of the sediments in the Shire-Zambezi basin, if for no other reason, then to call attention of geologists in that country to seek the explanation. The Permian section in this small area is, from available descriptions, almost three times the thickness in the surrounding areas, and compares with that in the Union, well to the south. Yet all evidence goes to show that this was a small non-marine basin more or less cut off from the eugeosynclinal area. The following explanations offer themselves to the author's mind.

* It has recently been reported from the N.W. Basin, and is presumably present in the Umaria fauna. See Post Script p.204.

Admittedly the area is heavily faulted, and it is, consequently, possible that there has been some repetition of beds that has gone undetected. The section is, however, backed by the authorities of Mennel and Dixey and if it is accepted as correct, it is possible that in this area block faulting occurred pari passu with deposition, and caused thick sediments to be deposited. But Dixey thinks that the Nyasa-Shire rift started only in Upper Jurassic time. If this is correct, some other explanation has to be found.

It should, however, be pointed out that this anomaly is independent of the reconstruction of Gondwanaland used in this paper, since it is cut off from the adjacent parts of Tasmania by the 'peninsula' and virtually lies in the heart of Africa. Had it not been so cut off from the sea, marine incursion would, very likely, have taken place.

BOULDERS IN TALCHIRS

Some of the boulders in the Talchir tillites have occasionally been stated to be similar to Vindhyan sandstones. The point has been discussed in a previous chapter, and it might be stated that this comparison has, perhaps, never been taken beyond the observations made on hand specimens. Fermor (1914: 168), compared them from memory. The occurrence of garnets in the Talchir shales in Singrauli has already been mentioned, and if they had been transported from the south, it follows that the boulders in the tillites should also have a source in that direction. The maroon to brick red quarzite boulders which, more than any other type, carry marks of striation in the Singrauli tillites, should have a source, then, in South India or Australia, even if it is supposed that the granite is of local origin. If these cannot be matched with some of the ferruginous quartzites in Cuddapah and Kurnool, they appear to have no source in South India. Whereas this may be due to the fact that the relevant beds have been eroded away, they might have been transported all the way from Western Australia or even east Africa. Ferruginous quartzite is a common rock type in the former of these two areas. If the sandstone boulders can really be matched with some of the Vindhyan sandstones, then the original band of these Vindhyans too was somewhere in the south.

The local granites in Peninsular India present such an infinite variety of types that it would not be impossible to match a boulder with some band or the other, yet no detailed work appears to have been done. A study of these presents a fascinating subject.

CURRENTS

It would be noticed that tillites and occasional glacial boulders are far more common on the east coast of Australia than in South America, though both the areas were, more or less, equidistant from the main centre of the ice. Apparently they go on decreasing as one proceeds north, yet are noticeable in the Marine Stage of the Middle Bowen Series of Queensland. Recent work on the ice bergs off the coast of Greenland indicates that floating ice-bergs follow certain fairly well defined routes. It is imaginable, then, that a current in the Samfrau from South America towards Australia was collecting these ice bergs off the coast of the present South Africa, and was responsible for the scattered occurrence of boulders. Teichert (1932: 88), has pointed out that fauna of Tethyan affinites was entering eastern Australia both from the south and the north. Fauna of Salt Range affinities has been found as far away as Bolivia, and this current might have been carrying it from the Tethys off the west of South America to Australia. A counter-clockwise current, due to the rotation of the earth, was almost inevitable around Gondwanaland, and would explain the movement, both in the Tethys-Rockies geosyncline and the Samfrau. Teichert has also pointed out that probably a warm current was flowing from north to south on the west coast of Australia. A barred basin, as suggested in this paper, would, inevitably, have a current entering it from the open sea. and moving away from the Equator it is likely to be warm, too. Most inland seas today have surface currents entering into them.

RAINFALL AND RANIGANJ COAL

Enough has been said in the previous chapter to show that coal in India is autochthonous. The restricted distribution of the coal in the Raniganj Coal Measures, however, requires a further consideration. While drainage of the land is likely to play an important part in the location of rain-forests, both tropical and temperate, they appear to be today more a function of rainfall, being restricted to areas which receive over 100 inches in the year. Towards the Upper Permian period general dessication was approaching, temperatures were rising and rainfall decreasing. It is, therefore, not surprising that Raniganj coal seams are more restricted, and decrease rapidly westwards. Probably the 100" isohyet passed through Raniganj then.

THE "TASMANTIS"

In a recent article Caster (1952) after comparing in detail - lithologically, faunally and florally - the Devonian formations of S. America and S. Africa states (ibid: 124) (the author apologises for quoting extensively from him and later in this section from Bryan) that "The present remnants of the "austral" Devonian sediments show every sign of structural interruption at the present coast lines. On both sides of the S.Atlantic the Devonian epicontinental seas must have extended into the area now occupied by deep ocean basin. In S.Africa this means a geosynclinal extension westward (? north-westward) of the Cape trough; in S.America the Parana basin epi-sea reached far beyond the present continent ..... the biotas on the two sides of the Atlantic share identical ("austral") cratonic elements, rather than geosynclinal". And again (ibid: 125) "This means that the Cape trough did extend over a great distance into the present deep Atlantic basin area, to connect with eastern Brazil (Piani) "boreal" development, which shares some striking faunal similarities with Bokkeveld - Witteberg.... These facts leave us with very little alternative other than to bridge the S.Atlantic basin with "continent".... In the L. Devonian there was no "S.Atlantic basin" in existence in any dimension or condition which would justify applying the modern name to it".

After, similarly, discussing the Carboniferous and Gondwana formations on the opposite sides of the S.Atlantic he adds (ibid: 143), "The colossal fact remains that the two sides of the ocean are astoundingly similar in over-all sequence both in sedimentation and in flora and fauna. Moreover they require cratonic ligation in order repeatedly to complete the sedimentary and general ecological picture". And concludes (ibid: 144-145): "To this writer there seems to be no satisfactory manner of accounting for the Carboniferous-Rhaetic relations as preserved in S.Africa and S.America without intimately connecting their history across the S.Atlantic basin. This history requires the absence of oceanic deep where now the basin exists. This means restoring a continental cratonic sector between the present borderland.... An Afro-American "Gondwanaland" seems, from the stratigraphic and paleontologic data now available, to have been a reality. Furthermore, this trans-Atlantic ligation, seems to have existed far back into the Paleozoic, so far, in fact, as to make any discussion of a S.Atlantic Ocean impractical until after the Rhaetic.... Thereafter, dissimilarity rather than linked development seem to be the characteristic of Africa and S.America".

An eastward extension of the Australian continent has, similarly, been discussed for several decades, though with this difference that in this case the existence of land is only inferred and no detailed comparison is, therefore, possible. Thus Clarke as early as 1878 (quoted by Bryan: 1944: 48) suggested that a former extension of eastern Australia has been lost by subsidence into the Pacific. Schuchert pictured it as "the eastern half of the Australasian continent, a land about 1,800 miles east and west, and 2,200 miles north and south", and included New Zealand, Fiji and Tonga in it. Andrew agreed, but thought it was somewhat smaller. Sussmilch and David (1919: 277; see also Walkom 1918: 102 _et_. _seq_.) evidently regarded it as of considerable size and referred to it as "a separate land area.... which existed to the east of Australian continent at least as far back as the begining of the Devonian period and probably as far back as the beginning of Palaeozoic era", They called it "Tasmantis", and thought that parts of the present day Queensland and N.S. Wales - the New England plateau - originally belonged to this 'lost land'.

More recently Bryan (_ibid_) has reviewed the evidence in some detail, and some of his observations are particularly interesting. Thus he states (_ibid_: 47) that, "back beyond the Mesozoic era there seems to be little direct evidence either for or against the existence of Pacific basin as such" and (_ibid_: 48)

"Quite clearly the minor topographic features of the land surface can be traced beneath the Pacific.... But many major geographical features also appear to be truncated at the coast line and something far more important than a relatively small change in sea level is indicated.... Geologically the incompleteness of Australia is even more marked". He agreed with Jensen's statement that "the island of New Caledonia is a remnant of a once continuous continent, the Melanesian plateau, which extended westward to eastern Australia and New Guinea and south perhaps to New Zealand" and thought that the "Brisbane schist was laid down in a mediterranean sea in the heart of a great Australasian continent".

Summing up the opinions Bryan had quoted, he says, "The only points of general agreement in the several interpretations of the Mesozoic era appear to be that (1) an eastern extension of the Australian continent (either in the shape of a continuous mass or a detached archipelago) reached far out into the Pacific, and (2) atleast by the end of the era the various portions of Australasia ceased to have any striking unity of geological history". He, therefore, concluded, "That a great Australasian continent existed immediately to the west of this Line (the Marshall Line) from as early as pre-Cambrian times and persisted throughout the Palaeozoic and Mesozoic eras".

