Out-of-Phase Holocene Climatic Trends in the Maritime and Continental Sectors of the Alaska-Canada Boundary Range

by
Maynard M. Miller & James H. Anderson
Foundation for Glacier & Environmental Research
Pacific Science Center, Seattle, WA 98109

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OUT-OF-PHASE HOLOCENE CLIMATIC TRENDS IN THE MARITIME AND CONTINENTAL SECTORS OF THE ALASKA-CANADA BOUNDARY RANGE

MAYNARD M. MILLER AND JAMES H. ANDERSON

ABSTRACT

Comparative field studies of Quaternary glacial sequences and palynological profiles in kettle-hole bogs are described with respect to the coastal and interior flanks of the Alaska-Canada Boundary Range on a transect from Juneau, Alaska (Taku District) to Atlin, B.C. (Cassiar District). Special attention is given to the problem of out-of-phase glacio-climatic fluctuations in the maritime versus continental sectors of this Cordilleran region, within the framework of secular changes since Valders time...ca., 10,500 to 11,000 yrs. B.P.

Based on radiocarbon dating of key horizons in the stratigraphic sequence, a table of climatic trends is noted for each region where today the mean annual sea-level precipitation regimes are 228 cm (in the temperate Sitka spruce and hemlock forest of the Juneau sector) and 25 cm (in the dry semi-arid white spruce and pine forests of the Atlin sector). References to "warmer and drier" and "warmer and wetter" designate precipitation regimes in each sector which characterized a period of increased storminess in the Thermal Maximum. All other adjectives (e.g., "warm", "cool") are relative to the respective Thermal Maximum conditions in each sector. The climatic characterizations are interpreted as follows:

	INTERVAL, YEARS B.P.	ATLIN (CASSIAR) DISTRICT	TAKU (JUNEAU) DISTRICT
	0 - 750	warm-wet	warmer-drier
	2,500-750	cold-dry (decreased storminess)	cooler-wetter
			cooling-wetting
	3,250-2,500	warm wet	maximum warmth and dryness
Thermal Maximum	5,500-3,250	warmer-wetter (increased storminess)	maximum warmth and dryness
			relative warming-drying
	8,000-5,500	warm-wet	cool-moist
	9,000-8,000	cool-dry	relative warming-drying
	10,000-9,000	cooler-drier	cooler-wetter
	10,500-10,000	cool-dry	coldest
	11,000-10,500	cooler-drier	coldest (Valders equiv.)

The significance of this climatic sequence is discussed in terms of secular shifts in the Arctic Front and related storm path positions along the North Pacific Coast during the Holocene. Corroborating

information is introduced from known variations of glaciers in this region since A.D. 1500 and from analyses of meteorological trends in the coastal sector where relatively continuous records have been maintained since A.D. 1840.

INTRODUCTION

Some unique aspects of late Quaternary glaciation on the northwest coast of North America are revealed by a comparative study of bog palynology and morpho-stratigraphic sequences on the maritime versus continental flanks of the Coast Mountains in the Alaska-Canada border region (Bostock, 1948). The main comparisons are made on a 240 km transect across the Northern Boundary Range from Juneau, Alaska (Taku District) to Atlin, B.C. (Cassiar District). The results of the study are discussed in this paper with special attention being paid to the detection of out-of-phase glacio-climatic fluctuations in the coastal as opposed to the interior sectors of this transect over the nearly 11,000 years since the advent of the Holocene.

THE PRESENT GLACIAL POSITION

The main glacierized sectors of the southern and northern Boundary Ranges include the Stikine Icefield (north and west of the Stikine River) and the Juneau Icefield (northwest of the Taku River) as noted in Fig. 1. Several hundred miles northwest of the Juneau Icefield and lying in the St. Elias Mountains extends the St. Elias Icefield where, in the Yakutat Bay sector, Tarr and Martin (1914) sixty years ago initiated the pioneering glaciological and glacial geological study of Alaskan glaciers for the National Geographic Society. These three large icefields represent most of the main existing glaciation in North America today. Each expanded to their presently configurated form about 2,000 yrs. B.P. They are Neoglacial in age and are not relict from earlier Pleistocene time. They represent contiguous areas of interconnected highland valley glaciers which total, respectively, about 2,600, 2,800, and 13,000 square km of névés and outflowing glacier tongues. They are typified by the Juneau Icefield and its receding Llewellyn Glacier (Fig. 2) on the continental flank of the range and the advancing Taku Glacier (Fig. 3). The Llewellyn Glacier drains north from the icefield into the dry interior of the northern B.C.-Yukon region, and the Taku glacier is nourished on the wet coastal flank of the range and flows south to a tide-water terminus.

In all of these sectors, today's glacial positions are close to the Neoglacial maximum. This has been evidenced by lake varve studies and radiocarbon dating of ice-buried forest remains (Hanson, 1932; Kulp, Feeley, and Tryon, 1951; Cross, 1968; Miller, 1956; Miller, Egan and Beschel, 1968). In some sectors, the Neoglacial positions

