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CLIMATIC CHANGES OF THE PAST AND PRESENT

BY
ERLING DORF

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ERLING DORF[1]

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INTRODUCTION

INHABITANTS of the so-called temperate zone are quite familiar with both unusual weather and rapidly changing weather conditions. Lately, however, even the climate—that is, the composite weather conditions over a period of years—has seemed somewhat unusual and the "reality" of changing climatic conditions has become not only apparent, but even newsworthy. Some people may be old enough to have recollections of "the good old days" when the climate was different: the winters at least seemed to have been much colder and the snows much deeper than they are today. Although reliable meteorological records do not go back very far, they do seem to show that major climatic changes rather than minor fluctuations are taking place. Present conditions *are* warmer than they were in the latter half of the 19th century.

* Based on the 1957 Ermine Cowles Case Memorial Lecture delivered before the Society of Sigma Xi, University of Michigan, November 13, 1957.

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In terms of the remote geologic past, however, today's climate is actually unusually cold. In fact, we are still living in a "glacial age" compared to the much warmer conditions of 35 to 40 million years ago. An examination of Figure 1 will show that, since the beginning of the Cambrian Period, 500 million years ago, the earth's climate has been considerably warmer than at present about two-thirds of the time. The evidence indicates that major climatic changes from this warmer "non-glacial" to much colder "glacial" climate have occurred several times during geologic history. The world today is in one of these glacial episodes, which only a few thousand years ago was frigid enough to support an ice sheet over most of Canada and as far south as the northern United States. Furthermore, it may be noted (Fig. 1) that the cooling trend which culminated in the most recent glacial episode really started back in the Oligocene Epoch and not, as some people still believe, in the Late Pliocene.

In the present paper three major topics are discussed: (1) the climatic changes of the remote geologic past from about 50 million to about 12,000 years ago, that is, from about the beginning of the Eocene Epoch to the end of the Pleistocene "Ice Age"; (2) the climatic changes of the immediate past, from the end of the "Ice Age" to the present; and (3) a prediction of the possible climatic changes of the near future and of the next few thousand years.

CLIMATIC CHANGES OF THE GEOLOGIC PAST

Methods of Study

One may ask: how is it possible for geologists to reconstruct climates of thousands or even millions of years ago? Since climates are conditions and not, therefore, subject to fossilization, the evidence for depicting ancient climates must come entirely by inference from whatever clues are available in the geologic record. Throughout their work geologists rely at the outset on the doctrine that the present is the key to the past. It is supposed that fossil plants and animals lived under approximately the same climatic conditions as their most closely related living relatives. In this respect assemblages of fossils rather than individuals have proved to be the more reliable. Certain morphological features, as shape, size, and marginal character of fossil dicot leaves are useful. They confirm the inferences obtained through other methods. Even the rocks possess certain features which indicate that they originated under a particular kind of climate.

Fossil plant remains are, in general, proven to be the most widespread and dependable indicators of ancient climates of the earth's land areas available. This is true in large part because plants are more sensitive than animals to their environment. A comparison of any map of the world's vegetation zones with one of the world's climatic zones will show how nearly the two coincide. Plants, moreover, are stationary and they can, therefore, not migrate nor burrow underground to escape the rigors of an unfavorable season. No palms or breadfruit trees, for instance, will live in the parks of New York, Chicago, or Ann Arbor, simply because the climate is too cold or, more specifically, the winter season is too cold. Such plants represent types which can be used as climatic indicators of the past. For example, Plate I illustrates a specimen of a palm and one of a cycad that were collected from the Eocene rocks on Kupreanof Island in southeastern Alaska. These leaves were associated with the remains of laurels, magnolias, acacias, peppers, and other forms which clearly indicate conditions much warmer than exist in that region today, in fact, they were subtropical. A collection of poplars, maples, elms, and oaks would, on the contrary, indicate temperate conditions of growth; and a fossil occurrence of northern spruce, larch, alpine fir, and birch would point to subarctic (boreal) conditions.

Although the above is true, it must be emphasized that not all plants are equally valuable as climatic indicators. Some forms are too cosmopolitan, that is, they are too tolerant in their requirements. For example, pines occur in modern forests from sea level to the mountain tops and from the subtropics to the subarctic. The common brake, or bracken fern, is equally at home whether in the tropics or in temperate regions. Clearly neither fossil pines nor fossil bracken ferns would be reliable indicators of particular climates of the past. The best climatic indicators of the past are obviously those forms whose nearest living relatives have the narrowest climatic requirements in modern forests.

Generally, conclusions based on a few climatic indicators should be confirmed, whenever possible, by inferences based on the study of an entire assemblage of fossil plants. This eliminates the possibility of a few unrepresentative forms giving erroneous conclusions regarding past climates. A number of tropical families have temperate relatives which appear to be "foreigners," climatically speaking, in the temperate forests. Magnolia, for instance, which belongs to a tropical family, extends into the temperate forests as far north as Massachusetts and southern Ontario and the persimmon, and the sassafras, both members of tropical families, extend as far north as southern New England. Along the Pacific Coast the pepperwood (*Umbellularia*) is another typical temperate representative of a normally tropical family. If such forms as these were found in a fossil plant assemblage whose composition was predominantly temperate, they would be regarded as foreigners and eliminated from the list of valid climatic indicators.

In spite of the appearance of a few anomalous plants in a collection, the general facies of the total assemblage gives the only safe and reliable basis for reconstructing ancient climates. It is useful, however, to apply another, quite independent, method of determining past climatic conditions by means of certain anatomical features of plants. The majority of the deciduous leaves in forests in the humid subtropics and tropics are relatively large and smooth-margined, whereas those in temperate forests are dominantly smaller and variously lobed or toothed along their borders (Bailey and Sinnott, 1915). The arrangement and number of stomata on leaves are also helpful in determining the conditions under which the leaves developed. Since these morphological features can usually be observed in fossil leaves, their use in making paleoclimatic inferences is of great value.

Among animals used in the study of ancient climates, the marine corals, especially the reef corals, are the most reliable. Contemporary reef corals live only in the warm, clear seas of the subtropics and tropics. It is, therefore a fair assumption that closely related reef corals, when found as fossils, likewise indicate warm, clear seas at the time they lived. The fossilized remains of alligators and crocodiles, manatees, and tapirs are generally regarded as proof of subtropical to tropical conditions, whereas the recovery of fossil bones or skeletons of reindeer, muskoxen, walrus, or the boreal lemming points to cold, subarctic conditions. The discovery that the proportion of oxygen isotopes in the shells of marine shellfish depends upon the temperature of the sea water in which the animal built its shell has been found of value in reconstructing the changing oceanic temperatures of the past (Piggot and Urry, 1942). This last has been a particularly welcome method, because it is completely independent of the actual species, genus, or family to which the shells may belong.

Geologists have also found it possible to confirm climatic inferences by means of certain characters of associated sedimentary rocks. Lowland glacial deposits, for example, which are not too difficult to recognize, clearly indicate a past episode sufficiently cold to allow for the development of lowland ice sheets. On the other hand, reddish sedimentary rocks, generally owing their origin to the red soils called laterites, are known to form only under conditions having an annual temperature of at least 60° F. and 40 inches of annual rainfall (Krynine, 1949). Evaporite deposits, including salt and gypsum, usually indicate that conditions were semiarid to arid during their formation. Extensive coal deposits, from such unlikely places as Antarctica and Spitsbergen, are generally interpreted as having accumulated during a humid, temperate to subtropical period.

The known physical conditions of a particular period of the geologic past have also been used to reconstruct ancient climates. Inferences derived from this source are based on the relative heights of continents, the relative amount of land versus water, the inferred direction and temperature of ocean currents, and the amount of volcanic activity. Climatic curves based on such studies approximate very closely those derived from the study of fossil organisms (Brooks, 1951, p. 1016).

