A Sediment Record of Abrupt Lake Level Change in West-Central Minnesota

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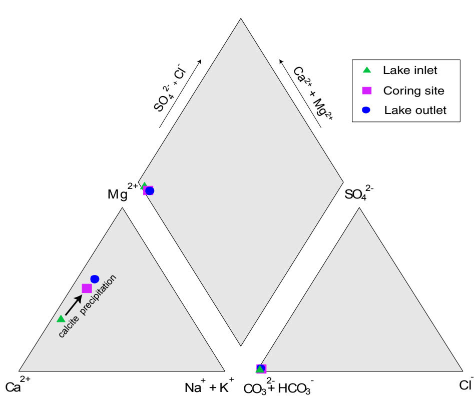
ABSTRACT

Records of historical events preserved in lacustrine sediments are valuable for testing the conceptual models used in paleolimnology. The effects of climatic forcing, watershed modification, and internal hydrologic dynamics are typically commingled in the geochemical signatures of sediments. Campbell Lake, Becker County, Minnesota, provides a record of abrupt lake-level drop unrelated to climate: in 1915 ditching reduced the lake surface area from 250 to 40 hectares and its average depth from three meters to one meter. We use a sediment core to assess the lake's response to this documented forcing, within the context of natural long-term variability. Existing paleoclimate studies from lakes in the region, as well as the historical record of anthropogenic impact to the lake, also make Campbell Lake a natural site to evaluate models of carbon and sulfur storage and carbon and oxygen stable isotope response to lake-level change.

The Campbell Lake core spans approximately the past 350 years, with excellent chronological control by ^{210}Pb dating for the period from 1860 to the present. While carbonate ^{13}C and ^{18}O begin a sustained negative trend around 1860, the approximate beginning of European settlement in the region, other indicators, such as mass accumulation rate (MAR) and C:S and C:N ratios, respond more sensitively to lake drainage. Evidence for the modern, charophyte-dominated macrophyte community does not appear in the sediments until around 1960.

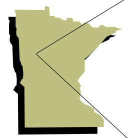
Watershed-scale effects apparently mask the stable isotopic response to local hydrological modification, while other geochemical proxies provide a better indicator of local basin-scale environmental change. Our research shows that abrupt forcing events may be only selectively manifested in the paleorecord.

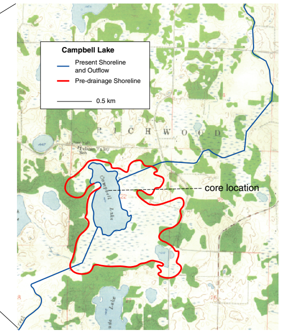
Aqueous chemistry

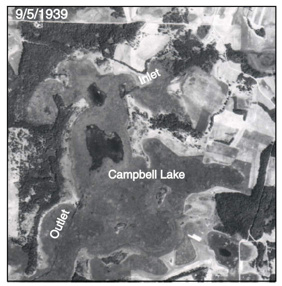


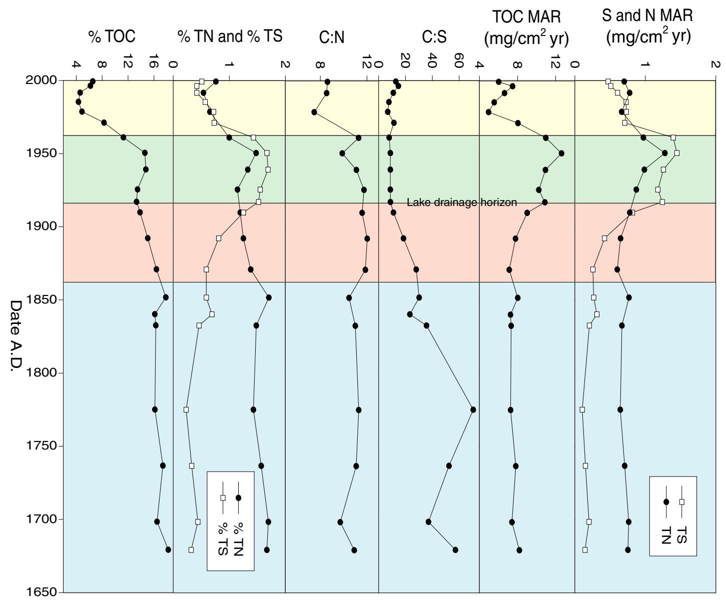
Site	pH	Alkalinity (mM/l as HCO_3^-)	Temp (°C)	DO (mg/l)	$^{13}C_{DIC}$ (VPDB)
Lake inlet	7.27	5.4	29.3	7.7	-5.76
Coring site	8.80	3.1	29.1	10.4	-6.62
Lake outlet	8.49	2.9	29.8	8.4	-5.95*

