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THE PAST CLIMATE OF THE NORTH POLAR REGION[1]

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The plants, coal beds, hairy mammoth and woolly rhinoceros; the corals, ammonites and the host of other marine organisms, chiefly invertebrate but including ichthyosaurs and other saurians, that have been discovered beneath the snow and ice of boreal lands have always made a most powerful appeal to the imagination of explorers and geologists. We forget entirely the modern whales, reindeer, musk ox, polar bear, and abundant Arctic marine life, and remember only the seemingly great contrast between the present and this subjective past. Nowhere on the earth is there such an apparent contrast between the present and geologic climates as in the polar regions and the mental pictures which have been aroused and the theories by means of which it has been sought to explain the fancied conditions of the past are all, at least in large part, highly imaginary.

Occasionally a student like Nathorst (1911) has refused to be carried away by his imagination and has called to mind the marvelously rich life of the present day Arctic seas, but for the most part those who have speculated on former climates have entirely ignored the results of Arctic oceanography. Recently, Kirk[2] has marshalled some of the evidence of the abundance of the present marine life in the Arctic, and he concludes from this survey that marine organisms are not dependable as indicators of geologic climates. I think this conclusion is impregnable, and therefore if we are ever to get any information regarding past climates, the evidence will be furnished by fossil plants, and not too precisely either. Here again prudence is the watchword; imagination must be entirely suppressed, and the distribution of recent plants must be understood and used.

A correct solution of the problem is not only of prime interest to geologists and paleontologists but it offers assurance to geophysicists confronted with the now fashionable belief in wandering poles, and

[1] Given in summary before the Paleontological Society at the December, 1928, meeting.

[2] Kirk, Edwin. Fossil marine faunas as indicators of climatic conditions. Ann. Rep. Smithsonian Inst. for 1927, pp. 299-307, 1928.

likewise comfort to meteorologists confronted with the traditional view of a lack of climatic zones during most of the eons of earth history. I propose to pass in review what we know of the past distribution of plants in the Arctic, after which I will endeavor to evaluate what they mean in terms of climate.

Aside from some very scrappy plant fragments from the Silurian of Norway, the oldest traces of land plants in the north occur in rocks of Devonian age. Devonian plants have been discovered within the Arctic Circle at the three localities shown on the accompanying map (fig. 1). These range from a few scraps, such as those found in Ellesmere Land and Spitzbergen, to the extensive flora found on Bear Island which embraces 31 named forms. These three floras are of upper Devonian age but not necessarily synchronous, since an earlier and a later horizon is represented on Bear Island and probably on Spitzbergen.

I have shown on the map (fig. 1) the occurrence of some other Devonian floras outside the Arctic Circle and some in lower latitudes in order to give an idea of the known geographical range of Devonian plants in the present North Temperate Zone. The oldest of these is the Lower Devonian flora of Röragen, Norway, embracing eight very interesting forms. Of particular interest are the Middle Devonian plants found in silicified peats at Rhynie in northern Scotland and the flora described recently from Germany, since these give us our first considerable insight into the structure of these ancient plants.

In looking over the list of identifications from Bear Island, all except Pseudobornia are seen to belong to widely distributed types, several are identical with species from the south of Ireland, and similar forms occur rather generally in lower latitudes. There are several seams of coal at both the older and younger horizons, to which Bothrodendron contributed a large amount of material. Beneath the coal seams are underclays with roots in place and the plant remains show no sorting—that is, delicate material is mixed with stems and branches of all sizes—both facts indicating conclusively that the bulk of the material was not transported but grew in the immediate vicinity. The same statement is true of the Devonian of Ellesmere Land.

The plants of the Devonian are so remote from living forms that I do not feel that any conclusions regarding the climate are warranted beyond the statement that they show that there were no climatic barriers to prevent most of the types found in Latitude 45° to 50° extending northward to Latitude 75°. There are, however, certain types which have not yet been found in the north, such as Eosper-

Fig. 1.—Location of Devonian and Lower Carboniferous northern floras.

1. Melville Island. Devonian
2. Ellesmere Land. Devonian
3. New Brunswick, Maine, etc. Devonian
4. Northeast Greenland. Lower Carboniferous
5. Spitzbergen. Devonian and Lower Carboniferous
6. Bear Island. Devonian and Lower Carboniferous
7. West Norway. Devonian
8. Rhynie, etc. Scotland. Devonian
9. Nova Zembla. Lower Carboniferous
10. Northern Urals. Lower Carboniferous
11. Siberia. Devonian.

matopteris from New York and Cladoxylon and Aneurophyton from Germany, that may possibly indicate more genial climates in those places than obtained farther north, and Pseudobornia seems to be a northern type, but until Devonian floras become much better known no adequate conclusions can be reached.

There are one or two points that deserve emphasis in this connection. These northern Devonian floras all consist of plants belonging to the Pteridophyte, Arthrophyte, Psilophyte, Lepidophyte and Pteridosperm phyla, and such existing representatives of these phyla as have survived to the present, though few and not directly filiated, such as Equisetum and Lycopodium, are singularly unaffected by temperature. For example, there are now two species of Equisetum and one of Lycopodium found within 10 degrees of the pole in northwestern Greenland (Ostenfeld, 1925). To be sure these modern Greenland forms do not reach the size of their Devonian relatives, but this is true of all existing members of these genera irrespective of latitude.

Moreover, all of these northern Devonian plants appear to have been bog types. This conclusion is indicated by their forming coal in place and by the structures disclosed in the silicified peats of Rhynie. Therefore, we conclude that the chief climatic factor was moisture rather than temperature. The fact that many of the Devonian plants were palustrine also gives force to an observation which I have elaborated in another place [1] that these Devonian plants while ancient and simple were not primitive and ancestral, but were the reduced descendants of more highly organized ancestors. Since speculation was to have no part in this discussion I refrain from elaborating my own belief regarding the more precise character of Devonian climate.

LOWER CARBONIFEROUS

(Dinantian or Culm)

Fossil plants have been found in the Lower Carboniferous, or Mississippian as Americans prefer to call it, at five or six localities within or near the Arctic Circle. These floras range in extent from a few doubtful specimens at some localities to the 59 nominal species described by Nathorst from Spitzbergen. The latter extend to 79° North Latitude, and a considerable flora of similar species to the number of ten at least is found between 80° and 81° North Latitude in northeast Greenland.

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[1] Berry, Edward W., Devonian Floras. Amer. Journ. Sci., Vol. 14, pp. 109-120, 1927.

