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SOME PROBLEMS OF THE QUATERNARY PALYNOLOGY IN THE WESTERN MAINLAND REGION OF THE CANADIAN ARCTIC

(Report and 3 figures)

J. Terasmae

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J. Terasmae

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

The problems concerning palynological studies of Quaternary deposits in the western Canadian Arctic are summarized and evaluated, and the relatively greater importance of certain aspects of pollen production, dispersal and deposition in the Arctic than in the more southern latitudes is pointed out. In the interpretation of the fossil pollen record the discussion emphasizes the need for awareness of limiting factors evident in palynological techniques. It is important to integrate palynological interpretations with evidence obtainable from other sources, such as glaciology, Quaternary geology, climatology, dendrochronology, geobotany and ecology, in order to suggest meaningful paleoecological and paleoclimatological reconstructions. The results indicate a causal relationship between Arctic vegetation and climate and hence, confirm the validity and usefulness of palynological studies in the investigation of postglacial and Quaternary environmental changes in the Arctic region.

SOME PROBLEMS OF QUATERNARY PALYNOLOGY IN THE WESTERN MAINLAND REGION OF THE CANADIAN ARCTIC

INTRODUCTION

In 1956 the writer reported on palynological studies of Quaternary beds, made on samples collected from sea cliffs by T.H. Manning during his exploration of Banks Island (Manning, 1956; Terasmae, 1956). Two of the important limitations facing initial palynological studies in a new region are the lack of palynological reference data and, inadequate knowledge of Quaternary geology of the region; these made the interpretation of the fossil pollen assemblages rather difficult. Palynological studies made earlier by J. Iversen in the Mackenzie Delta area (in Porsild, 1938), by Campbell (1952) in Yukon, and by A.Courtemanche on Bathurst Island (McLaren, 1963) had been hampered by similar difficulties.

In retrospect it is interesting to note that one of the conclusions reached by the writer on the basis of his studies made ten years ago (Terasmae, 1956) suggested that, "the long, warm interglacial periods such as Sangamon, Yarmouth, and Aftonian are probably represented by accumulation of organic deposits in the Far North and that further studies may disclose a much fuller sequence of Pleistocene deposits in the northern regions ... than has been expected so far." Subsequent investigations have fully confirmed the validity of this prediction. However more recent studies scattered throughout the Arctic have also focused attention on numerous new problems particular to the region. The purpose of this report is to summarize the experience gained from palynological studies of Quaternary deposits in the Canadian Arctic using selected examples from the western mainland region, and to discuss problems encountered during the investigations. It has become evident that the Canadian Arctic differs in several important aspects from the Arctic regions of U.S.S.R., Scandinavia and Alaska. Some of these features include the great latitudinal extent, about 2,000 miles, the cold Labrador Current flowing south along its eastern limit, the north-trending Cordillera in the west, and the cold Hudson Bay in the interior of the continent, at the southern limit of the Arctic region. The region is adjacent to the frozen (ice-covered) Arctic Ocean all along its northern limit. A large part of the Canadian Arctic is made up of islands. Owing to the climatic conditions, which are closely related and dependent on the above mentioned factors, the vegetation zones trend southeast across northern Canada. For example, the northern limit of forest zone (the forest tundra) extends from the Mackenzie Delta area in the northwest to south of Hudson Bay, and thence curves north in northern Quebec and south again along the Labrador coast (Fig. 1). Recent studies

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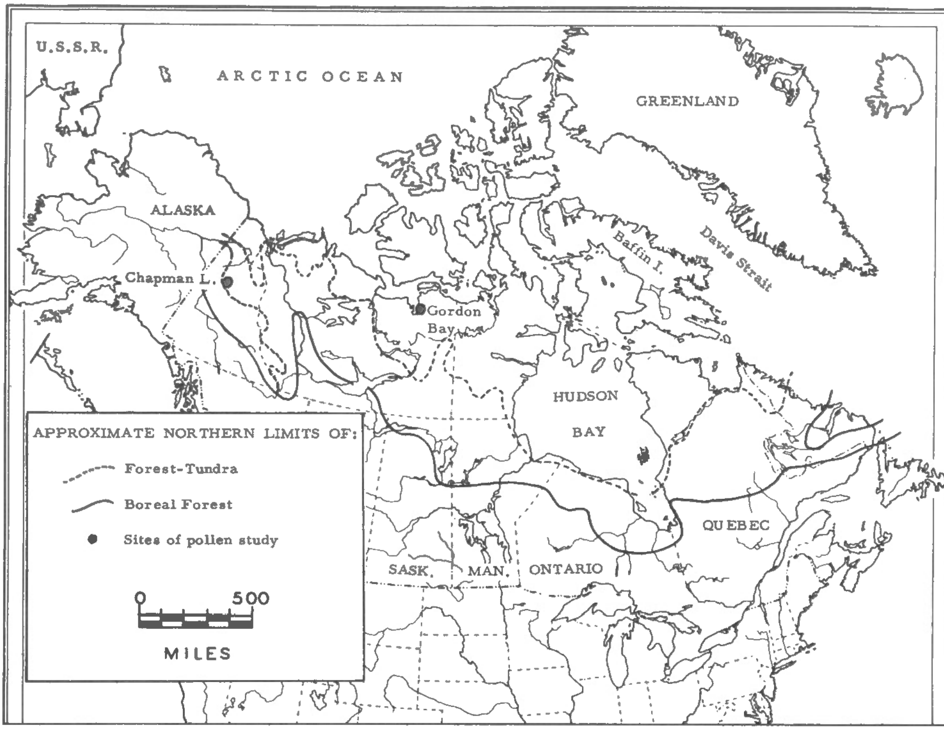

Figure 1. Index map, showing location of study sites and the northern limits of the boreal forest and forest-tundra regions. (GSC 200194-A)

by Bryson (Bryson and Wendland, 1967) and his colleagues (University of Wisconsin) have convincingly demonstrated that the northern limit of the forest tundra (Fig. 1) is controlled by the interaction of four predominant air masses - the cold Polar air from the north, the Pacific air from the west, the warm-moist air from the south, and the cool-moist Atlantic air.

