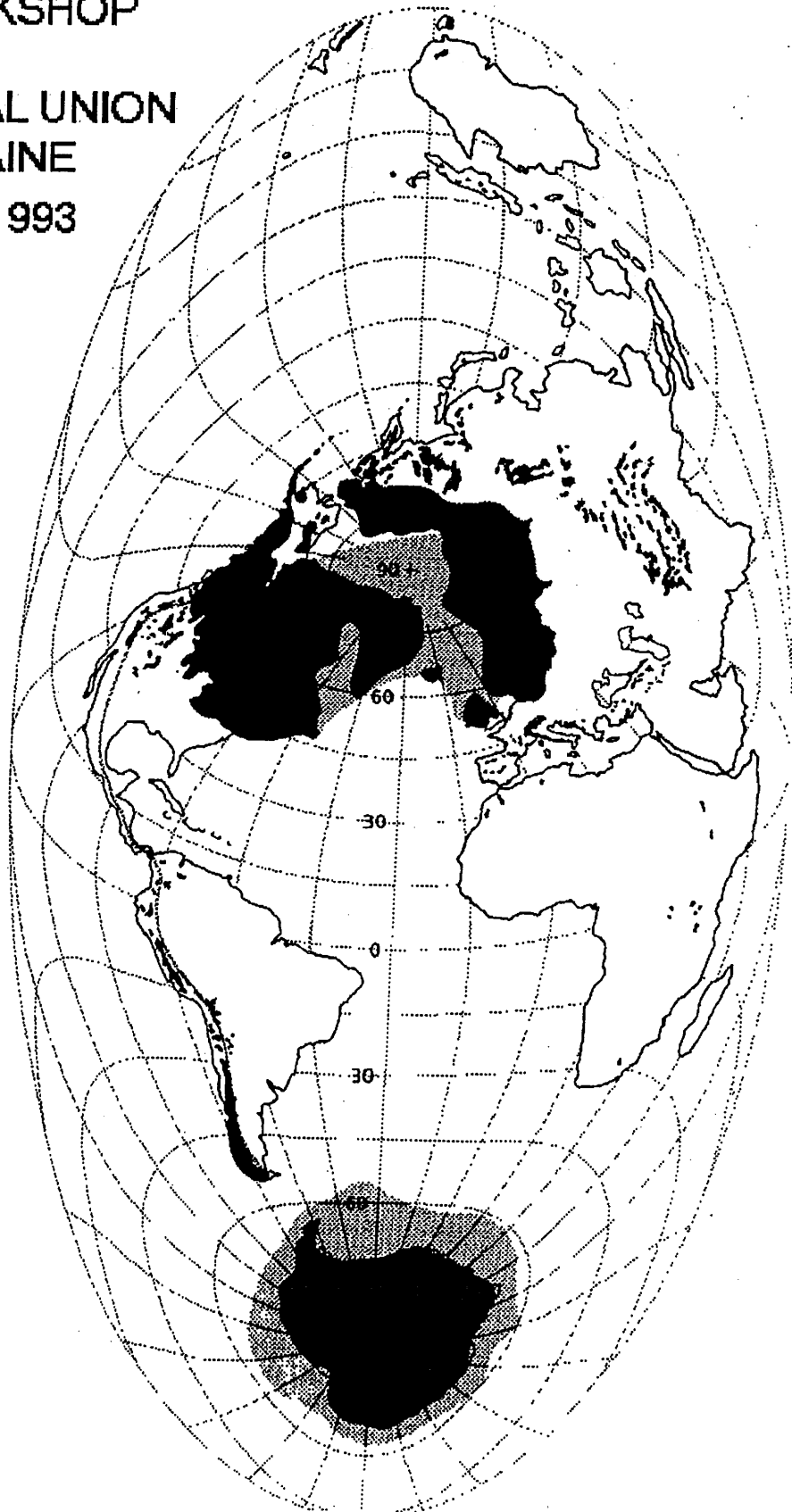


GLOBAL CHANGE RESEARCH AT THE
UNIVERSITY OF MAINE AND THE
MAINE GEOLOGICAL SURVEY:
EPSCOR II - III WORKSHOP

LOWN ROOM. MEMORIAL UNION
UNIVERSITY OF MAINE
TUESDAY, MAY 25, 1993
0800 - 1700

1st Annual



GLOBAL CHANGE RESEARCH AT THE UNIVERSITY OF MAINE and
MAINE GEOLOGICAL SURVEY: EPSCoR II-III Workshop

Lown Room, Memorial Union,
University of Maine, Orono, ME

May 25, 1993

PROGRAM AND ABSTRACTS

Schedule:

Welcome and Introduction - Daniel F. Belknap

Presentations, Morning Session:

MAINE TERRESTRIAL TRANSECT

- 0810: **Harold W. Borns, Jr.:** The Terrestrial Component of the
Maine EPSCoR Program: Present and Future
- 0825: **Kay Ashley and Harold W. Borns, Jr.:** Late Glacial History
of Central Aroostook County, Maine: The Younger Dryas
Problem
- 0840: **J.C. Strasser and Thomas K. Weddle:** Surficial Geology of
the Lower Aroostook River Valley, Maine:
- 0855: **Michael Kaplan:** The Glacial Geology of Southeastern
Washington County and Chronology of Ice Recession: a
Thesis Proposal
- 0910: **Christopher C. Dorion:** A Chronology of Deglaciation and
Accompanying Marine Transgression in Maine
- 0925: **Woodrow B. Thompson:** Maine Geological Survey
Investigations of Late-Glacial Stratigraphy and
Chronology of Deglaciation in Southwestern Maine
- 0940: **Robert A. Johnston, Joseph T. Kelley and Daniel F. Belknap:**
Glacial-Marine and Glacial-Lacustrine Sedimentation in
Sebago Lake, Maine: Locating the Marine Limit
- 0955: COFFEE BREAK

1010: **W. Roland Gehrels:** Relative Sea-Level Changes in the Western Gulf of Maine During the Past 5,000 ¹⁴C Years

1025: **Joseph T. Kelley:** The Role of the Maine Geological Survey Marine Program in EPSCoR Projects

GULF OF MAINE AND NORTH ATLANTIC

1040: **Daniel F. Belknap and Detmar Schnitker:** Deglaciation of the Gulf of Maine - Ice Shelves, Till Tongues and Paleoceanographic Changes

1055: **Tania S. Bacchus:** Late Quaternary Stratigraphy and Evolution of the Eastern Gulf of Maine

1110: **Walter A. Barnhardt and Joseph T. Kelley:** Late Quaternary Sea-Level Change and Evolution of the Maine Inner Continental Shelf: a Review of Investigations

1125: **Michael L. Prentice, Thomas B. Kellogg and Marianne Lagerklint:** Subpolar North Atlantic Surface Paleoceanography During the Last Glacial Cycle

1140: **Thomas B. Kellogg and Detmar Schnitker:** North Atlantic Core V27-114: Establishing a High-Resolution Chronology for Climatic Fluctuations

(Poster): **I. Marianne Lagerklint and Michael L. Prentice:** Mixed Layer Temperature and Salinity Changes in the Western North Atlantic Ocean During the Last Glacial Cycle

1200 - 1300 LUNCH BREAK:

