THE CONCENTRATION OF IN SITU ^{10}BE IN FLUVIAL SEDIMENTS AS A TOOL FOR DECIPHERING 6 MY OF GREENLAND ICE SHEET HISTORY FROM A MARINE SEDIMENT CORE

A Progress Report

By

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To

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Of

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I. Introduction

1.1. Motivation

My research involves measuring the concentration of in situ ^{10}Be in glacio-fluvial sediments from Greenland and an adjacent ocean sediment core spanning the past 6 Myr (Figure 1). Knowing the concentration of ^{10}Be in modern continental sediment samples will help me interpret the down core record, which may provide a new way of estimating timing of Greenland Ice Sheet (GIS) inception and inferring past ice extent and erosivity. Linking this ice sheet variability with records of past climate change may help to determine thresholds for ice loss and regrowth, which is an important step towards predicting how the ice sheet might respond to future climate change.

1.2. Project Goals

The first component of my research is to measure the ^{10}Be concentration in sediment sourced from different places on the Greenlandic landscape. Ice shields rock from cosmic rays, so I expect sediments sourced from glaciated versus ice-free terrain will contain different amounts of ^{10}Be and that sediments from different source areas will mix as they are transported through the landscape. The percent of sediment sourced from land exposed to cosmic rays was presumably greater during past warm periods when ice sheet extent was less and reduced during cold periods when ice sheet area increased. For additional background on ^{10}Be production, please see my proposal.

Sediment from Greenland is continually eroding and is eventually deposited off shore. Consequently, the ^{10}Be concentration of sediment eroding from

Greenland changes over time depending on the extent and duration of landscape exposure. In the second component of my research, I will develop a 6 Myr-long record of this ^{10}Be variability in an offshore marine sediment core. I planned to analyze two cores from ODP sites 918 and 987; however, sediment from site 987 was much finer than expected so I eliminated that core from my thesis.

1.3. Hypotheses and experimental approach

I anticipate the concentration of ^{10}Be in the core sediment to fluctuate over time because of changes in A) the duration and extent of landscape exposure, B) the rate of subglacial and preglacial regolith erosion, and C) the duration of sediment storage within the landscape and the timing of sediment transportation from continent to ocean.

To test hypothesis A, I am measuring the ^{10}Be concentration in sediments sourced from a variety of environments, including exposed hill slopes, from directly beneath the ice sheet, from older fluvial deposits, and from rivers that drain a mixture of glaciated and deglaciated terrain (Figures 2 and 3). I expect sediments sourced from exposed hill slopes to have higher ^{10}Be concentrations than sediments sourced beneath ice because previous cosmogenic dating indicates that most exposed portions of the landscape have been accumulating ^{10}Be since at least the Holocene (Figure 4).

To address hypothesis B, I am reviewing ^{10}Be concentration data measured on bedrock, boulder, and moraine surfaces along the eastern and western margins of Greenland. If ice does not erode 1–2 meters of bedrock and surficial material, then ^{10}Be can be inherited from a previous period of exposure. Different methods

were used to test for inheritance along the margins of the ice sheet, which include paired bedrock and boulder comparisons (Corbett, 2011) delta depth-profile measurements (Goehring et al., 2010), and geomorphologic assessment (Hakansson et al., 2007b).

In 9 of 14 areas studied, sub-ice erosion is sufficient to remove most or all ^{10}Be accumulated during previous periods of exposure (Corbett et al., 2011; Hughes et al., 2012; Rinterknecht et al., 2009; Roberts et al., 2009; Roberts et al., 2008; Young et al., 2011). Inheritance does occur, primarily at high elevations, on bedrock and boulder surfaces in Jameson Land and Store Koldewey Island, east Greenland, and in Upernavik, west Greenland (Corbett, 2011; Hakansson et al., 2007a; Hakansson et al., 2007b). Inheritance in bedrock and boulders indicates that both landscape surfaces and eroded material can be preserved under cold-based ice. Inheritance is also found in moraine and delta material from Scoresby Sund where inheritance accounts for 10–20% of the surface concentration (Goehring et al., 2010; Kelly et al., 2008).

In contrast to high ^{10}Be concentrations measured in some bedrock and boulder surfaces, cobbles taken directly from the ice or from nearby outwash have very low ^{10}Be concentrations, even in Upernavik where landscape concentrations indicate inheritance (Corbett, 2011). Low levels of ^{10}Be in cobbles suggest they were sourced from areas where the ice sheet is erosive. The overall range of ^{10}Be concentrations measured on Greenland suggests regional differences in ice sheet behavior, indicating that there will also be variability in the ^{10}Be concentration in sediments that reach the coring site. There has been little previous cosmogenic

research on sediments from Greenland, however, so measurements I make will help define the ^{10}Be concentration variability in sand-sized material.

