Effect of glacial retreat on sub-surface sediment accumulation in Glacier Bay, Alaska: evidence from 3.5 kHz records

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Abstract

Single-beam echosounder profiles of sub-surface sediment in Glacier Bay, Alaska, show a diverse range of lithofacies and sedimentary structures in the various environments within the Bay. Sediment cores compared with lithofacies interpretations show distinct sedimentation patterns at various depths within the cores. Trends in grain size and accumulation rates also show that there is a sediment gradient from the sampling area closest to the Grand Pacific Glacier terminus to the distant areas down the West Arm. Images from 3.5 kHz profiles illustrate more hummocky, discontinuous sediment as the distance from the Grand Pacific Glacier terminus decreases, and more laminated, continuous sediment as the same distance increases.

Introduction

Glaciers have a profound impact on the sedimentation processes that occur within the areas they overlay. Fjords such as Glacier Bay, Alaska have some of the fastest retreating glaciers on the planet and therefore have some of the most diverse sediment, ranging from boulders to the finest silts and clays (Hall and Benson 1995; Hallet et al. 1996). Overall, studying sub-surface sediments in systems like Glacier Bay can illustrate how sedimentary structures are connected to rates of deposition and accumulation and grain size.

To examine sub-seafloor sediment distribution in Glacier Bay with relation to deposition and glacial retreat, a 3.5 kHz study was conducted from March 18 to 22 2008 aboard the *R/V Thomas G. Thompson*. The survey focused primarily on the West Arm, Tarr Inlet and Geikie Inlet although surveys of opportunity were also conducted throughout the bay (Fig. 1). During this, different sedimentary environments were studied from profiles based on sediment layering, thickness and continuity of layers, and on documentation of features such as glacial moraines. Results from prior studies show that sedimentary facies vary with distance from the termini's of glaciers within Glacier Bay, and with numerous depositional environments (Cai et al. 1997). In 1997, Cai et al. interpreted and characterized five types of seismic facies and seven types of lithofacies within Tarr Inlet. The seismic facies range from unstratified to continuously stratified sediment, while the lithofacies range from weakly stratified diamicton to homogenous mud (Cai et al. 1997). Each of the different facies reflects a specific or multiple depositional environments. These environments consist of ice-proximal zones (area between the grounding line of the present termini to ~2.5 kilometers from the Grand Pacific Glacier), iceberg-zones (area highly influenced by iceberg rafting), and ice-distal zones (area furthest away from the glacier toe) that are determined by their distance from the glacier terminus (Fig. 2).

The objectives of this study are: 1) to determine the effects of glacier movement on subsurface sediment, 2) to compare sediment profiles in Tarr Inlet to interpretations and glacial environments previously established by Cai et al. (1997) and 3) to determine any noticeable patterns between sub-surface sediment profiles and their locations throughout Glacier Bay.

Methods

To determine how sediment accumulation is affected by glacial retreat, sub-surface sediment profiles were recorded both digitally and on hardcopy, using a hull-mounted Knudsen Engineering 320B Blackbox Echosounder on the *R/V Thompson* in Glacier Bay, Alaska. Profiles were recorded between March 18 and March 22 2008 at an average speed of 12knots using a frequency of 3.5 kHz. Survey lines of interest included the area between historical Stations 6 and 21 (Hooge and Hooge 2002). Specifically, the survey lines follow the general trend of the retreating Grand Pacific Glacier from the base of the West Arm to Tarr Inlet (Seramur et al. 1997; Fig. 1; Fig. 3).

The majority of the data collected by the 3.5 kHz were recorded using a 0.1875 second ping and a processing gain of 1. Because the water depth rarely reached > 400 meters, the echo sounder remained on a low frequency setting. These settings allowed for maximum clarity of the profiles with very little interference from overlapping reflectance. Event marks were made in five minute intervals along the profiles to record the latitude and longitude of the ship at a given time.

Subsequent to collection of the profiles, the data were analyzed digitally using Post Survey software produced by Knudsen Engineering (http://www.knudsenengineering.com/html/software/postsurvey.htm).

Concurrent to the 3.5 kHz survey, instantaneous sediment accumulation rates were determined by Christina Biladeau using suspended sediment traps and grain size analysis was performed by Aubrey Theiss using a sedograph. In addition, Kasten cores were collected by Justin Berquist. Results from these studies were incorporated into this study by providing information on sedimentary layers and lithology present in the 3.5 kHz profiles.

Results

The character of seafloor sediments as imaged by 3.5 kHz profiles throughout Glacier Bay range from extremely mounded to highly continuous sub-surface sediment.

In Tarr Inlet, from north of Station 11 to Station 21, mounds ranging from 40 to 80m in height are persistent along the track (Fig. 4a). However, in the short distance between Stations 12 and 21, the surface sediment is smooth, with no evidence of mounded formations (Fig. 4b).

From Stations 10 to 11, the sediment is mostly continuously stratified with the exception of two mounds that have been partially overlain by recently deposited sediment (Fig. 5).

Between Stations 8 and 10, the surface sediment is relatively smooth with the exception of the hummocky formations near Station 8 and the steeper formation near Station 10. The thickness of recorded sediment remains reasonably constant throughout the track at ~35m (Fig. 6).

From Stations 6 to 8, massive sediment formations (>100m high) with many internal hummocks are evident near Station 6, and as the track approaches Station 8 they become reduced in size (<60m) (Fig. 7). Sediment at Station 8 is extremely stratified with distinct layers ranging from 1-2m in thickness.

