The Problem of the Cochrane in Late Pleistocene Chronology

GEOLOGICAL SURVEY BULLETIN 1021-J

A CONTRIBUTION TO GENERAL GEOLOGY

THE PROBLEM OF THE COCHRANE IN LATE PLEISTOCENE CHRONOLOGY

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ABSTRACT

The precise position of the Cochrane readvances in the Pleistocene continental chronology has long been uncertain. Four radiocarbon samples bearing on the age of the Cochrane events were recently dated by the U. S. Geological Survey. Two samples (W–241 and W–242), collected from organic beds underlying surface drift in the Cochrane area, Ontario, are more than 38,000 years old. Two samples (W–136 and W–176), collected from forest beds near the base and middle of a 4- to 6-foot-thick peat section overlying glacial lake sediments deposited after ice had retreated north of Cochrane, have ages, consistent with stratigraphic position, of 6,380±350 and 5,300±300 years. These results indicate that the Cochrane area may have been under a continuous ice cover from before 36,000 until some time before 4500 B. C.; this conforms with the radiocarbon dates of the intervening substage events of the Wisconsin glaciation. The radiocarbon results indicate that the Cochrane preceded rather than followed the Altithermal climatic period and suggest that the Cochrane be considered a Wisconsin event of substage rank.

Presented geoclimatic data seemingly give a consistent record of a glaciation and eustatic sea level low between 7000 and 4500 B. C., which appears to correlate with the Cochrane as a post-Mankato and pre-Altithermal event. A direct relation between glacial and atmospheric humidity changes is revealed by comparing the glacioeustatic history of late Pleistocene and Recent time with independently dated drier intervals recorded from Western United States, Canada, and Europe. The combined geoclimatic record supports the concept of a fundamental climatic cycle with a base periodicity of about 500–600 (550) years, strong recurrences every 1,000–1,200 (1,100) years, and major recurrences every 3,000–4,000 (3,400) years.

Many radiocarbon dates independently substantiate the European Fennoscandian varve date of 8,800–8,100 B. C., the correlation of the Mankato with the Fennoscandian substage of the European chronology, and the correlation of the Cochrane with a post-Fennoscandian climatic event. Therefore, the correlation of the Cochrane with the Fennoscandian in the North American varve chronology appears untenable.

INTRODUCTION

The youngest recognized readvances of the ice margins during retreat of the Wisconsin ice sheet from North America were first described by Ernst Antevs (1925) from the type locality near Cochrane, northern Ontario, Canada. These readvances, also referred to as oscillations or halts, constitute the Cochrane age of the continental chronology and were subsequently treated in a series of papers dealing with the development and refinement of a varve chronology covering the retreatal events of the last ice age (Antevs, 1928, 1931, 1953). The Cochrane occupies a signally important position in the development of the late Pleistocene absolute chronology of North America because Antevs' meticulously and laboriously derived varve sequence, upon which this chonology has been based, terminates with it. Dating of the Cochrane in calendar years, therefore, has been requisite to the absolute dating by varves of the pre-Cochrane events of the Wisconsin glaciation and thus, indirectly, to the dating of important archeological finds of early man in North America, as well as fundamental to the elaboration of climatic history since the maximum advance of the last ice age.

The age of Cochrane is still highly controversial. Because of its importance to the late Pleistocene and Recent chronology, a suite of four samples of peat and wood collected from the Cochrane area were recently dated at the radiocarbon laboratory of the United States Geological Survey, Washington, D. C. (Rubin and Suess, 1955, 1956). The purpose of this paper is to discuss the implications of these four analyses in relation to other critical data and previous attempts to date the Cochrane. The conclusion is reached that the Cochrane marks an important period of halts, some time between 7000 and 4500 B. C., during final retreat of the Wisconsin ice sheet from the St. Lawrence region of Canada.

EVIDENCE FOR THE COCHRANE

As summarized in a recent paper (Antevs, 1953), the Cochrane is described as three separate readvances of the ice margin in the vicinity of Cochrane, Canada. These readvances were preceded by a generally rapid retreat of the ice margins from the position of the Mankato and Valders moraines in the United States and were followed by a rapid retreat and final disappearance of the continental ice sheet from the Hudson Bay region. The halts marking these readvances are recorded by an outwash apron or sandr (Icelandic) near Nellie Lake, 23 miles south of Cochrane; by remnants of an end moraine present in the Suskequa and Frederick House Rivers and at Cochrane in the vicinity of latitude 50° N.; and by the Turgeon Bend moraine, which lies about 50 miles north of Cochrane (fig. 55). On

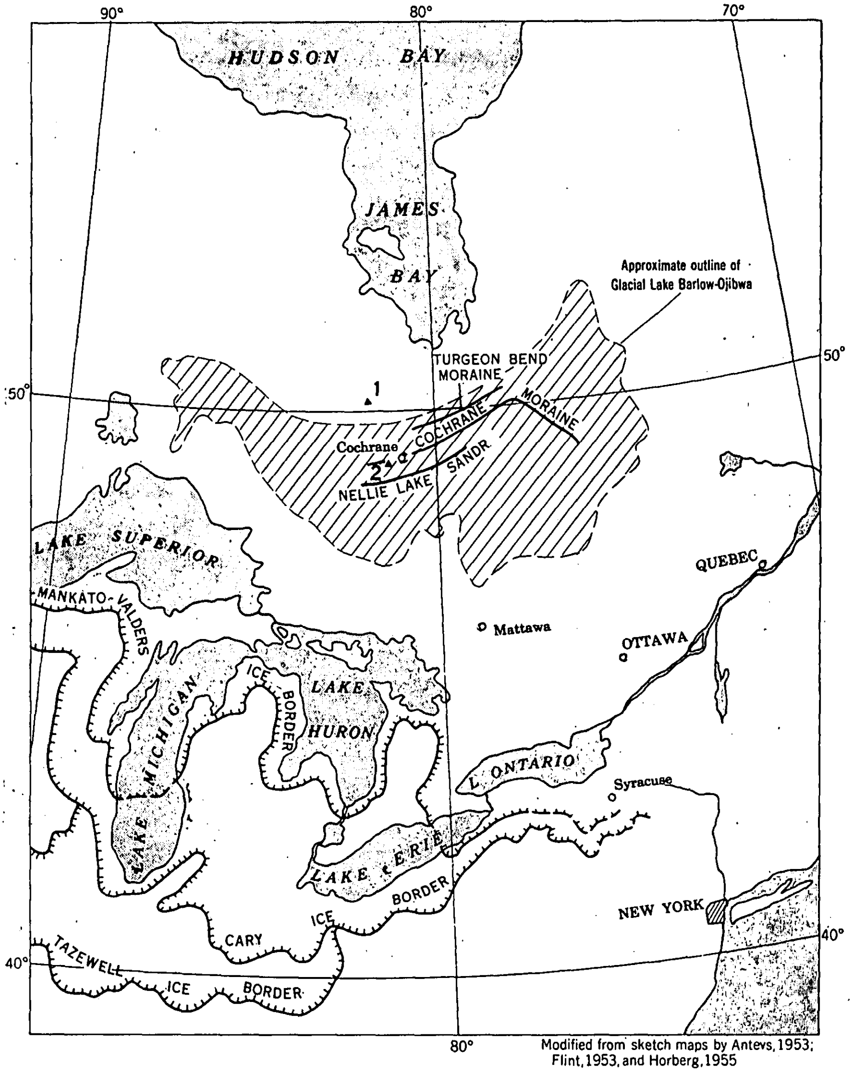

FIGURE 55—Sketch map of Cochrane, Ontario, and adjacent regions.

the basis of varve stratigraphy, Ernst Antevs postulates ice readvances of about 70 miles to Nellie Lake, 3 miles to the moraine at Cochrane, and an advance of an unknown distance (or a halt) to the Turgeon Bend moraine. According to his varve chronology, these three readvances took place in an interval of less than 1,000 years. Although R. F. Flint (1953, p. 914) considers the question of actual ice readvance within the Cochrane areas still unsettled, the moraine and sandr deposits would appear to demonstrate a related series of definite interruptions in the recession of the continental ice margins and, therefore, a significant climatic event in post-Mankato time.

