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

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Keck Geology Consortium: Projects 2009-2010
Short Contributions – SVALBARD

HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY

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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CHRISTOPHER FISHER COLEMAN: Wesleyan University
Research Advisor: Suzanne O'Connell

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FRANKLIN DEKKER: Franklin & Marshall College
Research Advisor: Christopher J. Williams

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JACALYN GORCZYNSKI: Mount Holyoke College
Research Advisor: Al Werner

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ALICE NELSON: Williams College
Research Advisor: Mea Cook

SEDIMENT CHRONOLOGY DEFINED BY CESIUM-137 IN THE DEEP MAIN BASIN OF PROGLACIAL LINNÉVATNET, WESTERN SPITSBERGEN, SVALBARD

ALEXANDER NERESON: Macalester College
Research Advisor: Karl Wirth

ALKENONE-INFERRED TEMPERATURE RECONSTRUCTION FROM KONGRESSVATNET, SVALBARD

DAVID A. VAILLENCOURT: University of Massachusetts Amherst
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ALEXANDER NERESON: Macalester College
Research Advisor: Karl Wirth

INTRODUCTION

The threats associated with future global climate change necessitate a better understanding of the ways in which Earth's environment may differ in the future. One valuable way of understanding this transformation is by studying what changes have occurred in the past. For a number of reasons, the Arctic is a critical region for such studies: we know that global climate change is likely amplified in the Arctic due to a system of positive feedbacks and that, in turn, the Arctic influences climate at lower latitudes via effects on global thermohaline circulation and atmospheric chemistry and circulation (Overpeck, et al., 1997). But given the "brief and geographically sparse" nature of the instrumental climate record there, we must turn to geological proxies to reconstruct past environmental conditions such as temperature, precipitation, and glacier mass balance. The rhythmically laminated sediments found in proglacial Linnévatnet in western Spitsbergen provide an opportunity for such a reconstruction, but before we can reliably interpret past changes we need to understand the modern processes influencing sedimentation in Linnédalen.

Towards this goal, this study quantifies the recent sedimentation rate in the deep main basin of Linnévatnet using fallout ^{137}Cs concentrations. The rate is compared with similar estimates put forth by previous workers who have used varve counts and paleomagnetic methods to quantify sedimentation rates over the same period. Results from each of these methods and the implications of this study are discussed.

Using Cesium-137 to Assign Dates

Atmospheric testing of nuclear weapons first began in the United States in 1945, although it was from 1961 to 1963 that the world's largest atmospheric tests took place. During this period, a number of radionuclides were introduced into the environment and yearly records for ^{137}Cs fallout from the atmosphere show a maximum in 1963 (Ritchie et al., 1973). Once in contact with soil, ^{137}Cs adsorbs to the finer particles within the top 5 cm of the soil profile. This interval is highly susceptible to erosion and during the subsequent 6 to 12 months, fine particles in this upper horizon can be eroded, transported, and ultimately, deposited in a basin. Ritchie et al. (1973) has shown this to be the case and reports that as a result, the maximum concentration of ^{137}Cs measured in lake sediments represents the year 1964.

FIELD SETTING

Linnévatnet is an elongate lake near the western coast of Spitsbergen in the high-arctic archipelago, Svalbard (Fig. 1). Oriented roughly north-south, it is approximately 5 km long, 1 km wide, and rests in a glacially over-deepened basin 12 m above sea level (Snyder et al., 2000 and Svendsen et al., 1989). It is fed by a braided river, Linnéelva, which delivers meltwater down-valley from the small valley glacier Linnébreen, some 8 km to the south. While this represents the major water and sediment inflow to the lake, several small intermittent streams also enter along the eastern and western valley walls (Perrault 2006). Linnévatnet's outlet is located at its northeastern corner and drains approximately 2 km north into Isfjorden. There are three distinct basins within Linnévatnet—two smaller, shallower basins at the south end are divided by a bedrock high that extends into a small elongate island. A larger, deeper basin lies at the northern end of the lake—distal from any major inflow—and contains depths reaching approximately 35 m. Linnévatnet is the best-known and one of the most-studied lakes in Svalbard and this research is part of a continuing scientific effort there.

