Beryllium-7 sorption to inorganic particles in Tahsis Inlet, Nootka Sound, B.C.

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Abstract

Sediment deposition from fluvial inputs is one of the main ways new sediment is introduced into seabeds, but many other processes can occur before the sediment reaches the seafloor. Beryllium-7 (^{7}Be) is a radioisotope that is produced in the atmosphere, brought down to the earth via rainfall and binds to sediment. Runoff and rivers then transfer this sediment to the ocean. With a 53 day half-life, ^{7}Be can be used to date sediment back to a year. The relationship between ^{7}Be and grain size has been studied many times but has shown no correlation. Since ^{7}Be binds to inorganic particles and is not grain size dependent, the idea that inorganic material controls sorption is what prompted this study. Tahsis Inlet in Nootka Sound, was chosen due to the nature of the inlet: multiple river deltas, the presence of a sill and a connecting passage to another fjord. Samples were analyzed for presence of ^{7}Be, grain size, total organic carbon, and inorganic material. Both river deltas had presence of ^{7}Be and most recently deposited sediment. Sediment grain size varied along the inlet with gravel, sand and some mud present at both river deltas and mud present at the deep stations farther away from the deltas. The samples that consisted mainly of sand had the highest amount of inorganic material, >90%, and supported the hypothesis that inorganic material is a main control for ^{7}Be sorption.

Introduction

Beryllium-7 (^{7}Be) is a radioisotope that is naturally produced by cosmic rays in the atmosphere and is transferred to the earth through precipitation (Yoshimori, 2005). Beryllium is highly reactive and is associated with sediment substrates. With a half-life of 53 days, it can effectively date sediment back to about 1 year (Holmes, 1998) and has been used extensively to understand the dynamics of particle transport in marine environments (Todd, 1989). Since ^{7}Be is a radioisotope that is effective for dating newly deposited sediments, the presence of this isotope in sediment samples can conclude that the sediment collected is most recently deposited and can be used to determine short-term sedimentation and water current patterns.

When ^{7}Be is introduced into an estuary, it readily associates with suspended, inorganic particles and binds in its particulate form, this is known as sorption (Dibb, 1988). Many researched have studied ^{7}Be relation to grain size and grain size composition but have found that there was no correlation between ^{7}Be sorption to particle composition or grain size (Olsen 1986, Roper 2003). One idea that this thought derived from is the inverse relationship of organic carbon to grain size. It is known that organic carbon will bind to finer sediments due to the higher amount of surface area present (Bergamaschi, 1997), and this idea was also hypothesized for ^{7}Be and its relationship to grain size. With finer sediments, such as mud, being suspended longer throughout the water column than coarser sediments, such as sand and gravel, finer sediments would have higher sorption than the larger, coarser sediments that have a faster sinking rate. Unfortunately, studies have found this to be inaccurate and conclude that grain size does not affect ^{7}Be sorption (Roper, 2003).

Since ^{7}Be attaches to inorganic particles, and organic carbon attaches to finer sediment particles, this study hypothesizes that ^{7}Be will bind to larger particles that have bound with little to no organic carbon.

Sampling took place in Tahsis Inlet in Nootka Sound, B.C. At the north end of the inlet is the town of Tahsis, which experiences an average of 191 days of rain with an annual average of 3.828 m total precipitation (Kingzett, 1995). The Leiner River is located at the north end of the Inlet and is a major contributor of fresh water. This fresh water input transports sediments from the river and surrounding areas into the inlet and is expected to have ^{7}Be present at the sample sites nearest to the river delta and composed of mainly of sand, as finer sediments are suspended in the water column and washed away by river flux.

The Tsowwin Narrows are located about 10 miles south of the Leiner River at the mouth of the Tsowwin River. The Tsowwin Narrows are formed by a sill that is located at the mouth of the river and has caused a drastic change in depth moving northward and southward of the sill. With the location of the sill and the proximity of the river input to the sound, ^{7}Be and a mixture of larger and finer grain sizes are expected to be more concentrated in and around the sill. With the sound close to the sill, tidal flux will also have an impact on sediment transport and is believed to cause mixing of sediment grain size that is found at and around the sill.

