

Instantaneous sediment accumulation rates in Tarr Inlet, Glacier Bay, Alaska

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Abstract

NetTrap sediment traps were used to collect particles settling through the water column in Tarr Inlet, Glacier Bay, Alaska, in late March 2008. The objective of this study was to determine the instantaneous sediment accumulation rate in and southeast of Tarr Inlet. Sediment accumulation rates varied from 18,225 g m⁻² yr⁻¹ <0.5 km away from the sediment source, to 420 g m⁻² yr⁻¹, 33 km away from the source. Rates determined by NetTraps were slower than those derived from ²¹⁰Pb geochronology, 651,900 g m⁻² yr⁻¹, done by Cai et al. (1997). This indicates that the rate at which sediment enters the bay is variable throughout the year. Even though rates in March were slower than those of the geological average, they were faster than the rate of the average open ocean, 16.6 g m⁻² yr⁻¹, and comparable to ocean coastal zones, 400 g m⁻² yr⁻¹, and Puget Sound, 3,000-15,000 g m⁻² yr⁻¹ (Lavelle et al 1985, Seibold and Berger 1993).

Introduction

Alaska is one of the few places that still has tide-water glaciers (Syvitski et al. 1987). Glaciers within Glacier Bay, Alaska are the fastest retreating glaciers on record leading to the highest known sedimentation rates in the world (Hall and Benson 1995; Hallet et al. 1996; Koppes and Hallet 2002). Even though documentation

of glacier retreat within Glacier Bay has been well documented for 225 years (Fig 1), to date few studies have documented the impact of this retreat on sedimentation rates within Glacier Bay (Hall and Benson 1995; Hallet et al. 1996; Cai et al.1997; Cowan et al. 1999; Koppes and Hallet 2002) Tarr Inlet, an inlet of Glacier Bay, (Fig 1) is located in Southeast Alaska and is fed by the Grand Pacific and Margerie Glaciers, as well as, river runoff. Instantaneous accumulation rates, rates determined by sediment traps deployed for 1-10 days, are unknown for Tarr Inlet in March and can provide a basis for determining the burial rate of benthic biology, toxins and carbon, along with information about seasonal sedimentation rate variability. The use of novel sediment traps provides new information on sedimentation rates within Tarr Inlet. Instantaneous rates for accumulation of sediments in late March 2008, are compared to geological average rates determined by ²¹⁰Pb analysis.

Quantifying sediment accumulation in glacier-fed systems is important because this can dramatically impact benthic biological communities. For example, if rates are high the benthic biology become stressed and their density decreases (Moore and Scruton 1957). Accumulation rates also determine how fast toxins such as polycyclic aromatic hydrocarbons (PAHs), are delivered to the seafloor and their burial rate. PAHs occur naturally in fossil fuels, yet anthropogenic activities are mainly responsible for PAH contamination (Curtosi et al. 2007). Glacier Bay hosts a high abundance

of commercially valuable fish, marine mammals and seabirds (Etherington et al. 2007). PAH contamination could cause extreme harm to this ecosystem such that there is a critical need to understand the rate at which PAHs are entering the water and sequestered through burial.

Carbon, in the form of carbon dioxide (CO_2), is a major cause of the greenhouse effect and global warming. The more CO_2 in the atmosphere the more warming the earth experiences (Berner and Lasaga 1989). Calcium carbonate in sedimentary rocks accounts for almost half of all carbon found on earth and the burial of calcium carbonate is the primary geological method for removing CO_2 from the ocean and atmosphere (Berner and Lasaga 1989, Ridgwell and Zeebe 2005). Although sedimentary organic carbon only accounts for about 20% of all carbon, when sequestered in sediment it releases oxygen to the ocean and atmosphere while reducing CO_2 concentration, causing a negative feedback for global warming (Berner and Lasaga 1989, Berner 2005).

One method for determining accumulation rates is ^{210}Pb geochronology (Nittrouer et al. 1979). For this method, accumulation rate is assumed to be constant over time so that the vertical profile of ^{210}Pb can be used to calculate the accumulation rate of sediment (Dellapenna et al. 1998). However, Moore and Scruton (1957) determined that sediment deposited near the mouth of the Mississippi river was deposited in regular and irregular layers. These differences were attributed to the fluctuation in amount of sediment being discharged into the system. Similar processes are expected in Glacier Bay, due to variable precipitation and the melting of marine and alpine glaciers (Cai et al. 1997). Instantaneous accumulation rates will be compared to average accumulation rates determined through ^{210}Pb geochronology done by J. Bergquist (2008).

