Relationships of fine-grained glacial sediment and total organic carbon in Glacier Bay, Alaska

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Abstract

Particulate organic carbon (POC) concentrations are observed in marine and alpine glacier deposits in Glacier Bay, AK. POC concentrations are compared and contrasted to amounts of specific surface area, grain size, and surface sediment morphology. Field methods include coring and laboratory methods consisted of sedigraph analysis to measure grain size, N_2 absorption to measure surface area, POC analysis, XRD for mineralogy. Sediment surface area was highest in sediment from Geikie Inlet while grain size was coarsest in Tarr Inlet around 52% sand. Higher concentrations of POC are correlated with higher surface area and finer grain size. However, the highest concentrations of POC are found at Station 23 in Geikie inlet where neither the highest surface area nor the finest sediment is found, but instead may be due to higher phytoplankton biomass and melt water discharge.

Introduction

The carbon cycle plays a critical role in the exchange of carbon on earth between sources and sinks. Particulate organic carbon (POC) is organic matter that falls through the water column and is buried in sediment. Such sources of POC may be terrestrial, such as from plants or the sources may be marine, such as phytoplankton. This study was conducted in Glacier Bay, Alaska where POC levels have been found to be considerably high, ranging from 0.16% total organic carbon(TOC) to 0.30% TOC (Table 1). Glacier Bay is a highly productive fjord with high phytoplankton biomass (Hooge 2002).

PARAMETER	TARR INLET	TARR INLET	QUEEN INLET	REID INLET	RENDU INLET (top of sampler)	RENDU INLET (bottom of sampler)
% TOTAL CARBON	0.31	0.34	2.21	2.01	1.51	1.49
% CO_3 AS CARBON	0.13	0.17	1.91	1.77	1.35	1.30
% TOTAL ORGANIC CARBON	0.18	0.17	0.30	0.24	0.16	0.19
% SAND	20.4	5.4	0.7	1.4	0.2	- -
% SILT	63.5	71.6	70.0	65.3	69.8	- -
% CLAY	16.1	23.0	29.3	33.3	30.0	- -

Table 1: TOC in certain locations within Glacier Bay (Cowan 1993).

Within Glacier Bay, there are two main types of glaciers, alpine glaciers and marine glaciers, also known as tidewater glaciers. Alpine glaciers have already began to recede onto land and the tow of the glacier does not directly touch the seawater. However, it discharges the melt water to form a glacial stream. These associated runoff stream deposit plant and tree material into the bay. Marine glaciers directly interact with the seawater. The tow of the glacier is in the seawater and calves into the bay. Therefore, any sources of carbon are being directly deposited into the seawater as the glacier melts or calves.

Several factors contribute to the amount of particulate organic carbon in finer sediments:

surface area, grain size, and surface morphology. One factor that will be looked at is possible sources of the POC and whether the POC comes from biological sources that can be seen through geological distributions of chlorophyll-a throughout the bay or terrestrial sources such as vegetated fjord walls (Cowan 1993). Higher amounts of POC tend to be associated with finer sediment, specifically clays (Mayer et al. 1985). As sediment decreases in size from sand (2 mm–0.5 mm) to silt (4 µm – 62 µm) to clay (<4 µm)(Blatt et al. 1980), amount of organic carbon in the sediment increases (Keil and Cowie 1999). Finer grains, more specifically clays, have a higher specific surface area, therefore, POC will adhere to the surfaces more readily (Keil and Cowie 1999). However, there is an exception to this: glacial flour. Glacial flour is caused by the crushing and abrasion of bedrock by a glacier and results in clay sized particles with brittle fractures (Brown et al. 1996). The primary minerals in glacial flour are quartz, feldspar, and chlorite (Chanudet and Fillela 2008). Primary minerals in clay are aluminum phyllosilicates (Guggenheim and Martin 1995). Not only is the mineralogy of these sediments different, but the surface morphology is different as well. Although clays and glacial flour are relatively the same phi size, their surface morphology contrasts in that glacial flour has relatively smoother surfaces in comparison to clay particles that have highly fractured surfaces.

