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Global Change and Climate History

Evidence of Climate Change over the Last 10,000 Years from the Sediments of Lakes in the Upper Mississippi Basin

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The study of lake sediments as recorders of past climate change has been a major focus of the Geologic Division's Global Change and Climate History Program. In particular, lakes of the Upper Mississippi Basin (UMB) provide some of the most detailed records of climate and environmental change during the Holocene (last 10,000 years). The UMB is particularly sensitive to climate change because the three airmasses that control the climate of North America (fig. 1) intersect here.

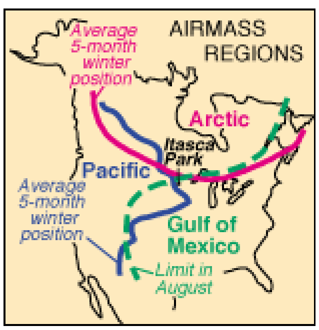

Figure 1. Airmasses that affect the climate of North America.

A warm, moist, Gulf of Mexico airmass dominates in the northern Great Plains during summer, and provides most of the annual moisture in the UMB, whereas the winter months experience competition between a cold, dry Arctic airmass and a dry Pacific airmass. As a result of the interactions among these these three airmasses, the gradual north-south climatic gradient in the Great Lakes region changes to a steep east-west climatic gradient across Minnesota and into the Dakotas. This change can be seen in a map of present vegetation in Minnesota (fig. 2), which shows a north-south forest-prairie border in southeastern Minnesota but an east-west forest-prairie border in northwestern Minnesota. Changes in the interactions of these airmasses produce climate changes on decadal, millennial, and even longer time scales; these changes can be rapid and extreme on human time scales. For example, drought conditions in the Great Plains occur whenever the Pacific airmass predominates, as it did during the dust-bowl years of the 1930's.

Sediments in lakes in the Upper Mississippi Basin provide archives of climate and environmental change over time periods that range from years to millennia. Cores documentation of Holocene paleoclimatic and paleoenvironmental changes. This documentation can be accomplished by detailed, multidisciplinary investigations of biological, sedimentological, and chemical characteristics of lake sediment once the relations between climate and the processes that produce lake sediments are known. In order to define rates and magnitudes of paleoclimatic and paleoenvironmental changes, a precise, high-resolution time framework (annual or decadal) is required. The highest resolution records come from lakes whose sediments contain identifiable annual increments of sediment (varves; inset, fig. 3).

One example of a lake with varved sediment is Elk Lake in the Mississippi headwaters region, Itasca Park, in northwestern Minnesota (fig. 2). On the surface, Elk Lake with its forested shores (fig. 3) resembles many of the other lakes in the "Land of 10,000 Lakes." However, the sediments underneath the lake contain varves that have marked off the seasons year after year for the last 10,400 years (inset, fig. 3).

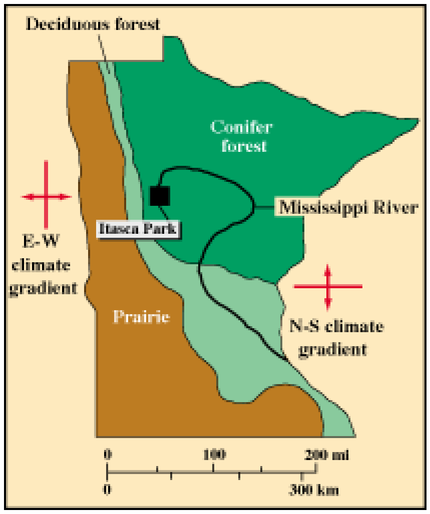

Figure 2. The present vegetation of Minnesota reflects the change from N-S climatic gradients in the Great Lakes region to E-W gradients of the Great Plains. The Mississippi River begins as the outlet to Lake Itasca in Itasca State Park.

