Botanical Records of the Rocks: with Special Reference to the Early *Glossopteris* Flora.[1]

By Prof. A. C. Seward, F.R.S.

Earlier Chapters of the History of the Plant World.

It may be helpful as a preliminary to my treatment of certain aspects of plant-life in former ages to glance at a table of contents of the geological history of the world. The crystalline rocks classed by geologists as Archæan represent inconceivably ancient land surfaces on which were accumulated vast piles of detrital material furnished by agents of erosion, and from time to time products of volcanic activity. Plants may have lived on the Archæan, or pre-Cambrian, continents; they probably did, but as yet we have no certain knowledge of them.

Passing higher in the geological series to the marine sediments and associated lavas and volcanic ash included in the Cambrian, Ordovician, and Silurian systems, we find clear evidence of the existence of lime-secreting Algæ, the precursors of some of the modern reef-forming seaweeds, and, in Silurian strata, a few traces of plants which probably lived on dry land. It is true to say that as yet we know practically nothing of the terrestrial vegetation of the world before the beginning of the Devonian period.

Attention has been directed by many writers to the recently acquired knowledge of the floras that have left well-preserved samples in rocks of the Devonian period: we speak of Devonian plants as the oldest known relics of terrestrial vegetation; but we cannot believe that in them we have the first of a succession of colonists which spread over the face of the earth. Whether they are regarded as the modified descendants of more ancient types, which evolved in the sea and afterwards accommodated themselves to existence above the tides; or whether we prefer to think of Devonian plants as descendants of Silurian or still older progenitors, the fact remains that their ancestry is shrouded in mystery. Stress has been laid on certain morphological features presented by members of the older Devonian floras; on the other hand, we must remember that the best-known of these extinct plants lived in swamps and under conditions that were favourable to their preservation as fossils. We know only in part.

A few plants have been recorded from Devonian rocks in South Africa, but the records so far obtained from beds below the Karroo system are very disappointing. Further research may yield valuable results.

Leaving the Devonian period we pass to the Carboniferous and Permian periods, and here there is much to discuss which has a special application to South Africa. At many localities abundant *disjuncta membra* of plants have been found in sediments deposited in shallow water near the coastlines, and in volcanic ash flung from craters over forest-clad regions beyond the reach of the sea. This Lower Carboniferous vegetation, though more varied than that of the latter part of the Devonian period, was its direct derivative. Identical genera and identical, or at least very closely allied, species have been found in north-eastern Greenland, in Spitsbergen, in Europe and North America, in South America and Australia.

Many instances of the wide geographical range of early Carboniferous plants might be given: it is evident that during the first half of the period the vegetation of the world, so far as we can tell, was less diversified than it is at the present day. Genera such as *Lepidodendron* and allied forms, *Asterocalamites*, the earliest, well-defined example of an Equisetalean type, *Rhacopteris* and *Clepsydropsis* among the ferns, *Cardiopteris*, which may be a pteridosperm, were common to both hemispheres. Here again we lack data from South Africa.

During the latter part of the Carboniferous period and the first half of the Permian period the vegetation of North America and Europe was also more uniform in composition than the floras of the old and new world to-day. Far-travelled members of this northern vegetation were discovered a short time ago in Sumatra and the Malay Peninsula: their geological age is either uppermost Carboniferous or Lower Permian. The coal seams of China, though probably rather younger in age than the richest seams of Europe and America, consist of the altered debris of forests which had spread across the world.

Before leaving the northern hemisphere attention must be directed to the records of a late Palæozoic flora scattered over a broad region stretching from northern Russia to the Pacific coast: its most striking peculiarity is the presence of *Gangamopteris* and some other types characteristic of the *Glossopteris* flora, which presumably, as immigrants from the southern continent, had found a passage across the Tethys Sea.

The *Glossopteris* Flora and the Late Palæozoic Ice Age.

