Seafloor Habitat Mapping and Classification in Glacier Bay, Alaska Phase I&2 1996-2004

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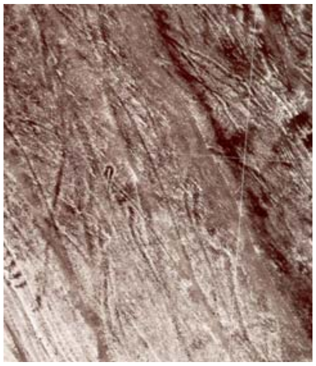

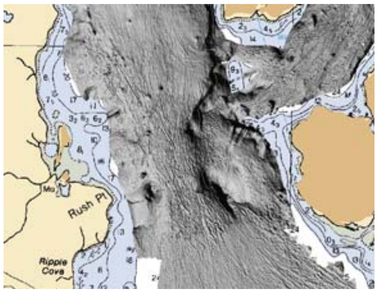

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MAPPING AND CLASSIFICATION OF SEAFLOOR HABITATS IN GLACIER BAY, ALASKA

INTRODUCTION AND JUSTIFICATION

Glacier Bay is a diverse fjord ecosystem with multiple sills, numerous tidewater glaciers and a highly complex oceanographic system. The Bay was completely glaciated prior to the 1700's and subsequently experienced the fastest glacial retreat recorded in historical times. Currently, some of the highest sedimentation rates ever observed occur in the Bay, along with rapid uplift (up to 2.5 cm/year) due to a combination of plate tectonics and isostatic rebound. Glacier Bay is the second deepest fjord in Alaska, with depths over 500 meters. This variety of physical processes and bathymetry creates many diverse habitats within a relatively small area (1,255 km^2).

Habitat can be defined as the locality, including resources and environmental conditions, occupied by a species or population of organisms (Morrison et al 1992). Mapping and characterization of benthic habitat is crucial to an understanding of marine species and can serve a variety of purposes including: understanding species distributions and improving stock assessments, designing special management areas and marine protected areas, monitoring and protecting important habitats, and assessing habitat change due to natural or human impacts. In 1996, Congress recognized the importance of understanding benthic habitat for fisheries management by reauthorizing the Magnuson-Stevens Fishery Conservation and Management Act and amending it with the Sustainable Fisheries Act (SFA). This amendment emphasizes the importance of habitat protection to healthy fisheries and requires identification of essential fish habitat in management decisions. Recently, the National Park Service's Ocean Stewardship Strategy identified the creation of benthic habitat maps and sediment maps as crucial components to complete basic ocean park resource inventories (Davis 2003).

Glacier Bay National Park managers currently have very limited knowledge about the bathymetry, sediment types, and various marine habitats of ecological importance in the Park. Ocean floor bathymetry and sediment type are the building blocks of marine communities. Bottom type and shape affects the kinds of benthic communities that develop in a particular environment as well as the oceanographic conditions that communities are subject to. Accurate mapping of the ocean floor is essential for park manager's understanding of existing marine communities and will be important in assessing human induced changes (e.g., vessel traffic and commercial fishing), biological change (e.g., rapid sea otter recolonization), and geological processes of change (e.g., deglaciation). Information on animal-habitat relationships, particularly within a marine reserve framework, will be valuable to agencies making decisions about critical habitats, marine reserve design, as well as fishery management. Identification and mapping of benthic habitat provides National Park Service mangers with tools to increase the effectiveness of resource management.

The primary objective of this project is to investigate the geological characteristics of the biological habitats of halibut, Dungeness crab, king crab, and Tanner crab within Glacier Bay National Park. Additionally, habitat classification of shallow water regions of Glacier Bay will provide crucial information on the relationship between benthic habitat features and the abundance of benthic prey items for a variety of marine predators, including sea ducks, the rapidly increasing population of sea otters, and other marine mammals.

MAPPING TECHNIQUES AND CONSIDERATIONS

REMOTE SENSING

Habitat mapping requires characterizing the physical and biotic factors that define where a species lives and is useful in predicting species distribution and abundance. In the marine environment, many subtidal resources can be sampled directly; however, applying these techniques on a large scale is often not feasible. Therefore, a major goal of marine habitat mapping is to develop the ability to describe bottom habitat using remote sampling techniques.

Multibeam echosounders and sidescan sonar provide rapid means of imaging the morphology and nature of the sediments on the seafloor. Both techniques use acoustic energy (sound) transmitted across the bottom; the sound is reflected back from hard and soft substrate with different energy strengths and an image is created from these energy differences; the relative position of the benthic features is derived from the time delay of the sound pulses.

Side-scan Sonar and Bottom Profiling

Sidescan sonar, which was developed in the 1970’s, is a technique where pulses are sent in a wide angular pattern down to the bottom to create high resolution images. The sonar pulses are most commonly sent from and received to a towed "fish" and are usually on frequencies between 100 and 500 KHz, with the higher frequency resulting in better resolution but less range. The high frequency of side-scan sonar results in excellent resolution (0.1 - 0.5 m) over a transect swath of 200-400 m.

Sub-bottom profiling is another benthic mapping tool. This technique uses sound to provide high-resolution definition of the seabed sediments down to about 50 m beneath the seafloor. These devices offer the potential to map sediment thickness and to examine the interactions between the benthic fauna and sediments.

Mulitbeam Echosounding

Multibeam echsounding is a relatively new benthic mapping technology. Like sidescan sonar, it sends out sound pulses and uses time delay and echo strength data (reflectance) to create images of the bottom. The mutlibeam ecosounder is usually mounted to the hull of a vessel and uses multiple acoustic beams, each with narrow width. An advantage of a multibeam system over sidescan sonar is that it generates quantitative bathymetric data. Digital processing is then used to generate shaded-relief topographic maps from the quantitative bathymetric data. In order for a multibeam system to accurately calculate positions from the multiple sound beams, precise measurements of the pitch, rolls, and heading of the ship are required. In addition, sound velocity profiling of the water needs to be conducted in order to determine the differences in travel times between the beams.

GROUND-TRUTHING

Any remote sensing benthic mapping technique requires direct, *in situ* observations determine the meaning and accuracy of the imagery (Oliver and Kvitek 1984, Able et al. 1987, Gabbianelli et al. 1997, Siljestrom et al. 1995, Wright et al. 1987). This ground-truthing is especially important when determining the relevance of reflectivity data and sub-bottom profiles to biota (Siljestrom et al. 1995, Able et al. 1987). For example, the presence of a relatively thin sediment layer over bedrock, while possibly indicated only by subtle changes in reflectivity, can greatly change the biological significance of the bottom type. Ground-truthing can be accomplished using a variety of techniques: direct observations by divers, drop cameras, towed cameras, and grab samples.

PROJECT OUTLINE AND PROGRESS

Due to the nature of the data collection methods that build upon each other, this project of mapping and classification of Glacier Bay's benthic habitats is broken into several phases. We have outlined the four expected phases of this project in Glacier Bay. This report represents the methods, results, and products for phase 1 and part of phase 2 as outlined below.

PHASE 1: Multibeam echosounding and sidescan sonar imaging of lower Bay.

Status:

1. Sidescan sonar conducted (1996-1998) at 5 sites:
    - i. Bartlett Cove, including areas extending past the terminal moraine
    - ii. Whidbey Passage and Drake reef area
    - iii. South Beardslee Islands (Bug Bay)
    - iv. North Beardslee Islands (Hutchins Bay)
    - v. Secret Bay
2. Multibeam sampling conducted in 2001. Covered an area extending from the entrance of Glacier Bay at Icy Strait, to the upper end of the main bay, at Tlingit Pt. Multibeam sampling was not conducted in the lower half of Muir Inlet due to time and financial constraints.

Products completed (included within this report):

Imagery and maps of the seafloor bathymetry and substrate

Carlson, P.R., P.N. Hooge, T.R. Bruns, K.R. Evans, J.T. Gann, D.J. Hogg, and S.J. Taggart. 1998. 1996 Cruise Report: Physical Characteristics of Dungeness Crab and Halibut Habitats in Glacier Bay, Alaska, U.S. Geological Survey Open-File Report 98-134

Cochrane, G.R., P.R. Carlson, J.F. Denny, M.E. Boyle, S.J. Taggart, and P.N.Hooge. 1998. Cruise Report M/V Quillback Cruise Q-1-97-Gb, Physical Characteristics Of Dungeness Crab And Halibut Habitats In Glacier Bay, Alaska, U.S. Geological Survey Open-File Report 98-791. http://geopubs.wr.usgs.gov/open-file/of98-791/ofr98-791.html

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Carlson, P.R., P. Hooge, G.R. Cochrane, A. Stevenson, P. Dartnell, and J.C. Stone, 2003. Multibeam bathymetry and selected perspective views of Glacier Bay, Alaska, U.S. Geological Survey Water-Resources Investigations Report 03-4141. http://geopubs.wr.usgs.gov/open-file/of02-391/

Carlson, P.R., P. Hooge, G.R. Cochrane, A. Stevenson, P. Dartnell, and K. Lee. 2003. Multibeam bathymetry and selected perspective views of main part of Glacier Bay, Alaska, U.S. Geological Survey Open-file Report 02-391. http://geopubs.wr.usgs.gov/open-file/of02-391/

. Carlson, P.R., P.N. Hooge, and G. Cochrane. In Press. Discovery of 100-160 Yr Old Iceberg Gouges and Their Relation to Halibut Habitat in Glacier Bay, Alaska. Proceedings of American Fisheries Society Symposium on Effects of Fishing on Benthic Habitats. Tampa, Florida, 12-14 November 2002.

PHASE 2: Ground-truthing of the lower Bay using direct diver observations, bottom video, and benthic grab sampling.

Status:

1. Direct diver observations conducted 1999-2001 in shallow water side-scanned areas
2. Bottom video and grab sampling completed in 2004 throughout the deep side-scanned areas and multibeam areas

Expected Products:

1. Geologic data layers to be used in the interpretation and analysis stage (phase 3)

PHASE 3: Development of habitat polygons and linkages to biological data

Status:

1. Geologic interpretation - 2004
2. Biological and geological linkages and analysis - 2005
3. Publications for lower Bay - 2005-2006

Expected Products:

1. An online habitat characterization map similar to those produced for other areas (e.g., Channel Islands National Marine Sanctuary; http://geopubs.wr.usgs.gov/open-file/of03-85/).
2. Possible collaborative journal articles about impact of geologic processes in Glacier Bay on the fisheries and habitat in general.
3. Collaborative journal articles about the distribution and movement of marine organisms and benthic habitat

PHASE 4: Upper Glacier Bay habitat mapping and classification

1. Multibeam echosounding and sidescan sonar imaging of upper Bay
2. Imagery and maps of the seafloor bathymetry and substrate for upper Bay
3. Ground-truthing of the upper Bay using bottom video and benthic grab sampling
4. Development of habitat polygons and linkages to biological data

METHODS

We characterized the benthic habitat using a combination of the side-scan sonar data, sub-bottom profiling data, multibeam bathymetric data, multibeam reflectance data, direct diver observations, underwater videography and physical sediment sampling.

STUDY SITES

The study focused on the lower and central regions of Glacier Bay that represent mud sand, gravel, cobble, boulder, and bedrock habitats at different depths (<80m for sidescan, < 400 m for multibeam), different slopes, and widely-varying current regimes.

Side-scan sampling and acoustic profiling occurred in five sites that represent both the full range of benthic habitats in the lower Bay as well as in the shallow (<80 m) mid-Bay habitats. The areas mapped using side-scan sonar methods are (Figure1.1, Table 1.1):

1. Bartlett Cove, including areas extending past the terminal moraine
2. Whidbey Passage and Drake reef area
3. South Beardslee Islands (Bug Bay)
4. North Beardslee Islands (Hutchins Bay)
5. Secret Bay

The multi-beam echosounding survey was conducted in an area extending from the entrance of Glacier Bay at Icy Strait, to the upper end of the main bay, at Tlingit Pt. and half way up Muir Inlet an area of approximately 500 sq. km.

The areas that were mapped using multi-beam echosounding techniques are (Figure 1.1, Table 1.1):

1. Mouth of Glacier Bay to Tlingit Point

REMOTE SENSING

Sidescan Sonar and Sub-Bottom Profiling

Sidescan sonar and sub-bottom profiling data were collected during three surveys: in August, 1996 using the M/V *Quillback*, and in October, 1997 and August, 1998 on the R/V *Alaskan Gyre.* A Klein 2000 sidescan system (Fig. 1) was used for geophysical surveying. The unit features 8 channels of processed data: 7 subsurface from the towfish (5 sonar and 2 instrumentation) and 1 surface (external analog input). Two sonar channels each were devoted to 100 KHz and 500 KHz sidescan data and a fifth sonar channel was used for 4KHz sub-bottom profiling.

A Leica Differential Global Positioning System (DGPS) was utilized for navigation and provided a position with accuracy of 1-5 m in DGPS mode. At times during the surveys differential signal was interrupted; the receiver provided a position with 30-50 m accuracy in non-differential mode. A KVH Industries Inc. azimuth digital gyro-compass provided ship headings with 0.5 degree accuracy. Navigation data were recorded using Yo-Nav version 1.19 (Gann 1992).

A Triton Elics Isis (Fig. 1) side-scan data recording system was used to simultaneously record 5 channels of data: port and starboard 100 KHz side-scan data; port and starboard 500 KHz side-scan data; and the sub-bottom profiling data. Typically, 2048 samples were recorded per channel over a swath width of 200-400 m yielding a resolution of 0.1 - 0.5 m of seafloor area for the side-scan data. The resolution of the profiler data is 1-3 m of sub-bottom depth (with penetration of tens of meters in soft sediment and a few meters in harder sediment).

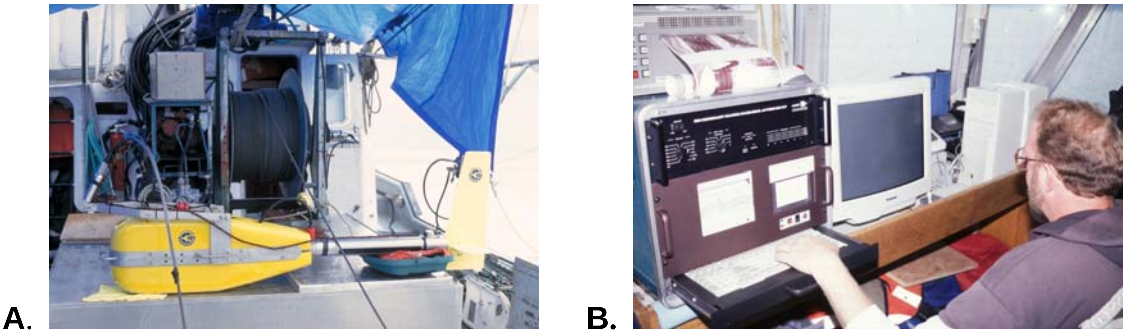

Fig. 1. A. Klein sidescan sonar and sub-bottom profiler in a towfish. B. Triton Elics Isis side-scan data recording system

Multibeam Bathymetry

Multibeam data were collected between May 29 and June 5, 2001. The R/V *Davidson*, a 167 ft. vessel, provided the platform for the multibeam bathymetric survey. Data were collected by a hull mounted Reson 8111 multibeam sonar mounted in a 24" pipe tapered cowling. The Reson 8111 operated at 100 khz with a depth controlled ping rate and 150^o across-track beam width (101 horizontal beams centered 1.5^o apart) and 1.5^o along-track beam width. Signal was controlled through a Reson 81-P Sonar Processor.

The position system was composed of two MBX-3 differential Global Positioning Systems (GPS), three NovAtel GPS antennas and multibeam computers with NovAtel GPS cards. The antennas were mounted on the deck above the Reson 8111. The central antenna was used for vessel position. The second and third antennas, offset 0.6 m either side the central positioning antenna, functioned as TSS Heading and Dynamic Motion Sensor (HDMS) master and secondary antennas. The HDMS was maintained as a backup but not utilized due to recurring heading loss caused by the steep mountain terrain. Positioning system confidence checks were conducted on a daily basis.

A Reson DMS-02-05 dynamic motion system with TSS SG Brown gyro measured survey vessel heading and attitude. Manufacturer's accuracies for the system were:

Pitch and Roll:	0.03^o
Heave:	5 cm or 5%, whichever is greater

The patch test calibration values used to reduce all soundings on the survey were as follows:

Navigation Timing Error: 0.0

Pitch Offset: 0.8

Azimuth Offset: 1.8

Roll Offset: 1.6

During data collection, weather was mild, with winds generally less than 15 knots, barometer steady, and seas less than 1 m. No time was lost to weather, although one survey area was re-arranged due to local winds 35 knots, gusting to 50 knots. Water currents provided operational challenges around Sitakaday Narrows, requiring the survey to be completed during the low flood current period on May 30.

Speed averaged 7.55 knots. Swath width varied with depth within each sheet. All lines were run at spacing no more than three times water depth. The line orientation for each survey was generally parallel to the contours in the area. The line spacing depended on the water depth and data quality, but never exceeded 3.0 times the water depth. Survey line spacing did not include in-fill line spacing, as line spacing was determined on a feature by feature basis.

The primary data set, positions, attitudes, and soundings, were collected with Racal Pelagos' Winfrog Multibeam (WFMB) integrated navigation software (version 3.23). WFMB operated on a Pentium based PC running Windows NT and used a Novatel GPS card for positioning. The WFMB software package used the 1 PPS output from the Novatel card to continually synchronize the PC clock with GPS time. During timing tests prior to the survey, WFMB was shown to have approximately a 4-millisecond RMS error between the ping and attitude time stamps.

All soundings were processed using Universal Systems CARIS Hydrographic Information Processing System (HIPS) and Hydrographic Data Cleaning System (HDCS) on Unix workstations (Sun Solaris V7) and an NT workstation.

A statistical analysis of the sounding data was conducted via the CARIS Quality Control Report (QCR) routine. Tie lines were run in each Sheet and were compared with lines acquired from the mainline scheme where applicable. Sounding data that passed the required quality assurance checks were imported into a CARIS HIPS workfile for the mean surface layer. The data was then suppressed using a constant term of 4 in HIPS using the Sounding Suppression Option and exported (sounding size 1.8mm). Final mean surface soundings were saved and plotted in Microstation SE.

Color or sun illuminated Digital Terrain Models (DTM's) (Fig. 2) were created in HIPS to aid in coverage and to help detect any errors in SVP, HPR, Tides, etc. DTM's were created at a 5 m grid size to assure data quality and full coverage. The DTM's were exported to a TIFF format and imported into AutoCAD for final review of coverage and systematic errors.

A Sea-Bird Model 19-03 Conductivity, Temperature and Depth (CTD) profiler, deployed from an A-Frame on the stern using a hydraulic line hauler, was used for determining sound velocity for the survey. Sound velocity casts were done at the beginning of each survey sheet and initially at 6 hr intervals. Later, due to isothermal and isohaline conditions of the majority of the water column, sound velocity casts were reduced to 6-10 hour intervals, depending on location. The SBE 19-03 delivers 2 samples-per-second. For each cast, probes were held at the surface for three minutes for temperature equilibrium. The CTD was then lowered and raised slowly (about 0.2 m/s) to maintain equilibrium. Between casts, the CTD was stored in a barrel of fresh water to minimize salt-water corrosion and to help hold the sensors at ambient water temperatures. Sound velocity profile data were acquired using SeaTerm v1.2 and were processed in Mathematica V 3.0.1.1x (SVP 06).

Backscatter data were collected by the Reson 8111 Multibeam system to enable classification of geologic features and sediment depth. Backscatter and wavelet data were collected to the width of the multi-beam swaths. A Triton Elics Isis data recording systems was utilized for processing backscatter images into bottom mosaics. Lines were reduced to nadir and overlaid for best presentation of geologic features.

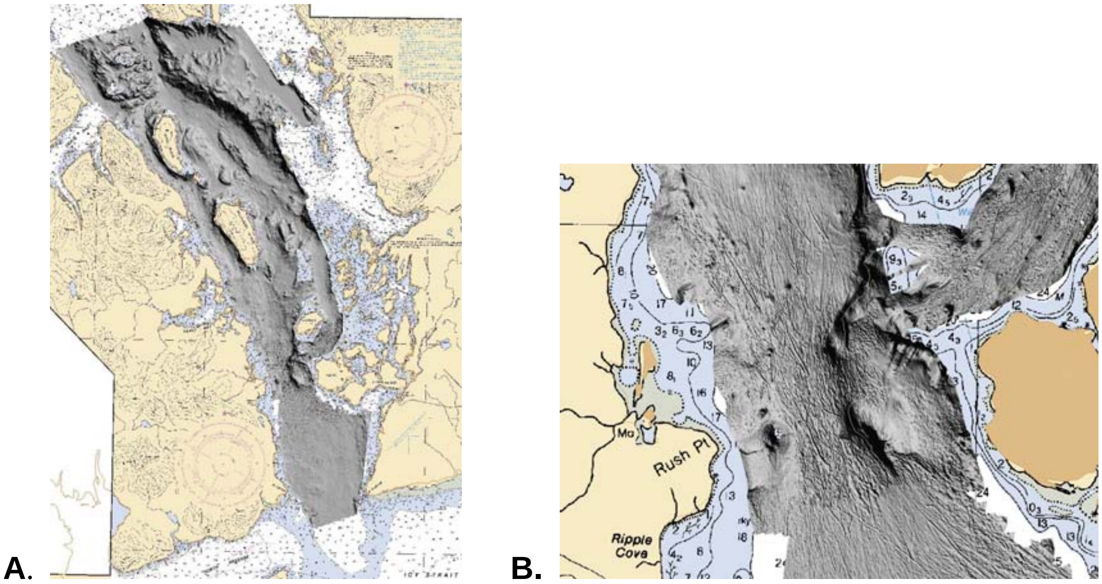

Fig. 2. A. Sun illuminated Digital Terrain Model (DTM) of the lower portion of Glacier Bay, Alaska created from the multibeam bathymetry data. B. Close up of Sitakaday Narrows showing details of ice gouging.

GROUND-TRUTHING

Shallow water ground truthing

Direct observations were conducted by scuba divers in sidescanned areas; in addition, locations representing each type of reflectivity pattern, sites with questionable reflectivity patterns and a random number of sites were surveyed. Due to the extensive areas imaged with sidescan sonar, high variability in substrates of the Bay, great depths of many areas, the limited (sometimes zero or near-zero) visibility, strong tidal currents and frigid water temperatures, ground-truthing of shallow areas required extensive efforts and technical solutions. It was especially critical to maintain safe operations in this very hazardous environment. We utilized several new dive technologies to enable coverage of wide areas at depth while maintaining a greater degree of safety.

Divers conducted long transects (1-2 km) at varying depths and slopes utilizing Farallon MK7 diver propulsion vehicles. The propulsion vehicles allowed divers to swim long distances and maintain mobility in the many areas with strong currents while minimizing physical overexertion, which can lead to decompression sickness.

The locations of physical features were mapped by utilizing underwater communications and an ArcView Geographic Information System (GIS). The communication system consisted of DiveLink voice activated wireless units in ScubaPro full face masks. Divers maintained contact with the research vessel and transmitted observations which were entered directly into GIS coverages. The research vessel maintained position directly above the divers by following bubbles, and latitude and longitude were associated with each observation through the Tracking Analyst extension to ArcView integrated with a Global Positioning System (Rockwell PLGR+ GPS). A test at 60 ft demonstrated that error associated with following divers' bubbles for precise positioning could not be distinguished from GPS error (4m Circular Error Probability (CEP)). Some additional error did arise when the boat had limited maneuverability or the captain lost sight of the bubbles and was thus unable to maintain position directly over the divers. Due to generally very calm conditions associated with the protected water in Glacier Bay, however, these occasions were limited.

An acoustic tracking system (Desert Star Systems Pilot) was also tested as a precise diver locating technique. This tracking system consisted of a baseline of three transducers plus a transponder carried by the divers; range and bearing to the diver fed into the onboard GIS system to determine latitude and longitude. Nevertheless, the system generated a large number of random positional errors and we discontinued use.

The maximum depths of side-scanned areas, 350 ft, were beyond diving limits, but examples of all reflectivity patterns and habitat types were found at depths above 190 ft. Since limiting diving solely to depths of 130 ft or less would have eliminated crucial sampling of substantial habitat and unidentified features, divers occasionally performed decompression diving and utilized mixed-gas open circuit regulators to conduct ground-truthing in deep habitats. Nitrox was utilized at mid-depths (60–100 ft) in order to extend dive times and survey long transects.

Substrate Classification

A modified Wentworth scale (Table 1) was utilized to visually classify primary, secondary and interstitial substrates along survey transects. The primary substrate was defined as single sediment type dominating the percent cover as the diver looked straight down on the bottom; the primary substrate type was the most common sediment type.

The interstitial sediment was the single most abundant of the smallest particles found in between the larger material. The interstitial surface was often a repeat of the primary or secondary surface (i.e. silt, sand, silt). The silt in this example was both the primary substrate and the interstitial sediment between the sand particles.

A variety of qualitative substrate modifiers were used to further describe the substrate, including: the relative hardness of silt; observations of very fine and course sand; large (cobble to pebble size) shells; presence of a thin layer of silt overlaying hard substrate; and comments about interesting morphology that could not be distinguished on the video (undulating landscape, for example).

The use of animal presence data has been demonstrated to be effective in creating habitat models (Dettmers 1999). In order to indicate habitats where marine flora and fauna occur, divers recorded presence of organisms observed along ground-truthing transects during the survey. All of the ground-truthing surveys were performed by a single observer in order to minimize the high probability for inter-observer error in performing visual assessments.

Table 1. Definitions of the substrate types based on a modified Wentworth scale.

Bedrock	A continuous rock surface
Boulders	Head size or greater (>256 mm diameter)
Cobbles	Billiard balls up to head size (64-256 mm diameter)
Pebbles	Pea size up to billiard ball size (4-64 mm diameter)
Granules	BB size to pea size (2-4 mm diameter)
Sand	Just gritty in fingers to BB size (0.06-2 mm diameter)
Mud	If stirred, a large proportion of the sediment stays suspended in water column; includes both silt and clay (<0.06 mm).

Video observations

A digital video (Canon Optura MiniDV) in an Amphibico Explorer underwater housing was mounted to the front of the diver propulsion vehicle. The video, linked with the audio underwater communications, was recorded along the length of the surveys in order to provide an unbiased record and to enable the sidescan image analysts to view observations with associated commentary. The videos were post-processed and digital photos associated with particular points along the ground-truthing surveys were clipped and linked to those points in the GIS file.

Deep water ground truthing

In order to characterize the seafloor and groundtruth the sonar maps, seafloor video-camera observations were obtained using the USGS mini camera-sled using procedures outlined in Anderson et al. (In press). The camera-sled was outfitted with 2 digital video cameras (a forward-facing camera and a downward-facing camera), paired lasers set 20 cm apart, a pressure transducer and altimeter. The forward facing video camera was recorded to digital videotape or dvd and was used as the primary field of view for real-time logging during the cruise. The downward facing camera was used occasionally for detailed observations and was used on several transects to produce a video-mosaic image to drop on the sonar map in areas of rapid change. Paired lasers were projected onto the seafloor to provided a visual reference to size objects, such as boulders (>25.5 cm), cobbles (>6.5 cm), and organisms. The camera was towed 1-2 m above the seafloor at a speed over ground between 0.5 and 1.5 knots. Speeds greater or less than this result in the camera either flying up off the seafloor or crashing into the substratum, respectively. To maintain a consistent altitude (range of 1-2 m) while navigating over the undulating seafloor, an electrical winch plays cable in or out with very little time delay due to the slow ship speed which eliminates catenary in the cable.

Camera lines were run in multiple directions over areas of uncertain substrate identified on the sonar maps. Observations characterizing physical and biological aspects of the seafloor were made to assess the accuracy of the sonar image in depicting both the types and the alongshore and offshore positions and dimensions of these seafloor features. Rapid real-time logging of video observations was facilitated using a keypad entry system. The keypad connects to a PC which has a NMEA serial signal from a GPS unit. The keypad is programmed to provide a coded text string to any software that will link time and position to a text comment and store the records in a text file. At the end of the camera line the text file can be converted easily into a .dbf file and imported into a GIS to be plotted directly onto the sonar imagery. This allows for video surveying plans to be modified in the field and for the development of still camera and sampling surveys which otherwise are often planned with a shot-gun approach in the office. The video can be logged in greater detail and the field logs can be edited in the lab if necessary.

We used a digital still camera system in areas less than 200’ deep to determine surficial seafloor sediment grain size where it is too fine to determine this from the video-camera. These images will be analyzed in the lab. We also collected grab and short core samples after the video survey when appropriate. These samples will also be analyzed in the lab. We obtained a short core that hopefully will be suitable for lead 210 analysis, which will provide very valuable information about rates of post glacial sedimentation to assist in modeling how rapidly the seafloor of Glacier Bay will change from coarse glacial and bedrock to fine sediment environment.

DATA ANALYSIS

Depending on which cruise, when processing sidescan data we used the methodology of Chavez (1984) and the USGS Mini image processing system (MIPS) as well as the methodology of Danforth (1997), through use of the USGS software packages X sonar. The slant-range, de-stripe, and beam pattern-processing routines were executed within Xsonar and ShowImage, which correct geometric and radiometric distortions inherent in the sonar data. The slant-range algorithm was used to remove the water column artifact from the sonograph and will correct the slant-range distance to true ground distance. The de-stripe routine corrects fluctuations in adjacent ping values within the sonar record. The beam pattern routine corrects variations in beam intensity with range. The processed data files were then mosaiced to form a composite image using PCI Remote Sensing Software. A linear stretch was applied to the final mosaics to enhance the contrast between low- and high-backscatter areas. The final mosaics were exported from PCI into TIFF format. The TIFF images were imported as GRID images into an Arc/Info database that also contains coastline, geology, and bathymetry coverages.

Multibeam echosounder data were processed by the contractor (see 'Data acquisition and processing report' and 'Descriptive report'), who corrected for vessel heading, vessel roll, vessel heave, vessel pitch, vessel speed, vessel squat and settlement, vessel draught, vessel positioning, vessel offsets, synchronized timing, velocity of sound in sea water, tidal time, and tidal heights. The raw data were collected digitally with no corrections applied but gross errors removed. Two sun-illuminated images from orthogonal directions were generated. Depth was then coded in color and gridded depth-encoded images were rendered using the processed data set. The grid image is a mean surface selection with grid spacing at the resolution of the smallest resolvable target size. Calibrated backscatter strength was outputted. A digital file containing the back-scatter strength for every ping averaged across 2 degree intervals over the whole of the multibeam ecosounder angular sector used for the survey was rendered. A digital file of strip images of backscatter strength across track was produced, which clearly identifies the changing backscatter due to changes in grazing angle. A backscatter strength mosaic was also rendered. An empirical, but documented, method was used to minimize the effect of varying grazing angle (e.g. a lambertian model that gains up the data in a predictable manner as the grazing angle lowers). The final products will be reprojected into NAD83 and integrated into the Glacier Bay Ecosystem GIS.

We will characterize the benthic habitat using a combination of the side-scan data, profiling data, multibeam bathymetric data, multibeam reflectance data, direct diver observations, underwater videography, physical sampling, onshore geologic mapping by Brew et al. (1978), and previous marine geology work (Carlson et al. 1977, Cai et al. 1997). Final interpretations will be output in the form of geo-referenced habitat polygons that will be combined with the existing Geographic Information System (GIS) database. Geophysical data will be interpreted using experience garnered in studying similar acoustic data from Glacier Bay and the Gulf of Alaska (Carlson et al. 1980, Carlson et al. 1992). Benthic maps will be integrated with concurrent NPS work conducting geomorphological and biological characterization and mapping of nearshore areas of

Glacier Bay. This integration will allow us to characterize habitat relationships from the benthic to upper intertidal.

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1. Figures and Tables Illustrating Locations and Time Periods of Benthic Habitat Sampling

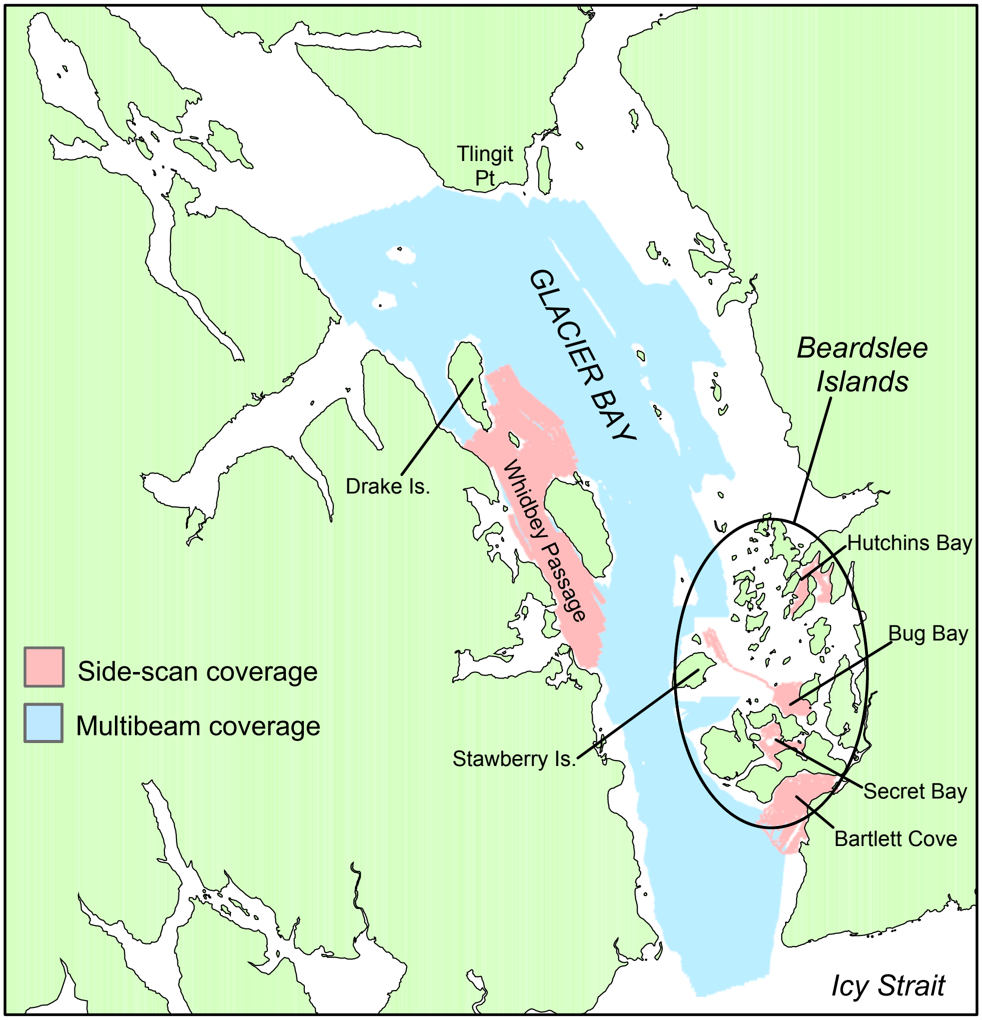

Fig 1.1. The remote sensing habitat mapping that was conducted in Glacier Bay using two techniques, side-scan sonar and multibeam echosounding. Whidbey Passage and the area east of Drake Island was surveyed using both techniques.

Table 1.1. Summary of the locations and years of the remote sensing data collection in Glacier Bay utilizing two techniques, side-scan sonar and multibeam echosounding. File names are provided as well as a cross-reference to figures in this report that show the coverage of the files.

TECHNIQUE	WHERE	YEAR DONE	FILE NAME	FIGURE IN REPORT
Side-Scan	east of Drake Is.	1996, 1997	drak.tif	Fig. 3.2
Side-Scan	Hutchins Bay, North Beardslee Is.	1997, 1998	hbay.tif	Fig. 3.3
Side-Scan	north & east of Strawberry Is.	1997	straw.tif	Fig. 3.4
Side-Scan	Bug Bay, South Beardslees Is.	1996, 1997, 1998	bug.tif	Fig. 3.5
Side-Scan	Secret Bay	1997	sbay.tif	Fig. 3.6
Side-Scan	Bartlett Cove	1996, 1997, 1998	bcove.tif	Fig. 3.7
Side-Scan	south Whidbey Passage	1998	wpasssc.tif	Fig. 4.4
Side-Scan	north Whidbey Passage	1998	wpassnc.tif	Fig. 4.4
Multibeam - bathymetry	Lower and central Glacier Bay	2000	mbbaths	Figs. in section 7

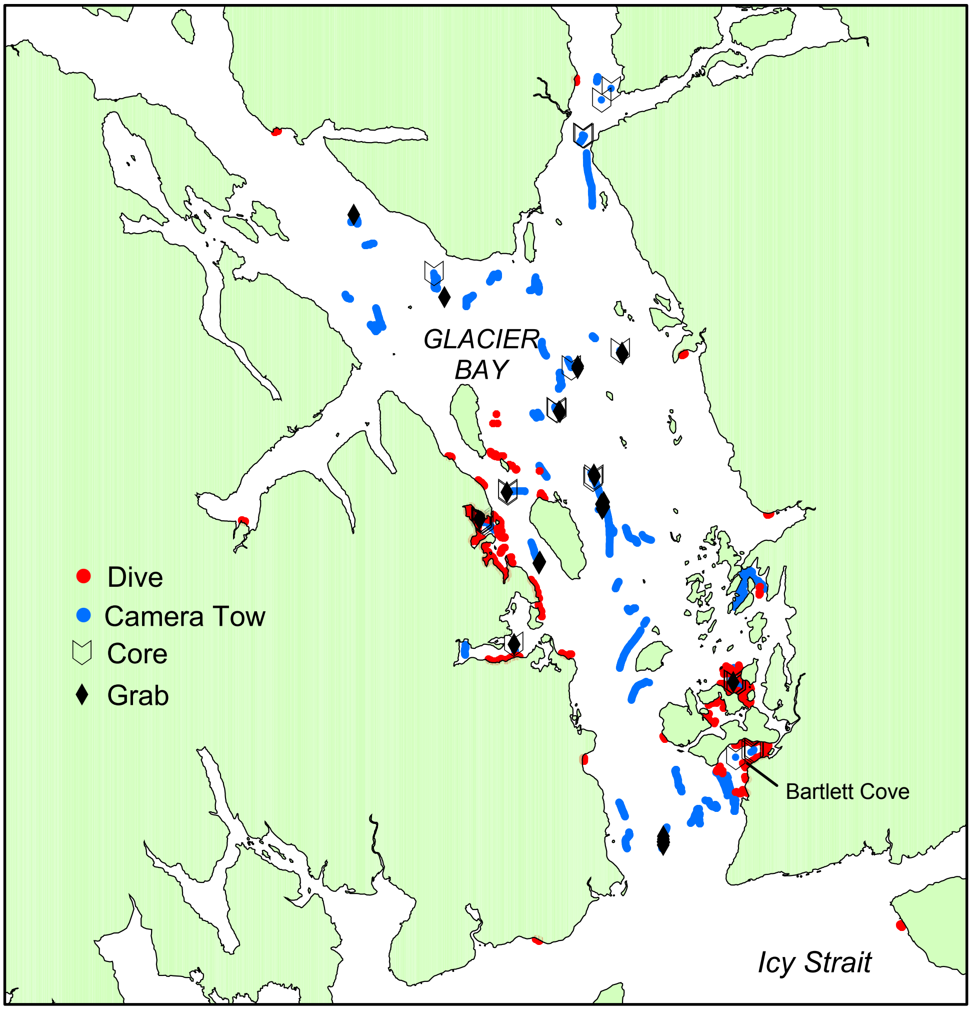

Fig 1.2. The ground-truth sampling that was conducted in Glacier Bay. Four techniques were employed to accomplish the ground-truthing: scuba dives in shallow water; camera tows in deep water; core samples; and sediment grabs.

