

Sediment accumulation rates in the West Arm of Glacier Bay, Alaska based on Lead-210 analysis

Justin Bergquist

Abstract

Unique climate, tectonics and temperate glacial dynamics make Glacier Bay one of the fastest eroding and rebounding landscapes in the world. Because Glacier Bay has one of the fastest sediment accumulation rates in the world, glacial fjord basins in the bay are a suitable way of observing rapid sedimentation that has occurred since the last ice age. The radioisotope ^{210}Pb is a useful tool because it is adsorbed from the water onto settling sediment particles. In March of 2008, four Kasten cores from Glacier Bay were examined by the radiochemical ^{210}Pb dating technique to calculate sediment accumulation rates from ^{210}Pb decay profiles. Sediment accumulation rates from the four cores ranged from 2.7 cm yr^{-1} to 0.97 cm yr^{-1} .

Introduction

Glacier Bay National Park and Preserve is located $\sim 100 \text{ km}$ west of Juneau, Alaska. This area of Alaska is composed of actively tectonic mountains and glacier carved fjords that receive as much as 8 meters of precipitation/snowfall annually (Powell & Molnia, 1989). Extreme weathering coupled with high uplift rates of these mountains and high basal lubrication of these temperate glaciers amplify the erosion

to the underlying substrate of shattered and altered rock comprised mostly of weakly lithified sediments of glacial origin (Hallet et al., 1996). In the late 19th century Glacier Bay was predominantly covered with glaciers from the Little Ice-Age period (Cai et al., 1997). In the following years, these glaciers have rapidly retreated, exposing numerous glacial-carved fjords. Variations in sediment input into the bay are directly linked to these retreats because the fjords are efficient sediment traps for sediment produced by tidewater glaciers (Koppes and Hallet, 2002). Complete sequences of glacial debris in the fjords allow assessment of the relationship between glacial sedimentation and the extent of glacier cover, glacier mass balance and history of retreat (Koppes & Hallet 2002). Hallet (1996) and others (e.g. Koppes and Hallet, 2002) have documented erosion rates of tidewater glaciers in Alaska on the order of cm yr^{-1} for the last century, an order of magnitude higher than the highest erosion rates in the world. Glacier Bay also has one of the highest sedimentation rates in the world (Table 1).

Previous sediment trap and sediment core ^{210}Pb data illustrate that sediment accumulation rates decrease away from the glacial termini of Tarr Inlet in three distinctive zones: Ice-proximal, Ice-berg and Ice-distal (Fig.1)(Cai et al., 1997).

In Tarr Inlet, the Ice-proximal zone is characterized by high and variable sediment accumulation rates ranging from tens of m yr^{-1} to tens of

Location	Glacier terminus	(km) from terminus	Accum. rate (cm yr ⁻¹)	Authors
Tarr Inlet	Grand Pacific Glacier	3, 6.5, 8.8 & 15	70, 40, 19 & 2-3	Cai et al., 1995
Muir Inlet	Muir Glacier	1.5, 26, 38 & 55	82, 0.5, 1.4 & 0.5	Cai et al., 1996
Queen Inlet	Carroll Glacier	proximal & distal	9 & 3	Carlson et al., 1996

Table 1: Displays previous Glacier Bay sediment accumulation rates from ²¹⁰Pb dating

