DOE/EV/10097-1 file
4-16-80

Progress Report to the Department of Energy
(3/1/79 - 2/29/80)
on Contract No. 79EV10097 entitled:

"Global Temperature Patterns 6000 Years Ago"

MASTER

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INTRODUCTION

The overall goal of our research is to illustrate the climatic patterns of 5000 to 7000 years ago over as wide an area of the northern hemisphere as possible. We plan to map the patterns in selected climatic variables at 5000 to 7000 years ago that can be reconstructed from pollen and marine-plankton data. Multivariate statistical methods permit using the modern distribution of these data in order to transform their fossil remains into climate estimates of past times (Webb and Clark, 1977). Given these goals and methods, we focused our research during the first eight months on assembling the available modern and fossil data from each of the main areas under study. We also held two workshop conferences to help organize our joint work.

In producing the paleoclimatic reconstructions, we require maps of modern pollen and marine-plankton data, maps of the pollen and marine-plankton data for 5000 to 7000 years ago, and calibration functions capable of transforming the pollen or marine plankton data into climatic estimates. Maps and a preliminary set of calibration functions already exist for central eastern North America (Bernabo and Webb, 1977) and are being produced with other funds for northwestern Europe and the western Soviet Union. Our main effort with Department of Energy funding has therefore been to add new data, maps, and calibration func-

DISCLAIMER

tions to this core data base and to increase the coverage to as much of the Northern Hemisphere as possible. Our main areas of study so far have been eastern Canada, the North Atlantic Ocean, southern and eastern Europe, Alaska, and East Africa (Table 1). Subcontracts to H. E. Wright (University of Minnesota), W. F. Ruddiman (Columbia University), and H. J. B. Birks (University of Cambridge) supported the work in the first three of these additional areas.

SPECIFIC PROGRESS

During the first eight months of our work, we have made good progress in organizing the joint effort and in collecting new data from eastern Canada and from eastern and southern Europe. We have held two workshop conferences to review what data are available and to plan for their calibration and mapping. The first workshop was held at Brown University on July 20, 1979 and was attended by T. Webb, W. F. Ruddiman, A. McIntyre, W. L. Prell, J. E. Kutzbach, and F. A. Street. During this workshop, we discussed the available data from 5000 to 7000 years ago from Africa, the North Atlantic Ocean, the Indian Ocean, eastern North America, and the western United States.

The second workshop was the first annual gathering of the Northeast North American Palynologists held at the Harvard Forest in Petersham, MA from September 21 to 24, 1979. During this workshop, we reviewed the available pollen maps for 5000 to 7000 B.P. that H. J. B. Birks and B. Huntley have prepared for Europe, the available pollen data that G. M. Peterson compiled while recently in Moscow, the work of Ruddiman and McIntyre in the North Atlantic, and the available pollen data from eastern Canada and New England. An agreement was reached that the 10 major groups of palynologists working in eastern Canada and New England will send their raw pollen data (some unpublished) to Webb at Brown for key punching, analysis, mapping, and distribution. The group will meet again in September 1980 in Quebec to review the maps gained from this joint effort.

Work is now underway at Brown to map the pollen data from eastern Canada. Forty-one cores from southern Quebec and four cores from southern Labrador have so far been added to the Brown data bank for computer mapping and analysis. Initial maps from southern Quebec are currently being prepared. During year two, data from the rest of eastern Canada will be added to the current data set; and maps of pollen, of temperature estimates, and of air-mass patterns will be produced for 9000 and 7000 years ago and for today. The pollen maps from eastern Canada will greatly enlarge on those mapped by Bernabo and Webb (1977).

Work was also recently completed at Brown with funding in part from Lawrence Livermore Laboratory (Webb et al., 1979). In this work, we mapped the patterns in precipitation estimated for 7000 years ago at 26 sites in the central Midwest (Figs. 1 and 2). We also prepared an initial report on the data available from radiocarbon-dated pollen diagrams in the western United States (Fig. 3; Table 1).

R. A. Laseski, a graduate student at Brown, has been preparing a data set of 50 samples of surficial lake-sediments from East Africa. When complete, this data set will provide a basis for interpreting the available East African pollen diagrams (Kendall, 1969). This study will provide a few quantitative estimates of past climatic conditions in this critical yet poorly studied area.

P. Anderson, another graduate student at Brown, completed analysis of three pollen diagrams from the North Slope of Alaska (Anderson, unpubl. ms). She is currently analyzing data from three other cores collected in northwest Alaska in April, 1979.

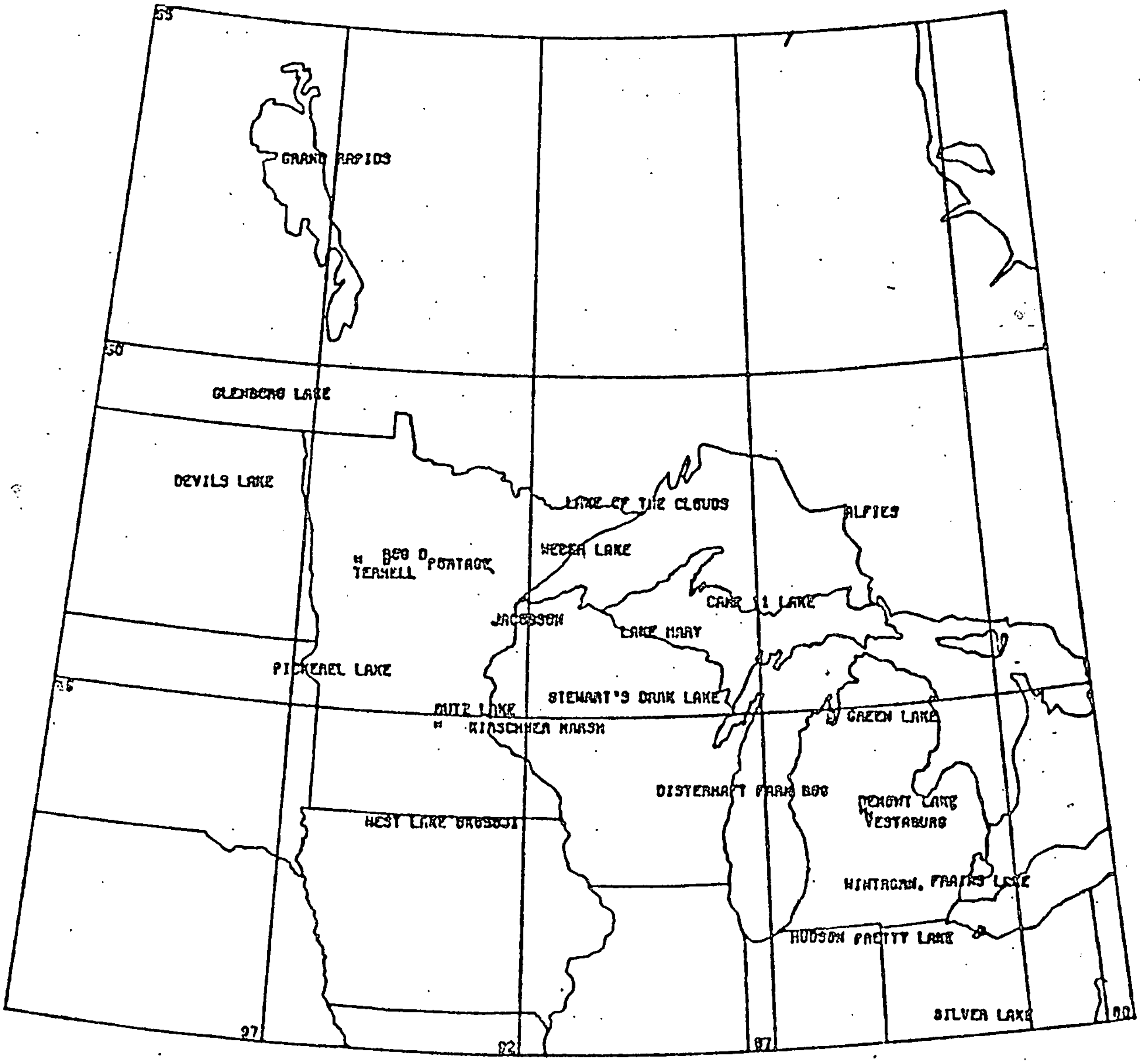

FIG. 1. Location of the 26 sites with radiocarbon-dated pollen data used in estimating annual precipitation at 7000 and 10,000 years ago.

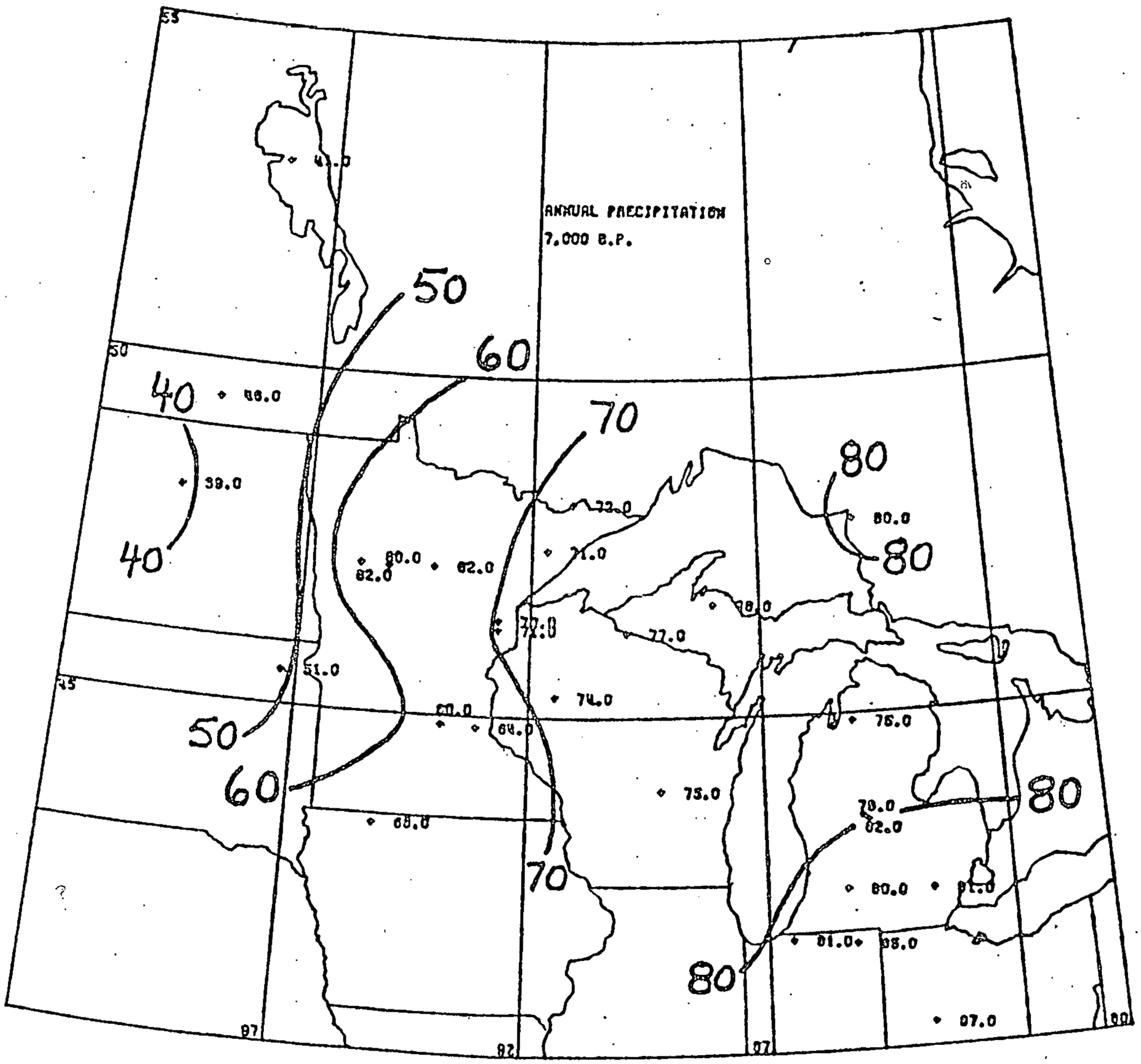

FIG. 2. The estimates of annual precipitation in cm for 7000 years ago.