Physiographic features of the Canadian Arctic have been recently described by Bird (1967). The popular term Barrens has been used frequently for the extensive, treeless region of northern mainland Canada, an area characterized by an abundance of bedrock outcrop in the Precambrian Shield areas, and commonly thin soil cover, lakes, bogs and fens. However, the first impression of a monotonous landscape commonly conceived while flying across some parts of the Arctic is deceiving. Both geologically and biologically the Arctic is as complex as other regions to the south. A closer examination will also reveal that its topography contains all the elements present in the rest of Canada. In fact, physiographic features such as, for example, moraines, eskers, bedrock structure, valley systems, ancient shorelines and glacial ice flow patterns are more evident because of the lack of a dense and high plant cover. For more detailed information the reader is referred to the following selected reports: Beschel, 1963; Bird, 1960; Blake 1963, 1966; Craig, 1960, 1961, 1964; Craig and Fyles, 1960, 1965; Dunbar and Greenaway, 1956; Fyles, 1963; Ives and Andrews, 1963; Lee, 1959; Polunin, 1948; Porsild, 1955, 1958; Savile, 1961, 1964; Terasmae et al., 1966. A further useful and interesting source of background information is contained in Smith (1964) a summary on the Canadian Arctic, written by twenty-nine specialists, experts in their respective fields.

In contrast to Canada, the main Arctic region of northern Europe and Asia extends as a rather narrow zone along the northern mainland coast adjacent to the Arctic Ocean (Kryuchkov, 1964). The Arctic islands are less numerous and smaller in areal extent. The warm Gulf Stream exerts a strong influence on the European Arctic region, and the Arctic Ocean off the Eurasian mainland remains ice-free longer during the year than along the Canadian Arctic Coast. The vegetation zones across the Eurasian Arctic have a generally east-west trend, except where broken by mountain ranges. The climatic regime, too, differs in the trends of gradients which have a more strictly northerly direction.

The Alaskan Arctic region is to a large extent dominated by the Pacific climatic regime and hence differs considerably from most of the Canadian Arctic. Physiographically the Alaskan Arctic also differs from that of Canada (Péwé, 1965). Mountain glaciation was the dominant feature in Alaska during the Quaternary whereas the Canadian Arctic mainland was covered by the continental ice sheet. Large areas in Alaska were not glaciated and served as refugia for plants and animals during the Ice Age. Such refugia existed in Canada only in Yukon and possibly in the Arctic Islands and small peripheral coastal areas not covered by the continental ice sheet.

The differences between Canadian and other Arctic regions, as outlined above, are also reflected in the palynological problems encountered. One of these problems is directly related to the size of the region and difficulties of access. In addition to the studies made by the writer, only three other palynologists (Courtemanche, Hegg, and Iversen) have made limited investigations of Quaternary deposits (excluding studies of modern pollen deposition and atmospheric pollen) in the Canadian Arctic during the last 30 years (Terasmae, 1967a). Studies made in the forest-tundra boundary zone are not considered in this context. The lack of palynologists working in the Canadian Arctic region, despite the greatly improved accessibility due to expanded aircraft facilities, remains a most serious problem.

Acknowledgments

Palynological samples collected by O.L. Hughes and W. Blake, Jr., in the Chapman Lake and Gordon Bay areas and their notes on the surficial geology of these areas have been invaluable for the writing of this paper. W. Blake, Jr., B.G. Craig and J.G. Fyles, Geological Survey of Canada, critically read the manuscript and offered many helpful suggestions. I also wish to gratefully acknowledge the help and interest of many other colleagues who have generously contributed from their specialized fields of knowledge on the Arctic region through numerous discussions related to the subject of Arctic palynology.

PROBLEMS OF POLLEN PRODUCTION AND DISPERSAL

In all Arctic regions the pollen production of local plants is commonly much lower and more erratic than in temperate latitudes. There are two primary reasons for this: 1) the lack of wind-pollinated tree species such as pine (Pinus) and oak (Quercus), which produce pollen in large quantities and grow in dense populations in the south, and 2) the severe climate which restricts the time available for effective pollen production, and the development of a dense plant cover in a regional sense. Wind-pollinated species are not absent, however, in Arctic vegetation; the dwarf birch (Betula), willow (Salix) and alder (Alnus) together with grasses (Gramineae) and sedges (Cyperaceae) are examples of wind-pollinated species but the total numbers of pollen produced by them are substantially lower than in the grasslands and forests of the south. Other Arctic species make a small contribution to the airborne pollen and are of importance only in the local sense. Pollen production by the Arctic vegetation has been studied in some detail in northern Scandinavia and the results obtained there can probably be adopted for the Canadian Arctic, where studies of airborne pollen and surface samples have been initiated recently by J.C. Ritchie, Bartley (1967) and the writer, to obtain reference data for interpretation of fossil assemblages.

It is important to remember that effective pollen production and dispersal, is essential for the reproduction of most boreal and temperate species whereas most Arctic plants are perennial, can reproduce vegetatively, and can survive several years without effective pollination.

