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Cruise Report of M/V *QUILLBACK* in Glacier Bay, Alaska: Physical Characteristics of Dungeness Crab and Halibut Habitats

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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. 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 possibly 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 West Arm and slightly less to the head of Muir Inlet to the east (Fig. 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. 1 & 2).

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 effects of commercial fishing within the National Park waters. These studies relate to the question of whether 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 nearshore study sites in water depths to 18 m (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 subbottom-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. 1 & 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 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 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 and 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.

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 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 1959, (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 American datum of 1927. It was updated in 1983, and this change in reference datum also results in uncertain bathymetric depths, especially in nearshore areas. Therefore, we began our study in each area with a perimeter trackline, 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; 2) the navigational data were not recorded quickly enough to provide instantaneous course corrections; and 3) in Bartlett Cove, we encountered two kinds of obstacles a) many boats anchored near the park 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 than 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.

Berg Bay---We began our cruise with nine SSS/3.5 khz track lines (lines 1-9; Table 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). 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. 3 & 4).

Between Francis and Drake Islands--This area is located about 30 km north of the entrance to Glacier Bay (Fig. 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 1) to study halibut habitats (Fig. 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 groove or channel-like feature that reaches a depth of 10 m below the sediment water interface (Fig. 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. 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).

<u>Beardslee Islands</u>--Our third study area is along the east shore of Glacier Bay and includes three shallow areas within the Beardslee Island complex (Figs. 1 & 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 the both sides of Link Island, an elongate low island, three km long and 0.5 km wide (Fig. 8). SSS/3.5 kHz lines 18-25 were run in the basin on the west side of Link Island (Table 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. 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. 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 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. 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 predominantly 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 depression at the center of the profile (Fig. 10) appears to be either a pit or trench, however the SSS does 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.

Four kilometers south of Link Island we ran two lines (lines 31, 32; Table 1) south of Kidney Island (Fig. 8) along the biologists "deep set" study segment. "Deep set" refers to this study area that is deeper than most of their other 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. 11). Figure 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. 11). Long and thin objects such as the buoy line leading from the crab pot in figure 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 of Eider Island (Fig. 8). We insonified the inner segment (lines 33-59; Table 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 subbottom reflections on the 3.5 kHz profiles that indicate sediment thicknesses as great as 30 m (Fig. 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).

Bartlett Cove--This Cove is a five km long reentrant on the east side of Glacier Bay, about eight km north of the bay entrance (Fig. 1 & 2). Bartlett Cove is the location of the National Park 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 1), but, due to interruptions in profiling by the presence of whales, we only insonified about 2/3 of the cove (Fig. 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

The Cove is partially protected from storm waves by a bay-mouth moraine that appears to be part of an extensive lateral moraine (Fig. 15a). The moraine and Bartlett Cove sedimentary basin can be clearly seen on Figure 15b. A minisparker 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 three km long and one 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. 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 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 about 50 m (Fig. 15a) and appears to be floored with finer sediment (Fig. 17b), possibly sand.

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. 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) 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. 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--note the four bayfloor multiples that emphasize the hardness of the bottom at this site.

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. 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.

The disrupted reflections (Fig. 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 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. 22 a & b) shows three 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 crab 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 sidescan 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). 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.

General observations--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 up 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. The NPS and USGS-BRD Field Station are jointly mapping the geomorphology and biota of the coast into a Geographic Information System using scanned and GPS georeferenced infrared aerial images as well as ground-truth samples. The extent of the intertidal environment as well as the nearshore 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.

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 subareas 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 20m with soft sediment cover of variable thicknesses, some that apparently contained free gas, probably methane.

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Figure 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 disruptions (D) of the three mosaiced lines are also results of the processing.

Figure 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.

Figure 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. V.E. = ~ 4:1.

Figure 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 of profile. Side-scan image across area does not show any elongation of feature, suggesting a pit. V.E. = ~4:1.