Several kilometers away from Tarr Inlet, Stations 22 to 23 in Geikie Inlet illustrate more internal hummocks than anywhere in the West Arm or in Tarr Inlet. It is also clear that the mounds on the seafloor surface have also been

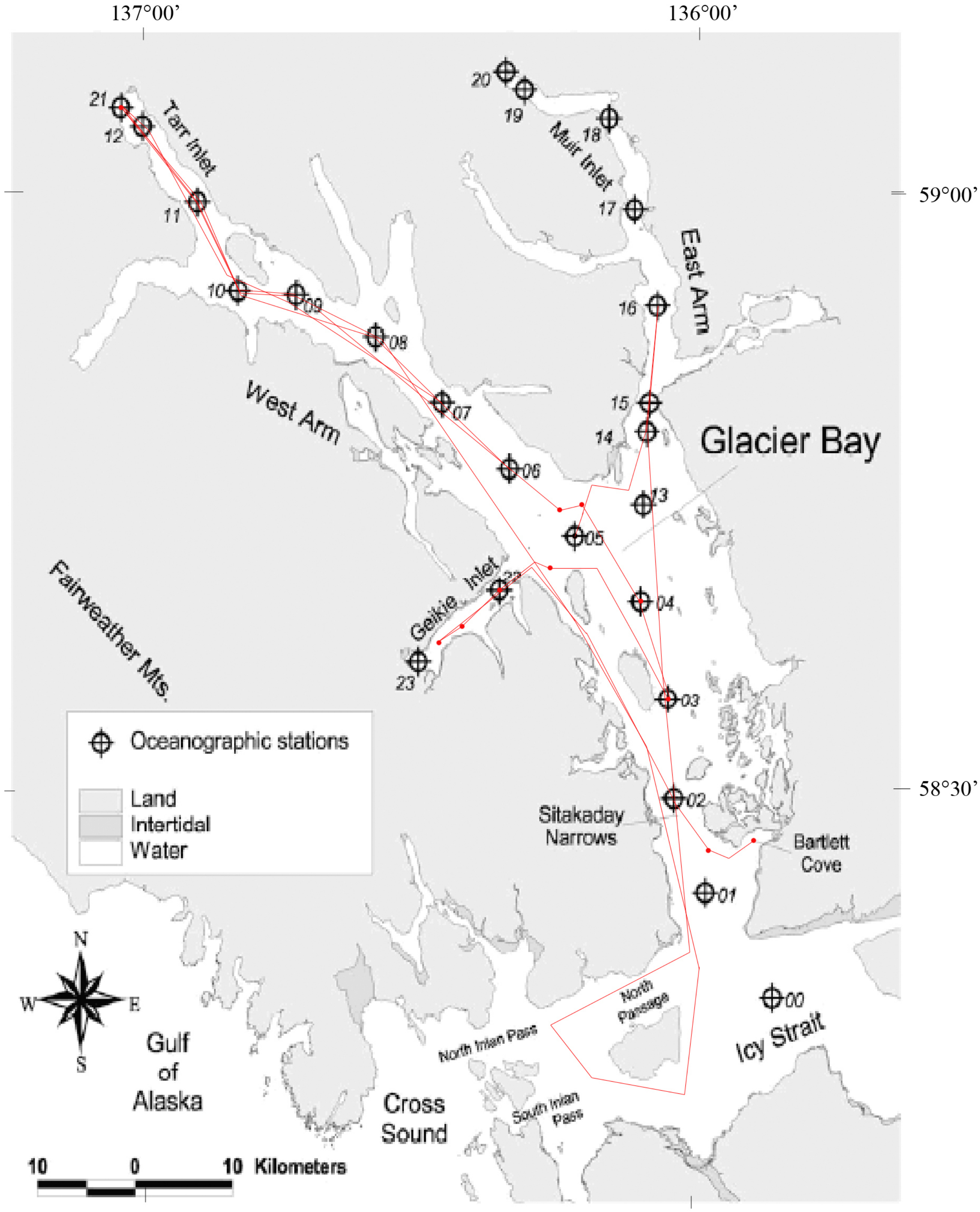

Fig. 1. Map of Glacier Bay, Alaska indicating the ship's 2 runs up the Bay to Tarr Inlet and then to the East Arm. Points indicate places where the latitude and longitude were taken from the 3.5 kHz data. Boxed area includes the base of the West Arm to the end of Tarr Inlet.

partially covered with highly stratified sediment (Fig. 8).

Discussion

Tarr Inlet

Profiles collected by he 3.5 kHz sonar within Tarr Inlet were compared to the lithofacies and depositional environment types previously determined by Cai et al. (1997). Station 21 is located within the ice-proximal environment, which is the zone closest to the Grand Pacific Glacier terminus (Fig. 2; Fig. 9). Work by Cai et al. shows that the ice proximal environment of Station 21 is characterized by mixed medium- to fine-sand and laminated mud throughout the 2 meters of sediment recovered in their sediment core. The 58 cm Kasten core recovered from Station 21 in this study can be compared to core number 94GC10 in the Cai study, which is characterized by alternating layers of sand and mud (Fig. 10). The mixture of varying sediment sizes is likely caused by both suspended particles and by meltwater from the glacier itself. It is important to note that these interpretations were made in 1997, such that a significant amount of new sediment has been deposited in the follow-on 11 years. The instantaneous sediment accumulation rate from Station 21 is ˜18,226 grams per square meter per year ($g/m^2/yr$) so after 11 years, ˜200,486 g/m^2 of sediment would have accumulated on the seafloor on top of where the samples from Cai et al. were collected (C. M. Biladeau unpubl.). This is evidence for there being a more rapid rate of deposition and accumulation near the edge of the Grand Pacific Glacier as compared to Station 8 located at the north end of the West Arm.