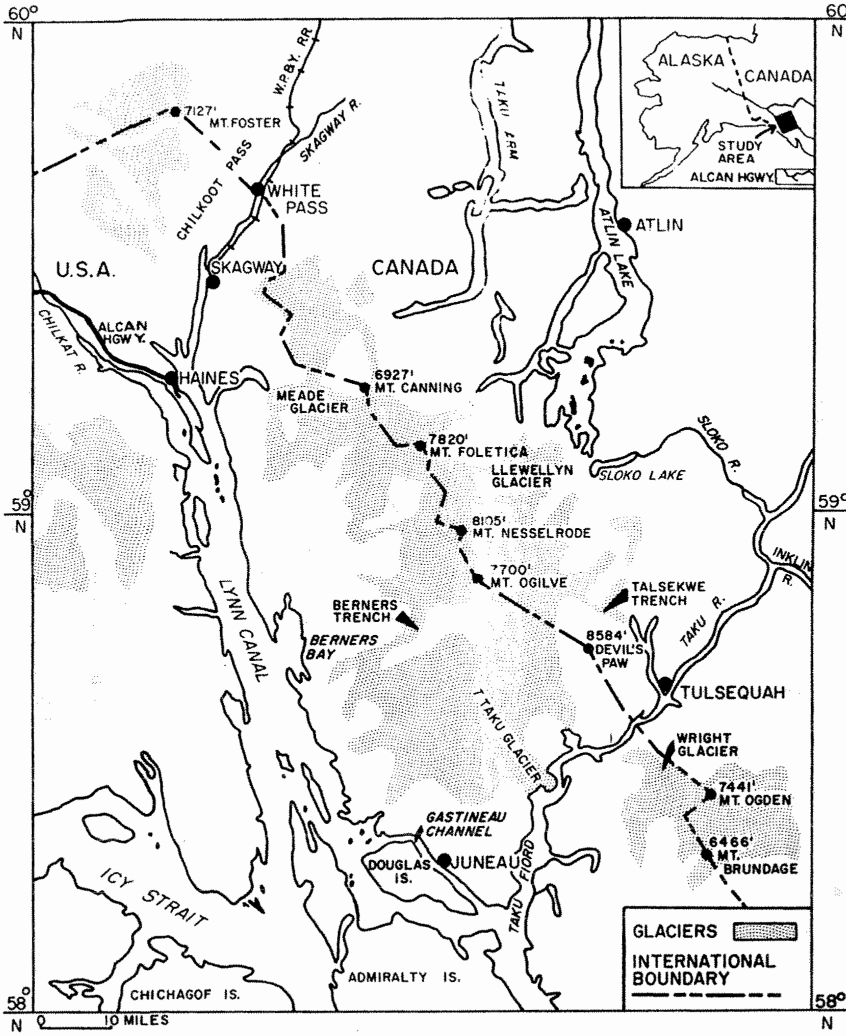

Figure 1. The Northern Boundary Range and the Juneau Icefield, in the Taku and Atlin Districts in the Alaska-Canada border region.

Figure 2. Receding Llewellyn Glacier, Northern B.C.

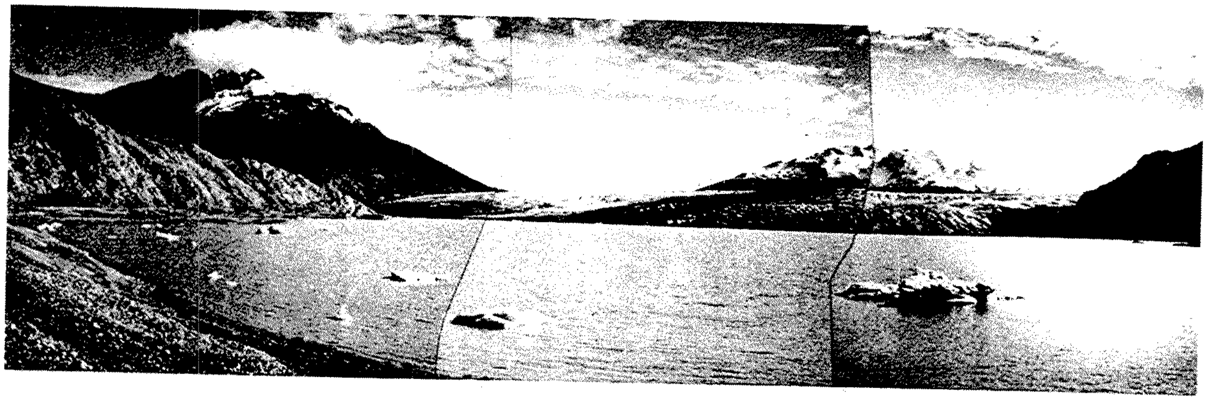

Figure 3. Ground Panorama of the Llewellyn Glacier, Northern British Columbia, 1969.

represent the most extensive advance of the Holocene. Evidence is given by radiocarbon dating of muskeg peat (Heusser, 1952, 1953, 1960, 1965; Heusser and Marcus, 1964) and dendrochronologic analyses of old spruce and hemlock forests invaded by glaciers during the late Neoglacial (Lawrence, 1950; Lawrence and Elson, 1953). As for early and middle Holocene conditions and, indeed, those of late Wisconsinan time, recourse must be made to morphological and palynological information, especially the climatic records contained in bog profiles. With respect to the interior valleys and adjoining sectors on the continental flank of these mountains recent glaciopalynological measurements and interpretations have been made and are the substance of the following paper. These include a Holocene chronology and considerations of the paleoglacio-climatic character of this region which lies at the northern end of the Cordilleran Pleistocene Ice Sheet.

BIO-CLIMATOLOGICAL STRATIGRAPHY

In this study, systemic consideration has been given to the palynology of kettle-hole bogs in the Atlin region of the Cassiar District. The palynological analyses are by Anderson (1970), based on our field work between 1965 and 1969. The purpose has been to compare Holocene sequences with those interpreted from muskeg bogs on the Alaskan side of the Juneau Icefield studied in an earlier Juneau Icefield Research Program by Heusser (1952). In the Atlin sector a typical low-elevation bog at 730 m elevation (Mile 16) and a higher level bog at 1,035 m elevation in the upper Fourth of July Creek Valley are illustrated in Figs. 4 and 5. The locations of nine such key sample sites are shown in Fig. 6. Pollen and spore diagrams are presented in Figs. 7 and 8 to show bog profiles at Mile 16, near the B.C.-Yukon border of the Atlin road, and at Jasper Creek about 40 km northeast of the Llewellyn Glacier terminus. From these and the other pollen profiles obtained, a tentative Holocene glacial-geobotanic-climatic chronology has been developed (Fig. 9). In this chronology, some pertinent climatic differences are outlined in a comparison with Heusser's published sequence for the maritime side of the Boundary Range.

By reference to the right hand column in Figs. 7 and 8, three distinct zones are shown to represent gross vegetation changes in the Atlin sector during the Holocene. These zones are also revealed by the form of related pollen profiles, denoting the nature of contemporaneous vegetation. Radiocarbon dates show that the boundaries between zones, however, are not necessarily contemporaneous from one bog to another. The basal (oldest) zone is the shrub zone, characterized by alder and birch, plus willow, grass, *Artemisia spp.* and other *Compositae*. Here we find a low frequency of tree pollen and dominance of shrub pollen. In the Mile 47, Jasper Creek and Wilson Creek bogs, this zone begins at the base and extends well up into

Figure 4. Mile 16 bog in recent burn area on the Atlin road. View west, in September, 1973.