At the stage of geological history we are considering, a broad expanse of water—the Tethys Sea—formed a west and east boundary between the northern continent and Gondwanaland. Let us now pass across the Tethys and take note of the conditions farther south. In that part of Gondwanaland that is now South Africa, as elsewhere in the southern hemisphere, there is proof of a long-continued reign of ice-sheets and glaciers. The occurrence of well-preserved impressions of plants at the base of the old boulder beds at Vereeniging shows that some members of the *Glossopteris* flora coexisted with the ice. The problem which I now propose to discuss is this: At what period did the Ice Age begin, and what is the geological age of the first phase of the *Glossopteris* flora?

The most important of recent contributions to the

[1] From the presidential address to Section K (Botany) of the British Association, delivered at Johannesburg on Aug. 1.

vexed question of the date of the Gondwanaland Ice Age and of the initial stages of the *Glossopteris* flora is from Prof. Schuchert, of Yale University (*Bull. Geol. Soc. America*, vol. 39, pp. 769-886; 1929). Though this is scarcely a suitable occasion for a full discussion of a controversial subject, it is not inappropriate to consider a few of the arguments advanced by the distinguished American geologist.

Prof. Schuchert concludes the summary of his views with these words: "It is therefore certain that the widely spread tillites (that is, the old boulder clays) are of Permian time and in all probability of late Middle Permian age. In any event, not even those of Australia can be of Upper Carboniferous time." He bases this very definite pronouncement mainly on the fossil animals obtained from marine strata associated with the Palæozoic boulder beds. After referring to views expressed by the late Dr. Arber and by myself that "the lowest beds containing remains of the *Glossopteris* flora are, in all probability, homotaxial with the Upper Carboniferous rocks of the northern hemisphere", he adds: "They believe that while the cosmopolitan Upper Carboniferous Flora was living in the northern hemisphere, the *Glossopteris* one was in existence south of the equator".

My view is that no Upper Carboniferous flora was in the strict sense cosmopolitan. Prof. Schuchert continues: 'This contemporaneity of the very different northern and southern floras . . . can not be maintained when the floras are checked into the stratigraphical and marine records. We will repeat", he adds, "that even though there are in none of the continents of the southern hemisphere, other than the west coast of South America, any known plant-bearing rocks of Upper Carboniferous age, yet in this single occurrence there is at hand a small plant assemblage of the cosmopolitan Upper Carboniferous Flora". These South American plants were assigned by Mr. Berry to an Upper Carboniferous horizon, but both Dr. Gothan and myself believe them to indicate a Lower Carboniferous age.

The glacial deposits are stated by Prof. Schuchert to be one of the finest means of making definite time correlations from continent to continent, but in another place he admits that the scattered tillites of Gondwanaland, though regarded as the products of one glacial age, are not all exactly of the same age. It may well be, he adds, "that the basal moraines in south-eastern Australia are somewhat older than those of other continents, as maintained by David and Süssmilch; but by no possible chance can the Australian tillites be stretched into the Upper Carboniferous, nor does it seem possible to place them even below the Middle Permian". Here we have an assertion which challenges criticism.

I am indebted to my friend Sir Edgeworth David for information on the succession of boulder beds and fossil-bearing strata displayed in a section in the Hunter River district of New South Wales: this section gives the sequence of events antecedent to and during the existence of the *Glossopteris* flora. In brief, the evidence furnished by the Australian sections indicates the existence of a flora, which in the northern hemisphere is accepted as Lower Carboniferous, at a stage followed by strata which have furnished the oldest members of the *Glossopteris* flora. The break in succession at this level, between the Kuttung and Lower Marine series, is regarded by Schuchert not merely as evidence of shifting of the scenes inaugurating a new type of vegetation—the *Glossopteris* flora—but also as representing a long interval of time during which rocks of Upper Carboniferous age were being deposited in the northern hemisphere. It is difficult to believe that events which occurred during the latter half of the Carboniferous period are entirely lacking in the geological records not only of Australia, but also of India and South Africa. The more probable view, in my opinion, is that the Lower Marine Series and the corresponding strata in Western Australia containing *Paralegoceras* are homotaxial with the Upper Carboniferous system in Europe and North America.

