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AGE OF PRE-NEOGLACIAL CIRQUE MORAINES IN THE CENTRAL NORTH AMERICAN CORDILLERA*

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ABSTRACT In the western mountains of the United States and Canada are pre-Neoglacial cirque moraines that lie up to about 3 km outside Neoglacial moraines. There is considerable uncertainty as to the ages of the outer moraines and whether or not they are age-equivalent from range to range. The variety of assigned radiocarbon ages found in the literature may be partly due to some authors' use of minimum-limiting dates as near-absolute dates, and use of dates that cannot be definitely related to the deposits in question. With one possible exception, all the dated moraines described in the literature could be as old as the type Temple Lake moraine of Wyoming which has a minimum age of about 11,400 yrs BP based on a recently obtained radiocarbon date. Nearly all paleoecological proxy data from the North American Cordillera, generally derived from continuous sedimentary records, suggest that early Holocene climate was warmer than at present. Global circulation models also suggest an early Holocene thermal maximum in the Cordillera, probably due to Milankovitch forcing. For these reasons a proposal gaining popularity in the literature that widespread "Mesoglaciation" occurred in early Holocene time is premature. We hypothesize that most, if not all, of the moraines in question are correlative and date from Late Pleistocene time.

RÉSUMÉ *L'âge des moraines de cirques pré-néoglaciaires du centre de la Cordillère nord-américaine.* Dans les montagnes de l'ouest des États-Unis et du Canada se trouvent des moraines de cirque qui s'étendent jusqu'à quelque 3 km des moraines néoglaciaires. On connaît mal l'âge de ces moraines externes et on ignore s'il concorde d'une chaîne à l'autre. La grande diversité des âges au radiocarbone que l'on trouve dans la littérature relève probablement en partie du fait que certains auteurs considèrent les dates minimales comme des dates significatives ou exploitent des dates qui ne peuvent pas être parfaitement attribuées aux dépôts étudiés. Toutes les moraines, sauf peut-être l'une d'entre elles, pourraient être aussi vieilles que la moraine de référence de Temple Lake, au Wyoming, dont l'âge minimal est de 11 400 BP selon une datation au radiocarbone récente. Presque toutes les données paléoécologiques indirectes trouvées dans la Cordillère nord-américaine, qui proviennent généralement de séquences sédimentaires, démontrent que le climat au début de l'Holocène était plus chaud que maintenant. Les modèles de circulation générale laissent également croire que la Cordillère a connu un maximum thermique au début de l'Holocène. Pour toutes ces raisons, l'hypothèse selon laquelle une mésoglaciation répandue se serait produite au début de l'Holocène est pour le moins prématurée. Les auteurs croient plutôt que la plus grande partie, sinon toutes les moraines dont il est question ici, sont corrélatives et datent du Pléistocène supérieur.

ZUSAMMENFASSUNG *Datierung der präneoglazialen Moränen im zentralen Norden der amerikanischen Kordilleren.* In den westlichen Bergen der Vereinigten Staaten und Kanadas gibt es präneoglaziale Hochtalmoränen, die sich bis zu ungefähr 3 km außerhalb der neoglazialen Moränen beobachten lassen. Es besteht eine beträchtliche Ungewißheit, was das Alter der äußeren Moränen betrifft, und ob sie von Stufe zu Stufe gleichaltrig sind oder nicht. Die in Veröffentlichungen vorgefundene Verschiedenheit der Radiokarbondatierungen mag zum Teil darauf zurückzuführen zu sein, daß manche Autoren die Minimalgrenzwerte als nahezu absolute Werte benutzen und sich auf Daten stützen, die nicht einwandfrei zu den betreffenden Ablagerungen in Beziehung gesetzt werden können. Mit einer möglichen Ausnahme können all in den Veröffentlichungen beschriebenen datierten Moränen so alt sein wie der Typus der Temple-Lake-Moräne von Wyoming, welche ein Minimalalter von ungefähr 11 400 BP. hat, gestützt auf eine neuere Radiokarbondatierung. Fast alle paläoökologischen Proxy-Datierungen von den nordamerikanischen Kordilleren, die im allgemeinen aus kontinuierlichen Sediment-Aufzeichnungen abgeleitet sind, lassen annehmen, daß das Klima im frühen Holozän wärmer war als in der Jetztzeit. Globale Zirkulationsmodelle legen auch ein thermisches Maximum in den Kordilleren im frühen Holozän nahe, welches wahrscheinlich durch den Milankovitch-Effekt hervorgerufen wurde. Aus all diesen Gründen ist eine Interpretation, die in den Veröffentlichungen immer populärer wird, wohl voreilig, daß im frühen Holozän eine ausgedehnte "Mesoglaziation" stattfand. Wir stellen die Hypothese auf, daß die meisten wenn nicht gar alle betreffenden Moränen zusammenhängen und aus dem späten Pleistozän stammen.