To define storage reservoirs and timing of sediment transport to the coring site, which is hypothesis C, I am reviewing studies of sediment transport off of Greenland. Coring and acoustic profiling data from fjords and the continental shelf suggest that sediments eroded during glacial retreat are stored in valleys and fjords (O'Cofaigh et al., 2001; Smith et al., 2000; Storms et al., 2012) and are not evacuated to the deep ocean until the next glacial advance (Wilken et al., 2006). Previous research matches my field observations of sediment storage along rivers in bars and flood plains. The timing of sediment transport suggests a lag between erosion and deposition controlled by the duration of glacial-interglacial cycles.

II. PROGRESS REPORT

2.1. Field Work

In early June 2012 I spent nine days in Greenland (Figure 1) collecting sediment samples from streams and rivers that drain the ice sheet and from areas not currently glaciated. Our fieldwork was centered on the east coast near the village of Tasiilaq (Figure 2) and on the west coast near Kangerlussuaq (Figure 3), where sampling occurred in 2011. We collected 43 samples (13 bedrock, 29 sediment, 1 erratic) from new locations and 7 replicate samples from locations along the Watson River (Kangerlussuaq) that were sampled in 2011.

Transport to field sites was done by helicopter, providing a view of the landscape as an entire system containing hill slope and sub-glacial sediment sources as well as rivers and streams, which transport sediment to the fjords. From this

perspective, I was able to identify places where sediment is stored including channel bottoms, banks, and flood plains.

2.2. Lab Work

For ^{10}Be extraction, it is necessary to have sand particles between 250–850 μm. Bedrock and boulder samples had to be crushed prior to sieving. After sieving, I put each sample through a magnetic separator to remove many of the heavy minerals. In early July, I finished this preparation for samples collected in June.

The core I analyzed was drilled by the Ocean Drilling Program at site 918 off the east coast of Greenland (Figure 1). We requested 305 evenly distributed samples spanning the first 550 m of the core, which we sieved and amalgamated into 30 samples for cosmogenic analysis, each ~200 g. Once amalgamated, I re-sieved the samples into grain size fractions between 125–850 μm. The majority of sample material fell between 125–250 μm and 250–500 μm. I used both size fractions for further processing, but initially kept them separate to minimize sample loss.

I etched the field and core samples in a series of hot, sonicated acid baths to isolate quartz through preferential dissolution of other minerals. I have completed all quartz production steps for samples collected in June. For core samples, I have finished initial etches, but the sediments contain a lot of fine-grained heavy minerals, which I need to remove using density separation. I am in the process of doing the density separation work.

Last year I was trained in the cosmogenic laboratory where I am working to isolate the ^{10}Be in each sample. I am able to process a batch of ten samples at a time

that also includes two blanks. I have processed my first batch of samples, which has been shipped to the Scottish Universities Environmental Research Centre (SUERC) accelerator mass spectrometry (AMS) facility in Scotland to test laboratory process blanks and ion beam currents, both of which are important for the success of the ^{10}Be analyses. I have six batches left to process, and I am on schedule to finish this work by the end of the fall semester 2012.

2.3. Data Review and Management

Over the summer, I compiled all of the ^{10}Be data published from Greenland (n=176) into a database containing information about the publication, sample location, sample type (bedrock, boulder, or sediment), ^{10}Be concentration, exposure age, and processing facility. These metadata allow me to compare my data to the data others have collected. The range of ^{10}Be concentration measured on Greenland is 6.0×10^2 to 1.66×10^6 atoms/g and the distribution is positively skewed (Figure 4). The median concentration is 5.4×10^4 atoms/g, which indicates Holocene exposure (8–12 ka). This data set is helping me understand how bedrock and boulder surfaces on Greenland are accumulating ^{10}Be, which I will be able to compare to the ^{10}Be concentration of sediments eroding from the landscape.

I also created a database for samples collected during the summers of 2011 and 2012, which contains the latitude and longitude for each sample location, the elevation, sample type, field notes, and AMS data for samples collected in 2011. The Geographic Information Systems course, which I am taking this fall, is giving me the tools I need to organize and interpret these data.

2.4. Initial Results

I have ^{10}Be concentration data from samples collected in the summer of 2011, which I will present in a poster session at AGU in December. Fluvial sediments were collected from rivers draining the Kangerlussuaq (n=11) (Figure 5) and Narsarsuaq (n=12) regions on the west and south coasts of Greenland (Figure 1).

In Kangerlussuaq, ^{10}Be concentrations range from 2.1 x 10^3 to 2.1 x 10^4 atoms/g with a median concentration of 4.8 x 10^3 atoms/g (Figure 5). In river sediments draining the Russell Glacier, concentrations range from 2.1 x 10^3 to 5.7 x 10^3 atoms/g, with a mean concentration of 3.9 x 10^3 atoms/g. The sample with a concentration of 2.1 x 10^4 atoms/g could be higher than the others because of an aeolian sediment contribution. This site and 6 others were re-sampled in 2012. The second highest measurement was from a gravel pit, and the ^{10}Be concentration of 9.0 x 10^3 atoms/g represents the concentration in glacial sediments deposited ~8 ka. This site was also re-sampled in 2012. River sediments from the Watson (n=3) have low concentrations of ^{10}Be (2.1–2.9 x 10^3 atoms/g) with low variability (standard deviation = 17%). ^{10}Be concentration in Watson River sediments is lower than the concentrations in sediment from the ice margin, adjacent river drainage, and fjord mouth.