2. 1996 CRUISE REPORT: PHYSICAL CHARACTERISTICS OF DUNGENESS CRAB AND HALIBUT HABITATS IN GLACIER BAY, ALASKA

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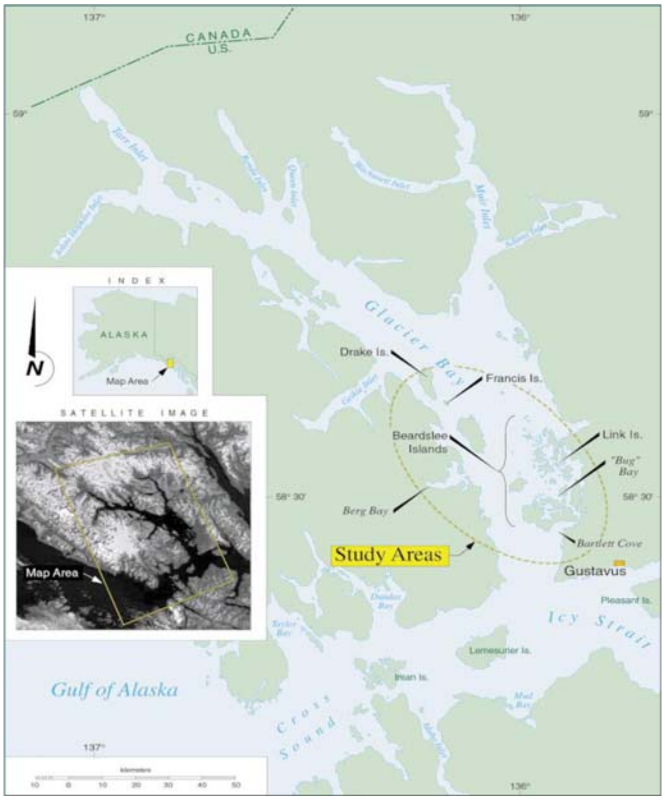
David J. Hogg[1], and S. James Taggart[2]

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY



Open-File Report 98-134

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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INTRODUCTION

Our research cruise of August 1996 involved the characterization of sea-floor habitats in lower Glacier Bay, including geomorphic, sedimentologic, and stratigraphic descriptions, based on acoustic imaging and profiling of the fjord floor. The purpose of the report is to describe this pilot cruise and its mission and show some preliminary results, including some examples of selected side-scan-sonar profiles and high-resolution acoustic profiles.

Glacier Bay National Park in southeastern Alaska (Fig. 2.1), was proclaimed a National Monument in 1925, and was upgraded to National Park status in 1980. This 3.3 million-acre park and preserve extends from Icy Strait on the south to Dry Bay in the northwest. The spectacular fjord system, which is the present Glacier Bay, is the product of multiple glaciations over possible longer than the past 100,000 years (Goldthwait, 1987). In 1794, an expedition led by Captain George Vancouver mapped the ice terminus position at the mouth of the present bay (Goldthwait, 1987). In the past 200 years, retreat of the large glacier that had filled Glacier Bay during late Neoglacial time (a time referred to as the Little Ice Age, Goldthwait, 1963), exposed an extensive fjord system about 100 km long from Icy Strait to the ends of Johns Hopkins and Tarr Inlets in the Wes Arm and slightly less to the head

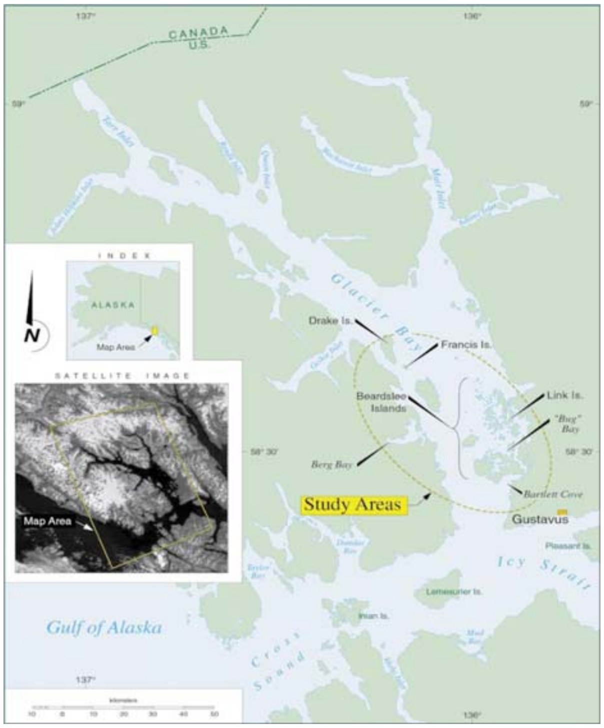

Figure 2.1. Location map of Glacier Bay, inset index map, and satellite image. Large map includes general locations of each targeted study area. Dashed elliptical line encloses specific study areas of Figure 2.2.

of Muir Inlet to the east (Fig. 2.1). As the most recent large glacier retreated, the newly exposed terrain and fjords have been undergoing rapid physical and biological transformations. Because of the rapid changes, this national park is a superb scientific laboratory in which to study glaciology, fjord sedimentation, succession of terrestrial plants, and changes in terrestrial and marine biological communities (Milner and Wood (eds.), 1990; Engstrom (ed.), 1995). Our report deals with bays and inlets in the lower 30 km of the main bay- -specifically, Bartlett Cove, Berg Bay, three areas in the Beardslee Island complex, and two small areas in the main bay, one between Drake and Francis Islands and a second in the Sitakaday Narrows region (Figs. 2.1 & 2.2).

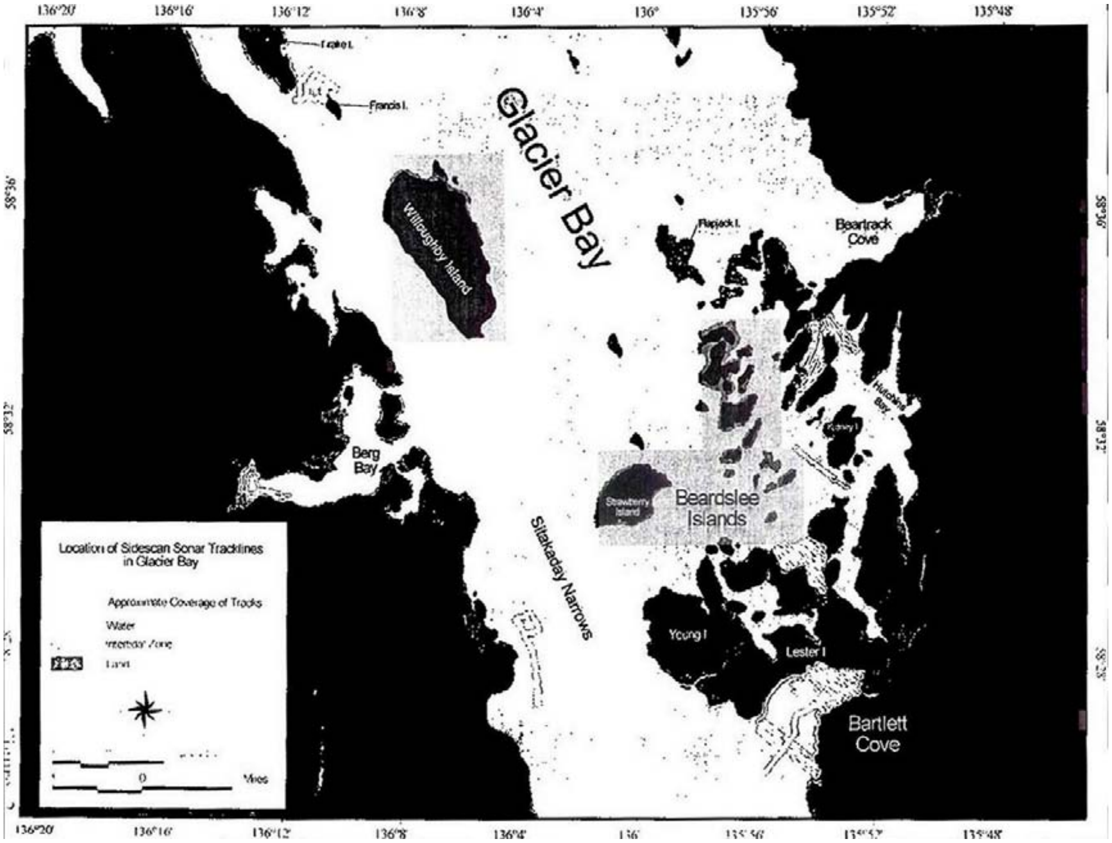

Figure 2.2. Location map of south Glacier Bay with tracks showing total coverage in each of the study areas- -Berg, Francis, Beardslees (Link, Spider and Bug), Bartlett, and Sitakaday. Width of track line shows range of side-scan sonar (SSS) coverage.

Biologists with the United States Geological Survey (USGS) Biological Resources Division (BRD), formerly with the National Park Service (NPS), requested help to determine the bottom characteristics and bathymetry of several field sites throughout Glacier Bay. These areas are the sites of continuing studies of Dungeness crab and halibut for which the biologists are attempting to ascertain life history, distribution, and abundance as well as determining the affects of commercial fishing within the National Park wasters. These studies relate to the question of weather or not commercial fishing should be allowed within the boundaries of Glacier Bay national Park. This question is a subject of debate involving the office of the Secretary of the Interior as well as the State of Alaska and many commercial interests. Bottom characteristics and bathymetry have been hypothesized to affect the distribution, abundance and behavior of these bottom dwellers. Examples include the distribution of Dungeness crab which varies widely from 78 to 2012 crabs/ha over the near shore study sites in water depths to 18m (O'Clair et al., 1995), and large differences seen in halibut distribution (Bishop et al., 1995), and halibut foraging (Chilton et al., 1995) according to bottom type. By combining side-scan and sub-bottom-profiling with population sampling (including diver-based observations of crabs and sonic tracking of individual halibut implanted with sonic tags), we hope to better understand the distribution and abundance of both crab and halibut.

This preliminary report shows the areas of data collection (Fig. 2.1 & 2.2) and displays some examples of the sea-floor habitats that were insonified on the cruise. Our preliminary interpretations accompany selected images.

DATA COLLECTION

The cruise, which included side-scan-sonar and acoustic profiling, began August 1, 1996 with one and one-half days of mobilization on the M/V QUILLBACK and ended with demobilization August 10. A total of 155 km of track line data were collected in the five study areas of lower Glacier Bay (Table 2.1). The acoustic data were collected using a Klein side-scan-sonar system (SSS) with an attached 3.5 kHz profiler (3.5 kHz). Also included in this report is part of a minisparker line (200 Joules) collected in Bartlett Cove on the NPS M/V NUNATAK in 1980. Estimates of resolution of these systems, abstracted from Carlson (1989), are as follows: (a) SSS – few to tens of cm of sea floor relief; (b) 3.5 kHz - ~1-3 m with penetration of tens of meters in soft muddy sediment and a few meters in some sandy substrates; (c) minisparker ~3-5 m with medium penetration of >100 m in mud, some sands, and even some diamictons. Resolution is a function of frequency; the higher the frequency, the greater the resolution, but the range of the SSS (and depth of penetration of 3.5 kHz and minisparker systems) is accordingly decreased. Belderson et al. (1972) state that for resolution of ~15 cm the maximum range will be ~300 m. Our range with a 500 kHZ fish is 100 m; thus the resolution of these SSS lines should be less than 15 cm. The SSS unit for most of the 1996 cruise used a 500 kHz source and a swath width of 100 m, but for the areas between Drake and Francis Islands and within Sitakaday narrows we deployed the SSS “fish” with a 100 kHz source with a swath width of 200 m. The fish was towed within ~30 m of the vessel and as close to the bottom as was practical, but whenever possible, no more than 10 m off the bottom. Because of the depth of the SSS/3.5 kHz fish, the profiles obtained with the 3.5 kHz system do not include the upper part of the water column. Thus, the depth scales on each of the 3.5 kHz images, included in the figures, do not show the water surface. The vertical time and depth scales pertain solely to the bottom sediment. With the added weight of the attached 3.5 kHz transducer, the wire angle was greatly reduced and the system towed fairly close astern.

Table 2.1. List of dates, times, locations, track lines, and distance attained on the R/V QUILLBACK cruise in Glacier Bay, Alaska, August 1-10, 1996

Mobilization 8/1/96
Test runs in Bartlett Cove 8/2/96

LINES	AREA	DATE	JULIAN	DATE_TIME	TRACKS
1-9	Berg Bay	8/3/96	JD 216	1711-2027	9.0 km
10-17	Drake/Francis	8/3	217	0007-0155	7.0 km
18-25	W side of Link I	8/4	217	1655-2148	13.0 km
26-30	NE side of Link I	8/4	217	2006-2148	8.0 km
31-32	So Beardslees	8/4	217	2225-2327	4.5 km
33-59	"Bug Bay"	8/5	218	1752-0027	33.5 km
60-114	Bartlett Cove	8/6-8	219	1846-0118	68.0 km
115-125	Sitakaday Narrows	8/9	221	1839-2245	8.0 km
126-127	Bartlett Cove	8/9	221	2321-2359	4.0 km
Demobilization		8/10/96		Total distance	155.0 km

The SSS data were recorded on an analog 18" Klein 531T wet-paper recorder, the 3.5 kHz data were recorded on an analog 9.5" EPC 1600 recorder. The SSS and sub-bottom data also were digitally recorded on the USGS-developed acoustic data acquisition system called MudSeis NT. The MudSeis NT is tightly integrated with the USGS real-time navigation system called YoNav (Gann, 1992). The YoNav/MudSeis digital package received input from the GPS receiver, fathometer, side-scan-sonar, and 3.5 kHz systems. Navigational accuracy was ~3-5 m. For more information on USGS equipment systems, visit the USGS Marine Facility World Wide Web site at http://marfacweb.wr.usgs.gov.

INTERPRETIVE METHODS

Characterization of marine sediments can best be determined by using combinations of continuous acoustic reflection and side-scan-sonar systems, bottom samples, and bottom observations by divers or by bottom camera or video. The bottom camera and/or video can be deployed by cable from the deck of a ship or as a part of a remote observation vehicle. All of these systems have been used by scientists in various studies in the Gulf of Alaska and Glacier Bay to study the variations of sediment type and sea floor morphology (e.g. Carlson et al., 1977; Cai et al., 1997). Because this was a trial cruise with limited space for sampling, we have used SSS/3.5 kHz profiling to see how useful they will be to the biologist's studies of sea-floor habitats. Sea-floor sampling provides vital sediment information to help calibrate the seismic reflection interpretations. In this report we rely on a few available samples and diver observations, but most of the interpretation is a product of the experience garnered in studying similar acoustic data from Glacier Bay and the Gulf of Alaska (e.g. Carlson et al., 1992, Carlson et al., 1980).

DESCRIPTION OF STUDY AREAS

In this section, we describe each of the areas insonified and show some examples of images. We studied each area in a similar manner as follows. We wanted to profile as close to shore as possible, but the inshore bathymetry was not well known on available charts, for two reasons: 1) As the glaciers have been retreating, the area has been slowly rebounding (i.e. sea floor is getting shallower). Perhaps the highest uplift rate recorded in North America, 4 cm/yr, was measured at Bartlett Cove between 1938 and, (Hicks and Shofnos, 1965). However, Brew et al (1995) also remind us that tectonic processes are also affecting vertical movement in this area. Thus, the shoreline has been slowly changing and as a result the near shore bathymetry which was last mapped a decade ago, is uncertain. 2) The geoid datum on which many of the charts are based is the North America datum of 1927. It was updated in 1983, and this change in reference datum also results in uncertain bathymetric depths, especially in near shore areas. Therefore, we began our study in each area with a perimeter track line, run as close to shore as possible, using the SSS/3.5 kHz system. Subsequently, we surveyed each area along a grid of parallel lines laid out in the long direction of the area to be surveyed, except for Bartlett Cove, where we ran the track lines across the width of the bay. The lines were plotted on a computer screen and then each line was followed as carefully as possible. However, this proved to be difficult for several reasons: 1) currents often were strong enough to cause deviations in the intended line; 20 the navigational data were not recorded quickly enough to provide instantaneous course corrections; and 3) in Bartlet t Cove, we encountered two kinds of obstacles a) many boats anchored near the park

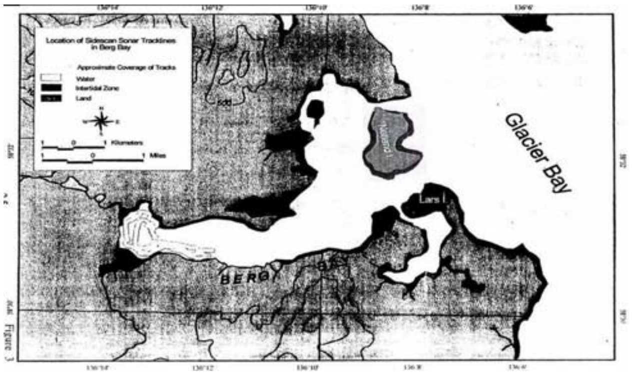

Figure 2.3. Location of track lines in west end of Berg Bay. Width of track represents width of SSS coverage. Corresponding 3.5 kHz profiles located along middle (nadir) of SSS swaths.

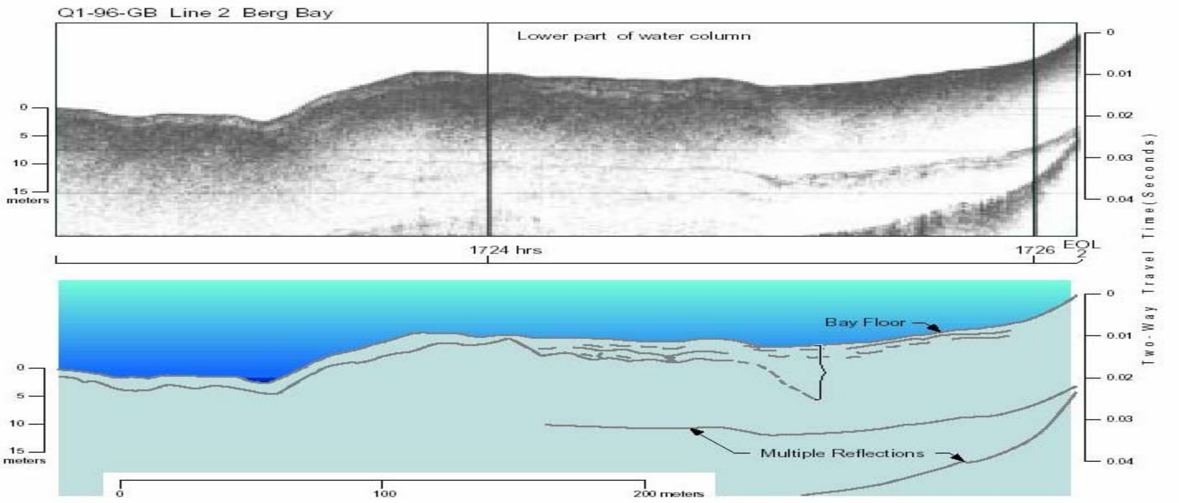

Figure 2.4. 3.5 kHz profile and interpretation from Berg Bay showing types of acoustic variations of sediment pile. Vertical scales apply solely to bottom sediment in all 3.5 kHz profiles illustrated. Because 3.5 profile is attached to SSS, vertical scales indicate approximated sediment, not water depths (based on water velocity of 1500 m/sec). Surface bounce reflection (visible on right side of profile) was sed to help identify sub-bottom reflections shown in interpreted profile. A possible explanation for small amount of penetration (a few meters), other than glaciated surface which would be hard and allow little penetration, might be presence of methane in sediment which greatly impedes penetration. Vertical Exaggeration (V.E.) = ~4:1

dock, and b) Humpback whales feeding in Bartlett cove. We encountered whales in two other areas, also, but not in the continuous manner we did in Bartlett Cove. Because NPS rules state that we could not approach closer that 1/8 mile to these whales, we had to shutdown, or alter our lines, or motor to the other end of the Cove. Often when we would start profiling again at the other end of the cove, the whales would approach us and appear there as well. The whales did not appear to be bothered by our equipment's acoustic signals, and were seemingly attracted by the output signals from the SSS and/or the 3.5 kHz system. This whale attraction, or rather distraction to us, occurred at least six times in the three days we worked in Bartlett Cove. It was a large enough operational problem for us that we decided to do our follow-up cruise in the off-season to avoid the Humpback whales.

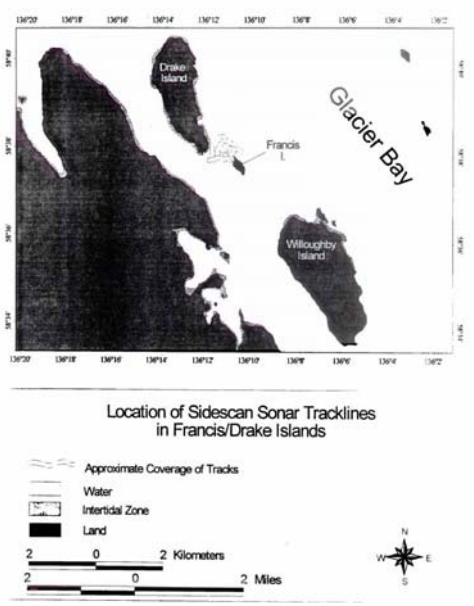

Figure 2.5. Location of track lines between Francis and Drake islands.

<u>Berg Bay</u>- - -We began our cruise with nine SSS/3.5 kHz track lines (lines 1-9; Table 2.1) at the far west end of this small, 6 km long bay, which is located on the west side of the main body, and about 20 km north of the entrance of Glacier Bay (Fig. 2.2). The water depths in the area we profiled ranged from 2 to 40 m. Brew et al. (1978), show Berg Bay to be surrounded by, and therefore we assume to be underlain by, Silurian and Devonian sedimentary rocks (largely graywackes and argillites with some limestone); however, at the western end of the bay, the Paleozoic sedimentary units are mapped to be overlain by Holocene sediments. These young sediments are probably largely a combination of till and outwash. The till was laid down when the Little Ice Age glacial advance resulted in Glacier Bay being completely ice-filled, and outwash deposited as the ice sheet retreated back up the main bay. Acoustic profiles (3.5 kHz) show

accumulations of about 5 m of non-reflective sediment on the several lines we ran across the delta forming at the west end of Berg Bay (Figs 2.3 & 2.4).

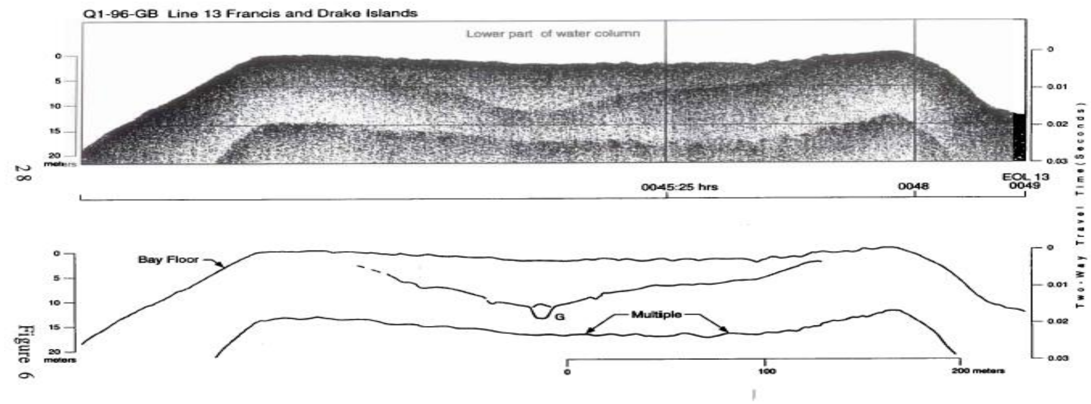

Figure 2.6. 3.5 kHz profile and interpretative sketch across ridge between Francis and Drake islands. Note hard surface at top of ridge, and strong multiple of that surface. Faint depression (G) aligns with similar feature we observed on two adjacent profiles, suggesting a groove or channel-like feature. V.E. = ~4:1.

Between Francis and Drake Islands - -This area is located about 30 km north of the entrance to Glacier Bay (Fig. 2.2). Brew et al. (1978) have mapped these islands as Silurian and Devonian carbonates. There is a pronounced ridge (~1 km long and ~0.4 km wide) between Francis and Drake Islands. The water depths where we profiled varied from 20 to 40 m. We insonified the ridge area along eight lines with the 100 kHz SSS and attached 3.5 kHz profiler (lines 10-17; Table 2.1) to study halibut habitats (Fig. 2.5). The ridge between these islands has a thin accumulation of sediment on the five lines. Three of the lines (12, 13 and 14) show a sub-bottom reflection that suggests a

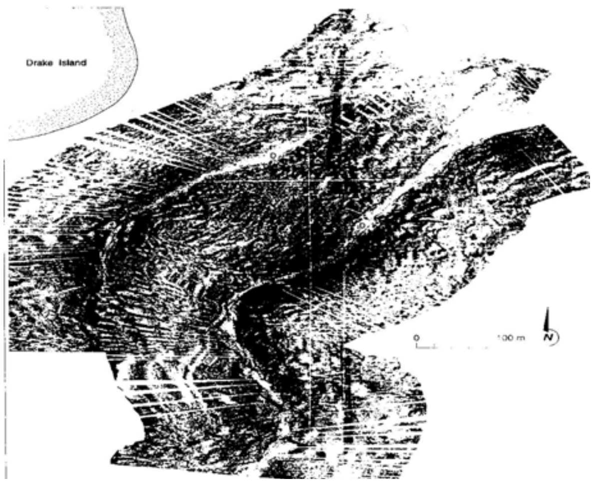

Figure 2.7. Part of preliminary SSS mosaic of ridge between Francis and Drake Islands. Note long gouge mark (GM), lower left of center about 200 meters in length. White thin wedge-shaped breaks in the SSS mosaic are a result of the preliminary processing technique and the irregular track lines caused by strong current over this ridge area. The two distributions (D) of the three mosaiced lines are also results of the processing.

groove or channel-like feature that reaches a depth of 10 m below the sediment water interface (Fig. 2.6 shows the groove on line 13). Seismic-reflection profiles of a lower frequency are needed to determine the depth extent of the feature. However, much of the surface morphology on the 3.5 kHz and SSS records is hummocky, which we interpret as a hard ridge with some furrows (Fig. 2.7). The ridge may be either bedrock, perhaps part of the island platform, or it could be a moraine as suggested by Cai et al. (in press). Cai et al. Interpretation, based on seismic-reflection profiles, is that an end moraine crosses the bay, and passes near these two islands. The moraine on the east shore of Glacier Bay, may be associated with this ridge, and is dated at 1845 AD based on tree-ring counts (Lawrence, 1958).

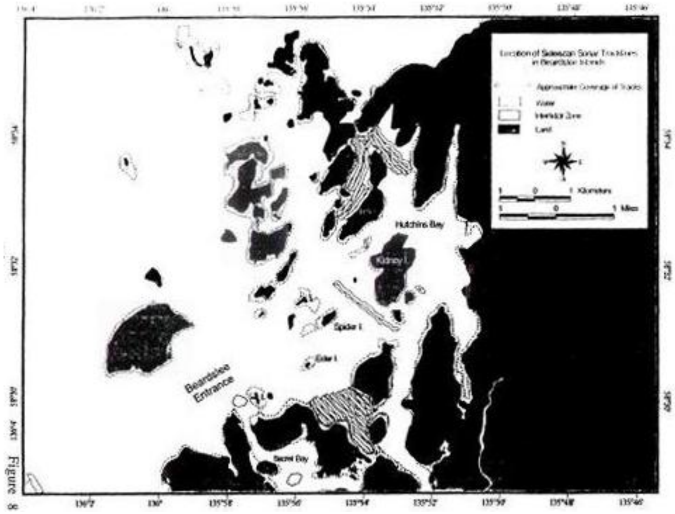

Figure 2.8. Track lines in Beardslee Islands area. Lines in 3 areas, top to bottom: northwest and northeast of Link Island; southwest of Kidney Island; and southeast end in "Bug Bay", southeast of Eider Island.

<u>Beardslee Islands</u>- -Our third study area is the east shore of Glacier Bay and includes three shallow areas within the Beardslee Island complex (Figs. 2.1 & 2.2). Brew et al. (1978) mapped all of the island complex as consisting of Quaternary sediment. This surficial sediment cover is probably largely a combination of ground moraine, deposited as the Little Ice Age glacier advanced, and end moraines and outwash deposits which were formed as this bay-filling glacier retreated. We began profiling in the northern part of the Beardslee Islands by surveying elongate shallow depressions on both sides of Link Island, an elongate low island, 3 km long and 0.5 km wide (Fig. 2.8). SSS/3.5 khz lines 18-25 were run in the basin on the west side of Link Island (Table 2.1). This basin has a maximum water depth of 15 m at mean lower low water (mllw) and contains thin patches of sediment less than 1.5 m thick (Fig. 2.9). On this cruise, a diver collected a bottom

sample from this area that was primarily mud containing a few granules and shell fragments. We interpret that these sediments were deposited since the Little Ice Age glacier retreated past this shallow basin. Between the small depressions, where muddy sediment has accumulated, the profiles showed harder irregular bottom, possibly ground moraine or outwash sands and gravels, which would restrict sound penetration (Fig. 2.9). The northeast-southwest oriented basin on the northeast side of Link Island has a maximum depth of 38 m (mllw). Along the northeast side Link Island (lines 26-30; Table 2.1), a 3.5 kHz profile shows ~3-4 m thick, sediment layer in the basin, but deeper reflections also show to a depth of ~18 m (Fig. 2.10). We interpret this sequence to be a thin layer of muddy recent sediment overlying a thick sequence of glacial outwash sediment, likely to be predominately muddy sands and gravels, a common constituent of glacial outwash deposits (Eyles and Eyles, 1992). Other SSS/3.5 kHz profiles in this area show thinner recent sediment cover and only hard bottom. The surface depressions at the center of the profile (Fig. 2.10) appears to be either a pit or trench, however the SSS does

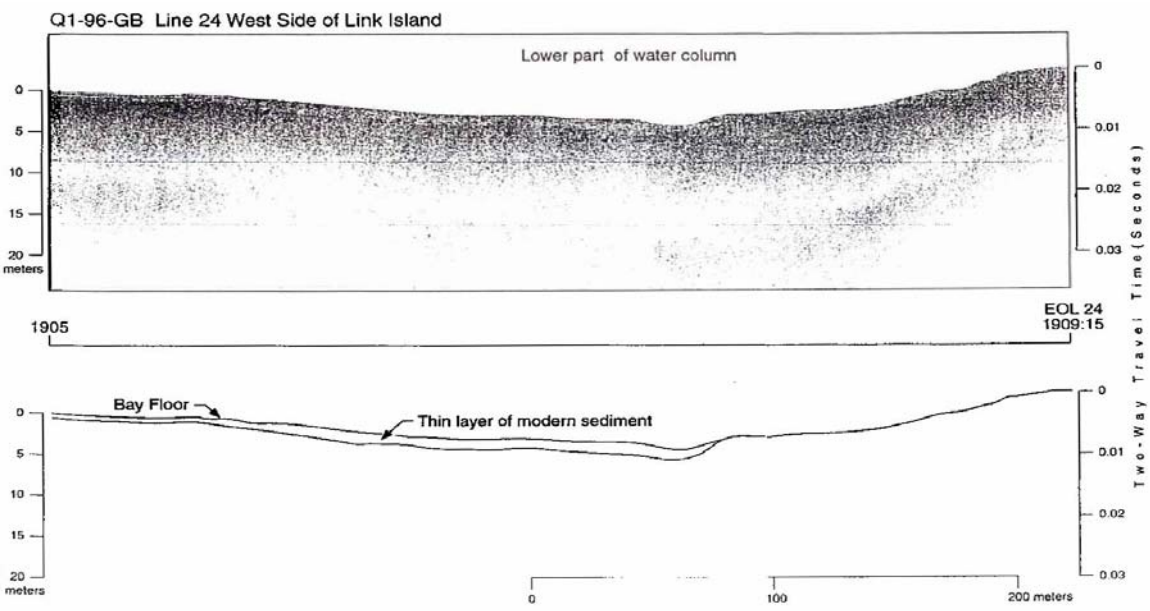

Figure 2.9. 3.5 kHz profile from northwest side of Link Island showing thin layer of modern sediment (deposited since Little Ice Age) commonly found throughout this small elongate body of water. Note lack of sound penetration (at right 1/3 of record), which is due to a rather hard bottom (sandy or gravelly), that prevents penetration of *sound.*

not show any continuation of the feature, so we interpret it to be a nearly circular pit at the nadir (position on image directly beneath SSS fish) of the sonogram. This apparently circular feature needs to be further investigated by divers.

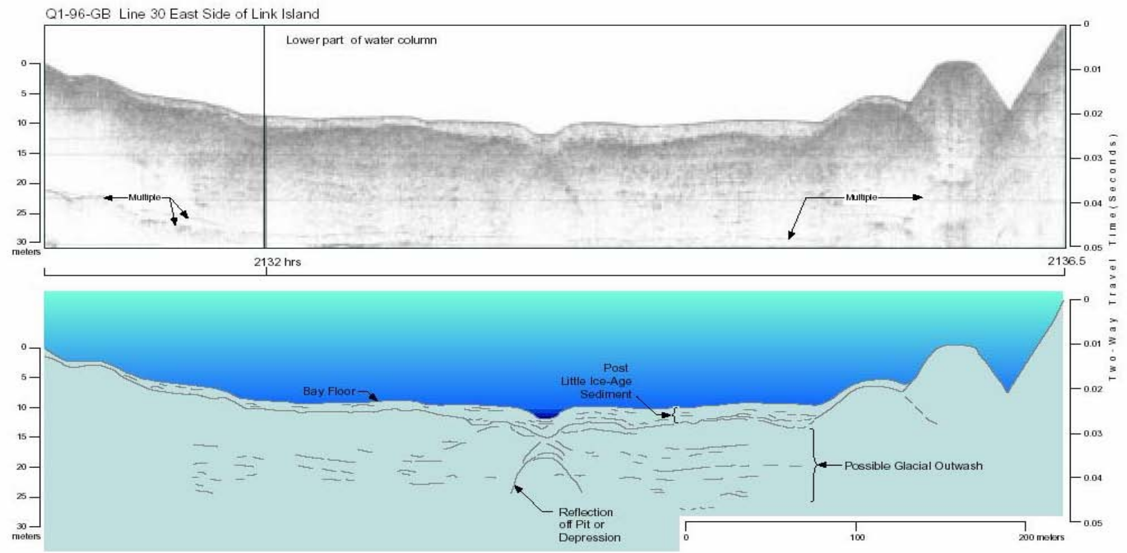

Figure 2.10. 3.5 kHz profile northeast of Link Island. Up to 5 m of soft sediment overlies some deeper reflections, which we suggest may be part of a large glacial outwash plain formed as the ice sheet retreated past this area. A well-defined depression occurs in middle profile. Side-scan image across area does not show any elongation of feature, suggesting a pit. V.E. = ~4:1.

Four Kilometers south of Link Island we ran two lines (lines 31, 32; Table 2.1) south of Kidney Island (Fig. 2.8) along the biologists “deep set” study segment. “Deep set” refers to this study area that is deeper than most of their study sites. The water depth was about 40-50 m along the two approximately parallel lines. The outline of a sunken boat clearly can be seen on the SSS image (Fig. 2.11). Figure 1.12 shows the 3.5 kHz acoustic image along the nadir of the SSS record. This profile shows the bay-floor relief near the location of the wreck seen on the SSS image. This boat imaged by the SSS apparently is a skiff that was collecting crab traps in ~1994 when the water turned rough. The heavily loaded skiff, with two people and many traps aboard, was reported to have nosed into a large wave and sank. The two occupants escaped, swam to shore and were seen by a passing airplane and subsequently rescued (Jim de la Bruere, personal communication, 8/4/96). The outline of the skiff can clearly be seen on the SSS image (Fig. 2.11). Long and thin objects such as the buoy line leading from the crab pot in figure 2.11, are more readily insonified; we can apparently image objects just a few cm in diameter. The line in the image appears to be much thicker, perhaps due to biological growth. The third Beardslee area, informally called Bug Bay, is located in the southern part of the Beardslee Islands complex, south or Eider Island (Fig. 2.8). We insonified the inner segment (lines 33-59; Table 2.1) of this bay where much of the surveyed area is more than 20 m deep and exceeds 30 m at its deepest point. Although the perimeter of the area insonified had little soft sediment cover, based solely on no penetration by the 3.5 kHz signal, the deeper portions of this bay show sub-bottom reflections on the 3.5 kHz profiles that indicate sediment thicknesses as great as 30 m (Fig. 2.13). The irregular, hummocky nature of the underlying acoustic basement also can be readily seen. We suggest that this hummocky reflection may represent the surface of glacial till laid down during occupation of this area by the Little Ice Age glacier that filled all of Glacier Bay slightly more than 200 years ago. Much of the sediment overlying the till is probably glacial outwash deposited as the ice sheet retreated up bay at a rate of 0.5 to 1.3 km/yr in this general area of Glacier Bay (Cai et al., in press).

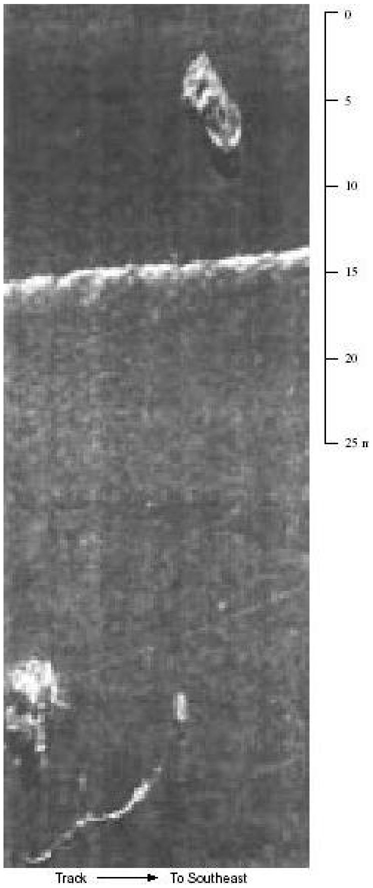

Figure 2.11. Side-scan sonar image of sunken skiff (S) and crab pots (P) in 40-50 m of water south of Kidney Island. At lower left corner of figure, elongate irregular blob or mound is probably pile of crab pots; this indicates kind of resolution possible. Slanted whitish line 1/3 from top is reflection off water-air interface. (See Fig. 2.8 for track lines).

<u>Bartlett Cove</u>- -This Cove is a 5 km long reentrant on the east side of Glacier Bay, about eight km north of the bay entrance (Fig. 2.1 & 2.2). Bartlett Cove is the location of

the National Park Service headquarters and lodge, thus the hub of tourist activities. The sheltered Cove provides a good anchorage for numerous fishing and pleasure craft. We collected a total of 72 km of track lines (line 60-114 & 126-127; Table 2.1), but, due to interruptions in profiling by the presence of whales, we only insonified about 2/3 of the cove (Fig. 2.14). The shoreline of Bartlett Cove consists of Quaternary sediment (Brew et al., 1978). The northwest side of the Cove is Lester Island, the southern most of the Beardslee Island complex. The southern and eastern shorelines consist primarily of glacial outwash debris deposited by the Bartlett River and originating from the rapidly retreating Little Ice Age glacier.

