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METHODS IN PALEOCLIMATOLOGY WITH REFERENCE TO CANADA

D.P. Kerr

INTRODUCTION

Paleoclimatology is a study of ancient climates and the principal task of its adherents is to reconstruct climatic conditions of the past. All of earth history except the most recent period is involved. In the last hundred years, precise instrumental records of climate have been systematically kept and consequently man has been able to define climatic conditions with great accuracy. For the few thousand years prior to the instrumental period, fairly accurate estimations of climatic characteristics and fluctuation have been made by scientists from a study of archeological sites, historical documents, tree rings, varves and other physical and cultural data. For the millions of years before the dawn of modern man, the record is incomplete, the evidence fragmentary and the reconstruction exceedingly difficult. Nevertheless, broad, yet significant, generalizations about ancient climates can be made from evidence furnished by biological and geological phenomena.

BIOLOGICAL PHENOMENA

Based on the assumption that the nature and distribution of plants and animals on the earth's surface is greatly influenced by climate, deductions have been made by paleoclimatologists about former climates from an examination of various fossils. In so far as biological evidence is offered as a measure of climatic conditions or as an index of climatic change, fossil plants are preferred to fossil animals. The latter, unless blocked by impassable barriers such as oceans or mountains, migrate quite easily in the face of rapid climatic deterioration. Plants are more securely anchored than animals and must suffer extinction in response to injurious conditions unless the climatic revolution allows a generous time interval for travel or adaptation.

The relationship of fossil plants to their climatic environment has been intensively studied by many scientists. Some climatologists who consider the determination of absolute values as the final goal of paleoclimatology have attempted to translate biological evidence into degrees Fahrenheit or Centigrade from which they have constructed impressive looking isotherm maps. That plants are "thermometers of the ages", however, is irreconcilable with botannical fact. Although admittedly, flowers, shrubs and trees have certain heat requirements, Seward[1] asserts that a careful study of the anatomy of extinct plants reveals more about the relationship of plants to water and light than to temperature. Furthermore, other factors such as soil, site and wind, to name only three, exercise a profound influence on plant distribution.

When the fossils under scrutiny are extinct types and cannot be connected with living species, it is impossible to estimate their climatic requirements. Consequently such species have a very limited climatic significance. If their world distribution can be plotted, climatic inferences may be drawn. For example, if the tree or bush under study grew within a wide latitudinal range, say 30 to 70 degrees, considerable climatic homogeneity probably prevailed over that expanse. If another plant grew at latitude 40 degrees in the same period, its climatic relationships if they are known, may be, with certain reservations, interchanged with those of the other species whose climatic requirements are unknown.

In the study of paleoclimatology, much importance has been attached to the discovery of palm, fig and fern fossils in high latitudes. For various reasons, such plants have been considered by many as being characteristic of areas with a tropical environment, such as the South Sea Islands. When they appear in fossil form embedded in the geological strata of Greenland or Alaska, astonishing statements about the former tropical climates of polar areas are made. In reality, at the present time, selected species of the palm and fig grow in many parts of the mid-latitudes. The cultivated fig ripens its fruit in Virginia and grows as high as 8000 feet in Peru; the palm thrives in the Sacramento Valley of California and in southern France. Tropical conditions did not have to be fulfilled for their former existence in arctic Canada, but obviously conditions were more genial than they are to-day.

Fossilized tree-ferns and allied species have been uncovered in late Paleozoic beds of eastern United States and have been offered by some climatologists as irremissible proof of a tropical environment. The fact that closely related survivals of these fossil plants grow in Malaya and other equatorial areas at the present time gives substance to this view. In addition, these fossil forms lack any regular rings of growth and tropical affinities are strongly suggested. On the other hand, botanists point out that contemporary species in tropical areas are much less robust than their ancestors and that the absence of growth rings could infer a swampy but not necessarily a tropical environment. Subtropical conditions, similar to those in the coastal lagoons of the Carolinas and Georgia,would satisfy the climatic requirements. Some modern ferns grow luxuriantly in areas like New Zealand where mid-latitude marine climates prevail.

From the foregoing review, it is obvious that there is no simple way of interpreting quantitatively the climatic significance of vegetation embedded in the rocks. Nevertheless, plants are a safe guide in obtaining relative data of climate through geological history. A paleoclimatologist can state with reasonable confidence from a study of ancient plants that certain periods were warmer or cooler, wetter or drier than others.