In Narsarsuaq, ^{10}Be concentrations range from 2.1 x 10^3 atoms/g to 3.47 x 10^4 atoms/g with a median concentration of 7.5 x 10^3 atoms/g (Figure 6). Narsarsuaq sediment samples fall into three groups; glacio-fluvial sediments from tongues of the ice sheet that approach the fjord, ice-sheet marginal samples inland of the fjord, and sediments sourced primarily from exposed hill slopes (Figure 6).

The glacio-fluvial sediments close to the fjord have concentrations between 2.1 x 10^3 and 6.4 x 10^3 atoms/g and ^{10}Be concentration increases downstream from the ice margin to the fjord mouth. Ice-sheet marginal samples farther away from the fjord have concentrations of 1.3 and 1.9 x 10^4 atoms/g. Sediment samples sourced from exposed portions of the landscape have concentrations between 8.6 x 10^3 atoms/g and 3.5 x 10^4 atoms/g.

2.5. Initial Interpretations

The data suggest that sediments being discharged by the Greenland Ice Sheet today contain varying concentrations of ^{10}Be and that the concentration of ^{10}Be in fluvial sand changes as that sand is transported downstream through deglaciated areas that contribute additional sediment.

In Kangerlussuaq, sub-glacially sourced sediments have relatively low levels of ^{10}Be (3.0 and 4.8 x 10^3 atoms/g) because much of the landscape from which the sediment is sourced is currently shielded from cosmic rays. Sediment with low concentrations of ^{10}Be could be sourced from surface material that experienced a short period of exposure, or depending on sub-ice erosion, could be sourced from a depth where production rates are reduced. Watson River sediment collected away from the ice had even lower concentrations of ^{10}Be, between 2.1 and 2.9 x 10^3 atoms/g. It is unclear why ^{10}Be concentration in Watson River sediment is lower than the concentration in sediments up stream at the ice margin and down stream at the fjord mouth. One possibility is that jökulhlaup events in 2007 and 2008, which significantly increased river discharge (Russell et al., 2011), could have mixed river sediments with sediments sourced from a depth where ^{10}Be production is reduced.

The Watson River was re-sampled in 2012 and hopefully additional data will help me to understand why Watson River sediments have a lower ^{10}Be concentration than sediments collected elsewhere in the Kangerlussuaq Valley.

In Narsarsuaq, glacially sourced sediment can be divided into two groups. Two samples from the margin of ice-sheet tongues that approach the fjord have concentrations of 2.2 and 4.8 x 10^3 atoms/g. Sediment from margins of the ice sheet at higher elevations, farther away from the fjord, have concentrations of 1.27 and 1.92 x 10^4 atoms/g. The lower ^{10}Be concentrations in sediments sourced beneath fjord-proximal portions of the ice sheet could be due to less mid Holocene exposure or to greater sub glacial erosion. Previous studies indicate that during Holocene warming, ice persisted longer in ice streams than adjacent uplands because discharge and ice thickness were greater in valleys (Roberts et al., 2009). If this were the case in Narsarsuaq, then the termini of the fjord-proximal tongues of the ice sheet may have fluctuated less during the Holocene than margins of the ice sheet at higher elevations. Along the same reasoning, if ice discharge were greater in portions of the ice sheet confined to the valleys, then there would be greater erosion there, resulting in deeper-sourced sediments being discharged close to the fjord than farther from the fjord. The two highest concentrations of ^{10}Be (2.49 and 3.47 x 10^4 atoms/g) were sourced from exposed hill slopes near Narsarsuaq, where bedrock and boulder concentrations (6.0 x 10^4 –1.15 x 10^5 atoms/g) indicate exposure since the Last Glacial Maximum.

Initial results indicate that ^{10}Be concentration in sediments is variable, both within and between regions studied (Figure 7). From reviews of sediment

transport, I can infer that sedimentation at the coring site likely occurs in pulses coincident with glacial advance, and because of storage, sediments deposited during glacial growth contain ^{10}Be accumulated during a prior period of exposure. I can use the variability in ^{10}Be concentration in sediments collected from the Greenlandic landscape today as an analog to the past and can infer that variability in ^{10}Be concentration in sediments is a function of not only exposure extent and duration, but also elevation, source area, and subglacial thermal regime. Data from an additional summer of fieldwork will help me to further define this variability.

III. REMAINING WORK

I have developed a time line to finish my lab work (barring unforeseen complications) by the end of the fall semester (Table 1). After cosmogenic processing is complete, the isotopic ratios will be measured at the SUERC AMS facility in Glasgow. I will have data for at least my first batch of samples this fall and I will have the rest of my data by mid January. This will give me data in time to make interpretations during the winter so that I can prepare a thesis to defend during the late spring (Figure 8).