Between Stations 21 and 11 is Station 12. This station is located within the iceberg zone (Fig. 2). Iceberg zones are comprised of sediment deposited from iceberg rafting (Cai et al. 1997). In the 3.5 kHz profile between Stations 21 and 11, large hilly structures are present with hummocky internal structures that could be evidence of boulders or a moraine formed when the glacial terminus was at this location (Fig. 10 a).

West Arm

As shown in the 3.5 kHz profiles, Stations 6 thru 10 contain a variety of sedimentary structure. Station 6 has several mounds that do not appear to be accumulating enough sediment to form distinct layers. In contrast, Station 10 is differentiated by stratified sediment ˜40m in thickness. This type of laminated sediment found at Station 10 is likely to be deposited by suspended fine particles sinking out of the water column (Cai et al. 1997). The ^{210}Pb sediment accumulation rate at Station 10 is ˜2.4 centimeters per year (cm/yr) at Station 10, and evidence from the 2m long Kasten core retrieved from this station shows an abundance of fine silt and clay (J. Bergquist unpubl.; Fig. 11). Station 11 also shows stratification, but the number of layers is greater and their thickness is less than at Station 10.

Geikie Inlet

Profiles collected from Stations 22 to 23 in Geikie Inlet are different from any other profiles collected throughout the bay. Internal structures are clearly visible and are most likely evidence of large boulders and glacial moraines formed and deposited when the Geikie Glacier extended into the inlet. Also, newer sediment that has been deposited on top of these structures is clearly stratified. Intact sedimentary layering in Geikie Inlet is likely the cause of the Geikie Glacier being ˜4 miles away from the head of the inlet and there being an absence of major sediment deposit. The ^{210}Pb sediment accumulation rate at Station 23 is ˜1.0 cm/yr, which is significantly lower that the accumulation rate at Station 10 in the West Arm (J. Bergquist unpubl.). The slower accumulation rate is to be expected in Geikie Inlet due to the glacier being a distance away on land. In contrast to Tarr Inlet where deposition is dependent upon glacial melt, deposition in Geikie Inlet is highly dependent on river runoff and suspended particles. Grain sizes in Geikie Inlet are the finest of all the sediment recovered in Glacier Bay (A. G. Theiss unpubl.).

Conclusions

- As the Grand Pacific Glacier retreats up Tarr Inlet, large amounts of poorly-sorted sediment are deposited near the terminus and as the distance from the terminus increases, deposition and accumulation rates decrease, and surface and sub-surface sediment become less mounded and more stratified.
- Sedimentary formations in the West Arm vary with location and no pattern can be distinguished other than the presence of what appear to be glacial moraines.
- Geikie Inlet sediment accumulation is not greatly influenced by glacial deposits but instead, is dependent upon the settling of fine-grained suspended sediment.
- Sediment that was stratified in 3.5 kHz profiles is more fine-grained and well-sorted than mounded sediment.

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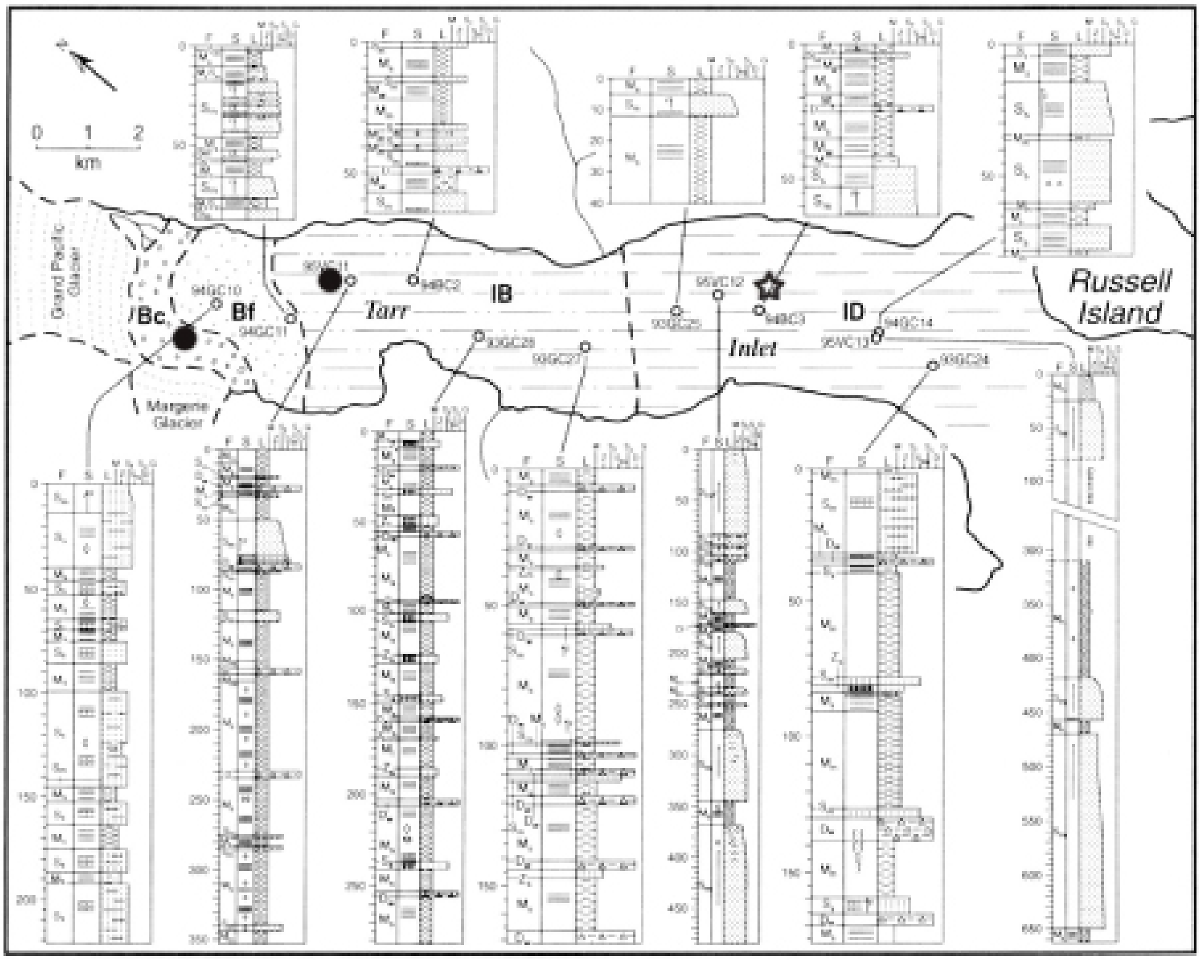