Methods

Sampling took place in the Tahsis Inlet between December 11th and 21st, 2015, starting at the mouth of the inlet, south of the Tsowwin Narrows, and continued north to the Leiner River Delta. A Van Veen Grab and Shipek were deployed from the *R/V Thompson* to collect these samples. A Van Veen was used at the coarser, larger sediment sites; for example, the sites around

the Tsowwin Narrows, where a Shipek would not be as efficient for collecting samples. The Shipek was used at the deeper sampling sites where sediment was much finer and easier to disturb. Approximately 150 g of wet material was collected to measure for ^{7}Be and organic carbon analyses and another 20 g of sediment for grain size analysis.

After sediment collection, the 150 g wet samples were baked in an oven, which was aboard the vessel, at 60° C for 24 hours. The dry samples were then crushed with a mortar and pestle and placed in the sampling jars for on-land analyses.

Once on land, ^{7}Be samples were each placed in a gamma spectrometer where they sat for 24 hours. The data produced by the gamma spectrometer was then exported to a computer for further analysis. The ^{7}Be samples were analyzed as "present", "not present" or "trace" according to the amount of ^{7}Be in the samples. The "present" samples were determined by a gamma radiation peak at 477 keV, where the number of counts at the peak was twice the background. The "trace" samples showed small peaks at 477 keV that fit a spatial pattern, but was not significant enough to be considered "present". Samples with no peaks had no ^{7}Be present and were labeled as "not present".

In order to determine grain size two procedures were used: wet sieving and pipette analysis. Before either procedure the samples were homogenized and oxidized of organic matter with 15 mL of 30% hydrogen peroxide. In order to separate finer particles, like mud, silt and clay, from larger particles, like sand, the samples were wet sieved through a 63 micron filter. Samples sets larger than 63 microns were baked and shaken through a set of sieves starting at -4ϕ and decreasing by 0.5ϕ increments and ending with +4ϕ sieve. The collections in each sieve were then weighed and recorded. Sample sets smaller than 63 microns were analyzed using pipette analysis. Sample sets were wet sieved through a +4ϕ sieve and placed in a 1 L column where 50 µm of dispersing

agent was added mixed well. Immediately after mixing, 20 ml was removed from the center of the cylinder. This sample was then transferred to a small beaker and set in the baking oven where it dried overnight. This process was repeated at intervals of 1 minute, 5 minutes, and 51 hours. All samples were placed in small beakers and baked until dry. Samples were then weighed and recorded. Both of these procedures followed the guidelines of the U.S. Geological Survey publication on sediment grain size analysis procedures (2000). All mass and grain size data were then further analyzed using GRADISTAT (Blott and Pye, 2001) and the median D50 phi grain size was recorded.

Total organic carbon was then analyzed for Loss on Ignition (LOI). For this procedure, 1 g of dried sediment from was placed in heat resistant beaker and baked at 400°C overnight (approximately 12 hours). The samples were then cooled and weighed again. LOI was determined by the percent mass lost from the initial sample weight. All weights were corrected for moisture/water content prior to the organic matter content calculations. Percent inorganic material was found by calculating the organic carbon percent and subtracting it from 100%. It is important to note that these samples were the same samples used to measure for ^{7}Be, but should not have affected the outcome of this analysis.

Results

Both the Leiner River and Tsowwin River had ^{7}Be present at their respective deltas. While the Tahsis River delta was not sampled, ^{7}Be was present close to the river mouth. Trace amounts of ^{7}Be were found in 3 samples surrounding the sill at the Tsowwin Narrows. Two samples, one north and one south, of the Zeballos Inlet also showed trace amounts present. The remaining samples showed no presence of ^{7}Be, these results can be seen in figure 1.

Samples at the Leiner River consisted mainly of sand with some mud and small amounts of gravel present. Samples from the top of the inlet moving south became gradually finer in grain size, consisting mainly of mud with little to no sand and gravel present. Samples throughout the narrows consisted mainly of gravel and sand, with little mud present. The Tsowwin River delta sample contained no gravel and was mostly sand. Samples south of the Narrows became muddier but still had significant amounts of sand present. This data can be seen in figure 2.

