PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Faculty: *AL WERNER*, Mt. Holyoke College, *STEVE ROOF,* Hampshire College, *MIKE RETELLE*, Bates College
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A PALEOCLIMATE RECONSTRUCTION OF LAKE LINNÉ, SVALBARD, NORWAY

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Research Advisor: Mea Cook

INTRODUCTION

The average annual temperatures in the Northern Hemisphere have been warmer over the past three decades than within the last eight hundred years (IPCC, 2013). To understand how much of that change can be attributed to anthropogenic greenhouse gas emissions, it is necessary to recognize the contribution of natural variability. Knowledge of the climate prior to industrialization can improve climate models and reduce the uncertainty of future climate predictions. The instrumental climate records in the Arctic, however, are sparse and span less than 70 years (D'Andrea et al., 2012). To reconstruct climate changes from before the instrumental record, we can use geological records such as varved proglacial lake sediments.

While varves are a useful tool for interpreting climate change, the thickness of varve couplets is not consistent throughout the lake (Smith & Ashley, 1985). With increasing distance from the outflow, sedimentation rates decrease and sub-annual layering becomes thinner. Previous studies have avoided the analysis of distal sediments due to concerns that varve laminations would be too thin to identify, count, and measure (Svendsen & Mangerud, 1997). While varves are thicker in cores proximal to the outflow, these laminations also record intra-annual fluctuations due to precipitation events and in-lake sediment distribution processes, and do not necessarily create an accurate climate chronology. To avoid measuring these short-term fluctuations, Dowey (2013) and Nelson (2010) analyzed cores from the deep main basin in Lake Linné (Sites H and I in Fig. 1).

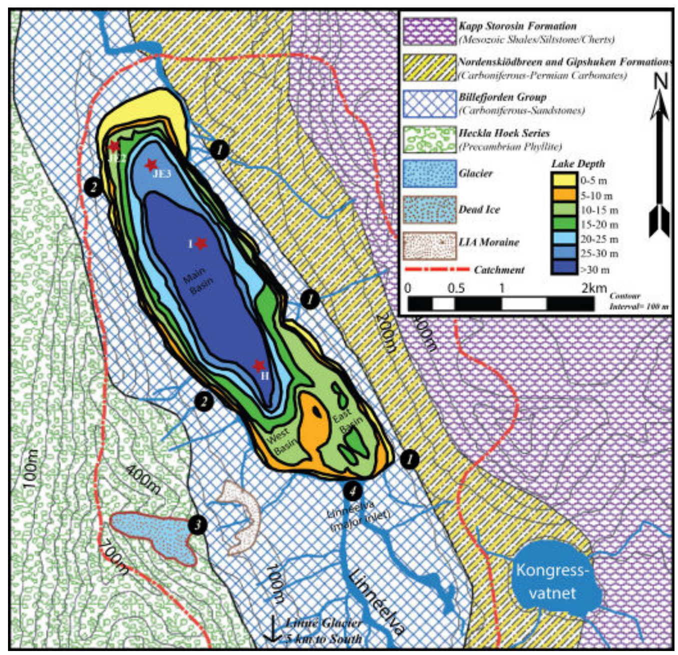

Figure 1. A map of the Linné valley showing the bedrock geology of the area, various sediment sources, the bathymetry of Lake Linné and the locations of the cores sampled in this project and previous studies (modified from Svendsen et al. (1989)).

The goal of this study is to analyze two cores (JE2 and JE3) from an even more distal location at the northern end of Lake Linné (Fig. 1). These cores are located further from the outflow than prior studies, and therefore have lower sedimentation rates and a more condensed climate record. Through analyzing and measuring the thickness of the varves in these distally-located sediments, I aim to create a high-resolution paleoclimate reconstruction that goes back further in time than previous records. Preceding studies have further omitted laminations that were speculated to be related to short-term mass movement events. Unlike these studies, I use high-resolution elemental XRF data in conjunction with information of previous provenance studies to identify depositional events in the sediment not related to environmental change. I also use elemental XRF data to correlate the two distal cores with a core collected by Nora Richter and Allie Balter from Site I (N&A) to assess whether cores from distal locations record the same major changes observed in more proximal cores in the lake. Through this analysis I hope to contribute to an understanding of climate change in the Linné Valley during the Late Holocene.

