THE AGE OF THE GONDWANA GLACIATION *

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Abstract

The stratigraphic and palaeontologic record of the Permian System in Gondwanaland is examined, particular stress being laid on points that have a bearing on the age of the basal tillites. It is believed that the term *Glossopteris* flora has been rather loosely used in the past and the austral Permian flora is, herein, described as the *Gangamopteris* flora in the Lower Permian, and the *Glossopteris* flora in the Middle and the Upper Permian. It is believed that the appearance, predominance, decline and finally the disappearance of the former genus, as a whole, are more important indicators of age than the presence or absence of any one genus or species. Apparent 'holdovers' of northern affinities are of no importance.

The various possibilities under which glaciation could have occurred in such widespread areas are discussed and it is pointed out that drift provides a reasonable working hypothesis. Anomalies in palaeontological, stratigraphic and glacial records are then sought and it is suggested that the only explanation is that glaciation was not simultaneous in all the areas, and there was considerable time-lag between refrigeration in one area and another. It, presumably, started in the 'Permo-Carboniferous' in Eastern Australia, and might have ended in the upper Middle Permian in South Africa, and, maybe, somewhat later in Tasmania.

It is suggested that the Permian Period ended with the Upper Coal Measures in New South Wales, the Raniganj Coal Measures in Peninsular India, the Lower Estrada Nova beds (of Oppenheim) in Brazil and the Ecca Series of South Africa.

The evidence leads to the conclusion that there, apparently, was no ice age, and instead the Gondwanaland continent itself was drifting on the South Pole before it started splitting up.

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Introduction

To anyone who has given this, perhaps one of the most fascinating problems in geological science today, its due share of careful consideration, it would be apparent that the most irrefutable argument in the armour of the uncompromising 'driftist' is the Permian glaciation of Gondwanaland. Even Coleman, that most uncompromising 'anti-driftist' himself, was forced to admit, though very reluctantly, that many problems connected with glaciation resolve themselves if drift has really taken place.

The age of the glaciation is universally regarded as lowest Permian—even though the Indian geologists continue to use the bogey term 'Permo-Carboniferous'—and glaciation is considered to have been simultaneous in all the continents from where the tillites are known. The absence of any signs of extensive glaciation in the northern hemisphere, and the possibility of warm climate having existed in the Lower or Middle Permian of New Zealand, however, pose questions which necessitate a reappraisal of the available evidence. Indeed, recent advances in knowledge make a reassessment essential. The following review is, therefore, none too early.

The necessity for this paper arose out of a comment by Prof. Kenneth E. Caster of the University of Cincinnati, in the course of a private communication, on a paper entitled 'Glaciation and Gondwanaland', by the senior author. Prof. Caster remarked that 'if you can prove your point, you will have made an important contribution to the documentation of Gondwana geology'. This was taken as a suggestion for a more detailed examination of evidence bearing on the age of the Gondwana glaciation than had been possible in the above-mentioned paper, and the results are presented herein. The above paper, originally presented to the Pan-Indian Ocean Science Congress, Perth (1953), has been published in the *Records of the Geological Survey of India*, Vol. 86, part 4 (Ahmad 1960).

Previous Literature

Perhaps the earliest reference to the age of the Gondwana beds, as may be expected, appears in the Indian literature where Feistmantel, on examining the plant fossils from Peninsular India, opined that they were of Mesozoic age. In this he later received ample support from some of the foremost palaeobotanists of the time, including McCoy and De Zingo, Saporta and Schimper, Carruthers and Bunbury and others. Very soon, however, the discovery of similar plants, associated with marine fossils from the Salt Range, obliged Feistmantel and others to revise their opinion. The general opinion, guided by the age determination of marine fossils by some of the most prominent Continental palaeontologists of the time, including Noetling, Koken and others, soon crystallized that the glaciation was 'Permo-Carboniferous' in age. The idea, apparently, was that it was partly Carboniferous and partly Permian, or else that the beds were lying on the boundary between the two geological ages and could not be assigned to either of them in their entirety.

By about this time glacial deposits were also reported from the other three southern continents and were promptly assigned a 'Permo-Carboniferous' age. A world-wide refrigeration was, consequently, envisaged.

David White (1908), on examining the flora from South America, however, thought that it was, perhaps, Upper Permian; but the real challenge to the age assignment came from Schuchert (1928 and 1935) who published two excellent summaries of the world Permian geology and came to the conclusion that the glaciation was 'Upper Middle Permian' in age. For many geologists in the countries concerned this was, apparently, entirely unacceptable, and David and Sussmilch (1933), Walkom (1944), Du Toit (1933) and Fox (1931) and others vigorously questioned his findings and conclusions.

Gradually, thereafter, it came to be settled, based on the age deduced from the ammonites found in Australia, that the basal tillite everywhere was Lower Permian in age, though occasionally it resulted in perplexities and confusions. At times, it appears, palaeontological evidence and the evolutionary stage of the fossils preserved and even incontrovertible stratigraphical evidence were summarily brushed aside to adjust the geological columns to the above age assignment by earlier stalwarts. A notable example of this is the *presumption* by Oppenheim (1935) of a hiatus, though none is seen in the field above the Lower Estrada Nova beds in Brazil. These views, however, did not take into account the real implications of the fact that glacial deposits occur throughout the entire section of the Permian System in Tasmania, though they appear to be absent from the equivalent horizons in Falkland Islands, which are about 10° nearer to the Pole.

Schuchert (1928), even though he had suggested an upper Middle Permian age for the glaciation, harboured some doubts about the perfect equivalence of the age of the tillite when he pointed out (p. 793): 'It does not appear from the inherent evidence of the tillites of the southern hemisphere that they are exactly of the same age, or that one or the other is older or younger.' Oppenheim (1935, p. 1735) was openly critical of the opinion treating all tillites as contemporaneous when he said that 'several geologists admit a certain contemporaneity between the Dwykas of Africa, Talchir of India, and Itarare of Brazil on the one hand and the glaciation of Australia, Tasmania and Western Argentina on the other. However, confirmatory evidence is lacking, and in the writer's opinion the relationship is doubtful, and can be sought only in the correlation of the probable centres of glaciation. The centres are apparently common for the sediments north of latitude 38°, embracing the areas of South Africa and South America; other centres should be assumed for areas south of this latitude and for other continents'. Even Du Toit (1929*a*, p. 99) appears to have been in some doubt about the perfect contemporaneity of all the glacial beds of Gondwanaland and pointed out that 'The evidence does not lend support to the view that the whole of it was covered at any one instant' (*see also* Du Toit 1948, p. 117). Elsewhere he considered that the Indian tillites might have been somewhat younger than those of South Africa. King (1958, pp. 56-57) appears to believe that glaciation started somewhere in Western Argentina in the early Carboniferous times and extended therefrom to cover South Africa, India, Antarctica and Eastern Australia. The Lower Carboniferous glacials of Eastern Australia do not, however, seem to find a place in this interpretation.

Ahmad (1960, 1961) has, on the other hand, taken into consideration the effect of continental drift, and has, accordingly, suggested that either there was a single extensive ice cap covering the entire, or almost the entire, Gondwanaland, or else the continent itself was drifting all the time. In the former case, the ice cap, on the Carey's 1951 assembly Ahmad used, could have been approximately oval in shape. With its centre over Madagascar, such an ice cap might have covered the entire area from which the glacial records have been reported. As it dissipated, it could have taken the deposition of the tillite nearer and nearer to the centre, ending finally in the Upper Permian times in Tasmania. In the latter case, the drift of the continent in a more or less regular clockwise direction brought different parts of the land at different times under the polar ice cap, which need not have been any bigger than the present Antarctic ice cap. Both these possibilities distinctly envisage that the tillites, as known today, are of different ages in the various continents, and even in different parts of the same continent. A brief analysis of the evidence was given, but a detailed appraisal was evidently called for, and the present paper sets out to supply the deficiency.

Several interesting papers on the geology of South American countries have appeared in the past few years and a significant addition to the knowledge about that continent was provided by the 'Handbook of South American Geology', published by the Geological Society of America. Older papers, however, retain their interest and have frequently been referred to. Bond's paper (1955) on the Madumabisa Shales, Thomas's (1954) correlation of the Umaria fauna, Romer's (1950) textbook of Vertebrate Palaeontology, and Caster's (1952) masterly analysis of the South American faunal affinities have all yielded valuable data for the correlation of the beds.

Recent advances in the field of palaeomagnetism have indeed very much revived interest in Continental Drift and the conclusions by Runcorn and Irving have been referred to in the passing; but for any student of the origin of oceans and continents their work is much more than of passing interest.

Stratigraphy

A general review of the stratigraphy of the five major constituents of Gondwanaland is called for, and the following account is, by no means, an exhaustive treatment of this vast subject. With a limited objective it lays stress on relevant points only. The discussion is, moreover, confined to the Gondwana and equivalent formations, and ends with the end of the Permian Period.

The only part of Gondwanaland where the Permian succession is indisputably complete is Eastern Australia. It is both over- and underlain by conformable beds, is fairly rich in plant and invertebrate fossils, and is not only easily studied, but has been examined in fair detail. It is, therefore, appropriate to begin the discussion with the Australian equivalent of the Gondwana formation, and what a pity it is that the geologists in that country have abandoned the convenient name lately used for it, the Kamilaroi System.

Australia

The Gondwana deposits of Australia are found in two distinct provinces, often referred to as the Eastern and Western Australia. These will here be taken up in that order.

Eastern Australia

The succession in the Hunter Valley is the most important in this province and is subdivided as below:

TABLE I

4.	Upper (New Castle) Coal Measures	4,500 feet
3.	Upper Marine Group	6,400 feet
2.	Lower (Greta) Coal Measures	300 feet
1.	Lower Marine Group	5,895 feet
		17,095 feet

The system conformably overlies the Carboniferous System and glaciation appeared very early in the latter. It continued intermittently till the end of the Upper Marine Group time. In fact, the boundary between the Permian and the Carboniferous formations has been only arbitrarily fixed where *Eurydesma hobartense* makes its first appearance in the glaciogene beds. About 3,000 feet above this appears *E. cordatum* in another period of refrigeration. In between these two horizons, and about 1,280 feet above the base, is a bed containing drift-specimens of *Gangamopteris*.

Five different species of *Gangamopteris*, and as many as twenty-six different species of *Glossopteris*, have been recorded from Eastern Australia. Though Walkom (1944, p. 7) and Voisey (1952, p. 53) are agreed that it is not possible to distinguish between the floras of the Upper and the Lower Coal Measures, David and Browne (1950, p. 376) point out that *Brachyphyllum* and *Schizoneura* and perhaps, also, (?) *Caulopteris* appear to be restricted to the upper beds. The fauna of the two marine groups is also practically indistinguishable (Voisey 1952, *see also* Walkom 1929, p. 166). These facts suggest very definitely that the two marine formations were not separated by a wide gap of time, and this might equally be true of the two coal measures. The only conclusion that this leads to is that, although the Upper Marine Group is a rather thick sequence, the commencement of the deposition of the Upper Coal Measures was not far removed in time from the end of the Lower Coal Measures. It, then, seems reasonable to place the three lower series in the Lower Permian, and presume that a considerably slower rate of sedimentation allowed the Upper Coal Measures to continue to the end of the Permian Period. It might even have commenced a little before the end of the Lower Permian times. The Tasman Geosyncline, which had the character of a typical eugeosyncline for a long time, might have started dying out or might have shifted eastwards from the present Australian landmass, and this slower rate of sedimentation could be a reflection of the change in the character of the basin in the second half of the Permian Period.

