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The phenomenon of the cyclic nature of the universe and its impact upon the earth's inhabitants is practically inescapable. In fact much of our culture has developed and evolved in response to the vast number of cycles that exist in our environment. A cycle constitutes a sequence of events which progresses until it attains the place or time where it began, but it need not exhibit rhythmicity or periodicity. Many cycles do have rhythmicity and the annual and diurnal cycles are perhaps the most important and significant in influencing living systems. Variation in the seasonal photo-period is an excellent example of a cycle that has a pronounced effect upon the reproductive cycles of many plants and animals. There is evidence that sunspot cycles have had strong influence in controlling not only biological periodicity in various activities of organisms, but even social and economic trends. Then there are the astronomic and cosmic cycles which involve the universe itself and may be measured in terms of millions and even billions of years, caused by the movements and relative positions of the components of the solar system and other bodies of the universe. The direct cause of a rhythmic cycle may be obscured because of the complexity of the ecological system of which it is a part. There has been a well pronounced rhythm of 9.6 years in the abundance of the lynx in Canada for 224 years, and in the abundance of rabbits, tularemia, and ticks, all of which may be part of the ecological system of

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the lynx. A 9.6 year rhythm for tent caterpillars in New Jersey, Atlantic Salmon in Canada, human heart disease in northeastern United States, and the acreage planted to wheat in the United States, however, probably does not relate to an ecological system in which these four components are involved. There are many economic cycles such as pig iron prices, cigarette production, cotton prices, and business failures that are evident, but for which there is no explanation at present. Dendrochronology has demonstrated a close correlation between the annual ring growth in trees and sunspot cycles. Dating of successive moraines by retreating Alaska glaciers in the past 200 years shows a close correlation with the 11-year sunspot cycle. In southwest Africa, pre-Cambrian varves 500 million to 1 billion years old show a cyclic rhythm of 11.5 years.

It is not my intention to discuss the causes of cycles but to review the interpretations of some of the records left by plants and animals and their chronological correlation with geological events and climatic trends. Only a few of these events are recorded, and their chronology in most cases can be only general and approximate. Man has always been interested in trying to interpret prehistoric events and conditions and to correlate the paleoenvironment with the paleobiota. The sciences of paleontology, climatology, paleoecology, paleogeography, archeology, geology, geobotany, geochemistry, and palynology, are some of the tools which have helped him obtain a picture of the past.

In the several billions of years of the earth's existence, there is evidence of innumerable cycles. As one goes back in the earth's history, however, the magnitude and generalities of the cycles increase and become less well defined because the record becomes more sparse and sporadic and more difficult to interpret. In addition to the fossil record of plants and animals, various earth processes such as diastrophism, volcanism, erosion, deposition, weathering, and glaciation provide evidence for cycles and chronology. One of the most interesting and intensely interpreted phases of past environments is that of climate. Paleoclimate is recorded and reflected in a number of ways by the fossil record and by geological processes, which in their interrelations may provide a very complex pattern which is not always easy to decipher. There is evidence in the records that climate has followed a cyclic pattern, and that these cycles have been of varying periods with the shorter superimposed upon the longer ones. Climate in itself is an expression of the conditions and characteristics of the atmosphere which are evanescent. It is the sum total of the weather over a period of time, either long or short. The atmospheric conditions of yesterday do not leave their record for long and in many cases not at all. Many earth processes are directly or indirectly controlled by climate which leaves its imprint physically in and on features of the earth. A strong wind may leave its record in fossil wave ripples on a sandy beach or playa lake, a heavy downpour may be recorded by a deposition of sediments, and a melting glacier may record its recession by moraines or the lamination of sediments in a nearby glacial lake. Changes in plant and animal populations representing biotic succession and migration of the past are also indicators of climatic trends and fluctuations.

One of the most interesting and significant interpretations of life, geological processes, and events of the past is that of chronology. While the evidence and records may be readily accessible, dating of their existence and happenings is not always possible. The relative stratigraphic positions of fossils indicate their time of existence in relation to one another, but not the absolute dates. Estimates have been made with some degree of accuracy, however, particularly of more recent events. They have been based upon observed earth processes and applying the chronology to similar processes of the past as evidenced by the strata and the stratigraphic position and relationships. These include rate of delta building, retreat of earth features by erosion, stream dissection, weathering, soil development, and deposition of sediments including varved clays, peat, and other organic materials. Abnormal strata, whose occurrence indicates an interruption by some external environmental change, also serve as chronological markers. These include such strata as volcanic materials, soil horizons, forest beds, oxidized peat, caliche, woody layers in peat, fire horizons, and others. These are especially valuable if their occurrence is fairly consistent and regional.

During the past ten years, the development of geochemical techniques has provided the means of fairly accurately dating materials of great age. The thousands of dates which have been obtained by geochemical means have enabled the chronologist to attach absolute dates to prehistoric materials and to construct a time table for many of the major events of the past million years.

The most significant and momentous geologic event of the Pleistocene was glaciation. During the earth's history there have been at least four periods when ice sheets formed and spread out from centers of accumulation, during which time the climate was probably cooler than at present. These glacial periods have been of comparatively short duration, however, and most of the time the earth has had a genial climate favorable for the existence and evolution of life. Previous to the Pleistocene, there is evidence that glaciation occurred during the late Proterozoic, the Carboniferous, and the Permian.