Fig. 2. Lithofacies distribution and types of sedimentary environments in Tarr Inlet. Both environment types and sediment types vary with distance from the glacier toe. Points in Tarr Inlet are waypoints where sediment was sampled in Cai et al. study. Each coring site is characterized by interpretations of the type of sediment present. Filled in points are locations of Kasten cores taken during this study and the star is Station 11 (no Kasten core from this station). Interpretations from Cai et al. are in a centimeter scale and show what kind of sediment is found at a particular depth within the core.

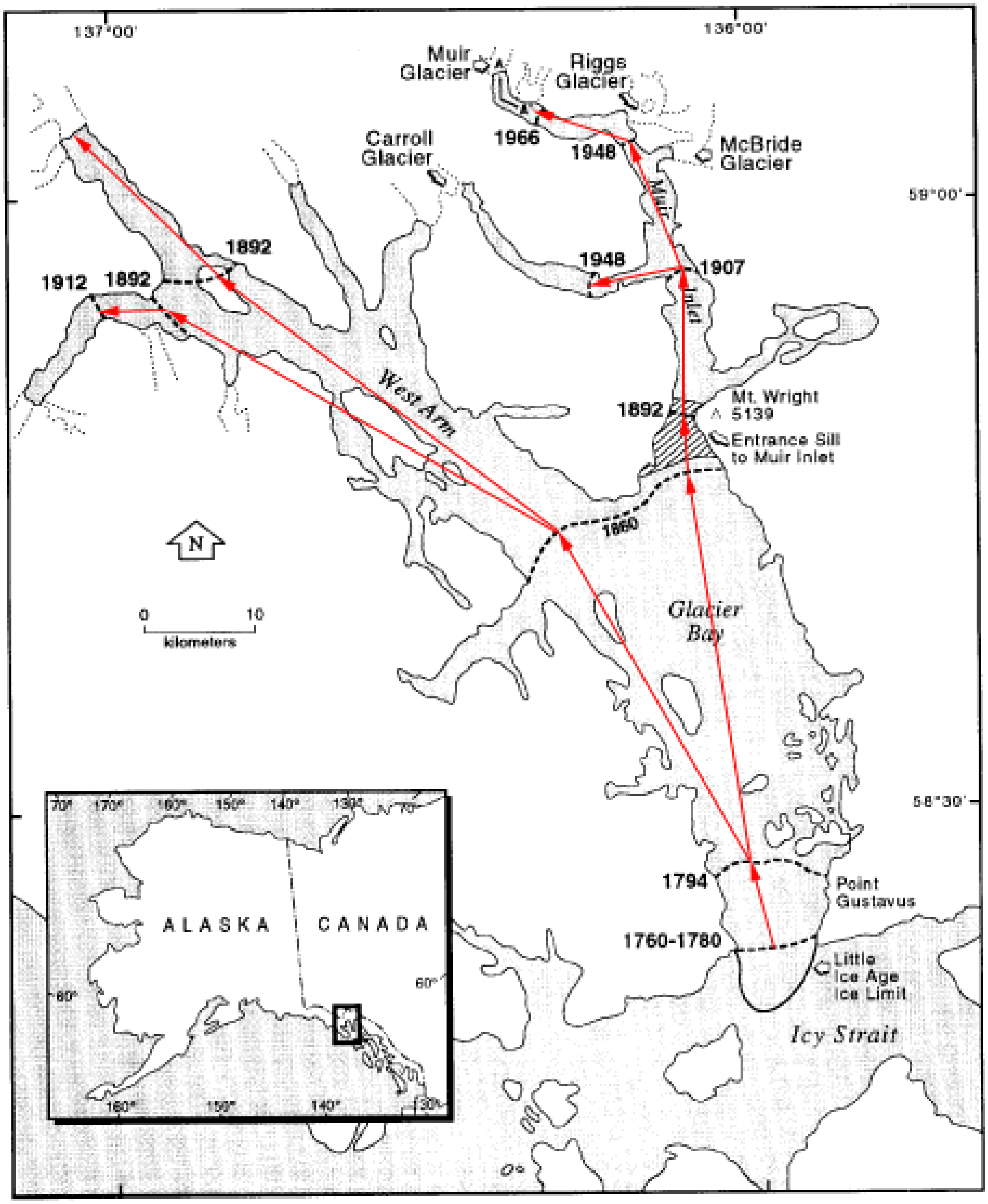

Fig. 3. Map of Glacier Bay, Alaska showing the glacial termini and direction of retreat (Powell 1981).