The Spitzbergen flora comprises 12 fernlike plants, 5 pteridosperms, 1 arthrophyte, 25 lepidophytes, 1 cordaites (wood), and 15 of uncertain botanical affinities. Stigmarias and various roots occur in place beneath the coal seams, showing that the vegetation was preserved essentially in place; and Lepidodendron stems have been collected up to 16 inches in diameter. There are no peculiar Arctic types in this most extensive known Culm flora nor are there any genera that are not common to floras of the same age from lower latitudes. The single wood, *Dadoxylon spetsbergense* Gothan, fails to disclose any seasonal growth changes, which might be expected to result from the Arctic night. No other traces of the Cordaitales other than this wood have been discovered here, which leads Nathorst to suggest that the wood may have been carried by currents from some more southern clime, where also the woods fail to show growth rings. This may be true, but on the other hand there is great specific variation in the degree to which growth rings develop in existing conifers, as Antevs has pointed out, and they tend to be absent under fairly uniform conditions of humidity. That this is an individual trait of this particular species and is probably without climatic significance is shown by the presence or absence of rings in Devonian and Mississippian Dadoxylon woods from lower latitudes. For example, *Dadoxylon beinertianum* Endlicher from Silesia, *Dadoxylon Tchichatcheffianium* Endlicher from Russia, and *Dadoxylon vogesiacum* Unger from the Vosges, all of the same age as the Spitzbergen species, show distinct seasonal rings, but other contemporaneous European species fail to show them.

I cannot see any very conclusive indications of climate in these Lower Carboniferous floras, other than the fact that they extended in places to within 10 degrees of the pole. Palustrine types predominate as in the case of the Devonian, and more than half the known forms are Lepidophytes which we have reason to believe show little response to temperature. Sphenophyllums are entirely wanting in Spitzbergen, but are found farther north in Greenland and occur on Bear Island, so that their absence in Spitzbergen is merely an accident of preservation or discovery. In general Arthrophytes are much rarer in the far north than in middle latitudes at this time and the same seems to be true of a number of genera of large fronded fern-like plants, which is taken to indicate differences due to latitude.

TRIASSIC

Triassic plants except in the latest or Rhaetic stage are scarcely, if at all known in the north polar region. There is a species of

Schizoneura recorded from the New Siberian Islands which may be Rhaetic and there are scattered Rhaetic plants in Greenland and Spitzbergen; and somewhat farther south in northwestern Norway (Andö) and southern Sweden.

The most extensive northern Rhaetic flora is that from Scoresby Sound, East Greenland, between 70° and 71° North Latitude. This comprises 51 named forms and several additional ones which are not named. Cycads and ferns predominate, and so far as we can judge at this lapse of time all belong to cosmopolitan Rhaetic types. Harris, who has given an excellent account of these plants concludes that they indicate a temperate climate, largely on the ground of the predominance of certain forms indicative of relatively pure stands and the absence of mixtures such as occur in recent tropical assemblages. He concludes also, from a study of the cuticles of many of the species, that moisture was plentiful. The wood of Dadoxylon in the Rhaetic of Spitzbergen has very feebly marked seasonal rings.

JURASSIC

Supposed Jurassic floras completely surround the pole and are extensively developed throughout Siberia, in Alaska, Greenland, Spitzbergen, Franz Josef Land, New Siberian Islands, and elsewhere. Formerly, many of these, as those in Siberia, were considered Middle Jurassic, but Nathorst is the authority for the statement that all of the more northern ones are post Oxfordian, and several, such as that of Spitzbergen, are on the border between the Jurassic and the Lower Cretaceous.

The Spitzbergen flora is the most extensive and, according to Nathorst, includes 2 horizons, one Portlandian and the other possibly as young as Neocomian. A combined list of these comprises 57 species, including 11 fern-like plants, 1 lepidophyte (Lycopodites), 1 arthrophyte (Equisetites), 4 cycadophytes, 4 Ginkgoales, 23 conifers and 13 of uncertain affinities. Nine different types of coniferous woods have been described and all show pronounced seasonal growth rings. Most of the generic types have a very great geographical range, but several, such as Phoenicopsis, Torellia and Drepanolepis, appear to be distinctly northern, and the predominance of conifers suggests a cool temperate climate. They are found in sandstones associated with coal seams and freshwater mollusks (Lioplax, Unio) and evidently grew in the vicinity of their burial place.

FIG. 2.—Location of Triassic and Jurassic northern floras.

1. Manchuria. Triassic and Jurassic
2. Ussuri. Jurassic
3. Amur. Jurassic
4. Trans Baikal. Jurassic
5. Irkutsk, etc. Jurassic

6-10. Alaska. Jurassic (?)

11. Bathursy Island. Jurassic
12. New Siberian Islands. Triassic (?) and Jurassic
13. Mouth of Lena. Jurassic
14. Solitude Island. Jurassic
15. Franz Josef Land. Jurassic
16. King Charles Land. Jurassic
17. Spitzbergen. Triassic and Jurassic
18. Northeast Greenland. Jurassic
19. East Greenland. Jurassic
20. Scoresby Sound. Triassic
21. Andö, Norway. Triassic
22. Scania. Triassic and Jurassic
23. Scotland. Triassic and Jurassic.

LOWER CRETACEOUS

Lower Cretaceous floras are found along the east coast of Asia, in Alaska, Greenland, and King Charles Land. From the last a number of coniferous woods have been described by Gothan. These show pronounced growth rings, said to be more prominent than in woods of the same age from central Europe. Nathorst records an incomplete trunk 32 inches in diameter and showing 210 seasonal rings. The most extensive Arctic flora of Lower Cretaceous age is that described by Heer from the Kome beds of western Greenland, but this, although generally considered to be of Barremian age, is subject to doubt as to age and content because collectors appear to have mixed several Cretaceous horizons. As it stands in the literature it comprises over 100 species, including 46 ferns (no less than 15 are referred to Gleichenia, and although these surely represent that genus they are artificially multiplied), 1 marsilea, 1 lycopod, 3 equisetums, 13 cycads, 20 conifers, 2 ginkgos, 5 monocotyledons, 3 or 4 dicotyledons, and 6 of uncertain identity. The abundance of ferns indicates a humid climate as does the presence of coal. This flora differs very little from those of corresponding age in lower latitudes (*e. g.,* the Kootenai of western Canada and Montana).

UPPER CRETACEOUS

Strictly Arctic Upper Cretaceous floras are limited to Alaska and Greenland but others of this age are found in northern Europe and eastern Asia. The most extensive is that from the two horizons in West Greenland known as the Atane and Patoot beds. These have in large part been described by Heer and there is a great and unwarranted multiplication of species. That from the Atane beds has 184 recorded species. It includes 31 ferns, 1 equisetum, 1 selaginella, 1 marsilea, 12 cycads, 2 ginkgos, 25 conifers, 4 monocotyledons, 94 dicotyledons and 14 of uncertain affinities.

The seemingly most incompatible plant is the authentically determined Artocarpus and this raises a question which cannot be decided without prejudice. If a genus which is tropical at the present time is found fossil associated with a preponderatingly temperate flora, which is to be given the most weight? The one or the many, bearing in mind the latitude where they occur? My own feeling is that the majority are less likely to have altered their environmental requirements than the minority, but this falls short of actual proof.

The Patoot flora includes 19 ferns, 1 equisetum, 19 conifers, 2 monocotyledons, 80 dicotyledons, and 2 uncertain.

FIG. 3.—Location of Cretaceous northern floras.

1. Japan
2. Sakhalin Island
3-4. Siberia
5. Klin
6-8. Alaska
9. Spitzbergen
10. Queen Charlotte Islands
11. Vancouver Island
12. Kootenai
13. Mattagami, Ontario
14. West Greenland (Kome, Atane, Patoot)
15. Scania
16. Wealden.