During the Pleistocene or "ice age" there were four or five major glaciations covering a period estimated from 300,000 to 1,000,000 years. There were at least four substages of the last glaciation known as the Wisconsin, and it is probable that each major glaciation had a number of substages or minor advances and retreats. Dating of deep-sea cores by geochemical techniques suggest that the Riss-Illinoian glaciation ranges from 100,000 to 125,000 years ago, the Mindel-Kansan from 165,000 to 200,000 years ago, and the Günz-Nebraskan glaciation from 265,000 to 290,000 years ago. Radiocarbon dating indicates that there were major glacial stages around 60,000 years ago and 20,000 years ago, with substages about 13,500, 11,000 and 7,000 years ago (table 1). These are probably all stages of the late Wisconsin glaciation, and the latter substages will be discussed later.

Because of the important part that radiocarbon dating has played in developing a late glacial and postglacial chronology it seems pertinent to present a brief discussion of the method. Radioactive carbon (C^{14}) is formed by cosmic rays bombarding nitrogen atoms in the earth's atmosphere. It emits beta rays and disintegrates to nitrogen. $Carbon^{14}$ has a half life of about 5,570 years, and by measuring the amount of C^{14} in a substance, it is possible to calculate the time elapsed since the active carbon was formed. Carbon dioxide of the atmosphere, soil, and water contains a minute fraction of C^{14} and is absorbed by plants and synthesized in their tissues. Animals eat plant material so they also contain C^{14}. Living organisms maintain an equilibrium between the rate of formation and the rate of decay, but upon death and cessation of metabolism, radioactive disintegration takes place and the total amount of C^{14} is reduced with time. The amount of C^{14} remaining indicates the amount of time elapsed since death of the organism. A maximum of 50,000 years can be dated with assurance of reasonable accuracy, but the possible error increases with age. Artifacts of known age up to 5,000 years have been radiocarbon dated, and the dates are reliable, while dates for prehistoric materials show a consistence to warrant confidence in the method. In addition to the source of laboratory errors, the interchange of C^{14} between organisms and the environment obviously results in the re-use of older carbon as well as dilution with ancient dead carbon. Percolation of ground water containing young carbon may result in its absorption by old carbonaceous material, thus presenting a younger date than is actually the case. A logical consistency in an ever-increasing number of dates of many different materials in many different situations vouches for the reliability and validity of the method. Peat, wood charcoal, shells, and bone are most commonly dated, while inorganic carbonates precipitated in saline lakes of the Great Basin have provided a significant chronology of their pluvial and postpluvial history.

Before the development of geochemical dating techniques, including radiocarbon assay, a fairly accurate chronology of the late glacial and postglacial time had been developed in northern Europe. Here the chronology was worked out on practically an absolute time basis by the study of varves, or layers of sediments deposited in standing bodies of water. In northern Europe and North America varves are associated with the melting of glaciers and are formed in glacial lakes as annual layers. The seasonal gradation of size of particle provides a sharp demarcation between the finer particles deposited late in the season and the coarser particles laid down early in the season of the following year. The thickness of the varves varies from year to year and if they are exposed in cross section, they may be counted and the number of years represented at a given site determined. The Swedish geologist, De Geer, recognized the potential value of varves in late glacial and postglacial chronology and in 1879 began a thorough and systematic study of varve beds. By measuring and counting the varves at one site he found considerable variation in thickness, and by correlating sequences of varve variation in thickness from one site to another, he was able to determine the time required for the ice to retreat from that site to one farther north. This correlation method is analogous to the cross-dating in tree-ring studies. A Finno-Swedish varve chronology includes about 11,600 years, of which 10,150 are considered to represent the northern European postglacial. This is strikingly similar to the radiocarbon date for the Two Creeks forest bed in Wisconsin, which marks the Mankato-Valders stage of the late Wisconsin and is generally accepted as the approximate beginning of the postglacial in North America, as will be discussed later.

One of the most important research tools in the study of paleoclimatology, history of vegetation, and chronology, especially for the Quaternary, is that of pollen analysis. Since the time of its inception, the study of fossil pollen in Quaternary deposits has been commonly spoken of as pollen analysis, but with more extensive application of the method and the identification of fossil spores of greater age, a broader, and more comprehensive and inclusive term was needed. In 1944 the term "palynology" was suggested by Hyde and Williams. Palynology from the Greek "paluno" means to strew or sprinkle; *cf.*, pale, fine meal; cognate with the Latin pollen, flour, dust; the study of pollen and other spores and their dispersal, and applications thereof. The term "palynology" was readily adopted by workers in the field and has been adopted as the official name for the science of pollen analysis and all of its ramifications.

Modern pollen analysis *per se* made its debut in 1916 at Oslo, Norway, when Lennart von Post presented the first modern percentage-pollen analysis in a lecture to the Scandinavian scientists' meeting. Fossil pollen grains were first observed in prequaternary sediments as early as 1836, and the significance of the occurrence of pollen grains in postglacial sediments was noted in 1893. The Swiss Geologist J. Fruh published a paper in 1885 on characteristics of peat in which he listed many of the pollen grains present. Other Germans and Scandinavians made early contributions to the literature on pollen in sediments, but von Post deserves the credit for working out the first pollen profiles in which changes in the pollen proportions were shown from bottom to top.