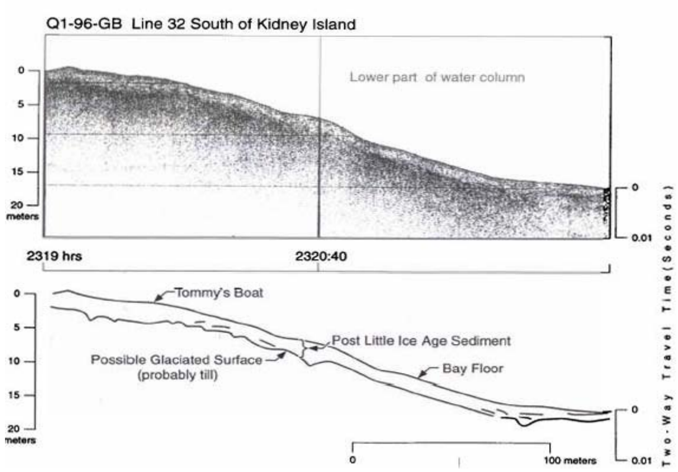

Figure 2.12. Acoustic profile from 3.5 kHz system run simultaneously with SSS system and shows general morphology of bay floor along track where sunken boat was observed on SSS imagery. 3.5 kHz system shows at least 3-4 m of soft sediment has accumulated in this area since Little Ice Age glacier covered this segment of Glacier Bay. V.E. = ~4:1

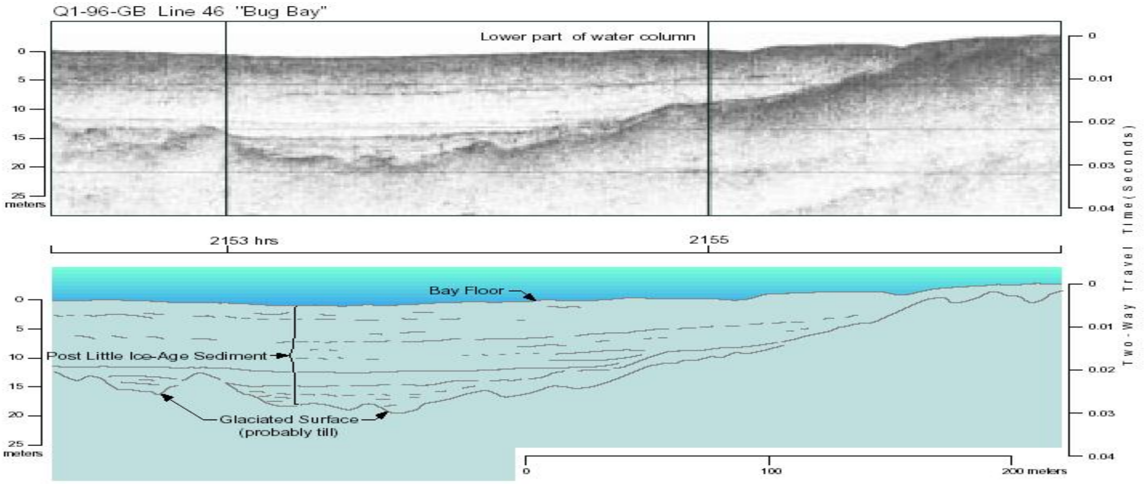

Figure 2.13. 3.5 kHz profile and interpretation of sediments underlying southeastern part of the "Bug Bay." Note thick sediment fill over hummocky glacial surface. V.E. = ~4:1.

The Cove is partially protected from storm waves by a bay-mouth moraine that appears to be part of an extensive lateral moraine (Fig. 2.15a). The moraine and Bartlett Cove sedimentary basin can be clearly seen on Figure 15b. A minsparker record, collected in 1980, shows at least 25 m of post Little Ice Age sediment in the basin. The water depth in the middle of the basin is nearly 60 m (llw). The moraine is nearly 3 km long 1 km wide and has a relief of about 15-30 m, based on our contouring of bathymetric sounding collected by National Ocean Service (1938-90). The SSS imagery of the moraine (Fig. 2.16, a-c) shows the locations of some large boulders, and some patches of small boulders, cobbles and smaller gravel intermixed with finer sediment, probably sand. Figure 2.17a exhibits the acoustic character of a hard, gravel rich surface typical of a moraine similar to those described by Carlson (1989) for other Alaskan fjord areas. In the central part of the moraine, bathymetry shows a tidal channel that reaches a depth of the 50 m (Fig. 2.15a) and appears to be floored with finer sediment (Fig. 2.17b), possibly sand.

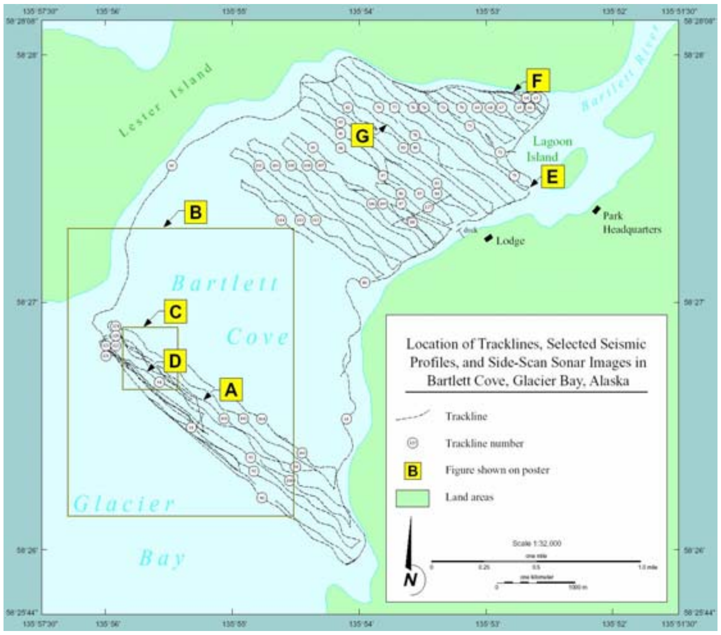

Figure 2.14. Trackline coverage of Bartlett Cove, including notations of figure locations.

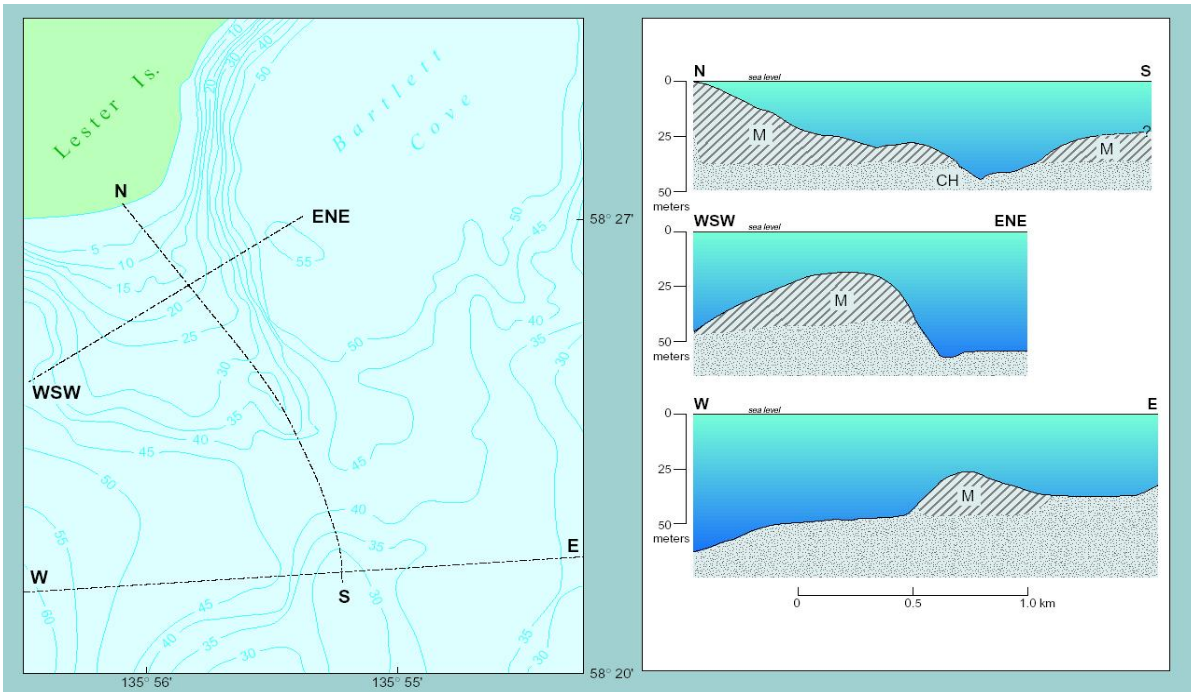

Figure 2.15a. Bathymetric map of moraine at mouth of Bartlett Cove and profiles along morainal crest (N-S) and across the moraine (wsw-ene) and (w-e). V.E. of profiles 10:1. Lined pattern shows surficial moraine. M on profiles shows approximate position where profiles cross each other. CH = location of channel that has been maintained by tidal currents. Bathymetry in meters, contoured by us from hydrographic soundings collected by National Ocean Service (1938-90) over many years by several different ships.

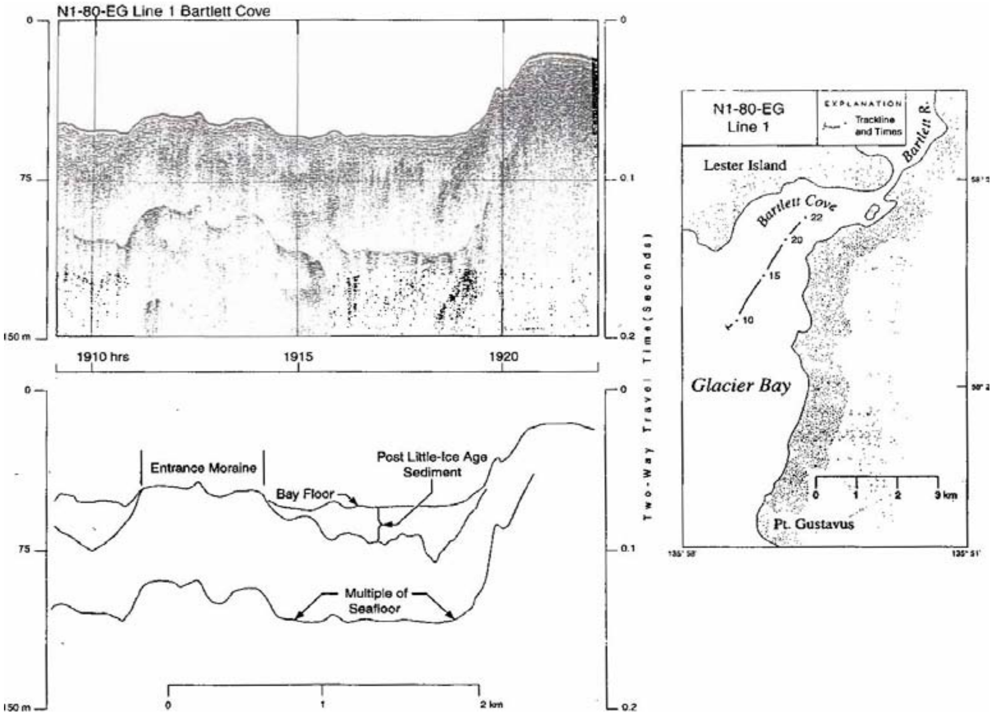

Figure 2.15b. Trackline map of Bartlett Cove and interpreted minisparker profile (collected in 1980 by USGS from M/V NUNATAK) showing relations of entrance moraine, cove floor and sediment fill since retreat of Little Ice Age glacier. V.E. = ~4:1.

At the inner end of the cove a delta is being built out from the Bartlett River as evidenced by a SSS image collected near the entrance to the inner lagoon (Fig. 2.18). Here a wedge of delta sand impinges on the mud that floors the deeper part of the cove. Grab samples collected on a cruise in 1997 (Carlson, unpublished data, 10/21/97)

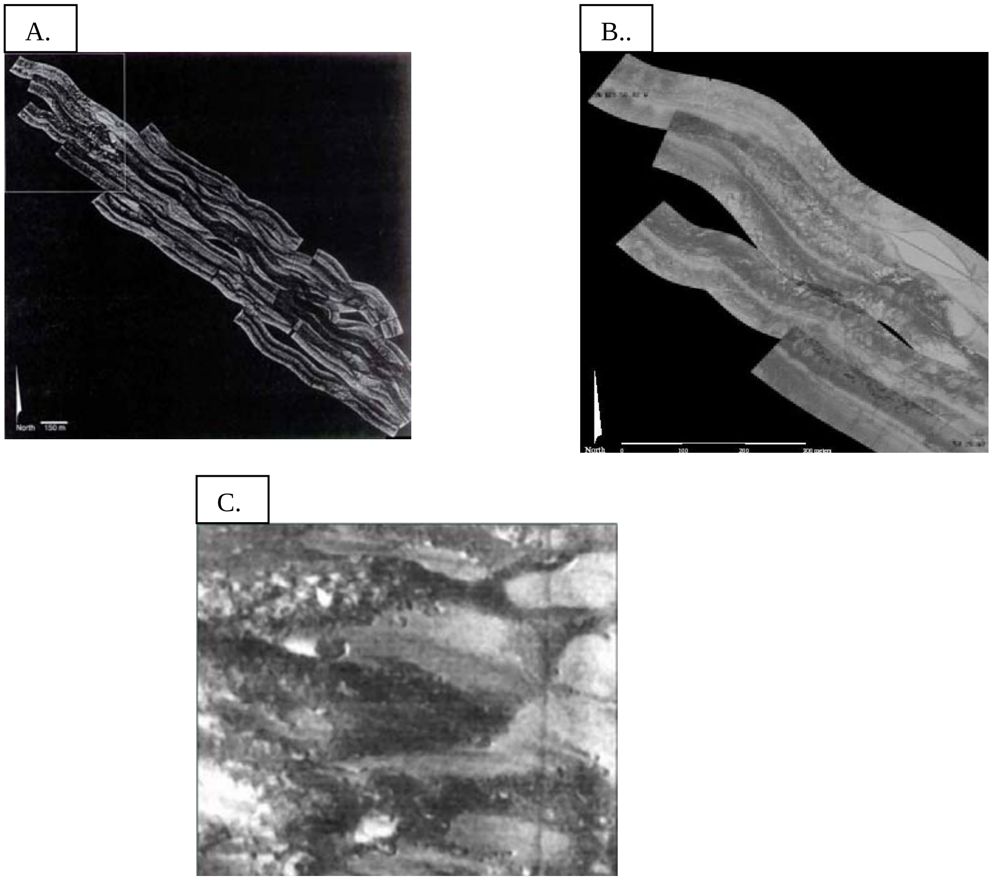

Figure 2.16a. Preliminary SSS mosaic of Bartlett Cove entrance moraine (see Fig. 2.14 for track line locations and compare with Figure 2.15 a, b for broad scale bathymetric and high-resolution seismic views of moraine). Box indicates location of Figure 2.16b. Figure 2.16b. Detailed SSS view of northern portion of moraine (see Fig. 2.16a for location with respect to full mosaic). *Note irregular patch nature of imagery and see Figure 2.16c for more detail.* **.** *Figure 2.16c. Example of close-up SSS view of upper portion of moraine seen in Fig. 2.16b. Light gray semi-oval shaped patches (right half of image) are finer sediment, probably sand amongst patches of black to dark gray mixed with white (left half of image). Blacker tones represent areas of high backscatter (harder or coarser material). White patches are shadows. Thus, black and white are areas with larger cobble to boulder size parts of moraine.*

provided ground truth for these interpretations. Two sets of features that we interpret as sand waves or megaripples can be seen on the image (Fig. 2.19). The crests of the sand waves are about five m apart. Figure 20 shows a 3.5 kHz profile across the sand shoal with little sound penetration through the sandy surface- -not the four bayfloor multiples that emphasize the hardness of the bottom at this site.

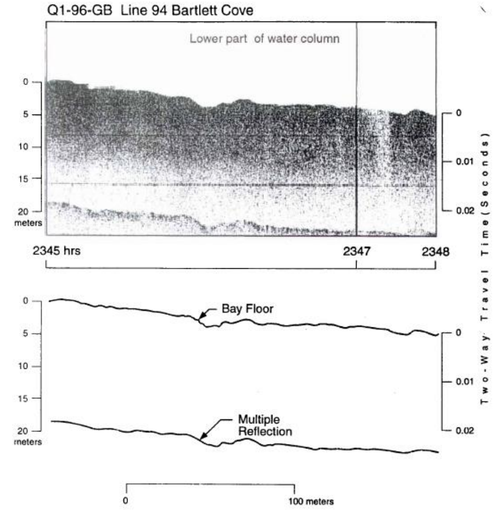

Figure 2.17a. Typical 3.5 kHz profile across hard rocky surface (note well defined multiple reflection) of entrance moraine. V.E. = ~4:1. See Figure 2.14 for location

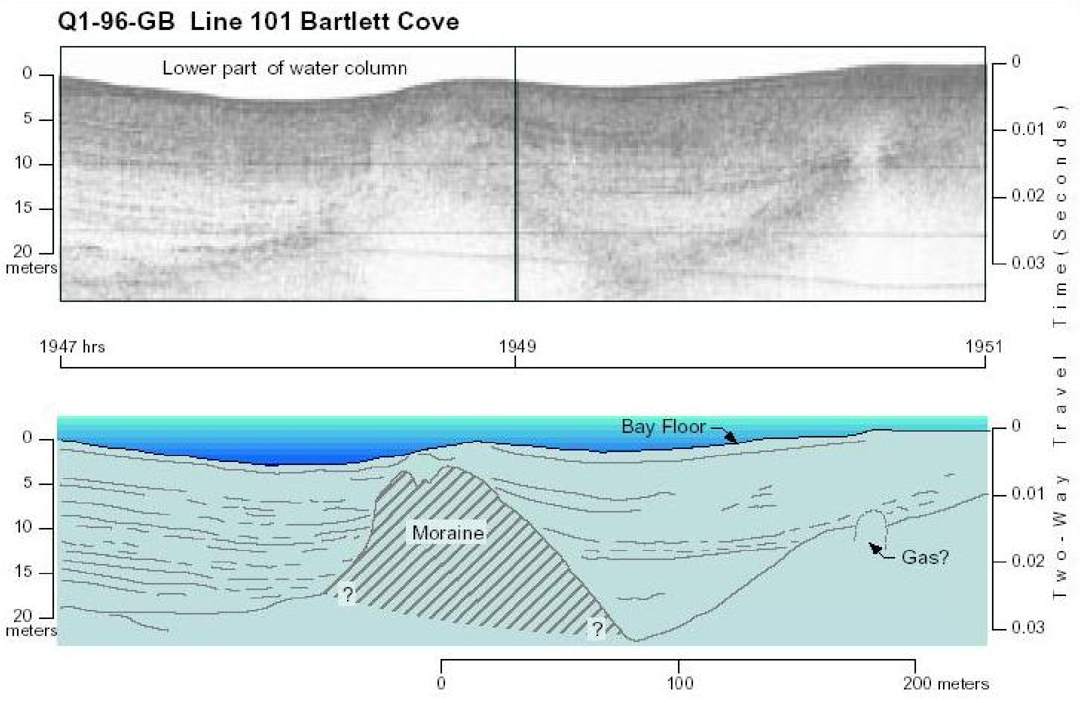

Figure 2.17b. 3.5 kHz profile shows buried portion of entrance moraine, where we interpret that a well-bedded fine-grained sediment (sandy to silty) from 2 to 20 m thick covers very irregular morainal surface. Note "g" which marks possible presence of gas-charged sediment. V.E. = ~4:1.

Within the cove, the thickness of muddy sediment overlying the glacial till and outwash is not known. Some of the 3.5 kHz profiles show considerable thickness of sediment, at least several tens of meters (Fig. 2.21a). In other places the penetration through the bottom sediment is restricted to just a few meters. The bottom sediment was initially interpreted to be a thin veneer of mud or other soft sediment over the glacial debris left from the retreating Little Ice Age glacier, however, some profiles suggested to us that other phenomena, such as gas charged sediment, may also be present.

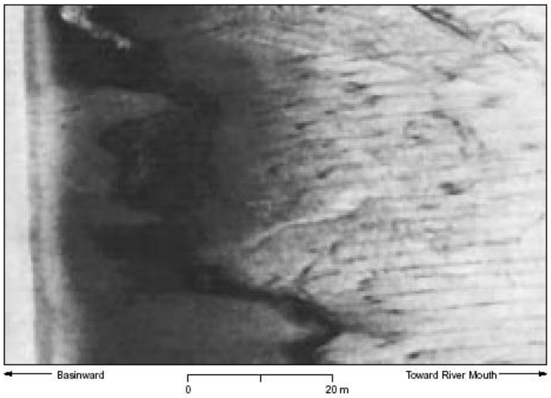

Figure 2.18. SSS imagery of Bartlett River delta sand (right ¾ of image) prograding over deeper soft sediment accumulating on deeper cove floor (dark portion at left part of image).

The disrupted reflections (Fig. 2.21b) on some records look like gas charged sediment may underly some of the basin. Given the diver-observed, anaerobic conditions of the mud in the Bartlett Cove basin (P. Hooge, oral communication, Oct. 20, 1997), methane deposits might be expected. Gas in the sediment also is indicated by the presence of gas bubbles at the water surface in parts of Bartlett Cove (observed by P. Hooge and P. Carlson, Oct. 20, 1997). The question arises as to the effects of the gas on marine life in this environment. This could also be a problem in some of the other bays. Other types of acoustic profilers and perhaps some cores will be needed to check for the presence of significant quantities of methane in the sediment- -a

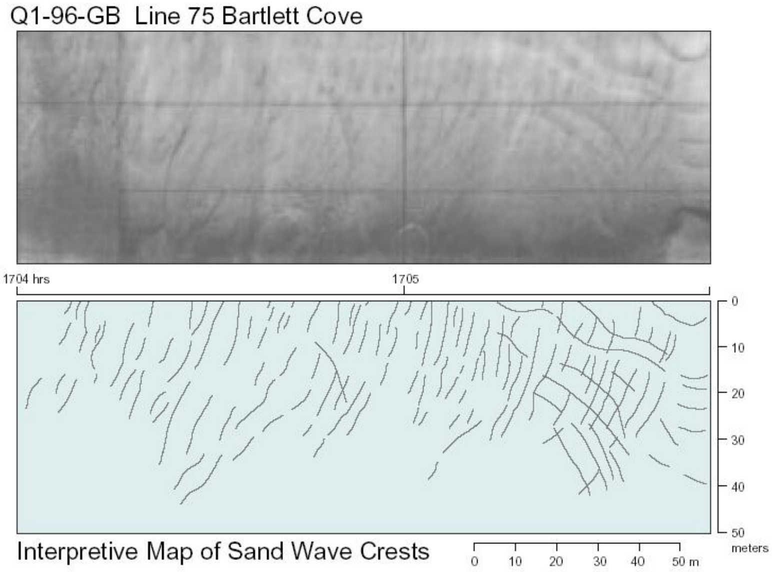

Figure 2.19. Enlarged portion of SSS image shown in Figure 2.18, over sand waves that formed on Bartlett River delta. Note on interpretive sketch two different sets of wave crests that have affected the sandy bottom surface. See Figure 2.14 for location.

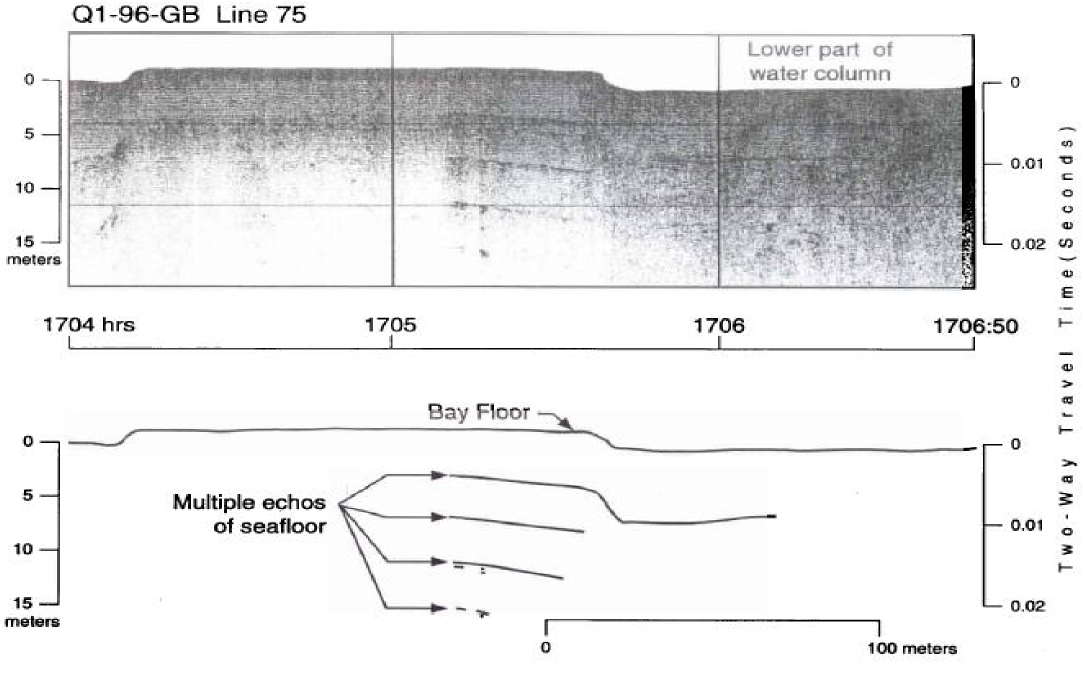

Figure 20

Figure 2.20. 3.5 kHz profile across shoal area of delta showing platform-like nature of delta in sand wave area. Multiple echoes of bay floor indicate hardness of sand surface. V.E. = ~4:1.

fairly common occurrence in subaqueous sediment. (Carlson, et al., 1985; Hampton and Kvenvolden, 1981; and Marlow et al., 1996).

Another SSS image of note (Fig. 2.22 a & b) shows tree holes several meters in diameter, that have been identified as locations of large collections of Dungeness crabs, observed during scuba dives conducted in the spring of 1996 (P. Hooge and S.J. Taggart, oral communication, 9/10/97). Dive transects revealed the presence of large aggregations of molting male Dungeness crab. Dungeness crabs are usually agonistic and cannibalistic. The presence of these aggregations suggest some sort of selfish herd or schooling phenomena (Hamilton, 1971) where individuals gain protection in numbers through greater vigilance (Bertram, 1978,Gosling and Petrie, 1981) and confusion of predators (Rubenstein, 1978). The use of these pits raises questions about the origins and persistence of these sizeable holes. Although SSS was unable to image Dungeness crabs, it may be used successfully to distinguish small differences in substrate that appear to control distribution. While the side-scan was unable to distinguish female crab aggregations, it successfully distinguished the sand that is the distinctive substrate on which these aggregations are found (P. Hooge, oral communication, Oct. 20, 1997).

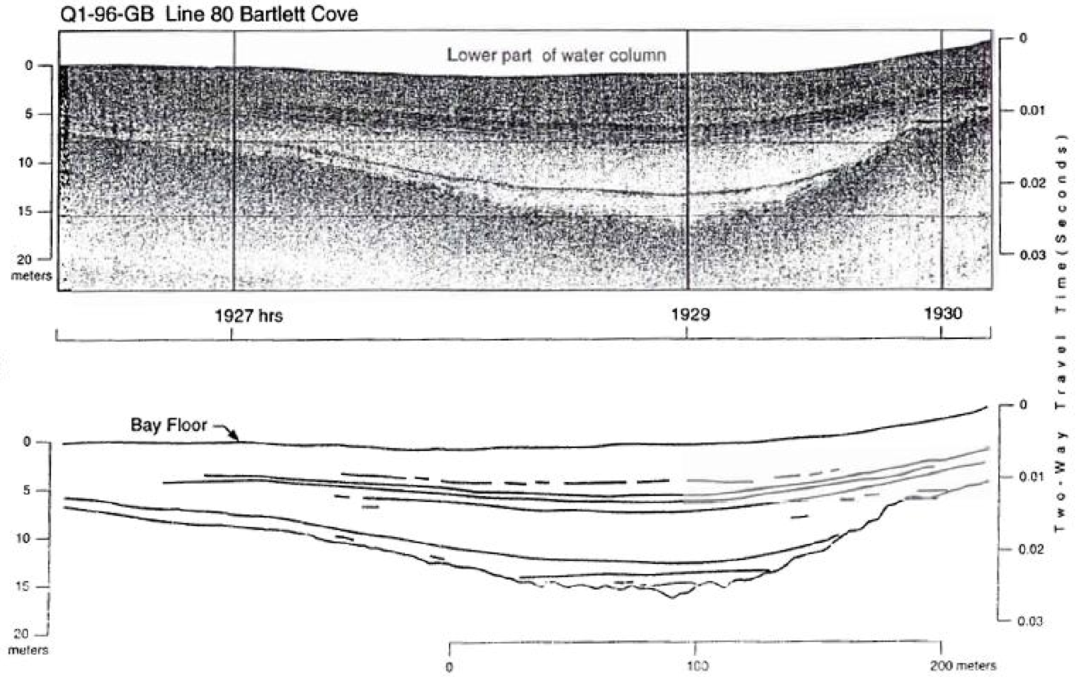

Figure 2.21a. In the deeper part cove, 3.5 kHz profile shows a least 15 m of sediment deposited since last retreat of ice from the area. Lowest reflection could be related to underlying glacial debris, however, as next profile (2.21b) will show, lack of sound penetration may also be a function of gas in the sediment. V.E. = ~4:1.

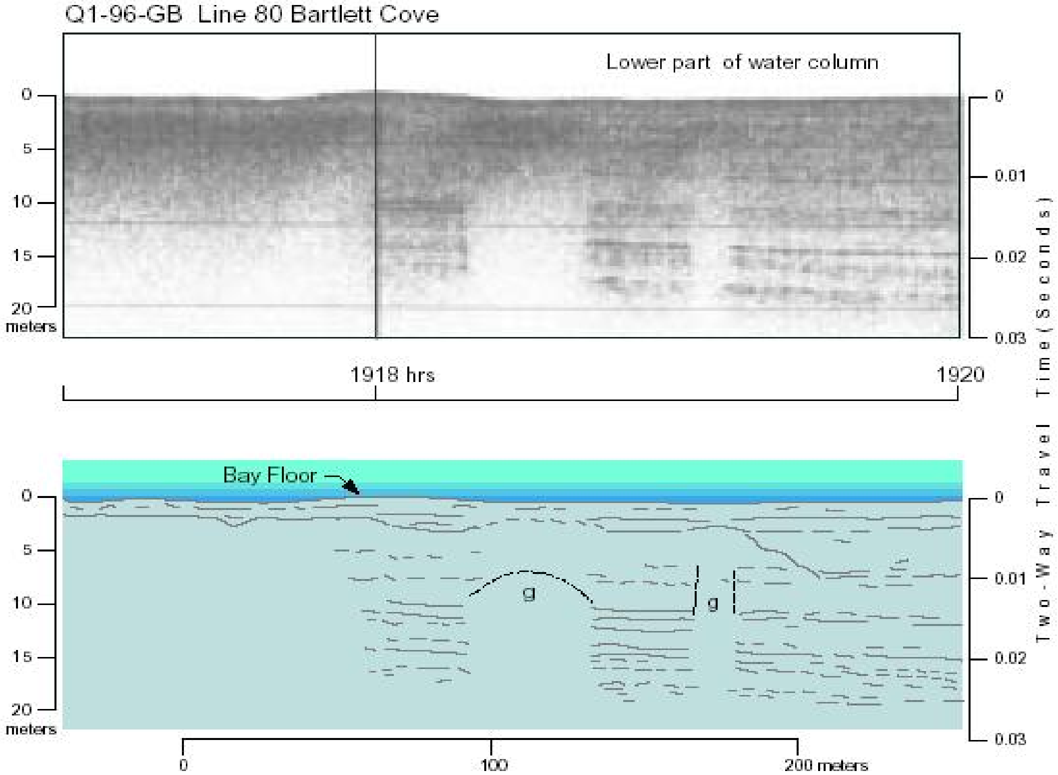

Figure 2.21b. Disrupted reflections in3.5 kHz profile are evidence that gas (g) exists in sediment column. V.E. = ~4:1.

Locations of both 2.21 a & b are shown on track line map of Figure 2.14.

Diver observation and sampling have begun to allow us to ground truth the patterns seen in the images which will then be extrapolated to the entire coverage area.

<u>General observations</u>- -Side-scan-sonar images seem to be able to pick up distinctive images of two species of kelp, Nerosistis and Fucus as well as able to distinguish a third collection made of Laminaria and Alaria. After mosaic georeferenced images are created, diver sampling will be able to ground truth the patterns seen in the images which can then be extrapolated to the entire coverage area. This data layer will then provide a tool to stratify sampling and to overlay abundance patterns. This will prove useful in combining with the coastal mapping database being built at the Park to determine the depth and extent of this biologically important habitat. Th NPS and USGS-BRD Field

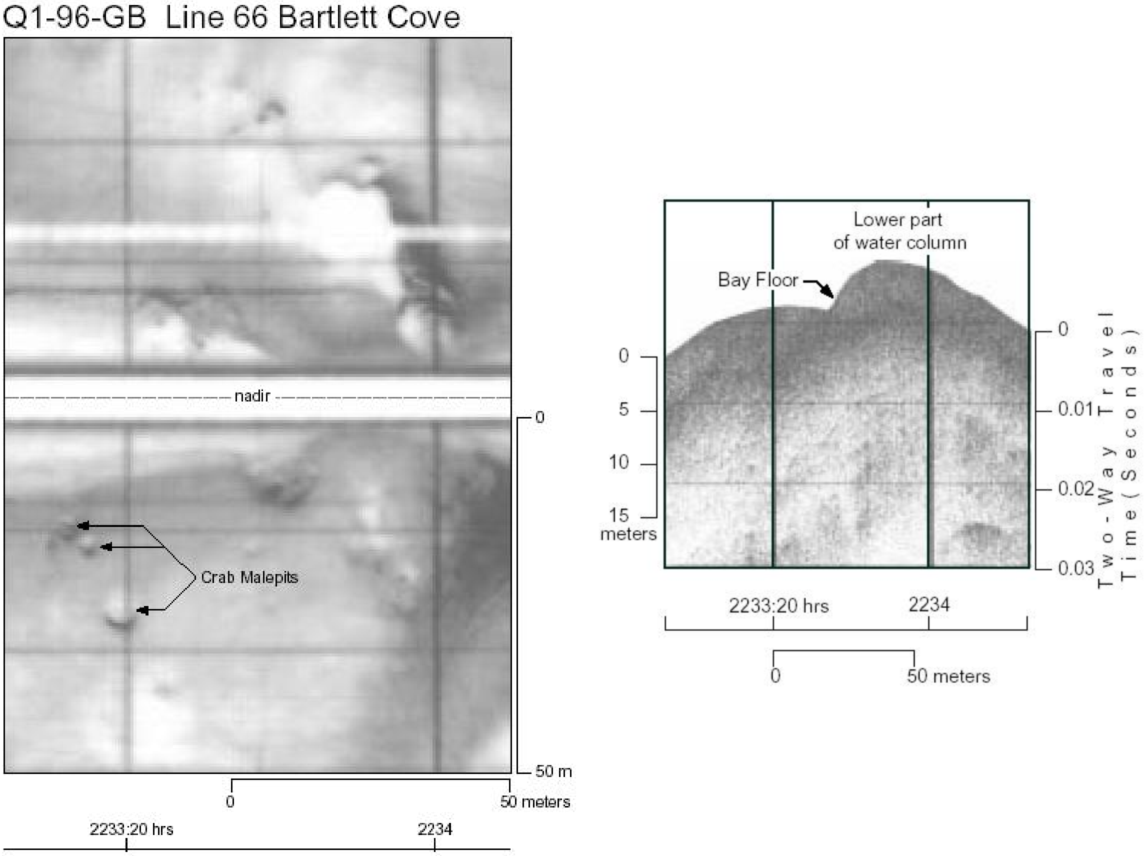

Figure 2.22a. Pits shown on SSS image (left) from upper Bartlett Cove (see Fig. 2.14) were apparently resting places for multiple male crabs seen during a dive in spring 1996. Pits are several meters in diameter. 3.5 kHz profile shown on right was collected simultaneously along nadir of SSS image. 3.5 kHz system shows general morphology in vicinity of pits but is offset from the nearest pit by about 20 m. V.E. = ~4:1.

Station are jointly mapping the geomorphology and biota of the coast into a Geographic Information System using scanned and PS georeferenced infrared aerial images as well as ground truth samples. The extent for the intertidal environment as well as the near shore benthic environment has been a distinct missing piece to this mapping effort. The combination of this database with the side-scan-sonar mosaic, distribution of sediment type, and an improved bathymetric model will provide a resource for many coastal research projects as well as resource management issues.

Figure 2.22b. Enlarged view of pits in Fig.2.22a. Black and white have been reversed on image to give a somewhat different perspective of these pits. On this image white is high backscatter off black wall of pit, black is low backscatter from the hole or depression of the pit.

SUMMARY STATEMENT

During the pilot cruise of August 1996, we collected a total of 155 km of track lines in Glacier Bay, which provide SSS imagery and 3.5 kHz profiles in five study areas of the southern part of the Bay. The acoustic portrayal of the bay floor showed significant changes in the bottom substrate characteristics from bay to bay and within each of the sub-areas investigated. We found a wide variety of environments in this recently deglaciated bay complex. The environments include: 1) moraines with varying sizes of boulders and cobbles; 2) moraines, where the coarser larger cobbles and boulders appear to be covered with finer sediment (sand and in some places mud); 3) relatively featureless muddy-bottom bays; 4) areas in bays with isolated dropstones either near the moraine or in some basins, separated from the moraines; 5) a submarine sandy delta front, with bedforms encroaching on the basin floor mud of Bartlett Cove, off the Bartlett River; 6) rocky insular slopes; 7) shallow basins with thin transparent recent sediment covering hummocky acoustic basement; 8) basins deeper than 20 m with soft sediment cover or variable thicknesses, some that apparently contained free gas, probably methane.

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3. 1997 CRUISE REPORT: PHYSICAL CHARACTERISTICS OF DUNGENESS CRAB AND HALIBUT HABITATS IN GLACIER BAY, ALASKA

October 15 through October 30, 1997
Glacier Bay, Alaska

Guy R. Cochrane[1]
Paul R. Carlson[1]
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Can also be found at:

http://geopubs.wr.usgs.gov/open-file/of98-791/ofr98-791.html

CRUISE OBJECTIVES

In Glacier Bay National Park, Alaska there are ongoing studies of Dungeness Crab (*Cancer magister*) and Pacific Halibut (*Hippoglosus stenolepis*). Scientists of the United States Geological Survey (USGS) are attempting to ascertain life history, distribution, and abundance, and to determine the effects of commercial fishing in the park (Carlson et al., 1998). Statistical sampling studies suggest that seafloor characteristics and bathymetry affect the distribution, abundance and behavior of benthic species. Examples include the distribution of Dungeness crab which varies from 78 to 2012 crabs/ha in nearshore areas to depths of 18 m (O'Clair et al., 1995), and changes in halibut foraging behavior according to bottom type (Chilton et al., 1995).

This report discusses geophysical data collected in six areas within the park in 1997. The geophysical surveying done in this and previous studies will be combined with existing population and sonic-tracking data sets as well as future sediment sampling, scuba, submersible, and bottom video camera observations to better understand Dungeness crab and Pacific halibut habitat relationships.

