High Frequency Climate Signals in Fjord Sediments of Glacier Bay National Park, Alaska

Ellen A. Cowan[1,3] and Ross D. Powell[2]

Abstract. More than 25 years of glacimarine research has provided the background to interpret the fjord sediment record in basins near tidewater glaciers in terms of paleoclimate. Key sedimentary products for interpreting this high frequency record are gravelly-mud beds and black layers that are deposited annually. During the meltwater season deep-water tidal rhythmites are organized in distinctive half-month packages by their thickness. Identification of these time-indicators within the record allows for establishment of a meltwater discharge proxy from tidewater glaciers. In turn, this proxy can be used to test the fluctuation of annual meltwater production with meteorological variables and the Pacific Decadal Oscillation (PDO).

Introduction

Research conducted for over 25 years on the glacimarine sedimentary environment in Glacier Bay National Park and Preserve sets the stage for interpretation of the paleoclimate record in fjord sediment deposits. This topic has recently come to the forefront in the geological community because of the initiation of studies to evaluate the dynamic interplay between climate and tectonics along the Alaskan margin (Gulick and others, 2004). Glacier Bay is of particular interest because of the well-documented history of glacial retreat from the Little Ice Age maximum position, and because of high sediment accumulation rates in basins adjacent to temperate tidewater glaciers (Hunter and others, 1996, Powell and Domack, 2002). This combination has the potential for producing a high-resolution record where days and weeks within the meltwater season can be identified. The purpose of this paper is to summarize our present understanding of the high-resolution record preserved in fjord sediments based on previous work in Glacier Bay and at Hubbard Glacier near Yakutat, Alaska.

Methods

Depositional processes from turbid plumes within baroclinic overflows from meltwater stream discharges within glacial fjords have previously been investigated with CTD casts, suspended sediment sampling, floc camera imaging at anchor stations, and with sediment traps (Cowan and Powell, 1991, Cowan, 1992, Hill and others, 1998). In addition, a tethered submersible has been used to visually investigate tidewater termini (Powell and Domack, 2002). These synoptic sampling techniques provide the link between climate forcing variables and spatial and temporal patterns of fjord sedimentation determined from sediment cores, grab samples and seismic-reflection profiles (Cai and others, 1997, Seramur and others, 1997). Water column and suspended sediment properties have been measured over time scales of 6 to 12 hours during both spring and neap tides because of variability greater than 7 m in the semi-diurnal tidal range in Glacier Bay. Seasonal variability also is of considerable importance because meltwater from tidewater glaciers contributes the bulk of sediment to the fjord (Hunter and others, 1996). We estimate from our seasonal sampling that the duration of the meltwater season is approximately 4 months, beginning abruptly in May and ending in late August with little or no discharge during winter (Cowan and others, 1999).

Several studies have been conducted by our research group in Glacier Bay using sediment cores up to 4 m-long to document the marine record of tidewater glaciers (Cai and others, 1997, Cowan and others, 1999). In these studies we developed a chronology using ^{210}Pb radioisotopes that compares favorably with bathymetric changes in ice-proximal areas. On September 7–8, 2004, we participated in a cruise onboard the *R/V Maurice Ewing* that collected data from Muir Inlet with the goal of developing a better understanding of Alaska's paleoclimate record. Two sediment cores, each about 17 m-long, were collected from basins in upper Muir Inlet (between Wachusett and McBride Inlets). The seasonal indicators and tidal rhythmites described below are important in interpreting the high-resolution climate record preserved in these cores.

Results

Recognizable sedimentary products are a result of forcing variables that reoccur at known time scales (table 1). Of particular interest for interpreting the paleoclimate record are gravelly-mud beds, (diamictons), black layers, and deep-water tidal rhythmites. Sediment transported by a large rainfall event has been documented at McBride Glacier but generally, this process likely occurs episodically (Cowan and others, 1988).

[1] Department of Geology, Appalachian State University, Boone, NC 28608

[2] Department of Geology and Environmental Geosciences, Northern Illinois University, DeKalb, IL 60115

[3] Corresponding author: cowanea@appstate.edu, 828-262-2260

Table 1. Forcing variables and time scales operating to record Paleoclimate in Glacier Bay Fjords.

