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

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Keck Geology Consortium: Projects 2013-2014
Short Contributions— Climate Change, Svalbard, Norway Project

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JOSH SOLOMON, Colgate University
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INTRODUCTION

Few places on Earth exhibit the sensitivity to climate change like the High Arctic. The melting of the cryosphere acts as both evidence for and drivers of climate change through the positive feedback loops that they create (IPCC, 2013). Documenting past trends allows us to put the shifts in modern climate into context. Paleoclimate proxies provide glimpses into the temperature and precipitation patterns of regions throughout geologic history. One valuable tool used to reconstruct climate in the Arctic is the analysis of varved lake sediments. Annually laminated sediments can provide a high-resolution record of sediment flux, controlled by glacioclimatic and watershed processes (O'Sullivan, 1983).

The Svalbard REU has been working since 2004 to solidify our knowledge of the complex proglacial lake sedimentary system, using the Linné glacial valley (Linnédalen) of Cape Linné (Kapp Linné), Spitsbergen as its field laboratory. The Svalbard REU has utilized a multifaceted approach to document the modern processes of sedimentation and to calibrate the estimated 9,500-year lacustrine sedimentary record of proglacial, Lake Linné (Linnévatnet). This ongoing monitoring of the lake, glacier, meltwater stream, and meteorological conditions in Linnédalen provides a valuable long-term data set to investigate annual variability and trends.

The study presented here addresses sedimentation and climatic data from August 2012 to July of 2013. Depositional processes were assessed using sediment traps across the lake. This was then compared to temperature, precipitation, and snowmelt, among other sources of data, during that same period of time in Linnedalen. A timeline of this year's melt season was then pieced together to discern the main drivers of sedimentation in the lake. Through this, we are better able to more accurately interpret the lake's sedimentary record and begin to assess the impact of climate change on sedimentation in the lake.

SITE DESCRIPTION

The archipelago of Svalbard lies between 74° and 81°N latitude, well above the Arctic Circle. The western coast of Spitsbergen, the largest of Svalbard's many islands, is where Kapp Linné is located (Fig. 1B). On this cape is the north-south oriented Linnédalen.

The Linnédalen catchment basin is 27 square km, of which 6.3% is glaciated (Snyder et. al, 2000). The glacier, Linnébreen serves as the main source of meltwater for the 6km long stream, Linnéelva, which flows into the south end of Linnévatnet. The lake is 4.7 kilometers long and 1.3 kilometers wide with a maximum depth of 37 meters. Ice covers the lake approximately 9 months out of the year, usually from September until July. The lake is an isochemical and isothermal monomictic lake (Bøyum and Kjensmo, 1978). The predominant source of sediment for Linnévatnet is Linnéelva. For this reason, the thickest sediment accumulation occurs at the south end of the lake where the mouth of the river is located (Svendsen et al., 1989).