TERTIARY

Tertiary plants from the Arctic have been encountered at very many localities, usually associated with coal. This, and plants with their roots in place as in the case of Equisetum in Spitzbergen; the association with fresh water mollusks, as in Greenland; or aquatic beetles, as in Spitzbergen and Iceland; as also the presence of fresh water diatoms in the matrix and the mixtures of branches and delicate foliage, prove conclusively that these Arctic floras and the associated coals cannot represent drift material from lower latitudes as some have supposed.[1]

The similarity in facies and their mode of occurrence, as well as the similar petrographic character of the intimately associated basalts suggest that all of these Tertiary Arctic floras are essentially similar in age, although it is clear that in Spitzbergen, Alaska and probably elsewhere, more than a single horizon is represented. Heer, the pioneer in this field, called them Miocene, just as Lesquereux called the Fort Union and Wilcox floras Miocene, but the Arctic Tertiary floras are certainly older than Miocene and younger than Ft. Union. This is indicated by the determination of the so-called Kenai flora of Alaska as of upper Eocene age, and if any one of them is proved to be upper Eocene none of the others can be older than middle Eocene or younger than Oligocene. Collateral evidence of their age is furnished by the age of the greatest extension of subtropical floras into the Temperate Zone, which is in upper Eocene (Jackson) to middle Oligocene (Vicksburg) time.

Plants or coal of Tertiary age are found at the numerous widely distributed localities shown on the accompanying sketch map (fig. 4). These completely encircle the pole and reach to within 8½° of it (Grinnell Land). These will be treated at greater length than the older floras because in some cases they are more extensive and also because they consist very largely of species belonging to existing genera, and hence can be discussed more intelligently than the older floras.

It may be well at the start to dispose of an oft quoted assertion, as for instance "most of Heer's determinations were based upon leaves, which give no data for generic identification" (Gregory, *op. cit.*, p. 413). I would readily admit that much of Heer's material was fragmentary, that he was over sanguine in some of his determinations,

[1] Gregory makes much of this idea, which as we have seen is easily disproved. Gregory, J. W., Congres Géol. Intern. Compte rendu Xème Session Mexico, 1906, p. 413, 1907.

FIG. 4.—Location of Tertiary northern floras.

1. Commander Islands
2. Japan
3. Sakhalin Island
4-8. Eastern Siberia
9-11. Northern Siberia
12. Central Siberia
13. Vancouver Island
14. British Columbia
15-18. Kenai
19. Mouth of the Mackenzie
20. Banks Land
21. Prince Patrick Island
22. Melville Island
23. Bathurst Island
24. North Devon
25-26. Ellesmere Land
27-28. West Greenland
29. New Siberian Islands
30. Nova Zembla
31. Spitzbergen
32. Iceland
33. North Ireland and Mull.

and described a great many more species than he should have done. Some genera do not have a characteristic leaf form, but to make such a statement of genera such as Liquidambar, Betula, Corylus, Ulmus, Platanus, Sassafras, Liriodendron, Acer, Potamogeton, Cornus, and Nymphæa, to mention but a few of those recorded from the Arctic Tertiary, is the height of misunderstanding. Moreover, as I pointed out in 1922 (*op. cit.,* p. 4) : " Plant fossils have this merit aside from any question of botanical identification, and this feature seems to have been lost sight of by numerous critics of paleobotanical practise: that the size and form of leaves, their texture, the arrangement and character of their stomata, and the seasonal changes in wood, afford criteria that are quite as valuable climatically even though the species or genus to which they belong remains undetermined." Furthermore, a great many of the generic determinations are corroborated by fruits and seeds, as for example, the genera Vitis, Acer, Nyssa, Hicoria, Juglans, Liriodendron, Fraxinus, etc.

As recorded in the literature the number of species varies from the single Pinus recorded from Bathurst Island, 5 species from Ellesmere Land, 6 species from Banks Land to 55 species from Iceland, 168 species from Spitzbergen, and 283 species from Greenland, the last being greatly overelaborated. I have shown [1] that Heer's 30 species of fossil plants from Grinnell Land (Lat. 81° 42′) represent not more than half that number; and that Viburnum, Alnus, Ulmus and Tilia represent Populus and Corylus. As thus revised the Grinnell Flora contains nothing extraordinary unless it be the supposed Nymphæa rootstock and this may really belong to one of the plants represented by fragments of grasses or sedges.

I will consider only the four most extensive of these floras in any detail. These are Iceland, Spitzbergen, Greenland and Alaska.

The Icelandic flora is preserved in tuffs, along with fresh-water diatoms, Unios, Potamogeton; and the wood and branches appear to have been broken off and buried by showers of ashes. The woods show sharply marked seasonal rings; and conifers, willows, alders, birch, and hazel are prominent. The only plants certainly determined that might not justly be considered cool temperate are the following: Platanus, Liriodendron, Acer, Juglans, Ginkgo, Fraxinus, Hicoria. Representatives of all of these except Ginkgo, which is not a native, and Liriodendron, which reaches its northern limit in southern New England, are hardy in northern New England (Platanus) or eastern Canada (Acer, Juglans, Hicoria, Fraxinus) at the present time.

[1] Berry, Edward W., Proc. Amer. Phil. Soc., Vol. 61, pp. 8-9, 1922.

The Spitzbergen flora comes from two horizons and the two total 168 species and are not essentially different in facies. They are associated with coal seams and are clearly continental palustrine associations. There are 4 ferns, a Ginkgo, 27 conifers, 27 monocotyledons and 80 dicotyledons. Three woods described by Gothan show marked seasonal rings. The warmer elements are Taxodium, Platanus, Juglans, Nymphæa, Magnolia and Nyssa. Here also oaks, hazels, willows, poplars and conifers predominate. There is not a single tropical or subtropical type and not one justly considered warm temperate.

The Greenland Tertiary flora comprises 283 nominal species and includes 8 fungi, 1 moss, 1 lycopod, 1 equisetum, 19 ferns (all temperate types), 1 Ginkgo, 28 conifers, 21 monocotyledons and 202 dicotyledons. The petrified coniferous woods show well marked seasonal rings and the only genus that is seemingly out of place in the far north is Taxodium, whose abundance in all Arctic floras and in proved temperate floras of other regions and other horizons shows that it was not out of place here. The monocotyledons include mostly miscellaneous leaf fragments, not generically determinable, as well as two supposed palms (Flabellaria). It has frequently been pointed out by others as well as by myself that the nature of the last cannot be considered as proving the presence of palms. The dicotyledons are very much overelaborated. Probably 100 species is nearer the correct figure than the 202 which Heer differentiated.