There has been much discussion on evidence, relevant to the age of the Glacial period and the *Glossopteris* flora, derived from the Indian Peninsula and from regions farther north. Prof. Schuchert, after mentioning the discovery of *Gangamopteris* and *Glossopteris* "in marine strata beneath fossils of the Productus limestone", goes on to say that this discovery proves that the *Gangamopteris* flora is of Upper Permian time.

The age of the Productus Limestone is a determining factor in Prof. Schuchert's contention, and as the evidence is outside my own province, I consulted Dr. Dighton Thomas, of the British Museum, who has made a special study of the palæozoological data bearing on the correlation and age of the Carboniferous and Permian rocks with particular reference to the problems under dispute. Dr. Thomas points out that "the question of the lower limit in age of the Productus Limestone series, and of the beds below them as far as the boulder bed, hinges on the means of determining the age of the Amb to Virgal series [of the Salt Range]". In his letter of April 19, from which he kindly allows me to quote, he goes on to say that the best means of settling the age of the Salt Range beds is furnished by the Brachiopods, a group which Prof. Schuchert "practically ignores". The evidence of the Brachiopods "would point to the Amb series (that is, essentially the lower Productus Limestone) being of Lower Permian age at the latest, and I cannot agree with Schuchert's reference of these beds to the Upper Permian". It follows that the underlying Speckled Sandstone, classed by Schuchert as Middle Permian, is "of high Carboniferous age".

In the same letter Dr. Thomas quotes the following statement by Prof. Schuchert: "The inter-regional correlations are made, however, not so much from the evolution of the Brachiopods as from that of the Ammonites", and, Dr. Thomas adds—"But there are no Ammonites in the succession under dispute in New South Wales, nor are there any in the whole Salt Range Series between the boulder bed and the base of the *Xenaspis carbonarius* zone; nor in South Africa, nor in South America". I have quoted only in part from Dr. Dighton Thomas's letter in the hope that he will publish in full his criticism of Prof. Schuchert's views.

We now pass to South Africa: as already stated, at Vereeniging impressions of *Gangamopteris* were found between the base of the Dwyka boulder bed and the underlying pre-Devonian platform. The Dwyka shales above the tillite have yielded *Eurydesma* and a crustacean, *Pygocephalus*: the latter is believed by Mr. Woods of Cambridge to indicate an Upper Carboniferous horizon. Prof. Schuchert attaches no importance to the crustacean. At a higher level is the so-called White Band, which, as Mr. Du Toit points out, affords a valuable connecting link between the South American and South African succession of strata.

An important consideration raised by the South African beds is the occurrence at Vereeniging of *Glossopteris* and *Gangamopteris* with *Lepidodendra*, *Sigillaria*, and *Psygmophyllum*, which furnish a strong argument in favour of an Upper Carboniferous or at latest a Lower Permian age. An assemblage of plants such as that discovered by Mr. Leslie at Vereeniging has never been found in Middle Permian beds: but Prof. Schuchert definitely states that the tillites which occur below the Vereeniging plant beds are not older than Middle Permian. A collection of plants recently submitted by Dr. Maufe to Mr. John Walton includes species of *Glossopteris* in company with several forms of *Sphenophyllum*, *Pecopteris arborescens* and other plants: comparison with northern floras indicates an age which is at the latest Lower Permian and not improbably near the top of the Upper Carboniferous. The evidence furnished by these and other South African plant-beds is directly opposed to Prof. Schuchert's view.

The summary, though necessarily very incomplete, may enable us to reconstruct in broad outline the closing scenes in the Palæozoic era on the continent of Gondwanaland. In the course of this phase, ice-sheets and glaciers spread from the remote south beyond the equator: lands that are now tropical were then ice-bound. The world was divided into at least two sharply contrasted regions, a northern region where rank vegetation covered thousands of square miles of swamp and low hills, and a vast southern continent where another and less luxuriant vegetation flourished in proximity to retreating glaciers.

