SEVENTEENTH
SIR ALBERT CHARLES SEWARD MEMORIAL LECTURE
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PLANTS IN THE ARCTIC, TODAY AND IN THE PAST

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Emeritus Professor, University of Oslo, Norway

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PROFESSOR OVE ARBO HØEG

FOR a lecture dedicated to the memory of Professor Sir Albert Charles Seward and in the institute bearing the name of his pupil, friend, and colleague, Birbal Sahni, it may be appropriate to choose a topic connected with the Arctic.

For Professor Seward the summer (1920) he spent in Greenland was not only a happy one, but also one of great importance for his research and scientific thinking.

The connection between Professor Sahni and the Arctic may seem so remote as to be almost non-existent. However, let me mention only the words palaeogeography, palaeoecology, and continental drift, and I think it becomes clear that the problems presented by the Arctic fossil floras are very close indeed to what evidently was near the centre of Professor Sahni's scientific interest.

Some of the most interesting problems connected with the fossil floras in the Arctic arise out of a comparison with the present living conditions in the same part of the world, or at least they become accentuated through such a comparison. Let us, therefore, first sacrifice a few minutes in order to consider the plants in the Arctic today and the conditions under which they live.

But first · What is the Arctic ?

It is easy, perhaps, too easy to say : It is the part of the world to the north of the Arctic Circle, 66°30'N. lat. This delimitation has nothing to do with climate and biogeography. It is better to say, as is often done now, that the southern limit of the Arctic is the July isotherm of 10°C at sea level. This corresponds more or less exactly to the northern limit of forest. To the north of it the vegetation is that of a tundra, if there is any vegetation at all.

This definition excludes almost the whole of the northernmost Norway, although the North Cape is beyond the 71st degree, 500 km to the north of the Arctic Circle. On the other side the Arctic then includes the whole of Greenland, with its southernmost end to the south of the 60th degree, about the latitude of Leningrad, Stockholm, and Oslo, and not very much more northerly than Scotland.

As an example of the conditions in the Arctic, let us consider Spitsbergen, not because it is particularly typical (in fact, it is most exceptionally favoured), but simply because I happen to have some personal experience from it.

Svalbard is the Norwegian administrative name of a group of islands, of which the biggest is Spitsbergen itself, reaching from about 76°30′ to beyond 80°. This means that it is closer to the North Pole than Lucknow is to Madras.

You arrive there by ship (there is no airport, according to international agreement). There is a small population of Russian and Norwegian coalminers, a very small Norwegian administration, a few meteorologists, but you have to rely on yourself if you are there on a scientific expedition. Now our expeditions sometimes have helicopters to help them to their working places, but mostly you have to go by small motorboats or rowing boats along the coast, or walk, carrying your provisions and collections on your back.

All through the summer you have sunshine, continuously, if the sun is not hidden

behind fog, or rain, or sleet. At all events there is no night in summer. The sun does not set at all. Towards the end of August the sun touches the horizon at midnight, a few weeks later you have a night of a few hours, with the sun just below the horizon. Gradually, and then rapidly, the nights become longer and finally last for all the 24 hours. The sun is continuously visible, wholly or partly, above the horizon for 127 days and nights, while it does not appear above the horizon at all for 112 days.

The climate is severe, but not at all so bad as one might expect from the proximity of the Pole.

The mean annual temperature is about 6° and 3°C below zero. Only for the four months from June till September the mean temperature is above the freezing point. On calm sunny days (which are far from so frequent as a visitor might like) the air temperature in favoured places in the central areas may rise to 16°, or even 18°, but far more often it is below 10° down to 5°, even in mid-summer.

There is permafrost everywhere, down to 150 m below the surface in the lowlands. In summer the soil thaws only down to 75 cm or a little more. This causes solifluction, polygon fields, and various other sorts of soil structure affecting the life of plants. To some species soil movements are disastrous, while other species seem to be adapted to them.

The annual precipitation (one cannot say rainfall, because most of it falls in the form of snow) varies from the coast to the inland, but is of the magnitude of 300 mm. In India that would mean arid conditions, while in a cold climate it is sufficient for the vegetation.

One might think that there would be no plant life at all in all this ice and snow and rock, but there is, mostly growing as scattered individuals, but sometimes in denser plant communities.

The monocotyledons are mostly grasses, sedges, and cottongrass. But there are more dicotyledons, altogether 150 species of vascular plants (colourslides).

There are no trees. Of shrubs, *Betula nana*, small specimens in a few favoured places. *Empetrum*, the same. Other shrubs are still dwarfer, creeping along the ground. Lignose stems have an extremely slow radial growth.

With the single exception of the pygmy species *Koenigia islandica* all herbs are perennial. Their underground systems are very well developed. They are adapted to the cool and short summer and develop rapidly as soon as the snow has melted. After the disappearance of the cover of snow and ice some of them need only a few days to grow up and open their flower buds, which were formed the previous summer, and perhaps three weeks to ripen their seeds.