The objectives of this study are: 1) to determine the instantaneous accumulation rate in

and around Tarr Inlet in late March 2008; 2) to compare instantaneous accumulation rates to yearly averages in collaboration with J. Bergquist; 3) to determine the burial rate of toxins in and around Tarr Inlet in collaboration with S. Keever (2008); and 4) to determine a rough estimate of carbon sequestration in Glacier Bay in collaboration with E. Wisegarver (2008). This study also tests the hypothesis that instantaneous accumulation rates will not match the geological average rates due to stochastic processes of sedimentation.

Methods

To recover sinking particles, NetTraps were deployed from the R/V Thomas G. Thompson in Tarr Inlet for approximately 24 hours, March 19-21, 2008. The NetTraps were modified after Peterson et al. (2005) to include a 1.25 m diameter opening, 1.25 m black canvas collar, 2 m long conical walls constructed of 50- μm -mesh nylon net and a 17.5 cm diameter x 17.5 cm canvas cod end collar. Two nets were deployed and retrieved in Glacier Bay, at historical Stations 21 and 8 (Table 1 and Fig 1) (Hooge and Hooge 2002). The top of the nets were 150 m below the surface and 70 m, Station 21, and 270 m, Station 8, off the bottom of the bay. Upon recovery, samples were placed in 2 L containers and frozen until processed in the shore-based lab.

Samples were analyzed at the University of Washington. The samples were partially thawed using a Microwave for 15 minutes then placed in a hot water bath until completely thawed. Sample splits were made using a 3 L graduated cylinder in which a spatula was used to homogenize the sample. Sample splits of 300 ml and 125 ml were taken from Stations 8 and 21, respectively and then stored in a cold room at 12°C . The rest of the sample material was centrifuged at 4000 rpm at 15°C in 11 and 22 minute increments, Stations 8 and 21 respectively, where upon the excess water was

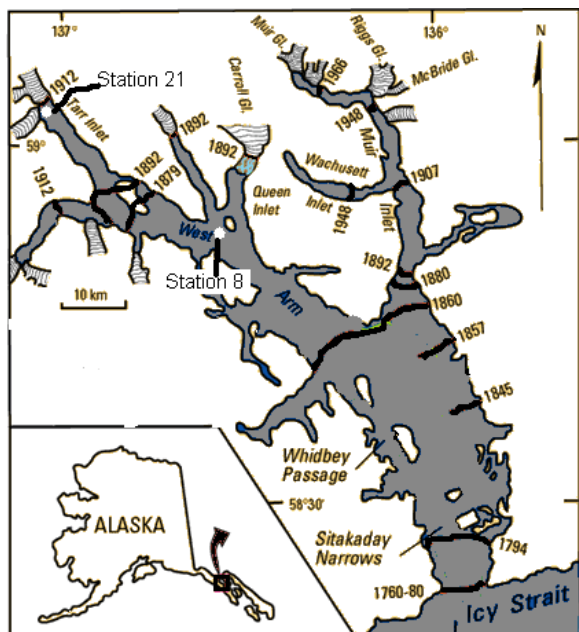


Figure 1: Map of Glacier Bay. Thick black lines with dates correlate to position of glacier in that year. Regions with thin light gray lines are modern glaciers. White dots indicate station locations. Map courtesy of USGS.

decanted off using a 10 ml pipette. Samples were placed in 20 ml vials and freeze dried for three days. Dried samples were weighed and height of compacted sediment was measured to determine volume of sediment.

Results

The measured accumulation rate for Station 8 was $420 \text{ g m}^{-2} \text{ yr}^{-1}$ and Station 21 was $18,225 \text{ g m}^{-2} \text{ yr}^{-1}$ (Table 1). Sediment from Station 8 was comprised of fine-grained silt and clay particles, $0.004 - 0.062 \text{ mm}$, and the largest particles were small sand grains, $0.25 - 1.0 \text{ mm}$, sample was tinted green. Station 21 contained high variability in grain sizes ranging from silt and clays, $0.004 - 0.062 \text{ mm}$, to large sand grains and ice rafted debris, $0.5 - 4 \text{ mm}$. General coloration of sediment was light gray (Table 1).

