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CHRONOLOGY OF NEOGLACIATION IN THE NORTH AMERICAN CORDILLERA

STEPHEN C. PORTER* and GEORGE H. DENTON**

ABSTRACT: Geological, botanical, and historical evidence, together with critical radiocarbon dates, permit reconstruction of a reasonably comprehensive picture of glacier fluctuations in western North America during the last three millennia. These fluctuations largely postdate the Hypsithermal interval as defined by Deevey and Flint (1957) and fall within the cool geologic-climate unit widely referred to as Neoglaciation. Following recession and disappearance of many residual Wisconsin-age alpine glaciers during the warmest part of the Hypsithermal, resurgence of glacier activity led to a possible widespread early Neoglacial advance close to 4600 years ago and to a major advance that culminated 2600 to 2800 years ago throughout the Cordilleran region. A long period of milder climate followed, during which most glaciers probably diminished in size; dated moraines deposited during this interval are restricted to Alaskan coastal glaciers, and their regional significance is not yet known. Glaciers throughout western North America again experienced marked advances during the last several centuries, and many attained their maximum Neoglacial positions. Recession has been general and rapid since the early 20th century, although local minor readvance and related glacier growth in recent years reflect a response to somewhat cooler and wetter conditions in the 1940's and 1950's. Glaciers in other parts of the world show broadly similar histories, indicating probable world-wide synchrony of glacier fluctuations in response to climatic change.

INTRODUCTION

Records of historic glacier variations in western North America, together with stratigraphic and morphologic evidence encompassing several millennia, indicate that post-Wisconsin alpine glaciers have responded to fluctuations of climate over a significant interval of time. More than two decades ago, Matthes (1939, 1940, 1942) reviewed existing data on recent glacier variations and suggested they constituted evidence of a "little ice-age", during which glaciers reached their greatest size "since the Pleistocene ice age". At that time details of the record were poorly known, and even now few areas have been studied intensively. Nevertheless, available geologic data, which is scattered widely through the literature, and absolute dates relating to post-Wisconsin glacier fluctuations permit the reconstruction of a reasonably comprehensive picture of glacier activity during the last 3000 years.

The principal objectives of this paper are to review the evidence for post-Wisconsin glacier fluctuations, to establish a chronology of glacier activity based primarily on radiocarbon dates, and to attempt to resolve existing inconsistencies in the terminology for post-Wisconsin time. Although moraines and other morphologic features of either un-

* Department of Geology, University of Washington, Seattle, Washington.

** American Geographical Society, New York, and Radiocarbon Laboratory, Kline Geology Laboratory, Yale University, New Haven, Connecticut.

doubted or probable post-Wisconsin age have been described from numerous localities in western North America, in this paper attention is directed only to those areas that contain important sequences and that have yielded absolute dates through radiocarbon analyses, tree-ring studies, lichenometry, and historical records. Supplementary data from other continents are presented to demonstrate the world-wide nature of the glacier fluctuations and their apparent synchrony.

Because of known variations in atmospheric radiocarbon concentration during the last 6000 years, radiocarbon ages for this interval normally do not correspond to calendar years, but an approximate correction can be obtained by using conversion data presented by Stuiver and Suess (1966). Most published radiocarbon dates have not been corrected, and this practice is followed here. However, corrections are necessary before valid comparisons can be made between radiocarbon and historical ages. In this paper all dates are reported in years before present (B.P.), with the year A.D. 1950 generally regarded as the standard year of reference for all dates.

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CONCEPT OF A "LITTLE ICE-AGE"

In a series of papers spanning more than a decade (1935, 1939, 1940, 1941, 1942, 1945, 1948), Matthes presented evidence, mainly from the Sierra Nevada (fig. 1), that pointed to a resurgence of glacier activity in western North America following a period of mild climate after the close of the Wisconsin Glaciation. It had been widely assumed that modern alpine glaciers throughout the world were shrunken remnants of former extensive Pleistocene ice masses and that the fresh moraines which border them were merely the youngest of a series of recessional drift bodies left as the glaciers dwindled in size. Matthes recognized that major trunk glaciers of coastal Alaska and Canada, as well as the large ice streams on Cascade volcanoes, probably persisted throughout the post-Wisconsin episode of milder climate but maintained that the same assumption could not be extended to all the numerous cirque glaciers that exist at present in the Cascade Range, the Sierra Nevada, and the principal ranges of the Rocky Mountain System. As evidence, he cited Antevs' (1938) interpretation of the recent geologic history of Owens Lake at the eastern foot of the Sierra Nevada. Using Gale's (1915) figure of 4000 years as the time required for influent streams to raise the salt content of the lake to its present level, Antevs reasoned that accumulation of salts began when the lake was regenerated, following complete desiccation during the postglacial "Climatic Opti-

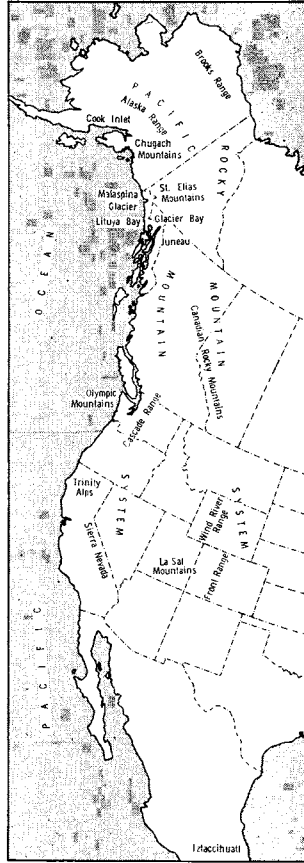


Fig. 1. Index map of North American Cordillera showing principal areas from which Neoglacial events have been described.

mum". Unlike certain other pluvial lakes in the Great Basin, Owens Lake did not inherit any of its salt from its larger Pleistocene predecessor, for older salt deposits had been buried beneath alluvium and eolian sediments during the period of desiccation. The salt content of the modern lake, therefore, provided a crude index of its age. Under the assumption that nearby alpine glaciers in the Sierra Nevada would respond to climate in much the same manner as the lake, Matthes (1939) proposed that when Owens Lake was dry the Sierra was essentially devoid of ice but that when the shallow modern lake formed with the advent of cooler and moister conditions following the "Climatic Optimum", small glaciers were regenerated along the crest of the range. "Those glaciers therefore are in all probability somewhat less than 4000 years old" (p. 520). By inference he extended the concept to include the majority of cirque glaciers that exist in other mountain ranges

of western United States and designated the period of renewed glacier activity the "little ice-age" (Matthes, 1939, p. 520).

Matthes (1940, 1941, 1948) noted two principal sets of moraines which he included in deposits of the "little ice-age". Massive unstable moraines bordering the termini of existing cirque glaciers are fresh and commonly have cores of stagnant ice. To Matthes they appeared comparable with "modern" moraines of the European Alps, which according to historic records were built during the early and middle 19th century. The massive ice-cored moraines contrast sharply with smaller outer concentric end moraines which, Matthes (1940, 1942) thought, probably dated to the 17th or 18th centuries, a time during which glaciers in the Alps attained their most extended positions since the last ice age. Even though Matthes apparently regarded the oldest "little ice-age" moraines as being but several centuries old, it is clear from repeated reference that he envisaged the initial rebirth of alpine glaciers as taking place more than three millennia earlier. He felt, however, that the "glacier oscillations of the last few centuries have been among the greatest that have occurred during the 4000 year period" (Matthes, 1939, p. 520) and marked the "culminating advances" of the "little ice-age" (Matthes, 1941).

NOMENCLATURE

A confusing array of names has been proposed for the interval of mild climate that followed the last major glaciation, among which are Alithermal, Climatic Optimum, Megathermal, Thermal Maximum, and Xerothermic. None were defined in precisely the same way, and arguments for and against using these terms have been advanced (for example, Antevs, 1948; Deevey and Flint, 1957; Cooper, 1958). We, however, prefer the term Hypsithermal, which has gained widespread acceptance since it was proposed in 1957 by Deevey and Flint, who adapted the word from Chiarugi (1936) and defined it as "the time represented by four pollen zones, V through VIII in the Danish system". When originally defined, the word was not capitalized, but the tendency among most workers has been to formalize the term through capitalization. The Hypsithermal has been recognized throughout much of the northwestern North American Cordillera through pollen studies (Heusser, 1960b), and its temporal span has been fixed by radiocarbon dating. Stratigraphic recognition of the Hypsithermal interval in the absence of pollen-bearing sediments or radiocarbon samples is possible where Hypsithermal soil or layers of volcanic ash of known age are preserved.

Terms proposed for the subsequent time interval, characterized by cooler climate and glacier advances, are nearly as numerous and no less confusing: Hypothermal (Cooper, 1958), katathermal (Chiarugi, 1936), "little ice-age" (Matthes, 1939), Medithermal (Antevs, 1948), and Neoglaciation (Moss, 1951). The appellation "little ice-age" adopted by Matthes was suggested initially by "a clever journalist" (Matthes, 1940,

p. 398). Matthes' use of quotation marks and lack of capitalization makes it obvious that the term was intended to be informal and temporary, but it has attained a degree of permanence through repeated use; not uncommonly it is capitalized and the quotation marks are excluded. In one paper, Matthes (1942) referred informally to "a lesser ice age" in describing alpine glacier fluctuations of the last 300 years which had been documented by Kinzl (1932), but apparently he intended this phrase to be synonymous with "little ice-age". An alternative interpretation, by which these terms were used to denote two separate intervals of post-Wisconsin glacier activity (Karlstrom, 1956), has introduced a degree of confusion. Objections to continued use of the term "little ice-age" have been enumerated by Cooper (1958, p. 942) and need not be repeated here.