Few studies have examined the characteristics of fine-grained sediment with respect to POC relations in Glacier Bay, AK. The importance of this topic to marine science is to relate geological characteristics to the chemistry in Glacier Bay and further the knowledge of glacial sediments. This research focuses on the hypothesis that lower concentrations of POC will be found in sediments underlying marine glaciers due to a lack of carbon sources such as phytoplankton that are less abundant because of deglaciation and sedimentation (Williamson 2001). An alternative hypothesis is that fine-grained sediment deposits from alpine glaciers will have higher amounts of POC because alpine glaciers and their associated runoff streams deposit plant and tree material that is previously eroded into glacial rivers. However, this assumption may be inaccurate, based on the concentration and location of glacial flour. Therefore, the concentration of POC in finer sediments around marine glaciers and alpine glaciers may not be due to the amounts of POC falling to the seafloor, but may be due to the types of sediment that make up the bottom of the bay.

Methods

A soutar core that was deployed at seven sites in Geikie Inlet and Tarr Inlet (Figure 1). To study the influence of alpine glacier, Geikie Glacier, one core was deployed as close as possible to the mouth of the river near Station 23 and two more cores were deployed further away from the mouth of the river, one in between Station 23 and Station 22 (Station 22A) and one at Station 22 (Table 2). The top 2 cm of sediment were extracted at each station and put into three separate bags and a glass vial. Each core sample extracted in Geikie Inlet was a light grey color with much benthic biology and plant material. To investigate the influence of marine glaciers, cores were taken at Station 21, Station 12, in between Station 21 and Station 11 (Station 11A), and Station 11 (Table 2) in Tarr Inlet, which is impacted by Marjorie Glacier/Grand Pacific Glaciers. Sediment at each station in Tarr Inlet was a dark grey color with no marine or terrestrial life apparent.

Once onshore, a scanning electron microscope (SEM) was used to take digital images of sediment from stations 21 and 23. Sediment at each station was examined in a magnification ranging from 5,000x to 30,000x (Chescoe and Goodhew 1990). Grain size analyses were conducted in Chuck Nittrouer's laboratory at the University of Washington. Approximately 0.7g of sediment

Station Number	Latitude	Longitude	Depth(m)
23	58°36.35	136°28.62	92
22 A	58°37.73	136°28.62	97
22	58°38.47	136°21.80	104
21	59°2.89	137°3.35	235
12	59° 2.02	137°0.97	284
11 A	58°59.97	136°58.337	318
11	59°58.04	136°54.517	318

Table 2: Locations and depths where cores were taken.

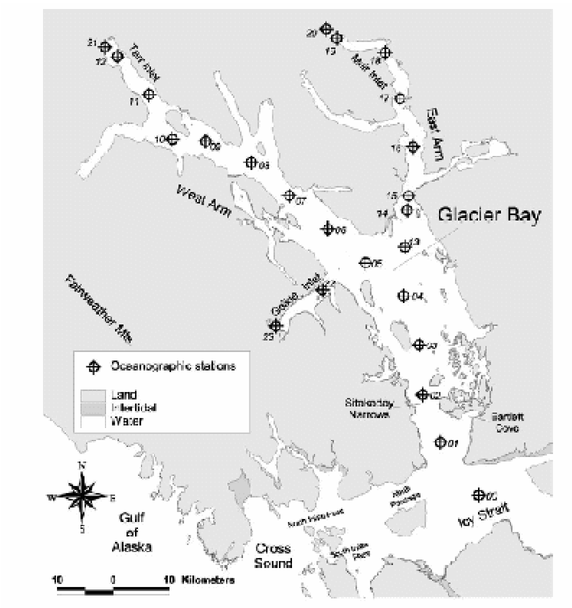

Figure 1: Map of Glacier Bay, Alaska and stations where cores were taken.

were sieved and sent through sedigraph analysis where the sand particles were wet sieved and separated into sands and silts/clays. This was followed by the use of a sedigraph to separate silts and clay by x-ray refraction (Bianchi et al. 1999). Surface area was determined through the BET method of measuring N_2 gas adsorption on the surface of sediment particles using an ASAP 2010 analyzer in Rick Keil's laboratory (IUPAC 1989). Amounts of organic carbon were determined in Aaron Morello's Laboratory. The sediment samples were dried, grounded, weighed out, and acid- fumed in an HCl fuming chamber for twenty-four hours and were done in triplicates. Then, they were run through a CE-440 elemental analyzer. The samples were then combusted at 1050°C, which in turn converted all elemental carbon to CO2 (Sharp 1974).

Results

Percent organic carbon content ranged from 0.09% at Station 11 in Tarr Inlet to a high of 0.81% at Station 23 in Geikie Inlet (Figure 2). Stations 22, 22A, and 23 in Geikie Inlet have higher values of percent organic carbon than Stations 11, 11A, 12, and 21 in Tarr Inlet (Figure 2).