Variable	Time Scale	Sedimentary Products
Seasons	Annual	Gravelly-mud and black layers
Tides and meltwater discharge	Fortnightly	Deep-water tidal rhythmites
Rainfall Events	Episodic	Rapid deposition of laminated sediment

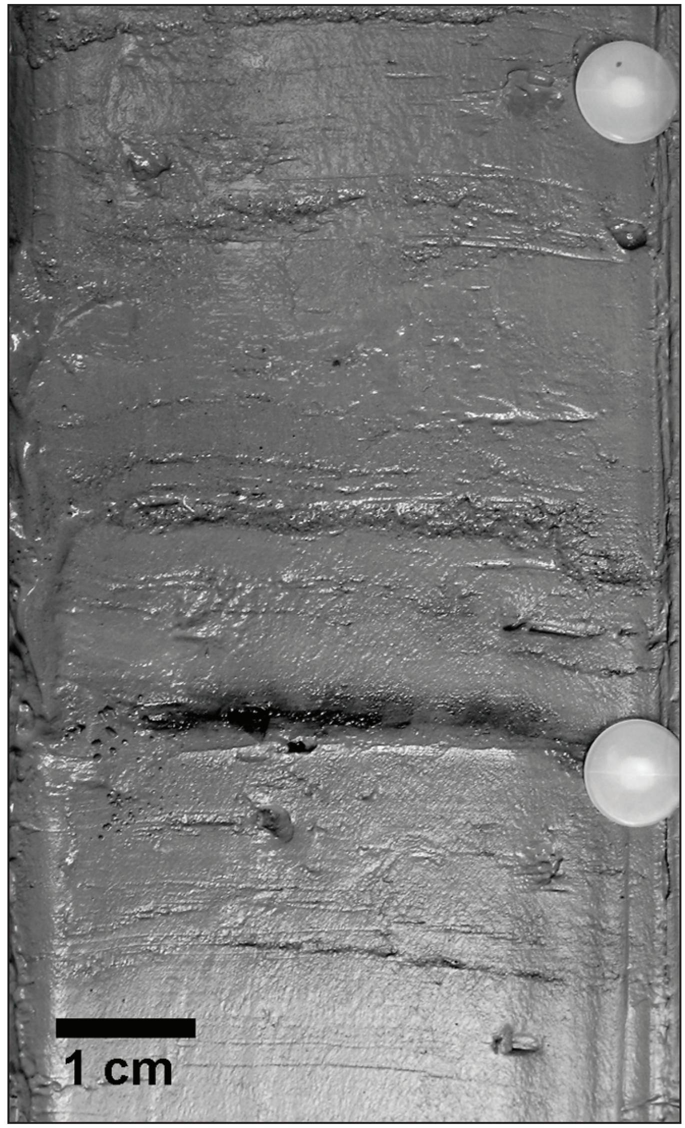

Figure 1. Photograph of EW0408-62JC showing interlaminated sediment with a black layer at 130 cm depth in core.

Gravelly-Mud Beds

Sedimentation throughout much of a glacial fjord distal from the glacier terminus is a result of mixing from two main source components, mud from streams and coarser particles from iceberg rafting (Powell, 1991). In summer, mud sedimentation is high due to active meltwater stream discharges and that mud dilutes any coarse material dropped by iceberg rafting. Locally, coarser debris may be deposited in higher concentrations either when icebergs are concentrated in a particular area due to bathymetric sills or by fjord circulation in gyres (e.g. Gottler and Powell, 1990). However, during winter and early spring when the glacier meltwater system is mostly inactive, icebergs and sea ice continue to raft sand and gravel into the fjord. This process produces a distinctive coarse-grained gravelly-mud or diamicton layer that may be several centimeters thick across the fjord (Cowan and others, 1997). Under winter conditions fine sediment from meltwater discharges is at a minimum and icebergs have a longer residence time within a fjord due to winter fjord circulation. This process may also occur in fjords without tidewater glaciers as winter sea ice becomes stranded on deltas and beaches during low tides freezing on sand and gravel that is later distributed when the ice floats off and circulates within the fjord (Cai and others, 1997, Cowan and others, 1999).