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INTRODUCTION

In numerous mountain ranges of western North America, some moraines lie up to about 3 km beyond more obvious and almost always present Neoglacial (post-Altithermal) moraines. These outer moraines represent depressions in equilibrium-line altitudes up to about 100 m below Neoglacial values. The moraines are known in some cases, and inferred in others, to be early Holocene or older in age, and are commonly designated only as "pre-Altithermal" (*e.g.*, CURREY, 1974). There is considerable uncertainty as to the specific age(s) of these moraines and whether or not they are equivalent in age from range to range (DAVIS, 1984).

This paper seeks to establish some order from the confusion concerning distribution and ages of pre-Neoglacial cirque moraines in the Cordillera of the conterminus United States and adjacent Canada. We (1) review the available radiocarbon ages and show that few can be closely related to the ice advances they supposedly date, (2) review theoretical paleoclimatic and proxy climatic data, and (3) conclude that the early Holocene was not a likely time for even a minor glacial advance in the North American Cordillera.

The conventional Holocene/late Pleistocene boundary of 10,000 yrs BP is used in this paper. We use the terms "Altithermal" and "Hypsithermal" interchangeably to mean the period of maximum warmth and dryness in the Holocene. We use the term "Neoglaciation" to mean the time of rebirth of alpine glaciers following the Hypsithermal, and the term "Little Ice Age" to mean the last few centuries of Neoglaciation.

DISTRIBUTION OF MORAINES

In Table I are listed known mountain ranges or sites with pre-Neoglacial cirque moraines considered early Holocene or late Pleistocene in age by respective authors. The list may not be exhaustive, but is at least representative. Included on the list are moraines with estimated dates based on relative-dating criteria (*e.g.* Hollowtop and Mason Lake moraines of HALL and HEINY, 1983), minimum-limiting tephra dates (*e.g.*, Crowfoot moraines of LUCKMAN and OSBORN, 1979), minimum-limiting radiocarbon dates (DAVIS, 1982), and purported absolute radiocarbon dates (*e.g.* BEGET, 1981). Pre-Neoglacial moraines are widespread in the North American Cordillera, as exhibited in Figure 1.

The spatial relationships of pre-Neoglacial moraines to Neoglacial moraines vary from range to range, and indeed from cirque to cirque. For example, in Glacier National Park, Montana, some pre-Neoglacial moraines are over one kilometer downvalley of Neoglacial moraines, some are partly buried by Neoglacial moraines, and some have been presumably completely obliterated by late Neoglacial advances (OSBORN, 1985). In general, the literature suggests that pre-Neoglacial advances in the northern Rockies (*e.g.*, Fig. 2) were less extensive relative to late Neoglacial advances than in the southern Rockies (*e.g.*, Fig. 3).

TABLE I

Pre-Neoglacial Cirque Moraines

BRITISH COLUMBIA	
1. Mt. Tatlow, Coast Ranges	(Ricker, 1983)
2. Shuswap Highland	(Duford and Osborn, 1978)
5. Purcell Mountains	(Osborn, unpubl.)
6. Kokanee Park, Selkirks	(Osborn, unpubl.)
7. Elk valley	(Ferguson, 1978)
ALBERTA	
3. Jasper National Park	(Luckman and Osborn, 1979)
4. Banff National Park	(Luckman and Osborn, 1979)
8. Highwood Pass	(Gardner *et al.*, 1983)
9. Waterton Lakes National Park	(Osborn, 1985)
MONTANA	
10. Glacier National Park	(Osborn, 1985)
19. Eastern Tobacco Root Range	(Hall and Heiny, 1983)
22. Beartooth Mountains	(Graf, 1971)
WASHINGTON	
11. Mt. Baker	(Easterbrook and Burke, 1972; Fuller *et al.*, 1983)
12. Glacier Peak	(Beget, 1981, 1983)
13. Enchantment Lakes	(Waitt *et al.*, 1982)
14. Mt. Rainier	(Crandell and Miller, 1974)
OREGON	
15. Upper Metolius River	(Scott, 1977)
16. Broken Top	(Dethier, 1980)
17. Mountain Lakes Wilderness	(Carver, 1972)
18. Wallowa Mountains	(Kiver, 1974)
IDAHO	
20. Lemhi Mountains	(Butler, 1984)
21. Copper Basin	(Wigley *et al.*, 1978)
WYOMING	
23. Absaroka Range	(Breckenridge, 1974)
24. Tetons	(Mahaney and Spence, 1984)
25. Wind River Range	(Moss, 1951 ; Currey, 1974 ; Mahaney, 1984 ; Zielinski and Davis, 1986, 1987)
28. southern Medicine Bow Mtns.	(Oviatt, 1977)
UTAH	
26. Wasatch Mountains	*(Madsen and Currey, 1979 ;* Anderson and Anderson, 1981)
27. north flank Uinta Mountains	(Schoenfield, 1969)
34. La Sal Mountains	(Richmond, 1962)
COLORADO	
29. northern Rocky Mountain N.P.	(Breckenridge, 1969)
30. northern Front Range	(Madole, 1976)
31. *central Front Range*	*(Benedict, 1973, 1981, 1985 ;* Birkeland and Shroba, 1974 ; Davis, 1982, 1987 ; Davis *et al.*, 1984)
32. Sawatch Range	(Nelson, 1954)
33. San Juan Mountains	(Andrews *et al.*, 1975)
CALIFORNIA	
35. *Mono Recesses*	*(Yount et al., 1982)*
36. Desolation valley	(Whiting, 1985)

Location numbers refer to sites designated on map in Figure 1.