In Greenland as in all known Tertiary Arctic floras the leaves of willows, poplars, birches, and hazels predominate, but there are many other genera whose identification cannot be disputed, such as Liquidambar, Alnus, Fagus, Quercus, Ulmus, Platanus, Sassafras, Fraxinus, Cornus, Liriodendron, Acer, etc. Vitis is represented by both leaves and seeds, and other genera also show fruits. The genera that appear to me to be highly questionable are the following: Castanea, Juglans, Pterocarya, Benzoin, Laurus, Myrsine, Apeiobopsis, Pterospermites, Zizyphus, Colutea, Dalbergia, Diospyros, Sapindus, and several others. I base this conclusion on the fossils and not on the probabilities of their presence. Some, such as Zizyphus and Ficus clearly do not represent those genera, in fact Heer's discussion shows his lack of conviction of the latter and he queried his determination.

Heer devoted considerable space to a discussion of the climatic significance of this as well as other Arctic floras and concluded that the Greenland plants indicated a mean annual temperature of 53.6° F., or a considerably lower figure than he estimated by the same methods for the supposed contemporaneous flora of Switzerland, thus clearly recognizing a climatic zonation.

The so-called Kenai flora of Alaska was originally described by Heer and additions to it have been published by Lesquereux and Knowlton. Hollick has been engaged in a revision of this and related floras from Alaska for a number of years, but his results are not yet published. That from the type locality as listed by Hollick in 1915[1] comprised but 40 named species and contains not a single tropical or subtropical type. Associated with the plants are thick coal seams and fresh water mollusca (Unio, Anadon, Amicola, Melania), as well as beetle elytra.

He states in a recent letter that localities in the southeastern coastal region of Alaska (Alexander Archipelago) have yielded a Tertiary flora that is distinctly indicative of warmer climatic conditions than those from farther north, including cycads, palms, and such dicotyledonous genera as Anona, Dillenia, etc., but he has not yet determined whether they are the same or different in age. In either case they support the conclusion that climatic zoning is indicated.

As listed by Knowlton[2] in 1919 the Kenai flora (so called) comprised about 120 species. The most abundant forms are willows, oaks, poplars, walnuts, beeches, birches, hazels, and alders—distinctly temperate, and cool rather than warm temperate types. Perhaps the most abundant plants individually, certainly the widest ranging geographically in northern latitudes (Holarctica), are the leaves of hazel bushes (*Corylus*). Of the 54 genera of Knowlton's list, the following nine are not present in the existing flora of North America: *Ginkgo, Glyptostrobus, Taxites, Hedera, Paliurus, Elaeodendron, Pterospermites, Trapa,* and *Zizyphus.*

It may seem that I am juggling the evidence in omitting these nine genera from further consideration, but let me point out that the three of these about which there seems to be no doubt regarding their identity, namely, *Ginkgo, Trapa,* and *Glyptostrobus,* are all temperate types in the existing flora. The remaining six genera are under more or less suspicion of quite a different order from any differences of opinion among paleobotanists regarding the identification of the hazels, birches, alders, etc., with which they are associated. Opinion might differ as to whether a particular species of the latter was a *Betula* or *Alnus,* an *Ulmus* or a *Carpinus,* or a *Planera;* or whether one or several species of *Corylus* should be recognized as distinct species; but opinion is unanimous that the choice is thus narrowed, whereas in the case of such things as *Taxites*—all any one knows is that it represents

[1] Hollick, A., U. S. Geol. Surv. Bull. 587, pp. 88-89, 1915.

[2] Knowlton, F. H., U. S. Geol. Surv. Bull. 696, pp. 786-789, 1919.

some Conifer. Why waste time trying to explain the climatic significance of *Paliurus,* a mostly extinct genus, when the particular fossil is probably not a *Paliurus;* or why concern oneself with an Arctic species of *Zizyphus* when the form in question is probably a *Ceanothus?* I ask, can any one prove that the form-genus *Pterospermites* is genetically related to the existing genus *Pterospermum?* or that *Elaeodendron* is a sound botanical identification? I think not!

On the other hand, the great mass of not only the Kenai but of all the Arctic Tertiary floras are the readily recognizable, normal units of a natural assemblage, which individually leave but slight room for differences of opinion regarding their identity. If fruits chance to be found in association with the leaves, they are such things as birch or alder cones, never the fruits of the " suspects " above mentioned.

Of the remaining genera listed in the Kenai flora, all but the following six are represented in the existing flora of Canada: *Æsculus, Diospyros, Ficus, Liquidambar, Sequoia,* and *Taxodium.* It may be said of these that the *Æsculus* may not be an *Æsculus,* but a *Hicoria;* that the two species that have been referred to *Ficus* do not belong in that genus; and that *Sequoia* is on the verge of extinction at the present time and its modern range bears little relation to its former range. The case of *Sequoia* is of especial interest in its bearing on my thesis. Formerly a Holarctic type, it survives today in a most restricted area particularly favored by humidity.

The remaining genera of the Kenai flora appear to be determined with reasonable certainty. Not only are 39 of these represented in the existing flora of Canada, but the following are still represented in the existing flora of Alaska, or adjacent areas in northwestern Canada, or as far north as Labrador and Hudson Bay in eastern Canada: *Abies, Acer, Alnus, Alnites, Andromeda, Betula, Carex, Corylus, Equisetum, Fraxinus, Myrica, Osmunda, Phragmites* (grass), *Picea, Pinus, Populus, Prunus, Pteris, Quercus, Sagittaria, Salix, Spiraea, Thuites,* and *Vaccinium.*

Seventeen of the Kenai species are conifers, and the only types that would seemingly be out of place in a cool temperate climate with well-distributed moisture are *Liquidambar, Paliurus, Taxodium,* and *Zizyphus.* I have already given reasons for discrediting the determinations of some of these, and all of them have frequently been found fossil in temperate assemblages.

The significant feature about these Eocene Arctic floras is that they show a comparable northward swing of not alone their northern limits, but also of their southern limits, which in turn is comparable to the northward advance of the Jackson flora that I have considered to be of the same age. The Jackson flora reaches Latitude 37° North. The most similar existing flora to that of the Jackson does not extend above Latitude 26° North, and then only under especially favorable conditions of situation with respect to warm ocean currents. This is a difference of 11 degrees. The flora of the Jackson was, moreover, a coastal flora, and I have not the slightest doubt but that had the Mississippi embayment extended five degrees farther North, its shores would have been clothed with the same Jackson flora, for at that time similar floras are found in the Paris Basin in Latitude 49° North, in southern England in Latitude 51° North, and along the expanded Mediterranean sea of the Old World.

The southern limit of the contemporaneous "Arctic flora" is about Latitude 45° North in North America (British Columbia), and about 57° North in Europe (Isle of Mull). It seems to me that the essential concordance of these facts is significant, and whatever may be thought of them, it would certainly seem to be difficult for any one to claim that these various Eocene floras mentioned do not show a climatic change in passing northward from the equator toward the pole. Moreover, at present—a time of, in many ways, an abnormal climate in a geologic sense; with rather sharp zoning, although not nearly so sharp as the textbooks would have us believe; a time of almost, if not quite, unprecedented land expansion in the Northern Hemisphere, which I believe expresses a casual relationship—the reliable members of these Eocene Arctic floras range much farther southward than they did in late Eocene time.

