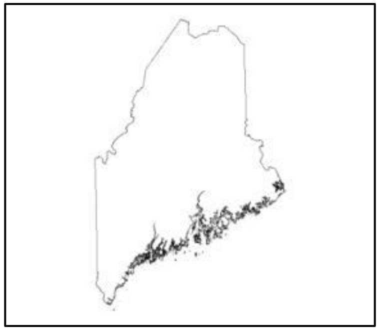
Geologic Site of the Month

December, 2000

Lake Levels and Climate Change in Maine and Eastern North America during the last 12,000 years



Text by
Maine Geological Survey

Introduction

Changes in lake levels during the last 12,000 years in eastern North America and Maine show spatially coherent patterns, implying climatic control (Harrison, 1989). Recent studies of the postglacial lake sediments in Maine and the Northeast have shown that climatic conditions during this period fluctuated from moist to warm and dry and back to moist, present day conditions. By looking at paleoclimatic data (sediment record, macrophytic plant fossils, C-14 dating, and sub-bottom profiles) from Maine and other New England lakes and comparing it to factors known to affect climate change, in particular insolation (the amount of solar radiation reaching the Earth), one will have a better understanding of the climatic changes of the last 12,000 years and this will serve as a fossil analog to possible future global warming events.

The "isolated basin" model of lake formation

Much of Maine has well preserved evidence for the last glaciation, when the Late Wisconsinan ice sheet traveled south from the Hudson Bay area. Evidence of the direction of the glacier movement is preserved in the northwest-southeast striations and grooves visible in the bedrock (Smith and Hunter, 1989). Approximately 17,000 years before present (BP), the ice reached its maximum extent extending beyond the current coastline onto the continental shelf. The weight of this glacier depressed the underlying land mass. The ice began to retreat from the shelf between 17,000 and 15,000 years B.P. (Smith and Hunter, 1989). As the ice withdrew, the land remained depressed due to the previous weight of the glacier, allowing marine waters to flood the coastal lowland. The land remained below sea level as it began to rebound until approximately 12,000 years B.P. when the present coastline was exposed above sea level.

The "isolated basin" model of lake formation

In Maine, the Late Wisconsinan glacier scoured numerous lake basins. Caldwell (1989) suggests that as the retreating ice sheet withdrew past the Maine coastline around 14,000 yrs B.P., many of these basins were filled with marine waters. An "*isolation basin*" model of lake formation (Haftsen, 1983), explains how a basin is depressed below sea level by the weight of a glacier and the rebounding process creates an isolated lake (Figure 1).

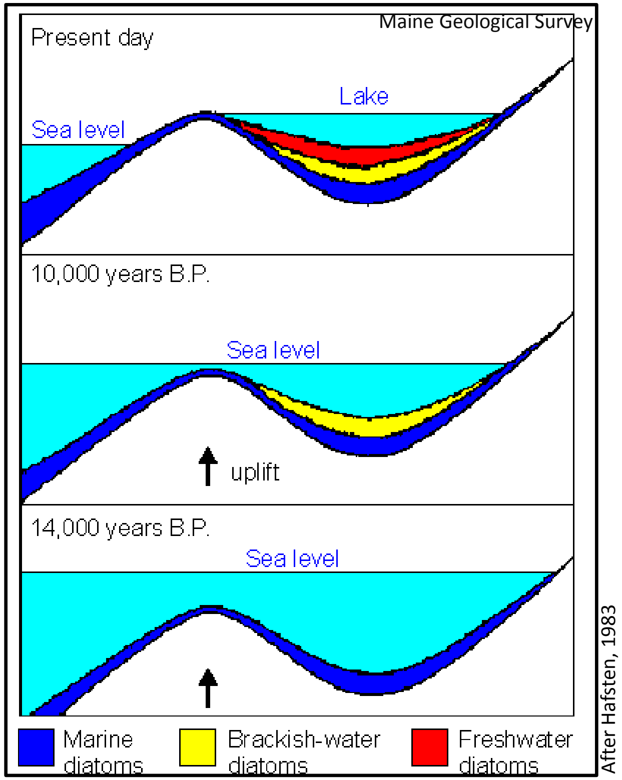


Figure 1. Model of lake basin development following glaciation.

