

# **Fine-grained sediment accumulation rates of southern Saratoga Passage**

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## Non Technical Summary

The Skagit River, which empties into Saratoga Passage, is the largest river in the region. The purpose of this study is to research the rates of fine-grained sediment accumulation in the southern portion of Saratoga Passage. Using radioisotopes, sediment samples collected were analyzed and accumulation rates were calculated through  $^{210}\text{Pb}$  dating.  $^7\text{Be}$ , another radioisotope, was used to determine the presence of short term fluvial sediment deposits into Saratoga Passage. Using the calculated accumulation rates and presence of  $^7\text{Be}$  found, a pattern of sediment deposition was created. It was found that sediment in southern Saratoga Passage is from multiple sources including the Skagit and Snohomish Rivers. Mixing of these sediments could be occurring and the average accumulation rate was found to be  $0.7\text{cm yr}^{-1}$ .

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Abstract

The Puget Sound is a large marine estuary. The Skagit River, the largest river in Puget Sound empties into Saratoga Passage and Deception Pass. Fine grained sediment, like silt and clay, is transported away from the river mouth where it is deposited onto the sea floor. Through geochronology, the fine-grained sea floor sediment can be dated. Using radioisotopes,  $^{210}\text{Pb}$  dating is done through an intricate laboratory process which can date sediment to about 100 years. In this research project, three box core samples were analyzed and then combined with three kasten core samples from previous research, to create a total of six stations. The data from these six stations, along with  $^7\text{Be}$  measurements were used to create a general sediment budget of southern Saratoga Passage. High accumulation rates and  $^7\text{Be}$  data showed that sediment in southern Saratoga passage appears to be coming from multiple sources. A large zone of mixing could be occurring in this region, where the multiple sources of sediment combine. Average accumulation rates for southern Saratoga Passage were found to be  $0.7 \text{ cm yr}^{-1}$ .

Rivers around the world transport hundreds of thousands of tons of water and sediment into the ocean. Sediment being transported down river can be deposited into several regions depending on its size. Larger sediment like sand is deposited closer to the river mouth often forming flood plain deltas. Fine-grained sediments, silts and clays, are transported farther away from the river mouth. Silts and clays can stay suspended and travel many kilometers away from the river depending on currents and conditions.

Fine grained sediments have a high surface area, compared to large grained sediments and therefore are an important tool in the dating of seafloor sediment. Radioisotopes such as  $^{210}\text{Pb}$  and  $^7\text{Be}$  are deposited onto the land from cosmic sources (Sommerfield et al, 1999), these isotopes bond to the surface area of silt and clay particles. Sediment on the seafloor can be dated using  $^{210}\text{Pb}$ , a radioisotope with a half life of 22.3 years.  $^7\text{Be}$  is another important radioisotope which can be used to locate recent river sediment which has been deposited (Sommerfield et al, 1999). Fine grained sediment is a good source of radioisotopes due to their small size; silts and clays are the primary type of sediment used for  $^{210}\text{Pb}$  dating.

*Background-* The Puget Sound, located in western Washington State, is a major resource of food, employment and recreational activities for the entire Pacific Northwest region. Stretching from Olympia to near the Canadian border, this marine environment heavily influences the look and feel of the entire area. While many rivers empty into the Puget Sound, the largest is the Skagit River which is located north of Seattle near the farming communities of La Connor and Mount Vernon. It is estimated that the Skagit River provides 34-50% of the total freshwater flow into Puget Sound (Yang et al. 2008). Not only does the Skagit River provide fresh water to the Puget Sound, it also transports a large amount of sediment from the North Cascade Mountains. Two to

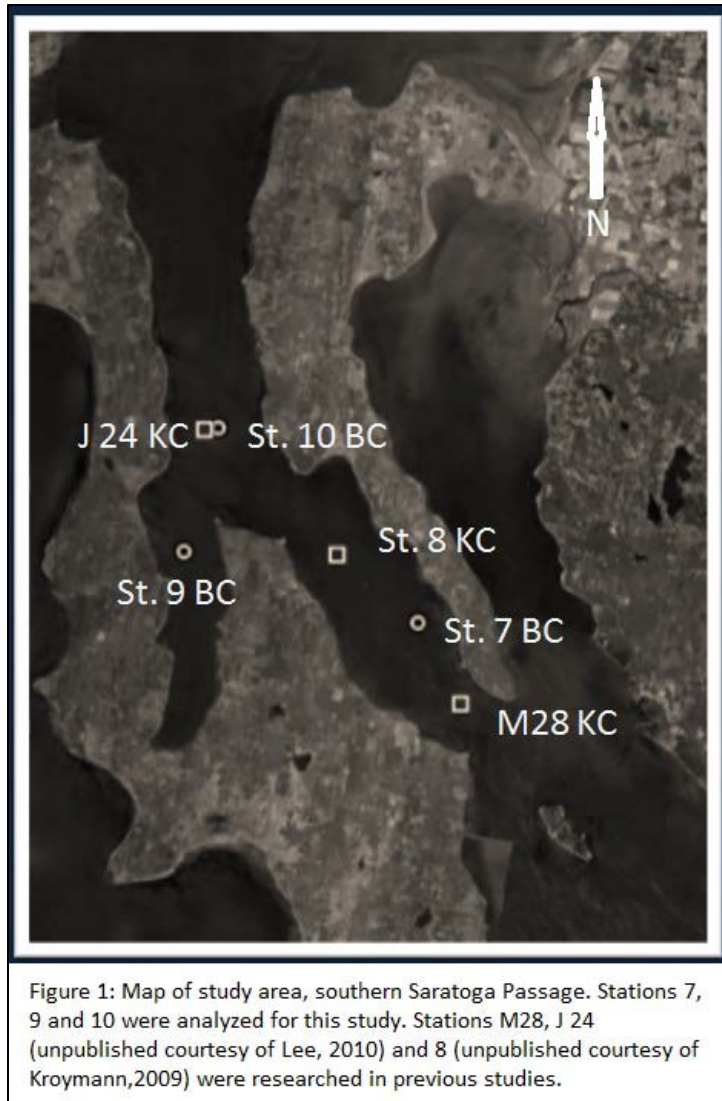
three million tons (Ebbesmeyer et al. 2001) of sediment is transported by the Skagit River into the Puget Sound each year.