It, however, appears that even though no new species appeared in the Upper Coal Measures, the over-all composition of the flora was, apparently, very different and there was a significant change in the ratio of the *Glossopteris* and *Gangamopteris* plants present. Thus, Schuchert (1928, pp. 866–886) has pointed out that in the Upper Permian beds the former genus predominates over the latter, whereas the opposite is the case in the Greta Coal Measures.

Walkom (1929, p. 163) points out that '*Gangamopteris* reaches its maximum development in the lower series of Coal Measures'. It would be pointed out later that this fact is of particular interest.

Gangamopteris, moreover, has not, so far, been reported from the area north of Clermont in Queensland nor from the Desert Basin in Western Australia. Teichert (1943) drew attention to this and suggested that the distribution was, apparently, controlled by climatic zones dependent upon latitude. Ahmad (1961) has, on the other hand, drawn attention to its presence within the tropics in other countries, and has accordingly suggested that ecological factors, other than temperature or latitude, might have been more important. In the Desert Basin the deposits are mostly marine and estuarine, and its absence might only have been fortuitous or due to the absence of freshwater deposits. The ecological conditions favouring a flourishing existence of the genus are referred to later.

It is also significant that although eight or nine advances of ice front have been recorded in New South Wales beds, and almost the entire Permian succession in Tasmania shows signs of glaciation, none of the later refrigerations appear to have affected the Western Australian succession, where, too, almost the entire succession is represented (Thomas and Dickins 1954). In all the four main basins in Western Australia a basal tillite is overlain by freshwater and marine sediments. The fauna preserved shows close affinities with the fauna in the Talchir Tillites in Peninsular India (Thomas 1954) in its lower part and has equally close affinities with the Salt Range *Productus* Limestone fauna in the upper part. Since a warm climatic condition has often been surmised for this Salt Range fauna, in which corals flourished, similar must have been the setting in Western Australia. This would, naturally, suggest that the change from the glacial conditions must have been very rapid. If this conclusion is found to be acceptable the position becomes extremely anomalous. It is an accepted principle that when marine fossils occur in glacial beds the existence of ground ice brooks no doubt, and topography as the main cause of glaciation is automatically ruled out. Yet, in the same latitude in Australia the climate appears to have been frigid on the east coast and warm, maybe even tropical, on the west coast, and no juggling of the sea currents or prevailing winds would be sufficient to explain the phenomenon. The isotherms at the time might, then, actually have been running in a north-south direction! More intriguing is the fact, as has been suggested hereafter, that in the Upper Coal Measures times the warm and frigid sides of Australia seem suddenly to have changed ends, and south-western Australia alone appears to be cold at the time.

The basal tillite in the Collie Basin is, moreover, overlain by coal measures. It has been suggested that the spore analysis from this horizon indicates a closer affinity to the Upper (New Castle) Coal Measures of New South Wales than to the Greta Coal Measures (Fairbridge 1952, p. 114). This is significant and the implications are yet to be fully realized. A tentative suggestion is made in a later section here (*see also* Ahmad 1960).

The entire evidence goes to indicate that ice moved from south to north, and this is as it should be if the Polar ice cap grew to enormous dimensions. Similar ice movement, it may be incidentally mentioned, is also reported from the Falkland Islands, but, like Western Australia, there is no indication of refrigeration after the basal tillites were deposited, and the later glaciations, as has been mentioned earlier, known so profusely from Eastern Australia and Tasmania, are completely absent. This could only mean, if the present latitudes were valid for the time, that either the Polar ice cap, after the first phase of expansion and recession, became exceedingly lop-sided or else the Lafonian Tillites of the Falkland Islands were the equivalents only of the last phase of the Australian glaciations, and the ice cap itself removed the records of the earlier phases. In either case the situation seems to be difficult to explain at the moment. Any explanation that can knit the known features into a pattern may hold the key to the solution.

The only known reptile, *Bothriceps major*, occurs in the New Castle Coal Measures, near the top of the formation. D. M. S. Watson thought it to be 'Nearly on the division between the Permian and the Triassic' (David and Browne 1950, p. 376). Even fishes are rare, and Eastern Australia is reported to have yielded only two species, *Urosthenes australis* and *Elonichthys davidi*, from the New Castle Stage. The occurrence of *Helicoprion davisii* in Western Australia has been used by Teichert in correlating the beds to the Permian of Europe.

Oil shales are known to occur on more than one horizon, and the bituminous bed in the Bulli Seam, about 10 feet in thickness, has been tried for commercial distillation. Oppenheim (1935, p. 1780) thought that 'This bed resembles the Iraty in its nature and stratigraphic horizon'. The Bulli Seam is very near the top of the Permian System, and it is hardly necessary to add here that the correlation suggested is rather vague.

Oil shales are also known from the Cygnet Coal Measures in Tasmania, and these are satisfactorily correlated to the Upper Coal Measures of New South Wales. It is thus possible that the deposition of oil shales was not only simultaneous, but was in a continuous belt from Tasmania to New South Wales. Banks (1952, p. 74) thought that coal and oil shales were contemporaneous, 'so that during the deposition of the coal the shore line can be more or less accurately located'. This suggests that oil shales are merely a marine facies of the allochthonous coal seams.

Oil shales, apparently very similar in character, have been reported from the Ecca Coal Measures in South Africa. In view of the above suggestion it may be considered that marine conditions extended into the coal basin in the eastern part of the Union; and the prevalent notion that in South Africa, except for a slight incursion in the west when the so-called White Band was deposited, marine beds are entirely absent, need not be correct. A reappraisal is highly desirable, and a detailed study of spores in all the beds is, indeed, called for.

Western Australia

Four, more or less, separate basins, with glacial beds at the bottom, are known from Western Australia. The Grant Formation in the Desert Basin is glacial and reaches the enormous thickness of 3,500 feet. It is separated from the overlying Poole Sandstone by a slight disconformity. Plant fossils occur in the latter, but no determinable *Gangamopteris* has so far been found from this basin. The overlying beds are all marine. The sequence in the North-west Basin is marine throughout and has yielded the now well-known bryozoa, *Calceolispongia*, known only from Western Australia, Timor, Tasmania and Peninsular India.

The Irwin Basin, to the south, is important because it contains coal measures and distinct plant fossils, including *Gangamopteris*, *Phyllotheca*, *Sphenophyllum* and *Sphenopteris*, etc. 'An interesting feature of the Coal Measures is the occurrence in them of the numerous "dumped" erratics, up to 2 feet long, often with distinct glacial striations' (Fairbridge 1952, p. 141). The suggestion by Fairbridge that these were rafted by floating vegetation, however, appears to be highly improbable. The apparent concentration of these erratics in small areas appears, on this hypothesis, difficult to explain. Also, the size of the individual inclusions is rather large for vegetation to transport over long distances, particularly when the river was in a turbulent state. The present authors are of the definite opinion that these could only have been rafted by ice, and an ice cap must have persisted, or reappeared, on land some distance away.

Fairbridge (1952) has, moreover, added that 'Teichert (1951) has pointed out that the western and eastern Australian Permian provinces are totally distinct as regards macro-fossils; for example there is not a single goniatite genus common and the characteristic pelecypod *Eurydesma* of New South Wales Lower Permian is absent'. As suggested earlier, this might only be the result of distinct climatic zoning, for, while *Eurydesma* is indicative of cold-water conditions, the west coast could have warm climatic conditions soon after the glaciation. *Eurydesma* has, however, since been reported from the glaciogene Lyons Group in Western Australia.

'International correlation of the Australian Permian is possible on the basis of the goniatites' (Fairbridge 1952), and, accepting this view, the beds in Peninsular India also cannot but be of lowest Permian age.

The sediments in Collie, Muja and Wilga Basins are entirely of freshwater origin, and there are a number of coal seams present. The coal is thought to be of drift origin. *Gangamopteris* is present along with *Glossopteris* and the presence of winged spores suggests a correlation with 'The Upper Permian (Tomago and New Castle) Coal Measures of New South Wales, as suggested by David (1932) long ago, and with the Lower Gondwanas of India in the other direction' (Fairbridge 1952). 'Winged' spores in India are known both from the Barakar and the Raniganj Coal Measures, but their frequency in the latter is distinctly very much higher. The Collie Basin seams may, then, be Upper Permian in age, and a very early Permian age, for the tillite at the bottom may not be tenable unless a disconformity is proved to exist between the glacial beds and the overlying coal-bearing formation. This, apparently, is not the case, and equating the glacial beds all along the west coast of Australia need not be correct.

The 'dumped erratics', mentioned above, become very significant under the circumstances and it is possible that there were really two distinct glacial periods in Western Australia also, though the later refrigeration was not recorded in the basins further north, where the change to warmer conditions must have been very rapid.

If the suggestions made above are confirmed by future work, and the correlation of the Collie Basin coal seams and the Irwin River Coal Measures (the former being slightly younger than the latter) with the Upper Coal Measures of New South Wales is found to be incontestable, the situation becomes exceedingly piquant. After the basal glacial deposits of both the provinces there is apparently no sign of frigid conditions in the northern basins on the west coast. But, while glaciation on the east coast appears to have definitely ended in the Upper Marine Group times, it appeared again in the equivalents of the Upper Coal Measures on the west coast, and in latitudes somewhat nearer to the equator! Thus, after the first phase, the glaciation itself appears to have been rather erratic, unless these facts can be connected by a cogent explanation.

India

It would be convenient to discuss the Indian Gondwana deposits also in two sections, the Peninsular and the Extra-Peninsular.

Peninsular India

The Permian part of the Gondwana System in the type locality of the Damodar Valley is subdivided as below:

TABLE II

Damuda Series	Raniganj Coal Measures	3,000 feet
	Barren Measures	2,000 feet
	Barakar Coal Measures	2,000 feet
Talchir Series		900 feet

The basal beds, with a few local exceptions where overlap has distinctly taken place, are invariably a tillite or a glacial bed. Greisbach has recorded erratics of up to 30 and 40 feet diameter from Ramkola and Tatapani coal-fields. He has (1880, p. 142) pointed out that 'many of the boulders of elongated shape are standing perfectly upright in the matrix and seem to have dropped from above into the fine clay'. Boulders up to 15 feet in diameter have been recorded from the Raniganj coalfield also. Except for the Ramgarh coalfield area, where shales and sandstones intervene in the boulder bed, only one tillite is recorded and greenish shales overlie this bed. Marine fossils have been found in two isolated areas from within the tillite in Peninsular India, Umaria and Manendragarh (Hasdo River). The fauna from the former was originally described by Reed, but has recently been restudied by Thomas (1954). Thomas is of the opinion that it has close affinities with the fauna from the Lyons Group of the Carnarvon Basin (basal glacial beds in the North-west Basin) in Western Australia, and places it distinctly in the Lower Permian. This has already been suggested above.

The macro-fauna from the Manendragarh bed has been studied by M. R. Sahni and D. K. Dutt of the Geological Survey of India, but the details are not available so far. The presence of more than one species of *Eurydesma* is, however, probable (Tewari 1958).

Plant fossils in the Talchir Series occur only in the uppermost shale beds, as well as in the associated sandstones. It may be significant that as many as eight species of *Gangamopteris*, though only four species of *Glossopteris*, occur in these beds. Other plants known belong to the genera *Euryphyllum*, *Voltzia*, *Samaropsis*, etc.