The principal controlling factors and means for pollen dispersal in the Arctic are the same as farther south. However, there are also some important differences of degree. Climate as a controlling factor is much more important in the Arctic than in the temperate latitudes. It is true that poor weather conditions (clouds, rain, low temperature) impede pollen dispersal in all regions, but in the Arctic the time available for pollen release and dispersal is shorter and the effect of unfavourable weather correspondingly more serious. Dispersal of pollen by insects is apparently less effective in the Arctic because smaller numbers of insects are involved in pollen dispersal per areal unit. Dispersal by water, however, is probably more important because at the time of break-up and melting snow, surface run-off partly coincides with the flowering of many species and effectively aids the dispersal of pollen by flowing water. Surface winds provide another effective means of dispersal because there is practically no obstruction by high vegetation in the form of tree cover. For reference on the mechanics of pollen dispersal the reader is referred to the excellent discussion by Tauber (1965). Although the incidence of winds is not necessarily greater in the Arctic than elsewhere in Canada, the relatively unobstructed flow of air, nevertheless, is more important in the Arctic environment for providing an efficient lift-off for any pollen released under favourable temperature, humidity, and cloud conditions.

PROBLEMS OF POLLEN DEPOSITION AND PRESERVATION

One of the important differences relating to deposition of pollen in the Arctic and in more southerly latitudes lies in the fact that in the temperate region, for example, plant flower and pollen deposition occurs chiefly after the end of winter season. The snow and ice have melted from the ground and lakes, the spring flood season has commonly passed and the freezing soil temperatures have disappeared. Under such conditions pollen falling on mineral soil surfaces is subjected to both chemical and bacterial attack, and in general is destroyed in a short time (Sangster and Dale, 1961, 1964). Acid soils with low pH values might present the only significant exception, and pollen is preserved favourably only in environments such as bogs and lakes.

In the Arctic, however, pollen production and deposition commonly coincides with or overlaps a late phase of the winter season. Although considerable melting of snow has occurred and some rivers and lakes may be partly or completely free of ice, some of the ground and water surface is still covered by snow and ice and the soil temperatures are frequently near or below freezing. Surface water and run-off is abundant and the flood season may be at its height. A relatively large proportion of pollen produced and dispersed during the Arctic spring and even later in the summer, falls on water-saturated ground, snow, ice, or lakes and rivers. Because of existing low temperatures, the bacterial and chemical break-down of pollen is slow, or occurs only after warming during the following summer season. The abundance of surface water run-off provides an effective means for transport of pollen and its deposition in lacustrine and alluvial sediments.

Conditions for pollen preservation in lacustrine, alluvial and boggy environments, which do not dry up annually, appear to be favourable. However, the low pollen production of Arctic vegetation and the predominantly inorganic nature of sediments combine to yield absolute pollen frequencies, i.e. the total number of pollen in a given volume of sediment, which is very much lower than those from the more southerly regions.

The repeated freezing and thawing within the active layer of certain Arctic pollen-bearing deposits does not in itself appear to have any detrimental effects on pollen preservation. However, if coupled with drying out, soil creep, and oxidation, the pollen is subject to destruction. In view of the above statements it may seem paradoxical that many Arctic plant detrital deposits, commonly classified as peat, contain no pollen or only a few poorly preserved pollen grains. In some cases the moss-remains in such deposits are well-preserved, whereas more commonly the plant detrital portion of the deposit is composed of fragments of lignified woody tissue, leaf cuticle, and bark. Some fern spores and fungal remains may be present, too. These deposits commonly contain much inorganic matter of silt and fine sand size, and depending on the relative amount of this matter they may be classified as 'organic silts'. The conclusions reached on the basis of studies made postulate a plausible explanation for the absence of pollen in many Arctic 'peats' by pointing to the mode of their deposition. The inclusion of silt and sand in Arctic peats indicates that such inorganic matter has been incorporated either by seasonal flooding or by wind action and possibly surface seepage water. In all these cases the surface layer of the deposit has been well aerated and the pH values raised resulting in oxidizing conditions, particularly during drying of the surface. The pollen present would have been subject to both chemical and biological attack and would have been destroyed in the process which, however, did not necessarily destroy many other kinds of plant detritus less affected by oxidation.

Further useful references to preservation of pollen in soil and other surface samples can be found in reports by Erdtman (1943), Dimbleby (1961), Havinga (1963), and Vasari (1965).

PROBLEMS OF REDEPOSITION

In palynological studies the redeposition of pollen is defined as contamination of a stratigraphic unit by pollen from older, or younger, units resulting in a mixed assemblage composed of pollen of different ages. In the boreal and temperate regions redeposition of pollen is generally an insignificant factor in studies of bog and lake deposits. Only the sediments, and sometimes alluvial deposits, of late-glacial age when environmental conditions were similar to those now obtaining in the Arctic, are subject to serious contamination by redeposition. However, there are exceptions to the general rule and hence, the sedimentological environments and processes deserve careful consideration in each case. For example, recycling of sediment can occur in some lakes owing to eroding currents and fluctuation of water levels. Lakes with significant inflow may receive older pollen derived by erosion from the watershed of the entering stream.

Atmospheric transport of pollen by moving air masses can introduce another source of contamination. The significance of long-distance, wind-transported pollen will be discussed in the next section of this report.

Redeposition of pollen in palynological studies of Arctic sediments is a particularly important factor. Surficial deposits, and frequently the soft bedrock strata, are susceptible to erosion by surface run-off and wind because of inadequate vegetation cover, an action similar to erosional processes in the semiarid southwestern United States. These processes are further aggravated by the presence of permafrost which effectively prevents the downward movement of surface water and hence, the unconsolidated deposits become saturated and are easily eroded. On sloping surfaces, mixing and overturning of soil strata can also occur by mass movement through solifluction. In such cases younger layers can be overturned and buried beneath older ones by downslope advance of solifluction lobes resulting in a disturbed and illegible palynological record provided that pollen is preserved during the process.

Redeposition of pollen in the Arctic environment is, furthermore, affected indirectly by climatic changes. An improvement of climate can result in a more complete vegetation cover and a corresponding reduction of erosion, but increased precipitation may increase the rate of erosion. The melting of ice caps and snow fields during a warming trend again exposes older pollen-bearing deposits for erosion and redeposition.