Presentations: Afternoon Session

GLACIOLOGY, CLIMATOLOGY, and MODELING

1300: **James L. Fastook:** The Finite-Element Method for Solving Conservation Equations in Glaciology

1315: **Sanjay Rajavelu, James L. Fastook and Michael L. Prentice:** Application of a Non-Steady-State Isotope Model to the Dome Argus - Wilkes Flowband, Antarctica

1330: **Ben Tupper:** High-Latitude Oceanic and Atmospheric Responses to Abrupt Climate Change

PALEOECOLOGY AND ARCHAEOLOGY

- 1345: **Michael Sanders:** Archaeology of the Bain Site, Nova Scotia
- 1400: **Daniel H. Sandweiss:** Mid-Holocene Climate Change in Northern Peru - Evidence, Implications, and Future Research
- 1415: **Ronald B. Davis, D.S. Anderson, M.E. Perera, K.E. Bates, R. Geredien, H.D. Hikel, T.E. Walls, and R.B. Gause:** Maine Peatlands: Relationships to Present, Past and Future Climates
- 1430: **Tristram C. Hussey:** Paleoecology of the Coastal Plain of South Carolina and its Implications for Climate History of the Southeastern U.S.
- 1445: **Patricio I. Moreno:** Full- and Late-Glacial Vegetation and Climate from the Chilean Lake District

ANTARCTICA AND GLOBAL TRANSECTS

- 1500: **George H. Denton:**
To Be Announced

Workshop Discussions:

- 1515 - 1700: Group Discussion of Interactions, Directions

Groups are encouraged to bring posters and display materials for discussion during the workshop session.

ABSTRACTS

Note:

1140: **Thomas B. Kellogg and Detmar Schnitker:** North Atlantic
Core V27-114: Establishing a High-Resolution Chronology
for Climatic Fluctuations

NO ABSTRACT AVAILABLE

(Afternoon Poster) **I. Marianne Lagerklint and Michael L.
Prentice:** Mixed Layer Temperature and Salinity Changes
in the Western North Atlantic Ocean During the Last
Glacial Cycle:

NO ABSTRACT AVAILABLE

1345: **Michael Sanders:** Archaeology of the Bain Site, Nova Scotia

NO ABSTRACT AVAILABLE

1500: **George H. Denton:** To Be Announced

NO ABSTRACT AVAILABLE

The Terrestrial Component of the Maine EPSCoR Program: Present and Future.

Dr. Harold W. Borns, Jr.

Abstract

The objective of the Terrestrial Component is to document the physical and biological history of the deglacial period in Maine approximately between 14,000 and 10,000 years ago. This history includes the geometry and high-precision chronology of ice-margin recession, positions, and associated terrestrial and marine biological changes in the areas where the ice-margin recession was accompanied by marine transgression, and in areas above the inland marine limit.

This record, when complete, can then be compared with the record of deglacial events in the North Atlantic Ocean, Greenland and northwestern Europe for the purpose of increasing our ability to understand the causes of the last termination.

EPSCoR supported research at Maine has focused on expansion and refinement of the deglacial events and changes as they have been previously understood. Considerable progress has been made in determining a high-resolution chronological framework of events. However, the problem before us is to fill in this enhanced framework of understanding.

Future research, beyond the support of EPSCoR, must be designed to accomplish the basic goals set forth in the EPSCoR proposal for the Terrestrial Component, and also to bridge, the gap between the terrestrial and the developing Gulf of Maine record that extends back to the beginning of the last termination.

Clearly, the completion of this research is beyond the funding capability of the current EPSCoR, as designed, and therefore proposals for the continuation of the Terrestrial Component must be submitted for competitive funding as soon as possible to agencies such as NSF or possibly NOAA. These must be based on the research results to date and on the scientific infrastructure provided to the University of Maine.

LATE GLACIAL HISTORY OF CENTRAL AROOSTOOK COUNTY, MAINE: THE YOUNGER DRYAS PROBLEM.

ASHLEY, Kay and BORNES, Harold W., Jr. Institute for Quaternary Studies,
5711 Boardman Rm.320, University of Maine, Orono, ME 04469-5711

Previous work in Nova Scotia and New Brunswick, Canada has proven that a late-glacial climatic oscillation expressed itself in North America. Despite physical and palynological evidence in Canada for an event centered on the Allerød-Younger Dryas chronozones, little conclusive evidence has been found for an equivalent oscillation in Maine.

The only physical evidence for an Allerød-Younger Dryas event in Maine is a deformed peat layer within a diamicton near Oxbow. Newman *et al.* (1985) reported ages on the peat ranging from $10,395 \pm 85$ to $11,760 \pm 145$ ^{14}C yrs B.P. New excavation of the site in 1992 did not reveal the peat. The presence of fine modern roots throughout the diamicton suggests that the earlier dates may be too young. Newman *et al.* reported a strong NNW-SSE stone fabric in the diamicton, which is consistent with regional flow directions and suggests that the diamicton may be a till. Regional basal organic ^{14}C dates suggest that the area was ice-free by Younger Dryas time (Davis & Jacobson, 1985).

Our strategy for trying to solve this problem has been to investigate the stratigraphy of the Oxbow region, in conjunction with ice-flow directions as determined by bedrock striae and till fabrics. Ongoing fieldwork has shown that the direction of strongest bedrock erosion records a presumed Late-Wisconsin ice flow event which occurred along a mean trend of $S26^\circ E$, based on 261 striation measurements at 30 localities. This indicates a mean flow from the NNW. The NNW-SSE-trending striae cross-cut a W-E set at some localities. Faint striation sets which cross-cut the NNW-SSE-trending striae have no consistent orientation. Till fabrics exhibit a mean trend of $S40^\circ E$, indicating flow from the NNW. A major drag fold found at the contact between the surface till and underlying gravel also indicates ice flow from the NNW (fold axis trend: $S66^\circ W$). The surface till has not been dated directly. The genesis of the diamicton at Oxbow and its relationship to the regional surface till remain unclear.

Two ponds in the Oxbow area, Hall Pond and Cranberry Pond, were cored in February, 1993. Cranberry Pond is directly adjacent to the Oxbow peat site. In both cores, gyttja grades downward into laminated muds and sands. The laminated sediments are interpreted as glaciolacustrine deposits. At Hall Pond, the laminated sediments grade downward into a stony clay, which is presently interpreted as till. At Cranberry Pond, the laminated sediments grade downward into a massive, stony, clay- and sand-rich unit (~25 cm thick) which has a sharp lower contact with laminated muds and sands. The laminated sediments below the stony unit are coarser than those above, with coarse sand and small pebbles. We were unable to penetrate through the glacial sediments at either site.

SURFICIAL GEOLOGY OF THE LOWER AROOSTOOK RIVER VALLEY, MAINE.

STRASSER, J.C., Dept. Earth and Environmental Sciences, 31 Williams Drive, Lehigh University, Bethlehem, PA 18015-3188, WEDDLE, T.K., Maine Geological Survey, Station 22, Augusta, ME 04333.