In the present discussion the reconstruction of past climatic conditions is limited to those of the Cenozoic Era, which began about 70 million years ago. The record of this portion of geologic time is more complete than that of more ancient periods. Furthermore, Cenozoic fossils show closer relationships to living plants and animals than is true of older fossils; hence, comparisons of the climatic requirements of Cenozoic with living assemblages are considered more reliable.

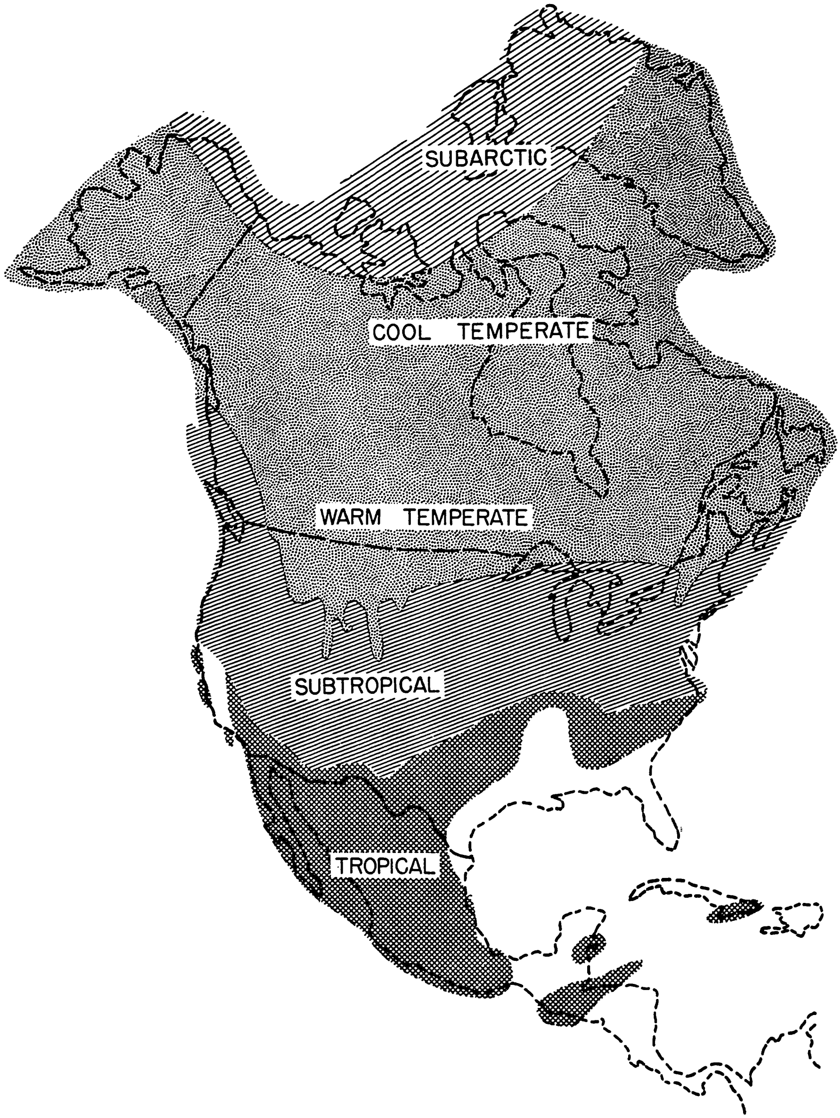
Tertiary Climates of North America

Late Eocene-Early Oligocene.—The inferred climatic zones[2] of the Late Eocene to Early Oligocene epochs, beginning about 40 million years ago and lasting until about 30 million years ago are illustrated in Map 1. The climatic zones of the preceding Paleocene Epoch, though not yet as well established, indicate somewhat cooler conditions. In both Europe and North America a general warming trend began before the end of the Paleocene Epoch and continued into the Eocene. As a consequence, by the end of the Eocene and continuing into the Oligocene the temperate forest belt in North America had shifted about 20 degrees of latitude farther north than its present position and, at the same time, the tropical forest belt extended about 10 to 12 degrees farther north than at present. In the Gulf Coast states, for example, there are numerous fossil remains of both Late Eocene and Early Oligocene forests whose nearest living relatives live in the tropical lowlands of northern South America and coastal Mexico. Fossil remains of these forests occur in widespread coastal plain deposits as far north as Tennessee and Missouri. Both mangrove swamp and beach jungle associations are represented. Some of the notable members of these floras include the date palm and the East Indian Nipa palm (Berry, 1937; Arnold, 1952). In the Cordilleran region fossils of subtropical vegetation are found in

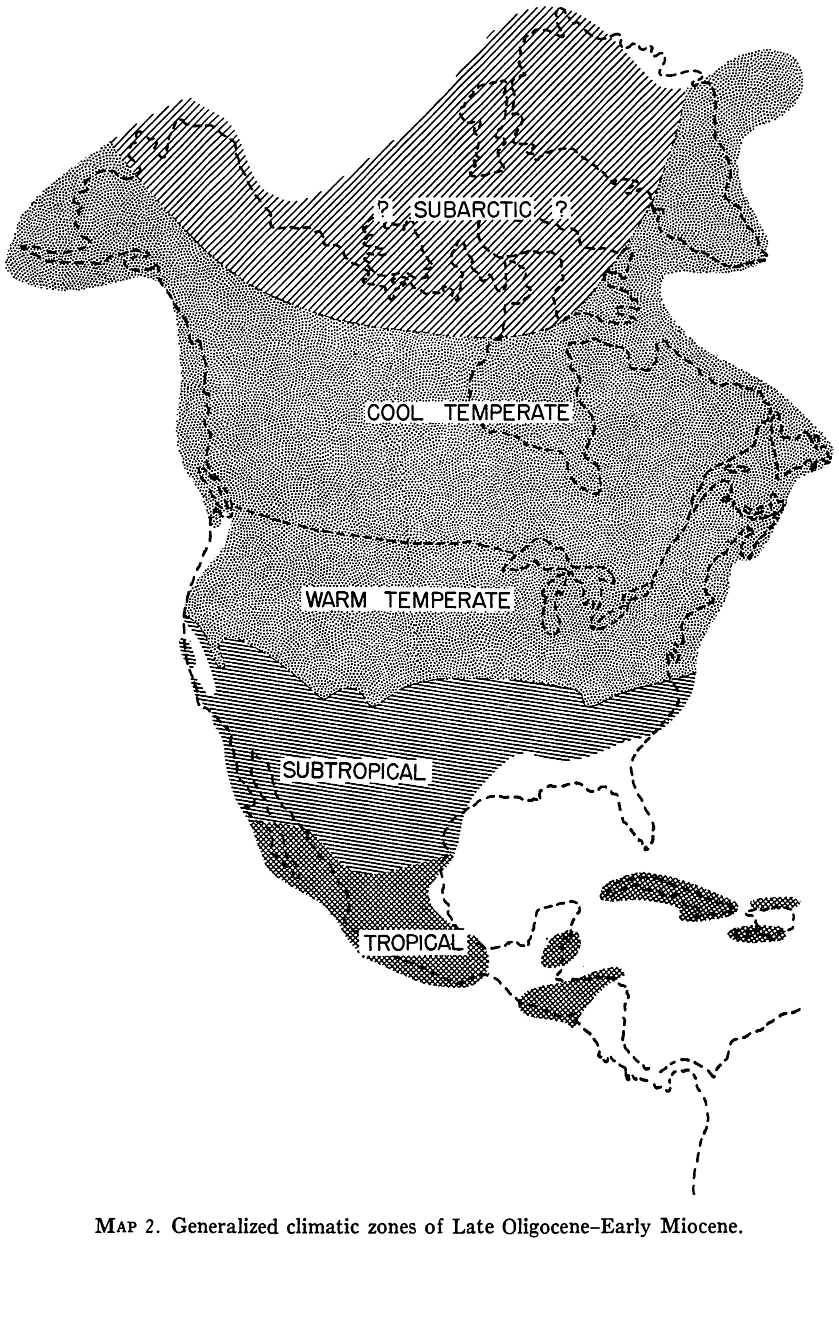
[2] The terminology for the climatic zones here and on the remaining figures is a slight modification of that used by climatologists and geographers: the term "temperate" is used as a general term for the zone of the middle latitude continental climates, including both the humid, warm summer and cool summer places, the semiarid steppe, the arid desert, and the marine, cool summer phase (during most of the Tertiary Period only the warm and cool temperate phases can be distinguished); the term "subtropical" includes the climate which many botanists refer to as "warm temperate"; for example, southeastern United States, which the majority of geographers and climatologists call "humid, subtropical" (Köppen and Geiger, 1936; Lackey, 1944).