RESEARCH AREA

Located 78°3'N and 13°50'E, Lake Linné spans a maximum of 4.7 km in length, 1.3 km in width and covers an area of 4.6 km^2 (Bøyum & Kjensmo, 1978). The sediment found in the lake originates from three distinct lithologies that characterize the Linné Valley watershed and strike north-south parallel to the lake (Fig. 1). Spanning the western flank of Lake Linné, the *Heckla Hoek* series is composed of phyllites and shales that originate from a Precambrian protolith. The *Billefjorden* group, deposited during the Late Carboniferous, is comprised of quartz-rich sandstone interbedded with carbon-rich shale beds and coal and is eroded by the Linné glacier 5 km to the south of Lake Linné (Svendsen & Mangerud, 1997). The *Nordenskiödbreen* and *Gipshuken* formations stretch along the eastern side of Lake Linné. Composed of gypsum, anhydrite and dolostone, these sedimentary sequences reflect depositional environments during the Middle and Upper Carboniferous and Early Permian (Ingolfsson, 2006).

Sediment enters Lake Linné through various transport processes. Hillslope processes, including snow avalanching and melt water runoff, contribute sediments from the *Nordenskiödbreen* and *Gipshuken* formations through five distinct alluvial fans (Points 1 in Fig. 1). Solifluction lobes near the northwestern shores of the lake further contribute sediments from the marine muds that surround the lake (Points 2 in Fig. 1). A glacial cirque 1 km south of the lake also erodes sediments from the *Heckla Hoek series*, most of which is eventually deposited into the southwestern basin (Point 3 in Fig. 1). Linnéelva, the river that runs through the Linné Valley, is responsible for transporting the majority of the sediments found in Lake Linné (Point 4 in Fig. 1). The river's primary water and sediment source originates from the Linné glacier that erodes exclusively from the *Billefjorden* group.

METHODS

During our fieldwork at Kapp Linné, I collected two cores (JE2 and JE3) using a Universal Short Corer in the northern end of Lake Linné (Fig. 1). In the laboratory I cut the tubing and used monofilament fishing line to split the cores into working and archive halves. I logged the visual stratigraphy (color, thickness and patterns of laminations) of both cores (Fig. 2) and used the Geotek and ITRAX core scanners to measure magnetic susceptibility, produce a X-radiograph image (showing variations in density) and conduct XRF elemental analysis.

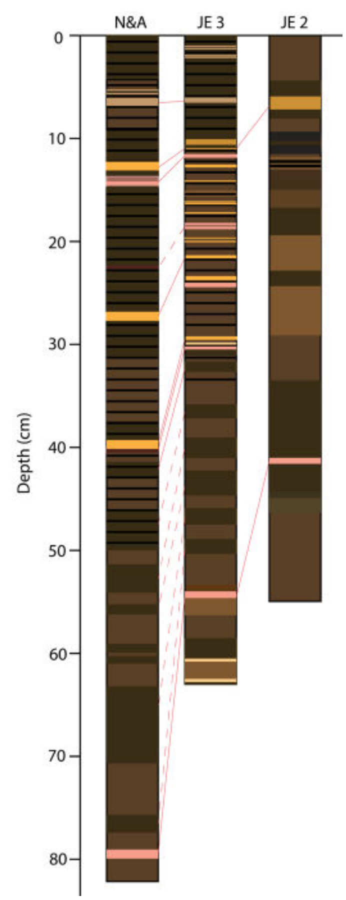

Figure 2. A cartoon of the visual stratigraphy throughout cores N&A, JE3 and JE2. Throughout all cores, a distinctive tan band is found at the top and a thin pink band is observed at the bottom.

Using a U-shaped sampling tray, I sampled the working halves of each core, conducted a series of acetone exchanges and impregnated the samples with an epoxy-resin mixture outlined in an resin-embedding technique modified from Pike and Kemp (1996). Once hardened, the samples were trimmed and processed into thin sections. I further used a spatula to sample 0.5-cm increments of the top 5 cm of each core. These samples were freeze-dried and sent to Northern Arizona University for plutonium analysis.

