Reports

A Possible Younger Dryas Record in Southeastern Alaska

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A stratigraphic record of climatic cooling equal in timing and severity to the Younger Dryas event of the North Atlantic region has been obtained from lacustrine sediments in the Glacier Bay area of southeastern Alaska. Fossil pollen show that a late Wisconsin pine parkland was replaced about 10,800 years ago by shrub- and herb-dominated tundra, which lasted until about 9,800 years ago. This vegetational change is matched by geochemical evidence for loss of organic matter from catchment soils and increased mineral erosion. If this event represents the Younger Dryas, then an explanation for a hemisphere-wide propagation of a North Atlantic climatic perturbation must be sought.

The Younger Dryas cold climatic interval about 11,000 to 10,000 ^{14}C years ago has been clearly documented at glacial and paleoecological sites in Europe (*1–3*), in North Atlantic sediment cores (*4*), and from Greenland ice cores (*5*). A plausible explanation is that the cold climate is the result of the temporary retreat of the unstable margin of the Laurentide ice sheet in western Ontario. Glacial retreat would have allowed meltwater from Glacial Lake Agassiz to pass through the Great Lakes and the Gulf of Saint Lawrence into the North Atlantic. Such a sudden influx of freshwater could have disrupted global thermohaline circulation and the northward transport of heat from the southern ocean (*6, 7*). Recent evidence from Maritime Canada (*8*) and a re-evaluation of late-glacial pollen sites from southern New England (*9*) indicate that a Younger Dryas event occurred there as well, and a distinctive stratigraphic reversal in the pollen percentages of spruce and other northern trees in Ohio indicates that the climatic effects extended upwind from the North Atlantic at least 10^2 to 10^3 km (*10*). In contrast, a Younger Dryas event is not apparent in the contemporaneous spruce forest between Nova Scotia and Ohio (*11*), presumably because vegetational ecotones were absent from the region at that time (*7*).

If the proximal cause for the Younger Dryas oscillation is related to North Atlantic events, then distant effects should not be anticipated, unless the North Atlantic perturbation were propagated around the globe by changes in general atmospheric-oceanic circulation. The search for a Younger Dryas record in distant areas has been diligent (*11*), but claims have been commonly challenged as being inadequately supported by dates or by paleoclimatic interpretations [for example, Markgraf (*12*) for southern Chile]. A minimum in the deuterium profile of the Vostok ice core from Antarctica is 1000 years too old, if the chronology based on an ice-flow model is correct (*13*). More recently, lake-level records of aridity in tropical and North Africa (*14*) and a humid phase in the Caribbean and Gulf of Mexico (*15*) that are coeval with the Younger Dryas indicate that varied climatic effects were felt well beyond the North Atlantic.

We have obtained a detailed lake-sediment climatic record from the Glacier Bay area in southeastern Alaska. Pollen and chemical stratigraphy suggest that a significant climatic reversal occurred in this region between about 10,800 and 9,800 years ago. The site is on Pleasant Island (58°21'N, 135°40'W) just beyond the limits of the Neoglacial ice advance, which was followed by the well-studied rapid ice retreat of the last 200 years (Fig. 1). The lake is located in Late Wisconsin drift at 150 m above sea level and is now bordered by a *Sphagnum* bog.

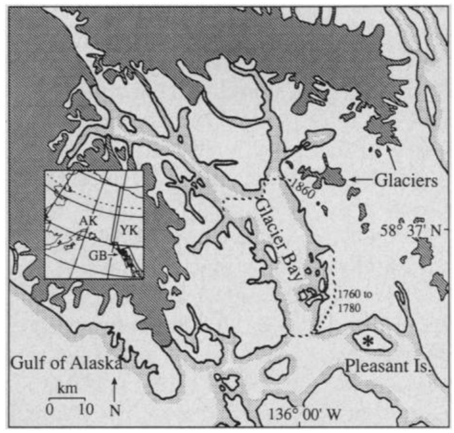

Fig. 1. The Pleasant Island core site in the Glacier Bay region of southeastern Alaska. Neoglacial ice margins are marked by dated isochrons. AK, Alaska; YK, Yukon; and GB, Glacier Bay.