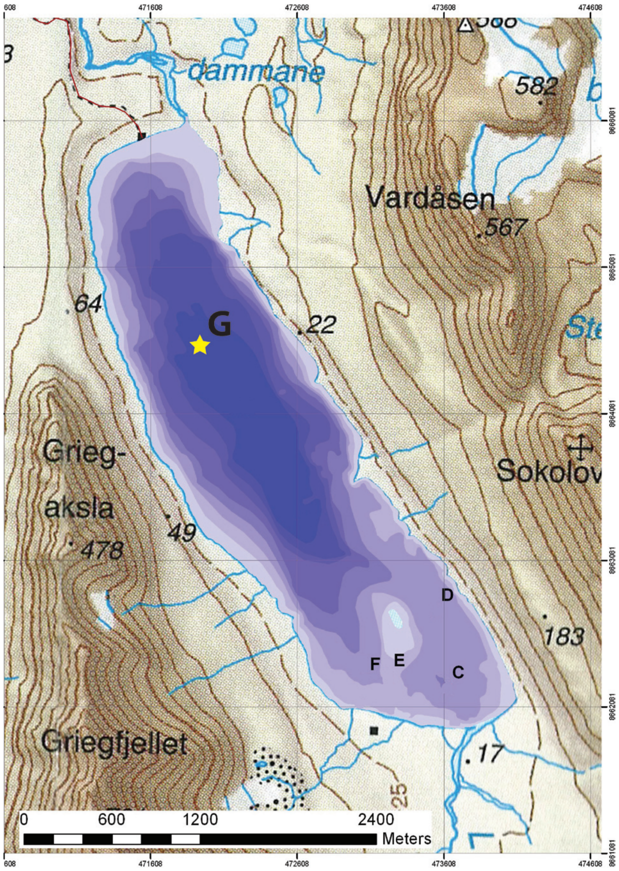

Figure 1. Map of field site. Linnévatnet can be seen at center with superimposed shaded bathymetry. Site G (marked with a yellow star) is located near the north end of the deep main basin. Bathymetric contour interval equals 5 m and topographic contour interval equals 50 m. Background map courtesy Norsk Polarinstitutt.

METHODS

Core Recovery and Initial Preparation

A sediment core, GC09-2, measuring 51 cm long was recovered from Site G (36.5 m depth, see Fig. 1) in Linnévatnet's deep main basin using a universal surface coring device. A clear sediment-water interface was noted, and after being transported from the field, the core was brought to the Limnological Research Center at the University of Minnesota where it was (1) split lengthwise, (2) described, (3) measured continuously for magnetic susceptibility using a Geotek point sensor, and (4) sampled down the center by pressing a U-channel into the sediment. The dimensions of the U-channel were 1.8 x 1.8 cm and cut to the length of the core. Sediment in the channel was then sliced into four intervals (0-10 cm, 10-15 cm, 15-20 cm, and 20-25 cm) which were subsequently dried thoroughly at room temperature. After drying, the 0-10 cm interval was divided evenly into vertical segments—first into thirds and then further into 36 discrete samples (S1 - S36). This process is illustrated in Figure 2.

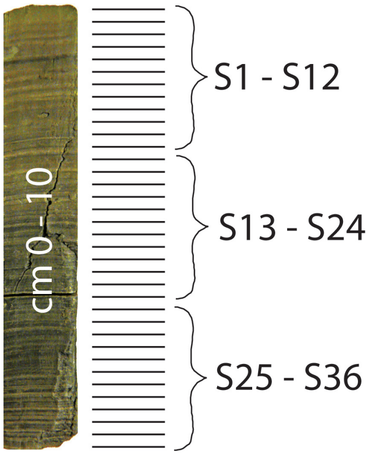

Figure 2. An illustration of the way in which core GC09-2 was split up for gamma ray analysis. After drying, the topmost interval (0-10 cm) was divided evenly into thirds and then further into 36 discrete samples. Note that samples S1-S36 are subdivided based on proportion (e.g. 1/3, 1/6…) and not original depth.