As part of the University of Maine EPSCoR research grant, preliminary field investigations of the surficial deposits in the lower Aroostook River valley indicate a complex deglacial history involving glacial lakes and at least one glacial readvance. During deglaciation, a large lake, Lower Glacial Lake Aroostook, occupied lowlands to the south and west of Presque Isle. The modern Aroostook River flows to the northeast, and glacial lake water was ponded in its valley between ice to the north and drainage divides to the south. Evidence for the lake includes subaquatic fans, deltas, spillways, and lake bottom sediments.

A complex stratigraphy is evident in many of the deposits at lower elevations. An extensive and thick till unit lies directly above thick stratified drift deposits, interpreted loosely as subaquatic fans. Well logs indicate a lower till unit also is present (Locke and others, 1989). Although no ages are available on any of these deposits, palynological evidence by Deevey (1959) and Mott and others (1986) indicates that the entire region was probably free of ice during the entire Younger Dryas. If the lower till is pre-Late Wisconsinan, then the stratigraphy may represent a single Late Wisconsinan advance and retreat of the ice. If, however, it can be established that the overridden stratified drift is younger than ca. 13,000 yr BP, then the upper till unit was deposited by either a single major readvance or multiple minor readvances during the Late Wisconsinan deglaciation.

The active ice margin receded northward or northeastward during the final phases of deglaciation. As the ice margin retreated, it deposited the Mars Hill and Fort Fairfield moraine complexes. The Mars Hill moraine complex may have been a dam for Lower Glacial Lake Aroostook during one of its phases. Future field work should focus on establishing a definite history of Lower Glacial Lake Aroostook, its various stages, and its drainage routes. In addition, a program to core bog and lake deposits could provide necessary palynological data and radiocarbon dates to establish a chronology of Late Wisconsinan and early Holocene events in northeastern Maine.

**THE GLACIAL GEOLOGY OF SOUTHEASTERN
WASHINGTON COUNTY; AND CHRONOLOGY OF ICE RECESSION**

Thesis Proposal

Michael Kaplan

Wave action along the coast in southeastern Washington County exposes sections of stratified end moraines, ice proximal and distal glaciomarine sediment, and hummocky ground moraine. Thus, there is an unique opportunity to study the glacial geology, both processes and history, of this area, specifically the proximal deposits associated with the ice margin. The estimated time for ice recession in the study area is 14,000 to 13,000 radiocarbon years B.P.. During this time there were significant climatic and oceanographic changes in Europe and the adjacent North Atlantic Ocean.

Within the study area is the Pond Ridge moraine and end moraine complex associated with the Pineo Ridge delta (Bornes et al., 1980). Several of the stratified end moraines are partially composed of subaqueous outwash and flow till interbedded with glaciomarine sediment (Bornes et al., 1980; Lepage, 1982; Ashley et al. 1992). The glaciomarine sediment in the largely studied Pond Ridge moraine contains fauna and seaweed (Stuiver and Bornes 1975, Lepage 1982; Bornes and Dorion personal comm.; my own observations). Similar largely unstudied moraines to the north and south, that contain glaciomarine sediment, could also contain marine fauna which can be used for radiocarbon dating.

OBJECTIVES

1) Surficial mapping

I am currently mapping the distribution of the moraines (i.e.; ice margin positions), and crudely, the associated surficial geology through air photo interpretation. Several methods that allude to ice-flow direction will be utilized such as striation, boulder and till fabric analyses.

2) Glacial Geomorphology

Previous glacial geologic studies (Embleton and King, 1975; Boulton 1972; Sugden and John, 1975; Eyles et al. 1983; and numerous studies in different regions) demonstrate that the glacial geomorphology is different in polar, subpolar and temperate environments. Air photo interpretation and field reconnaissance will allow interpretations based on the above studies. Specifically the overall nature of the geomorphology and whether there is any spatial (i.e. and temporal) changes from south to north.

3) Description of sediments and stratigraphy

Chronologic and paleoecologic information is meaningless without stratigraphic reference and a description of the relevant sediments. In conjunction with the geomorphology, a knowledge of the sediments, including fabric analyses, can aid in environmental interpretation.

4) To develop the absolute and relative chronology of events

Presently, there are several radiocarbon dates for the region, including at least three for the Pond Ridge Moraine (Bornes, 1980; Dorion, unpublished M.S. thesis). There are no dates(?) that are unequivocally associated with formation of the end moraine complex. There are several exposures in close proximity to the complex along Holmes Bay (and near Lubec?) that may yield shells.

Exposures can also yield shells for maximum and minimum dates on events such as the formation of the Pineo Ridge end moraine complex. The distribution of moraines, which I am mapping, is crucial for site selection. In addition, all radiocarbon dates can aid in establishing a relative chronology which includes undated events (e.g. the formation of another group of moraines).

Other objectives (includes future work)

1. To compare the results from objectives 1-4 with data from other regions (e.g. North Atlantic ocean and Europe). The development of a chronology is important for such an endeavor.
2. Knowledge of the ice margin position through time contributes to models of ice sheet extent (Denton and Hughes, 1981)
3. Delineation of the end moraine complex, along with future studies, can help to understand the cause of the uplift anomaly within this region, as indicated by topset-foreset elevation data (Thompson et al., 1989)
4. To compare with past and present research in Maine.

A CHRONOLGY OF DEGLACIATION AND ACCOMPANYING MARINE TRANSGRESSION IN MAINE.

DORION, Christopher C., University of Maine, Department of Geological Sciences, Room 119, 5711 Boardman Hall, Orono, ME 04469-5711.

The rate of recession of the Laurentide Ice Sheet across Maine during Late Wisconsinan time is actively debated. Ice receding from the Gulf of Maine reached the position of the present coast and deposited Pond Ridge Moraine in approximately 90 meters of water. The time of aggradation is bracketed by molluscs preserved in marine clay that is interbedded with subaqueous outwash at $13,810 \pm 90$ (*Nucula tenuis expansa*). Molluscs in marine clay draping over the moraine at $13,370 \pm 90$ (*Portlandia arctica*) indicate ice withdrawal by this time. By $13,075 \pm 90$ the ice margin was at or beyond the marine limit near Boyd Lake, Maine (fully articulated, *in situ* *Portlandia arctica* in the ice proximal marine sediments). These A.M.S. carbon 14 dates on marine macrofossils along this 150 kilometer transect from eastern coastal Maine to the inland marine limit yield an overall retreat rate of 148 flow-line meters per year. The marine transgression ended as land level rise exceeded sea level rise. The shoreline regressed to the present coast by $12,425 \pm 110$ as dated by *Mytilus edulis* deposited under washover fans on top of Pond Ridge Moraine. Possible ice-wedge casts in the depositional surface of the washover fans would indicate an arctic climate persisted after 12,425 years B.P.

Core logging, loss-on-ignition, and mollusc and foraminiferan facies from six lake cores identify the basic stratigraphic framework along the 150 kilometer transect. The vertical thickness of Laurentide Ice is constrained by two high elevation (825 and 670 m.a.s.l.) lake cores.