Specific surface area ranged from 2.17 m^2gwd-^{1} to 13.61 m^2gwd-^{1}. The highest specific surface area was found at Station 22 located in Geikie Inlet (Figure 3). Stations 22, 22A, and 23 in Geikie Inlet have higher specific surface area values than Stations 11, 11A, 12, and 21 in Tarr Inlet (Figure 3).With increasing specific surface area, % organic carbon increases (Figure 4). The correlation coefficient is 0.5637.

Grain size variations range from 0.76% sand and 99.24% silt/clay at Station 12 in Tarr Inlet to 52.45% sand and 47.55% silt/clay at Station 11 in Tarr Inlet (Figure 5). However, the finer grain sediment it primarily found in Geikie Inlet at stations 23, 22A, and 22. The coarser

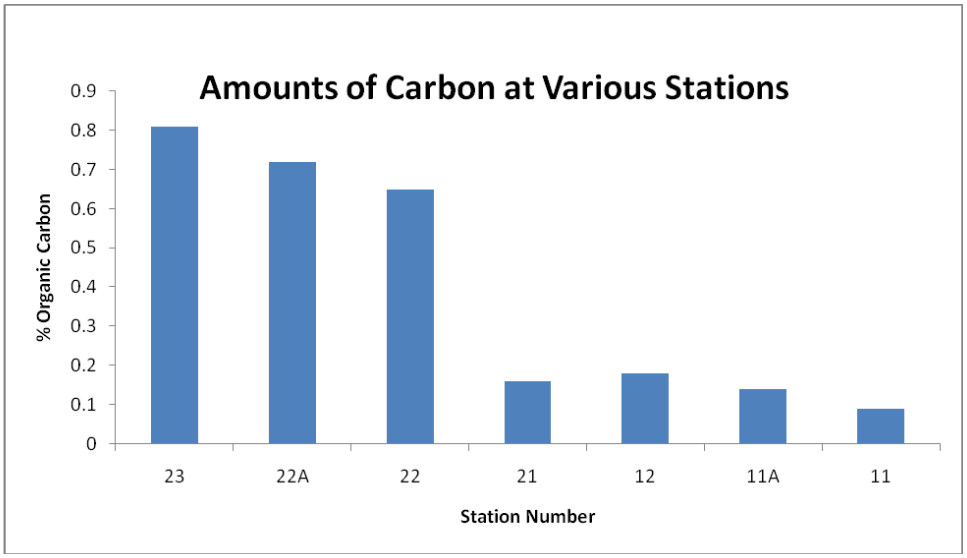

Figure 2: The distribution of TOC within Geikie Inlet and Tarr Inlet.

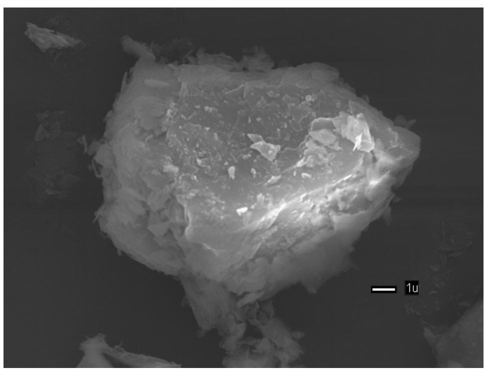

Figure 7: A 12µm particle with smaller particles adhering to the surface found at Station 23.

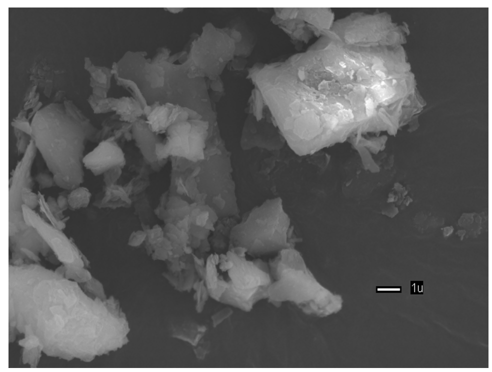

Figure 8: Silt-sized aggregates layered with clay-sized particles at Station 21 in Tarr Inlet.

sediment is primarily found in Tarr Inlet at Station 21, Station 11A, and Station 11, with Station 12 as an exception (Figure 5). However, there does not seem to be a correlation between TOC concentrations and the concentrations of sand (Figure 6).