It is apparent that redeposition can be both a complicating factor, and sometimes a useful indicator of environmental conditions in palynological studies of Arctic sediments. The usefulness of redeposition in palynological investigations depends on the extent to which it can be recognized and separated from the primary pollen and spore assemblages.

The presence of Mesozoic spores and pollen in Quaternary assemblages can be readily recognized, and may indicate the occurrence of, for example, Cretaceous rocks in the region. In certain glacial lake deposits, the renewed activity of glaciers may be indicated by a sudden increase in the numbers of redeposited pollen and spores due to erosion of bedrock by glacier ice.

Serious problems arise when the redeposited pollen is morphologically similar to modern pollen types, but is of Tertiary or Quaternary age. Tertiary assemblages, however, commonly contain pollen of exotic genera of plants (for example, temperate hardwoods and southern conifers) in some abundance, and can be recognized as redeposition. It is especially difficult to distinguish redeposited Quaternary pollen in late-glacial and postglacial assemblages. Differential preservation can yield helpful clues – the older pollen may be less well preserved, and sometimes it has a different colour tone than the pollen of the primary assemblage. Certain staining techniques and fluorescence microscopy can provide a useful method for recognizing redeposited pollen. In spite of this the presence of redeposited pollen in Arctic sediments remains a serious possibility of error, and deserves careful consideration whenever such error can be assumed to be present.

LONG-DISTANCE TRANSPORT OF POLLEN

Atmospheric pollen was collected on shipboard by Erdtman (1937) during his Atlantic crossing. The results of his study showed that pollen from European and American sources was present all the way across the northern Atlantic, although the absolute number of pollen dropped off rapidly away from the shore.

Polunin (1951) trapped atmospheric pollen and spores over the Canadian Arctic from an aircraft, and in his report summarized results of earlier studies. Several studies have shown that often pollen is carried by air many hundreds, and in certain cases more than 3,000 miles from a source, notably in cases where airborne pollen is found on offshore islands far removed from the continental source areas such as, for example, the recovery of Nothofagus pollen on Tristan du Cunha which had originated in southern South America (Hafsten, 1960; p. 37). More recently studies by Maher (1964) have indicated that pollen of several species, for example Ephedra, can be transported from the southwestern United States to the Great Lakes region, a distance of over 1,000 miles. Certain physical aspects of pollen dispersal have been discussed in detail by Tauber (1965). The writer has commonly found evidence of long-distance transported pollen in his study of surface samples from different regions in Canada (Terasmae et al., 1966; Terasmae, 1967a, 1967b). This evidence is much more obvious in Arctic samples, because of the low local pollen production. The pine (Pinus) and spruce (Picea) pollen from distant sources stands out clearly among the local predominantly non-arboreal pollen. In the temperate and boreal zones the pollen component of long-distance transport in an assemblage is commonly small compared with that of the locally derived pollen and hence, its influence on the interpretation of that assemblage is relatively insignificant. However, north of the boreal forest the importance of the long-distance transport of pollen in the total assemblage increases, and unless recognized as such may cause erroneous interpretation of the pollen record. Careful studies of the airborne pollen, and of assemblages obtained from surface samples, in relation to the modern vegetation help to provide the necessary reference data for a satisfactory interpretation of the postglacial palynological record (Terasmae and Mott, 1964, 1965; Ritchie and Lichti-Federovich, 1963).

INTERPRETATION OF THE PALYNOLOGICAL RECORD

The following discussion of palynological problems will be limited to post-Wisconsin time because of a more complete available record. It is necessary to review the palynological problems in the light of glacial history and the following deglaciation, because many of these problems are directly or indirectly related.

At the maximum of the last glaciation (Wisconsin) the continental ice sheets (the Cordilleran and the Laurentide) covered nearly all of Canada. Available evidence indicates that refugia for plants and animals, however, did exist in Yukon, Alaska, and northern Greenland (Peary Land). The existence of additional refugia, inferred mostly from botanical evidence, in the Arctic Islands, for example Banks Island and the northeastern coast of Baffin Island (Løken, 1966), and along the Atlantic and Pacific coasts, is still under debate.

South of the area covered by the Laurentide ice sheet, in the northern United States, evidence of boreal and tundra species has been firmly established by recent investigations of deposits of Wisconsin and late-Wisconsin age.

During the late-Wisconsin the Laurentide ice sheet gradually receded from its maximum limits with some halts and readvances. The retreat from the southern limit was approximately contemporaneous with that from the northern limit of glaciation. It was, furthermore, characterized by a complex sequence of numerous ice-dammed lakes along the ice sheet margin, and in coastal areas by marine transgression.

One of the important palynological problems is directly concerned with the late-glacial episode. The geochronological portion of the problem is related to the age of the late-glacial episode. In the peripheral areas of the glaciated region this episode has been dated at 10,000 to 12,000 years ago, and it becomes younger gradually as one follows deglaciation towards the centres of latest ice dispersal, resulting in a sliding time scale. However, as the continental ice sheet had disappeared from most areas by 7,000 or 8,000 years ago, the late-glacial episode came to an end in northern Canada at that time.

The botanical portion of the problem is concerned with the migration of plants into the newly deglaciated regions, and involves the investigation of probable source areas for such plant dispersal. Furthermore, it is concerned with the ability of species to invade these regions (their ecological tolerances and requirements) and the probable speed of migration. There is evidence that Arctic plants were growing south of the continental ice sheet margin in late-glacial time, about 12,000 years ago, and a migration from these source areas to reach the approximate present southern limit of the Arctic region by some 7,000 years ago would have required a rate of movement by the arctic species of about 1,000 miles in 5,000 years, or one mile in five years.