Lithofacies are divided into two broad groups: intramorainal and intermorainal. Intramorainal lithofacies are further divided into vertical sequences of the distal and proximal moraine and also the complete cross section. Most of the 40 kilometer wide coastal moraine belt is marked by intermorainal, ice distal, fossiliferous, thick deposits of laminated silty clays. Four facies describe the intermorainal stratigraphy: compact diamicton, a sparsely fossiliferous dropstone rich mud, highly fossiliferous laminated silty clays, and a cap of open-work, crudely-bedded pebble gravel. The facies are diachronous during both the onlap and offlap phases of the marine inundation. The transgressive facies accompanied the retreating ice margin inland while the regressive facies, consisting of littoral zone coarse deposits and washover fans, paralleled the relative sea level fall across Maine.

Seven additional crucial radiocarbon dates are currently in progress. In addition to refining the areal extent of Laurentide Ice they will also yield sediment accumulation rates in the inter- and intra-morainal lithofacies.

MAINE GEOLOGICAL SURVEY INVESTIGATIONS OF LATE-GLACIAL STRATIGRAPHY AND CHRONOLOGY OF DEGLACIATION IN SOUTHWESTERN MAINE.

THOMPSON, W. B., Maine Geological Survey, State House Station 22, Augusta, ME 04333.

The Maine Geological Survey (MGS) is collecting data on the late-glacial history of Maine under funding from the EPSCoR program, and through related studies of Quaternary deposits for the MGS surficial quadrangle mapping program and sand-and-gravel aquifer mapping project. These data will be compiled in collaboration with University of Maine EPSCoR participants, using the Survey's Geographic Information System to produce maps showing the sequence and configuration of ice-margin positions during recession of the late-Wisconsinan ice sheet, and the radiocarbon dates used to constrain this reconstruction.

The general stratigraphic relationships of glaciomarine deposits in Maine's coastal zone are well known, but the glacial chronology needs further refinement. Additional radiocarbon dates obtained by UM workers are clarifying the deglacial sequence in the eastern part of the coastal lowland. In southwestern Maine, MGS EPSCoR contractors (Kathleen Callum and Gwyneth Jones) collected shells from the Presumpscot Formation during the 1992 field season, in an effort to provide limiting dates on the time of deglaciation. Although there were problems with the AMS dating procedure, preliminary results indicate that deglaciation of southwestern coastal Maine occurred earlier than known from previous dates. We obtained radiocarbon ages of 14,820 +/- 105 yr BP on Portlandia shells from the Scarborough mammoth site, and 14,045 +/- 95 yr BP on shells from Freeport.

MGS surficial mapping in the interior of southwestern Maine (above the marine limit) is providing additional evidence of the progressive retreat of a coherent ice margin. Indicators of the position of the glacier margin include end moraines, meltwater channels, and heads-of-outwash for stratified drift units. Topographically controlled stagnation of ice masses probably occurred in some valleys as the glacier thinned over the mountains, but active ice flow persisted in other areas. The morphologic sequence concept, long used in southern New England, is proving to be a workable method for documenting ice retreat in this part of Maine. There is a growing body of evidence that late-glacial ice flow shifted to a more southerly, and even southwesterly, direction over the White Mountain foothills as the residual ice in this area became increasingly cut off from the main ice northwest of the Mahoosuc and Presidential Ranges.

Further coring and dating of lake-bottom sediments will be needed to constrain the deglacial chronology throughout the part of Maine above the marine limit. MGS will be working with UM EPSCoR participants during the 1993 field season to obtain this information. We will also search for new datable sites in the glaciomarine deposits, and continue ongoing research on glaciomarine deltas and shorelines in relation to sea-level change during deglaciation.

GLACIAL-MARINE AND GLACIAL LACUSTRINE SEDIMENTATION IN SEBAGO LAKE, MAINE: LOCATING THE MARINE LIMIT

JOHNSTON, Robert A., KELLEY, Joseph T., Maine Geological Survey, Department of Conservation, Station # 22, Augusta, Maine 04333, and BELKNAP, Daniel F., Department of Geological Sciences, University of Maine, 5711 Boardman Hall, Orono, Maine 04469-5711.

The marine limit in Maine marks a sea-level highstand at approximately 13 ka. It was inferred to cross Sebago Lake near Frye Island by Thompson and Borns (1985) on the Surficial Geologic Map of Maine, dividing the lake into a northern glacial-lacustrine basin and a southern glacial-marine basin. This study examined the accuracy of the mapped marine limit in the lake and the nature of glacial-lacustrine and glacial-marine facies in Maine. Recognition of the marine limit is usually based on mapped shorelines, glacial-marine deltas, and contacts with glacial marine sediments.

This study, in Maine's second largest lake, collected 100 kilometers of side-scan sonar images, 50 kilometers of seismic reflection profiles, and one core. Side-scan sonar records show coarse sand and gravel and extensive boulder fields at an inferred grounding-line position near Frye Island, where the marine limit was drawn. ORE Geopulse seismic reflection profiles reveal a basal draping or ponded unit similar to glacial-marine units identified offshore. Later channels cut more than 30 m into the basal stratified unit. In addition, till and a possible glacial-tectonic grounding-line feature were identified. Both small and large scale slumps and possible spring disruptions are found in several locations.

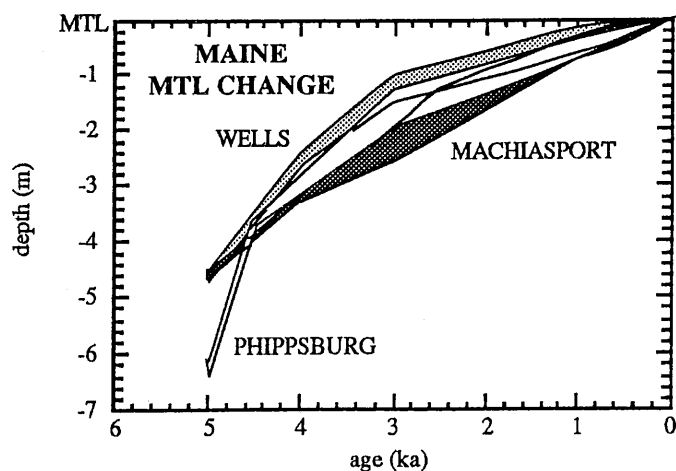
The top unit is an overlapping ponded Holocene lacustrine unit. Total sediment is much thicker in the southern basin; the northern basin, >97 m deep, north of the marine limit appears to have been occupied by an ice block. Retrieved sediments include 12 meters of rhythmites. Microfossil identifications and dating will resolve the environments and time of deposition in this core. Future work will include collecting additional seismic reflection and sidescan-sonar profile data, piston coring, and Geographic Information System data analysis and modeling.

RELATIVE SEA-LEVEL CHANGES IN THE WESTERN GULF OF MAINE DURING THE PAST 5,000 ^{14}C YEARS.

GEHRELS, W. Roland, Dept. of Geological Sciences.

Local Holocene sea-level studies in coastal Maine are an important part of EPSCoR's terrestrial component because they provide information for two areas of climate research. First, from along-coast trends of relative sea level, it is possible to obtain regional data on isostatic crustal behavior that constrain theoretical models of global glaciation and earth rheology. Second, Holocene coastal sediments provide the only feasible record to study sea-level oscillations on a centennial to millennial time scale.