Animal remains in geological structures are in some instances useful indications of climatic conditions. For example, contemporary cold-blooded reptiles cannot tolerate long periods of extremely cold or extremely hot weather. Their ancestors were limited in the same way. The discovery of reptile remains in polar areas suggests strongly warm conditions in a distant past. As Russell[2] states, however, caution must be exercised. From a superficial glance at mammoth bones discovered in Alaska, it might be inferred the animals lived in a tropical environment. From closer examination it is revealed that these beasts, although similar to their cousins such as the elephant in anatomical structure, differed from them in being covered with a thick coat of wool which enabled them to live in a cold climate.

GEOLOGICAL PHENOMENA

Geological phenomena yield much evidence on climates of the past. Tectonic forces, expressed through diastrophism and vulcanism derive energy from within the earth and consequently have no climatic significance. Various gradational agents however, such as running water, ice and wind, are either climatic elements or are indirectly controlled by climate. They mould the surface features of the earth. If the origin of land forms is studied carefully (geomorphology), the climatologist can often reach important conclusions of climatic conditions in the past.

The fact that glaciers were at one time much more extensive than now is unmistakably clear in an area such as British Columbia. Ridge-like heaps of gravel and boulders mixed with clay and sand (end moraines) are similar to those found at the present margin of a typical mountain glacier. Large numbers of smooth and faceted boulders (glacial erratics) lying in no organized manner through the valleys must have been transported by some powerful mechanism such as a glacier. Many examples may be cited from Southern Ontario proving that it was formerly overriden by great sheets of ice. One of the most important pieces of evidence concerning glaciation is located in the city of Toronto, in the Don Valley Brickyard. A remarkable sequence of geological layers has been uncovered; varved clay alternates with till and the whole unconsolidated mass rests on Ordovician shale. This formation has been intensively studied by many scientists, the most important of whom was the late Professor Coleman of the Univerisityof Toronto, a world authority on glaciation.[3]

From the many studies which have been made on glaciation, certain conclusions may be drawn. Large portions of the polar and mid-latitudes were covered by ice at various times during the last million years, a period which has been called the Pleistocene by geologists. In North America, the ice extended as far south as the Ohio and Missouri river valleys.

Careful study has revealed the occurrence of widespread glaciation in earlier geological periods. During the Late Paleozoic (C 250 million years ago) ice spread as far equatorward as tropical India where glacial materials of Permo-Carboniferous age have been authenticated. There is vague evidence for 2 other extensive glaciations, late Algonkian and late Acadian, but admittedly the record is very incomplete. Umbgrove[4] suggests a periodicity of 250 million years for major glaciations, with minor local glaciations intervening.

Glacial climates are not typical in the history of the earth. Less severe climatic conditions have prevailed throughout the long period of earth history. Glacial climates have been referred to as abnormal climates; the non-glacial as normal. We are at present experiencing either the close of a glacial epoch or merely an inter-glacial stage.

Running water is an extremely important agent in the moulding of land forms. Hills and mountains, if not disturbed by internal forces, literally waste away in the face of stream erosion. In humid areas where this action goes on continually, smoothly, rounded, subdued landscapes obtain (Appalachians). In dry areas, water flows intermittently but violently and sharp angular shapes, steep alluvial fans and rocky desert floors result. If the features of old landscapes can be reconstructed, then certain climatic conditions can be determined.

Apart from studying the morphology of land forms, paleoclimatologists probe beneath the surface geology into geologic columns for evidence of past climates. If ventifacts, rocks which have been polished by sandblast and which are found to-day only in desert or beach landscapes, are uncovered in geological formations, then arid conditions may be inferred. However, such deductions must be confined to late geologic time or that period when plants had evolved sufficiently to constitute an important element in the environment. In early periods, ventifacts were probably widespread even in humid areas when the lack of plant cover made the wind a dominant factor in erosion.

Coral reef structures are common in certain geological formations. They usually consist of limestone which has been built by millions of white spongy minute shell-forming animals (polyphs). At the present time corals grow only in warm seas where the temperature never drops below 65° F. Presumably ancient corals required similar conditions for development. They were widespread in the Devonian formation; in fact the rich oil deposits which are now being developed in Alberta are associated with such structures. Obviously the Prairies enjoyed a much more genial climate in the middle Paleozoic than they do now.

Salt deposits found in geological beds often indicate arid climates. Of great significance is the discovery of ancient soil remnants. The chemical and physical properties of soil are largely determined by the climate under which they develop. Consequently the discovery of ancient heavily oxidized soils in polar areas infers warmer and more humid conditions than prevail at present.