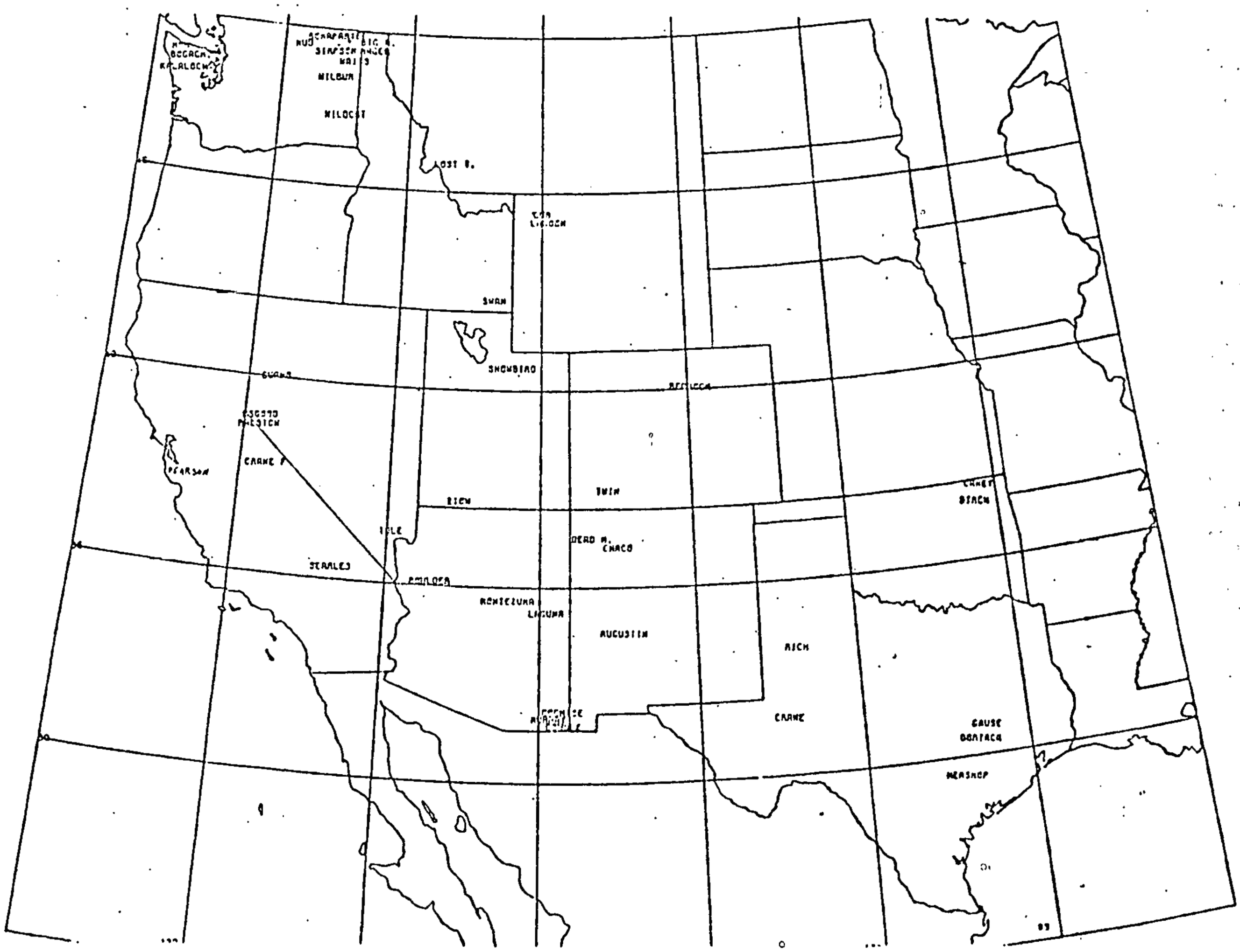

FIG. 3. Location of the sites with pollen data in the western United States. Only the data at Zion, Gause, and Boulder are not directly dated by radiocarbon dates. The first letter of each name is plotted at the sample location except where +'s mark the location for Ralston, Lagoon, Big M. (Big Meadow), Simpson, and Hoh.

Table 1. Western U.S. Pollen Diagrams: Notes on a Representative Group.

Site Name and Locality	Site Location and Elevation	Chronostratigraphic Information	The Site and Present Conditions	The Pollen Record and Interpreted Vegetation	Climatic Interpretation
C. Texas					
Hershop Bog	29°35'N 97°37'W 124 m	2002 ± 80 6006 ± 100 10,574 ± 160 from a 540 cm core. Max. age is ca. 11,000 B.P.	Domed-quaking peat bog. 155 m diameter, 5.4 m deep. Depends on seepage from Carrizo Fm.	Shift from 25% AP to 10% AP at 10.5K. AP = Oak and Birch. Change from Oak parkland to Oak savanna.	Drier conditions after 10.5K than before.
Larson, D.A., Bryant, V.M., Jr., and Patty, T.S. (1972). Pollen analysis of a central Texas bog. <u>American Midland Naturalist</u> 88, 358-367.					
Boriack Bog	ca. 30°30'N ca. 97°05'W ca. 100 m	3770 ± 80 9930 ± 160 14,115 ± 210 15,460 ± 250 from 540 cm core. Max. age is ca. 16,000 B.P.	1.4 hectare bog in Post oak savanna. Seepage from Carrizo sandstone Fm.	AP(*Alnus*) 70% from 16K to 8K, then Grass dominant. "Altithermal" period not well defined in pollen record.	Drier after 8K than before.
Bryant, V.M., Jr. (1977). A 16,000 year pollen record of vegetational change in central Texas. <u>Palynology</u> 1, 143-156.					
Gause Bog	ca. 30°50'N ca. 96°40'W ca. 90 m	No C-14 dates. Estimated to be older than 10,000 B.P. at base of 170 cm core.	3 ha. Bog formed in Corrizo Sands aquifer. *Sphagnum* on surface today. Located on western edge of Post Oak Savanna.	40% *Alnus* pollen up to 110 cm in core. Grass pollen dominates with 20% oak and 20% Composite pollen to surface.	Drier after 10K than before.
Bryant, V.M., Jr. (1977). A 16,000 year pollen record of vegetational change in central Texas. <u>Palynology</u> 1, 143-156.					
W. Texas					
Llano Estacado a) Rich Lake b) Crane Lake	a) 33°17'N 102°12'W 1000 m b) ca. 31°30'N ca. 20°40'W ca. 600 m	a) 17,400 ± 600 26,500 ± 800 at 125 cm and 350 cm levels in a 560 cm core. Max. age is possibly 33,000 B.P. Min. age (at top) may be no later than 15,000 B.P. b) No dates in 300 cm core of gypsum mud.	Llano Estacado is southern most extension of high plains with grassland and desert vegetation. a) Playa (dried up lake) today. No pollen in upper 40 cm. Llano Estacado Climate: Jan. Temp. = 2-7°C July Temp. = 25-28°C Ann. Precip. = 400-500 mm 8 surface samples	a) 26K - 33K: 15% *Pinus* pollen, 80% NAP. 26K - 17K: Gradual rise in % of *Pinus* pollen to 90% with 5% *Picea* after 17K to ca. 15K. Change from herb grassland to woodland. b) 3m - 2m = 90% *Pinus* pollen. 1.5 m to surface: 15% *Pinus* and 80% NAP.	26K - 15K: became wetter and colder than today. Postglacial time: dry like today. Some oscillations.
Hafsten, U. (1964). A standard pollen diagram for the southern high plains, USA, covering the period back to the early Wisconsin Glaciation. Report of VI INQUA, Warsaw, Vol. II: Paleobotanical Section, Lodz, 407-420.					

N. E. Oklahoma

Little Caney Alluvial Valley Copan area	36°56'N 95°56'W 218 m	69 ± 55 1981 ± 75 from a composite set of samples from archeological sites, eolian and alluvial deposits. Max. age is 1981 B.P.	Samples from several sections in valley where Little Caney R. has incised 6 m into its flood plain. Includes the Copan paleosol dated at 1330 ± 100 B.P. Located at transition from Cross Timbers post oak-blackjack oak (*Q. stellata* - *Q. marilandica*) forest to the west into the tall grass prairie to the east.	2K to 1K: 25% grass pollen, 20% *Ambrosia* 5% oak pollen. 1K - 69 B.P.: 20% Chenopod., 20% *Ambrosia*, 3% grass, 10% oak pollen. Modern: 30% oak, 10% hickory, 15% *Ambrosia* pollen. Interpreted that fewer oak trees in area at 1K to 2K than there today.	No interpretation given.

Hall, S.A. (1977). Geology and palynology of archeological sites and associated sediments. In "The Prehistory of the Little Caney River, 1976 Field Season." (D.O. Henry, Ed.) pp. 13-42, Laboratory of Archeology, Univ. of Tulsa, Tulsa OK, 141 p.

Birch Creek Valley Painted Shelter	36°32'N 96°08'W 212 m	1450 ± 80 at 55 cm in a 70 cm section from an archeological site. Max. age is ca. 1600 B.P. Age at top of section is ca. 600 B.P.	70 cm section from a rock shelter along a small stream in Cross Timbers postoak-blackjack oak forest. Tall grass prairie to the west and mixed prairie and oaks to the east.	Oak pollen dominates at 40 to 55%. 10% Ambrosia and 5% grass pollen. Slight rise in pine pollen %'s (2 to 6%) in upper 20 cm. Oak forest like today.	Climate like todays from 1600 to 600 B.P.

Hall, S.A. (1977). Geological and paleoenvironmental studies. In "The Prehistory and Paleoenvironment of Birch Creek Valley." (D.O. Henry, Ed.), pp. 11-31, Laboratory of Archeology, Univ. of Tulsa, Tulsa, OK, 134 p.

New Mexico

San Augustin Plains	33°50'N 108°00'W 2300 m	19,700 ± 1600 27,000 ± 4000 in upper part of 100 m core. 18,000 B.P. at about 600 cm. Max. age perhaps over 100K.	Core from playa in alkaline semidesert grassland. Ann. Temp. = 11.7°C Ann. Precip. = 407 mm	Very general pollen diagram. Last 10K = about 1.5 m. 20% *Picea* pollen 12 - 20% NAP, 60 - 70% *Pinus* pollen at 18K (ca. 6 m in core), 20% *Picea* pollen continues to 1.5 m when replaced by 20 - 30% semidesert scrub and grass pollen.	18K: Colder than present

Clisby, K.H. and Sears, P.B. (1956). San Augustin Plains -- Pleistocene climatic changes. *Science* 124, 537-539.

N. W. New Mexico

Chaco Canyon a) Gallo Wash b) Chaco Wash III c) Chaco Wash II d) Chaco Wash IV	36°01'N 107°53'W 1908 m	a) 2900 ± 330 5680 ± 120 6725 ± 110 5860 ± 700 Only bottom date from 635 cm section with pollen diagram. Other dates fitted in by correlation. b) No dates on 460 cm section. c) 1010 ± 90 at 75 cm in 410 cm section. d) 1025 ± 85 2170 ± 110 1655 ± 85 Top date fitted in by correlation in 240 section.	Sections of alluvial sediments in a modern arroyo that began eroding in 1860 A.D. 4 main alluvial units. Oldest dated at 5.6 to 6.7K. Pueblo Bonito excavations at Chaco.	7K - 6K: Pine zone with 60% pine pollen 6K - 1K: Chenopod. zone with 10% pine pollen, 50% Chenopod. pollen. 500K - 0: Pine- henop. zone with 40% pine pollen. Pinyon pine woodland today.	Climate arid from 5.8K to 2.4K and drier than today till 500 B.P.

Hall, S.A. (1977). Late Quaternary sedimentation and paleoecologic history of Chaco Canyon, New Mexico. Geological Society of America Bulletin 88, 1593-1618.

Chuska Mts. Dead Man Lake (3 other lakes studied but no dates for them)	36°15'N 108°55'W 2780 m	Three cores: 1) 3900 ± 300 date at 20 cm in 35 cm core that has younger sediments than the top of the long core. 2) 4 C-14 dates 19,400 to 28K in 810 cm core with 19.4K date at 160 cm.	12 hectare, 11 m deep lake at crest of mountains. Open *Ponderosa pine forest* around lake and down to 2250 m. Pinyon/juniper/sage to 1900 m, and steppe below that. Spruce/fir forest not in mts. today except in canyons above 2400 m; replaces P. pine in San Juan Mts. at 2900 m today. 6 surface samples. Ann. Temp. = 11°C Jan. Temp. = 1°C July Temp. = 25°C Ann. Precip. = 142 mm (at the nearest met. station).	5 pollen zones Core 1): before 4K: Picea and NAP decline. After 4K: Pinus pollen to 70%. 20% Chenop., 10% Artemisia pollen, 2% Quercus pollen. Evidence for compression and lowering of vegetation zones in glacial times. The alpine zone decreased in elevation more than the lower vegetation zones. Core 2): 65% NAP with 45% Artemisia, 10% Picea pollen from top to 28K. Alpine vegetation or spruce parkland Treeline depression of 8000 to 1000 m.	20K: Ann. Temp. 4 to 7°C lower than today. Climatic gradient up mountains was steeper than today. Postglacial: warmer than in glacial times.

Wright, H.E., Jr., Bent, A.M., Hansen, B.S., and Maher, L.J., Jr. (1973). Present and past vegetation of the Chuska Mountains, northwestern New Mexico. Geological Society of America Bulletin 84, 1155-1180.

