Evidence for a Younger Dryas–like cooling event on the British Columbia coast

Rolf W. Mathewes Department of Biological Sciences and Institute for Quaternary Research, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada

Linda E. Heusser Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964

R. Timothy Patterson Ottawa-Carleton Geoscience Centre and Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6, Canada

ABSTRACT

Two independent paleoclimatic records from the Pacific coast of Canada indicate that a late-glacial warming trend was interrupted by a return to colder conditions between about 11,000 and 10,200 radiocarbon yr B.P., correlative with the classical Younger Dryas chronozone of the North Atlantic region. Fossil benthic foraminifera from three cores from the continental shelf dated by accelerator mass spectrometry show peak abundances of the cold-water indicator species *Cassidulina reniforme* at this time. Fossil-pollen spectra from two sites on the Queen Charlotte Islands record a shift from forest to open, herb-rich vegetation after 11,100 yr B.P., probably in response to colder and wetter conditions identified by pollen-climate transfer functions. These preliminary data for a cold oscillation between ca. 11 000 and 10 000 yr ago in the northeast Pacific argue that this deglacial phenomenon was not restricted to the North Atlantic, but was a hemispheric—and possibly global—event.

INTRODUCTION

The brief but dramatic Younger Dryas cold interval between about 11,000 and 10,000 yr B.P. (radiocarbon years before 1950) is well documented in northern Europe and Atlantic Canada (Mott et al., 1986; Wright, 1989). There are also controversial suggestions of similar events outside the North Atlantic region (Rind et al., 1986). Confirmation of a Younger Dryas oscillation outside the North Atlantic region would have profound consequences in the search for a driving mechanism, because some models invoke processes restricted to the North Atlantic, such as meltwater surges from the St. Lawrence River or changes in the rate of formation of North Atlantic Deep Water (Broecker et al., 1988; Lehman and Keigwin, 1992). Confirmation of North Pacific cooling between 11 000 and 10 000 yr ago would thus demand a more global mechanism to account for such an event.

The report by Engstrom et al. (1990) of a palynological reversion of Younger Dryas age, involving vegetation change from forest to tundra at Glacier Bay, Alaska, is not the first from the Pacific Northwest. It has long been known that many pollen diagrams from near sea level in western Washington (Heusser, 1960, 1973, 1977) and from Marion and Surprise lakes (Mathewes, 1973) in southern British Columbia (Fig. 1) show isolated peaks in the abundance of mountain hemlock (*Tsuga mertensiana*) pollen near the Pleistocene-Holocene boundary. Mountain hemlock is characteristic of coastal subalpine vegetation at present, and the fact that it was formerly abundant near sea level indicates colder and wetter conditions in the past. On northern Vancouver Island (Fig. 1), peak values of mountain hemlock are present but indirectly dated at Bear Cove Bog (Hebda, 1983) prior to 9200 yr B.P. In a marine sediment core (END 87A-23; Fig. 1), pollen spectra from a late-glacial terrestrial surface dated at 10,400 yr B.P. also exhibit high values of mountain hemlock pollen, just prior to a marine transgression (Luternauer et al., 1989).

FORAMINIFERAL EVIDENCE

Core END 87A-23 and two others from the continental shelf were examined for fossil foraminifera (by Patterson) and ^{14}C dated by accelerator mass spectrometry (AMS; Fig. 2). For comparison with terrestrial dates, all marine shell ages were corrected for reservoir effects. The ocean surface-atmosphere reservoir difference for the early Holocene of this area can be estimated from dated wood-shell pairs (Southon et al., 1990) from the Queen Charlotte Islands and core END 87A-23. All marine shell dates were corrected by subtracting 730 yr from the reported values. This value is the rounded mean difference of 13 wood-shell pairs from the early Holocene; the mean age difference is 726 ±48 yr, and the range is 550–898 yr. In the North Atlantic, a typical correction for reservoir difference is −440 yr (Lehman and Keigwin, 1992).