Documentation of Holocene sea-level changes in coastal Maine is primarily based on radiocarbon dates obtained from salt marsh peats. Previous data are widely scattered, due to problems with conventional radiocarbon dating of peats, inadequate sea-level indicators, compaction, and imprecise surveying. To establish more accurate sea-level histories for four locations along the coast of Maine, I have developed a methodology which integrates: (1) AMS ^{14}C dating of salt marsh plant fragments; (2) precise definition of paleo-tidal elevations of sea-level indicators by comparing assemblages of fossilized foraminifera in peat samples with the modern zonation of foraminifera on the salt marsh surface; (3) high-precision surveying of salt marsh core sites; and (4) modeling of the paleotides in the Gulf of Maine.



Sea-level chronologies for the past 5,000 ^{14}C years have been completed for three locations: Wells ($43^{\circ}17'\text{N}$, $70^{\circ}34'\text{W}$), Phippsburg ($43^{\circ}45'\text{N}$, $69^{\circ}49'\text{W}$), and Machiasport ($44^{\circ}41'\text{N}$, $67^{\circ}24'\text{W}$). Radiocarbon analyses for samples from Gouldsboro ($44^{\circ}26'\text{N}$, $68^{\circ}01'\text{W}$) are underway. In contrast with previous work, resolution of the new high-quality data allows the conclusion that differential crustal motion has occurred along the coast of Maine during the past 5,000 ^{14}C years (Figure). This crustal motion is interpreted as the "tail" of a collapsing glacial forebulge. Slightly higher rates of contemporary sea-level rise in eastern Maine, as registered by the Eastport tide gauge, are probably glacio-isostatic in origin, rather than neotectonic. Tides along the coast of Maine had reached 65-70% of their present range by 5,000 BP and 95% by 2,000 BP. Significant regressional events, inferred from floral and foraminiferal analyses of peats, are dated at $2,770 \pm 65$ BP, $2,675 \pm 70$ BP, and 990 ± 60 BP in Phippsburg; and at $1,070 \pm 70$ BP and 490 ± 70 BP in Machiasport. Climatic-eustatic implications of these events remain speculative at this time.

The Role of the Maine Geological Survey Marine Program in EPSCoR Projects

Dr. Joseph T. Kelley, Maine Geological Survey

The EPSCoR program has successfully provided an opportunity to pool State resources with graduate students and faculty in the University of Maine System in a variety of projects dealing broadly with the subject of the impact of Global Climate Change. Many of the projects will be discussed individually by the students working on them; the following is a list funded MGS proposals interfaced with money and equipment provided by EPSCoR since 1991:

Sea-level Change and Salt Marsh Evolution in Wells, ME (NOAA, MGS, Gehrels, Jacobsons);

Shoreline Response in Maine to Projected Sea-Level Rise (EPA, MGS, Marine Law Institute-USM, Survey Engineering graduate students, SPO, EPSCoR equipment);

Historic Shoreline Retreat and E-Zones on the Maine Coast (NOAA, MGS, Survey Engineering graduate students, Geological Sciences graduate students, EPSCoR equipment);

Sand Resources and Inner Shelf Stratigraphy in the Western Gulf of Maine (MMS, MGS, Barhardt, Belknap, EPSCoR equipment);

Geological Framework of Casco Bay (EPA, MGS, Geological Sciences faculty and graduate students, EPSCoR equipment)

Sand Budget for Maine's Sandy Beaches (Sea Grant, MGS, Barber, EPSCoR equipment).

Deglaciation of the Gulf of Maine - Ice Shelves, Till Tongues and Paleooceanographic Changes

Daniel F. Belknap and Detmar Schnitker

The Gulf of Maine was occupied by Laurentide ice during peak Late Wisconsin glaciation, and probably during many earlier glacial periods. The full extent of the ice and the timing and mechanisms of deglaciation have been controversial. The Gulf of Maine and surrounding emergent regions preserve sediments that record this history. Studies of these sediments may produce models for dynamics of marine-based ice sheets in general, and as a case study for timing of deglaciation in the eastern North America. The EPSCoR and NSF Gulf of Maine project is a combination of detailed seismic stratigraphy, long cores, dating control, and detailed sedimentological and paleoecological analysis. In a recently completed Ph.D. dissertation, Tania S. Bacchus (1993) has defined the seismic facies and seismic stratigraphy of the eastern Gulf of Maine. We recognize six major seismic facies: Till - ice contact lodgment till; Till Tongues - ice-front meltout deposits; PGM - coarse proximal sub-ice-shelf glaciomarine; TGM - transitional iceberg dump and proglacial glaciomarine; DGM - distal glaciomarine; and M - postglacial open Gulf fine-grained sediments. This stratigraphy is consistent within the eastern and western basins, with variations particularly in the abundance of till tongues and TGM. Additionally, iceberg furrowing is a ubiquitous feature on shoals. The till tongues interfinger with PGM, and define grounding lines of ice shelves. Two types are recognized: marginal till tongues, first defined by King and Fader (1986) that record ice grounding lines, and axial till tongues (Belknap et al. 1992), that may represent the termini of ice streams. We are presently evaluating a possible link between these axial till tongues, presumed ice streams, and Heinrich events of the North Atlantic. Two M.Sc. theses have been based on microfossil analyses, a study of foraminifera by Barbara Lusardi (1992) and a study of diatoms by Dan Popek (1993). These, coupled with our prior microfossil studies and dating, define the paleooceanographic changes during deglaciation. Ongoing amino acid racemization (AAR), stable isotope, and AMS dating provide a chronology and correlation to large-scale oceanographic changes.

Foraminifera record paleoenvironmental changes consistent with the sedimentological and seismic facies interpretations. For example, the *Cibicides lobatulus* zone occurs in PGM, and is interpreted to signify sub-ice-shelf, proximal glacial conditions, while five later zones record successive increases in slope water inflow, establishment of open boreal conditions, and finally evolution toward modern tidally mixed conditions. Diatoms show similarly close associations with the sedimentary facies. PGM is barren of diatoms, indicating a light-excluding mechanism, such as an ice shelf, while TGM contains *Thalassiothrix longissima* zone, indicative of boreal oceanic conditions. *Thalassiosira gravida* found in lower DGM indicate pack ice and lower salinity surface waters, while *Chaetoceros* spp. indicate upwelling at ice edges.

Presently, we are continuing detailed microfaunal, AAR, AMS, isotopic, and geochemical analyses. One possibility is that our cores can be used to evaluate the Oldest Dryas and Younger Dryas climatic signals. Another new investigation involves pore waters. Pore waters extracted from late glacial sediments in the cores show a consistent $2^{\circ}/_{\infty}$ S decrease from modern bottom waters. Ongoing isotopic analyses may allow determination of paleotemperatures of these water masses, and can be compared to analyses of isotopes and AAR from foraminiferal tests.

Late Quaternary Stratigraphy and Evolution of the Eastern Gulf of Maine

by Tania S. Bacchus

At the end of the last glacial maximum the southeastern edge of the Laurentide Ice Sheet terminated in the ocean in the Gulf of Maine. The complex interaction of glaciological and oceanographic conditions produced sequences of glacial and glacial-marine deposits that differ from those found along the present-day marine ice margins of Antarctica. The basins within the eastern Gulf of Maine preserve a record of the sedimentary environments, fossil and isotopic archives of paleoceanographic and climatic changes during the last 18,000 years.

