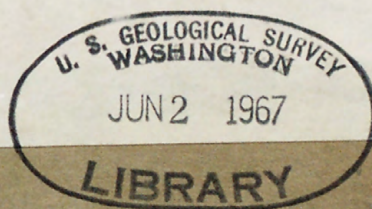


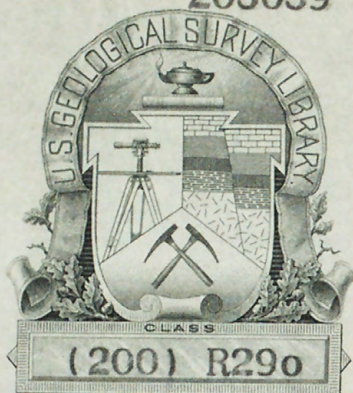
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Geologic climatic change and ice extent

by

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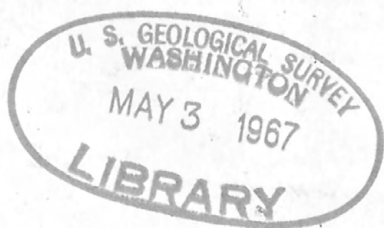
UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Cenozoic climatic change and its cause

By

Warren Hamilton



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CENOZOIC CLIMATIC CHANGE AND ITS CAUSE

By Warren Hasten

INTRODUCTION

The widely accepted paleoclimatic concepts that the earth's climate has cooled gradually throughout Cenozoic time, and that the tropics have become progressively narrower during the era, are invalidated by a global analysis of Cenozoic climatic changes. Miocene and Pliocene tropics were little if any broader than were those of warm parts of the early Pleistocene. Early Tertiary tropics differed from present ones so irregularly that there is no latitudinal symmetry to the changes, and a cause other than worldwide climatic change must be sought. After a brief summary of the evidence for paleoclimates, it is argued here that climatic belts maintained semiconstant widths throughout Tertiary time (although complicated by changing altitude of continents, configuration of shallow seas, and ocean currents), and that the record of each continent shows a unique long-term climatic change due primarily to continental drift.

QUATERNARY CLIMATES

The past few million years have been a time of great climatic oscillations, shown most spectacularly by the alternate growth and shrinkage of the continental ice sheets of the northern hemisphere. Glacial stages have been accompanied by drastic compression of the temperate climatic zones toward the tropics, but by relatively little change in the low-altitude tropics themselves. Major temperature changes have been generally parallel and synchronous at all latitudes in both hemispheres.

The present is part of a cool, semiglacial interval, intermediate between full-glacial and nonglacial conditions, and hence provides a poor basis for comparison with the generally nonglacial climates of pre-Quaternary time. Late Pleistocene interglacial climates were similar to those of the present.

Early Quaternary time included nonglacial periods, when cool-temperate conditions extended to earth's northernmost lands and presumably to Antarctica, and ocean currents were warmer in middle and high latitudes than they are now. Douglas fir, hemlock, and other moist-temperate trees grew on Seward Peninsula, northwestern Alaska (Hopkins and Benninghoff, 1953), 2,300 km beyond their present limit and north of the range of subarctic forest now. Early Pleistocene marine invertebrates of Seward Peninsula show that there was then no winter sea ice there (Hopkins and others, 1960). Kamchatka, beyond the present limit of all trees, supported temperate mixed forest (Douglas fir, Metasequoia, walnut, etc.) during earliest Pleistocene time, and walnut again during a later (interglacial?) early Pleistocene interval (Van'kovskiy, 1963), at least 2,400 km beyond present ranges. Subarctic forest grew at latitude 80° N. on Ellesmere Island (Craig and Viles, 1960), 1,900 km beyond the limit of trees now. Such changes indicate high-latitude annual temperatures at least 10° C warmer than present ones, and require an open Arctic Ocean to account for both warming and increased precipitation. Climatic indicators in middle latitudes show correlative warming of only 3 to 5° C, and those of the sea-level tropics show still less change.

No early Pleistocene data are yet available from Antarctica, but southward extension of temperate zones beyond present limits has been demonstrated in middle and high-middle southern latitudes.