The best record of ocean temperature comes from fossil foraminifera in core END 84B-04; peak abundance of the benthic cold-water indicator *Cassidulina reniforme* was between 11,070 and 10,170 yr B.P. This species is particularly abundant in cold waters of glacial or near-glacial regimes (Sejrup and Guilbault, 1980). *Islandiella norcrossi*, however, is typical of nonglacial environments, and it rose to maximum abundance at the end of the Pleistocene, soon after the *Cassidulina* decline in all three cores (Fig. 2). Other species whose abundances appear to be correlated inversely with *C. reniforme* are *Lobatula fletcheri*, *Epistominella vitrea*, and *Cribroelphidium excavatum*. The curves of these species indicate a pattern of tempera-

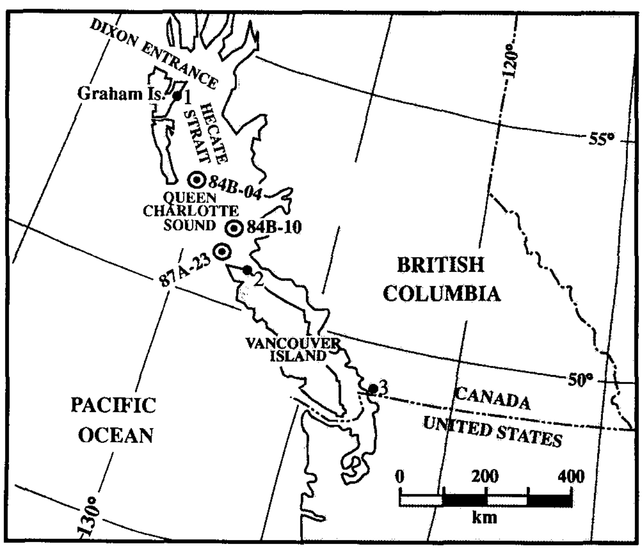

Figure 1. Map of Pacific Northwest showing study localities. Circled dots are marine sediment cores used for fossil foraminiferan analyses; numbered dots are important terrestrial pollen records mentioned in text; 1 is Cape Ball on Queen Charlotte Islands; 2 is Bear Cove Bog; 3 is Marion Lake.

ture change beginning with relatively warm waters prior to 11,290 yr B.P., followed by cooling to glacial or near-glacial conditions, and a return to warming by 10,170 yr B.P.