All plants with flowers originally adapted to insect pollination have difficulties on account of the scarcity of insects. There are no humble-bees, and very few, mostly small, lepidoptera. The flowers, if visited at all, may be sheltering small coleoptera and diptera (and perhaps acarina) which do not move much from flower to flower and, if regarded as pollinators, are very primitive. Practically all structurally entomophilous species have become self-pollinators or, a few of them, wind-pollinators, or they rely entirely on vegetative propagation (bulbils in *Polygonum viviparum* and *Saxifraga cernua*, runners in many other species). An exception is *Silene acaulis*. Beside bisexual individuals it has male and female ones, and even the unisexual female ones produce capsules with ripe seeds.

Most plants grow scattered and there is very little competition between the individuals except in rather rare cases when there is a continuous plant cover. There is no formation of real peat.

All this does not mean that the plants of the local flora do not thrive there. To the contrary. If you try to transplant them to more southern latitudes you will mostly have great difficulties in making them survive at all, not to mention producing flowers and seeds. The photoperiodicity is wrong, and so is the temperature. There is no doubt that if the summer temperature rises above a certain limit (which we would find very modest indeed), then they perish. Not only morphologically, but physiologically they are adapted to what we would call severe growing conditions.

The absence of forests in the Arctic is not primarily caused by low winter temperatures, but lack of sufficient warmth in summer.

In comparison with other areas on the same latitude the plant life in Spitsbergen is extremely favoured, not to speak of the Antarctic, where you have to go to the north of the South Polar Circle to find flowering plants.

There is, however, another contrast that is far more striking, and that is the contrast between the vegetation of today and that of the geological past.

Let us again keep to Spitsbergen and briefly consider the fossil floras known from that island.

For an island of its size, little more than one-fifth the area of Uttar Pradesh, Spitsbergen has a varied geology. Almost all formations are represented, many of them by abundantly fossiliferous beds.

The Old Palaeozoic sediments are thick, but faulted and metamorphosed and of no great interest from a palaeontological point of view. No true fossil algae have been found there.

All younger formations are slightly changed, and the beds often almost horizontal, except in a narrow zone along the west coast. Here the layers are much disturbed. In the "Festningsprofil" they are vertical and you can walk from the Lower Palaeozoic up to the Lower Tertiary over beds with sufficient fossils to date them.

From the Downtonian and Lower and Middle Devonian there are thick layers of sediments with numerous plant-bearing horizons. A list of species comprises, in the Downtonian, *Zosterophyllum*, *Prototaxites*, *Pachytheca*, and in the Lower and Middle Devonian *Drepanophycus* sp., *Psilodendrion arcticum*, *Protolepidodendropsis pulchra*, *Hyenia* (*Hyeniopsis*) *vogtii*, *Svalbardia polymorpha*, *Actinopodium* (*nathorstii*), *Enigmophyton superbum*. Some of these species, or even genera, are endemic, others are widespread. Not one of these plants looks in any way as if it had been growing under conditions like those in the Arctic today.

In one place there is a seam of cannel coal in the Middle Devonian and indeterminable remains of stems of small trees, almost certainly lepidophytes.

In Bear Island, halfway between Spitsbergen proper and the nearest point on the mainland of Norway, we have the Upper Devonian with an abundant *Archaeopteris* flora. There is a striking contrast between the present surface of this desolate barren small island with its poor flora, and the large leaves of *Archaeopteris* on the surfaces of the shaly sandstone. They look like fern leaves (which, of course, they are not) and must have measured at least one metre across, probably considerably more. The flora also comprises *Pseudobornia ursina*. A stem which Dr. H. J. Schweitzer found in the form of an impression, and which may have belonged to this species, was of a tree more than ten metres high. There are a few Upper Devonian coal seams, which were worked some years ago.

The Lower Carboniferous (Kulm) has left hundreds of metres of sediments from freshwater and brackish water, mostly of conglomerates and fine-grained and coarse sandstones, but locally with plant-bearing horizons and coal. Nathorst (1914, 1920)

described the flora on the basis of extensive collections. Among the species in Nathorst's lists are several species of *Lepidodendron*, ferns, and pteridosperms. The flora is related to that of the same age in Europe and other parts of the world. There is nothing to suggest that the climate was not a warm one, but whether " tropical" or " temperate " cannot be decided.

The Upper Carboniferous and Lower Permian, and then, after a hiatus, lowermost Triassic, are mostly marine. Then follow various Triassic and Jurassic sediments, partly marine, but also with some plants, not particularly well preserved, and thin coal seams.