HISTORICAL DEVELOPMENT OF THE COCHRANE PROBLEM

Pleistocene geologists generally accept the reality of the Cochrane oscillations as a significant climatic event, but the age of the oscillations has long been in dispute. In his early papers Ernst Antevs (1928, 1931) tentatively assumes that post-Cochrane time is the correlative of the Postglacial time of the northern European chronology and thereby assigns an age of about 7000 B. C. to the Cochrane. By counting back in time on the basis of varve counts and estimates for the gaps in his varve sequence, he derives an age of about 23,000 B. C. for the St. Johnsbury moraine of Vermont and an age of 34,500 to 35,000 B. C. for the New York moraines on Long Island (the Ronkonkoma and Harbor Hill moraines). He suggests that the St. Johnsbury moraine is the correlative of the Mankato substage of the Wisconsin stage and of the Pomeranian substage in Europe and that the New York moraines are the correlative of the Iowan substage of the Wisconsin stage and of the European Warthe glaciation.

Kirk Bryan and L. L. Ray (1940) present a critical review of Mr. Antevs' (1928, 1931) chronologies, emphasizing the inherent uncertainties represented by the many gaps in the North American varve sequence and by the suggested continental and transatlantic correlation of moraines. In a reestimate of available data, admittedly by rather arbitrary means, they derive an age of 8000 B. C.±1,000 years for the Cochrane by assuming that either post-Cochrane time is the equivalent of the European Postglacial (6800 B. C. to present) or that the Cochrane is the equivalent of the European Fennoscandian glacial substage dated about 8500 B. C. They follow Antevs in correlating the St. Johnsbury moraine with the Mankato and the Pomeranian but disagree with him in that they consider the Harbor Hill moraine a separate substage from the Ronkonkoma moraine. They suggest the following chronology for Wisconsin events and correlate with the European glacial sequence as follows: W1 (Wisconsin 1)–Iowan (Warthe), 65,000 B. C.; W2–Tazewell and Cary (Brandenburg), 35,000 B. C.; W3–Mankato (Pomeranian), 25,000 B. C.; W4–? (Scanian halt), 11,500 B. C.; Cochrane? (Fennoscandian), 8500 B. C.; and post-Cochrane (Postglacial), beginning about 6800 B. C. They emphasize that the ages suggested are but first approximations which, because of the magnitude of the inherent errors involved in their calculations, must be considered indicators of relative age rather than true figures. They note that the attempted correlation of the North American with the northern European sequence is somewhat unsatisfactory in that the Scanian halt in Europe has no apparent American counterpart. It is evident that the ages of the events, including the Cochrane, are derived solely by transatlantic correlations, whereas the ages of the earlier Wisconsin events are estimates based on combining Ernest Antevs' varve data with what Kirk Bryan and L. L. Ray consider the most probable correlations of the morainal sequence of the east coast with that of the Midwest and with European type sections.

In 1949, successful results obtained by dating archeological organic material of known age by the newly developed radiocarbon method were announced (Arnold and Libby, 1949), and a program was immediately inaugurated to further develop and test the method as a tool to be used in the solution of geologic and archeological chronological problems. By 1951 a sufficient number of geologic samples of unknown age had been dated to permit a cautious estimate of the validity of the radiocarbon method in supplying accurate dates (Flint, 1951). Two general results emerged: the radiocarbon dates in general agreed with the stratigraphic positions of samples, implying at least proper relative ages; and the dates obtained for geologic events were generally more recent than had been believed by many geologists. The most significant result bearing directly on the age of the Cochrane was the dating of the pre-Mankato interstadial (Two Creeks interval) at about 9500 B. C. This age is in apparent agreement with the varve date of just slightly older than 8800 B. C. applied to the pre-Fennoscandian interstadial (Alleröd horizon) of northern Europe and implies that the Fennoscandian is the equivalent of the Mankato and not the Cochrane.

Ernst Antevs (1953) reassesses his varve chronology in the light of the new radiocarbon data and argues, on the basis of similar position and sequence of moraines relative to ice sources, that the Fennoscandian must be the correlative of the Cochrane and not the Mankato, as implied by the radiocarbon age of the Two Creeks formation. By equating the 3 Cochrane readvances with the 3 Finnish Salpausselkä moraines (varve dated from 8800 to 8100 B. C.), he derives a new base line of 9300 B. C. for his pre-Cochrane varve sequence and dates the St. Johnsbury moraine (Mankato) at about 17,200–17,000 B. C., the New Britain moraine (Cary) at about 21,900–21,600 B. C., and the Harbor Hill moraine (Tazewell) at some time before 25,000 B. C. After summarizing the varve record for the Mankato to Cochrane interval (5,225 counted years (varves) and 2,625 estimated years), Antevs concludes that his estimates for the duration of this interval can be too low, but hardly too high. Thus the 9000 B. C. radiocarbon date for the Mankato must be too young by about a factor of 2. In an evaluation of radiocarbon dates, which do not agree with his varve-based chronology, he suggests that the main causes for radiocarbon error are contamination by younger organic material and old carbonates, and wet decomposition, which determines a chemical exchange affecting the original radioactive composition of the organic material. Whereas it is now generally recognized that occasional spurious radiocarbon dates may result from contamination of samples by both younger and older organic material, research on isotope fractionation (Craig, 1953) reveals no physiochemical basis for the contention that organic material preserved in a wet environment suffers a fractionation not experienced by material preserved in a dry environment.

A series of radiocarbon analyses run on samples collected from the pre-Fennoscandian Alleröd pollen zone in Denmark gave results in agreement with the Fennoscandian varve date (Anderson, Levi, and Tauber, 1953). Reruns of samples from the American Two Creeks and the European Alleröd zones by the more sensitive and accurate acetylene counting method developed by Suess substantiate the general accuracy of the ages derived by the original solid-carbon counting method of Libby (Suess, 1954). It would therefore appear that the radiocarbon ages of the Two Creeks interval and the Alleröd period and the essential contemporaniety of the related Mankato and Fennoscandian events are rather firmly established. The agreement between the radiocarbon and varve dates for the Fennoscandian is highly significant. Not only does this agreement appear to substantiate the essential accuracy of the Scandinavian varve chronology over the past 11,000 years, but it implies that properly analyzed radiocarbon samples provide results that may be accurate in a near-absolute as well as a relative sense, at least up to 11,000 years and presumably beyond.

In 1953 a new interpretation was introduced, adding to the Cochrane problem. E. S. Deevey (1953), following a suggestion by R. F. Flint (1953), placed the Cochrane as a post-Thermal Maximum event and a correlative of the "little ice age" of Matthes. According to Matthes (1949), the "little ice age" began around 2000 B. C.; and a "lesser ice age," around the end of the 16th century. The term "Thermal Maximum" was used by Flint and Deevey (1951) to designate the postglacial period of maximum warmth (essentially the Atlantic period of the Scandinavian climatic chronology), which has been referred to also as the Climatic Optimum, Altithermal, or xerothermic period (Deevey, 1953, p. 277–279).

As the Thermal Maximum is dated by Deevey from 5000 to 3000 B. C., this requires a post-3000 B. C. age for the Cochrane. A. C. Trowbridge (1954) disagrees. In a review of the literature dealing with Pleistocene chronology and sea-level changes, Trowbridge places the Cochrane as a pre-Thermal Maximum event and arrives at a Cochrane age of about 13,000–5500 B. C. by using the admittedly dubious method of averaging out previously published estimates. Trowbridge discards the possibility of the Cochrane as a post-Thermal Maximum event on the basis that an ice sheet large enough to reach as far south as Cochrane could hardly have melted away at the same time that the less extensive glaciers of the "little ice age" advanced. R. L. Nelson (1954), in a study of the glacial geology of the Frying Pan River drainage in Colorado, derives, from a quasi-quantitative evaluation of relative difference in weathering and erosional characteristics of glacial deposits, an age of about 3500 B. C. for a glaciation (Chapman Gulch) which he correlates with the Cochrane. Although the general validity and accuracy of the dating method and of his correlation of the Colorado events with the midcontinental sequence may be questioned, Nelson's attempt is noteworthy as a well-considered approach to the difficult problem of making relative geologic data yield results in absolute years.