The elemental XRF analyses of cores JE2, JE3 and N&A yielded elemental signatures of 39 elements along the cores. Not all of these data, however, showed abundance changes greater than the detection limit. I used the shale and sandstone values of Table 4.5 of Faure (1998)'s *Principles and Applications of Geochemistry* as a guide to determine which elements were high enough in abundance to be detectible by the ITRAX XRF scanner. I then conducted an autocorrelation test to eliminate elements that were indistinguishable from white noise at a 95% confidence level.

Independent of these statistical analyses, I further plotted the changes in elemental signatures according to the depth along the core. Through this process, I was able to visually evaluate the long-term trends and confirm the observable trends of the elements that passed the previous tests. Once I had chosen the meaningful elements to test, I plotted each element against one-another to look for correlations.

RESULTS AND DISCUSSION

Thin, finely laminated varves are visible in both JE2 (52 cm long) and JE3 (65 cm long). These varves disappear downcore, possibly due to changes in glacial activity. In JE3, for example, laminations can visibly be seen until 35 centimeters downcore, below which the sediment appears massive. Visually all cores can be correlated based on distinct changes in sediment color. A distinct tan band, for instance, can be identified near the top and a thin pink band is found near the bottom of cores JE2, JE3 and N&A (Fig. 2). This correlation suggests a decrease in sedimentation rates towards the northern end of the lake.

Through the statistical analyses of the geochemistry data, I conclude that calcium, manganese, potassium, iron, silica, rubidium, strontium and titanium show informative elemental trends in the cores. These elemental fluctuations illustrate a distinct correlation between cores JE3 and N&A, suggesting a possible basin-wide response to climatic changes and short-term events. Trends of evaluated elements in JE2, however, do not reflect the elemental patterns observed in the less distal cores (Fig. 3). Since JE2 is located close to the lake's shores, wave reworking may influence its sediment texture while the sediments may predominantly originate from the solifluced marine muds found at the north end.

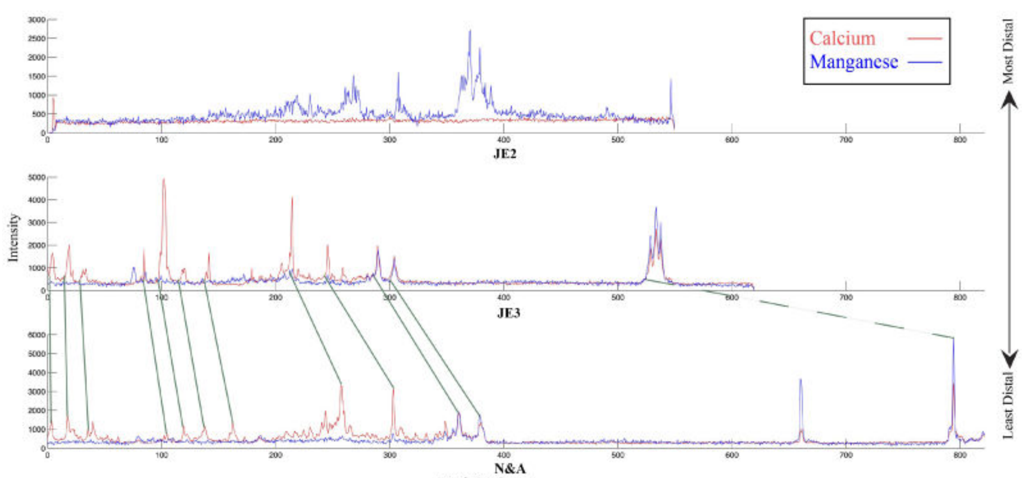

Figure 3. Fluctuations in calcium and manganese throughout cores JE2, JE3, and N&A. Trends in JE3 and N&A are very similar, while those in JE2 do not match the other cores. Calcium and manganese covary in the lower halves of both cores, but do not covary in the upper halves.