Black Layers

Distinctive black layers occur regularly in cores and grab samples from Glacier Bay fjords. They typically have an oily appearance and are several millimeters thick, becoming oxidized to reddish brown after being exposed to the atmosphere after the core is opened (fig. 1). Black layers may occur above gravelly mud beds suggesting that they form at the end of the winter before the meltwater season begins. A preliminary investigation using smear slides of the mud from a core collected on the *R/V Maurice Ewing* cruise shows centric diatoms occurring abundantly within black layers, whereas numbers appear to be low to absent in slides from other intervals in the core (fig. 2*A*, *B*). Although further detailed analyses are ongoing, our preliminary conclusions are that black layers seem to be a result of monosulphide minerals formed around diatom tests. This suggests that early diagenesis may result from the decay of organic matter producing H_2S that reacts with Fe^{3+} and forms new minerals. Due to the regular appearance of these layers in cores and x-radiographs, our initial working hypothesis is that they represent the accumulation of spring diatom blooms on the sea floor prior to the initiation of meltwater discharge.

Deep-Water Tidal Rhythmites

The sediment deposited most frequently in basins near glaciers consists of rhythmically laminated muds whose regular cyclicity in laminae thickness can be attributed to a lunar tidal cycle (Cowan and others, 1999). Individual couplets are formed of fine sand or silt with mud and are deposited by turbid plumes that originate from meltwater discharge. Couplets are organized into distinctive packages by their

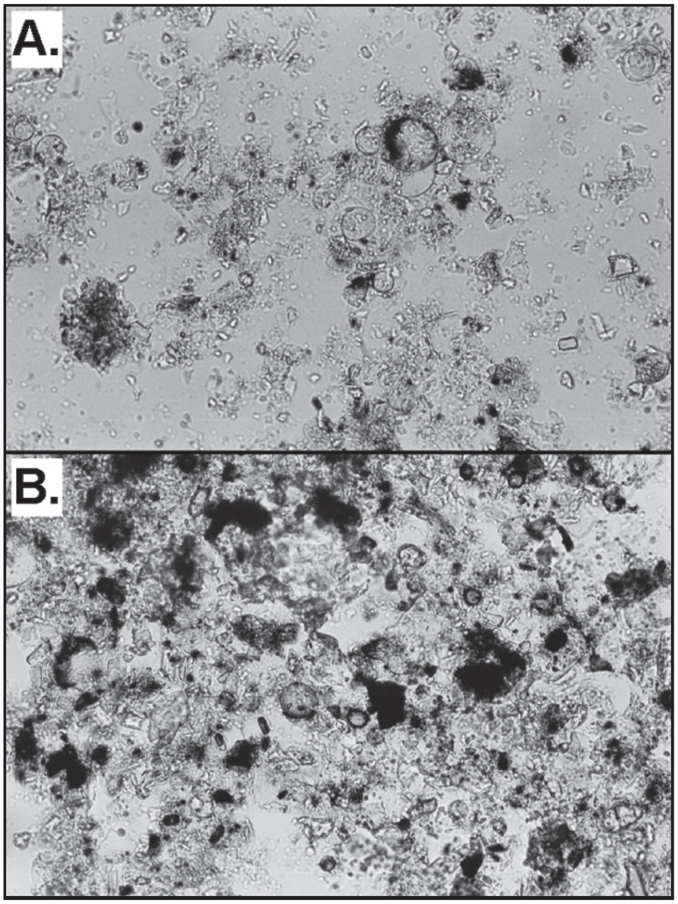

Figure 2. A. Smear slide of sediment from a black layer at 35 cm depth in core EW0408-62JC from Muir Inlet. Diatoms occur in abundance only in black layers. Horizontal field of view is 350 microns. B. Smear slide from 130 cm depth in core EW0408-62JC. Early diagenesis appears to form monosulphide minerals. Where decaying of organic matter produces H_2S that reacts with Fe^{3+}.

thickness representing one half-month, spring-neap tidal period. Each package is bound by thin couplets with a silt lamina and a very thin mud lamina. Over the duration of the fortnightly tidal cycle, couplets increase in thickness as each mud lamina thickens. These cycles recur as large and small packages downcore, which record alternating successive high- and low-amplitude spring tidal cycles (Cowan and others, 1999). Identification of this organization within the rhythmite record allows the comparison of sediment and meltwater discharge variations over successive two-week periods within a single meltwater season or between annual seasons.

Discussion

The analysis of long sediment cores from Glacier Bay fjords can yield a proxy record of recent glacial meltwater discharge. Gravelly-mud beds and black layers, deposited annually are key to interpreting this record. Deep-water tidal rhythmites, organized in distinctive one-half-month packages by thickness are a proxy for meltwater discharge from the tidewater terminus. This annually-resolved climate record then can be correlated with local meteorological data to test how meltwater production from tidewater glaciers varies in response to past high frequency climate changes such as the PDO.