CLIMATIC INFERENCES FROM PALEOGEOGRAPHY

Geologists have made great contributions to the study of earth history and indirectly to an understanding of ancient climates by their excellent reconstructions in map form of past landscapes. Such maps (see maps in reference 7 or reference 9) show with a reasonable degree of accuracy relative elevations and the distribution of land and sea in geological periods. They have been deduced from careful and intense analyses of the distribution of different series of rocks and the relative times of formation. By applying meteorological principles to these paleogeographies, the climatologist can reach significant conclusions about climatic conditions. Briefly the references will be made to North America and as far as possible, specifically to Canada.

Throughout most of the Paleozoic era the outline and relief of North America differed greatly from that of today. Seven elements dominated the physiography of North America; three geosynclines, the Appalachian, the Cordillera and the Ouachita; three borderlands, Appalachia, Cascadia and Llanoria, and one great stable interior. From time to time in this long period of earth history, the sea flooded the geosynclines and part of the interior and vulcanism and orogeny affected the borderlands. For the most part North America in the Paleozoic consisted of broad low islands surrounded by relatively warm seas.

When large sections of the continent were submerged beneath the sea during the Paleozoic, temperatures were much higher than those of today. The summers of southern Canada were probably similar but towards the north they were considerably warmer than at present.

Such thermal conditions can be deduced from land and sea distribution. Extremely cold air masses of winter form over large land areas where the air can stagnate within cold anticyclones and lose heat through terrestrial radiation. Undoubtedly since the land area of North America was smaller and interrupted by much open water, no intensely cold pools of air formed. Furthermore any cool air masses over the land would have been greatly modified with a trajectory over the water. At least throughout part of the Paleozoic, corals formed in the seas throughout high latitudes and consequently water temperatures must have been moderately high. In addition warm ocean currents were in all probability deflected into polar latitudes through the great gulfs and channels of Canada.

Deductions concerning precipitation may also be made. Because of the subdued nature of land surfaces, orographic rainfall was of little significance. Mid-latitude cyclonic rain was probably of less importance than today because of the weakness of the temperature gradient between land and sea and the resultant weakness of the Polar Front. Instability showers probably contributed most of the precipitation. On the other hand, because of the lack of high mountains, no rain shadow deserts existed.

A FEW CHARACTERISTIC FEATURES OF GEOLOGICAL CLIMATES IN CANADA

During the Paleozoic, arid conditions may have occurred from time to time in various parts of Canada. Salt and gypsum accumulated during the late Silurian in eastern Candda, during the upper Devonian in Manitoba, during the Mississippian in the Maritime Provinces and throughout most of the Prairies in the Permian. Those minerals formed in salty vestiges of the extensive seas and indicate an emergence of the land and a retreat of the sea. The true climatic significance is difficult to determine.

The coal measures of eastern Nova Scotia were laid down in the Pennsylvanian. The Paleozoic closed with the Appalachian Revolution which witnessed severe crustal deformation and widespread glaciation.

Continental climates must have prevailed throughout Canada in the Triassic period of the Mesozoic era. The sea was more restricted, the land wider and higher than during a typical period in the Paleozoic. The Appalachians were being worn away quickly but probably stood higher than the Rockies do today. Their influence on the climate must have been considerable.

In the Jurassic the great Coast Range batholith of British Columbia was intruded and parts of the Columbia Mountains in southeastern British Columbia were built. There are evidences of aridity in the western part of North America. Base-levelling all over the continent proceeded vigorously during the Cretaceous, when the last great transgression of the sea in North America occurred. The climate was quite genial over all of Canada. The Mesozoic closed with the great crustal unrest in western sections of Canada and the Rocky Mountains were built. Local glaciation followed in the Western Mountains.

In the Tertiary no great invaisions of the sea into the heart of the continent took place. Only minor transgressions along the coasts occurred. Most of the Tertiary deposits are continental and fresh water types. Climates with modified continental characteristics would be expected in the Tertiary period chiefly because of the restriction of the sea. However, great fresh water lakes formed from time to time and moderated the climate. The botannical fossil record shows sub-tropical plants growing in Arctic regions of Canada during the Eocene. However all have been uncovered in shore locations and the interiors of the Arctic islands could have had cooler climates. Tertiary coal has been discovered in Arctic Canada. During the Eocene and Oligocene the

Praries Provinces received enough rain to support a forest and a great host of forest dwelling mammals. In the Miocene and the Pliocene, the Plains and intermountain areas of Canada became dry. The great vertical displacement of land in the Pliocene set the stage for the Pleistocene glaciation. Most of Canada was covered with a great sheet of ice at least twice and probably four times during the last million years.

