Report for 2001MN3421B: Paleohydrologic response of the Mississippi Headwaters watershed to Holocene climate change

There are no reported publications resulting from this project.

Report Follows:

Paleohydrologic response of the Mississippi Headwaters Watershed to Holocene climate change

H.D. Mooers, Associate Professor and PI, (hmooers@d.umn.edu) and **P.C. Larson**, Research Assistant, Department of Geological Sciences, College of Science and Engineering, University of Minnesota, Duluth

Project duration: March 1, 2001 to June 30, 2003
Funding source: USGS-WRRI 104B National Grants Competition and the Water Resources Center

Summary

This study examines the sedimentary record of major changes in the hydrologic budget of three large lakes in the Mississippi Headwaters area (Cass, Leech, and Winnibigoshish) resulting from multiple diversions of the Mississippi River and its tributaries. Sediment cores collected from Cass and Leech Lakes, in combination with a core previously collected from Lake Winnibigoshish, provide a record of the effects of regional-scale climate-driven changes on the hydrology of the Mississippi Headwaters watershed.The lakes' hydrologic budgets were affected by a series of diversion events that altered the main course of the Mississippi, and altered the watershed areas and throughflow rates of the three lakes.

One of the diversion events is recorded as a prominent, abrupt change in the nature of carbon sedimentation in Lake Winnibigoshish. However, this and other diversion events are not apparently discernable in Cass and Leech Lake sediments. The cause of the radically different response of Winnibigoshish to a diversion event is still enigmatic; however, it implies the existence of an as yet unidentified control on the nature of lacustrine carbon sedimentation.

Ongoing geochemical, stable isotope, and diatom-nutrient calibration work will help distinguish the effects of climate-forced hydrologic variability from those of nutrient loading on sedimentation in the large Headwaters lakes.

Introduction

Most previous paleolimnological investigations in Minnesota have focused on interpreting the sedimentary records of relatively small lakes in small watersheds (Bradbury and Dean 1993, Winter 1997). While the high-resolution records found in these lakes are of undoubted value in interpreting past climatic and vegetation history, they are to some extent extremely sensitive to local conditions not reflective of the region as a whole (c.f. Schwalb and Dean 2002). In contrast, the sedimentary records of the largest lakes in a drainage basin might be expected to record a regional-scale signal of climate change. This study examines the sedimentary record of major changes in the hydrologic budget of three large lakes in the Mississippi Headwaters area due to multiple diversions of the Mississippi River and its tributaries.

During the late Holocene, drainage patterns in the Mississippi Headwaters underwent a number of realignments. Prior to circa 3000 years before present (3 ka bp), the main stem of the Mississippi River flowed from Lake Bemidji to Leech Lake, thence down the present-day Leech Lake River. The outlet of Lake Winnibigoshish flowed southward to the Leech Lake River, and Cass Lake's outlet flowed south to Leech Lake. After this time, three stream piracy events led to diversion of major portions of the watershed into a new Mississippi River channel. The Mississippi now flows from Lake Bemidji through Cass and Winnibigoshish, exiting Winnibigoshish by a new eastern outlet. Leech Lake lies in a much diminished watershed, and continues to drain toward the east.

During the mid-Holocene, Cass and Leech Lakes were characterized by large watershed:lake area ratios, while Winnibigoshish had a small one. This condition led to evaporation-forced hydrologic closure of Winnibigoshish, lower lake levels, eolian erosion of bottom sediment, and development of a dunefield on the eastern shore of the lake. These geomorphic relationships, and their implications for the paleohydrologic budgets of the lakes, indicates strong linkages exist between climate, hydrology, landforms, and the sedimentary records of the lakes.

Methods

Coring

Cass and Leech Lakes were cored in August 2001 using the University of Minnesota Limnological Research Center's ETH-Kullenberg system, a raft-mounted piston corer designed for use in deep water. Recovered cores are

9-cm in diameter. On both lakes, the coring location was the deepest part of the lake.

A 640-cm core was recovered from 44-m water depth in Walker Bay of Leech Lake. Sediment in this portion of the lake has a relatively high clastic component and corresponding high density, resulting in incomplete penetration of the coring device. However, the key late Holocene portion of the sediment record was completely sampled.

A 351-cm core was recovered in 34-m water depth in the northern portion of Cass Lake. Although short, this core terminates in glaciofluvial gravel and likely represents a complete postglacial section.

