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PALAEOBOTANICAL ASPECTS OF GEOCHRONOLOGY

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"In this age of specialization, which inevitably tends to confine thought to compartments, one is apt to overlook or to underrate the bearing of one branch of science upon another."

BIRBAL SAHNI
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THE late Professor Birbal Sahni belonged to the comparatively small band of workers in natural sciences who believe in the necessity of borderline research. He himself was both a botanist and a geologist, and a well-known authority in these subjects. But it is less widely known that he was an archaeologist also. It must not be thought, however, that his familiarity with these subjects meant that he was, so to speak, playing about in these different fields according to his moods. Quite the contrary; he deliberately sought to solve problems of one branch of science by the methods of the other. The theory of Continental Drift, for instance, was studied from the point of view of the distribution of fossil plants, or, in archaeology, the early cultivation of rice provided the link with botany. It is not surprising, therefore, that Professor Sahni showed an especial interest in geochronology, that young branch of geology which occupies itself with the construction of absolute time scales for the prehistoric and geological past. He realized that there are great possibilities in the Himalayas for the study of annual deposits of the *varve* type and their connection with pollen analysis, and he was equally convinced, when a committee on the measurement of geological time by means of radioactivity methods was instituted in India, that palaeobotany would be able to contribute usefully to this kind of work.

Strictly speaking, geochronology is concerned with time scales. But its methods are to a large extent based on the study of the biotopes of the past, and their succession in time. This is so because important chronological information is obtained from the composition of the faunas and floras of successive strata. They may indicate changes in climatic or other external conditions and thus provide us with a scale of climatic fluctuations. As these aspects are investigated, however, valuable ecological information is obtained about past *environments*. For this reason geochronology and the study of environments of the past (palaeoecology) are closely connected. This is particularly the case in the late geological periods, the Pleistocene and Holocene, when man was already in existence. The study of his environment thus becomes *prehistoric ecology* and for the technical reasons mentioned it is linked with that branch of geochronology which correlates absolute time scales with climatic sequences.

Although faunal evidence plays a part in the reconstruction of past climates, floral evidence is very important from the Tertiary onwards. In the late Pleistocene it provides relative time scales by way of pollen analysis which have in some areas been dated in years by the counts of varves (laminated glacial melt-water deposits). In the Holocene of south-western North America floral evidence in the form of tree rings has been used in the establishment of a chronological scale linked with the present-day calendar. This usefulness of botanical evidence is largely due to the fact that genera and species are closely related to, and often identical with, recent ones, so that one appears justified in applying the principle of actualism.

On the other hand, climatic inferences are difficult to obtain from pre-Tertiary material. Some progress has been made in the Permo-Carboniferous, and even the arid conditions of the European Triassic are confirmed by the flora, as Mägdefrau's study of *Pleuromeia* has shown. The present paper, however, is not primarily concerned with these earlier periods; it is intended to show, by means of examples, how botanical research contributes to palaeoecology and geochronology from the Tertiary onwards, and particularly so in connection with early man.

IDENTIFICATION OF FOSSILS

The most obvious application of botany to prehistoric ecology is the identification of fossil plants. In prehistoric and early historic dwelling sites, quantities of charcoal are found. Under Indian conditions, wood is probably rare, since the termites or white ants are likely to destroy all wood that has not become unpalatable as the result of impregnation with mineral salts. Metal salts have a preserving effect on wood. Thus iron nails and other iron objects supply hydrated iron oxide which preserves the cell structure of wood exceedingly well, as for instance in buried boats of the Anglo-Saxon and Viking periods of the British Isles (*ca.* A.D. 700-1200). Similarly, according to Pittioni, many wooden tools like shovels and ladders were preserved in copper mines of the Bronze Age in Austria (1500-500 B.C.) as the result of impregnation with copper salts. That wood survives in very dry climates, even in the hot zones, is well known, for instance, from Egyptian graves of predynastic and later age (from at least 3500 B.C. onwards). But very little rainfall is needed to support termites, so that in monsoon and tropical rain climates the limiting factor is temperature decreasing with altitude. Bacterial action also decreases with temperature. The forests of Mount Kenya in Africa contain quantities of dead wood at altitudes above 7,000 ft. In India, the large high valleys of the Himalayas are likely to be favourable to the preservation of wood.