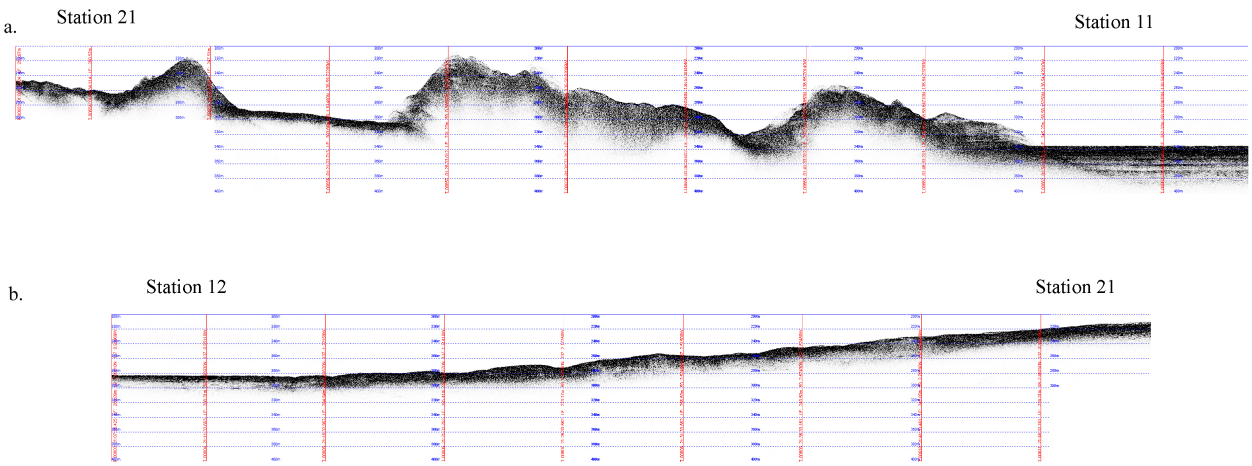

Fig. 4. a. 3.5 kHz profile from Station 21 to Station 11 illustrating several mounds along the surface sediment. b. 3.5 kHz profile from Station 12 to Station 21 showing the absence of surface mounds.

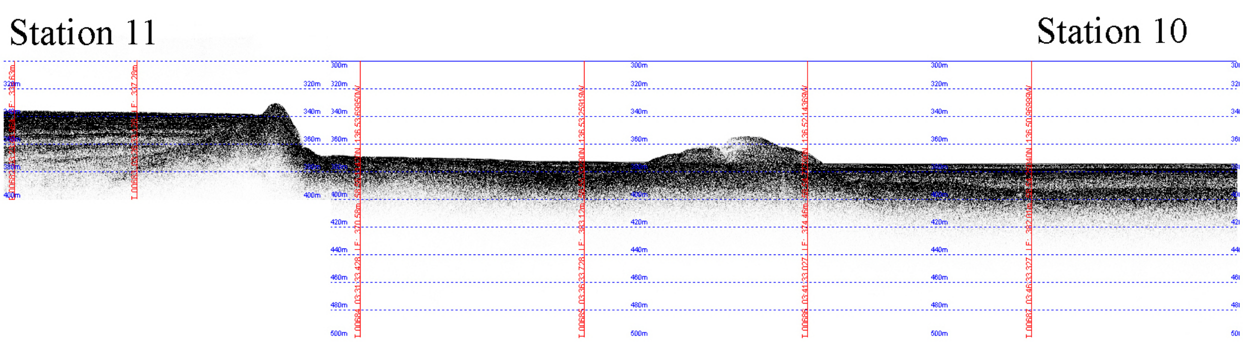

Fig. 5. 3.5 kHz profile collected between Stations 11 and 10 illustrating the low abundance of surface mounds. The two mounds that are present are partially covered with newer, stratified sediment.

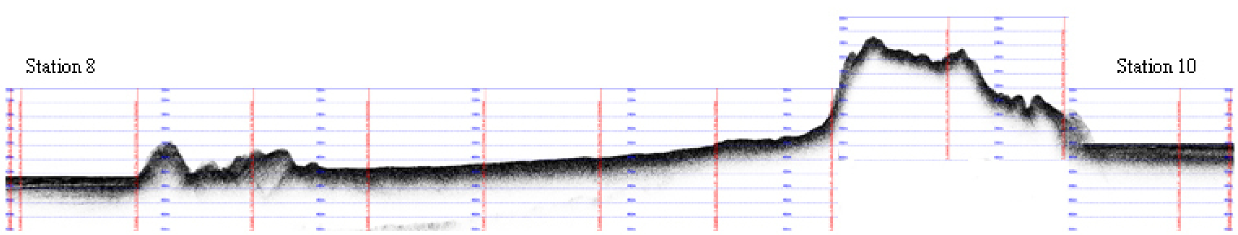

Fig. 6. 3.5 kHz profile from between Stations 8 and 10 showing the low abundance of surface mounds and a constant sediment reflection thickness of ~35m.