The Skagit River begins in the North Cascade Mountains and flows down to the farmlands of the Skagit River Valley. Colonization of the area by settlers in the late 1800's caused some dramatic changes to the river and surrounding area. By 1890, dykes and levee systems were set up along the Skagit River delta to help prevent tidal flooding from Puget Sound (Hood 2006). Logging, damming and bank hardening have all played there part in altering the Skagit as well. The construction of dams on the river has changed the amount of sediment that flows into Puget Sound and it is estimated that almost 47% of water and sediment in the Skagit River is trapped by dams (Hood 2006).

The purpose of this research paper is to look at where fine-grained sediment is transported after it is deposited into the Puget Sound from the Skagit River. The Skagit River empties into a constrained basin called Skagit Bay; the fresh water from the river can move north through Deception Pass or south down Saratoga Passage.  $^7\text{Be}$  has been found west of Deception Pass and within Saratoga Passage, indicating Skagit River sediment is quickly transported to both areas (Lee et al, 2010). Sediment leaving Deception Pass enters Rosario Strait, a large open basin with strong tidal currents, making it difficult to quantify the amount of sediment exiting Deception Pass. Upper Saratoga Passage has been studied in previous studies and has accumulation rates of  $\sim 1 \text{ cm yr}^{-1}$  however; southern Saratoga Passage is a relatively unstudied area, which is the focus of this paper. Combining research from this study and previous studies, a general idea of sedimentary processes occurring in southern Saratoga Passage will be formed.

## **Methods**

Sediment was collected using two different coring devices on two different research cruises. The first occurred on 5 April 2009 as part of a University of Washington research cruise on the R/V Barnes. Aboard the ship a box corer and kasten corer were used to retrieve sediment samples; stations 7, 8, 9 and 10 were all gathered on this cruise (fig. 1). The second cruise on 21 August 2009 was aboard the R/V Centennial; both coring devices were used to retrieve samples. From this cruise samples at station J24 and M28 were obtained (fig. 1).



*Field Methods-* A kasten corer is a 3 meter long square metal barrel which is used to obtain vertical profiles of seafloor sediment. This device is deployed over the side of the ship and sent down to the bottom where it is driven into the soft muddy seafloor. At the nose of the barrel is a trap door nose piece, which allows sediment to enter but not leave the barrel. The barrel is then brought back to the surface and sub sampled. Samples are obtained from the kasten corer by removing one side of the barrel, and exposing the entire length of the core. Clear plastic trays are placed end-to-end down the core, and then removed for x-radiography. The remaining sediment

is cut into 2 cm increments and placed into individual plastic bags. The first 50 cm of the core is saved completely, while the remaining length of core is sampled at alternate 2 cm depths.

A box corer is also a gravity corer, but it takes a shorter wider sample. The box corer has a large metal box which is 50 cm deep and approximately 30 cm wide. The device has a large metal spade which when the corer hits the seafloor, slides under the box and traps sediment in. The sediment is then brought to the surface and sub sampled. For sediment analysis, a circular 50 cm tube is placed down into the sample and then removed. This plastic tube is then sub sampled by one cm increments for the first 20 cm and then 2 cm increments to 50 cm. The sediment samples are placed into individual plastic bags and then taken to the laboratory for analysis.

*Laboratory Methods-* X-ray trays collected aboard the ship are processed and then used to allow researchers to see the sediment structure of the samples. The clear plastic trays, obtained during sub sampling, were placed into a Madison Medical Corporation Model VR 1020 X-ray system (Drexler et al. 2008) and x-radiographs were obtained. X-radiography gives a view of sediment layers and the stratigraphy of seafloor sediment.

$^{210}\text{Pb}$  dating is a useful tool to calculate the rate of sediment accumulation in the ocean. With a half life of 22.3 years, this technique can measure the accumulation of sediment for approximately one hundred years. (Jaeger et al. 1998) All of the sediment samples used in this research was dated using this method.

$^{210}\text{Pb}$  dating is a long and intricate process. First the sediment samples are dried at a temperature of  $\sim 60^{\circ}\text{C}$  to remove the pore water. They are then crushed into a fine powder; 5.0 g of sediment is placed into a beaker and spiked with 10 ml of a known activity of  $^{209}\text{Po}$  solution (Drexler et al. 2008). The spiked sediment is heated and mixed with 10 ml of 15.8 N  $\text{HNO}_3$ . The sediment is heated until near dryness; then it is followed by 6.0 N  $\text{HCl}$ , once again heated until

near dryness. The sediment is then poured into a tube and centrifuged three times, which causes the Po isotopes to be in the solution. This is left for ~ 24 hours with a silver planchet suspended in the solution. The silver planchet is analyzed by alpha spectroscopy, and activity levels for  $^{209}\text{Po}$  and  $^{210}\text{Po}$  are determined (Drexler et al. 2008).

## Results

Three box cores (station 7, 9 and 10) were analyzed by  $^{210}\text{Pb}$  dating and x-radiography for this research project. Using  $^{210}\text{Pb}$  dating, graphs of activity versus depth were created. Station 7 ( $48^\circ 4'36.72''\text{N}$ ,  $122^\circ 24'50.22''\text{W}$ ) located near the bottom of Saratoga Passage, has a 20 cm surface mixed layer followed by a region of active decay (fig. 2).