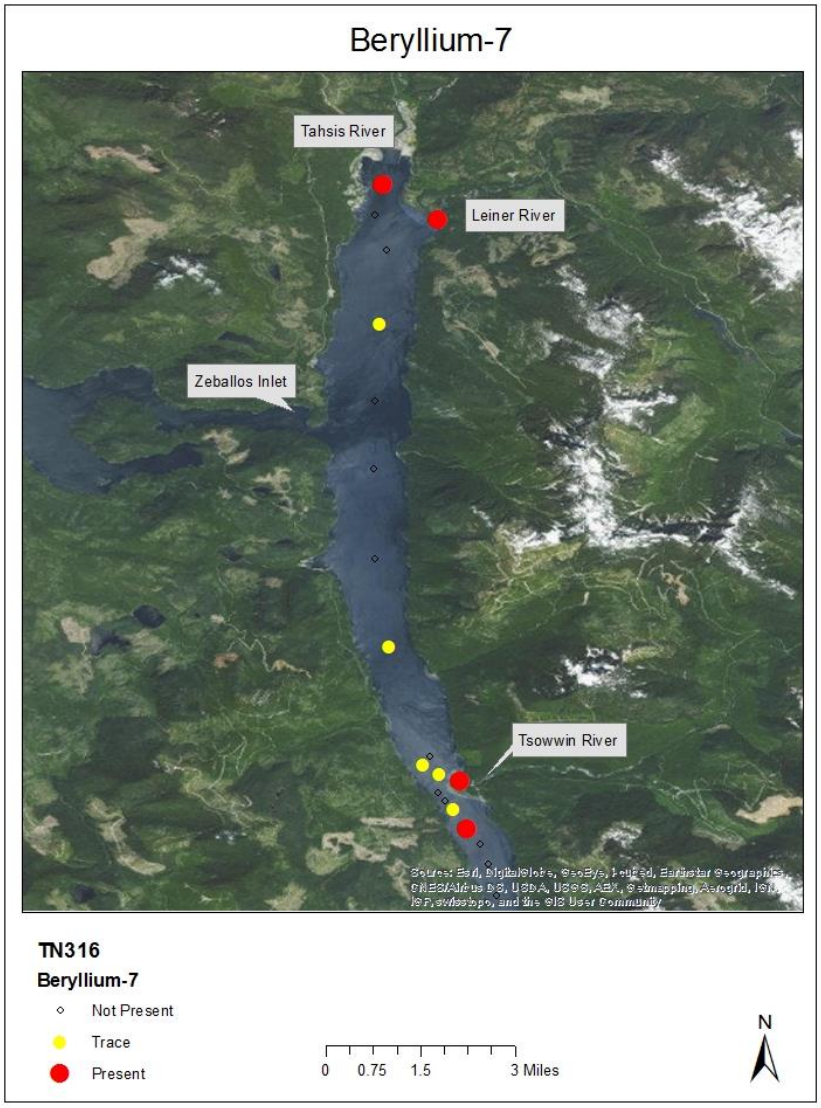

Figure 1: Station locations of ^{7}Be samples taken in Tahsis Inlet. Red points indicate a significant amount of ^{7}Be present, yellow points indicate trace amounts present and black points indicate no ^{7}Be present. Present and trace amounts of ^{7}Be seem to be confined around areas of river deltas. Map was constructed using Arc-GIS.