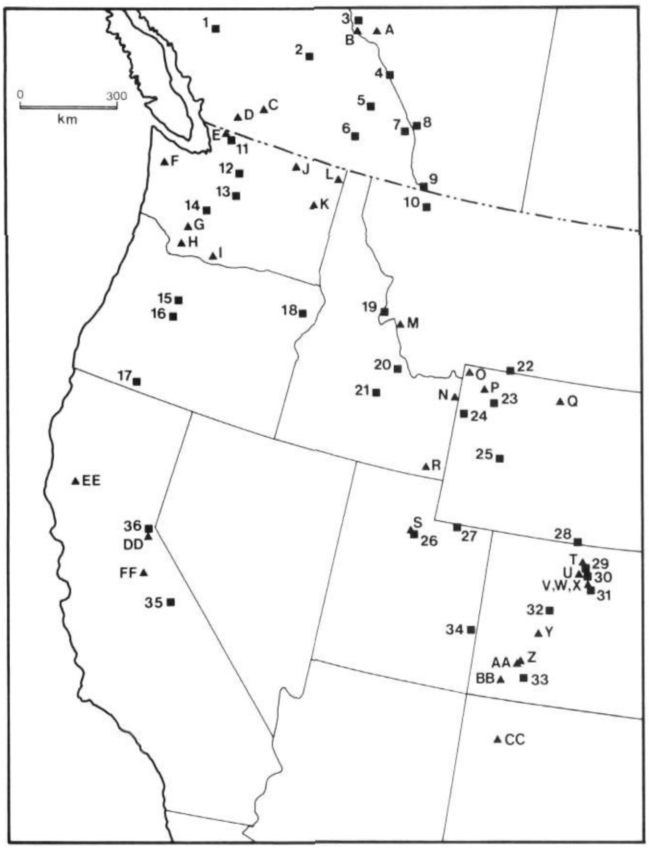

FIGURE 1. Map of sites in North American Cordillera with numbered pre-Neoglacial cirque moraines (Table I) and lettered paleoecological proxy data (Table III).

Carte des sites (numéros) de moraines de vallée amont pré-néoglaciaires de la Cordillère nord-américaine (tabl. I) et des sites (lettres) où des données paléoécologiques indirectes ont été recueillies (tabl. III).

ABSOLUTE AND MINIMUM-LIMITING DATES

The variety of dates assigned to pre-Neoglacial cirque moraines may be partly due to some authors choosing to interpret minimum-limiting radiocarbon dates as near-absolute ages for deposits. For example, BENEDICT (1973) estimated that the type inner Triple Lakes moraine in the Colorado Front Range is about 4000 years old, based on a radiocarbon date of 3865 $\pm$ 100 yrs BP (I-6986) from proglacial lake sediments exposed in a former drainage channel across the moraine. Unfortunately, radiocarbon dates from bog- and lake-bottom sediments rarely provide close minimum-limiting ages for glacial retreats, let alone glacial

FIGURE 2. View of terminal moraine of pre-Neoglacial Crowfoot Advance (right) and Neoglacial Cavell Advance (left and foreground) in a cirque below Mt. Norris, Glacier National Park, Montana.

Vue de la moraine frontale de la récurrence de Crowfoot datant du pré-Néoglaciaire (à droite) et de la récurrence de Cavell datant du Néoglaciaire (à gauche et au premier plan) dans un cirque en contre-bas du mont Norris, Glacier National Park, au Montana.