Colorado

La Plata Mts. Twin Lakes	37°28'N 108°06'W 3290 m	11 radiocarbon dates from 2545 to 9765 B.P. in a 395 cm core. Max. date ca. 10,000 B.P.	Core from edge of small, 1 m deep pond. Open Engelmann spruce-subalpine fir forest at site which is 250 m below treeline. 4 surface samples. July Temp. = 11.4°C Jan. Temp. = 8.5 Ann. Precip. = 1063 mm Maximum precipitation in July and August. Lapse rate in July is 7°C/km.	Picea and Pinus dominance throughout, (60 to 80%). Use ratios of pollen types to estimate treeline fluctuations. 9.8 - 8.6 K: tree line lower than today. Several changes since then.	Tree line changes imply a fluctuating climate over last 10,000 years.

Petersen, K.L. and Mehringer, P.J., Jr. (1976). Postglacial timberline fluctuations, La Plata Mountains, southwestern Colorado. Arctic and Alpine Research 8, 275-288.

Front Range Redrock Lake	40°05'N 105°32'W 3095 m	7 radiocarbon dates from 1640 to 9760 B.P. in a 180 cm core. Max. date of ca. 10,000 B.P.	2.1 hectare, 1 m deep lake. Limber pine, Engelmann spruce, subalpine fir, and other trees and shrubs on the slopes about the site. Timberline at 3300 m.	10K - 9.7K: 60% Artemisia pollen 9.7K - 8K: 40% Pinus pollen. Peak in Picea pollen. 8K - 0: 50% Pinus pollen with a rise in Betula pollen after 2.5K: Picea/Pinus ratio used to plot elevation changes of vegetation.	Evidence for early warming and later cooling. Changing throughout last 10K years.

Maher, L.J., Jr. (1972). Absolute pollen diagram of Redrock Lake, Boulder County, Colorado. Quaternary Research 2, 531-553.

Arizona

Montezuma Castle National Monument Montezuma Well	34°39'N 111°48'W 1120 m	8 C-14 dates, 7 on modern material, 3 of these are 17K to 24.7K dates and date ancient carbonates.	1 hectare water-containing limestone-sinkhole fed by artesian spring waters. 10 m deep. 300 cm core from sedge-peat mat less than 1 m under water at edge of sink. 56 cm core from center of lake. In lower Sonoran vegetation zone with some Juniper and abundant grass.	56 cm core shows increase in NAP and deep water pollen types at 21 cm level.	Nature of change not clear.

Hevly, R.H. (1974). Recent paleoenvironments and geological history at Montezuma Well. Journal of the Arizona Academy of Science 9, 66-75.

E. Arizona

White Mts - Mogollon Rim Laguna Salada	34°21'N 110°17'W 1900 m	3500 ± 60 at base of 190 cm core from center of lake and 7250 ± 170 at 110 cm level of 290 cm section exposed in arroyo to west of present lake. Max. age is not well fixed. Could be as much as 14K.	Spring and arroyo-fed lake in 2 km² basins. Seasonally dry lake. Pollen samples from center of lake; exposed lake sediments in arroyo west of the present basin. Pinyon pine - Juniper grassland region (Savanna - woodland). Ann. Temp. = 8°C Jan. Temp. = 1°C July Temp. = 17°C Ann. Precip. = 637 mm Some surface samples.	Today: 25% Juniperus 20% Pinus, and 50% NAP. 4 pollen zones. 7K and earlier: 60 - 70% Pinus pollen. 7K - 5K: Grass peak of 10%. After 7K: increase in Chenopod. pollen to 50% at top of arroyo section.	Drier climate after 7K.

Hevly, R.H. (1964). Paleoecology of Laguna Salada. Chicago Natural History Museum Fieldiana (Anthropology) 55, 171-187.

W. Arizona

Hualapai Mts. Boulder Springs Shelter	35°06'N 114°08'W 976 m	No C-14 dates. Dating from pollen and ceramic analysis, 800 to 1050 B.P. for 100 cm of sediments. Max. age estimated at 1050 B.P.	Archeological site, rock shelter. Desert vegetation. Semiarid climate. Ann. Precip. = 270 mm	NAP dominated spectra with 15 to 20% _Ephedra_ pollen.	May indicate climatic fluctuations from summer dominate biseasonal rainfall to winter-dominated regime.

Hevly, R.H., Heuett, M.L., and Olsen, S.J. (1978). Paleoecological reconstruction from an upland Patayan rock shelter, Arizona. _Journal of the Arizona-Nevada Academy of Science_ 13, 67-78.

S. E. Arizona

Willcox Playa Lake Cochise	31°50'N 109°50'W 1290 m	20,000 B.P. 22,000 ± 500 23,200 ± 500 in 42 m core. All dates from 150 to 210 cm. Max. age is between 70K and 210K.	Desert grassland and shrubs in Willcox Basin today (_Hilaria_, _Bouteloua_, _Aristida_, _Sporobolus_, and mesquite). No plants on playa -- too salty. Ann. Temp. = 32°C (?) Ann. Precip. = 469 mm Ann. Evap. = 1550 mm	No pollen counted above 200 cm, except at surface. No postglacial record. 20K: 90 to 100% _Pinus_ pollen.	20K: colder and moister than today.

Martin, P.S. (1963). Geochronology of pluvial Lake Cochise, Southern Arizona. II Pollen analysis of a 42-meter core. _Ecology_ 44, 436-444.

Cochise County Double Adobe Sulphur Springs Site	31°28'N 109°42'W 1234 m	9 C-14 dates between 7756 and 9350 B.P. from a 280 cm and a 100 cm section. Max. age is ca. 9000 B.P.	Pollen diagrams from north and south wall of an archeological site. Pollen spectra from a mammoth tooth are included. Desert grassland today.	3 of 6 pollen zones are illustrated. NAP dominates with Compositae highest in zone IV before 8K and Chenopod. pollen up to 50% after 8K in zone I and III.	Martin argued that the "Altithermal" (8-4K) may have been moister than today. Final proof not in hand.

Martin, P.S. (1963). Early man in Arizona: the pollen evidence. _American Antiquity_ 29, 67-73.

San Pedro Valley Murray Springs	31°35'N 110°10'W 1292 m	7 radiocarbon dates from 1550 (unit E) to 8270 (unit A) in 315 cm section. Max. age ca. 8270 B.P. or younger since date on eroded peat.	Stratigraphic section from a tributary arroyo to the San Pedro River. In desert scrub vegetation. 8 stratigraphic units from basal A to upper H.	Chenopod pollen dominates at base in units A to D and units F to H and short-spine Compositae pollen dominates in the 95 cm of unit E. Unit B deposited in 500 years between 4000 and 5000 years ago. Vegetation zones lower by 300 m.	Authors argued that higher pine pollen (up to 10%) in unit B (4-5K) imply moisture conditions.

Mehringer, P.J., Martin, P.S., Haynes, C.V., Jr. (1966). Murray Springs, a mid-postglacial pollen profile from southern Arizona. Interim Research Report No. 13, Geochronology Laboratories, Univ. of Arizona, Tucson, 16 pp.

Utah

Wasatch Mts. Little Cottonwood Canyon Snowbird Bog	40°34'N 111°45'W 2470 m	5 C-14 dates from from 1870 to 12,300 B.P. in a composite profile of 2 profiles. Max. age of ca. 13,000 B.P.	375 to 450 cm thick bog over 1 - 3 m of Hogum Fork till (13 to 14K old). Bog section includes 7 forest-floor mats with spruce and fir needles and roots and 6 clay-loam units. Engelmann spruce and subalpine fir at site with Douglas fir, aspen, willow, and alder nearby.	Sediment stratigraphy suggests several bog-meadow/forest replacements. Local sequence, not seen in regional pollen. 13K - 8K: 40% sage and NAP, up to 30% alder pollen. 8K - 5K: 60% spruce and 20% pine pollen. 5K - 0: 15% sage, up to 40% alder with peaks in spruce.	Uses spruce/pine ratio and conifer/other pollen ratio to trace temp. and moisture changes. 13K - 8K: cool, dry 8K - 5K: warm, wet 3K - 0: cool, dry.

Madsen, D.B. and Currey, D.R. (1979) Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah. Quaternary Research 12, 254-270.

Zion National Park Beatty Lake, Paria Lake, Sentinal Slide Lake, Trail Canyon lava Lake, Coalpits lava Lake	ca. 37°10'N ca. 113°W 1280 - 1910 m		Preliminary report of some potentially interesting sites. Pollen records also preliminary.		

Hevly, R.H. (1978). Paleoecology of Holocene and Pleistocene lacustrine sediments from Zion National Park, Utah. First Annual Conference of Research in National Parks, A.I.B.S. Publication, 151-158.

S. E. Idaho

N. E. Great Basin Red Rock Pass Swan Lake	42°17'N 112°01'W 1450 m	1850 ± 200 10,190 ± 250 12,090 ± 300 in a 805 cm core (with pollen). Max. age is oldest date.	10 ha lake in outlet of Lake Bonneville when at its highest (1430 m). In Artemisia steppe. Pollen and plant macrofossil data. 6 surface samples. Jan. Temp. = 6°C July Temp. = 21°C Ann. Precip. = 400 m Snowfall = 1250 mm	7 pollen zones 12K - 10K: 65% *Pinus* pollen with 20% *P. flexilis* type, 10 - 25% *Artemisia* pollen. 10K - 0: 15% (5 - 30%) *Pinus* pollen and 20 to 50% *Artemisia*, 5% Ambrosia, 10% Gramineae pollen. 8.4K - 0: 20% Chenopod. pollen. 3.1K - 1.8K: 30% *Pinus* pollen, with 10% *P. flexilis*, rest is *P. contorta* type. L. Bonneville lower than 1430 m by 12K and possibly by 13K.	12K - 10K: colder than today. 10K - 0: like today or warmer except from 3.1 to 1.8K when colder.

Bright, R.C. (1966). Pollen and seed stratigraphy of Swan Lake, southeastern Idaho: its relation to regional vegetational history and to Lake Bonneville History. Tebiwa, The Journal of the Idaho State University Museum 9, 1-47.

Montana/Idaho

Bitterroot Mts. Lost Trail Pass Bog	45°43'N 113°56'W 2152 m	16 radiocarbon dates from 60 to 585 cm and 125 to 11,200 B.P. in 625 cm core. Max. age ca. 12,000 B.P.	2 hectare bog and meadow. In subalpine fir zone (1900 - 2900 m).	*Artemisia* zone to 11,500 B.P. *Pinus* pollen dominates since then (80%). Peaks in *Artemisia* pollen about 600 years ago.	11.5K - 7K cooler than today. 7K - 4K: warmer. 4K - 0: cooler with perhaps more moist interval 3.7 to 3.4K.

Mehringer, P.J., Jr., Arno, S.F., and Petersen, K.L. (1977). Postglacial history of Lost Trail Pass Bog, Bitterroot Mountains, Montana. Arctic and Alpine Research 9, 345-368.

N. W. Wyoming

Yellowstone Park Cub Creek Pond	44°28'N 110°14'W 2523 m	11,630 ± 180 14,360 ± 400 in 840 cm core with Mazama ash layer. Max. age is ca. 14,360 B.P. in an ash horizon.	Hodge pole pine dominates with some spruce and fir.	14K - 11.6K: Tree-line lower by 500 m with 30 - 40% <u>Artemisia</u> pollen and 10% Betula. 11.6K - 0: 80% <u>Pinus</u> mostly <u>P. contorta</u> type. 4.5K - 0: 5% more <u>Picea</u> pollen.	14K - 11.6K: Cooler climate. 11.6K - 4.5K: warmer and/or drier climate. 4.5K - 0: perhaps a little cooler.

Waddington, J.C.B. and Wright, H.E., Jr. (1974). Late Quaternary vegetational changes on the east side of Yellowstone Park, Wyoming. <u>Quaternary Research</u> 4, 175-184.

Yellowstone National Park Abandoned lagoon above Yellowstone Lake	44°30'N 110°20'W 2384 m	2,470 ± 250 5,390 ± 250 9,240 ± 300 11,550 ± 350 on a 950 cm core. Max. age is ca. 13,000 B.P. or older.	Vegetation today: <u>Pinus contorta</u> about site with <u>Picea engelmannic</u>, <u>Abies dasiocarpa</u>, and <u>Pinus albicaulis</u> on slopes just 30 m above the site. Treeline at 3015 m.	2 main pollen zones. Upper one with 3 subzones. ca. 13K - 11.6K: 30%. <u>Artemisia</u> pollen with some <u>Juniperus</u> and <u>Picea</u> pollen and 40% <u>Pinus</u> pollen implies alpine vegetation. More trees in upper part of zone. 11.6K - 0: <u>Pinus contorta</u> zone. 70 - 80% Pine pollen. <u>P. albicaulis</u> pollen high till 10K. 10K - 5K: mainly <u>P. contorta</u> pollen. Hiatus in sediments possible. 5K - 0: more <u>Picea</u> and <u>Abies</u> pollen (5%).	13K-11.6K: Colder than today. 11.6K - 10K: Cooler and drier than today. Annual temp. of -1°C or 1.5°C colder than today. 10K - 15K: warmest and driest. 5K and 2.8K: Cooler pulses perhaps tied to neoglaciation.