northern California, Oregon, Washington, and northern Wyoming. In western Oregon, for example, Dr. Ralph W. Chaney and his students collected a great many well preserved leaves of Eocene age, including figs, laurels, cinnamons, avocados, and magnolias. These forms are typical of a forest dominated by large, smooth-margined dicot leaves whose nearest living equivalents are found in the lowlands of Central America (Chaney and Sanborn, 1933). Remains of this same forest occur also in the Eocene rocks of the John Day Basin of eastern Oregon, where the living desert vegetation presents a striking contrast to the lush, subtropical forest recorded in the rocks. Fossilized remains of marine faunas along the Pacific Coast confirm the northward extension of warmer tropical climate during the Eocene (Durham, 1950).

Numerous fossil remains of a forest transitional between subtropical and warm temperate are found in Late Eocene-Early Oligocene deposits of British Columbia as well as on Kupreanof Island in southeastern Alaska. Modern equivalents of this transitional forest, which included palms and cycads (Pl. I), lie more than 20° in latitude south of their Eocene occurrences. Farther east among the spruces, firs, and quaking aspens of the boreal forest of Yellowstone Park, Wyoming, my own field parties have collected many Middle Eocene fossils of lowland, warmth-loving forms, such as breadfruit, laurels, figs, and magnolias in association with more temperate elements, such as true redwoods, hickories, maples, and oaks. Southeast of Yellowstone Park a Late Eocene flora is closely related to the subtropical forests of the same age in Oregon and California (Dorf, 1953). Fossil bones of subtropical alligators have also been found in rocks of this age as far north as central Wyoming. In the eastern states the Brandon fossil flora of Vermont—largely made up of seeds, fruits, and pollens—is interpreted as transitional between the warm temperate and subtropical forests of this age (Traverse, 1955, pp. 21–34). Further south along the Atlantic coast, the bryozoans of the Eocene deposits of New Jersey indicate subtropical marine waters. Truly warm temperate forests, dominated by such forms as dawn redwoods, maples, beeches, oaks, sycamores, and basswoods, are widely recorded in rocks of this age in the belt extending from central Alaska to west-central Greenland and eastward to Spitsbergen and Siberia (Chaney, 1947). In Greenland the fossil-leaf beds occur on the bleak Arctic wastes of Disco Island, almost within sight of the glacial mantle of ice covering the mainland. Today the stunted vegetation, with prostrate willows and dwarf birches, is striking witness to the hardships of the polar climate and contrasts vividly with the warm temperate aspect of the fossil forests. Fossil remains of subarctic boreal forests, including spruces, pines, willows, hazels, and birches, have been found in the rocks of Late Eocene



MAP 1. Generalized climatic zones of Late Eocene–Early Oligocene.

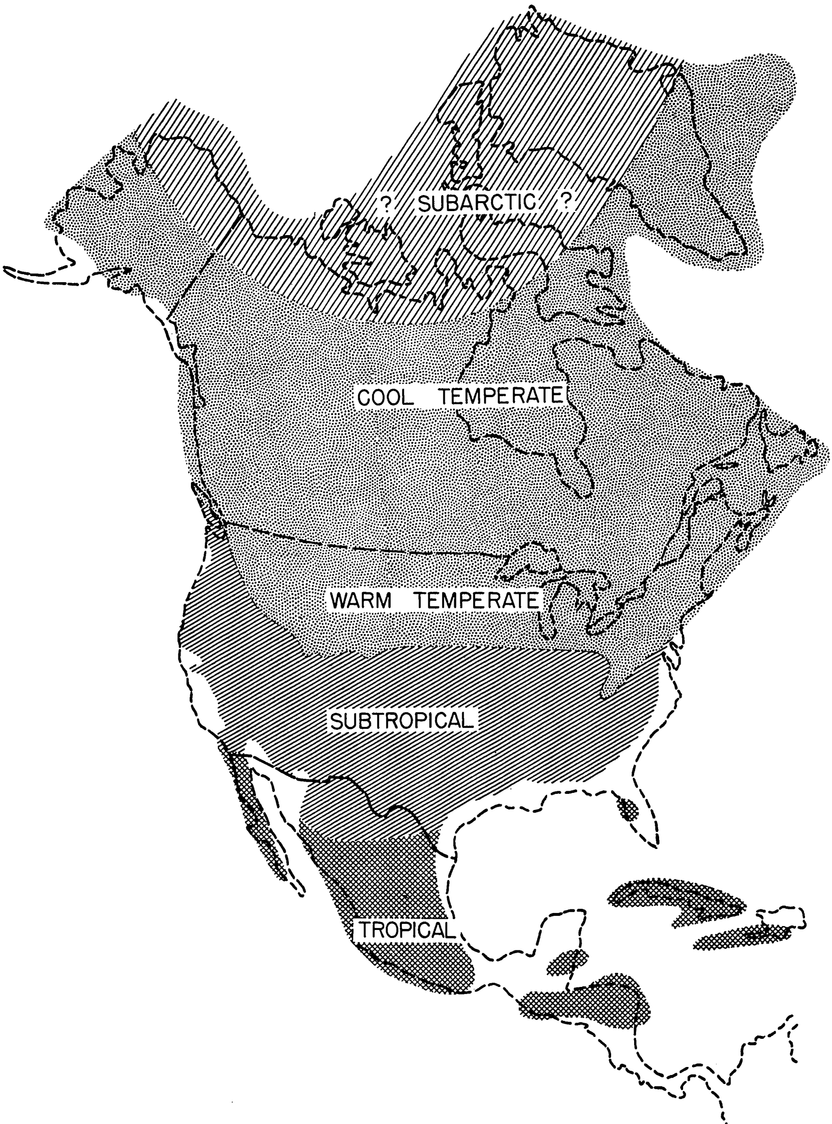


MAP 2. Generalized climatic zones of Late Oligocene–Early Miocene.

age as far north as Grinnell Land, only 8.5° from the North Pole (Berry, 1930, p. 10). There is no evidence of either a polar ice cap or a continental ice sheet on Greenland during this portion of geologic time. On the other hand, neither is there any evidence to support the view, unfortunately still often expressed, that the polar regions above the Arctic Circle supported subtropical or tropical forests during this time, or at any time, for that matter.

Late Oligocene - Early Miocene.—By the end of the Oligocene and the beginning of the Miocene Epoch, about 25 million years ago, the older subtropical forests of the Pacific Northwest had been replaced by warm temperate equivalents of the redwood forest association of the California Coast Ranges (Map 2). In eastern Oregon, for example, the Late Oligocene Bridge Creek flora from the John Day Basin contains numerous remains of a forest which included dawn redwoods, alders, maples, pepperwoods, dogwoods, tan oaks, hazels, and sycamores. This assemblage is essentially similar in its generic composition to the Late Eocene forest of central Alaska (Chaney, 1947). Its gradual southward shift in position during the course of 12 to 15 million years had apparently been accomplished without any major changes in its characteristic physiognomy. Eastward as far as the Dakotas the older subtropical forests appear to have moved to the south, with their places taken by warm temperate forests. This replacement was already under way earlier in the Oligocene Epoch, as is illustrated by the Middle Oligocene Ruby Basin flora of southwestern Montana which records a warm temperate forest dominated by dawn redwoods, oaks, beeches, maples, alders, and ash (Becker, 1956). Farther south in central Colorado the Florissant flora of the same age is an association of true redwoods and warm temperate hardwoods, in which there was a small lingering subtropical element as well as a few xeric forms (MacGinitie, 1953, pp. 36–42). Fossil records indicate that it was at this time that open woodland scrub and grasslands were beginning to develop in the lowland areas of the eastern Rockies and the Great Plains. In the southeastern United States the Oligocene Vicksburg flora, though small, is interpreted as a subtropical strand-line association (Berry, 1937). In marine deposits of Oligocene age, reef corals are known from as far north as 51.5° N. Lat. (at present their northern limit is about 32° N. Lat).