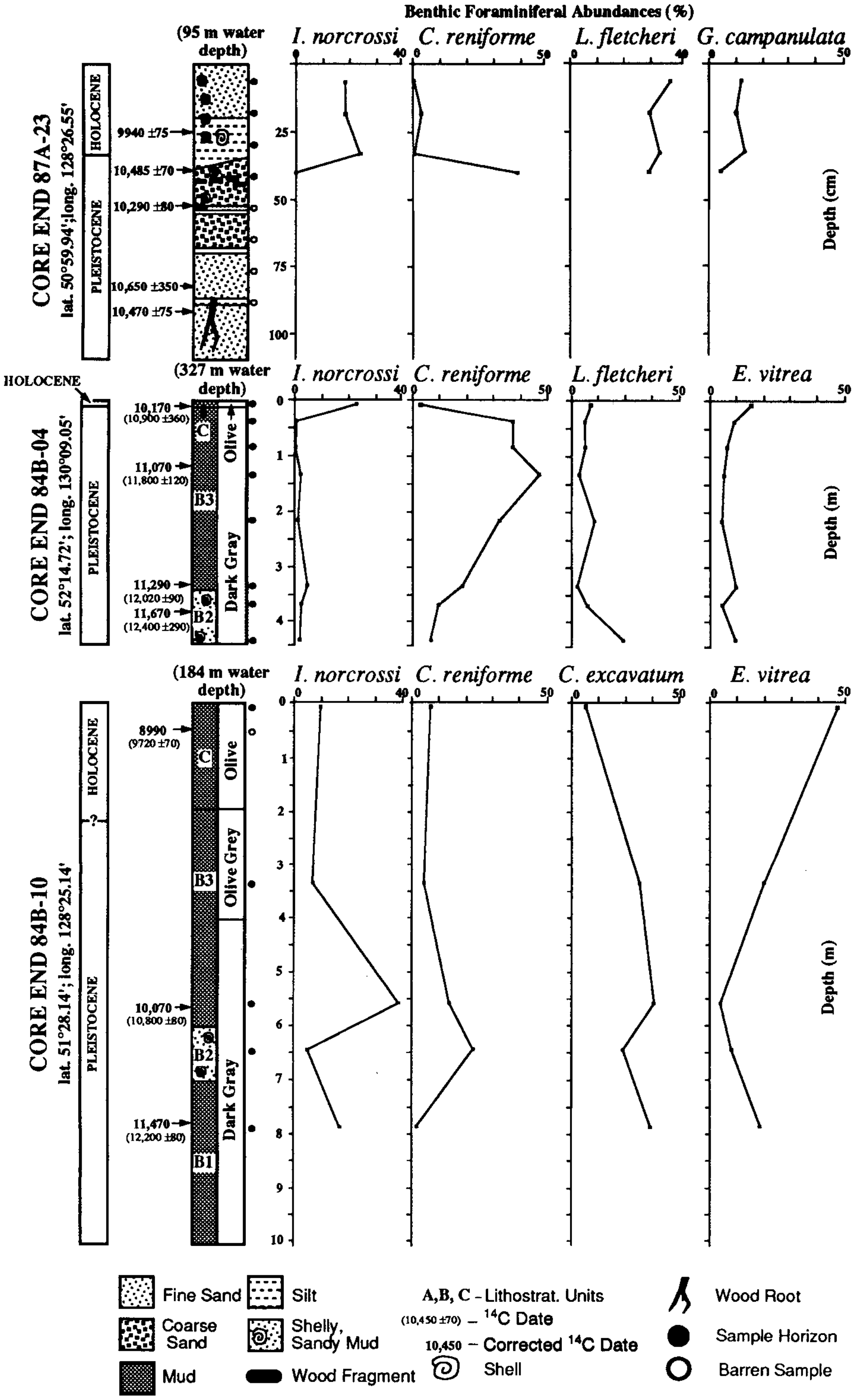

Figure 2. Stratigraphy, accelerator mass spectrometry (AMS) radiocarbon ages (error is one standard deviation), and relative abundances of selected benthic foraminifera from three marine sediment cores. Core END 87A-23 shows fossil terrestrial surface with rooted plant remains, overlain by transgressive marine sediments deposited after ~10,400 yr B.P. All ^{14}C ages are on wood or terrestrial plant detritus. Chronologies for cores END 84B-04 and 84B-10 use marine mollusc shells for AMS dating. These ages are corrected for reservoir effects by subtracting 730 yr from reported values (in parentheses) to make them comparable to terrestrial dates. Peak abundances of *Cassidulina reniforme* are best indicators for period of coldest water.

PALYNOLOGY AND PALEOCLIMATOLOGY

Pioneering palynological studies by Heusser (1955, 1960) on the northern Queen Charlotte Islands identified an early peak of mountain hemlock pollen in two long peat cores, suggesting late-glacial cool conditions. Subsequent studies of late-glacial pollen and plant macrofossils (Mathewes and Clague, 1982; Warner et al., 1982; Warner, 1984) from Cape Ball on Graham Island (Fig. 1) also identified vegetation changes that might reflect climatic fluctuations. Local pollen assemblage zone CBP-5 of Warner (1984) is particularly significant because it was defined by mountain hemlock pollen as well as pine and spruce and because it was estimated to have occurred between about 10,700 and 10,200 yr B.P. Because this time interval is within the classical Younger Dryas chronozone, confirmation of the chronology was needed by direct dating, and a critical assessment of the climatic significance of this zone was begun.