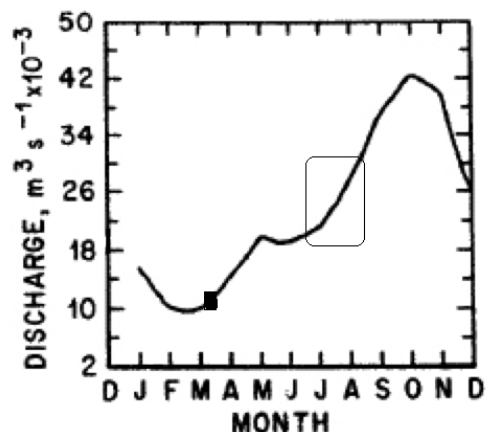


Figure 2: Graph showing the freshwater discharge in SE Alaska by month of the year. (Royer 1982). Solid square is time of the year of March 2008 research. Open square is time of the year that the Cai (1994) research was conducted.

Discussion

This study presents the first sediment trap results for the analyses of instantaneous sediment accumulation in Glacier Bay in winter. Sediment traps were done by Cai (1994) in the summer of 1989, 4-5 m off the fjord floor, deployed for 5-10 days. Instantaneous rates found in winter ranged from $18,225 \text{ g m}^{-2} \text{ yr}^{-1}$, less than 0.5 km away from the Grand Pacific and Margerie Glaciers, and $420 \text{ g m}^{-2} \text{ yr}^{-1}$, 33 km away from the glaciers (Table 1). The instantaneous sedimentation rate in the summer of 1989 was $1,510,500 \text{ g m}^{-2} \text{ yr}^{-1}$, for a station 2 km away from the glaciers, while the geological average determined by ^{210}Pb analysis was $651,900 \text{ g m}^{-2} \text{ yr}^{-1}$ (Cai 1994, Cai et al. 1997). Cai et al. (1997) attributed these differences to sediment being redeposited down-fjord. However, analysis of data for their station 4 km down fjord revealed similar instantaneous, $310,050 \text{ g m}^{-2} \text{ yr}^{-1}$, and geological average, $318,000 \text{ g m}^{-2} \text{ yr}^{-1}$, sedimentation rates. If the sediment was being redeposited down fjord than the geological sedimentation rate should be much larger

Station name	Latitude	Longitude	Accumulation rate (g/m ² /yr)	Location description	Sediment description
Station 8 ‡	58° 52.00' N	136° 35.60' W	420	Not near glacier input >26 km away	fine grained, mostly homogenous with some larger sand grains, green tint
Station 21 ‡	59° 2.89' N	137° 3.34' W	18225	Close to Grand Pacific and Margerie Glaciers < 1m, calving glacier	Variable grain size from very fine to small pieces of ice rafted debris, gray in color
Average Ocean*			16.6		
Average Coastal Zone*			400		
Puget Sound**			3,000-15,000		
Muir Inlet 1***			651900	2 km away from Muir Glacier	
Muir Inlet 2***			127200	6 km away from Muir Glacier	
Tarr Inlet §			651900	<2 km away from Grand Pacific and Margerie Glaciers.	

Table 1: Description of samples and sample sites. Comparison to other accumulation rates. ‡- indicate rates determined by traps. All others determined by ²¹⁰Pb. *-Seibold and Berger 1993. **-Lavelle et al. 1985. ***- Cowan et al. 1999. †-Cai et al. 1997.

than the instantaneous accumulation rate. An analysis to Cai's (1994) method discovered that he placed traps 4-5 m off the bay floor, traps within 10 m on the bottom have a high probability of collecting resuspended sediment (pers. comm. Keil), which could have caused the large difference between instantaneous and geological average rates at the site 2 km from the glaciers.