Analysis of high-resolution seismic profiles shows that five distinct seismic facies describe the glacial, glacial-marine and postglacial sediments in the eastern Gulf of Maine. Regional cross-sections clearly document differences in the glacial-marine and postglacial stratigraphy between Georges and Crowell Basins, south of Truxton Swell, and Jordan Basin to its north. Till occurs throughout the region as a thin veneer within basins, but thickens significantly over the ridges and swells separating basins. The ubiquitous presence of till suggests that grounded ice occupied the eastern Gulf of Maine some time in the recent past, although the exact timing is still a matter of debate.

The glacial-marine sediments are subdivided into three separate seismic facies representing different proglacial environments. Ice-proximal glacial-marine (PGM) facies of varying thickness mantle the entire area, occurring as a draped unit over pre-existing topography. Transitional glacial-marine (TGM) facies also occur as a draped unit, but they show onlap onto basin margins. Sediments of the TGM facies are restricted to areas south of Truxton Swell. Ice-distal glacial-marine (DGM) facies also mantle the entire area, but this facies occurs primarily as a ponded, infilling unit.

The nature and distribution of these glacial-marine facies within the eastern Gulf of Maine documents changes in the environment of deposition during deglaciation. In our model the PGM facies represents deposition beneath an ice shelf from debris fallout and suspension settling. The TGM facies probably represents calving from the front of each successive ice shelf, although it may also represent break-up of these ice shelves. The DGM facies represents deposition of suspended sediments from meltwater plumes with a minor component of ice-rafted debris. Stepwise ice-margin retreat from south to north through a series of grounding lines and associated pinning points is evident by these time-transgressive seismic facies that can be correlated across the region. The change from draped facies to more ponded facies probably reflects a changeover from ice-dominated processes during early deglaciation to marine-dominated processes in the late stages. Postglacial (M) facies overlie glacial-marine sediments everywhere in the region. The M facies also occurs as a ponded, infilling unit.

Extrapolated AAR chronology on glacial-marine sediments in basins south of Truxton Swell indicate ages ranging from 27,000 BP at the bottom to 14,000 BP at the top. AAR chronology from Jordan Basin indicates that all sediments are late Wisconsin in age. This suggests that ice was grounded on Georges Bank during middle Wisconsin times. Furthermore, during the late Wisconsin the grounding line position would have been on Truxton Swell. This reconstruction is not well supported by other studies in the area or the marine oxygen isotope record. A better constrained chronology may indicate that all the glacial-marine sediments in the eastern Gulf of Maine are late Wisconsin in age, which would be more consistent with the ice-proximal to ice-distal stratigraphy and the marine isotope record.

Late Quaternary Sea-Level Change and Evolution of the Maine Inner Continental Shelf:
A Review of Investigations

EPSCoR Meeting 25 May 1993

BARNHARDT, Walter A., Department of Geological Sciences, University of Maine
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Late Quaternary relative sea-level changes in the western Gulf of Maine generally conform to a pattern of a late-glacial highstand followed by rapid regression and then Holocene transgression, but local histories all differ in one crucial element: the timing and depth of the lowstand. Field evidence suggests a postglacial drop in sea level of 30-60 m, 3x-5x the depth predicted by geophysical models (Peltier, 1986). Differences in lowstand depth must be reconciled because they may reflect regional differences in ice loads and timing of deglaciation. Previous stratigraphic models of relative sea level in Maine, based on high-resolution seismic reflection data (Belknap et al., 1987) and constrained by a small number of offshore vibracores (Kelley et al., 1992), are equally unclear on the depth and timing of the maximum lowstand on the inner continental shelf. Seismic-geomorphic evidence for the lowstand consists of submerged terraces (paleoshorelines) and ancestral deltas which exist at various depths and whose ages are poorly known (Shipp et al., 1991). Based on published curves of eustatic sea level (Fairbanks, 1989) and Maine relative sea level (Kelley et al., 1992), complex isostatic crustal motions (including a brief period of renewed subsidence) are necessary to accommodate a lowstand depth of 60 m at 10.5 ka followed closely by a -20 m position at 9.0 ka. If the widespread -60 m terraces are not indicators of former sea levels, then knowledge of sedimentation patterns and the stratigraphic development of lowstand deposits becomes essential in resolving questions about the emergence of the Maine inner continental shelf.

As part of the EPSCoR project, 1024 km of new side-scan sonar records and 235 km of seismic reflection profiles were used to map the distribution of surficial sediments and to elucidate the region's late Quaternary stratigraphy. Based on these detailed seismic surveys, numerous vibracores were collected: fourteen from the Kennebec River paleodelta, two from inner Casco Bay, and seven from outer Saco Bay. Due to equipment failures and inherent difficulties penetrating coarse-grained shelf sediments, the cruise was shortened by several days, two study areas were not cored at all (Penobscot Bay, Narraguagus Bay), and approximately half of the cores measured less than one meter in length. However, the relatively few successful cores contained complicated sequences of fossiliferous, texturally heterogeneous sediments that were deposited during times of rapidly changing sea level and sediment flux. Hypotheses regarding the depositional environment of the sediments range from glacial marine to regressive/transgressive estuarine, fluvial, and deltaic. Samples for radiocarbon-age dating are ready for submission.

This aspect of EPSCoR has three principal objectives: 1. to clarify the ages of the various sedimentary facies and intervening unconformities (regressive or transgressive?), 2. to interpret the depositional environments that the facies represent, and 3. to further constrain the depth and timing of the lowstand of relative sea level on the Maine inner continental shelf. Additional geophysical surveys and coring expeditions are scheduled for July and August, 1993.

Sub-Polar North Atlantic Surface Paleoceanography During the Last Glacial Cycle

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The discovery of abrupt changes in ice-rafting in the sub-polar North Atlantic during the last glaciation (Heinrich-layers) and their association with asymmetric cycles in surface temperature has provided a promising framework for understanding climate change. The fundamental problem is to determine what drives these cycles. Our specific goal is to determine the role of surface temperature and salinity changes in the sub-polar North Atlantic in the Heinrich-layer cycles. Depending on location in the sub-polar North Atlantic, mixed-layer temperature and salinity changes reflect the melting history of ice sheets, local climate, surface currents and fronts, as well as buoyancy forcing on sub-surface branches of the global-ocean conveyor belt.

Our principal tools are census data for the planktonic foraminiferal fauna and the stable isotopic composition of selected planktonic foraminifers. The strategy is to infer temperature variations from the changing species composition of the planktonic foraminiferal fauna. We infer salinity variations from temperature-corrected variations in the $\delta^{18}\text{O}$ of the selected planktonic foraminifers. Our strategy at each core location is to examine planktonic foraminifers with different ecological preferences so as to monitor the mixed layer during different seasons and at different depths. For example, in polar waters we use the isotopic composition of the dominant polar foraminifer, *Neogloboquadrina pachyderma* (left-coiling), as a likely record of Spring and Fall bloom conditions. Additionally, we use a sub-polar foraminifer that may inhabit these polar waters only during peak warmth, such as *Neogloboquadrina pachyderma* (right-coiling), to provide a record of seasonal-minimum salinity.