After thoughtful consideration, we have elected to use the term Neoglaciation for the period of glacier expansion subsequent to maximum Hypsithermal shrinkage. The word has been widely adopted in recent years by workers in the Cordilleran region (for example, Birkenland, 1964; Birman, 1964; Crandell, 1965; Moss, 1951; Nelson, 1954; Richmond, 1965; Sharp, 1960) and is etymologically appropriate in that Matthes characterized the "little ice-age" as a period of *rebirth* of alpine glaciers, a concept that has not been seriously questioned. Both Moss (1951, p. 62) and Nelson (1954, p. 340) attributed the term to Matthes and used it interchangeably with "little ice-age." but it appears in none of Matthes' published works. Moss (1951) apparently was the first to use the word in print. We feel that the term Neoglaciation should be adopted universally and the journalistic phrase "little ice-age", which has quite adequately served its purpose, be allowed to pass into limbo.

ROCKY MOUNTAIN SYSTEM

Rocky Mountains of Western United States

Widespread evidence of post-Hypsithermal glacier activity exists in the ranges of the Rocky Mountains as far south as central New Mexico, but as yet few areas have been described in detail and none has been adequately dated by radiocarbon. Two principal episodes, based on moraines, rock glaciers, and protalus deposits, are recognized by Richmond (1965) throughout the Rockies of western United States and are referred to as the Temple Lake and Gannett Peak Stages of Neoglaciation. Interregional correlations are based principally on morphology and soils.

Ray (1940) summarized the glacial record of the southern Rocky Mountains and subdivided the youngest glaciation (Wisconsin) into five substages. In Rocky Mountain National Park in the Front Range of Colorado establishment of the youngest substage (Sprague = Wisconsin V) was based on fresh moraines and protalus ramparts. Richmond (1960) subsequently recognized two post-Wisconsin ice advances in the park, the older of which he designated Temple Lake (following the terminology of Moss, 1951) and equated with Ray's Wisconsin V

substage; the younger subsequently was named Gannett Peak (Richmond, 1965). Both include evidence of at least two secondary glacier pulsations.

The Wind River Range in Wyoming, widely regarded as the type area for glacial stages in the Rocky Mountain region, has a well-developed Neoglacial sequence which has been described by Hack (1943), Moss (1951), and Holmes and Moss (1955). Moraines built during the Temple Lake Stade in the southwestern Wind River Mountains were regarded by Holmes and Moss (1955) as either latest Wisconsin (Pinedale) or an early pulsation of the "little ice-age". They appeared "significantly older" than fresh "little ice-age" moraines (Gannett Peak of Richmond) and protalus ramparts within cirques that "may record more than one very recent advance". The interval between the Temple Lake and "little ice-age" advances was thought to have been short compared to the interval between Temple Lake and the recessional Pinedale moraines but was significantly longer than the time since the advance that built the fresh "little ice-age" moraines. The type Temple Lake moraine is now widely regarded as a manifestation of early Neoglacial activity.

Direct dating of Neoglacial moraines in the Rocky Mountains of western United States has not yet been possible, but several dates on associated alluvial sediments permit approximate ages to be assigned. The Gold Basin Formation in the La Sal Mountains of southeastern Utah was subdivided by Richmond (1962) into two members, each regarded as having been deposited during a period of expansion of alpine glaciers. The lower member, correlated by Richmond (1965) with the Temple Lake Stade, includes stream sediments possibly belonging to two episodes of alluviation related to glacier pulsations. The upper member, which is correlated with the Gannett Peak Stade, is separated from the lower member by a very weak soil, interpreted as reflecting a brief nonglacial interval preceding a period of renewed glacier activity. A radiocarbon date of 2800 ± 200 years on charcoal (W-143) (Rubin and Suess, 1955) from a paleoindian hearth in the lower member provides an approximate date for the Temple Lake glacial advance, inasmuch as the alluvium grades upstream into outwash from a moraine of Temple Lake age (Richmond, 1962). Other archeological sites in two alluvial units in the southwest regarded as Temple Lake equivalents have yielded dates suggesting that the older of the two was deposited between about 3100 ± 250 (W-621) and 1800 ± 160 (W-802) years ago, and the younger between about 1800 ± 160 and 1050 ± 250 (W-616) years ago (Richmond, 1965).

Rocky Mountains of Canada

A fresh, but deeply stream-notched cirque moraine in the Waterton region of southern Alberta was assigned to the "little ice-age" by Horberg (1954) and correlated with terrace gravels that overlie a peat bed. Radiocarbon dates of 3261 ± 250 (C-607) and 3327 ± 320 (C-606) years

on wood and peat from the buried organic horizon therefore provide a limiting age on the moraine which may have been built during the Temple Lake Stade.

The maximum Neoglacial advance on Crows Nest Mountain, south-east British Columbia, is recorded by till of a lateral moraine. A radiocarbon date of 4770 ± 120 years (I (GSC)-182) on charcoal from a soil horizon beneath the till provides a limiting date on the advance (Trautman and Walton, 1962).

Another limiting date on an early Neoglacial advance comes from Banff National Park where soil buried beneath ablation till has been radiocarbon dated at 6020 ± 90 years (S-191) (McCallum and Wittenberg, 1965, p. 233).

Glacier variations in the Canadian Rocky Mountains during recent centuries have been summarized by Heusser (1956). The earliest recognized Neoglacial advance occurred in the valley of the Robson Glacier, where a spruce tree, radiocarbon-dated at 450 ± 150 years (no laboratory number assigned), was sheared off by advancing ice and later buried by outwash gravel. In other valleys, botanical evidence indicates that glaciers reached their maximum stands in the second half of the 17th century or during the first quarter of the 18th century. Glacier recession began mainly toward the end of the 18th century and continued into the first half of the 19th century, at which time most glaciers readvanced, some to positions that exceeded their earlier maxima. General retreat during the remainder of the century slowed during the second and third decades of the 20th century but increased markedly thereafter. The overall behavior closely paralleled meteorological trends which show warming and decrease in precipitation from the last decade of the 19th century until late in the 1930's. Subsequent cooling and increase in precipitation has occurred since the early 1940's; however, glacier termini were still retreating in 1953, possibly implying a lag in response to climate change. Initial response was first detected in the Purcell Range of British Columbia where the Commander Glacier experienced terminal thickening in 1954 and during the following six years underwent a marked advance (West and Maki, 1961). Glaciers in nearby ranges showed comparable thickening and signs of incipient advance.

Brooks Range

Conspicuous fresh moraines in the higher parts of the north-central Brooks Range of arctic Alaska were regarded as the deposits of two separate glaciations by Detterman, Bowsher, and Dutro (1958), who designated them Alapah Mountain and Fan Mountain. The Alapah Mountain Glaciation was assigned tentatively to the late Wisconsin and the Fan Mountain to the Recent. However, detailed mapping and radiocarbon dating in the Anaktuvuk Pass area by Porter (1964, 1966) showed that the Alapah Mountain advance culminated about 2830 ± 120 years ago (Y-771) and therefore clearly is a post-Wisconsin event which occurred during the early part of Neoglaciation. Alapah

Mountain moraines are not found in all valleys but where present may lie as much as 10 miles beyond cirques. Although morphologically distinct, they are more subdued and their slopes more stable than the younger Fan Mountain moraines, which tend to have unstable slopes and not uncommonly have ice cores. The latter are confined largely to cirques and frequently are in contact with small remnant glaciers. The freshness of the drift and absence of vegetation cover suggests Fan Mountain moraines date to the later part of Neoglaciation and probably were built within the last several centuries.

Fresh moraines confined to the higher parts of the Schwatka Mountains in the southwestern Brooks Range were assigned to two episodes of glaciation by Fernald (1964), who named them the Ulaneak Creek and Modern glaciations. Ulaneak Creek glaciers extended as much as 8 miles down valleys, but most were confined to cirques. Fernald assigned this glaciation to the Recent; a correlation with the Alapah Mountain Glaciation of the central Brooks Range appears justified. Fresh rubbly moraines of the Modern glaciation lie within 2 miles of cirque headwalls and date to the very recent past.

Holmes and Lewis (1965) assigned a series of small moraines that lie beyond modern glaciers in the Mount Chamberlin area of the northwestern Brooks Range to the Katak Glaciation. They correlated them broadly with Fan Mountain and Alapah Mountain moraines of the Anaktuvuk Pass area and with end moraines beyond the Okpilak Glacier in the Mount Michelson area which Sable (1961) regarded as historically recent in age.

