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*Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen*

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*Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien*

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*Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos*

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*Students: Alena Giesche, Jessa Moser, Terry Workman*

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*Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt*

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*Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)*

*Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin*

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Short Contributions – SVALBARD**

**HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC,  
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Project Faculty: *AL WERNER*: Mount Holyoke College  
*STEVE ROOF*: Hampshire College  
*MIKE RETELLE*: Bates College

**DIRECTLY-CONTROLLED LICHEN GROWTH CURVES FOR WESTERN  
SPITSBERGEN, SVALBARD**

*TRAVIS BROWN*: College of Wooster  
Research Advisor: Greg Wiles

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# MODERN SEDIMENTATION PROCESSES IN A PROGLACIAL LAKE, LINNÉVATNET, SVALBARD, NORWAY

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Mount Holyoke College

Research Advisor: Al Werner

## INTRODUCTION

Concern about future climate change is a topic on the forefront of many minds around the world. The realization that the high latitudes will change more than low latitude locations and the need to distinguish natural climate variability from human-caused variability has made Arctic climate reconstructions during the last 2000 years a research priority (IPCC, 2007). In most cases, such reconstructions require a sensitive climate proxy, one that is well preserved and exhibits a reliable chronology. Glacier-fed lakes are such a proxy, as they contain important climate records and annual sedimentation couplets, or varves, which can be reliably dated (Snyder et al, 2000). From the information obtained from these lakes, a study of changes in the climatic system can be completed in order to better understand the Earth system as a whole.

Research at Lake Linné (Linnévatnet) is aimed at documenting arctic climate change. Cores recovered from Linnévatnet are well-layered and recent research using sediment traps and turbidity instruments demonstrate that the layers represent annual sedimentation (i.e. varves, McKay, 2004; Motley, 2006; Roop, 2007; Cobin, 2008; and Arnold, 2009). This study focuses on the sediment traps recovered from Linnévatnet, examining their grain size and stratigraphy, as well as on information obtained from temperature sensors distributed in the lake, to reconstruct sediment distribution processes during the 2008-2009 sedimentation year.

## SETTING

The Svalbard archipelago is located in the North Atlantic between 74° and 81° North latitude and 10° and 35° East longitude. Spitsbergen is the largest

island of the archipelago and located on its west coast is Linnédalen, approximately 5 kilometers east of Isfjord Radio, an old radio relay station, located on Cape Linné (Kapp Linné). Within the valley is Linnévatnet, a glacier-fed lake whose main inlet is the Linné River (Linnéelva), which is sourced by the Linné glacier (Linnébreen). Linnévatnet is orientated North/South and is 4.7 kilometers long, 1.3 kilometers wide, and reaches a maximum depth of 37 meters (Bøyum and Kjensmo, 1978).

The majority of sediment deposition in the lake occurs at the south end where Linnéelva enters the lake. This sediment is sourced from the underlying and adjacent geology found in the valley. Upon entering the lake, inflow water must contend with its temperature and density in comparison to that of the lake. In glacially influenced systems, the temperature and sediment concentration of the inflow water is the primary determinant in what type of flow occurs (Smith and Ashley, 1985). There are four types of flows that can occur based on the temperature and density differences between the lake and the inflow: interflow, overflow, underflow, and homopycnal flow.

The accumulation of annual sediment layers are called varves and can be seen in cores taken from the lake, as well as in the yearly sediment traps distributed throughout the lake. This deposition leaves behind a record that can be used to interpret the flow conditions and thermal stratification within the lake, as well as glacier melt and weather conditions in the valley, including temperature and precipitation, and valley runoff (Leemann & Niessen, 1994). Occasionally varves can be hard to interpret, but often varve thickness and mean grain size can be used as proxies for hydrological and meteorological events in the valley.

## METHODS

The main focus of this project is centered on the sediment traps distributed in Linnévatnet at five different locations. The collection and documentation of the 26 sediment traps is the focus of the methods discussed here. Many other instruments are deployed throughout Linnédalen including a weather station, two automatic cameras, lake temperature sensors, river temperature sensors, and snow depth sensors, which are also important to consider when trying to understand the valley system as a whole.