The entire available evidence goes to indicate that the movement of ice was, generally speaking, from south to north. Certain inclusions in the tillite in the Salt Range could have travelled over 500 miles and are said to have been transported from the Aravalli Ranges. A poleward journey of glaciers for such a long distance—and the distance could have been considerably greater for the glaciers presumably continued further north—is, to say the least, a very complicating factor. In the Pleistocene Period it is not known to have happened anywhere. Indeed, most glaciologists rule out the possibility of a poleward journey for glaciers for any considerable distance.

The Damuda Series (comprising the Barakar Coal Measures, the Barren Measures and the Raniganj Coal Measures) overlie the Talchir Series generally conformably, though in places a slight disconformity is discernible. This might have been the result of the change in the environmental conditions, and no importance need be attached to it. In the western part of the Damodar Valley the Barren Measures are not separable from the overlying Raniganj Coal Measures, though the continuity of deposition makes it inevitable that a part of the sequence be assigned to the formation.

The entire section in the type area is composed of freshwater beds. Plant fossils abound at all horizons and allow fairly fine correlations. Certain species of *Gangamopteris*, apparently, disappeared, for only four species are known, and of these only one, *G. cyclopteroides*, continues to the top of the Raniganj Coal Measures (Jacob 1952, Appendix table). This species appeared in the Talchir Series, and is, therefore, of no value for correlation purposes, nor is it diagnostic of age. *Glossopteris* becomes the dominant genus and the number of species recorded swells fourfold from the underlying Talchir Series. Apparently this came about only gradually, and no catastrophic change is indicated. A number of other genera are known from the Damuda Series, and the entire composition of the flora is taken into consideration in determining the age of any bed or particular horizon.

No *Gangamopteris* is known from the Triassic Panchet Series, though some species of the rival genus, *Glossopteris*, continued in the Lower Triassic beds, and co-existed with the typical Triassic genus, *Thinnfeldia* (*Dicroidium*). Though no inference need be drawn from the fact at this stage, the disappearance of *Gangamopteris* seems to have synchronized perfectly with its disappearance in Australia, and the present authors believe that this could not be altogether fortuitous.

There is only an insignificant admixture of northern species in the Indian Permian flora and Sahni (1926, p. 243) invoked parallel evolution to explain the presence of the few known forms when he stated that: 'When we speak of an admixture of northern forms in the gondwana floras there is a tendency to lose sight of the fact that identical or similar forms already existed in the south. It is, therefore, quite natural, and in fact easier, to trace to *them* the origin of the admixture than to postulate southward migration from the northern continent.' The presence of a strong admixture typical of northern and southern floras in the South Rhodesian beds will be referred to later. It may, however, be pointed out at this stage that Sahni's is the only explanation that appears to be satisfactory, for migration from the north, completely avoiding the Indian continent, and even parts of Africa that lie on the route, appears difficult to envisage.

Gondwanosaurus bijoriensis and *Brachyops laticeps* were, till recently, the only vertebrates known from the Permian beds of Peninsular India, and come from the Raniganj horizon. A recent discovery by the senior author (along with Shri C. Nageshwar Rao) has been described by their colleague Shri C. Tripathy (*in press*) as *Rhinesuchus wadii*. The material available is only the cast of a part of the skull, but the horizon is distinctly from near the top of the Raniganj Coal Measures in the Singrauli Coalfield. *Brachyops* is closely allied to *Bothriceps* from Eastern Australia and may even be identical, while *Rhinesuchus* has been reported from South Africa, East Africa and Madagascar. There will be reason to refer to these later.

Extra-Peninsular India

Outside Peninsular India, Gondwana beds have been recorded from a narrow belt which might be continuous from one end of the Himalayas to the other. It has been carefully studied only from the Salt Range and Kashmir. In the former area, plant beds with *Gangamopteris* occur a few feet above the tillite, and slightly below the *Eurydesma* horizon. It would, thus, appear that freshwater conditions prevailed for a while after glaciation and then marine transgression took place. By the time the *Eurydesma* fauna came to the region, considerable time after the glaciation might have elapsed, and yet the climatic conditions must have been cold enough for this peculiar fauna. In Eastern Australia *E. cordatum* occurs about 3,000 feet above the horizon with *E. hobartense,* but both the species occur together in the Salt Range. It, however, appears to be reasonable to consider this horizon as equivalent to the *E. cordatum* horizon of Australia.

Above this horizon of typically cold-water *Eurydesma* fauna there are a hundred feet of barren beds, and these, in turn, are succeeded by the well-known warm-water *Productus* Limestone beds (Schuchert 1935, p. 19). This change in the character of the fauna, indicative of climatic conditions, is exceedingly significant. The conclusion is inescapable that considerable time was taken in the deposition of the 100 feet of barren shales, covering the period of the departure of frigid conditions and its peculiar fauna, and the arrival of warm climatic conditions along with the fauna accustomed to these new environments.

Gangamopteris has been discovered in several areas of Kashmir also and Middlemiss (1919, p. 293) has shown that in the lower beds it predominates over the rival genus. Elsewhere no *Glossopteris* has ever been found, though *Gangamopteris* is abundant. Amphibians, *Actinodon risiensis* and *Archegosaurus ornatus,* as well as fishes, have been found from different localities, but their exact horizon cannot yet be compared with the better known type-section in Peninsular India.

South America

Like Australia and India, South America can also be treated in two sections, Brazil and Argentina, and these will here be taken up in that order.

Brazil

The geological picture of the Gondwana succession in South America is not yet clear and Mendes (1952, p. 335) only recently lamented that 'The Gondwana of southern Brazil, generally speaking, lacks stratigraphical details, while its fauna and flora ought to be more carefully studied; until then their proposed correlation with Argentine, Africa, Australia and India is almost pure speculation'. It is, therefore, not surprising that fairly divergent opinions are commonly held by local geologists. As many as eight papers were submitted to the 19th International Geological Congress, while Mendes (1952) and Oliviera *et al.* (1956) published elsewhere during the last few years. Almost the only point of importance that appears to stand undisputed is that there is no unconformity or disconformity between the glacial beds at the bottom and the top of the so-called Passa Dois Series. The Irati Shales form the bottom of the Passa Dois Series, and carry the well-known genus, *Mesosaurus*. There is, however, a distinct unconformity above the Passa Dois Series and the overlying Santa Maria beds may be 'Middle or Upper, rather than Lower Triassic' (Romer 1952, p. 251); and von Huene would readily agree to this. The following table is, however, based on the recent paper by Oliviera *et al.* (1956), and covers the geology of Brazil and Uruguay:

TABLE III

System	Series	Group	Formation	Thickness (in metres)
Permian	Passa Dois	Rio do Rasto	Poco Preto Esperanca Serrinha	250
		Estrada Nova	Therezina Serra Alta Irati	400
Pennsylvanian	Tubarao	Guata	Palermo Rio Bonito	250
		Itarare		500

The present authors do not entirely agree with this classification and have drawn liberally from other sources. It, however, appears interesting to record that 'In Rio Grande do Sul and in the southern Catarina there is only one tillitic zone, called the Orleans tillite by I. C. White; in the Taió region of Santa Catarina there are two tillites, called by O. Barbosa the Lontras and Pastagens tillites. In the northern Catarina and in Parana there occur four tillites, and, in Sao Paulo, O. Barbosa and F. M. de Almeida record five tillites, called by Barbosa the Salto, Elias Fausto, Rafard, Mombuca and Juru Mirim tillites. The Rafard and Mombuca probably correspond to the third Paràna tillite (Juru Mirim) of Sao Paulo and Parana. They may be correlated with the single Orleans tillite of southern Santa Catarina and Rio Grande do Sul; thus in the whole southern part of the region the lower tillites are lacking'

(Oliviera *et al.* 1956, p. 32); and so are, apparently, the younger tillites as well. These authors, however, have not offered any explanation of the phenomenon. It may, yet, be suggested that the most probable explanation may be that the ice cap retreated towards the north or the north-east. It is equally probable that it extended from that direction in the first instance also. Only under such circumstances it appears possible for younger tillites to be deposited where they exist in the area, while maintaining a conformable sequence in the southern part of the basin. And this applies to the bottom tillites as well.

On the other hand, inferred movement of ice, from other lines of evidence, is distinctly towards the west in Argentina and the coastal parts of Uruguay. The retreat of ice in this area could have been to the east or the south-east. The northward movement of ice, indicated on the Falkland Islands, may have, yet, another centre of glacial dispersion or there may be some other explanation for it.

Leaving aside the last-mentioned area for the time being, the only possible explanation, then, is that there were two ice caps, one to the north of Sao Paulo and the other somewhere in the Atlantic, east of Uruguay. Oppenheim (1935, p. 1737) substantially agreed with this when he pointed out that the 'Southern American continent shows two glacial centres, one in the north-east comprising the glacial beds of Brazil, Uruguay, Argentina and Bolivia, where there are signs of glacier movement towards the west, and the other in the south and south-east connected with Falkland Islands and the northward movement of the Antarctic glaciers'. Alternatively, it may be presumed that the ice cap itself shifted from a highly vulnerable equatorial seat to only a slightly less, if at all, vulnerable position in the temperate, but open, sea. In view of the absence of the younger tillites in the south, as pointed out above, it becomes obvious that such a shifting could not have been direct, but must have taken place via either well to the west or well to the east. The occurrence of a Permian tillite in Bolivia, where the movement of ice was from west to east (Washburne 1932, p. 177), tilts the balance in favour of the former possibility, but independent evidence is needed on the point.

Inter-tillite coal seams are reported from Parana and this emphasizes the length and importance of the breaks. The frigid conditions must have completely disappeared, and a cold wet climate must have prevailed to enable the slow-depositing coal seams to be formed. Mendes (1952, p. 338) suggests that 'it is not unlikely that a *Glossopteris* flora may be present' along with this inter-tillite coal, and this would suggest that the flora distinctive of the southern coal measures had, probably, already established itself before the glacial conditions had completely disappeared (*see also* Barbosa 1952, p. 319). On the other hand, it appears interesting to point out that during the Pleistocene glaciation such repeated *complete* changes in environmental conditions are not, apparently, known to have taken place, and coal does not seem to have been formed anywhere.

Distinct plant fossils have been recovered from three or four definite horizons in a number of localities. The lowest horizon, according to Barbosa and Almeida (Mendes 1952, p. 340), may be in the Itarare Group. It carries *Gangamopteris*, *Glossopteris*, *Noeggerathiopsis*, etc. The highest horizon in which *Gangamopteris* has been found, according to Dolianiti (1952, p. 297), may be above the Iraty Shales, presumably in the Serra Alta beds of the above table.

Oliviera *et al.* (1956, Table 4, p. 18) place the Tubarao Series in the above table in the Pennsylvanian. The present authors are, however, of the opinion that there is very little justification for placing any beds with *Glossopteris* in the Carboniferous. Indeed, in the entire succession there appears to be no horizon in which *Gangamopteris* might have been the predominant genus, and for which even a Lower Permian age may justifiably be suggested. It has been demonstrated in the earlier section that this genus did not appear for quite some time *after* the initiation of the Permian Period in India and Australia, and there is not the slightest justification to brush aside the evidence from these two countries. On the other hand, the indications are that in Brazil the flora was already present when the glaciation arrived there, and probably *Gangamopteris* had long since passed its acme. Much importance is, however, being attached to obvious 'hold overs' and to suspected affinities to North American faunas. The recent discovery of a living specimen of *Coelacanth* fish from the sea off the coast of Africa, that used to be its original habitat almost 200,000;000 years ago, may be freakish, but has given food for thought to many palaeontologists and stratigraphers. The importance attached to *Loxomma* by Oliviera *et al.* (1956, p. 32) may, then, not be its due.