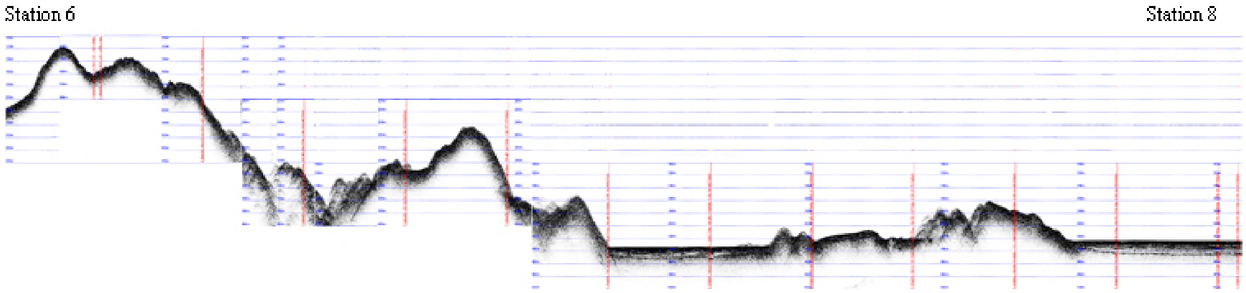

Fig. 7. 3.5 kHz profile from Station 6 to Station 8 showing the variety of sedimentary formations. Internal hummocks are found near Station 6 while stratification is found at Station 8

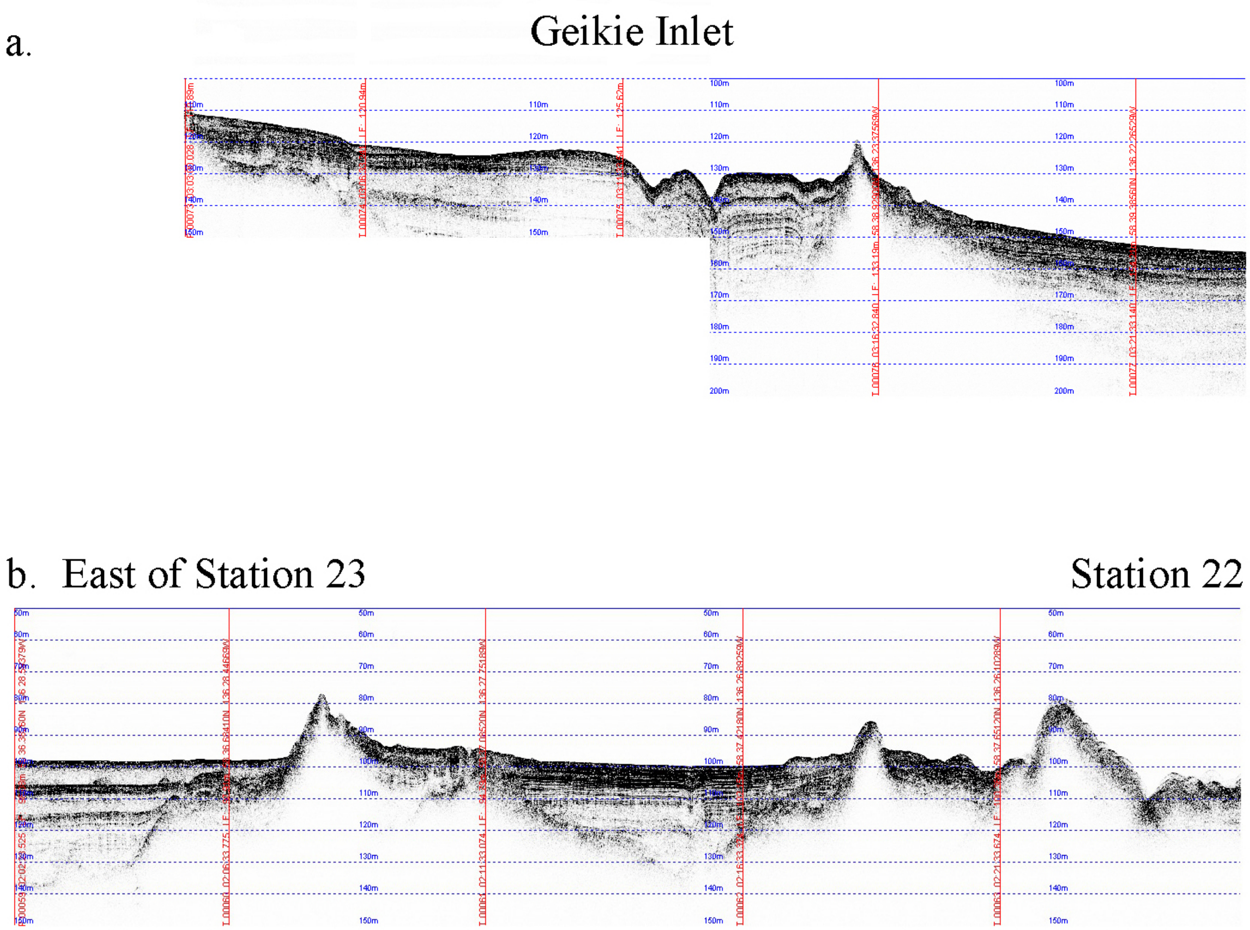

Fig. 8. a. & b. 3.5 kHz profiles from Geikie Inlet show many internal reflections and several thin layers (<2m) of stratified sediment.