All the authorities quoted above believed that this land mass has faulted down. But "there is no evidence in the existing gravity data of foundered land bridges in the deep oceanic basins, unless these parts of the dense oceanic crust were held up out of isostatic equilibrium and foundered to establish isostatic equilibrium" (Ewing: 1952: 90). This opinion has a universal support from all geophysicists and what is true of narrow land bridges is more forcefully true of vast continental land masses.

Thus, one is almost obliged to agree with Arthur Homes (1929: 340) when he says, "Clearly it is as difficult to sink continent as it is to tear them forcibly apart, and in the absence of a clear geophysical lead one must choose between the alternatives of vertical or lateral displacement on their individual merits in relation to other problems. Here continental drift has more than one decided advantage". In the reconstruction used in this paper, Antarctica is believed to have been this "lost land" of Bryan, Schuchert, Sussmilch, David and others. It is supposed to have drifted away at the end of the Mesozoic era or very soon after it. Some current postulates do indicate that, may be, 'drift' is not as impossible as it was believed to be.

CHAPTER VIII

RECONSTRUCTIONS OF GONDWANALAND

A fairly detailed picture of the palaeogeography of Gondwanaland during the late Palaeozoic and the Mesozoic has been presented in the preceding pages. Carey's (1951) reconstruction of the former giant continent was used throughout, and some reasons were given for this preference. It will, however, not be altogether out of place to give a brief review of some of the main theories dealing with Gondwanaland, and the various attempts at reconstruction that have been made since the news of tillites, similar to what Blanford had reported from India, started pouring in from the three southern continents.

These reconstructions have taken, as is well known, two distinct lines, one based on orthodox concept of the essential fixity of the continents, and the other depending on their mobility, as suggested by Taylor and Wegener. The problem has been discussed on several occasions. An important symposium was held in New York in 1926, and the papers submitted on the occasion were later published, (Van der Gracht: 1928). Holmes wrote a review in Nature (1928: 431-433), and discussed the evidence produced very dispassionately, something that appears to have been lacking at the meeting itself. Recently a symposium on the subject was held in England (1950) and some welknown scientists participated (Ad. Sc. VIII), while in America at yet another symposium on "Problems of land connections across the South Atlantic" the problem was revived and discussed, though only in a restricted form. Thus though considerable interest has been created and great progress has been made, solution has evaded the scientists, and the two schools remain as sharply devided as ever before.

To explain the peculiar distribution of flora and fauna in these continents, 'land-bridges' are, by some, envisaged to have existed in the past. Fairly wide in the beginning these hypothetical bridges have gradually been reduced to 'slender isthmian or island arcs' (Dunbar: 1949:308). Apart from the failure of this conception in explaining the occurrence of glaciation within the tropics, its very widespread distribution in the Southern Hemisphere, its presence in India to the exclusion of the rest of the Northern Hemisphere, and many other points, there is the great inherent difficulty of sinking these, so called, land bridges. As Holmes (ibid:432) has pointed out, "If there is ocean where there was land, then the former sial of that area must now exist somewhere else", also "the only alternative to laterial drift is removal of the sial at the base by magmatic currents in the substratum, but if this be a possible method of sinking land-bridges, then it implies a process capable of transporting continents". It, however, appears difficult to explain "the remarkable similarity between S. American and African reptilian fauna in the M. Triassic" (Romer: 1952:252) and similar cases of other vertebrates, and the entire benthonic assemblages. Holland (1944) stressed the case of Mesosaurus when he stated that "In Cape Colony there is a thin band of black clay in the Dwyka series and at the same horizon in S. America the Irati shale is composed of exactly similar material, also forming a thin bed. In each area there are well preserved remains of a small primitive, free-swimming reptile, Mesosaurus — obviously a delta scavenger — which is not known elsewhere in the world. If S. Africa and S. America were always separated, as they are now, by an ocean 4,000 miles wide, it is very unlikely that the bones of Mesosaurus would be found in both areas, and in similar deltaic clays very nearly, if not exactly, of the same age". The only point that Holland did not stress in the above quotation is the fact that Mesosaurus was incapable of crossing deep oceanic stretches.

It hardly seems necessary to go into great details of the difficulties that confront the concept of the fixity of the continents. These have been pointed out by Wegener, Holmes, Van der Gracht, Du Toit, Caster and others, and the reader is referred to the works of these eminent scientists. But a point which, it appears, did not receive the emphasis it deserved, is indicated by the direction of the ice movement as seen on striated platforms. These are marked on map, Fig. VII, and it will be noted that with the possible exception of India, they are always from the sea inland. Thus in South Africa it is from the east and north-east, in Australia and Tasmania it is from the south, and in the tiny Falkland Island it is from the north. The two striated platforms known from India are so far inland that any inference may be drawn about the location of the ice cap. One, however, wonders where the centres of these glaciations were for the other three continents? An ice cap could, undoubtedly, be located on an ocean, but like the Arctic cap, it would not deposits a tillite. If the Palaeozoic glaciation had several ice centres in different oceans, where were the glaciers from them collecting the large amount of material they have deposited?

Then, again, why is it that no tillites are known to occur in New Zealand? And from what little is known of Antarctica, they do not seem to be present there either, not atleast in the Beacon Sandstone. Instead, New Zealand had a warm climate in Permian time, when the rest of the Southern Hemisphere was partly or wholly ice covered. (Hornibrook: 1952: 25; also Heathereed: 1952:26).

Caster (1952) has emphasized the similarities between various formations in Africa and their counter-parts in S. America, and has pointed out that these could only be explained by bringing the two continents together i.e. by accepting a westward drift of the latter in respect to the former. If this be accepted, the drift of other continents needs no further evidence. Charles Schuchert has pointed out that the central Asiatic mountain ranges represent a shortening of the crust by about 1,800 miles in a comparatively short period of the earth's history. If this be due to the cooling and contraction of the earth, why is it that the most severe and most extensive contraction took place so late in the history of the earth? This contraction in the circumference will mean a contraction of several hundred miles in the radius of the earth resulting, perhaps, in large scale transgressions. There does not seem to be any evidence of this.

These are some of the arguments advanced by those who believe in drift. Though the theory is still referred to as Wegener's, and the basic idea has remained more or less unaltered, the details have since been worked out more fully, and basically altered many of Wegener's important points. He was not only handicapped by lack of information, but was a poor advocate of his case. His was, nevertheless, a pioneer's effort, correct in principle, but wrong in details. And he put a bit too valiant a fight for it. Like Ptolemy's map of the world, or the discoverers' picture of Australia or America, it could not but be wrong. "As Van der Gracht insists again and again, the details of the picture and particularly the mechanical and physical explanations, will require generations of research" (Holmes: ibid: 433).

It will, perhaps, suffice to point out a glaring mistake in Wegener's map. His Upper Carboniferous map (1924 : 6) has no place for the deep geosyncline that existed in South Africa at the time, whereas only a shallow sea covers the eastern part of Australia. Many have criticised, and justly so, his climatological studies and the positions of his poles and Equator during the different periods. and this criticism need not be repeated here.

The theory was enthusiastically taken up by Du Toit who (1927) culminated his years of research with "Our Wandering Continents". His work was, undoubtedly, a great advance on Wegener's effort, and backed by more accurate information, as well as personal knowledge of several continents, he was able, effectively, to reply to many of the objections that were tearing the 'Origin of Continents and Oceans' to pieces.

Thus, though based on lines originally suggested by Wegener, he brought in many points of detailed similarities between Africa and S. America (now restated and added to by Caster and others) and greatly enhanced the force and prestige of the theory. His was still a pioneering effort, and he never claimed that his reconstruction was the last word. Progress in knowledge during the last two decades makes a reassessment necessary, and it is essential to point out why Du Toit's reconstruction fails to satisfy.

Thus, he appears to have a very hazy idea of the extent of the Tethys and confuses it with the 'Samfrau' geosyncline. An outstanding example is his statement that "The succession in Spiti, India, provides close parallel with that in New South Wales" (Du Toit : 1937 : 68). He has, however, placed the former in Tethys and the latter in the 'Samfrau', and does not even explain if these two seas had any direct communication between them. His map, Fig. XVII, in any case, does not show any connection on the east. More important than this is the fact that the continuation of the 'Samfrau', for a considerable distance between South Africa and Antarctica runs through an area where there is no proof of land having ever existed, and a geosyncline cannot be located in such a position. This appears to be against the fundamental conception of a geosyncline which must constantly be fed, and Du Toit would certainly not invoke sinking of the land to explain this anomaly.