A continental series of sediments, formely regarded as Jurassic, is no doubt Lower Cretaceous. The flora comprises *Ginkgo*, *Podozamites*, *Baiera*, *Pinites*, *Elatides*, and some other genera, known from all over the world, as well as fossil wood of conifers. The wood is of interest because of its growth rings. There are also coal seams in the Lower Cretaceous. Again : Not the slightest trace to indicate that the plants should have grown under " Arctic " conditions.

The Upper Cretaceous is not present.

The Tertiary formation consists of something like 2000 m of sandstones, shales, and conglomerates, predominantly deposited in freshwater. It is probably not younger than Eocene.

The Tertiary flora of Spitsbergen is fairly rich in species, but not particularly well preserved. It is spread over several horizons. There are coal seams, some of them of considerable thickness, particularly in the lower part of the series. There are many leaves of angiosperms, and twigs and other remains of conifers, and *Ginkgo spitsbergensis* with cuticle. Also *Equisetum* and poorly preserved ferns.

Chiefly on the basis of Svein Manum's revision of older determinations of megafossils together with the results of his palynological work we can mention some of the more characteristic genera and species

Ginkgo spitsbergensis S.M.

Torellia rigida Heer. In a certain quantity.

Metasequoia occidentalis makes up the main part of the Taxodiaceae.

Schloemer-Jäger has shown (1958) that there is true *Sequoia langsdorfii* at Ny-Ålesund on the west coast of Spitsbergen. She referred some other remains to a new species of *Taiwania*. *Taxodium* and *Glyptostrobus* not certain.

Pinus pollen abundant.

Sciadopitys pollen is found in most samples, but in small percentages. (According to Manum, the microfossils prove that evergreen conifers were abundant, and that it was not only deciduous forms like *Metasequoia* that ranged northwards, beyond the 79th degree in Spitsbergen and to 82° in Grinnell Land, as had been suggested by previous authors.

Cercidiphyllum, " one of the principal hardwood elements of the Spitsbergen Tertiary flora " (Manum).

Acer probable, *Tilia* not proved.

Betulaceae abundant, chiefly *Betula* and *Alnus*.

Fagaceae doubtful.

Ulmaceae represented by megafossils.

Ericales found as pollen tetrads.

Monocotyledoneae : Heer named 36 species, but (according to Manum) only very few of these are convincing.

Does this early Tertiary flora of Spitsbergen tell us anything about the climate there at that time ? It is so much nearer to us in time, and so much more closely related to living plants, than the pre-Tertiary floras that it ought to give a safer basis for conclusions.

Now, there are innumerable sources of error if we try to use the morphology or taxonomic relationship of plant fossils as a basis for conclusions as to the ecological conditions of the place where they lived.

We have no time here to go fully into these problems, but a few points will have to serve as reminders.

Palms today are mostly restricted to tropical and subtropical countries, but *Trachycarpus* and *Chamaerops* grow well in British parks. The overwhelming majority of the Araceae also belong to lower latitudes, but *Calla palustris* grows far north in Scandinavia. If *Selaginella selaginoides* or *Isoetes lacustris* were found only as fossils, one would go very wrong by drawing conclusions about their habitats from an analogy with their living relatives. Cacti do not grow only in hot arid places, but some species thrive in such altitudes that they may be covered by snow in winter.

In a maritime temperate climate glaciers can go right down to levels where they become neighbours of orchards, as on the west coast of Norway, or even tree ferns in New Zealand.

We do not associate forests with permafrost, but in Siberia there are well-developed forests on permafrost over enormous areas.

Certain leaf forms may be characteristic of certain climates, but only if the material is large enough to permit of statistical treatment.

To take some examples from the Animal Kingdom :

Whales are generally marine, but there is your peculiar Ganges dolphin. Elephants and rhinoceros today belong to hot countries, but not so during the Pleistocene. To most people corals are associated with tropical seas, but a few genera are found far north of the Arctic Circle.

We could find many more examples of this kind. There is, then, good reason to be cautious. However, keeping this in mind we must be allowed to draw some conclusions from the composition and character of the early Tertiary flora of Spitsbergen.

As in the older fossil floras of Spitsbergen there is nothing whatever of an " Arctic " character. The predominance of trees, the size of leaves, the length of internodes, the width of growth rings are all characters incompatible with Arctic conditions as we know them today. On the other side, to judge by the taxonomic relationships there is nothing tropical about the flora. There are no palms, no representatives of the many dicotyledonous families that constitute a large and conspicuous element in tropical or even warm temperate forests.

Schloemer-Jäger thought that the climate of the early Tertiary in Spitsbergen had been a warm temperate one. Manum, on the basis of his very thorough study, came to the conclusion that it had been moderately warm. This conclusion is no doubt correct. The plants, as far as known, have living relatives that either grow wild in Central or even Northern Europe, or they are able to grow there if introduced from Asia or North America, perhaps with the exception of *Taiwania*. The living species of *Ginkgo*, *Metasequoia*, *Sciadopitys*, and *Cercidiphyllum* have no difficulties if planted in South Norway, and most of the other genera are well known from the natural European forests.