Figure 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 that fell off boat as it nosed into waves and sank. Near bottom of figure, elongate double-arced line may be a buoy line leading from one of crab pots; this indicates kind of resolution possible. Slanted whitish line 1/3 from top is reflection off water-air interface. (See Fig. 8 for track lines).

Figure 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 13. 3.5 kHz profile and interpretation of sediments underlying southeastern part of "Bug Bay." Note thick sediment fill over hummocky glacial surface. V.E. = ~ 4:1

Figure 14. Trackline coverage of Bartlett Cove, including notations of figure locations.

Figure 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 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. = ~14:1.

Figure 16a. Preliminary SSS mosaic of Bartlett Cove entrance moraine (see Fig. 14 for trackline locations and compare with Figures 15 a,b for broad scale bathymetric and high-resolution seismic views of moraine). Box indicates location of Figure 16b.

Figure 16b. Detailed SSS view of northern portion of moraine (see Fig. 16a for location with respect to full mosaic). Note irregular patchy nature of imagery and see Figure 16c for more detail.

Figure 16c. Example of close-up SSS view of upper portion of moraine seen in Fig. 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.

Figure 17a. Typical 3.5 kHz profile across hard rocky surface (note well-defined multiple reflection) of entrance moraine. V.E. = ~ 4:1. See Figure 14 for location.

Figure 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.

Figure 18. SSS imagery of Bartlett River delta sand (right 3/4 of image) prograding over deeper soft sediment accumulating on deeper cove floor (dark portion at left part of image).

Figure 19. Enlarged portion of SSS image shown in Figure 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 14 for location.

Figure 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.

Figure 21a. In the deeper part of cove, 3.5 kHz profile shows at 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 (21 b) will show, lack of sound penetration may also be a function of gas in the sediment. V.E. = ~4:1.

Figure 21b. Disrupted reflections in 3.5 kHz profile are evidence that gas (g) exists in sediment column. V.E. = ~4:1. Locations of both 21 a & b are shown on track line map of Figure 14.

Figure 22a. Pits shown on SSS image (left) from upper Bartlett Cove (see Fig. 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.

Figure 22b. Enlarged view of pits in Fig. 22 a. 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 back wall of pit, black is low backscatter from the hole or depression of the pit.