The "isolated basin" model of lake formation

As the land began to rebound, the actual marine level continued to rise at a slightly higher rate. During this interval the lake basin would be filled with marine waters and corresponding marine sediments would be deposited. When the rebound exceeded the rise in sea level, the basin would become isolated and freshwater sediments would be deposited. In looking at a stratigraphic section cored from such a lake, one would see the following: at the bottom a scoured bedrock basin floor overlain by marine sediments; then a section composed of brackish deposits, reflecting the transition from the marine environment to the closed freshwater environment; and the top section would be composed of freshwater sediments. The marine fine-grained silt and clay are named the Presumpscot Formation (Bloom, 1963). The vegetation and fossil pollen records of these sediment cores mark the change from a marine environment to an organic-rich lacustrine (lake) environment.

Fluctuations in water levels of these closed lakes, which are particularly sensitive to changes in the balance between precipitation and evaporation, provide a detailed climatic record of variations in regional and continental moisture and aridity (Smith and Street-Perott, 1985). The current spatial distribution and relative extent of such lakes can be directly related to the mean position of major features of the atmospheric circulation (Street-Perrott and Harrison, 1985). Examination of the patterns of lake-level variations and reconstructions of regional hydrological changes can be used to test climatic reconstructions from climates simulated by general atmospheric circulation model experiments, which try to simulate historic climate patterns (Harrison, 1989).

The "isolated basin" model of lake formation

Pollen and sedimentological analyses of the lake sediment record from these "isolated" lakes reveals that significant variations in climate occurred during the last 12,000 years. The two key factors which caused these climatic changes and the associated lake level fluctuations, are the retreat and disappearance of the Laurentide ice sheet and the orbitally induced changes in insolation. These factors forced the sequence of regional climatic change across eastern North America, which in turn caused the sequence of changes in vegetation and regional water budgets. The lake-level data, determined by sediment core analysis and mapping paleo-shorelines, for Maine and eastern North America show that conditions were on average wetter than today during the late glacial period, then became rapidly drier after 10,000 yrs B.P., with a maximum aridity, indicated by low lake levels, occurring at 6,000 yrs B.P.

Climate models and Maine lakes

Sub-bottom profiles, showing wave-cut shorelines and erosional facies, from Sebago Lake, Taylor Pond, and Lake Auburn in central Maine, indicate lake-levels 2-6 m lower than present during the mid-Holocene (Figure 2). Macrophytic plant fossils from the paleo-shoreline sediment indicate shallow water vegetation and have maximum and minimum C-14 dates of 8,800 and 6,700 yrs B.P. Current sediment core analyses and sub-bottom profiles from two other Maine lakes show preliminary results of a greater than 6 m lake level drop at 6,000 yrs B.P.

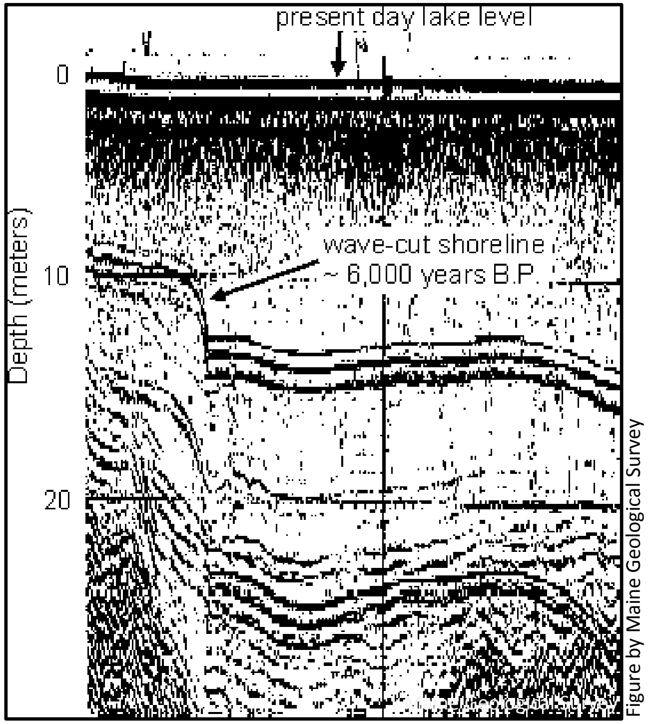


Figure 2. Sub-bottom profile from Sebago Lake, Maine showing present day lake level and lake level at 6,000 years B.P.