There are five mooring sites in Linnévatnet, mooring sites C, D, E, F, and G (Fig. 1). Each mooring is composed of two to five sediment traps attached at different depths in the water column to a nylon rope that is weighed down by a large rock and kept taught by a 30 cm buoy (Fig. 2). Mooring C is located close to the inlet stream and is the focus of the five moorings and this study. Of the five moorings, it is the most proximal to the inlet stream and its sediment traps collect the most sediment, which is also the most distinctly layered, resulting in the assumption that this mooring is the most representative of the spring melt. It is located 400 meters from the edge of the Linnéelva delta in 15 meters of water and has four sediment traps attached to it at 1.5 meters, 4.5 meters, 8.5 meters, and 12.5 meters depth from the buoy. The buoy is located 1 – 2 meters below the lake surface to prevent the disturbance of the mooring by winter ice and summer waves. At the location where a sediment trap is attached to the mooring line, a temperature sensor is also attached. Upon location and retrieval, each sediment trap and its associated temperature sensor were detached from the mooring line. Onshore, the receiving tubes of the traps were then detached, dewatered, and packaged for travel. Back in the lab, the sediment traps were cut open, described, photographed, X-rayed, and subsampled at 0.5 cm intervals. These samples were run in a Beckman Coulter LS 13 320 Particle Size Analyzer at Bates College to determine their mean grain size and a textural plot of each trap was made.

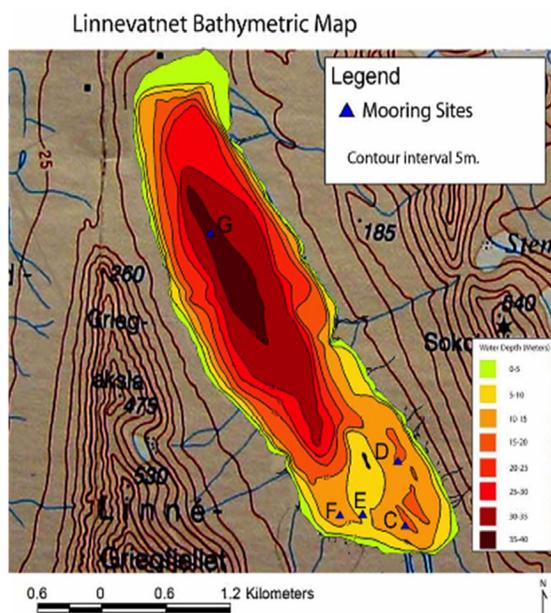


Figure 1. Bathymetric map of Lake Linné (Linnévatnet), Svalbard, Norway showing the five mooring sites, C, D, E, F, and G.

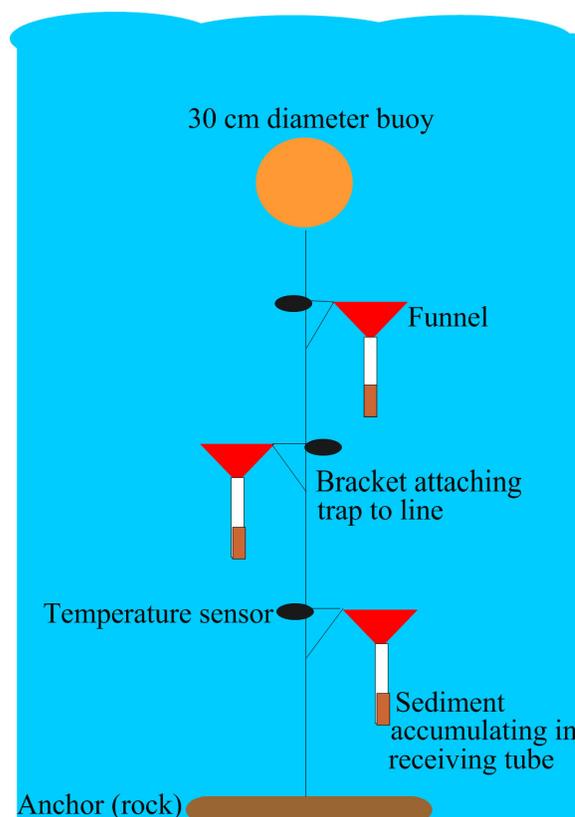


Figure 2. Schematic of a mooring found in Lake Linné (Linnévatnet), Svalbard, Norway with three sediment traps attached. The buoy is located one to two meters below the water's surface.

Also located at mooring site C is a mooring line with 15 temperature sensors attached at 1 meter intervals that record the temperature of the surrounding lake water and light intensity every 10 minutes. To more easily interpret the data, separate time series were created based on the timing of the melt season and, within those times series, divisions based on depth were made. The resulting time divisions were April 5, 2009 to May 2, 2009, May 3, 2009 to May 30, 2009, May 31, 2009 to June 27, 2009, June 28, 2009 to July 4, 2009, July 5, 2009 to July 11, 2009, July 12, 2009 to July 18, 2009, and July 19, 2009 to July 25, 2009. The resulting depth divisions were from 14 meters to 11 meters above the anchor, from 10 meters to 4 meters above the anchor, and from 3 meters above the anchor to the anchor. These divisions correspond to assumed flow regimes, overflow, interflow, and underflow respectively. The temperatures within each depth division were then averaged to produce only three columns of temperature data representative of the three depth divisions.