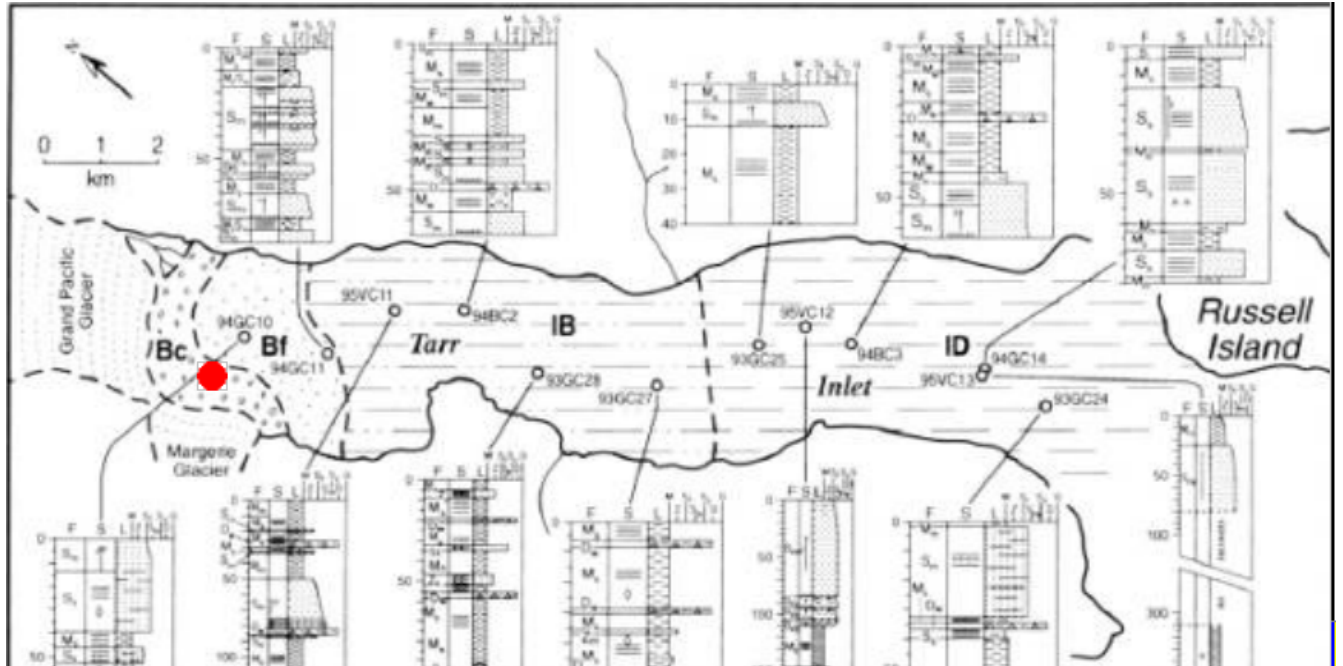


Figure 1: This is a diagram of Tarr Inlet. The left side of the figure is Northwest and the right side is Southeast. Bc and Bf compose the Ice-proximal zone, IB is the Ice-berg zone and ID represents the Ice-distal zone (Cai et al., 1997). If this figure is turned 90 degrees to the right it resembles the black box of Tarr Inlet in Figure 2. The red dot indicates location of KC-21.

cm yr⁻¹, with an average of 3-4 m yr⁻¹. Sediment accumulation rates in the Ice-berg zone: upper (closer to glacier terminus), middle and lower (furthest away from glacier terminus), range from 100 cm yr⁻¹, 40 cm yr⁻¹, and 19cm yr⁻¹, respectively. In contrast, rates in the upper and lower areas of the Ice-distal zone, range from 6 cm yr⁻¹ to 3.2 cm yr⁻¹ (Cai et al. 1997).

“Interest in glacial erosion has recently broadened to a much wider community of earth scientists because of its role in the controversial and globally significant interplay between

climate and topography that includes chemical weathering as in important sink of atmospheric CO²” (Hallet et al., 1996).

Determination of sediment accumulation rates is critical to calculating sediment yields from glacial erosion. The radioisotope ²¹⁰Pb can be used to measure sediment accumulation by the adsorption of excess ²¹⁰Pb activity by sediment particles in the water column (Jaeger et al., 1998). Excess activity is any activity that exceeds the background activity of the parent ²²⁶Ra (Nittrouer et al., 1984). ²¹⁰Pb half-life

of 22.3 years makes it a valuable tool in dating sediment within the last century (Jaeger et al., 1998). “Due to analytical and environmental constraints, a radioisotope generally can be used to examine sedimentation for a period of about 4 to 5 times its half-life”(Nittrouer et al., 1984). Usually, the exponential decay profile of ^{210}Pb decreases with depth in the sediment (Jaeger et al., 1998). This study provides quantitative analyses of ^{210}Pb to examine sediment accumulation rates in various locations with in Glacier Bay.