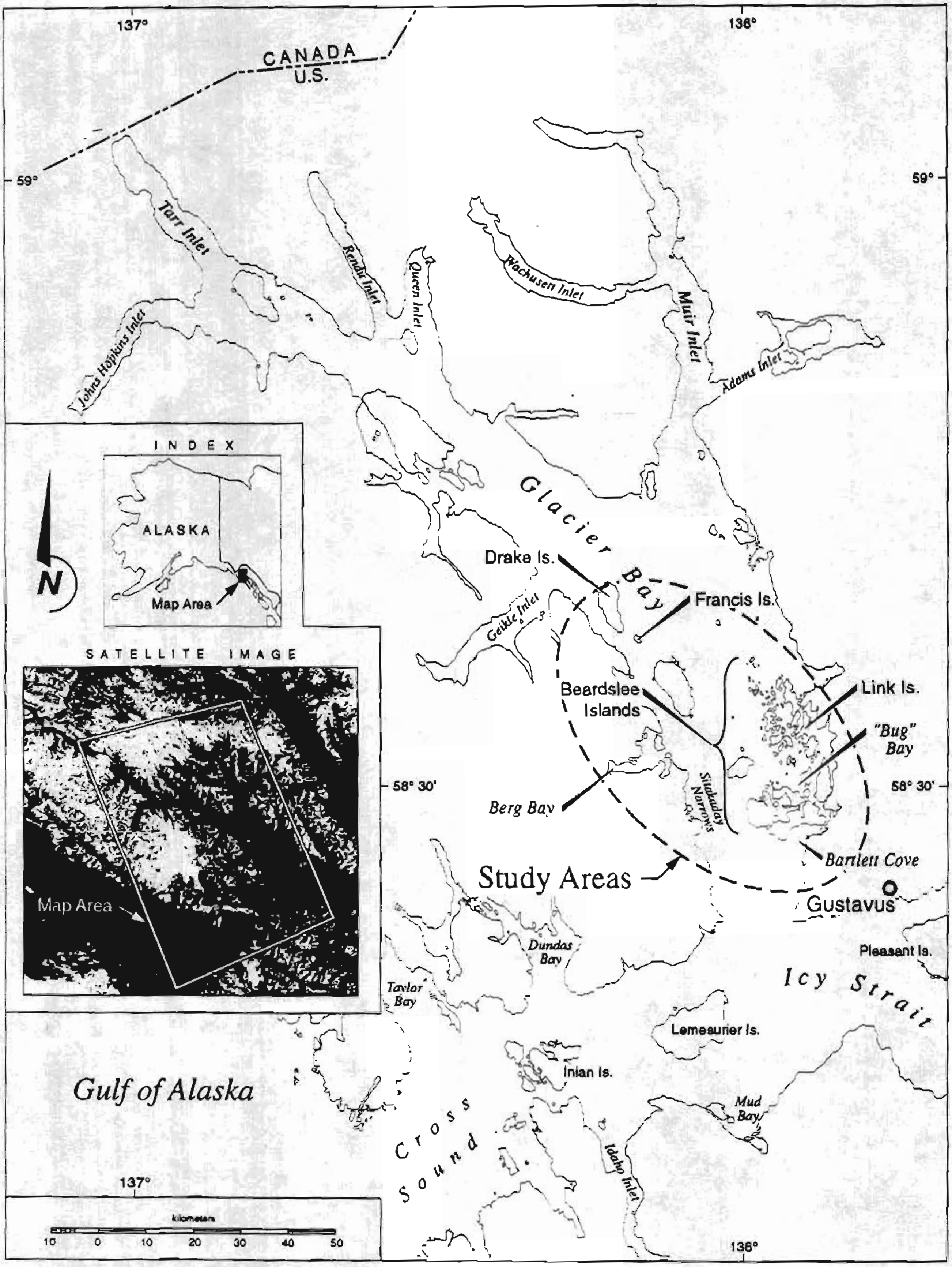