Figure 1: Map of Greenland showing the sample locations (red circles) and the core site (purple triangle). During the summer of 2011, samples were collected in Kangerlussuaq and Narsarsuaq and in June of 2012, I helped to collect additional samples near Kangerlussuaq and also near Tasiilaq.

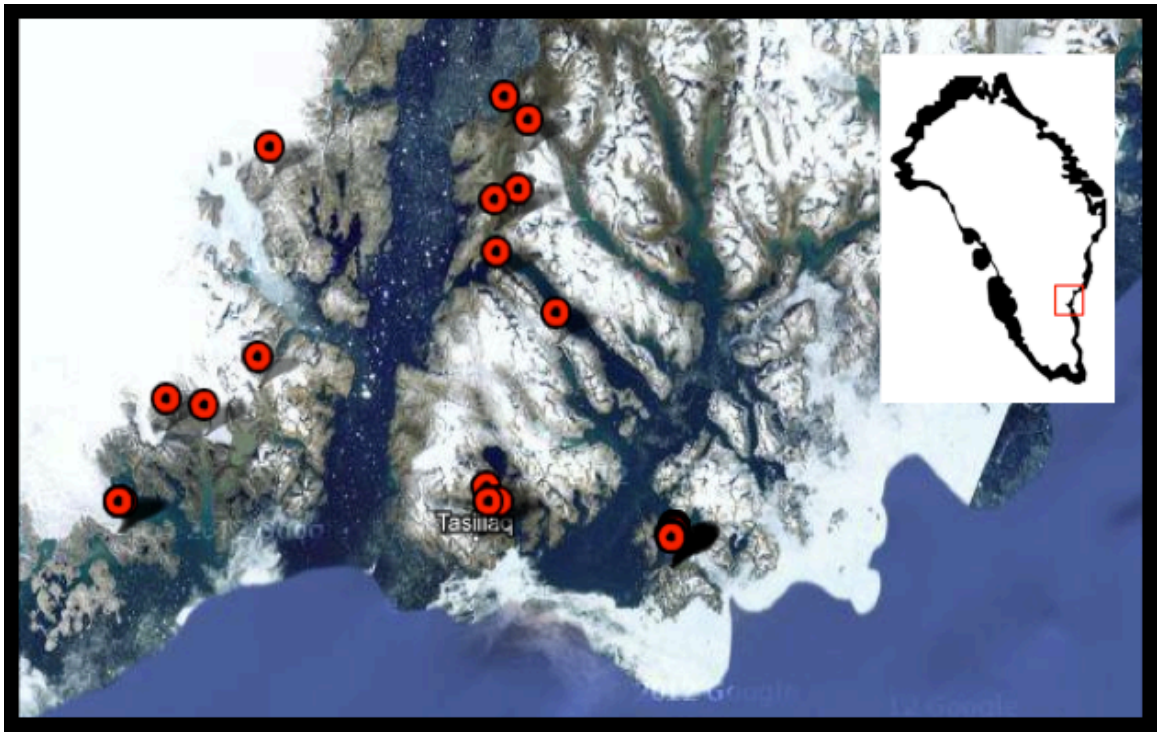


Figure 2: Map showing 2012 sample locations near the village of Tasiilaq on the east coast.