By 1955 a sufficient number of radiocarbon results were available from both the United States and Alaska to permit dating of glacial events throughout Wisconsin and post-Wisconsin time, to assess better the radiocarbon results relative to geologic interpretation, and to establish more firmly their validity (Flint and Rubin, 1955; Horberg, 1955; Karlstrom, 1955). Two major conclusions were derived independently by the authors of these three papers: (1) glacial events of Wisconsin age are compressed into a somewhat surprisingly short period of time and relate to a major glaciation that began before 23,000 B. C., reached a maximum about 18,000–16,000 B. C., and was in oscillating retreat up to and after 9000 B. C.; and (2) the logical and consistent agreement of the great number of radiocarbon dates with geological interpretation indicates that the radiocarbon method gives essentially correct relative ages, and probably nearly correct absolute ages as well, which can be used as a basis of intraregional and extraregional correlations.

Leland Horberg (1955) radiocarbon dates the Wisconsin events as follows: Farmdale, greater than 23,000 to 20,000 B. C.; Farmdale, Iowan, and Tazewell complex to 18,000 B. C.; Tazewell to 15,000 B. C.; "Brady" to 12,000 B. C.; Cary to 10,000 B. C.; Two Creeks to 9000 B. C.; Mankato to 6000 B. C.; followed by a period extending to the present which Horberg informally terms "the postglacial." He suggests that the radiocarbon dated Valders drift represents a minor advance that occurred shortly after retreat from the maximum position attained during Mankato time. Because the Cochrane is not discussed as a separate event, the presumption is that Horberg considers it either part of the Mankato substage or a postglacial event. R. F. Flint and Meyer Rubin (1955) restrict their discussion to pre-Mankato events but restate a previous conclusion that the Mankato (with maximum estimated roughly at 9000 B. C.) is the correlative of the European Fennoscandian substage. Their interpretation of the radiocarbon ages for the pre-Mankato events is in essential agreement with Horberg's. T. N. V. Karlstrom (1955) suggests, from an assessment of critical Alaskan and continental radiocarbon-dated stratigraphic sections, the following sequence: Early Wisconsin events, including the Farmdale (Leighton and Willman, 1950) and Iowan substages, beginning before about 35,000 B. C.; middle and late Wisconsin substages beginning about 17,000 B. C. (Tazewell), 13,500 B. C. (Cary), 10,500 B. C. (Mankato), and 7000 B. C. (Cochrane); and Recent glaciations beginning about 3500 B. C. and A. D. 500 ("little ice age"), and A. D. 1500 ("lesser ice age"). The Cochrane is correlated with an Alaskan glaciation dated between about 7000 and 4500 B. C. The supporting data bearing on this correlation will be discussed later in this paper. The dated boundaries of the author's absolute chronology are placed near culminations of integlacial, interstadial, and lesser rank retreatal phases immediately preceding recorded periods of significant glacial advance.

In one of his most recently published papers bearing directly on the age of the Cochrane, Ernst Antevs (1955a) discusses new pollen and radiocarbon data from Canada, which he presents as demonstrating a pre-Altithermal age for the Cochrane. He considers that the Cochrane, as a pre-Altithermal event, must be the correlative of the Fennoscandian and thus that the radiocarbon-supported correlation of the Mankato and Fennoscandian cannot be accepted. Minor revisions are presented for his varve chronology. The Lake Willoughby moraine, rather than the St. Johnsbury moraine of Vermont, is made the equivalent of the Valders (Mankato), which he now dates around 16,500 B. C. This figure may be contrasted with his earlier figures for the Mankato of around 17,000 B. C. (Antevs, 1953) and of around 25,000 B. C. (Antevs, 1931). This progressive downward revision in the length of the varve chronology is not the product of new varve data so much as of reestimates of the durations represented by the gaps in the varve sequences, and of changes in correlations between moraines on the east coast and type sections in the Midwest and in northern Europe. The delineation of the precise ice boundaries for Wisconsin events from the Midwest to the east coast, as well as the transatlantic correlations, remains a subject of some conjecture and of no small controversy. Because of these uncertainties, Antevs' figures may be accepted as shrewd first approximations but not necessarily as precise figures.

PURPOSE OF THIS PAPER

The above brief review of the literature indicates that the Cochrane problem lies at the center of a basic conflict between the recently derived radiocarbon chronology and the North American varve chronology of Mr. Antevs. This conflict can be posed in the form of a question: Is the Fennoscandian the climatic correlative of the Cochrane or of the Mankato? A second unresolved question, important for its bearing on the precise position of the Cochrane in the late glacial chronology, is whether the Cochrane is pre- or post-Altithermal in age. Pertinent data bearing on these two questions will be marshalled below in an effort to solve the Cochrane problem. The stratigraphic implications of new radiocarbon results from organic samples collected in the Cochrane area will be discussed first. The radiocarbon-derived age will then be assessed as to general validity within the framework of proposed late-glacial and postglacial chronologies of both North America and Europe (pl. 31).

ACKNOWLEDGMENTS

For helpful comments and criticisms offered on preliminary drafts of this paper the author is indebted to Björn Andersen, of the University of Oslo, Norway; V. K. Prest, of the Canadian Geological Survey; and the late Leland Horberg, of the University of Chicago. Appreciation is expressed to Hans Suess and Meyer Rubin, of the U. S. Geological Survey, for general counsel on the radiocarbon dating of the continental chronology and for laboratory analyses of the author's samples. Particular appreciation is expressed to Mr. Rubin, who was of great help in interpreting the early and middle Wisconsin events discussed in this paper. The author's interpretations are in part the product of information and ideas contributed by others; nonetheless, some uncertainty and general disagreement remain, and the author accepts complete responsibility for his conclusions.

The author, like most Pleistocene researchers, is greatly indebted to Ernst Antevs, whose early and continued dedication to the difficult task of establishing an absolute chronology for North America has developed in American geologists an awareness of the philosophy and methodologies that may be employed and who has also laid for them, by a lifetime of detailed and diversified research, an excellent foundation for subsequent work and continuing progress.

NEW RADIOCARBON DATA BEARING ON THE AGE OF THE COCHRANE

GEOLOGIC SETTING

The Cochrane moraines occur in an area which is largely underlain by extensive deposits of varved and laminated lacustrine clay and silt deposits, locally containing ice-rafted pebbles, cobbles, and a few boulders. These deposits constitute the "Clay Belt" of northern Ontario and Quebec, and were laid down in an extensive proglacial lake (Barlow-Ojibwa) (fig. 55). This lake was largely confined on the south by the Great Lakes-Hudson Bay divide (the height of land) and on the north by the retreating margin of the continental ice sheet (Antevs, 1925; Flint, 1953). Final drainage of proglacial lake waters from the Cochrane area took place when the ice margin had retreated far enough north to allow water to escape to Hudson Bay.

Ernst Antevs (1953) postulates that glacial lake Barlow-Ojibwa was drained before the readvances of the ice margin near Cochrane, but the field evidence presented earlier (Antevs, 1925) implies that a lake existed, at least locally, during and following the readvances. Several exposures of undisturbed surface deposits of laminated silt and clay, observed near Cochrane by the author in 1954, are a record of lake deposition during final retreat of the ice margin and at a time when it lay somewhere to the north of Cochrane. The exact position of the ice margin when the lake waters finally escaped into Hudson Bay is not evident from the available geologic evidence. The answer to this question, and the question as to whether this late proglacial lake history is a natural extension of glacial lake Barlow-Ojibwa or a separate event, must await the results of the current mapping program in northern Ontario by the Canadian Geological Survey. The author believes, however, that final drainage of lake waters probably did not take place until some time after the ice margin retreated north of the Turgeon Bend moraine. This is based on the premise that an active ice cap, centered in the Hudson Bay region (the Laurentide ice sheet of Flint, 1953) and large enough to reach as far south as the Turgeon Bend moraine, would probably have completely filled the Hudson Bay trough and would thus remain, at least up to this stage of retreat, an effective barrier to northward drainage.