Preservation of wood other than by mineral salts or dryness is usually associated with boggy situations, since water excludes air and thus retards the decomposition of wood. Bogs altogether furnish many other remains of plants, like leaves, seeds and pollen, and, as the deposits of bogs grow, a stratified series is formed which often indicates climatic changes.

In Europe, peat sections frequently contain prehistoric objects and evidence of living sites in the form of wooden floors, etc. No such finds have as yet been made in India, but they are to be expected in suitable localities. For the reasons stated they are most likely to occur in bogs at altitudes of over 5,000 ft., where ponds and lakes were gradually filled in with vegetation, and a search should be made for bogs containing archaeological remains in Kashmir, Nepal and elsewhere.

In this connection, another problem deserves to be mentioned. It is that of the formation of peat in humid-tropical climates. Such peats have hardly, if ever, been investigated, though they must exist today, for instance, in the deltas of large rivers, since there is fossil evidence from coal deposits that they existed in the past. The most instructive case known to me is that of the Eocene brown-coal deposits of the Geiseltal near Halle in Germany.

This vast area was investigated by a number of workers under the leadership of Weigelt. Unlike the vast majority of humus accumulations, the Eocene Geiseltal swamp was saturated with water containing calcium carbonate, and flora and fauna were fossilized under alkaline conditions. The biotope has been described somewhat as follows. Vast inundation forests separated the permanent water-courses from the rock of the rims of the basin. They were dry and parched in the dry season. When the floods of the rainy season arrived, organic mud, washed from the dry and powdery surface of the ground, was swept away and re-deposited in layers. Dead wood and other remains of organisms were impregnated with calcium carbonate, and thin layers of this material were frequently formed. Pollen is well preserved, as are even the cuticles of the leaves and pigments and muscle fibres of animals. The climate was tropical, and the flora comprised palms, Sapindaceae, Anonaceae, Papilionaceae, Proteaceae and other families, including conifers.

It is conceivable that similar seasonal swamps have been forming in suitable localities in the lowlands of India during the Pleistocene and later. They would afford the material for an investigation of tropical climatic fluctuations contemporary with the Ice Age and the Postglacial.

In all this work, the essential prerequisite is the correct identification of the plant remains which in many cases are fragmentary and poorly preserved. Wood and charcoal are the most frequent type of macroscopic material from prehistoric sites. For their identification it is necessary to have an identified charcoal collection and a set of wood blocks and sections on microscopic slides, including cross, radial and tangential sections. This is a comparatively simple matter in Europe where the number of species is small. But in India it will require patience and devotion to obtain and prepare the necessary material; though the Forest Research Institute, Dehra Dun, is fortunate in already possessing a virtually complete collection of samples of Indian woods.

That archaeological material will not be wanting is exemplified by the result of Professor Sahni's visit to Harappa (*ca*. 2500 B.C.). Charcoal of a species of conifer was discovered which showed that the inhabitants of this prehistoric city were trading with the peoples of the mountains whence the wood must have been imported.

CLIMATIC INTERPRETATION OF FLORAS

Floras, as found in geological and archaeological deposits, are often interpreted as indicating certain climatic conditions. This is done in two ways. It is assumed that each of the species required the same climate in the past as it does at the present. This assumption is probably approximately correct for the latest geological periods, especially the Holocene and the later Pleistocene. In the earlier Pleistocene, some of the species may not yet have been completely adapted to the climatic conditions in which they are encountered today, and still less so in the Tertiary. The animal world has furnished incontestable evidence for this state of things, and it must be admitted as a serious possibility for plants also. The main field of application, therefore, is in the Holocene, and the entire climatic sequence from the Late Glacial to the present day, as established in Europe and North America, is based on the assumption that no adaptive changes have taken place in that comparatively short space of time of, say, 20,000 years.