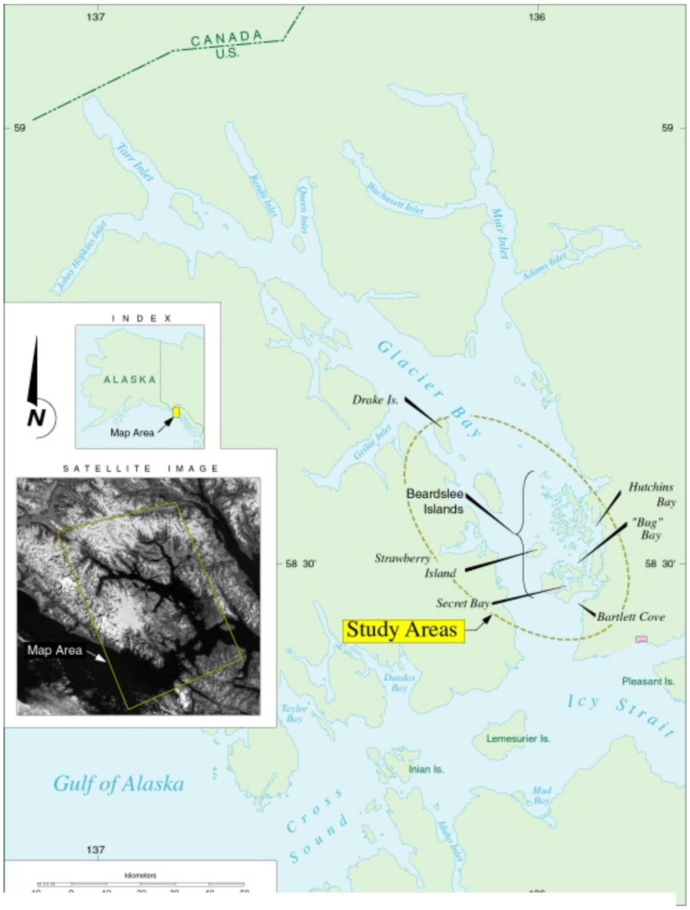

Fig. 3.1

GLACIER BAY PARK

Glacier Bay National Park is a 3.3 million-acre park and preserve that extends from Icy Strait and Cross Sound in the south to the Canadian border in the northwest (Figure 3.1). In the last 200 years, the large glacier that filled Glacier Bay during late Neoglacial time (commonly referred to as the Little Ice Age, Goldthwait, 1963), has retreated, exposing about

100 km of a spectacular fjord system that has developed over possibly the past 100,000 years (Goldthwait, 1987). As the glacier has retreated, the newly exposed benthic habitat has undergone rapid physical and biological changes making it an ideal site to study glaciology, fjord sedimentation, and species succession (Milner and Woods, 1990; Engstrom, 1995).

Commercial fishing is one of the major sources of income in the adjacent communities. There is also an economically important recreational fishery in the area. But, significant questions have been raised in Congress as to whether fishing should be allowed in Glacier Bay Park. Mapping of the benthic habitat will result in improved management of the fisheries resources in the area.

KLEIN 2000 SIDESCAN SURVEYING SYSTEM

A Klein 2000 sidescan system was used for geophysical surveying. The unit features 8 channels of processed data, 7 subsurface from the towfish (5 sonar and 2 instrumentation) and 1 surface (external analog input). Two sonar channels each were devoted to 100 KHz and 500 KHz sidescan data and a fifth sonar channel was used for 4KHz subbottom profiling.

NAVIGATION SYSTEMS

The 1997 Glacier Bay survey was navigated with a Leica Differential Global Positioning System (DGPS) which provided a position with accuracy of 1-5 m in DGPS mode. At times during the cruise, differential signal was interrupted. In non-differential mode, the receiver provided a position with 30-50 m accuracy. A KVH Industries Inc. azimuth digital gyro-compass provided ship headings with 0.5 degree accuracy. Navigation data were recorded using Yo-Nav version 1.19 (Gann, 1992).

DATA ACQUISITION AND PROCESSING

We used the M/V QUILLBACK, owned by the United States Minerals Management Service and operated by the National Park Service, for our geophysical surveying. Side-scan-sonar imaging (side-scan) and seismic reflection profiling (profiling) began on October 15 after two days of mobilization and ended October 30 with one day of demobilization. A Triton Elics Isis brand side-scan data recording system was used on the cruise, that simultaneously records 5 channels of data; port and starboard 100 KHz side-scan data, port and starboard 500 KHz side-scan data, and profiler data. Side-scan data shown in this report are 100 KHz data. Typically, 2048 samples were recorded per channel over a swath width of 200-400 m yielding a resolution of 0.1 - 0.5 m of seafloor area for the side-scan data. The resolution of the profiler data is 1-3 m of sub-bottom depth (with penetration of tens of meters in soft sediment and a few meters in harder sediment).

The sidescan-sonar data were processed following the methodology of Danforth et al. (1991, 1997), through use of USGS software packages Xsonar and Showimage. The slant-range, destripe, and beam pattern-processing routines, executed within Xsonar and Showimage, correct geometric and radiometric distortions inherent in the sonar data. The slant-range algorithm removes the water column artifact from the sonograph and corrects slant-range distance to true ground distance; the destripe routine corrects fluctuations in adjacent ping values within the sonar record; the beam pattern routine corrects variations in beam intensity with range. The processed data files were mosaiced to form a composite image using PCI Remote Sensing Software. A linear stretch was applied to the final mosaics to enhance the contrast between low and high backscatter areas. The final mosaics were exported from PCI in TIFF format. The TIFF images were imported into an arc/info database (Geiselman et al., 1997) that contained coastline, geology, and bathymetry coverages.

SIDESCAN SONAR MOSAIC IMAGERY

The 1997 sidescan images are displayed here (Fig 3.2 – Fig 3.7). Interpretive efforts are ongoing for each of these areas.

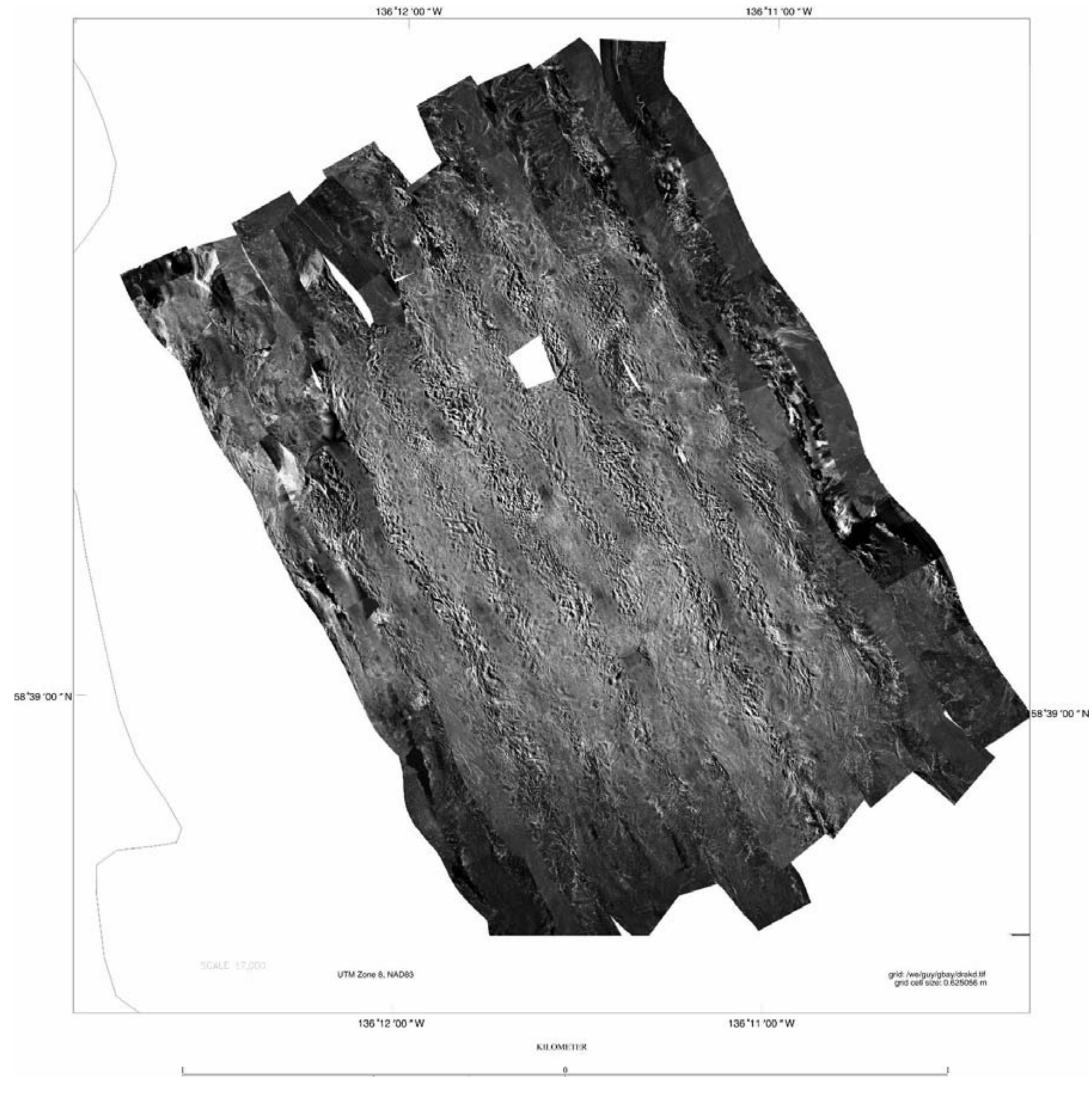

Fig. 3.2 Drake Island

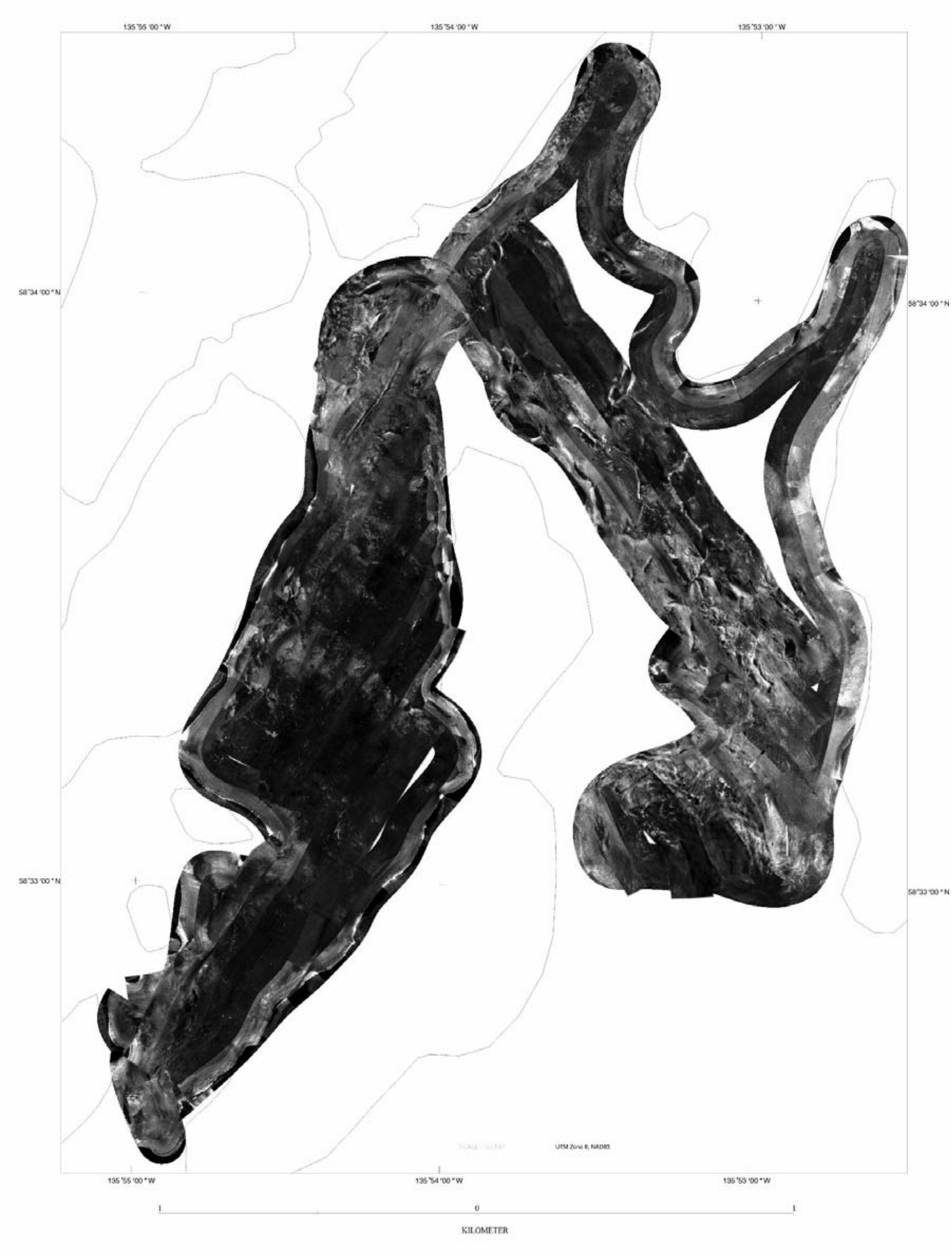

Fig. 3.3 Hutchins Bay

Fig. 3.4 Strawberry Island

Fig. 3.5 Bug Bay

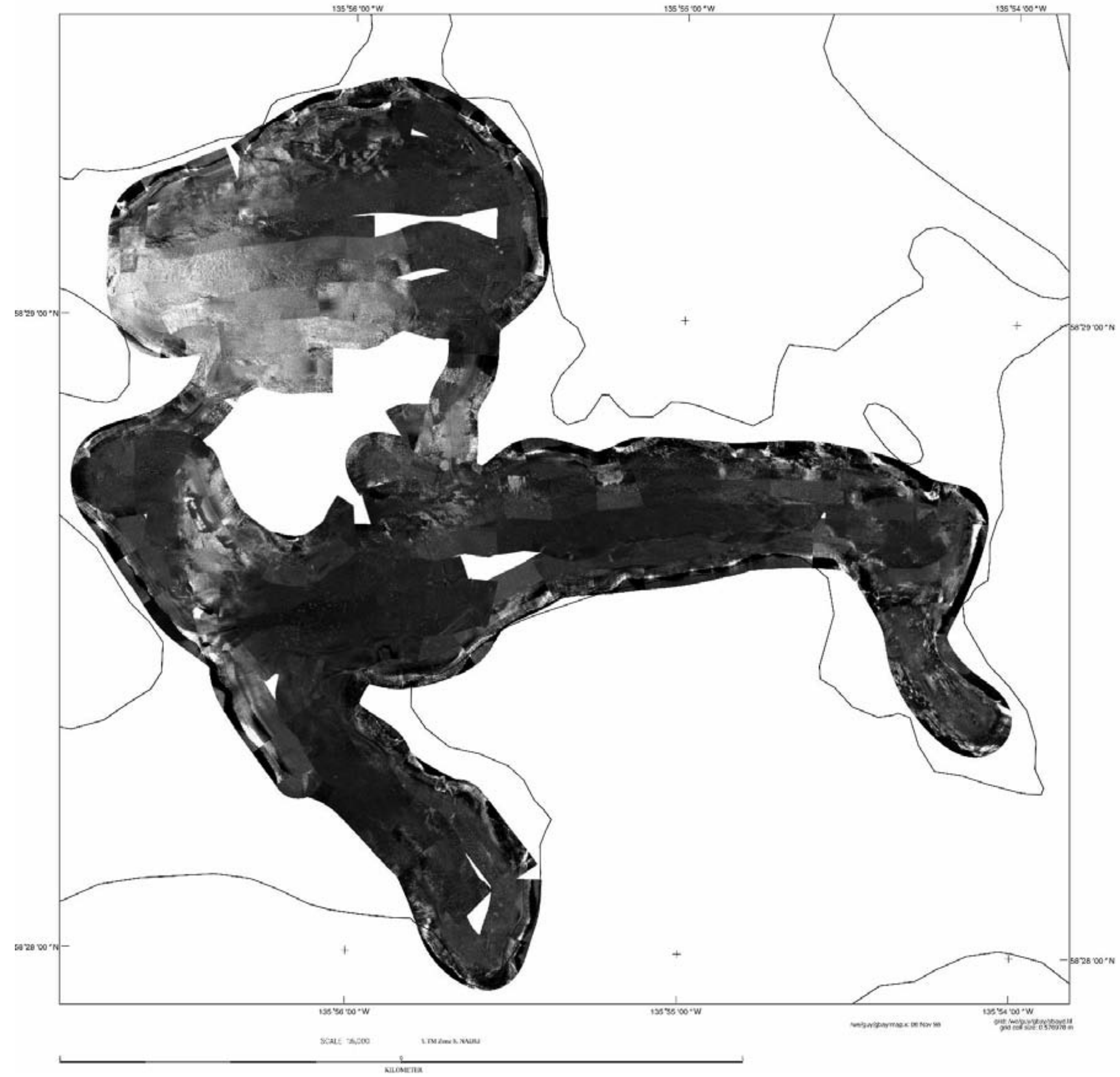

Fig. 3.6 Secret Bay

Fig. 3.7 Bartlett Cove

ANALYSIS OF SIDE SCAN IMAGERY (AN EXAMPLE)

In a future report, we will characterize the benthic habitat using a combination of the side-scan data, the profiling data, onshore geologic mapping by Brew et al. (1978), and previous marine geology work (e.g. Carlson et al., 1977; Cai et al., 1997). Final interpretations will be in the form of georeferenced habitat polygons which will be combined with the existing Geographic Information System (GIS) database (Geiselman et al., 1997). Our interpretation of the geophysical data will be based on the experience garnered in studying similar acoustic data from Glacier Bay and the Gulf of Alaska (e.g. Carlson et al., 1992, Carlson et al., 1980). We are using a variety of techniques (scuba, delta submersible, rebreathers, drop camera) to visually confirm our interpretation of the geophysical data. We plan to test the predictive value of the interpretation by conducting fish population studies in the areas where the geophysical data interpretations exist.

In this report we present an analysis of the sidescan image collected to the west of Strawberry Island (see above). Based on geologic mapping on Strawberry Island, we know that the surficial sediments are Quaternary age (Brew et al., 1978). Possible interpretations of the sidescan image include layered or structurally deformed bedrock, lateral moraines, or sediments grooved by the passage of large icebergs. A bedrock seafloor habitat will support a much different benthos than that supported by other adjacent bottom types including lateral moraines, or sediments grooved by the passage of large icebergs. Examination of the sub-seafloor seismic data (150 Kbytes)
shows a prominent sub-seafloor reflection which rules out exposed bedrock as a possible interpretation, except at two locations where the reflector may intersect the sea floor at distances of 7 m and 68 m. Samples of the rock are needed to define what geologic units underlie the onshore sediment. Sampling, planned next year, with closed-circuit diving equipment (i.e. rebreathers) may provide bedrock samples from the area.

The criss-crossing pattern of grooves seen in the sidescan image east of Strawberry Island rules out lateral moraines as an interpretation of the seafloor habitat. Our preferred interpretation of the data is that the seafloor is composed of coarse sediment grooved by the passage of large icebergs. The earliest period when large icebergs would have calved up stream of this area is when the glacier terminus was in the Strawberry Island area between 1794 and 1845 (American Geographical Society, 1966). Sediment grooving could have occurred in more recent times as icebergs calving further up stream passed Strawberry Island on their way south. Using the habitat characterization scheme of Greene et al. (1995), this habitat would be described as Intermediate shelf, grooved gravel and boulder, flat bottom, with probable winnowing by tidal and riparian currents.

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4. 1998 CRUISE REPORT: PHYSICAL CHARACTERISTICS OF DUNGENESS CRAB AND HALIBUT HABITATS IN WHIDBEY PASSAGE, ALASKA

August 19 through September 1, 1998
Glacier Bay, Alaska

Guy R. Cochrane[1]
Paul R. Carlson[1]
Michael E. Boyle[1]
Gregory L. Gabel[1]
Philip N. Hooge[2*]

Open-File Report 00-032

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Denali Park, AK 99755

Suggested citation:

Cochrane, G.R., P. R. Carlson, J. F. Denny, M. E. Boyle, and P. N. Hooge. 2000. Cruise Report R/V Tamnik Cruise T-1-98-GB, Physical Characteristics Of Dungeness Crab And Halibut Habitats In Whidbey Passage, Alaska, U.S. Geological Survey Open-File Report 00-032.

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DATA ACQUISITION AND PROCESSING

We used the M/V Tamnik, owned by the United States Geological Survey, Biological Resources Division, for our geophysical surveying. Combined side-scan-sonar imaging (side-scan) and seismic reflection profiling (profiling), and towed bottom camera work began on August 21 after two days of mobilization, and ended August 31 with one day of demobilization.

A Triton Elics Isis brand side-scan data recording system was used on the cruise, that simultaneously records 5 channels of data; port and starboard 100 KHz side-scan data, port and starboard 500 KHz side-scan data, and profiler data. Side-scan data shown in this report are 100 KHz data. Typically, 2048 samples were recorded per channel over a swath width of 200-400 m yielding a resolution of 0.1 - 0.5 m of seafloor area for the side-scan data. The resolution of the profiler data is 1 3 m of sub-bottom depth (with penetration of tens of meters in soft sediment and a few meters in harder sediment).

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ANALYSIS OF SIDE SCAN IMAGERY (AN EXAMPLE)

In a future report, we will characterize the benthic habitat using a combination of the side-scan data, the profiling data, onshore geologic mapping by Brew et al. (1978), and previous marine geology work (e.g. Carlson et al., 1977; Cai et al., 1997). Final interpretations will be in the form of georeferenced habitat polygons which will be combined with the existing Geographic Information System (GIS) database (Geiselman et al., 1997). Our interpretation of the geophysical data will be based on the experience garnered in studying similar acoustic data from Glacier Bay and the Gulf of Alaska (e.g. Carlson et al., 1992, Carlson et al., 1980). We are using a variety of techniques (scuba, delta submersible, rebreathers, drop camera) to visually confirm our interpretation of the geophysical data. We plan to test the predictive value of the interpretation by conducting fish population studies in the areas where the geophysical data interpretations exist.

We present a preliminary analysis of the sidescan image collected to the west of Willoughby Island (see above). Figure 4.2 shows a portion of the sidescan mosaic produced from the Whidbey passage data set. The criss-crossing pattern of grooves seen in the southern portion of the sidescan image is produced in coarse sediment by the passage of large icebergs similar to the area east of Strawberry Island (Cochrane et al., 1998). The earliest period when large icebergs would have calved up stream of this area is when the glacier terminus was in the area between 1794 and 1845 (American Geographical Society, 1966). Sediment gouging could have occurred in more recent times as icebergs calving further up stream passed Willoughby Island on their way south. A preliminary interpretation of the sidescan data is shown in figure 4.3. Using the habitat characterization scheme of Greene et al. (1995), this habitat would be described as Intermediate shelf, gouged gravel and boulder, flat bottom, with probable winnowing by tidal currents.

Based on geologic mapping of Brew et al. (1978), we know that bedrock (type 4, figure 4.3) in the area is Silurian/Devonian carbonate rock. Types 2 and 3 (figure 4.3) are differentiated on the basis of thickness of recent sediment covering the glacially modified seafloor. The Basin Slope habitat figure 4.3 is an area of steeply sloping seafloor at the western edge of the deeper bay waters.

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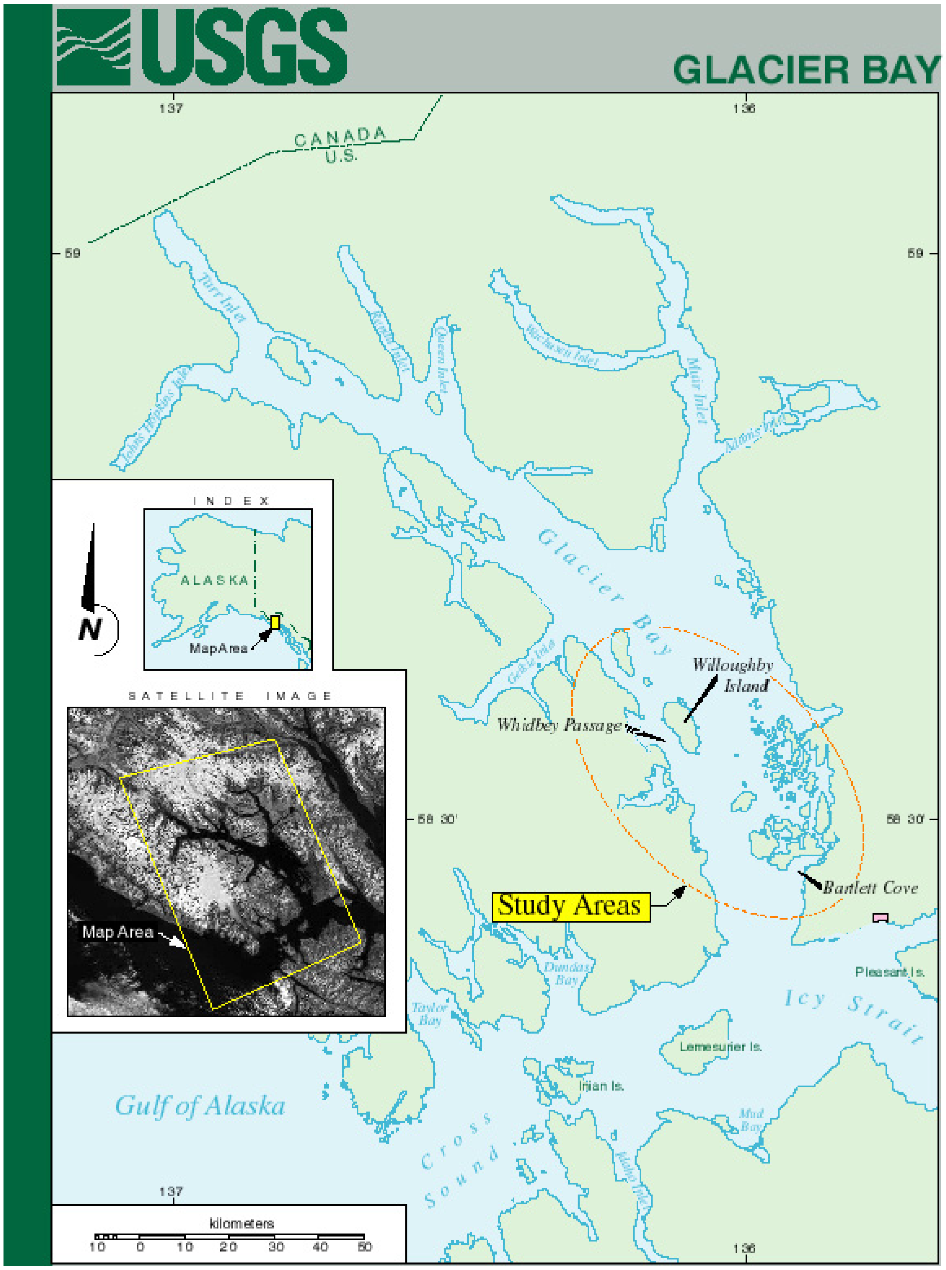
USGS
GLACIER BAY
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Tarr Inlet
Johns Hopkins Inlet
Reid Inlet
Queen Inlet
Wachusett Inlet
Muir Inlet
Adams Inlet
Glacier Bay
Geikie Inlet
Willoughby Island
Whidbey Passage
Study Areas
Bartlett Cove
58 30'
58 30'
INDEX
ALASKA
MapArea
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SATELLITE IMAGE
Map Area
Dundas Bay
Taylor Bay
Pleasant Is.
Icy Strait
Lemesurier Is.
Inian Is.
Mud Bay
Cross Sound
Idaho Inlet
Gulf of Alaska
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kilometers
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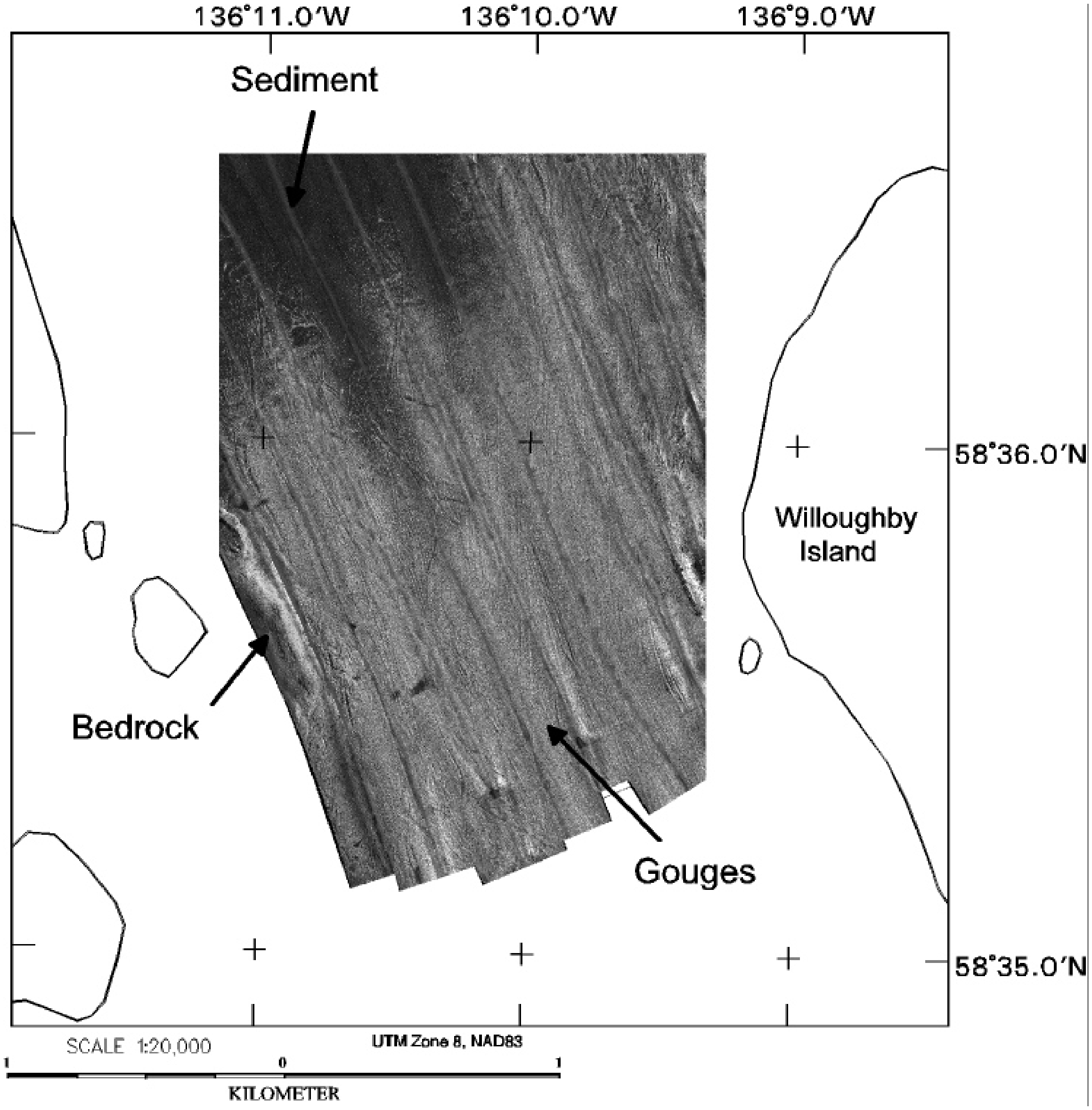
Fig. 4.1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136°10.0′W
136°9.0′W
Sediment
58°36.0′N
Willoughby Island
Bedrock
Gouges
58°35.0′N
SCALE 1:20,000
UTM Zone 8, NAD83
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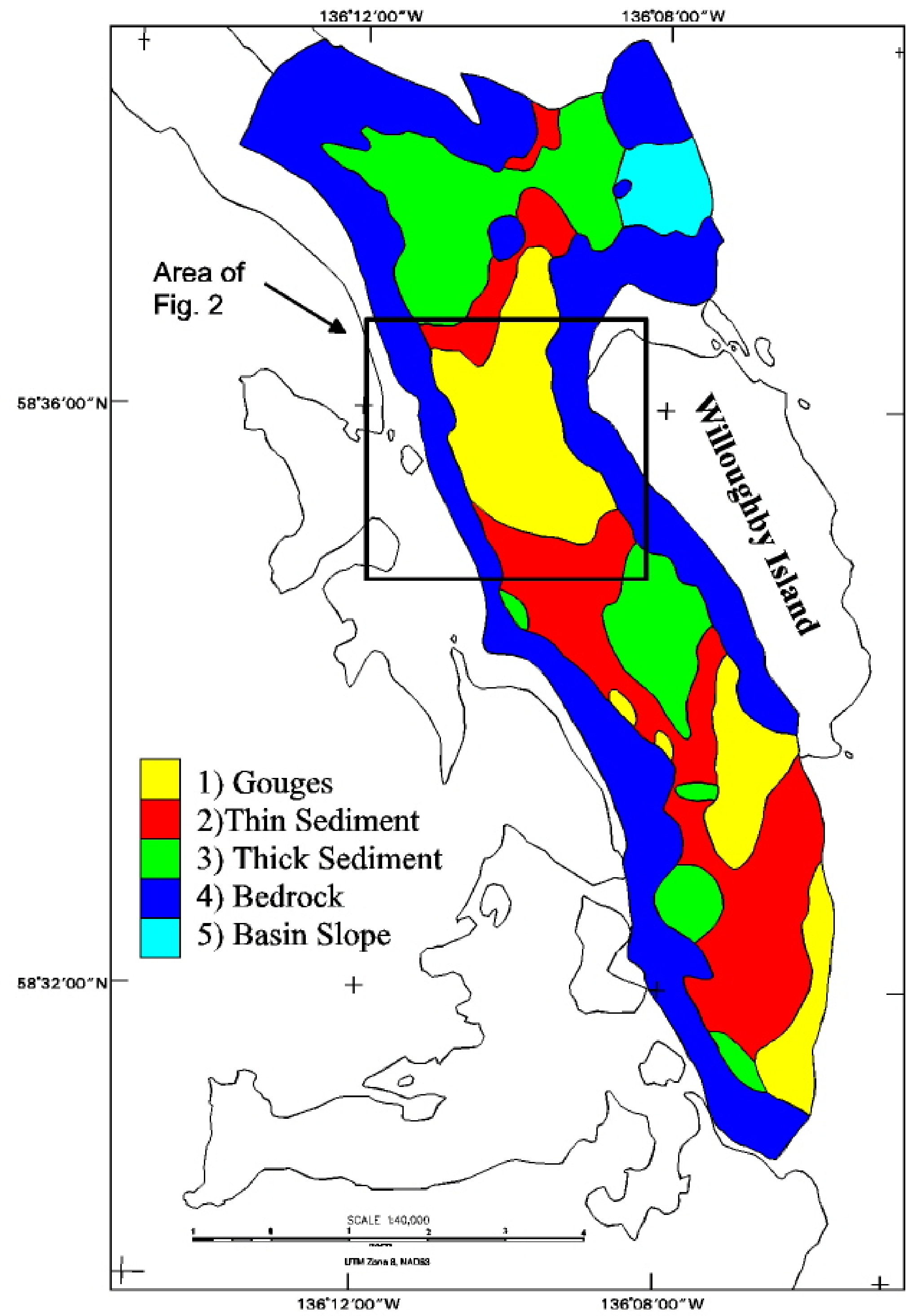
1
KILOMETER

Fig. 4.2


136°12′00″W
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Area of Fig. 2
58°36′00″N
58°36′00″N
Willoughby Island
1) Gouges
2)Thin Sediment
3) Thick Sediment
4) Bedrock
5) Basin Slope
58°32′00″N
58°32′00″N
SCALE 1:40,000
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2
3
4
UTM Zone 8, NAD83
136°12′00″W
136°08′00″W

Fig. 4.3

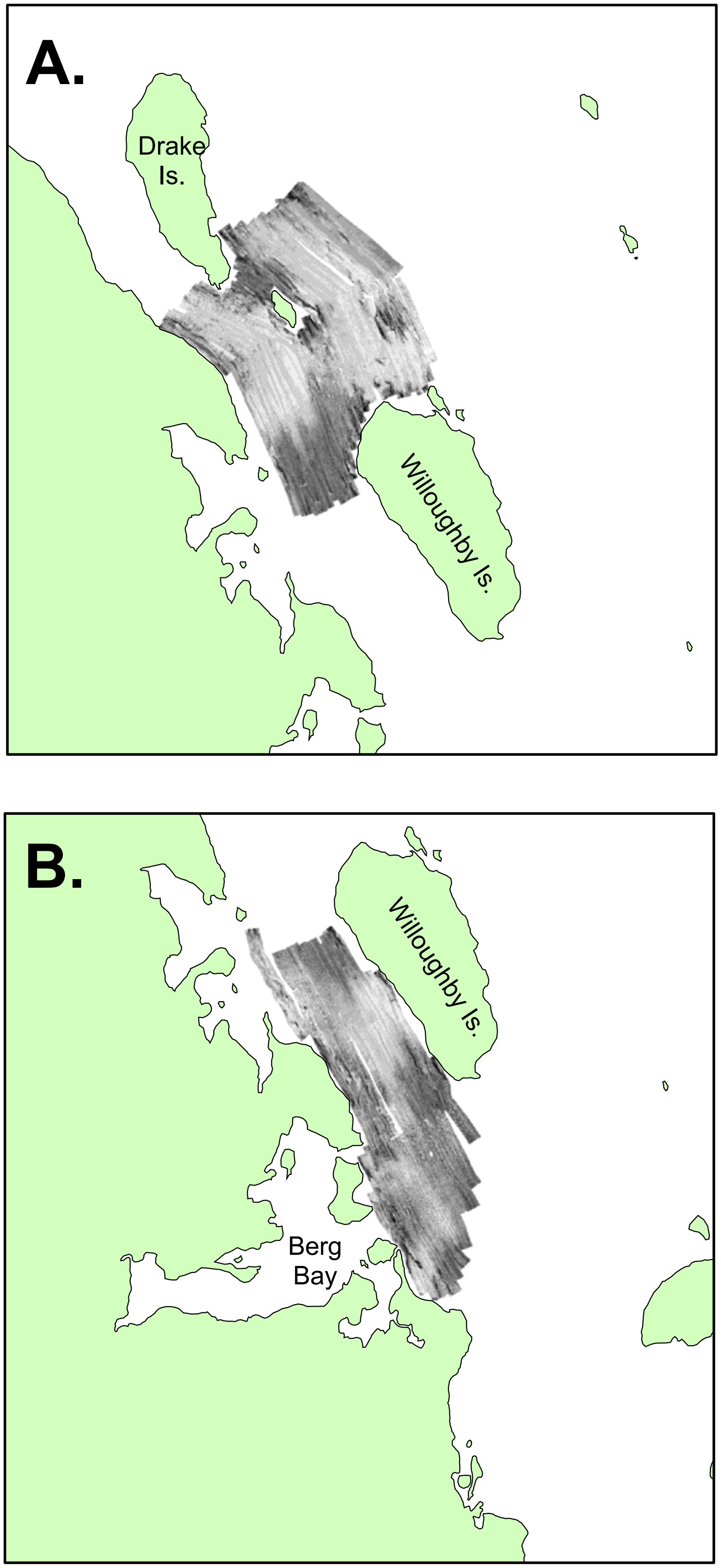

Fig 4.4. The sidescan sonar images from (A) north and (B) south Whidbey Passage that collected in 1998. Note: these images were not a part of the original 1998 cruise report, but were added here for completeness of this compliation report.