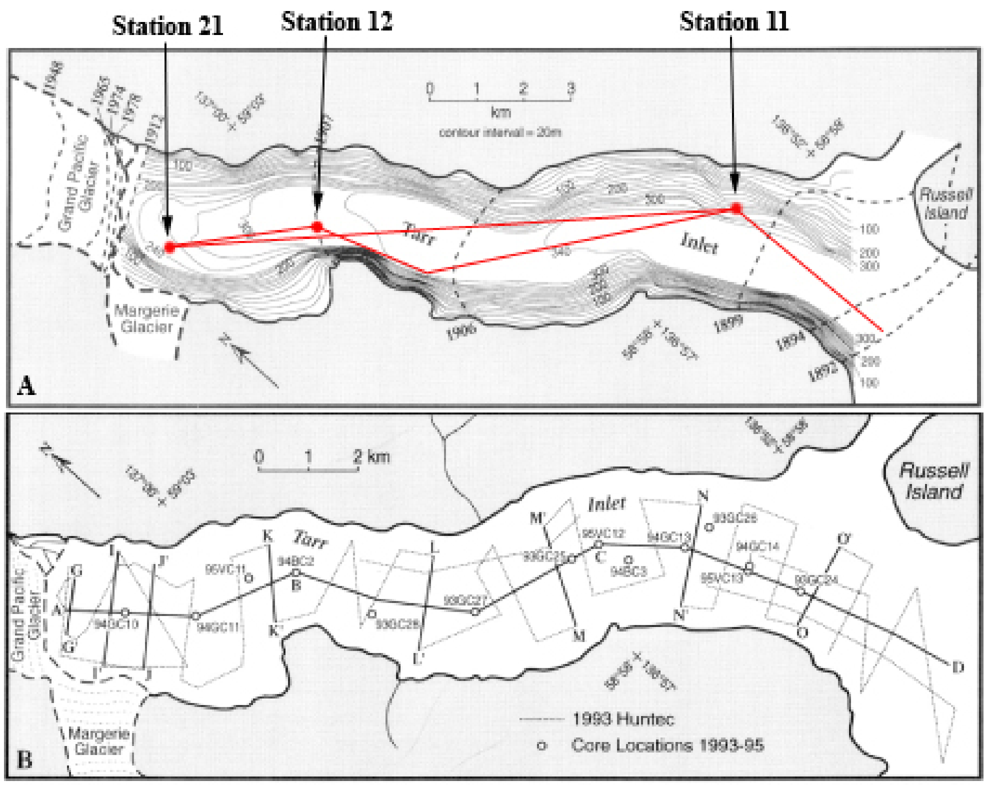

Fig. 9. a. Glacial terminus in Tarr Inlet and bathymetry in meters (Cai et al. 1997). Lines indicate *R/V Thompson* tracklines and points indicate coring sites; b. Lines indicate where Huntec seismic profiles were taken during Cai et al. study. Unfilled Circles are where cores were taken during the same study. (Cai et al. 1997).