Deserts have apparently been more extensive in cool periods like the present than they were under either glacial or nonglacial parts of the Pleistocene. Both margins of deserts retreated equatorward during warm periods, whereas during warm periods tropical margins moved poleward while temperate margins probably underwent little change. (See Fairbridge, 1966, for data contradicting some established assumptions regarding the tropical limit of Pleistocene deserts.)

Nonglacial Pleistocene periods have thus resulted in cool-temperate conditions in the northernmost lands of the Arctic, and quite likely in at least the lower parts of Antarctica. Temperate and warm-temperate zones similarly extended far poleward of their present limits. There was relatively little correlative expansion of the tropics, whose limits moved no more than 5° of latitude into now-temperate regions, although rather more into low-latitude regions now deserts. The tropics were largely confined to latitudes below 30° , although they reached 35° locally. Temperate conditions can prevail at the poles when the tropics are little broader than they are now, and the existence of temperate paleoclimatic indicators in polar latitudes proves nothing about the limits of the correlative tropics.

LATE TERTIARY CLIMATES

The progressive changes in Miocene and Pliocene temperate continental climates of northern middle latitudes have been documented ably by many workers who have shown that, as regional and mountain altitudes increased during the late Tertiary, climates became progressively more rigorous and more differentiated areally.

Land floral and marine faunal provinces of the eastern United States remained similar during the Miocene, Pliocene, and warm parts of the Pleistocene. Along the western states, tropical marine Miocene faunas extended a little north of present limits (Bandy, 1960; Natland, 1957), and land floras indicate winters warmer than now. (Durham's (1950) contrary, widely cited conclusion that the Miocene tropics extended much farther north has been thoroughly refuted by Bandy, Natland, and others.) The Miocene sea was a little warmer than the warm Pleistocene one in Europe and the Middle East. In Japan, subtropical marine faunas and land floras extended considerably north of subsequent limits during parts of the Miocene, which alternated with cooler parts. The now-barren Koryak region (north of Kamchatka) bore a temperate Miocene flora which included elements of warmer climate (as, swamp cypress) than did the Pliocene flora, but even the Pliocene forest included hemlock, hornbeam, and other temperate, not cold-temperate, trees (Egiazarev and others, 1963). There was probably no low-altitude tundra in the northern hemisphere within Tertiary time, although most paleoclimatologists assume it to have covered great regions.

In the southern hemisphere, South America, Australia, and New Zealand had Miocene climates warmer than Pliocene or warm Pleistocene ones, but southern Africa did not. New Zealand marine faunas indicate subtropical and warm-temperate conditions to have extended farther south in the Miocene than in or since the Pliocene, although tropical conditions were not reached (Bell, 1954; Squires, 1958, p. 23-25); land paleofloras of *Nothofagus* (southern beech) and podocarps (conifers) indicate consistently moist, temperate climates, although a little warmer in the Miocene than subsequently (Ceuper, 1960). Lower and middle Miocene invertebrates of southern Australia (but not Tasmania) are largely tropical, and

includes giant tortoises and crocods, large Foraminifera, and corals (but not reef-building corals) (Gill, 1961; McWhae and others, 1956). The south limit of tropical waters along the east coast of Africa was by contrast in the same position in the early Miocene as it is now (Klug, 1953, p. 63).

The general limit of Miocene tropics was at about the 30th parallels, the notable exceptions being Europe, the Middle East, Japan, and Australia, in each of which the tropics reached regions now near the 40th parallels.

EARLY TERTIARY CLIMATES

Paleocene, Eocene, and Oligocene climatic indicators are distributed about the world with markedly less latitudinal symmetry than are younger ones. Eocene warm-climate markers extend far poleward of later Cenozoic ones in some continents, but the reverse is true in others.