Baker, R.G. (1970). Pollen sequence from late Quaternary sediments in Yellowstone Park. <u>Science</u> 168, 1449-1450.

Nevada

Guano Cave Fishbone Cave	ca. 40°00'N ca. 119°30'W 1350 m	8 C-14 dates from 3200 to 15,760 B.P. in two series of samples from both caves. Max. age is dated by oldest date in 10 cm of lake silts at Level 6 of Fishbone Cave	Sections of cave deposits from caves in the desert. The caves were cut by a high stand of L. Lahontan. Ann. Temp. = 10.6°C Jan. Temp. = 0°C July Temp. = 23°C Ann. Precip. = 166 mm	Composite diagram made from different samples. Pollen stratigraphy is rough. 15K: 1 level with high <u>Pinus</u> pollen, rest high NAP. 7K to 2K or 0: Desert pollen types dominate, some rise in AP near top.	15K: mostly dry 7K - 2K or 0: Dry or drier than today.

Sears, P.B. and Roosma, A. (1961). A climatic sequence from two Nevada caves. <u>American Journal of Science</u> 259, 669-678.

S. Nevada

Mohave Desert Tule Springs	36°19'N 115°11'W 555 m	7480 ± 120 9000 ± 1000 12,400 ± 350 in 3 separate sections comprising a composite postglacial profile with some overlap from 12.4K to ca. 6.5K. Hiatus at site from ca. 12.4K to 22K, then 2 dates of 22.6K and 31.2K for the max. age at the site.	Pollen data from lake sediments. Some work associated with archeological sites. In Mohave Desert today with creosote bush and bursage. Ann. Temp. = 17.8°C Jan. Temp. = 6.4°C July Temp. = 30.6°C Ann. Precip. = 101 mm	12.5K: Dominance of <u>Artemisia</u> and <u>Juniperus</u> as occurs in N. Nevada today. 30% pine pollen, 15% <u>Artemisia</u> pollen. 12K: Gradual change to sagebrush and shadscale (<u>Atriplex</u>) as Chenopod. pollen rose to 60% and pine pollen decreased 15%. ca. 6.5K: 2% <u>Pinus</u>, 15% Chenopod., and 70% Compositae pollen: conditions like today.	12.5K: colder than today. 12K - 7.5K: trend toward warmer drier conditions with some short intervals that may have been wetter and cooler. ca. 6.5K: climate similar to todays.

Mehringer, P.J., Jr. (1967). The environment of extinction of the late-Pleistocene megafauna in the arid southwestern United States. <u>In</u> "Pleistocene Extinctions." (P.S. Martin and H.E. Wright, Jr., Eds.), pp. 247-266, Yale University Press, New Haven, CT.

Martin, P.S. and Mehringer, P.J., Jr. (1965). Pleistocene pollen analysis and biogeography of the Southwest. <u>In</u> "The Quaternary of the United States." (H.E. Wright, Jr. and D.G. Frey, Eds.), pp. 433-451, Princeton University Press, NJ.

California

Yosemite and L. Tahoe Areas a) Hodgdon Ranch b) Crane Flat c) Soda Springs d) Osgood Swamp	a) 37°45'N 119°52'W 1400 m b) 37°45'N 119°45'W 1850 m c) 37°50'N 119°20'W 2750 m d) 38°50'N 120°00'W 1980 m	a) No dates in 685 cm of stratigraphic section. b) 950 ± 70 1580 ± 80 2040 ± 100 in 275 cm section from an archeological midden. Max. age of 4000 B.P. possible. c) No dates in 138 cm core. d) 2830 ± 200 9900 ± 800 in 440 cm core. Max. age of 12,000 B.P. possible	Sites near Mono Lake. a-c) Sections from archeological sites. d) 300 m diameter lake,1 m deep water before artificially drained in 1963. 33 surface samples from 2 altitudinal transects.	d) 12K - 10K: 40% <u>Artemisia</u> pollen till 10K. 10K - 0: 70% <u>Pinus</u> pollen 2.8K - 0: Higher <u>Abies</u> and <u>Ericaceae</u> pollen.	End of glacial climatic conditions by 10K. Cooler after 2.8K.

Adam, D.P. (1967). Late-Pleistocene and recent palynology in the central Sierra Nevada, California. <u>In</u> "Quaternary Paleoecology", (E.J. Cushing and H.E. Wright, Jr., eds.), pp. 275-301, Yale University Press, New Haven, CT.

near L. Tahoe Ralston Ridge Bog	38°51'N 120°07'W 2580 m	1145 ± 90 1345 ± 95 2595 ± 85 Last date at base of 102 cm core. Max. age = 2595 B.P.	Bog is 250 m from crest of Sierra Nevada. Several small springs account for peat growth at site. Near Osgood Swamp (Adam, 1967).	Complacent pollen record with 60% Diplox. pine, 15% Haplox. pine, 25% <u>Tsuga</u>. 4 root horizons from 35 to 75 cm may indicate periods of relative dryness and decreased spring discharge. Two of these are dated by the 2 younger C-14 dates.	Drier at 1100 to 1300 B.P. than today or at 2500 B.P.

Sercelj, A. and Adam, D.P. (1975). A late Holocene pollen diagram from near Lake Tahoe, ElDorado County, California. <u>Journal Research U.S. Geological Survey</u> 3, 737-745.

San Francisco Peninsula Weeks Creek Pearson's Pond	37°21'N 122°15'W 365 m	1545 ± 85 2190 ± 85 3040 ± 95 in 210 cm core. Max. age is 3400 B.P.	Small pond in grassland and chaparral with redwood and mixed evergreen forests in stream valleys. Some marl in sediments. Ann. Precip. = 900 mm	20 to 40% TCT pollen (probably from <u>Sequoia</u>) in core. 3.4 - 3.0K: 10 - 20% <u>Pinus</u> and <u>Corylus</u> pollen but none from 3K to 0. Active record with Chenopod., <u>Quercus</u>, Gramineae, and TCT pollen. Human disturbance indicated by rise in % of Grass pollen in upper 30 cm.	Two wet intervals from 2.3 to 1.9K and from 13. to 1K.

Adam, D.P. (1975). A late Holocene pollen record from Pearson's Pond, Weeks Creek Landslide, San Francisco Peninsula, California. <u>Journal of Research, U.S. Geological Survey</u> 3, 721-731.

S. California

Searles Lake	35°17'N 117°20'W ca. 530 m	Well-dated from 12,730 to 21,200 in parting mud of organic lake sediments.	Pollen data from Upper Salt and Parting Mud in core L-31. Dried up lake bed located in SW corner of Basin Range province. Was part of a chain of lakes, those upstream in the high Sierras (e.g., Mono L., Adobe L.) connected by the Owens R. Desert scrub, bare areas and phreatophytes in basin today. Desert scrub to 1300 m on mt. slopes. Some <u>Ceanothus</u>, <u>Juniperus</u>, pinyon-juniper woodland above 2120 m in Panamint Mts. Ann. Temp. = 19.1°C Jan. Temp. = 8°C July Temp. = 30°C Ann. Precip. = 97 mm	Modern pollen: 35% woodland pollen (pine, oak, sage, juniper). 20% Compositae, 30% Chenopod. pollen. 23K - 10K: 75% woodland pollen types. 10K to top of Upper Salt unit: 50% woodland pollen types. Increased amounts of Chenopod., Compositae pollen. Oscillations in amounts of these pollen types.	Climate drier and warmer after 10K. Oscillations in climate in last 10K.

Leopold, E.B. (1967). Summary of palynological data from Searles Lake. In "Pleistocene Geology and Palynology of Searles Valley, California." Guidebook for Friends of the Pleistocene, Pacific Coast Section, 52-60.

Roosma, A. (1958). A climatic record from Searles Lake, California. <u>Science</u> 128, 716.

N. Idaho

Selkirk Range Hager Pond	48°36'N 117°58'W 860 m	12 C-14 dates from 2670 to 9510 B.P. for a 970 cm core with Mazama ash. Max. age is ca. 10,000 B.P.	Hemlock/<u>Pachistima</u> vegetation type 7°C in January 17°C in July 800 mm Ann. Precip. Peat since 2700 B.P. over lake sediment.	5 pollen zones. 50 to 80% pine pollen. Highest pine 10K to 8K and 6K to 0. 10% fir and hemlock since 2.5K.	10K - 8.3K: cooler, moister. 8.3K - 3K: warmer, drier 3K - 0: cooler, moister

Mack, R.N., Rutter, N.W., Bryant, V.M., Jr., Valastro, S. (1978). Reexamination of postglacial vegetation history in northern Idaho: Hager Pond, Bonner Co. <u>Quaternary Research</u> 10, 241-255.

N. E. Washington

Colville R. Valley Waits Lake	48°12'N 117°46'W 610 m	8 C-14 dates from 3530 to 11,950 B.P. in a 1060 cm core of calcareous sediments. Dates corrected using Mazama and Glacier Peak ashes. Mazama ash dated at 8K and 11.9K date 50 cm above 11.3K G.P. ash. Max. age is ca. 12,500 B.P.	180 hectare lake, core from its shore. Peat over gyttja and marl in upper 100 cm. Douglas fir/*Physocarpus* vegetation type.	50 to 75% Pine pollen throughout core. 15 to 20% *Artemisia* pollen until 5K. 75% Pine after 5K. *Alnus*, grass pollen also decrease at 5K. 4 major pollen zones. Modern climax forest of Douglas fir since 2.3K.	10K - 12.5K: cool, moist 6.7K - 10K: warmer 5K - 6.7K: drier 5K - 0: like today

Mack, R.N., Rutter, N.W., Valastro, S., and Bryant, V.M., Jr. (1978). Late Quaternary vegetation history at Waits Lake, Colville River Valley, Washington. *Botanical Gazette* 139, 499-506.

Selkirk Mts. Big Meadow	48°43'N 117°33'W 1040 m	8 C-14 dates from 1170 to 10,460 B.P. with Mazama ash in 1030 cm core. Max. age is earlier than 11,000 B.P., ca. 12,500 B.P.	Fen in glacially eroded trough, 55 km north of late Pindale limit. In hemlock (*T. heterophylla*) series or *Abies grandis* zone. Jan. Temp. = 5°C (1975) July Temp. = 21°C (1975) Ann. Precip. = 700 mm	5 pollen zones. Base to 10K: 25% sage pollen, 40% pine pollen. 6.5K - 0: 75% pine pollen. 2.4K - 0: Climatic climax of *Tsuga heterophylla*. (*Tsuga* pollen continuously above 2% after 3K).	9.7 - 3.3K: warmer than today.

Mack, R.N., Rutter, N.W., Bryant, V.M., Jr., and Valastro, S. (1978). Late Quaternary pollen record from Big Meadow, Pend Oreille County, Washington. *Quaternary Research* 59, 956-966.

Sanpoil R. Simpson's Flats	48°25'N 118°45'W 535 m	11 C-14 dates from 1970 to 10,010 B.P. in a 850 cm core with Mazama ash. Max. age is dated at 10,010 B.P.	A mire with 250 cm peat over gyttja with Mazama ash over marl. Within area of Fraser glaciation (19K to 10K). *Pinus ponderosa*/*Festuca* vegetation around site with *Pseudotsuga menziesii* in the valley. Jan. Temp. = 13°C July Temp. = 20°C Ann. Precip. = 400 m (at Republic, WA, 800 m)	4 pollen zones. NAP (*Artemisia* + Grass) 35% till Mazama ash. Diplox. *Pinus* pollen from 50 to 80% at 6.7K.	Climate warmer than today after 6.7K to 4K. Other climate changes possible but subtle

Mack, R.N., Rutter, N.W., and Valastro, S. (1978). Late Quaternary pollen record from the Sanpoil River Valley, Washington. *Canadian Journal of Botany* 56, 1642-1650.

Okanogan R. Valley a) Mud Lake b) Bonaparte Meadows	a) 48°37'N 119°31'W 655 m b) 48°46'N 119°04'W 1021 m	a) 5 C-14 dates from 8030 to 11,490 B.P. in a 500 cm core with Mazama and St. Helens Wn ashes. b) 14 C-14 dates from 1480 to 10,000 B.P. in a 633 cm core with Mazama (2 units) and St. Helens Wn ashes.	a) small pond, 890 cm of sediment with pollen analyzed in upper 500 cm. b) 112 hectare fen with 490 cm of peat over 143 cm of gyttja. Detailed study of Mazama ash shows two distinct ash falls (6.8 to 7K).	4 pollen zones. 11.5K - 10K: Haplox. pines and *Artemisia* dominant. 10K - 5K: Diplox. pines and *Artemisia* dominant. 5K - 0: Modern vegetation dominated by Douglas fir.	11.5K - 10K: cool 10K - 5K: warmer and drier. 5K - 0: less warm and dry.

Mack, R.N., Rutter, N.W., and Valastro, S. (1979). Holocene vegetation history of the Okanogan Valley, Washington. *Quaternary Research* 12, 212-225.

Mack, R.N., Okazaki, R., and Valastro, S. (1979). Bracketing dates for two ash falls from Mount Mazama. *Nature* 279, 228-229.