Figure 5. Fourth of July Creek bog, showing palsas.

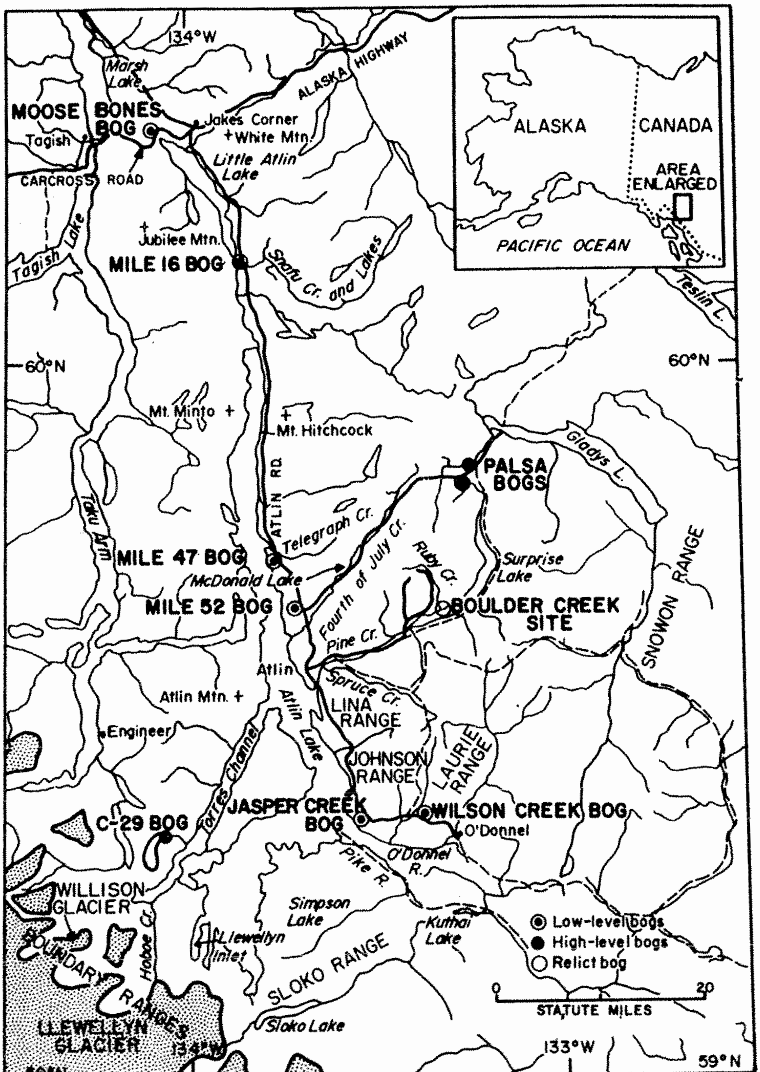

Figure 6. Atlin Region map showing sampling sites. Modified map courtesy of the National Geographic Society.

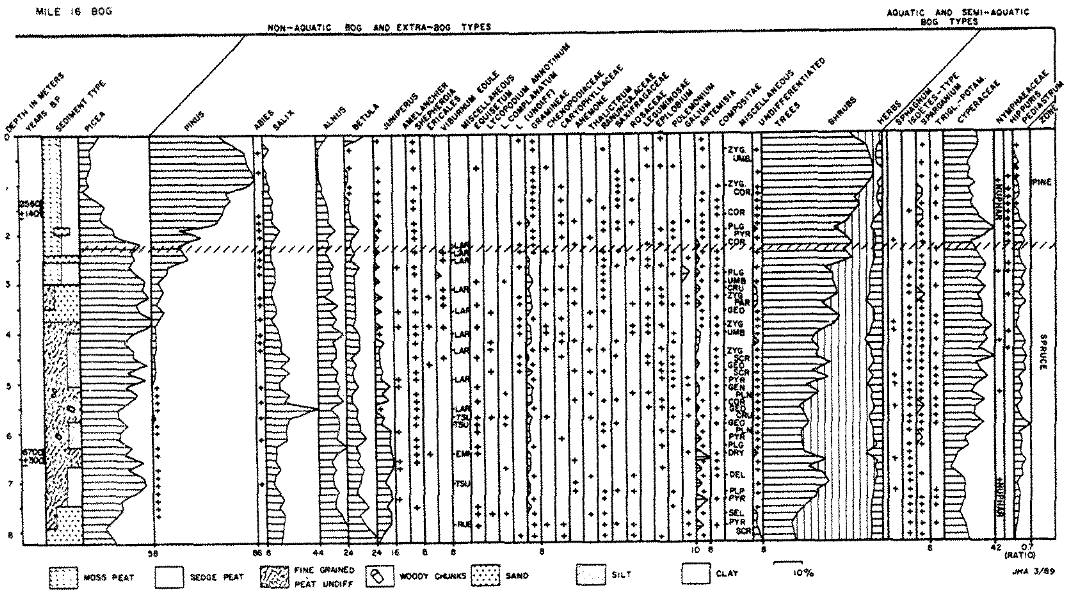

Figure 7. Pollen and spore diagram, Mile 16 bog.