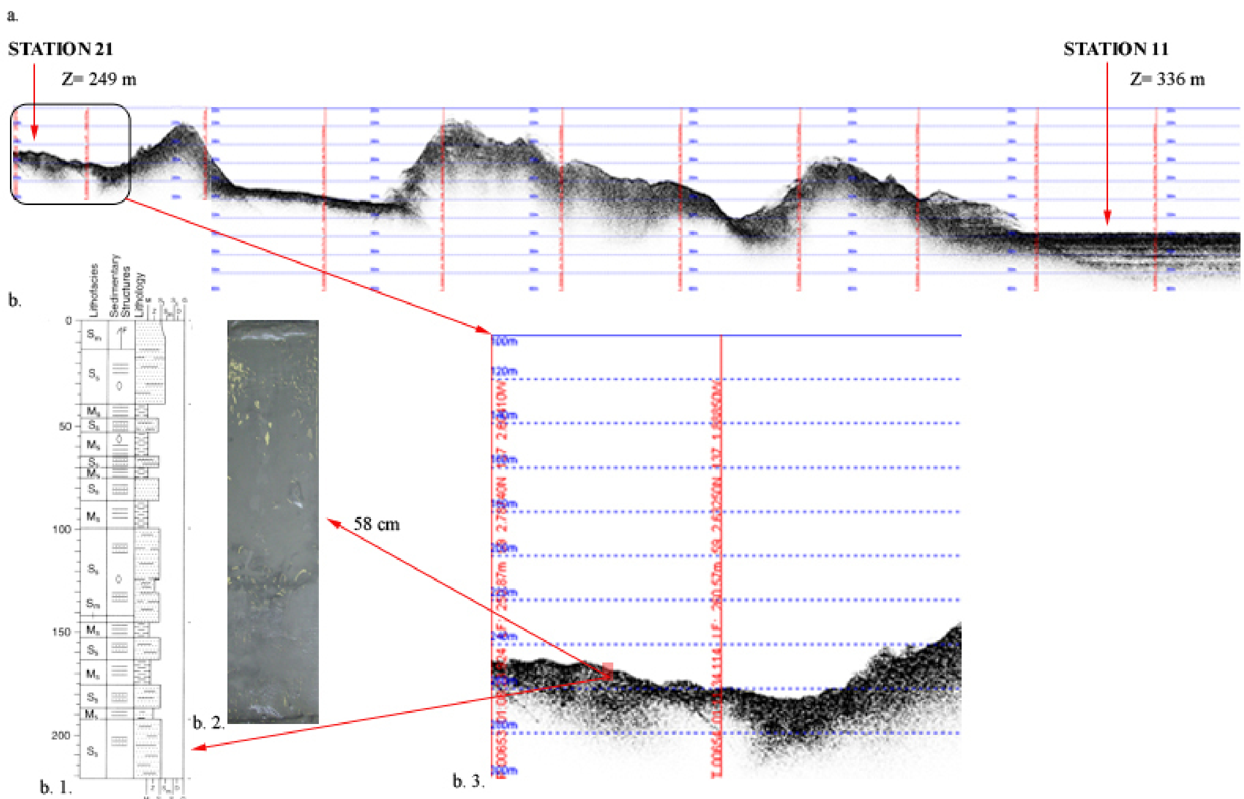

Fig. 10. a. 3.5 kHz profile between Stations 21 and 11; b. 1. Interpretation of lithofacies as determined by Cai et al. (1997). S correlates to sand, M correlates to mud. Subscript s correlates to fine-grained, subscript m correlates to medium-grained; 2. Kasten core sampled from Station 21 at a length of 60 cm; 3. Magnification of 3.5 kHz profile taken from Station 21.

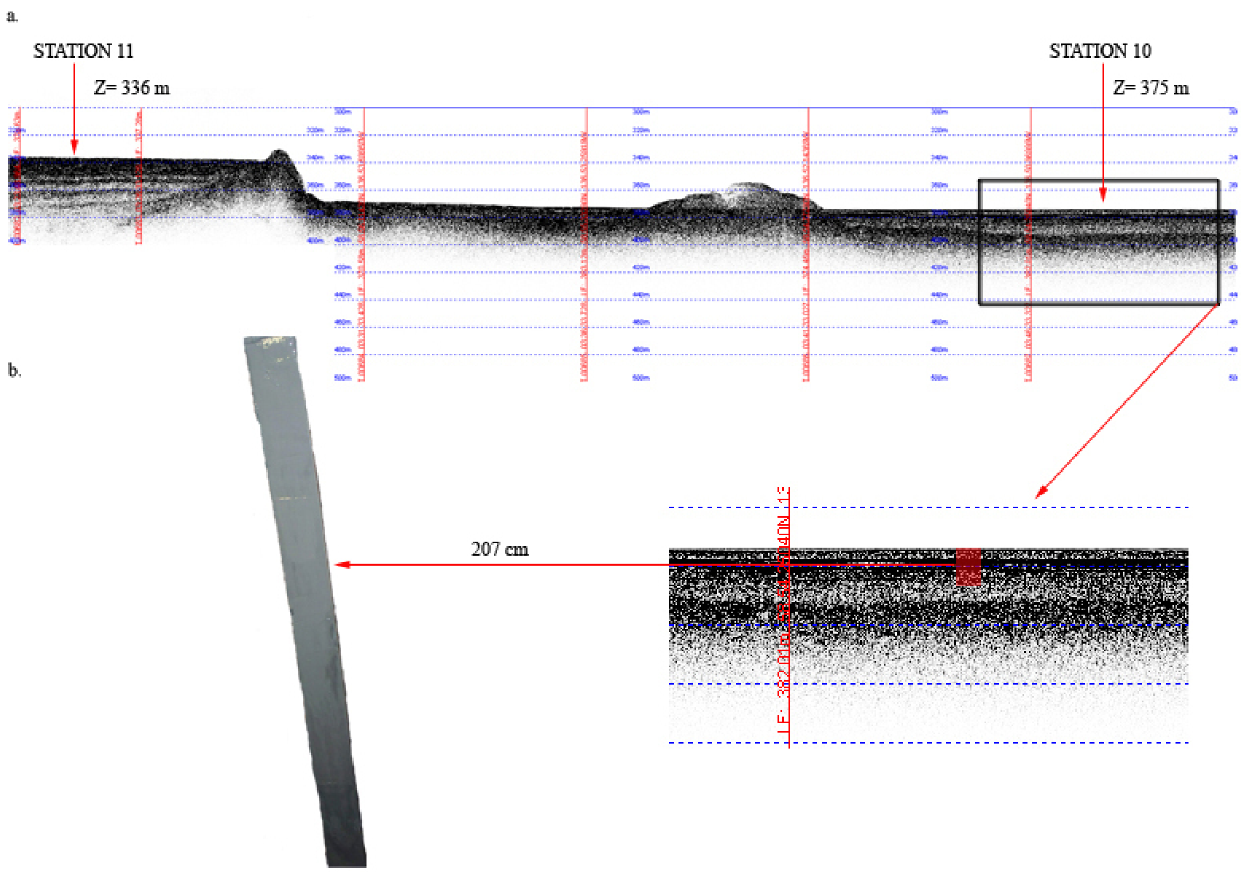

Fig. 11. a. 3.5 kHz profile between Stations 11 and 10; b. Kasten core sampled from Station 10 at a length of 207 cm. Profile from Station 10 is magnified.