E. Washington

Columbia R. Valley Fen near Creston (Wilbur Bog)	47°45'N 118°32'W 763 m	9390 ± 480 Mazama ash and Glacier Peak ash in 245 cm core. Max. age is ca. 13,000 B.P.	Fen formed in depression left by "scabland" flood waters of glacial Lake Missoula (15 to 20,000 B.P.) Sage-grass (<u>Artemisia-Festuca</u>) vegetation type with ponderosa pine and aspen at the site.	2 pollen zones. Decrease in haplox. pine, spruce, fir, and <u>Artemisia</u> pollen at ca. 10K. Mainly treeless vegetation to 10K. Notes 10K date for frost polygon at Marmes Rockshelter, 140 km south of Creston.	Climate interpreted to be drier and warmer after 10K.

Mack, R.N., Bryant, V.M., Jr., and Fryxell, R. (1976). Pollen sequence from the Columbia Basin, Washington: reappraisal of postglacial vegetation. <u>American Midland Naturalist</u> 95, 390-397.

S. E. Washington

Snake R. System Wildcat Lake	46°48'N 118°10'W 340 m	400 ± 60 900 ± 70 in a 400 cm core with Mt. St. Helens W ash of 450 B.P.	1-3 ha., 1-3 m deep lake in channeled scablands. In grass steepe (<u>Agropyron-Festuca</u>) vegetation type. Ann. Precip. = 400 mm. 2/3 falls Nov. to April.	Pollen complacent from 1.1K to 40 cm level when pigweed pollen increases 5 to 30% and pine pollen decreases 60 to 20%.	No major climatic change in last 1000 years.

Davis, O.K., Kolva, D.A., and Mehringer, P.J., Jr. (1977). Pollen analysis of Wildcat Lake, Whitman County, Washington: the last 1000 years. <u>Northwest Science</u> 51, 13-30.

N. W. Washington

Olympic Peninsula 1) Hoh R. Valley a) Bog-Site 1 b) Bog-Site 6 2) Sea Cliff Peats near Kalaloch	1) 47°50'N 124°15'W a) 146 m b) 195 m 2) 47°35'N 124°20'W 3 to 35 m	1 a) 14 C-14 dates from 250 to 15,600 B.P. in a 580 cm core. Max. age is oldest date. b) 18,000 ± 800. 2) 14 C-14 dates from 16,700 to >47,000 B.P. in 26 m section.	1 a) 21 hectare bog near forest of western hemlock (<u>Tsuga heterophylla</u>) and western red cedar (<u>Thuja plicata</u>), with some Douglas fir (<u>Pseudotsuga menziesii</u>) and Sitka spruce (<u>Picea sitchensis</u>). Some 6 m high lodgepole pine on the bog. Several surface-sample sites. 1) Ann. Temp. = 9°C Jan. Temp. = 3-7°C July Temp. = 16°C Ann. Precip. = 2600 to 3200 mm. Measured lapse ratio of 6°C/km. 2) Exposed peats in sea cliffs in region of Pacific coastal forest.	1 a) 13K - 9K <u>Pinus Picea</u>, <u>Tsuga</u> pollen increase to replace NAP. 9K - 7K: <u>Alnus</u> pollen increase to replace <u>Pinus</u>. <u>Pseudotsuga</u> broad peak (10%) from 10K to 3K. 7K - 0: <u>Tsuga</u> pollen increase to replace <u>Alnus</u>. 3K - 0: <u>Thuja</u>, <u>Tsuga</u> pollen highest, <u>Picea</u> pollen lower. 2) 18K - 20K: 75% NAP. Tundra, treeline 1300 m lower.	18 - 20K: colder by 7°C or more than today. 8K - 6K: warmer than today by 2°C. 1K-100 years ago: colder than today.

Heusser, C.J. (1977). Quaternary palynology of the Pacific slope of Washington. <u>Quaternary Research</u> 8, 282-306.

Olympic Peninsula Bogachiel R. area	47°51'N 124°16'W ca. 200 m	20,100 ± 750 30,000 ± 800 in 275 cm bog section. Max. age is ca. 31,000 B.P.	Section from a bog just outside a moraine and the glaciated area. In cloud forest today with some tree flora as in nearby Hoh Valley. July Temp. = 15.4°C Jan. Temp. = 3.7°C Ann. Precip. = 2974 mm but only 120 mm falls in July and August.	Pollen stratigraphy for past 10K years much like that in Hoh Valley.	Climate changes similar to those in Hoh Valley.

Heusser, C.J. (1978). Palynology of Quaternary deposits of the lower Bogachiel River area, Olympic Peninsula, Washington. <u>Canadian Journal of Earth Sciences</u> 15, 1568-1578.

She will be using these data along with published data from Alaska and the Yukon to map the patterns in pollen data for 9000, 7000, 6000, and 5000 years ago.

The specific progress made by each of the subcontractors (Birks, Ruddiman, and Wright) is given in Appendices A to D. These short reports describe the compilation of data in Europe, the North Atlantic, and Labrador.

In Europe (Appendices A and B), Birks has prepared maps of the fossil pollen data from northwestern Europe on other funds. With D.O.E. money, he has prepared maps of the modern pollen data, and he has also added data from southern and eastern Europe. These will be used in calibrating the fossil data during the second year of this project.

In the North Atlantic (Appendix C), Ruddiman has mapped the location of the cores with radiocarbon dates and has presented a map of these cores with preliminary temperature estimates. He will be building upon this initial survey during the second year of this project, and he will also be adding what data are available from the North Pacific Ocean.

In Labrador (Appendix D), Wright and co-workers have collected cores and surface samples and are preparing these data to be added to the pollen data being compiled by Webb with cooperation of the other palynologists at the Workshop at Petersham. Wright's data fill a major gap in the network of eastern Canadian data and will allow mapping of this large sector of North America to proceed with a reasonably uniform data set.

In addition to this work, we were able to use Lawrence Livermore Laboratory funding to gain the help of F. A. Street from the University of Oxford. She produced a thorough literature review of lake-level data from the western United States and a preliminary mapping of the lake levels in the West from 24,000 years ago to present (Webb _et al_., 1979). She has also completed surveys of lake level data from Africa and other continents (Street and Grove, 1976, 1979) and has agreed to work with us to map the lake levels for 9000 and 7000 years ago in Africa, India, and the western United States.

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Street, F.A. and A.T. Grove, 1976. Environmental and climatic implications of late Quaternary lake-level fluctuations in Africa. Nature, 261: 385-390.

Street, F.A. and A.T. Grove, 1979. Global maps of lake level fluctuations since 30,000 yr B.P. Quaternary Research 12: 83-118.

Webb, T. III and D.R. Clark, 1977. Calibrating micropaleontological data in climatic terms: a critical review. Annals of the New York Academy of Sciences 288: 93-118.

Webb, T. III, F.A. Street, and S. Howe, 1979. Precipitation and lake-level changes in the West and Midwest over the past 10,000 to 24,000 years. Final Report prepared for Lawrence Livermore Laboratory, Livermore, CA, 102 pp.

APPENDIX A

Modern pollen maps for Europe: A progress report

by H.J.B. Birks and B. Huntley, The Botany School,
University of Cambridge, Cambridge CB2 3EA, England

As part of the project to map fossil pollen data and to derive quantitative temperature estimates for 6000 years ago in Europe it is necessary to assemble all the available present-day pollen data for Europe. These data, once mapped, can then be calibrated in terms of present-day climate to derive transfer-functions that express numerically the relationship between modern pollen and modern climate. By assuming that these functions are invariant in time, they can then be used to reconstruct past climate from fossil pollen data.

With financial support from the U.S. Department of Energy, maps of modern surface pollen have been prepared for northern and central Europe. The maps are based on published and unpublished data either from core-top samples or from surface samples. In both cases samples have only been included if they come from lakes or from bogs or fens large enough to reflect the regional rather than the local pollen rain. Pollen data from moss polsters from within woods have been excluded, although data from moss polsters from treeless vegetation (e.g., arctic tundra) have been included.

A total of 539 samples has been assembled, and pollen percentages for 55 taxa have been extracted and tabulated. The data base also includes information about the nature of the sample, whether it is lacustrine, bog, or fen, and, in the case of core-top samples, an indication of how reliably the sample can be associated with the present-day. Since the maps to be discussed here were drawn (July, 1979), further work has been undertaken in order to extend the data base to include southern and eastern Europe. This work is still going on, although it is now approaching completion. To date a further 51 samples have been added.

The surface pollen maps which have been prepared were drawn for 49 taxa using all sites; and then, for the 18 most abundant taxa maps, were prepared separately using lacustrine sites only and terrestrial sites only. The values plotted on the maps are pollen percentage values based either on the sum of tree and shrub pollen for woody taxa or on the sum of all terrestrial pollen for non-woody taxa. In the few cases of pteridophyte or bryophyte taxa, the sum used is the sum of all terrestrial pollen plus the individual spore taxon. The sum of tree and shrub pollen is used for woody taxa in order to eliminate the effects of local non-woody types such as Cyperaceae and Ericaceae, and also partly to eliminate anthropogenic influence on the vegetation as it is reflected by weeds, cereals, Gramineae, etc.

Taken individually the surface-sample maps give firstly phytogeographical information relating to the distributional ranges of the taxa, and secondly they give information about the patterns of abundance of the taxa. For example, *Abies* (fir) pollen (Fig. 1) is clearly limited in its distribution to the present range of trees in the major mountain chains of Europe, with its highest pollen values in the Alps and Carpathians. *Picea* (spruce) pollen (Fig. 2) contrasts with this, having a wider distribution around the Central European mountains and also a wide area of occurrence in boreal areas of north-eastern Europe and Scandinavia. It too reaches its highest pollen values in the Alps and Carpathians but also has high values in the mountains of Sweden and Norway. *Quercus* (oak) (Fig. 3) contrasts with both of these, being a thermophilous, deciduous tree, and is found throughout much of Europe except Scandinavia. It has, however, wide areas in which its pollen is found only sparsely and it shows a clear pattern of greater pollen abundance in the northwestern part of the European mainland and southern Britain.

These varying patterns of distribution and abundance can be related to the spatial distributions of the formations of forest vegetation described by ecologists and plant sociologists. These formations, in turn, can be related in broad terms to the existing climatic patterns in Europe. In general the maps for non-woody taxa are less easily interpretable although some important patterns emerge. Thus Ericaceae (Fig. 4) pollen is most widely distributed and most abundant along the western seaboard of Europe while Chenopodiaceae (Fig. 5) and Artemisia (Fig. 6) pollen are present in greatest abundance in the area of the south-east European Steppe.

Comparison of the maps based on lacustrine and terrestrial samples only revealed no important differences, supporting our use of both types of sample in the overall data set.

In order to summarize the combined information present in the maps for the woody taxa, principal components analyses were carried out using the 28 woody taxa with maximum values 2% or with non-zero values in 8 sites. The results of these analyses were displayed by plotting maps of the component scores of the sites for the first 6 axes of the analyses. Two analyses were carried out using firstly a correlation matrix of uncorrected pollen percentage values and secondly a covariance matrix of pollen values transformed initially using the correction factors proposed by S. Th. Andersen and J. Iversen for Europe.

The results of the two analyses differed in a predictable way with the first analysis dominated by rare taxa while the second gave a more useful picture. The axes extracted in this case related to the broad vegetational patterns in northern Europe. They showed the modern pollen data could clearly discriminate tundra, coniferous forest, and deciduous forest, and further to be capable of discriminating Alpine from Boreal coniferous forests and of distinguishing eastern and western European facies within the deciduous-forest zone. Thus both north-south and east-west vegetational gradients were clearly and unambiguously identified within the surface pollen data.

Because these broad vegetational patterns are generally assumed to be related to the broad patterns in climate, these results suggest that some relationship between surface pollen spectra and climate can be established for Europe.

The expansion of the data base to include southern and eastern Europe will extend the cover of samples to include the Mediterranean forest zone and the western edge of the steppe region. It is hoped that analysis of this data set, when complete, will show that these vegetational units can also be distinguished by their modern pollen spectra.

Further work is now planned using all available climatic data from Europe to calibrate the surface pollen data in terms of major climatic variables. It will then be possible to experiment with paleoclimatic reconstructions for 6000 B.P. based upon these calibrations.