The chronology of the late-glacial sediments from Pleasant Island was established on the basis of a series of six conventional radiocarbon dates on bulk organic sediments, four AMS (accelerator mass spectrometry) dates—three on conifer needles and one on an unidentified woody fragment—and an ash layer from the late Wisconsin eruption of Mount Edgecumbe (Table 1). Although the conventional ^{14}C dates are stratigraphically conformable, the bulk dates at 182 to 190 cm (10,110 ± 100 years ago), 244 to 252 cm (11,620 ± 120 years ago), and 262 to 268 cm (11,950 ± 120 years ago) differ from the adjacent AMS dates on conifer needles (9,080 ± 105, 11,040 ± 100, and 10,880 ± 95 years ago, respectively) by 800 to 1000 years (differences in core depths have been accounted for in this estimate). The error can probably be attributed to inputs of ^{14}C-depleted car-

Table 1. Radiocarbon dates in years ago from Pleasant Island lake sediments.

Lab number	Core depth (cm)	^{14}C date*	Corrected date†	Dated material
Beta-28340/ETH-4734	181 to 182	9,080 ± 105		Spruce needles
Beta-34582/ETH-6076	243	11,430 ± 120		Woody fragment‡
Beta-37238/ETH-6604	258	11,040 ± 100		Pine needles
Beta-37239/ETH-6605	264	10,880 ± 95		Pine needles
WIS-1947	182 to 190	10,110 ± 100	9,260	Organic sediment
WIS-2100	210 to 218	10,530 ± 110	9,680	Organic sediment
WIS-1948	244 to 252	11,620 ± 120	10,770	Organic sediment
WIS-1949	262 to 268	11,950 ± 120	11,100	Organic sediment
WIS-1950	276 to 282	12,280 ± 120	11,430	Organic sediment
WIS-1951	296 to 304	13,760 ± 120	12,910	Organic sediment

*The uncertainty limits represent 1 SD from counting statistics; AMS dates (Beta/ETH samples) are adjusted by ^{13}C for total isotope effects. †Conventional ^{14}C dates (all WIS samples) are corrected by −850 years on the basis of the AMS dates on conifer needles; an uncertainty of ±120 years is associated with this correction. The uncertainty in the corrected dates is therefore increased by this amount over that of the original dates. ‡Unidentified.

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bon from carbonate-rich tills in the catchment. We assumed that this reservoir or "carbonate" error was constant (850 years) during late-glacial times and the conventional dates were corrected accordingly. The corrected dates of 10,770 and 9,680 years ago delimit the timing of the Younger Dryas event.

We rejected the single AMS date on the unidentified woody fragment at 243 cm because it is 400 to 500 years older than the two AMS dates on identified pine needles from deeper in the core. The date on this unidentified fragment (11,430 ± 120 years ago) is indistinguishable from the adjacent conventional date on bulk organic sediment at 244 to 252 cm (11,620 ± 120 years ago), and thus the sample may have been contaminated by aquatic carbon or may have been reworked from older material in the catchment. The remaining AMS dates from identified macrofossils and the Edgecumbe tephra at 11,100 to 11,430 years ago constrain our chronology such that the corrected dates for the putative Younger Dryas event should not be in error by more than a few hundred years (*16*). There is still a similar level of uncertainty in the dating of the European Younger Dryas; compare Swedish radiocarbon chronology (*2*) and recent AMS ^{14}C dates from Ireland (*17*).

At the base of the core, willow, grasses, sedges, and ericaceous shrubs, all indicative of tundra vegetation, dominates the pollen sequence. Lodgepole pine (*Pinus contorta*) increases in sediments deposited about 12,200 years ago where it reaches 80% of total pollen, indicative of a well-stocked pine parkland or forest. Pine pollen decreases upward to 15% as alder (*Alnus crispa*, a shrub species) increases, and in 10,800 year old strata tundra pollen with abundant Ericaceae, grasses, sedges, *Artemisia*, Tubuliflorae, Apiaceae, Ranunculaceae, and *Sanguisorba* prevails again. Higher in the section, in strata dated at 10,000 years ago, the abundance of herbaceous pollen decreases as alder increases, and at about the 9400-year-old level replacement of alder by Sitka spruce (*Picea sitchensis*) and hemlock (*Tsuga mertensiana* and *T. heterophylla*) indicates that the area became fully forested. A possible short-lived vegetational response to the Edgecumbe ashfall, in which alder and herb pollen increase at the expense of pine, occurs at a level dated ~500 years older than the purported Younger Dryas event on Pleasant Island.