The immediate and direct interpretation of pollen profiles is into terms of vegetational succession during the time represented and within range of pollen dispersal to the site of the sediments. The various stages of succession as recorded by the composition of the vegetation, indicate the environmental influence upon the vegetation as well as the normal vegetation succession controlled by the synecological and autecological characteristics of the species involved. Paleoclimate in its general trends is perhaps the most significant direct interpretation of the vegetational record.

Considerable attention has been paid to the chronological aspects of pollen analysis, and correlated with other sources of chronological data, a rather definite and probably fairly accurate late glacial and postglacial sequence of events has been determined. Radiocarbon dates have been the most significant factors in building this chronology. It is interesting to note, however, that the general chronology and sequence of late glacial and postglacial events and climate as interpreted from pollen profiles and varves before the advent of radiocarbon dating have been remarkably accurate. The postglacial period of northern Europe, beginning about 10,000 years ago, as based upon varved clay sequences and recurrence surfaces, is divided into five phyto-climatic periods (table 2). The first stage is known as the Pre-Boreal which persisted for about 600 years and was characterized by forests of birch and pine and a cool wet climate. This was succeeded by the warmer and dryer Boreal stage lasting about 1000 years during which time the forests were composed largely of pine and hazel. In Sweden, this period may have lasted for 1500 years. A longer period of continued warmth and greater moisture was characterized by forests of oak, elm, and linden. Including a transition stage, this period, known as the Atlantic, persisted for about 4000 years in Denmark (table 2). A well defined interval, known as the Sub-Boreal succeeded the Atlantic and the climate became warm and dry supporting forests of oak, ash, and linden. The end of this stage is marked by a well oxidized stratum of peat of wide spread occurrence in the peat beds of northern Europe, overlain by fresh and unoxidized peat. This layer has been dated at about 600 B.C. The final postglacial stage of perhaps 2500 years duration to the present, saw a return to cooler and wetter climate supporting forests of oak and beech in Denmark and alder, oak, and birch in the British Isles (table 2).

While these periods are marked by general climatic conditions, there have been many lesser fluctuations during each stage, and during the last several thousands of years there have been rather marked changes in glacial movements that suggest corresponding changes in climate.

The warmest and driest stage during the postglacial in northern Europe, the Sub-Boreal, has been called the xerothermic period. The end of this time is marked by a recurrence horizon in the peat beds of northern Europe. In fact there are numerous such horizons in the peat sediments, which are characterized by a layer of oxidized woody peat, indicating a lowering of the water table in the bogs, resulting in humidification of the organic material. With a return to wetter conditions and subsequent raising of the water table, the shrubby vegetation was replaced with bog mosses. In cross section, a distinct horizon is evident. The Swedish postglacial chronology includes a total of 5 recurrence surfaces, and probably more, dating back to about 3500 B.C. (table 3). Since recurrence surfaces constitute a change from drier to moister climate, they denote recurring dryness at general intervals of 500 to 600 years and 1000 to 1200 years in support of a fundamental climatic cycle of about 550 years and another at about 1100 years interval. These periods of alternating drought and moisture have been almost synchronous throughout Europe since 2300 B.C., and may correspond to similar cycles of bog drying and regeneration in North American bogs.

An excellent point of departure for considering the postglacial time in North America seems to be about 10,000 to 12,000 years. One of the significant radiocarbon dates is that of wood from the Two Creeks forest bed in Wisconsin, located in wave-cut cliffs of Lake Michigan in northern Manitowoc County, Wisconsin, about 25 miles within the maximum extent of the Mankato ice. An average age of about 11,400 years for five samples of wood and peat was determined. Inasmuch as the ice overrode the forest and moved another 25 miles south, the ice (Mankato maximum) is younger and a figure of about 11,000 years seems to be reasonable. Many additional radiocarbon dates from materials that indicate a similar chronological relation to their encompassing drifts, suggest that 11,000 years for this maximum advance of the last stage of the late Wisconsin glaciation was fairly consistent throughout the northern United States. The Two Creeks forest interval probably represents a warmer period more or less concurrent with the Alleröd of northern Germany and Denmark, during which forests of birch and pine flourished between 11,000 and 12,000 years ago (table 2).

In eastern United States, Deevey has carefully worked out a chronology of vegetation changes for at least 15,000 years showing a close chronological correlation with the northern European sequence (table 2). The first was tundra which persisted until 14,000 years ago, followed by forests of spruce, pine, and birch for 1000 years or so. A brief return to tundra conditions is suggested by pollen of tundra herbs, again to be invaded by forests consisting of spruce, pine, fir, and oak during the Pre-Boreal. Continued warming favored increase of pine during the Boreal, while persistent warmth accompanied by increased moisture during the Atlantic, favored oak and hemlock for several thousands of years. A warm but dryer climate permitted hickory to flourish during the Sub-Boreal, while cooler and moister conditions during the sub-Atlantic saw forests of oak and chestnut predominate the scene during the past 2000 years. In the last few centuries the increase in spruce and fir may indicate cooling.