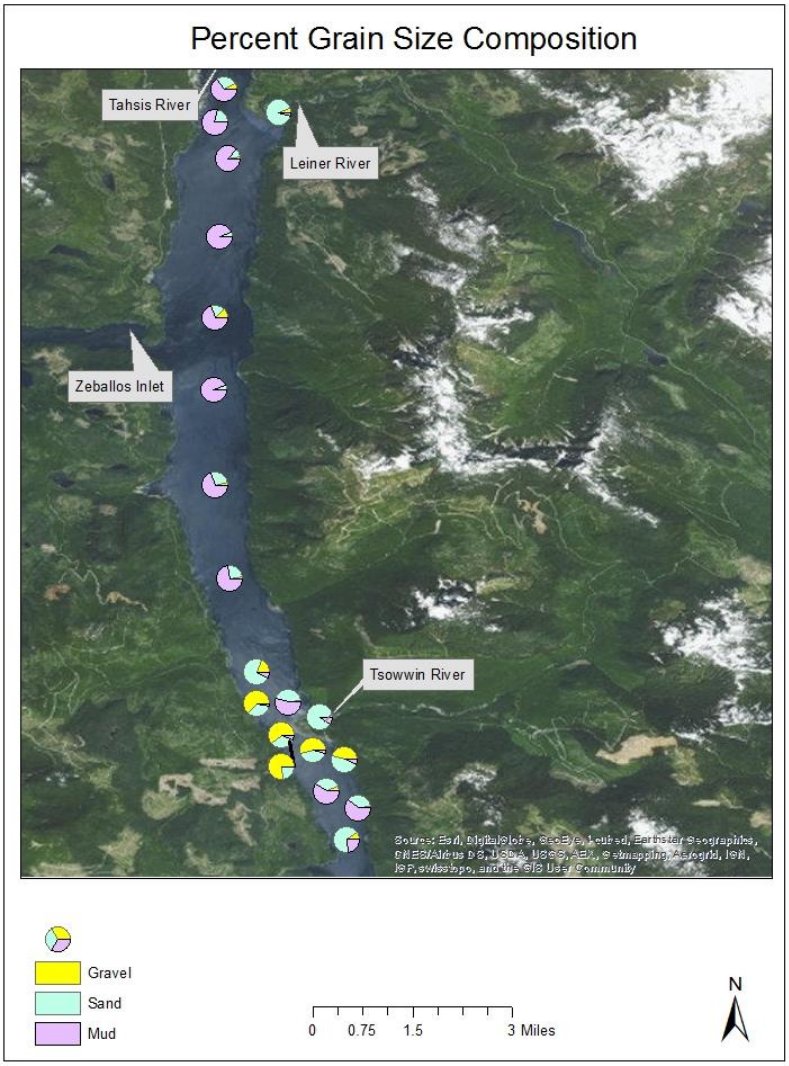

Figure 2: Percent grain size composition of each sample at respective sample locations in Tahsis Inlet. Gravel is represented by yellow in the pie chart, sand by blue and mud by purple. Samples near the river deltas are coarser and become finer in grain size the further away from the deltas. Map was constructed using Arc-GIS.

LOI was used as a proxy for total organic carbon (OC) present in the samples and is a common way to analyze OC in sediments. Samples found at and around river deltas had little organic carbon present, with <4.6% OC in all the delta samples. As sample sites moved farther away from the river deltas, OC increased in samples, ranging from >10.432% OC to 17.150% OC, as seen in table 1.

Station #	Organic Carbon %
T01A	1.983
T01	10.432
T02	10.495
T03	14.422
T04	16.525
T05	13.901
T06	17.150
T07	13.928
T08	13.252
T09	2.479
T10	2.100
T12	16.654
T15	4.582
T16	3.322
T18	3.075
T20	2.515
T21	2.190
T22	11.748
T23	10.881
T24	3.677

Table 1: Organic Carbon % present in samples. Station start at the north end of the inlet (T01A) and move southward to the end of the inlet at station T24. T01A and T16 are the river delta sample stations that have the least amount of organic carbon present.

Discussion and Conclusion

It is common to find ^{7}Be in many river deltas, as rivers are one of the main sources of sediment deposition. It was not surprising that the samples with ^{7}Be "present" and "trace" were mainly cluster around both river deltas and at sample site T01, which was closest but not in the Tahsis River delta. Samples located close to the Zeballos inlet showed no presence of ^{7}Be, which could have been expected due to the passage being an inlet into another fjord system where sediment deposition could have occurred. To hypothesize about why there was no ^{7}Be present near this passage could be due to water flowing out of Tahsis Inlet into Zeballos Passage, or it takes longer than ^{7}Be's half-life to deposit sediment from the passage to the inlet. Further research would need to be conducted in and around Zeballos Passage to conclude why there is not ^{7}Be present in this area.