Figure 3 shows relative frequency changes in selected pollen types (Warner, 1984; Mathewes, 1989) at Cape Ball site 5. This is the oldest known postglacial pollen record in British Columbia (Warner et al., 1982), beginning at 15,400 yr B.P. The continuous presence of pollen of spruce, pine, and both western and mountain hemlock in the lower part of the herb zone at site 5 suggests the early presence of these tree taxa on the Queen Charlotte Islands (Heusser, 1989; Mathewes, 1989), although reworking from older Quaternary deposits cannot be ruled out, owing to very low absolute pollen abundances (Mathewes, 1989).

There is macrofossil evidence for local pine and spruce trees after 11,100 yr B.P., as peat began to form at this locality (Warner, 1984; Mathewes, 1989), but initial pollen percentages are low or erratic. Herb pollen was abundant, and grass (Poaceae) percentages increased sharply between 185 and 195 cm, suggesting an open conifer parkland rather than closed forest (Fig. 3). Pollen of the temperate western hemlock (*Tsuga heterophylla*) is not yet recorded, but mountain hemlock pollen is present, and reaches values of 4%. This species is usually underrepresented in pollen surface samples (Hebda, 1983; Peteet, 1986); pollen may be 4% in areas where mountain hemlock makes up ~40% of the tree cover (Hebda, 1983). Values up to 10% on the Queen Charlotte Islands generally define subalpine parkland and alpine tundra plant communities (Warn-