Methods

Field Methods

Kasten cores sampled from areas near previous sediment studies were used to augment information on accumulation rates and also to determine if sedimentation rates have changed with climate since the last studies of the 1990s. Four Kasten cores of various lengths were obtained near Glacier Bay National Park historical CTD stations (Hodge and Hodge, 2002), Station #s KC-10, 16, 21 and 23 (Table 2).

These environments include Tarr and Muir Inlets and other inlet mouths in the West Arm, which are fed by the John Hopkins, Lamplugh, Reid and Geikie glaciers (Fig. 2).

Seabed Sampling

Sediment sampling in Glacier Bay was performed onboard the R/V *Thomas G. Thompson* during a cruise in March 2008. To broadly characterize layering in the sub-sea floor and sediment thicknesses, 3.5 kHz surveys were conducted. These data were important in determining optimal sampling sites. In addition, EM300 multi-beam surveys were co-located to provide additional information on bottom topography. Following preliminary survey studies, a Van Veen grab (Fig. 3) or Soutar core (Fig. 4)



Figure 3: Picture of a VanVeen grab sampler (photo by Brittany Kimball).

sample of the proposed site was conducted to determine the presence of boulders or areas of coarse-grained sediment accumulation that would prevent taking a Kasten Core (Fig. 5). Where sampling was permissible, a Kasten core was taken and recovered on deck.

The Kasten corer was assembled (See Appendix A) and deployed on board. Sediment cores recovered with the Kasten corer were measured, described and digitally imaged upon recovery. Kasten cores were sub-sampled immediately at 2 cm intervals and homogenized on board for geochemical studies. Two sediment samples from every 2 cm interval were bagged and labeled for archive and laboratory analyses back at the University of Washington Marine Science sediment lab. Sediment baggies were stored in a refrigerator on board.

Core #	Date	Time	Location	Lat/Long	Water depth	Core length
KC-10	3/20/2008	22:15	S. of Russell Island	58.89° N, 136.83° W	369 m	207cm
KC-16	3/21/2008	21:02	E. of Hunter Cove	58.89° N, 136.09° W	294 m	68 cm
KC-21	3/20/2008	17:15	N. Tarr Inlet	59.04° N, 137.05° W	217 m	58 cm
KC-23	3/18/2008	16:58	W. Geikie Inlet	58.60° N, 136.47° W	99 m	93 cm

Table 2: Displays Cruise 217 Kasten core locations, dates and times taken, latitudes and longitudes, water depths and core lengths.



Figure 4: This is a picture of a Soutar Box core on the stern of the R/V *Thompson* (photo by Brandon Knox)

Laboratory methods

On shore, laboratory procedures include pre lab and ^{210}Pb lab procedures (T. Drexler. 2007)(See Appendix B). ^{210}Pb activities were determined by the ^{210}Po method (Benninger et al., 1979;



Figure 5: Picture of Kasten core being recovered on the stern of the R/V *Thompson* in North Tarr Inlet(photo by Eric Collins).

Nittrouer et al. 1979). The ^{210}Po method is applicable because ^{210}Pb and its granddaughter ^{210}Po are in secular equilibrium within the seabed (Nittrouer et al., 1979). Five grams of dried sediment was spiked with ^{209}Po as a yield determinant, chemically leached with hot concentrated HNO_3 and 6 N HCL , and ^{210}Po was autodeposited onto silver planchettes (Jaeger et al. 1998). The ^{210}Po activities were measured by alpha counting the planchettes with Ortec Plus and PC alpha spectrometers for 23-24 hours or until 80,000 seconds of counting was completed.