Postglacial lake drainage and thus, presumably, post-Turgeon Bend events near Cochrane are recorded by peat accumulation in broad saucerlike depressions, which determine the many poorly drained muskeg surfaces on the otherwise flat, forested, and cultivated lake-bottom plains. Dissection of the bottom land surface has reached depths of more than 100 feet along major drainage lines. Frederick House River crosses the area in a terraced valley cut in, and locally through, a thick section of laminated clay and silt resting on till and glaciofluvial deposits.

SAMPLES COLLECTED FROM BENEATH COCHRANE DRIFT

Two samples from Ontario, dated by the U. S. Geological Survey's radiocarbon laboratory, were taken within the area covered by the postulated Cochrane readvances. These came from beneath till units exposed along a bluff on the Missinaibi River, 6 miles upstream from the mouth of the Soweska River (loc. 1, fig. 55). The samples were collected by O. L. Hughes and submitted through the courtesy of V. K. Prest, both of the Geological Survey of Canada.

Sample W–242 ("W" is the prefix of all samples dated at the Washington U. S. Geological Survey laboratory), peat from a continuous layer under 20 feet of surface drift including till, records a pre-Cochrane time when the area was ice free and the climate sufficiently ameliorated to allow the growth of vegetation. The age of the sample was outside the present range of radiocarbon dating, and a conservative limit was set at greater than 38,000 years. Sample W–241 is wood from a gravel layer, underlying the above-mentioned peat layer and separated from it by 3 feet of a till-like deposit. This was also determined to be greater than 38,000 years old.

Continued work in the Cochrane area may eventually reveal the presence of younger organic zones underlying Cochrane drift. However, all available radiocarbon results from uppermost organic beds underlying surface drift, both in southern Canada and the northern part of the United States, are consistent with the concept that parts of Canada were continuously under ice from the inception of the Wisconsin glaciation until final dissipation of the continental ice sheet. Samples, all of which proved by radiocarbon dating to be older than 30,000 years, were collected from surface drift in Toronto (W–121), Hillsborough, Nova Scotia (W–157), Port Talbot, Ontario (W–100), St. Pierre-les-Becquets section, Quebec (W–189), Bronson, Minn. (W–102), and Ironton, Minn. (W–101). As brought out by R. F. Flint and Meyer Rubin (1955), the ages of samples (23,000–16,000 B. C.) taken from organic zones underlying early Wisconsin drift in the United States are consistent with geographic position; that is, the older ages occur in the north and the younger in the south. This data compels consideration of the Wisconsin glaciation as made up essentially of one major phase of advance followed by one major phase of retreat, with relatively minor oscillations of the ice border during both advance and retreat determining the substage events. The evidence of the Cochrane in post-Mankato time fits well in this new conceptual framework. The fact that the Cochrane oscillations apparently took place in a proglacial lake environment, however, minimizes the chance that vegetation zones that may have formed before the readvances will be found in the stratigraphic section of the Cochrane area.

SAMPLES COLLECTED FROM SURFACE DEPOSITS IN THE COCHRANE AREA

Two wood samples were collected by the author in 1954 from a peat section directly overlying laminated lake silts, exposed by road construction operations on the Trans-Canada Highway about onehalf mile east of Frederick House River Crossing, west of the town of Cochrane (loc. 2, fig. 55).

The exposed mossy peat section, 4–6 feet thick and with permafrost in the lower few feet, directly overlies undisturbed laminated lake clays and silt containing a few scattered pebbles. Two distinct buried forest layers, with prostrate trunks, limbs, and tree stumps in place occur approximately 2 feet and 3½ feet down in the peat section. An upper woody peat bed, about 6 inches to a foot below the surface, may represent a third buried forest zone or the root zone of a forest no longer present on the wetter parts of the muskeg surfaces. All the woody layers had stratigraphic continuity throughout the one-fourth mile length of the exposed peat section. Similarly, two woody layers were observed in the upper parts of peat sections exposed in shallow drainage ditches of roads crossing other muskeg basins in the area. The stratigraphic continuity of these forest layers and their presence in many separate peat sections suggest that they may record events of regional, rather than local, environmental significance.

Sample W–136, wood from the forest layer near the base of the peat section, provides a minimum date for drainage of glacial lake waters and for the final withdrawal of the ice margin north of the Cochrane area. The age of the sample is 6380 ±350 years (4430 B. C. ±350 years). Sample W–176, wood from the middle forest layer, is 5300 ±300 years (3350 B. C. ±300 years) in age, which, considering sample W–136, is in agreement with the stratigraphic positions of both samples and implies a not unreasonable interval of about 1,100 years duration for the accumulation of the intervening foot or so of mossy peat.

Peat from the base of a 10½-foot-thick peat section overlying gray homogeneous clay near Dugwal, 34 miles due south of Cochrane, Ontario, was collected in 1952 by Heikki Ignatius and J. A. Elson. The sample (Y–222) gave an age of 6730 ±200 years (4780 B. C. ±200 years) and is interpreted as providing a minimum date for the last glaciation in the Cochrane area (Preston, and others, 1955). This sample is consistent in stratigraphic position and age with the samples collected by the author near Cochrane.

AGE OF THE COCHRANE AS DERIVED FROM RADIOCARBON DATA

Results of radiocarbon tests of samples collected from the Cochrane area imply a Cochrane age between 36,000 B. C., or slightly older, and 4500 B. C. The results are consistent with the radiocarbon-dated Mankato and pre-Mankato substages of the Wisconsin and provide a logical extension of the Wisconsin chronology, back in time from the maximum (Tazewell in Illinois) to the beginning phases of the Wisconsin glaciation and forward in time from the post-Tazewell Mankato advance that took place late in the Wisconsin retreatal phase. As the Valders (Mankato) maximum is dated around 9000 B. C., the Cochrane, as a still later event, may be bracketed between 9000 and about 4500 B. C. The new radiocarbon data do not permit precise dating of the boundary between the Mankato and Cochrane but are consistent with a post-Fennoscandian and a pre-Altithermal age for the Cochrane events.

CORRELATIVE EVENTS OF THE COCHRANE

Most geologists agree that the concept of worldwide contemporaneity of both large- and small-scale climatic trends is supported by the radiocarbon dating of the Two Creeks interval and Alleröd horizon and by the historically dated glacial advances of the past few centuries. Such contemporaneity in climatic trends is slowly becoming demonstrable, too, on the basis of long-period weather records. If the radiocarbon-derived Cochrane age is correct, climatic events which are directly correlatable should be recorded elsewhere in the world. It is believed that glacioeustatic sequences recorded in Alaska, northern Europe, and elsewhere demonstrate the post-Fennoscandian age of the Cochrane, substantiate the radiocarbon-based Mankato-Fennoscandian correlation, and support the placing of the boundary between the Mankato and Cochrane at around 7000 B. C. A significant relation between glacial and atmospheric humidity changes is revealed by comparing the glacioeustatic history of late Pleistocene and Recent events with the recorded drought intervals in Western United States and the recurrence surface sequence of southern Sweden.

GLACIOEUSTATIC EVENTS IN SOUTH-CENTRAL ALASKA

Results of investigations by the author in south-central Alaska, briefly summarized by Karlstrom (1955), indicate a systematic series of glacial advances and coincident low-sea-level periods which seem to be closely correlatable with oscillations in ice-margin and sea-level positions in other parts of the world. A series of ice oscillations recorded by the innermost belt of the Naptowne morainal complex of Wisconsin age in Alaska is believed to have coincided with three low-sea-level oscillations inferred from coastal bog stratigraphy and radiocarbon-dated between 7000 and 4500 B. C. It seems reasonable to assume that the Cochrane oscillations are bracketed in the same time interval. The Alaskan glacial chronology over the past 12,000 years is summarized in plate 31.