There is little doubt that during the past 11,000 years, since the last continental glaciers melted, there was an increase in temperatures to a degree higher than at present, followed by cooler or wetter climate or both. In some parts of the northern hemisphere there was also a decrease in moisture which is well recorded by the increase in xerophytic vegetation, lowered lake levels, and higher timberlines. This period of warmth and dryness, which varied in length in various parts of the world, has been recognized by a number of terms,

GENERAL CHRONOLOGY OF THE PLEISTOCENE

Years B. P.*	North American Glacial Stages	Northern European Glacial Stages
6,500 - 7,500	Cochrane	Ragunda Pause
10,000 - 11,000	Mankato-Valders	Fenno-Scandian
13,500 - 14,500	Cary	Scanian
17,000 - 18,000	Tazewell "Classical Wisconsin"	Pomeranian
30,000 - 40,000	Farmdale	Frankfurt Brandenburg
45,000	Interglacial	Interglacial
55,000 - 70,000	Early Wisconsin (Iowan)	Warthe
100,000	Sangamon Interglacial	Interglacial
120,000	Illinoian Glacial	Saale
180,000	Yarmouth Interglacial	Interglacial
200,000	Kansan Glacial	Elster
260,000	Aftonian Interglacial	Interglacial
300,000 ?	Nebraskan	

* The letters "B.P." as used here indicate "Before Present".

TABLE 1

Estimated dates of the major glaciations during the Pleistocene and the substages of the late Wisconsin beginning with the Tazewell. Dates are from many sources including radiocarbon and other geo-chemical techniques, varves, peat stratigraphy, volcanic ash and pumice, lakes sediments, and pollen profiles.

Yrs. B.P. 1000	Glacial Sequence			Pollen Sequence Denmark N. Germany	Pollen Sequence British Isles	European Cultural Stages	Pollen Sequence N. E. United States	Yrs. B.P. 1000
	Glacial			Sub-Atlantic	Sub-Atlantic		Sub-Atlantic	
1				Beech-Oak	Alder-Oak Birch	Iron	Oak-Chestnut	1
2	Glacial			Cool-Wet	Cool-Wet			2
	Glacial							
3				Sub-Boreal Oak-Ash Linden	Sub-Boreal Alder Mixed Oak	Bronze	Sub-Boreal	3
4	Glacial	POSTGLACIAL		Warm-Dry	Warm-Dry	Neolithic	Oak-Hickory	4
5			HYPSITHERMAL	Atlantic Oak-Elm Linden	Atlantic Oak-Elm Oak Pine			5
6							Atlantic	6
7	Cochrane					Mesolithic	Oak-Hemlock	7
				Warm-Wet				
8								8
9				Boreal Pine-Hazel	Boreal Pine-Hazel		Boreal Pine	9
10				Pre-Boreal Birch-Pine	Pre-Boreal Birch		Pre-Boreal	10
11	Mankato			Younger Dryas Park-Tundra	Younger Dryas Park-Tundra		Spruce-Fir	11
12	Two Creeks Interval			Alleröd Birch-Pine Warmer	Alleröd Birch Warmer		Pine-Oak	12
13				Older Dryas	Older Dryas	Paleolithic	Tundra	13
				Bolling Park-Tundra	Tundra		Spruce-Pine	
14	Cary	LATE GLACIAL		Oldest Dryas			Tundra	14
15								15
16								16
17								17
18	Tazewell							18

TABLE 2

Late-glacial and postglacial stratigraphy of northern Europe and northeastern United States with substages of the late Wisconsin glaciation and cultural stages of Europe. (From Deevey and Flint and Karlstrom).

Yrs. B.P. 1000		Great Basin (Antevs)	Alaska	Sweden	Blytt-Sernander Climatic Sequence Sweden	Glacial Sequence N. America	P.N.W.	Japan (Tsukada)	Northern Alaska (Livingston)	Southeastern Alaska (Heusser)	Coastal Washington (Heusser)	Yrs. B.P. 1000
0–1	NEOTHERMAL	Medithermal	V	I	Sub-Atlantic	Glacial		Tsuga	Tundra	Muskeg Regeneration	W. Hemlock	1
1–2		Rebirth of Lakes and Glaciers	IV	II	Cool-Wet	Glacial		Picea	Alder Decline	Invasion of Coast Forest	Maximum	2
2–3			III	III	Grenz-Horizont	Glacial		Abies		W. Hemlock Maximum	Pine	3
3–4		Cooler Wetter		IV	Sub-Boreal Warm-Dry	Glacial			Tundra	Lodgepole		4
4–5		Altithermal Warmer than	II	V			THERMAL INTERVAL	Quercus Fagus	Alder Maximum	Coast Forest Predominance	Douglas Fir Maximum	5
5–6		Present			Atlantic			Ulmus Pterocarya		W. Hemlock Sitka Spruce		6
6–7		Disappearance of Lakes and Glaciers	I		Warm-Wet	Cochrane			Tundra Dwarf Birch		W. Hemlock Oak	7
7–8			GLACIATIONS IN GLACIER BAY AREA	RECURRENCE HORIZONS IN SWEDISH BOGS								8
8–9		Anathermal Warmer			Boreal Warm-Dry			Betula	Herbaceous	Lodgepole		9
9–10					Pre-Boreal Sub-Arctic			Picea Pinus	Tundra		Lodgepole	10
10–11		Pluvial Lakes			Arctic Younger-Dryas	Mankato				Lodgepole Parkland	Lodgepole Parkland	11
11–12					Alleröd						Mt. Hemlock Fir	12
12–13												13
13–14						Cary					Lodgepole Parkland	14
14–15											Non-Arboreal Pollen High	15

TABLE 3

Late-glacial and postglacial pollen sequences from western North America correlated with the Great Basin, Sweden, and Japan. (from Heusser, Antevs, Karlstrom, and Hansen).