EXISTING ARCTIC FLORAS

Greenland is the most illuminating of Arctic Lands because it is much the largest, and therefore more likely to preserve endemic species, and to receive immigrants from other Holarctic lands. Although mostly covered by ice which rises to an altitude of more than 8,000 feet in the interior, it has island peaks (nunataks) with recent plants. Moreover the northeastern part appears never to have been glaciated.

About 400 species of recent vascular plants have been recorded from Greenland and at the south trees may reach heights of 10 or 12 feet. North of the Arctic Circle the number of plants is fewer, but Ostenfeld (1925) records 125 species north of Latitude 76° and 108 between Latitudes 78° and 80°, including 2 equisetums, a lycopod, 3 ferns, 32 monocotys and 70 dicotys, including Salix and Vaccinium.

In an earlier paper (Ostenfeld, 1923) this author describes the flora of the north coast and records 70 species of plants from Latitude 82°.

This brief statement will be sufficient to indicate that there are other and more important factors than cold. The almost entire absence of vascular plants (a single species as I recall it) from Antarctica shows the part geography plays in the problem. The absence of trees in Lapland (Kihlman) shows the part taken by cold desiccating winds. The northern limits of many tree species in coastal Alaska and Norway will indicate the ameliorating climatic effects of warm ocean currents and humidity.

EXISTING ARCTIC CLIMATES

This is a complex subject which cannot be discussed in this connection beyond pointing out certain observed facts which support the thesis of the present discussion. These are the slower heating and cooling of water bodies as compared with land areas, with their respective influence on air temperatures and pressures, their influence on the amount of water vapor in the air and the resulting effect of humidity on equability.

The climatic influence of the northward drift of oceanic waters may be illustrated by the course of the present day isotherms over the north Atlantic, a somewhat hackneyed illustration but nevertheless the most striking. I am showing a few of the isotherms for January and July in figures 5 and 6. Those for January which show the full effect of the rapid radiation and quick cooling of the land, contrast most markedly with the slow radiation and cooling of the ocean. At this time the zero isotherm reaches Latitude 35° in Asia and about Latitude 74° north of Norway, a difference of 39°. Much the coldest place is in northern Siberia which is 10° to 20° colder than at the pole itself. The −30° isotherm reaches almost to the pole north of the Atlantic and swings to approximately Latitude 55° in Siberia—a difference of about 35° of latitude. The midsummer isotherms naturally smooth out these curves somewhat but even at this season the isotherm of 5° swings from about 62° in southern Greenland to 80° just west of Spitzbergen and the oceanic effect is clear as far eastward as Nova Zembla.

A few figures quoted from Sir John Murray's calculations will serve to emphasize the relations referred to. The energy radiated by the lowering of the temperature of a cubic meter of water 1° is sufficient to raise the temperature of more than 3,000 cubic meters of air 1°, and a second calculation shows that the heat released by lowering by 1° a stratum of water 200 meters deep and of 700,000 square kilometers area would suffice to raise the temperature of a stratum of air 4,000 meters deep over the whole of Europe on an average of 10°.

I have not attempted to evaluate the effects of the present ice cap on Greenland or of the present altitude of the land surface, as all

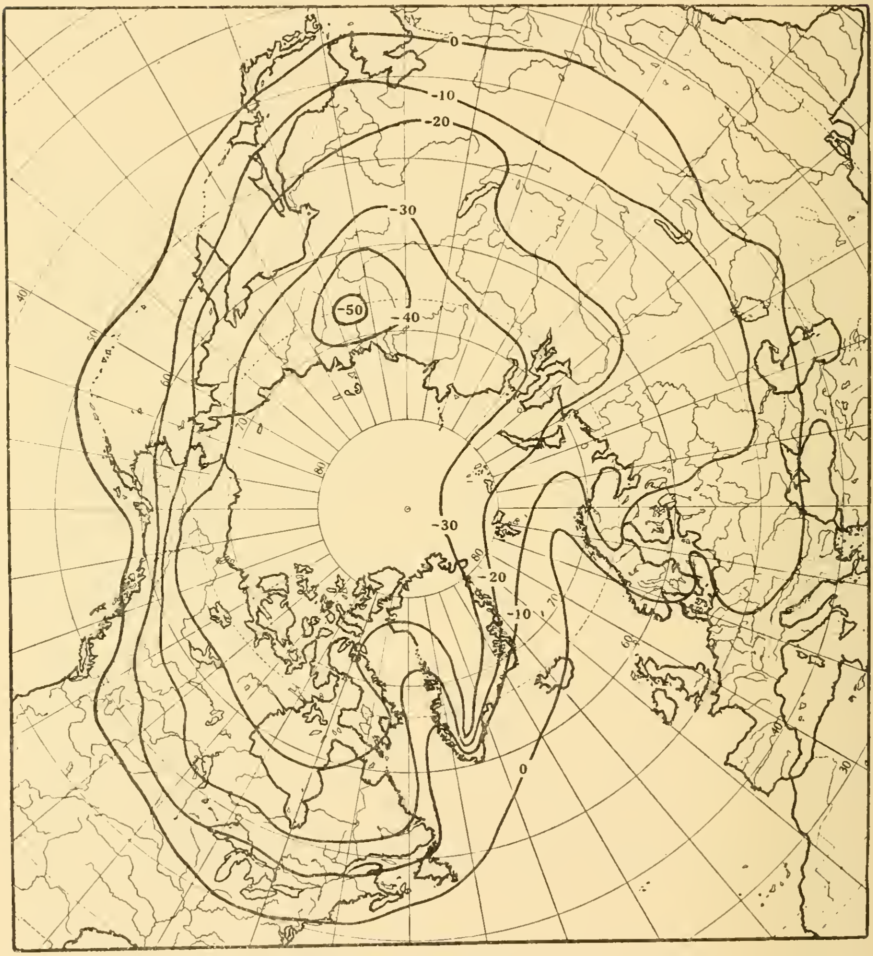

FIG. 5.—Midwinter isotherms at the present time.

I wish to do in this brief discussion is to emphasize in a graphic way the major thermal effect of land and water.

The Arctic is an oceanic basin and shows a remarkable climatic contrast with the elevated glacier-covered Antarctic continent. A few of the probable climatic effects which would follow if the Arctic received ocean waters from the Pacific or across Eurasia from ancient Tethys, or became ice free during the summer are discussed very briefly in a subsequent section of this paper.

FIG. 6.—Midsummer isotherms at the present time.

SOME PALEOBOTANICAL MISCONCEPTIONS

Although I have on previous occasions emphasized the lack of climatic value of most of the plant types which paleobotanists have relied upon as indicating tropical climates, this subject should not be passed over without some comment in the present connection.

The principal evidence upon which tropical climates have been predicated falls into three somewhat dissimilar categories. First it rests upon tradition which never had any basis. For example the conception that the flora of the Carboniferous grew in a supertropical climate with a humid atmosphere charged with carbon dioxide, of which Köppen and Wegener make such specious use, had as its original basis the 18th century idea that the strange plants associated with the coal had been swept to Europe from the tropics by Noah's flood and the further fact that the habit and venation of certain fern-like Carboniferous plants, now referred with strong probability to the Pteridosperms, resembled certain existing tropical ferns.