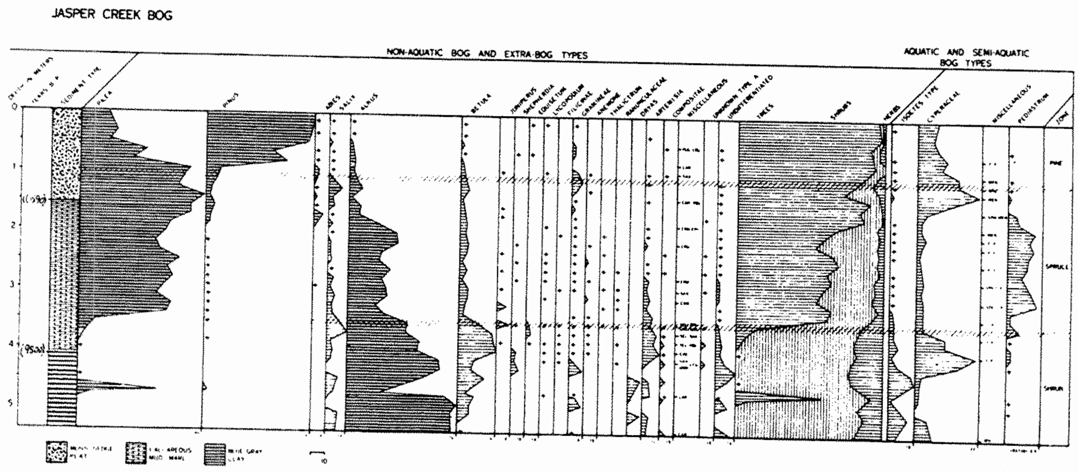

Figure 8. Pollen and spore diagram, Jasper Creek bog.

blue-gray clay sediments, where there are generally low pollen counts.

Above the shrub zone occurs a spruce zone, characterized by a rapid increase in the dominating white spruce pollen percentages. The pollen counts of the principal shrubs here represent willow, alder and birch and decrease to levels intermediate between the shrub zone and an overlying pine zone. The pine zone is the uppermost and is characterized by high percentages of pine pollen with relatively lower spruce pollen percentages. Alpine fir grains also occur here, but are less frequent in the surface (younger) stratigraphy.

Scarcity of aspen and poplar pollen in the bog sediments has been attributed by Anderson (1970) to its low preservability in the alkaline environment of this limestone region. Actually today aspen is a very prominent constituent of the vegetation of the Atlin region.

In conjunction with the palynologic sampling, seven bog sediment samples were obtained for radiocarbon dating. The Mile 16 Bog samples were taken at depths of 150 and 655 cm (Fig. 7). In the Mile 47, Mile 52 and Wilson Creek Bogs, radiocarbon samples were obtained at or near boundaries between major sediment types. Two samples were obtained from Mile 47 Bog, one of which was divided into organic and inorganic fractions. One sample each was collected from Mile 52 and Wilson Creek Bogs. These permit the calculation of probable sediment accumulation rates and an extrapolation of tentative dates to other levels. Cross correlations of key pollen profiles between bogs helps establish the chronologic framework. In Fig. 8, the dates in parentheses denote such corrections. Although there can be errors in this kind of extrapolation at least it gives an estimate of the age and development of the bogs. The age of the bottom sediments in the Mile 16 bog section is suggested to be approximately 8,000 yrs. B.P. On a similar basis the oldest sediments, determined by such correlation in the Jasper Creek profile, were deposited at least 11,000 yrs. B.P.

The analyses give some indication of the earliest dates of deglaciation at the southern end of the Atlin valley. Also the dates are commensurate with C^{14} ages relating to bog development since deglaciation in adjoining highland sectors N.E. of Atlin, including the Fourth of July Creek Valley (Fig. 6). From this we know that by no later than 9,000 years B.P., most of the Atlin valley was deglaciated for some 110 km south of the late Wisconsinan moraines. at the northern end of Little Atlin Lake and hence that most of this region was deglaciated by the beginning of the Holocene. In the late Glacial to early Holocene warming, final retreatal positions of the ice were close to the location of subsequently developed maximum Neoglacial moraines near the present periphery of the Juneau Icefield.

CHRONOLOGIC INTERVALS OF THE HOLOCENE AND RELATIONSHIP OF STORM PATHS

A provisional time sequence of Holocene climatic and glacial events for the Taku-Atlin region is given in the geobotanic chronology of Fig. 9. Here nine discrete time zones are shown, extending backward from the youngest to the oldest (i.e., to Valders time about 11,000 yrs. B.P.). Related changes in general storm path positions are idealized diagrammatically in Fig. 10. These shifts in position have been related to a solar-climatic control mechanism (Miller, 1956, 1972b, 1973). The chronosequence and zonal characteristics in successive time intervals are outlined in the following tabulation.

Time Interval I

This period includes the present to about 750 yrs. B.P. and essentially embraces the "Little Ice Age". This included minor fluctuations in late Neoglacial climate and related glacier variations during this most recent interval of increased glaciation. In the Atlin region, the climatic character was generally warmer and drier than the preceding interval but warmer and wetter on the coast (see below), with minor fluctuations respectively between wetter and drier conditions. Actually, the palynological method is not sensitive enough to reveal the short-term climatic pulsations of the "Little Ice Age"; however, glaciological and glacio-meteorological techniques have been applied to delineate such fluctuations. Thus, a three-fold warming and cooling pattern superimposed on a general warming trend especially notable since the mid-1700's has been well documented for the period since deposit of the first major Little Ice Age moraine around 1,600 A.D. (Beschel & Egan, 1965). Furthermore, there is evidence in the bogs of an increase in precipitation during some of these fluctuations including a recent rejuvenation of subsurface ice and growth of palsas in the higher elevation bogs (Fig. 5) related to regional cooling since the late 1940's (Anderson, Miller and Tallman, 1974; and Tallman, 1974). Allied with this there has been a substantial build up of glacier ice in the ice-field sectors. In fact, all of the glaciers since the 1950's at higher elevations have responded to late Neoglacial climatic perturbations (Miller, 1970, 1973), supporting the contention that the Arctic Front[1] throughout the Holocene shifted back and forth across the axial zone of the Boundary Range shared by the Taku and Atlin Districts. In the generally warm-moist situation of today, the