It is suggested that the northern mainland Arctic and the Arctic Islands were colonized by Arctic plants from the northern refugia in the Yukon, the Arctic Archipelago (for example, Banks Island), Baffin Island and probably coastal Labrador. The presence of late-glacial arctic vegetation in the Yukon has been confirmed by palynological studies (Fig. 2).

A conclusion reached from this reasoning would require a mixing of the present Arctic flora by plant populations from a number of different source areas. For testing this hypothesis palynological and paleobotanical studies can provide only partial answers. It is unknown at present to what extent the existing Arctic flora is made up of elements from the different late-glacial refugia. There is little hope that palynological studies can contribute significantly to the solution of this problem. However, it seems probable that taxonomical and genetic investigations of modern species will prove much more useful in combination with paleobotanical studies (see Löve, 1962, and references quoted in that report).

Once the Arctic vegetation became established within its regional limits following deglaciation, further changes in relative species dominance and distribution ranges were caused by factors other than the normal successional development and migration. Climatic factors have apparently been especially important in controlling the long-term trends in the dynamics of the vegetative cover in the Arctic. It is these trends which can be investigated by palynological and paleobotanical methods. Such studies are concerned with problems of interpretation of the fossil plant record in terms of paleoecological and paleoclimatological conditions.

In addition to problems discussed earlier in this report, however, the intricate plant-soil relationships further complicate the interpretation. For example, one such important relationship concerning the influence of vegetation on permafrost, was summarized recently by Brown (1966). This summary clearly indicates that vegetation is one of the main factors affecting the dynamics of a permafrost regime through modifying and changing the air-soil heat exchange. Add to this the factors of net radiation, snow cover,

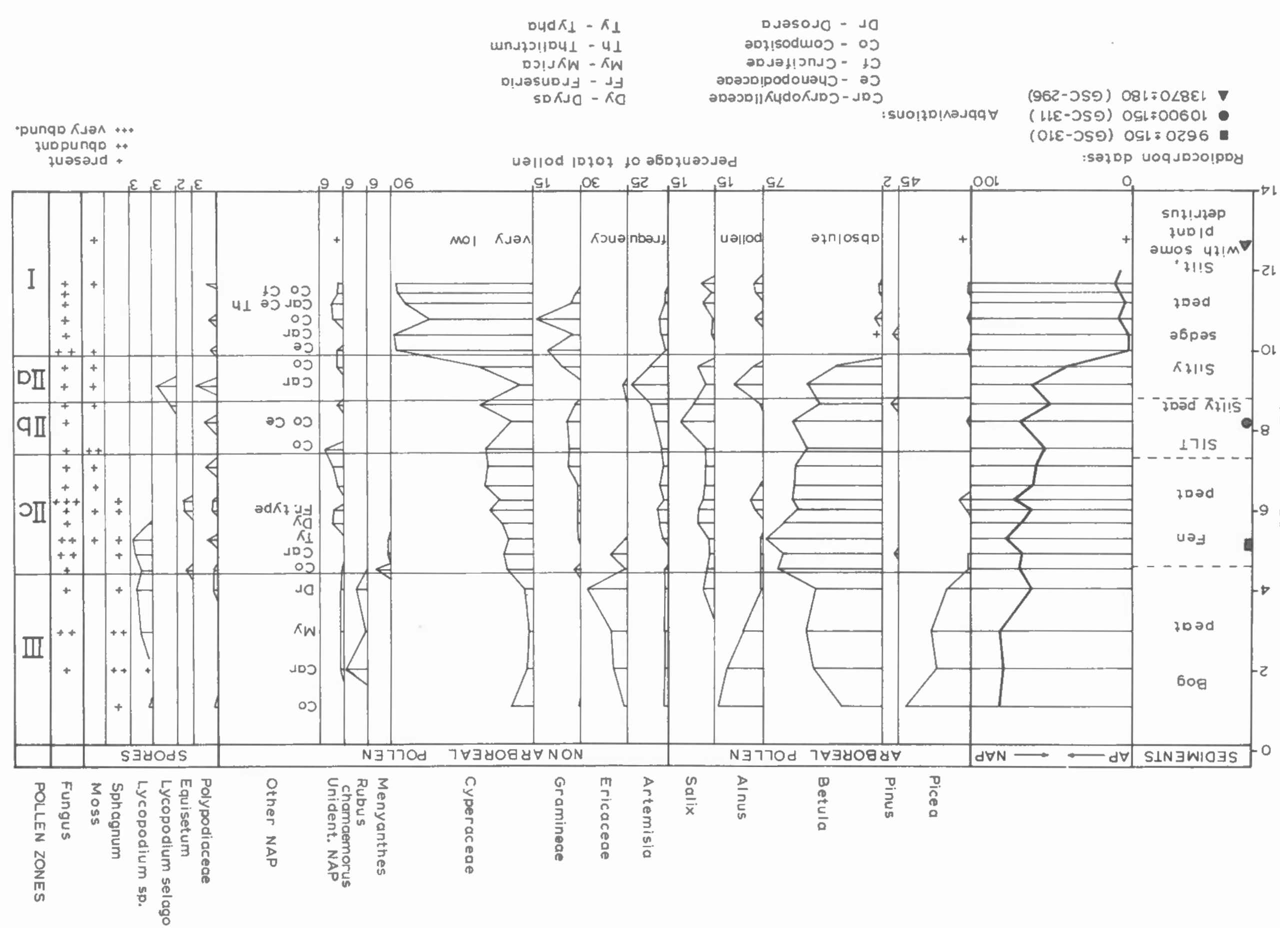

Figure 2. Pollen diagram of postglacial and late-Wisconsin deposits at Chapman Lake, Yukon. (GSC 200194-E)

ground thermal and geological properties, surface relief and slope orientation, and surface and subsurface drainage and one has a complex and dynamic system which hardly ever reaches an equilibrium. It is difficult to ignore, however, the overruling importance of climatic factors in this system when a change in one or several of the climatological parameters can easily set the system into motion. Evidence on hand indicates that changes in climate are reflected by changes in the vegetation. However, such changes are difficult to study on a short-term basis. The evidence for the long-term trends of change, nevertheless, has been obtained by paleobotanical and palynological investigations.