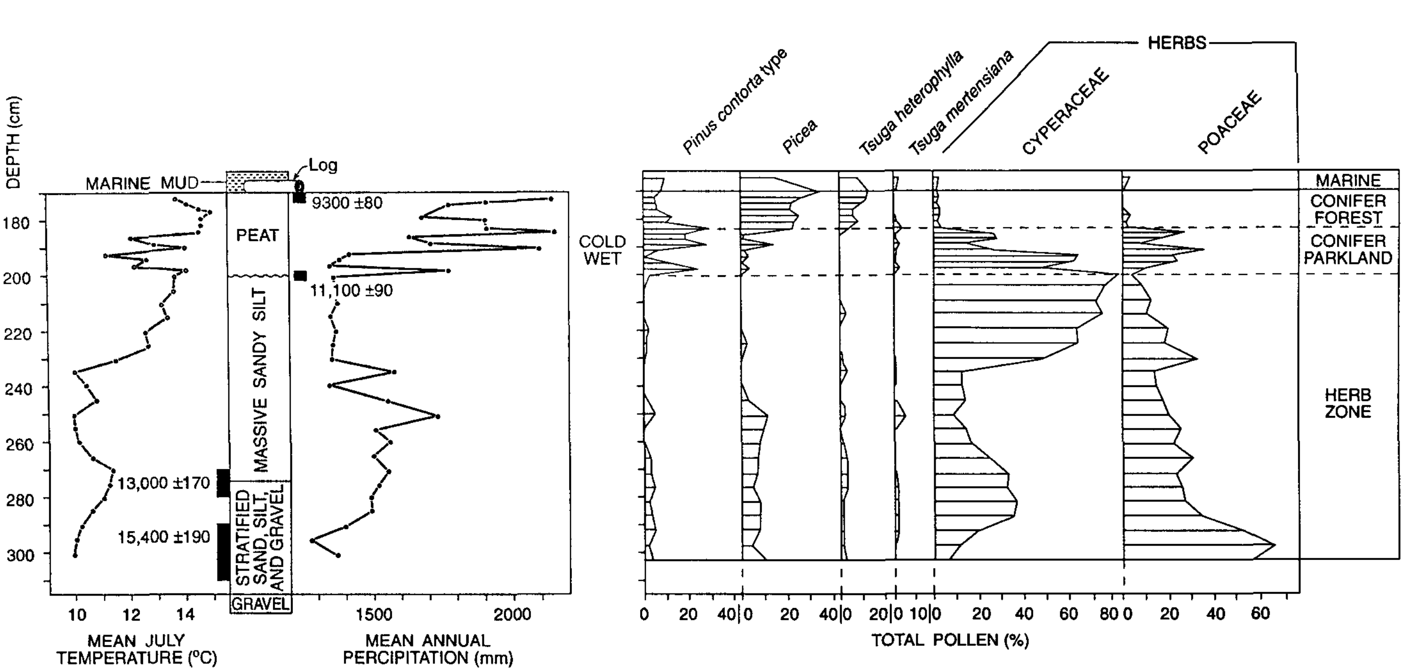

Figure 3. Terrestrial paleoclimatic reconstruction based on pollen-climate transfer functions from site 5 at Cape Ball (Queen Charlotte Islands), sea-cliff exposure of late-glacial and Holocene sedimentary strata. Grass (Poaceae) pollen is major predictor of temperature. Radiocarbon dates shown are on bulk organic materials, and stated error is two standard deviations. Abrupt drop in temperature curve at 11,100 yr B.P. marks beginning of cold and wet interval, similar in age to classical Younger Dryas event in North Atlantic region. Warming trend was reestablished by ~10,000 yr B.P.

er, 1984; Mathewes, unpublished data). Local presence of mountain hemlock is a good indication of cool and moist climatic conditions (Heusser, 1960; Hebda, 1983; Peteet, 1986).

Pollen counts for this locality were converted to paleoclimatic estimates (by Heusser) of mean July temperature and annual precipitation, using the calibration equations developed for the Pacific Northwest coast (Heusser et al., 1980). The transfer functions are based on climate data from 43 meterological stations and 13 pollen taxa from 178 coastal lowland surface samples. These represent modern coastal environments ranging from tundra on the Aleutian Islands to redwood forests of northern California. The standard errors for the equations are 1.1 °C (13%) for reconstructed temperature and 620 mm (19%) for annual precipitation. The main predictors of precipitation are western hemlock and pine pollen; grass, hemlock, and pine are the best predictors of temperature. The same equations have been applied previously to other Pacific Northwest pollen sequences (Heusser et al., 1980; Mathewes and Heusser, 1981; Heusser et al., 1985). They accurately reconstructed early Holocene warm and dry conditions (Mathewes and Heusser, 1981) that have been confirmed by subsequent study. These transfer-function results are a useful test for comparison with the marine foraminiferan record and with paleoecological analysis of fossil pollen.

In Figure 3, samples between 11,100 and ~10,200 yr B.P. (by interpolation of dates) show a drop of about 2–3 °C in summer temperature, as well as increasing precipitation, and are interpreted as indicating a cold and wet interval. Grass (Poaceae) pollen is one of the most important predictors of temperature, and its peak values in this interval match the coolest reconstructed temperatures. This makes ecological sense in light of the high factor loadings for grass pollen from coastal tundra-surface sample sites in Alaska (Heusser, 1985, p. 158). The high grass interval is followed by increases of spruce and western hemlock pollen, and by drastic declines in herb pollen, corresponding to renewed warming in the paleotemperature curve. The decline in reconstructed temperatures from this peat bed between ca. 11,100 and 10,200 yr B.P. represents the strongest deviation in temperature trends during the 15000 yr postglacial history of the Queen Charlotte Islands.