In conclusion, the evidence used in paleoclimatology is indirect. However from data supplied by biological and geological phenomena and by the application of meteorological principles to much of the data, reasonably accurate descriptions of past climates can be made.

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SOME NOTES ON POST-GLACIAL CLIMATIC CHANGE

IN EASTERN CANADA

F. Kenneth Hare

ABSTRACT

This paper reviews the several methods in use for the reconstruction of past climates, and discusses the evidence so far obtained by each method in Eastern Canada. It presents little new material. The methods discussed are (i) pollen analysis, (ii) tree-ring analysis, (iii) statistical analysis of climatological data. Some attempt is also made at general conclusions as to post-glacial changes of climate east of Hudson Bay and the Great Lakes.

INTRODUCTION

Climatic change is so much a topic of the day that many meteorologists are beginning to wish they knew more about it. In the 1920's and 1930's, when the present writer first became interested in the weather, it was fashionable to deny the existence of the remarkable fluctuation then in progress. Meteorologists, full of confidence in the capacity of random distribution to account for mild winter after mild winter, were very apt to deny categorically that the obvious warming up had any lasting significance. Even as a boy the writer thought it was odd when ten consecutive English winters went by with temperatures above the so-called "normal".

Today there is no more scepticism. The reality of the present fluctuation is well established, and debate concentrates on what caused the change, and how long it will last. The writer's purpose in this paper is to marshal the flimsy and inadequate evidence bearing on post-glacial changes of climate in eastern Canada, long a neglected land in this field.

In such discussions, one must distinguish between climatic variations, which are long period changes of a persistent character, and climatic fluctuations, whose period can be reckoned in decades. There is no formal distinction between the two; not enough is known about climatic change to make a quantitative definition desirable, though such a definition has been attempted.

POLLEN ANALYSIS AND ALLIED METHODS

(1) THE POST-GLACIAL TIME SCALE

The reconstruction of past climates poses two distinct problems, first, the establishment of the climates themselves, and second, the dating of the period from which the evidence is drawn. Since observational evidence takes us back only into the eighteenth century, it is plain that indirect methods have to be used. Of these methods, that of pollen spectrum analysis is the most valuable in estimating the climates themselves; it has, however, to be supplemented by other methods to establish dating. Together these methods have enabled European scholars to establish the main elements of post-glacial climatic change in that continent, and to apply a confident time scale to them.

The raw material for such studies comes out of peat-bogs, raised beaches, old lake-beds and other sites where plant material may have accumulated. The useful material comprises (i) leaves, stems, flowers, etc., of such a nature that the species can be determined; and (ii) pollen grains.

From the study of such sites, it has been possible to reconstruct the nature of the vegetation that surrounded them in former times. Moreover, by carefully working downwards through the deposits, one can reconstruct, not only the flora of the past, but also the sequence of changes through which the flora has gone. These changes can in turn be interpreted climatically, for in most cases the climatic affinities of the important species are approximately known.

The accepted post-glacial time scale for Europe was worked out late in the nineteenth century by Blytt and Sernander[1], who used macroscopic plant materials from southern Scandinavia. Pollen spectrum analysis has since confirmed the sequence in most particulars. Table 1 sets out the scale as it is now usually employed:

Table 1. Divisions of Late Glacial and Post-Glacial Time in Northern Europe

Dates	Divisions	Characteristics
A.D.1952		
	Sub-Atlantic	Cooler and moist. Oak forests continue retreat. Spread of widespread peat bogs in Atlantic coastal areas.
B.C.500		
	Sub-Boreal	Warm, though less so than in previous division. Possibly drier. Oak forests begin to retreat, pine to increase. Beach and hornbeam spreading.
B.C.3500		
	Atlantic	Warm and moist. Mixed oak forests. Climate oceanic in character.
B.C.6200		
	Boreal	Warmer. Forests spread, chiefly pine at first, later with increasing oak. Apparently fairly dry, with continental characteristics. N.B. Initial stage sometimes separated as Pre-Boreal.
B.C.7900		
	Late Glacial	Ice still covers much of Scandinavia. Tundra vegetation widespread. Cool in general but with warm interval 10000 to 9000 B.C. (Allerød oscillation)
B.C.12000		

In the past 15000 years, therefore, the north European climate appears to have warmed up to a maximum in Atlantic or early sub-Boreal times, and thereafter to have cooled off considerably. There was a corresponding northward spread of oak forest, adapted normally to a warm environment, followed by a partial retreat. The term climatic optimum is usually applied to the phase of greatest warmth and maximum spread of forests.