On the other hand, it seems equally, if not more, unjustifiable to treat all *Glossopteris*-bearing beds as Permian, as Oliviera *et al.* seem to do. It is certain that both in India and Australia some species of this genus survived and do appear in the Triassic beds. In South Africa it appears even in the Molteno beds, often regarded as *Upper* Triassic in age.

Such correlations, unfortunately, leave one with the impression that attempts are being made to adjust the age of the basal tillite to fit in with a preconceived notion, long held by many geologists, and well expressed by Schuchert, that ice ages provide the most precise means of correlation. The age of the Itarare glacials is, thus, being brought to the level where it could be safely put as Permo-Carboniferous. A classic example for this was provided by Oppenheim (1935, p. 1743) when he pointed out that 'there is probably unconformity between the Triassic and the underlying Permian. In spite of the palaeontologic evidence, no supporting stratigraphic evidence has yet been observed in the field'. And the entire palaeontologic evidence goes to suggest that the beds above his Lower Estrada Nova beds, i.e. Therezina, Rocinha and Serrinha beds (*see* Table IV below), as well as the Upper Estrada Nova, belong to the Triassic System. The only established unconformity, as has been pointed out earlier, is above these latter beds, and the overlying Rio do Rasto Group is indisputably Upper Triassic. Thus, the hiatus above the Lower Estrada Nova is being presumed only to justify the placing of the basal tillites in the Lower Permian age. Similarly, the Irati Shales, the undoubted equivalent of the White Band, are being brought down in the succession and placed in the Lower Permian by placing the Rio do Rasto beds in the Permian (as shown in Table III above) and the unconformity at the top of the Passa Dois Series as the dividing line between the Palaeozoic and the Mesozoic in the region. Considerations like those of Oliviera *et al.* (1956, p. 38), that 'the Permian age of the Rio do Rasto Group is proved by the Conchostracean fauna and *Glossopteris* flora', need not hold. Indeed, these may prove quite the opposite of what is being claimed!

The present authors, therefore, find themselves in agreement with Oppenheim (1935, p. 1728) when he ends his Upper Permian with the Lower Estrada Nova beds (= Serra Alta beds in the above table), and places the rest of the succession in the Lower Triassic. For purposes of comparison his table is given below:

TABLE IV

Upper Triassic	Sao Bento Series	Rio do Rasto Group
	Unconformity	
Triassic	Passa Dois Series	Upper Estrada Nova Therezina, Rocinha and Serrinha beds
	Assumed unconformity	
Upper Permian		Lower Estrada Nova Iraty group
	Tubarao Series	Palermo and Rio Bonito group
Lower Permian	Itarare Series	Itarare tillites and glacials

Indeed, he points out that 'the group (Upper Estrada Nova) is characterized by the presence in various beds of Triassic Mollusca'; and again (Oppenheim 1935, p. 1748): 'The Upper Estrada Nova includes a great fauna of lemellibranchs unquestionably of Triassic age.' He emphasized that (p. 1752) 'according to von Heune and other writers, the Rio do Rasto appear definitely to belong to the Upper Triassic', and correlates it with the Molteno beds of South Africa. Whereas this need not be entirely correct and von

Heune has himself slightly amended the age interpretation of this bed, placing it now in the uppermost Middle Permian or only slightly later, Martin (1952, p. 282) agrees with the above very substantially and believes that there is no unconformity between the Rio do Rasto and the Estrada Nova, and places the upper part of the former as equivalent of the Molteno bed of South Africa. He correlates the latter with the Lower Beaufort and Raniganj of South Africa and India respectively.

Only one species, *Gangamopteris cyclopteroides*, is known, as against five or six species of *Glossopteris*. All these species are long ranging and hardly suitable for correlation. In the higher beds of Oliviera *et al.*'s Rio do Rasto bed *Glossopteris* is associated with *Estheria* and *Leaia*. The former of these molluscas occurs in the Upper Coal Measures of Eastern Australia, but only in the Triassic beds of India. *Leaia* is not so far known from India, but elsewhere it occurs in the top beds of the Permian System and Bond (1955, pp. 88–94) has discussed its stratigraphic position in detail. He points out that it occurs in the Madumabisa Shales in South Rhodesia, Upper Coal Measures in Eastern Australia and the Estrada Nova beds in Brazil. Since the name Estrada Nova has been differently used by different authors, it is not clear to which exact horizon he is referring. Bond is, however, obliged to introduce ecology and thus leaves the door wide open for re-interpretation of its exact horizon. It can yet be stated with confidence that if it has any stratigraphic significance, as suggested by its occurrence in Australia and South Africa, it cannot but belong to the topmost Permian horizon, at the earliest.

Though fossil fishes are known from the glacial beds, land reptiles and other vertebrate forms appear in great variety and abundance only in the Santa Maria beds, which are here regarded as entirely Triassic, and may be quite high up in that System.

Argentina

The position in Argentina has long been found confusing and a firm correlation with the Brazilian succession has, therefore, not been possible. Vague suggestions have, however, often been made to compare the sequence in Argentina with that in Eastern Australia. It would, nevertheless, appear that the real basis for this is the recognition of an eugeosynclinal belt in this area, comparable in many respects with that in Australia. Many geologists have suggested a genetic correlation between these widely separated basins, emphasizing the synchroneity of orogenic activity in the uppermost Permian or the Lower Triassic Period (Ahmad 1961).

The position, as it obtains in Argentina, is that Gondwana beds are known from five or six isolated areas, and there are material differences in successions. This, of course, is quite natural for an eugeosynclinal basin but has hindered close correlation. The sequence in Precordillera is exceedingly interesting. It is 3,000 metres (about 10,000 feet) thick and the basal 300 metres (about 1,000 feet) comprise a reddish conglomerate underlying a dark shale and glacial conglomerate with *Glossopteris*. Apparently there is no reason to suspect that glaciation was responsible for the basal conglomerate and the indication, therefore, is that the Permian Period, somehow, started in at least this area without any refrigeration.

Frenguelli (1952, p. 187) has, on the other hand, drawn attention to the exceedingly interesting section in the La Rioja area, the type locality for the Patquia Series. He considers that the 'Totoral beds at the base of the Patquia Series represent the stratigraphical and chronological equivalents of the Barakar beds at the base of the Damodar Series'; also that the 'Totoral marks the oldest Permian time in Argentina'. Moreover, he adds: 'In La Rioja, the uppermost portion of the latter beds (Agua Colorado of Upper Carboniferous age) just beneath the strata with *Barakaria* are represented by layers containing species of *Calamites*, *Lepidodendron*, *Gondwanidium* and *Gangamopteris*, namely *G. cyclopteroides* Fst.' There is obviously no reason why these beds should also not be treated as of Permian age. The glacial beds appear at a *higher* horizon and Frenguelli (1952) has no hesitation in opining that 'Evidently this assemblage, of an unmistakable glacial nature, can be assigned to the *top of the Lower Permian Series*' (italics by the present authors). This, then, was another consideration why this Argentinian succession, where alone a definite Middle Permian glaciation was known to have occurred outside Australia, was being compared with that in Eastern Australia. Yet, it hardly seems necessary to emphasize the difference which lies in the fact that whereas in Argentina there is no evidence of an earlier glaciation in the Permian Period, and there was, almost certainly, but one period of refrigeration, glaciation in Eastern Australia, as has been pointed out earlier, was repeated in distinct waves, from the beginning of the Permian Period, and was almost never completely absent till the end of the Upper Marine Group, which could have been Lower to Middle Permian in age.

The Permian beds of the hills to the south of Buenos Aires begin with a tillite, considered to be 900 metres (about 3,000 feet) thick (Harrington 1956, p. 139). Frenguelli (1952) equates this tillite with the one mentioned above, i.e. it also belongs to the top of the Lower Permian. *Eurydesma*, as well as *Glossopteris* and *Gangamopteris*, occur in these beds.

Harrington (1956) also described the section from the sub-Andean ranges, Sierra de los Llanos and Bajo de Velis, where the formations begin with a conglomerate (in part glacial). It may be reasonable to presume that this also belongs to the same glacial horizon as those discussed above, for no younger period of refrigeration is recorded here. Nowhere, thus, is there more than one glacial bed present, and the conclusion is, therefore, not altogether unwarranted that glaciation in Argentina was towards the middle of the Permian Period.

It, then, becomes evident that the confusion has here, again, been caused merely because the starting point of all correlations was based on the wrong surmise that basal tillites everywhere were coeval, and could not but be of the lowest Permian age. In places, as in the case of Argentina, where there was definite evidence of only a later glaciation, it was apparently presumed that the record of the earlier glaciation was either not known or had been removed before the deposition of the later beds.

In the Falkland Islands the succession offers close parallels with the South African Permian section (Adie 1952*a*, p. 401), and the Lafonian Tillites are very similar to the Dwyka Tillites. These are overlain by slates and sandstones, again very similar to the South African Permian succession. It is, therefore, not necessary to go into any great details of these.

Africa

The large continent of Africa shows the presence of Gondwana type of sediments only from its eastern, central and southern portion and will, accordingly, be discussed here in two sections separately.

South Africa

The Karroo System of South Africa received early attention, and the facts of its geology are well known and well established. The following description, confined only to the Permian Period, is based mainly on Du Toit and Haughton (1954) and Haughton (1952):

TABLE V

3.	Beaufort Series (12,000 feet)	Lower Beaufort Beds.
2.	Ecca Series (10,000 feet)	Upper Sandstones and Shales Middle Shales Lower Sandstones and Shales
1.	Dwyka Series (3,150 feet)	Upper Shales Tillite and Boulder Bed

Only one glacial horizon is known, and though in the north it frequently transgresses on to the gneisses, in the south it is underlain by a bed of shales of indefinite age. The tillite is followed by a thick shale formation, which passes into marine environments on the west.

Du Toit carried out a detailed study of the glacial deposits and came to the incontrovertible conclusion that the ice cap was centred round the Tropic of Capricorn. More important than this was the conclusion he drew that the centre of ice radiation distinctly shifted from west to east and in the end the glaciers radiated from somewhere in the present Indian Ocean, beyond the east coast of Natal. As in the case of India, the glaciers were moving into a region of temperate climate and the question has naturally been asked as to what caused this ice to melt. Ahmad (1961) has also raised the question as to where were they collecting all the morainic material they have deposited on the coast of Natal, for the size and proportion of large inclusions in the tillite suggest the presence of large nunataks in the region.

It is exceedingly significant that in Central Africa the movement of ice, as worked out in the Congo Basin (Veatch 1935, p. 149) as well as elsewhere, was from east, south-east and south. Some of these appear to have crossed the equator and continued for at least four or five degrees of latitude in the northern hemisphere. These glaciers are, thus, supposed to have been traversing a distance of around 25° of latitude in tropical country and yet they failed to dissipate! They might indeed have ended up beyond the 4° N. latitude from where they are known at present, but their deposits have not been preserved.

The tillite in South Africa could be as much as 2,500 feet in thickness and is overlain by a bed of shales. The well-known 'White Band' occurs in this formation and contains the *Mesosaurus*, very similar, if not identical, with the species known from South America. Lithologically, too, the bed bears close similarities to the Iraty Shales. No one has seriously questioned the correlation of these two beds lying across the ocean. In fact the occurrence of these stratigraphically, lithologically and very distinctly palaeontologically, identical beds continues to baffle many a geologist who does not subscribe to the drift hypothesis. At the same time, it appears to the present authors, the argument has been, if anything, rather over-emphasized by the protagonists of 'drift'.