The issues raised above can be best clarified and illustrated by a few selected examples of palynological studies made.

A pollen diagram (Fig. 2) from the Chapman Lake area in Yukon (Fig. 1) covers a time episode extending back to approximately 14,000 years B.P. This site is in the Blackstone River valley northeast of Dawson, or northern flank of the southern Ogilvie Ranges (the geological setting has been described by Vernon and Hughes, 1966). In this diagram, the interval from about 14,000 years B.P. to a little more than 11,000 years B.P., as indicated by the supporting radiocarbon dates, is characterized by high relative percentages of Cyperaceae (sedges, cottongrass, etc.) and Gramineae (grass) pollen, and low percentages of willow, alder, and birch. Spruce pollen occurs sporadically in the basal sediments of this core. It is inferred from these assemblages that the regional vegetation was dominated by a sedge (Carex) and cottongrass (Eriophorum) tussock tundra, similar to modern vegetation in, for example, central Seward Peninsula, Alaska (Colinvaux, 1964a), and in eastern Chukchi Peninsula (Derviz-Sokolova, 1965). Pollen assemblages similar to those of the basal Chapman Lake core were found in surface samples from Point Barrow area, Alaska, by Livingstone (1955). It is interesting to note that a pollen diagram compiled by Livingstone (1955) from sediments cored in Chandler Lake, on the northern slope of the Brooks Range, Alaska, bears strong resemblance to the Chapman Lake diagram and hence it is suggested that the trends of pollen graphs in this diagram reflect regional events, rather than merely local succession of vegetation. Further support for this reasoning can be found in palynological studies made by Colinvaux (1964a) in Alaska and by Mackay and Terasmae (1963) in the Mackenzie Delta area. It is concluded that the basal part of the Chapman Lake diagram (zone I in Livingstone's (1955) pollen sequence) represents high arctic tundra vegetation. As summarized by Livingstone (1955) for Point Barrow, the probable climate for zone I was characterized by low precipitation (about 10 cm annual mean), cool summers (July mean temperature about 4°C) and by cold winters (January mean temperature about -27°C). The mountain glaciers in the Chapman Lake area were probably receding during pollen zone I.

As indicated by the pollen zone I/II boundary a significant change in the climatological regime occurred about 11,000 to 12,000 years ago. An increase in temperature is inferred from the rather sudden rise in the birch pollen graph. It is assumed that this temperature rise was sufficient to allow migration of birch into the Chapman Lake area during subzone IIa. This subzone is further characterized by maxima of alder and Artemisia (wormwood and sage) pollen, and a decrease in grass and Cyperaceae pollen. Colinvaux (1964a) interpreted Artemisia maxima as possibly indicating loess deposition or frost heaving, and he associated early alder maxima with either increased precipitation or poor drainage. The writer suggests that the slight increase in temperature was accompanied by a corresponding slight increase in precipitation. Such conditions would have been conducive to invasion of birch, increased frost heaving, and more available surface moisture. Furthermore, these conditions would have resulted in a readvance of mountain glaciers (the last glaciation; as described by Vernon and Hughes, 1966, in the Chapman Lake area). The climate in general remained considerably colder than the present during subzone IIa.

A slight re-expansion of the grass and Cyperaceae tussock tundra with some willows occurred during the following subzone, IIb, as inferred from the pollen sequence, and indicates a return of drier climate. Both alder and Artemisia were less abundant, or disappeared locally, whereas birch retained its dominance because temperature remained higher than during zone I. The mountain glaciers again probably receded during this episode, some 11,000 to 10,000 years ago. The silt layer in the Chapman Lake core may be related to this episode of drier climate and possible loess deposition in the Blackstone River valley.

Subzone IIc remained cooler than the present but a definite warming trend during the later part of this subzone is indicated by the birch dominance. Subzone IIc was relatively warmer than IIa, however, with a slightly increasing moisture regime, as indicated by beginning of muskeg development probably some 10,000 years B.P. in the core stratigraphy. The grass and Cyperaceae tussock tundra was replaced and invaded by muskeg in which birch, alder and willows were abundant. The appearance of Sphagnum (peatmoss) and Lycopodium (club-moss) spores and pollen of Ericaceae (the heath family) and Menyanthes (buckbean) support this interpretation. The temperature in subzone IIc was probably too warm for a build-up of mountain glaciers.

Another significant change in the climatological regime occurred at the zone II/III boundary. Although the muskeg build-up continued there was a definite increase in temperature which probably slowed the rate of peat accumulation owing to dry episodes during the summer season. This temperature increase is indicated by the invasion of spruce and alder together during the early part of zone III. As stated by Péwé (1958) the warming of climate in mid-postglacial time caused some thawing of permafrost in Alaska, and a similar trend in Yukon would have provided better drained sites for spruce and suitable stream bank habitats for alder through intensified erosion by rivers. An age of about 6,000 years was established for the zone II/III boundary by Livingstone (1957) in the northern Brooks Range. Birch remained abundant in zone III but the relative importance of it and the willows decreased owing to the expansion of spruce and alder in the Chapman Lake area. The Chapman Lake diagram is incomplete at the top and a time episode of perhaps as long as 2,000 years is not represented, as indicated by a comparison with other pollen diagrams from east of the Yukon Territory. The writer is aware of the probable weakness involved in the attempted correlation between the pollen record from Yukon and that from the Bathurst Inlet area. The two areas are different in physiography, climatology and botany. In addition, much of Yukon lies in the boreal forest and forest tundra regions, whereas the Bathurst Inlet area is part of the true Arctic. However, the attempted correlation is somewhat strengthened by supporting evidence supplied by pollen diagrams from the Mackenzie delta area (Mackay and Terasmae, 1963), and from the northern slope of the Brooks Range (Livingstone, 1955). Further confirmation for this suggested correlation must be obtained through additional studies of pollen bearing deposits in the intervening areas.