But the same assumption has been made not only for interglacial and early Pleistocene floras, where it is still yielding consistent results, but also for the Tertiary, where it is impossible to decide how consistent the results are. The information on Tertiary climates provided by text-books is, in large measure, based on estimates made long ago by O. Heer in Switzerland and which presuppose that genera like *Salix, Cinnamomum*, etc., lived under similar climatic conditions as they do today. This approach does not necessarily lead to wrong results, but as a method it is unsatisfactory. Harrassowitz summed up the situation as follows: We have found that in the determination of Tertiary climates one always starts from present-day conditions. One could, with equal justification, start from the past, which was tropical. In fact, this approach would be more logical. In using the usual method one forgets that plants are adaptable.

As regards insect faunas, which depend on vegetation, Zeuner says that the curious mixture of diverse climatic elements in the insect fauna of the Miocene cannot be explained by assuming an average climate expressed, for instance, as the mean of the various requirements of the modern relatives of the Tertiary forms. The "mixture" is due to the fact that some forms, which in that period lived under subtropical conditions, appear in recent times as adapted to a cooler climate. These elements constitute the recent holarctic fauna (and flora), whilst the less adaptable ones have become restricted to suitable areas or died out altogether.

Since the Upper Miocene, central Europe has experienced climatic fluctuations on a large scale. As a result, a considerable proportion of the fauna of that time withdrew to more southerly regions. Others were able to adapt themselves to the changing climate and shifted their areas of distribution but little, though their morphological characters were modified more or less profoundly. Finally, a third portion of the fauna of the Upper Tertiary was unable either to spread to climatically more suitable regions or to adapt itself, and it became extinct. The outcome of these processes is the wide scattering of the relatives of Tertiary forms as we encounter it at the present day.

For these reasons, the climatic interpretation of floras (as of faunas) should, wherever possible, be based on structural or physiological adaptations to certain types of environment or climate. Examples illustrating this method will be given presently (p. 453). At this point it is necessary further to emphasize the complexity of the situation by referring to the influences of migration rates and of earth movements on the climatic character of a flora.

Floras of Pleistocene or Holocene age often have a composition different from the present-day flora of the locality, and this is usually explained in terms of climate. Some differences, however, are due to geographical factors of migration. The genus *Thuja*, for instance, was present in Europe in the Last Interglacial (at the Mousterian site of Ehringsdorf near Weimar, central Germany). *Rhododendron ponticum* occurred in the Alps during the Great Interglacial (at Hoetting near Innsbruck, Austria), and is now restricted to a few localities in Spain, apart from its main area on the Black Sea. Both plants grow well in the present climate of western and central Europe, and in England *Rhododendron* has established itself as an escape from parks in many places. Clearly their absence from the wild flora is not due to climatic causes, but rather to the short duration of the Postglacial period, which has not afforded enough time for re-immigration from their refuge areas. A fossil flora, therefore, must not be interpreted simply as a function of the climate. Its geographical position and the time which was available for the immigration of species has to be taken into consideration.

Occasionally it becomes necessary to regard earth movements as an interpretation preferable to the more usual one of climatic fluctuations. An example will make this clear. Following a suggestion of Birbal Sahni, G. S. Puri has described the flora of the Pleistocene Karewa formation of Kashmir in a number of interesting publications. The material which came from an elevation of 10,600 ft. revealed a flora characteristic of subtropical rain-forest conditions, and most of its constituents are consistent with an altitude of 4,000-6,000 ft. This discrepancy can be explained in one of two ways. Either the climate was such in Karewa times that the flora in question could grow some 5,000 ft. higher up than at the present, or the beds containing the flora were lifted up by earth movements after they had been formed. That climatic changes occurred in the course of the formation of the Karewa beds is likely, since varved deposits are included in this series. They suggest glacial phases. It is easy to interpret a cold flora found at an unusually low elevation by assuming a glacial phase. But in India it is much more difficult to explain a warm flora at an unusually high elevation, as it would imply the gratuitous invention of a period considerably hotter and moister than the present. This is the case of the Karewa flora, and tectonic upheaval has nearly always been regarded as the correct explanation of its occurrence at an altitude of over 10,000 ft. Sahni and others have shown that this upheaval was connected with the formation of the Pir Panjal range.

The Karewa series has an added interest in that its upper members have yielded a few flakes which appear to be human artefacts. Sahni collected this evidence in 1936 to show that part of the Himalayan uplift is younger than the appearance of man in India.