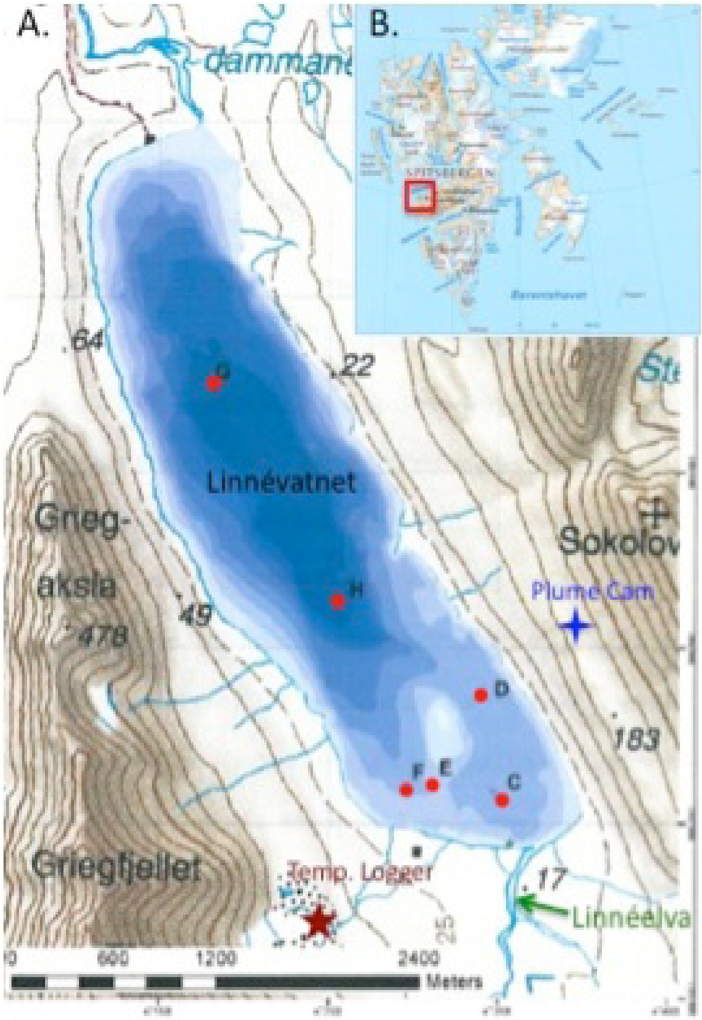

Figure 1: A) A topographic map of Linnédalen with the location of each mooring, the plume camera, and the temperature logger. B) The boxed off area shows the location of Kapp Linné in relation to the rest of Svalbard.

METHODS

For the 2012-2013 season, there were six separate mooring locations strategically placed around the lake to ensure that sedimentation processes were accurately characterized. The locations of these moorings, C, D, E, F, H, and G, can be seen on the map in Figure 1. The standard mooring consisted of sediment traps and ONSET Water Temp Pro temperature loggers, spaced every few meters depending on the depth of the mooring. Moorings C and H also had an In-Situ Inc. 9500 Pro XP/e Troll that measured turbidity. The bottom most sediment traps positioned about 1 meter above the lake floor at Moorings C (15 m deep), D (15 m deep), and H (30 m deep) are the focus of this study. Comparison of the proximal to distal basal sediment traps affords differences in sedimentation rates and depositional patterns to be determined.

Gardener's (1980) sediment trap design of maximum efficiency was used. It had a receiving tube with a funnel covered by a grid baffling. This season's sediment traps had 4.8-inch diameter funnels and receiving tubes of .62 inches in diameter. The sediment traps were recovered from Linnévatnet on July 19, 2013. The traps were then sealed using zorbitrol, an absorbent powder that stabilizes water, and packaged for transport back to the lab.

Temperature in the valley was recorded by a HOBO temperature logger at the base of a Little Ice Age cirque near the southwest corner of the lake (Fig. 1). HOBO water temperature loggers provided both lake temperature profiles at each mooring and river inflow temperatures. This camera was angled toward the mouth of Linnéelva at the south end of the lake to document when the river started flowing, when the snow melted off the landscape and sediment plumes entered the lake.

The intervalometer deployed during the previous field season was retrieved on July 19, 2013 at Mooring C. Dr. Tim Cook of the University of Massachusetts designed this instrument to record the timing and magnitude of sedimentation events as they settle in this enhanced sediment trap. The device has a 10cm diameter funnel that directs sediment into the 1.8cm diameter receiving tube. The device has LED light sources and corresponding receivers on opposite sides of the trap every 2 mm. An inverting Schmitt trigger turns a switch once the accumulating sediment blocks the light from reaching the other side of the tube. This increases the voltage that is being recorded by a HOBO logger every 30 minutes. Over the course of the season, the timing of every 2 mm of sedimentation collected was logged. The sediment receiving tube was redeployed so the stratigraphy was visually recorded and a small core was taken so it could be brought back for lab analysis.