A chronology based on eustatic sea-level changes has universal application. Insofar as sea-level changes result solely from changes in land-ice volume, they must affect all ocean basins simultaneously and thus be recorded by parallel hydrologic changes in all coastal areas of the world. However, changes in sea level have demonstrably resulted from a multiple of factors, including isotasy and disastrophism as well as eustasy, and the proof of eustasy is difficult at best. One approach, satisfied in part by the Alaskan evidence over the past 10,000 years, is to prove contemporaneity between regional glacial and sea-level changes. A more indirect approach is to demonstrate that the postulated sea-level changes simultaneously affected more than one ocean basin (and were thus presumably eustatic) rather than having strictly local geographic expression (thus being presumably diastrophic or isostatic in genesis). Substantiation for the eustatic nature of the Alaskan (North Pacific Ocean) sea-level history may be found in apparently parallel sea-level changes in the Atlantic Ocean, as recorded from the interconnected Baltic sea basin and from greater Bermuda.

SEA-LEVEL CHANGES OF GREATER BERMUDA

Organic samples from submerged cedar forest and peat beds about 50 feet below present sea level on greater Bermuda gave dates, respectively, of 9550 B. C. ±700 years and 6650 B. C. ±500 years (Kulp, 1953). The dated peat layer is one of several peat layers intercalated in muddy sediments overlying the forest layer. According to Kulp, they probably relate to recurring low stands of the sea during initial retreat of the continental glaciers from the late Wisconsin maximum (Mankato). The Bermuda evidence thus provides a clear record of a series of post-Mankato low sea-level phases which are in general conformity with the comparable part of the Alaskan sequence.

HYDROLOGIC CHANGES IN THE BALTIC BASIN AND THEIR RELATION TO GLACIAL EVENTS

The hydrologic history of the Baltic basin has been worked out in some detail (Magnuson, Granlund, and Lundqvist, 1947; Sauramo, 1939, 1954). It is closely integrated with the Blytt-Sernander climatic sequence derived from bog stratigraphy, the Swedish pollen zones, and Granlund's recurrence zonation in the standard Swedish Late-glacial and Postglacial chronology (pl. 31). Although controversy exists on some of the details of this hydrologic history, there is general agreement that the Baltic basin experienced two major periods of marine transgression after the retreat of the Baltic ice cap margin from the Fennoscandian moraines.

The first transgression of the North Sea into the basin occurred during the Finniglacial retreat and culminated around 7000 B. C.—the Rhabdomena stage of the Yoldia Sea (Sauramo, 1939). This part of the Yoldia is renamed the Echineis Sea in a more recent paper

(Sauramo, 1954). The second transgression, as represented by the Litorina Sea, culminated about 4500 B. C. during the Atlantic climatic period dated between about 5500 and 3000 B. C. These two periods of transgression are separated by the Ancylus Lake period, during which the marine connection with the North Sea was largely or completely disrupted and the Baltic Sea was filled with fresh to brackish water. The transition from the Yoldia Sea to Ancylus Lake is explained on the basis that isostatic upheaval of Scandinavia, temporarily proceeding at a faster rate than the general Postglacial rise in sea level, separated the Baltic basin from the ocean and determined an interior lake with restricted outlets to the ocean. The traditional view that the level of Ancylus Lake was higher than the ocean level is seriously questioned by Sauramo (1954), who presents evidence indicating that the Baltic Ancylus was actually a bay of the ocean, its water almost fresh because of the restricted nature of its outlet through the Danish Sound. In the light of this and of the new evidence implying essential contemporaneity of the Ancylus Lake period with a previously unrecognized eustatic low-sea-level phase as recorded in Alaska and greater Bermuda, it is apparent that the Baltic Ancylus could have resulted, completely or in large part, from a marine regression that accompanied a regeneration of continental and alpine ice masses.

The northern European glacial chronology is generally considered to end with bipartition of the waning ice sheet in the vicinity of Ragunda (the zero year of the Swedish varve chronology and the beginning of the Ancylus Lake period). However, there is recorded in the Swedish mountains, near the zero year, a series of ice-margin oscillations (Degeer, 1954; Brooks, 1952) which may correlate directly with the postulated Ancylus period marine regression.

A more detailed sequence of post-Fennoscandian glacial events appears to be recorded in Norway by a distinctive morainal sequence (Björn Andersen, personal communications). The Norwegian Ra moraines are considered to be of Fennoscandian age. Behind these moraines are found several pronounced morainal groups, the youngest of which belong to the Romeriks-Rigeris morainal system. In many valleys the moraines of this system form dams holding in the large East Norwegian lakes, and in some fjords these moraines are directly associated with elevated strandlines. The Scandinavian strandline specialists believe that this morainal system corresponds to the f-stage in the strandline chronology. The f-strandline, in turn, is correlated by Matti Sauramo and others with the Ancylus period in the Baltic basin. If this correlation is correct, there is direct evidence in Norway of a series of ice oscillations during Ancylus time, in agreement with the Swedish glacial record at Ragunda.

Interpreted in a glacioeustatic sense, there is a striking agreement in sequence and time between the major hydrologic changes in the Baltic basin and the radiocarbon-dated glacial sequence of Alaska. A similar climatic relationship is apparently recorded from the Cochrane area. According to Antevs (1953) the Cochrane oscillations were immediately preceded by a period of rapid retreat (the Timiskaming), which therefore appears to be the climatic correlative of the Yoldia Sea transgression. As implied by the new radiocarbon results, the Cochrane preceded the Altithermal (Atlantic climatic period) and thus preceded the culmination of the Litorina transgression dated at 4500 B. C. and the equivalent highest sea-level stand (of apparent worldwide record) attained in post-Pleistocene time (Fairbridge, 1950; Stearns, 1945).

POST-COCHRANE BOG RECORD AND CLIMATIC HISTORY

The continental glacial history terminates with the final withdrawal of the continental ice margin north of Cochrane. Post-Cochrane climatic events in Canada must be inferred largely from evidence of marine invasions of the Hudson Bay region and from bog and pollen stratigraphy (Flint, 1953; Antevs, 1955a). The radiocarbon-dated peat section near Cochrane records three periods during post-Cochrane time in which forests invaded bog terrain that had previously supported only a mossy plant cover. As present-day forests in the area are restricted to the better drained sites surrounding the margins of the poorly drained bog area, the suggestion is that the buried forest layers may represent drier periods in the past when the bog surface supported a more extensive forest cover, either because of a regional lowering of the water table, a decrease in atmospheric humidity, or both. Comparison of the post-Cochrane bog record with the North American and northern European climatic chronologies indicates that the forest beds formed during inferred periods of warmer and drier climate, while the overlying peaty beds formed, in general, during periods of cooler and wetter climate.

NORTH AMERICAN POST-COCHRANE CLIMATIC CHRONOLOGY

The most detailed chronology available from North America has recently been summarized (Antevs, 1955b). The post-Cochrane part of this chronology is based largely on geoclimatic dating of archeological sites in the arid and semiarid Western United States. Its integration with the North American varve chronology and with the northern European Postglacial chronology is derived by a series of correlations matching long-continued temperature conditions and changes as inferred from both glacial and vegetal sequences. According to this scheme post-Cochrane time is subdivided into three main temperature ages: the Anathermal (period of rising temperatures, 8000–5500 B. C.), the Altithermal (period of maximum temperatures, 5500–2000 B. C.), and the Medithermal (period of decreasing temperatures, 2000 B. C. to present). The time boundaries applied to these temperature ages, like those for the Cochrane oscillations, are derived by Ernest Antevs from correlations with the presumably equivalent temperature ages inferred from the dated Swedish chronology. In contrast, the drought periods that subdivide the cool, wet Medithermal age are independently dated on the basis of dendrochronologic, archeologic, and selected radiocarbon data. These divisional periods are the Fairbanks drought (ca. 500 B. C.), the Whitewater drought (A. D. 330), the Great drought (A. D. 1272–1299), and an unnamed drought (A. D. 1573–1593). Despite his use of radiocarbon data in dating the Fairbanks drought, many radiocarbon datings of climatic events in Western United States are discarded by Antevs as spurious because they do not agree with the results obtained through his correlations of inferred temperature ages. He contrasts the independently dated drought periods with the major high-temperature Altithermal period (also referred to as the Long drought) and considers that these periods represent changes in, and conditions of, moisture which cannot be used for long-range correlations because of limiting geographic factors.