Again, Du Toit recognised that "The Archaean rocks of India and Western Australia are not only similar lithologically, but show the same general strike" (ibid : 126), yet he puts them so far apart in his assembly that any such resemblace is likely to be brushed aside as mere coincidence. That these two countries have more identical geological features than the general statement above makes out has been pointed out in the preceding pages. Some of these had not been discovered when he was writing, and so his prophesy that "any close resemblance in the structure of these two lands would hardly be anticipated" was doomed from the beginning. More important, however, is the fact that Du Toit places N.W. Australia almost in the Tethys, which was an eugeosyncline. Western and northwestern Australia show no evidence of being even close to one, and were, at the most, part of an autogeosyncline, as has been suggested earlier. Epeirogenic evidence, thus, does not support his assembly.

A similar failure to interpret the evidence correctly is shown by his demonstration of the "marvellous parallelism" shown by the stratigraphy and orogeny of South America, South Africa and Australia. He correctly emphasises that the phenomena are highly improbable with those "continents stationed at their present distances". But the distance between Australia and South Africa has only been slightly reduced in his concept of Gondwanaland. Only the 'grain' has been rectified by rotating the former.

PLATE XV.

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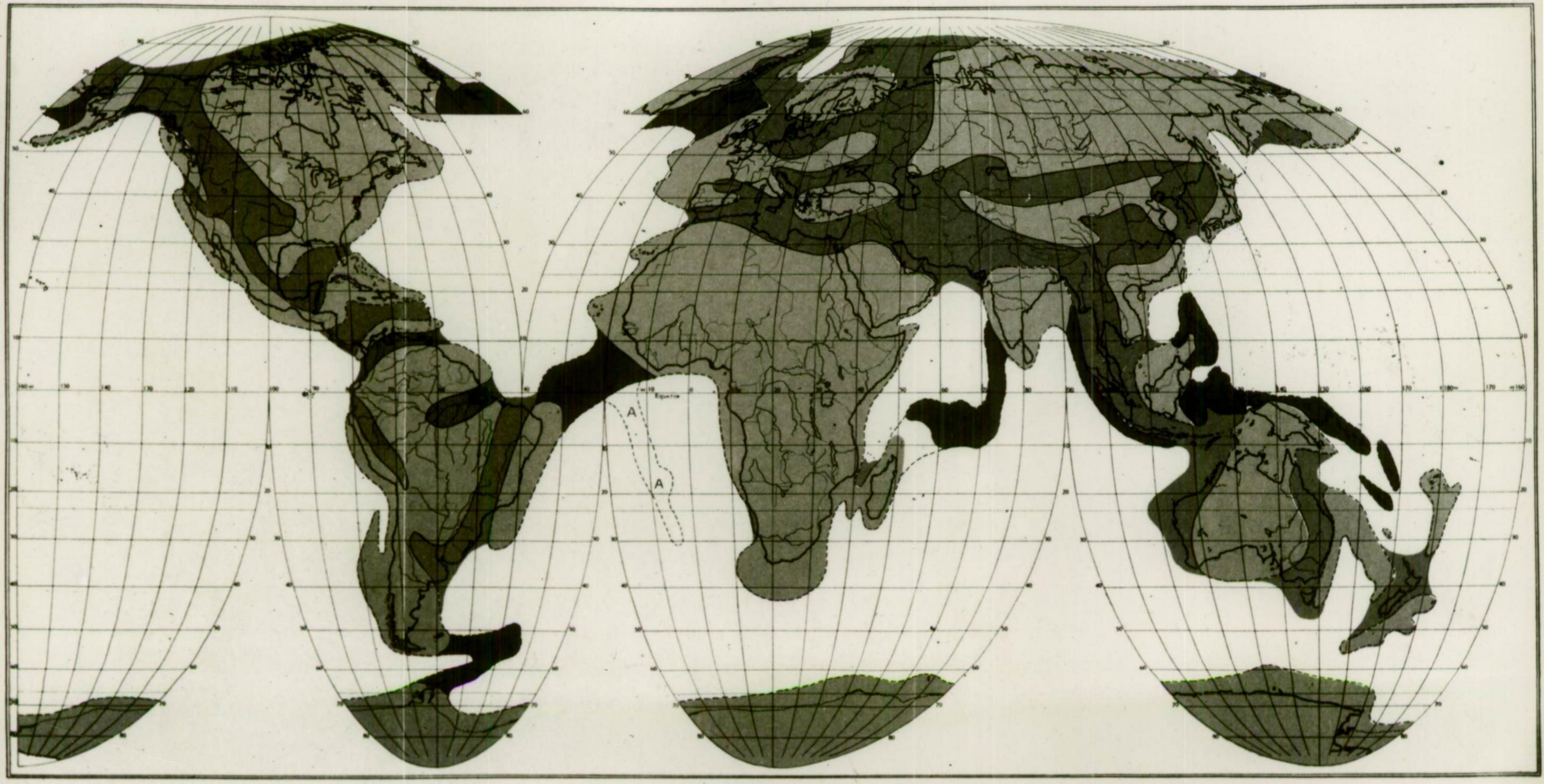


SYNTHETIC PALEOGEOGRAPHIC MAP OF ALL PERMIAN TIME

On Goode's Homalographic Projection

Oceans—*white.* Inland and shelf seas, and mediterraneans. Late Carboniferous in northern South America introduced to show geosynclines—. Lands. Land bridges and isthmian links. *A, A,* a probable isthmian link of Mesozoic time

Du Toit seems to be, somehow, (and this appears surprising) undecided about Burma, Indo-China and even China. Though he does not include these countries in his maps, passages like, "During the Upper Silurian, negative movement of the Continent deepened the main geosyncline of Eastern Australia and brought in the sea over Tasmania, past Melbourne to Cobar and thence by way of Charleville to Chillagoe at least, Dutch New Guinea, Burma, China and onwards" (1937 : 59) give an impression that he includes them in Gondwanaland (see also ibid : 84; and 126 et seq.). This is untenable.

Similarly, though he claimed (ibid : 75) that "One of the chief merits of Displacement Hypothesis lies in its professed ability to explain the present day distribution of such Palaeozoic glacial remains", the absence of glacial remains from the New Zealand Permian beds and from the Beacon Sandstones in Antarctica, as has been pointed out earlier, forms weighty argument against his reconstruction. This absence is, easily explained on the reconstruction used here (Fig. VII).

One could point many more similar anomalies and weaknesses in his reconstruction and in his description but that would be going beyond the limits set here. The capital argument in this paper has been the isopach map and epeirogeny, and his assembly should be tested on this touchstone.

He places Peninsular India against Kaiser Wilhelm II Land, Tasmania against Victoria Land and South Africa closest to Louis Philippe Land. This would presume that Gondwana formation exists over almost the entire Antarctica. So little is known about the geology of that continent that any such supposition cannot be classed as wild, yet the available evidence goes to show the existence of the formation only form Adelie Land and the adjacent area. Scott's Antarctic Expedition found Glossopteris within 5^o of the Pole and one may, at the most, suppose a belt running from Adelie Land to about the Pole. In Fig.10, (ibid : 20) of his book he shows this distribution himself. To suppose its existence, now or in the past, over atleast Coatsland and Kaiser Wilhelm II Land would hardly be justifiable. He has not given a map of the Permian Period, which is the most important for the purpose of discussion of this subject, but his figure 12 (ibid : 90), shows the land-forms in Jurassic and Cretaceous Periods (see Plate XVII). Plate XIX is an attempt to place the cratons and basins shown in Plate IV on Du Toit's assembly of Gondwanaland. A comparison with Plates IV and V would show that this reconstruction is not supported by available evidence as to the character of the basins. Comparison of Plate XVII with Plates VIII, IX, X, XI, XII and XIII shows the same for Mesozoic Era.

Earlier it has been pointed out that these similarities in the forms of the basins on the opposite coasts of continents are a strong argument in favour of the reconstruction used here. These are lost on any other reconstruction of Gondwanaland, and these very similarities appear to be merely accidental. A single such feature could be explained as due to similarity in the conditions of deposition, but with their multiplicity, the odds against this possibility mount, and point to the contiguity of these land areas in the past ages. Du Toit himself pointed out (1927 : 118) that "geological evidence almost entirely must decide the probability of this hypothesis for those arguments based upon zoo-distribution are incompetent to do so".

Recent work in S. America, however, demonstrates that Argentina had closer faunal, floral and even climatic affinities, atleast from Carboniferous to Rhaetic, with parts of Eastern Australia than even with S. Africa (Caster: 1952: 125 and 137). This tempts one to bring east Australia nearer to S. America than they are, perhaps, even in Carey's reconstruction used here. But on Du Toit's Gondwanaland map these continents are so far apart that the affinities cannot satisfactorily be accounted for. Time and again Du Toit appears to be suggesting that Australia and Africa should be closer together, but confronted with his own map he seems to recede. Thus he mentions that "no marine strata of age between Devonian and Lower Triassic have yet been found on either side of the midsections of Africa and Peninsular India or on the southern side of Australia" (1937 : 58), but he does not give due importance to the fact in his reconstruction.