Lake Winnibigoshish was previously cored using a modified Livingston corer. A 575-cm core was recovered in 20-m water depth. Similar to Leech Lake, sediment in the lower portion of the sequence has a relatively high clastic component and corresponding high density, resulting in the inability to recover a complete postglacial section. However, the key late Holocene portion of the sediment record was completely sampled.

Sediment dry bulk density

Sediment dry bulk density was determined by weighing 1-cm^3 samples of water-saturated sediment, freeze-drying, and weighing of the dried sediment. Sediment water content (porosity) corresponds to water loss during drying, and dry bulk density to the mass of dried sediment divided by the original volume.

Magnetic susceptibility

Whole-core magnetic susceptibility for all three cores was measured at the Limnological Research Center, University of Minnesota. Magnetic susceptibility is a proxy measurement for the relative amount of clastic material in the sediment.

Carbon analyses

Inorganic carbon and total carbon content of sediment from the recovered core was determined by coulometry at the Large Lakes Observatory, University of Minnesota Duluth. The organic carbon content of sediment is calculated by subtracting the inorganic from the total carbon content.

CHNS analyses

Sediment total carbon, nitrogen, sulfur, and hydrogen contents are being analyzed using a LECO at the Large Lakes Observatory, University of Minnesota Duluth. Results of these analyses will allow assessment of the origin of organic carbon stored in the lakes' sediments.

Diatom nutrient calibration

Diatom analysis of sediment samples from all three lakes is being conducted by J. Kingston at the Natural Resources Research Institute, University of Minnesota Duluth.

Results to date

Core stratigraphy

The Lake Winnibigoshish core consists of 300 cm of silty marl in the basal (pre-diversion) interval. The diversion event is recorded as the abrupt appearance of fine-grained sand in the sediments, marking the beginning of a 28-cm thick clastic-rich fining-upward sequence. The upper 247 cm of the core are black sapropel.

The Leech Lake core recovered 640 cm of silty marl occasionally interrupted by minor beds rich in detrital organic material, and thin sand lenses.The Cass Lake core recovered 351 cm of organic-rich marl. No abrupt changes in the nature of sedimentation were recorded in either lake's sediments.

Carbon coulometry

Cass and Leech Lake sediments have relatively low organic carbon contents, while the pre-diversion interval in the Winnibigoshish core has very low organic carbon, contrasted by very high organic carbon in the post-diversion interval (Figure 1a). Cass and Leech Lake sediments are characterized by relatively high carbonate contents, while Winnibigoshish has high carbonate in the pre-diversion interval succeeded by relatively low carbonate contents (Figure 1b).

Magnetic susceptibility

Leech Lake sediments have the overall highest magnetic susceptibility of the three lakes, reflecting relatively abundant influx of silt to Walker Bay (Figure 2). Of particular interest are peaks at 260, 434, 450, 480, and 501 cm core depth. These coarser-grained, clastic-rich intervals likely represent mass flows, perhaps in response to lake level instability.

Cass Lake sediments have very low magnetic susceptibility, reflecting the very low input of clastic sediment to the northern basin of the lake through the Holocene. This is despite evidence that mid-Holocene lowstands may have resulted in significant sediment redistribution from the littoral zones of the lake.

Lake Winnibigoshish sediments have relatively high magnetic susceptibility in the pre-diversion interval, suggest-