Station 9 ( $48^\circ 5'13.08''\text{N}$ ,  $122^\circ 32'29.04''\text{W}$ ) located at the mouth of Holmes Harbor,

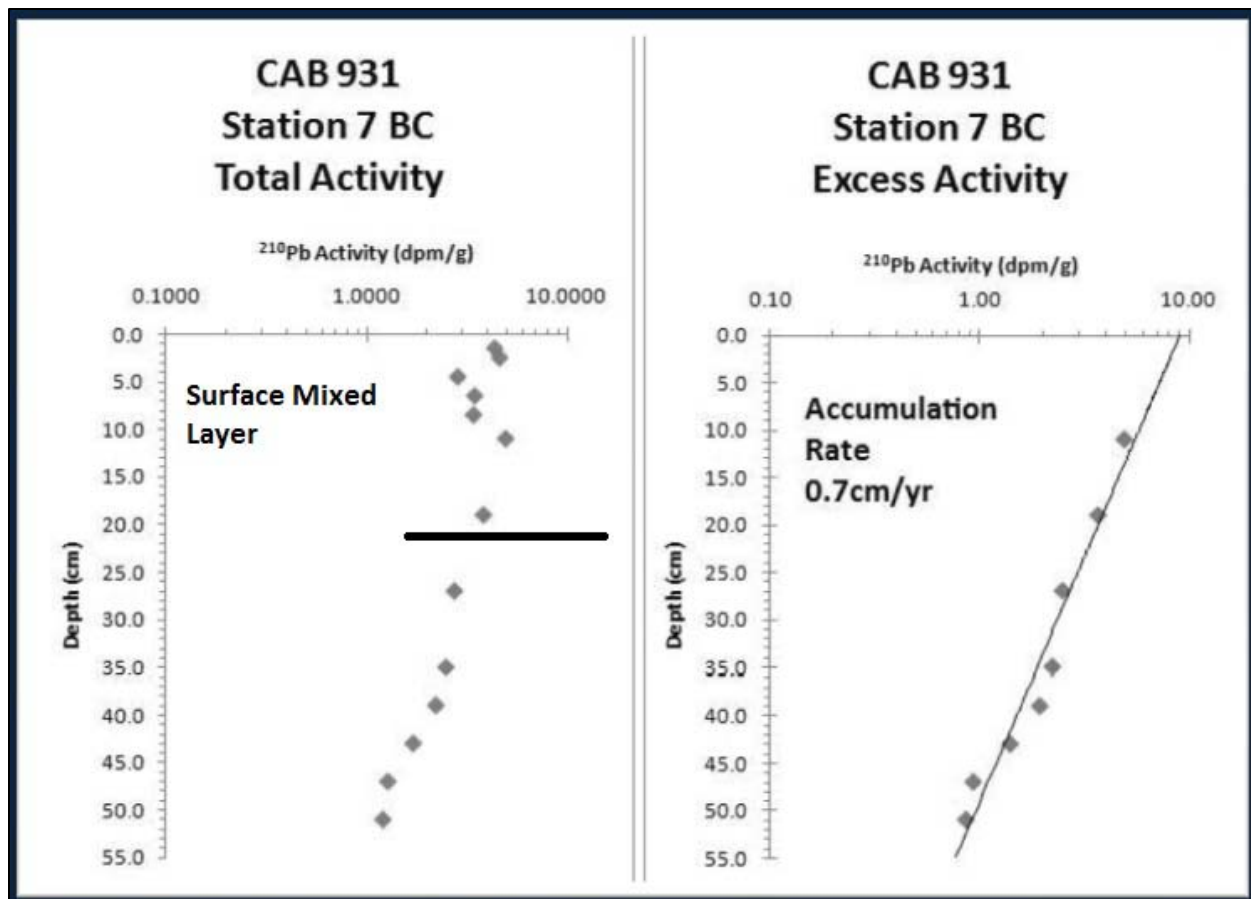
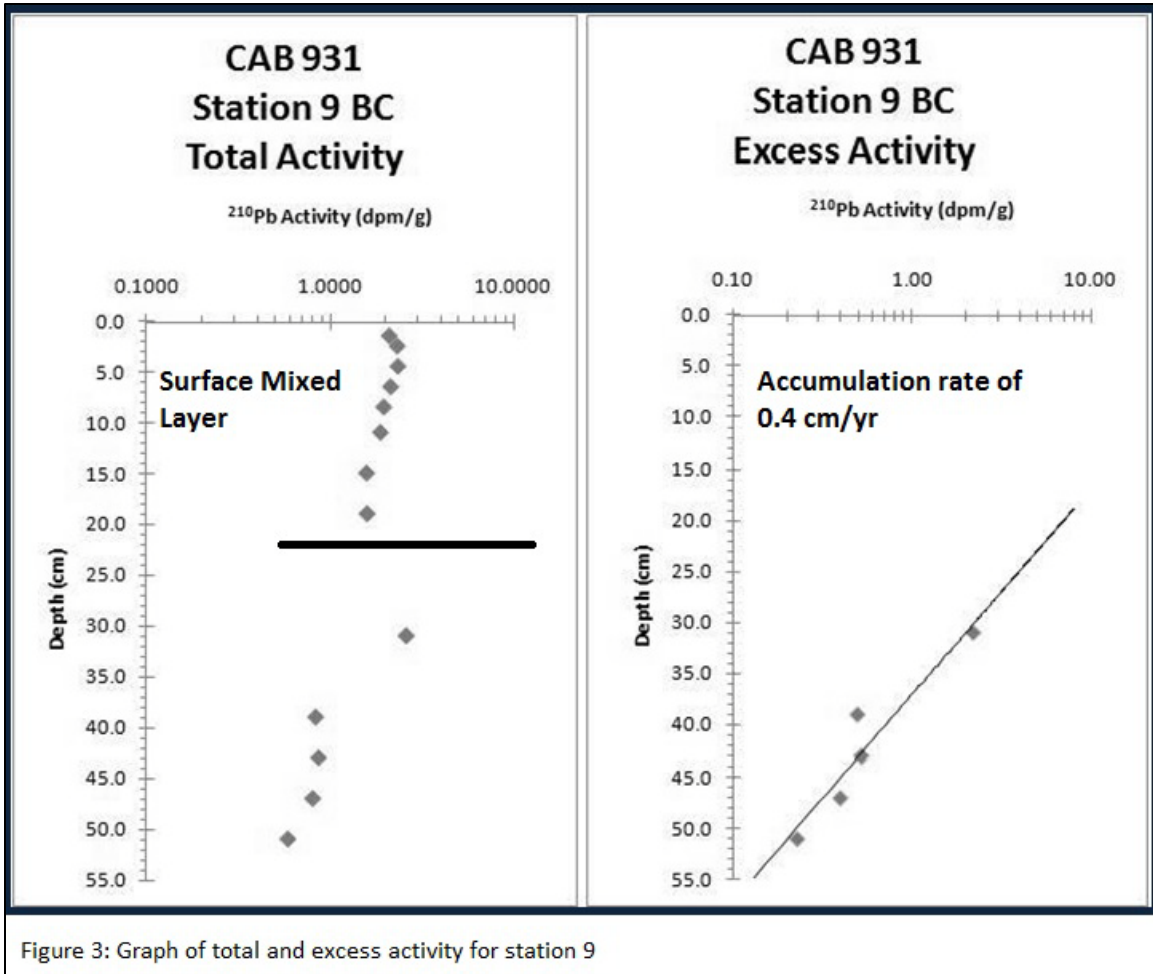
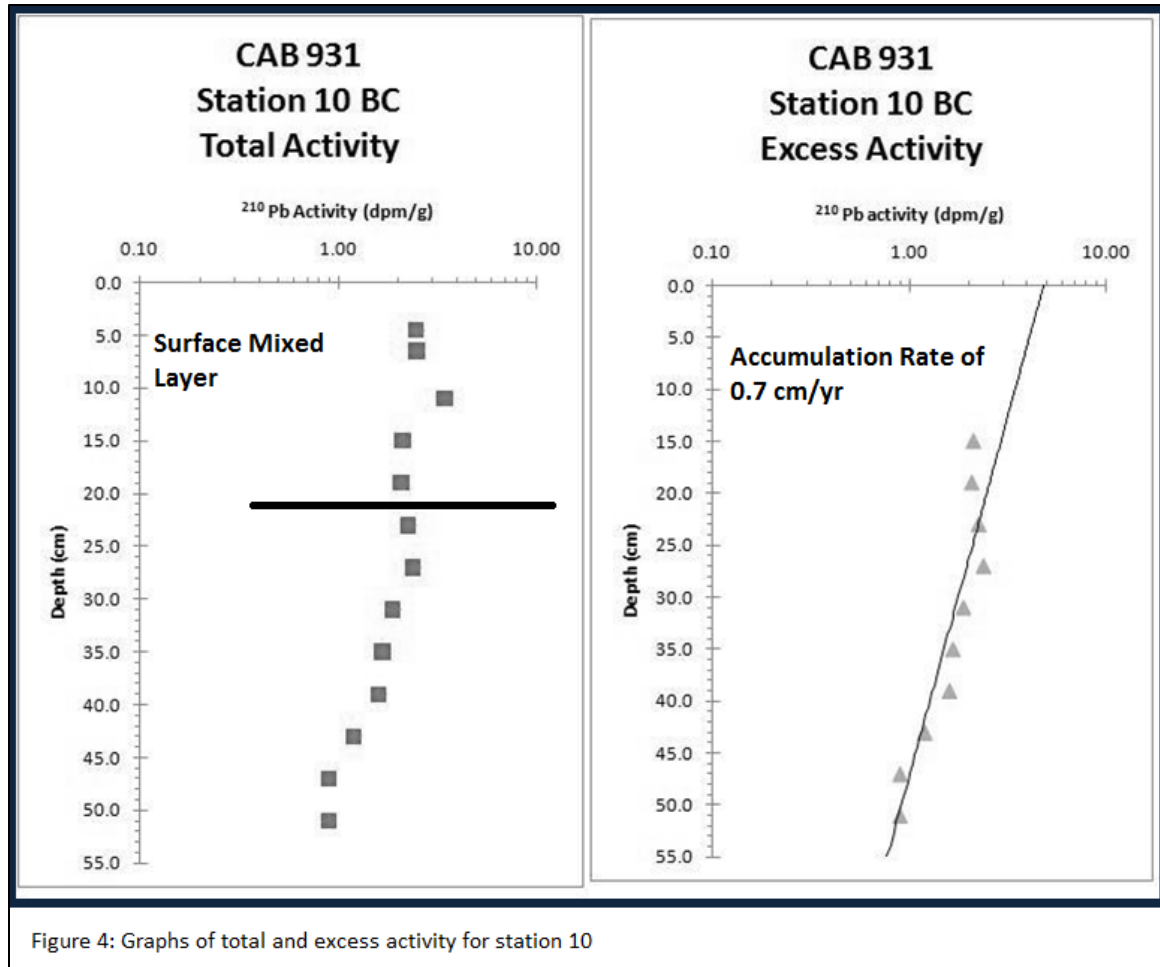


Figure 2: Graphs of total and excess activity of station 7.

showed a surface mixed layer of about 20 cm. This is then followed by a region of no data points and then an area of active decay (fig. 3).