These varved sediments yield abundant biological, chemical, and mineralogical components that can be related to climate and environmental change. Most of the sediment components are produced in the lake (for example, organic matter, siliceous shells of diatoms, precipitated calcium carbonate), but small amounts of silt and clay are blown into the lake by the wind. The thickness of the varves (fig. 4, left) is a function mainly of the amount of wind-borne silt and clay that is delivered to the lake. Much of the wind-borne silt and clay consists of the mineral quartz, so that varve thickness and relative abundance of quartz (fig. 4) are both indicators of windiness. Because of its heavy silica shell, the diatom Aulacoseira (fig. 4, right) requires turbulence to keep it in the photic zone, and this also means windy conditions. Most of the sodium in sediments is in plagioclase feldspar that is very sensitive to chemical weathering (decomposition) and, therefore, to available moisture. In a wet climate, plagioclase decomposes, and the sodium goes into solution and ends up in the ocean (which is why the sea is salty). In a dry climate, plagioclase is not so easily decomposed and so it is retained in soils, which are then washed or, as in the case of Elk Lake, blown into lakes.

Figure 3. On the surface, Elk Lake with its forested shores resembles many other lakes in glaciated regions of the Midwest, but sediments underneath the lake contain annual layers (varves) that have marked off the seasons year after year.

Applying these proxy variables to interpreting the Holocene record in Elk Lake, we get our first clues from the succession of terrestrial vegetation in the region as indicated by the pollen in the sediments. After the last ice sheet retreated into Canada a little more than 10,000 years ago, the area was dominated by a spruce forest, which was rapidly replaced by a pine forest as the climate got warmer. Then, about 8,500 years ago, the pine forest began to be replaced by prairie vegetation dominated by grasses, sagebrush (fig. 4), and oak as the area became markedly drier. Studies of pollen in other lakes and bogs in the UMB show that during this "prairie period" (about 8,500 to 4,000 years ago) the forest-prairie border that is now in western Minnesota (fig. 2) migrated eastward by as much as 150 km. Dryness during the prairie period is further indicated by the markedly higher sodium content of the sediments (less available moisture to break down the plagioclase feldspars). More turbulence in the lake water, presumably from more wind, is indicated by the abundance of the diatom Aulacoseira (fig. 4). Increased wind-borne dust is indicated by the thicker varves and marked increase in quartz. This mid-Holocene drought affected a large portion of North America, and active dune fields formed in Minnesota, the Dakotas, Nebraska, and elsewhere in North America. The prairie period probably documents an extended period of time when the dry Pacific airmass (fig. 1) exerted a dominant control on the climate of North America, just as it did during the dust-bowl. However, the dust-bowl drought pales in comparison to the mid-Holocene drought, and points out how susceptible the UMB is to climatic change.

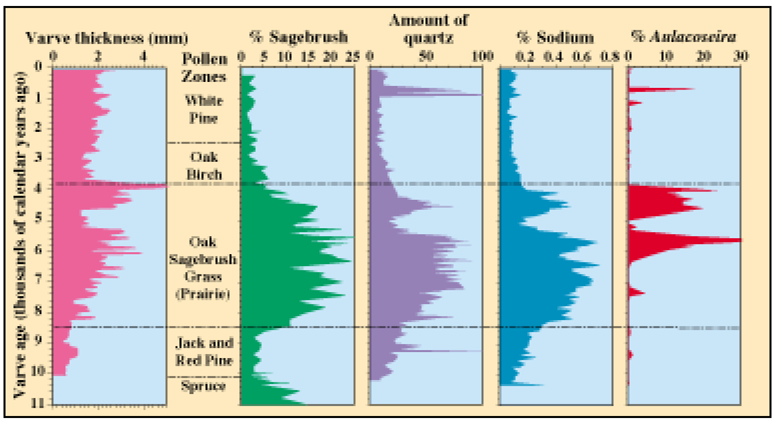

Figure 4. Several Proxy indicators in the varved sediments of Elk Lake show that 8,000 to 4,000 years ago, dry, warm, windy, dusty prairie conditions with sagebrush vegetation occupied this region of Minnesota that is now forested.

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