Middle Miocene - Late Miocene.—By the Middle to Late Miocene Epoch, about 18 to 12 millions years ago, the fossil plant record of western North America indicates a slight reversal of forest migrations (Map 3). A small subtropical element, which included palmettos, avocados, mahogany, and lancewood, returned north at least as far as Oregon and Washington (shown in the Mascall and Latah floras; Chaney, 1938, p. 387). Other



MAP 3. Generalized climatic zones of Middle Miocene–Late Miocene.

members of these two floras were of typically warm temperate aspect. From northern Mexico an element of hardy drought-resistant shrubs and chaparral moved north into southern California and the Great Basin regions, where there was a marked development of semiarid steppes (Axelrod, 1940). Fossil fish remains from the Miocene of southern California point to subtropical marine conditions that lasted well into the Late Miocene (David, 1943, pp. 47, 87, 96, 113, 174). Some time before the close of the Miocene Epoch, or early in the Pliocene, the climate began to change again and the cooling trend was resumed. In the Great Plains area the Miocene fossil record indicates a gradual development and spread of open grasslands and savannahs at the expense of true forests (Elias, 1942, pp. 15–18). Farther east the Miocene forests of the Virginia area were similar to the South Atlantic and Gulf Coast swamp forests of the present day. The Mid-Miocene deposits of Virginia have yielded bones of the southern manatee and crocodiles; neither of these warm-water animals occur north of Florida today. In the southern states the Miocene forests show a continuing replacement of tropical elements by subtropical and warm temperate forms (Berry, 1937).

Late Pliocene.—Near the end of the Pliocene Epoch, about 2 million years ago, the fossil records of forest distribution indicate an approach toward present climatic conditions (Map 4). Along the west coast of the United States, as a result of the cooling trend, the southward shifting of forest belts had continued since the Late Miocene trend. Major topographic changes brought about by the Cascadian mountain-building revolution produced a great variety of habitats and exerted a stronger influence than previously on the distribution of floral associations. Desert vegetation developed in the Great Basin and the interior of northern Mexico because of lower rainfall and greater seasonal temperature ranges (Chaney, 1944; Axelrod, 1944). Grasslands in the Great Plains appear to have reached essentially their modern aspect and distribution. In the southeastern states, Pliocene floras were wholly modern in general facies and were made up of species whose living forms are mostly native to the same region today (Berry, 1937).

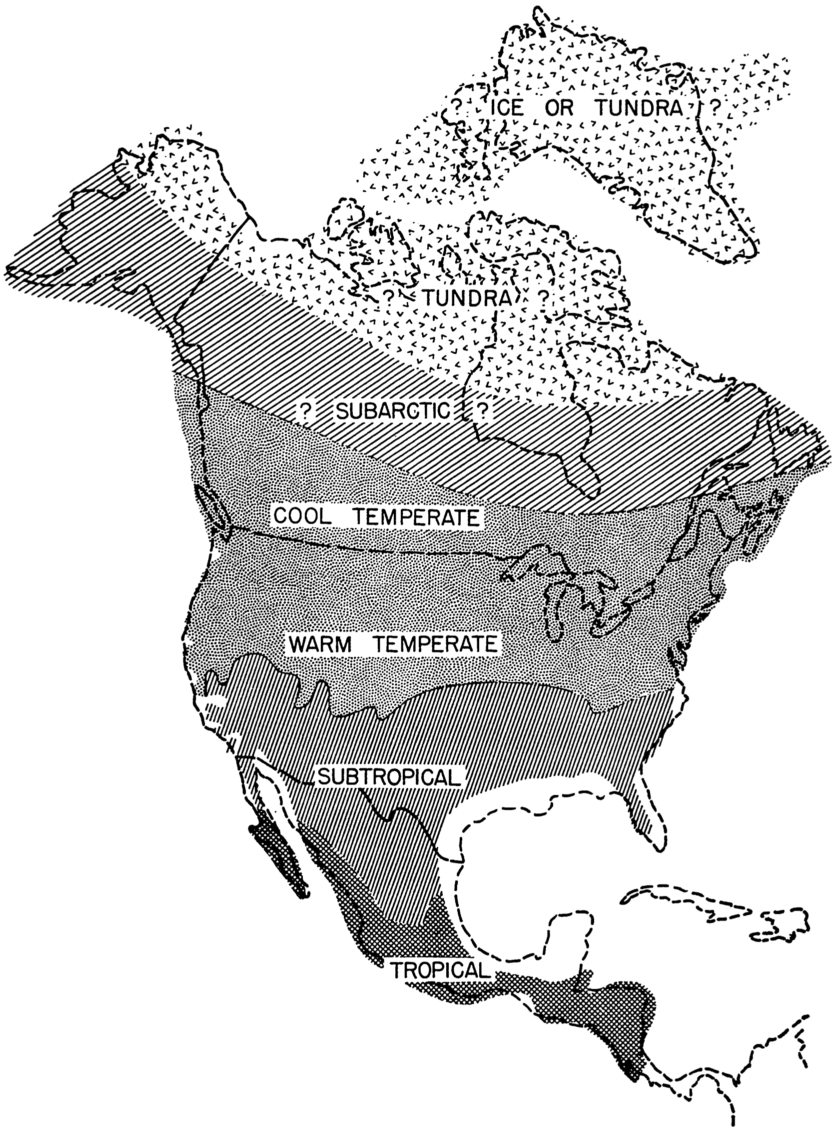
Corroborative Evidence

The inferred trend from warmer conditions in the Eocene Epoch to much cooler conditions in the Pliocene has been amply substantiated by certain characters of the fossil leaves. In the Eocene floras of North American middle latitudes the dominantly large, smooth-margined leaves with elongate tips indicate humid subtropical to tropical conditions. But such leaf forms are gradually replaced in the succeeding Oligocene, Miocene, and Pliocene Epochs by the smaller, toothed or lobed leaves characteristic of more temperate conditions. This gradual cooling off has been further confirmed by study of the sequence of Tertiary marine faunas of the Pacific states (Durham, 1950). A drop in oceanic temperatures during the Tertiary has also been inferred from the gradual equatorward shifts of the northern limits of coral reefs and a gradual change in oxygen isotope ratios in shells of bottom-dwelling foraminifera from the mid-Pacific (Emiliani, 1954). On land, the record of the Tertiary mammals of western North America shows essentially the same general cooling of the climate (Colbert, 1953, pp. 266–70).

Tertiary Climates of Western Europe

In western Europe, for comparison, the fossil record of both plants and animals indicates the same climatic trend from essentially tropical conditions in the Eocene to progressively cooler and cooler conditions to the end of the Pliocene (Reid and Chandler, 1933, pp. 50–59) and, as in North America, the episode of maximum warmth occurred in the Eocene Epoch. The types of both fossil plants and invertebrates indicate that the preceding Paleocene Epoch began with a somewhat cooler climate. A gradually warming trend began before the Middle Paleocene and continued into the Eocene. The Eocene episode of maximum warmth is well illustrated by the tropical flora of the Eocene London Clay. This fossil flora, obtained from a region lying at about 50° N. Lat., finds its nearest living counterpart at about 10° N. Lat. in the lowland tropical rainforest of the Indo-Malayan region. The remains of alligators, crocodiles, the pearly nautilus, and large warm-water volutes in Eocene marine deposits of western Europe indicate subtropical-to-tropical marine waters far north of their present limits. Plant remains of the Eocene forests of Spitsbergen, collected about 11 to 13 degrees from the North Pole, include species of beech, sycamore, linden, oak, and water lilies—an assemblage whose modern equivalents are among the dominants of the temperate forests and lakes and now live 15 to 20 degrees farther south on the Continent (Heer, 1868, pp. 60–62). The fossil plant record of western Europe shows that a gradual change from the tropical conditions of the Eocene to subtropical in the Oligocene and warm temperate in the Miocene took place. This cooling trend apparently continued into the succeeding Pliocene Epoch, which ended with a climate believed to have been quite similar to the cool temperate conditions of western Europe at the present time. The annual mean temperature of the region is estimated to have dropped about 15° C. from the Eocene to the end of the Pliocene.