At two places *Gangamopteris* has been found crushed between the tillite and the gneisses below and Du Toit (1929*b*, p. 244; *see also* Du Toit 1933, p. 649) has emphasized this by arguing that the flora was *already* flourishing in South Africa when glaciation began its work of erosion and deposition. The genus, however, is very rare in higher beds and no trace of it remains after the Upper Ecca Series. On the other hand, at Walikale, in Congo, the flora has *Gangamopteris* as an overwhelming constituent (Veatch 1935, p. 124). In fact this author has pointed out that no *Glossopteris* has been found in the area so far, and this reminds one of parts of Kashmir! The movement of ice in this area was from east to west and the plant fossils made their first appearance in the shales overlying the tillites. This may be significant, for, as has been pointed out earlier, the flora, both in India and Australia, did not appear for quite some time after the initiation of the glaciation. The suggestion is, therefore, obvious that, though the flora reached all the continents simultaneously, the glaciation in South Africa, as also in South America, was later than the glaciation in India, Australia and even, perhaps, parts of Central Africa. This argument leads to the conclusion that the tillites in Congo and South Africa are, probably, not of the same age. The alternative, that the flora arrived in South Africa earlier than in the areas mentioned above, appears difficult to envisage.

After the withdrawal of glacial conditions, the shales and sandstones of the Ecca Series came to be deposited. The genus, *Gangamopteris*, continued, though exceedingly rarely, and in only one species, the ubiquitous *G. cyclopteroides*, till it is last found in the Upper Sandstones and Shales. It is hardly possible to consider that this absence from higher beds is due to any want of thorough search. On the other hand, *Thinnfeldia* (*Dicroidium*), known from the Lower Triassic beds both in India and Australia, does not appear till the Molteno beds are reached. In Brazil also it seems to be rare, and the first *Dicroidium* appears only in the Santa Maria beds. The possibility, then, cannot be ignored that the genus was not habituated to cold climatic conditions, and appeared in the different areas only when the climate had suitably ameliorated.

Originally it was thought that *Archaeosaurus* and *Eccasaurus* came from the Ecca Series, and these were a very disturbing element in the intra-Gondwanaland correlations. Current opinion, however, throws considerable doubt about the horizon from which these fossils were recovered (Du Toit and Haughton 1954, p. 335), and the opinion now seems to be crystallizing that the vast number of fossil vertebrates known from South African Gondwana beds come only from the Lower Beaufort and higher beds.

Coal and oil shales have been reported from Natal, and, if Banks' (1952, p. 74) interpretations of the origin of these is correct, marine incursions, as has been suggested earlier, must have been frequent in the area. They have not yet been recognized as such by the local geologists.

The Beaufort Series overlies the Ecca Series conformably, and *Glossopteris* continued to exist throughout the entire succession and into the Molteno bed, considered to be Middle or Upper Triassic in age. A remarkably explosive development of vertebrate life appears to have taken place at this stage. The Lower Beaufort Series is placed by the African geologists in the Upper Permian age and it is, thus, remarkable that, while vertebrates were so numerous in South Africa, the rest of the world was yet inhabited by a very few of them. Only three or four species (represented, perhaps, by a single specimen in each case) are known from the Indian successions and only one has, so far, been found in Australia. The same is true of South America where *Mesosaurus* and its allied form *Stereosturnum* are the only types known till one gets into the Rio do Rasto Group (Table IV). Romer (1950, p. 528) has emphasized the point for the northern hemisphere when he stated that 'In the Middle and Upper Permian, in which therapsids are numerous in South Africa, *there are* *few known vertebrates of any sort in the deposits of North America and most of Europe'* (italics by the present authors). But in the succeeding Lower Triassic Period vertebrates appear to have been abundant everywhere, and the suggestion, made earlier, appears to take root that a fundamental mistake has, somehow, been committed in placing the lower part of the Beaufort Series in the Permian System. The Permian System should, accordingly, end with the end of the Ecca Series, where *Gangamopteris* finally disappeared.

East and Central Africa

In Nyasaland, the Karroo System is divided into (*a*) a basal conglomerate and sandstone, (*b*) a middle shale, coal and mudstone, and (*c*) an upper grit and limestone. The basal conglomerate is, presumably, of glacial origin (Reed 1949, p. 104) and is interbedded with sandstones. The overlying shales have yielded reptiles, such as *Dicynodon, Endothiodon, Rhinesuchus* and a number of other types, 'denoting the middle of the Lower Beaufort Series' (Du Toit and Haughton 1954, p. 358). An Upper Carboniferous or Lower Permian age for the glacial bed at the bottom is practically ruled out here unless a disconformity is proved to exist between the lower and the middle formations. Apparently it does not exist.

In South Rhodesia a basal tillite is overlain by the Wankie Coal Measures (Bond 1952). A mixed northern and southern flora was discovered in these beds and Walton (1929), who described this, stressed the importance of *Sphenophyllum* and *Pecopteris*, known to him from the European Carboniferous. He, therefore, assigned an Upper Carboniferous age and it followed that the tillite, discovered later, found underlying the flora, should be, if anything, somewhat older. It is, therefore, particularly interesting to note that *Pecopteris* has been described from the Upper Permian Raniganj Coal Measures in India, and continues into the Lower Triassic Panchet Series (Jacob 1952, p. 166, Appendix); while *Sphenophyllum* is known from the Barakar Coal Measures, that have ever been regarded as Lower Permian.

Walkom (1938, p. 188) considered these as 'hold overs' and deplored that 'quite frequently these "hold overs" are singled out and stressed as age indicators—in reality they always indicate an age greater than the actual age of the beds in which they occur'. He, therefore, becomes more specific and states: 'This, I believe, may be the case with the Wankie beds in Rhodesia where *Pecopteris* and *Sphenophyllum* may not outweigh the *Glossopteris* flora in the determination of age.' It is, therefore, gratifying to note that even before Walton had expressed the oft-quoted opinion about the age of these beds on the discovery of the northern species, Maufe (1919, p. 30) had, on the basis of the *Glossopteris* flora, suggested a Raniganj rather than a Barakar age for the Coal Measures.

Elsewhere, Frenguelli (1952, p. 185) has drawn pointed attention to another aspect of the same question when he stated that 'attention may be drawn to the several species which were once identified with similar European Carboniferous forms but that recent and more accurate determinations have proved to be different and peculiar species of the southern hemisphere'. And Walkom has questioned the identification of certain species of *Lepidodendron* from the Karroo beds of South Africa, same as Du Toit has expressed doubts about the so-called *Glossopteris* flora from Russia, while Birbal Sahni (1936, p. 329) was sceptical about the existence of the same in the Tonkin area. And who would know these genera better than these eminent scientists of their times? The last named author has shown even a preparedness to account for these occurrences of supposed northern genera as a result of 'parallel evolution' from the earlier cosmopolitan flora (1926, p. 243), rather than accept them as migrated from the north. And this deprives these species of any stratigraphic importance. On the other hand, Hoeg (1937) and Halle (1937) are prepared to discount the presence of Gondwana elements in the Angara flora. It would, thus, appear that migration of the Permian flora from north to south or in the opposite direction was, perhaps, not as common as has often been supposed in the past.

Exceedingly interesting is the evidence available from the Congo area. The absence of *Glossopteris* in the Walikale area has already been referred to, and Renier (Veatch 1935, p. 124) is credited with the remark that this flora was older than that found at Lukuga and Luena in the south. Elsewhere Veatch (1935, p. 8; *see also* pp. 84 and 126) envisages two ice advances, the latter advance resulting in folding the interglacial beds in the southern belt. Both these points appear to be of peculiar significance when interpreted later in this paper.

In the Tanganyika Territory, Stockley (1932, pp. 612–618) has subdivided the Gondwana beds into eight subdivisions, with a conglomerate, K_1, suspected to be glacial, at the base. The overlying beds, K_2-K_4, he places as the equivalents of the Upper Ecca Series, followed by younger beds above. He, obviously, finds himself in the circumstances unable to equate the basal conglomerate bed with the Dwyka Tillite and admits that 'The most doubtful question is the age of basal conglomerate'.

For Madagascar the age of the basal tillite appears to be satisfactorily fixed by the presence, not only of marine fossils, but also of a number of varieties of *Gangamopteris cyclopteroides*, as well as *G. major* and, apparently, only one species of *Glossopteris* in the Sakoa Group. The discordantly overlying Sakamena Group, however, is distinctly of Triassic age.

The suggestion is, here, advanced that in Africa the basal tillites are of more than one age and the areas in which they occur lie scattered, more or less haphazardly, and often in proximity to one another. Their preservation was dependent upon the epeirogenic conditions that obtained locally and only incidentally on the extent of the ice cap. A westward movement of the ice along the equator, as pointed out above, can only be justified if the centre of ice accumulation at the time was much further north than is generally envisaged for the South African ice cap; and the flora in this northern area is distinctly older than that in the beds further south. A distinct shifting of the ice cap in South Africa, as proved by Du Toit, may suggest that the ice cap was *not* very large, for it probably never covered the entire area of the Union at one time (Du Toit 1929*a*, p. 99). It may, then, be imagined that the centre of glaciation shifted from a central African position in early Permian times to an unknown area, and then, in the Middle to Upper Permian times, it traversed across the south of the continent from west to east, almost along the Tropic of Capricorn. The early Permian ice cap, apparently, failed to reach the Union territory, whilst the later ice cap did not extend to the Walikale area, though it, apparently, touched the southern Congo area, and there disturbed the earlier formed glacial beds.

Antarctica

Information about the geology of this vast continent is as yet so meagre (*see also* Adie 1952*b*) that it can hardly be brought in as an evidence in any scientific discussion. It is, however, relevant to point out that in the Beacon Sandstones, that have a conformable sequence which extends from the Devonian to the Cretaceous Period, there does not appear to be any glacial horizon in the strata that could possibly represent the Permian refrigeration. It, however, emphasizes the fact that throughout this period of earth-history not only the basin in which these remarkable sandstones were being deposited was free from any glacial interference, but a large hinterland of this basin was also exposed to normal agents of erosion and river transport. This appears inexplicable when it is remembered that a Devonian glaciation is well known from South Africa and South America, and a Carboniferous glaciation has been extensively reported from South America and Eastern Australia. Thus, not only that the three major glacial records of the southern hemisphere are, apparently, not represented in the Antarctica, but the indications are that, on the contrary, it was free of ice.

The only other significant fact known is that *Glossopteris* has been found in the debris in transport by glaciers emanating from within 5° of the Pole. Although this certainly does indicate that at the time these beds were being deposited freshwater conditions prevailed in the area, and the ice cap was definitely absent, the evidence as to the age of these beds is not complete. The genus is known to continue into the Triassic Period, when the entire earth was having a warm climate and there might not have been any ice cap on the earth, not even on the Poles. Environmental conditions of the Triassic beds in Queensland (Australia), however, do not indicate that the climate was really so warm, and coal was deposited in many areas in Eastern Australia.