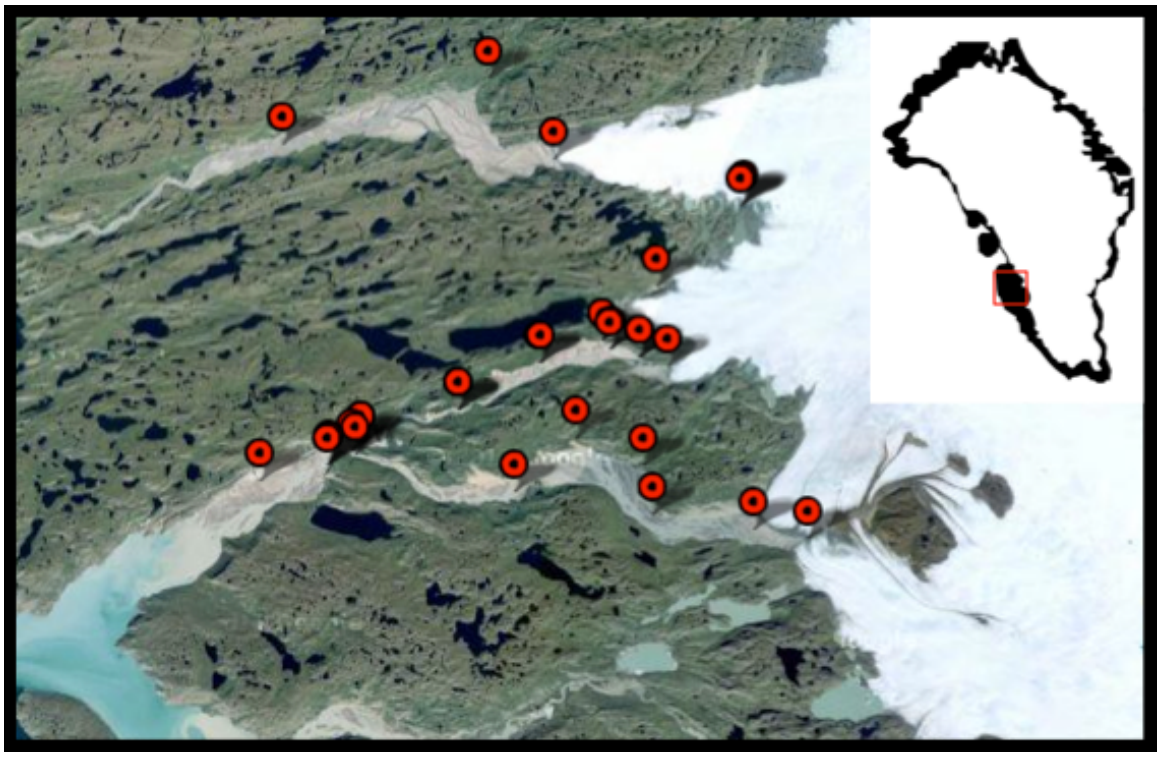
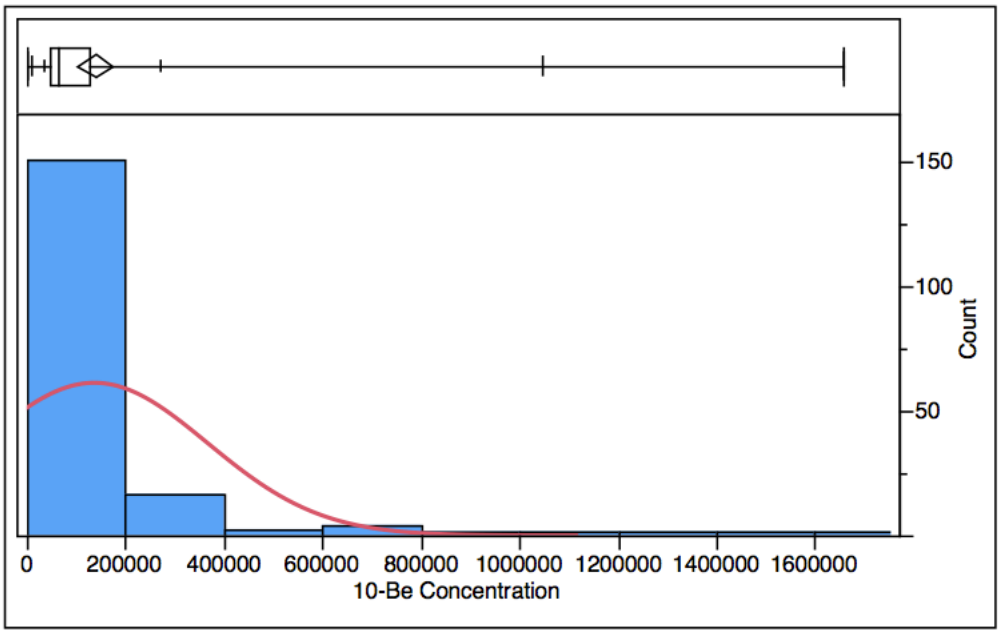


Figure 3: Map showing 2011 and 2012 sample locations near Kangerlussuaq on the west coast.

A.



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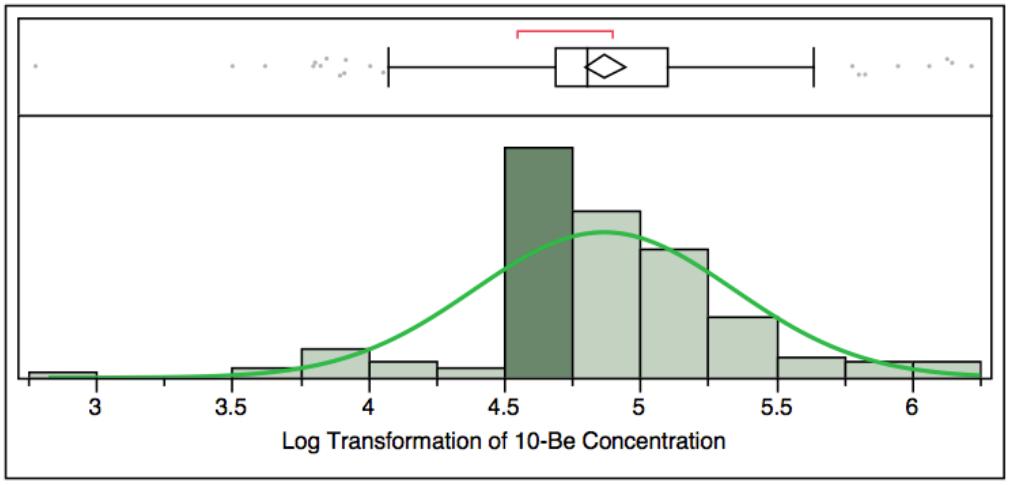

Figure 4: A) Previously published measurements of ^{10}Be concentration on Greenland (n=176) range from 6.0 x 10^2 –1.66 x 10^6 atoms/g. The distribution is positively skewed and passes the Shapiro-Wilk test for normality (p=0.469). B) The histogram shows the data with a log-base 10 transformation. The transformed distribution passes the Shapiro-Wilk test for normality (p=0.929).