1000 Yrs. B.P.	P.N.W.	East. U.S.	G. Basin	P.N.W.	Puget Sound	South Central B.C.	Eastern Washington	Willamette Valley	Oregon Cascades	Lower Klamath Lake	Northern Klamath Lake	Volcanic Ash Pumice	Radiocarbon Dates Yrs.	1000 Yrs. B.P.
0–1	POSTGLACIAL		MEDITHERMAL	COOLER-WETTER	Hemlock Predominance	Lodgepole Douglas Fir Spruce	Yellow Pine Maximum	Douglas Fir Oak	Hemlock	Lodgepole	Lodgepole			
1					Douglas Fir Fir		White Pine	Hemlock	Lodgepole White Pine	White Pine Yellow Pine	Yellow Pine	Newberry		1
2		DEEVEY'S HYPSITHERMAL			White Pine		Lodgepole	Fir	Fir			Pumice	2054	2
3					Cooler Moister	Cooler Moister	Cooler Moister		Yellow Pine		Grasses Composites			3
4			ANTEV'S ALTITHERMAL	THERMAL INTERVAL	Douglas Fir Decline	Yellow Pine Maximum	Grasses Chenopods Composites	Pumice		Grasses	Grass Chenopod Composite	Willamette Pumice		4
5–6					Hemlock Increase Volcanic	Thermal Interval Volcanic	Volcanic	Elephant Bones	Yellow Pine Maximum	Yellow Pine Maximum	Maximum	Mount Mazama Pumice	6453	5, 6
7					Ash Douglas Fir Maximum	Ash	Ash Thermal Interval	Oak Maximum				Washington Ash	6750	7
8–9			ANATHERMAL	WARMING	Douglas Fir Increase	Warming	Warming Drying	Warming Drying	Yellow Pine Douglas Fir	Yellow Pine White Pine	Yellow Pine White Pine		Ft. Rock Sandals	8, 9
10–11					Lodgepole Predominance and Maximum	Lodgepole White Pine Douglas Fir Spruce	White Pine Lodgepole Yellow Pine	Douglas Fir Hemlock Spruce Fir Lodgepole Maximum	Lodgepole Maximum	Lodgepole	Lodgepole		Puget Lowland Peat	10, 11

TABLE 4

Composite pollen profiles from many peat sections in the Pacific Northwest showing postglacial forest sequences correlated with radiocarbon dated pumice and ash. The "thermal interval" is shown from 8000 to 4000 years ago. (from Hansen).

	Oregon	Utah	Nevada	California
Glacial	Summer Lake	Salt Lake	Pyramid Lake	Searles Lake
Tioga-Mankato	Winter	Provo	Dendritic	Parting Mud (10-23,000 yrs.)
Tahoe (Pre-Wisconsin)	Chewaucan	Bonneville	Lahontan	Bottom Mud (32-46,000 yrs.)

Table 5

Pluvial (glacial) stages of Great Basin lakes and mountain glaciation in the Sierras and chronologically correlated with radiocarbon dates from Searles Lake. (from Allison, Antevs, Blackwelder, and Flint and Gale).

including "xerothermic period," "climatic optimum," "thermal interval," "thermal maximum," "altithermal," "megathermal," and "hypsithermal." It is not the purpose of this paper to discuss the semantics or evaluate these terms in relation to which best describes this accepted concept of a post-glacial temperature maximum. It suffices to say that such climatic development did take place and that it was fairly consistently regional in its extent and magnitude. It is also uncertain as to the exact period of time involved, but it is immediately recognized that the time limits assigned are determined by the individual's concept as to what the limits or boundaries of temperature and moisture are and what latitudes and altitudes are involved. Upon the basis of peat stratigraphy, varves, and recurrence horizons, before the advent of pollen analysis, Scandinavian bogs were interpreted as showing a cool-dry Boreal period, a warm-moist Atlantic, and a warm-dry Sub-Boreal period, the latter designated as the "xerothermic" and the Atlantic as the "climatic optimum." Chronological correlation with De Geer's varve sequences indicates the climatic optimum between 6,000 and 4,000 years ago and the entire time of the thermal interval or period as extending from about 9,000 to 2,500 years ago.

In the Pacific Northwest, pollen analyses of many peat sections located in several different phytogeographic and climatic regions, correlated with radiocarbon dates of bottom peats and volcanic ash and pumice horizons, reveal a remarkably consistent and regional sequence of climate and chronology. Radiocarbon dates of bottom peat in the Puget Sound region indicate that about 11,000 - 13,000 years comprise the time represented. Beyond the glacial boundaries, physiographic events resulting from glacial retreat set a similar date for peat sections in unglaciated areas. In general, the pollen profiles indicate increasing warmth and desiccation to a maximum and then a return to cooler and moister conditions in more recent time. It does not seem possible to interpret the profiles as the five or six climatic stages as has been