SEM digital photographs show surface structures of clay-sized particles at Station 23 in Geikie Inlet (Figure 7) and Station 21 in Tarr Inlet (Figure 8). Samples from both stations appear to have sediment with sharper, jagged edges and flat surfaces adhering to one another. Samples from Station 23 have a larger abundance of aggregates.

Discussion

Higher concentrations of TOC are found in Geikie Inlet in comparison to Tarr Inlet. This trend may be due to the amounts of specific surface area, grain size distributions, flocculation, and phytoplankton distributions. TOC in Tarr Inlet in consistent with the results found by Cowen in 1993. However, Geikie Inlet proves to have at least 0.35% more TOC than any locations previously studied.

In comparison to sediments from the NE Arabian Sea (Keil and Cowie 1999), fine-grained sediment in Glacier Bay, AK shows the

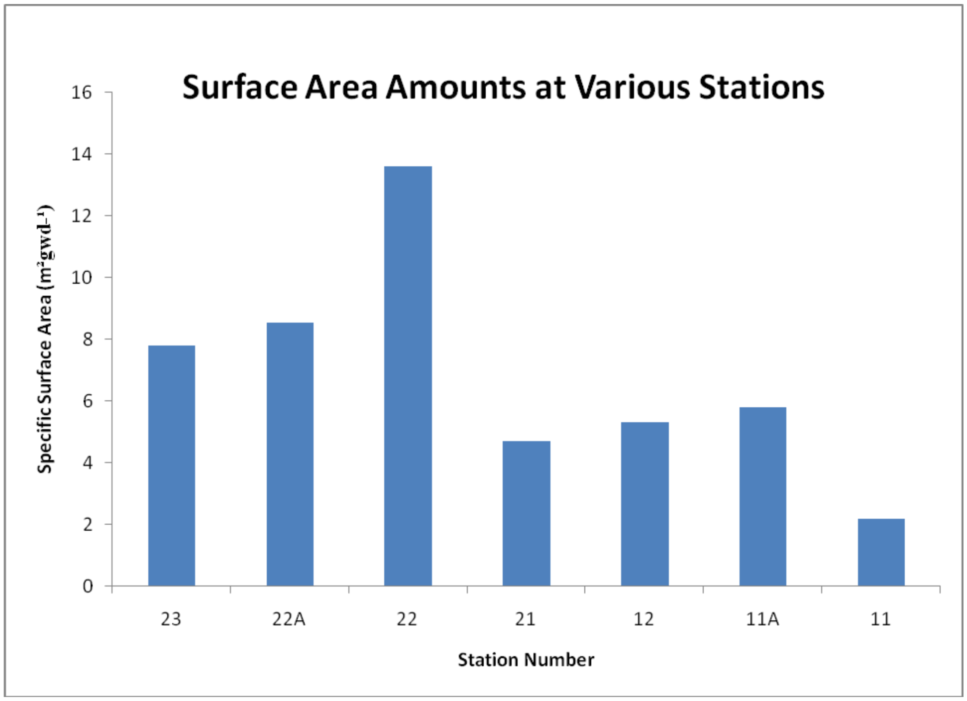

Figure 3: Surface area values of sediment within Geikie Inlet and Tarr Inlet.