5. Data acquisition and processing report: Multibeam echosounding (Thales contractor)

UNITED STATES GEOLOGICAL SURVEY AND NATIONAL PARK SERVICE

GEOLOGICAL AND HABITAT MAPPING

DATA ACQUISITION AND PROCESSING REPORT

Thales Document No: TGP-2251-RPT-01-00

Applicable to:	**Thales GeoSolutions (Pacific), Inc.**
Controlled by:	**Survey Manager** **Thales GeoSolutions (Pacific), Inc.** **3738 Ruffin Road** **San Diego, CA 92123**
Telephone:	**(858) 292-8922**
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REPORT CERTIFICATION
FOR

UNITED STATES GEOLOGICAL SURVEY
AND
NATIONAL PARK SERVICE

GEOLOGICAL AND HABITAT MAPPING
2251

This issue of the report has been approved by:

1.	Project Manager	Robert Pawlowski	___________________________
2.	Survey Manager	William Gilmour	___________________________

This report has been distributed to:

1.	United States Geological Survey	1 Copy
2.	National Park Service	1 Copy
3.	Thales GeoSolutions (Pacific), Inc.	1 Copy

The following versions of this report have been issued:

0	03/10/01	Geological and Habitat Mapping	TG / DA	WG	RP
REV	DATE	DESCRIPTION	APPROVED		

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1. EQUIPMENT

The Data Acquisition and Processing Report describes the hardware and software configurations of the equipment used to perform the multibeam echosounder (MBES) survey at Glacier Bay. The R/V Davidson acquired all sounding data at Glacier Bay. The R/V Davidson was utilized for the collection of sound velocity profiles and multibeam data in shallow to medium water depths. An equipment list and vessel description are included in Appendix A and B, respectively.

The Glacier Bay survey was completed in 8 days, averaging 2.08 square kilometers per hour. Operations at Glacier Bay were conducted mostly in protected waters, providing an ideal sea state for the collection of MBES data. The weather was mild, with winds generally less than 15 knots and seas less than 1 meter. No time was lost to weather, although one survey area was re-arranged due to localized winds that measured 35 knots with gusts up to 50 knots. The currents at Sitakaday Narrows provided additional operational challenges requiring surveys to be completed during the minimum flooding period of currents on May 30.

There was no significant downtime accrued during the survey at Glacier Bay, as survey operations were completed without major impediment. Lost survey time associated with hardware and software was minimal. Intermittent losses of DGPS observations were encountered in isolated regions of the survey area, in particular, the areas around the eastern side of Glacier Bay, near Sturgess and Leland Islands. The loss of DGPS can be attributed to the masking of GPS signals, due to the mountainous terrain in those areas. Winfrog acquisition software caused some minor delays, as software crashes were experienced three times during the surveying of main scheme lines. The software failures required the vessel to break line, until the software returned online, upon which, the survey line was reacquired at the point of failure and the survey continued. Each software crash resulted in a loss of less than 15 minutes.

There were very few problems encountered during the processing of multibeam echosounder data. Any data gaps that occurred, such as those lines interrupted due to software failure and shoaling, the lines were resurveyed and fitted within the existing data set.

1.1. SOUNDING EQUIPMENT

The R/V Davidson provided the survey platform for the deployed Thales survey team and representatives from the US Geological Survey, Biological Resource Division as well as the Coastal and Marine Geology Team. The R/V Davidson was equipped with a hull mounted Reson SeaBat 8111 with option 033 (pseudo sidescan). The Reson 8111 system operates at a frequency of 100 kHz with a depth controlled ping rate. The signal is controlled through a Reson 81-P Sonar Processor. The Reson 8111 has 101 horizontal beams, centered 1.5B apart (150B across-track beam width) and has a 1.5B along-track beam width. It transmits and receives a sonar signal to measure the relative water depth over the 150B swath. The system was used in water depths ranging from 15 to 450 meters. The range scale, gain, power level, ping rates, etc. were a function of water depth and data quality. Any changes to these parameters were noted on the survey line logs (see Separate 1).

Average survey speeds at Glacier Bay were nominally 7.5 knots. Survey lines were orientated roughly parallel to the contours in the area. The line spacing depended on the water depth and data quality, but never exceeded three times the water depth. Survey line spacing did not include in-fill line spacing, as line spacing was determined on a feature by feature basis.

1.2. SONAR IMAGERY

No towed side scan sonar data was collected during survey operations at Glacier Bay. Although backscatter data was collected with the Reson 8111 Multibeam systems' option 033 (pseudo sidescan) to allow the creation of the imagery deliverables and to also facilitate the cleaning of bathymetry line data.

Backscatter data was collected at slant ranges up to the total range setting of the multibeam swath system.

The Reson 8111 multibeam sonar produces backscatter records along with range and angle packets used for bathymetry. The 8111 can generate backscatter in one of two distinct modes. For this survey, backscatter data was collected on a beam-by-beam basis. The backscatter from an individual beam is referred to as a snippet.

While a standard sidescan image is produced using one large beam on each side of the sonar, snippets are produced individually from each beam in the multibeam sonar. Snippets can be laced together, end to end, to produce a sidescan type image. The advantage in snippets stems form a large improvement in signal to noise ratio in the image, the result of using a focused beam rather than a broad beam to sample the backscatter.

Snippet data were logged in two formats during survey operations: raw snippets and combined snippets. Both data types are contained within the XTF files. Snippets are combined within the Reson 8111 processor to produce a sidescan like image of superior quality. The Reson 8111 combined snippets were used to produce the backscatter deliverables for this project. Processing software for the raw snippets is still under development.

1.3. POSITIONING EQUIPMENT

The R/V Davidson was equipped with NovAtel GPS antennas and multibeam computers with NovAtel GPS cards. The NovAtel GPS card is a twelve-channel GPS receiver that outputs a WGS84 geographical position and a One Pulse Per Second (1 PPS) timing stamp. The Winfrog Multibeam (WFMB) software package uses the 1 PPS output from the NovAtel card to continually synchronize the PC clock with GPS time.

Two MBX-3 differential receivers that used U.S. Coast Guard (USCG) network of differential beacons were used to supply RTCM corrections. Each MBX-3 receiver used a different USCG beacon, receiving Gustavus and Biorka Island respectively. For USCG beacon station information see the table below:

Table 1-1 USCG Beacon Information

USCG STATION	ID	LATITUDE	LONGITUDE	FREQ.	TX. RATE	RX. NO.
Gustavus	892	56.418333 N	135.696667 W	288 kHz	100 BPS	1
Biorka Island	890	56.855000 N	135.534722 W	305 kHz	100 BPS	2

WFMB was configured to write three separate positions into its .RAW data files. These were the 303 Pseudorange Console (PR-Console), the 303 Console (Console), and the 300 Davidson data files. The 303 records are always raw antenna positions and do not include vessel offsets or Kalman filtering. The 300 records include both antenna offsets and filtering.

The PR-Console and Console are independently calculated pseudorange positions. The PR-Console is generated by WFMB as a weighted arithmetic mean of the pseudorange positions calculated from the two Radio Technical Commission for Maritime Services (RTCM) sources listed above. The Console position is the pseudorange position calculated within the NovAtel card using a single RTCM source.

WFMB attached the PR-Console positions to the associated bathymetry data in the .XTF files. These positions were taken as a reasonable estimate of the true position and were checked against the Console and 300 Davidson positions at the end of every line for gross error. This method of positioning amounts to a real time verification of the RTCM sources since at least two RTCM sources would have to fail independently in a contrived manner to generate an erroneous position that appeared reasonable.

WFMB was configured to let the operator know when GPS positions were out of specified parameters. During periods of high Horizontal Dilution of Position (HDOP) (exceeding four) or when the number of satellites dropped below four, data acquisition stopped.

1.4. SOFTWARE

1.4.1. Acquisition

The primary data set of positions, attitudes and soundings were collected with Thales GeoSolutions (Pacific) Inc. Winfrog Multibeam (WFMB) integrated navigation software. WFMB operated on a Pentium based PC, running Windows NT and used a NovAtel GPS card for positioning. Digiboard serial interface cards were installed to provide serial ports for all devices.

The WFMB software package uses the 1 PPS output from the NovAtel card to continuously synchronize the PC clock with GPS time. During timing tests prior to the survey, WFMB was shown to have an approximate 4 millisecond RMS error between ping and attitude time stamps.

The following display windows are made available in WFMB for operators to monitor data quality:

1. Devices: The Devices window shows the operator which hardware is attached to the PC. It also allows the operator to configure the devices, determine whether they are functioning properly and view received data.
2. Graphic: The Graphic window shows navigation information in plan view. This includes vessel position, survey lines, background plots and charts.
3. Vehicle: The Vehicle window can be configured to show any tabular navigation information required. Typically, this window displays position, time, line name, heading, HDOP, speed over ground, distance to start of line, distance to end of line, and distance off line. Many other data items are selectable.
4. Calculation: The Calculation window is used to look at specific data items in tabular or graphical format. Operators look here to view 1 The accelerometer package for the TSS HDMS was mounted in the hull of the vessel just over the 8111 multibeam transducer head PPS performance, monitor nadir of MBES, the GPS satellite constellation, and positional solutions.
5. Waterfall: The Waterfall display can be configured to view backscatter, bathymetric or sidescan data.
6. Profile: The Profile window displays the current multibeam profile and vessel attitude.
7. Ping Scroller: The Ping Scroller window displays the current profile and a short history of profiles. The profile scrolls down the window and can be filtered by beam number and quality.
8. QC View: The QC View window displays binned soundings in plan view. The bin size is user defined and can be filtered by beam number and quality.
9. 3-D View: The 3-D window displays a 3-D mesh of the current line of profiles. The mesh can be rotated to a user-specified angle and can be exaggerated vertically.

Winfrog Multibeam writes Extended Triton Format (XTF), RAW, and DAT files to the hard disc. The XTF files contain all multibeam bathymetry, position, attitude and heading data required by CARIS to process the soundings, as well as the backscatter data required by Triton ISIS to process the pseudo sidescan. The RAW and DAT files contain position, RTCM, HDOP, attitude, heading data and event records. The DAT files were not used in the processing on this survey. The RAW files were used for positioning, heave, pitch and roll QC.

1.4.2. Processing

All soundings were processed using Universal Systems' CARIS Hydrographic Information Processing System (HIPS) and Hydrographic Data Cleaning System (HDCS) on Unix workstations (Sun Solaris V7) and an NT workstation. Processed soundings were then used to create the ASCII formatted data set listings and the sun illuminated Digital Terrain Models (DTM's) deliverables.

HPTools V 8.9.5 was used to calculate zoned tidal correctors using CARIS navigation files that were exported from CARIS NT.

AutoCAD Map R 3.0 was utilized for general survey planning, reviewing coverage plots, creating fill-ins and survey line re-runs, etc.

TritonElics ISIS V 5.0 and DelphMap V 2.5 were utilized for processing backscatter data used to create backscatter strength mosaics.

1.4.3. Sound Velocity Profiles

Sea-Bird CTD sound velocity profile data were acquired using SeaTerm V 1.2 and were processed with Thales GeoSolutions (Pacific) Inc.' SVP1 V 1.0 SVP processing software. Complete lists of software and versions used on this project are included in Appendix A.

2. QUALITY CONTROL

Multibeam soundings and backscatter data were acquired in XTF using WFMB. XTF data can be directly processed with the Triton ISIS software. In order for the XTF data to be used by CARIS HDCS and HIPS processing packages, it must be converted to HDCS format using the XTF to HDCS routine.

2.1. SOUNDINGS

Prior to each survey line being converted using the XTF to HDCS function, the vessel offsets, patch test calibration values, static draft and dynamic measurements were entered into the vessel configuration file. Once the data was converted, the SVP and static draft files were loaded into each line and then corrected in HDCS. The attitude, navigation and bathymetry data for individual lines were all examined for noise, as well as ensuring the completeness and correctness of the data set. Filter settings used during processing of the survey line data obtained with the 8111 were set to 65nadir. The 65nadir filter rejected beams greater than 65 degrees on either side of nadir. Note: Rejected does not mean the sounding data were deleted, the data was flagged as being rejected and could have been reinserted into the data set during HDCS line and subset editing. The filter setting used on each line was noted on each line log.

In high noise areas, additional filters may have been applied to specific screens or entire lines. In these instances, the additional filters are noted on the line logs.

After each individual line was examined and cleaned in HDCS swathEdit, the tide file was loaded and the lines merged. Subsets were created in CARIS HDCS Subset Edit mode and adjacent lines of data were examined to identify tidal busts, sound velocity errors, roll errors and clean any remaining noise.

Color and gray scale, sun illuminated DTM’s were then created in HIPS to aid in coverage and to help detect any errors in SVP, tides, heave, pitch and roll, etc. The DTM’s were created at the specified 5 meter and 10 meter grid intervals. The DTM’s were exported to a TIFF format and imported into AutoCAD for final review of coverage and systematic errors.

Statistical analysis of the sounding data was conducted via the CARIS Quality Control Report (QCR) routine. Tie lines were run in each Block, where applicable, and compared with the survey line data acquired from the mainline scheme. The Quality Control Reports are in Separate 3.

2.2. BACKSCATTER

Multibeam echo sounder and backscatter data were collected and initially processed onboard the acquisition vessel. Backscatter products were reviewed by the onboard client representatives and classified for bottom type, geologic characteristics, and physical structure. Initial sun enhanced imagery was provided onboard for the Glacier Bay area to ensure data quality.

Prior to processing, some adjustments had been made to the XTF files to ensure precise geo-encoding. The XTF files delivered with this project contain these modifications:

1. Sonar range information, stored in the Reson bathymetry packet, was copied to the sidescan channel header. This was required for processing the data in TritonElics Isis software.
2. The position recorded in the XTF file indicated the location of the GPS antenna. A position for the Reson 8111 head was calculated using offsets, from the antenna to the 8111, and vessel attitude (pitch, roll, and heading). The sonar head position was written into the XTF files, replacing the antenna position.

3. CORRECTIONS TO SOUNDINGS

3.1. SOUND VELOCITY PROFILES

Sound velocity casts were performed nominally every four to five hours. Water conditions began as isothermal and isohaline, enabling a constant sound velocity across the entire working area. After initially establishing the sound velocity trends throughout the survey area, sound velocity casts were reduced to intervals from six to ten hours, depending on tide, water depth and the beginning of a new survey area.

The Sea-Bird Model 19-03 Conductivity, Temperature and Depth (CTD) profiler with a WetStar fluorometer was used for determining sound velocities and indications of chlorophyll fluorescence. The acquired phytoplankton concentration data was processed by the onboard USGS personnel.

The SBE 19-03 delivered CTD samples at a rate of two samples-per-second. For each cast, probes were held at the surface for three minutes for temperature equilibrium. The CTD was then lowered and raised slowly (about 0.2 m/s) to maintain equilibrium. Between casts, the CTD were stored in a barrel of fresh water to minimize salt-water corrosion and to hold them at ambient water temperatures. Refer to Appendix C for Calibration Reports.

Sound velocity profiles were collected at the following times and locations for the Glacier Bay survey site:

Table 3-1 Sound Velocity Profiles for Glacier Bay Site

DATE	JD	TIME (UTC)	SVP FILE NAME	LATITUDE	LONGITUDE	DEPTH (m)
29/05/01	149	04:15	2001_149-0415.sv1	58.341764 N	136.020794 W	50
29/05/01	149	08:31	2001_149-0831.sv1	58.421917 N	135.966717 W	61
29/05/01	149	12:27	2001_149-1227.sv1	58.445389 N	135.958108 W	50
29/05/01	149	16:28	2001_149-1628.sv1	58.360100 N	135.951508 W	70
29/05/01	149	21:45	2001_149-2145.sv1	58.449203 N	136.000825 W	47
30/05/01	150	03:47	2001_150-0347.sv1	58.431608 N	136.009967 W	56
30/05/01	150	11:38	2001_150-1138.sv1	58.496019 N	136.059872 W	88
30/05/01	150	17:25	2001_150-1725.sv1	58.456381 N	136.019214 W	50
31/05/01	151	01:41	2001_151-0141.sv1	58.499331 N	136.058342 W	100
31/05/01	151	08:53	2001_151-0853.sv1	58.557744 N	136.116239 W	90
31/05/01	151	14:05	2001_151-1405.sv1	58.495725 N	136.073847 W	85
31/05/01	151	21:15	2001_151-2115.sv1	58.601233 N	136.171744 W	107
01/06/01	152	01:41	2001_152-0141.sv1	58.626392 N	136.159964 W	120
01/06/01	152	06:05	2001_152-0605.sv1	58.628181 N	136.215325 W	140
01/06/01	152	11:15	2001_152-1115.sv1	58.614436 N	136.149997 W	110

DATE	JD	TIME (UTC)	SVP FILE NAME	LATITUDE	LONGITUDE	DEPTH (m)
01/06/01	152	19:56	2001_152-1956.sv1	58.609469 N	136.086111 W	245
02/06/01	153	03:39	2001_153-0339.sv1	58.610792 N	136.097325 W	220
02/06/01	153	09:47	2001_153-0947.sv1	58.524600 N	135.972564 W	69
02/06/01	153	16:31	2001_153-0947.sv1	58.600844 N	136.079753 W	227
03/06/01	154	04:38	2001_154-0438.sv1	58.684892 N	136.315019 W	151
03/06/01	154	10:50	2001_154-1050.sv1	58.689939 N	136.278531 W	162
03/06/01	154	17:09	2001_154-1709.sv1	58.714711 N	136.268819 W	222
04/06/01	155	00:38	2001_155-0038.sv1	58.679150 N	136.177153 W	240
04/06/01	155	07:59	2001_155-0759.sv1	58.735331 N	136.185061 W	212
04/06/01	155	14:23	2001_155-1423.sv1	58.741322 N	136.173206 W	181
04/06/01	155	19:45	2001_155-1945.sv1	58.667058 N	136.023817 W	170
05/06/01	156	03:17	2001_156-0317.sv1	58.675461 N	135.997058 W	150
05/06/01	156	11:01	2001_156-1101.sv1	58.677650 N	136.024764 W	175
05/06/01	156	13:23	2001_156-1323.sv1	58.527314 N	135.977050 W	70
05/06/01	156	18:20	2001_156-1820.sv1	58.520211 N	135.962586 W	65
05/06/01	156	22:58	2001_156-2258.sv1	58.443397 N	136.006772 W	57

Individual SVP plots can be viewed in Separate 2.

The following graph is an example of sound velocity profiles showing raw data sets from two sound velocity probes in black and processed data in red and blue. Please note that CARIS HDCS has a 0.1 m resolution in depth and a 0.1 m/s resolution in velocity for its SVP calculations. Data was decimated to obtain these values for use in CARIS. The fat green line on the graph below shows the velocity step function that is used by CARIS in its constant velocity model. On all the following graphs, the red and blue lines trace the vertices of the velocity step function.

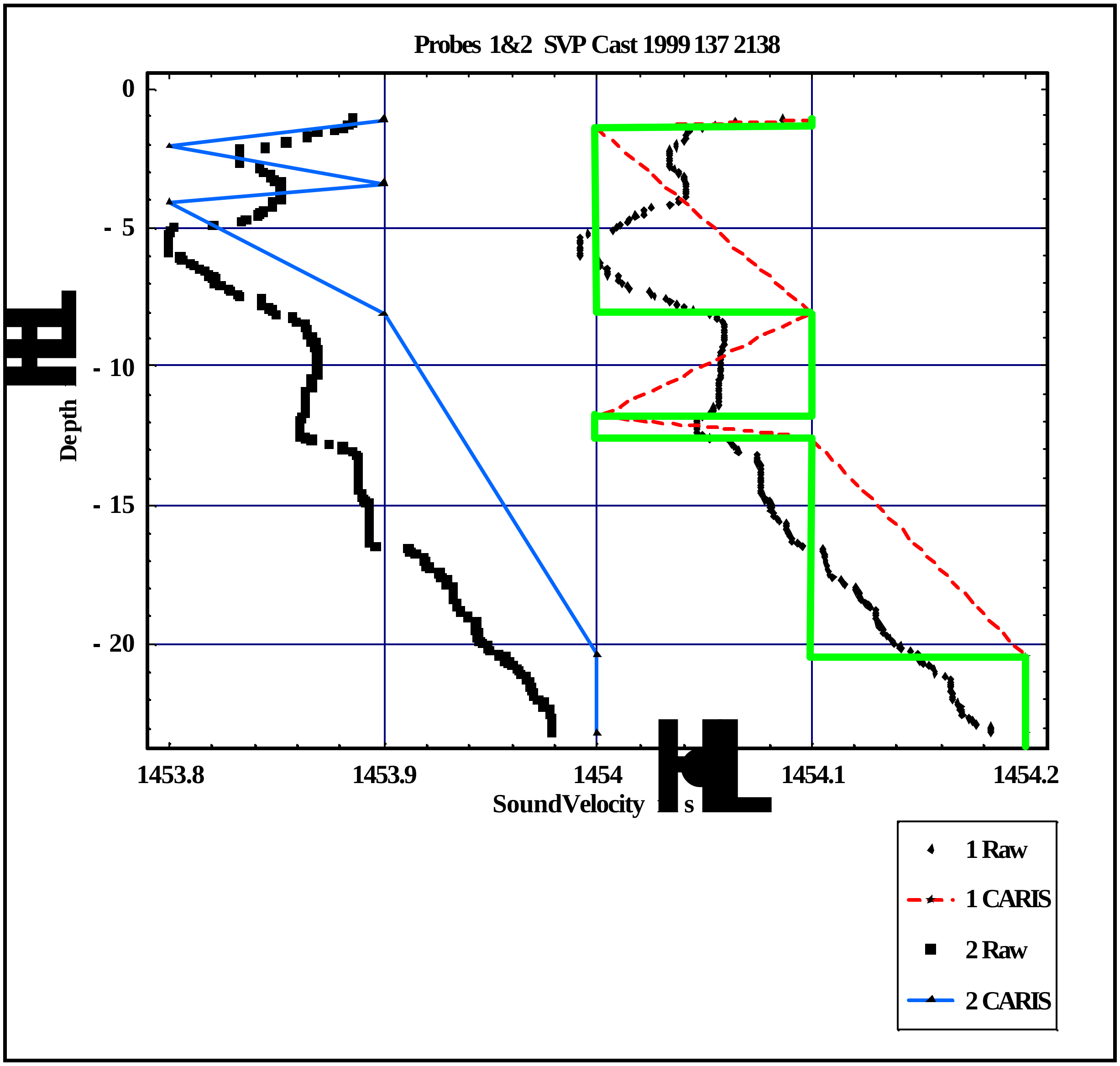

Figure 3-1 Sound Velocity Profiles

3.2. SETTLEMENT CURVE

To perform the squat settlement test, the R/V Davidson was equipped temporarily with Trimble RTK GPS equipment. The squat settlement tests were performed by first establishing a 500 meter line in the direction of the current. The survey vessel occupied the south end of the line for two minutes, logging RTK data. The line was then run heading north at 2 knots and then south at 2 knots. The survey vessel again occupied the south end of the line. This scenario was repeated at various speeds.

Measurements were reduced to the vessel's common reference point (CRP). Consequently, vessel squat had virtually no effect on transducer elevation. Static measurements at the end of the line were used to establish tidal correctors. All data sets were corrected for heave, pitch and roll and reduced to the vessel's CRP.

A settlement curve for the Davidson, with the Reson 8111 installed, was calculated from RTK GPS derived altitude data. The tests were conducted in Puget Sound, off the coast of Seattle on 14 May, 2001 (Julian Day 134). Trimble receivers were used at the base station and remote site. RTK positions and altitudes were logged using Winfrog Multibeam at one-second intervals.

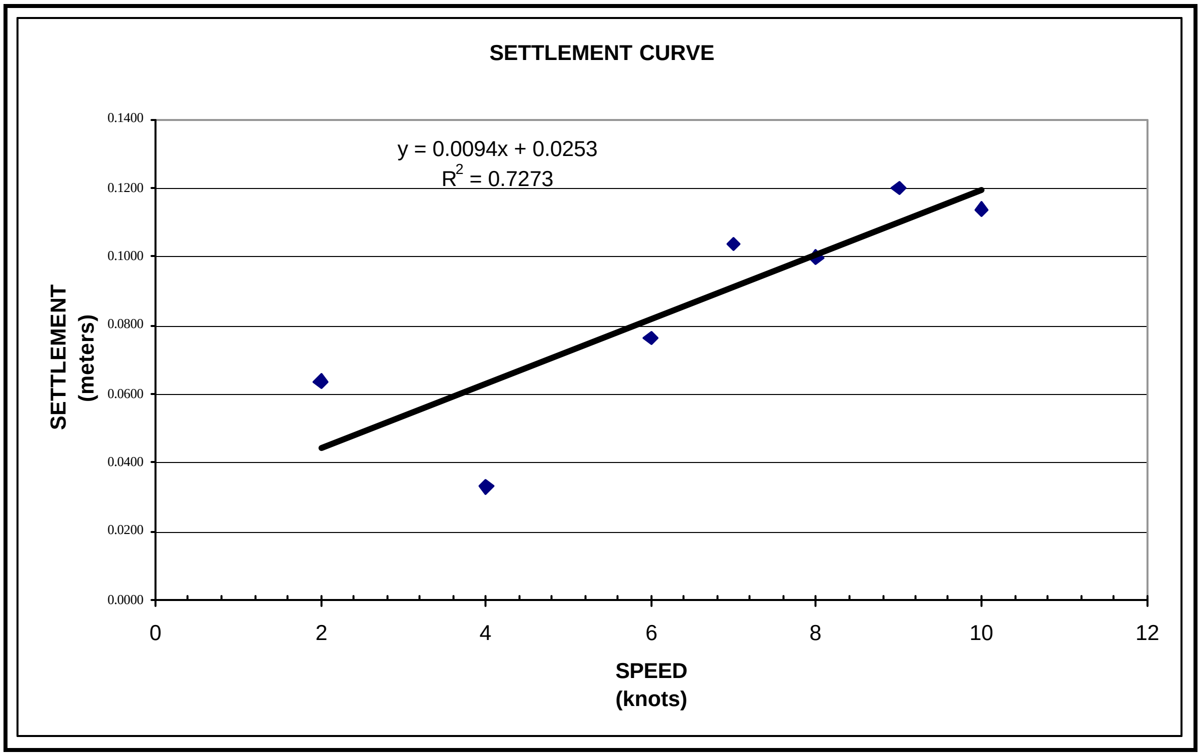

Figure 3-2 R/V Davidson and Reson 8111 Settlement Curve

The results of the squat settlement test for the Reson 8111 are shown in the following table:

Table 3-2 Calculated Settlement

SPEED (kts)	SETTLEMENT (m)
2	0.0635
4	0.0330
6	0.0763
7	0.1036
8	0.0998
9	0.1199
10	0.1138

Note: Vessel speed was noted on the survey line logs.

3.3. STATIC DRAFT

Static draft was measured from tabs on both sides of the vessel, the average was taken, and then the correction to the CRP was applied. The table below shows the draft values for the R/V Davidson used in data processing.

Table 3-3 Static Draft Measurements

Sample #	DATE (UTC)	JULIAN DAY	TIME (UTC)	PORT (m)	STBD (m)	DRAFT (m)
1	29/05/01	149	16:00	-2.16	-2.26	-2.21
2	30/05/01	150	18:25	-2.16	-2.21	-2.19
3	02/06/01	153	16:31	-2.18	-2.16	-2.17
4	03/06/01	154	17:09	-2.19	-2.17	-2.18

3.4. TIDES

Soundings were reduced to MLLW using verified tidal data from NOAA gauge at Juneau, AK. The tidal zoning correctors applied to each block are as follows:

Table 3-4 Tidal Zoning Correctors from Juneau, AK

ZONE	TIME	RANGE RATIO
G1	00:30:00	1.03
G2	00:27:00	0.99
G3	00:21:00	0.96
G4	00:15:00	0.93
G5	00:09:00	0.90

LCMF Inc. was contracted to provide final tidal zoning for the Glacier Bay survey area. The verified tidal data were then used to correct acquired bathymetric data. The limits of the tidal zones at Glacier Bay, as derived by LCMF, can be viewed in the following diagram:

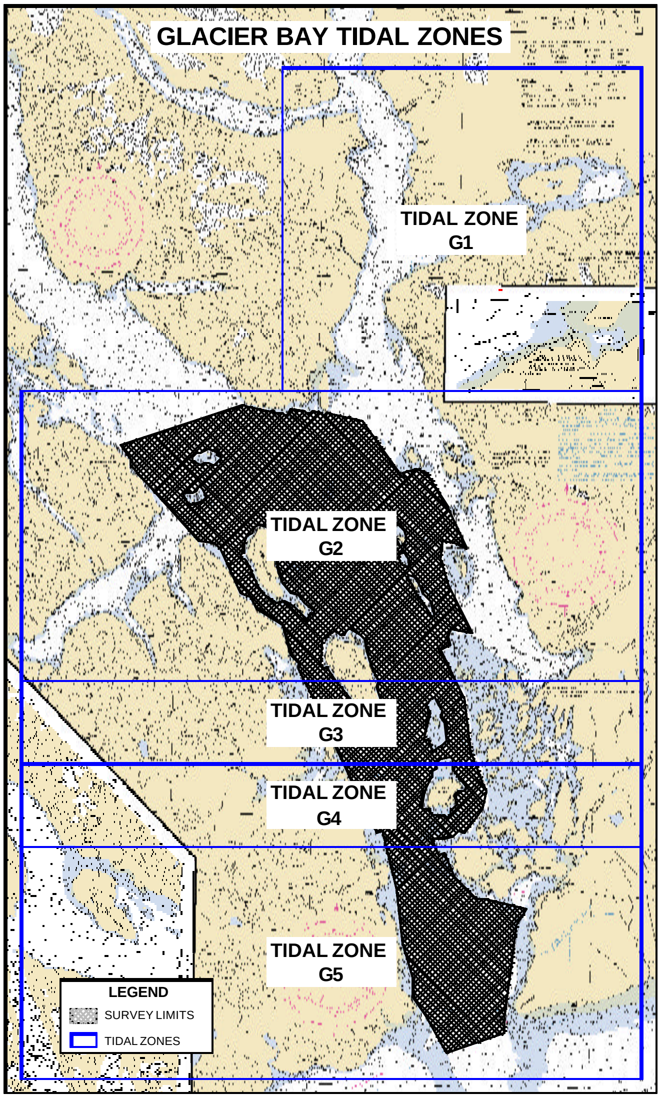

Figure 3-3 Glacier Bay Tidal Zones

3.5. VESSEL ATTITUDE: HEADING, HEAVE, PITCH, AND ROLL

Vessel heading and dynamic motion were measured by a SG Brown Meridian Surveyor Gyrocompass and TSS DMS2-05, respectively, for the Glacier Bay survey. A TSS HDMS system was maintained as a back-up system, but was not utilized due to recurring heading errors. The HDMS errors were associated with signal interference caused by the steep, mountain terrain and internal system problems, causing intermittent losses of signal.

The SG Brown Gyrocompass was permanently installed within the navigation room, behind the wheelhouse on the R/V Davidson. The TSS DMS2-05 accelerometer block was mounted in the hull of the vessel, slightly aft of the multibeam transducer.

The operational accuracy's for these systems, as documented by the manufacturers, is as follows:

Table 3-5 Heading and Dynamic Motion Sensor Accuracy's

DEVICE	MEASUREMENT	ACCURACY
TSS DMS2-05	Pitch and Roll	0.03°
TSS DMS2-05	Heave	5 cm or 5%
SG Brown Gyro	Heading	0.20°

The heave filter in the DMS2-05 was set to medium throughout the entire survey at Glacier Bay. The majority of survey lines were run with a 4 to 5 minute run-in to ensure that the heave sensor had stabilized. Unfortunately, 4 to 5 minute run-ins were not possible in some of the more aberrant and shallower areas.

The patch test calibration values used to reduce all soundings for the Glacier Bay survey were as follows:

Table 3-6 Patch Test Results, 26 May 2001

TEST	MEAN CORRECTION
Navigation Timing Error	0.00
Pitch Offset	0.80
Azimuth Offset	1.80
Roll Offset	1.60

3.6. BACKSCATTER

The digital backscatter data stored in XTF files were processed in Isis Sonar V 5.0 and DelphMap V 2.5. Each line was processed individually. The final mosaic was a merged image of all the individual lines. Notable aspects of the backscatter processing include:

1. Time Varied Gains (TVG) were set to compensate for signal strength variations resulting from power and gain adjustments to the 8111 and grazing angle.
2. Data from outer edges of the scans were clipped, where there was sufficient overlap, leaving only higher quality, near range data.
3. Vessel pitch was used to refine the position of each scan line on the seafloor during geo-encoding.

4. The mosaic was created on a DTM of the bathymetry. Typically, backscatter data is mosaicked using a flat seafloor assumption, resulting in across track errors in the imagery. For this project, the bathymetric DTM was used to refine the geo-referencing of the imagery resulting in a precise and accurate backscatter image of the seafloor.

Appendix A – Equipment List and Software Versions

Equipment

Table A-1 R/V Davidson Equipment

SYSTEM	MANUFACTURER	MODEL	SERIAL NO.
Multibeam Sounder	Reson	SeaBat 8111 Processor	23279
		SeaBat 8111 Transducer Array	Transmit/Receive 0100050/0700016
		8111 Firmware Dry: 8111-2.07-996C Wet: 8111-1.00-CA00	
DMS	TSS	DMS2-05	004104
Gyrocompass	SG Brown	Meridian Surveyor	2165
HDMS	TSS	IMU Processor V5.3/V3.0/V1.2	049 013
GPS Receivers	NovAtel	NovAtel GPS Card, PC Series	450017
GPS Receivers	NovAtel	NovAtel GPS Card, PC Series	96230005
CTD Profiler	Sea-Bird Electronics	SBE 19 Plus	193520-290
RTCM	CSI Inc.	CSI MBX-3	9830-2023-0001
RTCM	CSI Inc.	CSI MBX-3	9834-221-0002

Software

Winfrog Multibeam V 3.23 05/18/01

Winfrog V 3.1

HPTools V 8.9.5

CARIS UNIX V 4.3

CARIS NT V 5.1

World Tides 2001

MapInfo Professional V 5.0

AutoCAD Map Release 3

SeaSave Win32 V 1 .20

SeaTerm V 1.20

DATCNV V 4.248

SVP V1.0

Chart-X V 2.6

MicroStation SE V 05.07.01.14

Ribbit Cable & Pipe V 1.4

ArcView GIS V 3.2

POS/MV Controller V 3.0

TritonElics ISIS SONAR V 5.0

CARIS Version in Use

CARIS version 4.3 installed on 09-24-98.

UPDATES/PATCHES

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xtfToHDCS	-updated 09-24-98
ConvertToHDCS	-updated 09-24-98
hdcs	-updated 09-24-98
hdcsLineMerge	-updated 09-24-98
resontoHDCS	-updated 09-24-98
ConvertToHDCS	-updated 01-21-99
HDCS	-updated 01-21-99
ProgramSettings	-updated 01-21-99
hdcs	-updated 01-21-99
hdcsLineMerge	-updated 01-21-99
xtfToHDCS	-updated 01-21-99
bin/refohdcs	-updated 03-18-99
bin/swathedit	-updated 03-18-99
cld/refohdcs	-updated 03-18-99
refohdcs.com	-updated 03-18-99
refohdcscl.com	-updated 03-18-99
refomany.com	-updated 03-18-99
refomanycl.com	-updated 03-18-99
refohdcs.frm	-updated 03-18-99
refohdcscl.frm	-updated 03-18-99
refomany.frm	-updated 03-18-99
refomanycl.frm	-updated 03-18-99
sys/makehist.cla	-updated 12-06-99
sys/SWATHEDIT	-updated 03-18-99
hips/bin/hdcs	-updated 04-01-99
hips/bin/hdcsLineMerge	-updated 04-01-99

hips/bin/xtftoHDCS	-updated 04-01-99
hips/bin/suppsoun	-updated 03-23-01
hips/sys/HDCS	-updated 04-01-99
hips/sys/ConvertToHDCS	-updated 04-01-99
hips/sys/programSettings	-updated 04-01-99
hips/form/export_dxf.frm	-updated 04-01-99
hips/com/export.com	-updated 04-01-99
hips/com/DXFcorrect.awk	-updated 04-01-99
caris/bin/sun4_2/cared.x	-updated 05-13-99
caris/system/msgfil.dat	-updated 05-13-99
bin/makehist	-updated 06-15-01

Appendix B – Vessel Descriptions

R/V Davidson

The R/V Davidson is a 153 foot 833 GRT survey vessel capable of extended duration offshore survey operations (see Figure B-1). The R/V Davidson accommodates a vessel and survey crew, acquisition hardware, and the processing center for reducing acquired data to field quality products. Additional information about the R/V Davidson can be seen in the table below:

Figure B-1 R/V Davidson

Table B-1 R/V Davidson Specifications

SURVEY LAUNCH	R/V DAVIDSON
Official Number	D1066485
Owner	Venture Pacific Marine Inc.
Year Built	01/02/67
Length	153 ft
Beam	38 ft
Draft	17.75 ft
Gross Ton	250
Net Ton	833
Power	1800 hp

Prior to operations, the keel was cut just aft of mid-ship and the Reson 8111 multibeam sonar was mounted in a 24 inch pipe tapered cowling on the hull (see Figure B-2). The conical cowling protected the sonar head, forward and aft, by a crescent shaped skid. The accelerometer package for the TSS DMS2-05 was mounted in the hull of the vessel just aft of the 8111 multibeam transducer head.

Figure B-2 Hull Mounted Reson 8111

Three NovAtel antennas were mounted on the ship's mast for positioning and heading. The central antenna was used for vessel position. The two HDMS antennas were offset 2.0 meters, fore and aft, of one another. The forward antenna functioned as the HDMS master antenna while the aft antenna functioned as the HDMS secondary (see Figure B-3). A spare NovAtel GPS antenna was mounted between two differential antennas behind the ship's mast (see Figure 3-1).

The SBE CTD was deployed from an A-Frame on the stern using a hydraulic line hauler.

Figure B-3 Primary GPS and HDMS Antennas

Figure B-4 Spare GPS and Differential Antennas

Offsets are used in Winfrog for display purposes only. Offset values were applied to the data in CARIS HDCS as specified in the vessel configuration file. The vessel offsets used are shown in the following table:

Table B-2 R/V Davidson Vessel Offsets

FROM	TO	X	Y	Z
CRP	DMS2-05 Motion Sensor	0.010	-2.62	-2.310
CRP	8111 Transducer	0.000	0.000	2.040
CRP	Primary Navigation GPS Antenna	0.010	3.820	-23.280
CRP	Backup Navigation GPS Antenna	0.050	-5.950	-14.360
CRP	HDMS Master Antenna	0.150	5.070	-23.450
CRP	HDMS Slave Antenna	0.150	3.070	-23.450
CRP	HDMS Accelerometer	0.000	0.000	0.000
CRP	Draft Measuring Point, Port	-5.790	0.000	-5.260
CRP	Draft Measuring Point, Starboard	5.790	0.000	-5.280

Note: All units are meters.