PALYNOLOGY AND DATING OF A SECOND SITE

To better resolve and date these changes, the older, thicker, and presumably more complete peat bed at Cape Ball site 6, about 4 km north of site 5 (Mathewes and Clague, 1982), was reinvestigated palynologically (by Mathewes, Fig. 4). Pine pollen (*Pinus contorta*) was abundant near the base of the section (~12,000 yr B.P.), and spruce (*Picea*) pollen did not increase until after 11,200 yr B.P. Pollen zones CB-2 and CB-3 are dominated by coniferous tree pollen both as percentages and as total pollen accumulation rates (20000–50000 grains $\cdot$ cm^{-2} $\cdot$ yr^{-1}). Spruce pollen peaked quickly, and declined suddenly at 10,730 yr B.P., to be replaced by sedge (Cyperaceae), grass (Poaceae), and other herbs (pollen zone CB-4, Fig. 4). A similar shift from tree or shrub to herb dominance is typical of many pollen diagrams linked to the Younger Dryas event (Mott et al., 1986; Rind et al., 1986; Engstrom et al., 1990). Zone CB-4 is suggestive of open conifer parkland growing under cool and wet conditions, with reduced pollen sedimentation (~10000 grains $\cdot$ cm^{-2} $\cdot$ yr^{-1}). Western hemlock was absent at this locality before ~10,200 yr B.P., when trace amounts of its pollen first appeared (Mathewes and Clague, 1982), and then increased rapidly to high levels that were maintained throughout the Holocene (Mathewes, 1989). Palynological differences between sites 5 and 6 are to be expected, because small basins 4 km apart will record local vegetation variations as well as regional trends. Differences in peat sedimentation rates and possible gaps in peat deposition could also cause palynological variations. The most important finding, however, is that reversion from early forest expansion to more open, herb-rich parkland vegetation is recorded at both sites, and this suggests a regional cooling event. A new radiocarbon date (10,730 ±60 yr B.P.; Beta-53849) at the spruce decline (and herb increase) suggests that the maximum cooling at Cape Ball occurred relatively late and lasted only about 500 yr. It may be significant that at one of the best dated Younger Dryas localities at Ballybetagh, Ireland (Cwynar and Watts, 1989), AMS dates indicate a sim-