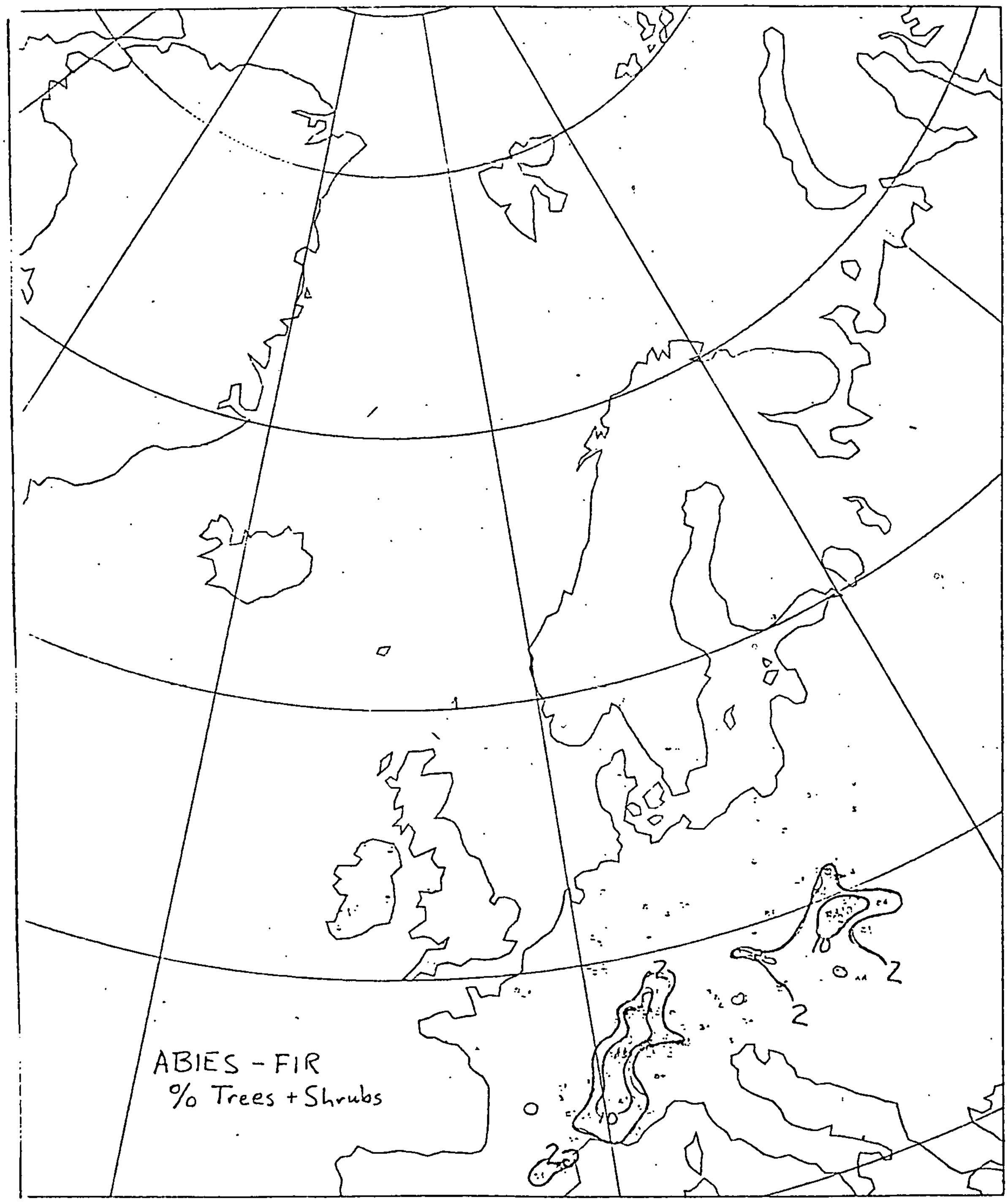

Figure 1. Contemporary distribution of fir pollen plotted as a percent of all tree and shrub pollen counted in samples of surficial lake-sediments and peats.

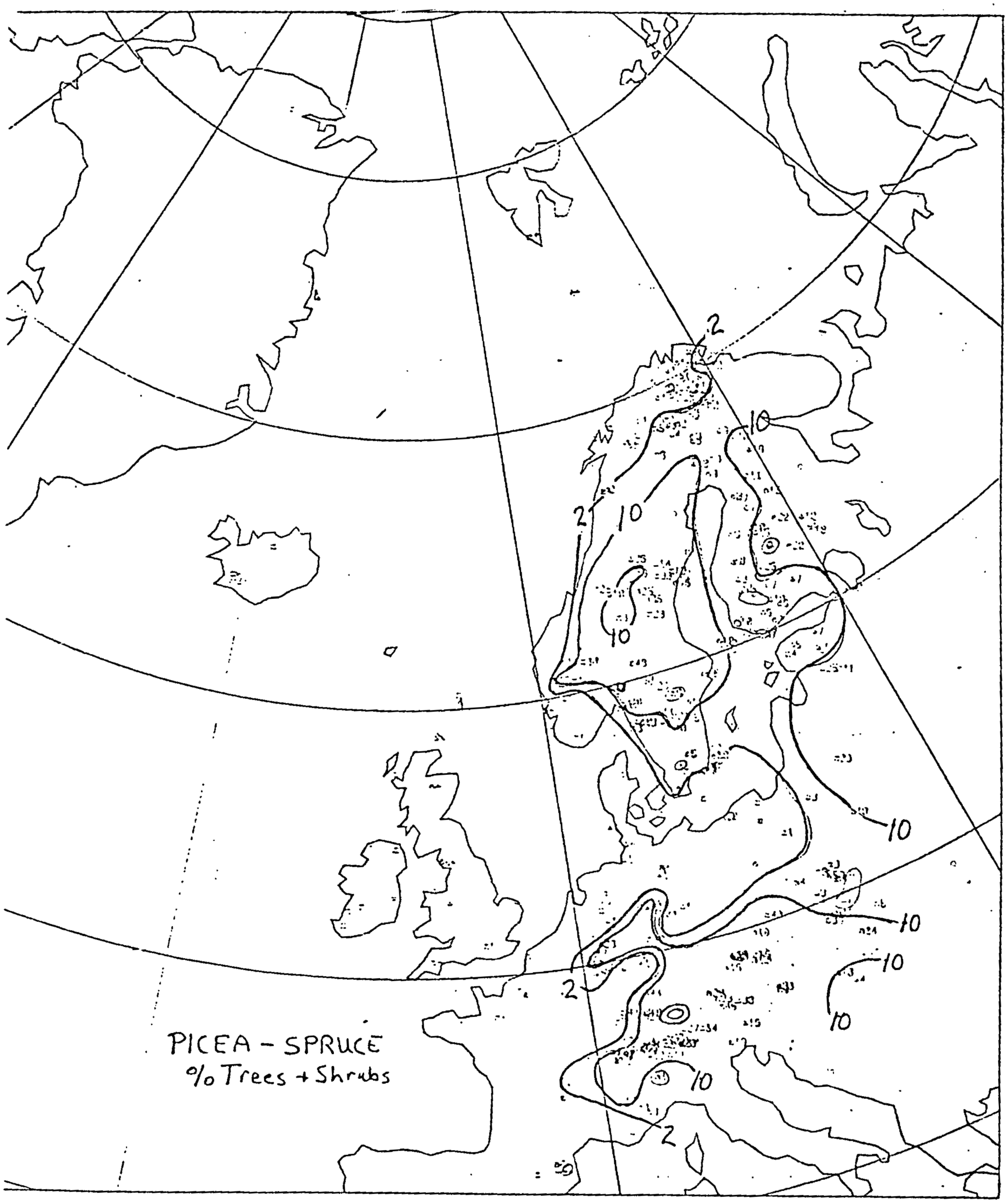

Figure 2. Contemporary distribution of spruce pollen plotted as a percent of all tree and shrub pollen counted in samples of surficial lake-sediments and peats.

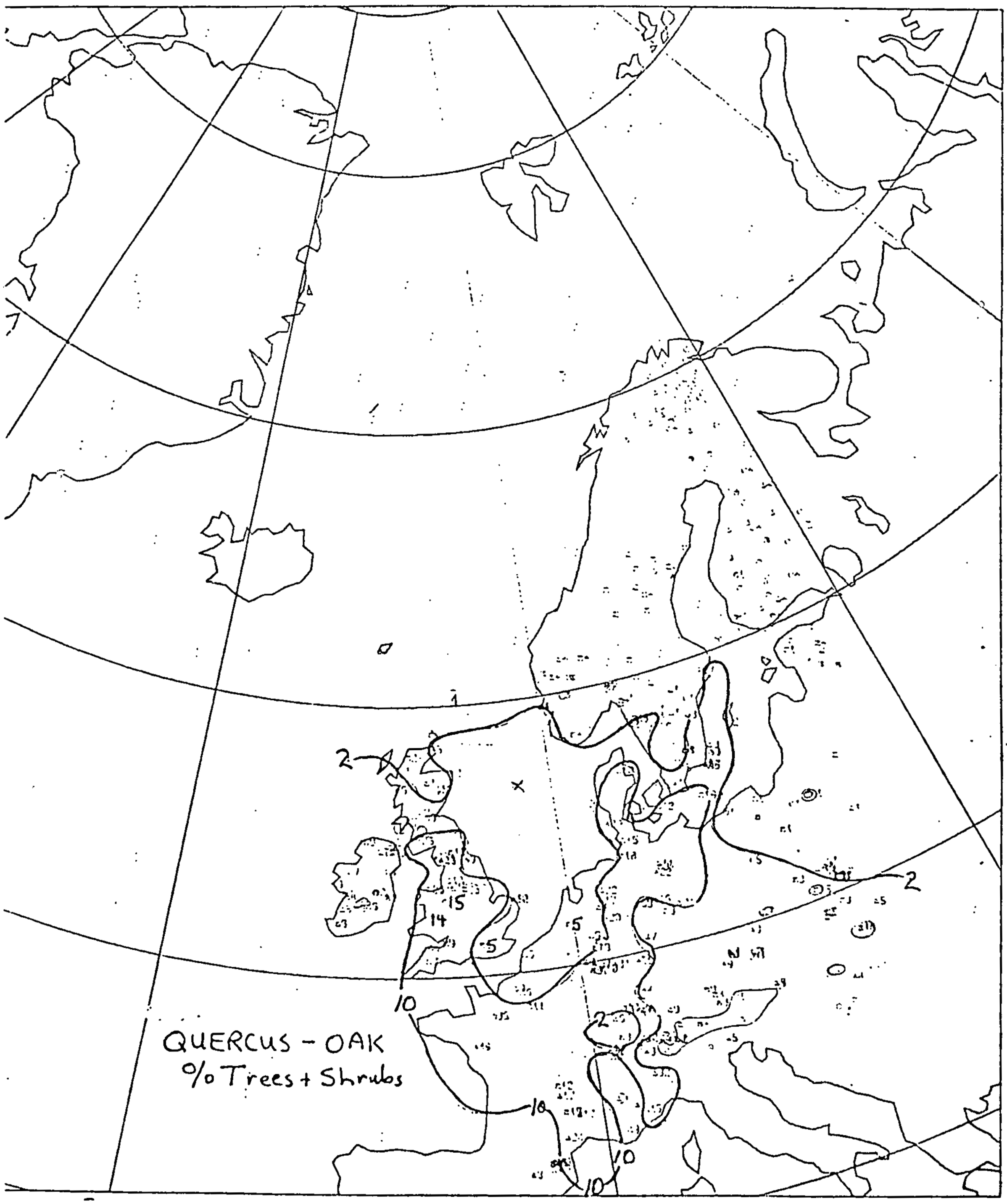

Figure 3. Contemporary distribution of oak pollen plotted as a percent of all tree and shrub pollen counted in samples of surficial lake-sediments and peats.