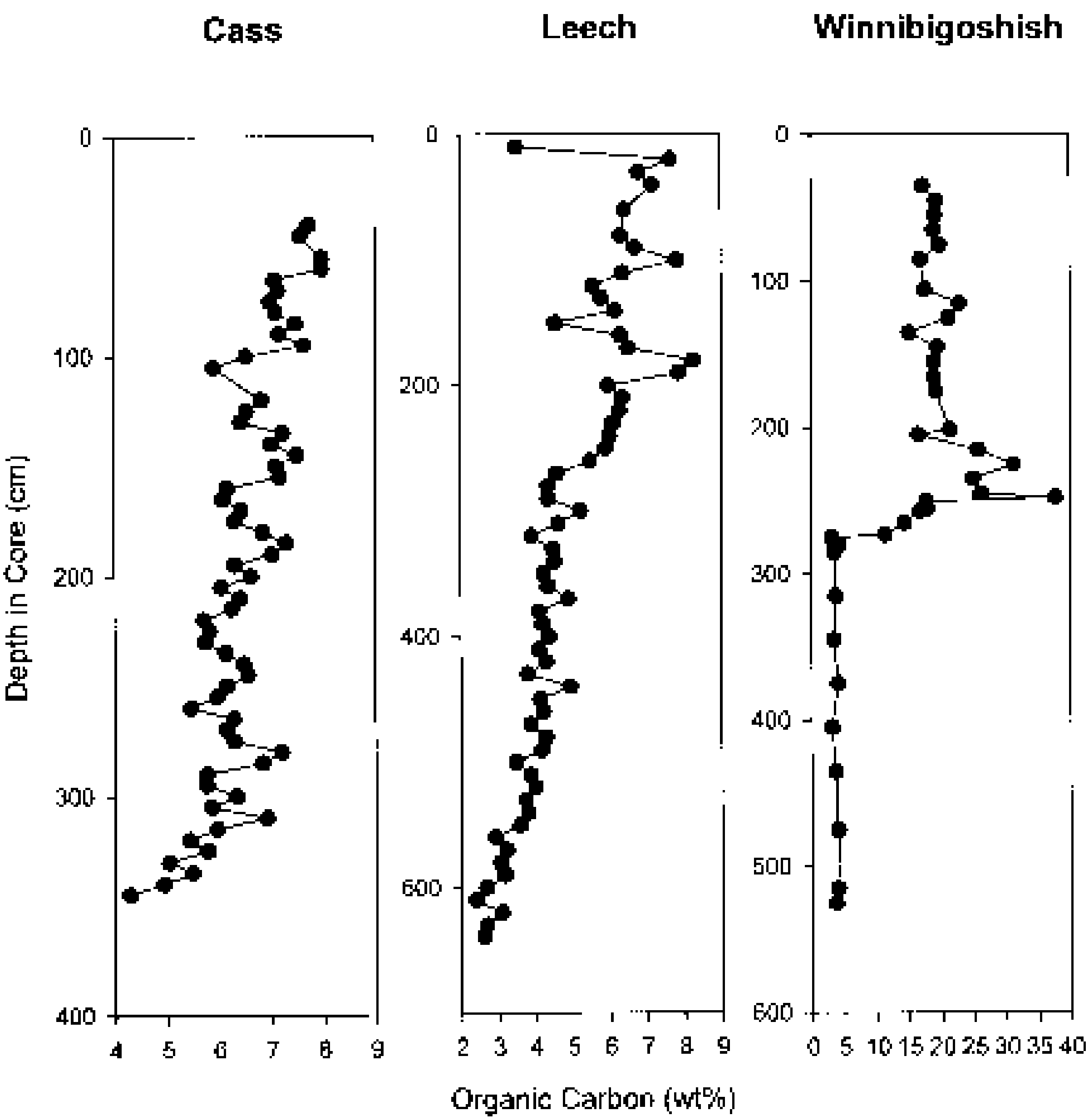

Figure 1a. Organic carbon content profiles for Cass, Winnibigoshish, and Leech Lakes.

ing fluctuating lake levels may have resulted in a small, but steady, influx of silt from the littoral zone to the deep basin. These magnetic susceptibility peaks are absent in the post-diversion interval, suggesting lake level, and therefore the shoreline, was stable through this period.