Name of Site	Location	Radiocarbon Dates	Cultural Materials
Tule Springs	South Central Nevada	23,000	Obsidian Flakes, Scrapers, Camel, Bison, Horse, Mammoth
Lindenmeier	Northeastern Colorado	10,780	Folsom Points, Stone Implements, Carved Bones, Knives, Charcoal, Bison, Camel Bones
Lehner Site	Southeastern Arizona	12,000	Clovis Fluted Points, Charcoal, Mammoth, Bison, Horse, Tapir
Fort Rock Cave	South Central Oregon	9100	Points, Scrapers, Awls, Atlatl Spur, Sagebrush Sandals
Five Mile Rapids	The Dalles Oregon	9700	Points, Scrapers, Choppers, Bird, Fish, Other Animal Bones
Danger Cave	Wendover, Utah	11,000	Stone Artifacts, Netting, Mats, Basketry, Mountain Sheep, Deer, Antelope
Leonard Rock Shelter	Lovelock Nevada	11,000	Atlatl Points, Shell Beads, Scrapers, Etc.
Denbigh Flint Complex	Cape Denbigh Norton Sound Alaska	5000 R.C. 8500 Est.	Microblades, Fluted Point
Frazer River Canyon	British Columbia	8000	Points, Bones, Artifacts Related to Fishing

TABLE 6

Radiocarbon dates of materials from cultural sites in western North America. (from Wormington).

done for Europe and eastern North America. Apparently there was a single major period of maximum warmth and desiccation, rather than the alternating dry and wet warm of the Boreal, Sub-Boreal, and Atlantic.

In the Puget Sound region, the thermal interval is not well defined because of the influence of the Pacific Ocean. While increases and predominance of western hemlock during the past 4000 years and its partial replacement of Douglas fir, suggest a preceding warmer and dryer climate, the postglacial forest sequence in this region probably represents normal forest succession from the pioneer invaders to the climax of the present. In eastern Washington and Oregon, however, the thermal interval is well portrayed by a pronounced expansion of drought-resisting vegetation consisting of grasses, chenopods, and composites (table 4). Many of the plants represented in the pollen profile are halophytic and emphasize the existence of xerophytic conditions, because they probably invaded the dry beds of alkaline lakes. In the Willamette Valley of Oregon, an influx and expansion of oak with decrease of conifers depicts the warmer and dryer conditions. In south central British Columbia, a well-defined yellow pine maximum further substantiates the development of warmth and dryness, and attests to their widespread and regional occurrence.

In addition to the radiocarbon date of 11,000 years for bottom peats in the Puget Sound region, which marks the minimum date for deglaciation by the ice of Mankato equivalent, an extremely important chronological marker is present in most of the Washington peat sections in the form of a layer of volcanic ash. The source of this ash has been traced to Glacier Peak in north central Washington, and radiocarbon dates of peat immediately underlying the ash horizon range from about 6700 to 5300 years ago. The author, before radiocarbon assay, estimated the date of this ash layer at about 6000 years, based upon its stratigraphic position in the peat sections and pollen profiles (table 4). Another equally valuable radiocarbon date is that for the eruption of Mount Mazama in south central Oregon, which left the caldera holding Crater Lake. Charcoal from trees which were first charred by the incandescent gases that rolled down the slopes and then buried by pumice, have been dated at about 6500 years. Pumice from Mount Mazama, in peat sections in the northern Great Basin of southern Oregon, occur well above the beginning of the thermal interval, and about in the same relative stratigraphic position as the Washington ash from Glacier Peak (table 4). Thus in the Pacific Northwest, both west and east of the Cascade Mountain range, there is strong evidence that the thermal maximum can be bracketed between 8000 and 4000 years ago. This is consistent with Ernst Antev's dating of the Altithermal of the Great Basin from 7500 to 4000 years ago (table 3). In coastal Alaska, British Columbia, Washington, Oregon, and California, Heusser interprets from many peat sections and pollen profiles a thermal interval (hypsithermal) in the middle third of the recorded vegetational history. In northern Alaska, Livingston relates an expansion of alder into the tundra to the thermal maximum within the time boundaries of that of the Pacific Northwest, while Tsukada believes that replacement of conifers by forests of oak, beech, and elm in Japan reflect this same period of maximum warmth and desiccation (table 3).

In the Great Basin of western United States, the stages of glaciation to the north are considered to have been concurrent with pluvial periods during which time the lakes were deepened and enlarged. Shorelines and terraces of these ancient lakes are very evident and have received a great deal of study and analysis by various workers, and have been chronologically correlated with glacial stages to the north. Antevs has set the postglacial in the Great Basin as beginning at the time that postglacial temperatures had reached about the same point as those of today. Chronologically this is based upon the Finno-Swedish varve chronology of De Geer, Liden, and Sauramo which sets about 10,150 years ago as the beginning of the postglacial in Europe. This date also marks the beginning of the Pre-Boreal climatic stage. Antevs has named the postglacial in the Great Basin the Neothermal which he divides into a period of increasing warmth, the Anathermal; a period of maximum warmth and desiccation, the Altithermal, from 7500 to 4000 years ago; and a final period of greater moisture and lower temperatures, the Medithermal (table 3). The end of the thermal interval is marked by the fact that the present salinity of Great Basin lakes, Abert and Summer lakes in south central Oregon and Owens Lake in east central California, is such that could not have taken more than 4000 years to be attained. Antevs believes that during the Altithermal these lakes dried up and their salt sediments were either blown out or buried by sand. With the advent of a wetter climate these lake basins were again filled and the lakes freshened. According to Matthes, the fluctuations of glaciers in the western mountains are closely correlated chronologically with the pluvial periods and the levels of the lakes in the Great Basin. He suggests that the modern glaciers came into being within the past few thousands of years after virtually disappearing during the warm dry Altithermal.