* Extended sample holding time

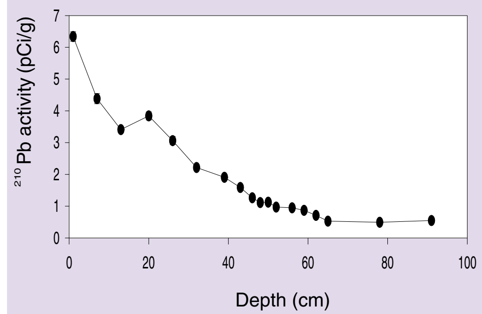




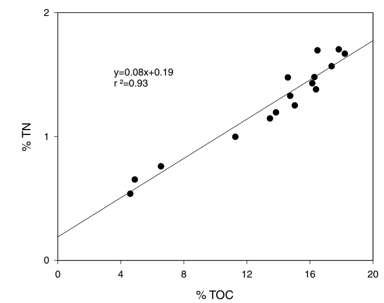


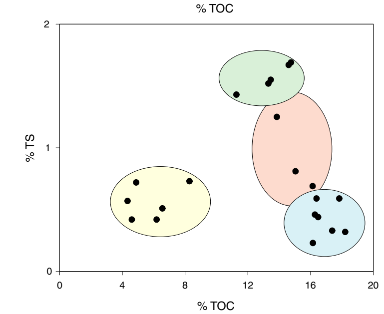


Pre-settlement sediments have generally high concentrations of organic carbon and low sedimentary sulfur and nitrogen values, with C/N and C/S values indicative of a mix of algal and terrestrial organic matter and low rates of sedimentary sulfate reduction. Following settlement, sedimentary N, S and C begin to rise. C/N and C/S ratios may document slightly higher inputs of terrestrial OM, perhaps related to increased surface runoff and erosion, increased productivity, and elevated levels of sulfate reduction. Total sulfur accumulation peaks, and C/S reaches a minimum, following drainage of Campbell Lake. During this time TOC and TN also peak, while C/N ratios decline slightly, likely indicating peak algal productivity coupled with elevated rates of sulfate reduction and sulfur retention. The latter is likely related to either reworking of sulfur-rich sediments from fringing marginal wetlands, or increased availability of easily metabolizable OM. High OC concentrations lend credence to the former. Roughly 50 years after drainage, the lake became dominated by *Chara* beds. C/S values remain low in this interval, likely due to increasingly oxic conditions in porous sediments, and declining TOC and TS concentrations.



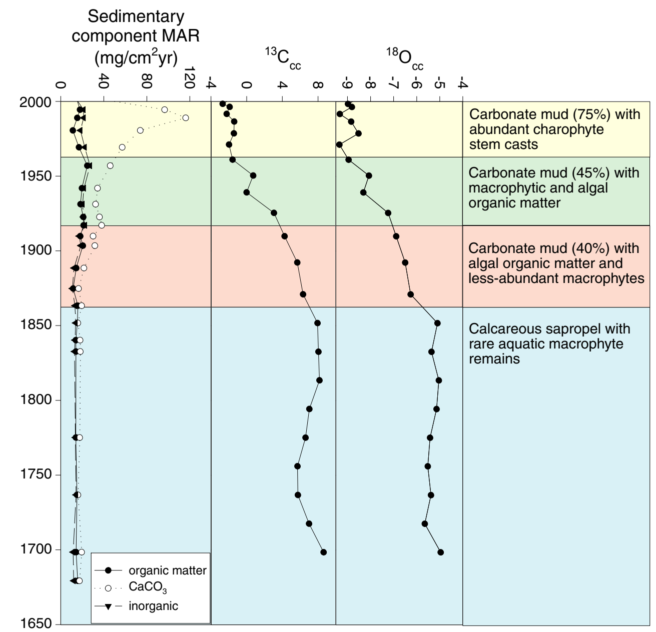
We used a ^{210}Pb chronology based on ^{210}Po counting by alpha spectrometry. The activity profile is straightforward, achieving a background ^{210}Pb level of 0.5 pCi/g near 1845 A.D.





Total organic carbon versus total nitrogen crossplots indicate that although most sedimentary nitrogen is organically-bound, some inorganic nitrogen (0.19%) is present. This likely indicates high rates of sedimentary nitrogen mineralization in anoxic sediments.

Sedimentary sulfur versus organic carbon crossplots show four data populations which correspond to the four phases of Campbell Lake's recent history: pre-settlement, post-settlement, post-drainage, and Charophyte-dominated. Each of these phases represents a distinct diagenetic environment (see below).



MAR: The mass accumulation rate of each sediment component begins to increase at settlement due to increased erosion and nutrient input. Carbonate MAR then jumps sharply around 1960, as calcifying charophyte algae begin to dominate the macrophyte community. Organic MAR decreases slightly, more likely due to decreased preservation under oxic shallow-water conditions than to decreased organic productivity.

^{18}O: Contrary to our expectations, a negative trend in ^{18}O begins well before lake drainage, continuing across the 1915 horizon without obvious deflection at the time of drainage. We infer that changing land use led to incremental changes in the distribution of hydrologic fluxes through the watershed, resulting in greater weighting of winter precipitation in lake water balance. Land-use change may also have shortened overall surface water residence time at the watershed scale.

^{13}C: Unusually positive ^{13}C values below the settlement horizon suggest the presence of diagenetic calcite. $CaCO_3$ formed in methanogenic sediments is typically enriched due to high microbial fractionation which leaves residual dissolved inorganic carbon (DIC) in pore waters highly enriched in ^{13}C. The up-core negative trend in ^{13}C may indicate increasing importance of SO_4^{2-} reduction as a metabolic pathway: this process does not fractionate carbon isotopes, and so produces DIC with values similar to the organic matter from which it is derived. A coeval increase in sedimentary S accumulation supports this hypothesis.

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