Stratigraphic changes in sediment chemistry indicate that soils are more inorganic where the pollen data show a return to tundra vegetation. Where tundra pollen are replaced by pine (12,200 years ago), the organic content of the sediment increases and the clastic component (as illustrated by Al_2O_3) decreases. These geochemical changes record the progressive accretion of soil organic matter and the concurrent decrease in mineral-soil erosion that accompanied the succession of tundra to conifer parkland (*18*). Higher in the core the chemical profiles show a marked reversal (~10,800 years ago) where sedimentary organic content decreases from 24 to 14% and Al_2O_3 rises from 6 to 7%. This geochemical shift implies that mineral erosion increased substantially and that local vegetational changes were sufficient to cause a pedogenic reversal during this period, which lasted until the time of reforestation about 9800 years ago.

The temporary return of tundra after full development of lodgepole pine parkland is as clear a response to climatic reversal as is apparent in any of the Younger Dryas sites in northwestern Europe. It is not contemporaneous with any known readvance of glaciers in the area or elsewhere in the Pacific Northwest, in strong contrast to Europe where glacial readvances are well documented (*3*). The Sumas readvance of the Puget lobe in southern British Columbia at 11,500 years ago is a tempting candidate for glacial response to climatic cooling , but the advance may have resulted from a reduction in the rate of calving as isostatic uplift brought the glacial terminus above sea level (*19*). Besides, the ice was already in retreat by 11,000 years ago (*20*). In southeastern Alaska a marine terrace on the Chilkat Peninsula, cut between 13,350 ± 100 and 9,220 ± 80 years ago, may represent the cessation of isostatic rebound related to a stillstand or readvance of Glacier Bay ice (*21*).

Additional palynological evidence for a Younger Dryas correlative in the Pacific Northwest is equivocal. Although most pollen records from Washington State and southern British Columbia do not show evidence of significant climatic changes during this time interval, a few show increases in mountain hemlock and other species (*22*); Rind *et al.* (*11*) suggested that these changes may represent evidence of a cooler or wetter climate. More convincing is a peat profile from Graham Island in the Queen Charlotte archipelago from which cooler summer temperatures between 11,000 and 10,000 years ago have been inferred by means of pollen-climate transfer functions (*23*). Peak values for mountain hemlock, a rise and sudden decline in spruce, and increases in grasses and sedges characterize this interval.

On the other side of the North Pacific, isotopic and micropaleontological records from high-resolution marine cores provide strong evidence for Younger Dryas type cooling near northern and central Japan (*24*). Here the return of subarctic foraminiferal assemblages with higher $^{18}O/^{16}O$ ratios than in preceding assemblages indicates that the polar front was displaced to the south between 11,000 and 10,000 years ago. However, pollen records from these marine cores and from the Japanese archipelago do not show the contemporaneous return of boreal vegetation that might be expected from the reappearance of colder waters offshore (*25*).