Joyce's (1951) reconstruction (Plate XX) is interesting in so far as he, apparently independently, arrived at the conclusion that the loops of the Scotia need straightening out, a point that had been made by Carey earlier in his address at the Pan-Indian Ocean Science Congress. Joyce recognised that East and West Antarctica were seperate blocks and may still be separeated when he pointed out that "the possibility of a passage existing between the two seas (Ross and Weddell) still cannot be ruled out" (ibid: 84). And his details of the structure of S. American-West Antarctican part of Gondwanaland are very informative. But otherwise his reconstruction does not appear to be satisfactory. A significant flaw concerns India. The Baluchistan "geoflexure" is very much like the Scotia 'loops' and should similarly be opened up. But instead he has added to its "flexure" by rotating India in an anti-clockwise direction. By doing this, moreover, he placed W. India against W. Australia, and so far as the knowledge goes, they have very little in common. His placing of East Antarctica is very similar to that of Du Toit and open to question. Further, it is not clear why he wants the Scotia arc itself to be 'somewhat sinusoidal' and does not open it fully and attempt alternative reconstructions.

His paper, however, is very informative and his comparison of the Precordillera, Central Cordillera and Hinterland a notable addition to knowledge.

King (1951) offered a reconstruction (Plate XX) professedly to remove certain small discrepancies in Du Toit's reconstruction. He, accordingly, thought that "Antarctica .... should be brought towards S. Africa and rotated slightly, thus somewhat shortening and straightening both the Palaeozoic Samfrau geosyncline and the belt of Tertiary folding". His demonstration of the Nigerian rift is exceedingly interesting, but most of the other evidence he has produced is rather speculative. Thus to match the Black Rock Mts. from Crown Prince Martha Land with those of Drakensberg volcanics merely on the evidence of whalers' distant sighting of it is not a scientific procedure. Moreover, his contention that part of the Indian Ocean is original sea ignores the significance of the Java-New Guinea trough. The position of India on his map also seems to be erroneous, for the Tethys appears to abut against W. Australia on one side and Arabia on the other, and its continuation is lost. Tethys was the dominating feature then, and its significance is not at all recognised in his reconstruction. He has not opened the Scotia arc and, like Du Toit, retains East and West Antarctica together.

PLATE XVI.

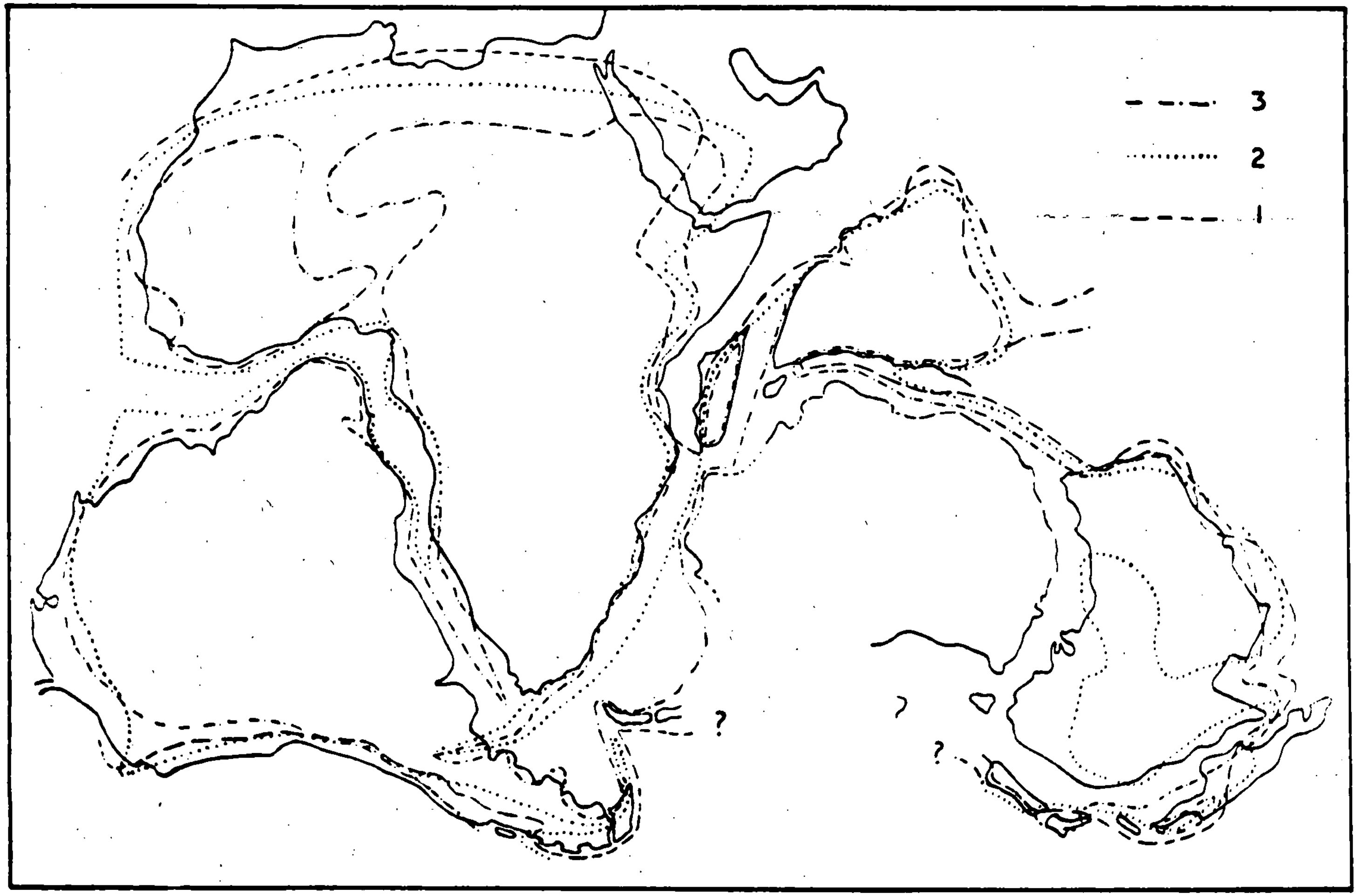


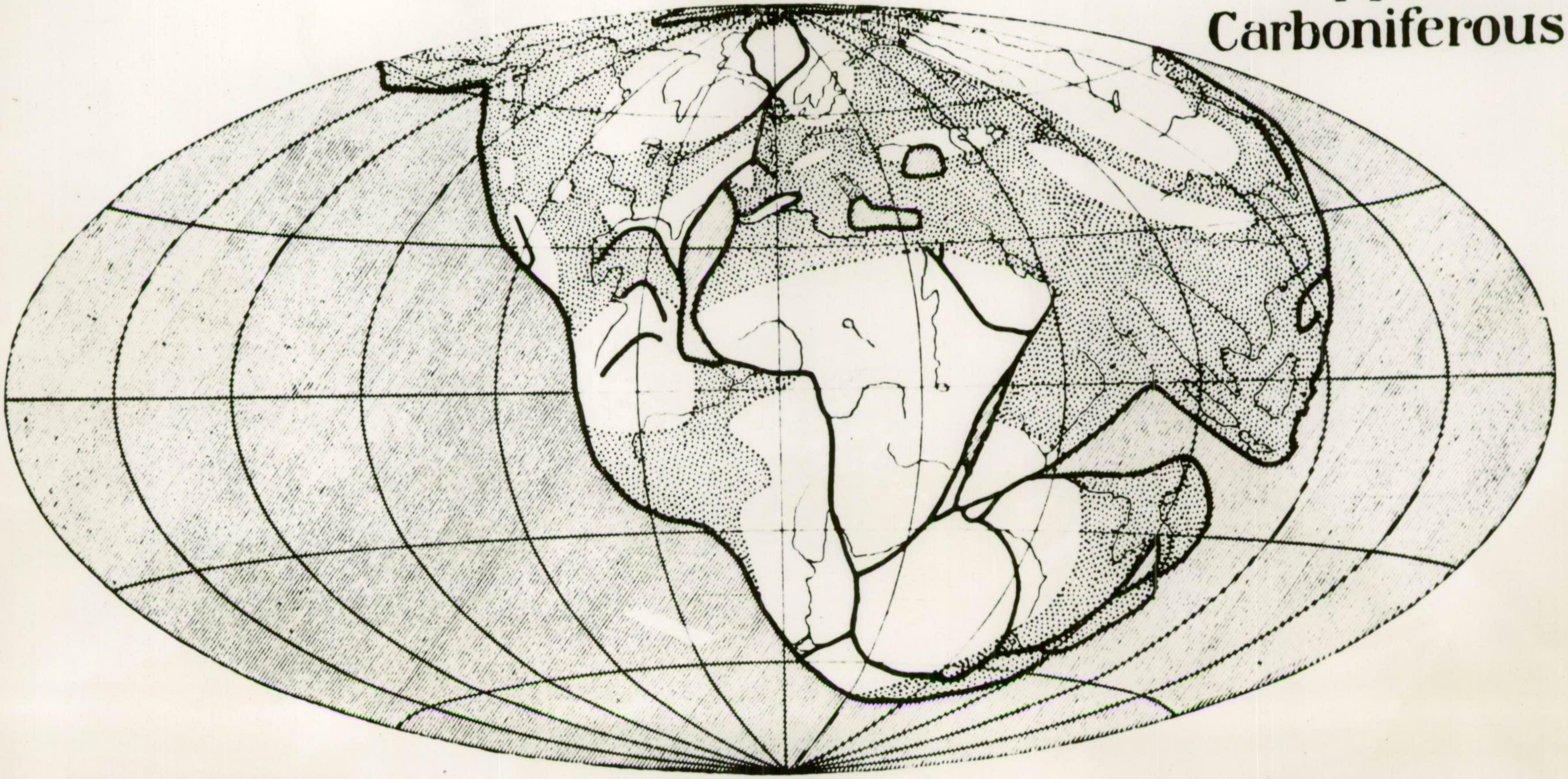
FIG. 12.—Showing the margin of Gondwana at three periods during the Mesozoic Era. 1. Early Jurassic; 2. earliest Cretaceous; 3. latest Cretaceous.