For the March 2008 study at Station 21 the instantaneous accumulation rate, 18,225 g m⁻² yr⁻¹, is much slower than the geological average, 651,900 g m⁻² yr⁻¹, from Cai et al. (1997). ²¹⁰Pb geochronology done by J. Bergquist did not retrieve a deep enough core and therefore geological average rates are from Cai et al. (1997). This difference in my data versus Cai (1994) may likely be attributed to variable discharge of freshwater into the bay during different seasons (Fig 2). For example, February and March see the lowest input of freshwater in SE Alaska, ~ 10,000 m³ s⁻¹, compared to the rest of the year

(Royer 1982). Freshwater input and glacial melt water introduce sediment into a fjord system (Cowan 1992; Etherington et al. 2007). The input of new water to the bay is near its lowest rate during March, and is consistent with the observation of instantaneous sedimentation rates being slower than the geological average during this experiment. In contrast, the instantaneous rate in October, when freshwater discharge is at its peak, 42,000 m³ s⁻¹, is hypothesized to be a much faster rate compared to the ²¹⁰Pb derived average, to compensate for the low sedimentation rates in winter. Sedimentation data from summer 1989, mentioned previously, had similar instantaneous, 310,050 g m⁻² yr⁻¹, and geological average, 318,000 g m⁻² yr⁻¹, rates. This is expected since the summer months is when freshwater discharge is at an average flow, 26,000 m³ s⁻¹ (Fig 2) (Royer 1982). Seasonal variability is not unique to Glacier Bay or glacier effected environments, but are also found in

environments that are associated with rivers. Dabob Bay, Washington, an arm of Puget Sound, has been examined on a monthly basis to look at variability of sediment accumulation throughout the year (Hedges et al. 1988). Data from sediment traps revealed seasonal changes in sediment accumulation, lowest in June and peaked in December. This trend was similar to the amount of river discharge and precipitation for that region, correlating variable freshwater input to variability in sediment accumulation (Hedges et al. 1988).

Sedimentation rates are highly variable with respect to location (Table 1). Both Stations 8 and 21 have a much higher accumulation rate than the average open ocean, $16.6 \text{ g m}^{-2} \text{ yr}^{-1}$, and the average coastal zone, $400 \text{ g m}^{-2} \text{ yr}^{-1}$ (Seibold and Berger 1993). Station 21 surpasses the maximum sedimentation rate in Puget Sound of $15,000 \text{ g m}^{-2} \text{ yr}^{-1}$ (Lavalle et al 1985). Variation of sedimentation rates between environments is due to the amount of available sediment and the efficiency of processes to transport the sediment. There are four main inputs of sediment into an environment: rivers, glaciers, wind and volcanoes (Seibold and Berger 1993). Glacier Bay receives sediment from glaciers, rivers and wind, while coastal zones receive sediment from primarily rivers and some wind. The open ocean gets its sediment from wind carrying small dust particles, which is why the accumulation rate is so low (Seibold and Berger 1993). Puget Sound is delivered sediment through its many rivers and streams, yet is still small in comparison to Glacier Bay.

No PAHs were found in Glacier Bay (Keever 2008). PAHs were expected in Glacier Bay due to high ship traffic in the summer months (pers. comm. Sharman). One possible reason that PAHs were not detected in Glacier Bay could be the high sedimentation rate buried the PAHs from the previous summer and the samples taken at the surface would not have been exposed to PAHs. Another possibility is that the PAH compounds are released into

the air and could disperse and not accumulate traceable amounts in the bay.

Glacier Bay, with its high sedimentation rates, has the potential to bury large amounts of organic carbon (OC). Station 21 had a 0.21% OC and Station 8 sediment contained 1.64% OC (pers. comm. Wisegarver). Given the sediment accumulation rates for March and an estimated area for each station, rough calculations determine that Glacier Bay buries approximately $1.2 \times 10^9 \text{ g OC yr}^{-1}$. When compared to the oceans burial rate of $1 \times 10^{14} \text{ g OC yr}^{-1}$, Glacier Bay seems insignificant, contributing only about 0.001% of the total carbon burial. Yet relative to total area it is disproportionate to carbon burial, burying six times more carbon than the area is estimated to bury. This is similar to temperate fjords making tidewater glacier-fed fjords important for studying OC burial in situ (Nuwer and Keil 2005).

Conclusion

In conclusion,

- The instantaneous sedimentation rates are $420 \text{ g m}^{-2} \text{ yr}^{-1}$ and $18,225 \text{ g m}^{-2} \text{ yr}^{-1}$ for Stations 8 and 21, respectively.
- The instantaneous rate is slower than the geological average derived from ^{210}Pb analysis. Indicating stochastic sedimentation processes.
- There are no PAHs being brought and sequestered in Glacier Bay.
- Glacier Bay is estimated to sequester $1.2 \times 10^9 \text{ g OC yr}^{-1}$.

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