The sediment traps were split back in the lab for analysis. The bottom traps from moorings C, D, and H, in addition to the intervalometer core, were processed for grain size analysis. Grain size measurements were made every 0.25 cm with the Beckman Coulter LS 13 320 Particle Analyzer at Bates College using the method developed by former REU student Meg Arnold (Arnold, 2009). Each sample was put in different 50 ml centrifuge tubes with 1ml of hydrogen peroxide to disintegrate organic material, 20 ml of deionized water and 17 ml of dispersant solution. This was then shaken with a Vortex Genie and sonicated by a Fisher Scientific 60 Sonic Dismembrator to deflocculate aggregated particles. The samples were run through the grain analyzer three times with the average grain size from these trials presented in this study.

Table 1: The results of initial lab measurements, deamplified accumulation values, and the mean grain size of the sediment traps analyzed are shown in this table.

	INT-V*	C1	D1	H1
Length (cm)	4.75	15.25	13.75	6.25
Accumulation (mm)	2.42	2.56	2.21	1.11
Mean Grain Size (µm)	16.7	15.56	10.92	7.78

RESULTS

The observed sediment trap length showed significant spatial variability across the lake. Due to a smaller funnel size the intervalometer and the other annual sediment traps, the trap lengths were standardized using funnel and receiving tube area calculations (Table 1). This deamplified value represents the total unconsolidated sediment that would have been deposited on the lake floor. Table 1 illustrates the decrease in total length, accumulated sediment, and mean grain size moving from C to D and then to H. Figure 2 shows the grain size plots or each trap.

The intervalometer is located at the same site as C and varies slightly in both mean grain size and total accumulation. An image of the intervalometer core is presented in Figure 3 at the same scale as the uncorrected grain size data. Figure 3 also includes the intervalometer voltage data over the course of the entire year. The total voltage recorded before retrieval was 1.5 volts. With every .06 volts corresponding to 2 mm of sedimentation, the intervalometer recorded a total of 5 cm. This was only 0.25 cm more than the measured and sampled length of the intervalometer core that was taken indicating that only a minor amount of sediment was lost when the intervalometer was subsampled.