The assembly is otherwise so similar to that of Du Toit that what has been said earlier against the latter's reconstruction applies to this too, and consequently does not seem to be suitable.

More recently Carey (1954) has offered a new reconstruction after a detailed study of "geoflexures" from all over the world (see Plate XXI). Its details are not available at the time of writing this review, and the paper has, apparently, not yet been published. But this new map of Gondwanaland is almost identical with that of Du Toit. What has, therefore, been said against Du Toit's reconstruction also applies generally to this, particularly the absence of glacial deposits from the known Carboniferous and Permian formations of New Zealand and also, perhaps, from Antarctica. Moreover the significance of such occurrences as of oil shale in the Permian beds of East Australia and S. Africa, of glistening sandstones in the Triassic formations of the same area and of the same horizon, of Stichtite in Tasmania and in the Barberton district of S. Africa, of charnockite-associated-with-khondalite etc. is lost if Antarctica intervenes between East Africa and Australia. The close similarities in the Permian fauna from West Australia and Umaria (India), as suggested recently by Thomas, lends support to the assembly used in this paper.

PLATE XVII.

Upper Carboniferous



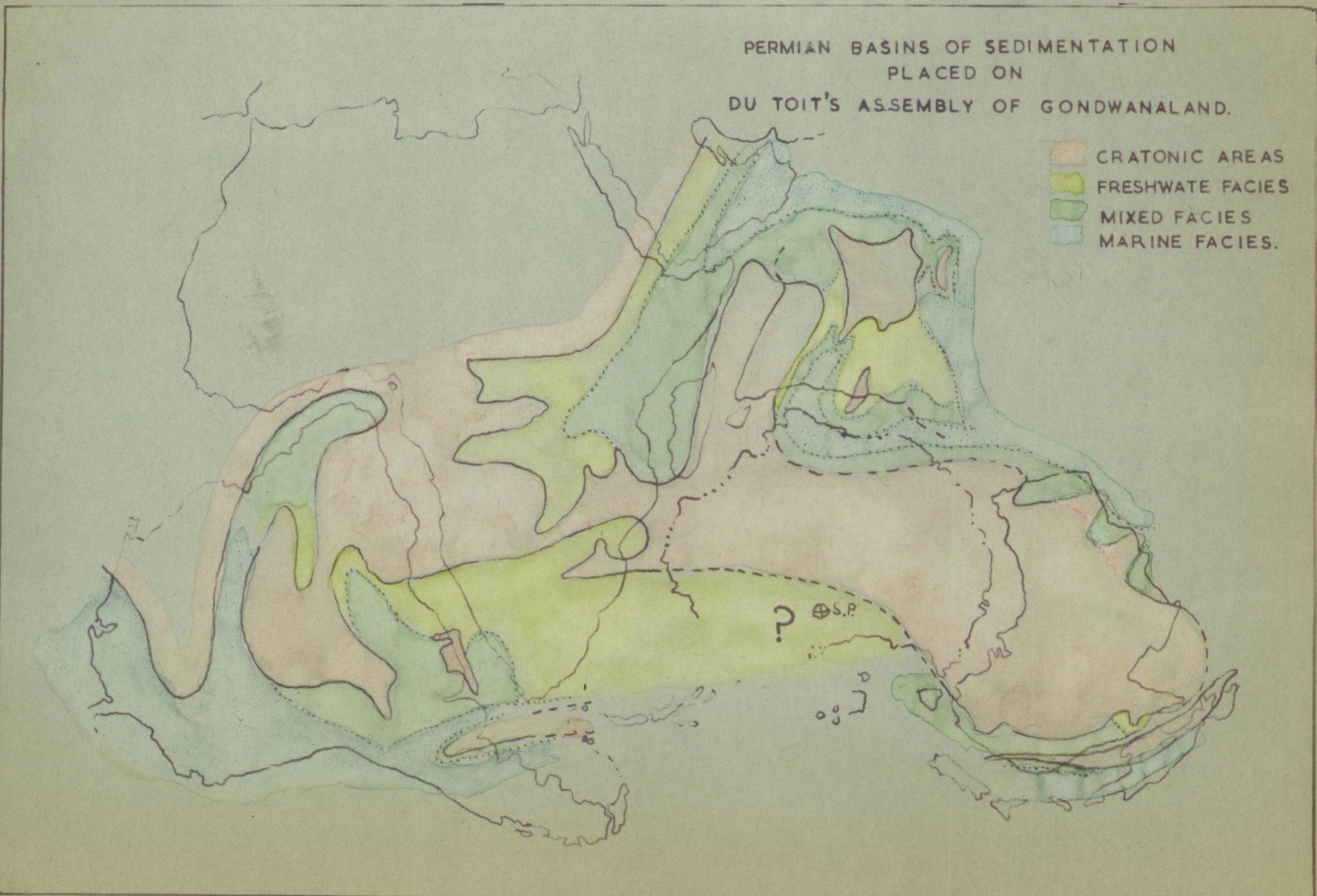
WEGENER 1924 P. 6.

The major contribution that this map makes is the emphasis on the "orogenic girdle" of Gondwanaland, and while this is certainly very interesting, a reconstruction cannot be supported on this basis alone. In any case, it was preserved on the original reconstruction as well.

Recently Rode (1953,a) has advanced the theory of "sheet movements" and he aims to explain the origin of continents "which originally were closely packed like playing cards piled up together within the region of Central Asia". The mechanism he suggests is best explained in his own words (ibid: 15-16). "When the subcrustal magma is molten and under great gravitative pressure of the overlying continental mass, it is invested with great intrusive force. It breaks through thick sheets of overlying rock masses through cracks, fissures and bedding planes separating them into a number of sheet blocks. These are carried bodily from regions of high gravitational potential to regions of low potential and a temporary equilibrium is set up". A repitition of the process is envisaged to split up these sheets into newer sheets, which then move off, and this process has gone on.

He deals in detail with three specific examples, two of these from India. With parts of these Indian areas the author is very familiar, and they will be discussed here in some detail. The great difficulty with Rode, however, is that he does not give the source of his information and the reader is left to wonder if it is original. The drawback stands in the way of a proper appraisal of his theory, particularly when his statements differ from published literature.

Rode bases his case by quoting the supposed "identical" formations from Satpura and Rewa Sheets. But the section quoted on page 4 is not correct in so far as the Iron Stone Shales do not occur any where outside the Raniganj Coalfield, and it was because of this that the term 'Barren Measures' was introduced for the same formations. Even the Barren Measures are not distinguishable west of Karanpura Coalfield, and elsewhere in the Son-Damodar Valley the Raniganj Coal Measures are supposed to directly overlie the Barakar Coal Measures. Moreover, the published literature indicates that the beds above the Barakar Coal Measures in S. Rewa Coalfields have not yet been classified and are still grouped as 'Supra-Barakars'. Hughes, who originally mapped the area, introduced the term and Gee (1928) retained it when he re-surveyed a part of it. A party from the Palaeobotanical Section of the Geological Survey of India has been working at the problem for the last few years and has not yet succeeded in producing a finalized picture. Rode's section is, therefore, all the more surprising, and reads like the "composite" Standard succession of the Gondwana System in Peninsular India given by Fox (see Table III above).