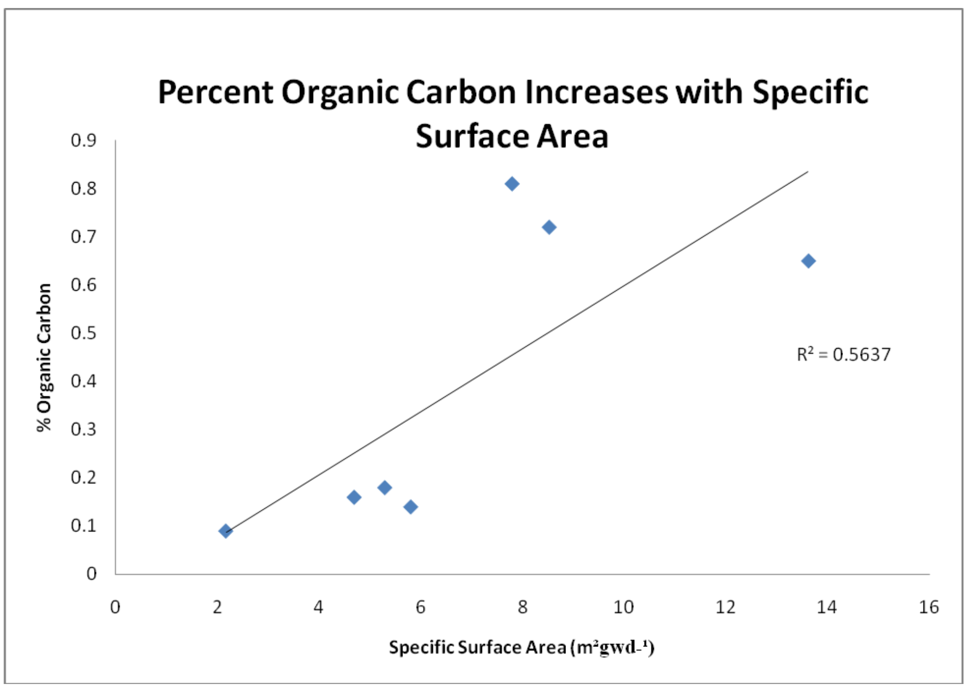

Figure 4: Correlations between amounts of TOC and specific surface area.

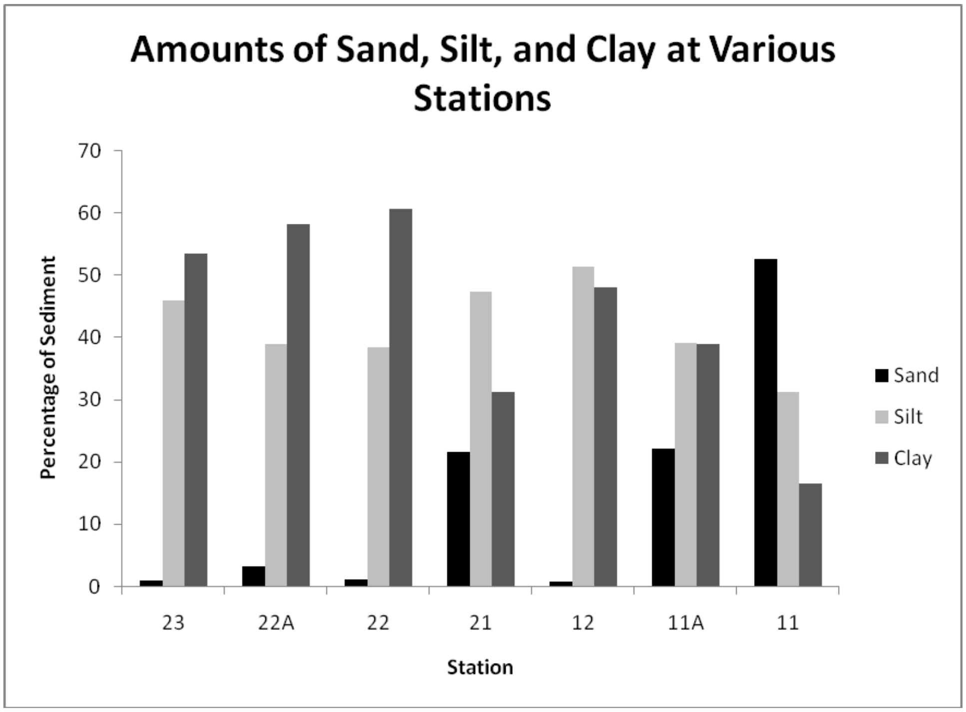

Figure 5: Sediment size distributions at Geikie Inlet and Tarr Inlet.