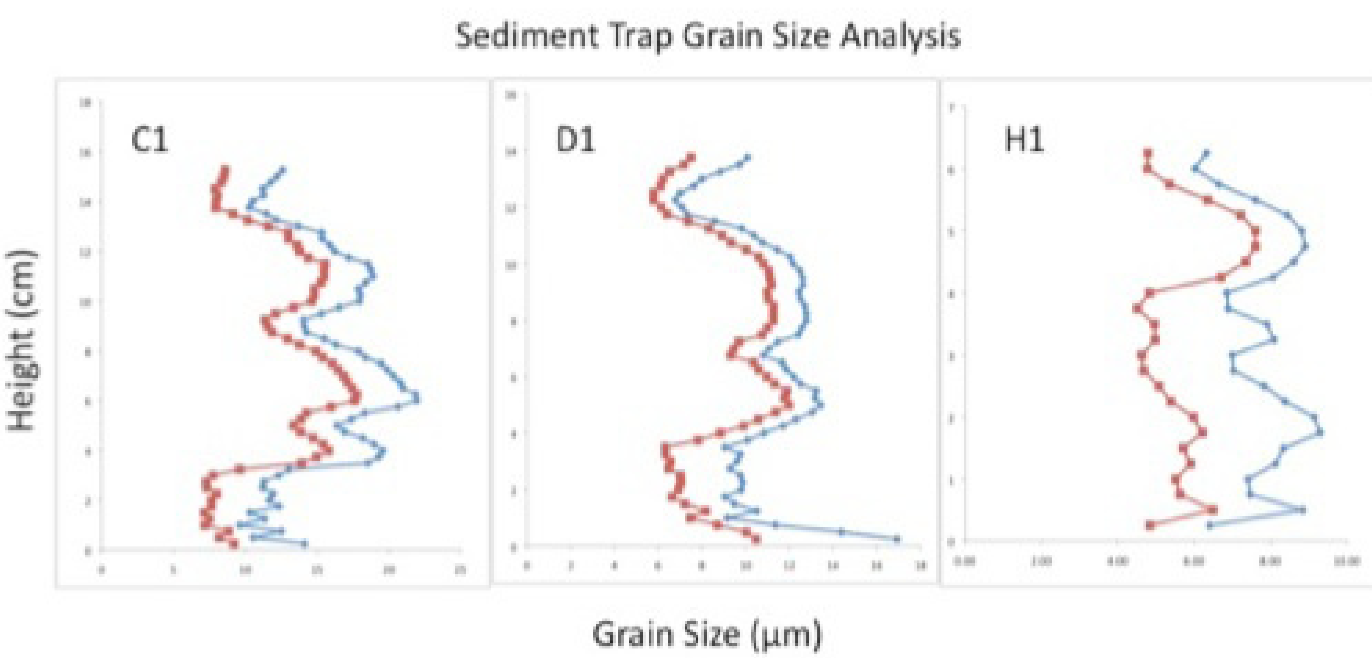

Figure 2: Grain size stratigraphy of the sediment traps. Data values plotted represent the mean grain size for each 0.25cm of the trap.

There were a series of small voltage increases in the fall followed by three distinct increases during the spring melt. The fall sedimentation makes up the bottom 1 cm of the trap and occurred sporadically from late August until early November. This sediment is darker in color and has a relatively high grain size. The first of the spring sedimentation events occurred during the interval 6/18-6/22. It was darker color sediment and transitioned into a lighter color. This event had a number of smaller jumps over the five-day period and accounted for 0.75 cm of deposition. The second event contributed approximately 1.25 cm from 6/28-6/29 and went from light color to a darker color with a fairly distinct line in the middle at about 2.6 cm. Finally, 7/1-7/2 brought about the most sediment, depositing the remaining 1.75 cm at the top of the trap. It was a fairly homogeneous color but shows a consistent drop in grain size over time.

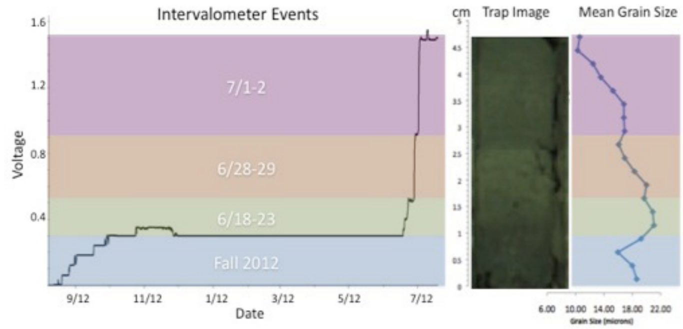

Figure 3: The Intervalometer voltage readings, an image of the Intervalometer sediment trap recovered, and the corresponding grain size data. The four unique sedimentation events are projected onto both the voltage and grain size plot.