The date scale in Table I is based on the elaborate technique of varve analysis, developed in Sweden by Baron de Geer[2]. This system depends on the examination of the deposits of laminated clay found in the beds of former or present-day ice-margin lakes. In such lakes, annual bands of sediment are deposited - called 'varves' - that can readily be identified and counted. De Geer and his colleagues have painstakingly extended the counting process to the entire extent of the past 15,000 years, during which the Scandinavian ice-sheet retreated from the south shore of the modern Baltic to the high plateaus of central Scandinavia. Moreover, the peat-bogs and lake-deposits that yielded the fossil plants worked on by Blytt, Sernander and their successors have been dated by correlation with the varve sequence.

The technique of pollen analysis owes its origins primarily to von Post, who worked on the peat-bogs of Sweden. The typical peat-bog contains acid, oxygen-poor waters that greatly inhibit the normal bacterial decay of organic tissue. Pollen grains, highly resistant even in well-aerated environments, are virtually indestructible when pickled in peat. The trees and shrubs surrounding each bog deposit an annual rain of pollen that slowly accumulates in the bog. A vertical core through the bog therefore supplies a record of the changing composition of the vegetation that may well cover thousands of years. The pollen can readily be identified as to species when separated out from other material by powerful reagents such as the caustic hydroxides.[3]

Pollen-analysts normally present their results in the form of spectrum-diagrams enabling one to see at a glance the relative abundance of pine, hazel, oak, spruce, etc. They also construct maps showing the range of significant species at critical dates.

In general, pollen analysis has confirmed the sequence established by Blytt and Sernander. It has, however, greatly refined and enlarged our knowledge of the composition of the forests of the past. Correspondingly, it has sharpened and extended our conception of the sequence of climates.

Within the past two or three years attempts have been made to date peat and other plant remains by means of the new radioactive Carbon-14 technique. Results so far (largely unpublished) seem to confirm estimates of age based on varve analysis fairly closely; more is made of this point below.

(2) APPLICATIONS IN CANADA AND U.S.A.

Most of the above methods have been more recently applied to North America. Because of the vast areas to be covered, however, we are much less sure of the changes that have occurred in post-glacial climates.

Varve analysis has bden applied to North America by E. Antevs, who has introduced considerable refinements of de Geer's original methods. The work has enabled Antevs to trace the retreat of the last glacier from its terminal moraines on Long Island to the vicinity of James Bay. Unfortunately the series is broken near the international boundary, and the two components can only be linked by dubious estimates based on the speed of recession of Niagara Falls. Moreover, only a guess can be made (Antevs suggests 9,000 years) for the time taken from the James Bay stage to the present day. Absolute dating of peat and lake deposits is hence a thing of the future, though Carbon-14 dating is now being attempted, and is discussed below.

Pollen Analysis. The most significant studies bearing on eastern Canada are those of Deevey, who has shown that a close parallel exists between the sequence of climates in New England and those accepted in northwest Europe. Deevey's work depends primarily upon sections from lake-beds in Connecticut and northern Maine.[4] Significant studies have, however, been carried out actually on Canadian soil. In 1930 Vaino Auer investigated peat-bogs in eastern Candda, including the Maritimes[5]; unfortunately his sections seem according to Deevey, to have been incomplete.[6] A little later Bowman investigated a bog on the Matamek River, near Seven Island, Que., with interesting results.[7] Still more recently a Scandinavian pollen-analyst, C.G. Wenner, has published an elaborate investigation into the bogs of Labrador, and has attempted to correlate the climatic sequence he finds with the European time scale.[8] Finally Flint and Deevey have published within the past year (1951) a cross-correlation between Europe and eastern North America in which the time-scale is rendered quantitative by the use of Carbon-14 dating. In the same paper, Carbon-14 dating is also applied to a few significant areas in northern Europe.[9]

If one looks at these results as a whole, one is struck by the remarkable parallelism between European and American climatic changes. The parallel is close enough for one to be able to use the European terminology, as is shown in Table II.