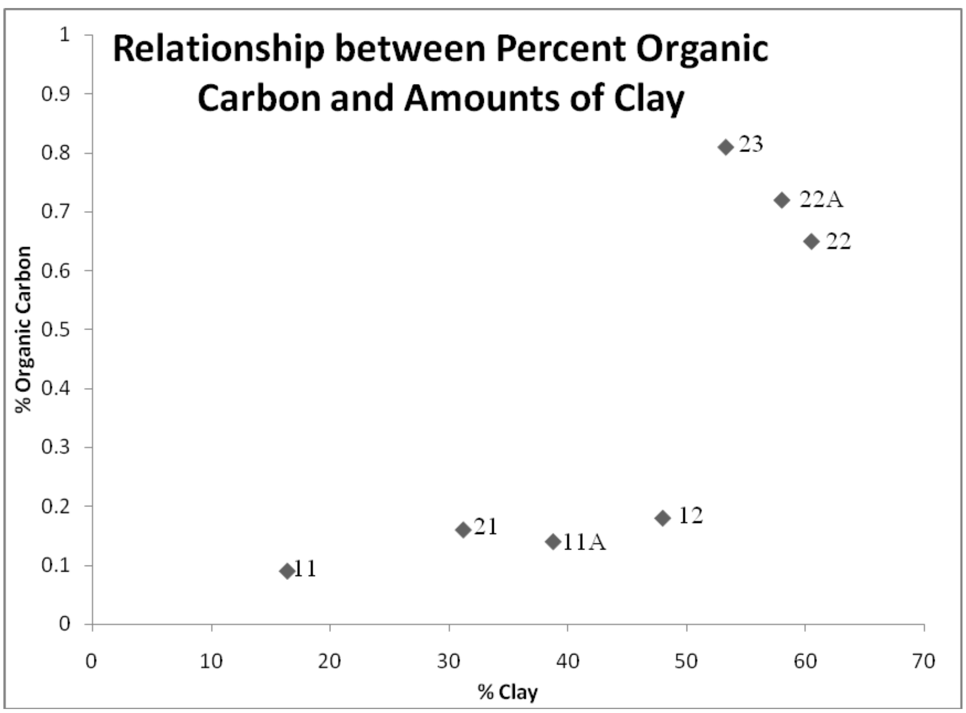

Figure 6: Inconclusive relationships between TOC and clay-sized particle concentrations at Geikie Inlet and Tarr Inlet.

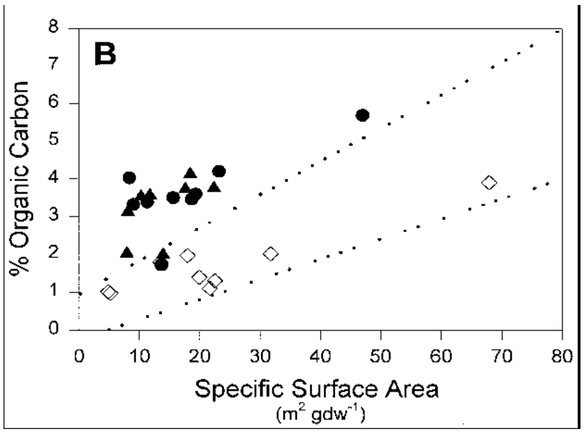

Figure 9: Organic Carbon in sediment in the Arabian Sea increases with specific surface area (Keil and Cowie 1999).

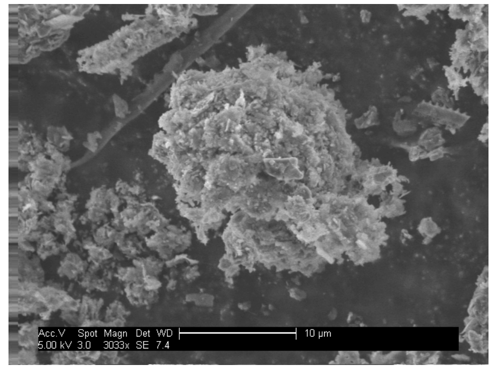

Figure 10: Silt-sized aggregate made up of clay particles (Arnarson and Keil 2007).

same pattern that increasing surface area correlates with increasing organic carbon (Figure 9). Higher amounts of surface area found in Geikie Inlet also prove to have higher amounts of POC than in Tarr Inlet. However, the highest surface area found at Station 22 does not correlate with the highest amount of POC. This could be due to a lack of organic carbon at this station. Therefore, it is true that there is a positive correlation between increasing surface area and increasing percent organic carbon, but there may be influences such as the lack of input of POC or high sedimentation rates which may affect these amounts.

Not only is the majority of sediment in Geikie inlet clay-sized, but high TOC values are found there, as was expected to be found with finer sediment. However, Grain-size distributions were considerably variable within Tarr Inlet. The trend within Tarr Inlet is the low amounts of TOC. It may be possible that Geikie Inlet is an example of the assumption that higher amounts of TOC are found with clay-sized particles (Mayer et al. 1985). Tarr Inlet may be an exception to this idea. However, it may be more likely that there is a lack of organic carbon sources in this location.