Principal accomplishments to date are detailed faunal and isotopic records for a high-sedimentation rate core in the central sub-polar North Atlantic, V27-114, as well as reconnaissance investigations of a few nearby cores. Detailed age-models have been constructed based on AMS ^{14}C dates as well as event correlation to other well-dated records in the North Atlantic. Our data show significant mixed-layer salinity changes that have not been recognized previously.

Future work will concentrate on the western sub-polar North Atlantic during the last deglaciation (isotope stage 1/2 transition) as well as the last glacial period (isotope stages 2 and 3). This work will include generation of detailed isotopic records on multiple species of planktonic foraminifers from two sites in the western North Atlantic that monitor meltwater run-off from the Laurentide Ice Sheet (M. Lagerklint). Detailed isotopic records will also be generated for sites in the eastern North Atlantic that monitor the Polar Front and North Atlantic Current system.

The finite-element method for solving conservation equations in glaciology

Dr James L. Fastook

May 17, 1993

Abstract

Many of the equations that arise in glaciological modeling are of the type derived from the behavior of some flux-like quantity as it flows into and out of some differential volume, area, or length extracted from the total domain of the problem. Conservation of mass, conservation of momentum, and conservation of energy lead to the three basic equations that all glaciological models must ultimately address. Each of these conservation equations, when combined with an appropriate constitutive relationship that connects the flux-like variable to the gradient of the state variable, provide us with a differential equation that must be solved as we attempt to model a particular physical phenomena.

The continuity equation arises from combination of the mass conservation equation and a constitutive relationship, such as a column-averaged flow law that connects surface slope (gradient of the state variable) and velocity (a factor of the flux variable). The differential equation is usually formulated in terms of an ice thickness, and can be used to solve for the ice surface configuration in a 1-D (flowband) or 2-D (map-plane) regime. Conservation of momentum combined with a generalized flow law expressed in terms of the strain-rate tensor leads to a solution for the vectorial velocity field within either 2-D flowband or map-plane domains or 3-D volume domains. Conservation of energy combined with Fourier's Law relating heat flux to temperature gradient leads to solutions for the scalar temperature field in 1-D, 2-D, or 3-D domains.

The finite-element method (FEM) is a standard numerical technique which can be successfully applied to any of these conservation equations, either in a steady-state or a time-dependent situation. The domain on which the conservation equation is to be solved can be complexly irregular, with no need for the curvilinear or normalized coordinates often required by the finite-difference method. Boundary conditions can be easily specified along this irregular boundary as a mixture of essential boundary conditions (specified state variable) or natural boundary conditions (specified flux or specified linear combination of flux and state variable). Gridding within the domain of the problem can be non-uniform and irregular, with the grid spacing adaptable to the smoothness and availability of the underlying data or to the smoothness of the anticipated solution. By appropriate choice of the degree of the interpolating polynomial, derived quantities that depend on derivatives of solved-for quantities can be easily obtained not just at nodal points or element centroids, but at any arbitrary position within the domain of the problem.

APPLICATION OF A NON-STEADY STATE ISOTOPE MODEL TO THE DOME ARGUS - WILKES FLOWBAND, ANTARCTICA

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May 17, 1993

Abstract

The non-steady state isotope model of Rajavelu et al.[in prep.] is applied to a flowband that originates at Dome Argus and terminates at Wilkes. The flowband length is approximately 2121 kilometers. The model is calibrated with the following observed field data:

- surface elevation profile for the flowband,
- present day temperature at sea level (T_{NSL}),
- temperature distribution over the ice surface,
- isotopic content of precipitation along the flowband.

The modeling experiment to be discussed is designed to test the applicability of the model and to demonstrate to a certain extent the difference in performance between a steady-state and a non-steady state model. The experiment involves the simulation of the present day flowband configuration for non-steady state and steady state conditions. For the non-steady simulation the model is driven by a time-series T_{NSL} record for the period 6 Ma B.P. till present. This record is obtained from an interpretation of a tropical planktonic foraminifer core. For the steady state simulation the model is run for 1.5 Ma with present day T_{NSL} of -14° C.

The present day average isotopic content computed by the model for the non-steady state simulation is -51.65 ‰, and -47.56 ‰ for the steady state simulation. The results differ because in case of the non-steady state simulation the average is influenced by the presence of previously deposited flux. The value is more negative for the non-steady state case as a result of colder temperatures in the past. On the otherhand the steady state model implies a isotope equilibrium condition and therefore gives less negative values.

Abstract

High Latitude Oceanic and Atmospheric Responses to Abrupt Climate Change

Ben Tupper

Introduction

Recent paleoclimatic data indicate that short period oscillations and rapid changes in climate system were superimposed upon the long term climate changes associated with the Quaternary Ice Age cycles. Rapid climate change may occur even in the absence of external forcing variation or changes in the chemical make up of the atmosphere. Interpretations of these changes and oscillations invariably include the fast response climate variables, namely the atmosphere and to a lesser extent the ocean.

A noticeably abrupt climate change occurred over the course of the 1960s and 1970s. The University of Maine possess the equipment necessary to access the high resolution data available for the study of this abrupt climate change. The spatially and temporally extensive data from this time period is mostly digitize for computer assisted access and analysis. Study of this recent abrupt climatic change, while small relative to some reflected in the geologic record, may provide clues for interpretation of past rapid climate change.

The research proposed extends recent regional high latitude climatic analyses toward a high latitude northern hemisphere climate response model. The research necessitates the two part study of northern hemisphere meteorological data: Arctic storm tracks and spatial and temporal changes in temperature, precipitation, and pressure patterns. The observed high latitude hemispheric climate relationships will be accommodated in a climate response model.

1345: **Michael Sanders:** Archaeology of the Bain Site, Nova Scotia

NO ABSTRACT AVAILABLE

Abstract: Mid-Holocene Climate Change in Northern Peru--Evidence, Implications, and Future Research. Dan Sandweiss.

I will discuss current and projected research on mid-Holocene climate change on the north coast of Peru (9° to 4° south latitude). Primary evidence for climate change so far comes from marine mollusks found in archaeological middens; a study of vertebrate fauna (fish, sea mammals, sea birds) from the same middens is in progress. Several other climatic records from the Andean region suggest mid-Holocene climate but without the clarity of the coastal data. Future research will involve more excavation and further analysis of archaeological materials, especially isotopic and trace element studies of mollusk valves, plus pollen studies and work with Holocene segments of cores from the continental shelf adjacent to the north coast of Peru. Should the evidence for a different mid-Holocene climate in northern Peru be confirmed, it would suggest that the El Niño phenomenon functioned quite differently (or not at all) at that time. Such a finding would have implications for climate dynamics under conditions of global warming, as the mid-Holocene was apparently warmer than today.

MAINE PEATLANDS: RELATIONSHIPS TO PRESENT, PAST AND FUTURE CLIMATES

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OBJECTIVES, APPROACHES, PROGRESS & PRELIMINARY RESULTS

Our objectives are to elucidate the present and past relationships of Maine peatlands to climate, and to predict future peatland responses to potential changes of climate. The predictions will be based on (1) the present numeric relationships with climate of the peatlands and their components, and (2) responses of the peatlands and their components to past changes of climate. Our approaches include the use of canonical correspondence analyses (CCA) on existent biological, chemical, and physical data (including climate) from >100 Maine peatlands, to reveal meaningful relationships. The peatlands represent the full ranges of geographical and ecological variation of peatlands in the state. If supported by CCA, the data will be used to calibrate regression models for inferring past climate change and future peat-land response to climate change. The calibrated regressions will be applied to peat contents (e.g., plant macrofossils; rhizopods) in multiple peat cores from several peatlands. The past changes may serve as analogues of future changes.