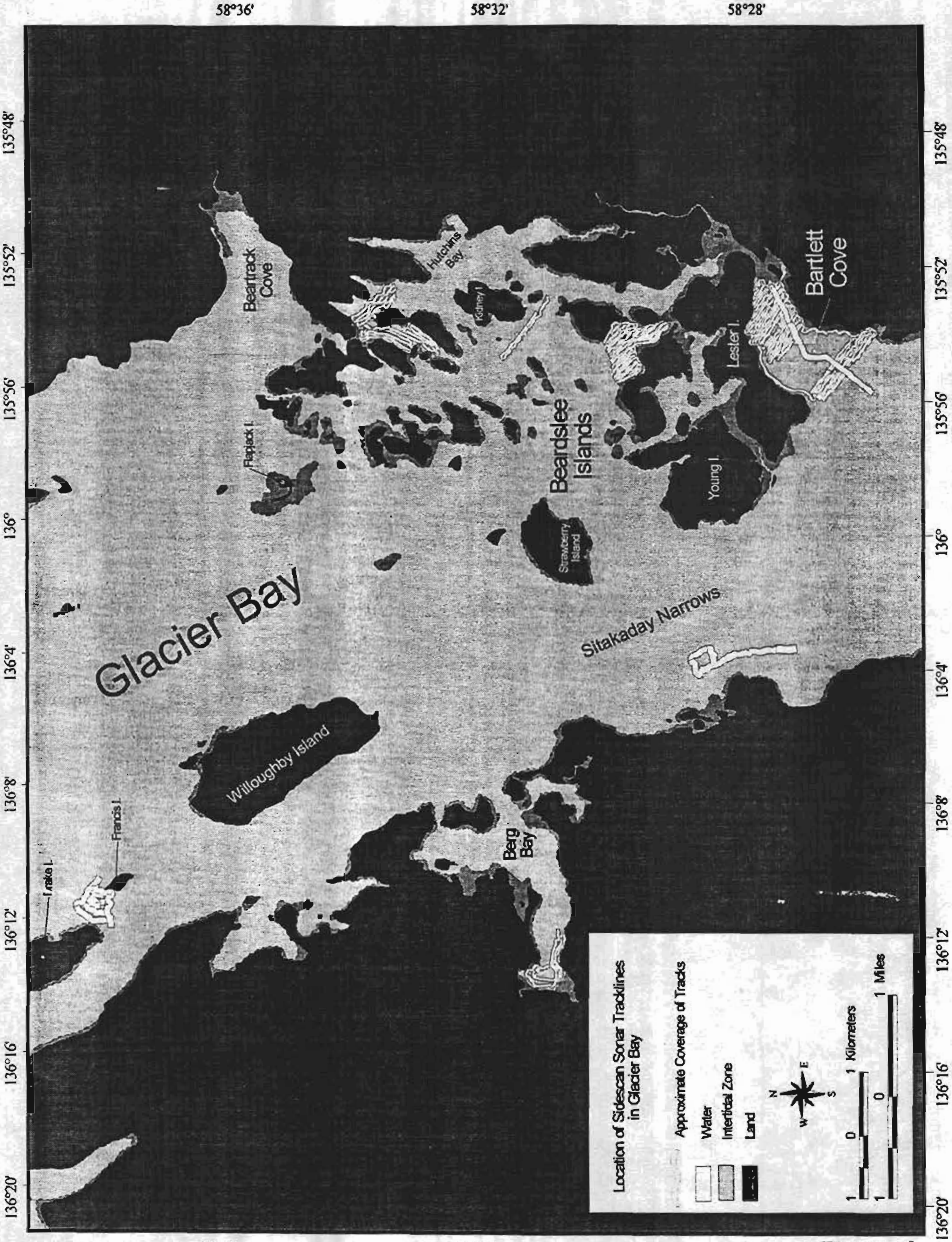