Tropical planktonic Foraminifera along the west coast of North America reached present latitude 60° N. within Late Cretaceous time, but less than 30° N. by the beginning of the Paleocene; their limit was 35° N. in late Paleocene time, and 30° during and since the late Eocene (Bandy, 1960; Hearnaday, 1965, p.33). Early Tertiary subtropical and warm-temperate corals and mollusks extended far north of present limits (Durham, 1950). Warm-temperate and subtropical plants ranged far north of present limits throughout the United States, though more so in the west than in the east, during the early Tertiary. By late Oligocene time, land floras and coastal marine faunas in the southeastern States indicated temperatures comparable to those maintained during the rest of the Tertiary. Temperate forests, generally not well dated, grew throughout the present Arctic during the early Tertiary. In the Paleocene forest of the Cook Inlet region of southern Alaska, subtropical plants were dominant over warm-temperate ones (Wolfe and others, 1965).

The Alpine region, the Middle East, and most of the Himalayan region were fully tropical during the Eocene, and tropical conditions extended to southern Britain. Climates graded northward to strictly temperate in the Siberian Platform and Arctic Siberia during the Paleocene and Eocene, and by Oligocene time the zones had shifted southward. The northern margin of the Eocene tropics in Japan lay in southern Honshu; the Oligocene was markedly cooler there, the Miocene warm again.

The Eocene was by contrast comparable to the present, and the Paleocene was cooler, in Australia, where the warmest part of the Cenozoic was the middle part of the era. Large tropical Foraminifera such as Nummulites occur in middle and upper Eocene strata of northwestern Australia, but not in older Tertiary ones despite their position well within the present tropics (McWhae and others, 1956), and not in any Eocene strata in southern Australia (Glassner, 1959). Warm-water planktonic Foraminifera including Globorotalia do however occur in Eocene beds as far south as Perth on the west coast (McWhae and others, 1956, p. 130). In New Zealand, Eocene and early Oligocene corals, mollusks, and Foraminifera indicate coastal waters cooler than present ones, and markedly cooler than late Oligocene and Miocene waters (Squires, 1958; Fleming, 1949; Couper, 1960).

Tropical Eocene waters extended at least as far south as 27° S. in Southwest Africa, and as far as southern Mozambique and Madagascar along eastern Africa; there are no dated Eocene deposits farther south. Deep-ocean Paleocene sediment 800 km southeast of Cape Town, however, contains five species of Globorotalia (Herman, 1963).

Land floras and vertebrates of southern Chile and Argentina indicate Eocene and Oligocene climates warmer and milder than present ones but markedly cooler than the early Miocene there. Temperate Nothofagus and podocarps grew also in Antarctica during the early Tertiary.

The equatorial current system of the central Pacific is now, and has been throughout late Cenozoic time, symmetrical to the equator; but lower Tertiary abyssal sediments deposited beneath that tropical current have a very irregular distribution, extend far beyond modern limits in some sectors but not in others, and are not symmetrical to the equator (Riedel and Funnell, 1964, pls. 31, 32). Either the Eocene current system bore little resemblance to the latitudinally controlled one of late Cenozoic time, or else the belt of sediments formed beneath it has been variably rotated and offset tectonically.

CAUSE OF CENOZOIC CLIMATIC CHANGE

The Cenozoic climates of various regions are illustrated schematically on figure 1, which is based on evidence such as that summarized in the preceding sections. Worldwide cooling in middle latitudes appears to be indicated during the past 15 million years or so. As has been generally inferred, this cooling of nontropical continental climates is probably due in large part to the correlative increase in both continental and mountain altitudes during late Cenozoic time. Interdependent chilling of high-latitude air and water produced big changes in weather patterns and ocean currents, and in most northern regions winters became colder and precipitation became less evenly distributed through the year.

The lack of parallelism of the climatic curves for the first 50 million years of the Cenozoic however demonstrates that worldwide climatic changes, symmetrical latitudinally to the equator, cannot have been the major cause of the trends. Most Tertiary paleoclimatologists (as, Dorf, 1960; Durham, 1959; Khrishtofovich, 1959; MacGinitie, 1958; and Schwarzbach, 1963--but see Schwarzbach, 1965) have assumed, largely on the basis of the northern-hemisphere records, that the early Tertiary tropics were much broader than were those of the later Cenozoic. This assumption is disproved by the southern-hemisphere data. There was no southward expansion of the tropics during Eocene time to correspond to the hypothesized northward expansion.