The Gordon Bay pollen diagram (Figs. 1 and 3) from the Bathurst Inlet area, Northwest Territories, is estimated on basis of available radiocarbon dates to cover a time span from the present to about 2,500 years B.P., assuming a more or less uniform sedimentation rate for the deposits. In the middle part of this diagram the alder maximum is a prominent feature. Similar alder maxima have been found in other diagrams, for example, in the Mackenzie Delta area, and support the suggestion that this alder maximum is a regionally significant feature. This maximum falls in the time episode from 2,200 to 2,000 years B.P. as indicated by radiocarbon dates. A date of 2,280 ± 150 (GSC-785) years was obtained for shells at a depth of about 25 feet in the Gordon Bay section. It is postulated that a warming trend in climate with increased moisture and summer run-off may have favoured expansion of alder by providing better snow protection in winter and more abundant stream bank and valley bottom habitats through increased erosion.

The episode of alder dominance was followed by somewhat drier climatic conditions, with temperature probably remaining unchanged. It is probable that the distribution ranges of spruce and pine extended northward during this episode, as indicated by small maxima in the spruce and pine pollen graphs near the top of the diagram. This episode may have occurred from about 2,000 to less than 1,000 years ago.

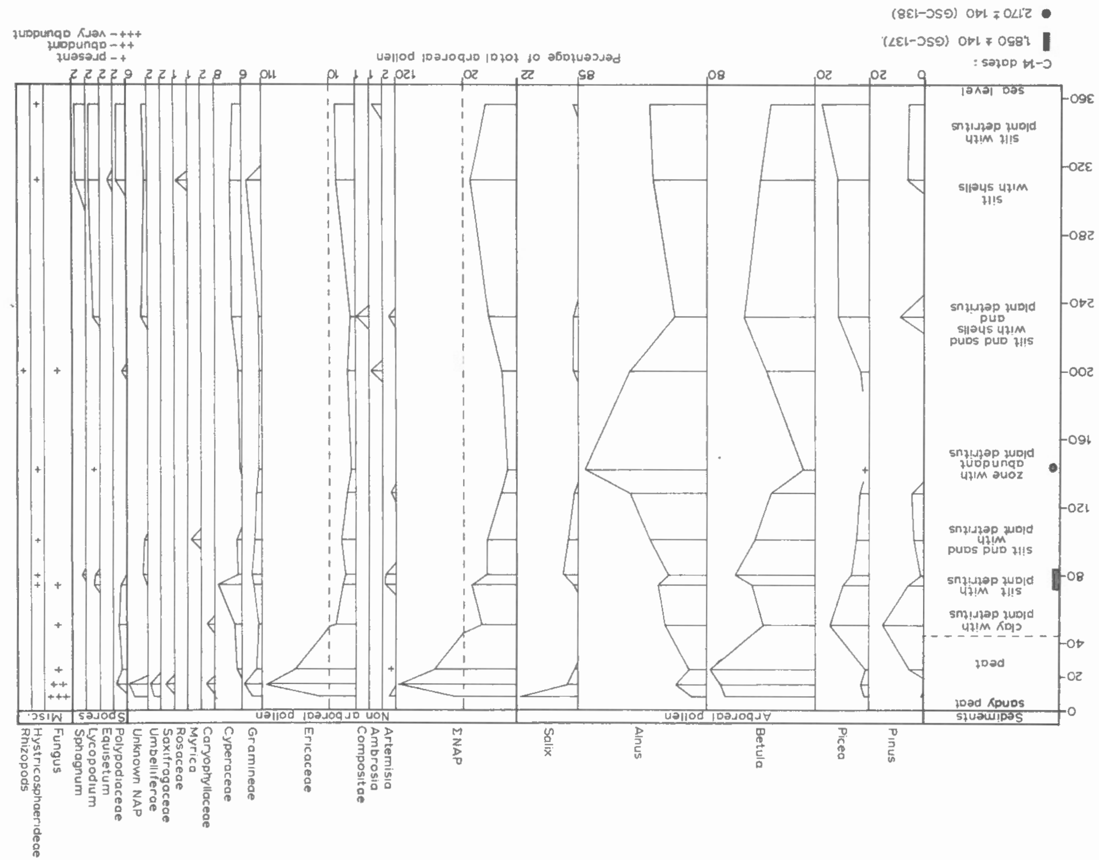

Figure 3. Pollen diagram of postglacial deposits at Gordon Bay, Bathurst Inlet, Northwest Territories. A date of 2,280 + 150 years (GSC-785) was obtained for marine shells at the 307-319 inch depth. The date GSC-137 is on marine shells, and GSC-138 on plant detritus. (GSC 200194-G)

A significant deterioration of climate followed, as indicated by the rise in the birch graph. It is assumed that a lowering of temperature was the reason for this change. That the moisture also increased is indicated by build-up of the peat cover beginning about 400 years ago (date on base of peat 400 ± 140 years (GSC-172) in the Melville Sound area; Blake, 1963). It is probable that this event correlates with the well-established climatic deterioration some 300 to 400 years ago.

This climatic trend again reversed, as indicated by the more recent increase in the relative percentage of willow pollen. The palynological features of the Gordon Bay diagram are supported by similar trends in the pollen graphs in diagrams compiled by the writer on samples collected by W. Blake, Jr. from the Melville Sound and the MacAlpine Lake areas in the western Canadian Arctic, northeast and east of the Gordon Bay area.

The interpretations made by the writer have been summarized in Table I, and it must be emphasized that this compilation is necessarily tentative and is open for corrections and further revision.