Gamma Ray Spectroscopy

All measurements of ^{137}Cs were made using the high-resolution germanium diode gamma ray detector and multichannel analyzer at Macalester College. The relative efficiency of the detector (Canberra model GC1518) is rated at 15%. The 1σ standard deviation of four measurements of sample S10 was 2.03 pC g^{-1}, or 13% relative to the measurement of 15.66 pC g^{-1}. In an attempt to locate the ^{137}Cs maximum, samples were first analyzed together in bundles and thereafter on an individual basis. All measurements were collected over a period of >3 hours and the total counts at 661.7 keV were converted into curies per gram (Ci g^{-1}) by comparison with a Spectrum Techniques 137Cs standard. To account for the effects of any non-uniform shrinking that occurred during the drying process, special care was taken in assigning a stratigraphic position to individual samples (S1-S15). First, the masses of all samples were taken and summed to find the total dry mass of the 0 – 10 cm interval. Then each sample's position was determined on the basis of the sample's mass as a fraction of the mass of the entire 0-10 cm interval, using the top of the core as a 0.0 g datum. However, in the case of the lower three intervals (10-15 cm, 15-20 cm, and 20-25 cm), which were not divided further after drying, stratigraphic position was simply decided to be at the midpoint of their intervals (e.g. the measurement of the 20 - 25 cm block was plotted at a stratigraphic position of 22.5 cm depth).

RESULTS

Sediment Character and Magnetic Susceptibility

Core GC09-2 is very clay-rich and ranges in color from medium/dark brown to gray. Visible laminations vary in thickness from 1 to 3 mm and there are distinctively light yellow/orange colored bands in the interval from 11-13.5 cm. Laminations are deformed slightly downward near the edges of the core tube, resulting in a three-dimensional doming effect that increases with depth. Visual stratigraphy in the top 15 cm of GC09-2 was a very close match to the stratigraphy seen in another core, GC09-1, recovered from the same site (Fig. 3). This strongly indicates that the top of the core represents the true sediment-water interface. Magnetic susceptibility, which is largely dependent on the concentration and size of magnetic mineral grains, is relatively constant along the core profile (approx. 5.5-6.5 SI units, see Fig. 4). The two exceptions to this are peaks corresponding to the bright yellow/orange bands in the 10.5 – 12 cm interval with maxima of 9.3 and 8.1 SI units.

Gamma Ray Spectrometry

The ^{137}Cs activity profile in GC09-2 shows a well-defined peak at 2.20 cm depth. As seen in Figure 4, activity levels begin to increase from background levels of zero (at 2.93 cm depth) to 21 pCi g^{-1} at the peak, and then decrease to zero again (1.22 cm depth). Negative values for ^{137}Cs activity are simply the result of on-average higher count values for energies surrounding the peak than within the peak region itself. The ^{137}Cs maximum does not appear to closely correspond with any visually distinctive lamination(s) in the sediment.

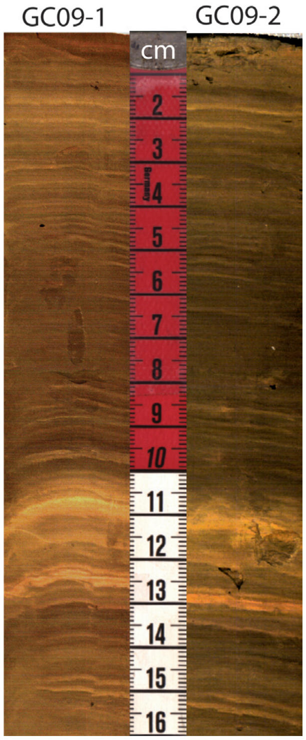

Figure 3. A comparison of two cores taken from Site G. Matching lamination stratigraphy strongly suggests that the top of GC09-2 represents the true sediment-water interface.

DISCUSSION

The usefulness of lacustrine sediments as a proxy for past climate change is predicated on our ability to understand the suite of modern environmental conditions that give rise to certain patterns of sedimentation. Importantly, quantification of recent sedimentation rates in Linnévatnet's deep main basin using ^{137}Cs profiles does just that: it offers insight into the pattern of sedimentation over a period for which climatic conditions are known, namely 1964-2009. Ideally this can serve as a calibration point for