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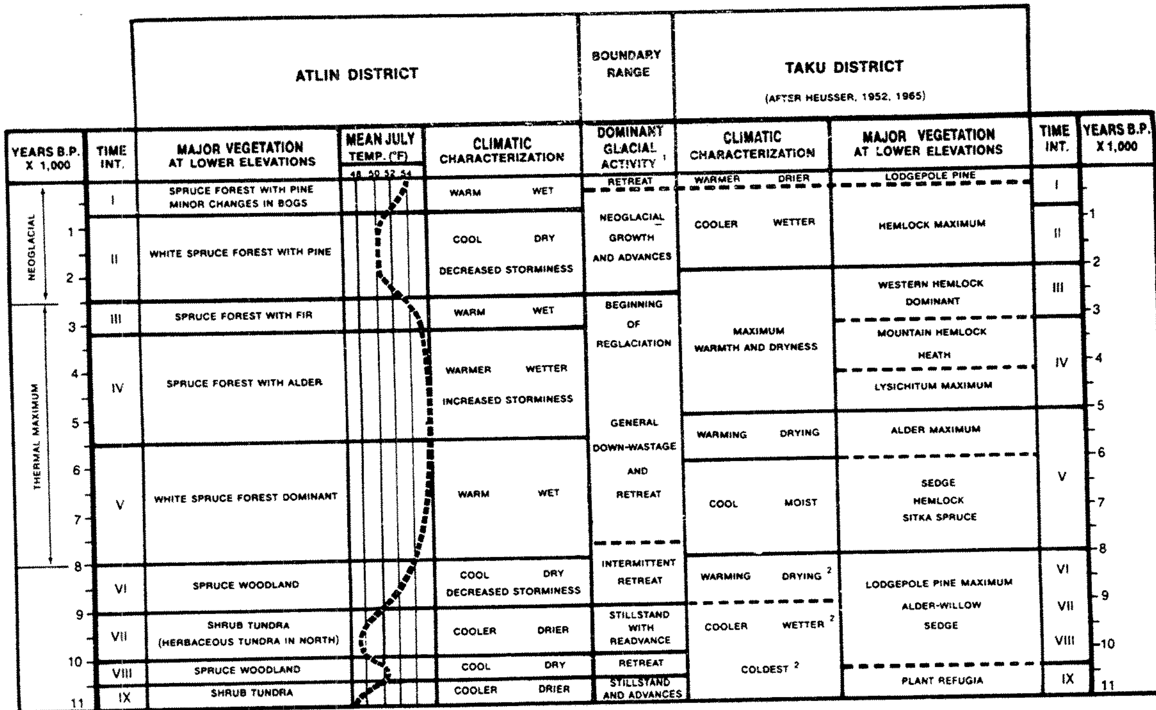
[1] The line of demarcation between the high pressure anti-cyclonic continental weather conditions and the low pressure cyclonic maritime conditions on the coast.



[1] low-névé glacier

[2] inferred by present authors

Figure 9. Holocene Chronology for the North Pacific Continental Margin, Alaska-Canada.

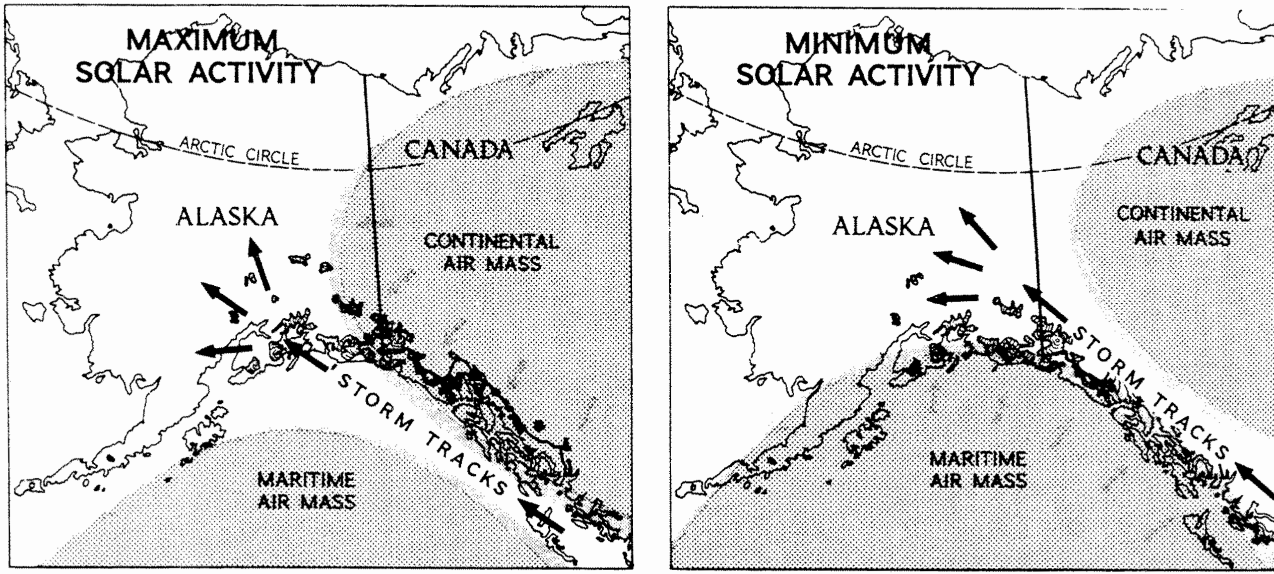


Figure 10. Diagrammatic representation of storm path relationship and the Arctic Front between opposing atmospheric pressure cells on the North Pacific Coast. Modified map courtesy of the National Geographic Society.

storm paths[2] have a strongly maritime orientation with freezing levels significantly higher than in the preceding interval. Associated with this has been downwasting and general retreat of glaciers with low névés and a notable thickening and advance of glaciers with high névés.

Time Interval II

For this period (2,500-750 B.P.) the palynological record suggests cooler and drier conditions than in the "Little Ice Age". This involved a situation in which the average position of the Arctic Front and associated storm paths shifted inland with increased dominance of the maritime pressure cell and lowered freezing levels. The result was decreased storminess and less precipitation in the inland areas and a corresponding cooler and wetter situation in the coastal part of the Taku District. Associated with this were Neoglacial advances on lower névé glaciers and retreatal conditions on high névé glaciers. Early Neoglacial advances in the northern Boundary Range reflect conditions of lowered temperature and increased maritimity across the range; but decreased storminess is also indicated by the increase in dry climate vegetation in the interior Atlin region revealed by the bog pollen record. A greater proportion of pine in the Atlin valley reflects a higher frequency of forest fires resulting from these drier conditions (Anderson, 1970). It is significant that the relatively cool-dry climate of the Atlin valley at that time was quite out-of-phase with the climatic character of the Alaskan coast. This relationship was first suggested by Miller (1956, p. 512) to explain divergences in the climatic environment of muskeg areas at low elevation and glacio-climatic trends at high elevation on the Juneau Icefield. The late Holocene (Time II) condition is also considered comparable to the beginning of the Holocene (Time Intervals VI and VIII).