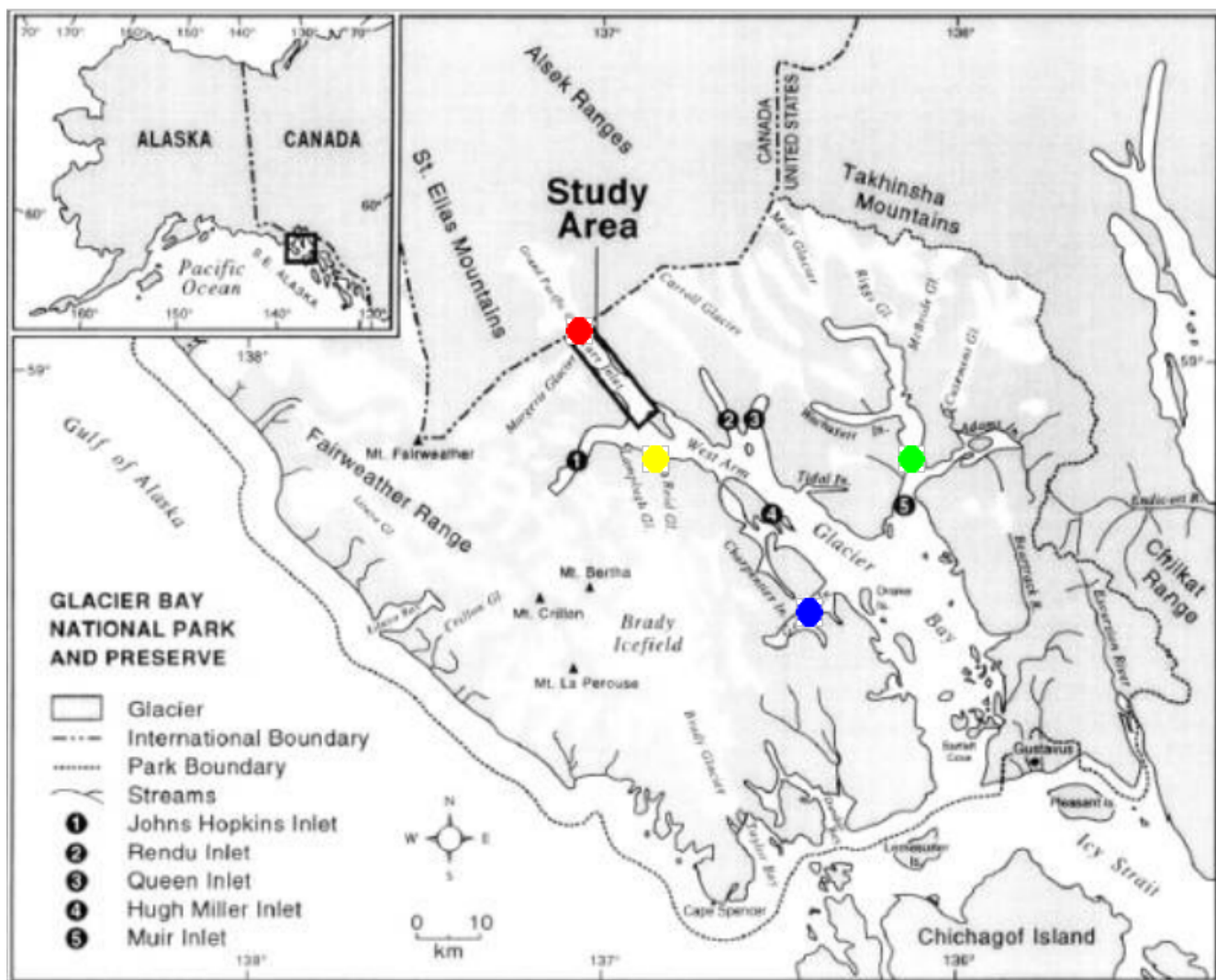


Figure 2: Displays color-coded dots for Kasten core locations from Table 2. Red indicates KC-21, Yellow indicates KC-10, Blue indicates KC-23 and Green indicates KC-16 (Cai et al. 1997)

Analytical methods

Spread sheets provided by Tina Drexler were used for calculating ^{210}Pb activities from ^{210}Po activities and ^{209}Po Spike. These spreadsheets also calculated porosity, salt corrected porosity, bulk density, salt corrected sample mass and sediment accumulation rates.