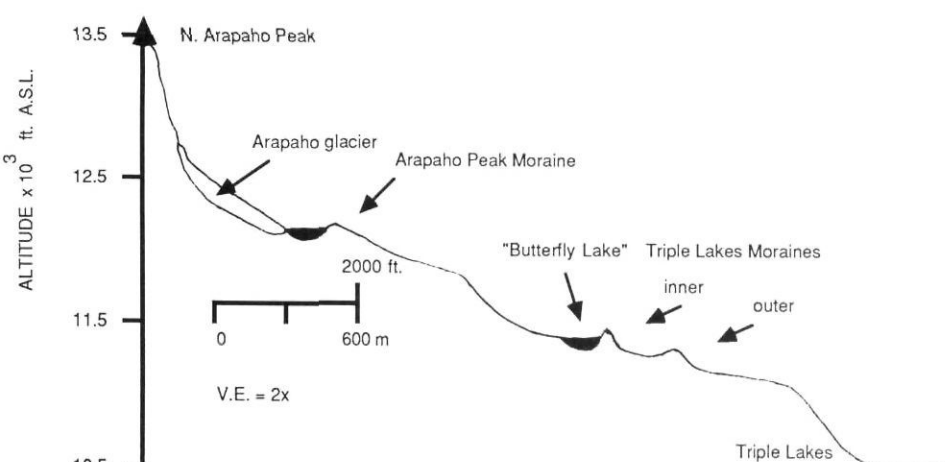

FIGURE 3. Schematic profile of Arapaho cirque, Colorado Front Range, showing Arapaho Glacier, Arapaho Peak moraine (Little Ice Age), and the type Temple Lake moraines. Radiocarbon dates from "Butterfly Lake" indicate that the Triple Lakes moraines are late Pleistocene in age. Note distance and elevation drop from Arapaho Glacier to the Triple Lakes moraines.

Profil schématique du cirque d'Arapaho, Colorado Front Range, montrant le glacier d'Arapaho, la moraine d'Arapaho Peak (Petit Âge glaciaire) et les moraines de référence de Temple Lake. Les datations au radiocarbone du «Butterfly Lake» indiquent que les moraines des Triple Lakes datent du Pléistocène supérieur. À remarquer la distance et la baisse d'altitude entre le glacier d'Arapaho et les Triple Lakes.

advance (*e.g.*, DAVIS and DAVIS, 1980 : SUTHERLAND, 1980 ; COTTER *et al.*, 1984). Several radiocarbon dates obtained by the senior author from lake-bottom sediments behind (upvalley of) the type inner Triple Lakes moraine indicate that the moraine is considerably older than Benedict's estimate. Two of these dates (Table II), 9915 ± 380 (Gx-11,365) and 10,410 ± 520 (Gx-11,774), were recently obtained from detrital organic material from the bottom sediments of a 7.2 m core (DAVIS, 1987). However, even these dates could be considerably younger than the underlying deposit, as one usually never knows whether the lowermost lacustrine sediments have been retrieved in a coring operation.

Other uncertainties may arise where radiocarbon dates cannot be unequivocally related to the deposits in question. For example, BENEDICT (1973) estimates that the Satanta Peak Advance of the Colorado Front Range began between 12,000 and 11,000 yrs BP, using a minimum-limiting date of 9915 ± 165 yrs BP (I-6335) for the type Satanta Peak moraine in Caribou Lake cirque. This date is from organic matter overlying "outwash" in a pit 100 m *outside* the lateral position of the moraine. Benedict assumes, but provides no evidence, that the outwash is contemporaneous with deposition of the moraine. Therefore, although we feel that the moraine is probably at least 10,000 years old, the radiocarbon date itself has little meaning ; the dated organic matter could be associated with a substrate not related to the moraine. Another radiocarbon date, 9215 ± 105 yrs BP (I-11,092), which BENEDICT (1981) ascribed to a moraine of the Satanta Peak Advance in the nearby Fourth of July valley, is similarly from organic matter overlying fluvial sediment assumed, but not demonstrated, to be outwash from a particular glacial advance. Thus, the type Satanta Peak moraine in Caribou Lake cirque and the type Triple Lakes moraines in Arapaho cirque could be equivalent in age.

Table II lists dates obtained from tephra or organic matter found only *on, within*, or *behind* pre-Neoglacial cirque moraines. Of the 17 dates listed, 14 are from on top of or behind moraines. Because these moraines show similar degrees of weathering and represent similar depressions in equilibrium-line altitudes (DAVIS *et al.*, in prep.), and because these dates are all minimum-limiting, all the associated moraines could be as old or older than the oldest radiocarbon date (11,400 ± 630 yrs BP ; Gx-12,719) in Table II. A discussion of this date for the type Temple Lake moraine in Wyoming appears in ZIELINSKI and DAVIS (1986, 1987).

Three radiocarbon dates listed in Table II are from charcoal incorporated within deposits believed to be till. The Lemhi Mountains date (7100 ± 120 yrs BP ; Beta-2163) is from a moraine about one kilometer from the cirque headwall in Mountain Boy valley (BUTLER, 1984). BUTLER (1984) was unable to determine whether the charcoal pre-

TABLE II

Minimum-limiting Radiocarbon Dates On, Within, or Behind Pre-Neoglacial Cirque Moraines