Axis used: X positive toward starboard
Y positive toward bow
Z positive into the water

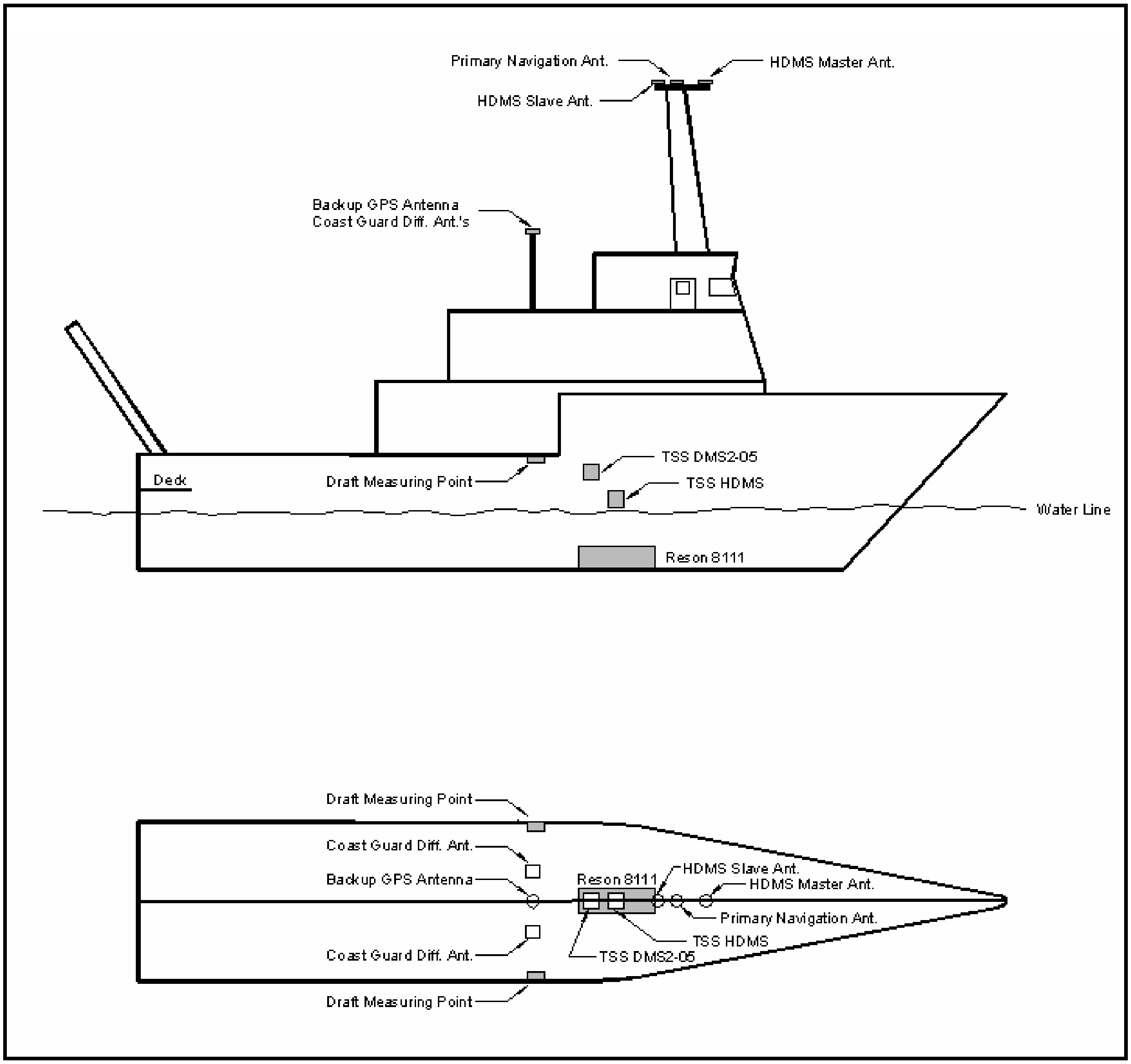

Figure B-5 R/V Davidson Equipment Layout

Appendix C – Calibration Data

6. Descriptive report: Multibeam echosounding

(Thales contractor)

UNITED STATES GEOLOGICAL SURVEY AND NATIONAL PARK SERVICE

GEOLOGICAL AND HABITAT MAPPING

DESCRIPTIVE REPORT

Thales Document No: TGP-2251-RPT-01-00

Applicable to:	**Thales GeoSolutions (Pacific), Inc.**
Controlled by:	**Survey Manager** **Thales GeoSolutions (Pacific), Inc.** **3738 Ruffin Road** **San Diego, CA 92123**
Telephone:	**(858) 292-8922**
Facsimile:	**(858) 292-5308**

REPORT CERTIFICATION
FOR

UNITED STATES GEOLOGICAL SURVEY
AND
NATIONAL PARK SERVICE

GEOLOGICAL AND HABITAT MAPPING
2251

This issue of the report has been approved by:

1.	Project Manager	Robert Pawlowski	______________________________
2.	Survey Manager	William Gilmour	______________________________

This report has been distributed to:

1.	United States Geological Survey	1 Copy
2.	National Park Service	1 Copy
3.	Thales GeoSolutions (Pacific), Inc.	1 Copy

The following versions of this report have been issued:

0	03/10/01	Geological and Habitat Mapping	TG / DA	WG	RP
REV	DATE	DESCRIPTION	APPROVED		

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1. Acquisition and Processing Logs
2. Sound Velocity Profile Data
3. Crossline Comparisons
4. Miscellaneous Logs
5. Charts, Plots, and Graphics

1. AREA SURVEYED

Thales GeoSolutions (Pacific), Inc. was contracted by United States Geological Surveys and National Park Service to perform a detailed multibeam echosounder survey at Glacier Bay under Alaska Department of Fish and Game contract number IHP-01-091. The survey required digital, high-resolution multibeam bathymetry along with calibrated backscatter in the area.

The Glacier Bay survey area was located in Southeast Alaska, and was comprised of a series of open water areas, interspersed with shoals and islands. The survey covered an area of 425 square kilometers, in water depths of approximately 15 to 450 meters. The bathymetry at Glacier Bay is marked by deep channels between steep sloped islands of elevations greater than 1000 meters, glacial moraines, and numerous offshore rocks, shoals and islets. The survey area covered waters south of the fork between Muir Inlet and the west fork of Glacier Bay extending south into Icy Strait. The survey area at Icy Strait overlapped the 1999 NOAA hydrographic survey H10883.

Glacier Bay survey operations began on May 29, 2001 and ended on June 6, 2001.

The Glacier Bay site is bounded by the coordinate listing below:

Table 1-1 Glacier Bay Survey Limits

Point	Latitude	Longitude
1	58.353524 N	136.000731 W
2	58.375332 N	136.023369 W
3	58.388489 N	136.040550 W
4	58.400751 N	136.041860 W
5	58.420821 N	136.053762 W
6	58.455000 N	136.061667 W
7	58.490466 N	136.080981 W
8	58.489330 N	136.088106 W
9	58.497405 N	136.092977 W
10	58.504627 N	136.090495 W
11	58.512195 N	136.095488 W
12	58.520102 N	136.108789 W
13	58.519004 N	136.116635 W
14	58.543200 N	136.137450 W
15	58.546676 N	136.132633 W
16	58.553172 N	136.135801 W
17	58.556240 N	136.139818 W
18	58.561845 N	136.147157 W

Point	Latitude	Longitude
19	58.564649 N	136.150934 W
20	58.569868 N	136.164396 W
21	58.589344 N	136.182406 W
22	58.593493 N	136.181578 W
23	58.598046 N	136.190954 W
24	58.617534 N	136.203543 W
25	58.626829 N	136.233212 W
26	58.633075 N	136.242503 W
27	58.635659 N	136.252814 W
28	58.662074 N	136.276878 W
29	58.667145 N	136.287034 W
30	58.667380 N	136.303262 W
31	58.713695 N	136.387496 W
32	58.717564 N	136.386974 W
33	58.725704 N	136.399433 W
34	58.751667 N	136.255000 W
35	58.750568 N	136.247736 W
36	58.747947 N	136.213888 W
37	58.748144 N	136.207196 W
38	58.745332 N	136.201679 W
39	58.749743 N	136.197980 W
40	58.749159 N	136.180806 W
41	58.746946 N	136.177525 W
42	58.748051 N	136.173697 W
43	58.748881 N	136.172670 W
44	58.748491 N	136.161255 W
45	58.746521 N	136.158253 W
46	58.747438 N	136.155449 W
47	58.748158 N	136.154958 W
48	58.743628 N	136.110943 W
49	58.708965 N	136.063961 W
50	58.709673 N	136.059319 W
51	58.712245 N	136.062085 W
52	58.715091 N	136.047707 W
53	58.712411 N	136.033547 W
54	58.691751 N	136.009136 W
55	58.689731 N	136.008558 W
56	58.666451 N	135.985301 W
57	58.669204 N	135.999679 W
58	58.670040 N	136.014738 W
59	58.659162 N	136.015354 W
60	58.643018 N	136.007220 W
61	58.612942 N	135.977972 W

Point	Latitude	Longitude
62	58.615341 N	136.001918 W
63	58.611310 N	136.006758 W
64	58.605456 N	136.004338 W
65	58.603751 N	136.011953 W
66	58.603372 N	136.015509 W
67	58.572916 N	135.985571 W
68	58.540086 N	135.976221 W
69	58.520473 N	135.960671 W
70	58.515537 N	135.957704 W
71	58.504900 N	135.963022 W
72	58.489960 N	135.981848 W
73	58.490702 N	135.989384 W
74	58.487786 N	135.995799 W
75	58.486637 N	136.006466 W
76	58.485986 N	136.021350 W
77	58.475812 N	136.013301 W
78	58.476593 N	136.006130 W
79	58.463052 N	135.994036 W
80	58.448988 N	135.967125 W
81	58.448895 N	135.956345 W
82	58.443456 N	135.907622 W
83	58.433333 N	135.918333 W
84	58.376727 N	135.932565 W
85	58.366667 N	135.931667 W

The following diagram illustrates the extents of the Glacier Bay survey:

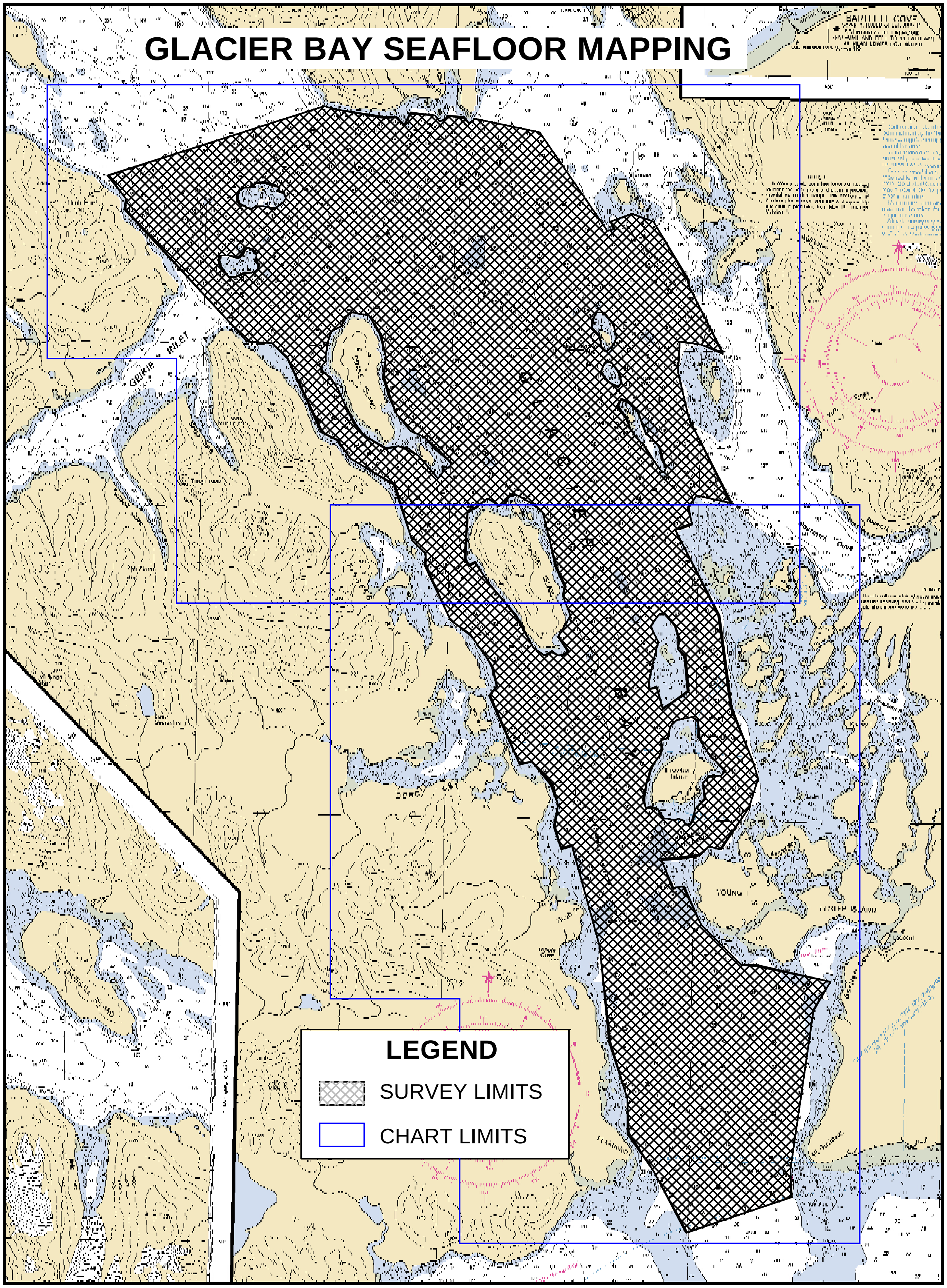

Figure 1-1 Glacier Bay Survey Extents

2. DATA ACQUISITION & PROCESSING

Refer to the TGP-2251-RPT-01-00 Data Acquisition and Processing Report for a detailed description of all equipment, survey vessels, processing procedures and quality control features. Items specific to this survey and any deviations from the Data Acquisition and Processing Report are discussed in the following sections.

2.1. EQUIPMENT & VESSELS

The R/V Davidson acquired all sounding data at Glacier Bay. The Davidson, which is 153 feet in length with a draft of 17.75 feet, was equipped with a Reson 8150 and 8111 for medium to deep-water multibeam data acquisition. For the Glacier Bay survey, multibeam data was acquired exclusively with the Reson SeaBat 8111 (Processor S/N 23279 and Transducer Array S/N Transmit 0100050 Receive 0700016) with option 033 (pseudo side scan). Vessel heading and attitude were measured using a SG Brown Meridian Surveyor Gyrocompass and TSS Dynamic Motion Sensor DMS2-05, respectively. XTF files were logged in Winfrog Multibeam V 3.23 05/18/01. The multibeam computer was equipped with a twelve channel NovAtel GPS receiver card; that output a WGS84 geographical position and a One Pulse Per Second (1 PPS) timing stamp. The Davidson was also equipped with a Sea-Bird CTD (SBE 19 Plus SN 290) for sound velocity profiles.

Refer to TGP-2251-RPT-01-00 Data Acquisition & Processing Report for a complete listing of equipment and vessel descriptions.

2.2. QUALITY CONTROL

2.2.1. Crosslines

The Glacier Bay survey area was divided into fourteen blocks to ease survey operations. Quality control tie lines were planned to measure 5 percent of the main scheme line length. Because of the irregular shapes of the survey blocks, 15 tie lines were surveyed across the blocks. The total cross line length was 66.4 km (35.9 nautical miles) or 4.7 percent of the total main scheme miles. A total of 57 tie line crossings were examined using the CARIS HIPS Q/C report. The majority of QC tie lines passed the specified vertical accuracy of IHO Order 1 hydrographic surveys, at the 95 percent confidence level. A listing of those cross lines that did not pass at the 95 percent confidence level is given in the following table:

Table 2-1 CARIS QC Failed Beams

CARIS QC FILE	TIE LINE	SURVEY LINE	# OF FAILED BEAMS
gb_qc021	GB-06-TIE01	GB-06-00690	38
gb_qc022	GB-07-TIE01	GB-07-00700	4
gb_qc023	GB-07-TIE02	GB-07-00950	32
gb_qc024	GB-08-TIE01	GB-08-02200	12
gb_qc025	GB-08-TIE01	GB-08-01750	10
gb_qc026	GB-08-TIE01	GB-08-01000	37
gb_qc027	GB-08-TIE02	GB-08-00400	45
gb_qc030	GB-09-TIE02	GB-09-03550	3
gb_qc031	GB-09-TIE02	GB-09-00600	19
gb_qc036	GB-10-TIE01	GB-10-04120	2
gb_qc039	GB-12-TIE02	GB-11-FILL14	10
gb_qc040	GB-12-TIE02	GB-11-08250	5
gb_qc042	GB-12-TIE02	GB-11-03600	13
gb_qc044	GB-12-TIE01	GB-11-01920	36
gb_qc045	GB-12-TIE01	GB-11-03900	10
gb_qc046	GB-12-TIE01	GB-11-05300	22
gb_qc047	GB-12-TIE01	GB-11-08250	4
gb_qc048	GB-12-TIE01	GB-11-10200	4
gb_qc050	GB-12-TIE02	GB-12-02610	6
gb_qc051	GB-12-TIE02	GB-12-00350	23
gb_qc052	GB-12-TIE02	GB-11-12880	18
gb_qc054	GB-13-TIE02	GB-13-01700	18
gb_qc055	GB-13-TIE02	GB-13-00350	33
gb_qc056	GB-13-TIE01	GB-13-00500	1
gb_qc057	GB-13-TIE01	GB-13-01940	39

Note: The QC reports were generated based on the given accuracy specification of:

$$\pm\sqrt{[a^2+(b*d)^2}$$

Where:

a = 0.5,
b = 0.013 and,
d = depth.

However, since a variance of a difference, rather than a variance from a mean is being used, the a and b values defined in the makehist.cla file within CARIS will use:

$$a = 0.5*\sqrt{2} = 0.707$$
$$b = 0.013*\sqrt{2} = 0.018$$

The majority of QC failures can be attributed to the accuracy and repeatability of the DGPS horizontal positioning and the steep slopes of the Glacier Bay basin (see Figure 2-1, Figure 2-2, and Figure 2-3). The accuracy of a typical DGPS unit is between 1 to 3 meters, and with the intermittent coming and going of satellites in Glacier Bay; it was not uncommon to get a 1 to 3 meter navigation jump. Although a navigation error of this magnitude is well within NOS horizontal accuracy specifications, the associated depths for those positions may fall outside the vertical accuracy specifications. Figure 2-4 shows graphically how navigation errors affect vertical errors and how rapidly they can both affect the specified survey accuracy. For example, with a 1.5 meter navigation error at a water depth of 25 meters, and a bottom sloping more than 20 degrees, the majority of the beams can fall outside of the 95 percent confidence level.

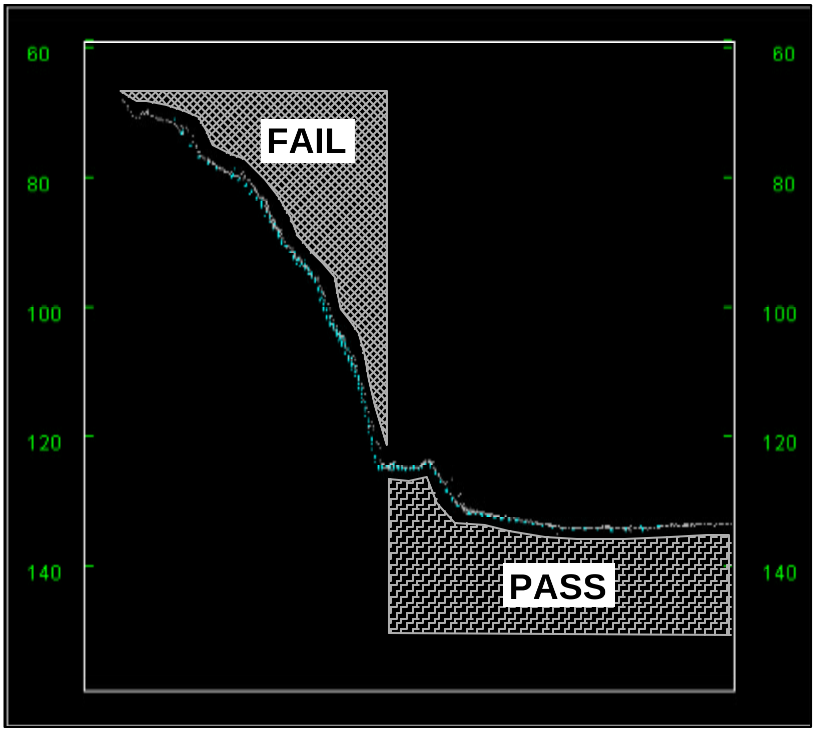

Figure 2-1 QC Report 21 Cross-section

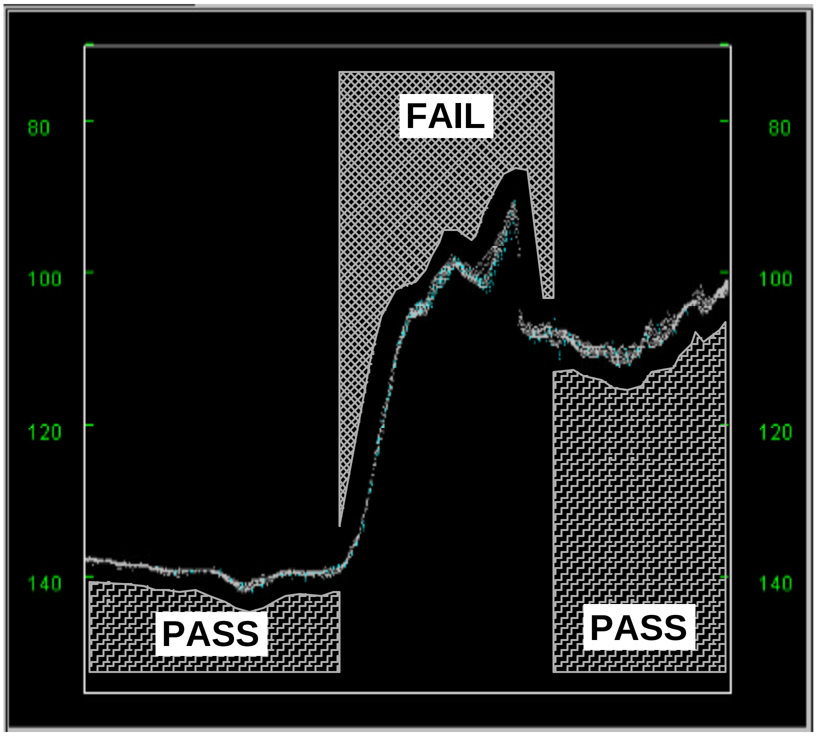

Figure 2-2 QC Report 23 Cross-section

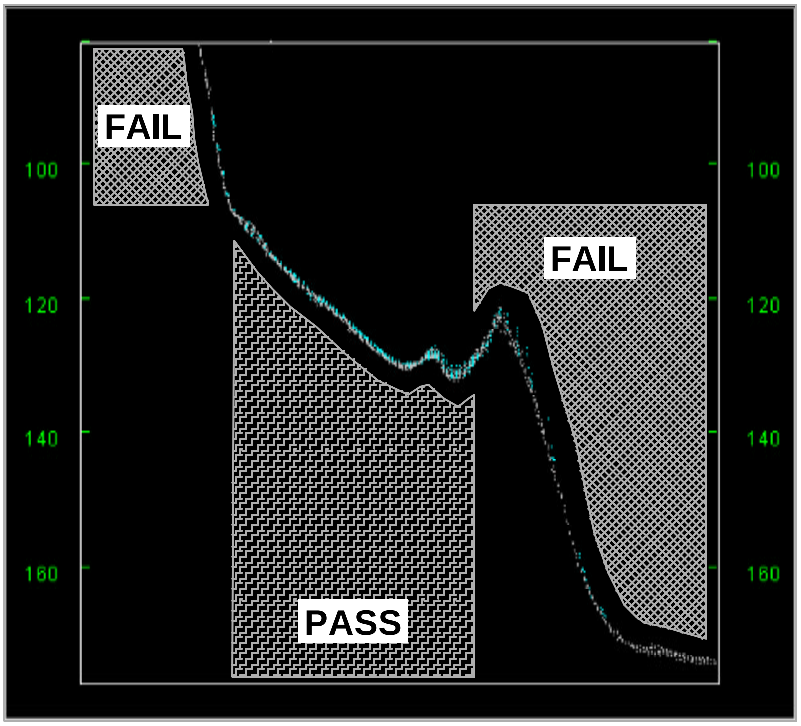

Figure 2-3 QC Report 55 Cross-section

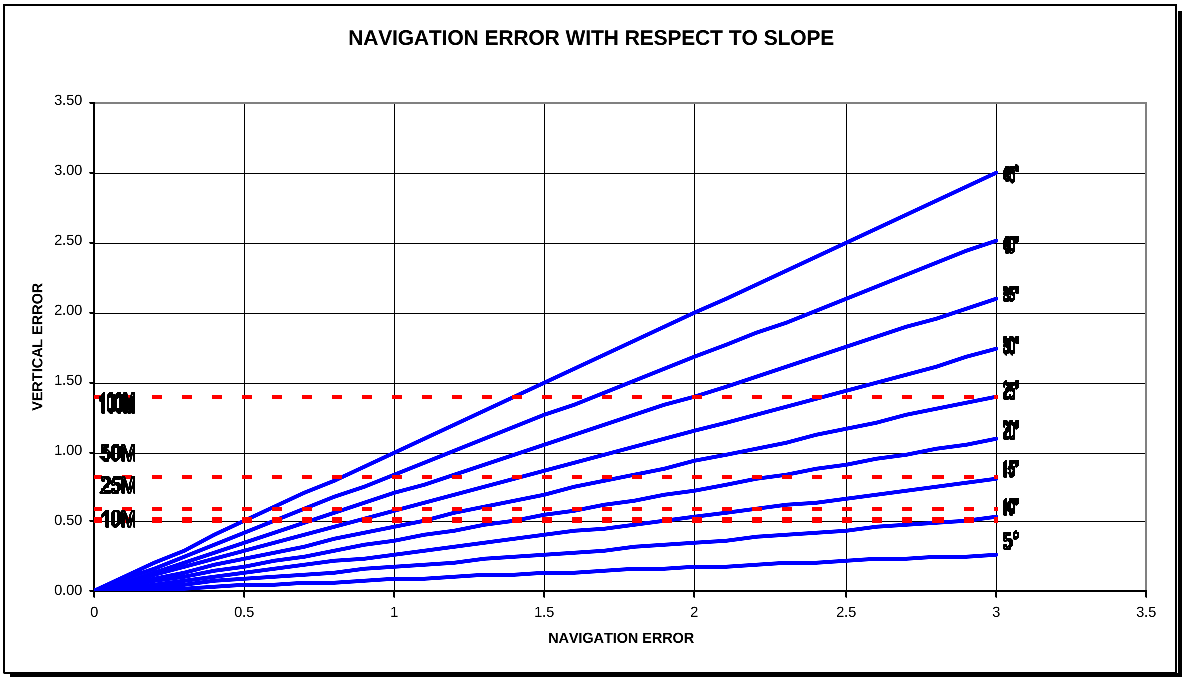

Figure 2-4 Navigation Error with Respect to Slope

2.2.2. Data Quality

Throughout the survey at Glacier Bay, the quality of acquired multibeam and backscatter data was generally good, due to the favorable weather conditions within the area, during the time of survey. There were instances when CARIS HIPS Q/C reports yielded an unfavorable number of failed beams. As demonstrated in the previous section, the failing beams can be attributed to the masking of GPS signals by the steeply sloped topography at Glacier Bay.

2.2.3. Quality Control Checks

Refer to the TGP-2251-RPT-01-00 Data Acquisition and Processing Report for the results of the multibeam patch tests conducted prior to the survey at Glacier Bay.

Positioning system confidence checks were conducted on a daily basis using the graphics interface of the acquisition computer. Winfrog Multibeam (WFMB) had built in QC windows, were the positioning data were displayed and monitored in real-time. The graphics window was configured to show the navigation information in plan view. This includes vessel position, survey lines, background plots and charts. The vehicle window can be configured to show any tabular navigation information required. Typically, this window displays: position, time, line name, heading, HDOP, speed over ground, distance to start of line, distance to end of line and distance off line. The Calculation window is used to look at specific data items in tabular or graphical format. On-line operators look here to view 1 PPS performance, GPS satellite constellation, and positional solutions.

2.3. CORRECTIONS TO ECHO SOUNDINGS

Refer to the TGP-2251-RPT-01-00 Data Acquisition and Processing Report for a detailed description of all corrections to echo soundings.

2.4. BACKSCATTER

Processing of the backscatter data revealed an intensity problem starting at nadir and faded across the swath to the outer edges. This resulted in a dark streaked mosaic that limited interpretation of geologic features within the vicinity of nadir. While gains, filters, and manipulation during processing reduced some of the problems within the imagery, a clean mosaic could not be compiled at sea.

The backscatter processing was further complicated by a range scaling problem within the WFMB acquisition software. The data was compressed to a constant scale, producing an image that was severely distorted within the overlapping areas of adjacent images. The problem was rectified by Thales GeoSolutions (Pacific), Inc. (TGPI), in San Diego. The various problems with the backscatter data resulted in TGPI having to further manipulate the imagery data in San Diego before final mosaics could be produced.

3. HORIZONTAL & VERTICAL CONTROL

3.1. HORIZONTAL CONTROL

The horizontal control datum for this survey was the World Geodetic System of 1984 (WGS84). All positions were collected in WGS84.

Two MBX-3 differential receivers, that used U.S. Coast Guard (USCG) network of differential beacons, supplied RTCM corrections to the acquired GPS pseudorange measurements; which subsequently produced WGS84 DGPS positions.

3.2. VERTICAL CONTROL

All sounding data were reduced to MLLW using verified tidal data from one tide gauge located at Juneau, Alaska. The tide gauge at Juneau is operated and maintained by NOAA. The tidal data was downloaded at the Thales GeoSolutions (Pacific), Inc. office in San Diego and subsequently emailed to the R/V Davidson at the end of every Julian day.

Table 3-1 Vertical Control Station Specifications

NAME	SIN	LATITUDE	LONGITUDE	ESTABLISHED
Juneau, AK	9452210	58.298333 N	134.411667 W	14/05/36

LCMF Inc. was contracted to provide final tidal zoning for the Glacier Bay survey area. The verified tidal data were then used to correct acquired bathymetric data.

Appendix A – Progress Sheet

A chronological list of activities occurring at Glacier Bay for R/V Davidson is given below:

Table A-1 Glacier Bay Progress

YEAR	JULIAN DAY	DATE	START TIME (UTC)	COMMENTS
2001	149	29/05/01	01:00	Embarked USGS/NPS team
2001	149	29/05/01	02:00	Underway to Glacier Bay Site
2001	149	29/05/01	04:15	Commenced Survey at Glacier Bay, Block 1
2001	150	30/05/01	10:51	Deferred Block 1 survey. Commenced Block 2
2001	150	30/05/01	17:08	Deferred Block 2 survey, Resumed Block 1
2001	151	31/05/01	00:48	Completed Block 1. Commenced Block 3
2001	151	31/05/01	11:20	Deferred Block 3 survey, Resumed Block 2
2001	151	31/05/01	17:29	Completed Block 2. Resumed Block 3 survey
2001	151	31/05/01	19:31	Completed Block 3. Commenced Block 4
2001	152	01/06/01	01:00	Completed Block 4. Commenced Block 5
2001	152	01/06/01	05:47	Completed Block 5. Commenced Block 6
2001	152	01/06/01	07:34	Completed Block 6. Commenced Block 7
2001	152	01/06/01	10:36	Completed Block 7. Commenced Block 8
2001	152	01/06/01	19:27	Completed Block 8. Commenced Block 9
2001	153	02/06/01	05:24	Completed Block 9. Commenced Block 10
2001	154	03/06/01	03:05	Completed Block 10. Commenced Block 11
2001	155	04/06/01	15:49	Completed Block 11. Commenced Block 12
2001	156	05/06/01	03:37	Completed Block 12. Commenced Block 13
2001	156	05/06/01	13:25	Completed Block 13. Commenced Block 14
2001	156	05/06/01	22:26	Completed Block 14. Commenced tie lines
2001	157	06/06/01	01:30	Completed tie lines. Glacier Bay Survey Completed. Return to Bartlett Cove
2001	157	06/06/01	02:00	Disembarked USGS team

7. Map series: Multibeam bathymetry and selected perspective views of main part of Glacier Bay

P.R. Carlson
P.N. Hooge
G.R. Cochrane
A. Stevenson
P. Dartnell
J.C. Stone

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Suggested citation:

Carlson, P.R., P. Hooge, G.R. Cochrane, A. Stevenson, P. Dartnell, and J.C. Stone, 2003. Multibeam bathymetry and selected perspective views of Glacier Bay, Alaska, U.S. Geological Survey Water-Resources Investigations Report 03-4141.

Can also be found on web: http://geopubs.wr.usgs.gov/open-file/of02-391/

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SHEET ONE

Introduction

Glacier Bay is a diverse fjord ecosystem with multiple tidewater glaciers and complex biological, geological, and oceanographic patterns that vary greatly along its length. The bay was completely glaciated prior to the 1700's, and subsequently experienced the fastest glacial retreat recorded in historical times (Fig. 1). As a result, some of the highest rates of glacial sedimentation and uplift are observed here.

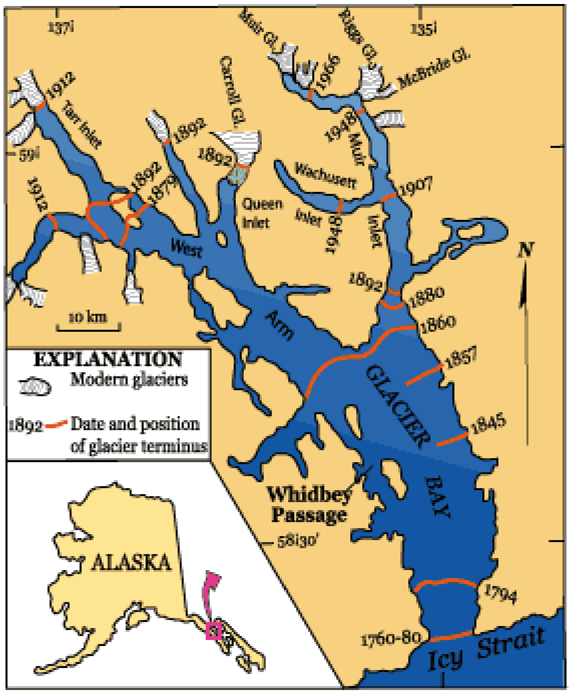


Figure 1. Location map of Glacier Bay National Park showing terminus positions and dates of retreat of the Little Ice Age glacier that completely filled the bay somewhat more than 200 yrs ago. The 1794 terminous line near the mouth of the bay is where Capt. George Vancouver and crew observed the massive glacier face during their hunt for the Northwest Passage. The 1879 glacier terminous position was mapped by John Muir during his first of several visits to Glacier Bay. Trapezoid outlines the Whidbey Passage study area. Modified from Seramur et al. (1996).

Glacier Bay is the deepest silled fjord in Alaska, with depths of over 450 meters. The variety of physical processes (for example icebergs gouging, see Fig. 2) and depths creates many diverse habitats within a relatively small area. Mapping benthic (seafloor) habitats is thus crucial to understanding and managing Glacier Bay's complex marine ecosystem and the marine species therein. High-resolution multibeam mapping of the bay, funded jointly by USGS and the National Park System, provides an unprecedented new baseline for resource and habitat assessment. Full integration of the new data set will require additional ground-truthing data (sampling) and analysis. The USGS goal is to develop integrated geological and oceanographic habitat models for the marine benthos in Glacier Bay, as a step toward determining the habitat relationships of critical species and resources within the Park.

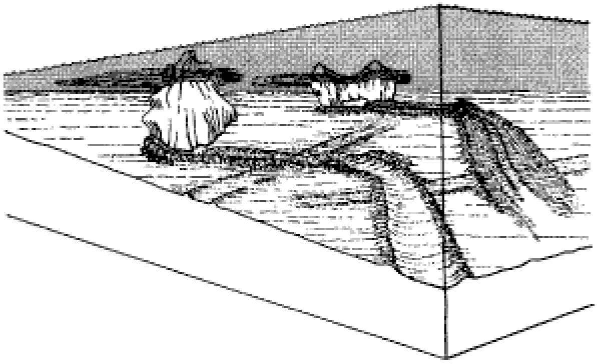


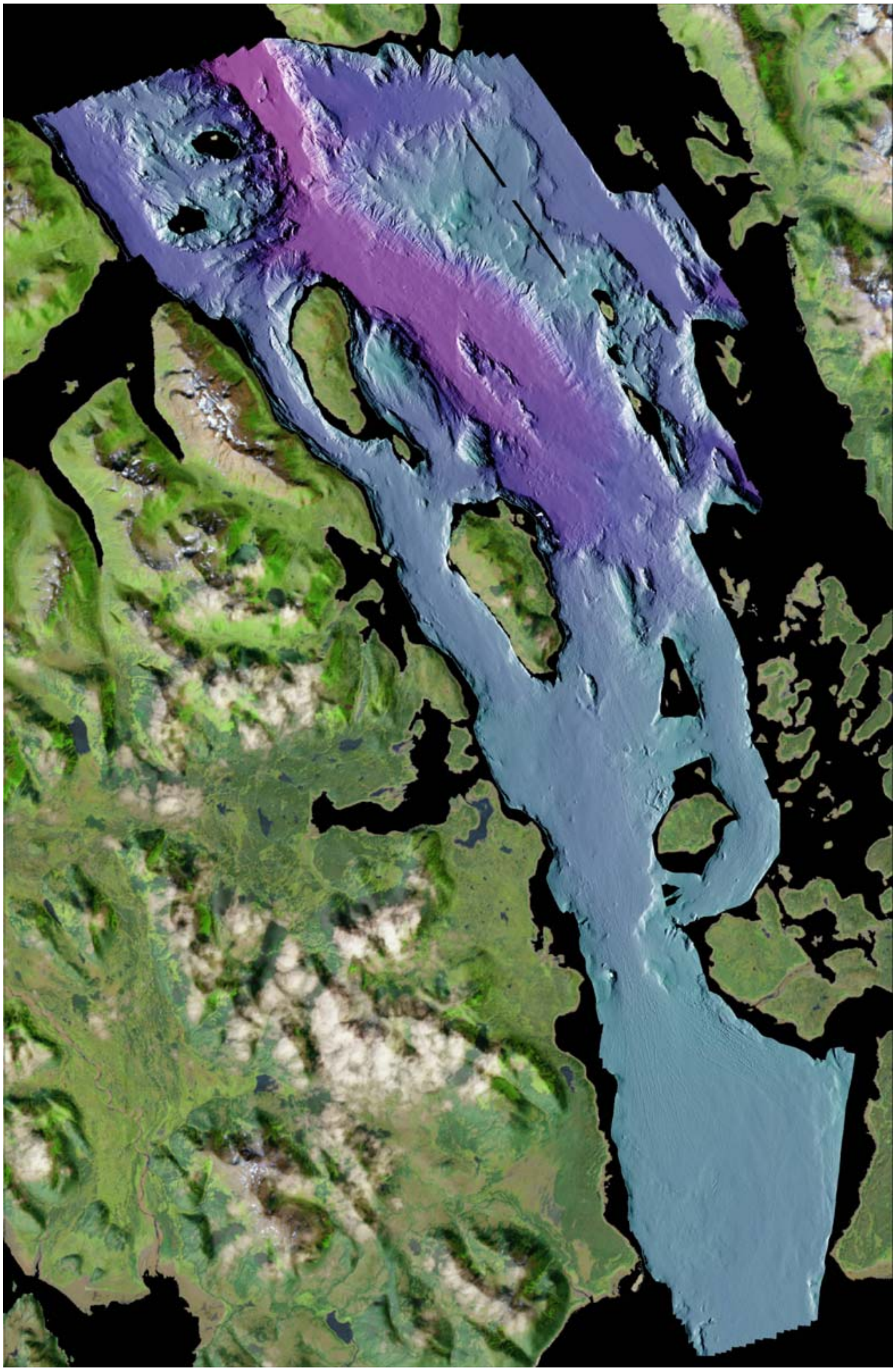
Figure 2. Single icebergs that come in contact with the seafloor will produce grooves in unconsolidated sediments ranging from mud to coarse gravel. These iceberg gouges may change shape and direction in response to changes in tidal currents. Illustration from Reimnitz et al. (1973).