Station 10 ( $48^{\circ} 7'54.96''\text{N}$ ,  $122^{\circ}32'6.96''\text{W}$ ) located ~ 2.5 km north of Holmes Harbor showed a surface mixed layer of about 20 cm followed by an area of active decay (fig. 4).





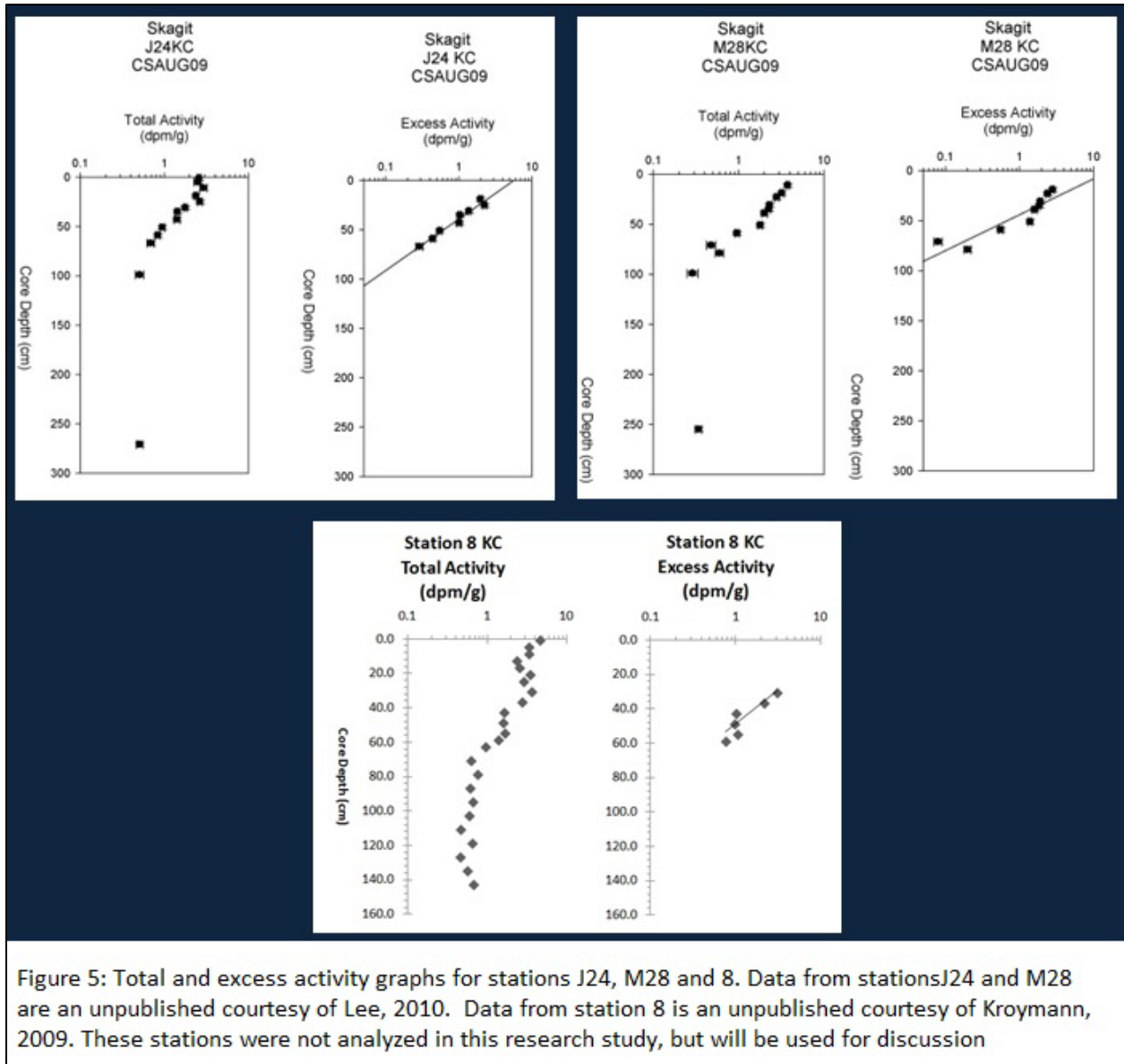
## Discussion

The three box core samples (station 7, 9, and 10) analyzed for this research will be combined with previous research to create modern (100 yr) fine-grained sediment budget for Southern Saratoga Passage. Previous research used in this discussion (station 8, M28 and J24) were completed by the author and with collaboration from colleagues (fig. 5).

*Interpretation of  $^{210}\text{Pb}$  profile:* To calculate accumulation rates for each station sampled, a graph of excess activity was created by subtracting total activity levels from the supported levels, usually around  $0.4 \text{ dpm g}^{-1}$ . Using the equation below (Nittrouer et al., 1984) accumulation rates for each station can be calculated.