Now having simplified the data for certain time periods and depths, it was graphed in order to visually represent the temperature readings. Running averages of the data were taken and the most representative interval was at 66 percent, which helped to smooth the data while still being representative and took into consideration the time stamp of the data as a multiple of six. The running average was then subtracted from the three original columns of data producing residuals, which were graphed to show anomalous temperatures.

## RESULTS

Observations of the sediment traps after retrieval in the field displayed distinct color banding of light and dark layers (Fig. 3). This visual stratigraphy disappeared once the sediment traps were dewatered and exposed to air. The digital images of the sediment traps taken in the lab showed the homogenization of the colored layers seen in the field. The X-ray images showed the differing densities of the sediment found in the sediment traps. The darker parts of the images show the less dense sediment, or the clay, while the lighter parts show the more

dense sediment, or the silt (Fig. 3). Results for the grain size analysis at mooring C are described as C1, C2, C3, and C4, where C1 is closest to the surface. These results are summarized in Table 1 and the grain size analysis graph for C3 (found to be the most illustrative) is included in Figure 3.

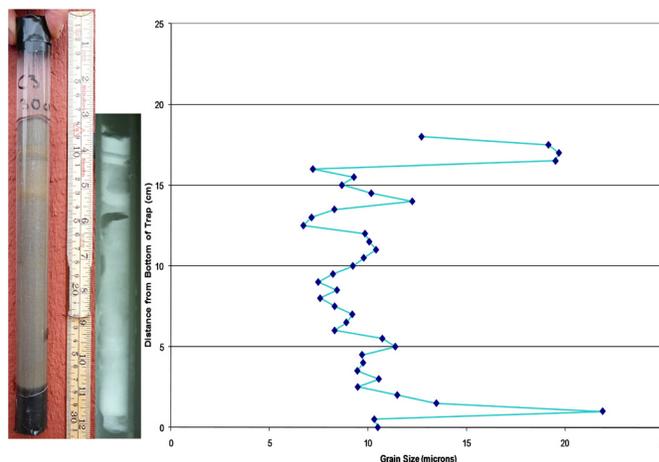


Figure 3. Field photograph, X-ray, and grain size analysis of sediment trap C3 aligned for direct comparison. Note light and dark layers in both the field photograph and the X-ray, which can be correlated to the grain size analysis graph. Sediment trap C3 is located on the mooring line 8.5 meters from the buoy at mooring site C.

	C1 (12m)	C2 (9m)	C3 (5m)	C4 (1m)
Initial	12.07	10.09	10.50	13.48
Mean	9.94	10.81	10.69	12.88
Median	9.00	9.54	9.76	10.65
Max	14.51	24.35	21.91	23.72

Table 1. Summary of the results from the grain size analysis of the four sediment traps found at mooring site C of Lake Linné (Linnévatnet), Svalbard, Norway. Grain sizes are given in micrometers and meters denote distance from anchor. Mooring site C is located 400 meters from the edge of the delta associated with the inflow stream of the lake.

The 15 temperature mooring data was broken into seven time divisions, graphed, and normalized on the same scale (-1.3 to 1.3) in order to better view the anomalies. The first two divisions, from April 5 to May 2 and May 3 to 30 respectively, showed little to no temperature anomalies (from -0.1 to 0.1). The next time series from May 31 to June 27 saw the

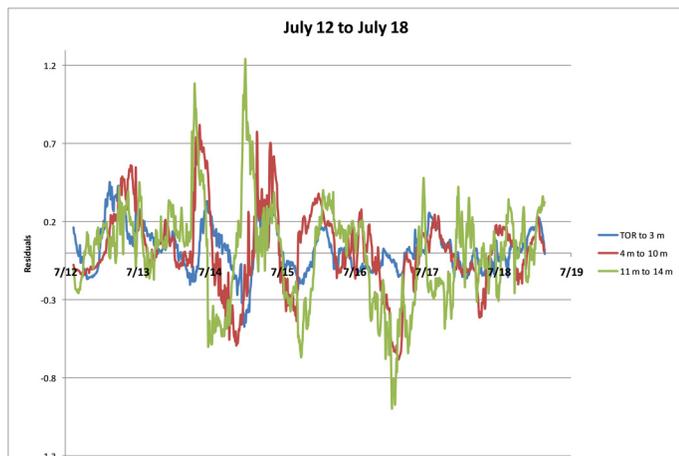


Figure 4. Temperature anomalies ( $^{\circ}\text{C}$ ) at mooring site C in Lake Linné (Linnévatnet), Svalbard, Norway from July 12th to July 18th, 2009 depicting variation from the average lake water temperature at three depth divisions, the top of the anchor to 3 above the anchor, 4 meters above the anchor to 10 meters above the anchor, and 11 meters above the anchor to 14 meters above the anchor.

beginning of the anomalies registered by the uppermost temperature sensors, from 11 m to 14 m from the anchor, with values from -0.3 to 0.2. The time series from June 28 to July 4 continued to register temperature anomalies from the uppermost temperature sensor, but also began to register anomalies from the two other depth divisions, 4 m to 10 m above the anchor and from the top of the anchor to 3 m above it respectively, with a range from -0.3 to 0.5. From July 5 to July 11, all of the depth divisions display an increased variability with a range from -0.3 to 0.4. The following time series, from July 12 to July 18 displays the most temperature variability, ranging from values below -0.8 and above 1.2 (Fig. 4). The last time series, from July 19 to 25, shows reduced variability from the last times series, but still displays a range of -0.3 to 0.3.