General Discussion

It would, at this stage, be useful to discuss the various possibilities under which glaciation could have occurred in such widely separated areas. More important, indeed, is the selective distribution of glaciation in the areas known, and the presence of warm-water fauna in the Middle Permian of New Zealand (Hornibrook 1952, p. 25; *see also* Wellman 1952, p. 21) when Eastern Australia, and maybe Argentina, were strongly refrigerated. The probable absence of any glacial record from the Beacon Sandstone in the Antarctican Permian has already been referred to, and lends strong support to the view. Important also is the consideration calling for explanation for the repeated widespread transgressions of the sea when so much water was lying locked up in the 'greatest ice age the world has ever witnessed'. In Eastern Australia it, indeed, appears that transgression and refrigeration went hand in hand, and the withdrawal of glacial conditions brought in freshwater conditions!

A theoretical consideration of the genesis of the glacial deposits under the circumstances leaves no option but to consider that these could have been formed under one or more of the following possibilities:

(*a*) that the continents have remained more or less fixed in their present positions and glaciation occurred in the form of isolated ice caps under some unknown, but very unusual, conditions;

(*b*) that the continents have remained fixed, and one extensive ice cap covered the entire area from which glacial records are known, including also the areas around, from which these might have been subsequently removed;

(*c*) that the continents were once together to form one compact land-mass—the Gondwanaland of the 'driftists'—and all the areas showing glacial records were covered by one extensive ice cap;

(*d*) that though drift has taken place, it was not a single ice cap that covered the present continents, and instead there were several major centres of ice radiation;

(*e*) that not only that the drift has taken place as a result of the splitting up of Gondwanaland, some time in the Mesozoic Era, but that at no stage before this event of supreme importance was the giant continent itself completely stationary. The idea (Ahmad 1960, pp. 666–668) being that the entire continent, situated at the South Pole, was drifting all the time, and was thus bringing different parts of the land under the Polar ice cap at different times. Such an ice cap need not only have been one of about the same size as the present Antarctican ice cap, but one of a smaller size could probably do. This ice cap might have completely, or very nearly, disappeared by the beginning of the Triassic Period, though it certainly reappeared later;

(*f*) that the Pole itself was wandering, and was affecting different continents at different times.

A brief consideration of the possibilities enumerated would indicate that (*f*) is ruled out by geophysical considerations. A major shifting of the earth's axis of rotation, in spite of all the re-thinking that is being given to the subject currently, is still not considered possible. Even after the recent researches of Runcorn (1956) and Irving (1958) and others on palaeomagnetism, indicating a definite movement of the Pole in relation to the present land masses, the explanation offered is based more on a distinct sliding of the earth's crust than on the shifting of the earth's axis.

Possibility (*b*) demands such an extensive ice cap, covering almost the entire southern hemisphere, and a sizable part of the northern, too, that it again appears to be quite unthinkable and may be ruled out, without further consideration.

On the other hand (*a*) also calls for a world-wide cooling, and Coleman (1925) was a strong advocate of this view. Yet, the researches of Dunbar (1924), Ma (1951–56), Hornibrook (1952) and others do indicate, in no uncertain terms, that warm climatic conditions did co-exist in many parts of the world, and these include Texas, NW. Africa, perhaps also parts of Angaraland (Sahni 1938*a*, p. 147), New Zealand, and even India and parts of Western Australia (in Middle Permian times). Numerous attempts have been made in the past to explain the phenomena and to fit in the known features maintaining the present distribution of land masses, but have invariably collapsed at about the first hurdle. Even Coleman (1926, p. 259), a very uncompromising opponent of 'drift' in any form that he was, was obliged to admit failure in explaining the glacial phenomenon with permanent continents and oceans, and yielded, ever so reluctantly, that 'if there was such a Permo-Carboniferous continent in the southern hemisphere, within 45° of the Pole, many difficulties would be removed in accounting for the known glaciation'. The present authors, therefore, feel justified in submitting that for the purposes of the present study it is not necessary to take this possibility into serious consideration. It was, indeed, a recognition of these almost insurmountable difficulties that Arthur Holmes (1929, p. 340) remarked that 'the opponents of drift have no way of explaining the distribution of late Carboniferous glaciation of Gondwanaland'. His 'late Carboniferous glaciation' is here regarded as of Permian age.

This leaves the alternatives (*c*), (*d*) and (*e*), and all these envisage drift in one form or the other. It may, however, be admitted that, if all the southern continents are brought together under the drift hypothesis, the isolated ice caps, contemplated on the different continents, would more or less coalesce by themselves, and the possibility (*d*) would, automatically, merge with case (*c*), as is shown on Du Toit's (1937, Fig. 9) and Ahmad's (1961) maps.

The two alternatives, then, that deserve serious consideration are: (i) a vast ice cap covering an extensive area of Gondwanaland; or (ii) a small ice cap, with the giant continent drifting all the time. In the first case the recession of the ice cap, towards the end of the glaciation, would take the deposition of the tillite nearer and nearer to the centre of ice radiation, so that the tillites near the central area would be somewhat younger than those along the periphery, at the acme of the glaciation. The earliest record of glaciation is, admittedly, in the lowest Permian in Australia as also in India, whilst the highest is, undoubtedly, in the Upper Permian beds of Eastern Australia and Tasmania, ignoring the interpretations suggested in the above pages. The age of the tillites in all other parts of Gondwanaland should, then, range between these limits. It would, certainly, be wrong to consider them coeval everywhere.

It, here, appears desirable to point out that an ice cap, or the glaciers emanating from it, transport debris all the time. It is a continuous process and goes on whether the ice cap is growing or receding. But a growing ice cap tends to become cannibalistic when it ends on land surface, and itself removes the deposits formed earlier. Only the deposits left behind while the ice cap is receding have a chance of being preserved. On the other hand, when a glacier ends over a sea area, the deposits formed, both while the ice cap was receding and while it was growing, are likely to get preserved. Under the above interpretation, it is, then, possible that the basal beds in Eastern Australia and Tasmania were formed while the ice cap was still growing, for all these indicate marine environments. The outer periphery of the ellipse could have been covered only at a later stage, and India, Central Africa, Brazil and other areas might, thus, have been affected more or less simultaneously. The later glacials in Eastern Australia were, on this hypothesis, formed almost towards the end of the refrigeration.

In the second case, on the other hand, it is not only presumed that the glaciation was *not* of the same age everywhere, but there *might not have been any real ice age*. An ice cap, no bigger than the present Antarctic ice cap, could, with a drifting Gondwanaland, form glacial deposits in different areas at slightly different times. If, therefore, it could be demonstrated that the glacial beds everywhere were not coeval, there would be a strong *prima facie* case in favour of either of the above two possibilities; and if, in addition, it could be shown that it was not coeval, even along the peripheral zone of the first case, the case for the second possibility would be considerably strengthened.

Unfortunately the Permian beds lie with more or less distinct unconformity over older formations in all the areas outside parts of Eastern Australia, and perhaps Kashmir, and palaeontological evidence is nowhere strong enough to clinch the issue. Great stress has, as pointed out earlier, been placed on the commonly held view, the inspiration for which presumably came from the example of the Pleistocene glaciation, that records of glacial conditions provide the best means for correlation. While this need not be correct, a reappraisal of the evidence produced above is desirable at this stage. Attempts would, later, be made to demonstrate that anomalies of floral and faunal records readily fall into a pattern and really explain themselves if the interpretation offered here is found acceptable.

The floral evidence.—A recapitulation of the evidence produced above would indicate that it is, somehow, really not correct to describe the austral Permian flora as *Glossopteris* flora, *Glossopteris-Gangamopteris* flora, or even as *Gangamopteris* flora. The present authors are very definitely of the opinion that, whatever might have been the relationship between these plant genera, it is only reasonable, if evidence based on the Indian and Australian occurrences has any validity, to describe them as two distinct Permian floras in Gondwanaland. Thus, the *Gangamopteris* flora would take its rightful place as the typical and distinctive flora of the lowest Permian times, while the *Glossopteris* flora would become the predominant flora of the Middle and Upper Permian times. There was, undoubtedly, extensive intermingling of the two from almost the very inception, and it certainly lasted to the very end of the Permian Period, but the general character and composition, and as to which genus at any stage played the major partner, was never in doubt. The period of acute rivalry and equal importance might have been fairly low in the Permian; and perhaps even well before the Middle Permian times the *Glossopteris* had definitely gained over the *Gangamopteris*. It is possible that it was the failure to recognize this basic reality that has resulted in the confusion of opinions and correlations.

Considering the environmental and climatic conditions of the period, it would be noticed that in India, after the basal glaciation, the climate probably warmed up sufficiently to allow heavy plant growth. The thick coal seams in the Barakar Coal Measures, and even perhaps in the top beds of the Talchir Series, also signify that the sinking of the crust was very slow. In the overlying Barren Measures there are no workable coal seams, and most observers in the field believe that the sediments were deposited under considerably warm climatic conditions. While the absence of coal may merely signify that the epeirogenic conditions were ever so slightly more disturbed, the conclusion about the progressive amelioration of the climate need not be ruled out.

It is also possible that there was a slight recession in climate in the Raniganj period, but the change to warmer conditions, with the approach of the distinctly warm Triassic Period, must have been, more or less, continuous. On the other hand, in Eastern Australia glacial conditions prevailed intermittently till after the middle of the Permian Period and distinct glacial beds and evidence of rafted glacial material exist. *Gangamopteris*, however, maintained the general pattern it appears to exhibit in India—a pattern of sudden dominating appearance very low in the Permian, gradual decline thereafter, and complete disappearance at almost exactly the end of the Permian Period. This could neither be fortuitous nor entirely ecological, and its significance should be given its due.

It is, then, hardly necessary to point out that the undoubted rarity of *Gangamopteris* in the Gondwana beds of South America and South Africa is interesting. In such large continents all possible permutations and combinations of the ecological conditions necessary for the genus to flourish must certainly have been present, and its failure is, therefore, very significant.

The earliest *Gangamopteris* in Eastern Australia appears about 1,200 feet above the base of the Permians. It may be argued that this was due to the sediments being predominantly of marine character in the area, but it certainly occurs about 800 feet above the base of the Talchir Tillite in India, and about 700 feet above the base of the overlying shales, which could have preserved the plant. 'Fox ... believes that in India the ... flora came in long after the ice had disappeared' (Sahni 1938*a*, p. 141), and this is the general consensus of opinion. In Brazil it may be present within the glacial beds (Barbosa 1952, p. 319), but in South Africa it was certainly flourishing when glaciation started to cover the land with ice, and it is found crushed between the Dwyka Tillites and the underlying granites. Du Toit uses this as an argument in favour of his thesis for an earlier appearance of the flora in South Africa, but he starts with the presumption that the tillites were coeval everywhere. On the other hand, it is equally, if not more, probable that the flora appeared more or less simultaneously everywhere, but the glaciation itself was not contemporaneous everywhere.

Indeed, if the admitted rarity of *Gangamopteris*, as pointed out above, is also taken into consideration, the suggestion becomes strong, perhaps inevitable, that the glaciation itself was, apparently, of later age in South Africa than, say, in India.