$$A = \frac{\lambda z}{\ln \frac{C_0}{C_z}}$$

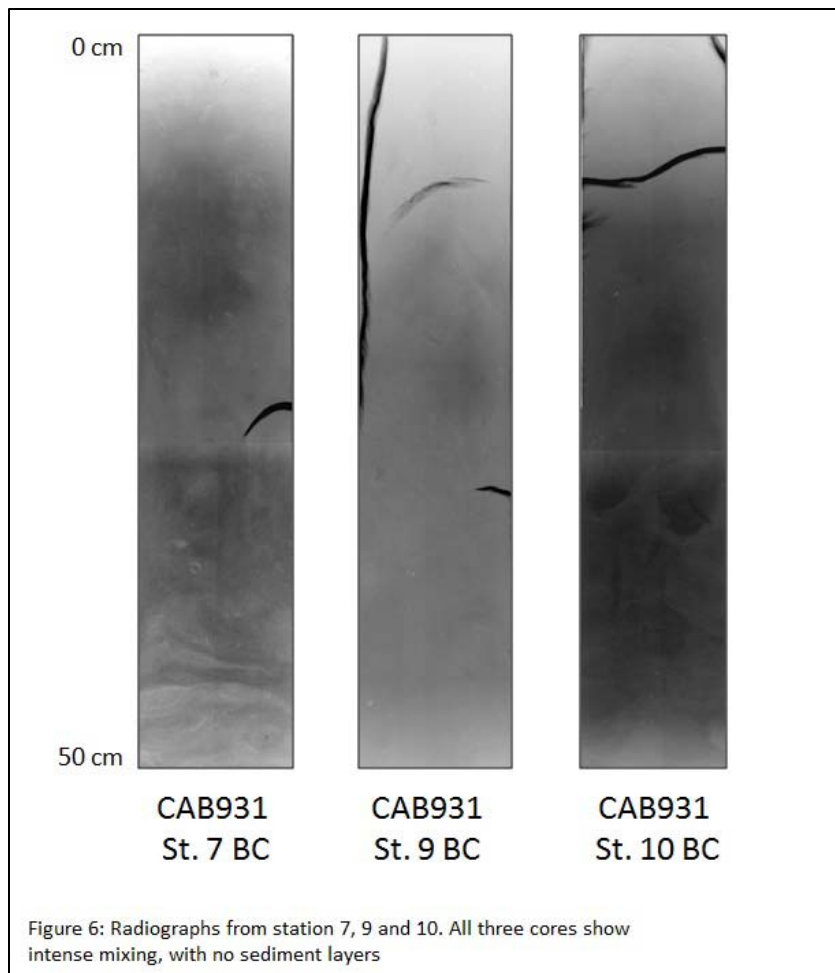
The components of this equation breakdown into the following:  $\lambda$  is the decay constant,  $z$  is the depth of active decay,  $C_0$ ,  $C_z$  are the activity levels at the start and end of region of active decay.



Station 7 had a calculated accumulation rate of  $0.7 \text{ cm yr}^{-1}$ . Station 9 had a calculated accumulation rate of  $0.4 \text{ cm yr}^{-1}$ . Station 10 had a calculated accumulation rate of  $0.7 \text{ cm yr}^{-1}$ . Station 8 had an accumulation rate of  $0.7 \text{ cm yr}^{-1}$  (unpublished courtesy of Kroymann, 2009).

Station M 28 had an accumulation rate of  $0.8 \text{ cm yr}^{-1}$  and station J 24 had an accumulation rate of  $0.7 \text{ cm yr}^{-1}$  (unpublished courtesy of Lee, 2010).

Surface mixed layers of these stations averaged around 20-30 cm thick. Bioturbation, mixing of seafloor sediment by benthic organisms, is high in this region. X-radiographs taken of stations 7, 9 and 10 (fig. 6) show mixing throughout the entire core; fine sediment structures are not found in these samples.



Residence time of sediment kept in the surface mixed layer is calculated by dividing the depth of the surface mixed layer by the accumulation rate. Residence times calculated for the stations are: 29 years (station 7), 45 years (station 8), 48 years (station 9), 29 years (station 10), 25 years (M 28) and 28 years (J 24). Previous studies conducted in this region have found residence

times between 1.5 to 68 years (Carpenter et. al. 1984).

*Sources of sediment found in Southern Saratoga Passage:* There are several sources which could be supplying sediment to Southern Saratoga Passage. Sediment transported by the rivers is one source, while bluff and cliff erosion could be another.

$^7\text{Be}$  is a short-lived radio isotope with a half life of 53 days (Sommerfield et al, 1999). It is found on the surface of terrigenous soils which are eroded and carried by rivers, eventually being deposited into the ocean. With such a short half life,  $^7\text{Be}$  is only able to be traced for around 200 days, 4 or 5 half lives (Sommerfield et al, 1999).

Recent study of Southern Saratoga Passage (unpublished courtesy of Sampelayo, 2010) found the presence of  $^7\text{Be}$  around station 7 and 8 and south of M 28 (fig. 7). The presence of this radioisotope means that there has been a recent deposit of fluvial sediment to the area. Measurements for  $^7\text{Be}$  were also taken in upper Saratoga Passage and showed no sign of  $^7\text{Be}$ .