The gradual cooling off of western Europe during the Tertiary Period is further confirmed by the relative proportions of woody to herbaceous plants in the geologic sequence. The proportion of woody species shows a



MAP 4. Generalized climatic zones of Late Pliocene.

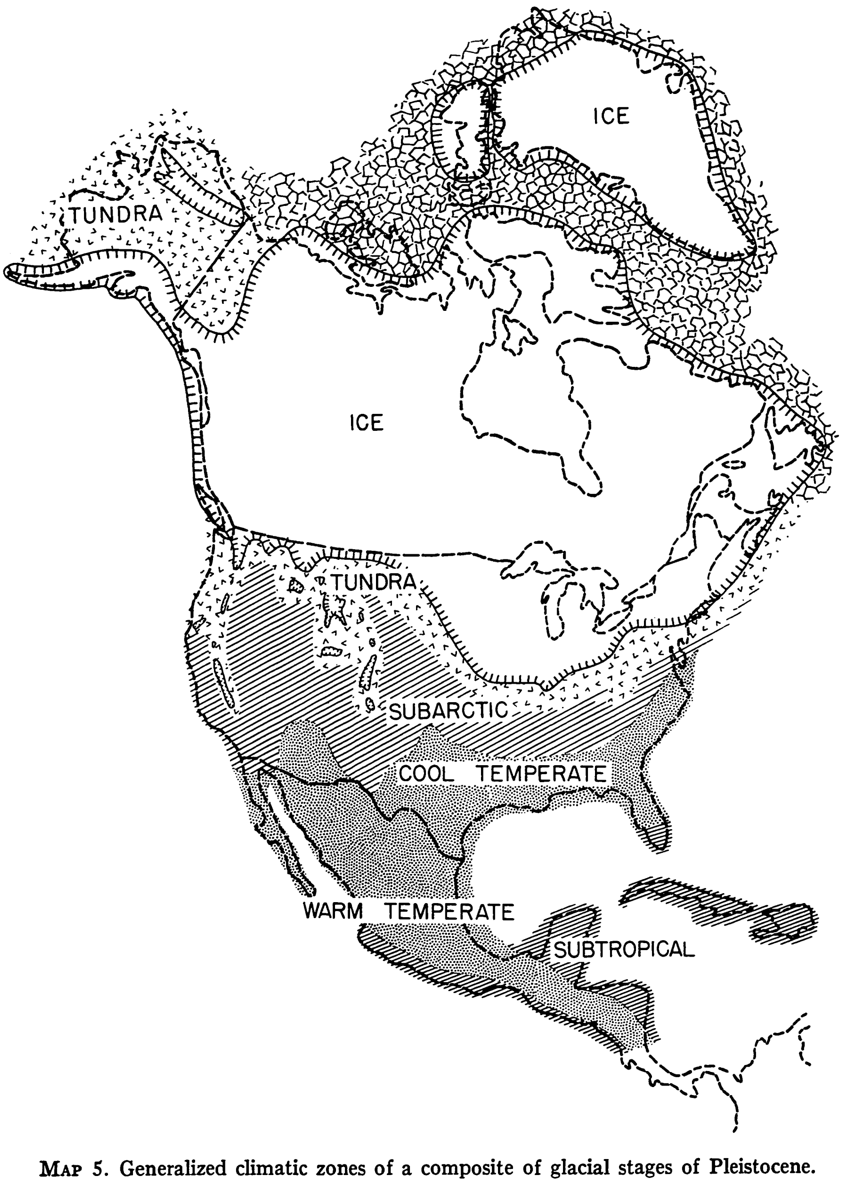
downward progression from 97 per cent in the Eocene London Clay, to 57 in the Oligocene and to 22 in the Late Pliocene. Twenty-two per cent compares closely with the figure of 17 per cent for the woody species now in the region (Reid and Chandler, 1933, p. 53). This reduction in the course of time parallels the geographical reduction noted in living forests, from about 88 per cent woody species in the tropical lowlands of the Amazon Basin to about 10 per cent in the subarctic vegetation of Iceland.

Independent studies of Tertiary marine invertebrates and fishes, and of terrestrial insects, corroborate the climatic inferences based on fossil plants (Davies, 1934; Theobald, 1952; Schwarzbach, 1950). Evidence from the rocks themselves, the Tertiary laterites of Europe, has led to the same general conclusions regarding climatic changes as have the studies based on the fossil record (Harassowitz, 1926, pp. 544–88).

Quaternary Climates

Glacial.—In the Pleistocene, or "Glacial," Epoch the cooling trend, which had begun in the Oligocene Epoch, led to the formation and slow spread of lowland ice sheets in higher latitudes. Beneath the ice all plant and animal life was obviously obliterated. As the ice sheets spread southward from central Canada and extreme glacial climate caused a farther and more rapid southward shift of the forests south of the ice margins. Just how far south the forests were driven is a matter of debate. For many years both paleobotanists and botanists have believed that forest belts shifted only slightly (Berry, 1926, p. 99; Braun, 1950, pp. 458–72), but evidence for major forest migrations over wide distances has been accumulating during the past decade (Deevey, 1949, pp. 1360–66, 1375; Frey, 1953). The latter view is that supported here (cf. Map 5).

There are numerous Pleistocene records of both subarctic plants and animals far to the south in North America. Occurrences of northern spruce and fir are found in the lowlands of northern and central Florida, south-central Texas, northern Oklahoma, and southern Kansas (Deevey, 1949, pp. 1360–61; Davis, 1946; Potzger and Tharp, 1947). Cones of white spruce and Canadian larch, twigs of the northern arbor vitae, and the delicate remains of two species of northern mosses have been recorded in southeastern Louisiana, up to 1000 miles south of their present southern limits (Fisk, Richards, Brown, and Steere, 1938). Fir and northern pines occur on the coastal plain of North Carolina and larch in southeastern Georgia (Buell, 1945). Cold-temperate diatoms, whose living forms are characteritsic of New England and eastern Canada, are abundant in northern and central Florida (Hanna, 1933). In southern California there is a Pleistocene record of a kind of vegetation now found growing between 8 and 10 degrees farther north along the coast. A possible indirect effect of



MAP 5. Generalized climatic zones of a composite of glacial stages of Pleistocene.