In the preceding paragraphs some of the factors have been indicated which might affect the apparent climatic aspect of a fossil flora. It is necessary to be on the look-out for such factors and if possible to make allowance for them before climatic inferences are drawn. But in many localities, for instance peat-bogs, the climatic factors have dominated the others, and it has been possible to reconstruct from them climatic sequences which have become the framework of stratigraphy from the climax of the third phase of the Last Glaciation onwards. This applies mainly to Northern Europe. A similar stratigraphy has been developed in North America. Nothing has yet been done in India, although suitable peat-deposits exist in many places in the Himalayas and possibly in the high mountains of the Peninsula also. It would be well worth while to tackle this problem of the Indian Holocene succession, and I feel sure that it would amply reward the investigators, as it might afford a possibility of correlating climatic fluctuations north and south of the Gangetic plains.

CHRONOLOGICAL METHODS

Several of the methods used in geochronology, either directly or indirectly, are based on the investigation of plant-remains, and it will be worth while to regard them briefly from the Indian point of view.

Tree-Ring Analysis

The study of the variation of ring-widths in cross-sections of trees and their correlation has been developed into a successful method of dating ancient human dwellings in the southwestern United States. There, the climate has for the last two or three thousand years been relatively dry, and annual ring-growth has been a function mainly of the amount of rainfall. The rings, therefore, provide clear records of droughts. By correlating the inner rings of a modern tree with the outer ones of a log coming from a somewhat older tree, overlaps can be recognized, and, provided sufficient material is available, ring sequences can be developed for certain periods of the past which are of considerable value in chronology. The tree-ring chronology of south-western North America already goes back about 2,000 years.

In India, this method would afford excellent opportunities for geochronological work wherever wood and ancient timber are preserved. The termites and high temperatures combined with rainy seasons, however, are very destructive, and the chances of finding wooden structures preserved are moderately good only in the neighbourhood of the desert areas. Dry areas at great altitudes are far more promising, and it is conceivable that the archaeology of Central Asia will one day be dated by means of tree-ring chronologies.

Pollen Analysis

The chronology of the Postglacial of Europe is largely based on the combination of countings of glacial varves with sequences of climatic phases established by means of pollen-analysis. This micro-botanical method of investigating peat and other vegetable deposits has largely replaced the earlier macroscopic identification of remains, though the latter has, of course, not been abandoned. Pollen-analysis affords means of estimating quantitatively many more constituents of a flora than can be recognized by macroscopic examination. On the other hand, it is mainly restricted to wind-pollinated species.

Pollen-analysis is bound to play an important part in the establishment of the Postglacial or Holocene sequence of climatic fluctuations in India. This work is, however, complicated by the very large number of genera and species composing Indian forests compared with the small numbers occurring in Europe. It will be necessary to study the recent pollen of relevant species before work on pollen-bearing deposits can be undertaken. For a start, the most promising areas will lie in the temperate forest zone of the Himalayas. Here it will be necessary to look for peat bogs and ancient lake beds.

Glacial varved clays, i.e. clay or silt deposits with an annual rhythm of deposition, are known from the Himalayas. They occur, for instance, in the Karewa series. Norin, moreover, has carried out some counts in Himalayan varve-deposits. A beginning has thus been made towards the establishment of a varve-chronology for India. Much work will have to be done before a well-correlated and dated record has been compiled. It might one day provide an absolute chronology for the Indian Holocene (and thus the later Stone Age and the Metal Ages). But whether it will ever be possible to establish a direct long-distance correlation of varve-series from India and from Sweden remains extremely doubtful for climatic reasons. Norin is probably too optimistic in considering this possible, and it is safer for India to stand on her own feet in this respect.

The chances are relatively high in northern India that polliniferous varved clays will one day be found. Such deposits have recently been described by Welten from Switzerland. Whilst varved clays are normally very barren, pollen is occasionally found in varved deposits in high mountain ranges, where the seasonal changes (including a frosty winter) are very marked and where trees grow not far from glaciers. Such cases are likely to occur in the Himalayas. It will be worth while to look for them, since such deposits afford a possibility of linking varve counts directly with pollen spectra.