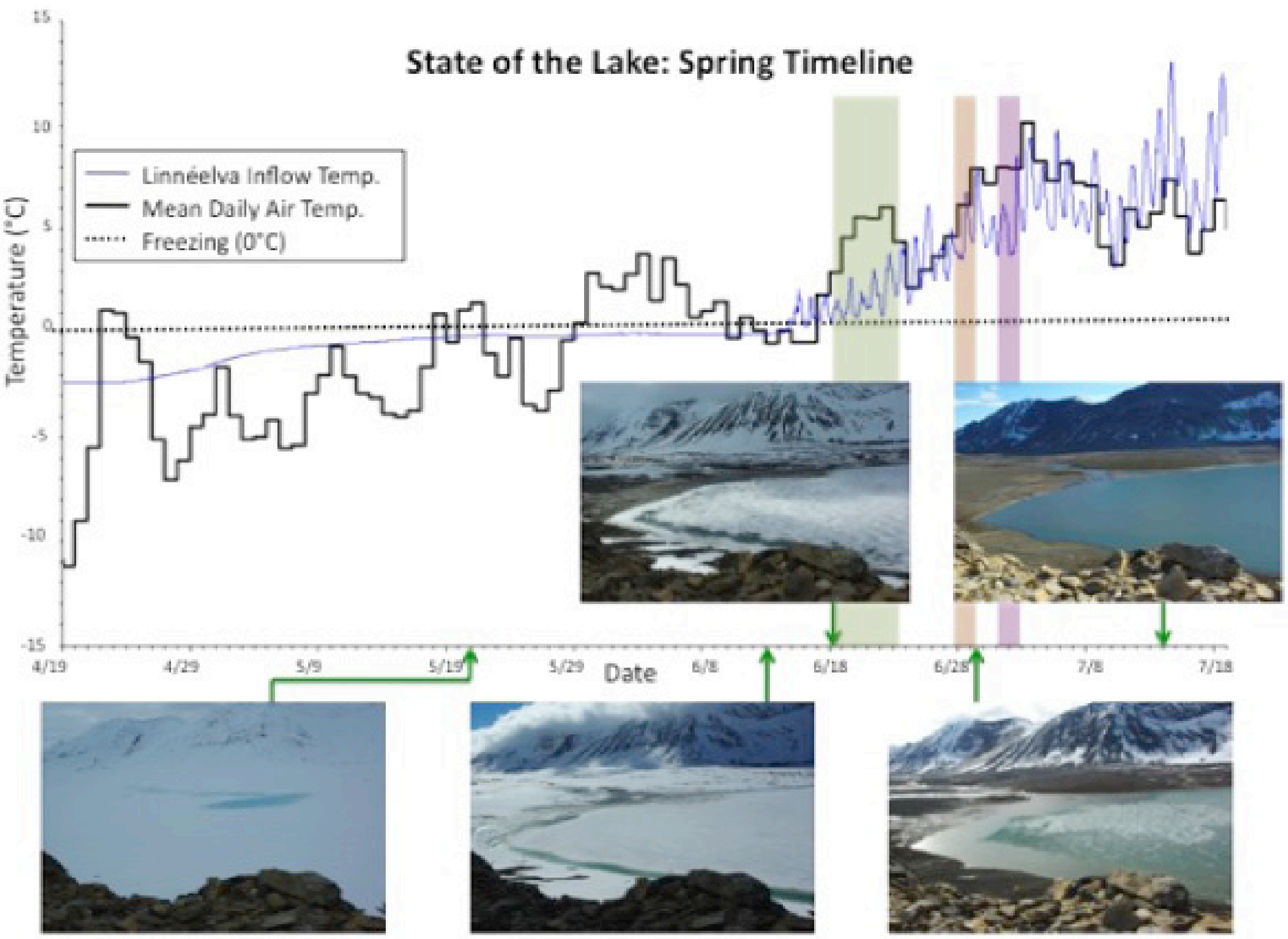

Figure 4: A timeline of the spring melt season showing the relationship between air temperature, inflow temperature, snow melt, the break-up of lake ice, and the sedimentation events as determine by the intervalometer voltage.

The average daily air temperature and lake inflow temperatures from 4/19 to 7/19 are plotted on the timeline in Figure 4 along with some representative plume cam photographs of Linnévatnet. Average daily temperatures rose above freezing for the first time on 4/24 before dropping below freezing again. Sporadic warm days were recorded during the middle to end of May before average daily temperatures held mostly above freezing on 5/30. The temperature of Linnéelva rose above freezing for the first time on 6/15 when it experienced diurnal fluctuation. Following that day, the water continued on a trend of warming with diurnal fluctuations in temperature.