PACIFIC MOUNTAIN SYSTEM

Mexico

Post-Wisconsin moraines on the west side of Iztaccihuatl volcano in Mexico were assigned by White (1956, 1962) to the Ayolotepito Substage of the "Neothermal" Stage. Terminal moraines, 3 or 4 recessional moraines, and protalus ramparts that lie within a few hundred yards of modern glaciers were correlated with the Gannett Peak Stade of Richmond (1960). White considered moraines of an older advance (Alicalic Substage) to be late Wisconsin in age but correlated them with the Temple Lake Stade of the Rocky Mountains. If the later correlation is correct, the currently accepted post-Hypsithermal age of Temple Lake deposits suggests that the Alicalic moraines may reflect early Neoglacial advances on Iztaccihuatl.

Sierra Nevada and Trinity Alps

Three pulses of possible post-Tioga (= post-late Wisconsin) glacier activity were identified in the central Sierra Nevada by Birman (1964), who named them Hilgard, Recess Peak, and Matthes. Moraines of Hilgard age represent the earliest phase and were built by glaciers as much as 7 miles long. Stabilized rock glaciers mantled with lichen-covered boulders were correlated with Recess peak moraines which lie

within 2 miles of cirque headwalls. Moraines of Matthes age are confined to cirques, some of which contain small remnant glaciers and perennial snowfields. Associated with them are rock glaciers, protalus ramparts, and taluses, all composed of fresh, angular, unstable rubble. The rock glaciers are thought to have originated earlier in Neoglaciation but to have been reactivated during Matthes time. Massive morainal embankments of Matthes age which lie adjacent to existing glaciers in many cirques commonly have ice cores (Matthes, 1948).

Birman, following Matthes (1939, 1941, 1942), believed that the youngest deposits and associated remnant ice bodies, which he assigned to the Matthes Glaciation, date to the latter half of the 19th century. Ring counts of trees on Recess Peak moraines provide a minimum limiting age of 250 years for that advance, and Birman suggested probable correlation with glacier activity in the Alps during the 16th and 17th centuries. However, a widespread blanket of pumice around Mammoth Mountain, south of Mono Lake, rests directly on wood radiocarbon-dated at 1440 ± 150 years (W-727) and mantles nearby moraines regarded by Janda (1965; personal communication, 1965) as probably being Recess Peak in age. Moraines of Matthes age lack pumice. Therefore, the Recess Peak advance may have occurred in the earlier part of the Neoglacial interval. Although Birman (1964, p. 75) favored an age of less than 4000 years and pre-17th century for the Hilgard, he stated that possibly it is latest Wisconsin, a view held by some other workers in the Sierra (Birman, 1964, p. 11, 74; Morrison, 1965, p. 268).

A similar Neoglacial record has been studied in the east-central Sierra near Bishop by Rahm (1964), who designated a three-fold morainal sequence, from oldest to youngest, Wonder Lakes, Basin Mountain, and Gilbert.

A three-fold sequence of small, fresh-appearing moraines in the higher parts of the Trinity Alps in northwestern California was assigned a probable post-Hypsithermal age by Sharp (1960). The outermost and oldest moraines, built by small glaciers up to 0.9 mile long, may be two to three thousand years old. The youngest moraines are thought to date to the mid-19th century.

Cascade Range and Olympic Mountains

Neoglacial moraines on Mount Rainier have been assigned to two stades of the Winthrop Creek Glaciation by Crandell and Miller (1964; Crandell, 1965). Distinctive pyroclastic layers of known age permit approximate dating of moraines with which they are associated. Moraines of the Burroughs Mountain Stade were built between about 3500 ± 250 (W-1115) and 2040 ± 200 (W-1393) years ago and lie but a short distance beyond moraines of the Garda Stade. Some Garda moraines are overlain by an ash layer dated at between 400 and 500 years old, but others lack the ash. The oldest Garda moraines bear trees that began growing early in the 13th century, but in most valleys tree-ring studies indicate that recent glacier maxima were reached at various

times from the middle of the 14th century to the middle of the 19th century. Although end moraines built during the middle of the 19th century are common to many of the glaciers, no consistent pattern has been discerned among older moraines, owing either to insufficient data or to varied behavior of the different glaciers. Between the middle of the 19th and the middle of the 20th centuries, glaciers on Mount Rainier experienced overall retreat (Meier, 1963; Harrison, 1956), and the glacierized area shrank from 140 square kilometers (66 square miles) to about 88 square kilometers (34 square miles) (Post, 1963). Beginning about 1950, a widespread resurgence of glacier activity was noted on Mount Rainier and elsewhere in the Pacific Northwest, and many glaciers actively advanced or achieved a near-equilibrium condition, apparently in response to decreasing temperatures and increasing precipitation (Bengston, 1956; Hubley, 1956; LaChapelle, 1963; Meier, 1965).

An early Neoglacial advance of South Cascade Glacier in the North Cascade Range of Washington produced a massive moraine half a mile beyond the present position of the terminus (Meier, 1964). A tree that had been sheared off and buried by the advancing glacier was exposed upvalley from the moraine during recent ice recession. A radiocarbon date of 4700 ± 300 (W-1030) on the wood gives a maximum limiting age for the moraine. Subsequent more extensive advances occurred in the 16th and 19th centuries and produced several small moraines beyond the massive older moraine. Since 1900 the glacier has receded continuously.

The climax of the maximum Neoglacial advance of Sphinx Glacier in the Mt. Garibaldi area of southwestern British Columbia has been dated at 460 ± 40 years (Y-347) by wood from a tree killed and buried by the advancing ice (Barendsen, Deevey, and Gralenski, 1957, p. 909). Wood from an old forest which covered a now-barren nunatak on the east side of Mt. Garibaldi has been dated at 5260 ± 200 years (Y-140 bis.) (Stuiver, Deevey, and Gralenski, 1960). The sampled tree, which was rooted in place, had been covered by glacier ice until about A.D. 1940. Although the relationship suggests glacial growth close to 5200 years ago, evidence for terminal advance of glaciers at that time is lacking in the Garibaldi area (W. H. Mathews, personal communication, 1966). Historical, botanical, and geological evidence cited by Mathews (1951) indicates that in the late 1940's glaciers throughout the Garibaldi area were retreating from more advanced positions attained during the early part of the 18th century and the middle of the 19th century. During these advances glaciers apparently reached a greater size than at any time since the waning of the late Wisconsin Cordilleran ice sheet.

A record of recent glacier activity in the Olympic Mountains of Washington is preserved in a series of moraines that borders the Blue Glacier on the north flank of Mount Olympus. Tree-ring studies by

Heusser (1957) indicate that the age of the two oldest moraines is greater than 700 years; the oldest firmly dated advance occurred about 1650. Fluctuations of the terminus produced a series of four moraines between about 1820 and 1920. Subsequent rapid recession ceased about 1950 when thickening of the snout was noted, and since that year the position of the terminus has been essentially stationary. Shortly before 1810, the adjacent Hoh Glacier achieved its maximum stand of the past five centuries. Extensive recession followed and showed a marked increase in rate between 1933 and 1952.

Coastal Mountains of southern Alaska and Yukon Territory

The Neoglacial record in the mountains of southern Alaska and Yukon Territory generally is incomplete because most evidence of early Neoglacial fluctuations is hidden beneath glacier ice or drift of the youngest major advance which, in this region, typically was the most extensive of the Neoglaciation.

One of the most complete Neoglacial sequences is that described by Karlstrom (1964) from the Kenai Peninsula in the Cook Inlet region of coastal Alaska. Fresh-looking moraines between more modified moraines of Naptowne (last-Wisconsin) age and the fronts of existing glaciers were assigned to the Alaskan Glaciation. Two distinct series of end moraines, designated Tustumena and Tunnel, were recognized and further subdivided into three and two episodes, respectively, on the basis of morphology and stratigraphy. The Tustumena advances fall within the earlier part of Neoglaciation, as indicated by a radiocarbon date of 2370 ± 200 years (W-78) on a log buried in till of the youngest advance (Tustumena III). A maximum limiting age is given by a date of 4700 ± 450 years (L-237G) on woody peat collected from the base of a bog. The peat was interpreted by Karlstrom as representing a change from dry to moist conditions and was correlated with expansion of alpine glaciers during the Tustumena phase. Wood beneath till of Tunnel I age was dated at 1385 ± 200 years (W-318), whereas logs incorporated in till of the Tunnel II advance were dated at 400 ± 150 years (L-117K) and < 300 years (L-163G). Two younger prehistoric readvances are indicated by minor moraines, and historic readvances were recorded in the late 1890's, 1916, around 1940, and around 1950.

On the basis of dendrochronology and lichenometry, Péwé (1957; 1965) dated advances that built young moraines fronting several glaciers in the Alaska Range. Advances of the Black Rapids, Canwell, and Castner glaciers culminated about A.D. 1650 (?) and 1830; advances of the nearby Gulkana Glacier culminated about A.D. 1580 (?), 1650 (?), 1830, and 1875. Evidence of more extensive Neoglacial advances of the Gulkana Glacier is lacking. A radiocarbon age of 2000 ± 200 years (W-674) for a log embedded in terrace sediments along the upper Susitana River dates a time of extensive alluviation, possibly correlative with a post-Hypsithermal glacial advance in the mountains (Rubin and Alexander, 1960). Wood buried within the "10-foot terrace" of the

Copper River was dated at 850 ± 200 years (W-592) and provides a date within the last significant period of stream aggradation, regarded as contemporaneous with a minor glacial episode (Rubin and Alexander, 1960, p. 171). Farther south in the Chugach Mountains, the Matanuska Glacier probably maintained a retracted position during Hypsithermal time and subsequently readvanced, depositing several moraines which probably date to an interval lasting from a few thousand years ago to slightly before A. D. 1898 (Williams and Ferrians, 1961).