European students accustomed to the modern accumulations of peat in high latitudes concluded quite as illogically that peat could not accumulate in the present equatorial region because of the rapid oxidation there, so added carbon dioxide to make growth extraordinarily rapid and great moisture to prevent rapid oxidation. The carbon dioxide stimulation would also conveniently account for the enormous size of some of the calamites and lepidodendrons as compared with their diminutive survivors the equisetums and clubmosses.

Then Koorders and Potonié described a peat bog from Sumatra and others have been subsequently described from other tropical lands, and there has been much readjustment of views, which might have been accomplished much earlier if the experts on geological climates had ever visited the tropics or even consulted the report on the peat deposits of Florida published by the Geological Survey of that state.

There is not space at my disposal to follow the vagaries of opinion, but it may be stated in the most positive way that *temperature* or the position of any region with respect to the equator,[1] that is between hot or cold climate, is not a factor in the formation of either peat or coal. Second the tropical idea relies on representatives of long lived, vigorous groups with very many species, which either in the past or in the present have become adapted to a variety of habitats, as is usually the case in large vigorous groups of all kinds of organisms.

As outstanding examples I may cite just a few types such as the palms, and figs, or such genera as Cinnamomum and Zizyphus. The great bulk of the existing palms are tropical and they are one of the first types of plants visualized when we think of tropical climates, whether we picture the Arab and his date palms or the South Sea Islander and his cocoanut palms. Nevertheless certain palms extend to approximately 39° South in Chile, 44° South in New Zealand, 34° North in California, 35° North in North Carolina and 36° North in Japan, and commonly are hardy several degrees north of their natural limits, as in the Sacramento valley in California, or in southern

[1] Not considering the subtropical arid belts of high pressures.

France. The greater limits of cultivated forms is usually not a result of cultivation so much as it is of selecting the species that will grow in a particular environment. In nature the proper species is subject to the historical factor of there having been ancestors in the region or in a region offering access to the particular region. For example our native Californian palm (Neowashingtonia) is a plant of sandy alkaline soils whose range seems to be conditioned by the geologically late submergence of the Colorado Desert area, and to bear no relationship to latitude. In the present tropics certain palms range upward to nearly 10,000 feet, as in the wet parts of the northern Andes (Ceroxylon, Geonoma, etc.).

The genus Ficus, to which the cultivated fig belongs, is one with upwards of 600 existing species of a great variety of habitats, and with probably as many fossil species, extending back to the dawn of the Upper Cretaceous. Various members range well into the temperate zone, both geographical and altitudinal. The cultivated fig generally ripens its fruits in Baltimore. I have seen it in the temperate altitudinal zone in Bolivia, and Weberbauer[1] records an altitudinal range for it through 8,255 feet in Peru.

Cinnamomum is the genus to certain members of which the names cinnamon and camphor trees are applied. The genus is large and ranges from the Upper Cretaceous to the present. Although the majority of existing species are confined to the tropics some extend for considerable distances into the Temperate Zone, in fact the commercial supply of camphor comes in large part from Formosa and Japan, and the tree is hardy in the southern parts of the latter country. Introduced into Florida it has been widely seeded by birds and is perfectly hardy throughout that state.

Zizyphus is a large genus also going back to the Upper Cretaceous, whose present center of population is southern Asia and the Sunda Islands. The new world species are practically confined to the tropics, but in the old world there are distinctly temperate species in southern Europe and eastern Asia. It has run wild in Louisiana, and characteristic fruits occur in the Pleistocene of the Atlantic coastal plain as far north as Long Branch, New Jersey. Obviously as a fossil. Zizyphus entirely lacks a tropical significance.

A third source of error is the common assumption that because a particular type of plant has its home in the equatorial zone it is necessarily a tropical plant. The type most frequently alluded to in fossil Arctic floras as indicative of a once tropical climate is the tree ferns, the term embracing a variety of species in several genera.

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[1] Weberbauer, A., Archiv. Asoc. Peruiana Progreso Ciencia, tomo 2, p. 60, 1922.

As a matter of fact tree ferns reach their maximum development in temperate rain forests, as in New Zealand (Lat. 40° S.), or in similar situations in tropical uplands, as was pointed out by Alexander von Humboldt over 100 years ago. They reach their greatest profusion in South America in the temperate part of the montaña zone of the eastern Andes. They grow luxuriantly on the mountains of central Africa at altitudes where they are buried in snow for part of each year, and as fossils their climatic significance is wet temperate and not tropical.

There are a great many other genera or species in the same category. I have seen Anonas and Ingas (cultivated) at 10,000 feet in the Andes perfectly hardy, and a large number of generic types that are commonly thought of as lowland tropical above the tropical altitudinal zone—such things as *Dodonaea viscosa, Sapindus saponaria* and *Swietenia mahagoni.* In fact it was my own observations in the Andes that first turned me from the paleobotanic tropical tradition.

Another misinterpreted type is the Gleichenia type of ferns (now segregated in several genera) very common in the Cretaceous floras of Greenland, but largely absent from the northern hemisphere in recent floras. Although commonly confined to low latitudes at the present time, it is by no means confined to the tropical altitudinal zone; in fact, where I have seen it (Yungus of Bolivia) it is prominent above the tropical zone, as it is also in Hawaii, Peru, Ecuador, Asia, etc. Representatives reach 54° South in Chile and 40° South in New Zealand.

All this is related in any account of fern distribution (*e. g.,* Die natürlichen Pflanzenfamilien, 1902), and still Gleichenias, along with palms, cycads, and tree ferns always appear in the paleobotanists tropical repertoire.

I suppose that constant reiteration of facts like the foregoing will have to be continued over many years before the news reaches those who write on paleoclimatology, and at least another generation will elapse before writers of geological text books cease to talk about the tropical climate of Tertiary Greenland.

Juniperus communis Linné is found as far north as the North Cape, which is at least 20° farther north than any other member of the family Cupressinaceae is found in the Eastern Hemisphere (Nathorst, 1911). Sassafras, of the mostly tropical family Lauraceae, extends northward to southern Maine, or about 13° beyond the bulk of the family. Diospyros, of the mostly tropical family Ebenaceae, extends northward to southern Connecticut, or about 12° beyond the bulk of the family.

Nor must it be lost sight of that at those times in the past when certain groups were varied and abundant, as were the seed ferns in the Paleozoic or the cycads in the Mesozoic, they were quite likely to have shown the features of dominant organisms, both plant and animal, and to have occupied more environmental niches than the depleted survivors of the cycad phylum do at the present time.

In Newfoundland and western Labrador the larch (*Larix americana*), the balsam poplar (*Populus balsamifera*), the paper birch (*Betula papyrifera*), and the balsam (*Abies balsamea*) fail to reach the Straits of Belle Isle (52°) whereas they all extend far above Latitude 60° in Alaska and the first crosses the Arctic Circle. Podocarpus just fails to reach the Tropic of Cancer in Cuba. A Chilean species reaches 42° South Latitude in Chile. The northern limit of forests crosses the Arctic Circle in Alaska and reaches 70° North Latitude in Norway, the latter 20° north of the tree line on the Atlantic coast of North America.