Table II. Sequence of Late-Glacial and Post Glacial Climates in Eastern North America, after Deevey, Wenner, Bowman and others

Divisions		Characteristics
Europe	New England (Deevey)	
Sub-Atlantic	C_3	Cooler, moist. Some retreat of spruce-fir forest in Labrador. Hemlock again significant in New England, with beech and chestnut. Several brief dry phases.
Sub-Boreal	C_2	Warm, drier. Marked cooling at end of period. Oak continues dominant in New England; hemlock declines, hickories spread.

Atlantic	C_1	"Climatic optimum", 4000-1000 B.C.; warm, moist, becoming drier. Oak-hemlock forests in New England. Spruce-fir forest at greatest extent in Labrador; hemlock reaches Seven Islands area.
Boreal	B	Pine forests cover New England, spruce-fir attains Labrador peninsula. Climate warm and apparently fairly dry.
Pre-Boreal	A	Spread northward of birch and alder, then of spruce and fir. Alder reaches Labrador.
Late Glacial	L3 L2 L1	Grass-sedge tundra in New England, with middle period (L2) of birch-woods, presumably corresponding to Alleröd oscillation of Table 1. Proven only in Maine.

The correlations presented in Table II follow the latest views of Flint and Deevey, and differ slightly from Wenner's. A continuous sequence of events can be postulated as follows:-

(1) About 11,000 years ago the retreating Laurentide glacier suddenly re-advanced (the Mankato sub-stage) towards a landscape that was tundra (July mean temperature about $45^{\circ} - 50^{\circ}$) in Maine and spruce-fir forest (probably with July temperature about $50^{\circ} - 55^{\circ}$) in Wisconsin. It overrode and destroyed a forest near Two Creeks, Wis., that has been precisely dated at 11,400 years ago (about 9,450 B.C.). Similar Carbon-14 dating of the Alleröd warm spell in Europe gives an age of about 10,800 years (8850 B.C.). Here, too, there was then an abrupt readvance of the ice and a resumption of tundra vegetation to the south of it. According to Flint and Deevey (op.cit. p. 266) these figures show that de Geer's varve chronology (used in Table I above) is about 2,000 years older than the correct figure at this stage.

(2) The Mankato readvance was short-lived, and glacial retreat was soon resumed and accelerated. Climate apparently warmed up fairly regularly, and the forest zones marched northwards with the amelioration. Birch-alder thickets were in the van, followed by spruce-fir forests akin to the Boreal forest of today; then came pine forests (without any real equivalent today) which in turn were followed by deciduous forests dominated by oak associated with the mesothermal conifer, hemlock. The pine forests spread from West Virginia about 7000 B.C. reaching Connecticut and Minnesota about 6000 B.C. and Maine in 4000 B.C. (Flint and Deevey, op.cit., p. 258); here again Carbon-14 dating has been used.

(3) Between about 4000 and 1000 B.C., the "climatic optimum" was attained. Tundra was banished to northern Ungava, and the spruce-fir forests of Labrador were at their greatest areal extent. Hemlock and maple had reached Seven Islands, and New England was covered by rich deciduous forests dominated by the oak. The present author has estimated that July temperatures in southern Quebec were about 4° F. higher than they are today.

(4) The climatic optimum was at first humid, as the vigour of the hemlock shows. Later, however, as Atlantic passed to sub-Boreal in Europe, a marked drying out seems to have occurred. In New England the hemlock yielded to the hickories. In the St. Lawrence Valley various "xerothermic" species (i.e., those at home in warm, dry conditions) of trees and herbs entered the flora from the southwest.[10]

(5) In most recent times - within the past millenium - the climate seems to have become suddenly much cooler and wetter, as in Europe. Hemlock and even spruce reappeared in New England and the St. Lawrence Valley, though hemlock's northern treeline is now more than 200 miles south of its maximal advance. The period - the sub-Atlantic of European pollen analysts - also saw the spread of beech and chestnut in New England. In Labrador-Ungava there was some retreat of the spruce-fir forest and an expansion of the tundra.

The method of pollen analysis can thus be seen to imply a sequence of post-glacial changes in climate closely akin to those of Europe. The most recent change of climate - the present-day fluctuation - is so recent as to have made little impact on the vegetation's composition. To examine it, one must turn to the remaining methods of study, tree-ring analysis and the statistical methods of climatology.