In the northeast St. Elias Mountains of Yukon Territory, Neoglacial and pre-Neoglacial drift surrounding the termini of the Kaskawulsh and Donjek Glaciers has been mapped and studied (Denton and Stuiver, 1966; Borns and Goldthwait, 1966; Krinsley, 1965). Both glaciers are northeast-flowing outlet glaciers of the intermontane icefield which mantles the Icefield Ranges of the St. Elias Mountains. Evidence of major glacial events of late Wisconsin and Neoglacial age is afforded by two superposed loesses which are separated by a buried soil of Hypsithermal age. Distribution and thickness of the loess sheets indicate that the outwash trains of these glaciers constituted the main source of silt for both loesses. The loess-soil sequence implies, therefore, that two episodes of outwash deposition were separated by a period of nondeposition and soil formation. The lower loess unit was deposited during the recessional phase of the last major glaciation (Kluane) of the area which is correlated by radiocarbon dating with the classical Wisconsin Glaciation of central North America. Soil development in the upper 10 to 16 inches of the lower loess occurred during the Hypsithermal interval when substantial glacier retreat led to cessation of loess deposition over much of the lower Kaskawulsh and Donjek valley trains. Deposition of the upper loess unit on the Hypsithermal soil resulted from renewed valley-train activity accompanying early Neoglacial readvance of both glaciers. The presence of the loess-soil sequence throughout a wide area near the terminus of the Kaskawulsh Glacier and through a distance of 13.7 miles above the present terminus along the west valley margin (15 miles above young Neoglacial moraines surrounding the terminus) suggests that the Kaskawulsh Glacier receded at least this far during Hypsithermal time. Presence of the same stratigraphic sequence throughout a large area marginal to the Donjek terminus implies substantial Hypsithermal retreat of that glacier as well.

A radiocarbon date (Y-1483) of grass buried in place at the base of the lower loess deposit indicates that shortly prior to 9780 ± 80 years ago ice of the Kluane glaciation receded behind the position now occupied by the outermost Neoglacial moraines surrounding the terminus of the Kaskawulsh Glacier. A close minimum age of 2640 ± 80 years for the initial Neoglacial advance of the Kaskawulsh Glacier is given by a date (Y-1435) of grass buried in place at the base of Neoglacial

loess near the present Kaskawulsh terminus. Information bearing on fluctuations that postdate this initial Neoglacial advance and that predate a major advance during the last few centuries is scanty. That both glaciers were more extensive during this interval than during the Hypsithermal is suggested by apparent continuity of loess deposition near the present termini.

The most recent episode of glacier expansion is represented by fresh moraines surrounding the termini of both glaciers. Undisturbed buried Hypsithermal soil formed on the lower loess sheet borders the moraines, indicating that they mark the maximum extent of the glaciers during Neoglaciation. Radiocarbon ages of spruce logs embedded in the end moraines provide (1) dates of glacier advance and (2) maximum limiting dates for moraine construction. Samples from the outermost Kaskawulsh moraine were dated at 450 ± 100 (Y-1354), 390 ± 80 (Y-1490), and 110 ± 80 (Y-1489) years; those from the Donjek were dated at 290 ± 80 (Y-1484) and 230 ± 80 (Y-1485) years. A spruce stump whose top was sheared off when the Kaskawulsh Glacier attained its maximum stand was dated at 270 ± 60 (Y-1480) years. Retreat from the Neoglacial maximum began before A. D. 1865 for the Kaskawulsh Glacier and before A. D. 1825 for the Donjek Glacier, as indicated by ring counts of trees presently growing on the outermost moraines. Differences in morphology and vegetation cover of the moraines suggest that in both cases recession was characterized by one or more stillstands or readvances.

Neoglacial events in the Malaspina, Lituya Bay, and Glacier Bay districts on the south flank of the St. Elias Mountains have been studied in some detail. Two recent advances are recognized in the Malaspina district (Plafker and Miller, 1957). Logs from moraines of the oldest and most extensive were dated at 1200 ± 160 (W-374) (Icy Bay) and 830 ± 160 (W-559) (Yakutat Bay) years old. An additional date (I-439) indicates that 560 ± 75 year ago ice which built the outer moraine in Yakutat Bay sheared off a tree that now lies buried beneath the moraine (Trautman and Willis, 1966, p. 163). The advances recorded in this region by these dates are isolated occurrences which may reflect climatic events or, alternatively, may be related to "surges" not directly associated with climate. Following recession between A. D. 1400 and 1700 glaciers experienced another advance which culminated between A. D. 1700 and 1791. Sharp (1958, p. 24) reported an age of < 300 years (L-238) for wood overrun during the youngest advance of the Malaspina Glacier. Subsequent to the culmination of the latest advance recession and stagnation have occurred.

The Neoglacial history of the North and South Crillon Glaciers, which flow southwest from Mt. Crillon toward Lituya Bay, has been studied by Goldthwait, McKeller, and Cronk (1963). Although the glaciers coalesce locally in their lower reaches, each has a distinct terminus; North Crillon Glacier ends in Lituya Bay, whereas South Crillon Glacier

terminates in Crillon Lake. Prior to 9150 ± 275 years ago (I-547), North Crillon Glacier receded behind the position of its subsequent maximum Neoglacial stand. Radiocarbon ages of logs buried by or embedded in Neoglacial till in the Lituya Bay area suggest that the Crillon Glacier system underwent expansion about 1050 (I-466, I-548) years ago. The age of a log within the Neoglacial terminal moraine near Crillon Lake implies that the Neoglacial maximum was attained subsequent to about 390 ± 160 (W-371) years ago. By the time of LaPerouse's visit to Lituya Bay in A.D. 1787, recession had led to separation of the two ice streams, so that each glacier terminated in the bay. The subsequent history has been characterized by advancing termini, an unusual situation, as most glaciers of the region retreated during this time.

In Glacier Bay, ice of Wisconsin age receded to a point behind the position of modern glacier termini before 7075 ± 250 (I-58-4) years ago (Goldthwait, 1963). Hypsithermal outwash, deposited through an interval of about 5000 years, contains remnants of buried forests (Haselton, 1966). An early Neoglacial advance began in the upper reaches of Glacier Bay shortly before 2735 ± 160 years ago (I-59-15), but the extent of the advance is unknown. The outermost Neoglacial moraine, which lies at Bartlett Cove near the lower end of the bay, is dated by two stumps (Y-132-83; Y-132-86) which were overwhelmed by advancing ice less than 300 years ago (Lawrence, 1958; Goldthwait, 1963). Retreat had begun by the time of Vancouver's visit to Glacier Bay in A. D. 1794; ecological studies suggest that the retreat probably began between A. D. 1735 and 1785 (Cooper, 1937, p. 47). Since that time, total recession locally has exceeded 60 miles (Lawrence, 1958).

The outermost Neoglacial moraines of Lemon Creek Glacier near Juneau represent the most extensive ice advance since some time before $10,300 \pm 600$ years ago (L-297G) (Heusser and Marcus, 1964). The earliest radiocarbon dates of post-Hypsithermal glacier reexpansion are those of trees overrun by advancing ice of the Mendenhall Glacier about 2790 ± 130 (Y-132-80) and 1090 ± 60 (Y-132-84) years ago. Glaciers in the area had reached their Neoglacial maxima and had begun to retreat shortly before A. D. 1750 (Lawrence, 1950; Heusser and Marcus, 1964). Subsequent glacier behavior has been characterized by general recession with minor readvances or stillstands.

Close agreement of Neoglacial events among areas in coastal Alaska and adjacent parts of Canada suggests a regional pattern characterized by (1) initial recognized glacier expansion shortly before 2600 to 2800 years ago and (2) a major advance which, except for glaciers in the Malaspina district, culminated during the last several centuries and represents the maximum Neoglacial stand. The timing of the latter culmination varied from locality to locality, occurring about 200 years ago in Glacier Bay and the Juneau area, within recent decades in Prince William Sound, and somewhere between these two extremes elsewhere. In view of modern glacier behavior in these mountains, which indicates

that some glaciers probably were not in phase with the regional pattern, it is not possible as yet to tell which of several dated isolated glacier advances, occurring after the initial Neoglacial expansion and before the youngest major advance, represent events of regional scope, nor are the magnitudes of these advances known.

Recent glacier behavior in coastal Alaska is reasonably well known as a result of numerous observations (see Field, 1932, 1937, 1947, and 1957). Although recession, especially in Glacier Bay, has been the general trend during the 20th century, many glaciers have been out of phase and have recorded advances, particularly in Prince William Sound where several recently attained their maximum extents of at least the last 400 years (Field, 1957). Throughout the region there are instances of discordant behavior of neighboring glaciers. A notable example is the Taku Glacier which since 1900 has been steadily advancing while nearby glaciers have been receding (Field, 1954). Especially spectacular among recent advances of Alaskan and adjacent Yukon glaciers are very rapid, short-lived "surges" which probably are related more directly to glacier mechanics than to climatic events. These "surges" were especially common from 1905 to 1910 (Tarr and Martin, 1914, p. 168-174) and during the last few years (W. O. Field, personal communication, 1966; Post, 1966).