Radiocarbon Date[1]	Laboratory Number	Location (Reference)	Position of Sample[2]
6800	(Mazama tephra)	Alta., B.C., WA, OR, MT (several authors)	O
7100 ± 120	Beta-2163	Lemhi Mountains, ID (Butler, 1984)	W
7390 ± 250	Gx-4039	Shuswap Highland, BC (Duford and Osborn, 1978)	O
7515 ± 180	Gx-4644	Wasatch Mountains, UT (Madsen and Currey, 1979)	B
7655 ± 240	Gx-6716	Selkirk Mountains, BC (Osborn, unpubl.)	O
7690 ± 115	St-3898	Mitchell Bog, Front Range, CO (Madole, 1976)	O
7940 ± 190 7380 ± 150	Gak-8216 Gak-8361	Titcomb Lakes, Wind River Range, WY (Mahaney, 1984)	B
8380 ± 90 8350 ± 50	W-4277 USGS-1070	Glacier Peak (Beget, 1981, 1983)	W or B
11,400 ± 630 8300 ± 475 6500 ± 230	Gx-12,719 Gx-12,277 Gx-3166D	Temple Lake moraine, Wind River Range, WY (Zielinski and Davis, 1986, 1987 ; Currey, 1974	B
8460 ± 140	I-5449	Satanta Peak moraine, Front Range, CO (Benedict, 1973)	O
8759 ± 280	W-950	Mt. Rainier, WA (Crandell and Miller, 1974)	B
10,410 ± 520 9915 ± 380 6430 ± 70	Gx-11,774 Gx-11,365 W-4793	Triple Lakes moraines, Front Range, CO (Davis, 1982, 1987 ; Davis *et al.*, 1984 ; this paper)	B

[1] See text for discussion of minimum-limiting radiocarbon dates.
[2] O = on moraine, W = within moraine, B = behind moraine.

dated the glacial advance, post-dated the deposit (*e.g.* root material burned *in situ*), or was roughly contemporaneous with moraine deposition. Therefore, this moraine may have only a minimum-limiting radiocarbon age.

BEGET's (1981) two radiocarbon dates from near Glacier Peak in Washington (Table II) are the only ones actually claimed to absolutely date deposition of a cirque moraine. In this case, charcoal was sampled at a depth of one meter in a gully through what is described as ground moraine overlying the White Chuck cinder cone. From these radiocarbon dates, BEGET (1981) inferred that about 8400 years ago a small glacier advanced up and over the upvalley rim and about 0.6 km across the White Chuck cinder cone. A subsequent, less extensive, Neoglacial advance of this glacier left a moraine banked against the outside of the upvalley rim of the cinder cone. On the basis of these dates and correlation to other poorly dated moraines throughout the world, BEGET (1983) proposed the term "Mesoglaciation" for a period of early Holocene climatic cooling that led to glacial advances of a magnitude roughly equivalent to that of ice advances during Neoglaciation.

We were unable to locate the charcoal locality in the White Chuck cinder cone, although we did find the general area of the sampling site. BEGET (1981) recovered charcoal from a flat low area upvalley from some moraine ridges and bounded on the other three sides by slopes. At the head of the longest slope is a small pond which appears to occasionally overflow down the slope (Fig. 4). Presently a deep gully connects the pond and the flat low area. Schist clasts and lapilli, the constituents of BEGET's (1981) ground moraine, are being moved downslope in the gully, forming colluvium indistinguishable from till. The genesis of such diamicts is notoriously difficult to determine (EYLES, 1983, p. 13 ; FOWLER, 1984 ; DAVIS and WAITT, 1986). Some of the till and charcoal in or just above the flat low area could have been reworked by slope processes prior to deposition of Mazama tephra, which appears in some gully exposures, as well as on the moraine ridges. Thus, the moraine ridges could be considerably older than the radiocarbon-dated charcoal.

FIGURE 4. View of a portion of the White Chuck cinder cone near Glacier Peak, Washington. Gully (A) drains onto a partly snow-covered depression (B), containing BEGET's (1983) charcoal locality. Moraine ridges (arrow) in background.

Vue d'une partie du cône de scories de White Chuck près de Glacier Peak, dans l'état du Washington. Le ravin (A) se déverse dans une dépression en partie couverte de neige (B) où se trouve le site à charbon de BEGET (1983). La crête morainique est indiquée par une flèche.

In summary, available radiocarbon-dated evidence does not indicate whether pre-Neoglacial moraines are absolutely equivalent from range to range, but it does not preclude the possibility. We propose the simplest hypothesis, that these moraines are broadly contemporaneous and represent a stillstand or a minor readvance of receding alpine glaciers during the Late Wisconsinan. Thus, we hypothesize that these moraines date older than 11,400 yrs BP, or are late Pleistocene in age, with the possible exception of the moraines in the White Chuck cinder cone near Glacier Peak. Even if radiocarbon dates in the White Chuck cinder cone are from till and are closely limiting ages for the moraines there, we see no widespread evidence for glacier advance and climatic cooling in the North American Cordillera for the period 8500 - 8000 yrs BP.