Time Interval III

Continuing wetness, from 3,250 to 2,500 yrs. B.P., is connoted by the appearance of alpine fir in the Atlin spruce forest, with decreasing temperatures, lowered freezing levels, and reduced storminess. At the end of this interval, mean July temperatures apparently decreased to close to the present level, about 12° C. At the end of the Thermal Maximum this may be compared to the sub-Boreal.

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[2] In this context, storm path refers to peripheral circulation of the subarctic cyclone and not to the track of the cyclonic center which in the northern Pacific area moves generally in a northeasterly direction and hence normal to the south and southeasterly winds of the peripheral circulation.

Anderson's (1970) interpretation is that it ended about 1,000 years later in the Atlin area than in the Taku District as reported by Heusser (1952), making it contemporaneous with the sub-Boreal of other regions. Nevertheless at the end of this interval, the Arctic Front shifted inland and Neoglacial time began. With less stormy and cooler conditions, lowered freezing levels presaged a resurgence of many of the large glaciers on the Juneau Icefield.

Time Interval IV

With Holocene temperatures and precipitation reaching their maximum from 5,500 to 3,250 yrs. B.P., mean July temperatures were probably as high as 13° C and precipitation was as great as at present. The warmer and wetter conditions meant higher freezing levels and increased storminess. Dominant trees were spruce with alder. The low névé Boundary Range glaciers shrank to their post-Wisconsinan minima, with some thickening of higher elevation cirque glaciers and the high est crestal névés. Main trunk glaciers in the Atlin valley receded well up into the Boundary Range, some miles south of the present position of the Llewellyn Glacier (Fig. 2). On the Alaskan coast, forests grew far up into the present ice-covered valleys of the Taku, Mendenhall, Herbert and other maritime glaciers. Maximum downwasting of all but the highest Juneau Icefield névés culminated the progressive deglaciation trend that had begun in Time VII some 6,000 years earlier.

More extensive and luxuriant vegetation characterized the apex of this interval, which compared to the Atlantic period of other regions and the late Hypsithermal (Thermal Maximum) identified by Heusser in muskeg on the Alaskan Panhandle. The Arctic Front was positioned much nearer the coast and sufficiently west of the Juneau Icefield that even the maritime Taku Glacier (Fig. 3) had a terminus some 14 miles up-valley compared to its subsequent Neoglacial maximum. With increased temperatures there was also increased atmosperic turbulence and storminess responsible for the continuing wetter conditions.

Time Interval V

This period lasted from 8,000 to 5,500 yrs. B.P. In the beginning, regional temperature in the Atlin sector approached present levels, marking the beginning of the Thermal Maximum. With its waxing and waning phases, this extended over 5,000 years, about half of the Holocene. Precipitation in the Atlin area was at today's level (280-305 mm per year) or higher, i.e. nearly semi-arid, but in comparison with preceding time intervals relatively wet[3], thus promoting

[3] Use of the term "wet" only designates a wet precipitation regime relative to the drier and more continental conditions characterizing the preceding cool and dry spruce woodland and cooler and drier tundra vegetation of time Intervals VI, VII, VIII, and IX.

widespread development of spruce forest vegetation.

At the outset, highland glacier regimes were oscillating, with changes taking place rapidly. Overall the trend was thinning, and retreat of low-névé glaciers, reflecting a rise in mean freezing levels. At the end of the interval, the terminus of the Llewellyn Glacier presumably reached a position not far from its present position.

Time Interval VI

During this short interval, from 9,000 to 8,000 yrs. B.P., a significant and intermittent downwasting and retreat of the main Atlin valley glacier took place, with formation of the series of recessional moraines and side-valley kame deltas at the northern end of Atlin Lake. Ameliorating climate in this interval at the onset of the Thermal Maximum presaged the change to warmer and moister conditions from the relatively cold and dry conditions of the preceding interval. In the southern sector this promoted growth of a spruce woodland. The Mile 47 and Mile 52 Bog areas (Fig. 6) were exposed as was the Mile 16 bog site, although ice cores in the ground moraine had presumably not yet melted out to create the kettle in which the latter bog developed. This time interval is considered by Anderson (1970) as a "third and final subdivision of a period comparable to the pre-Boreal in other regions or the contemporaneous Early Post-glacial recognized by Heusser (1960) in Southeastern Alaska".

The mean position of the Arctic Front was again moved toward the coast by dominance of the Polar anticyclone. The result was decreasing storminess and raised freezing levels and cool-dry climatic conditions in the Atlin area compared to the relatively warming-drying, though still basically cool and moist, conditions which presumably were developing at the coastal flank of the Boundary Range. From glaciological interpretations (Miller, 1963, 1961), the consequence of this climatic trend would have been increasing retreat of inland glaciers with low névés and advance of both inland and maritime glaciers with high névés. Glacial regimes may have been comparable to those characterizing Interval II in the early half of the Neoglacial.

Time Interval VII

This period, from 10,000 to 9,000 yrs. B.P., was characterized by a shrub tundra vegetation, with herbaceous tundra in the northern sector of the Atlin region. The prevailing cooler and drier climatic conditions represented the coldest part of the Holocene. Storminess was lessened because there was less atmospheric energy. Significantly, palynological interpretations suggest that cooler and moister conditions prevailed along the Alaskan coast, with inland orientation of storm tracks and notably depressed freezing levels. The main valley glaciers on the coast responded by crowding forward as did low névé inland glaciers, including the trunk glacier down the Atlin valley. Highland glaciers also became increasingly chilled and reverted to thermally polar to sub-polar conditions, with lessened flow rates resulting in still-stands. Extensive kame terraces on each flank of the Atlin valley in its northern sector corroborate this interpretation. With low temperatures, the mean Arctic Front probably again shifted inland and for long periods lay over the southern part of the Atlin region. Regional glaciation at this time was likely in the Lesser Mountain Ice Sheet Phase of Miller (1964).