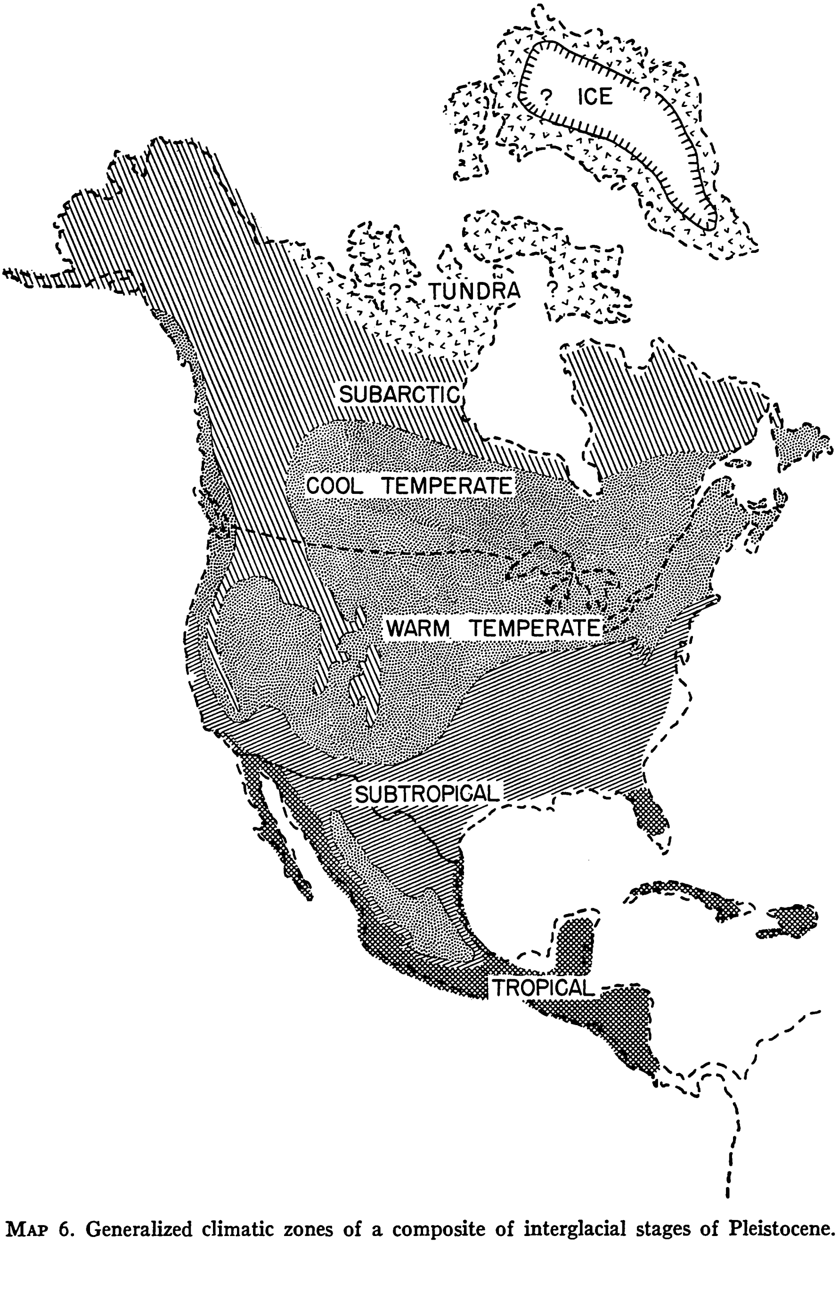
the shifting of temperate forests as far south as shown in Map 5 is the presence today in the mountains and high plateaus of Mexico and Central America of remnants of the typical warm temperature to subtropical association normal to the lowlands farther north in the United States.

Among the vertebrates the records of musk oxen as far south as Mississippi, Texas, Oklahoma, and southern California indicate a considerable southward shift, as does the record of reindeer in southeastern Kentucky, Iowa, and central Nevada. Wooly mammoth remains are known from as far south as west-central Florida and southern Texas. Walrus bones have been found along the Atlantic coast as far as South Carolina and Georgia, over 1000 miles south of the southern limit of the modern walrus (Hay, 1923). Fossils of the northern moose are recorded from Oklahoma, Kentucky, and South Carolina. Conies, which live above timberline in the Rocky Mountains at the present time, occur as fossils in the Pleistocene deposits of Pennsylvania and Maryland. Fossils of western marmots are found from 2500 to 4500 feet below their present lower limit in central New Mexico (Deevey, 1949, pp. 1374–75; Stearns, 1942).

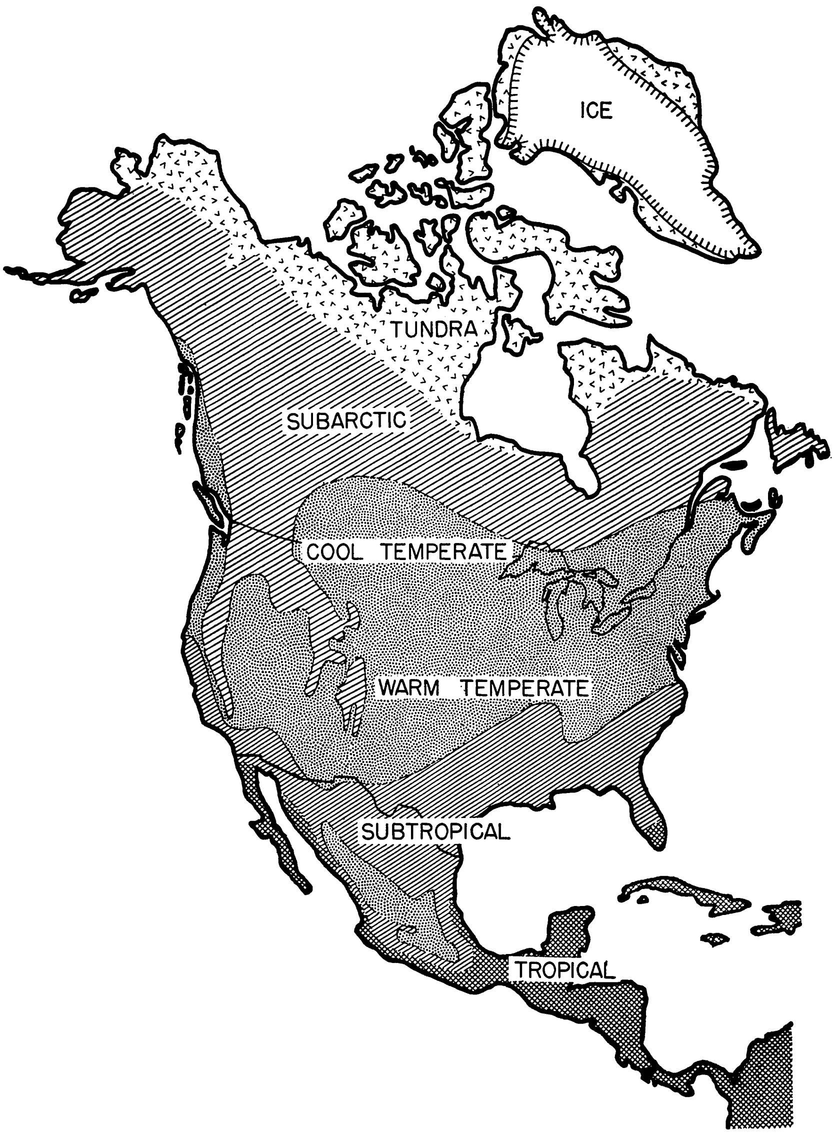
Among the invertebrates there is a record of a cold-water assemblage in southern California and of subarctic Foraminifera as far south as the Sigsbee Deep in the middle of the Gulf of Mexico (Trask, Phleger, and Stetson, 1947).

In western Europe extensive records of both faunas and floras of glacial age show that subarctic (boreal) conditions extended south as far as the shores and adjacent lowlands of the Mediterranean.

Interglacial.—Alternating with the glacial stages were the interglacial. During several of these the climates appear to have been somewhat warmer than today (Maps 6 and 7) and, as the ice sheets melted away, a rapid northward shift of the forests took place, extending them into the newly exposed glaciated wastelands of the north. At Toronto, for example, both the plants and invertebrates of a late interglacial age indicate conditions about 2 to 3° C. higher than today (Flint, 1957, p. 340); the plant remains include the pawpaw, red cedar, and osage orange, whose northern limits today are several hundred miles south of Toronto. On the Seward Peninsula of Alaska occurrence of fossil plants of an early interglacial age indicate a climate both warmer and more humid than in the same region today (Hopkins and Benninghoff, 1953). Cape Cod has a record of an interglacial forest similar to that of present-day Virginia and North Carolina. On Long Island an interglacial shellfish fauna points to water temperatures higher than now in the region, and in New Jersey the record of a manatee indicates conditions like those off the present coastline of Florida. In Pennsylvania there are interglacial records of tapirs of Central American aspect and of



MAP 6. Generalized climatic zones of a composite of interglacial stages of Pleistocene.