Of direct significance for the purposes of this paper is Antevs' (1955a) correlation of the forest succession of Mont Tremblant Park, Quebec, with his absolute chronology (fig. 56). Pollen studies of bog and lakelet deposits in Mont Tremblant Park (Potzger and Courtemanche, 1954) indicate a forest succession of five different forest types from which the following climatic changes are inferred: Forest type I (warm climate); Forest type II (cooling climate); Forest type III (warm, dry, climate, xerothermic age); Forest type IV (cool and wet climate); and Forest type V (cooler, perhaps wetter climate). Based on the inferred temperature changes and the fact that the pollen record is obtained from an area lying to the south of the Cochrane moraines, Forest Type I is correlated with the Timiskaming retreat; and type II, with the Cochrane halt. Forest type III is correlated with all of the Anathermal and part of the Altithermal age. Type IV is correlated with parts of the Altithermal and the succeeding Medithermal age. Boundaries between Forest types III and IV and between Forest types IV and V are dated, respectively, about 4000 B. C. and just before the beginning of the Christian era.

This correlation is used by Antevs as independent evidence of the pre-Altithermal age of the Cochrane and thus as supporting evidence for the correlation of the Cochrane with the Fennoscandian. As

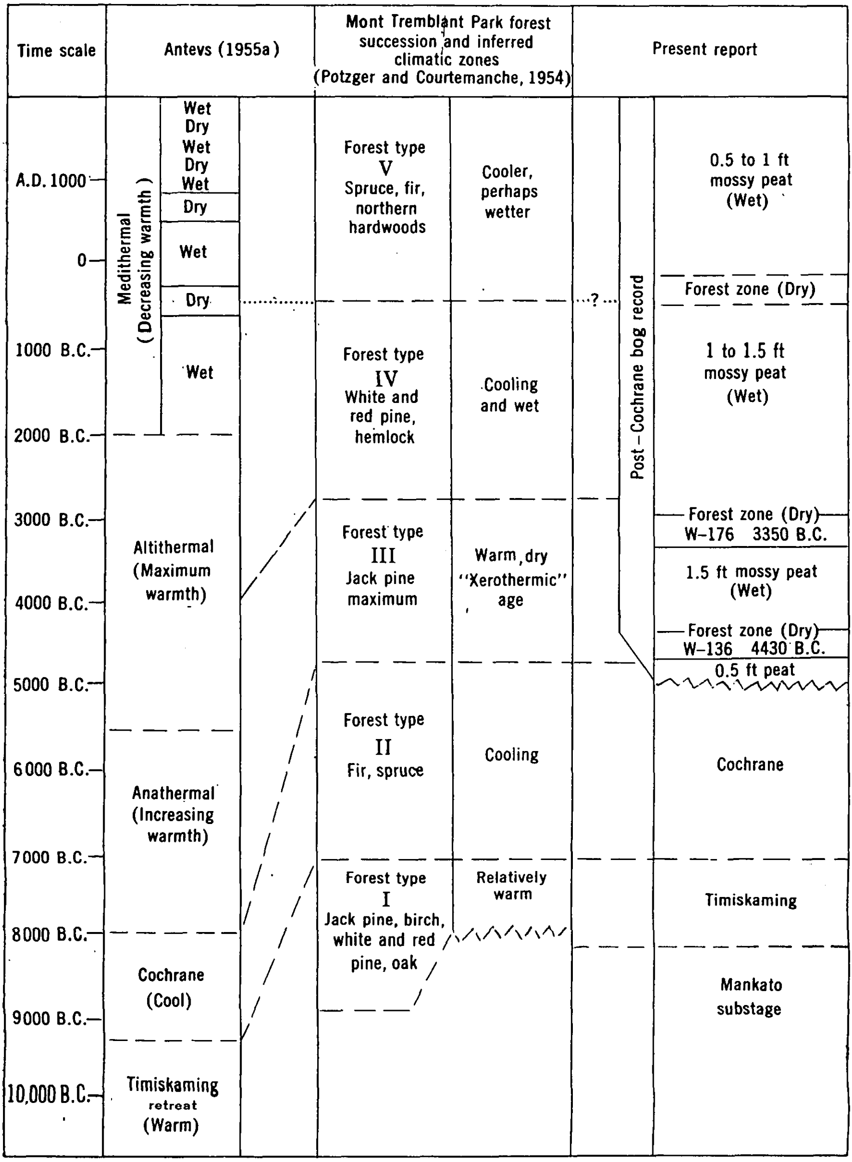

FIGURE 56.—Correlation of the Mont Tremblant Park, Quebec, forest succession with the North American geoclimatic chronology.

discussed in this paper, the Cochrane is indeed pre-Altithermal but is also post-Fennoscandian. As shown in figure 56 the Mont Tremblant Park forest sequence would appear to be fully consistent with this interpretation and with the radiocarbon-dated Cochrane bog record. As dated, the two lower forest layers fall near the middle of the Altithermal age and appear to represent two periods of maximum dryness near the culmination of maximum postglacial warmth. They may thus be logically correlated with the xerothermic age as represented by Forest type III. Therefore, overlying mossy peat beds, as correlatives of the periods represented by Forest types IV and V, appear to have been deposited at a time of generally increased moisture and decreased temperatures. The uppermost undated forest bed in the Cochrane bog seemingly records an important but temporary shift toward drier conditions which, in the Mont Tremblant Park area, may be represented by the transition from Forest type IV to V. This transition is dated by Ernst Antevs as just before the beginning of the Christian era, which appears to make it the equivalent of the Fairbanks drought period (ca. 500 B. C.) recognized in Western United States. Interestingly enough, the post-Atlantic (Altithermal) period of maximum dryness recognized in the European chronology also falls just before the beginning of the Christian era (that is, ca. 600 B. C.). The Swedish record of moisture changes in Postglacial time is one of the most detailed and accurately dated climatic chronologies available from Europe and will be discussed in some detail.

RECURRENCE SURFACE SEQUENCE OF SWEDEN

The detailed Swedish record of Postglacial changes in atmospheric humidity is largely derived from stratigraphic studies of raised bogs in southern Sweden. Erik Granlund (1932), in his fundamental contribution to an understanding of raised-bog formation, describes a series of stratigraphic boundaries or recurrence surfaces (Ry). Each recurrence surface records a return to moister conditions and renewal of peat growth after a period of stability and humification of the bog surface. In a study of hundreds of bog sections, Granlund found that owing to peculiar local conditions some bogs contained no recurrence surfaces, whereas others contained several. By using pollen and archeological evidence for correlation and absolute dating, he demonstrates that the recurrence boundaries group around five different stratigraphic levels, which are dated as follows: Ry I, ca. A. D. 1200; Ry II, ca. A. D. 400; Ry III, 600 B. C.; Ry IV, 1200 B. C.; Ry V, 2300 B. C. Recurrence surface III represents a major climatic break in the Swedish sequence and marks the boundary between the major sub-Boreal and sub-Atlantic phases of the Blytt-Sernander climatic sequence. This event is also considered to be the correlative of the Grenzhorizont (Weber, 1910), a major period of bog drying recognized in the stratigraphy of north German bogs and for a time considered to represent all of sub-Boreal time.