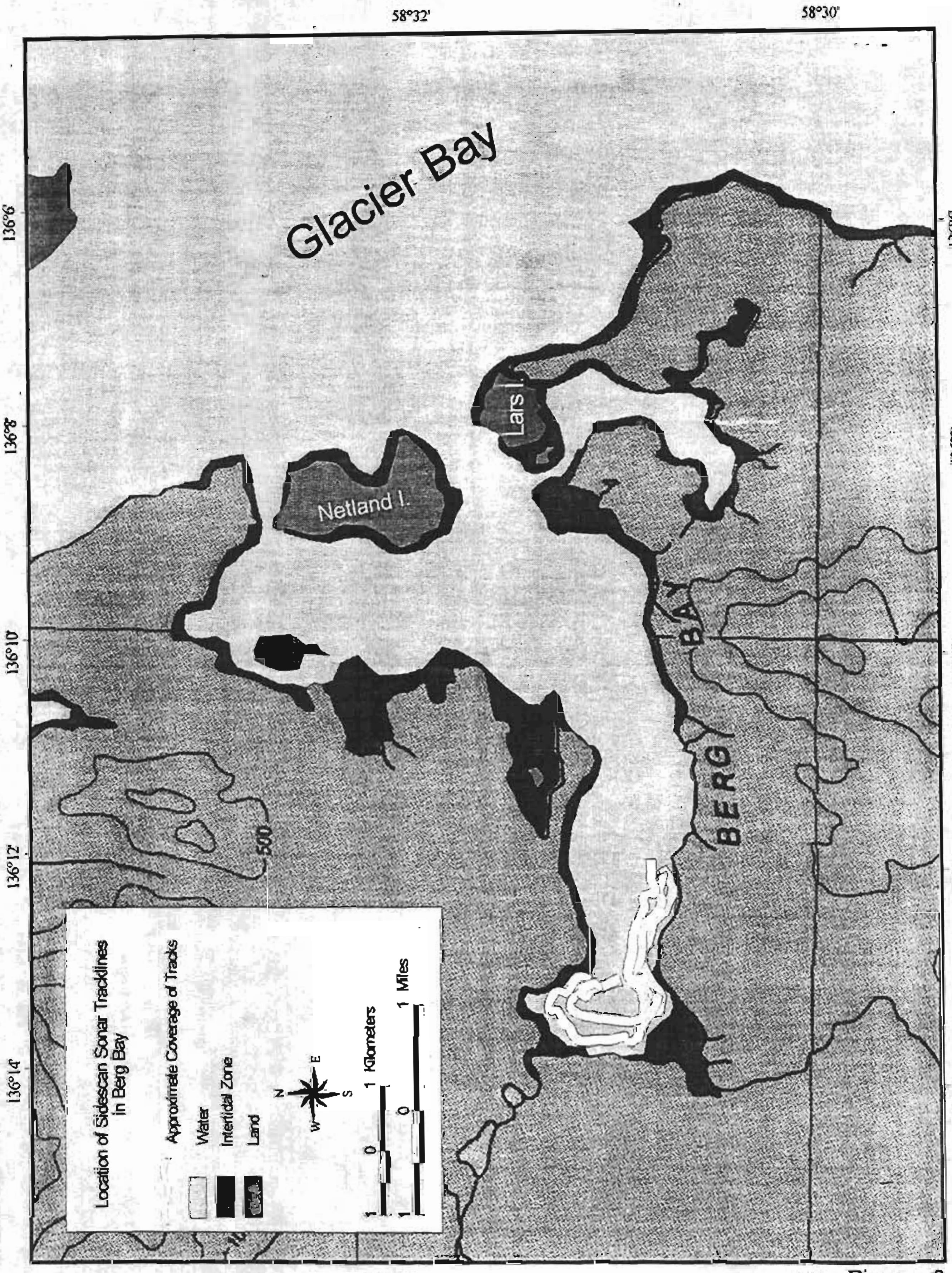