## DISCUSSION AND CONCLUSION

In previous years, interpretation of the deposition of the sediment in the lake has been centered on weather events occurring in the valley, looking at such variables as rain, wind, and temperature. This project continues that pattern, but includes lake water temperature anomalies. Five major rain and wind events can be seen in the weather data after the river temperature data indicates that the river has started

flowing. These occurred on June 16-18, June 24-25, June 30, July 8, and July 21. The last four events can be seen in the temperature anomaly data, but the first cannot. This correlation implies that wind and rain events cause increased discharge, which can then be seen as flows of exotic inflow water in the lake. The depth of these flows can be tracked in relation to which temperature sensors react when we know a weather event is occurring or has just occurred.

In addition to these four events, many other events can be seen in the temperature anomaly data. These other events can be explained by other events occurring in the valley besides wind and rain, which have been correlated to events already. Melt events from the surrounding mountains and land could be a source. The warming of the surface water over an extended period of time by the sun could cause the reaction of the uppermost temperature sensors in a positive manner, while, conversely, lake ice could cause the uppermost temperature sensors to react in a negative manner. Myriad high discharge processes could cause these events in the temperature anomaly data and this is where the need for future work resides. This study hoped to prove that the lake temperature anomaly data can be used as a proxy for events in the valley, events that deposit sediment on the lake bottom and in the sediment traps. As the major events registered by the weather station are also registered by the lake temperature anomaly data, this goal has been achieved.

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## REFERENCES

Arnold, M., 2008, Sedimentation in High-Arctic

- Lake, Linnévatnet, Svalbard: A Modern Process Study Using Sedimentation Traps. Unpublished Bates College B.S. Thesis.
- Bøyum, A. and Kjensmo, J. 1978, Physiography of Lake Linnévatnet, Western Spitsbergen. *Verein Limnology*. v. 20, p. 639-614.
- Cobin, P., 2008, Evaluation of Modern Sedimentation Process in a Proglacial Lake: Linnévatnet, Spitsbergen, Svalbard. Unpublished Mount Holyoke College Thesis.
- IPCC 2006 Report: [http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4\\_syr\\_spm.pdf](http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf)
- Lamoureux, S.F. and R.S. Bradley 1996. A Late Holocene Varved Sediment Record of Environmental Change from Northern Ellesmere Island, Canada. *Journal of Paleolimnology* 16:239-255.
- Leeman, A. and F. Niessen 1994. Varve Formation and the Climatic Record in an Alpine Proglacial Lake; Calibrating Annually-Laminated Sediments against Hydrological and Meteorological data. *The Holocene* 4: 1-8.
- Leon, B., 2007, Recent Sedimentation Chronology of Linnévatnet, a High Arctic Proglacial Lake, Svalbard, Norway. Unpublished Bates College B.S. thesis.
- McKay, N., 2004, Characterization of Climatic Influences on Modern Sedimentation in an Arctic Lake, Svalbard, Norway. Unpublished independent study.
- Motley, B., 2006, Sedimentation in Linnévatnet, Svalbard During 2004-2005: A Modern Process Study Using Sediment Traps. Unpublished Bates College B.S. Thesis.
- Roop, H., 2007, Sedimentation in a Proglacial Lake: Interpreting Inter and Intraannual Sedimentation in Linnévatnet, Spitsbergen, Norway. Unpublished Mount Holyoke College B.A. Thesis.
- Smith, N.D., and Ashley, G., 1985, Proglacial lacustrine environments. Ch. 4, in *Glacial Sedimentary Environments*, eds. Ashley, G., Shaw, J., and Smith, N.D.; S.E.P.M. Short course no. 16, pgs. 135-215.
- Snyder, J.A. 2000. Holocene cirque glacier activity in western Spitzbergen, Svalbard: Sediment Records from Proglacial Linnévatnet. *The Holocene* 10, no. 5: 555-563.
- Svendsen, J.I. J.Y. Lanvik J. Mangerud and G.H. Miller 1987. Postglacial Marine and Lacustrine Sediments in Lake Linnévatnet, Svalbard. *Polar Research* 5: 281-283.
- Werner, Al, 2007, <http://www.mtholyoke.edu/proj/svalbard/welcome.shtml>.