MAP 7. Generalized climatic zones of the Present.

peccaries whose nearest living relatives range only as far north as Arizona, New Mexico, and Texas. Farther west, in southwestern Kansas, interglacial records of a Gulf Coast box turtle and the rice rat point to conditions warmer than at present (Hibbard, 1955, p. 202). Sediment cores from the bottom of the Atlantic Ocean show layers of interglacial deposits with the remains of Foraminifera of warmer waters than those of the region today (Bradley, 1940).

CLIMATIC CHANGES OF THE NEAR PAST AND PRESENT

The knowledge of climatic changes since the last of the ice sheets (the Cochran readvance) depends in part upon the fossil record and in part on archeological and historical records. On the basis of the pollen record there was a period of somewhat higher temperatures than today (the so-called Thermal Maximum or Hypsithermal), which lasted from about 5000 to about 2000 B.C. (Fig. 1). This was apparently followed by a general cooling, which reached a minimum in about 500 B.C., and a subsequent rise in temperature. Archeological records indicate that the last major warm episode before the present occurred about 1000 to 1300 A.D. During this time a colony of about 3000 Norsemen grew crops and raised both cattle and sheep in southwestern Greenland (Ahlmann, 1949, p. 165) and vineyards were productive as far north as southern England. Beginning in about 1600, however, the climate began to change toward cooler conditions. Glaciers in the northern hemisphere began to readvance; in the Alps several valley settlements were completely overrun by advancing valley glaciers. This cooling episode led to the so-called "Little Ice Age," which lasted from about 1650 to about 1850. Since 1850 the general climatic trend has been toward warmer conditions.

In broad retrospect, then, where do we find ourselves today, near the middle of the twentieth century, in the everchanging pattern of climatic cycles? In the first place, it is quite clear that for the past million years or so (up to and including the present time) the earth has been subjected, geologically speaking, to an abnormally cold climate (see Fig. 1). The greater part of at least the last 500 million years, however, has had a warmer, nonglacial climate rather than the colder glacial climate of the past million years. In the second place, it is evident that the earth is not in one of the truly frigid glacial stages, but is rather in one of the slightly warmer interglacial stages, that it is perhaps about two-thirds of the way out of the last glacial stage, so to speak. By comparison with the long duration of past interglacial and glacial episodes in earth history, it is generally believed that we shall return to another glacial stage in about 10,000 to 15,000 years. Such a prospect, with its accompanying ice sheets devastating northern lands and settlements is not a happy one to contemplate in terms of physical, economic, or political consequences.

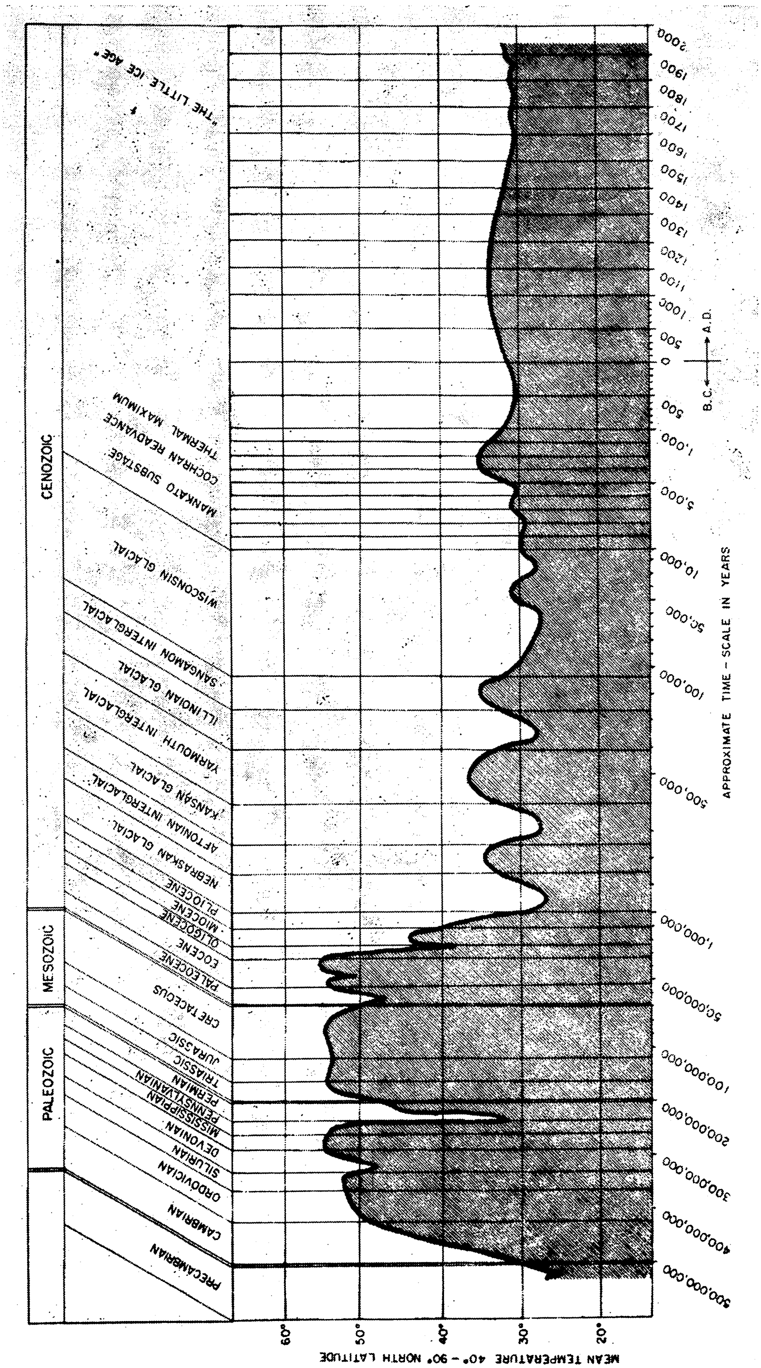


FIG. 1. Generalized temperature variations during the geologic past. After Brooks, 1951.

In the meantime we are apparently well along in a general world-wide warming trend (Fig. 2). In the United States the rise in mean annual temperature, since 1920, has been about 3.5° F., and the rise in winter temperatures has been about twice as much as that in summer temperatures (Visher, 1954, Part VII). In Boston winter temperatures are about 3.5° F. higher than they were a hundred years ago. In Philadelphia the temperature has risen more than 3° F. since 1880, and in Montreal more than 2.5° F. since 1850. In the years between 1931 and 1952 New Jersey's mean annual temperature has been above normal 18 years, below normal 3 years, and normal only 1 year; Michigan's temperature in the same interval has been above normal 15 years and below only 7 years. The U.S. Weather Bureau (1953) reported that during the same period all but 8 of the 48 states had annual temperatures which were above normal the majority of the years; those which were below normal during most of the years were the three Pacific coast states (California, Oregon, and Washington), four western states (Arizona, Idaho, New Mexico, and Montana), and one southern state (Texas). In both the Middle West and the Great Plains, the records of cities such as St. Louis and Kansas City indicate a similar rise in temperatures: 1.9° F. for the former since 1880, and 1.4° F. for the latter since 1894 (Oltman and Track, 1951, p. 17). It has been observed, however, that the greatest temperature increases during the last hundred years have been in the Arctic regions. In Spitsbergen, only about 10 to 12 degrees from the North Pole, the mean winter temperatures have risen about 14° F. since 1910 (Willett, 1950). Ice-free ports there are now open to navigation about 7 months of the year as compared with only 3 months fifty years ago (Ahlmann, 1953, p. 32). If the warming trend of the north polar region should continue at its present rate, it has been estimated that the entire Arctic Ocean would be navigable all year long within about a hundred years. At the opposite end of the world, according to recent reports from the Weather Bureau (Wexler, 1958), the Antarctic region has undergone a rise of about 5° F. in average temperature in the last fifty years. There has been no appreciable rise, however, in the mean annual temperatures in the tropical regions of the world.