This was the pre-Boreal interval, or early Postglacial according to Heusser's (1960) interpretation, representing a glacio-climatic oscillation not generally delineated elsewhere (although in the mid-continent chronology of the Great Lakes region there is evidence of a post-Valders resurgence-Valders II). It also may correlate with the Sumas Stade of S.W. British Columbia and the Sittakanay stage in the Taku Valley of N.W. British Columbia (Miller, 1956).

Time Interval VIII

From 10,500 to 10,000 yrs. B.P., in the inland sectors this interval represents a short oscillation slightly warmer and relatively wetter than the preceding and subsequent intervals. The main Atlin valley trunk glaciers of Wisconsinan age apparently then suffered a remarkably rapid 24-33 km retreat from the maximum late-Wisconsinan position at the embankment moraines near Jake's Corner on the Alaska Highway (Fig. 6). They reached a stillstand in the vicinity of what is now Mile 24 on the Atlin Road. In the Jasper Creek and Wilson Creek bog areas, the vegetation changed from shrub tundra to spruce woodland similar to but drier than the present vegetation found at 1,280 to 1,370 m in the Atlin region.

It is suggested that mean July temperatures were above 10° C and that precipitation rose to perhaps as high as 205-250 mm per year. The mean position of the Arctic Front was somewhat farther inland than in Time VII, yet closer to the coast than in Time IX, thus probably well south of the Atlin region. At the onset of this period, this should have resulted in the passage of increased ice from higher névé glaciers into the main fiords on the coast. At the end, these degraded into retreat as freezing levels lowered and storminess decreased.

Time Interval IX

This interval, from 11,000 to 10,500 yrs. B.P., is presumed as the final stage of large-scale Wisconsinan glaciation in the Taku-

Atlin region. This glaciation established the outermost moraine complexes within the peripheral distributary valleys of the Coast Range. In the Atlin sector, this would be the end-stage of embankment moraines which today are crossed by the Alaska Highway at the northern end of Little Atlin Lake (Fig. 6). In the Taku District, it would be represented by the older surface tills and related slump deposits in Gastineau Channel and Lynn Canal immediately south and west of the Juneau Icefield (Fig. 1). Where these tills lie above the highest marine terraces they are somewhat stained and slightly weathered. Where exposed in the lower fiord areas, just above present sea level, they are overlain by thin unweathered blue-gray till and diamictons which were initially laid down in Time VIII as discussed above.

In the interior Atlin region, the moraines and pitted outwash of the Moose Bones Bog area and knob and kettle topography and gravel terraces of the White Mountain-Squanga Lake region in the Teslin Valley were formed at this time. In the Atlin Valley, the Mile 16, Mile 47, and Mile 52 bog sites were still covered by ice, but the Wilson Creek and Jasper Creek bog locations had become exposed by glacial thinning during this transition into the Holocene.

Vegetation in the vicinity of these bogs was shrub tundra, indicating mean July temperatures of 7.8^{o} to 9^{o} C and a mean precipitation of probably less than 203 mm. The climatic character was cooler and direr than in any subsequent interval, although a short comparable interval also developed during period VII as previously noted. There was a cooler and moister counterpart along the Alaskan coast, at which time the inland fiords, including Lynn Canal, were largely filled with ice. The morphogenetic character of this glaciation would be equivalent to the Intermediate Mountain Ice Sheet Phase (Miller , 1964). From this and the evidence of glaciated cirques within 90 m of present sea level (Miller, 1961), it is concluded that freezing levels were right down at tide water and that the Arctic Front had dominant inland orientation. At this time its mean position likely rested well over the Atlin region.

Interval IX is also presumed to represent only part of a larger interval extending back into the Wisconsinan Age. In may be comparable to the tail end of the Port Huron maximum in the American mid-continent chronology and to the younger Dryas Stade (Pollen Zone lc) of the European chronology. Distinct evidence of an ameliorated Two Creeks (Allerød) intra-glacial following this stage in the Atlin area, with corresponding milder conditions in the Taku (coastal) areas, is not clear, although this may be represented by the conditions cited for Time Interval VIII. Therefore, assuming Interval IX to represent only the last 500 years or so of a final major Wisconsinan glaciation it could be related to the Late Glacial Phase III suggested by Heusser (1960) from palynological study of the North Pacific maritime region and to the Inklin stage of late-Wisconsinan glaciation delineated by Miller (1956, 1972a) from study of Pleistocene stratigraphy in the contiguous Taku District.

THE WISCONSINAN-HOLOCENE BOUNDARY

The second author suggests that Interval VIII (10,500-10,000 yrs. B.P.) could possibly be the first distinct subdivision of the Holocene Epoch, although the first author inclines to reference it as a Valders equivalent (Bothnian in Scandinavia). This latter interpretation would correlate it with the Tulsequah stage in the Taku Valley, B.C. and with the upper blue-gray till and associated diamictons in the Juneau area (Miller, 1956, 1963). In Anderson's interpretation, the lower Holocene-Wisconsinan boundary would rest at about 10,500 yrs. B.P. and represent the beginning of pre-Boreal or Early Postglacial time. With Miller's interpretation, this boundary would be at 9,500-10,000 yrs. B.P. More recent radiocarbon dates in the Atlin region may favor the latter view. For example, the broad upland glaciers at the head of tributary valleys in the region between Gladys, Surprise and McDonald Lakes (Fig. 6) are now known to have begun downwasting and retreating between 9,000 and 10,000 yrs. B.P. This is shown in bogs well within areas of late-Wisconsinan ice cover at the 915 to 1,065 m level where peat was developing as early as 9,800 to 8,800 yrs. B.P. The evidence is radiocarbon dating of heath twigs from the base of the palsas in bogs of the upper Fourth of July Creek Valley (Fig. 5 and 6), with dates of 8,050 $\pm$ 430 yrs. B.P. (GX2694), and 9,315 yrs. B.P. (GX2695).