In the eastern Canadian Arctic some palynological studies have been made by the writer (Terasmae et al., 1966), but these studies are still inadequate for formulating any meaningful hypothesis related to postglacial paleoecological changes.

DISCUSSION

The evidence presented in this report, and the palynological studies made by Livingstone (1955, 1957), Heusser (1960), and Colinvaux (1964a, 1964b) in Alaska all indicate that the late-Quaternary and postglacial Arctic vegetation has not followed a simple, unidirectional development but shows evidence of several changes that can be best explained by assuming that climatic fluctuations were the controlling factor for the observed changes.

However, the inadequate basic botanical and ecological data and the numerous palynological problems discussed earlier have left the interpretations of pollen diagrams open to doubt and criticism. It is important, therefore, to examine evidence obtainable from other sources in order to establish whether the palynological interpretations of climatic changes can be confirmed or should be reconsidered in the light of existing contradictory evidence. The necessary additional evidence can be gleaned, for example, from glaciological studies and investigations concerned with Quaternary stratigraphy and chronology, and from studies of the permafrost regime in the arctic regions.

TABLE I.

A probable correlation of late-Wisconsin and postglacial chronology, pollen zones, climatic fluctuations and changes in vegetation.

Pollen zones	Approximate time intervals in years	Inferred mountain glacier fluctuations and changes in climate	Probable changes in vegetation
	300 – present	A warming trend.	
	300 – 400	Cold episode; advance of mountain glaciers.	Rise in birch dominance.
	400 – 1000	Colder; increasing moisture.	
Zone III	1000 – 2000	A drier episode; probable retreat of glaciers.	Alder graph declines; a small rise in spruce graph.
	2000 – 5000	Increased moisture; beginning of temperature decline; possible advance of glaciers	Alder maximum.
	5000 – 7000	Temperature rise to a maximum, warmer than present. Some thawing of permafrost.	Rise in spruce and alder pollen graphs.
Zone IIc	7000 – 10,000	Glacier retreat; rising temperature.	Grass-sedge tussock tundra invaded and locally replaced by muskeg with birch, alder and willows.
Zone IIb	10,000 – 11,000	Glacier retreat; decreasing moisture, colder than present.	Grass-sedge tussock tundra with birch and willows.
Zone IIa	11,000 – 12,000	Glacier advance; slightly warmer and more moisture.	Birch rise; alder and Artemisia maximum.
Zone I	12,000 – 14,000	Glacier retreat; cold and dry.	Grass-sedge tussock tundra.

The following comments are based on reports published by Hopkins (1959b), Hopkins et al. (1960), Goldthwait (1963, 1966), Karlstrom (1964), McCulloch et al. (1965), Péwé (1966a, 1966b), Porter (1964), Denton (1965), Krinsley (1965), Denton and Stuiver (1966), and Borns and Goldthwait (1966). There appears to be a reasonably good agreement between the general results of the above studies, but some differences nevertheless exist in the more detailed chronologies and correlations. The general trend of glacier retreat began about 14,000 to 15,000 years ago, and with minor readvances this trend reached a maximum some 7,500 years ago (Goldthwait, 1963) when the extent of mountain glaciers was less than today's.

A reversal of the warming trend, however, set in some 3,000-4,000 years ago, and the advancing glaciers overrode forests in the Glacier Bay area, Alaska, about 2,700 years ago according to Goldthwait (1963). This definite deterioration of climate marks the beginning of the Neoglacial episode (Denton and Stuiver, 1966). The mountain glaciers probably retreated somewhat in the following episode of 2,000 to 1,000 years ago, but advanced strongly again beginning some 600 years ago and reached the maximum advance limit of the Little Ice Age some 200 to 300 years ago as shown by Goldthwait (1963). The glaciers have retreated since that time with some minor readvances.

According to Péwé (1958, p. 17) a warming of climate caused some thaw of permafrost about 5,000 to 6,000 years ago. In the Canadian Arctic Archipelago Savile (1961) concluded from his studies that some of the northwestern islands had been covered by permanent snow fields, or thin ice caps 200 to 300 years ago. Savile also postulated that such a snow cover may develop within 100 years on the low-lying islands.

Further data for evaluating the feasibility of the interpretations made by the writer can be obtained from reports by Löve and Löve (1963), Hopkins (1959a), Hopkins and Sigafoos (1951), and others concerned with studies of recent environments. It is probable that archeological studies will yield considerable useful information related to paleoenvironments when further studies improve the presently known record.

Still another and different approach, however, is available for checking and evaluating the vegetation-climate relationships in late postglacial time. As shown by Lamb (1965) a detailed climatic record can be compiled from many sources for the last several hundred years. This compilation is based on climatological principles and utilizes the knowledge of weather patterns based on actual meteorological records. Fritts (1965) has demonstrated the use of dendroclimatological techniques in a study of climatic changes during the past 500 years. These rather more precise climatological sequences can be correlated with palynological studies, which can then be used to extend the climatological record back in time with more confidence.

In the final analysis it can be suggested that the conclusions reached through paleoecological interpretation of palynological and paleobotanical evidence find some support in studies made in other fields concerned with paleoenvironments and climatic changes and hence one can assume a causal relationship between the palynological record and climatic changes. However, the available interpretations are in need of further refinement. Detailed studies in selected areas are required to confirm and elaborate the presently held views, which are commonly open for criticism and frequently based on assumptions without firm factual foundation.

The experience gained from the studies made points to the need for careful site selection in palynological programs. The best sites are found near the boundaries between different vegetation regions, or otherwise in ecologically sensitive areas where an environmental change is most likely to be reflected and recorded by a corresponding change in vegetation. Lake sediments have yielded, furthermore, the most continuous and best preserved palynological records with the least amounts of contamination by redeposited pollen and spores.

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