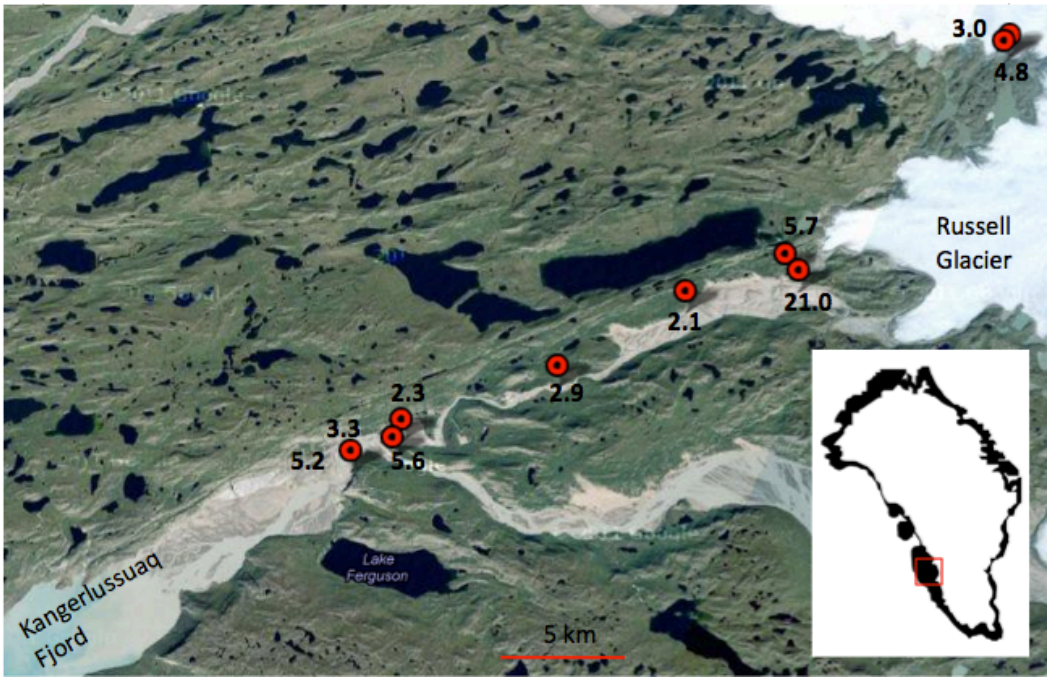

Figure 5: Map of 2011 sample sites near Kangerlussuaq on the west coast. ^{10}Be concentrations are given in thousands of atoms/gram. The main drainage pictured is the Watson River, which flows from the margin of the Russell Glacier to the Kangerlussuaq Fjord.