OTHER GLACIATED AREAS

Northern Hemisphere

Canadian Arctic.—Field work by Andrews (ms) in north-central Baffin Island indicates that during the last 7000 years the western and northwestern margin of the ice cap on Baffin Island has experienced overall slow retreat interrupted by stillstands or readvances. A readvance of the ice margin during the King phase led to the construction of well-developed moraines as much as 30 kilometers beyond the present west margin of the Barnes Ice Cap. Lichen studies suggest (1) an age of about 2400 years for the outer part of the King moraine complex, (2) younger moraines date from the 7th, 10th, and 14th centuries, and (3) the northwest margin of the ice cap expanded during the early and middle 17th century, and subsequently built recessional moraines that date to 1740, 1790, 1890, 1905, and 1920. Locally, the younger advances appear to have overridden moraines of the King phase. Limited recession has taken place during the last few decades, but the west margin of the ice cap still is largely in contact with ice-cored moraine that dates to the 17th century.

Greenland.—Data concerning Neoglacial climatic events in Greenland are scarce, and responses of the Greenland Ice Sheet to Neoglacial climatic changes are poorly known. Early Neoglacial moraines were found in front of glaciers in west Greenland by Beschel (1961) who noted a general similarity to Alpine moraines described by Heuberger (1954) and Heuberger and Beschel (1958). Moraines of the Narssarssuaq stage in the Julianehåb district of south Greenland were regarded as early

Neoglacial (early sub-Atlantic) by Weidick (1963). From A.D. 980 to about 1540 Norse colonies existed in southwest Greenland under generally warmer conditions than prevail today (Koch, 1945, p. 266-268). Coffins entwined in roots are embedded in ground now perennially frozen, suggesting cooling subsequent to their burial during the latter half of the 15th century (Nørlund, 1924, p. 241). Along the west coast of Greenland, at least, the cooling was accompanied by advance(s) of glaciers. Lichen studies suggest that the earlier advance occurred between A.D. 1500 and 1600 (Beschel, 1961); historical records indicate that glaciers also advanced to historic maximum stands about 1750 and 1890 to 1900 (Weidick, 1963). Recession occurred during the first four decades of the present century, after which it slowed or partially ceased.

Iceland.—From the beginning of colonization in A.D. 870 until at least A.D. 1200, glaciers in Iceland were more restricted than in the 1930's (Ahlmann, 1953, p. 39). During this time farms were built near glaciers at localities that were subsequently overrun or nearly overrun by advancing Neoglacial ice early in the 18th century. The last three centuries have been characterized by general glacier expansion which included several major and minor advances. The most extensive advance culminated between A.D. 1750 and 1760, the next most extensive between 1840 and 1850; minor advances culminated between 1710 and 1720, possibly between 1810 and 1820, and about 1890 (Thorarinsson, 1943). Recent behavior has been marked by general recession and at present the glaciers are smaller than at any time since the late 17th century. A special feature of the recent history of outlet glaciers of Vatnajökull, an ice cap in southeastern Iceland, has been repeated, short-lived "surges" (Thorarinsson, 1964b) which are apparently similar to those reported previously for glaciers of coastal Alaska. Although advances of the last few centuries generally were the most extensive since the last major ice age, tephrochronologic studies show that in a few cases end moraines lying beyond those of the recent maxima may date from an early Neoglacial advance (Thorarinsson, 1949, p. 250; 1956; 1964a).

Supplementary information on climatic trends in the North Atlantic area comes from historical records of the amount and distribution of sea ice in the waters surrounding Iceland and southern Greenland (Koch, 1945, p. 243-298; Schell, 1961). The amount of ice, which probably reflects climatic trends, was low from A.D. 800 to 1200, was higher from 1200 to 1400, decreased slightly from 1400 to 1600, and increased greatly from 1600 to 1900.

Europe.—Little direct evidence of Neoglacial glacier fluctuations prior to those of the last few centuries is available for the Caledonian mountain range of Norway and Sweden. During the Hypsithermal most glaciers probably disappeared. Pollen studies suggest that the change from sub-Boreal to sub-Atlantic conditions, about 2600 to 2900 years ago, was marked by onset of cooler, moister climate which probably was preceded by gradual climatic deterioration (Fries, 1965, p. 60); as a result

glaciers probably were regenerated. Evidence from bogs in western Norway, including pollen diagrams and recurrence horizons, implies that the Roman Iron Age (around A.D. 50 to 400 in Scandinavia) was characterized by a climate warmer than that before or after (Hafsten, 1960, p. 449-450). During the late 1930's, several arrows, with wooden shafts intact, were found in the mountains at sites from which snowbanks had recently disappeared (Hoel and Werenskiold, 1962, p. 57; Thorarinsson, 1940, p. 139). The oldest arrows date from A.D. 400 to 600 and the youngest from post-reformation times in Norway. Because a prerequisite condition for preservation of the shafts is a continuous cover of snow and ice, the occurrence of the arrows strongly suggests that the associated snowbanks had similar volumes about A.D. 400 to 600 and about A.D. 1930 to 1940 and that they were larger during the intervening time. A corollary is that the melting during the present century is the greatest since the Roman Iron Age. Quite probably these changes in snowbank volume parallel similar trends in glacier volume during this time interval.

Historical records provide evidence of glacier fluctuations in parts of Norway during recent centuries (Faegri, 1948; Hoel and Werenskiold, 1962, p. 59-72, and references therein). The history of outlet glaciers of Jostedalbreen in west-central Norway is best known. These glaciers began to advance between A.D. 1660 and 1700; by A.D. 1750 they had attained their greatest Neoglacial extent, destroying several farms in the process. Subsequent recession has been interrupted by several minor readvances, especially between 1807 and 1812, 1835 and 1855, 1904 and 1905, and 1921 and 1925. A similar recent history for Engabreen, an outlet glacier of Svartisen in northern Norway, is suggested by the date of a stump overrun by advancing ice 350 ± 100 years ago (no laboratory number published) and by historical records indicating that the advancing glacier damaged several farms in A.D. 1723 (Liestøl, 1960, p. 64-65).

Glaciers in the Caledonian mountains of northern Sweden are bordered by a series of Neoglacial moraines. The time when some of these moraines were last covered or partly covered with glacier ice is indicated by old photographs and measurements of the positions of the termini. In 1807 glaciers in the Sulitelma district were touching the middle moraine of three now visible in front of most of the glaciers, and from at least 1898 to 1908 they were touching the innermost of the three moraines (Bergström, 1955b, p. 363-364). In the Kebnekajse area, during the first decade of the 20th century, glaciers experienced a slight advance which culminated about 1910 at positions generally less than 100 meters inside the moraine marking the maximum Neoglacial position (Schytt, 1959, p. 224-226). Rabots Glaciär, however, reached its maximum Neoglacial extent in 1910 (Schytt, Jonsson, and Cederstrand, 1963, p. 300-301). The glaciers maintained their advanced positions until about 1920-1930 when they began a rapid retreat which has continued to the present day. The time of ice retreat from moraines beyond the positions of 1807 or 1910 can only be estimated from vegetation cover on moraines. Bergström (1955b)

estimated that most glaciers of northern Sweden probably attained Neoglacial maxima about A.D. 1735 \pm 50, although in several cases older moraines, probably of Neoglacial age, lie outside those built in the mid-18th century. Stork (1963) concluded that ice last retreated from the outermost moraine fronting Storglaciären in the Kebnekajse area more than 150 years ago; the outer moraines fronting Tarfalaglaciären may be much older.

Recently, Østrem (1964, 1965) discovered that many moraines fronting glaciers in Scandinavia have ice cores. In many cases the ice cores originated when snowbank ice was covered with glacial drift during a glacier advance. Furthermore, because moraine ridges can survive overriding by ice, quite probably ice-cored moraines might be constructed during several successive advances (Østrem, 1965, p. 35). A radiocarbon chronology of ice-cored moraines fronting Gråsubreen, Jotunheimen, Norway, has been obtained by dating small organic particles originally transported onto the snowbanks by wind (Østrem, 1965, p. 4-5). Because the particles consisted of old humic matter as well as contemporary organic material, Østrem (1965, p. 17) used a correction factor of 1000 years for the dates obtained. The radiocarbon dates imply that moraine construction occurred at intervals between about 6000 and 300 years ago. The moraines are progressively younger away from the glacier, suggesting that the outer (younger) moraines probably were deposited by ice that advanced over the inner (older) moraines. The dates from Gråsubreen, if confirmed by further studies on other ice-cored moraines, suggest that the history of glacier fluctuations in Scandinavia since the last major glaciation may be more complex than once thought.