PERMIAN BASINS OF SEDIMENTATION
PLACED ON
DU TOIT'S ASSEMBLY OF GONDWANALAND.
CRATONIC AREAS
FRESHWATE FACIES
MIXED FACIES
MARINE FACIES.
?
S.P.

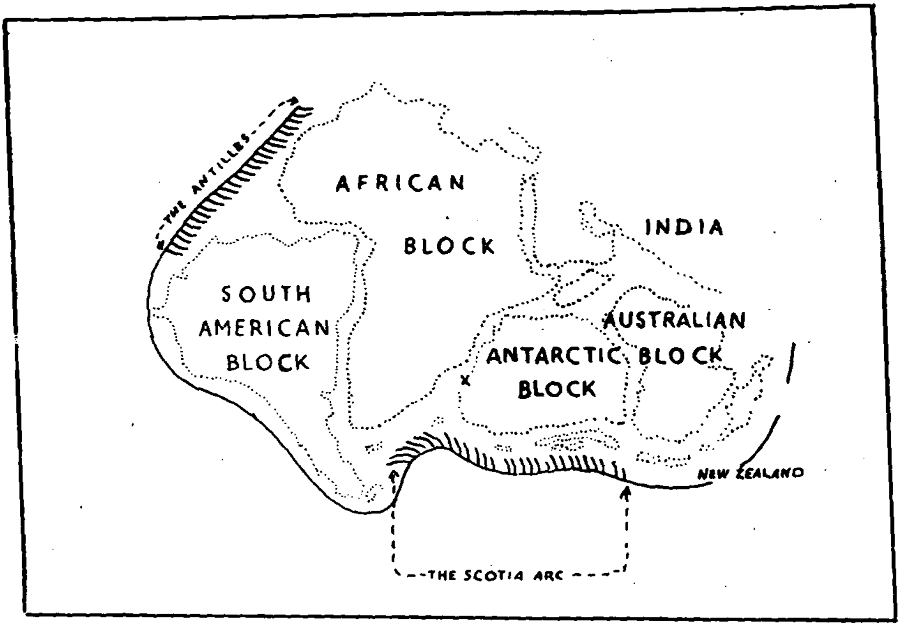
More important is the fact that the total thickness of the Permian beds in the Satpura area appears to be several times more than that in the Rewa area, and thus the intimate correspondence made out by Rode is contradicted by the principles of the epeirogeny.

Then, he gives (ibid: 5) a table of "structural correspondence" but again quotes the stratigraphy given on page 4, only splitting up some parts of it and grouping the others. Thus, he does not indicate why the Barakar beds of Sarguja and Sanhat should be treated separately and in what respect they correspond to the Barakar beds of Pench-Kanhan and Mohpani respectively. The same is true of the Upper Gondwana beds of Chand Bhakar and Sagali Palamau as against those of Narbada Valley and Jabalpur, and also of the Talchir Series. No where does this table bring out structural features unless these be in the "arcuate trap dikes and sills".

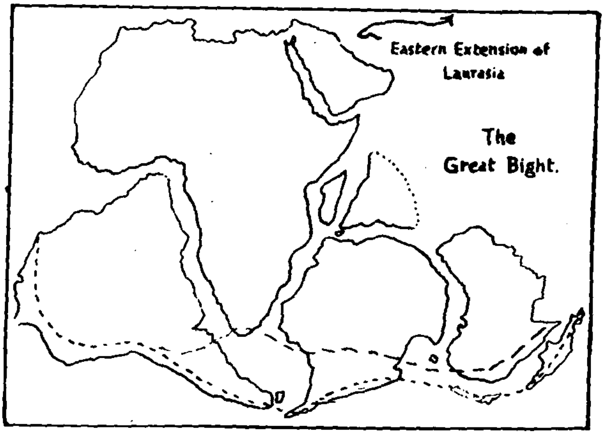
He points out (ibid: 6) that the "agency of this spectacular sheet movement appears to be no other than the subcrustal magmatic activity which gave rise to the Deccan Trap", and (ibid: 13) "It is possible that this magmatic activity started its intrusive phases in the Lower Gondwana period in very restricted proportion. It, however, gradually gained momentum and in the Tertiary period it flooded vast areas leading to extensive rifting, fragmentation and sheet movements". But then he adds "India thus appears to have acquired its present configuration both in the Peninsular and Extra-Peninsular regions in the post-Mesozoic period and more particularly in the Pliocene and Pleistocene period through extensive sheet movements". The implied meaning appears to be that the Deccan Trap activity was of Pliocene-Pléistocene age, whereas the accepted opinion in the country regards it as of Cretaceous to Palaeocene age. Rode, however, gives no reason to justify this sweeping change in age interpretation of the Deccan Trap. Similarly he (ibid: 11) alters the age of the Panjal Volcanics of Kashmir, and the Mandi (and Kheora) traps to match with the Tertiary volcanics of the Indus Basin in Ladakh. Panjal Volcanics are generally considered to be of Carboniferous to Triassic age, though they could belong to the Deccan Trap period.

Similarly, he points out (ibid) that, "The Jurassic of western Salt Range between Chidru and Kalabagh just coincide with the Jurassic formations of Spiti. A reference to the relevant sections in Chapter V above will, however, indicate that this is far from being the case. They differ both lithologically and stratigraphically.

The points raised above, though by no means exhaustive, are of detail and are exceedingly important since the



PART OF PANGAEA IN LOWER PALAEOZOIC AFTER J.R.F JOYCE
(ADVANCEMENT OF SCIENCE VIII)



READJUSTED ASSEMBLY OF GONDWANALAND
AFTER L.KING, (GEOLOGICAL MAGAZINE
LXXXVII)

theory is based on these very supposed similarities, yet the most inexplicable part of the thesis is the basic idea of this 'sheet movement'. He does not explain how from below the moving sheet there appeared formations "identical" with those that existed above it. Wegener's comparison between two pieces of a 'torn newspaper' was understandable, but the occurrence of identical formations - with included fauna and flora - piled one on top of another in several layers is just incomprehensible. But Rode shows it is his Fix. IX. Thus S. America, Africa, N. America, Australia etc. were piled one on top of another in the Central Asian region, and have since drifted away as 'sheets'. He does not even indicate what foundation the comparatively thin S. American sheet, for example, found when it left the African sheet below, and drifted away into the oceanic regions. He does not discuss what the relations of the sial and sima were when all the present sialic layers were lying in a big heap. One wonders as to how the African-S. American block managed to cross the Himalayan Ranges which were already becoming formidable in the late Tertiary Period, or was it earlier and they travelled across the Tethys, the existence of which he admits, nor why S. America floated so far in the present Atlantic Ocean and did not settle down to the west of Africa. He does not say how the problems of palaeoclimatology are affected by his hypothesis.

But the most surprising part of the theory comes from the sister volume (1953 b) where he states (ibid: 8-9) "The continental Tertiary Siwalik formation evidently marks the different stages in the evolution of the Himalayas and may thus be considered as tectonic sediments. Do the Talchirs, Barren Measures, Moturs, Kamthis and Upper Gondwanas also represent similar tectonic sediments though of earlier age? The coincidences are remarkable". Indian geologists will certainly not accept that all conglomerates, tillites and agglomerates known from the country are of the nature of fault breccia left behind by moving sheets.

Thus Rode's hypothesis is neither supported by facts of field geology nor by weighty theoretical considerations, some of which have been mentioned above. It, in fact, cuts across many basic principles of geology.