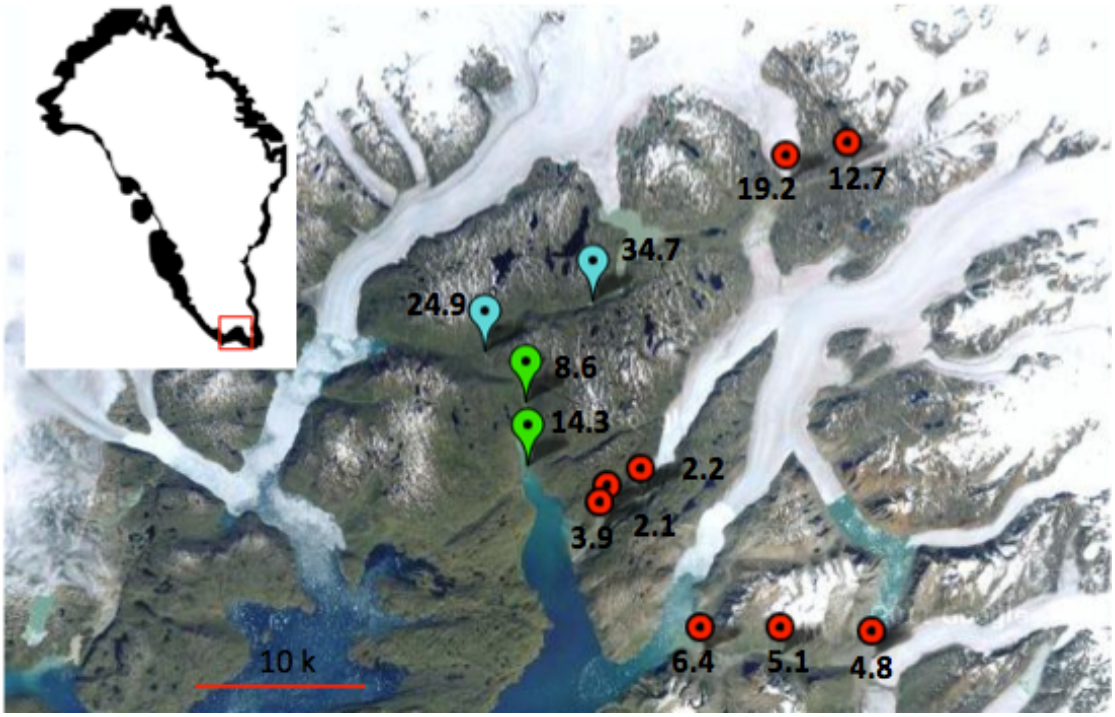

Figure 6: Map of 2011 sampling sites near Narsarsuaq on the southern coast. The red dots represent the locations of sediment samples sourced from the ice sheet. The blue teardrops represent samples sourced from exposed hill slopes and the green teardrops are the sampling sights on the margins of the fjord. ^{10}Be concentration is given in thousands of atoms/g.

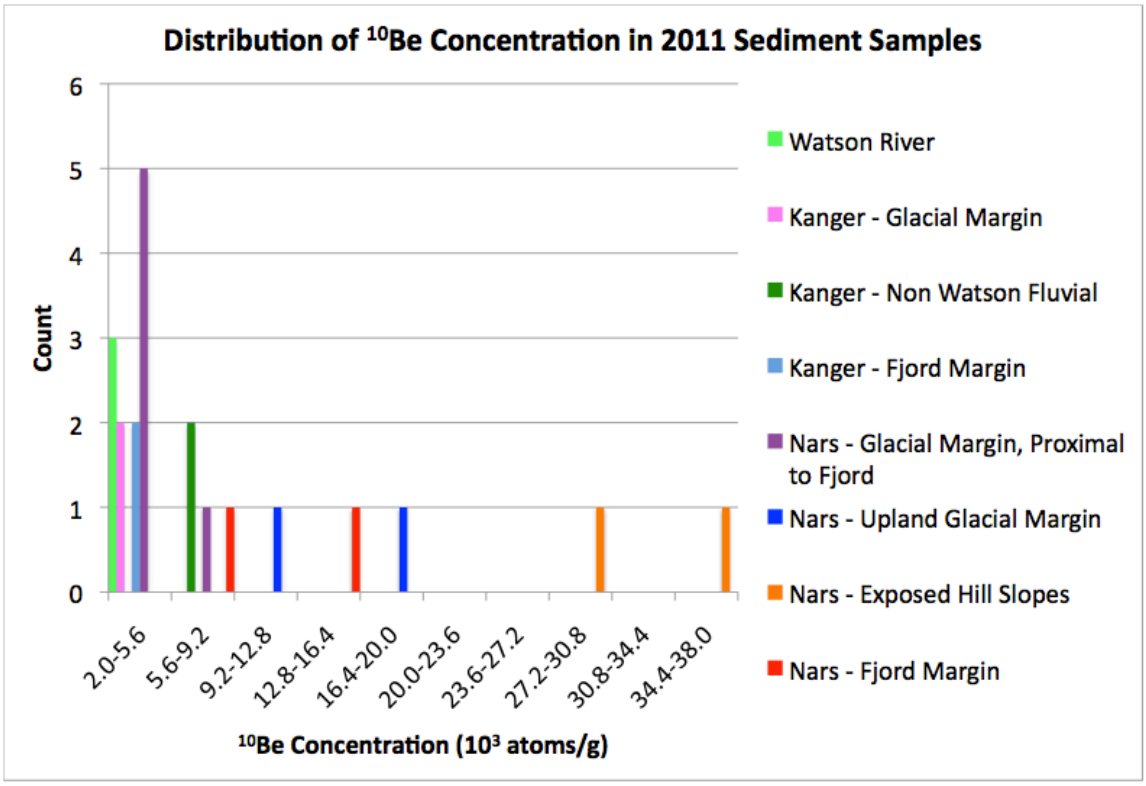

Figure 7: Histogram showing the distribution of ^{10}Be concentration in samples collected in 2011 near Kangerlussuaq (Kanger, Figure 5) and Narsarsuaq (Nars, Figure 6). This distribution suggests the range of ^{10}Be concentration in present-day sediments, and thus helps inform the ^{10}Be concentration in sediments eventually deposited at the coring site.

Table 1: Table showing the laboratory work that is already finished as well as the timing to process the rest of the samples by the end of the fall semester.

	Sample Preparation	Quartz Production	^{10}Be extraction	Data Acquisition
Summer 2011 *65 samples*	✔	✔	✔	✔
Summer 2012 *36 samples*	✔	✔	September/October	January
Hole 918 *30 samples*	✔	Early October	November/December	January

September	• Cosmo lab processing (2 batches) • Prepare progress report
October	• Finish quartz production for core • Cosmo lab processing (2 batches) • Present progress report
November	• Prepare for AGU • Geospatial analysis of published ^{10}Be data • Cosmo lab processing (2 batches) • Begin processing data for the first batch
December	• Present at AGU • Cosmo lab processing (1 batch)
January	• Receive, process, and begin to interpret AMS data • Begin geospatial analysis, update sample database and maps with additional data
February, March	• Data interpretations • Writing
April	• Figures • Writing
May	• Defend Thesis

Figure 8: Timeline to finish my lab work, make interpretations, and defend my thesis.