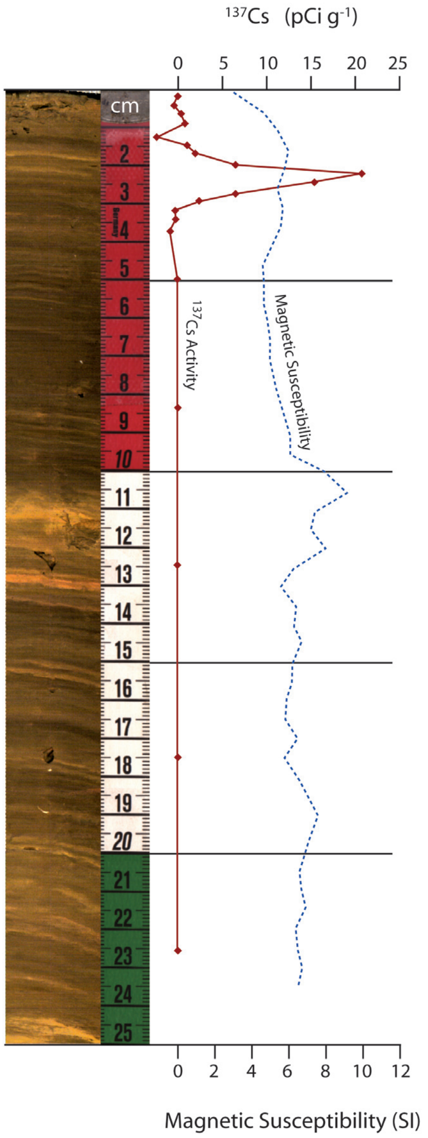

Figure 4. Cesium-137 and magnetic susceptibility profiles for GC09-2. The ^{137}Cs maximum at 2.2 cm depth represents the 1964 AD time horizon. Peaks in magnetic susceptibility occur at depths of 10.5 cm and 12 cm and correspond to distinctive visual stratigraphy.

estimating the age of any core horizon, but in order to feel confident in applying this estimate, we must consider error inherent in the analysis and compare the results presented here to estimates made by previous researchers.

Error Analysis

The 1σ standard deviation of repeated measurements of sample S10 is 2.0 pCi g^{-1} for a measurement of 15.66 pCi g^{-1}, not likely great enough to affect the general shape or position of the ^{137}Cs spike along the core profile. The most plausible source of error, however, originates from the method by which stratigraphic positions were determined. The 0-10 cm interval was divided proportionally and samples S1-S15 were assigned their position based on their mass as a fraction of the mass of the entire 0-10 cm interval—a process that assumes a constant sediment density over that interval. In the absence of density measurements for each sample, I nonetheless maintain that this assumption is justified based on the generally uniform sedimentology of GC09-2 and based on descriptions from Bøyum and Kjensmo (1978) and Pratt (2006) who found little variation in the specific gravity and bulk density of the top 25 cm of sediment cored from Linnévatnet's deep main basin.

Main Basin Sedimentation Rates

Based on the work of Ritchie et al. (1973), the well-defined peak seen in the ^{137}Cs profile is thought to represent the 1964 time horizon. Though fallout ^{137}Cs maxima also exists for the years 1959 and 1986, they are relatively insignificant in comparison to the 1963 maximum and can typically only be resolved in basins with high sedimentation rates (Van Metre et al., 2004). For this reason, they will not be considered here. Given these assumptions, the 137Cs peak at 2.20 cm depth in core GC09-2 suggests a mean sedimentation rate of 0.49 mm year^{-1} over the last half-century at Site G. Figure 5 compares this estimate with the results of three other researchers who have estimated sedimentation rates in Linnévatnet's deep main basin.

Pompeani et al. (2008) used a method of varve counting which resulted in varying average sedimentation rates across the length of his core (1.08 mm to 1.95 mm yr^{-1}), and an average of 1.55 mm yr^{-1} over the period from 1964 to 2008. Mortazavi (2009) made estimates based on paleomagnetic data and her study resulted in two age models: Model I, based on a sharp dip in declination at 33 cm, indicates a sedimentation rate of about 0.18 mm yr^{-1} for the 65 cm core. Model II, in which declination data for parts of her core were rotated 180°, indicates that sedimentation rates were widely variable within the core but were close to 3.5 mm yr^{-1} in the top 20 cm. Note in Figure 5 that, although the rate calculated in this study is slow in comparison to these previous estimates (3x slower than Pompeani et al. and 7x slower than Mortazavi), it is not unreasonably so. This is claim is supported by the findings of Arnold (2009) who made an indirect measurement of lake-bottom deposition at Site G by measuring the material captured in sediment traps deployed for a year-long period. Her estimate (0.5 mm yr^{-1}) is very close to the rate found by this study and supports the notion of sedimentation rates of <1 mm yr^{-1} for the main basin. However, if the rate presented here is to be preferred over the others, it comes with potential implications for understanding Linnévatnet patterns of sedimentation; namely that some recent years are poorly recorded by the archetypical silt-clay couplet, or varve. In the future, this issue might be resolved by comparing varve counts to ^{137}Cs profiles that have been measured on the same core or series of cores.