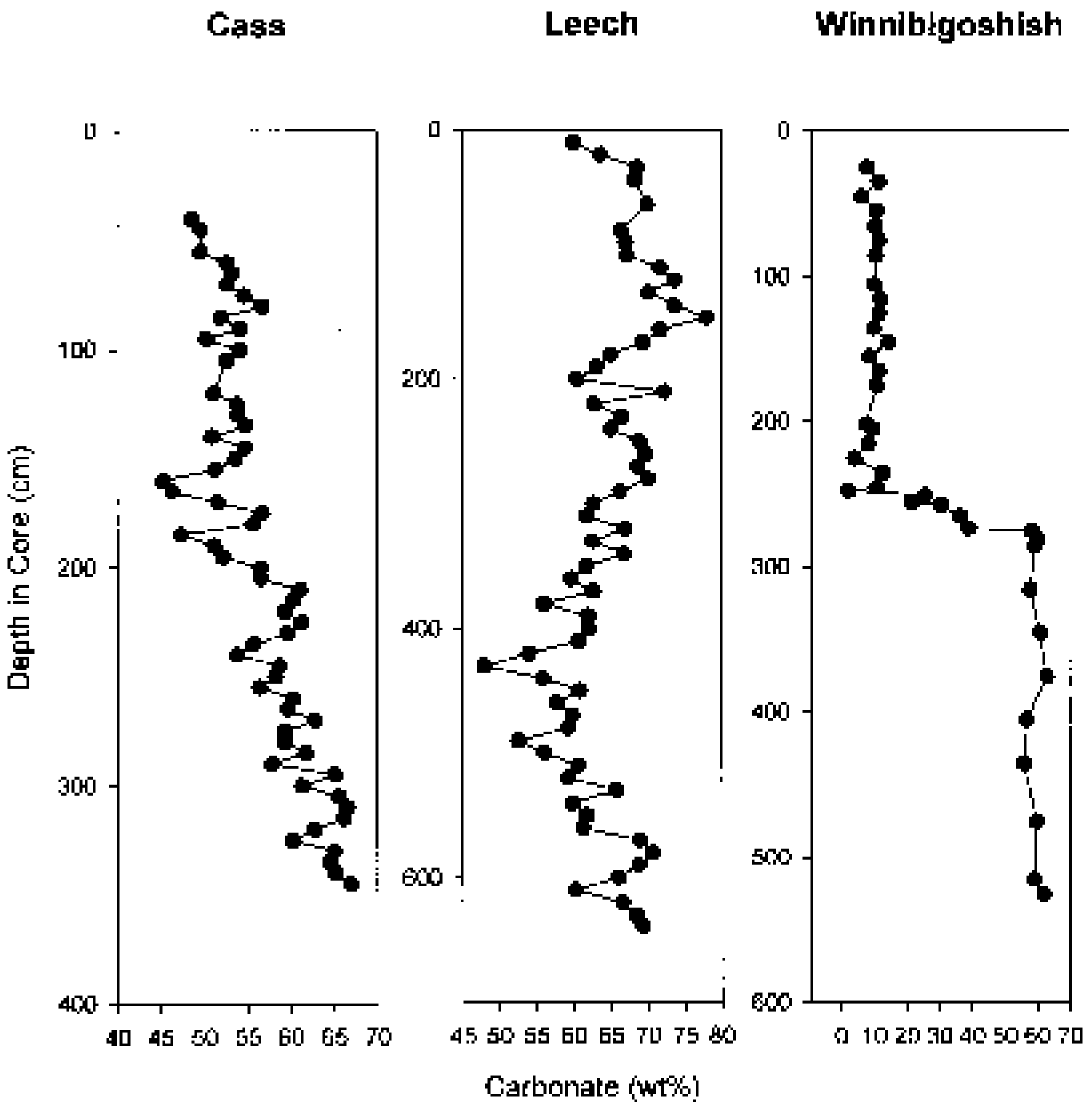

Figure 1b. Carbonate content profiles for Cass, Winnibigoshish, and Leech Lakes.

Description of ongoing work

As described above, results of diatom-nutrient calibration and CHNS analyses are pending. In addition, some of the radiocarbon dates for the sediment cores are still pending. Final results will complete the geochemical picture of the evolution of these large lakes during the Holocene.

Stable isotope analyses

The carbon and oxygen stable isotope compositions of ostracod and marl carbonate found in the lake sediments will be performed in 2003.

Diatom-nutrient calibration

Diatom population concentration and taxa will be counted, and the resulting data integrated with existing and ongoing diatom-nutrient calibration data for the Minnesota region (Kingston et al. 1990, Ramstack 1999, Kingston 2002). This diatom-nutrient calibration set references diatom abundance and taxa in modern bottom sediments to a variety of water-quality parameters, including water turbidity, Secchi transparency, color, and dissolved silica, chlorophyll-a, phosphorus, and nitrogen contents. The results of these analyses will be used to assess long-term changes in the nutrient status of the three Headwaters lakes. Particular emphasis is being placed on quantifying changes in nutrient status corresponding to transitions in the nature of sedimentation recognized in the cores.