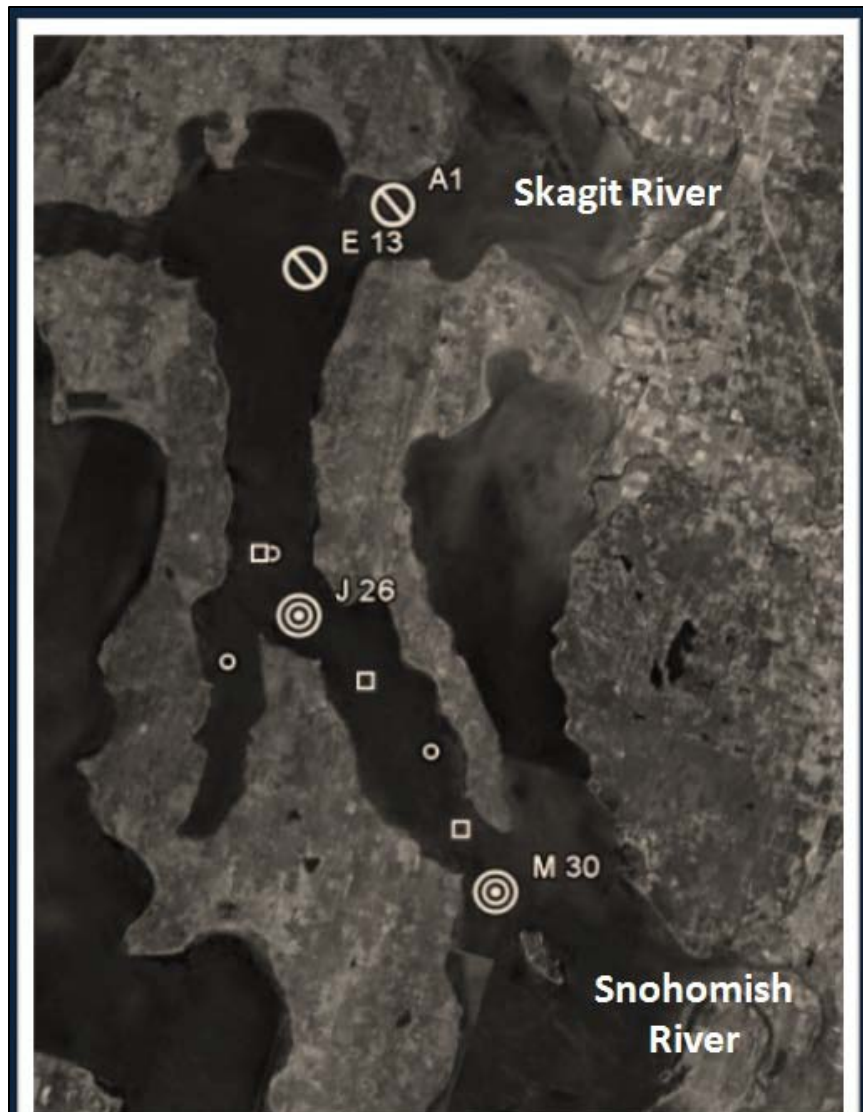


Figure 7: Map of Saratoga Passage with stations studied for Be-7 marked (unpublished courtesy of Sampelayo). Stations with bulls eye are areas with Be-7 present, stations with a circle and slash are areas where no Be-7 was found.

Therefore it would be concluded that the presence of  $^7\text{Be}$  did not come from the Skagit, but another source. For there to be a reading of  $^7\text{Be}$ , there needs to be a large amount of sediment deposited which could be caused by a storm or flooding event. The end of Saratoga Passage is located near the mouth of the Snohomish River. With the river mouth being close to the opening to Saratoga Passage it is possible that some of the sediment in southern Saratoga Passage was delivered via the Snohomish River. Based on the  $^7\text{Be}$  results, the accumulation of sediment in Saratoga Passage could be a combination of both Skagit and Snohomish derived sediment.

*Complete picture of Southern Saratoga Passage*

Sediment accumulation in Southern Saratoga Passage is a complicated process, with sediment input from various rivers, the Skagit River from the north and the Snohomish River from the southeast. The presence of  $^7\text{Be}$  in southern Saratoga Passage but not in the northern Saratoga Passage stations shows that the sediment is coming from the Snohomish River.

Accumulation rates calculated in this region also imply a similar relationship. Figure 8 demonstrates the layout of stations and the relating accumulation rates. M 28, the southernmost studied station, showed an accumulation rate of  $0.8 \text{ cm yr}^{-1}$  which is higher than stations 7, 8, 10 and J24.

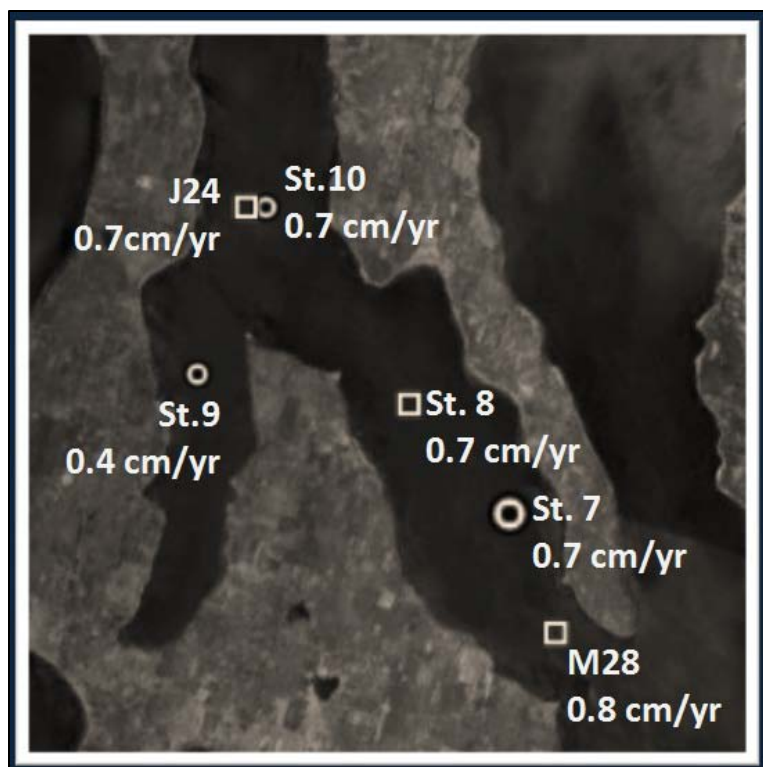
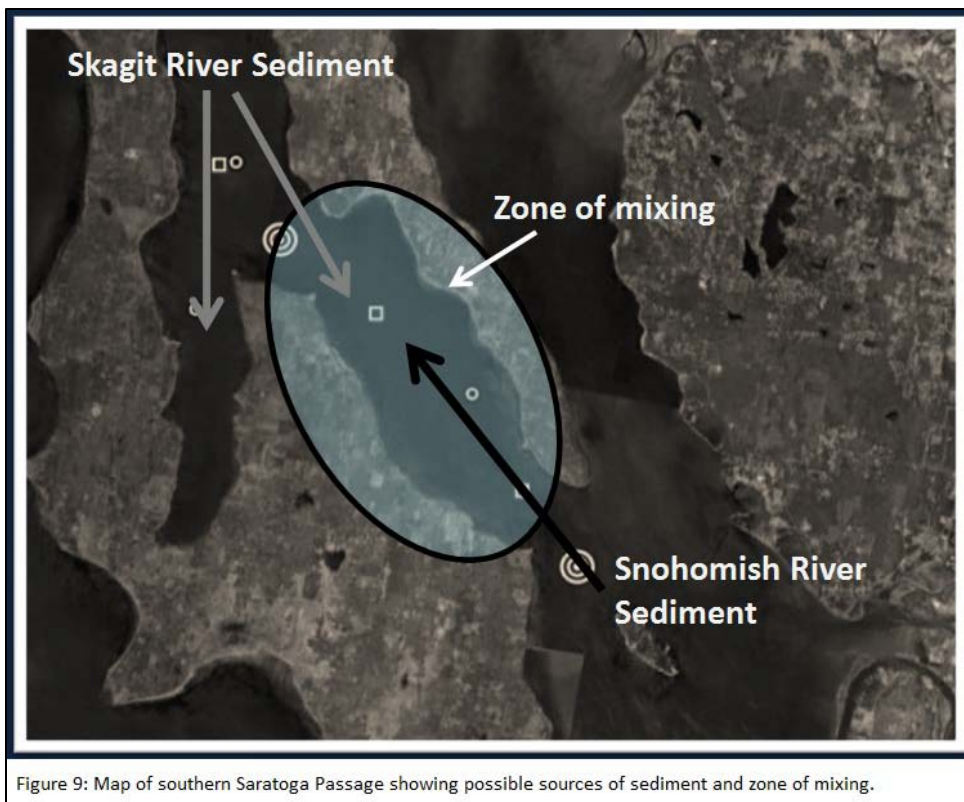