What have been some of the notable results of this warming trend during the last hundred years? Glaciers throughout the world have been melting away at a rapidly increasing rate. Brooks (1949, p. 24), the eminent British paleoclimatologist, stated that "Since the beginning of the 20th Century glaciers have been wasting away rapidly, or even catastrophically." In the Juneau region of Alaska, all but one of the numerous glaciers began melting away as far back as 1765. Muir Glacier, for example, has retreated as much as two miles in 10 years. Baird and

Fig. 2. Changes in mean annual temperature, 1920 to 1940, in degrees Fahrenheit. After Willett, 1950.

Sharp (1954, p. 143) have referred to the "alarming retreat of glaciers" in the Alaskan region; along the Pacific Coast of North America and in Europe they believe the glacial melting "appears to be progressing violently." In the north polar region, measurements of melting of the ice islands in the Arctic Sea indicate an approach toward an open polar sea (Crary, Kulp, and Marshall, 1955). In only a few regions of the world, such as the Pacific Northwest, are there any records of glaciers advancing during the past century, and these have been mostly since 1950 (Hubley, 1956). The warmer temperatures have also caused a general rise of the snow line throughout the mountainous regions of the world, even in the tropics: in northern Peru it has risen about 2700 feet during the 60 years.

Believed in large part to be the result of the melting of the world's glaciers, sea level has been rising at a rapidly increasing rate, amounting to as much as a 6-inch rise from 1930 to 1948 (Marmar, 1948). This is about four times the average rate of sea level rise during the past 9000 years, as recorded by Shepard and Suess (1956). It should be noted that more than a six-fold increase in the rate of sea level rise occurred in the mid-1920's at the same time there was a striking change in the rate of glacial melting in the north (Ahlmann, 1953, Fig. 11).

Changes in vegetation brought about by the warmer temperatures include the encroachment of trees into the subpolar tundra as recorded in Alaska, Quebec, Laborador, and Siberia. In the Canadian prairies the agricultural crop line has shifted from 50 to 100 miles northward as a result of the lengthening of the growing season by as much as ten days. In parts of northern New England and eastern Canada the birch trees have been dying off over large areas, and the spruces and balsams have begun to suffer as a result of the rise in summer temperatures. In Sweden the timberline has moved up the mountain slopes as much as 65 feet since 1930 (Ahlmann, 1953, p. 35).

In the animal world many southern types of both birds and mammals have been extending their habitat ranges northward as a result of the warming trend. The cardinal, the turkey vulture, the tufted titmouse, and the blue-winged warbler, as well as the warmth-loving opossum, have slowly moved their ranges into the northern United States. A good many central European species of animals have been shifting their ranges northward into Scandinavia, Greenland, Iceland, and the Faero Islands. Twenty-five species of birds alone are reported to have invaded Greenland from the south since 1918 (Jensen and Fristrup, 1950). Codfish from the Atlantic have replaced the seals in the waters along the coast of Greenland. It is reported that compared to a shipment of 5 tons of codfish from Greenland in 1913, the 1946 shipment had risen to over 13,000 tons; the Greenland Eskimos have become cod fishermen instead of seal fishermen (Kimble, 1950). Farther south tunafish have moved northward into the waters off New England, and tropical flying fishes have become increasingly common off the coast of New Jersey.

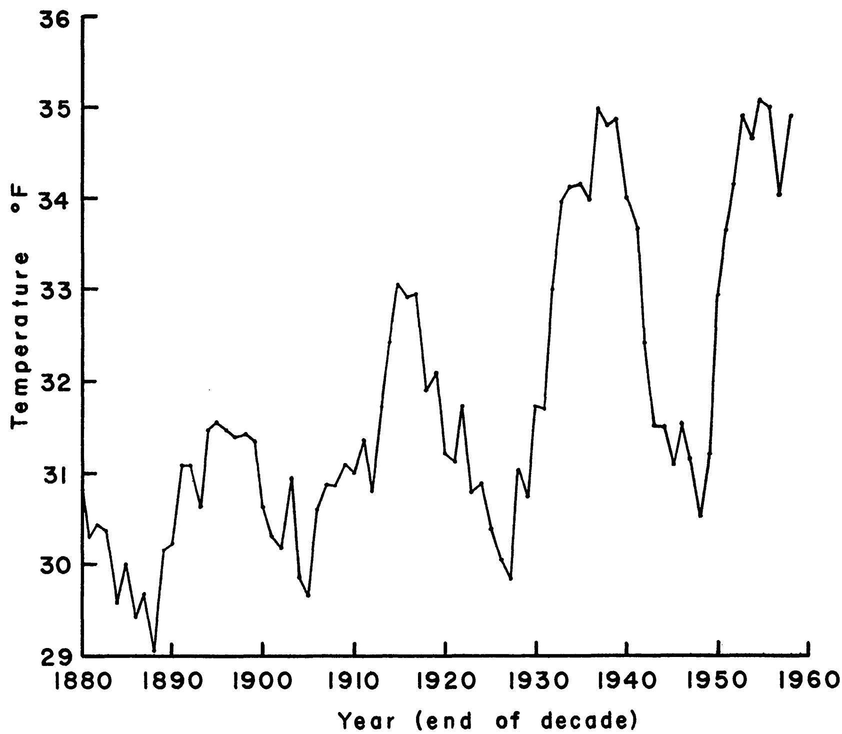


FIG. 3. January temperatures in New York City, 1871 to 1958, ten-year running means. After Spar, 1954.

In spite of its numerous and striking effects, the warming trend of the past hundred years has not been worldwide nor uniform in direction. Over most of the northern hemisphere there have been rather regular cyclic fluctuations from warmer spells to colder spells, each lasting a decade or so. Most of the eastern and central United States is at present in a decade that is somewhat colder than the one which ended in 1955. These shorter cyclic fluctuations are observable in both summer and winter temperatures. As shown in Figure 3, for example, the ten-year averages of

January temperatures in New York City show colder 10- to 11-year cycles followed quite regularly by warmer 10- to 11-year cycles since at least 1880 (Spar, 1954). Even here it may be noted that the trend is upward, that is, the average temperatures of the last few decades have been warmer than those of the decades prior to 1900. Certain regions of the world, moreover, have actually experienced a cooling trend during the time that most of the rest of the world was warming up. Such regions (Fig. 2) include the Hudson Bay Region, the west coast of North America, central South America, and the East Indies (Willett, 1950).

POSSIBLE CLIMATIC CHANGES OF THE NEAR FUTURE

The usefulness of observations from the past has been demonstrated in many fields to be of real value in the forecasting of events in the future. In the words of Byron, "The best prophet of the future is the past." Unfortunately, as one is reminded much too often, the forecasting of either weather or climate on the basis of past performance is notoriously even less reliable than predicting the future actions of human beings or race horses. Several climatologists expressed the opinion, in the late 1940's, that the 1930–1940 decade marked the culmination of the trend toward higher temperatures, and that a reversal of the trend had begun. In the middle 1950's, when it had become quite obvious that the reversal had not occurred and that the rising temperatures had continued after a short colder cycle, opinions were revised to the effect that it was the 1940–1950 decade which marked the maximum of the warming trend, which was due for a reversal. Other climatologists have stated their belief that the present warming episode will continue for at least a few centuries. Brooks (1949, p. 24), in his forecast of the future, stated that the melting of the world's glaciers "may be expected to continue until either the reduced ice-cap reaches a new position of stability, or until some meteorological 'accident' reverses the trend and ushers in a new period of re-advance."

Extrapolation of the known climatic curves into the future is one of the more reasonable approaches to the prediction of possible future trends. Such extrapolation suggests (1) that the earth is at present still in an interglacial stage but heading toward another glacial stage, perhaps 10,000 to 15,000 years hence; (2) that the winters are getting slightly colder again and should continue to average colder until about 1965; and (3) that though marked by minor alternating colder and warmer cycles, the general trend of increasing warmth should continue for at least two or three hundred years over most of the lowland regions of the northern hemisphere.

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PLATE

EXPLANATION OF PLATE I

Fossil palm (left) and fossil cycad (right) from the Eocene of Kupreanof Island. U. S. Geological Survey.

PLATE I