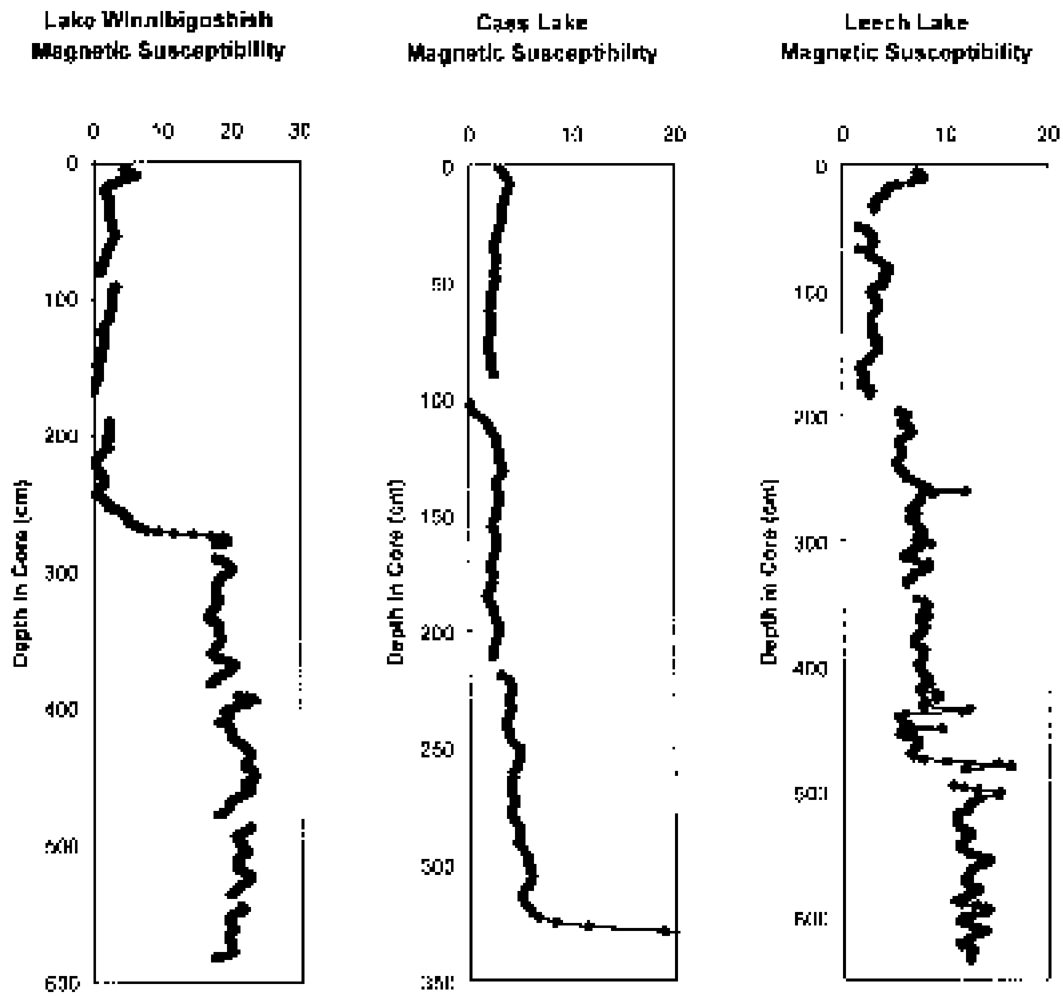

Figure 2. Magnetic susceptibility profiles for Cass, Winnibigoshish, and Leech Lakes. Units SI.

Sedimentology

Two undergraduate research projects by University of Minnesota- Duluth students investigating the sedimentology of Lake Winnibigoshish and its surroundings have been initiated in conjunction with this project:

K. Smith will examine the carbonate mineralogy of the lower portion of the Lake Winnibigoshish core by X-ray diffraction in an effort to determine if evaporative controls on carbonate sedimentation were present. The carbonate mineralogy of lacustrine sediment is often a function of salinity; low-salinity waters precipitate low-Mg calcite, while increasing salinity favors precipitation of high-Mg calcite or aragonite. Presence of high-Mg calcite or aragonite in Winnibigoshish's sediments will provide strong evidence of hydrologic closure and evaporative concentration of the lake prior to diversion of the Mississippi River into its watershed.