The general latitudinal symmetry of present marine and continental tropical climates has no parallel in the irregular, lepsided distribution of Eocene indicators of such climates. Late Cenozoic climatic changes have been broadly parallel throughout the world but early and middle Cenozoic ones make no such picture. Each continent or subcontinent shows unique climatic changes.

The divergences from latitudinal symmetry of climates are, to be sure, less for the early Tertiary than for preceding geologic periods. In Early

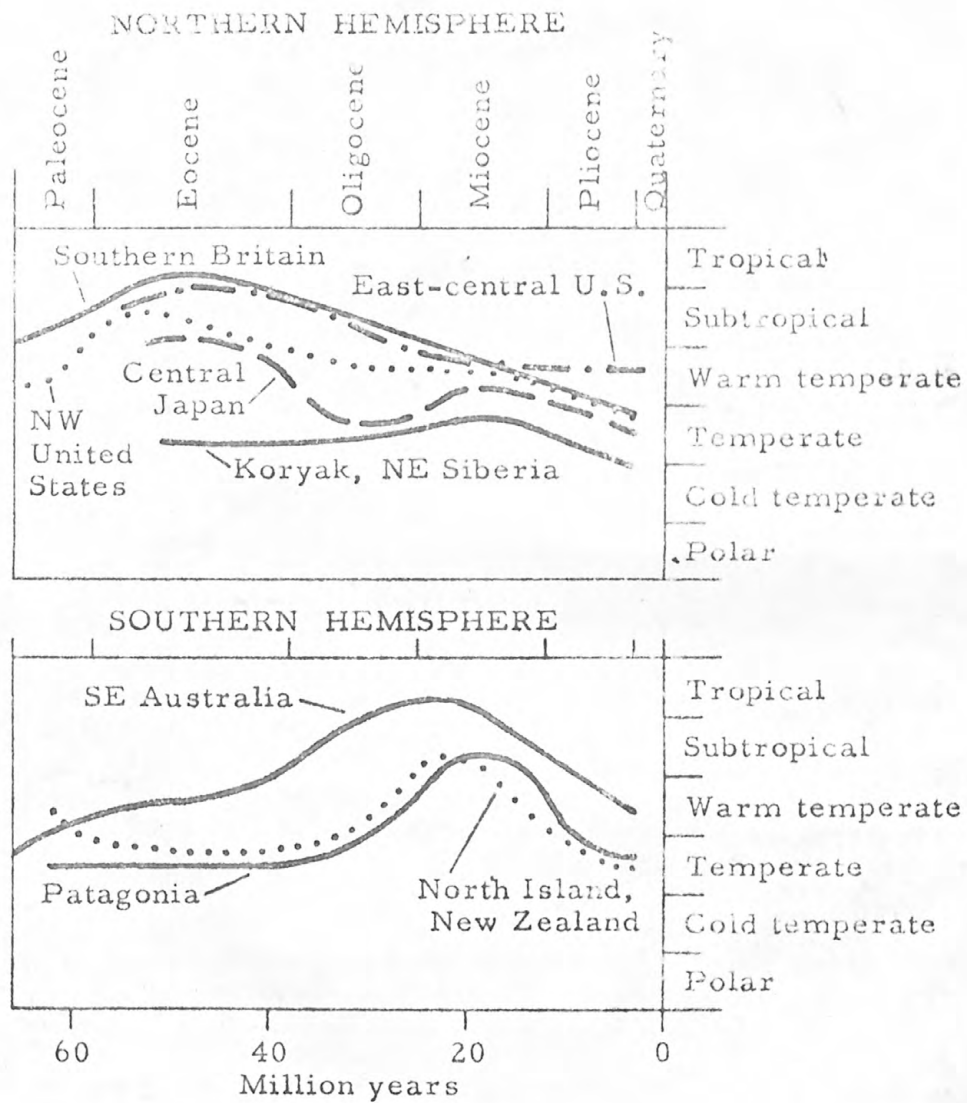


Figure 1. Climates of Cenozoic time. The curves are based largely on evidence from land floras and from shallow-water marine invertebrates. Quaternary glacial, interglacial, and present climates are not shown. The lack of parallelism of the curves for pre-Miocene time demonstrates that worldwide climatic changes cannot explain the diverse trends.