Climate models and Maine lakes

Climate models show a major change in atmospheric circulation patterns over eastern North America, induced by the retreat and lowering of the Laurentide ice sheet, increased summer insolation and decreased winter insolation, between 12,000 and 9,000 yrs B.P. (Webb, 1987). With the close proximity to the ice between 12,000 and 9,000 yrs B.P., cooler and moister conditions prevailed in Maine, even though solar insolation was increasing.

At 9,000 yrs B.P., with the effects of the ice sheet much reduced, the high summer insolation caused strong heating in the southwest and created an enhanced monsoon low. This resulted in greater southerly flow of air into the northeast, bringing more precipitation from the Gulf of Mexico. However the increase in precipitation in the northeast was not sufficient to counteract the evaporative effects of higher summer insolation, so conditions drier than present prevailed over the eastern part of North America. The lake level data from Maine and the northeast support this climate model. They show drier conditions at 9,000 yrs B.P., while the monsoonal flow explains why the water level in most lakes in the Midwest remained high (Harrison, 1989).

Climate models and Maine lakes

At the time of the mid-Holocene thermal maximum in Maine around 6,000 yrs B.P., most climate conditions (Figure 3) were at or near modern values except for the orbitally-induced insolation which was greater than today (Webb et al, 1993). The still-large seasonal radiation extremes continued to be the dominant influence on North American climate with a significantly warmer (+20 degrees C) summer condition (Kutzback, 1987). The return to wetter conditions occurred gradually, but lake levels were similar to today by 2,000 yrs B.P.

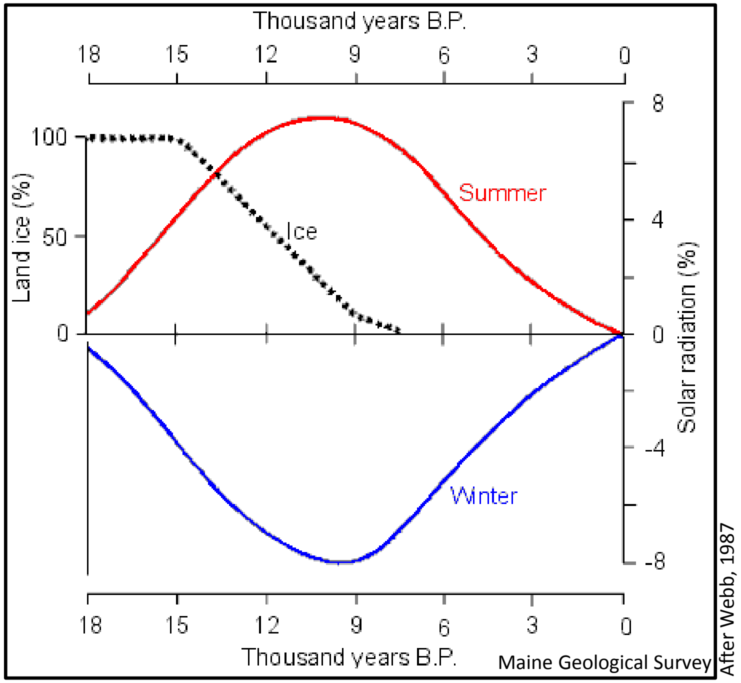


Figure 3. Land ice volume as a percentage of 18,000 years B.P. ice volume, and solar radiation (summer and winter), for the last 18,000 years for the northern hemisphere.