As expected, sediment grain size and organic carbon were highly correlated. Finer sediment have a larger surface area that organic carbon can bind to, and with most samples being finer in grain size, more organic carbon was present in the samples, figure 3. While sampling the deeper stations between the two rivers, both the Van Veen and the Shipek grabbed evidence of underwater landslides that contained high amounts of organic material such as wood, leaves and shells. This provides more opportunity for organic carbon to bind to finer sediments. These landslides are due to the high amounts of deforestation in the surrounding areas of the inlet. Deforestation sites were seen multiple times around the inlets in Nootka Sound and are a major contributor to sediment movement from land to sea. When trees and other shrubbery are cut down and uprooted, there is nothing left to hold the sediment in place. With the high amounts of rainfall and winter water runoff, this sediment and other organic material is washed away in the runoff and deposited into the inlets. Furthermore, this sediment deposition can lead to the introduction of

harmful heavy metals into the ocean. These anthropogenic metals, which are hypothesized to come from the deforestation and mills around Tahsis Inlet, can bind to sediments and are deposited into the inlet. This can be harmful to the marine life and other organisms if these metals are ingested.

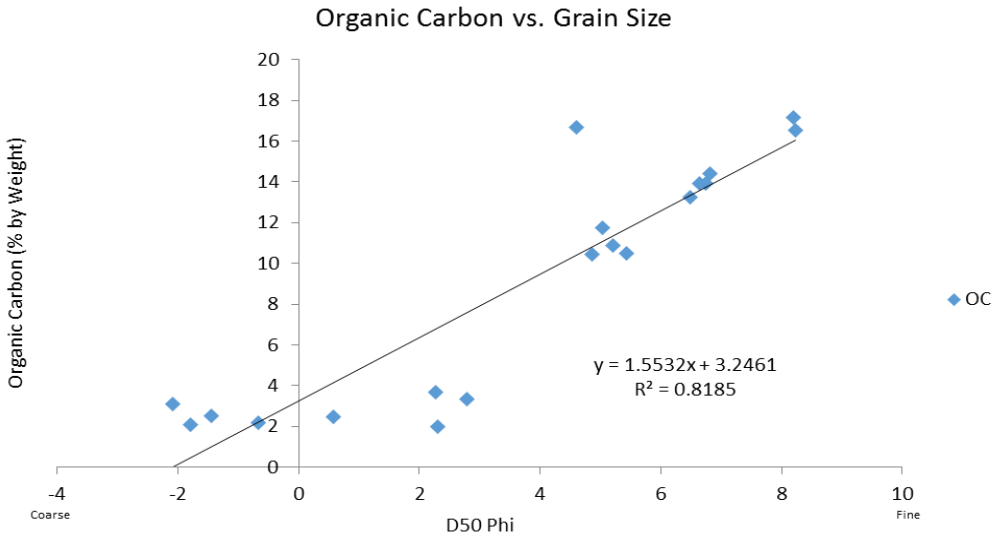

Figure 3: The relationship between organic carbon and grain size. Organic carbon is measured in percent by weight and grain size is measure in D50, median phi size, for each sample. There is a positive correlation between organic carbon and grain size, as D50 decreases organic carbon increases with an R^2 value of 0.8185.

After comparing data from figures 1 and 2, it can be concluded that there is no correlation between ^{7}Be presence and grain size. Between the four samples that had ^{7}Be "present" T01A, T01, T16 and T21, the sediment grain size of the samples consisted of 89.1% sand, 65.7% mud and 27.3% sand, 90.3% sand, and 48.1% sand and 44.5% gravel, (respectively).