An argument stressed by Prof. Schuchert in the presentation of his case for the Middle Permian age of the *Glossopteris* flora and the boulder deposit is based on the marine fossils. The only piece of evidence furnished by marine fossils available in the Indian Peninsula is unfavourable to his view. Moreover, the *Paralegoceras* of Western Australia and the South African crustacean *Pygocephalus*, support the opinion that the *Glossopteris* flora was evolved before the close of the Carboniferous period. If the *Glossopteris* flora is not older than Middle Permian, we are left in complete ignorance of the state of the plant world in Gondwanaland during the long interval between Lower Carboniferous and Middle Permian time.

I have dwelt longer than I intended on certain questions connected with the *Glossopteris* flora, but the publication of Prof. Schuchert's stimulating, and I would add, provocative article, is my excuse. He has stated his case clearly though not convincingly and has collected a mass of material for which many of us are grateful. We are not yet in a position to make positive statements on the age of the *Glossopteris* flora or on the precise correlation of the late Palæozoic plant beds of Gondwanaland and those north of the Tethys Sea. More evidence is needed. Meanwhile, I am not shaken in my opinion that if we could transport ourselves back through the ages into a forest of the northern hemisphere in the latter part of the Upper Carboniferous period, and thence travel by aeroplane to the land that is now South Africa, we should find retreating glaciers and a vegetation in which *Glossopteris* and *Gangamopteris* were prominent plants.

A Critical Stage in the History of the Plant World.

There is another exceptionally interesting problem worthy of South African investigators. It is this: the closing stages of the Palæozoic era in the northern hemisphere were marked by widespread crustal displacements. Crustal movements are a determining factor in the evolution of the plant kingdom: in other words, geological revolutions afford an impressive example of the co-ordination of the inorganic and organic worlds, a theme which has been elaborated by General Smuts in his fascinating book "Holism and Evolution".

The vegetation of the early part of the Permian period, though generally similar to that of the latest stage of the Carboniferous period, was relatively much poorer in genera and species. There were connecting links between the Palæozoic and the early Mesozoic floras, but in the main the two floras differed widely from one another. The more orderly succession of plant-bearing strata in most parts of the southern hemisphere justifies the hope that an intensive and comparative study of the transitional stage between the earliest and the latest phase of the *Glossopteris* flora will furnish valuable data. In this field of work Mr. Du Toit has shown the way: may his example be followed.

Fossil Plants as Tests of Climate.

I now propose to intercalate a few words on another question of general interest. Fossil plants of many different ages frequently occur in unexpected and, from some points of view, very inconvenient places where they raise problems which have so far baffled the ingenuity of students. The best examples are from Arctic regions, and there is also the rich Jurassic flora described some years ago by Prof. Halle from the edge of the Antarctic region. In brief, there are numerous examples of fossil floras from the Arctic or Antarctic which are composed of genera and of plant forms regarded as characteristic of temperate or sub-tropical habitats at the present day. If we plot on a map of the Arctic regions the distribution of ancient floras, it becomes clear that no shifting of the earth's axis, even if this favourite device were admissible, would give a satisfactory explanation of the contrast between the past and the present.

Discarding as inadequate, and as a method wholly displeasing to astronomers, an attempt to create geographical environment consistent with palæobotanical facts by altering the position of the north pole, we turn to the alternative of rearranging, within the Arctic circle, the distribution of land and sea and the consequential shifting of cold and warm oceanic streams. Dr. C. E. P. Brooks suggests a possible rearrangement of land and water which, he believes, would go some way towards the provision of climatic conditions such as the fossil plants of the Tertiary period appear to demand; but it would seem from a more recent contribution by Dr. G. C. Simpson that we cannot hope to obtain all we need, or nearly all we need, by any method of redistribution of land and sea on the assumption of a fixed pole, and without recourse to Wegener's hypothesis of drifting land areas.