Sediment accumulation rates of ^{210}Pb were measured in dpm g^{-1} (disintegrations per minute per gram dry weight). “A characteristic profile of ^{210}Pb activity contains a nearly homogeneous surface layer, below which activities de-

crease logarithmically to a constant low level (background). The background level represents ^{210}Pb supported by a ^{226}Ra in the sediment. Excess ^{210}Pb activity at each point in a core is determined by subtracting supported ^{210}Pb activity from total ^{210}Pb activity” (Nittrouer et al., 1984).

If the sediment and ^{210}Pb fluxes remain continuous, then a vertical profile of ^{210}Pb can be used to calculate an accumulation rate (A) using the following equation (Nittrouer et al., 1984):

$$A = \frac{\lambda_z}{\ln \frac{C_0}{C_z}}$$

where C_0 = activity of ^{210}Pb at an upper level of the profile; C_z = the activity of ^{210}Pb at a distance z below level of C_0 ; and λ = the decay constant of $^{210}\text{Pb} = 0.031 \text{ yr}^{-1}$ (Nittrouer et al., 1984)

Results

KC-23

KC-23 was characterized by lighter brown colored mud at the top with a progressively darker grey mud towards the bottom (Fig 6). Total ^{210}Pb activities varied from 3.6990 to 0.6489 dpm g⁻¹. The resulting excess ^{210}Pb activities ranged from 3.2718 to 0.2217 dpm g⁻¹. The sediment accumulation rate was $\sim 0.97 \text{ cm yr}^{-1}$ (Fig. 7). Porosity ranged from 0.6936 to 0.4650 (Fig. 8).

KC-21

KC-21 was characterized with a muddy top 30 cm, sandier mud at 30- 40 cm depth and sandy with smaller cobbles at 40- 57 cm depth. Total ^{210}Pb activities varied from 0.6891 to 0.2593 dpm g⁻¹ (Fig. 9). No excess ^{210}Pb was visible. KC-21 ^{210}Pb total activity was averaged for a background level of 0.4272 dpm g⁻¹. Porosity ranged from 0.5489 to 0.2964 (Fig. 10)

KC-10

KC-10 was characterized by very soupy mud all the way through the core (Fig. 11) Total ^{210}Pb activities varied from 1.0497 to 0.3770 dpm g⁻¹. The resulting excess ^{210}Pb activities were 0.6225 to 0.0384 dpm g⁻¹. The sediment accumulation rate was $\sim 2.7 \text{ cm yr}^{-1}$ (Fig 12). Porosity ranged from 0.6686 to 0.4762 (Fig. 13).



Figure 6: Picture of KC-23 from Geikie Inlet. The length of the core is $\sim 92 \text{ cm}$ (photo by Brandon Knox).

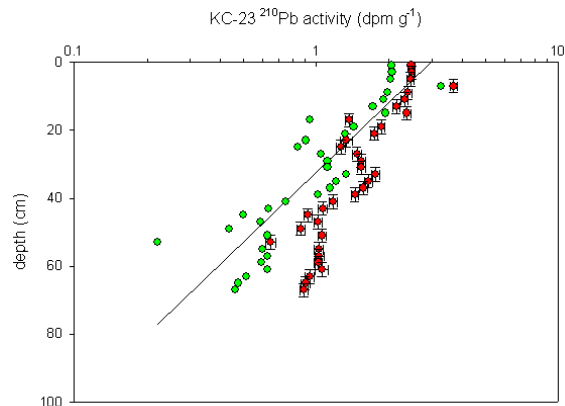


Figure 7: Displays KC-23 ^{210}Pb activities logarithmically vs. depth. The red plots are total activities and the green plots are the excess activities. The Linear regression line of the green excess activity is a component of finding the accumulation rate A . Using equation 1, the accumulation rate is 0.97 cm yr^{-1} .