A similar study was conducted in Puget Sound from 2008 to 2009, specifically looking at the Skagit River Tidal Flats. Samples collected at the mouth of the river consisted mainly of sand with some silt and clay present (Webster, 2013). As sample sights moved farther away from the river mouth, sediment grains decreased in size mainly to silt and clay. This occurred with ^{7}Be

concentrations as well. Where ^{7}Be was present in Saratoga Passage and Deception Pass, the sediment grain size in the sample was >90% sand (Webster et al., 2013).

While a slight trend may be present, it cannot be accepted. With a constant flow of water from the river, sediment is being transported out and away from the river mouth. Finer sediments have a longer residence time in the water column and can be transported further away from the river delta by the current. Larger sediments sink faster in the water column and are more likely to settle at and around the river mouth, especially when a sill is present. This is hypothesized as to what is occurring at both river deltas.

Since ^{7}Be binds to inorganic particles, the "present", "trace" and "not present" samples were plotted against percent inorganic material. There was a trend that occurred showing that samples that had ^{7}Be "present" or "trace" were the sediments that had >90% inorganic material, figure 4, and would support the main hypothesis. In 2014, a study was conducted by Weifeng Yang looking at geochemical proxies that give a more detailed understanding to their interactions with particles. Results showed that inorganic nanoparticles determined the sorption of radioactive particles such as ^{210}Pb and ^{7}Be (Weifeng, 2015). This study provides a further understanding as to why ^{7}Be binds to inorganic material.

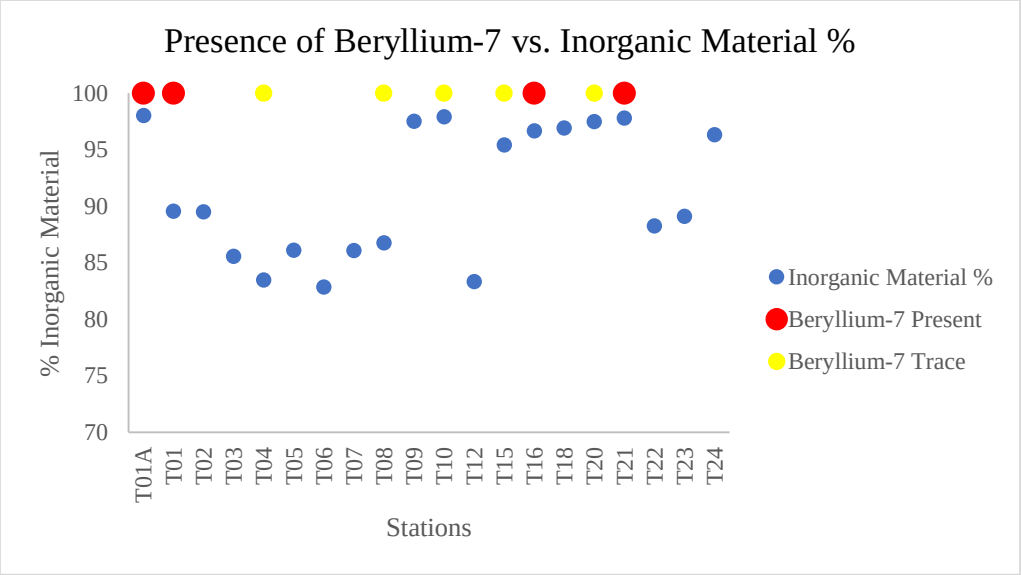

Figure 4: The relationship between Beryllium-7 "present", "trace" and "not present" versus the percent inorganic material present in all samples. The samples that had "present" or "trace" ^{7}Be were >90% inorganic material and as percent inorganic material decreased, ^{7}Be was no longer present.

Future work

With the complex geochemistry of ^{7}Be in fjords and estuaries, future work could involve studying other factors that may control sorption of ^{7}Be, such as salinity, pH and atmospheric influx (Dibb, 1989). These factors were not taken into account in this study and may provide more useful information into the dynamics of ^{7}Be sorption and sedimentation processes. Studying these factors in a controlled setting can provide valuable information that may not be obtainable in a setting that may be "overwhelming". This study could also further the understanding for the use of ^{7}Be pairing with other radioisotopes to trace organic compound cycling in oceanic environments (Weifeng, 2015).

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