Permian time, for example, all the lands of the northern portion of the present Arctic had a tropical or subtropical climate, while at the same time now-tropical peninsular India and central and southern Africa underwent continental sea-level glaciation. Such evidence from older records, coupled with the evidence of paleomagnetism (which generally indicates low magnetic paleolatitudes for tropical indicators and high ones for polar indicators), in my view proves that great and complex continental drift has occurred, with constantly changing patterns, throughout at least Phanerozoic time. Repeated triangulation within California and Japan demonstrates present differential crustal motion at horizontal velocities of meters per century--more than fast enough to account for great continental drift; and even so, geologic arguments indicate that such internal differential velocities within small parts of continents are likely to be much lower than are relative velocities between different continental masses.

The major climatic changes shown by Paleocene, Eocene, and Oligocene of each continent probably are due primarily to motions of those continents through climatic zones whose latitudes changed relatively little. The changes during the Miocene and Pliocene are also due partly to such motion. Integration of the Cenozoic data with comparable data from the Mesozoic record, with biogeographic and paleomagnetic information, and with continental and oceanic structural considerations leads me to conclusions such as these:

1. The main mass of North America has moved northward since early Eocene time, and has rotated slightly clockwise as though about a pivot near the east coast. Latitude has increased throughout the late Cenozoic in the west but has been unchanged since the middle Oligocene in the east.
2. Europe and interior Siberia have moved northward. Very complex deformation by rifting, oroclinal folding, strike-slip faulting, and agglomeration has affected the Alpine-Himalayan-East Asian region, and Alaska and eastern Siberia.
3. Peninsular India has moved northward into Asia from an Eocene position as an island continent at the south margin of the tropics.
4. Australia moved northward from Cretaceous to Oligocene time, but during late Miocene and subsequent time its motion has had a southward component; the present conjunction with New Guinea is a very late Cenozoic development.
5. New Zealand also moved first northward, then southward, within the Tertiary and has, in the process, drifted farther from Australia into the Pacific.
6. Scant data suggest that Africa has moved northward during the late Cenozoic, but possibly southward during the early and middle Cenozoic; and that South America may have moved northward during the middle Cenozoic but southward since.

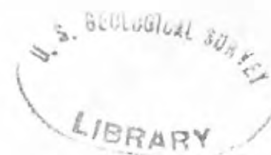
There have probably been only two periods of widespread continental glaciation within Phanerozoic time--the first in the earliest Permian (and latest Carboniferous?), the second in the Quaternary. Both have coincided with the temporary concentration of large land masses at high latitudes. The Quaternary has been a time also of uncommonly high mountain and continental altitudes and the Permian is generally assumed to have been similar although this cannot really be demonstrated.

The occurrence within the Quaternary of glaciation can thus be explained in terms of high latitude and high altitude of the continents, but the irregular alternation of glacial, semiglacial, and nonglacial periods within it requires further explanation. Postulations either of warming of the Arctic as a cause of glaciation (as, Ewing and Donn, 1956, 1958, 1959) or of alternation of climates in northern and southern hemispheres are disproved by data now available. Elimination of other possible mechanisms (see Fairbridge, 1961) appears to leave fluctuations in radiation received as the cause of meteorologic changes which produce self-accelerating glaciation and deglaciation when threshold limits are passed. The contributions to such radiation fluctuations of changes in the sun and in the earth's magnetic field and other geophysical attributes appear to be still beyond quantitative valuation.

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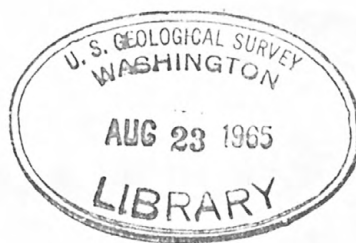
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