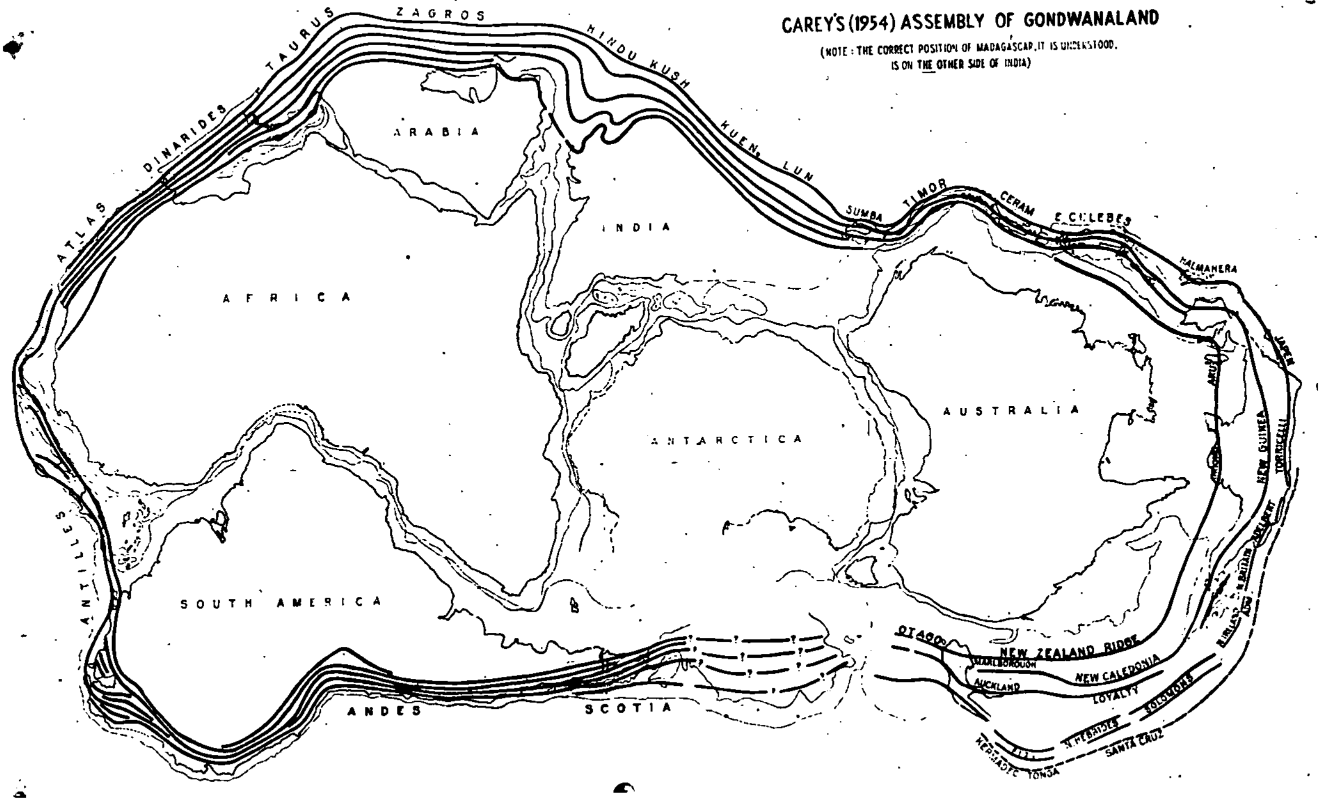
It was not the purpose of this chapter to go into the details of the various reconstructions or to offer criticisms of the different schools of thought and theories, but only to point out why Carey's (1951) assembly appeared better. If the technique employed in this paper is correct - it is in general the same as used by Eardley (1951) for the palaeogeographic maps of N. America - and it has been widely employed in the American oilfields, this argument alone seems to be strong enough to hold the reconstruction on its own.

Put the continents in any other position and the basins on opposite sides would not be similar in character and would fail to make sense.

The only difficulty that the author can see in Carey's reconstruction is that the movements of East and West Antarctica appear to be rather complicated. This study also suggests that, perhaps, Australia as well as India should be shifted further to the 'south', so that east Australia gets nearer to Argentina.

CAREY'S (1954) ASSEMBLY OF GONDWANALAND

(NOTE: THE CORRECT POSITION OF MADAGASCAR, IT IS UNDERSTOOD, IS ON THE OTHER SIDE OF INDIA)



CHAPTER IX
CONCLUSIONS

This paper sets out to study the palaeogeography of Gondwanaland for the Gondwana Period by drawing isopach from lines to elucidate the forms of the basins and cratonic areas. The technique is modern, though not new. Isopachs have been used for over two decades, to indicate the form of the basin. Yet it has here been admitted that the maps presented here are not the last word in themselves. As work proceeds in all these areas, and more authentic measured sections and exact correlations are available, changes would be desirable in the forms of basins. Such information would, however, generally go to add to the details, and is not very likely to change materially the general form of the basins.

More has been said about the Indian Gondwana System, and the author has, generally, been critical of the views held there. This, certainly, is not because 'familiarity breeds contempt'. More work has been done there than in Australia, and the views held there were generally more definite. The author differed from these and had to give his reasons. If this leads the Indian Survey, to which incidentally the author also belongs, to re-examine critically the available evidence, a good part of the purpose will be served. Controversy is the life blood of scientific progress.

It has been demonstrated that the Gondwana Formation in

India was not deposited in long, narrow faulted valleys or fresh water lakes, but the author agrees with Gee, Jowett and a few others that those areas were originally much more extensive and that their preservation is due to subsequent faulting. That their concept was not based on well founded scientific arguments and not backed by substantial field evidence, is indicated by the fact that they failed to convince Fox and others, who formulated the theory. The fact that the thickness of the sediments does not, in any area, show any sign of decreasing towards the east has been taken to mean that the deposition was not in fresh water lakes either. Fox, however, appears to have taken Blanford's words as gospel. The conclusion here drawn is based essentially on the evidence of lithological characters and other field evidence, some of it original, and the isopach maps confirm this. Sufficient evidence has been produced to show that the sediments bear none of the features one would expect from a contemporaneously faulted basin, and Fox's surmise was due to mis-interpretation of the data. Apparently the basin was merely sagging, yet the possibility of some minor faults having occurred contemporaneously is not denied. The evidence about the type of the geo-synclines is interpreted in terms of modern terminology.

The cause of the extensive faulting has been suggested by Carey, and agreeing with him, the author fixes the age as from Middle to Upper Cretaceous for which there is some field evidence. It is remarkable that in Carey's reconstruction of Gondwanaland the faulting continues into Australia without any major change in direction, and that in Africa, too, seems to have been affected by his "Baluchistan geoflexure". Dixey (1938: 56) assigns an "Uppermost Jurassic to early Cretaceous" age to the Nyasa-Shire Rift. Professor Hills (Personal Communication) considers that the faulting in Western Australia too, is largely Cretaceous in age.

Though it has only a little bearing on the subject under consideration here, the author finds no reason to subscribe to the view generally held in India that Peninsular India has not been subjected to any major uplift since Pre-Cambrian times. On the other hand there is good reason to believe that the Vindhyan Ranges, as seen today, were uplifted only in the post-Permian period. The trend of the isopachs suggests that deposition was going on there during the Damuda Period, and there is no evidence to the contrary. Aravallis, too, were apparently submerged during the Jurassic and Cretaceous Periods, though the evidence is not very definite on the point.

Fox's theory about the allochthonous origin of the Indian coal is categorically refuted. Though it is admitted that thin, impure coal may be formed of drift wood, it is not believed possible for the thick Indian seams to have been so formed. This is in agreement with the views of the leading authorities on the origin of coal today. Similarly, the author has shown that the Umaria marine bed had a more natural likely connection to the south-east, rather than to the north as suggested by Fermor, and agreed to by Fox. This has received strong support from the recent discovery of a new locality, about 90 miles to the E.S.E., of marine fossils from the Gondwana beds. Here they are reported to occur in the lowest part of the tillite. Presumably marine beds were extensively deposited in the south eastern area and passed by inter-tonguing into fresh water deposits in India on the west and perhaps also in Australia on the east, these being yet unexplored. The conditions prevailing are supposed to be similar to those of the type Permian in Perm and to the Phosphoria formation in America. The north coast of Sumatra and the Digul-Fly Basin of south New Guinea are supposed to be the modern examples of the type of boundary between fresh water and marine deposits. It is supposed that the Umaria Bed is a remnant of these tongues, preserved by not being exposed, like the area to the south-east, during the Triassic Period.

The entire evidence goes to suggest that all the continents were together till at least Jurassic Period. There is reason to believe that at about the close of that period South America started to drift westward from Africa, while India-Australia and perhaps also Antarctica started their eastward journey, hand in hand. Till the end of the Cretaceous they had, apparently not separated, or at least the separation was not effectively felt. But soon after the three appear to have parted.

Du Toit's reconstruction has been discussed in some details, and some of its weak points have been brought out. It is shown that no other assembly of this fascinating land will fit together with the isopach maps presented here. A fairly convincing _prima facie_ case is made out for Carey's reconstruction of Gondwanaland as used in this paper. The similarities in the basins on the opposite sides, the associations of similar rock types and minerals in the basement complex, the occurrence of identical Cretaceous fauna, etc. all go to show that Australia was much closer to India, and both were closer to Africa, than they are today. Many of the problems that had puzzled the geologists for decades resolve almost by themselves on this new map. The absence of the vertebrates and fresh water fossils from the Indian Lower Gondwana beds, has a very simple explanation. Similarly the absence of tillites from the area around the Zambezi is explained as due to the centre of the ice cap being located there. The more or less complete disappearance of the Lower Carboniferous flora has a more reasonable explanation than that suggested by Du Toit. A very thought provoking inference concerns the age of the Dwyka Series. It is suggested that their top is somewhat younger than the tillites in the Upper Marine Series of New South Wales, and slightly younger than even the Woodbridge Formation of Tasmania. It is, consequently much younger than the Talchir Series of India. In many other features this reconstruction appears to offer the only plausible solution.