Figure 8: Map of southern Saratoga Passage with stations and calculated accumulation rates

These stations are located closer to the Skagit River and therefore if it was the only source of sediment to this region the accumulation rate of M28 would be lower than the northward stations. This higher rate of sediment accumulation could be related to the station's proximity to the mouth of the Snohomish River. Another interesting result is the similarity of accumulation rates throughout most of southern Saratoga Passage. The majority of the stations studied have accumulation rates of around  $0.7 \text{ cm yr}^{-1}$ . This is a relatively high accumulation rate, but with the contribution of sediment from two large rivers it is possible.

This region of southern Saratoga Passage, north of station M 28 and south of station 10, could be a zone of mixing of the two sediment sources (fig. 9). Skagit and Snohomish sediment is both deposited in this region creating an area of uniform accumulation rates (see fig. 8).

Station 9 is located inside Holmes Harbor, an inlet of Saratoga passage. The



accumulation rate of this station was calculated to be  $0.4 \text{ cm yr}^{-1}$  which is much lower than the surrounding regions. One reason for this lower accumulation rate is due to the bathymetry of the harbor. Holmes harbor has a sill

located at the entrance which restricts some of the sediment flow into this region.

Overall sediment found in southern Saratoga Passage is possibly from two fluvial sources, the Skagit and Snohomish Rivers. Bluff erosion may also be a contributing factor but is not focused on in this paper. Most of the region has similar accumulation rates of around  $0.7 \text{ cm yr}^{-1}$ , which could be due to the input of sediment from both river sources. Higher accumulation rates and the presence of  $^7\text{Be}$  in the southernmost sections of Saratoga Passage demonstrate the importance of looking at the Snohomish River as a source of sediment to this system.

#### *Previous Regional Work*

Southern Saratoga Passage is a relatively new study area. Recent studies began in 2009 and are included in this paper. Station 8 (unpublished courtesy of Kroymann, 2009) was extensively studied for accumulation rate and sediment stratigraphy. The accumulation rate was determined to be  $0.7 \text{ cm yr}^{-1}$  and the surface mixed layer was  $\sim 30\text{cm}$ . X-radiography of the 3m core found highly mixed sediment through the entire length of the core. The accumulation rate was also compared with previous studies done in the region in the 1980's. The accumulation rate of station 8 had to be converted from  $\text{cm yr}^{-1}$  to  $\text{g cm}^2 \text{ yr}^{-1}$  to be able to be compared with previous studies. It was calculated to be  $0.32 \text{ g cm}^2 \text{ yr}^{-1}$  (unpublished courtesy of Kroymann, 2009). Research conducted by Lavelle at a station located near station 10 (from this research) found accumulation rates of  $0.44 \text{ g cm}^2 \text{ yr}^{-1}$  (Lavelle et al, 1985). Other research done by Carpenter at a location near station 8 found an accumulation rate of  $0.38 \text{ g cm}^2 \text{ yr}^{-1}$  (Carpenter et al., 1984)

Research has also been conducted in the upper portion of Saratoga Passage, near the mouth of the Skagit River. Accumulation rates for that region have been found to range around  $1.0$  to  $1.2 \text{ cm yr}^{-1}$  (unpublished courtesy of Lee, 2009). The higher rates of accumulation in

comparison with stations studied in this research are in agreement with higher rates being located near the Skagit River mouth. It would be expected to find higher rates of sediment accumulation near the river mouth with the rates decreasing away from the sediment source.

### **Conclusion**

- High sediment accumulation rates are found in Southern Saratoga Passage
- Southern Saratoga Passage sediment accumulation is derived from multiple sediment sources
- A zone of mixing occurs in this region where sediment sources are combined together
- Southern Saratoga Passage is a complex sediment system with multiple sources and processes which are occurring. More research needs to be done in this region to further the amount of information regarding sedimentary processes in this area.

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