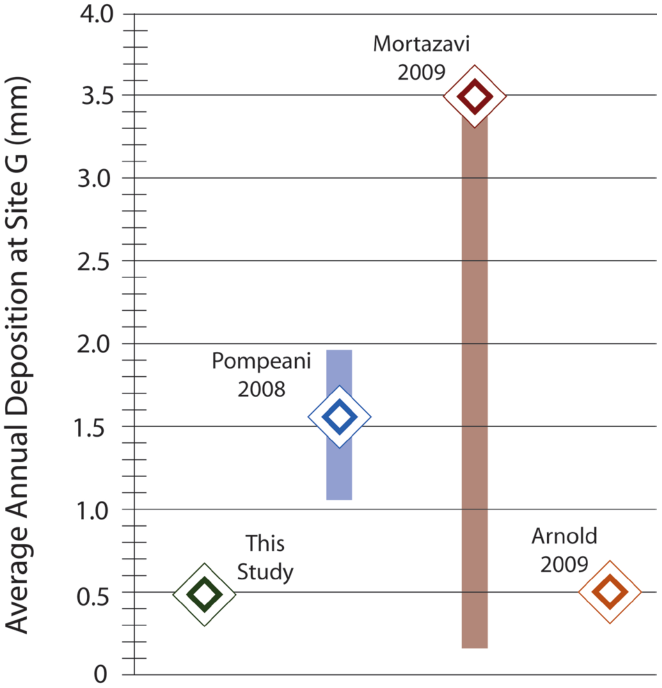

Figure 5. Average annual sedimentation at Site G calculated for the period 1964 -2009 AD (colored diamonds). The blue bar reflects a variation in average sedimentation rates from 1.08 and 1.95 mm yr^{-1} on the interval from 1635 - 2008 AD in Pompeani et al. The red bar indicates the range of rates presented by Mortazavi's two age models: Model I suggests rates as low as 0.18 mm yr^{-1}, while Model II suggests rates greater than 3.5 mm yr^{-1}.

Sedimentation Events in Linnévatnet

Using the estimated sedimentation rate of 0.49 mm year-1, the top 25 cm of GC09-2 records the depositional history in Linnévatnet back to the year 1498 AD, assuming no differential compaction of the core. With this, it is possible to look for evidence of known environmental events to see if they correspond to changes in core stratigraphy; this has been done in a very preliminary way here. First, given sedimentation rates, I have approximated the time period over which measurable concentrations of ^{137}Cs were deposited in the deep main basin. Its first appearance occurred in 1949-1950 and is present in measurable concentrations through about 1990-1991. This time interval is not unreasonable considering that the first atmospheric tests of nuclear weapons began in 1945 by the United States and in 1949 by the USSR. Given Cesium-137's slow rate of diffusion and chemical exchange of from a fixed site of deposition (Carrigan et al., 1967), this span of time is thought to be a reliable representation of the actual rate at which fallout ^{137}Cs cycled through the depositional system in Linnédalen. Further, the lack of bioturbation in Linnévatnet sediments adds confidence to the notion that the shape and position of the ^{137}Cs peak has remained constant since those sediments were deposited.

The average deposition rate was also used to estimate the ages of distinctive laminations seen in the core that occur prior to the ^{137}Cs anomaly. One such set of distinctively thick and brightly-colored laminations is located on the interval from 10.5 - 12 cm depth. On this interval, there is a peak in magnetic susceptibility suggesting (1) an increase in either the size or concentration, or both, of magnetic minerals and (2) a departure from the status quo of depositional processes and/or a change in sediment source within Linnédalen during this period. In light of this information it might be expected that these layers correspond to known environmental events. In fact, using the ^{137}Cs profile, these layers date to the period from 1764-1795 AD, an apparent correlation to the timing of maximum ice extent estimated for a nearby glacier during the second culmination of the Little Ice Age on Svalbard—around 1770-1800 AD (Alden, 2007).

Using fallout ^{137}Cs profiles to quantify recent deposition in Linnevatnet's deep main basin provides valuable insights into understanding sedimentation patterns there. By refining the procedures followed here and by extending them to other cores, we can provide an important standard which serves to confirm or deny interpretations of sedimentation events and the environmental conditions which conspired to create them.

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