It might here be pointed out that this paper, though primarily of academic interest only, is likely to have far reaching effects in the search for coal deposits particularly in the Trap covered areas of Peninsular India.

Map, Plate V, gives the names suggested for the land areas and basins for the Permian Period which this study has brought out. Some of these names have been used by earlier authors, while others are being introduced now. Many of these basins, islands and peninsulas can be recognised in the Mesozoic Era as well. Further study may reveal that they were present in the earlier period as well.

POSTSCRIPT

Two important contributions dealing with the Umaria Bed have been made since this paper was in an advanced stage of typing. The first is a short note reporting the discovery of marine fauna from Hasdu River bed some 90 miles E.S.E. of Umaria. In contrast to the bed in Umaria, where the fauna occurs either in the top bed of the Talchir Series or the bottom bed of the Barakar Coal Measures, this new bed is reported to be associated with the lowest bed of the tillite almost directly overlying the gneisses. This would indicate that either the marine conditions were more extensive towards the S.E. or that the ice cap retreated in a general southward direction. Both of these interpretations support the views expressed earlier in this paper.

The fauna has not been studied so far, but is reported to contain a large lamellibranch.

The other paper is an abstract of a paper by Dr. G.A. Thomas, comparing the Umaria fauna with W. Australian fauna. An oral communication on this subject has already been referred to, but this paper contains the results of specific comparison, and is therefore, very important . Thomas states "The fauna is a small one....... All the forms show very close resemblance to species in the Lyons Group, particularly with a fauna in beds 1,500 ft. from the top. The Lyons has forms close to _Productus_ (_Linoproductus_) _umariensis_ Reed, and its varieties, "_Spirifer_" _nasarhensis_ Reed, _Ptychomphalina_ _umariensis_ Reed and a new primitive species of _Calceolispongia_, an unusual crinoid genus found only in Western Australia, Tasmania, Timor and in the Umaria Bed.

Also mention should be made of _Eurydesma_ now known in the Lyons and probably present in.... (Umaria)".

The significance of this correlation has already been stressed.

APPENDIX I

INDEX TO LOCALITIES

Adelie Land	Antarctica	62.00 S; 140.00 E
Aden	Arabia	12.45 N; 45.4 E
Amb	Pakistan	34.18 N; 72.53 E
Aravalli Hills	India	25.20 N; 73.40 E
Arnhem Land	Australia	12.20 S; 137.00 E
Assam	India	26.00 N; 92.00 E
Attock	Pakistan	33.53 N; 72.17 E
Aurunga	India	24.00 N; 84.4 E
Baluchistan	Pakistan	28.00 N; 65.00 E
Bhutan	India	27.00 N; 30.00 E
Bihar	India	25.10 N; 85.30 E
Bikaner	India	28.00 N; 73.30 E
Bokaro	India	23.40 N; 85.50 E
Bowen Basin	Australia	20.25 S; 147.30 E
Brisbane	Australia	27.27 S; 153.2 E
Burt Range	Australia	26.7 S; 127.40 E
Byans	India	29.30 N; 80.00 E
Calcutta	India	22.34 N; 88.24 E
Collie Basin	Australia	33.25 S; 116.30 E
Cracow	Australia	23.26 S; 150.14 E
Cuddapah	India	14.28 N; 78.52 E
Cutch (Kutch)	India	24.00 N; 70.00 E
Cuttack	India	20.28 N; 85.54 E

Damodar R.	India	23.30 N;	87.00 E
Dangin	Australia	32.1 S;	117.19 E
Darjeeling	India	27.3 N;	88.18 E
Dawson	Australia	24.14 S;	149.47 E
Digul R.	New Guinea	2.00 S;	139.00 E
Ellore	India	16.43 N;	81.9 E
Fly R.	New Guinea	8.00 S;	142.00 E
Garhwal	India	31.00 N;	79.00 E
Gascoyne R.	Australia	24.20 S;	115.00 E
Gatton	Australia	27.33 S;	152.16 E
Geraldton	Australia	28.48 S;	114.32 E
Godavari R.	India	16.28 N;	82.00 E
Gold Coast	Africa	6.00 N;	1.00 W
Guntur	India	16.16 N;	80.29 E
Gympie	Australia	26.15 S;	152.40 E
Hazara	Pakistan	34.20 N;	73.10 E
Helidon	Australia	27.30 S;	152.8 E
Hunter R.	Australia	32.20 S;	150.45 E
Hutar	India	23.49 N;	84.3 E
Indus R.	Pakistan	24.30 N;	68.00 E
Ipswich	Australia	27.36 S;	152.45 E
Jaisalmer	India	26.40 N;	70.50 E
Jharia	India	23.45 N;	86.15 E
Johilla	India	23.00 N;	81.20 E

Kachch	India	See Cutch
Kaiser Wilhelm II Land	Antarctica	67.15 S; 88.00 E
Kalabagh	Pakistan	32.58 N; 71.37 E
Karanpura	India	23.40 N; 85.10 E
Kashmir	India	34.00 N; 76.00 E
Kasipur	India	19.0 N; 79.00 E
Kazan	Russia	55.50 N; 49.10 E
Kimberley	Australia	16.20 S; 126.00 E
King Sound	Australia	16.50 S; 123.20 E
Kirana Hill	Pakistan	32.00 N; 73.00 E
Kistna R.	India	16.00 N; 78.55 E
Korea State	India	23.32 N; 82.19 E
Kumaon	India	30.00 N; 78.00 E
Kurasia	India	23.13 N; 82.24 E
Kurnool	India	15.50 N; 78.5 E
Laidley	Australia	27.36 S; 152.23 E
Lainsburg	Africa	33.12 S; 20.53 E
Lochinvar	Australia	32.44 S; 151.29 E
Lotus Creek	Australia	22.21 S; 149.6 E
Louis Philippe Land	Antarctica	63.30 S; 58.00 W
Lyons R.	Australia	24.50 S; 115.20 E
Mackenzie	Australia	25.50 S; 157.40 E
Macpherson Range	Australia	28.15 S; 153.00 E
Madhya Pradesh	India	22.0 N; 80.00 E

Margaret R.	Australia	17.40 S; 127.30 E
Minilya R.	Australia	23.50 S; 114.00 E
Narbada R.	India	21.38 N; 74.00 E
Natal Downs	Australia	21.40 S; 146.9 E
North West Basin	Australia	114.00 S; 25.00 E
Oman	Arabia	23.30 N; 57.00 E
Ongole	India	15.30 N; 80.6 E
Orissa	India	21.00 N; 85.00 E
Pench Valley	India	22.10 N; 78.45 E
Perm	Russia	58.00 N; 56.15 E
Pir Panjal	India	34.00 N; 75.00 E
Pokolbin	Australia	33.00 S; 151.30 E
Pranhita R.	India	19.20 N; 80.00 E
Pyrenees Orientales	France	42.35 N; 2.20 E
Quetta	Pakistan	30.12 N; 67.00 E
Rajahmundry	India	17.00 N; 81.48 E
Rajmahal	India	25.3 N; 87.50 E
Rajputana	India	27.00 N; 74.00 E
Ramkola	India	23.38 N; 82.59 E
Raniganj	India	23.36 N; 87.9 E
Rewa	India	24.31 N; 81.19 E
Robe	Australia	37.10 S; 139.44 E
Salt Range	Pakistan	32.30 N; 72.00 E
Satpura	India	21.30 N; 76.00 E
Simla	India	31.6 N; 77.13 E

Singhbhum	India	22.24 N; 85.30 E
Singrauli	India	24.00 N; 82.00 E
Socotra	Indian Ocean	12.30 N; 50.00 E
Sohagpur	India	23.20 N; 82.15 E
Son R.	India	25.00 N; 84.20 E
Spiti	India	32.00 N; 78.00 E
Sunday R.	Africa	33.30 S; 25.57 E
Surghar Range	Pakistan	33.00 N; 71.00 E
Sydney	Australia	33.50 S; 151.00 E
Talcher	India	20.57 N; 85.14 E
Tawa	India	22.10 N; 78.30 E
Tooday	Australia	31.28 S; 116.25 E
Trichinopoly	India	10.50 N; 78.4 E
Umaria	India	23.32 N; 80.51 E
Umia	India	23.30 N; 69.00 E
Uttar Pradesh	India	28.00 N; 80.00 E
Uttatur	India	10.50 N; 78.46 E
Vindhya Pradesh	India	24.00 N; 81.00 E
Vindhyan Range	India	23.00 N; 76.00 E
West Maitland	Australia	32.44 S; 151.36 E
Yampi Sound	Australia	16.7 S; 123.40 E
Yilgarn	Australia	30.40 S; 119.00 E
Zambesi R.	Africa	15.40 S; 32.40 E
Zanskar Range	India	77.00 N; 33.30 E

APPENDIX II

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