MESOZOIC AND PALAEOZOIC CHRONOLOGY

In the epochs preceding the Pleistocene, palaeobotanical research is at present important mainly as a method of establishing detailed stratigraphical subdivisions. That micro-botanical investigation of sediments will play an increasingly significant part in this work has been pointed out repeatedly by Sahni, particularly with reference to the age of the Deccan Trap and the Purple Sandstone of the Salt Range. The statistical analysis of spores and pollen from such early rocks is possible, and the day may come when short-period fluctuations of the climate are found in the Permo-Carboniferous as they have been found in the Pleistocene and Holocene.

ANATOMY AND CLIMATE

It has been pointed out that the practice of determining the climate of a remote period (Tertiary and earlier) by assuming that species and genera have not changed their climatic requirements in the course of time is open to criticism. There is a wide field open for the palaeobotanist who wants to substantiate the climatic requirements of fossil plants by an investigation of their anatomical and physiological adaptations. To take a simple example, tall-growing broad-leaved evergreen plants are sensitive to frosty winters, because evaporation continues from the large surfaces of the leaves while the roots are unable to obtain water from the frozen soil. The presence of such plants in a fossil flora, therefore, suggests that the winters were mild.

Another example is the density of venation of dicotyledonous leaves. It is a function of evaporation (among other factors). Huber, Maximov and others have established that the density of venation on foliage increases (a) with the height above the root, (b) with the intensity of sunshine, (c) with a decrease in atmospheric humidity (so that of two plants of the same species the specimen occupying the drier habitat has the denser venation), and (d) with increased aridity of the soil (so that for instance of two related species the one living in the drier soil has the denser venation). The modifications caused by (c) and (d) afford a means of obtaining climatic information from the structure of fossil leaves, provided that the venation is sufficiently well preserved. Some years ago, the present writer made an attempt to determine the climate of the Upper Miocene of Oeningen (Baden) from such evidence. Briefly, it was found that temperate trees in ordinary localities had venation densities indicated by the following values (total length of veins in mm. per square centimetre): *Juglans regia*, 568, 569; *Acer pseudoplatanus*, 611. In sunny positions, the figures are higher: *Quercus pubescens*, 795; *Acer campestre*, 905. In an extremely dry and hot locality in the central Kaiserstuhl Hills in the rift valley of the Rhine, the following values were obtained: *Juglans regia*, 1296; *Quercus pubescens*, 1095. Mediterranean species have values of the following order: *Quercus coccifera*, 924; *Quercus ilex*, 1031; *Acer monspessulanum*, 1324.

By comparison, the Upper Miocene leaves exhibited venation densities of this order: *Acer trilobatum*, 999; *Quercus neriifolia*, 898; *Populus latior*, 1114; *Cinnamomum scheuchzeri*, 1266; *Cercis cyclophylla*, 1591. These figures correspond to those of Mediterranean species. Evaporation, therefore, appears to have been more intense in Baden in the Upper Miocene than at the present. This information, combined with other evidence, provides an interesting picture of the local climate of the time. Evergreen species suggest that frost was rare or absent, and " dripping tips " were about as frequent in Oeningen as they are in the temperate flora today. Rainfall, therefore, is likely to have been ample, perhaps seasonally, in spite of the high evaporation rate deduced from the density of venation. The climate, thus, seems to have been a subtropical or Mediterranean one with a dry and a wet season. The luxuriance of the Oeningen flora, however, was due to local conditions, for it was growing on the edge of a lake.

There are many other ways in which anatomical features lend themselves to a climatic interpretation. Sahni, for instance, has alluded to the possible use of the structure of the stomata, and their number is known to be connected with the rate of evaporation. W. N. Edwards has found that the percentage of dicotyledonous trees with entire leaf-margins increases as one passes from cold forests to the tropics, and that the Middle Eocene flora of Alum Bay, Isle of Wight, with a percentage figure of 80-90, is strongly suggestive of tropical rain-forest conditions.

This kind of approach to the problem of past climates is undoubtedly full of promise. It will bring immediate reward in the form of ecological information, and in the course of time is likely to contribute to chronology also.