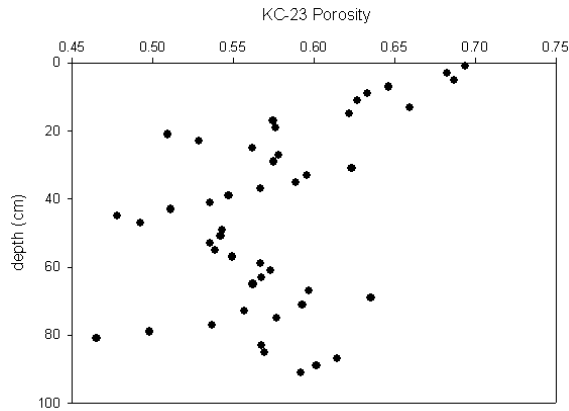


Figure 8: Displays Porosity of the sediment vs. depth for KC-23

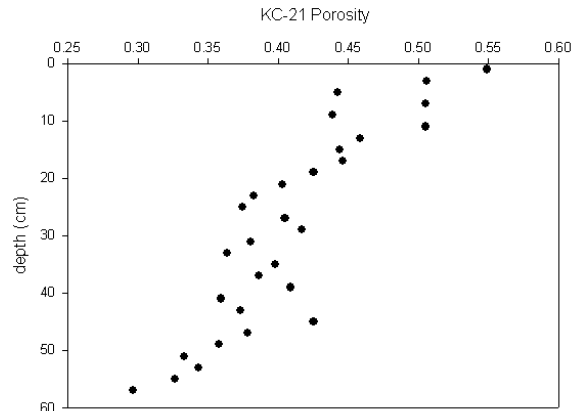


Figure 10: Displays Porosity of the sediment vs. depth for KC-21

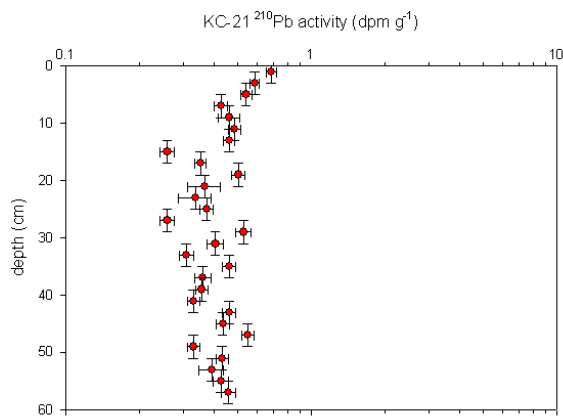


Figure 9: Displays the ^{210}Pb activity logarithmically vs. depth of KC-21. The red dots indicate total activity. There is no excess activity. The vertical line represents the total activities averaged. The average of $0.4272 \text{ dpm g}^{-1}$ was used as a background activity for the other cores.

KC-16

KC-16 was characterized by lighter brown mud in the top 10 cm, getting progressively turning to darker grey mud with black bands intertwined into the sediment (Fig 14). No time remained for ^{210}Pb analysis of this core. KC-16 ^{210}Pb analysis will be conducted for a symposium in June 2008.

Discussion

There was no grain size analysis conducted on any of the sediment. So all observations of grain size were based on sight and touch during wet and dry weighing and crushing.

KC-21 was poorly sorted, composed of sand, mud, pebbles and cobbles. This variability of the sediment makes sense because the core was recovered within 1 km of Grand Pacific and Margerie Glacier termini. This area is near the morainal bank of the glacier. It resides in the Ice-proximal zone, lying on the border of the bank core and bank front zones. Cai and others 1997 explain that evidence from many bottom grab samples and ROV submersible observations (Powell et al. 1991)(Dowdswell & Powell 1996) indicate that deposits of these bank core environments are mixtures of dimictons, gravel, rubble, sand and mud. The bank front environment was composed mostly of stratified sand interbedded with thin laminated mud (Cai et al., 1997). Ekman grab samples from this area also revealed mixtures of gravel sand and mud (Cai et al., 1997).

This core didn't reveal an accumulation rate. This could have been because of the lack of fine particles for ^{210}Pb to attach to. Another theory is that gravity flows dumped the recently accumulated sediment on top of the sediment



Figure 11: This is a picture of KC-10, recovered between Reid Inlet and Russell Island. The core was 207 cm long (Photo by Brandon Knox).