Evidence based on the distribution of *Glossopteris* alone appears to run contrary to the suggestion made above. This genus in South Africa seems to have reached its acme in the Lower Beaufort Series and continued into the Molteno Sandstones. Du Toit (1929*b*, p. 250) has made the surprising observation that this Molteno flora has distinct Jurassic affinities, and yet the presence of *Glossopteris* in this association is equally authenticated. It is, thus, possible that while the persistence of cold climatic conditions in this area permitted the *Glossopteris* flora to linger on, zonal fossils, typical of the younger geological ages, were also trying to enter the area and have left their imprint. Molteno beds are, however, regarded to be of Upper Triassic age, and this appears to be reasonable. Indeed, much need not be seen in this apparent prolificity of the *Glossopteris* in the Lower Beaufort Series, for *G. retifera*, a peculiar and very typical species characteristic of the Raniganj Coal Measures in India (though it is present in the Barakar Coal Measures also), which in that country does not continue into the Triassic, appears only in the lowest beds of the Beaufort Series (Du Toit and Haughton 1954, p. 292). It, nevertheless, is true that both in India and Australia *Glossopteris* definitely disappears very early in the Triassic Period; in fact, in the latter country it appears to have been far more rare after the Permian Period than in India. It is, therefore, considered likely that, like *Dicroidium*, the distribution of *Glossopteris* also was controlled by ecological conditions. It, presumably, favoured a cool, temperate climate, and co-existed with the latter genus only for a short while when warmer climatic conditions began to control the distribution of flora. Du Toit (1929*b*, p. 247) has pointed out that 'In South Africa the boundary between Palaeozoic and Mesozoic, based merely on the plant life, would undoubtedly have to be drawn at the top of the Middle Beaufort Stage; that is to say at between the Lower and Middle Triassic, appreciably later than is demanded by the standard geological table'. It, therefore, hardly needs to be repeated that climate suitable for the unique austral Permian flora persisted longer in this area, and was responsible for this anomaly. Knowlton (1919, p. 501) was obviously correct when he pointed out that 'plants inherently possess the qualities which permit them to exhibit the more reliable criteria as to the climatic conditions'.

The faunal evidence.—It would be convenient to discuss separately the evidence based on vertebrate and invertebrate fossils.

(A) *Vertebrates.*—The occurrence of the *Mesosaurus* in the Iraty Shales, as well as the Dwyka Shales, has long been emphasized, and no one has, to the authors' knowledge, questioned their equivalence. Caster (1952, p. 129) has described this as a 'true geological moment'. A point that does not seem to have received the attention it very well deserved is the stratigraphic position of these shale beds in relation to the basal tillites in the two regions. In Brazil there is a considerable thickness of beds, comprising the entire Guata Group, and even, perhaps, parts of Itarare (Table III), indicating a definite recovery from refrigeration when coal seams were repeatedly deposited and transgressions and regressions took place, before the Iraty Shales came to be deposited, and the *Mesosaurus* appeared. It hardly seems necessary to emphasize that in an intra-cratonic basin the deposition of these 700 feet or so of beds must have taken a considerable amount of time. In South Africa, on the other hand, the *Mesosaurus* appeared even before the glacial conditions had completely disappeared. This can only mean that glaciation itself ended somewhat earlier in Brazil than in South Africa. And if the conclusion in the preceding paragraph, based on floral assemblage, is added to this, it becomes obvious that whereas the glaciation in South America and South Africa was younger than the glaciation in India and the lowest Permian glaciation in Eastern Australia, that in South Africa was somewhat younger than its counterpart in South America. The migration of the centre of ice accumulation and radiation, demonstrated by Du Toit in South Africa, also becomes significant now, and it is possible that this migration was also responsible for this difference in age of glacial beds in Brazil and South Africa. In order to maintain the continuity of this movement, and to reduce the time-lag between the deposits in the two regions, it appears desirable, if not actually necessary, to presume that the two continents were much closer together at the time. In other words, the two continents have since drifted apart. And if Africa and South America have been involved in 'drift', the drift of other continents hardly needs further evidence.

Evidence yielded by other vertebrate fossils leads to equally interesting conclusions. The earliest vertebrates from Peninsular India are *Gondwanosaurus bijoriensis*, *Brachyops laticeps* and *Rhinesuchus wadii*. The only form known from Australia so far is *Bothriceps major*, and it is very closely allied to *Brachyops*. Although both these types appear in beds considered to be definitely Permian, Romer (1950), impressed by their advanced morphological characters, considered them as distinctly Triassic. Du Toit (1928, p. 388), speaking about the South African occurrences, has opined that, 'judged by their contained fossil animal life, a formation would tend to appear somewhat younger than would be deduced from the study of its vegetation'. Romer (1950, p. 528) agrees with him substantially when he, comparing the 'Middle' Permian therapsids of South Africa and Russia, makes the significant remark, 'some Russian types appear to be slightly older in time of appearance and somewhat more primitive than those of South Africa'. The possibility, then, presents itself that the beds from which these therapsids are reported in South Africa may not be Middle Permian at all. Caster (1952, p. 141) was even more specific when he pointed out that, 'Despite the floral affinities with the underlying Permian, the Middle Beaufort reptiles are judged by vertebrate palaeontologists as Lower Triassic'. Caster (*personal communication*) has pointed out that this view is based upon the opinion expressed by Romer, who is emphatic on the point. The possibility, then, presents itself that, maybe, the Palaeozoic-Mesozoic boundary in South Africa should be drawn at a somewhat lower horizon than has actually been done in the past. *Rhinesuchus*, that may become the latest link in the correlation, has been known from the Upper Permian of East Africa, and has now been recorded from the uppermost Permian beds of India. In South Africa, however, it occurs in the so-called Middle Permian also. Again, the suggestion is that either this form appeared in South Africa considerably before it did in East Africa and India, or else the beds placed in the Middle Permian of South Africa are really younger.

If the suggestion made in the preceding paragraph is acceptable, it would appear that vertebrates appeared in all parts of Gondwanaland almost simultaneously in the uppermost Permian times, and the law of homotaxis has not been successfully defined. In South America and South Africa they are represented by the *Mesosaurus*, while in India and Australia the types known have been described as *Brachyops* and *Bothriceps*, though they, too, may be identical. In addition, there is *Rhinesuchus* tying India and Africa together. Then, in the Lower Triassic, there was an explosive evolution of vertebrates all over the world, and in this the continents that constituted Gondwanaland were full partners.

At a symposium on 'Discrepancies between the chronological testimony of fossil plants and animals', organized by the Indian Science Congress in 1938, the question was discussed and the general consensus of opinion is best summarized in the words of Birbal Sahni (1938*b*, p. 161): 'The supposed discrepancies are in most cases due to our own mistakes.' The mistake in the present case appears to have been due, as has been emphasized earlier, to the wrong initial presumption that the basal tillites everywhere in Gondwanaland were coeval, and were a result of universal refrigeration. This, indeed, led on to a wrong evaluation of the importance of certain zonal fossils, particularly the genera *Glossopteris* and *Gangamopteris*.

(B) *Invertebrates.*—Evidence from the invertebrate fossils is rather inconclusive so far as the intra-Gondwanaland correlations are concerned. In Australia a reasonably rich fauna is available from various horizons, and from different basins, which might have resulted in different environmental conditions being fully represented. The fauna has, moreover, been carefully collected and studied. In India the Salt Range fauna indicates cold-water conditions below and warm-water conditions for the *Productus* Limestone higher up. The two are separated by a 100-feet bed devoid of any fossils. In South America several faunal assemblages have been found at various horizons in the Brazilian and Argentinian basins. Unfortunately, they all seem to be in urgent need of restudy, preferably by someone who is familiar with the Australian and Indian faunas. There, moreover, appears to be some admixture of North American species in these South American faunas, but it may not be correct to lay any great stress on these. South Africa has, so far, yielded a very small collection of marine invertebrate fossils. These belong to the, by now, well-known *Eurydesma-Conularia* fauna, which is also known from Eastern and Western Australia, Peninsular and Extra-Peninsular

India, as well as Argentina. It has, already, been pointed out that this was a fauna typically attached to cold climatic conditions and, consequently, has no value for correlation purposes. If the interpretation offered above is found acceptable, it might be taken for granted that this fauna followed the frigid conditions wherever the ice cap migrated.

Fusulinae from the Salt Range were studied in detail by Schuchert (1932, p. 540) and he concluded that the age of glaciation could only be 'late Lower Permian' in the area. If this is acceptable, glaciation in India need no longer be regarded as the equivalent of the basal Australian refrigeration. Unfortunately, however, the fusulinae came from the Lower *Productus* Limestone and considerable time might have elapsed between the glaciation and the appearance of the fauna. Schuchert has made an allowance for this in his estimation of the age of the glaciation, but it remains a mere conjecture.

The only thing the marine fauna seems to have helped establish is the fact that the basal glacial bed in New South Wales was really basal Permian, and that in the North-west Basin very low in the Permian. As against Schuchert's above-mentioned correlation, the latter fauna is satisfactorily correlated with the Umaria Marine bed in Peninsular India, thanks to the recent restudy of the fauna from the latter area by Thomas, and the discovery of *Calceolispongia*, a genus almost as unique as the *Mesosaurus*, as also of some other common species. The age of Talchir glaciation may also, then, be regarded as very low in the Permian Period.

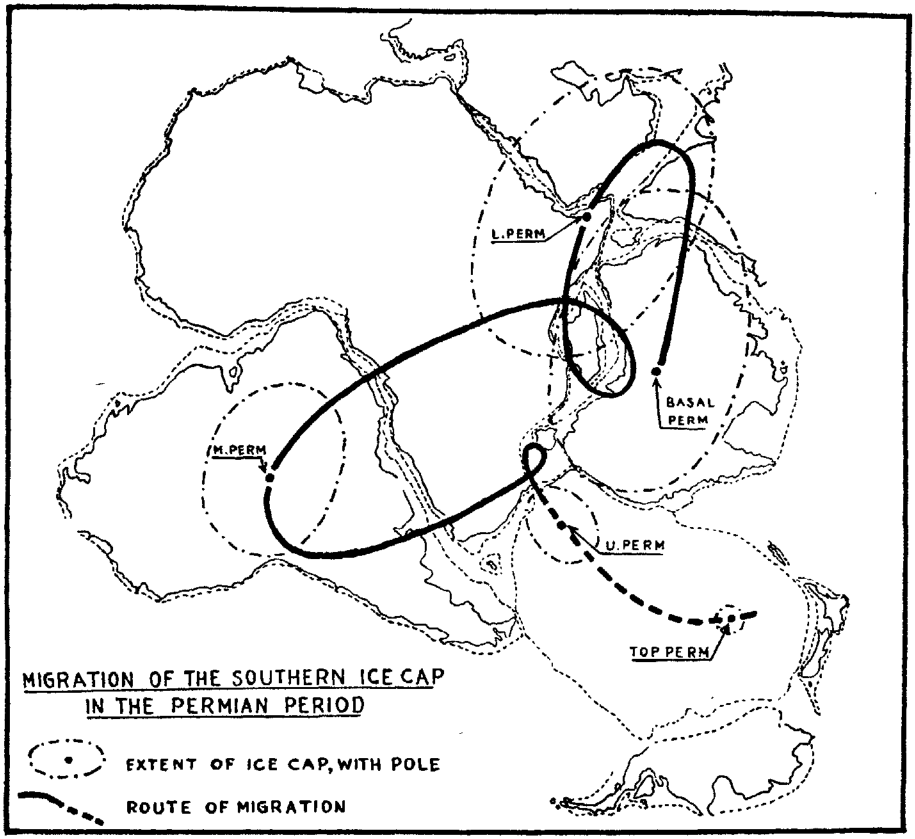
The stratigraphic interpretations.—Stratigraphic information, quoted in the earlier sections, appears to lend distinct support to the views expressed here. To recapitulate, it may be pointed out that in Brazil the Estrada Nova beds pass upwards into the Rio do Rasto beds without any break. The latter are distinctly Triassic, and the age of the former could, therefore, only be uppermost Permian, and the Iraty Shales somewhat older. This age interpretation must also hold for the White Band of South Africa, and, incidentally, leads to the conclusion that the Dwyka Tillite, perhaps, really was of 'upper Middle Permian' age—the age originally suggested by Schuchert (1928; *see also* 1935). He, however, subscribed to the view that refrigeration was world-wide, assigned this age to the glaciation in all parts of Gondwanaland, and invited an avalanche of criticism. The present interpretation would suggest that the Ecca Series represent the rest of the Estrada Nova Group, and the greater thickness of the former was merely due to deposition having been in an active eugeosyncline. Stress has already been laid on the occurrence of coal seams within the period of refrigeration in Brazil, and the conclusions that are to be drawn were suggested. Stratigraphic evidence from Argentina is, as has been pointed out earlier, unequivocally in favour of a Middle Permian age of the glaciation in that country; and there is no basis to presume that this was due to some unusual circumstance, restricted only to that region, and not applicable elsewhere, not even to Brazil. Evidence produced above from Tanganyika territory as well as Nyasaland is equally emphatic on the point that glaciation certainly was not basal or even Lower Permian; and that from South Rhodesia appears to support the view that glaciation there, too, was not basal Permian in age.