We are left with two other alternatives: the adoption of Wegener's views or some modification of them; or the possibility that plants are less trustworthy as indices of climates than has generally been supposed. It may be that a combination of these two methods of attack is the clue to our problem. Let us take the second first: assuming that the ferns to which reference has been made flourished on the parallels of latitude where their remains have been found, and assuming such amelioration of the present Arctic conditions by a rearrangement of land and water as meteorologists permit, there must have been in the past, as there is to-day, a long and relatively dark period of sleep, and a summer no longer than the growing season now available for the almost miraculous development of Arctic plants. Can we imagine, to take one instance, the Cretaceous flora of Greenland enduring a sunless Arctic night more than six months in duration?

There is another, and to my mind an important and neglected consideration; we are too prone to speak of such a genus as *Gleichenia* as tropical because it happens to be one of the commoner ferns in tropical countries; but like many other genera characteristic of the warmer parts of the world, it includes species which grow vigorously at an altitude of 10,000 ft.-12,000 ft. where the climate is by no means tropical. Is it not legitimate to suggest that a plant that is now confined to the tropics may at a much earlier stage of its career have been able to live under other conditions? Is it unscientific to express the opinion that we may think of plants not only as organisms which have changed in form and structure in the course of thousands or millions of years, but also as organisms which have changed in their susceptibility to external factors?

I suggest that there is a tendency to rate too highly the value of extinct plants as guides to climatic conditions, and I would emphasise the desirability of obtaining more definite information than is at present available on the effect of continuous light and continuous darkness, under suitable temperatures, on plants which do not at present occur in Arctic habitats. Even if the foregoing suggestions have any merit, and if we have underestimated the capacity of plants to survive Arctic seasons, there is still a serious obstacle to surmount before it is possible to imagine, let us say, the Rhætic vegetation of Scoresby Sound and that of southern Sweden flourishing in regions separated from one another by at least ten degrees of latitude.

Wegener speaks of the upper portion of the earth's crust as travelling in an easterly and westerly direction; he also assumes a slight movement of the poles. If it is permissible to postulate a drifting of fractured slabs of the crust in a north and south direction, we can then think of the disunited pieces, now occupying positions more or less remote from one another, as the severed portions of a formerly compact region. To take a concrete example: the Rhætic plant beds of eastern Greenland, now remote from those of Sweden, may formerly have been portions of one mass well to the south of the Arctic circle. This may be merely a figment of the imagination; but such evidence of correspondence, both in the succession and nature of the stratified rocks and in the fossil contents, as Mr. Du Toit has obtained from a comparative study of the rocks of South America and South Africa, or as Mr. Harris is finding in his comparison of the Greenland and Swedish Rhætic strata, is arresting enough to make us pause before abandoning the principle of continental drift.

PALÆOBOTANY AS A KEY TO THE PRESENT DISTRIBUTION OF PLANTS.

If time allowed it would be tempting to deal with still another aspect of palæobotany; the importance of a critical study of the floras which immediately preceded the Pleistocene Ice Age. Progress made in recent years in the improvement of methods of deciphering the relics of plants of other days increases the confidence with which it is possible to recommend, as a promising field of work, the investigation of Tertiary floras. The Tertiary floras were more uniform than the floras of to-day. We cannot understand the present distribution of human races if we confine attention to the present, nor can we appreciate the significance of the geographical distribution of floras and their composition unless we consult the herbaria of the rocks.

Low Frequency Sound Waves and the Upper Atmosphere.

By E. H. GOWAN.

THE transmission of low frequency sound waves, such as those from explosions, to very great distances has been an accepted fact for some time, but for careful investigations it was inevitable that mechanical instruments should eventually replace the ear in receiving the waves. These instruments have the advantage of being more certain, more accurate, and of producing a permanent record. Some types show the form of the wave, and all are more sensitive to the longer wavelengths which may be completely missed by the ear, even though they are not quite outside the