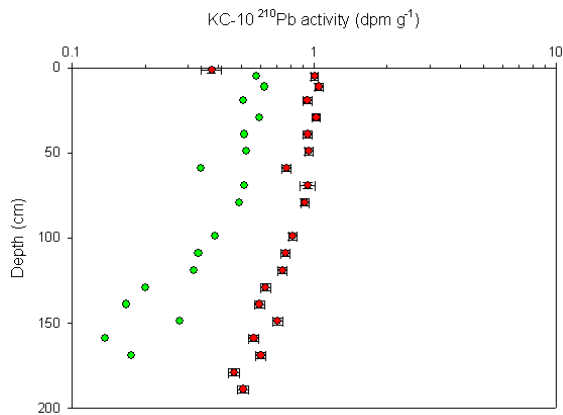


Figure 12: Displays the ²¹⁰Pb activities logarithmically vs. depth of KC-10. The red plots are total activities and the green plots are the excess activities. The Linear regression line of the green excess activity is a component of finding the accumulation rate *A*. Using equation 1, the accumulation rate is 2.7 cm yr⁻¹ Displays KC-10.

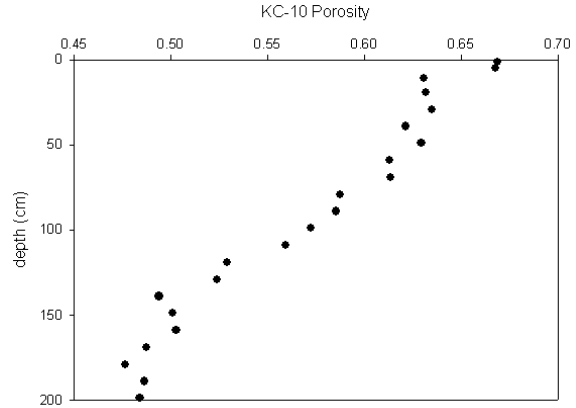


Figure 13: Displays Porosity of the sediment vs. depth for KC-10.

further down slope (Cai et al., 1995). Just when I thought this core was worthless, it proved to be a valuable tool. The low activity was averaged, revealing a background activity to subtract from the total activities of the other cores and leave us with excess activities, resulting in accumulation rates.

KC-23 was composed mostly of mud with very little sand. We were hoping to get closer to the head of Geikie Inlet, but ice prevented us from getting any closer than two thirds of the way in. We knew there was no tidewater glacier actively feeding this inlet, so the accumulation rate could not be that large. I was still impressed that this core revealed an accumulation rate of 0.97 cm yr⁻¹. On a geologic time scale this rate is still remarkable.

KC-10 was the largest core we obtained. It was composed of the soupiest of mud. This core revealed an accumulation rate of 2.7 cm yr⁻¹. I was not surprised that this core had a higher accumulation rate than the prior, because it wasn't as compacted as the other cores. This core has Reid Glacier feeding it, which is a tidewater glacier. Tidewater glaciers offer the highest rates of sedimentation to fjords. Just northwest of KC-10 Lamplugh Glacier also feeds into the West Arm, which could only increase the chances of the area sampled to get even more sedimentation from an outside source.



Figure 14: Picture of KC-16, recovered from Muir Inlet. The length of the core is ~68 cm (photo by Brandon Knox).

The accumulation rates that I discovered were on the low end of the spectrum compared to previous studies. I have not come across other accumulation rates for these KC-23 and KC-10, maybe they will prove valuable for future studies.

Porosity describes the fraction of void space in the sediment, containing air or water. It is measured as a fraction between 0 and 1. Porosities of KC-23 and KC-10 were very similar, higher than KC-21 because of their muddy compositions. Muddy sediment also holds more water. The porosity was lower in KC-21 than the other cores, accounting for the poorly sorted sediment present. Poorly sorted material has lower porosity because water or air gaps are filled with random sized particles of rock.

KC-16 was composed mostly of mud, with dark bands. ^{210}Pb analysis of this core has not been conducted yet. Therefore a sediment

accumulation rate cannot be calculated. Future analysis will be included in later text.