Summary

The lake level data for Maine and eastern North America show that on average conditions were wetter than today during the late glacial period, then became rapidly drier after 10,000 yrs B.P. (Harrison, 1989). From 10,000 to 6,000 B.P., arid conditions prevailed in Maine with a maximum aridity at 6,000 yrs B.P., when most of the lakes in Maine and the northeast were at their lowest levels (Figure 4). This general trend towards increasing aridity during the early and mid-Holocene is also consistent with independent evidence from pollen calibration (Bartlein, 1984). This pattern is similar to the pattern of change in summer insolation.

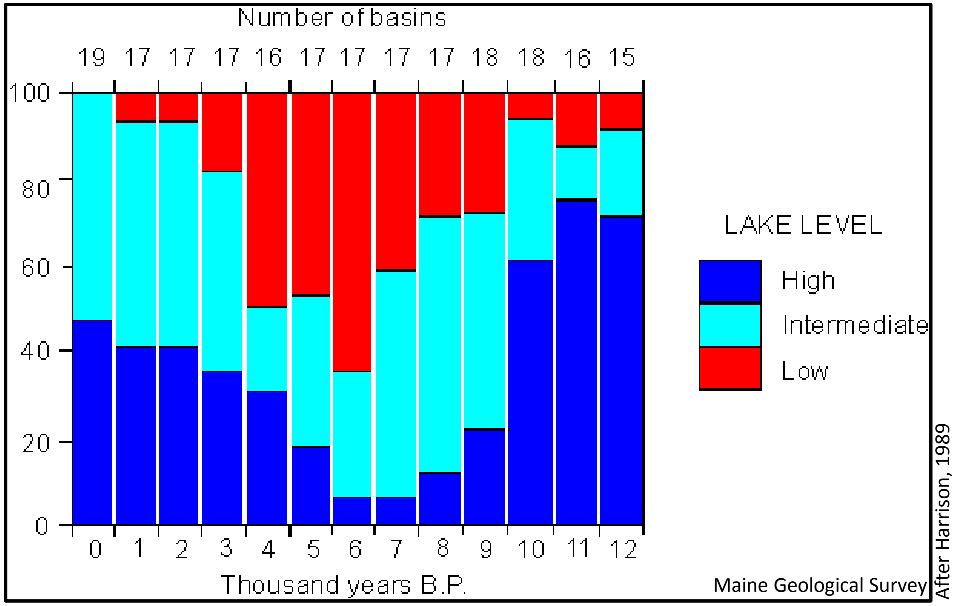


Figure 4. Lake level data for eastern North America, showing conditions wetter on average than today during the late glacial period, then becoming rapidly drier after 10,000 yrs B.P. Maximum aridity occurred at 6,000 years B.P. The return to wetter conditions occurred gradually, with lake levels similar to today by 2,000 years B.P.

Summary

Using evidence of changes in lake levels to reconstruct the hydrological changes over Maine and the Northeast during the mid-Holocene, we see how these results can be explained by the effects of known changes in insolation as simulated in the climate models. Variations in the seasonal and latitudinal distribution of solar radiation caused by changes in earth-sun geometry are at the core of our understanding of late-Quaternary climatic changes. The general similarity (warmth) between the paleoclimate data and the model results implies that changes in the orbitally induced insolation used in the climate simulations induced the climatic changes inferred from the data.

The spatial and temporal coherency in the patterns of lake-level changes over eastern North America and Maine during the last 12,000 yrs implies that the lakes have responded to climatic changes. Changes in hydrological balance inferred from the lake-level data agree with those predicted by climate modelsat the broadest scale.

An understanding of the regional patterns of lake-level behavior over North America, requires an appreciation that the paleo-atmospheric circulation was at least as complex as that of the present day. A reasonable level of explanation of the observed patterns has been achieved by consideration of insolation changes.

Since the warm and dry period around 6,000 yrs B.P. in Maine and the eastern North America are similar to, if not greater than, the projected future rise in temperature as a result of possible greenhouse effects, it appears appropriate that more effort should be devoted to understanding the nature, causes, and consequences of climatic changes that have occurred in the Holocene, and thus to anticipate the implications of similar changes in the future.

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