Aggregates within Glacier Bay appear to have a different morphology than typical aggregates that are consisting of clay. Typical clay aggregates appear to have more layers, higher surface area, and less jagged structures (Figure 10). The seafloor of Glacier Bay is dominated by glacial flour (Cai 1994). Therefore, it may be assumed that these clay-sized particles found in the bay are glacial flour. A higher abundance of these aggregates are found within Geikie Inlet which may account for the higher concentrations of POC. But in relation to actual clay aggregates found in that of the Arabian Sea (Keil and Cowie 1999), POC concentrations as well as amounts of surface area are considerably low. Therefore, these aggregates that appear to be made up of glacial flour may not have enough surface area for organic carbon to adhere to.

Sediment from Station 23 shows evidence of CaCO3 being directly deposited into the sediment (Figure 11). Glacier Bay has high levels of primary production, and therefore, high phytoplankton biomass (Etherington et al. 2007). Within Glacier Bay, chlorophyll-a concentrations are the highest within Geikie Inlet and extremely low within Tarr Inlet (Table 3). These significantly high levels of chlorophyll-a with Geikie Inlet are a likely cause for the high amounts of TOC found in this area. Furthermore, melt water discharge from alpine glaciers contain high amounts of organic carbon (Etherington et al. 2007). Conversely, Tarr Inlet's high sedimentation rates and low chlorophyll-a concentrations may be the reason for low TOC

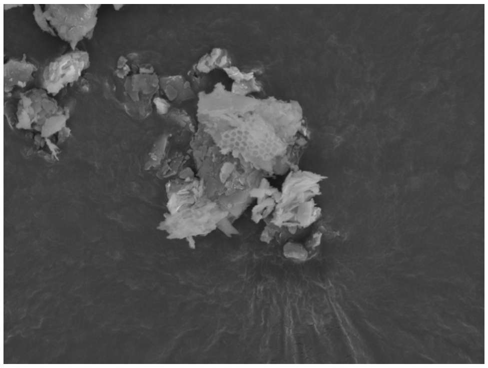

Figure 11: A dinoflagellate within sediment at Station 23 in Geikie Inlet.

concentrations.

Conclusion

- As surface area increases, organic carbon concentrations increase.
- Grain-size varied within Tarr Inlet, however TOC was consistent. Not only was clay-sized particles consistent within Geikie Inlet, but TOC concentrations were consistently high as well.
- Particles within Glacier bay are most likely glacial flour aggregates and have a different type of morphology than aggregates consisting of clay particles
- Amounts of TOC in each area most likely varied based on location. Sediment distributed by alpine glaciers appear to contain more TOC than sediment found near marine glaciers.

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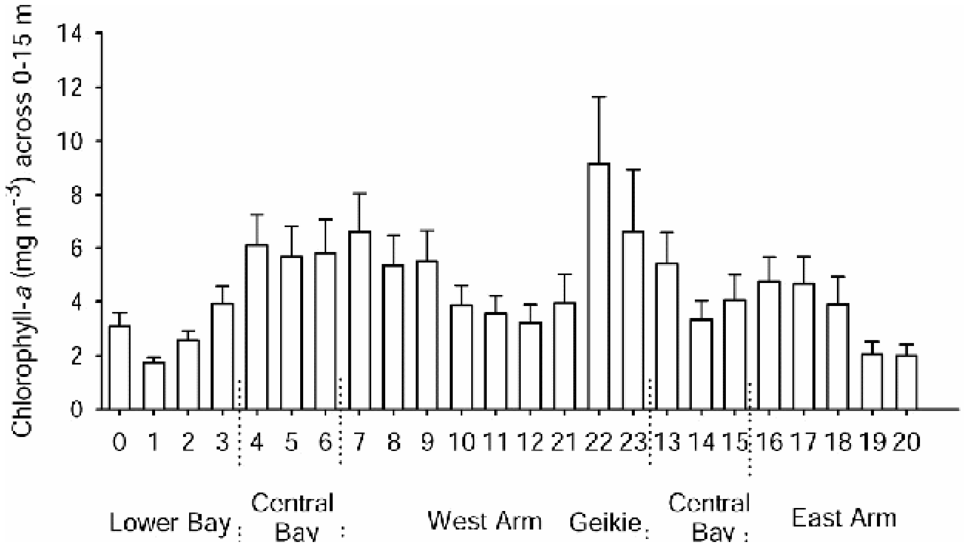

Figure 12: Chlorophyll-a distributions within Glacier Bay (Etherington et al. 2007).

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