THEORETICAL CONSIDERATIONS

The Milankovitch theory of global climatic change suggests that solar radiation at mid- to high latitudes of the Northern Hemisphere reached maximum values at about 10,000 yrs BP (BERGER, 1978). The earth received 5 to 10 % more solar radiation in the Northern Hemisphere summer 9000 to 10,000 years ago than it does today, because obliquity was slightly greater then than now and because perihelion occurred in June rather than in January as it does now (SCHNEIDER, 1986). Sensitivity experiments with atmospheric general-circulation models suggest that July temperatures were about 5°K warmer than today about 9000 years ago in continental interiors, such as the North American Cordillera (KUTZBACH, 1981 ; KUTZBACH and GUETTER, 1984a,b). Patterns of temperature estimates derived from pollen data for eastern North America and Europe agree favorably with model results for July temperatures about 6000 years ago (WEBB, 1984). However, patterns of temperature estimates derived from pollen data for western North America as a whole at about 9000 years ago have yet to be attempted.

PALEOECOLOGICAL PROXY DATA

Palynological evidence from north-west Canada suggests a thermal maximum in the period 11,000 to 9000 yrs BP, probably due to Milankovitch forcing (RITCHIE *et al.*, 1983). In contrast, most palynological data derived from eastern and central North America support a mid-Holocene peak in warmth at about 6000 years BP (WEBB, 1984). Surface albedo of the Laurentide Ice Sheet could have influenced atmospheric circulation patterns such that paleoecological sites in eastern and central North America did not record the early Holocene warm interval (RITCHIE *et al.*, 1983). However, paleoecological sites from the central North American Cordillera were probably less influenced by Laurentide Ice than were sites to the east during the early Holocene. Thus, a review of paleoecological data (Table III) derived from mountainous regions of western North America (Fig. 1) is relevant in light of the proposed "Mesoglaciation" between 8500 and 8000 yrs BP.

Paleoecological data for timberline fluctuations at the Tonquin Pass site in the Canadian Cordillera (Fig. 1) suggest that the early Holocene following 9700 yrs BP was generally warmer than at present, although possibly a period of cooling occurred between 9200 and 8700 yrs BP (KEARNEY and LUCKMAN, 1983a,b). Based on these data KEARNEY and LUCKMAN (1981) suggested that the Crowfoot Advance (LUCKMAN and OSBORN, 1979) occurred either between 9200 and 8700 yrs BP or prior to 9700 yrs BP. Additional evidence from the nearby Watchtower Basin (Fig. 1) suggests that treeline has been higher than at present since 8800 yrs BP (LUCKMAN and KEARNEY, 1986), so probably the most recent period of pre-Neoglacial cooling there did not occur between 8500 and 8000 yrs BP.

MATHEWES (1985) reviewed palynological records from both coastal and interior British Columbia and suggested that a "xerothermic interval," a period of maximum July temperature and minimum precipitation, occurred between about 10,000 and 7500 yrs BP. The interpretation was based on both qualitative data (*i.e.* presence of bracken ferns and high percentages of alder and Douglas-fir) and numerical reconstructions using transfer functions. In the southern interior of British Columbia, HEBDA (1982) summarized palynological evidence indicating a grassland maximum between 10,000 and 8000 yrs BP, with a climate warmer and drier than the present.

Pollen and Macrofossil evidence from western Washington also suggest that the period from 10,000 to 7000 yrs BP was the warmest and driest of the Holocene. Cordilleran ice retreated from the Puget Lowland by about 13,000 yrs BP (WAITT and THORSON, 1983) and some cirques in the

TABLE III

Paleoecological Proxy Data Sites for Early Holocene Climate in the North American Cordillera

Site[1]		Material[2]	Reference
A.	Excelsior and Watchtower Basins, AB	pollen & wm	Kearney and Luckman, 1983a, Luckman and Kearney, 1986
B.	Tonquin Pass, BC	pollen & wm	Kearney and Luckman, 1983b
C.	Yale area, BC	pollen	Mathewes, 1985
D.	Marion Lake, BC	pollen	Mathewes, 1985
E.	Pangborn Bog, WA	pollen	Hansen and Easterbrook, 1974
F.	Hoh River valley, WA	pollen	Heusser, 1974
G.	Davis Lake, WA	pollen	Barnosky, 1981
H.	Battleground Lake, WA	pollen & pm	Barnosky, 1985
I.	Carp Lake, WA	pollen	Barnosky, 1984
J.	Bonaparte Meadows, WA	pollen	Mack *et al.*, 1979
K.	Waits Lake, WA	pollen	Mack *et al.*, 1978a
L.	Big Meadow, WA	pollen	Mack *et al.*, 1978b
M.	Lost Trail Pass bog, MT	pollen	Mehringer *et al.*, 1977
N.	Cub Lake, ID	pollen	Baker, 1984
O.	Gardiner's Hole, WY	pollen	Baker, 1984
P.	Cub Creek Pond, WY	pollen	Waddington and Wright, 1974
Q.	«Beaver» and Sherd Lakes, WY	pollen	Burkart, 1976
R.	Swan Lake, ID	pollen	Bright, 1966
S.	Snowbird Bog, UT	pollen	Madsen and Currey, 1979
T.	La Poudre Pass, CO	beetles	Elias, 1983
U.	Mount Ida Ridge Pd., CO	beetles	Elias, 1985
V.	Lake Isabelle, CO	beetles	Elias, 1985
W.	Blue Lake valley, CO	pollen	Nichols *et al.*, 1984
X.	Redrock Lake, CO	pollen	Maher, 1972
Y.	Alkali Creek Basin, CO	pollen	Markgraf and Scott, 1981
Z.	Hurricane Basin, CO	pollen	Andrews *et al.*, 1975
AA.	Lake Emma, CO	pollen & wm	Carrara *et al.*, 1984
BB.	Twin Lakes, CO	pollen	Petersen and Mehringer, 1976
CC.	Chaco Canyon, NM	pollen	Hall, 1977
DD.	Osgood Swamp, CA	pollen	Adam, 1967
EE.	Clear Lake, CA	pollen	Adam, 1967
FF.	Balsam Meadow, CA	pollen & pm	Davis *et al.*, 1985