References

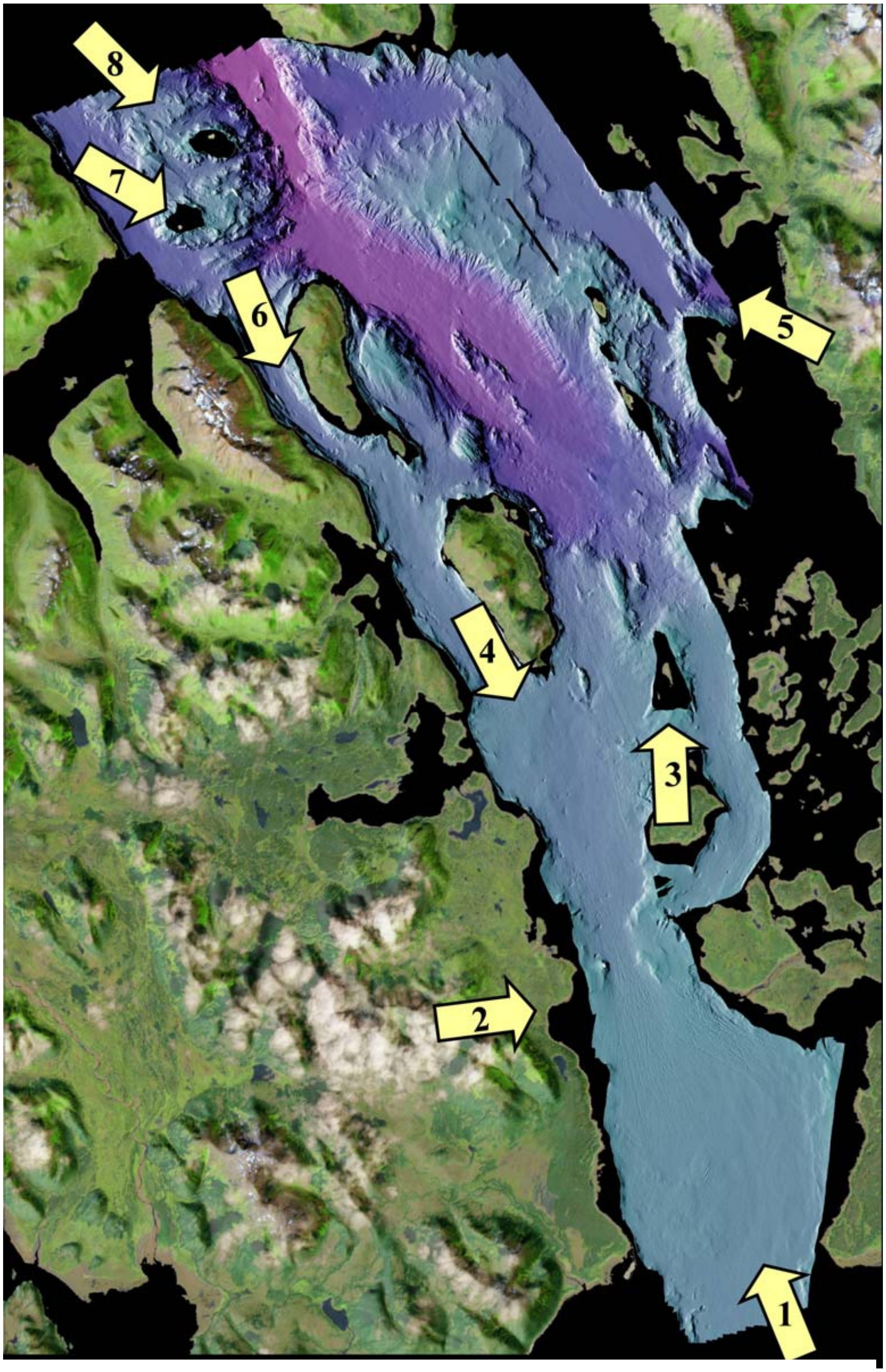
Seramur, Keith C., Powell, R.D., Carlson, P.R., 1996. Evaluation of conditions along the grounding line of temperate marine glaciers: an example from Muir Inlet, Glacier Bay, Alaska. Marine Geology 140, 307-327.

Reimnitz, E., P.W. Barnes, and T. R. Alpha, 1973, Bottom features and processes related to drifting ice on the Arctic Shelf, Alaska: USGS Miscellaneous Field Studies Map MF-532.

(The images that follow illustrate the bathymetry (measurement of water depth relative to sea level – oceanic equivalent of topgraphy) of Glacier Bay, with pink representing deeper areas, and light blue representing shallower areas. These images were creating using the multibeam echosounding data collected in 2000.)

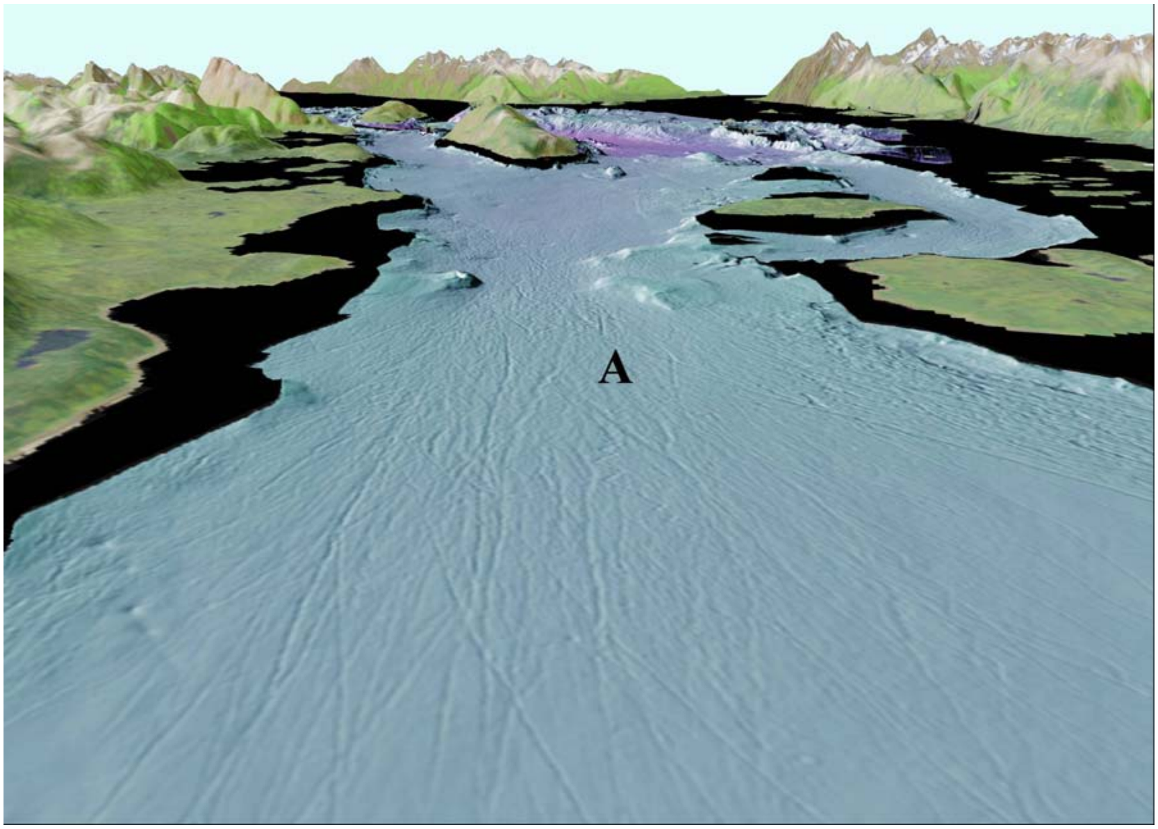


SHEET TWO



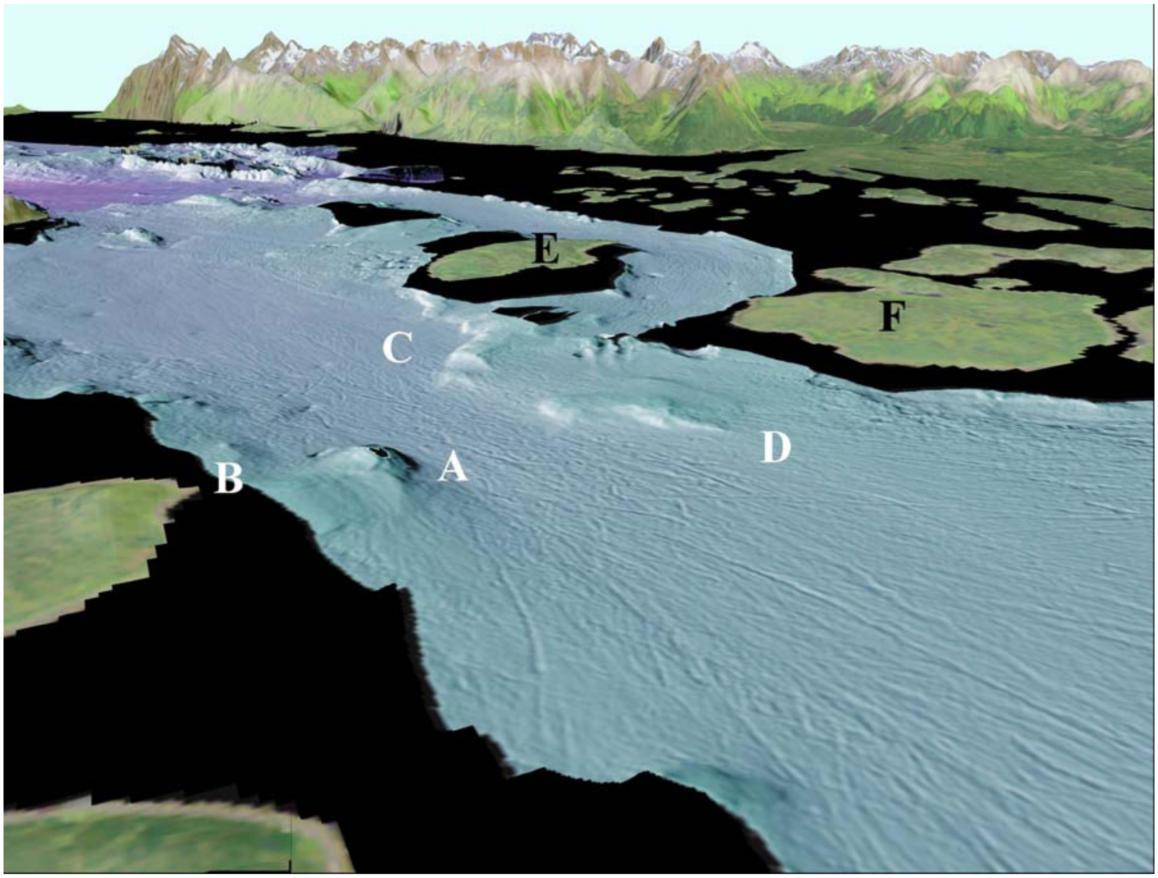
The arrows illustrate the location and direction of view in the figures shown on the following pages.

LOCATION ONE. View of the entrance to Glacier Bay looking northerly. The terminus of the Little Ice Age glacier was at this approximate location in 1794 when Vancouver's exploration discovered the glacier (see Fig 1; sheet 1). Linear gouges (A) are likely caused by icebergs grounded on the coarse bottom sediment of Sitakaday Narrows (see Fig 2; sheet 1). The bergs were pushed through the Narrows by tidal currents that reach speeds up to 7 knots. The distance across the bottom of the image is about 4.5 km (2.8 miles) with 2x vertical exaggeration



⇧1

LOCATION TWO. Sitakaday Narrows viewed from southwest to northeast showing a bedrock knob (A) off Rush Point (B). Iceberg wallow pits (C) and gouges (Fig1) (D) show changes in travel path and bottom clearance of icebergs due to tidal current effects. The wallow pits can be as deep as 5 m (16 ft), while the gouges can be as deep as 2.5 m (8 ft). Strawberry (E) and Young (F) Islands are east of the Narrows. The distance across the bottom of the image is about 2.5 km (1.5 miles) with 2x vertical exaggeration.



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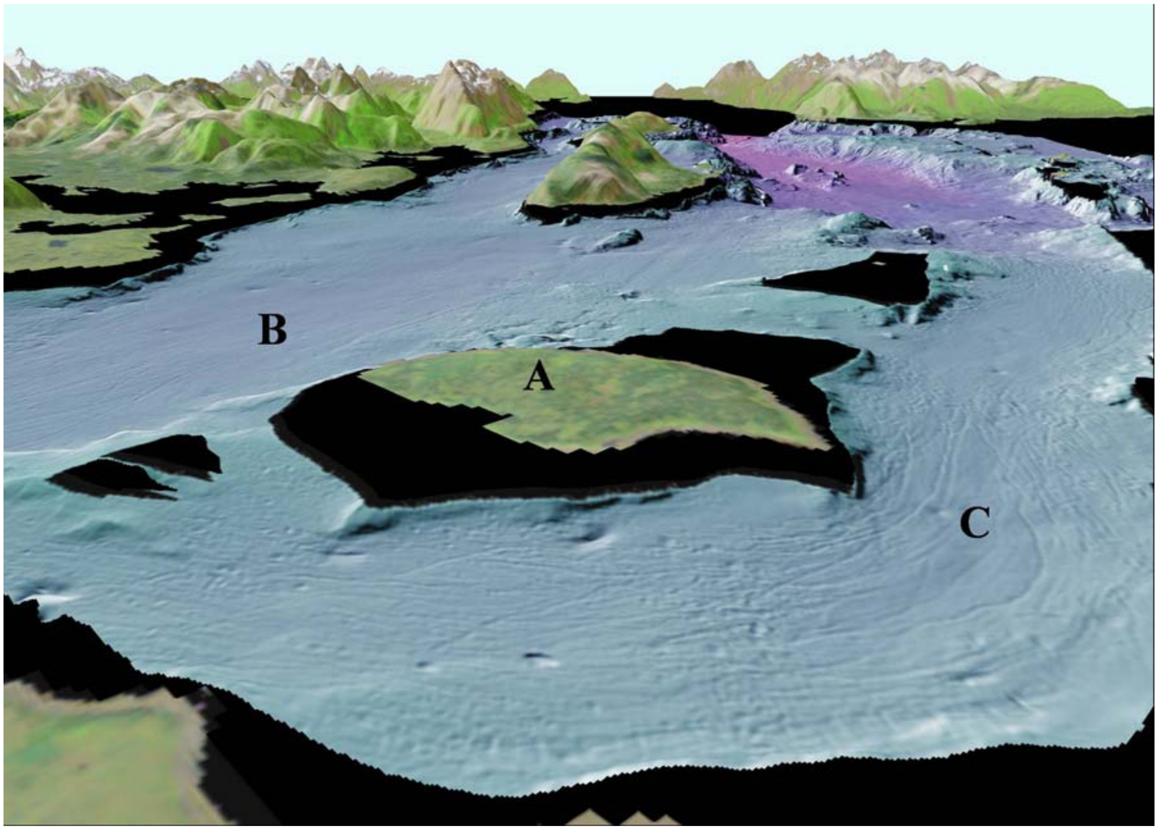
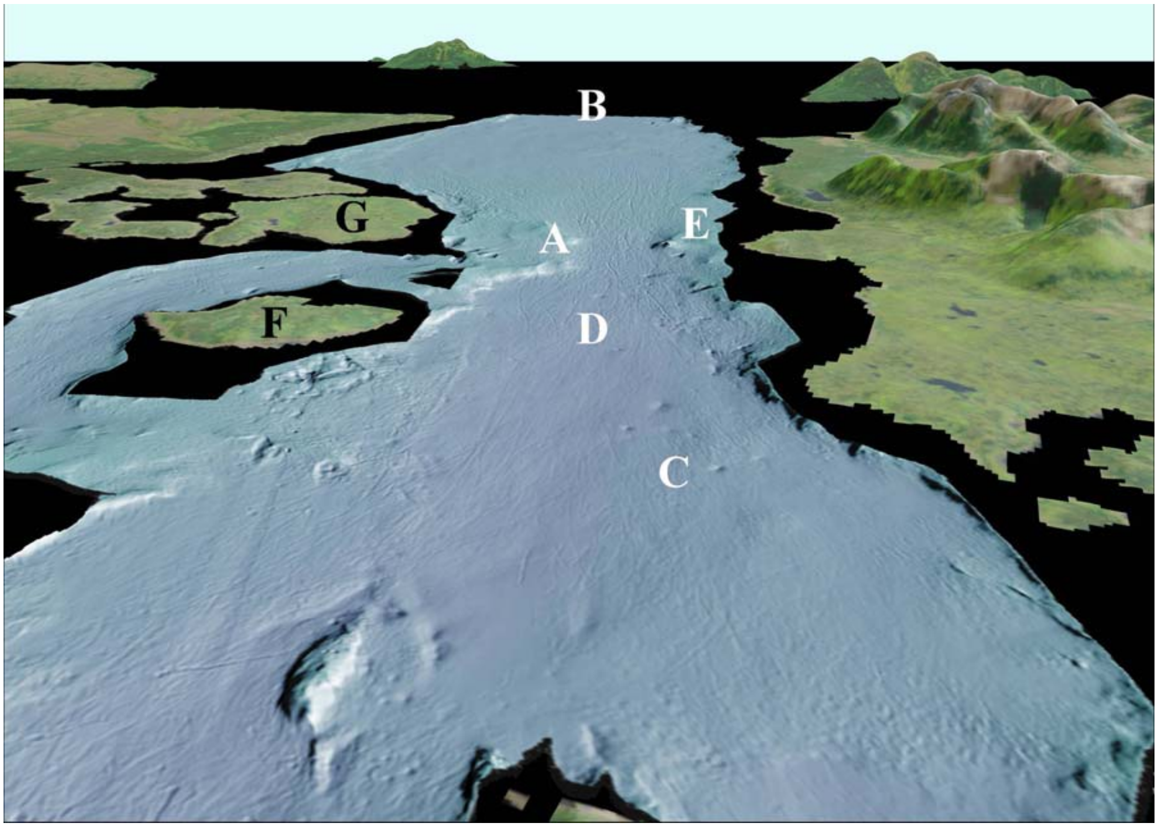
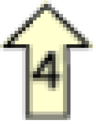
LOCATION THREE. View of Glacier Bay looking northwest over Strawberry Island (A) and Glacier Bay main passage (B). Iceberg gouges (C) turn the corner around Strawberry Island and bend southwest toward the main passage. The distance across the bottom of the image is about 4.5 km (6.1 miles) with 2x vertical exaggeration.

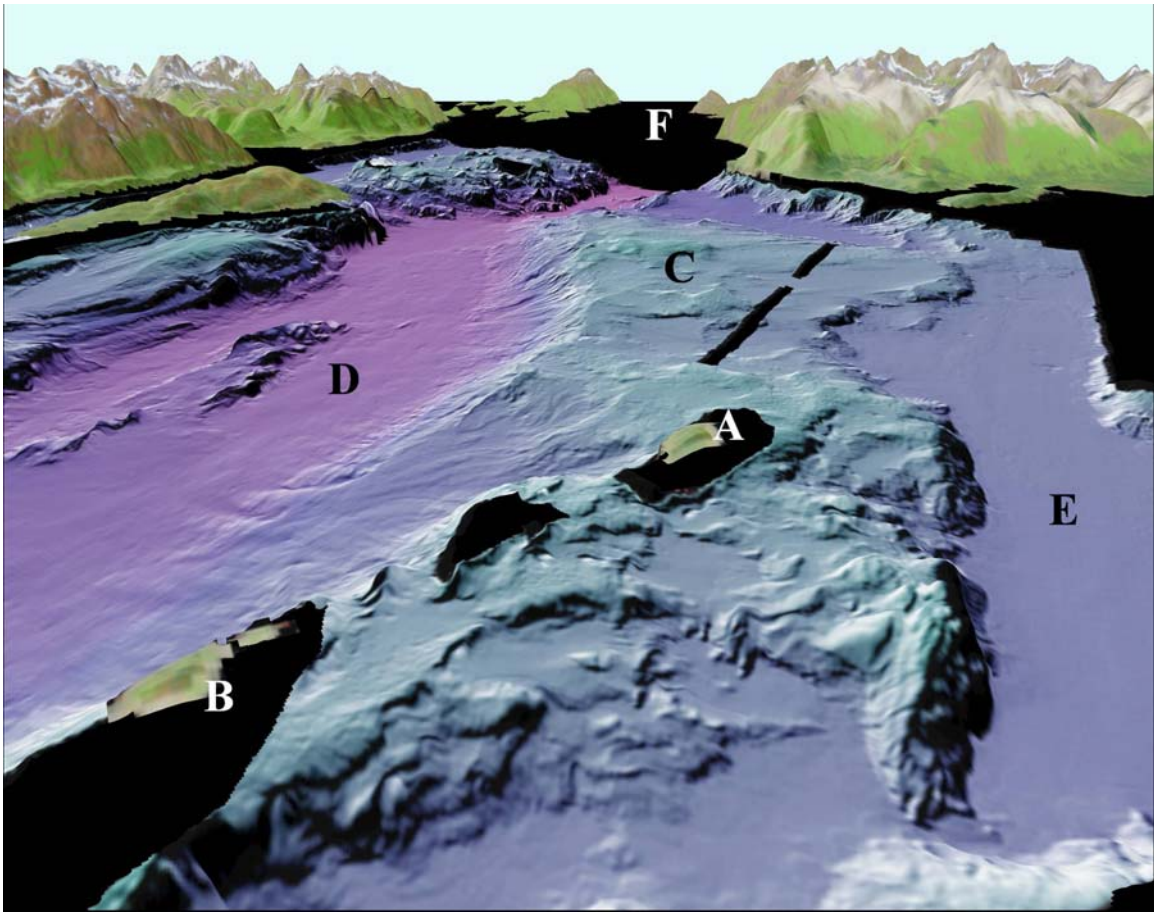


LOCATION FOUR. View looking south from over Willoughby Island toward Sitakaday Narrows (A). The entrance to Glacier Bay at Icy Strait (B) is in the distance. Iceberg wallow pits can be seen at (C), while ice gouges (D) extend south through and beyond Sitakaday Narrows. A bedrock knob (E) on the west side of the Narrows shoals to about 6 m (20 ft). Strawberry (F) and Young (G) Islands are on the east side of the Narrows. The distance across the bottom of the image is about 5 km (3.1 miles) with 2x vertical exaggeration.





LOCATION FIVE. View looking northwest over North (A) and South (B) Marble Islands. These islands are part of a bedrock high (C) that runs northwest to southeast within Glacier Bay. Glacier Bay main passage (D) is to the west of the bedrock high, while Beartrack Cove deep (E) is to the east. The opening to the north (F) is the entrance to the West Arm of Glacier Bay (see Fig 1; sheet 1). The distance across the bottom of the image is about 3.5 km (2.2 miles) with 2x vertical exaggeration.



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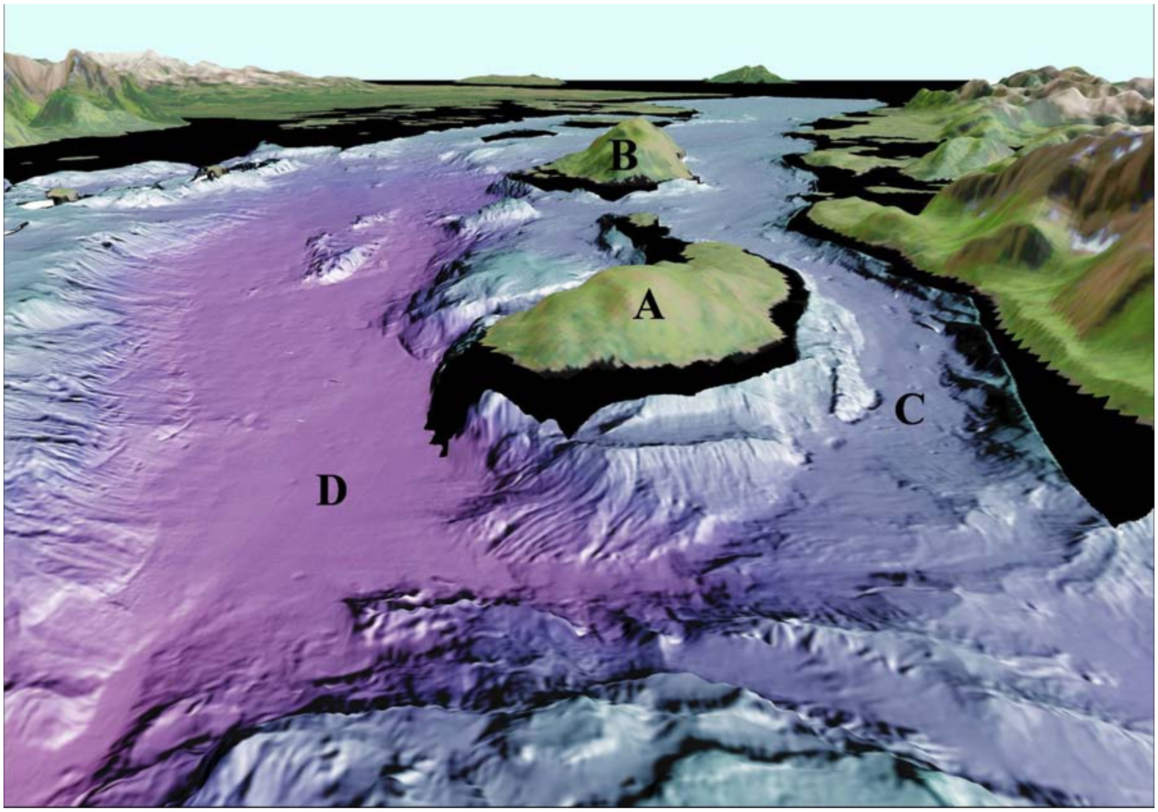
LOCATION SIX. View looking southeast down the main part of Glacier Bay. The two islands in the center are Drake (A) and Willoughby (B) Islands. Whidbey Passage (C) runs between Drake Island and the mainland and extends south along Willoughby Island. The Main Passage (D) runs east of Drake Island. Whidbey Passage is a glacially carved passage that varies in water depth from 95 m to 170 m (310 ft to 560 ft) along its axis, while the main passage varies in water depth from 250 m to 350 m (820 ft to 1150 ft) along its axis in this image. A glacier terminus was located near Willoughby Island in the mid 1800's (see Fig 1; sheet 1). The distance across the bottom of the image is about 5 km (3.1 miles) with 2x vertical exaggeration.



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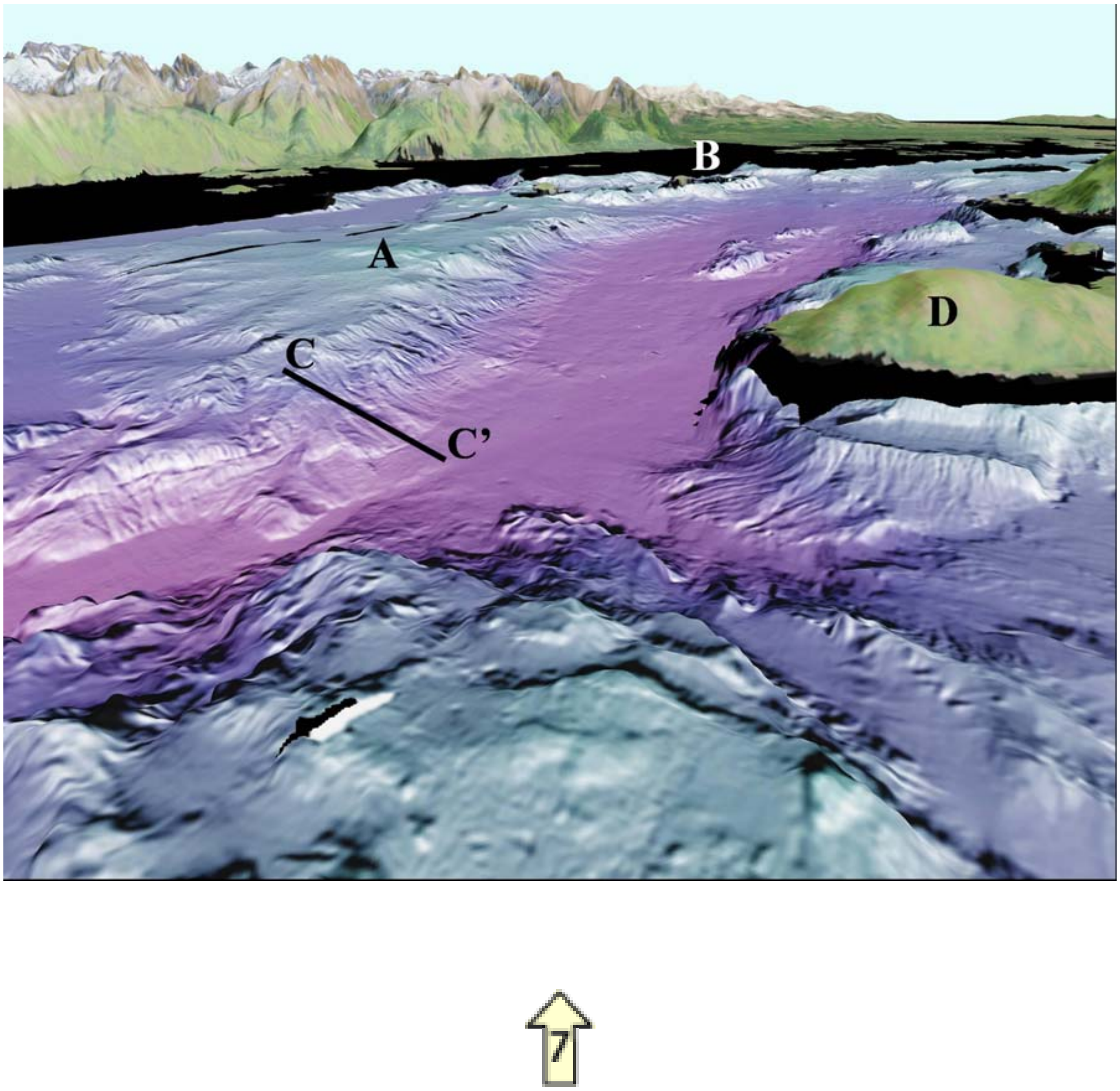
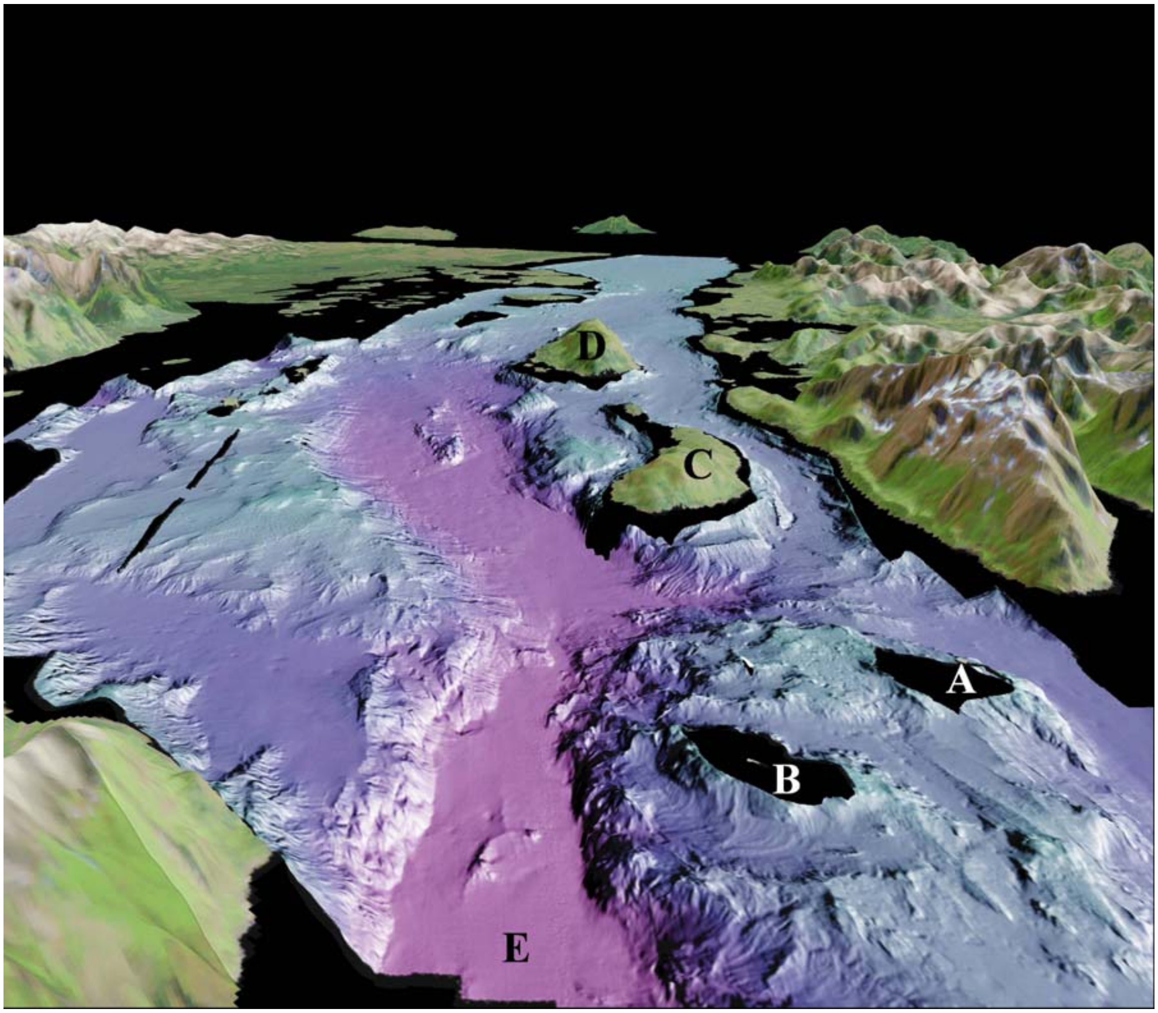
LOCATION SEVEN. View looking easterly from the West Arm of Glacier Bay. A bedrock high (A) extends northwest from the Marble Islands (B). The slope at C to C' drops from about 100 m to 325 m (328 ft to 1070 ft). A part of Drake Island (D) marks the west side of the main passage. The distance across the bottom of the image is about 3.3 km (2.0 miles) with 2x vertical exaggeration.



LOCATION EIGHT. View looking south from the entrance of West Arm of Glacier Bay. The two prominent bedrock highs in the foreground are Geike Rock (A) and Lone Island (B). The two islands toward the south are Drake (C) and Willoughby (D) Islands. The terminus of the Little Ice Age glacier was at the approximate location of (E) in the 1860's (see Fig 1: sheet 1). The distance across the bottom of the image is about 10 km (6.2 miles) with 2x vertical exaggeration.



8

8. Data set: Multibeam bathymetry and selected perspective views of main part of Glacier Bay

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U.S. GEOLOGICAL SURVEY

Suggested Citation:

Carlson, P.R., P. Hooge, G.R. Cochrane, A. Stevenson, P. Dartnell, and K. Lee. 2003. Multibeam bathymetry and selected perspective views of main part of Glacier Bay, Alaska, U.S. Geological Survey Open-file Report 02-391.

This Open-File Report contains the bathymetry data from the 2001 multibeam survey of lower Glacier Bay, Alaska. The data are provided in two formats (XYZ and ESRI GRID) that can be used in a number of GIS and other software packages.

Data can be found and downloaded from:

http://geopubs.wr.usgs.gov/open-file/of02-391/

XYZ format

- The data are available in comma delimited XYZ (x-coordinate, y-coordinate, value) format.
- FGDC Compliant Metadata for ASCII XYZ format

ArcInfo GRID format

- The data are also available in ArcInfo GRID format that can be used directly in ESRI ArcInfo, ArcView, or any other GIS or remote sensing software package that supports ESRI GRID format. In ArcView, the GRID files will be most useful with the Spatial Analyst Extension.
- FGDC Compliant Metadata for ArcInfo GRID format

9. Scientific paper: Discovery of 100-160 Year Old Iceberg Gouges and Their Relation to Halibut Habitats

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Discovery of 100-160 Yr Old Iceberg Gouges and Their Relation to Halibut Habitat in Glacier Bay, Alaska

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Version 8/20/03

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ABSTRACT

Sidescan sonar and multibeam imagery of Glacier Bay revealed complex iceberg gouge patterns at water depths to 135 m on the floor of Whidbey Passage and south to the Bay entrance. These previously undiscovered gouges formed >100 yrs ago, as the glacier retreated rapidly up Glacier Bay. Gouged areas free of fine sediment supported greater biodiversity of halibut than nearby sediment-filled gouges, probably due to increased habitat complexity. Small Pacific halibut *(Hippoglossus stenolepis)* were found more frequently in sediment-free gouged areas, presumably due to higher prey abundance. In contrast, large halibut were found more frequently on soft substrates such as sediment-filled gouges where they could bury themselves and ambush prey.

INTRODUCTION

Glacier Bay, in southeast Alaska (Fig. 1) was formed by multiple glacial advances and retreats throughout much of the Pleistocene epoch (Goldthwait, 1987). In 1794, members of Captain George Vancouver's crew reported the presence of a massive wall of ice blocking what is now the entrance to Glacier Bay (Vancouver, 1798; ref. in Grove, 1988). Since then, the glacier has retreated about 100 km up the bay, exposing a magnificent fjord system (Fig. 1). As the ice front retreated, it left remnants of end moraines, which were dated at 1845, 1857, and 1860 by tree-ring cores (Fig. 1) (Cooper, 1937; Lawrence, 1958). The 1845 and 1857 tree-ring dated moraines provide dates of the ice terminus position nearest to the Whidbey Passage halibut study area (Fig. 1). Since 1879, when John Muir first visited Glacier Bay, the ice front positions have been systematically and accurately mapped (Fig. 1), first by boat by numerous scientists including Muir (1895) and Field (1964), by aerial photography (Post and LaChapelle, 1971), and eventually by satellite imagery (Hall et al., 1995).

Following the ice front retreat, ecological successions of plants, soil, and terrestrial animals have been observed in this spectacular natural laboratory (Cooper, 1923; Lawrence, 1951; Dinneford, 1990). In the past two decades, biologists have turned their attention to the marine realm (Sharman, 1990; Bishop, et al., 1995) and recently have joined forces with marine geologists to study the biological and physical characteristics of bayfloor habitats in Glacier Bay (Carlson et al., 1998; Carlson et al, 2002; Cochrane and Carlson, 1998; Hooge and Carlson, 2001). This paper reports the discovery of some large, complex gouges in a deep-water Pacific halibut (*Hippoglossus stenolepsis*) habitat, within Whidbey Passage, located in the west-central part of lower bay and even longer gouges in shallower water depths 20 km south of Whidbey Passage in the southernmost part of Glacier Bay. (Fig. 1). We discuss the probable age of the gouges, their physical characteristics, how they were formed, how they have been modified, and we make some preliminary associations of size and age of halibut occurrences to the variations in benthic substrate.

EFFECTS OF GLACIAL RETREAT ON THE SEAFLOOR

The glacier that filled Glacier Bay began its retreat from the mouth of the bay ~200 ya (Goldthwaite, 1963). The massive glacier retreated past the Whidbey Passage study area by about 160 ya and reached the upper end of the main bay by 1860 (140 ya) where the bay-filling glacier bifurcated (Fig. 1). As the glacier retreated from Whidbey Passage to the head of the lower bay (~1845-1860), calving from the terminus of the massive glacier likely generated huge bergs. Some of the bergs, as they were channeled down Whidbey Passage, had deep enough keel depths to impact the bay floor and form gouges (Fig. 2). Subsequently, the West Arm glacier retreated rapidly up fjord (~2 km/a) until 1879, whereas, in Muir Arm the glacier was pinned on its entrance moraine from sometime after 1860 until at least 1892 (Seramur et al, 1997) and then began its rapid retreat (Fig. 1). Massive icebergs from both West Arm and Muir Inlet may have contributed to the gouging, but the West Arm bergs had the most direct and deeper water route (up to 400 m depth) into Whidbey Passage (Fig 1). In contrast the deepest keeled iceberg to come from the Muir terminus soon after 1860 appears to be limited to less than 60 m depth due to sill depth. Additional evidence providing support for abundant ice transiting from West Arm into the main bay was reported by Ovenshine (1967). He found many glacial erratics that had mineralogy typical of the Fairweather Range (such as staurolite, chiastolite and biotite-quartz schists) on the beaches of the lower part of the bay.