One of the most conspicuous evidences of the high lake levels in the Great Basin pluvial stages are well defined terraces considerably higher than the present level of the lakes. These terraces represent long time stages of lake levels that were maintained by the greater precipitation probably contemporaneous with the glacial stages to the north. These Pleistocene lakes have been correlated, and some of the major ones are the lakes Provo and Bonneville in the Salt Lake basin, Dendritic and Lahontan in the Pyramid Lake basin of Nevada, and the Winter and Chewaucan lakes in south central Oregon. All of the first named of each pair have been chronologically correlated with the Tioga mountain glaciation in the Sierra and the Mankato-Valders of central United States, and the second ones may have been concurrent with the Sierra Tahoe and an earlier Wisconsin (Iowan) glaciation (table 5).

Stratigraphic studies and radiocarbon dates of sediments in Searles Lake, a dry lake in southeastern California, provide dates that have tentatively been correlated with the pluvial stages of Great Basin lakes. Two deep lakes are recorded implying a pluvial climate, each of which was followed by near-desiccation representing a warmer and dryer climate or interpluvial stages. The later pluvial climate persisted from about 23,000 to 10,000 years ago, and was contemporaneous with the classical Wisconsin glaciation, while the earlier pluvial from about 46,000 to 32,000 years ago was synchronous with Lake Lahontan of the Tahoe-pre-Wisconsin glaciation (table 5).

The late glacial and postglacial saw the extinction of most of the large mammals that existed abundantly during the Pleistocene in North America. Radiocarbon dates of animal remains, dung, and associated organic materials indicate that most of the extinction took place between 10,000 and 3,000 years ago, varying in different parts of the continent. Seven species have persisted as late as 2000 years ago in Florida, but no remains from Alaska have been dated at less than 16,000 years ago. In western United States, most of the large mammals became extinct before 6000 years ago. These include the mastodon, woolly mammoth, giant bison, horse, sloth, shrub-ox, dire wolf, big beaver, bear, cats, tapir, camel, cave deer, and others. The cause of their extinction is a mystery and a number of theories have been expressed, such as early hunters, climatic changes, and epidemics. Mastodon bones buried in a shallow swamp near Silverton, Oregon, have been dated on the basis of their stratigraphic position in the pollen profile well above the beginning of the thermal maximum as indicated by its recorded influx and expansion of oak (table 4). They have been dated at not older than 6000 years, which would be one of the most recent occurrences in the western United States.

Perhaps one of the most interesting and fascinating aspects of Pleistocene chronology is that concerning the time of arrival of man on the scene. It is now generally accepted that man *(Homo)* made his first appearance in the Pleistocene, possibly 300,000 years ago during the Günz (Nebraskan) glacial stage. This is based upon the occurrence of hominid fossils in stratigraphic sequence that have been correlated with the Pleistocene glacial stages as based upon temperature variations of equatorial, tropical, and temperate marine surface waters determined by oxygen isotopic analyses of pelagic foraminifera from deep sea cores, radiocarbon and ionium dates of deep sea cores, and comparison with insolation curves. When *Homo sapiens* appeared is a problem of taxonomy as well as dating, however, and it is possible that he did not evolve more than 100,000 years ago and probably less. The last hominid forms to evolve seem to have been Neanderthal man and Cro-Magnon man, which were contemporaneous. The former became extinct by the end of the last glaciation, however, while Cro-Magnon persisted and has flourished. In terms of European cultural stages, Paleolithic man was able to persist through the late Wisconsin glaciation, which culture may have survived until the end of the late glacial Fenno-Scandian of northern Europe (Mankato) during tundra conditions (table 2). The beautiful paintings in the Lascaux Cave in central France are at least 15,000 years old as determined by radiocarbon dates of charcoal found in the cave. The beginning of the postglacial about 10,000 years ago, has also been designated as the end of the Paleolithic and the dawn of the Mesolithic cultural stage, which saw ameliorating climatic conditions in the North Temperate zone. The Neolithic stage in Denmark, northern Germany, and the British Isles began near the end of the warm wet Atlantic between 5000 and 6000 years ago. This was followed by the Bronze Age from 3500 to 2500 years ago which ended with the warm dry Sub-Boreal delineated by the recurrence horizon known as the Grenz-Horizont of the Sernander climatic sequence (table 3). The cooler and wetter climate of the sub-Atlantic is thought to have been concurrent with the Iron Age, and includes the Roman occupation of parts of the British Isles. In the Mediterranean Basin, radiocarbon dates indicate that man has existed there for at least 50,000 years, the present limits of determination by radiocarbon techniques.

The chronology of man in North America did not receive the intensive study that it did in Europe, and until the advent of radiocarbon dating, one or two millennia were considered to be sufficient antiquity to cover the period of occupation. The first discovery that provided evidence for a probable greater antiquity was that of pollen analysis upon which are based the climatic sequences correlated with those of Europe. In Lower Klamath Lake, Oregon, pollen analysis of peat sections shows a fossil lake bed under 13 feet of peat which had been occupied by early man, evidently resulting from the warmth and drought of the Thermal interval. This interval is substantiated on the basis of the aforementioned fluctuation of Great Basin lakes. It is obvious, however, that the hominid record in North America does not begin with pre-*Homo sapiens* forms. This fact immediately presents the problem as to the time and source of the invasion of the New World by early man. While a number of mythical hypotheses have been advanced, they are hardly worth mentioning in view of the vast amount of evidence that has been uncovered which refutes them. This evidence, as studied and interpreted by archeologists, includes tools and implements that depict technological stages, methods of subsistence indicating the use of the environment in getting food, clothes and shelter which point to their adaption to climate, and their cultural attributes which outline their socio-economic patterns. The vast amounts of time and space involved and the comparatively small number of widely-spaced occupational sites discovered further complicate the problem. There seems to be little doubt, however, that the paleontologic, geologic, and geographic evidence of Tertiary and Quaternary times points with assurance and confidence to the conclusion that the Old and New Worlds have at intervals, and for fairly long periods, been connected by a land bridge across Bering