[1] Letters refer to sites designated on map in Fig. 1.
[2] wm = wood macrofossils. pm = plant macrofossils.

North Cascade Range were ice-free as early as 11,250 yrs BP (WAITT *et al.*, 1982). Douglas-fir, alder, and bracken ferns became common on the Pacific Slope (HEUSSER, 1974) and an oak savanna became more widespread than it is today in the southern Puget Trough by 10,000 yrs BP (BARNOSKY, 1985). Dominance of Douglas-fir over western hemlock in the southern (BARNOSKY, 1981) and northern Puget Lowland (HANSEN and EASTERBROOK, 1974) between 10,000 and 7000 yrs BP suggests warmer and drier summers than at present (HEUSSER, 1977). Local temperate taxa and low lake levels also suggest a warm and arid climate in southwestern Columbia Basin by 10,000 yrs BP (BARNOSKY, 1984). Pollen records from northeastern and north-central Washington (MACK *et al.*, 1978a,b ; 1979), where Cordilleran Ice withdrew about 12,500 yrs BP, suggest that warming began between 10,000 and 9000 yrs BP, and continued until about 4000 to 3000 yrs BP.

Pollen sites that record the early Holocene in Idaho, Montana, Utah, and Wyoming are included in BAKER's (1984) fine review paper. At Lost Trail Pass Bog in southwestern Montana, glacial ice withdrew about 12,000 yrs BP (MEHRINGER *et al.*, 1977). Here the dominance of white bark pine between 11,500 and 8500-7500 yrs BP suggests summer temperatures cooler than at present. By 7000 yrs BP increases in Douglas-fir and lodgepole pine suggest summer temperatures warmer than today. The pollen sampling interval during the early Holocene suggests that any unrecognized climatic deterioration superimposed on an already generally cool climate at Lost Trail Pass Bog during this time was shorter than about 300 yrs. At Cub Lake, Idaho, pine increased as grass and sage decreased during the early Holocene, suggesting an open savanna (BAKER, 1984). At Gardiner's Hole, Wyoming, lodgepole pine leveled off between 11,000 and 7000 yrs BP, before declining afterwards, suggesting that the warmest and driest part of the Holocene occurred earlier at high elevations than at low elevations (BAKER, 1984). At Cub Creek Pond, Wyoming, a rise in spruce, followed by increases in pine, created a mixed forest vegetation following deglaciation until about 8800 yrs BP; spruce, fir, and white bark pine declined and lodgepole pine increased at about 8000 yrs BP (WADDINGTON and WRIGHT, 1974), suggesting a continued warming trend. In the Bighorn Mountains in north-central Wyoming, BURKART (1976) found spruce, usually indicative of a cool climate, to dominate during the early Holocene, with increases in pine pollen much later. However, lodgepole pine is not well adapted to near-timberline conditions, and thus was slow to migrate upslope and become prominant in the pollen record in the Bighorns (BAKER, 1984). At Swan Lake in southeastern Idaho, which was unglaciated, a sage-grass steppe replaced a mixed forest about 10,800 yrs BP (BRIGHT, 1966), suggesting a probable change to a warmer and drier climate. Only at Snowbird bog in Utah do late-glacial conditions appear to prevail until 8000 yrs BP (MADSEN and CURREY, 1979). Here spruce and pine increased between 8000 and 5000 yrs BP, suggesting warm conditions (MADSEN and CURREY, 1979) ; however, a varied depositional history in an unusual topographic setting make paleoclimatic interpretations from this site difficult (BAKER, 1984).