Although Erik Granlund found no recurrence surfaces older than 2300 B. C., he considers that the recurrence phenomenon is reflected in the pollen spectra throughout Postglacial time, which he subdivides into a series of recurrence zones. Recurrence zone boundaries below Ry V are correlated with the upper part of pollen zone IV; the boundary between pollen zones IV and V; pollen zone VI, or the transition between Ancylus Lake and Litorina Sea; pollen zone VIII, which marks the beginning phase of Ancylus Lake; and the transition between pollen zones IX and X (transition between the Baltic ice lake and Yoldia Sea periods). Subsequent work in northern Europe revealed the presence of additional Recurrence surfaces (Nilsson, 1935; Von Post, 1946).

The generally accepted Swedish Postglacial chronology now includes Mr. Granlund's original recurrence surface sequence plus two older surfaces, dated ca. 2900 (Ry VI) and 3500 B. C. (Ry VII). According to this chronology Mr. Granlund's recurrence boundary between zones 6 and 7 as presented in his 1932 paper corresponds to Ry VI, VII occurs within zone 7, and the older recurrence boundaries are dated about 4600 B. C., between 5800 and 5500 B. C., between 7000 and 6500 B. C., and about 8000 B. C.

As each recurrence surface represents a change from drier to moister atmospheric conditions, the dated series records recurring dryness at general intervals of 500–600 years and 1,000–1,200 years, and supports the concept of a fundamental climatic cycle with a periodicity of about 550 years and a tendency for a stronger impulse at about 1,100-year intervals. As dated, it is evident that Mr. Grunlund's recurrence-zone boundaries appear to reflect the same general periodicity. According to Deevey (1953) the recurrence surfaces, representing cycles of alternating drought and moisture, are known to have been approximately synchronous throughout Europe since about 2300 B. C. Similar cycles of drying and bog generation appear to be recorded in many of the North American bogs as well, but no attempt has been made to correlate specific North American events with those of this European sequence.

The conformity of the Postglacial climatic history of Europe, as represented by the recurrence sequence, with that of North America was first appreciated by the author from a comparison of the Swedish record with the radiocarbon-dated Alaskan glacial sequence (pl. 31). Nearly all the recorded periods of increased atmospheric humidity in Europe are matched by periods of glacial advance in south-central Alaska. The consistency of the two records, although not perfect, is sufficient to support strongly the concept of parallel climatic histories as directly expressed by essentially synchronous changes in atmospheric conditions. Thus W. H. Ahlmann's suggestion (1953) that the periods of increased atmospheric humidity, as represented by the intervals between recurrence surfaces, may have favored glacial advances would appear to be fully supported by the glacial record in Alaska. Although Antevs (1955b) considers that long-range correlations of moisture conditions and changes are not possible because of restricting geographic factors, the Western United States drought periods are essentially contemporaneous, as dated, with comparable periods recorded in the Swedish and Alaskan sequences. His Fairbanks, Whitewater, and Great droughts closely correspond in time and sequence with Ry I, II, and III and with the equivalent periods of glacial retreat in Alaska.

The conformity in climatic record between such widely separated areas as northern Europe, Western United States, and Alaska is all the more striking because of the greatly differing climatic zones and types of geologic records and because the corresponding climatic events in all three regions were independently and internally dated; that is, not dated by extraregional correlation of apparently similar sequences of events. The record for Western United States is one of inferred changes in moisture affecting alluvial and soil processes in a continental semiarid or arid environment. The record for Sweden is one of moisture changes affecting the formation of raised bogs in an extremely wet, cool, maritime environment. In contrast the south-central Alaskan record is one of climatic trends affecting the regimen of alpine glaciers in a somewhat colder, modified maritime environment. The drought events of the Western United States are dated by a combination of dendrochronologic, archeologic, and radiocarbon data; those of Sweden, largely by historical cross dating, with refinements of dating made possible by complete integration within the varve, pollen, and hydrologic sequences of the Scandinavian Postglacial chronology. The dates applied to the Alaskan events are derived exclusively from radiocarbon stratigraphic data.

A significant climatic cycle—widespread, if not universal—involving changes in atmospheric humidity is thus implied. It is, then, not surprising that the radiocarbon-dated post-Cochrane bog sequence, by its alternation of forest and mossy peat beds, appears to record major events of this same humidity cycle. As previously discussed, the dated forest zones fall within the age boundaries of the generally recognized Postglacial period of maximum warmth (essentially the Atlantic period of the Scandinavian climatic chronology), which in this country has been variously referred to as the Altithermal, Thermal Maximum, or xerothermic age. More significantly, both dated forest layers (4430 B. C. ±350 years and 3350 B. C. ±300 years) appear to represent 2 periods of drier conditions about 1,100 years apart which, within the statistical limits of counting error, can be considered contemporaneous with the drought periods marked by the Swedish recurrence boundaries dated around 4600 and 3500 B. C.

The stratigraphy of the post-Cochrane bog thus appears to represent a North American bog-drying sequence which closely parallels that inferred from the Swedish evidence and to provide direct evidence of climatic subdivision, heretofore unrecognized, of the Altithermal period and the correlative period of major glacial retreat in Alaska. A similar threefold subdivision of the Timiskaming retreat is implied by direct correlation with the Swedish recurrence sequence. Recurrence boundaries dated ca. 7000 and 8000 B. C. fall near the beginning and end of the Timiskaming retreatal period as dated in this paper and presumably represent intervals of more rapid retreat immediately following the last Mankato oscillation and immediately preceding the maximum Cochrane advance. A mid-Timiskaming interval of increased atmospheric humidity ca. 7500 B. C. has not yet been formally recognized from North American climatic data. However, insofar as a climatic trend toward increased atmospheric humidity could be expected to determine a retardation in the rate of glacial retreat, a halt, or even a readvance of the ice margin, it is possible that the post-Mankato, pre-Cochrane Pembroke moraine near Mattawa, Ontario, as described by Antevs (1953), may provide evidence of this mid-Timiskaming climatic event.

The combined geoclimatic data from Alaska, northern Europe, Canada, and Western United States are consistent with the generally accepted post-Mankato glacial history of general retreat to a postglacial minimum centered in the Altithermal (Atlantic) followed by a period of general glacial regeneration (essentially the "little ice age" of Matthes). The presented data further indicate that the post-Mankato period is subdivisible into a cyclical series of secondary glacial retreats and advances superimposed on the broader glacial record. These secondary glacial events show a direct relation to changes in atmospheric humidity as independently inferred from dated geoclimatic records and appear to record a fundamental climatic cycle with a base periodicity of about 550 years and with a stronger recurrence about every 1,100 years. Whether these cyclical changes in atmospheric humidity resulted primarily from temperature changes or from precipitation changes is uncertain. It is believed, however, that precipitation may have been the primary meteorological factor with lower temperatures resulting as a secondary factor from increased cloudiness during the recorded intervals of higher atmospheric humidity, glacial advance, and marine regression.

Although the chronology proposed in this paper appears internally consistent with the basic geologic data from both Europe and North America, it seemingly contradicts the climatic history traditionally applied to the Boreal (warm and dry), Atlantic (warm and wet), and sub-Boreal (warm and dry) periods of the European Blytt-

Sernander classification as most recently presented by Deevey (1953). The inferred warm, dry climates for both the Boreal and sub-Boreal periods is difficult to reconcile with the glacioeustatic evidence of general glacial advances which seems to require either increased precipitation, lowered temperatures, or both, for the Boreal and sub-Boreal periods relative to the intervening Atlantic period. The Blytt-Sernander climatic inferences are fundamentally derived from stratigraphic evidence of topogene (lake-basin) bog types present in the coastal areas of Sweden. The bog record indicates generally lower lake levels (ground-water levels) during the Boreal and sub-Boreal periods, and generally higher lake levels during the intervening Atlantic period (Magnusson, Granlund, and Lundqvist, 1949, p. 368). The inference of relative dryness for Boreal and sub-Boreal time therefore appears to be based on the assumption that intervals of lower lake levels must equate with intervals of lower atmospheric humidity. Consideration of the geologic environment of the coastal Swedish bogs and the hydrologic history of the adjacent Baltic basin suggests that this interpretation is not the only, nor the most likely, one to be drawn.