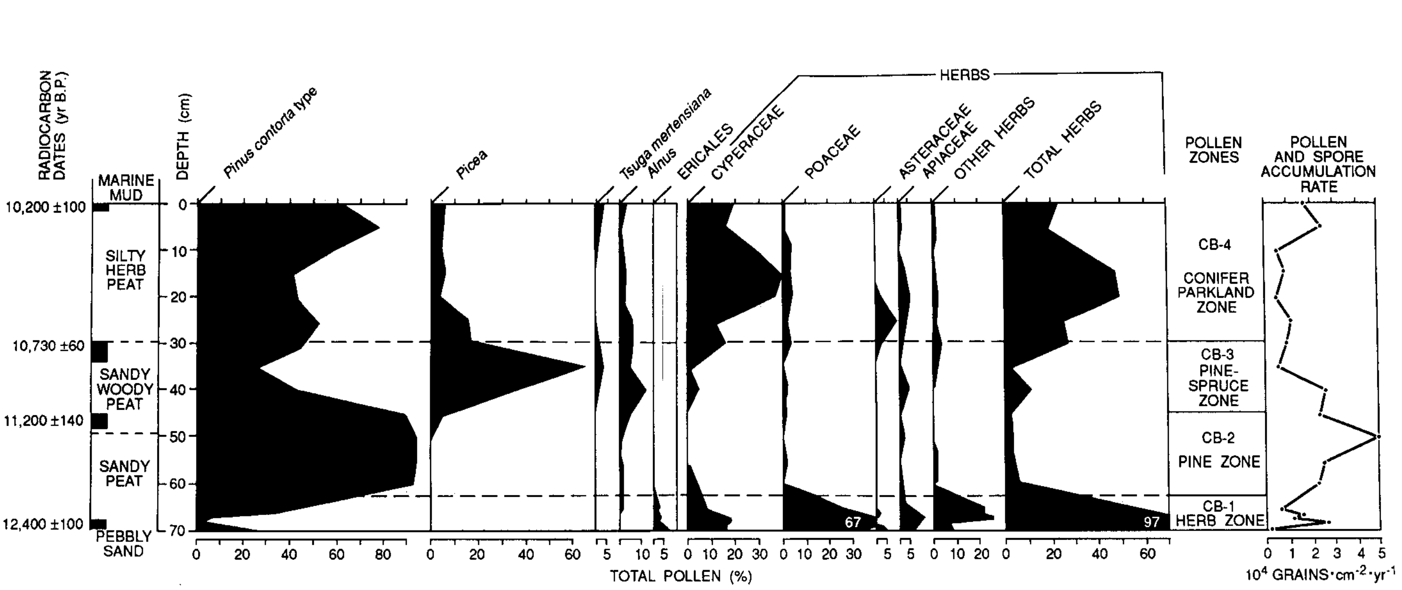

Figure 4. Pollen diagram from site 6 at Cape Ball (Queen Charlotte Islands), showing selected pollen frequencies, radiocarbon dates, and curve of pollen-accumulation rates. Pollen percentages recalculated from Mathewes and Clague (1982); spores were excluded from calculation sum. ^{14}C date (11,200 ± 140 yr B.P.; SFU-162) on 4-cm-thick slice of peat records initial rise of spruce pollen in zone CB-3. Subsequent decline in spruce and rise in total herb pollen during CB-4 are interpreted as representing cool and wet conditions between 10,730 ±60 (Beta-53849), and ~10,200 yr B.P., coeval with classical Younger Dryas cooling event.

ilar age between 10,600 and 10,100 yr B.P. for the classical Younger Dryas cooling.

SUMMARY

The findings reported here indicate that a cooling event similar in timing and effect to the classical Younger Dryas occurred on the Pacific Northwest coast. Because evidence is scanty, it is premature to speculate about details of possible driving mechanisms (Broecker et al., 1988; Harvey, 1989) for cooling in this area. The preliminary indications from our marine and terrestrial data support the view that both the ocean and atmosphere are involved, as in the North Atlantic. Furthermore, the maximum cooling on land appears to have occurred between 10,730 ±60 and ~10,200 yr B.P. on the Queen Charlotte Islands, correlating well with the timing of the Younger Dryas in Europe and eastern North America. Further paleoecological studies coupled with AMS dating are clearly necessary to confirm these results, which suggest that a hemispheric or global driving mechanism may be responsible for the observed cooling event.

ACKNOWLEDGMENTS

Supported by the Natural Sciences and Engineering Research Council of Canada and the Geological Survey of Canada. We thank J. Lutemauer for providing cores for foraminiferan analyses and B. Warner for raw data used in pollen calibration.

REFERENCES CITED

Broecker, W.S., Andree, M., Wolfli, W., Oeschger, H., Bonani, G., Kennett, J., and Peteet, D., 1988, The chronology of the last deglaciation: Implications for the cause of the Younger Dryas event: Paleoceanography, v. 3, p. 1–19.

Cwynar, L.C., and Watts, W.A., 1989, Accelerator-mass spectrometer dates from the bogs of Ballybetagh, Ireland: Quaternary Research, v. 31, p. 377–380.

Engstrom, D.R., Hansen, G.S., and Wright, H.E., Jr., 1990, A possible Younger Dryas record in southeastern Alaska: Science, v. 250, p. 1383–1385.

Harvey, L.D., 1989, Modelling the Younger Dryas: Quaternary Science Reviews, v. 8, p. 137–149.

Hebda, R.J., 1983, Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, B.C.: Canadian Journal of Botany, v. 61, p. 3173–3192.

Heusser, C.J., 1955, Pollen profiles from the Queen Charlotte Islands, British Columbia: Canadian Journal of Botany, v. 33, p. 429–449.

Heusser, C.J., 1960, Late-Pleistocene environments of North Pacific North America: American Geographical Society Special Publication 35, 308 p.

Heusser, C.J., 1973, Environmental sequence following the Fraser advance of the Juan de Fuca lobe, Washington: Quaternary Research, v. 3, p. 284–306.

Heusser, C.J., 1977, Quaternary palynology of the Pacific Slope of Washington: Quaternary Research, v. 8, p. 282–306.