Progress and results from our first year of participation in EPSCoR include:

- (1) Establishing and cleaning up the following data from throughout Maine:
 - vegetation data from 650 relevés in 96 peatlands,
 - interstitial water and peat chemistry from 289 relevés in 51 peatlands,
 - bryophyte and lichen taxa of 51 peatlands,
 - maximum and mean peat depths in 268 peatlands,
 - modes of origin and main hydroseral stages in 51 peatlands, and
 - 3 to 30 year weather data from 63 stations.
- (2) Produced maps (mostly by GIS) of moisture deficit, potential evapotranspiration, bio-degree days (2° C base), growing days (2° C base), peatland types, bryophyte and lichen taxa, and peat depths. These maps indicate that the geographic limit of raised bogs is at a moisture deficit (allowing 10 cm depletion of soil water storage) of 2 cm and ribbed fens at - 5 cm (excess). Peat depths in raised bogs are maximal close to the southern limit of the raised bog zone. Northward, depths may be limited by bio-degree days and/or growing days.
- 3) Refined CCA and regression procedures (forward selection; weighted averaging regression).
- (4) Performed CCA and produced biplots of bryophytes/lichens and environmental factors. These analyses suggest that degree of minerotrophy is the most important factor determining biological distributions and that climate plays a significant yet secondary role.
- (5) Performed exploratory multivariate statistical analyses of peatland vegetational (vascular, bryophyte and lichen taxa, together) and environmental data. These analyses also suggest that degree of minerotrophy is the most important factor determining biological distributions and that climate plays a significant yet secondary role.
- (6) Planning has been underway for:
 - establishment of permanent plots for long-term monitoring of peatland responses,
 - studies of differential decomposition/representation of plant macrofossils for vegetational interpretation of the macrofossil record (possibly part of Ph.D. thesis), - study of fen origins and development (M.S. thesis)

Background reading

Davis, R.B. 1993. Potential responses of boreal peatlands near their southern limit to a warming and drying of climate. Proceedings of the conference: A Regional Response to Global Warming: New England and Eastern Canada, 19-21 May 1993, Portland, Maine.

Abstract:
Paleoecology of the Coastal Plain of South Carolina and its implications for climate history of the Southeastern U.S.

Tristram C. Hussey

In May 1992 a core 8.5 m long was recovered from Clear Pond, Horry County, SC. High resolution (100-200 yrs between samples) pollen analysis of the core supports hypotheses of rapid vegetation and climate change in the Southeast. This record is one of only three high resolution records in the Southeast that does not contain sedimentary hiatuses through the full-late-glacial interval. This record is critically important because its proximity to the coast (14 km) provides data on the influence of North Atlantic Ocean phenomena.

Clear Pond's record extends uninterrupted for about 20 ka. Pollen data for the site contain the three pollen zones generally present in the Southeast, but with some important differences that suggest both coastal and edaphic effects. These differences include a drier full-glacial vegetation than previously noted in the Carolinas and two short periods of probable hydrologic change during the early and late Holocene. No evidence is present for a Younger Dryas-type climate reversal at Clear Pond. Holocene pine-oak vegetation developed after about 8000 yr BP.

Because of this record's high resolution, it can be compared to data from Lake Tulane, FL (Grimm, *et al.*, 1993), Anderson Pond, TN (Delcourt, 1979), and Tannersville Bog, PA (Watts, 1979), all of which reveal events in unglaciated North America. Clear Pond and other sites experienced a period of rapid vegetation and climate change *circa* 14,000 yr BP. This interval suggests widespread climate change that followed the last ice advances of the Laurentide Ice Sheet in eastern North America. The mechanisms for this rapid climate change may include the Gulf of Mexico, the Atlantic Ocean, continental or hemispheric weather patterns (e.g., the jet stream), or a combination of all of these. Until now, effects along the Mid-Atlantic coast were unknown, Clear Pond provides an important link between peninsular Florida, the Cumberland Plateau, and eastern Pennsylvania.

**FULL AND LATE GLACIAL VEGETATION AND CLIMATE
FROM THE CHILEAN LAKE DISTRICT.**

Patricio I. Moreno

The Late Pleistocene history of the Chilean Lake District (39°-41°S) has been the focus of numerous palynological and (to a lesser extent) glacial geologic studies, for the last 35 years. Despite the abundance of palynological studies in the Lake District, only 16 pollen sites are of late glacial age, and only two of them are continuous during this whole time span (Heusser 1974, 1981). The goal of my thesis is the palynological analysis of the Puerto Octay Southern Spillway site. Emphasis is being put on the development of a high resolution pollen stratigraphy and a detailed AMS chronology.

The vegetation of the area is characterized by the altitudinal and latitudinal zonification of the plant communities [in an altitudinal gradient: lowland deciduous forest (LDF), the Valdivian rainforest (VRF), the North Patagonian rainforest (NPRF), the Subantarctic rainforest (SARF), and the alpine tundra (AT)]. The distribution of these plant communities is strongly influenced by the local topography and the climatic gradients, the occurrence of volcanic eruptions and earthquakes constitute important disturbance agents as well.

As a consequence of a finer time resolution, my preliminary results portray a vegetation and climatic history more complex than previously reported:

20-18 ka: the presence of AT taxa (Nassauvia, Valeriana, Empetrum, Lycopodium magellanicum), Maytenus distichia (transition between (SARF and AT), Nothofagus dombeyi-type (possibly N. pumilio) and Misodendron (possibly M. oblongifolium, parasite of the latter), and traces of Donatia fascicularis (Magellanic moorland taxon), suggest a climate much colder and rainier than the present around the site.

18-15.5 ka: the increase in arboreal pollen (AP), the presence of Lycopodium fuegianum, Astelia pumila, the rise in Donatia fascicularis, and some of the taxa found at 20-18 ka, suggest a gradual trend of warming under a rainy regime. The end of this warming trend is established by the decline of Myrtaceae, after having increased abruptly. The timing of this warming trend correlates with the Varas interstade.

15.5-12.5 ka: the decline of the previous mesic taxa, and the presence of taxa with affinities for cold and wet climates, suggest stadial conditions that correlate with the Llanquihue III glacier advance. This cooling event is punctuated by a short warm episode at ca. 13.8 ka, reflected in the rise of mesic taxa (Myrtaceae, Hydrangea, Eucryphia/Cladcluvia, etc.). The sharp decrease in AP, reflected in the 13.6 ka maximum of Cyperaceae, seems to indicate a rapid and drastic cooling.

12.3-10 ? ka: the rapid (less than 120 years) and drastic increase of Myrtaceae and associated mesic taxa, seems to indicate a warming and possibly a reduction in rainfall. After this event, there is a decline in these taxa, and a concomitant increase in NAP at 11.3-10.5(?) ka. An interpretation for this event awaits further analysis and AMS dates.