Conclusions

In hindsight, I would have done many parts of this experiment differently. I would not have run so many samples for the ^{210}Pb analysis. I was trying to get high definition results by analyzing every 2 cm of sediment. The downside was that I ran out of time to finish KC-16. It would have been better to conduct more coring in inlets with tidewater glaciers actively feeding the fjord with sediment to get higher accumulation rates. I might also use a different coring device so that cores could be split and x-rayed on board the research vessel. I would have also taken more detailed pictures of the cores that were level and flush with the plane of view. If time allowed, sediment grain size analysis could give a more accurate description of actual classification of the sediment.] In hindsight, I would have done many parts of this experiment differently. I would not have run so many samples for the ^{210}Pb analysis. I was trying to get high definition results by analyzing every 2 cm of sediment. The downside was that I ran out of time to finish KC-16. It would have been better to conduct more coring in inlets with tidewater glaciers actively feeding the fjord with sediment to get higher accumulation rates. I might also use a different coring device so that cores could be split and x-rayed on board the research vessel. I would have also taken more detailed pictures of the cores that were level and flush with the plane of view. If time allowed, sediment grain size analysis could give a more accurate description of actual classification of the sediment.

Conclusions

- KC-21 revealed an averaged background ^{210}Pb activity of $0.4272 \text{ dpm g}^{-1}$

- KC-23 revealed a sediment accumulation rate of 0.97 cm yr⁻¹
- KC-10 revealed a sediment accumulation rate of 2.7 cm yr⁻¹

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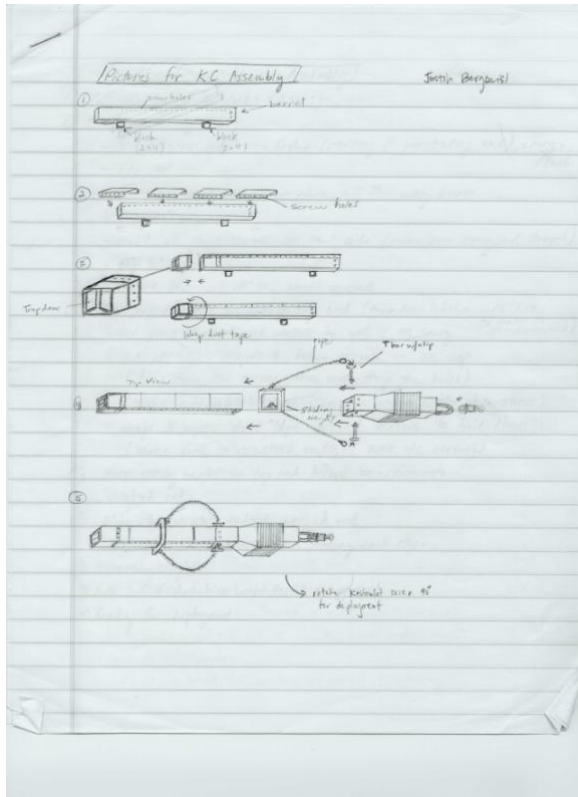


Figure 15: Directions for Kasten Corer Assembly

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0.1 Appendix A

1. Place open barrel on blocks.
2. Barrel Assembly
3. Put lids on in Alpha-numeric order (starting at penetrating end), make sure they are flush.
4. Flip barrel 90°
5. Insert two short screws on one side of each plate all of the way down one side of the core barrel.
6. Flip barrel 180°
7. Insert all the short screws on the other side of the core barrel (make sure they are snug but not stripped).
8. Flip barrel 90°
9. Insert the rest of the short screws on the first side of the barrel.
10. Place trap door end on penetrating end (trap door end and penetrating end have matching letters)
11. Use a mallet to get it on snug (put a piece of wood in between mallet and trap door end cap to ensure no metal to metal contact)
12. Insert at least 5 of 8 of longer screws in on the cap (don't force the screws or they will strip the holes)(screws don't need to be flush, they are primarily for shear strength).
13. Wrap 3 layers of duct tape around the screws to hold them in the holes (make sure tape is stuck on tight).
14. Place sliding weight on top end of barrel before barrel insertion into weighted end.
15. Slide barrel into weight package assembly.
16. Insert 2 T-bars with pins, facing each other
17. Assembly complete
18. Make sure shackle is weight tested before deployment