EXPLANATION OF PAST ARCTIC CLIMATES

It is perhaps fatuous to point out that climate, either present or past, depends upon a variety of factors, both cosmic and terrestrial. Of the former the only one that is of practical importance is solar—that is, radiant energy from the sun, since it is inconceivable that other heavenly bodies or the introduction of kinetic energy by meteorites exert any appreciable effect.

The amount of solar energy reaching the earth depends upon the sun's activity, which is variable; on the distance of the earth from the sun, which is also variable; and more practically in so far as terrestrial climates are concerned, on the condition of the earth's atmosphere, especially with respect to the amount of ozone, water vapor, carbon dioxide, and dust present, all of which again are variable. The latitude, determining the angle of incidence of the sun's rays, is an obvious factor, as is also the geographic pattern and the topography, including altitude under the latter. The geography determines whether the sun's energy falls on the land or the water, it determines the temperature gradient between the equator and the poles and the consequent force of the planetary winds and ocean currents, and in less obvious ways is of the greatest significance, as the following illustration will make clear.

The North and South Equatorial currents in the Atlantic are so situated that the South Equatorial, the stronger and the larger of the two, is divided by Cape San Roque into a larger, northern or Guiana current; and a smaller, southern or Brazil current. Some authors, *e. g.*, Guppy, are inclined to consider the South Equatorial as bipartite throughout, calling the Guiana current the Main Equatorial current. The point is immaterial in the present connection since all I desire to show is that the shape of eastern South America and the latitude of Cape San Roque are purely fortuitous in so far as their relation to climate is concerned, and yet if the latter had happened to lie a few degrees north of its present position much of the water that ultimately contributes to the Gulf Stream would have turned southward to augment the Brazilian current, and the climate, especially of Europe and the Arctic, would be profoundly modified. It has been estimated that if Cape San Roque were 2° north of its present position there would be a shift of 40% of the Equatorial current which would be deflected southward instead of northward. The same results would be attained if the southern trades were not stronger and more constant than the northern trades, because of the relative amounts of land and water in the northern and southern hemispheres.

Scant attention will be devoted to the various theories that have been advanced to explain geological climates. These range from that of Croll, in its original or modified form, based upon the eccentricity of the earth's orbit and the obliquity of the ecliptic, which was doubtless a factor at all times, but hardly a controlling one; through those theories that rely on changes in the atmosphere, such as alterations in the amount of carbon dioxide (Tyndall, Arrhenius, Chamberlin)[1] amounts of volcanic dust (Humphreys), to the extreme form of the hypothesis advanced by Manson, and elaborately defended by Knowlton, that a combination of cloudiness progressively diminishing during earth history, and a terrestrial control due to a cooling earth, instead of a solar control as at present, are the primary factors which explain past climates. Finally there are those highly speculative hypotheses such as Chamberlin's reversal of the oceanic circulation, and a group which predicate a wandering of the poles in various ways, now fashionable in the revived form put forward by Wegener.

I have quite possibly omitted other proposals that might be mentioned, and I have now to mention the theory, if it can be called a theory, which is the main thesis of the present paper, namely: that it seems to me possible to interpret geological climates in the light of demonstrated changes in topography and geography, including under the latter differences in the distribution of land and water and the transfer of energy by currents.

[1] It is of interest to note that Neumayr in 1883 pointed out that excesses of CO_2 would be impossible since the absorption by the oceans would maintain an almost perfect balance.

This idea, as applied to the Pleistocene glaciation, was first advanced, I believe, by Lyell, and in its more general application has been recently put upon a scientific basis by Brooks, with whom I am in perfect agreement to the extent of the evaluation of these as major factors, but also in my firm conviction that arm chair philosophy with its fondness for highly speculative and catastrophic hypotheses, has no place in a uniformitarian world or in 20th century science, but belongs in the medieval age of human thought.

Climate, in a uniformitarian geology, occupies a somewhat anomalous position, which the scientific world has been slow to recognize, namely, that the history of the human race has been run under climatic conditions which, from the point of view of earth history, are exceptional. Man was evolved subsequent to the relative elevation and the great extension of the continents which ushered in the Pleistocene glaciation, and therefore what is normal in human experience, is abnormal for the bulk of geological climate.

While, therefore, we recognize that the climatic factors and the meteorological elements are the same now as always, their combination to form actual climates has depended upon a great many factors, among the chief of which was the size, shape, position, and relative elevation of the land masses. It may be remarked parenthetically that numerous theories of the causes of, or descriptions of geological climates have been advanced by students ignorant of meteorology, and also usually ignorant of the relationship of organisms to their environments, and the last is strikingly true of Köppen & Wegener's recent Die Klimate der geologischen Vorzeit (1924).

In attempting, a few years ago, to explain the extension of floras nearly to the poles during the late Eocene, I relied chiefly on the submergence of continental areas in the middle Eocene and the resulting free oceanic connections at that time between equatorial and Arctic waters, pointing out that these Arctic floras were coastal floras and therefore under the régime of an oceanic climate.[1] Essentially the same explanation was put forward independently in connection with Jurassic climates a few months later by Kerner von Marilaun.[2] An additional and important factor has since been brought forward by Brooks,[3] who points out that the temperate gradient is a simple function, whereas the influence of the ice increases as the square of the

[1] Berry, Edward W., A possible explanation of upper Eocene climates. Proc. Amer. Phil. Soc., Vol. 61, pp. 1-14, 1922.

[2] Kerner von Marilaun, F., Sitz. k. Akad. Wiss. Wien, 1922.

[3] Brooks, C. E. P., The problem of mild polar climates. Quart. Journ. Roy. Meteor. Soc., Vol. 51, pp. 83-94, 1925.

radius. Hence a coincidence of minor factors sufficient to effect an overturn in the one or the other direction, that is, toward ice formation or melting, would suffice to induce a wide extension of polar ice, or to prevent the polar regions from maintaining a permanent ice cap. If this is true then it seems quite probable that there was little polar ice during those times already enumerated when temperate floras invaded the polar regions. This would mean profound changes in the distribution of barometric pressures and consequent wind circulation, and in fact, in all of the elements which constitute climate. It would mean that in western Greenland, for example,. where the most extensive late Eocene Arctic flora has been found, the present day glacial anti-cyclonic winds would be replaced by westerly or southwesterly winds blowing from the relatively warmed waters of Baffins Bay, and this would satisfactorily explain the details of the floral facies. This does not mean that there would be tropical climates in the Arctic or that the region would not be ice bound in the winter season. The protective effect of snow, and cold sufficient to cause a cessation of plant activity during the Arctic night are a physiological necessity. Otherwise most vascular plants could not maintain themselves. They tend to die either if active in darkness or if exposed to desiccation by air and wind when the ground water is frozen.

Regarding the general history of discussions of geologic climates I believe that most paleontologists who have written on this topic, especially those dealing with the pre Cenozoic periods, have had little basis in fact for their speculations. They seem to me to be utterly oblivious to the great amount of modern work on the distribution of marine organisms; and their ideas of the climatic significance of a trilobite, eurypterid, or ammonite is purely a tradition inherited from the distant past when all strange organisms were associated with torrid climates.