VEGETATION AND MAN

One of the non-botanical methods used in the reconstruction of past environments, and one, which is important in the establishment of the climatic chronology of the Pleistocene, is palaeopedology or the study of fossil soils. Soils are known to be mainly determined by the type of rock on which they form and by the climate. But these two factors also determine the type of vegetation. Certain types of soils, therefore, are indicators of certain types of plant associations and, where these soils occur in the fossil state, they suggest that such plant associations were present at the time of their formation. Since the artefacts of early man are frequently found on buried land-surfaces, valuable information may be gained from the soils about the vegetation from which prehistoric man obtained his living and some of his raw materials.

In northern Gujarat, for instance, a very constant horizon of a reddish soil is found on top of fluviatile gravels and sands containing an Acheulian industry. This soil is different from the brown steppe soils which are forming at the present day and resembles the reddish soils of the dry forests of the foothills of the Deccan and Rajputana. The inference is that a similar type of forest covered the plains of northern Gujarat in that period.

Other examples could be given. It should be obvious, however, that the prerequisite for such work is a careful mapping of present-day plant-associations in relation to the soils on which they grow. This is a task for the plant ecologist, who can thus contribute valuable information to the study of ancient environments and, indirectly, to geochronology. A survey of types of natural vegetation in relation to soils is most desirable in India not only for the investigations which form the subject of this paper; it would undoubtedly be well worth while from the purely economic point of view.

CULTIVATION OF PLANTS

A field of environmental archaeology in which botanical research plays the dominant part is concerned with the change-over from the economic stage of food collection to that of food production. It is marked by the subjugation of certain food plants to the control of man, with the manifold modifications this process has produced in their morphology. Archaeological investigations yield interesting material for the study of which a trained botanist is not always available. In Europe, knowledge of the types of grain cultivated by the farmers of the Neolithic and the Bronze Age has been advanced considerably in recent years. In India, almost everything remains to be done, though material is not wanting. In the mound of Khokra Kot near Rohtak in the Jumna valley, Sahni found the shapes of the husk of rice impressed in clay which resemble *Oryza sativa* var. *plena*, a kind which has more than one grain in each spikelet. Moreover, actual cuticles recovered from terracottas after chemical treatment showed cells and stomata. The evidence thus strongly suggested to Sahni that this variety of rice was grown by the Yaudheya tribes about 2,000 years ago.

TIME ASPECTS OF EVOLUTION

The considerations contained in the preceding paragraphs are concerned, directly or indirectly, with the development of chronologies. *Absolute* chronologies (in years) to which the palaeobotanist contributes are based either on the counting of annual growth-rings or of annual layers (varves), or on rates of weathering or astronomical rhythms. With the time-scales obtained from the rates of radioactive disintegration of minerals the palaeobotanist is not immediately concerned, although he is often able to contribute to stratigraphy (or *relative* chronology) without which the age estimates would be meaningless.

It is possible, moreover, to reverse one's attitude, to accept the time-scales which have been suggested for the period since the beginning of the Cambrian and to apply them to the evolution of life as evidenced by palaeontology. In this way, some indication is obtained of time-rates of evolution, such as the "life-times" of species and genera, and the rates of production of new species observable in various groups in arbitrarily fixed periods of unit-time. It is indeed important for the worker on evolution to be able to express such changes as a function of time. Most of the work has so far been done on groups of animals; only Small has considered plants, particularly diatoms. A very wide field is here open to the palaeobotanist and valuable results are bound to come forth from the chronological study of the evolution of groups of plants the classification of which has been worked out with care.

CONCLUSION

The term *geochronology* was coined by H. W. Williams in 1893 to describe studies in which the geological time-scale is applied to the earth and its inhabitants. It is only fair to continue using the term in the wide sense which was originally given to it, and this has been done in the present paper. Later on, however, the term became associated with one restricted method, viz. the counting of glacial varves as practised by de Geer in Sweden. But the great American geologist Charles Schuchert maintained the comprehensive meaning of the word when, in 1931, he interpreted geochronology as the age of the earth on the basis of sediments and life. Both Williams' and Schuchert's definitions emphasize the close relationship between geochronology and stratigraphy, and the stratigraphy of terrestrial sediments is in no small measure based on palaeobotany. Birbal Sahni was right, therefore, in emphasizing that indirectly, and to a smaller extent directly, palaeobotany is destined to be one of the major factors in the further development of geochronology.

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