Alaskan stratigraphic studies indicate two types of lake-basin bog records that must be interpreted in an opposite geoclimatic sense. Type I (coastal lowland topogene bogs) records higher lake levels during periods of glacial retreat and lower lake levels during periods of glacial advance. In contrast, type II (upland topogene bogs), like the raised-bog or ombrogene bog type used by Granlund (1932) in his recurrence surface studies, records the reversed hydrologic relations to glacial change. Type I is genetically related by the control of base level on regional ground-water levels in humid areas to the eustatic controlled Thalassostatic terrace type, and type II to the more directly atmospheric controlled Climatic terrace type as described by F. E. Zeuner (1950). The Blytt-Sernander climatic classification, based as it is largely on this coastal lowland topogene bog record, may thus be interpreted more directly in terms of glacioeustatic rather than atmospheric humidity changes. By this interpretation the Boreal and sub-Boreal intervals of lower lake levels become periods of generally increased atmospheric humidity (cool and wet rather than warm and dry) relative to the Atlantic interval of higher lake levels as a period of generally decreased atmospheric humidity (warm and dry rather than warm and wet) in general agreement with the North American geoclimatic data.

RANK AND GEOLOGIC AGE OF THE COCHRANE

The rank and geologic age of the Cochrane in late Pleistocene chronology has long been in dispute. As previously discussed the

Cochrane has been variously considered the last substage of the Wisconsin, possibly a late phase of the Mankato substage, and a post-Wisconsin event. The rank of a geologic event must be assessed largely on the basis of intensity and duration as related to other comparable events of established rank status. The relative intensities of a series of glacial events may be roughly established by comparison of distances between moraines and estimated distances covered during advances. Relative durations may be determined by dating boundaries between advances.

Distances between end moraines of the Wisconsin substages, including the Cochrane moraines, are as follows: Tazewell to Cary, 130 miles; Cary to Mankato, 130 miles; Mankato to Cochrane, 400 miles. Estimated minimum distances of advance to maximum position are given for the Lake Michigan lobe by Horberg (1955) as follows: Farmdale, 300 miles; Iowan, 400 miles; Tazewell, 250 miles; Cary, 445 miles; and Mankato (Valders maximum), 100 miles. Antevs (1953) estimates that a distance of about 70 miles was covered by the maximum readvance of ice in the Cochrane area to Nellie Lake. Assessment of recent radiocarbon results (Karlstrom, 1955) implies a time difference ranging from 3,000 to 4,000 years between substage events throughout the late Pleistocene and Recent. As dated in this paper, the Cochrane is from 2,000 to 4,500 years younger than the Valders maximum. As the Cochrane readvances are dated by maximum and minimum ages, the Cochrane maximum must fall between these dates. Thus on the basis of relative morainal positions, estimated distances of readvance, and temporal relations, it appears that the Cochrane is comparable to the earlier substage events of the Wisconsin and should therefore be considered an event of substage rank within the standard Pleistocene chronology.

Whether the Cochrane should be considered Wisconsin or Post-Wisconsin in age depends largely on the placement of the upper boundary of the Pleistocene epoch in the standard continental chronology. In this country there are at present two major schools of thought on this problem. C. B. Hunt (1953), among others, retains the traditional concept of the Recent as a geologic time interval of epoch rank following the Wisconsin glacial stage of the Pleistocene epoch and considers that stratigraphic and faunal evidence from Western United States strongly supports using the Altithermal interval as the boundary between the two epochs. Flint (1949), among others, considers that the extent of present glaciers and ice caps indicates that we are still in the ice age and thus still in the Pleistocene epoch. He equates Recent with postglacial time which he distinguishes from the formalized Postglacial period in the Scandinavian chronology and considers that both terms are only of local value, of subordinate stratigraphic importance, and that both should be used only in an informal way. In Flint's classification we are still in the Wisconsin age, and the Altithermal (his Thermal Maximum) is considered to be a subordinate event within the Mankato substage. The author's research on Pleistocene chronology and climatic controls strongly suggests yet another possibility. By this concept the Altithermal is considered to fall near the culmination of an interglacial period which separates the Wisconsin glacial stage from a still unnamed glacial stage that may attain its maximum extent within the next 20,000 years. A similar conclusion was suggested by Cesare Emiliani (1955) in his study of ocean temperature changes as recorded in deep sea cores from the Atlantic and Pacific Oceans. No matter which concept of the Altithermal is accepted it is evident that the Cochrane, because it precedes the Altithermal, must be considered of Wisconsin age.

SUMMARY AND CONCLUSIONS

The radiocarbon samples from the Cochrane area which are discussed in this paper broadly bracket the Cochrane oscillations between greater than 36,000 and just before 4500 B. C. These results form a consistent sequence with the radiocarbon dates obtained for the intervening substage events of the Wisconsin glaciation. Because the Cochrane is post-Valders maximum, it may be dated between 9000 and 4500 B. C. Thus dated, the Cochrane can be correlated with a glaciation and low eustatic sea-level phase recorded in south-central Alaska (7000–4500 B. C.) and with the post-Fennoscandian, pre-Atlantic Baltic Ancylus Lake period (Boreal, 7000–5500 B. C.) of the Swedish Postglacial chronology. Corroborative evidence for parallel climatic histories for continental North America, Alaska, and northern Europe is found in the apparent agreement between Granlund's humidity cycle, as represented by his dated recurrence sequence, and the glacial and climatic events recorded in Alaska, Canada, and Western United States. His recurrence boundaries (drought periods) dated around 7000 and 4600 B. C. closely bracket the Cochrane oscillations as dated in this paper and coincide with the end of the pre-Cochrane Timiskaming period of rapid glacial retreat and with the oldest period of bog drying, as represented by the lower radiocarbon-dated forest layer in the post-Cochrane bog sequence near Cochrane. Comparison of relative morainal position, estimated distances of readvance, and temporal relations imply that the Cochrane is comparable in rank to the Mankato and earlier Wisconsin substage events. Its pre-Altithermal age would appear to require that the Cochrane be accepted as a substage event of Wisconsin age.

A fundamental conflict between the independently derived radiocarbon-dated and varve-dated Wisconsin glacial sequence is apparent from a direct comparison of the two chronologies as summarized in this paper. Antevs discounts the validity of the radiocarbon chronology on the basis that the radiocarbon ages do not agree with the ages derived from his varve sequences. His chronology is based on a broken varve sequence and tied to the present by a transatlantic correlation of the Cochrane with the varve-dated Fennoscandian substage of Europe. Beyond the question of whether the correlation of the Cochrane with the Fennoscandian is valid, the many gaps in the North American varve sequence, and possible errors in cross dating separate varve sections and in correlations of moraines, require acceptance of the derived varve ages of Wisconsin events as perhaps shrewd first approximations but not necessarily as true figures.

In opposition to the North American varve chronology, available radiocarbon data substantiate the stratigraphic correlation of the Fennoscandian with the Mankato and the varve date of ca. 8800 B. C. for the Fennoscandian substage. The validity of the correlation of the Mankato with the Fennoscandian is further supported by the radiocarbon results presented in this paper, which imply the correlation of the Cochrane as a post-Mankato and pre-Altithermal event, with a post-Fennoscandian and pre-Atlantic glaciation and marine regression. The essential agreement in time and sequence between the discussed radiocarbon-dated events of North America and comparable varve, pollen, and archeologically dated climatic events of Northern Europe provides additional evidence of parallel climatic histories and argues strongly for acceptance of properly interpreted radiocarbon results in a near-absolute, as well as a relative, sense. Such acceptance requires that the Cochrane-Fennoscandian correlation be discarded as untenable and that all absolute chronologies directly or indirectly based on this transatlantic correlation be reappraised in the light of available geologic and radiocarbon evidence. In reaching this conclusion, the author recognizes that individual radiocarbon results may give rise to erroneous geologic interpretations but feels that sufficient radiocarbon data is now available to provide a satisfactory test of the accuracy of the analytical method and of the derived geologic interpretations.

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U. S. GOVERNMENT PRINTING OFFICE: 1956