Strait between Alaska and Siberia. The land connection between the two continents was controlled by glaciation and deglaciation, resulting from fluctuation of sea level as ice either melted or accumulated. Paleontological evidence suggests that a seaway existed during the middle Eocene but that during the glacial stages they became connected by a land bridge. This means that during the past 100,000 years there have been at least two long periods during which such a land bridge existed. The first was in response to an early Wisconsin glaciation, perhaps 75,000 to 50,000 years ago, and a second during the late Wisconsin between 25,000 and 10,000 years ago, since which time no connection has existed. Although the land bridge must have existed during a period of an Arctic climate and must have supported only tundra vegetation, it provided a pathway for early man into the New World and for the migration of plants and animals back and forth.

The inundation of the land bridge at the termination of the last major stage of Wisconsin glaciation (Mankato) eliminated access to the New World by terrestrial flora and fauna, including man. Entry of man into the New World from Siberia must have taken place during one of the glacial stages, the latest of which could have occurred less than 10,000 to 15,000 years ago. Man also could have come during one of the earlier glacial intervals, about 50,000 years ago. Radiocarbon dates of 10,000 years for materials associated with man's culture substantiate the forgoing evidence for his migration over the land bridge during the late Wisconsin or at an earlier glacial stage. The central part of Alaska and western Yukon Territory were not glaciated during the late Wisconsin stage and in spite of the cold climate that must have existed the summers were sufficiently warm so as to maintain a food chain composed of both plants and animals that permitted man to subsist. Slow migration eastward into interior Alaska and the Yukon during both glacial and interglacial intervals was possible, and then southward movement along the east flank of the Rocky Mountains in British Columbia took place, although the archeological evidence for the latter is quite sparse. The existence of an ice-free corridor during most of the late Wisconsin is evidenced by pollen analysis of peat sections along the present Alaska Highway and in western Alberta, in which forest-tree pollen is present near and at the bottom of muskegs as much as six meters deep. This enabled continued migration southward during the late Wisconsin by any migrants whose ancestors had taken advantage of the Bering land bridge during or before the early Wisconsin glaciation. Although there is no direct evidence for this, it is more than conjecture. It is substantiated by many radiocarbon dates that man reached Central and South America more than 10,000 years ago. This does not suggest any phenomenal speed of migration, however, because at a rate of one mile per year, the southern tip of South America could be reached in about 10,000 years.

While most of the radiocarbon dates for occupation materials range in the vicinity of 10,000 years, several are greater, and the Tule Springs site in south central Nevada has been dated at 23,000 years (table 6). If this is true, it adds support to the idea that man's arrival in the New World was before the late Wisconsin maximum of about 15,000 years ago. Early man and the megafauna of the late Pleistocene were apparently contemporaneous until about 8000 years ago, and since then, man had to get along without whatever these large mammals furnished him in the way of food, clothing, and shelter.

Many thousands of years after the first invasion by *Homo sapiens* of the New World from the west, another invasion from the east took place. The earliest record of this migration is found in Greenland and in the records set down by the Norsemen who founded a colony numbering as many as 3000 persons in southwestern Greenland about 1000 years ago. The colony thrived for about three hundred years, and then a cooling period began about 1600 A.D. and lasted until at least the middle of the 18th century. During this time of cooling, the so-called "Little Ice Age," glaciers in Alaska and northern Europe probably advanced to their greatest maximum since before the Thermal maximum. From 1750 to 1800 A.D. there was a pronounced retreat, with a readvance attaining a maximum about 1850, and then general retreat again until the present. In a detailed study of the retreat of Herbert Glacier 25 miles north of Juneau, Alaska, Lawrence discovered a series of about twenty parallel crescentic moraines marking a recession of the glacier beginning about 1740 A.D. He ascribed the systematic morainal deposition as correlative with a 11-year sunspot cycle with moraine formation occurring with low sunspot number intervals which reflected increased glacier nutrition, while retreat is correlated with a high sunspot number resulting from reduced nutrition.

In summary, I have briefly, and with many gaps, pointed out some of the cyclic and chronological events of the Pleistocene, a time of marked climatic changes. This was a period of perhaps a million years that saw four or five major periods of glaciation in the northern hemisphere. It was a time during which man apparently evolved his present state of mental and physical development. It was a time of great displacement of biota by the ice sheets as they radiated from their centers of accumulation northward as well as southward. The latter part of this ice age, saw the extinction of a large number of species of megafauna which grew up with early man, and undoubtedly provided him with a source of food, clothing, and shelter before he developed primitive agricultural practices. This same early man in western United States witnessed several volcanoes eject vast quantities of lava, ash, and pumice, the last two of which serve as excellent chronological markers and provide us with the basis for some fairly good dates for postglacial forest history and climatic fluctuations. There is no reason not to believe that we will have more glacial stages within the next 10,000 years, more or less.

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