During the last 300 years, glaciers in the European Alps generally were more extensive than at any time within the preceding few centuries. The earliest 17th-century glacier advances overwhelmed mountain villages, several of which are still covered by ice. Because villages would not have been built at localities that were or had been threatened by glacier ice, glacier termini probably were retracted for at least several hundred years prior to the advance of the 17th century. Many major and minor advances characterized this period of glacier expansion. Kinzl (1932) concluded that major advances occurred in the early 17th century, in the 1820's, and in the 1850's. He further concluded that these advances were the most extensive since the last major ice age. However, it has since been discovered that probable early Neoglacial moraines lie in front of some glaciers and may date to between about 2750 and 2450 years ago (Heuberger, 1954; Heuberger and Beschel, 1958). Radiocarbon dates of several moraines and till sheets have confirmed the existence of post-Würm glacier advances prior to the past few centuries; however, it is not known to what extent these advances are of regional rather than local significance. Two dates of stumps and roots in place and recently exposed by retreating ice suggest that trees were overrun by the advancing Great Aletsch Glacier about A.D. 1200 \pm 70 (B-32 and B-71); the site had been

ice covered from that time until the recent retreat (Oeschger and Röthlisberger, 1961, p. 191-192). Chelen Glacier, located above the Goeschenalp reservoir, Switzerland, advanced several miles beyond its A.D. 1850 position between 2280 ± 120 (B-380) and 1650 ± 80 (B-381) years ago (Gfeller and Oeschger, 1963, p. 308-309); however, Röthlisberger (personal communication, 1966) has good evidence that this advance is an isolated event unrelated to change of climate. One of the most significant dates from Switzerland is that of a log from a moraine fronting Oberaar Glacier which points to an advance about 4600 ± 80 (B-254) years ago (Gfeller, Oeschger, and Schwarz, 1961, p. 19). Finally, Mayr (1964) has discovered stratigraphic evidence in the Stubai Mountains, Tyrol, for five "post-altithermal" glacier advances which he has placed at 3350 to 3250 years B.P., 2850 to 2250 years B.P., 1550 to 1200 years B.P., about A.D. 1150 to 1250, and A.D. 1600 to 1850.

Southern Hemisphere

Africa.—Two episodes of "post-Pleistocene" glaciation were recognized by Downie (1964) on Mount Kilimanjaro in equatorial Africa. During the initial episode, or "Little Glaciation", moraines were built approximately 1000 feet higher than those built during the "Main Glaciation" of probable Würm age. Fresh moraines beyond modern glaciers were built during two phases of the "Recent Glaciation" which reached a climax about 200 years ago. Since the 1880's glacier termini have experienced rapid recession.

Recent glacier activity in the Ruwenzori Range is recorded by morainal loops beyond present glacier margins. The outer limit of each of four lichen zones on moraines was interpreted by Bergström (1955a) as marking the limit of a recent advance. Although the inner two moraines and lichen zones appear to date from about 1900 and 1930, the outer moraines and zones could not be dated precisely. Sediments in nearby lakes were interpreted as reflecting six oscillations of glaciers prior to the most extensive Neoglacial stand. According to Whittow and others (1963) the snowline has risen from 13,350 to 13,500 feet in 1906 to 15,000 to 15,580 feet at present.

Australia and New Zealand.—According to Costin (1965), stable solifluction terraces at altitudes above 6800 feet on Mt. Kosciusko in New South Wales were active during the "little ice-age". Radiocarbon dates of a buried organic horizon beneath two terraces suggest continuous activity beginning about 3000 years ago (Y-1093: 2980 ± 180 ; Y-1092: 2910 ± 130 ; Y-1094: 2860 ± 160 ; Y-1095: 2250 ± 130 ; and Y-1096: 1540 ± 160) and lasting at least into the 18th century (Y-1090: 170 ± 100 ; Y-1091: 120 ± 130).

McKellar (1955) described four groups of moraines that border the termini of Hooker and Mueller Glaciers in the Mt. Cook area of New Zealand and suggested that the next-to-youngest group probably dates to about A.D. 1890, whereas the oldest is at least 200 years old. Botanical

studies by Lawrence and Lawrence (1965) indicated that the Mueller, Fox, and Franz Josef Glaciers achieved their recent maxima in the 18th century. The outermost well-developed moraine of Mueller Glacier was built between A.D. 1730 and 1785, while an inner moraine is dated at A.D. 1890. Glaciers experienced fluctuating recession during the first half of the 20th century, punctuated by several episodes of readvance (Mercer, 1962a). Since 1962 both Franz Josef and Fox Glaciers have thickened and are advancing (Lawrence and Lawrence, 1965).

South America.—Studies of lake sediments from the eastern cordillera of Colombia by van der Hammen and Gonzalez (1960) led to the recognition of a relatively cold interval of climate which they correlated with the sub-Atlantic of Europe. Radiocarbon dates indicate that it began about 2650 to 2850 years ago. Sub-Atlantic conditions in Tierra del Fuego began sometime before 2240 ± 60 years ago (Y-183-IV), the age of a bog horizon assigned by Auer (1958) to the early sub-Atlantic.

Unequivocal evidence of glacier advances during the earliest part of Neoglaciation is scanty in South America. Mercer (1962b, p. 10, 14, 18) suggested that certain moraines in the Andes which have been ascribed to Wisconsin advances may be post-Hypsithermal; conceivably they are early Neoglacial, but proof is lacking.

Studies by Heusser (1960a, 1961), Lawrence and Lawrence (1959), and Muller (1959, 1960) of the glacial history of the Laguna San Rafael area in southern Chile are among the most comprehensive in the Southern Hemisphere. A series of moraines assigned to the Tempanos Glaciation was regarded as late Wisconsin in age (greater than about 9000 years old) by Muller (1959). Heusser (1960a), however, maintained that the moraines were built about 4000 to 5000 years ago in view of the fact that basal peat from a lake between the outer two Tempanos moraines was dated at 3740 ± 400 years (Y-738-2). He regarded fresh till, which lies close to the modern glacier terminus and overlies pollen-bearing organic sediments dated at 6850 ± 200 years (Y-737), as being Tempanos in age, but Muller assigned the till to advances of the last few centuries. As Heusser (1961) pointed out, an age of 4000 to 5000 years for the Tempanos moraines is difficult to reconcile with the apparent lack of evidence in the nearby pollen records of a glacier advance at that time. Furthermore, the general absence of advances of comparable age throughout the cordillera makes the postulated age somewhat anomalous. The argument hinges on whether the fresh till near the present terminus is correlative with Tempanos moraines or with nearby late Neoglacial moraines, a question that will not be resolved until more data are available.

Neoglacial moraines near the southeastern margin of the South Patagonian Icefield have been studied recently by Mercer (1965). Four end moraines beyond the terminus of the Adela Glacier in the valley of the Río Fitz Roy were designated, from oldest to youngest, Fitz Roy I, II, III, and IV. A minimum age of 800 ± 85 years (I-984) for the Fitz Roy III moraine was obtained by dating basal peat from a bog between

moraines II and III. Tree-ring studies indicate an age of about 270 years for the outer Fitz Roy IV moraine and a pre-1900 age for a fresh inner moraine.

Mercer designated two sets of moraines that parallel the margin of the Upsala Glacier, longest glacier in South America, Pearson I (oldest) and Pearson II. A log embedded in till correlated with the Pearson I moraine and situated about halfway between the present glacier margin and the maximum limit of Pearson I drift was dated at 2310 ± 120 years (I-988), thereby defining a time when the earliest advance was in progress but before construction of the Pearson I moraine. Basal peat from a bog just inside the moraine was dated at 1995 ± 100 years (I-985), placing a minimum age on the moraine. Mercer estimated from tree-ring data that the glacier reached its most recent maximum at the Pearson II moraine about A.D. 1600 and remained near this position until about 1760, when it began to recede. A standstill or minor readvance occurred early in the 19th century, followed by recession to the present position.

The maximum Neoglacial advance of the nearby Dos Lagos Glacier is dated at close to 1595 ± 100 years (I-987), the age of a submerged stump in a lake impounded when the glacier reached its greatest extent. A younger advance, nearly as extensive as the older, is marked by a fresh moraine which supports trees as much as 200 years old. The earliest advance of the adjacent Cerro Norte Glacier was less extensive than a recent advance which is dated at about 390 ± 85 years (I-989).

Heusser (1961) summarized the known history of Patagonian glacier variations for the last several centuries, noting that during the late 17th century glaciers were in a state of recession. By the last half of the 18th century widespread advance had occurred, and many glaciers appeared to have reached their maximum recent stands. Fluctuation of ice margins characterized the next half century, followed by a general recession, punctuated by halts and readvances, until 1910. Rapid recession took place between 1910 and 1940. During the 1950's several glaciers showed evidence of growth and began to advance.

Antarctica.—The Neoglacial history of the Antarctic Ice Sheet, which contains most of the Earth's ice, is nearly unknown. Limited historical documentation of ice-front fluctuations points to stability of glacier margins since 1911 in the McMurdo Sound region (Péwé, 1962), since 1937 in MacRobertson Land and Kemp Land (Mellor, 1959), and between 1937 and 1947 along extensive areas of the coast of Queen Maud Land to Mirniy (Liestøl, 1953). Schytt (1961, p. 198) suggested that the inland ice sheet in Queen Maud Land is now in equilibrium, and Koerner (1961) drew the same conclusion for glaciers of the Trinity Peninsula. However, in some areas of Antarctica, mainly farther north than those mentioned above, glaciers have recently receded (Nichols, 1960, p. 1431; Cameron, 1959, p. 22). Aside from these observations, no indisputable data of the Neoglacial chronology of Antarctic glaciers are available.