Heusser, C.J., 1985, Quaternary pollen records for the interior Pacific Northwest coast: Aleutians to the Oregon-California boundary, *in* Bryant, V.M., Jr., and Holloway, R.G., eds., Pollen records of late-Quaternary North American sediments: Dallas, Texas, American Association of Stratigraphic Palynologists Foundation, p. 141–165.

Heusser, C.J., 1989, North Pacific coastal refugia—The Queen Charlotte Islands in perspective, *in* Scudder, G.G.E., and Gessler, N., eds., The outer shores: Skidegate, British Columbia, Queen Charlotte Islands Museum, p. 91–106.

Heusser, C.J., Heusser, L.E., and Streeter, S.S., 1980, Quaternary temperatures and precipitation for the north-west coast of North America: Nature, v. 286, p. 702–704.

Heusser, C.J., Heusser, L.E., and Peteet, D.M., 1985, Late-Quaternary climatic change on the American North Pacific coast: Nature, v. 315, p. 485–487.

Lehman, S.J., and Keigwin, L.D., 1992, Sudden changes in North Atlantic circulation during the last deglaciation: Nature, v. 356, p. 757–762.

Luternauer, J.L., Conway, K.W., Barrie, J.V., Blaise, B., and Mathewes, R.W., 1989, Late Pleistocene terrestrial deposits on the continental shelf of western Canada: Evidence for a rapid sea-level change at the end of the last glaciation: Geology, v. 17, p. 357–360.

Mathewes, R.W., 1973, A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia: Canadian Journal of Botany, v. 51, p. 2085–3103.

Mathewes, R.W., 1989, Paleobotany of the Queen Charlotte Islands, *in* Scudder, G.G.E., and Gessler, N., eds., The outer shores: Skidegate, British Columbia, Queen Charlotte Islands Museum, p. 75–90.

Mathewes, R.W., and Clague, J.J., 1982, Stratigraphic relationships and paleoecology of a late-glacial peat bed from the Queen Charlotte Islands, British Columbia: Canadian Journal of Earth Sciences, v. 19, p. 1185–1195.

Mathewes, R.W., and Heusser, L.E., 1981, A 12,000-year palynological record of temperature and precipitation trends in southwestern British Columbia: Canadian Journal of Botany, v. 59, p. 707–710.

Mott, R.J., Grant, D.R., Stea, R., and Occhietti, S., 1986, Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerod/Younger Dryas event: Nature, v. 323, p. 247–250.

Peteet, D.M., 1986, Modern pollen rain and vegetational history of the Malaspina Glacier District, Alaska: Quaternary Research, v. 25, p. 100–120.

Rind, D., Peteet, D., Broecker, W., McIntyre, A., and Ruddiman, W., 1986, The impact of cold North Atlantic sea surface temperatures on climate: Implications for the Younger Dryas cooling (11–10 ka): Climate Dynamics, v. 1, p. 3–33.

Sejrup, H.P., and Guilbault, J.P., 1980, *Cassidulina reniforme* and *C. obtusa* (Foraminifera), taxonomy, distribution, and ecology: Sarsia, v. 65, p. 79–85.

Southon, J.R., Nelson, D.E., and Vogel, J.S., 1990, A record of past ocean-atmosphere radiocarbon differences from the northeast Pacific: Paleoceanography, v. 5, p. 197–206.

Warner, B.G., 1984, Late Quarternary paleoecology of eastern Graham Island, Queen Charlotte Islands, British Columbia [Ph.D. thesis]: Burnaby, British Columbia, Simon Fraser University, 190 p.

Warner, B.G., Mathewes, R.W., and Clague, J.J., 1982, Ice-free conditions on the Queen Charlotte Islands, British Columbia, at the height of the late-Wisconsin glaciation: Science, v. 218, p. 675–677.

Wright, H.E., Jr., 1989, The amphi-Atlantic distribution of the Younger Dryas paleoclimatic oscillation: Quaternary Science Reviews, v. 8, p. 295–306.

Manuscript received June 29, 1992
Revised manuscript received October 26, 1992
Manuscript accepted November 10, 1992