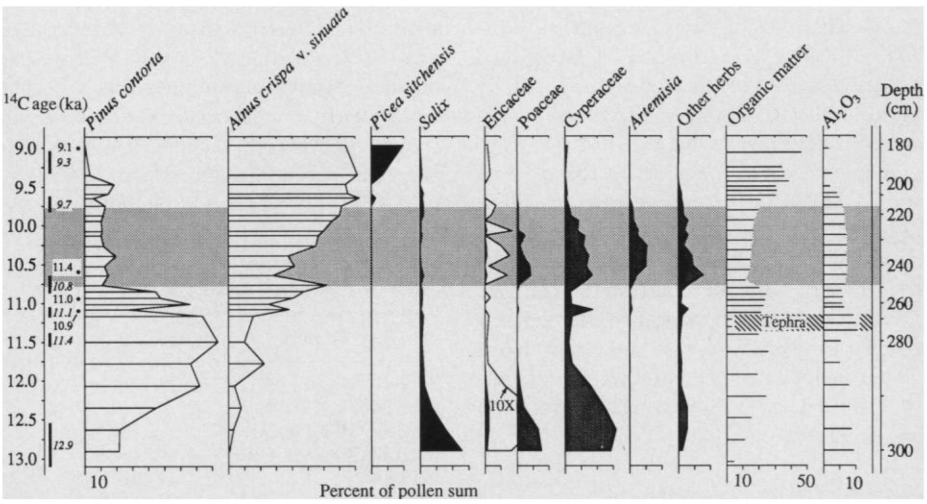

Fig. 2. Late Wisconsin pollen and geochemical profiles from Pleasant Island lake sediments. A possible Younger Dryas event is marked by the shaded zone. The ^{14}C time scale (1 ka is 1000 years before present) is corrected for carbonate error by the AMS dates (●); corrected conventional dates are shown in italics; the AMS date of 11.4 ka is rejected because of possible contamination. Core depth is measured from the sediment-water interface. Other herbs include Tubuliflorae, Apiaceae, Ranunculaceae, and *Sanguisorba*; a 10× exaggeration curve is shown for Ericaceae. Organic matter was measured by loss-on-ignition at 550°C, and Al_2O_3 by lithium borate fusion and DC plasma spectroscopy (*18*). Scale for organic matter is percent dry weight; Al_2O_3 is in weight percent.

The Pleasant Island sediment core provides a continuous record of late Wisconsin environments in southeastern Alaska but by itself does not demonstrate that the Younger Dryas occurred in this region. If a similar climatic signal can be found in lacustrine sediments from other sites in the area, then the existence of the Younger Dryas event will be established for the Pacific Northwest, and a mechanism will be required for transmitting this well-established North Atlantic climatic perturbation around the Northern Hemisphere, if not the globe.

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El Niño–Southern Oscillation Displacements of the Western Equatorial Pacific Warm Pool

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The western equatorial Pacific warm pool (sea-surface temperatures >29°C) was observed to migrate eastward across the date line during the 1986–1987 El Niño–Southern Oscillation event. Direct velocity measurements made in the upper ocean from 1986 to 1988 indicate that this migration was associated with a prolonged reversal in the South Equatorial Current forced by a large-scale relaxation of the trade winds. The data suggest that wind-forced zonal advection plays an important role in the thermodynamics of the western Pacific warm pool on interannual time scales.

The Southern Oscillation is a large-scale seesaw in atmospheric pressure between the eastern subtropical Pacific and the maritime land masses of Australia and Indonesia (*1, 2*). Pressure differences between these two regions drive easterly trade winds, which are the principal forcing function of tropical ocean circulation. The trade winds converge in the western Pacific in regions of deep atmospheric convection and high rainfall rates. A drier air mass then returns eastward aloft before descending in the subtropical high region of the eastern Pacific. Periods when the pressure is unusually high in the west and low in the east are associated with El Niño, an oceanic phenomenon characterized by weakened trade winds in the central and western Pacific and sea-surface temperatures (SSTs) that are warmer than usual from the coast of South America to west of the date line (*3*). El Niño–Southern Oscillation (ENSO) episodes occur on an irregular cycle of about 2 to 10 years, the most recent of which occurred in 1986 to 1987 (*4, 5*). Although the origins of ENSO may be traced to the tropics, its manifestations are felt worldwide through disruptions in the atmospheric general circulation and associated weather patterns (*1, 6*).

The western Pacific warm pool, defined by SSTs > 29°C, has recently taken on a special significance in ENSO studies (*7, 8*). The SSTs in the western equatorial Pacific are the highest in the world ocean. Such high temperatures lead to tremendous variability in deep convection because the ability of the atmosphere to hold water vapor increases nonlinearly with temperature (*9*). During ENSO, the warm pool and deep convection associated with converging easterlies are observed to migrate eastward across the date line. This migration of the warm pool has generally been attributed to wind-driven zonal current advection, on the basis of model studies (*7, 10, 11*) and empirical mass-balance studies (*12–14*). However, until recently there have been no direct current measurements west of the date line suitable for testing this hypothesis. In this report, we present moored and shipboard velocity measurements for 1986 to 1988 and show that the western Pacific warm pool is responding to current variations in a manner consistent with inferences drawn from models, theory, and earlier empirical studies.

To place these measurements in perspective, we review the broad outlines of air-sea interaction on ENSO time scales as discussed in the context of several simple coupled ocean-atmosphere models (*15*). In these models, warm tropical SST anomalies generate anomalous deep atmospheric convection fed by convergence of surface winds. This surface convergence leads to a significant weakening of the trade winds west of the warm SST anomalies. The ocean responds rapidly to this weakening: surface currents locally accelerate eastward, and

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