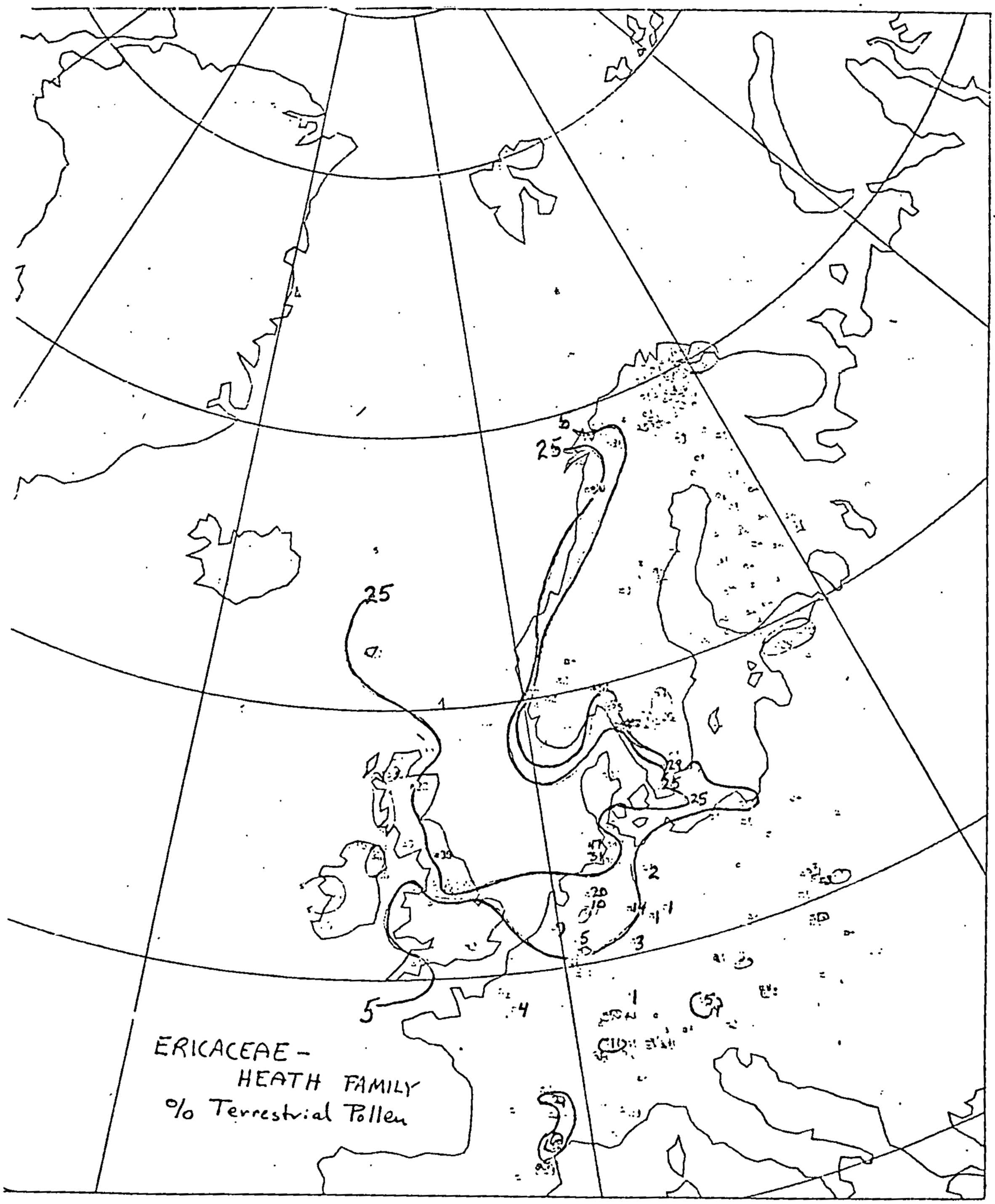

Figure 4. Contemporary distribution of heath pollen plotted as a percent of all terrestrial pollen types counted in samples of surficial lake-sediments and peats.

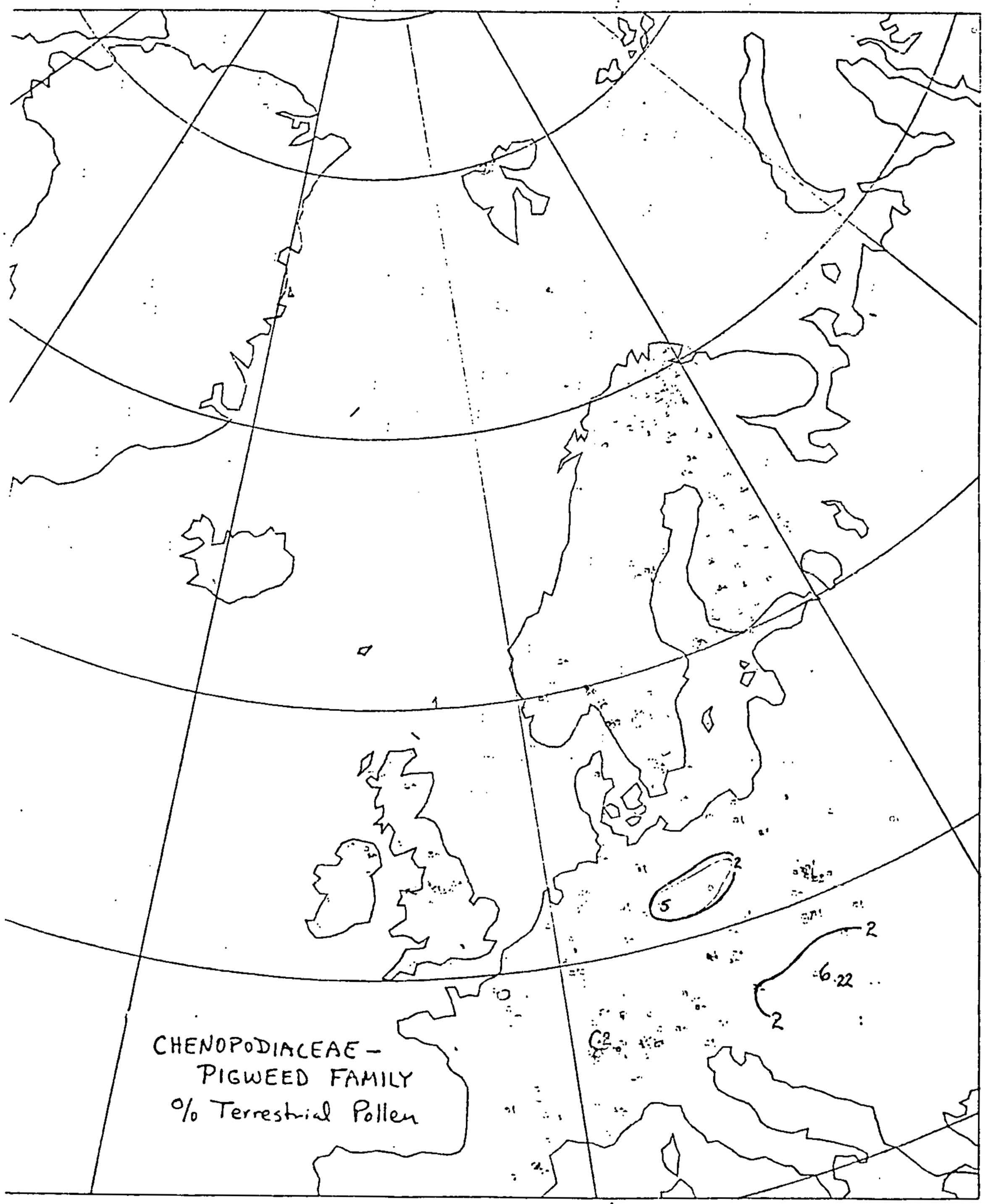

Figure 5. Contemporary distribution of pigweed-family pollen types counted in samples of surficial lake-sediments and peats.

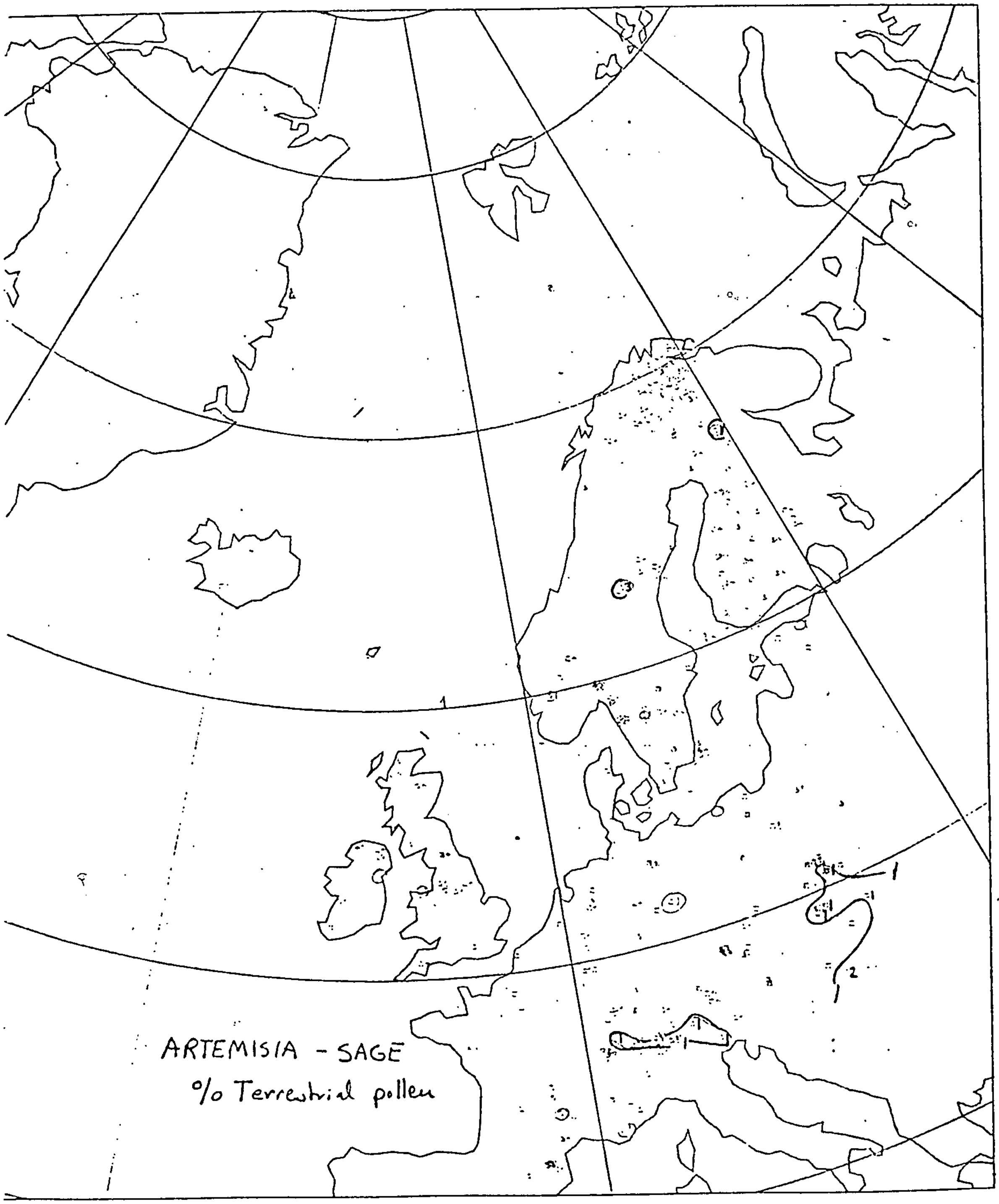

Figure 6. Contemporary distribution of sage pollen types counted in samples of surficial lake-sediments and peats.

APPENDIX B

Changes in forest limits in Northern Scotland 6000 years ago: A progress report by H.J.B. Birks, The Botany School, University of Cambridge, Cambridge CB2 3EA, England

In mid-Holocene times (ca. 6000 years ago), the northern limits of *Quercus* (oak) and *Pinus* (pine) in north-west Scotland extended further north than they do today. The precise timing and extent of this northward expansion and subsequent retreat are not known with any precision. To provide such precision, intensive field work was done in the Loch Maree area of north-west Scotland, an area critically positioned in relation to mid-Holocene changes in tree distributional limits. Cores from three lakes and four bogs were obtained for detailed pollen analysis, and buried pine stumps beyond the present-day limit of pine both latitudinally and altitudinally were collected for radiocarbon dating. The results of these studies should contribute important new insights into our understanding of mid-Holocene shifts in forest vegetation and thus, by inference, of climatic change in northern Scotland. This study will give detailed information that will complement the general patterns evident on the pollen maps for all of Europe.

APPENDIX C

Dated Holocene marine cores: A progress report

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We are in the process of gathering all available C^{14}-dated cores from North Atlantic deep-sea sediments. Results to date are shown in Figure 1, with all cores indexed as to quality of dating control (number of dates and spacing of dates relative to the 6000 B.P. level). With the data compilation still incomplete, there are already a surprisingly large number of dated cores.

Of the dated cores, relatively few have biotic census counts or sea-surface temperature estimates at the desired 6000-year level. Those that do are shown in Figure 2, with the estimated summer sea-surface temperature and departure from modern temperature indicated.

These values are <u>not</u> validated as final estimates of sea-surface temperature. They have not been evaluated for the effect of bioturbational mixing which alters the deep-sea record. The most likely effect of mixing on these estimates is to make them appear too cold by mixing late-glacial (11,000-year) sediment up to the 6000-year level. Two possible strategies for eliminating this problem in the future are: (1) only including cores with thick post-glacial sediment sections (50 cm); or (2) attempting to remove the mixing effect by modeling.

By March, 1980, we will complete the compilation of all C^{14}-dated North Atlantic cores, including final versions of Figures 1 and 2 included here. We will also evaluate all cores with respect to sedimentation rate and water depth, as these are critical factors in assessing the validity of the paleoclimatic message.

Because our funding last year was cut from the requested $25,000 to a bare-boned $5000, we have included no compilation of the North Pacific Ocean (except for three cores shown in the lower left corner of Figure 1) as originally outlined in the proposal.