On this basis the Holocene should be considered to represent that time since the beginning of the final major deglaciation, i.e. in reference to formerly glaciated regions. Another way of stating it is, that interval of time since the last major glaciation. In a periglacial or non-glacial region, this definition should include the interval since culmination of the last large-magnitude fluvial or pluvial change. Although this interpretation of the Holocene can imply different lengths of time for different regions, it would appear to be a more meaningful and appropriate chronological unit for regional application than the arbitrary time-span of 14,500-14,000 yrs. B.P. suggested by Mercer (1972) as comprising the post-Wisconsinan in terms of the time "since global temperatures began to rise toward fully interglacial levels".

SYNCHRONEITY AND THE TELECONNECTION PROBLEM

The described sequence of biogeoclimatological subdivisions of the late Wisconsinan and Holocene Epochs for the North Pacific <u>coastal region</u> shares some similarity to sequences interpreted in other regions of the Pacific Cordillera. The best synchroneity is found in specific time intervals of this chronology applied solely to maritime regions west and southwest of the coast mountains and as far south as Washington State (Heusser, 1965). It differs, however, in interpretation of the climatic character in corresponding time intervals between coastal and inland sectors, specifically between the maritime and continental flanks of the Alaska-Canada Boundary Range. In some cases the subdivision boundaries are more or less contemporaneous, but in others they are not. Further understanding of these kinds of differences must come from more detailed comparative studies of Pleistocene and Holocene stratigraphy on both flanks of this range and at both high and low elevations. But pending this, there are still some significant interpretations to be made from our observations. In fact, the very development of more precise teleconnectional evidence depends on one important relationship which has been elucidated by our investigations to date and to the authors' knowledge not recognized in any previous study. This is that the development of cool and moist conditions in the Alaskan coastal zone have been paralleled by development of approximately contemporaneous cool and slightly drier climatic conditions in the inland sectors of northern B.C. and the Yukon. Similarly, the development of warm and relatively drier oceanic climatic conditions on the coast appear to have prevailed at times when the interior areas experienced a trend toward relatively warmer and wetter climates. This out-of-phase characteristic demands careful scrutiny and analysis from a glaciological position.

GEOGRAPHICAL AND LATITUDINAL INDICES FOR OUT-OF-PHASE CLIMATIC TRENDS

To be understood these paradoxical secular trends require detailed comparison of the behavior of existing glaciers on opposite flanks of the range. The following conclusions derived from our study of glaciological regimes concern the past several centuries on the Juneau Icefield. They are first noted for clarification and then invoked as a reasonable explanation of the out-of-phase "anomaly."

The chief factors causing fluctuations of modern glaciers in the Alaska-Canada Boundary Range are: (1) cyclic changes in the level (elevation) of maximum snowfall; (2) periodic lateral shifting of storm paths; and (3) possible effects of changing temperature conditions within the ice. Taken in conjunction with known meteorological trends at some 70 weather stations on the north Pacific Coast, these interpretations are in agreement with the usual conditions associated with deglaciation in high latitudes, i.e. "warmer and wetter" conditions (v. Fig. 9, Time Interval I) accompanying a rise in temperature and "warmer and drier" conditions typifying the middle latitudes (Willett, 1965, p. 63). In contrast, conditions causing intense glaciation are generally colder and wetter (Time Intervals VII and IX). Thus over the past two centuries the general tendency in the Boundary Range has been towards deglaciation in the high latitude sense..i.e., a high latitude index.

"Warmer and drier" conditions in the last 200 years, and "cooler and wetter" conditions in the preceding 1,700 years, has been suggested by the pollen studies of Heusser (1952) in muskeg peat bogs of southeastern Alaska. Such is the condition expected in middle latitudes--i.e., a middle latitude index. This apparent difference between sea level areas and the presently glaciated sectors of the highland as well as at comparable latitudes in the interior region would appear to be intimately connected with secular shifts in storm belts. The problem as to whether more or less precipitation occurs at any one locality at any one time is, of course, a matter for special study and one which must always be integrated into the regional picture. We recognize the difficulties involved in a theoretical discussion without use of regional aerological data and also that there are likely other climatological aspects to be considered. Nevertheless, the general trend of changes indicated agrees with the field data concerning ice fluctuations in the névé areas of the present glacial position.

CONCLUSION

We conclude that the explanation of differences shown in the climatological characterization in the chronology of deglaciated terrain on opposite flanks of the Boundary Range relates to sensitive shifts of the arctic front across the range during late Pleistocene and Holocene time and to concomitant vertical changes in freezing levels, i.e. levels of maximum snowfall. The nature of short-term shifts has been considered in glaciological reports to involve 80 to 90 and possibly 180, 940 and 2,400-2,600 year recurrences (Miller, 1973, p. 182). But the geological and palynological techniques and other evidences upon which the chronology in Fig. 9 has been based are not as precise and won't permit a conclusive interpretation of such "cyclicity". There is, however, a hint of approximately 1,000 and 2,500 year interval spacings and a further implication that the pre-Neoglacial part of the Holocene might represent an 8,000 to 10,000 year "interglacial".

Our explanation of the opposing climatic characteristics found on opposite flanks of the Boundary Range still finds validity when referenced to the Little Ice Age regime changes of existing glaciers in the transitional zone of the Juneau Icefield. The results of our long-term glaciological research program (Juneau Icefield Research Program) have, therefore, served usefully to guide interpretation of the complex paleo-climatic correlations in the deglaciated sectors. The implications of these interpretations are great with respect to the comparison of paleo-climatological profiles in other regions where storm path shifts have had significant effects during the Pleistocene and Holocene. One such sector where this analytical approach should prove to be most useful is in the marginal zones along the southern periphery of the Laurentide Ice Sheet, across a large area of the Northern American continent; and indeed even in such areas as North Africa and Southern Europe and in Asia Minor and Mesopotamia where vast changes of climate have taken place over the past 15,000 years coincident with the rise of civilization.

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