CHRONOLOGY AND CLIMATIC TRENDS

Available geologic evidence and radiocarbon dates from the North American Cordillera indicate that, with few exceptions, glaciers were retreating during the early part of the Hypsithermal interval, following extensive wastage during the closing phases of the Wisconsin Glaciation. A number of limiting dates on recession of late Wisconsin alpine glaciers fall within the range of 7000 to 9000 years B.P. (fig. 2). Radiocarbon dates on buried organic-rich soil horizons from localities overrun by Neoglacial ice point to greatly diminished size or possible disappearance of glaciers during the mild Hypsithermal.

An advance of South Cascade Glacier in Washington about 4700 years ago and possible glacier expansion on Mt. Garibaldi in British Columbia about 5300 years ago may be related to an initial period of widespread glacier growth during the Hypsithermal interval. Heusser (1966b; written communication, 1966) has gathered pollen evidence that suggests a climate cooler and more moist than that of today during Atlantic time between about 5500 and 4500 years ago in southeastern Alaska, a condition consistent with glacier expansion at that time. Alternatively, however, these isolated events may constitute special cases unrelated to regional climatic trends and possibly reflect glacier "surges" of short duration similar to those reported from northwestern North America in recent years (Post, 1960; 1965; Meier, 1965). The existing ambiguity can be resolved only by obtaining supporting evidence and additional dates from other areas.

Otherwise, most radiocarbon dates *directly* associated with early Neoglacial ice advances cluster between about 2600 and 2800 years and come from areas of such diverse latitudes as the Brooks Range of Arctic Alaska, the northeastern St. Elias Mountains of Yukon Territory, southeastern coastal Alaska, and the La Sal Mountains of Utah (figs. 2 and 3). Several maximum limiting dates fall within the range of 3000 to 5000 years, whereas moraines of the earliest Neoglacial advance in the central Cascade Range of Washington are bracketed between about 3500 and 2000 years by radiocarbon-dated layers of volcanic ash. Many of the dates fix the age of early Neoglacial maximum ice stands, suggesting that widespread growth of glaciers probably began sometime before 2800 years ago.

Almost all known radiocarbon-dated advances or maxima within the interval between the earliest widespread Neoglacial advances and the equally widespread advances of the last few centuries are restricted geographically to Alaskan coastal glaciers. Neither the relative extent nor the regional significance of those advances is known as yet, and caution must be used in assigning climatic implications in view of the frequency

Fig. 2. Radiocarbon dates related to Neoglacial ice advances in western North America (solid circles). Open circles are dates relating to Wisconsin ice recession. Horizontal lines indicated limits of error for each date. Arrows denote date is maximum (←) or minimum (→) limiting date. Local stadial names are indicated where appropriate.

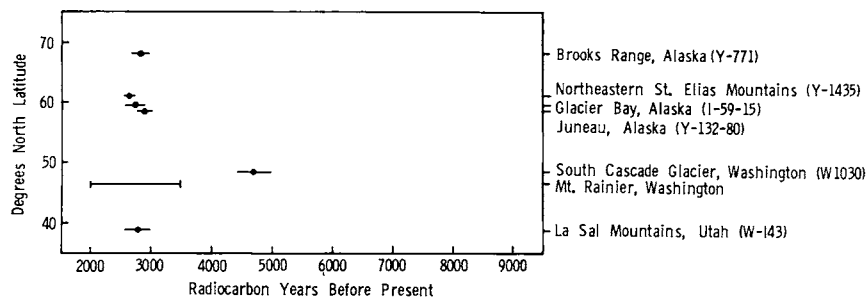


Fig. 3. Radiocarbon dates *directly* associated with initial post-Wisconsin glacier advances in North American Cordillera during Hypsithermal and early Neoglacial times. Horizontal lines indicate limits of error for date. Indicated limits of initial Neoglacial advance at Mt. Rainier are based on radiocarbon-dated layers of volcanic ash.

of glacier "surges" in this area. Three-fold morphologic subdivisions of Neoglacial drift in the Sierra Nevada (Birman, 1964; Rahm, 1964), the Trinity Alps (Sharp, 1960), and the Brooks Range (Porter, 1964) possibly point to an intermediate interval of glacier activity between the earliest and the latest episodes of advance which might correspond to the period from about 800 to 1800 years ago, within which fall many of the dates from coastal Alaska. Evidence from lands bordering the North Atlantic Ocean, however, suggests that this was a period characterized, in that region at least, by climate nearly as mild as that of the present.

During the last several centuries, glaciers throughout the Cordilleran region experienced marked advances, and many attained their maximum Neoglacial positions. The time of this interval is well fixed by radiocarbon and botanical dates as well as by some historical records. After reaching their recent maxima, commonly within the last half of the 19th century, glaciers began a fluctuating recession which increased in rate during the second, third, and fourth decades of the present century but subsequently decreased in response to cooler and wetter conditions beginning in the 1940's. Thickening of glaciers and advancing termini noted in a number of areas since the middle 1950's appear to reflect a delayed response to this climatic reversal.

Evidence from glaciated areas in other parts of the world indicates broadly similar histories of Neoglaciation. Lichen studies suggest that early Neoglacial moraines in arctic Canada were built about 2400 years ago, whereas similar moraines in West Greenland probably date to the third or fourth millennium B.P. Several dates from the Alps provide maximum limiting ages for early Neoglacial advances comparable to those from western North America. Data from the Southern Hemisphere are scarce, but radiocarbon dates show that a major glacier advance in Patagonia culminated between about 2300 and 2000 years ago; periglacial activity began in Australia about 3000 years ago and therefore was essentially contemporaneous with Neoglacial ice advances in western

North America. Abundant evidence shows that glaciers in the Canadian Arctic, in Greenland, in Iceland, in Europe, and in the Southern Hemisphere were growing during the 17th, 18th, and 19th centuries and in most cases achieved their maximum Neoglacial stands. Since the end of the last century, glaciers have experienced extensive wastage accompanied by terminal recession.

An advance of Oberaar Glacier in the Swiss Alps about 4600 years ago may reflect an initial Neoglacial expansion of glaciers similar to those recorded for South Cascade Glacier and on Mt. Garibaldi. Pollen evidence from southern Chile indicates cooler and moister climate between about 6500 and 4500 years ago, suggesting possible glacier expansion at that time (Heusser, 1966a).

Combining data from the North American Cordillera with that from other parts of the Northern Hemisphere permits construction of a generalized curve of glacier fluctuations during Neoglaciation (fig. 4). Although based on all information currently available, this curve should be considered tentative for several reasons: (1) That part of the curve extending from about 2600 to about 400 years B.P. is based largely on indirect climatic evidence rather than radiocarbon dates associated with

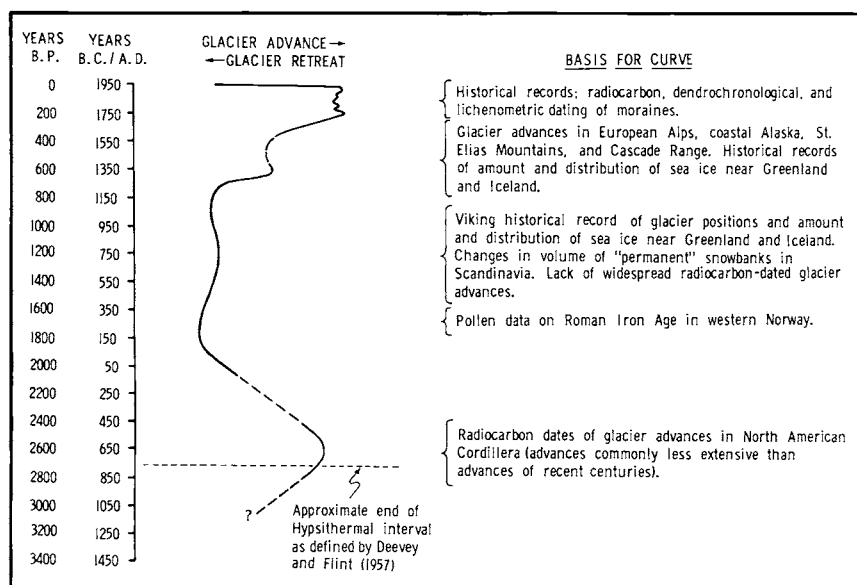


Fig. 4. Generalized curve of glacier fluctuations during Neoglaciation (dashed where data are poor or lacking). Most information from alpine areas (see text for sources). Horizontal axis has no absolute scale; total known Neoglacial advance ranged from more than 15 miles for Kaskawulsh Glacier and possibly more than 60 miles for ice in Glacier Bay to less than a mile for some small Scandinavian and Cordilleran glaciers. Although the curve probably reflects the general situation, for an individual glacier any of the Neoglacial advances may have been the most extensive. A possible early Neoglacial advance close to 4700 years ago has purposely been omitted because its regional significance is still somewhat obscure.