Works Cited

Corbett, L. B., 2011, Investigating the timing of deglaciation and the efficiency of subglacial erosion in central-western Greenland with cosmogenic 10-Be and 26-Al [Master of Science Specializing in Geology: The University of Vermont, 174 p.

Corbett, L. B., Young, N. E., Bierman, P. R., Briner, J. P., Neumann, T. A., Rood, D. H., and Graly, J. A., 2011, Paired bedrock and boulder (10)Be concentrations resulting from early Holocene ice retreat near Jakobshavn Isfjord, western Greenland: Quaternary Science Reviews, v. 30, no. 13-14, p. 1739-1749.

Goehring, B. M., Kelly, M. A., Schaefer, J. M., Finkel, R. C., and Lowell, T. V., 2010, Dating of raised marine and lacustrine deposits in east Greenland using beryllium-10 depth profiles and implications for estimates of subglacial erosion: Journal of Quaternary Science, v. 25, no. 6, p. 865-874.

Hakansson, L., Briner, J., Alexanderson, H., Aldahan, A., and Possnert, G., 2007a, Be-10 ages from central east Greenland constrain the extent of the Greenland ice sheet during the Last Glacial Maximum: Quaternary Science Reviews, v. 26, no. 19-21, p. 2316-2321.

Hakansson, L., Graf, A., Strasky, S., Ivy-Ochs, S., Kubik, P. W., Hjort, C., and Schluchter, 2007b, Cosmogenic (10)Be-ages from the Store Koldewey island, NE Greenland: Geografiska Annaler Series a-Physical Geography, v. 89A, no. 3, p. 195-202.

Hughes, A. L. C., Rainsley, E., Murray, T., Fogwill, C. J., Schnabel, C., and Xu, S., 2012, Rapid response of Helheim Glacier, southeast Greenland, to early Holocene climate warming: Geology, v. 40, no. 5, p. 427-430.

Kelly, M. A., Lowell, T. V., Hall, B. L., Schaefer, J. M., Finkel, R. C., Goehring, B. M., Alley, R. B., and Denton, G. H., 2008, A Be-10 chronology of lateglacial and Holocene mountain glaciation in the Scoresby Sund region, east Greenland: implications for seasonality during lateglacial time: Quaternary Science Reviews, v. 27, no. 25-26, p. 2273-2282.

O'Cofaigh, C., Dowdeswell, J. A., and Grobe, H., 2001, Holocene glacimarine sedimentation, inner Scoresby Sund, East Greenland: the influence of fast-flowing ice-sheet outlet glaciers: Marine Geology, v. 175, no. 1-4, p. 103-129.

Rinterknecht, V., Gorokhovich, Y., Schaefer, J., and Caffee, M., 2009, Preliminary Be-10 chronology for the last deglaciation of the western margin of the Greenland Ice Sheet: Journal of Quaternary Science, v. 24, no. 3, p. 270-278.

Roberts, D. H., Long, A. J., Schnabel, C., Davies, B. J., Xu, S., Simpson, M. J. R., and Huybrechts, P., 2009, Ice sheet extent and early deglacial history of the southwestern sector of the Greenland Ice Sheet: Quaternary Science Reviews, v. 28, no. 25-26, p. 2760-2773.

Roberts, D. H., Long, A. J., Schnabel, C., Freeman, S., and Simpson, M. J. R., 2008, The deglacial history of southeast sector of the Greenland Ice Sheet during the Last Glacial Maximum: Quaternary Science Reviews, v. 27, no. 15-16, p. 1505-1516.

Russell, A. J., Carrivick, J. L., Ingeman-Nielsen, T., Yde, J. C., and Williams, M., 2011, A new cycle of jokulhlaups at Russell Glacier, Kangerlussuaq, West Greenland: Journal of Glaciology, v. 57, no. 202, p. 238-246.

Smith, L. M., and Andrews, J. T., 2000, Sediment characteristics in iceberg dominated fjords, Kangerlussuaq region, East Greenland: Sedimentary Geology, v. 130, no. 1-2, p. 11-25.

Storms, J. E. A., de Winter, I. L., Overeem, I., Drijkoningen, G. G., and Lykke-Andersen, H., 2012, The Holocene sedimentary history of the Kangerlussuaq Fjord-valley fill, West Greenland: Quaternary Science Reviews, v. 35, p. 29-50.

Wilken, M., and Mienert, J., 2006, Submarine glacigenic debris flows, deep-sea channels and past ice-stream behaviour of the East Greenland continental margin: Quaternary Science Reviews, v. 25, no. 7-8, p. 784-810.

Young, N. E., Briner, J. P., Stewart, H. A. M., Axford, Y., Csatho, B., Rood, D. H., and Finkel, R. C., 2011, Response of Jakobshavn Isbrae Greenland, to Holocene climate change: Geology, v. 39, no. 2, p. 131-134.