The identification and removal of sediment layers not associated with seasonal climate variability help to produce a more accurate climate reconstruction. The spikes in calcium concentrations throughout JE3 and N&A are interpreted as such short-term mass movement events that carry sediment from the eastern *Nordenskiödbreen* and *Gipshuken* formations into the lake. In a previous study of the geochemistry of sediment sources, Perreault (2006) found that the carbonates of these formations contained different assemblages of calcite and dolomite. Graphs of calcium vs. manganese in both cores reveal two distinct sediment signatures (Fig. 4). One trend is characterized by low concentrations of calcium with a wide variation in manganese. The other can be identified by an increasing concentration of calcium and an increase in manganese. This second trend is clearly visible in Figure 3, where spikes in calcium and manganese occur at the same locations throughout the lower half of both cores. Towards the middle of JE3 and N&A this relationship between calcium and manganese disappears. Possible explanations to this abrupt trend include a change in the carbonate sediment source from dolomite to calcite or an environmental change.

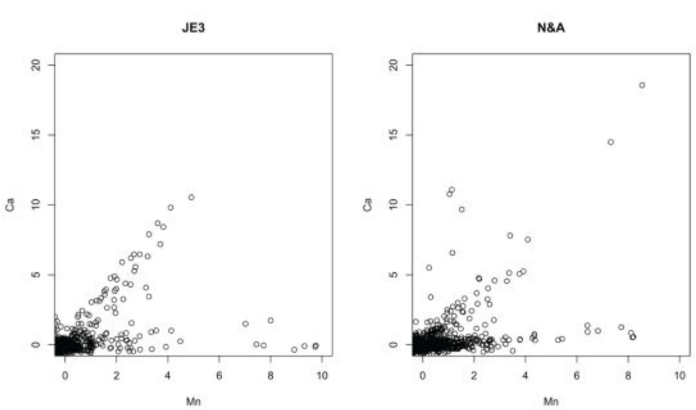

Figure 4. Scatter plots comparing concentrations of calcium and magnesium in cores JE3 and N&A. Trends of two sediment sources are clearly visible in the cores.

Although they are not as clear, changes in rubidium and strontium can also be used to correlate the cores. Similar to the calcium spike, strontium and rubidium concentrations drastically change 10 cm and 12 cm downcore of JE3 and N&A, respectively (Fig.5). The relatively stable abundances of these two elements throughout the cores supports Tiedmann (2013)'s observation that fine-grained minerals are similarly distributed throughout the lake.

The synchronous spikes of strontium, rubidium and calcium further suggest that changes in these elemental abundances are associated with those of calcium. As a result, mass movement events that produce spikes in calcium may dilute the strontium and rubidium concentrations, thus producing an abrupt downward trend in the two elements.

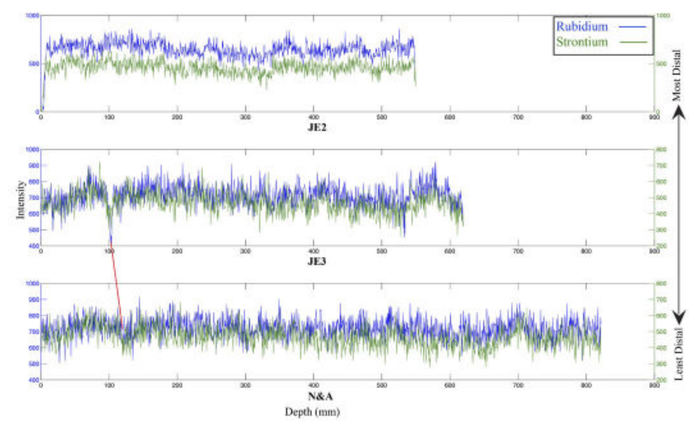

Figure 5. Changes in rubidium and strontium throughout cores JE2, JE3, and N&A. In both JE3 and N&A, downward spikes of rubidium and strontium are associated with upwards spikes in calcium. Despite a noisy signature, rubidium and strontium appear to show similar trends.

CONCLUSION

Visual analysis of cores JE2, JE3, and N&A portray a clear correlation between the cores. Although visually JE2 is similar to the other cores, elemental XRF analysis does not show trends that resemble those seen in JE3 and N&A. This suggests different sediment sources in areas at the north end of the lake. Perhaps JE2 is predominanty influenced by locally eroded marine muds that are resuspended by wave action. The fluctuations in calcium and manganese in JE3 and N&A reveal an abrupt change that most likely are associated with a adjustment in the sediment source or change in the environment.

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