Additionally, qualitative precipitation assessments were conducted. Precipitation was visible in the photographs on 4/24, 5/18, 5/17, 5/20, 5/23, 5/27, 6/4, 6/9, 6/16-6/18, 6/26, 6/27, 6/30-7/1, and 7/7. With the exception of the 5/20 event, all noted precipitation in April and May was snowfall. All June precipitation was rain. By the end of June, there was no longer snow left in the valley. The ice had totally evacuated the lake by 7/4 allowing the wind to create currents in the lake.

Troll data at Mooring C and H was consistently at between 0.8 and 10 FNU on the turbidity scale for all but a few events. The Troll at Mooring H shows an event from 6/28-6/29 but it only reaches 70 FNU. It shows another event from 7/2-7/3 that gets above 200 FNU. C shows only one noteworthy turbidity event, which began late on 7/1 and peaked on the morning of 7/2 at 638 FNU. It continued above 100 until the morning of 7/3. Plumes were visible on 6/28, 6/30, 7/1, 7/3, 7/5, 7/14, 7/15, and 7/18. The plumes that did occur after this date were all located in the southeastern corner of the lake, likely driven in that direction by the northwest originating winds.

Analysis conducted by fellow project student Dana Reuter of Mt. Holyoke College pieced together the hydrologic temperature fluctuation as recorded by the lake mooring temperature loggers. Among other important events, she determined that overflows dominated the flow events early in the season until the turnover of the monomictic lake occurred on 7/1. No major thermal anomalies were recorded after this time. The last of the major sedimentation events occurred on this day, settling out finer grained sediment the next day.

DISCUSSION AND CONCLUSIONS

As was to be expected, the most sedimentation and the coarsest sedimentation occurred closest to the inflow stream at C1 and the least and finest at the more distal H1 trap. The coarser grain sediment falls out of the water column, while the finer grained material is able to stay suspended out to the location of H.

The complexity of this year's sedimentation can be seen in the dynamic grain size data across all of the sediment traps. The theoretical ideal varve suggests a dark, fine-grained fall/early winter layer and a lighter, coarser grained layer representing spring melt. The Intervalometer revealed three distinct sedimentation events. Figure 2 illustrates the variability, yet there are definite trends that can be noted across all three of the traps. Even the more distal sediment traps reflect the individual sedimentation events, rather than homogenizing them all.

By putting all of the environmental data of the spring together, the causes of each sedimentation event can be determined with some certainty. The 6/18-6/22 event occurred after three weeks of high temperatures and just three days after Linnéelva thawed. It also rained for all of those three days before the sedimentation was recorded. The event lasted longer and deposited less sediment likely because the thaw did not occur instantaneously. The ice break up at the mouth of the river as seen in the plume cameras continued for about a week. This first event of the spring was followed by four days of high temperatures and sunshine. The two days prior to the 6/28-6/29 event brought rain to Linnédalen, melting a significant amount of the snow in the valley. All of this water in the valley carried down a significant amount of sediment, but only the turbidity at H increased, suggesting an overflow. Finally, the 7/1-7/2 event deposited the most sediment. Linnévatnet was cloudy with sediment for the few days between the last two events. The troll data from both moorings C and H shows an underflow occurring during this last sedimentation event.

This would imply that Linnéelva's varve formation, even further away from sources of sediment, is comprised of a number of distinct dramatic events, rather than a reflection of seasonal averages. It is important to take this into consideration when deciding where in the lake to retrieve sediment cores. As temperatures continue to rise in the High Arctic, it is easy to envision an earlier melt season and a longer summer period in which the lake is thawed. While this would imply a longer amount of time for sedimentation to occur, it is apparent that other factors, such as precipitation, date of lake overturning, temperature variability, and wind direction will determine the how much sediment is deposited and where in the lake it will accumulate.

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