known glacier fluctuations. However, much of the climatic data is well documented and probably most glaciers responded in synchrony with changes of climate. (2) Much of the curve, except for that part representing the past 400 years, is based on data of rather restricted geographic distribution. Construction of the curve therefore involved making the assumption that major climatic and glacier fluctuations were broadly synchronous, at least throughout the Northern Hemisphere. (3) Some available data contradict the curve. For example, between about 1800 and 500 years ago several glaciers in northwestern North America were advancing, whereas the curve, which for this period is based largely on information from the North Atlantic region, depicts glaciers in a retracted position. However, not uncommonly a small percentage of glaciers in the coastal mountains of Alaska are out of phase with the majority, and in recent years they have shown persistent advance, despite a general regional pattern of shrinkage (Miller, 1964). Therefore, for the present at least, the better-documented climatic data from the North Atlantic area are used in reconstructing what is believed to be the general situation. (4) Data reflecting isolated cases of glacier advance during late Atlantic and early sub-Boreal time between about 5500 and 4000 years ago are purposely omitted from the diagram because the nature of the fluctuations is not yet clear. If due to "surges" or other non-climatically induced causes, they do not belong on the curve. However, the possibility remains that the advances occurred in response to a widespread climatic shift, the evidence for which is as yet poorly documented. Keeping in mind the stated reservations, figure 3 depicts the fluctuations of glaciers during Neoglaciation and, by inference, the climatic fluctuations to which they responded. In the Northern Hemisphere at least, Neoglaciation was characterized by at least two main intervals of glacier growth, the first beginning shortly before about 2800 years ago and culminating about 2800 to 2600 years ago, and the second occurring during the last few centuries and in many areas culminating near the middle of the last century. These intervals of glacier expansion were separated by a milder interval during which glaciers generally were smaller. For many glaciers, the advance of the last few centuries was the maximum post-Hypsithermal advance, and evidence of earlier Neoglacial fluctuations is absent or obscure. However, for any given glacier, any one of the principal Neoglacial advances may have been the most extensive, for commonly there is no uniformity of moraine chronology within any given region, let alone within all of western North America or the Northern Hemisphere. For example, on Mount Rainier in the Cascade Range of Washington, the outermost Neoglacial moraine of the Winthrop Glacier was built sometime between 3500 and 2000 years ago, that of the Carbon Glacier was deposited about A.D. 1217, that of the South Tahoma Glacier about A.D. 1540, and that of the Nisqually Glacier about A.D. 1845 (Crandell and Miller, 1964; E. L. Hendricks, personal communication, 1965). The inconsistency observed in this restricted area and for western North

America in general probably reflects varied behavior patterns of different glaciers as a result of variations in meteorological conditions, net-budget distributions, and dynamic response characteristics (Meier, 1965).

FLUCTUATIONS OF SEALEVEL

The possibility that sealevel has fluctuated in response to fluctuations in volume of Neoglacial ice has been the subject of considerable debate. The question is not easily resolved owing to the presence of data that are susceptible to varied interpretation. Fisk (1944), McFarlan (1961), and Godwin, Suggate, and Willis (1958) believed that sealevel attained its present position about 5000 to 6000 years ago and has remained stationary since that time. Fairbridge (1961) maintains that short-term oscillations of sealevel above and below its present position have occurred since about 3000 to 5000 years ago. Shepard (1964), on the other hand, has reviewed a variety of data which he interprets as showing a slow but steady rise of sealevel through the last 6000 years. Important new evidence bearing on the problem has been presented by Bloom and Stuiver (1963) and by Scholl and Stuiver (in press). Bloom and Stuiver (1963) have shown that submergence of the Connecticut coast occurred at the rate of 0.6 of a foot per century between about 7000 and 3000 years ago, but during the last 3000 years the rate has been only half as great. Between about 4400 and 3500 B.P., sealevel rose across the western margin of the Florida Everglades at a rate of about 1.0 foot per century; about 3500 B.P. the rate of rise diminished by a factor of five, and since 1700 B.P. the rate of rise has averaged only 0.1 of a foot per century (Scholl and Stuiver, in press). In neither area is there evidence that sealevel has risen appreciably above its present position during the past 4000 to 5000 years. Although curves from different areas show a different degree of submergence as a function of time due to tectonic instabilities, the change in submergence rate about 3500 B.P. is found in all curves and seems to be due to eustatic sealevel rise. It is immediately apparent that the observed change in rate of coastal submergence and the first well-documented Neoglacial ice advances were approximately synchronous, but a cause-effect relationship cannot be convincingly demonstrated. The rather abrupt decrease in the rate of sealevel rise about 3500 B.P. may be related to regeneration and growth of alpine glaciers during Neoglaciation. But equally possible it may have resulted either from widespread disappearance of residual Wisconsin-age ice in high latitudes toward the end of the mild Hypsithermal interval or from changes in volume of the Greenland and Antarctic Ice Sheets. Because no well-documented evidence exists on Neoglacial fluctuations of these two large ice sheets, the possible effects on sealevel of variations in their volume cannot yet be evaluated. However, the new coastal data cited above give evidence of a small but persistent eustatic rise of sealevel throughout the past 3000 years, a relationship that can best be explained by melting of ice on Antarctica and/or Greenland. The question of whether minor fluctuations of glaciers during Neoglaciation led to cor-

responding subtle oscillations of sealevel remains unanswered. The carefully assembled evidence from Florida and Connecticut suggests, however, that if such oscillations did occur, there is little likelihood they will be detected through stratigraphic studies.

DEFINITION OF NEOGLACIATION

Although the term Neoglaciation has been used widely since it first appeared in print, it has never been carefully defined. Moss (1951, p. 62), following a suggestion by Matthes, used it for "the minor glacial pulsation" represented by small, very fresh moraines fronting existing glaciers in the Sierra Nevada and suggested that it probably postdated the "so-called Climatic Optimum". Sharp (1960, p. 321) used the term "simply as a short convenient designation for a readvance of ice subsequent to shrinkage during the Hypsithermal interval". Others have employed the term without clarifying their exact usage, although implying that it was broadly equivalent to the "little ice-age" of Matthes.

Any definition of Neoglaciation must take into consideration the preceding interval of milder climate. Deevey and Flint (1957) defined the Hypsithermal as a *time-stratigraphic unit* encompassing the period of formation of pollen zones V through VIII in the Danish system. Some of the most accurate dates available for the end of the Hypsithermal in Europe are from a raised bog near Emmen, Netherlands, and bracket the transition from pollen zone VIII (sub-Boreal) to zone IX (sub-Atlantic) between 2865 ± 140 (GRO-480) and 2595 ± 140 (GRO-479) years B.P. (T. van der Hammen, written communication, 1965). Heusser (1960b) believes that the date of the transition from Hypsithermal to late-postglacial conditions in northwestern North America varied with latitude, being around 4000 years ago along the western Gulf of Alaska, 3500 years ago in southeastern Alaska, around 3000 years ago in southern British Columbia, Washington, and Oregon, and around 2500 years ago in California. By this interpretation the upper boundary of the Hypsithermal is time-transgressive, and the length of the late-postglacial interval increases with increasing latitude, a relationship Heusser attributes to greater influence in the north of south-flowing masses of polar air.

It is readily apparent that glaciers were growing in western North America toward the end of the Hypsithermal as defined by Deevey and Flint, and that many achieved their maximum Neoglacial stands approximately at the time of the zone VIII to zone IX transition in Denmark. Clearly it becomes impossible to define Neoglaciation as a time-stratigraphic unit that immediately followed the Hypsithermal without excluding from it the period of initial glacial growth prior to 2800 years ago. The problem is resolved by defining Neoglaciation as a *geologic-climate unit* which, at any single place, is "defined by the boundaries of some kind of stratigraphic unit. These local stratigraphic boundaries may be isochronous surfaces, but the different stratigraphic boundaries that define the limits of the geologic-climate unit in different latitudes are not likely to be isochronous" (Am. Comm. Strat. Nomenclature, 1961,

p. 660). Because for any given area the initial recognizable Neoglacial advance may fall anywhere within the last five millennia, a broad non-restrictive definition is desirable if the term is to be widely useful. We propose, therefore, to define Neoglaciation as the climatic episode characterized by rebirth and/or growth of glaciers following maximum shrinkage during the Hypsithermal interval. Very likely maximum shrinkage coincided with the period of maximum warmth which, from various evidence, is thought to have occurred sometime between 8000 and 5000 years ago (Lundqvist, 1965, p. 187; Heusser, 1966b). The definition is provisional, however, because future additional information bearing on possible regional glacier fluctuations during the Hypsithermal may necessitate revision of the definition or adoption of a new nomenclature. Because Neoglaciation is defined as a geologic-climate unit whose lower boundary may be time transgressive whereas the Hypsithermal interval is a time-stratigraphic unit and therefore is restricted by time-parallel boundaries, in some areas the two intervals may overlap, while in others they may be mutually exclusive. Ideally the Hypsithermal should be redefined as a geologic-climate unit if its boundaries are not isochronous from region to region, as Heusser's work (1960b) suggests.

Although a type area for Neoglaciation has never been formally designated, the term was first employed in the Wind River Range of Wyoming (Moss, 1951) and has been used subsequently by Richmond (1965) to include two principal episodes of glacier advance (Temple Lake and Gannett Peak), the type localities for which are in the Wind Rivers. However, because the entire record of Neoglaciation may not be present in this or any other single mountain range and can be fully understood in all its details only by study of a much broader geographic region, we feel it would be appropriate to designate the North American Cordillera as the type region for this important climatic event.

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