In stating my belief in a greater uniformity of climate during the past than obtains at the present I do not wish to be understood as advocating such unsound beliefs as the entire absence of zonation, such as many paleobotanists have defended (Jeffrey, Knowlton), or a similar uniformity throughout all time. Both are equally disproved both by geological observations and meteorological principles. Jeffrey, for example (Anatomy of Woody Plants, Chapter XXX, 1917), holds that the more ancient the epoch the warmer the climate, and that there has been a gradual and progressive refrigeration during geologic time; that the organization of secondary wood in extinct plants furnishes the most reliable evidence of climatic conditions; that toward the end of the Paleozoic, growth rings appeared in woods in high latitudes; that in the Triassic, growth rings were developed ten degrees nearer the equator than had been the case during the Paleozoic; that in the Jurassic, the tracheids first developed tangential pitting which was at the end of the annual ring, and accompanied by storage elements (wood parenchyma).

None of the statements in the foregoing paragraph are facts of observation. There is no geological or paleontological evidence indicating a progressive climatic cooling during geologic time, and the Permo-Carboniferous glaciation was admittedly more extensive than that of the Pleistocene. The presence or absence of growth rings exhibits what might be called constitutional variations quite independent of climate, not that they really are independent, but two associated species under an identical climate will behave differently with respect to this feature of their anatomy. Growth rings appear in some Paleozoic woods many degrees nearer the equator than Jeffrey admits,[1] and in marine formations deposited off low coasts so that they cannot be considered to have been upland types. Several Lower Carboniferous examples have already been cited. The Paleozoic genus Mesoxylon shows tangential pitting, which, according to Jeffrey, first appeared in the Jurassic; and the citation of a wood from the Triassic of Arizona as an argument for the advance equatorward of cooler climates during the early Mesozoic is particularly disingenuous, as it is perfectly clear that the growth rings in this case have nothing to do with temperature, but are due to periodic lack of moisture in that region, as exemplified by the contemporaneous gypsum deposits.

Similarly in the recent elaborate work on geologic climates by Köppen & Wegener, already alluded to, these authors offer explanations to account for climates during the successive geologic periods, which climates have not been proved to have ever existed.

As I have pointed out on previous occasions, paleobotanists in general have entirely lacked objective experience outside the temperate zone, and have invariably overestimated temperatures. They have been prone to use the present distribution of the fancied or real relatives of their fossil forms as if temperature were the sole factor in the environment, and have stopped with the geographic occurrence, with the apparently simple trust that all lands in the equatorial zone were at sea level and wet tropical. A sojourn in the Arctic climate beneath the equator on the backbone of South America would do much to correct this misapprehension, as would also some experience in the temperate rain forests of different regions.

I had intended to indicate current conceptions of contemporaneous paleogeography on the maps showing the plant localities but have

[1] Several have been named in the preceding paragraph devoted to Mississippian Arctic plants and others could be added.

not done so although I did publish such a map for the Eocene in 1922. This intention was abandoned for the reason that it was not possible to compile maps that did not cover too much time nor in which the extrapolation was not so great as to destroy any real value.

Arldt has compiled maps which represent a synthesis of opinions and showing the areas of agreement and disagreement among specialists and to these the reader is referred. The debatable North Atlantic continent and the Gondwana continent would, if they ever existed, have had a profound effect on climate. Whether or not they were ever realities I am not prepared to say. I can, however, make the following statements with a considerable degree of certainty, namely: That there was a wide extent of land in the Northern Hemisphere from late Mississippian through the Permian. That the Arctic was landlocked in early and middle Triassic and that there was a wide transgression of the sea in the Neo Triassic. That the maximum Jurassic transgression was about Oxfordian; that of the Lower Cretaceous was in the Neocomian; that of the Upper Cretaceous was in the Emscherian; that the late middle Eocene was a time of wide sea transgression and low lying lands; and that during the Miocene, the age to which Heer assigned the Arctic Tertiary floras, the amount of land in the Northern Hemisphere was nearly as great as it is at the present time.

It will be seen that there is a correspondence between times of sea extension and Arctic floras and times of land extension and no traces of Arctic floras. This correspondence is not exact, and so little of paleogeography is objective, that I would not want to appraise it for more than it is worth, but in so far as it is known it does offer corroboration of my thesis.

I had expected to attempt an estimate of the meteorological conditions at the various times at which fossil floras are found in the Arctic, but after abandoning any hope of getting reliable paleogeographic data I have also abandoned the former. Brooks has published some interesting meteorological estimates using as a basis those parts of Arldt's maps where authorities agree, but it should be pointed out that majorities are quite as likely to be wrong in science as in politics, and if generalizations are valid (which of course they are not) then minorities are usually right.

There are, however, a few considerations that may be put forward as having a high degree of validity, namely the importance of ice as a third factor, added to the long recognized rotational (planetary) and geographic (distribution of land and water and altitude) factors in influencing the distribution of pressures and consequently of prevailing winds. And also the effect of the volume of fresh water carried into the Arctic basin by rivers in the formation of ice and the effect of current-borne ice in maintaining subnormal density and consequently the identity of the present day cold currents as they move southward. Once they become of normal density they disappear below the surface and lose their climatic influence.

Another factor of considerable importance climatically, especially in connection with the theory of Brooks, is the amount of reflection from the earth's surface. I do not have the exact figures, but estimates given to me orally by W. J. Humphreys, are about 7 per cent from land or water and about 70 per cent, or ten times as much, from the surface of snow and ice. If there has been the wide fluctuations in polar ice as Brooks predicts, then reflection is a factor which can not be safely neglected.

At the present time in high latitudes the prevailing wind circulation is easterly with a southward moving component at the surface. If the ice cap were gone we would have westerly winds in high latitudes with a poleward component at the surface.

If Bering Strait was open and less shallow, a great volume of warm Pacific water would pour into the Arctic and greatly ameliorate the climate, as would also be the case if a Cretaceous seaway bisected North America, or a Devonian or Eocene seaway bisected Eurasia, such as are shown on current paleogeographic maps. If the best available sources are utilized in plotting Eocene seaways nearly all the Tertiary coal occurrences and floras in the Arctic range themselves along the easterly coasts of such seaways.

CONCLUSIONS

The major factor in the polar extent of temperate floras is not primarily the direct effect of temperature so much as it is the fact that above 32° F. water is a liquid and below 32° F. it is a solid. Asa Gray said "Plants are the thermometers of the ages." I have no doubt that terrestrial vegetation when properly interpreted is the safest guide to geological climates, but as thermometers they are pretty poor and we have no means of calibrating them.

There is no unequivocal botanical evidence of tropical or subtropical climates at any time in the Arctic. There is no evidence from paleobotany of a lack of climatic zonation at any geological period from which fossil plants are known, although at such times the evidence points to a relative mildness and a lack of sharp zonation, as compared with the present.

The distribution of the known fossil Arctic floras with respect to the present pole proves conclusively, as Seward pointed out in 1892 (p. 53), that there could have been no wandering pole.