The glacial occurrences.—Anomalies in occurrences of glacial beds have already been referred to in fair detail. In this category belong the presence of a single glacial bed in the Lafonian Tillite of Falkland Islands, when areas much nearer the equator had several ice advances; the occurrence of several ice horizons in Eastern Australia in contrast to a single horizon on the west coast; the presence of glacial boulders in the Irwin River Coal Measures when East Australia had no glaciation; the suggestion that the tillites in north Congo and Madagascar may be older than those of South Africa, South Rhodesia and Nyasaland; the presence of five glacial horizons in the north as against two in the south of the Brazilian Gondwana Basin; and the suggestion that the Argentinian glacial beds may all be of about the Middle Permian age. Equally important is the *absence* of any refrigeration in the Permian succession of New Zealand and presumably also in the Beacon Sandstones of Antarctica.

It has also been emphasized that glaciers normally should not, for any considerable distance, move towards the Pole, for this would be defying the laws of physics. But, both in India and South Africa, this has, on the evidence available, definitely taken place, and it may be true also of Brazil. On a somewhat different footing is the case of the Congo Basin, where it is supposed that ice travelled for over 20° of latitude to reach the equator, and yet it did not dissipate, and instead continued for another 4° or 5° of latitude in the northern hemisphere. Even in Natal, the presence of thick glacial beds in the east, almost in the coastal area, when the ice cap was centred out in the open sea, has raised the question as to where the glaciers were collecting the immense quantities of debris they have left behind, particularly when there is no evidence of any significant regression of the sea having taken place to expose the narrow continental shelf (*see also* King 1953, pp. 2165 *et seq.*).

Du Toit and Haughton (1954, pp. 327-328) point out that in South-west Africa 'The Dwyka glacials are the product of two separate ice bodies'. The lower of these was, it is concluded, formed by 'ice moving southwards from Windhoek Highlands'; whereas the normal thicker one was formed by ice 'invading the region from east-north-east'. It is, then, possible that the basal tillite was formed when the centre of ice radiation was moving *westward* through Central Africa in the Lower Permian times, and the glaciers emanating from this just touched this part of South-west Africa. The upper tillite, which is very similar to the Dwyka Tillite in South Africa, must, then, have been formed when the centre of glaciation was traversing the continent from west to east. The ice cap at this stage, apparently, reached up to the southern part of the

Congo Basin, from where Veatch, as pointed out earlier, has recorded two distinct ice advances. This easily explains the significantly different character of the tillites in both the areas.



TEXT-FIG. 1

The present authors are, therefore, of the opinion that there is hardly any justification for regarding the basal glacial deposits in *all* parts of Gondwanaland as of 'Permo-Carboniferous' or even of Lower Permian age. They, on the other hand, feel justified in believing that it is, presumably, only for the New South Wales glacial beds that a 'Permo-Carboniferous' age may be used. In India the glaciation might have been Lower Permian in age, while in South America it was, apparently, of about Middle Permian age. The South African glaciation is satisfactorily dated as slightly younger than that of Argentina and may be placed as 'upper Middle Permian'. The repetition of glaciation in Eastern Australia, the occurrence of dumped erratics in the Irwin River Coal Measures, the glaciation in Central Africa, presumably occurred some time between the Lower Permian and the Middle Permian.

Of the two alternative hypotheses considered earlier as capable of explaining the incidence of glaciation in the Gondwana period, it was suggested that, in the case of there having been one extensive ice cap, the age of the glacials along the periphery, i.e. in Kashmir, Congo, Brazil, Argentina, etc., would have been almost the same. This was irrespective of the Gondwanaland assembly used, and was equally true on Du Toit's, as on Ahmad's, map. It has, however, been demonstrated above that this, perhaps, was not the case, and the tillites in Brazil are, for instance, distinctly younger than their counterpart in Kashmir. This could have been possible only under the second hypothesis, i.e. that the ice cap was not very large, but that Gondwanaland itself was at the Pole and was drifting all the time. Ahmad (1960, Fig. 2) has deduced the course of this drift from the Devonian to the Triassic Period, and the present study lends support to the views expressed therein.

Ahmad has used an assembly of Gondwanaland by Carey (1951). Since Carey himself has since suggested a new assembly of the continent (1958), and future work may produce evidence to support this or some other assembly, it may be necessary to make changes in Ahmad's map—slight changes are called for even as a result of this study (Text-fig. 1)—but the basic idea would probably remain sound. The evidence to hand is in favour of Carey's 1951 assembly, as far as the placing of the major continental blocks is concerned. The comparative scarcity of glacial deposits in the Northern hemisphere may, however, support the return to Pangaea by Carey.

It may also be mentioned here that Carey rotates the Falkland Islands through an angle of 90° and this explains the apparent northward movement of ice in these islands.

It appears gratifying to note that recent researches in palaeomagnetism (Irving 1958; Runcorn 1956 and others) do suggest that Gondwanaland was probably drifting all the time. In the present study this line of evidence has not been taken into consideration, yet it would be noticed that the Polar positions, deduced by Irving and Ahmad, in many cases, almost coincide.

Conclusions

The age and cause of repeated glaciations in Gondwanaland, particularly the more well-known Gondwana glaciation, have been the subject of discussion amongst the geologists of the world for over a century now. The present authors present here a fairly detailed study of evidence bearing on the age of the Permian tillites in different countries and arrive at certain conclusions which have a definite bearing on the possible cause of glaciation. Thus, they point out that *Gangamopteris* not only appeared some time after the glaciation in India and Australia, but also that at its very first appearance it was far more abundant, both in number of species and the number of plants, as indicated by the number of leaf impressions preserved, than its rival, the *Glossopteris*.

The genus, however, declined rapidly and, perhaps, even before the Middle Permian times it was already eclipsed by the latter. One or two species, nevertheless, continued till the end of the Permian Period, but *Glossopteris* definitely lasted into the Mesozoic, and is found in the Upper Triassic beds, as a 'hold over' in South Africa. The authors, therefore, insist that the Permian Period witnessed two floras, a *Gangamopteris* flora very low in the Permian Period, and a *Glossopteris* flora, characteristic of the Middle and Upper Permian.

This pattern of floral life does not hold for South America and South Africa, where *Glossopteris* appears to have been the predominant genus from the lowest Gondwana sediments known. The authors, therefore, draw the natural conclusion that, perhaps, glaciation in these regions appeared later, and the lowest Permian Period is not represented in the successions studied, unless the Lower Dwyka Shales, till recently included in the Karroo System, are reincluded and treated as such (Adie 1952*a*, p. 405).

Considerable supporting evidence is available from vertebrate remains whose prolificity in the so-called Permian beds of South Africa, in contrast to their rarity in the rest of the world, had remained an unsolved problem for decades. If, as is suggested in the preceding pages, it be presumed that a fundamental mistake had been committed in correlations of the intra-Gondwana beds, this anomaly appears to be very satisfactorily solved. The present authors suggest that the cause of most of these mistaken correlations has been the early idea of Schuchert and others that records of climatic changes, which could not but be universal, provide the best means of correlations.

The authors, thus, point out that the vertebrates in all parts of Gondwanaland appeared towards the end of the Permian Period. Correlation links are provided by *Bothriceps-Brachyops* in Australia and India, *Rhinesuchus* in India and Africa, and *Mesosaurus* in South Africa and South America.

This changed interpretation of the age of the Karroo System also provides the explanation for yet another anomaly, that the South African vertebrates, from the so-called Middle Permian, appear to have Triassic affinities, for the beds from which these have been recovered either belong to the topmost beds of the Permian, or are actually of Triassic age. It would, thus, appear that the close of the Permian may correspond with the end of the Upper Coal Measures in New South Wales, the Raniganj Coal Measures in Peninsular India, the Serra Alta Formation of Oliviera *et al.* (Lower Estrada Nova of Oppenheim) in Brazil and the Ecca Series in the Union of South Africa.

It is believed that the Collie Basin tillite is younger than the basal tillites in the Irwin River and other Western Australian basins, and may correspond to the Irwin River Coal Measures horizon. The overlying coal-bearing beds in the Collie Basin would, then, be just slightly younger than the Irwin River Coal Measures, and not its exact equivalent. It is also surmised that there is no justification for treating any element of the *Gangamopteris* or *Glossopteris* flora as older than Permian, and that there is definite evidence to support the contention that the Dwykas are younger than the Itarare, and the glaciation in Argentina occurred in the Middle Permian times, and might itself have been younger than the Itarare.

Estheria and *Leaia* are two freshwater forms known. The former is known from the Panchet Series (Triassic) in India, the topmost beds of the Upper Coal Measures in Eastern Australia, the top of the Passa Dois Series in Brazil, and the Lower Beaufort Series in South Africa. *Leaia* is not known so far from India, but occurs with *Estheria* in Africa and Australia and presumably somewhat earlier in South America. The boundary between the Permian and Triassic beds should, then, be so placed as not to leave them very far above or below the line of division.

It is believed that the *Eurydesma-Conularia* fauna, to which great importance has been attached in the past, need not necessarily own the significance bestowed upon it. The present authors agree with Schuchert that it was a typically cold-water fauna, and hence they believe that it must have been migrating with the migration of the climatic conditions conducive to its life cycle.

The interpretation of age, as suggested above, appears to be in full accord and to fall in a perfect pattern with a drifting Gondwanaland, as suggested earlier by the senior author. It is, thus, concluded that *there was no Permian Ice Age in Gondwanaland.* The continent, before it split up into a number of, by now far-flung, pieces, was, presumably, itself located at the South Pole and was drifting all the time. Different areas came under the influence of the Polar climatic conditions at different times and, *if the epeirogenic conditions were favourable*, the tillites that were formed have been preserved. The basal glacials in Eastern Australia are, thus, placed in the lowest Permian Period, followed successively by those of the northern basins of Western Australia, India, parts of Congo Basin, higher horizons in Eastern Australia, Collie Basin, ? Madagascar, basal beds in South-west Africa, Brazil, Argentina, and finally South Africa, Falkland Islands, Tanganyika territory and Nyasaland. It is possible that the topmost horizon in Tasmania came at even a later date.

Seward (1938, p. 322) borrowed Du Toit's statement to emphasize that 'In its attitude towards climatic anomalies revealed by fossil records "Orthodoxy is indeed endeavouring to defend a wholly untenable position"; this in the reviewer's opinion is true.'

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