Water depths of 100 m throughout much of Whidbey Passage and as much as 50 meters in the lower bay, requires large icebergs in order for their keels to plow the bottom. Considering that ~85% of a bergs mass is submerged, the total thickness of the berg must be ~120m in order to scour the bottom in most all of Whidbey Passage (Fig. 1). Glacial scour, visible as glacial polish, and striations high on the rock walls of adjacent Willoughby Island, elevation 494m (USGS, 1990, 1:250,000 topographic map) above sea level, plus 100m to the floor of the passage, suggests ice thickness of near 600 m, thus the calving of icebergs <1/4 that thickness is quite reasonable to assume. Iceberg ploughing or scouring has been reported from considerably deeper water in other areas in the world. Two examples are the northern Barents Sea where Solheim et al. (1988) have imaged intense iceberg plough marks in water depths of 210-220 m and Scoresby Sound where Dowdeswell et al. (1993) have collected acoustic records of iceberg scours most prevalent at depths of 300-400 m.

FIELD METHODS AND OBSERVATIONS

The halibut have been studied in Glacier Bay for several years. (Hooge and Taggart, 1998). In this Whidbey Passage study, halibut were caught and measured. More than 1500 have been marked wih wire tags. An additional ninety-seven halibut had 3.5 kHz transmitters surgically implanted. These fish were tracked using a bow-mounted, dual hydrophone that was capable of tracking the fish at distances up to 2 km and at depths to 500 m. Searches for these sonically tagged fish were conducted every 2-3 months for four years.

In 1998 we used a Klein towed sidescan sonar system (SSS) and an attached 3.5 kHz acoustic profiler to map habitats in Whidbey Passage for comparison to locations of halibut caught by long-line in 1996-97 (Hooge and Taggart, 1998). Navigation was by Differential Global Positioning System (DGPS) that provides vessel location to an accuracy of ~1-5 m in DGPS mode. Images revealed some spectacular gouges (Fig. 2) on the 100 m deep floor of Whidbey Passage, a U-shaped, bedrock-walled, 2.5 km wide by 15 km long valley (Fig 1). Formation of gouges from trawling activity in the area was ruled out by several park service personnel who possessed extensive local knowledge of fishing methods and history. Thus we turned our thoughts to icebergs as their creators. Some of the SSS images consist primarily of high backscatter (HBS). The high backscatter indicates a hard surface where little fine sediment filled the gouges and adjacent area. Some places the SSS image consists mainly of low backscatter (LBS), thus a softer surface with some faint gouge outlines that suggested the gouges were nearly filled with fine sediment.

Two video camera drift transects were occupied in the Whidbey Passage area at the end of the 1998 SSS cruise. One camera site was located where little fine sediment filled the gouges and the adjacent area. At the second site the gouges were nearly filled in with fine sediment. We chose the camera sites on the variation in backscatter on the SSS images. In the area of little fine sediment, there is HBS. At this video station we observed numerous cobbles and boulders of varying sizes. As our boat drifted, we observed visually a seafloor relief of a couple meters, usually the result of large amounts of cobbles and boulders, in the form of a ridge, likely one wall of a gouge. At the station with LBS the video captured imagery of billowing clouds of fine sediment being stirred up when the video sled contacted the bay floor. There were also noticeably fewer boulders and cobbles, probably because many had been covered by a blanket of fine sediment. There was a dramatic increase in the number of visible cobbles and boulders seen in the areas of HBS compared to the more sediment-covered gouges where the backscatter was significantly lower. Many of the boulders, particularly in the HBS area, were very large (up to several meters in diameter). In the area of HBS, many of the boulders and cobbles had sessile organisms such as basket stars attached.

On subsequent cruises, in 1999 and 2000, we ground-truthed some of the SSS images via SCUBA dive transect. SCUBA lines transected areas with and without surface expressions of ice gouging, which we will refer to as gouged and ungouged areas. SCUBA dive transects were conducted at water depths between ~25 and 60 m. On four dive transects across areas imaged on SSS as having little fine sediment (i.e., high backscatter), one of us (Hooge) observed parallel ridge and trough features with numerous pebbles, cobbles, and boulders, and an estimated relief from trough to ridge of 1 to 3 m. These features were interpreted to be gouges. The central portions of the gouges were covered by sediment, and the troughs of two of the gouges were excavated to greater depth than the surrounding seafloor. Nearby gouge-filled areas were dominated by fine sediments with little or no pebbles or cobbles and only occasional boulders.

In June 2001, a hull-mounted RESON SeaBat 8111 multibeam echo sounding system was used to collect imagery throughout the main bay to supplement the side-scan coverage of benthic habitats and to determine the distribution of gouge features. On this cruise, navigation was also by GPS. The multibeam imagery revealed additional seabed features including bedrock knobs and even longer gouges, up to 5 km in length, near the bay entrance. The preservation of these presumably older gouges in the lower part of the bay was even more startling in this shallower water region previously thought to be an area dominated by sediment deposition.

MORPHOLOGIC FEATURES AND LIKELY MODES OF FORMATION

Iceberg gouges imaged by SSS and MB systems in Whidbey Passage and the lower part of the bay are quite variable in linear appearance, ranging from single straight, to criss-crossing, to sinuous, to simple curves, and in some cases to double gouges (Fig. 2a). The gouges were created by deep-draft keels of large icebergs being transported through the bay waters by the tidal currents, and perhaps slightly affected by wind acting upon the relatively small part of the iceberg projecting above the water. In several places we discovered impact pits or wallows about 20 m in diameter, sometimes as a single feature and once as many as three pits along a single gouge (Fig. 2b). These features form where the berg temporarily comes to rest on the bottom and then lifts off, perhaps due to a flood tide that causes the berg to rise. Similar features were caused by large pieces of sea ice coming to rest in near shore waters of the Beaufort Sea (Reimnitz and Kempema, 1982). Along one gouge track (~20m wide) in Whidbey Passage we observed chatter marks (Fig. 2c). Apparently the keel was very close to the bay floor and in some rhythmic way bumped along touching the bottom in a fairly regular manner over a distance of ~500 meters. One gouge, several km long, was imaged by multibeam 20 km south of Whidbey Passage (Carlson, et al, 2002). It had a pronounced zig-zag pattern probably caused by several reversals of the tide during the time the berg was in intermittent contact with the bay-floor sediment.

The gouges range in width from 5-20 m, and have an estimated relief of 1-2 m. The longest ice gouges that we have imaged on our side-scan sonar records were ~1km long. However, in the southern-most part of the bay, several gouges imaged by multibeam were several kilometers long (Fig. 3), and one gouge measured 5 km long. For comparison, Syvitski et al (1983) observed iceberg scour marks from a submersible in the Canadian Arctic that varied in width from 10-30 m and relief from 0.5-6 m.

Four relief features present in the Passage, are listed from large to small: 1) Large features e.g. gouges and attendant ridges consisting of boulders (up to 3 m in diameter), to sand size material, built up on sides of gouges (also called berms) are often present with sessile organisms such as sea pens and basket stars. In addition to forming the gouges, the bergs can become grounded in shallower water, overturn, and dump gravel on the bay floor, sometimes creating mounds of boulders or smaller gravel. Bergs melt as they travel down fjord or bay and may then release the coarse and fine sediment frozen within, also forming mounds. 2) Intermediate size bottom features e.g. small boulders to cobbles (often with attached sessile organisms such as sea pens and basket stars), small gouges, and sand waves. 3) Small size features e.g. pebbles, shells, small pits, and mounds, including features such as burrow openings, mud volcanoes, and piles of fecal debris. 4) Very small relief features e.g. ripple marks, fecal coils, protrusions of infauna such as polychaete worm tubes, siphon expulsion holes, and trails from organisms such as sea urchins, Triton snails, hermit crabs and Tanner crabs.

Overlying these bottom features is sediment deposited from suspension from the water column. Suspended particulate matter, that includes inorganic particles of silt and clay and organic matter produced by diatoms and other microscopic plant and animal matter, is constantly raining through the water column in various concentrations. Fine-grained sediment sources include fresh water streams and glacial melt water issuing from glaciers and the surrounding shores and the fine sediment released by melting of the icebergs. Muddy sediment that issues from the glacier terminus as suspended sediment can be carried far down bay before it settles out. However, much of the settling occurs near the active glacial terminus, where the concentration of suspended sediment can exceed 500 mg/L (Cowan and Powell, 1990). In Whidbey Passage, some of the gouges are comparatively free of the very fine sediment, whereas others have been partially filled in by it. In other places the suspended sediment has nearly to completely covered the gouges to the extent that only a faint outline of the gouge remains. In the lowermost bay (Fig. 3), the ice gouges appear to be relatively free of fine sediment. This is likely due to the strong flushing action of the currents that attain speeds of up to 8 knots through the narrows located ~12 km south of Whidbey Passage (Hooge, et al., 2001).

The seabed physical features of Whidbey Passage are characterized by four different substrates based on the SSS imagery (Fig. 4): 1. Bedrock - high backscatter, irregular, but unpatterned; 2. Gouges nearly free of fine sediment - linear gouges that have mostly high backscatter; it is not likely that any gouge areas are completely free of fine grained sediment deposited from the overflow plume that issued from the glacier terminus; 3. Gouges partly infilled with fine sediment - a mix of high and low backscatter, indicating that the suspended sediment has been deposited in sufficient quantities to partially fill in the gouge areas; 4. Areas of low backscatter - the gouge outlines are nearly to completely obliterated by the blanket of fine suspended sediment.

EFFECTS OF ICE GOUGING ON HALIBUT COMMUNITY

The halibut catch locations were superposed on a SSS derived substrate map (Carlson, et al., 1999). The effects of ice gouging on the benthic community were examined by both direct observations of the number of sessile species and by the distribution of Pacific halibut. The number of species observed in gouged areas by the drop camera and on SCUBA transects was significantly higher than in nearby gouge-filled or ungouged areas. Four SCUBA transects (n=4) were combined with two video transects from the drop camera (n=2). Presence and absence of all identifiable sessile fauna were recorded. Wilcoxon Matched Pairs Signed Rank Test, n=6, Z=-2.201, P=0.027. Differences in species numbers between the substrate types were large; a total of 55 species from 9 Phyla were present in gouged areas, while 24 species from 4 Phyla were found in gouge-filled areas. Gouged areas displayed a mix of species, including all 24 of those from the soft-bottomed areas, as well as additional species associated with harder substrates. The species composition observed in gouged areas was similar to that of other areas in Glacier Bay with a mix of both hard and soft substrates and similar vertical structure from rocks and boulders.

Halibut locations were correlated with the four categories of physical characteristics of the floor of Whidbey Passage derived from the SSS imagery (Fig. 4). Of 304 halibut captured on research longlines in Whidbey Passage, there was a highly significant tendency for smaller halibut (<100 cm fork length) to be caught both on bedrock and on substrate with detectable gouges. In contrast, large halibut were found more frequently on soft substrates. Small halibut (>30 cm and < 100 cm fork length) were found more frequently on bedrock, and exposed gouges (categories 1 and 2) than on soft-bottomed habitats (categories 3 and 4, Fisher's Exact Test $P<0.02$). Removing the high association between small halibut and bedrock habitats (category 1) there was still a significant tendency for small halibut (<100 cm fork length) to be captured on exposed gouge habitats (category 2) as compared to soft bottomed habitats (category 3 and 4, Fisher's Exact Test $P<0.05$). After adjusting the expected halibut numbers for the proportions of habitat types found within the area fished, there was a highly significant difference between expected and actual habitat use (Chi-Square = 14.32, df=3, and $P<0.003$). Areas with bedrock and unfilled gouges (category 1 and 2) were selected more frequently than expected by small halibut, and soft sediment areas (category 3 and 4) were selected more frequently than expected by large halibut (Fig. 4).

These trends correspond to ontogenetic diet differences that we have observed in Glacier Bay, where small halibut appear to forage by active predation and large halibut by sit-and-wait tactics (Hooge and Taggart, 1998; Chilton et al, 1995). We hypothesize that active foraging should be more productive in rocky habitats, where preferred and/or more abundant prey may be available due to both the increased sessile species diversity and to the enhanced physical structure of the environment. Likewise, ambush foraging should be more successful in soft-bottomed habitats where the larger halibut could bury themselves. Rocky iceberg-gouged zones therefore represent unrecognized productive benthic habitat.

These results demonstrate that extensive gouging observed in the seafloor of central and lower Glacier Bay is most likely a product of historical ice scour from large bergs calved during the catastrophic retreat of the glacier. These gouges with little or no soft sediment fill are associated with significant differences in benthic habitat and community structure compared with sediment-filled gouges or areas lacking evidence of gouging. Whereas ice scour has detrimental effects on community structure on short time scales (Conlan and others, 1998), over a longer time period it may increase species diversity by providing a variety of interspersed habitat types.

CONCLUSIONS

1. Ice gouges are plentiful on the floor of much of the lower portion of Glacier Bay, as observed first by side-scan sonar collected in 1998 in Whidbey Passage, and later by multibeam imagery collected in 2001.
2. Gouges observed in Whidbey Passage require large icebergs with keel depths >100 m. These huge icebergs probably traveled through the area shortly after the glacier retreated (between 1845 and 1860) when the lower bay was being deglaciated and until about 1879 when the West Arm Glacier bifurcated and began retreating into Johns Hopkins and Tarr Inlets. West Arm was a major contributor of large icebergs, because the deeper waters of this arm, as compared to Muir Inlet, allowed deeper draft bergs to enter Whidbey Passage.
3. Four types of seafloor geologic habitats were identified: 1) bedrock, 2) gouges with sparse fine sediment cover; 3) gouges partly filled with fine sediment; and 4) gouges nearly to totally covered by the fine glacial flour (clayey silt).

4. Halibut caught in the study area were divided into 2 size groups. Large halibut, >100 cm length, preferred an unstructured seafloor of soft fine sediment where they likely burrowed into the substrate to wait for prey. Small halibut, <100 cm in length, that are much more active pursuing their prey, preferred the harder substrate of bedrock and coarse sediment prevalent in the unfilled ice-gouge complexes.

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FIGURE CAPTIONS

Fig. 1. Location map of Alaska and Glacier Bay National Park showing terminus positions and dates during retreat of glacier. Polygon outlines Whidbey Passage study area. Bathymetry, in meters. Arrows show possible routes of travel of large ice bergs with deep-keel depths (>100 m) that likely excavated complex and numerous gouge patterns in Whidbey Passage.

Fig. 2. Examples of sidescan sonar images showing variety of ice berg gouges in study area. Scale lines are 25 m apart. a.) Portside view of sidescan sonar image of bottom sediment of Whidbey Passage showing complex nature of ice-berg gouges. Dark is high backscatter, indicative of hard bottom consisting of coarse gravel to boulder size sediment. Light is low backscatter indicative of fine sediment (silt & clay). Note how soft sediment is beginning to obliterate outline of gouges near top of image. b.) Side-scan image of ice-berg wallow marks. c.) Chatter marks evident on side scan image in northern part of Whidbey Passage.

Fig. 3. Multibeam image of lower Glacier Bay showing extensive ice-berg gouges from just above Icy Strait to Willoughby Island (W.I.) through Whidbey Passage (W.P.) are visible beyond the narrows.

Fig. 4. Map of bayfloor habitats based on SSS imagery in Whidbey Passage area and catch locations of large (>100cm long) and small (<100cm long) halibut. Types of bay floor habitat in Whidbey Passage are: bedrock; ice gouges essentially free of fine sediment cover; gouges partially filled with fine sediment; and gouges barely perceptible to completely covered by fine suspended sediment (clayey silt) deposited from meltwater run-off plumes.

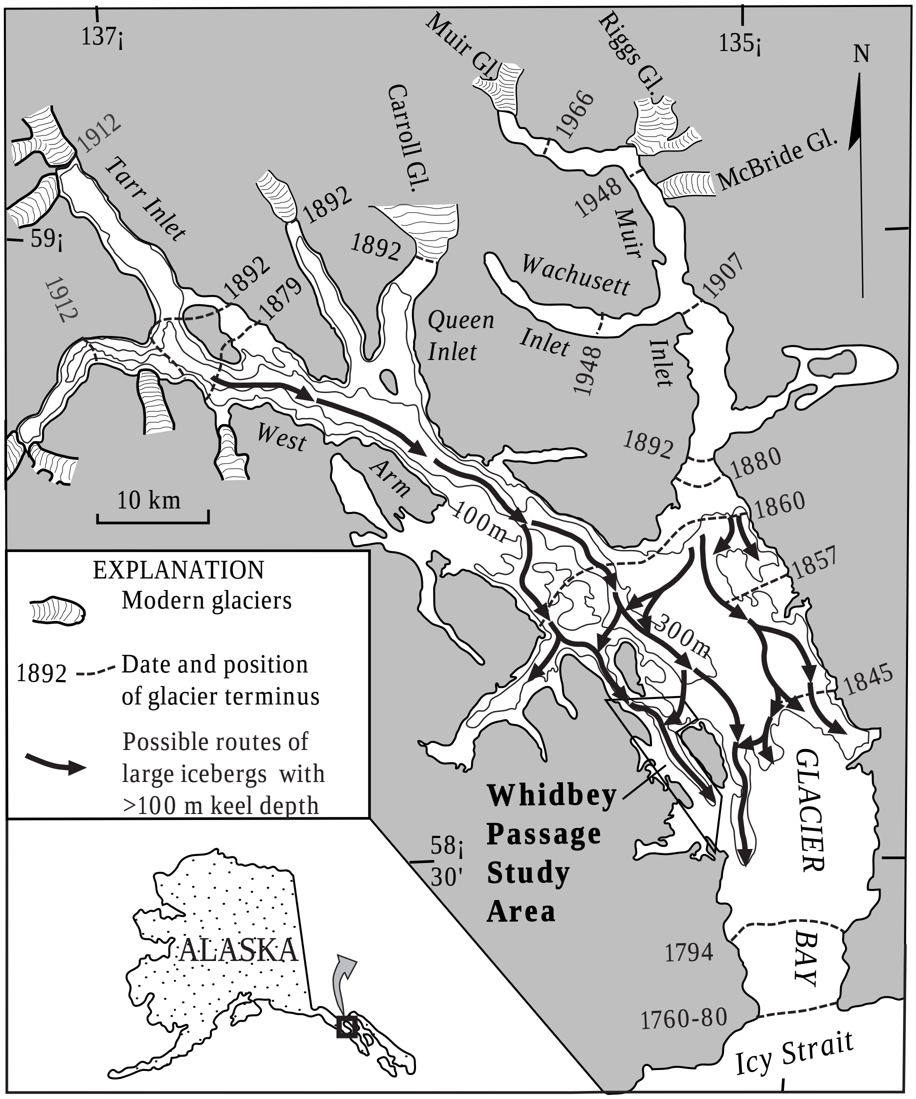
137¡
135¡
N
Muir Gl.
Riggs Gl.
Carroll Gl.
McBride Gl.
1966
1912
Tarr Inlet
1892
1948
Muir
59¡
1892
1912
1892
Wachusett
1907
1892
1879
Queen
Inlet
Inlet
1948
Inlet
West
Arm
1892
1880
10 km
100m
1860
1857
300m
1845
EXPLANATION
Modern glaciers
1892
Date and position
of glacier terminus
Possible routes of
large icebergs with
>100 m keel depth
Whidbey
Passage
Study
Area
GLACIER
58¡
30'
ALASKA
1794
BAY
1760-80
Icy Strait

Figure 1

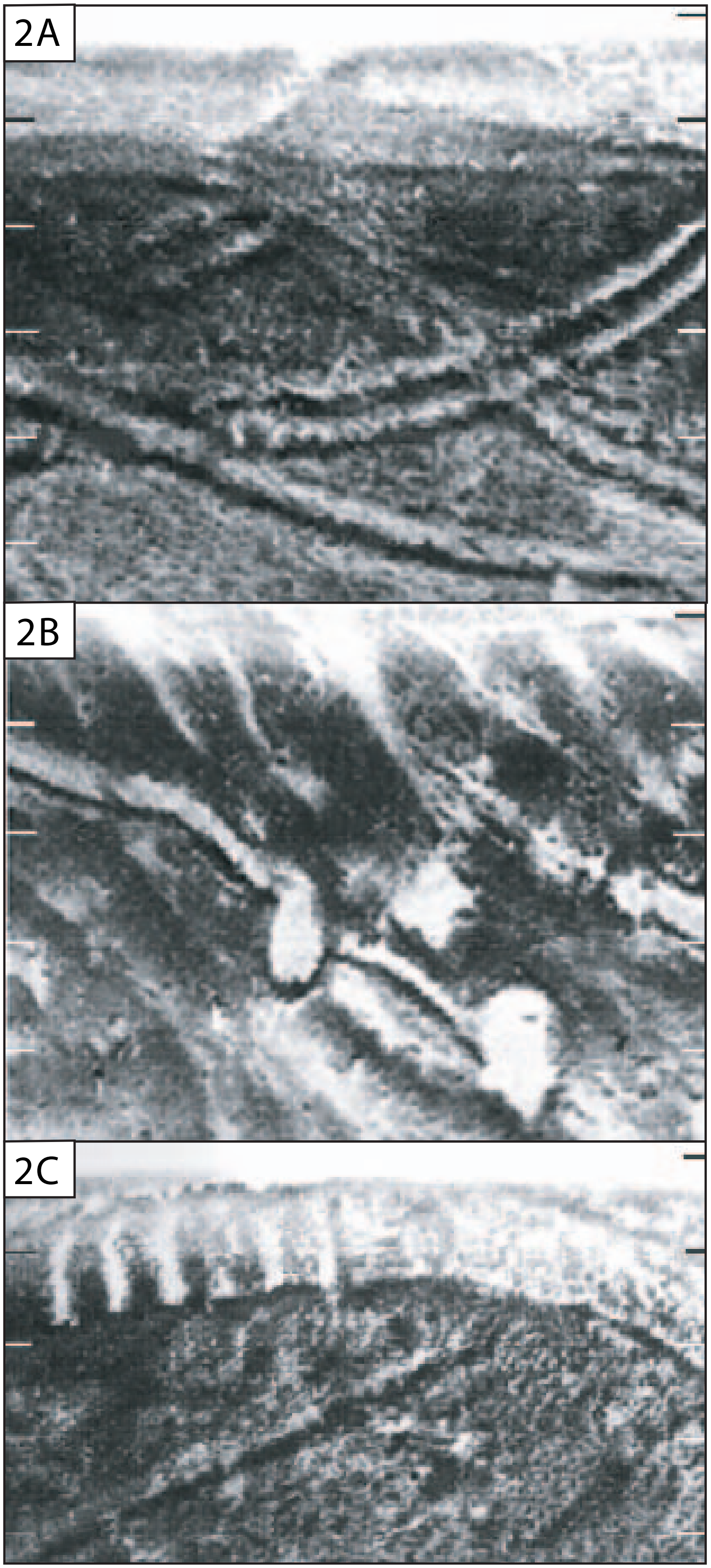

Figure 2

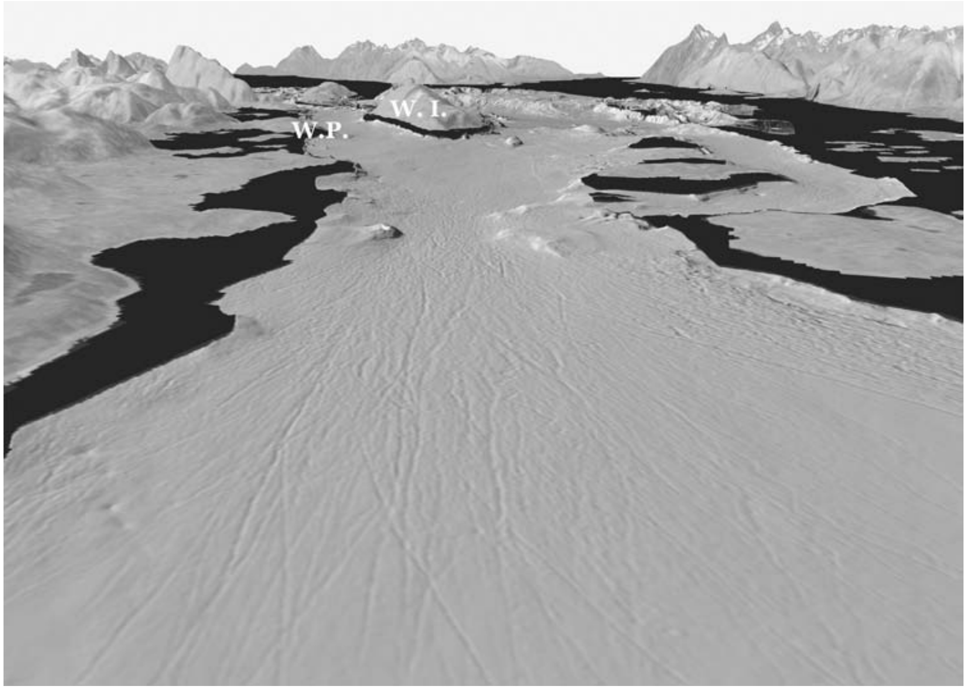

Figure 3

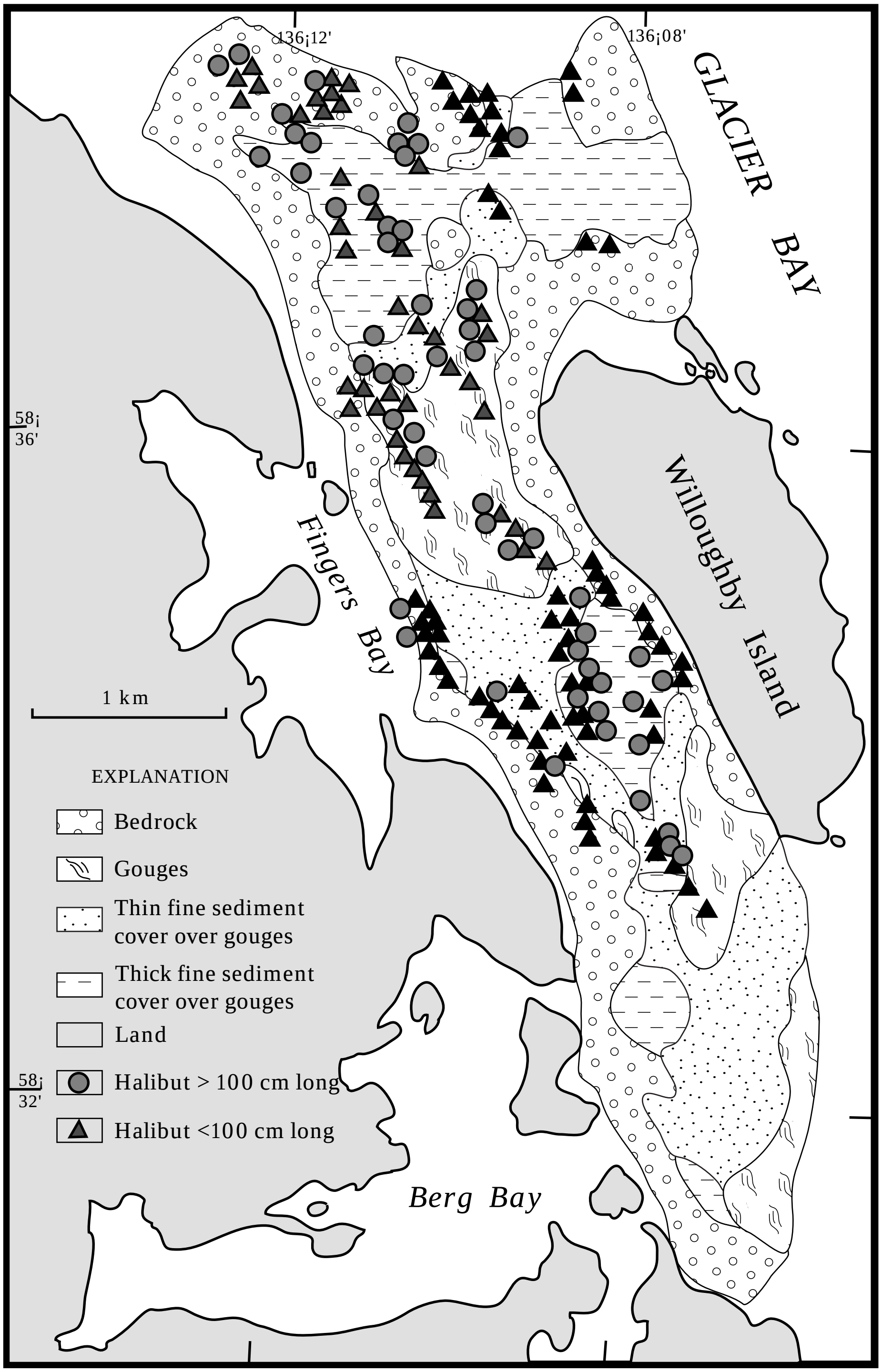
136¡12'
136¡08'
GLACIER BAY
58¡ 36'
58¡ 32'
Willoughby Island
Fingers Bay
1 km
EXPLANATION
Bedrock
Gouges
Thin fine sediment cover over gouges
Thick fine sediment cover over gouges
Land
Halibut > 100 cm long
Halibut <100 cm long
Berg Bay

Figure 4

10. Note: Aggregative Behavior By Molting Male Dungeness Crabs *Cancer magister* (Decapoda: Cancridae)

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ABSTRACT

This paper reports on the first observations of aggregative behavior in male Dungeness crabs *Cancer magister*. Groups of males with minimum numbers of between 36 and 112 individuals were observed on three separate occasions. Four to eight males were sampled in each group, all of which were found to have just recently molted. The locations of all male aggregations were near female aggregations. The aggregations occupied unique geomorphologic features, which were imaged using side-scan sonar.

INTRODUCTION

Aggregative behavior has been observed in many species of crustaceans. Aggregations associated with mating have been reported in red king crab *Paralithodes camtschaticus* (Stone et al., 1993), lyre crab *Hyas lyratus* (Stevens et al., 1992), and Tanner crab *Chionoecetes bairdi* (Stevens et al., 1994). Aggregations to avoid predation occur in spiny lobsters *Panulirus interruptus* (Zimmer-Faust, 1985) and the spiny spider crab *Maja squinado* (Stevcic, 1971). Aggregations of molting individuals have been observed in the nine-spined spider crab *Libinia emarginata* (Carlisle, 1957; Degoursey and Auster, 1992). No aggregative behavior has been described for male Dungeness crabs *Cancer magister*, although females have been observed to form brooding aggregations (Armstrong et al., 1988; O'Clair et al., 1996 and pers. obs.). This paper describes three separate observations of molting male Dungeness crab aggregations and the side-scan sonar imaging of the unique bottom features in which these aggregations were found.

MATERIALS AND METHODS

This study was conducted in Glacier Bay, Southeast Alaska (59° N, 136° W), a recently deglaciated (between AD 1700-1970) Y-shaped fjord estuary with deep marine basins (200-450 m) terminated by remnant relatively shallow moraines and tidewater glaciers at the heads of the fjords. Observations of crab aggregations were made in Bartlett Cove (58° 27' N, 136° 54' W), and the northern Beardslee Islands (58° 34' N, 136° 54' W), where water temperatures were between 6° and 8° C.

Side-scan sonar images were obtained using a Klein model 530T side-scan sonar system (SSS) with an attached 3.5 kHz sub-bottom profiler. The SSS imaging was done using the 500 kHz, 0.2 degree beam, very-high resolution transducer, which is capable of resolving objects a few cm across. We used the 100 m range and towed the SSS towfish approximately 10 m off the bottom. The sediment classified in this paper as silt may range from clayey silts to silty clays (<0.063 mm).

Data on crabs were collected by divers using SCUBA. Numbers of crabs were determined by single diver counts except for group 1 which was the minimum of two counts by separate divers. Positions were determined at diver floats using Y-encrypted code Global Positioning System (GPS) receivers (Rockwell) with an accuracy of 5 m. The distance between the observed male aggregations and known female aggregations was tested for significance using a Monte Carlo simulation (Barnard, 1963) that compared the distances between 10,000 random locations within all diver-searched areas and the nearest female aggregation. These randomly-generated distances were ranked and compared to the actual distances. This simulation was conducted using the Movement program (Hooge and Eichenlaub, 1998).

RESULTS

Three molting male aggregations were observed. The first was observed 14 August 1995, in Bartlett Cove (Fig. 10.1). Group 1 consisted of at least 112 individuals. Eight mature (>165 mm carapace width) crabs were captured; all were soft-shelled males indicating that they had recently molted. None of the crabs were buried in the silt sediment. The water depth was 8 m below mean lower low water (MLLW). These individuals were found in a roughly circular depression about 5 m wide. The depression's walls were steep and between 50-100 cm high. Upon the diver's approach, the entire group immediately took flight in different directions. Due to this rapid flight, estimates for all groups are minimums and group size was probably larger. Two days later, a repeat dive at the same location revealed no aggregation in the pit or nearby (20-50 meter) area.

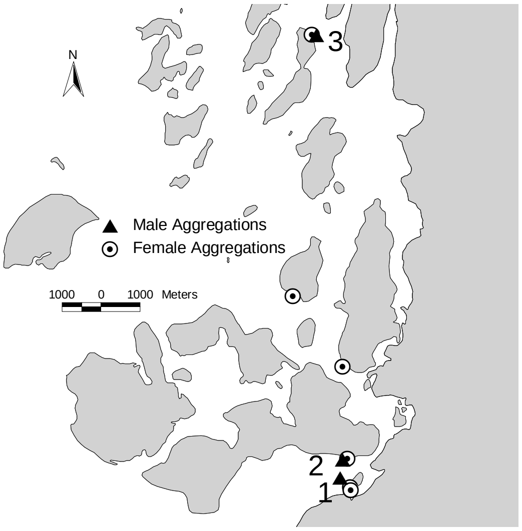

Fig. 10.1. Locations of molting male aggregations (numbered) and nearby female aggregations in the Beardslee Island/Bartlett Cove area of Glacier Bay, Alaska. All known aggregations are depicted; however the area searched is much smaller than the total area

Group 2 was observed on 15 September 1995, also in Bartlett Cove, 460 m from the location of Group 1 (Fig. 10.1). Group 2 was found in a similar depression about 1 m deep and 5 m wide, in silt substrate. The water depth was 12 m (MLLW). This group contained at least 69 individuals. Six individuals were captured, all of which were mature (>165 mm) males, and all of which had recently molted. This group also detected the diver's approach early, and rapidly scattered.

Group 3 was found in the northern Beardslee Islands (Fig. 10.1) on 20 September 1996, and contained at least 36 individuals. Four of these were captured; all were recently molted mature (>165 mm) males. This location consisted of an inclined trench approximately 5 m wide and 30 m long. One end of the trench began at the depth of the surrounding substrate and the other end was 3 m deeper. The depth at this location was 11 m (MLLW).

Distance from the nearest known female aggregation averaged 200 m for these three groups. Distances for Groups 1, 2, and 3 were 350 m, 131 m and 118 m, respectively. Each aggregation was significantly closer to a female aggregation than would be expected randomly (Monte Carlo Simulation, $\overline{x} \pm SD = 1650 \pm 620$, Group 1 $P < 0.05$, Group 2 $P < 0.01$, Group 3 $P < 0.001$). At least 261, 100-m dive transects have been conducted in the Bartlett Cove area and 243 in the North Beardslee area between 1992 and 1997. Male aggregations have only been observed in three of these 504 dive transects.

In August of 1996 we mapped both Bartlett Cove (Fig. 10.2) and the north Beardslees with side-scan sonar. Group 1 (Fig. 10.2B) was located at the edge of a deltaic sand deposit associated with the Bartlett River. Part of the deltaic area can clearly be seen in the image. Group 2 (Fig. 10.2A) was entirely in a silt area, but it was less than 100 m from the deltaic sandbank. The pits in which Groups 1 and 2 were found appear to be relatively rare. No additional depressions of this size and shape have been

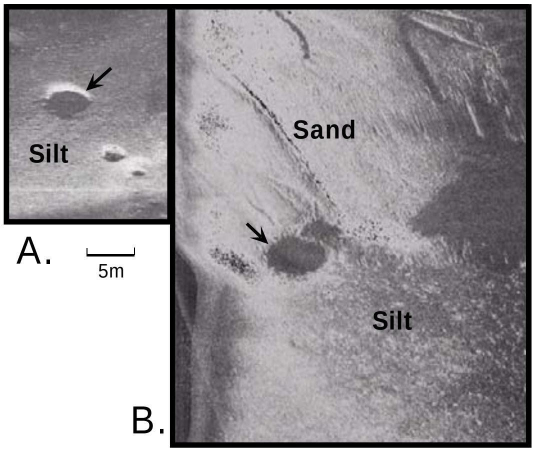

Fig.10.2. Side-scan sonar images depicting two of three locations where molting male aggregations were observed. Pits with aggregations are shown with arrows; A shows pit containing Group 2, B shows pit containing Group 1. Both images are reversed to show shadows as dark, and are scaled to the same size.

observed in SSS images taken over approximately 5000 hectares in Glacier Bay, although many smaller pits have been observed. However, trenches such as the one where Group 3 was found are more common and may represent historical ice gouges.

DISCUSSION

Aggregations of molting individuals similar to our observations of male Dungeness crab have been described for the spiny spider crab (Carlisle, 1957), the nine-spined spider crab (Degoursey and Auster, 1992), red king crab (Dew, 1990) and two species of *Cancer, C. borealis* and *C. irroratus* (Auster and DeGoursey, 1983). It was suggested by Carlisle (1957) and Degoursey and Auster (1992) that these aggregations serve the purpose of protection from predation. Although the aggregations of male Dungeness crab documented in this study do not exhibit the three-dimensional "pod" structure seen in other species we hypothesize that they nevertheless serve similar functions. Given the vulnerability of molting Dungeness crabs to a wide range of predators and the early intruder detection and rapid flight by the observed groups, we hypothesize that these aggregations are formed to reduce the risk of predation. These aggregations suggest a selfish herd or schooling phenomenon (Hamilton, 1971) in which individuals gain protection in numbers through greater vigilance and confusion of predators (Bertram, 1978; Rubenstein, 1978). Alternatively or in combination with selfish herd effects, the physical features in which the aggregations were found may offer increased protection from predation, and the rarity of these features may serve to aggregate the crabs. In the study by Dew (1990) some aggregations of red king crab took advantage of unique physical features. Adult Dungeness crabs have been described as cannibalistic in some situations (Breen, 1987). Our observations of dense aggregations of vulnerable individuals suggest either that the crabs are aware that nearby conspecifics are molting (and thus are not dangerous), or that cannibalism among adults is a byproduct of the traps from which most such reports are derived.

The proximity of male aggregations to female aggregations may be due to the timing of male molt following female molting and mating and the attraction of males to female aggregations. The aggregations we observed probably consist primarily of post-reproductive males. Alternatively, there may be characteristics of the habitat near female groups that are also beneficial to male aggregations.

The relatively unique geomorphological features that two of the groups were using may offer more protection than the surrounding areas. We do not know how these features formed, and the similarity of their size, shape and depth is notable. The gully used by the third aggregation is more common in the area.

That only three of more than five hundred dive transects revealed molting male aggregations is also noteworthy, although small aggregations of nonmolting males have occasionally been observed (C. O' Clair, 1996). Several reasons may account for this rarity of observation; the aggregations appear to be transient or short-lived, individuals rapidly disperse when disturbed, the locations are relatively small, cryptic and possibly rare, and the population of males in this area is heavily harvested.

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