Management Implications

Glacier Bay National Park contains a unique paleoclimate record for Southeast Alaska deposited since the end of the Little Ice Age. This record is especially valuable because of the detail with which glacial terminus positions have been mapped over time and because of the documentation of modern glacimarine processes. We recommend that Park management plans include provisions that permit scientists to access this irreplaceable sediment record for future generations.

Acknowledgments

The National Science Foundation provided funding for this work. We appreciate the contributions of many students and colleagues who participated in the field studies of tidewater glaciers.

References Cited

Cai, J., Powell, R.D., Cowan, E.A., Carlson, P.R., 1997, Lithofacies and seismic-reflection interpretation of temperate glacimarine sedimentation in Tarr Inlet, Glacier Bay, Alaska: Marine Geology, v. 143, p. 5-37.

Cowan, E.A., 1992, Meltwater and tidal currents: Controls on circulation of a small glacial fjord: Estuarine Coastal Shelf Science, v. 34, p. 381-392.

Cowan, E.A., Cai, J., Powell, R.D., Clark, J.D., and Pitcher, J.N., 1997, Temperate glacimarine varves: an example from Disenchantment Bay, Southern Alaska: Journal of Sedimentary Research, v. 67, p. 536-549.

Cowan, E.A., and Powell, R.D., 1991, Ice-proximal sediment accumulation rates in a temperate glacial fjord, southeastern Alaska, *in* Anderson, J.B., and Ashley, G.M., eds., Glacial marine sedimentation; paleoclimatic significance: Geological Society of America, Special Paper 261, p. 61-73.

Cowan, E.A., Powell, R.D., and Smith N.D., 1988, Rainstorm-induced event sedimentation at the tidewater front of a temperate glacier: Geology, v. 16, p. 409-412.

Cowan, E.A., Seramur, K.C., Cai, J., and Powell, R.D., 1999, Cyclic sedimentation produced by fluctuations in meltwater discharge, tides and marine productivity in an Alaskan fjord: Sedimentology, no. 46, p. 1109-1126.

Gottler, P.F., and Powell, R.D., 1990, Iceberg-rafted debris in McBride Inlet, Glacier Bay, Alaska, *in* Milner, A.M., and Wood, J.D., eds, Proceedings of the Second Glacier Bay Science Symposium, 1988: U.S. Department of the Interior, National Park Service, p. 56-61.

Gulick, S., Jaeger, J., Freymueller, J., Koons, P., Pavlis T., and Powell, R., 2004, Examining tectonic-climatic interactions in Alaska and the Northeastern Pacific: EOS, Transqactions of the American Geophysical Union, no. 85, v. 43, p. 433, 438.

Hill, P.S., Syvitski, J.P.M., Cowan, E.A., and Powell, R.D., 1998, In Situ observations of floc settling velocities in Glacier Bay, Alaska: Marine Geology, no. 145, p. 85-94.

Hunter, L.E., Powell, R.D., and Lawson, D.E., 1996, Flux of debris transported by ice at three Alaskan tidewater glaciers: Journal of Glaciology, no. 42, p. 123-135.

Powell, R.D., 1991, Grounding-line systems as second order controls on fluctuations of temperate tidewater termini, *in* Anderson, J.B., and Ashley, G.M., eds., Glacial Marine Sedimentation—Paleoclimatic Significance: Geological Society of America, Special Paper 261, p. 75-94.

Powell, R.D., and Domack, E.W., 2002, Modern glacimarine environments, chap. 12, *in* Menzies, J., ed., Modern and past glacial environments: Woburn, Mass., Butterworth-Heinemann, p. 361-389.

Seramur, K.C., Powell, R.D., and Carlson, P.R., 1997, Evaluation of conditions along the grounding line of temperate marine glaciers: an example from Muir Inlet, Glacier Bay, Alaska: Marine Geology, no. 140, p. 307-328.

Suggested Citation

Cowan, E.A., and Powell, R.D., 2007, High frequency climate signals in fjord sediments of Glacier Bay National Park, Alaska, *in* Piatt, J.F., and Gende, S.M., eds., Proceedings of the Fourth Glacier Bay Science Symposium, October 26–28, 2004: U.S. Geological Survey Scientific Investigations Report 2007-5047, p. 46-49.

Close up view of Lamplugh Glacier, one of few remaining tidewater glaciers in the park. (Photograph by Mayumi Arimitsu, U.S. Geological Survey.)