TREE-RING ANALYSIS

Tree-ring analysis is a well-established botanical technique that has just passed its first half-century of usefulness. It was first developed by A.E. Douglass, for long the leader of the well-known Arizona school of "dendrochronology", as the technique is sometimes grandiloquently called. The most comprehensive study of the practical problems presented by the method is that of Waldo S. Glock[11], and an excellent review of its climatological potentialities has been given by Zeuner.[12]

The ordinary trees of the broadleaved and coniferous forests add a distinct ring of woody tissue to their boles each year. Since the texture of this new wood varies with the season of its formation, one can easily identify the individual annual rings. The width of these rings diminishes with the years as the trees grow older, but the width - i.e., the extent of radial growth - is also much influenced by the weather of the growing season; if the latter is, for example, very cold and dry, the ring is usually very thin, or may be entirely suppressed. A warm, moist year generally produces a wide ring of very coarse cells. A set of cores taken by borer from trees in a vicinity therefore enables one to do two things:-

(a) one can date the rings by counting back from the present day, or from some clearly identifiable episode in the tree's history; and

(b) one can infer something about the year-to-year variations in weather, and also about any secular climatic change that may have affected the area.

In North America, tree-ring analysis has been used more to establish the chronology of the past 1500 years than for climatological purposes. Douglass and his collaborators in Arizona, for example, have used logs employed in Indian hogans and other material (chiefly the yellow pine, Pinus ponderosa) to date former Indian sites in the semi-arid southwest. Much work has also been carried out on the Californian Sequoia gigantea, by means of whose rings an approximate record of summer moisture availability has been carried back 3,000 years. But very little work has been undertaken in the sub-Arctic and in Canada as a whole, for most of our trees have much shorter lives, and offer less remarkable awards.

It is well-known that radial-growth in the coniferous trees of the sub-Arctic is primarily determined by summer temperatures. Thus Hustich,[13] Erlandsson,[14] Giddings[15] and others have shown that species as diverse as Scotch Pine (Pinus silvestris), European spruce (Picea Abies) and White Spruce (Picea glauca) are very largely governed in radial growth by July mean temperature, at least near the Arctic tree line. Precipitation seems to be a negligible factor in these latitudes, as is the temperature earlier and later in the growing season. Accordingly the growth rings of such trees are useful indicators of mid-summer temperatures. As one passes southwards through the forest, no doubt the thermally effective season lengthens to include other months.

This principle has been used in eastern Canada by an American ecologist, J.W. Marr, who worked near the coastal and Arctic treelines of northern Quebec in 1939. The results remained unpublished until 1948, but are now well substantiated. Marr found enough mature trees near Great Whale River, Que., and Richmond Gulf, Que., to take his chronology back over 200 years.[16] He concludes that summer temperatures have varied very little during that period:

> Annual radial growth has been so uniform at Gulf Hazard during the past 230 years that only 41 growth rings are sufficiently below average width to permit visual detection of the deviation ....At Great Whale River only 27 detectably narrow and only 11 conspicuously narrow layers have been formed in 160 years---- The fact that every tree studied had formed a complete layer each year of its life proves that conditions have remained consistently well above the absolute minimum for trees.[17]

Still more recently, Hustich himself has worked on the growth rings in the same area, though his results are less easy to interpret in climatological terms. In substance, the tree-ring record seems to show that the deterioration of summer climate already established for the sub-Atlantic phase by pollen analysis had been arrested in Labrador-Ungava by the eighteenth century.

ANALYSIS OF CLIMATOLOGICAL DATA FROM PAST CENTURY

The third and final method with which this paper deals can be dismissed fairly briefly on several counts. Since climatological records are numerous only from the past century, statistical analysis of such data can be made to apply only to the latest phase of the present climatic fluctuation. This applies with special force to Canada, from which detailed climatic records of any length are very sparse. Moreover the statistical method is the one most familiar to readers of this particular series, since the usual vehicle for publication of such results is one or other of the meteorological journals.

The analysis of station records has one striking advantage over the biological methods so far described. The latter bear primarily on the climate of the growing season; their bearing on winter conditions is obscure, and probably negligible. The analysis of climatological data has shown that winter has been much more strongly affected than has summer by the present fluctuations, and the biological methods can give only a limited impression of the changes involved.

The most significant work of this type on the climates of eastern Canada is that of H.C. Willett.[18] He analysed the temperature records published in successive volumes of World Weather Records, and drew world maps of the changes at 20-year intervals. In eastern Canada he depended on Moose Factory-Moosonee and St. John's, Nfld., a choice that strikes the present author as unfortunate, for neither is ideal as a climatological station. Willett's results confirm and render quantitative what is generally assumed about the present fluctuation of temperature:

(i) The present fluctuation dates from about 1885. No significant trend is detectable before that date.