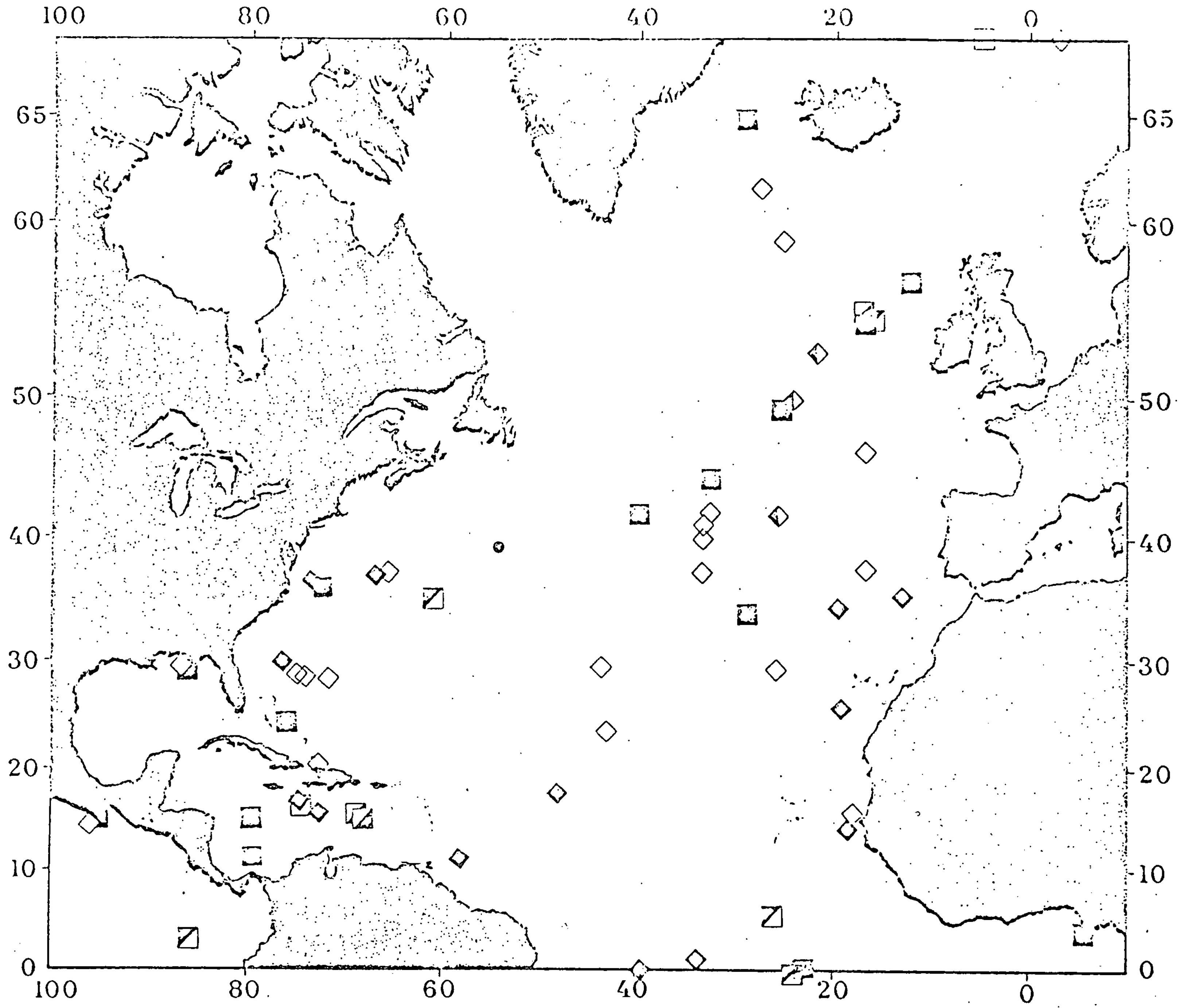
Comment

Our current impression is that there is a surprising number of well-dated North Atlantic cores which have never been the source of biotic censuses or estimates of sea-surface temperatures. Other oceans have generally smaller, but still considerable, data bases already available for possible future work to derive valid estimates of ocean climate 6000 years ago.

FIGURE LEGENDS

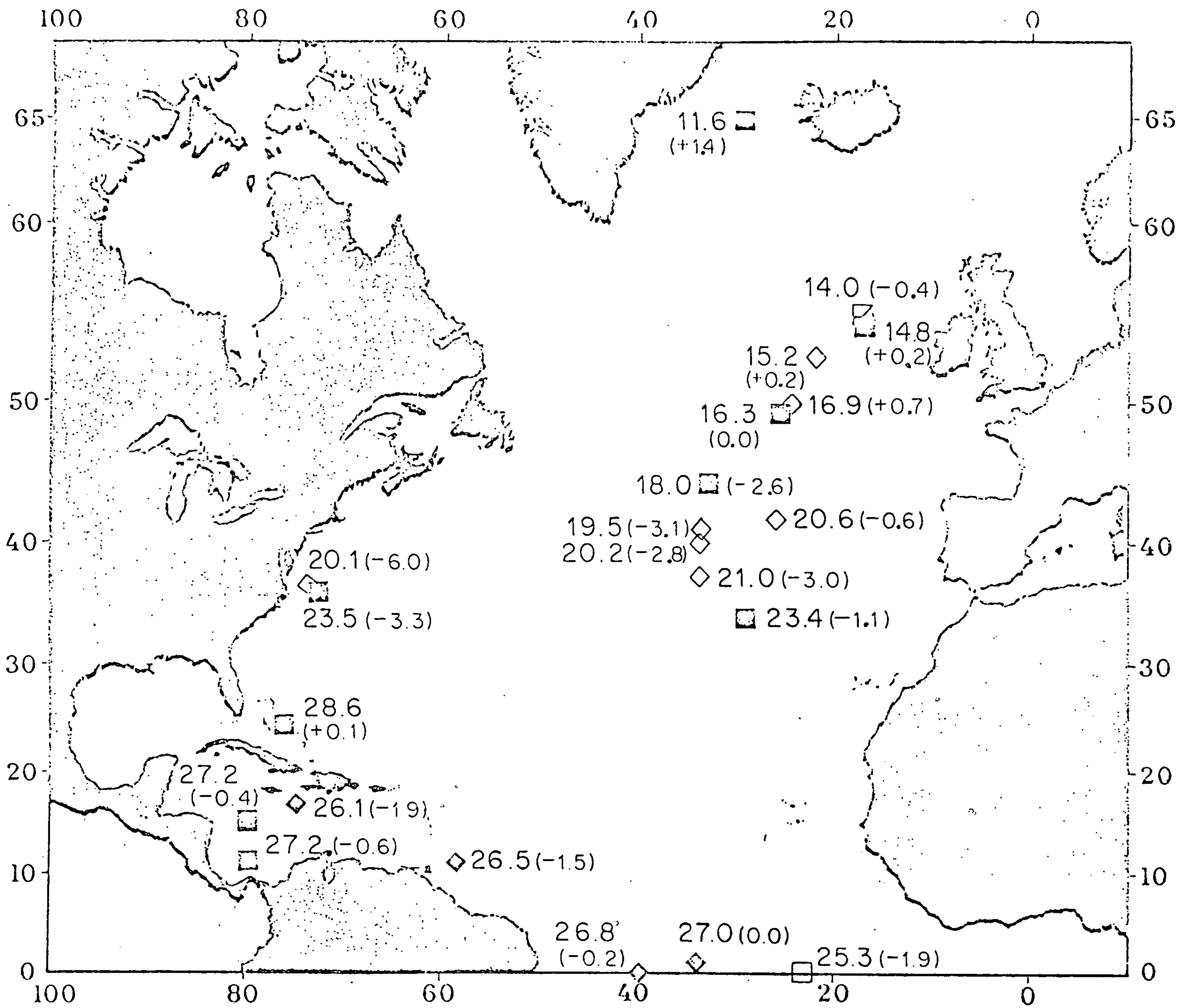
Figure 1. Cores with radiocarbon control. Filled box: bracketing radiocarbon dates, both between 3000 and 9000 years B.P. (before present). Half-filled box: bracketing radiocarbon dates, one within the 3000 - 9000 year interval. Empty box: bracketing radiocarbon dates, neither within the 3000 - 9000 interval. Filled diamond: one radiocarbon date 6000 - 9000 years B.P. Empty diamond: radiocarbon date, older than 9000 years B.P. Filled circle: one radiocarbon date, 3000 - 6000 years B.P. Empty circle: one radiocarbon date, less than 3000 years B.P.

Figure 2. Cores with radiocarbon control (as in Fig. 1) and estimates of summer sea-surface temperature 6000 years ago. Bold numbers are temperature estimates. Smaller numbers in parenthesis are departures from modern temperatures (atlas values).



CORES WITH C^{14} CONTROL

Figure 1



ESTIMATED SUMMER SEA-SURFACE TEMPERATURE
6000 YEARS AGO

Figure 2

APPENDIX D

Landscape and climatic history of Labrador: A progress report by H.E. Wright, Jr., H.F. Lamb, D. Engstrom, D.R. Foster, Limnological Research Center, University of Minnesota, Minneapolis MN 55455

The research program on environmental and climatic history of Labrador has five main aspects. (1) Pollen stratigraphy of lake sediments to provide a stratigraphic and paleoecological framework for subsequent research, (2) collection of surface sediments from lakes spanning the vegetation zones from forest in the south to tundra in the north, (3) investigation of the climatic record as demonstrated by changes in the inferred forest extent and species composition in the forest tundra, (4) research into the nature of limnologic change and of lake/watershed interactions during the change from tundra to forest ecosystems, and (5) investigation into the frequency of forest fire and its role in the boreal forest ecosystem.

1. Pollen stratigraphy. Pollen percentage and influx diagrams for three lake-sediment cores from southeastern Labrador are subdivided into three regional pollen assemblage zones: (I) *Betula*-*Salix*-Cyperaceae zone, 10,500 to 9000 ^{14}C yrs. B.P.; (II) *Alnus*-*Abies*-*Picea* zone, 9000 to 5000 B.P.; (III) *Picea* zone, 5000 B.P. to present. Pollen influx was low in zone I, rose in zone II, and then abruptly increased further in the upper part of zone II when tree pollen was first deposited. Influx reached a maximum about 4000 years ago and declined substantially after 2500 B.P.

An early phase of tundra was succeeded 9000 years ago by birch-alder shrub-tundra as the climate warmed. Trees then colonized the shrub-tundra at 6000 B.P., arriving late in contrast to sites farther south and west. The initial forest community is interpreted as a park-tundra of white spruce with abundant fir and probably with some tree birch. After a period of about 700 years, fir declined in favor of black spruce as soil conditions began to deteriorate. The formation of peat was probably accelerated at this time.

The pollen record from a site on the south coast shows that the coastal region was never forested. The record of pollen influx shows distinct similarities to that of the inland sites, suggesting that climate was most temperate about 4000 years ago and that a sharp deterioration took place about 2500 B.P.

2. Modern surface-sediment samples. During the 1979 field season, 70 lake surface-sediment samples were collected from the forest, forest-tundra, and tundra zones. Limnologic parameters were measured, such as pH, alkalinity, conductivity, color, etc. The sediment samples will be analyzed for diatoms and pollen; the results are expected to form an objective basis for the interpretation of fossil assemblages contained in the cores.

3. Climatic reconstruction. In 1977 and 1979 a series of lake-sediment cores were collected from boreal forest to the tundra. An area on the northwest flank of the central highlands, south of Mistastin Lake, was selected as being likely to show the most detailed and precise record of forest-limit changes. Lakes in this region proved to contain deeper sediments than elsewhere and thus will provide maximum precision in the climatic record. Duplicate cores were taken in order to provide sufficient material for accurate C-14 dating and for macrofossil analysis. Pollen analysis so far shows a stratigraphy not unlike the sequence to the south, but pollen influx to the sediment shows a much greater

range and a lower mean value than that found in the forest proper. Thus the potential for climatic reconstruction in the area is good.

4. Paleolimnology. Research in the southeast (1 above) suggested that when forest trees colonized the birch-alder tundra at 6000 B.P., forest-litter accumulation in the lake watershed caused rather marked changes in the lake itself. Specifically, the lake seems to have changed from a relatively productive system with predominantly autochthonous organic input to the sediment to one with primarily allochthonous input of terrestrially derived humic material. Simultaneously, the lake changed in color from clear to tea-colored dystrophic water. This hypothesis is currently being further tested by analysis of diatom, pigment, and chemical contents of the sediments.

5. Fire history. Forest fires play an important role in the maintenance of productivity and in species composition. Labrador, with its oceanic climate of cool, wet summers and a short growing season, would be expected to be rather less affected by forest fire than would more continental parts of the boreal forest. Yet black spruce, which is adapted to fire in its seed reproduction, is the predominant species in the forest today, and fir is much less common than it was 6000 - 5000 years ago. Jordan (1975) shows that lake sediments contain more charcoal after this fir maximum, suggesting that increased fire frequency might account for the decline of the species. Regeneration after fire is markedly slow in Labrador, particularly in northern areas. Hence an appreciation of the role of fire is important in any reconstruction of climatic change based on tree-limit fluctuations. The successional communities are less diverse than more southerly parts of the boreal forest, but birch and aspen often form pure stands after fire on richer sites, eventually giving way to fir -

spruce forest. Detailed pollen analysis of forest-floor peat profiles, as well as lake sediments, will elucidate the fire history of the region.

Reference

Jordan, R., 1975. Pollen diagrams from Hamilton Inlet, Central Labrador, and their environmental implications for the northern maritime Arctic. Arctic Anthropology 7: 92-116.