R. Smith is examining the sedimentology of eolian sediments in the Headwaters area to determine the extent of eolian activity in the mid-Holocene Winnibigoshish Dune Field. While Grigal and others' (1976) radiocarbon dates have firmly established the presence of eolian activity adjacent to Lake Winniboshish during the mid-Holocene, the areal extent of this activity is unknown. Comparing sediment characteristics and dune morphology of known mid-Holocene and known early Holocene (immediate post-glacial) dunes will allow assessment of the area of the Winnibigoshish Dune Field and volume of sand active during the mid-Holocene. This, in turn, will allow a more precise reconstruction of the effects of mid-Holocene aridity on the lake's hydrologic budget.

Summary of important findings

In Lake Winnibigoshish, diversion of the Mississippi River into the basin and the corresponding increased throughflow rate is accompanied by a radical shift in the nature of carbon sedimentation in the lake, from entirely carbonate to entirely organic carbon. Pre-diversion sediments in the core have very little organic carbon (3-4%) and carbonate contents of 60%. Post-diversion sediments have organic carbon contents of ~20% ranging up to 37%, and carbonate contents generally <12%.

However, a similar diversion and increase in throughflow rate of Cass Lake is not reflected in its carbon sediment record. Similarly, complementary decreases in the throughflow rate of Leech Lake are not reflected in its carbon sediment record. Cass Lake sediments record a gradual increase in organic carbon content from 5-8%, and a complementary decrease in carbonate from 65-50%. In Leech Lake, sediments record a gradual, steady increase in organic carbon from 2-8%, while carbonate varies from 48-78%. This pattern is similar to those reported by Dean (1999) in numerous lakes in Minnesota.

Dean (1999) has suggested that the shift from carbonate to organic carbon preservation in lake sediments is driven by increasing primary productivity. The transition in Lake Winnibigoshish is the most rapid reported in any lake in Minnesota. A 1-cm thick layer of nearly pure organic material in the core immediately following the diversion event suggests diversion was accompanied by increased nutrient loading. However, while the instantaneous increase in watershed area may have delivered increased nutrients to the lake, the presence of Cass Lake serving as a nutrient sink just upstream argues against this hypothesis. Alternately, pre-diversion carbonate sedimentation in Winnibigoshish may have been forced by evaporative concentration of lake water, a condition that was relieved with the initiation of increased throughflow. Results of the diatom-nutrient calibration study will help distinguish between these two hypotheses.

Our results suggest that the nature of lacustrine carbon sedimentation is controlled in part by a threshold condition, one which has not been reached in most lakes in Minnesota, including Cass and Leech Lakes. The incremental increase and decreases in throughflow experienced by Cass and Leech during the late Holocene were apparently not of sufficient magnitude to trigger radical change in carbon sedimentation, while the increase experienced by Winnibigoshish was. This suggests that future climate-induced hydrologic changes in the Mississippi Headwaters basin, rather than being gradually manifested, may be characterized by rapid onset of perturbation of lacustrine ecosystems.

References

Bradbury, J.P., and W.E. Dean, eds. 1993. Elk Lake, Minnesota: Evidence for Rapid Climate Change in the North-Central United States. *Geol. Soc. America Special Paper* 276.

Dean, W.E. 1999. The carbon cycle and biogeochemical dynamics in lake sediments. *J. Paleolimnology* 21: 375-393.

Grigal, D.F., R.C. Severson, and G.E. Goltz. 1976. Evidence of eolian activity in north-central Minnesota 8,000 to 5,000 yr ago. *Geol. Soc. America Bull*. 87: 1251-1254.

Kingston, J.C., R.B. Cook, R.G. Kreis, K.E. Camburn, S.A. Norton, P.R. Sweets, M.W. Binford, M. Mitchell, S.C. Schindler, L.C.K. Shane, and others. 1990. Paleoecological investigation of recent lake acidification in the northern Great Lakes states. *J. Paleolimnology* 4: 153-201.

Ramstack, J.M. 1999. Pollution trends in Minnesota lakes: the use of fossil diatoms as paleoindicators of human impact. Bethlehem: Lehigh University, 72 p.

Schwalb, A. and W.E. Dean. 2002. Reconstruction of hydrological changes and repsonse to effective moisture variations from North-Central USA lake sediments. *Quat. Sci. Reviews* 21: 1541-1554.

Winter, T.C., ed. 1997. Interdisciplinary Research Initiative: Hydrological and Biogeochemical Research in the Shingobee River Headwaters Area, North-Central Minnesota. U.S. Geological Survey, Water Resources Investigations Research 96-4215.