(ii) The rise in general world temperature since 1885 has amounted to 1.0° F. for the year as a whole, and to 2.2° F. for the winter alone.

(iii) The rise of temperature has been most striking in the northernmost Atlantic districts, especially round Greenland and Spitzbergen.

At this point, however, Willett departs from proven fact and embarks upon speculation, though it is speculation of an eminently reasonable and penetrating kind. His suggestions are so significant that they will be quoted verbatim:

> The indications are that this rise of temperature in the Arctic is almost circumpolar in extent, but the data, particularly over northeastern North America, are not sufficient to prove this as a fact. In the absence of data in this region, it was decided to represent in the analysis a break in the circumpolar temperature rise in the Hudson Bay area. The analysis was made in this manner because in other respects this temperature change pattern resembles very closely the temperature anomaly pattern which characterised the past winter,

> and which is highly typical of a stronger than normal polar anticyclone in western Canada, and a strong development of the sub-tropical high in the western Atlantic....Under these conditions cold outbreaks occur from north central Canada into the western United States, and southeastward from Hudson Bay to Labrador, while the eastern United States remains abnormally warm under the influence of the Bermuda high.[19]

In other words, Willett attempts to reconstruct the probable history of recent years over eastern Canada by deduction from observed circulation patterns. He concludes that these districts have not shared in the recent upsurge of winter temperatures, an opinion which will raise many Canadian eyebrows. His Figure 5 shows a decrease of 1° F. for the 20-year winter temperature change centred on 1930 over a broad trough from Southampton Island across Labrador-Ungava to Newfoundland. The available data from Moose Factory and St. John's, Nfld., appear to support this interpretation.

The present writer recently attempted to lessen the size of the observational gap to which Dr. Willett refers by analysing the records of two old established climatological stations directly in the line of Willett's belt of no amelioration. These are Southwest Point, Anticosti Island, Que., an exposed coastal station in the Gulf of St. Lawrence, and Belle Isle, the rocky, bleak island that stands at the Atlantic mouth of the Strait of Belle Isle. He used the method of 10 year sliding means spaced at pentade intervals. Both July and January records were examined. Results can be summarised as follows:-

(a) At both stations mean July and mean January temperatures have increased over the period 1885-1945;

(b) Both stations, and also Moose Factory - Moosonee and St. John's, display a rise to a maximum between 1895 and 1905 (January) and 1900 and 1910 (July), a sharp decrease to a minimum about 1920, and a subsequent general rise to the end of the period. At Moose Factory - Moosonee, however, neither season had recovered to its 1900 - 1905 level.

(c) The curves are remarkably parallel to those for the same months from most north European and Icelandic stations. The cold period ending about 1920 appears to have been experienced very widely round the Atlantic basin. Moreover the other changes appear to have been nearly, though not entirely, in phase around that basin.

(d) Since 1920, the rise of winter temperature at both Belle Isle and Southwest Point has been remarable, amounting to almost 4° F. in both cases.

The author feels that these results cast real doubt on the validity of Willett's inferences. They also illustrate the dangers of accepting the result of statistical analysis of too thing a network of climatological stations.

CONCLUSIONS

Two conlusions stand out in the author's mind as he writes these last words. The first is the lamentable backwardness of our own country in this class of work. If we set our own results alongside those of the Scandinavians, who live in a region strikingly similar to ours in recent history, our cheeks must burn and our curiosity strengthen. Is it possible that our own peat-bogs, lake-floors and forests can yield a similar record, properly examined? It seems very likely, and it is to be hoped that an increasing volume of research will be undertaken in these fields. The second conclusion is that meteorologists are strikingly ineffective in this fascinating field. Only one meteorological climatologist has been mentioned by name above. This is all the more significant when one realises that the ultimate explanation of these changes is dynamical: it has to do with the mechanics of the general circulation of the atmosphere. Yet among modern meteorologists only a handful-men like Brooks, Willett and Lysgaard - have anything effective to say about climatic change. The donkey-work has been done by botanists and glacial geologists. It will perhaps sum up the writer's disquiet if he quotes from Faegri:

> Absolute values have long been considered the final object of palaeoclimatology. I think we should today try to look further afield: what we need is not a series of individual figures of local significance, but the circulation patterns of former periods. To establish them is the primary object of palaeoclimatological research.[20]

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