Even so, however, this is far from Spitsbergen, and the climate today very different.

It is not a question of mean annual temperature. The essential point is the summer temperature and perhaps the length of the summer. If there is a sufficiently high total sum of warmth in summer, many species of trees and shrubs are able to stand a cold winter. In parts of North America the winter is extremely cold, but the summer long and very warm, and many species of trees and shrubs can grow there, while they cannot endure the climate of the southern coast of Norway with its much milder winter. There is forest in Siberia in places where the winter is colder than anywhere else on the Northern Hemisphere.

Also the light factor should be taken into consideration : The plants in the Arctic are

adapted to a photoperiodicity very different from that of the temperate zone. However, in northernmost Norway, on 70°N lat. there is forest of *Betula pubescens* and *Pinus silvestris*, and also *Populus tremula*, *Alnus incana*, and other lignoses grow well to the north of the Arctic Circle, in a summer of continuous sunshine, certainly of shorter duration than in Spitsbergen, but equally bright. This has no adverse effect on them, although the same species grow many degrees further south where the day rhythm is entirely different. Evidently a fargoing adjustment is possible without any morphological changes.

A long winter night does not affect the deciduous trees. To an evergreen the dark winter may be dangerous, but only if it is so mild that respiration goes on while assimilation has stopped.

It seems, then, that the essential point is the summer temperature. It is above all this factor that must have been different when the Tertiary flora covered Spitsbergen.

How has that been possible? How to explain this discrepancy between the present and the past?

In our days two ideas immediately present themselves: Continental drift and pole wanderings.

Continental drift used to be a matter for belief, strong belief, rather than knowledge. It explained elegantly certain problems and raised innumerable new ones, and nobody could say how it worked.

Research during the last few years in palaeomagnetism and sea-floor geology has changed the situation entirely.

New facts are. The fundamental difference between ocean floors and continents from a geological point of view. The value of palaeomagnetism as evidence of earlier positions of the magnetic pole. Sea-floor spreading. And, we may say as a consequence of all this: Continental drift.

These facts, however, have not provided us with a golden key to a cupboard containing answers to all problems of palaeogeography and palaeoclimatology.

One thing is that the position of the magnetic pole is not always identical with that of the North Pole, that is, the earth's axis. Further there are lots of unanswered questions about the relative position of the continents. That applies in particularly high degree to the Arctic regions.

Let us return to our Arctic zone.

The Tertiary flora of Spitsbergen could easily be explained by moving North America and Europe together and pushing the unpleasant North Pole away from us, into the northernmost end of the Pacific. Yes, easy, at the first moment. But, it does not work.

Even in some of the latest palaeogeographical maps we find that America and Europe are shown lying closely together, with, as it seems, complete disregard of what happens to the Bering Strait. Now, if anything is certain it is clearly the impossibility of imagining a Bering Strait so wide that it would form an impassable obstacle to wanderings of animals and plants for any length of time. It is true that there have been periods when it was much wider than today, but that was only temporary subsidence due to vertical movements, and not to drift of the two bordering continents. At least as frequently in the geological history the Bering Strait has been replaced by a land bridge.

Thus, it seems impossible to break the ring of land surrounding the Polar Basin.

Another fact is that in Spitsbergen, Iceland, Greenland, Ellesmereland and Grinnell Land, Alaska, and various places in Siberia, there are fossil floras of Tertiary age, corresponding in character to that of Spitsbergen.

With the land masses around the Polar Basin in approximately the same position as today there is, in the early Tertiary, nowhere else to place the North Pole than where it is now. Also the maps of pole

wanderings published on the basis of palaeomagnetism show, fortunately, that it should have reached, approximately, that position at the beginning of the Tertiary.

How can we then explain that the summer temperature close to the 80th degree of northern latitude has been as it is now more than twenty degrees further south ?

I cannot see that the question of former climates in the Arctic can be solved without accepting a general rise in the temperature of the atmosphere and, probably, a greater uniformity.

That is, perhaps, not too difficult to accept.

In our days it happens in the interior of northernmost Norway, about 70°N lat., that the air temperature over a week or two is as much as 25°C. This must be the result of a certain, and rather rare, constellation of factors. Meteorologists can probably tell us if the constellation that is exceptional today, can have been the normal earlier in the geological time.

We are living in an abnormal period in the earth's long history, in the shade of the Pleistocene ice ages. There have been glaciations in earlier periods, too. But mostly the normal climate has been warmer than today, and evidently more uniform.

Continental drift and pole wanderings should not make us forget that there are also other factors that have caused changes in the climate of the various regions.

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