All paleoecological sites in Colorado except Alkali Creek basin were glaciated (Fig. 1). A sequence of peats from the La Poudre Pass site provides abundant insect fossil assemblages which suggest that altitudinal treeline was close to the site from 9500 yrs BP to the present (ELIAS, 1983). An altitudinal series of four other insect fossil assemblages in the Colorado Front Range suggests a climatic optimum from 9000 to about 7000 yrs BP (ELIAS, 1985). In contrast, MAHER (1972) interpreted spruce : pine ratios from Redrock Lake in the Colorado Front Range to suggest that timberline was lower and climate was cooler and moister than at present from 10,000 to 7600 yrs BP. However, NICHOLS (1982) suggested that timberline was higher and climate was warmer than at present during the early Holocene, which was later supported by means of palynological studies from an altitudinal series of sites in the nearby Blue Lake valley (NICHOLS *et al.*, 1984). At Alkali Creek basin in west-central Colorado, the only site below treeline in a sage steppe, MARKGRAF and SCOTT (1981) suggest that climate changed from cool-moist to warm-moist at 10,000 yrs BP. At Hurricane Basin in the San Juan Mountains in southwestern Colorado, ANDREWS *et al.* (1975) suggest that climate was somewhat cooler than the present before 8400 yrs BP, based on spruce: pine ratios. However, ANDREWS *et al.* (1975) also found that treeline was at the site during the early Holocene, based on spruce macrofossils found in bogs. Wood macrofossils and pollen from the Lake Emma site in the San Juan Mountains suggest that deglaciation occurred as early as 15,000 yrs BP and that from about 9600 to 7800 yrs BP treeline was at least 70 m higher than present (CARRARA *et al.*, 1984). At Twin Lakes in the La Plata Mountains in southwestern Colorado, PETERSEN and MEHRINGER (1976) found evidence for timberline lower than at present before 9800 yrs BP. However, they also suggest that the treeline advanced upwards at least twice prior to 6000 yrs BP, probably about 8500 and 6700 yrs BP, which could have been caused by climatic warming.

Pollen records are not available for the early Holocene in mountainous New Mexico ; however, HALL (1977) found evidence for pinyon and ponderosa pine dominating the Chaco Canyon area between 7000 and 5800 yrs BP. At Clear Lake, an unglaciated tectonic basin in the northern Coast Range of California, ADAM (1967) found decreases in pine and the cypress-yew family along with increases in oak, composites, and grass to their maximum Holocene levels about 10,000 yrs BP. Osgood Swamp in the northern Sierras, glaciated during late Pleistocene time, provides pollen evidence suggesting a change from vegetation dominated by sage to one dominated by pine about 10,000 yrs BP (ADAM, 1967). The increase of juniper and cedar during the early Holocene probably suggests a higher treeline and warmer climate (ADAM, 1967). Palynological evidence from the southern Sierras suggests that the early Holocene was not only warm, but also very dry (DAVIS *et al.*, 1985).

In summary, in most paleoecological sequences from western North America the early Holocene sharply contrasts the late glacial (BAKER, 1984). In the northwestern United States and in western Canada the Holocene temperature maximum occurred between 10,000 and 7000 yrs BP. In the Sierras pollen evidence suggests a continuous uninterrupted warming through the Holocene. In the Yellowstone area of the Rocky Mountains upward movement of treeline and vegetational belts did not begin until about 8000 yrs BP, but there is little evidence for climatic reversals during the early Holocene. In Colorado an abundance of pollen, wood macrofossil, and insect fossil evidence suggests that the early Holocene was the warmest part of the postglacial. In general, sampling intervals in continuous depositional records suggest that if climatic reversals did occur, they were shorter than 200 to 300 yrs duration and probably not as pronounced as the late Holocene cooling related to Neoglaciation.

CONCLUSIONS

1. In cirques of the North American Cordillera pre-Neoglacial moraines that lie up to about 3 km beyond Neoglacial moraines could be correlative and probably date to the late Pleistocene (*i.e.* at least 10,000 yrs BP), rather than the early Holocene.

2. Nearly all of these pre-Neoglacial moraines have minimum-limiting radiocarbon dates or age assignments based on relative dating data that may underestimate the age of the deposits.

3. Of these pre-Neoglacial moraines, the type Temple Lake moraine in the Wind River Range in Wyoming provides the oldest minimum-limiting radiocarbon date (11,400 ± 630 yrs BP).

4. Nearly all paleoecological proxy data from the mountainous regions of western North America suggest that climate rapidly warmed to values higher than those of the present during the early Holocene.

5. Milankovitch forcing functions could explain the early Holocene thermal maximum in the mountainous West predicted by global circulation models.

6. In a cirque near Glacier Peak in Washington a "till" upvalley of moraines that is radiocarbon-dated at about 8400 yrs BP could be a debris flow deposit. Thus, a proposal for a period of early Holocene cooling, or "Mesoglaciation", based on the 8400-yr date may be premature.

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