137°
136°
CANADA
U.S.
59°
59°
Tarr Inlet
Reid Inlet
Queen Inlet
Wachusett Inlet
Muir Inlet
Adams Inlet
Johns Hopkins Inlet
INDEX
ALASKA
Map Area
N
Glacier Bay
Drake Is.
Francis Is.
Geikie Inlet
SATELLITE IMAGE
Map Area
Beardslee Islands
Link Is.
"Bug" Bay
58° 30'
58° 30'
Berg Bay
Sitakaday Narrows
Bartlett Cove
Study Areas
Gustavus
Pleasant Is.
Dundas Bay
Taylor Bay
Icy Strait
Lemesurier Is.
Inian Is.
Gulf of Alaska
Mud Bay
Cross Sound
Idaho Inlet
137°
136°
kilometers
10 0 10 20 30 40 50

Figure 1



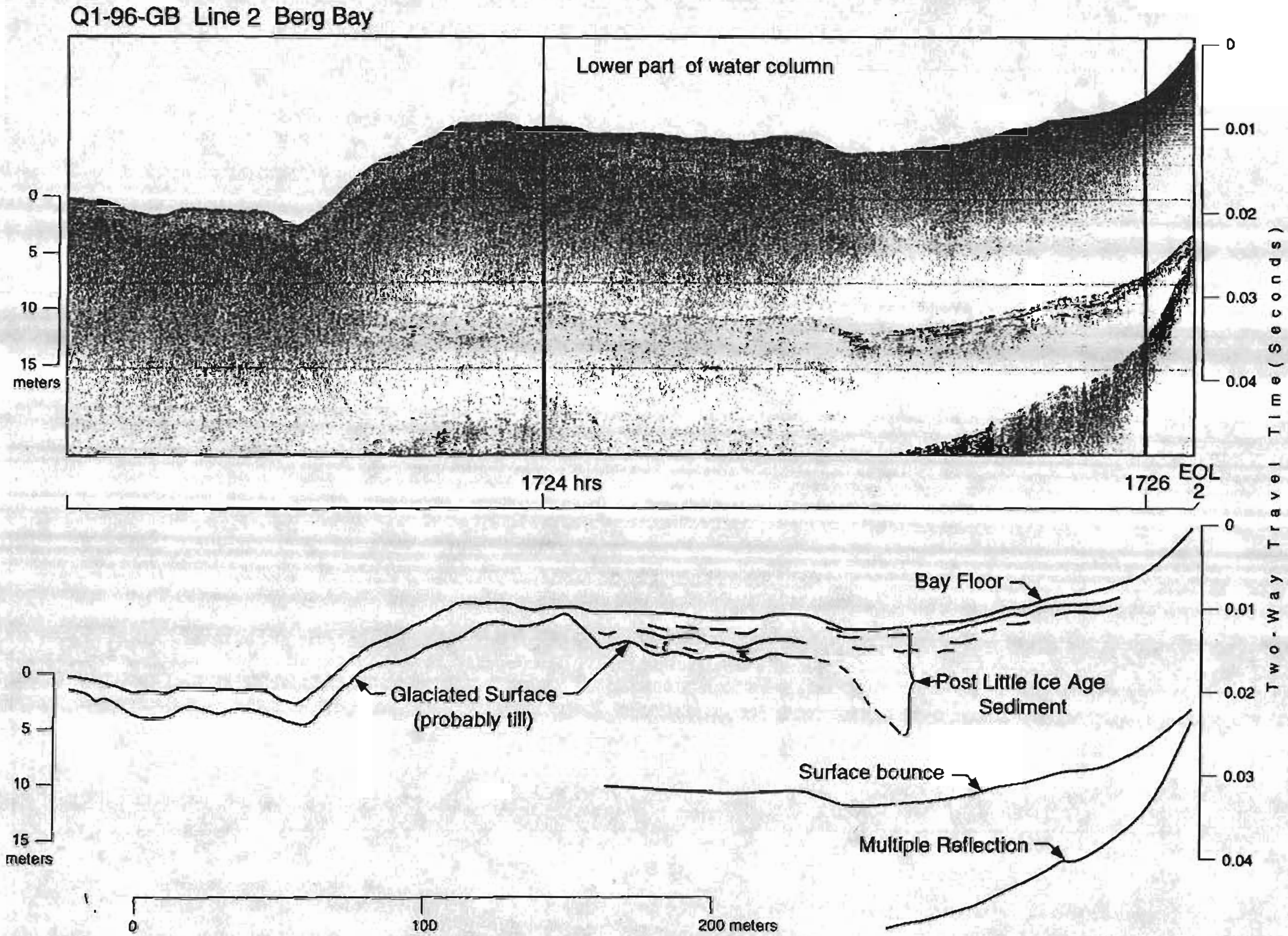
Location of Sidescan Sonar Tracklines in Glacier Bay
Approximate Coverage of Tracks
Water
Intertidal Zone
Land
Kilometers
Miles
Glacier Bay
Beardslee Islands
Bartlett Cove
Sitakaday Narrows
Willoughby Island
Berg Bay
Beartrack Cove
Hutchins Bay
Strawberry Island
Young I.
Lester I.
Kidney I.
Flapjack I.
Francis I.
58°36'
58°32'
58°28'
135°48'
135°52'
135°56'
136°
136°4'
136°8'
136°12'
136°16'
136°20'

Figure 2



58°32'
58°30'
136°6'
136°8'
136°10'
136°12'
136°14'
Glacier Bay
Lars I.
Netland I.
BERG BAY
500
Location of Sidescan Sonar Tracklines in Berg Bay
Approximate Coverage of Tracks
Water
Intertidal Zone
Land
N
E
S
W
1 0 1 Kilometers
1 0 1 Miles

Figure 3



Q1-96-GB Line 2 Berg Bay
Lower part of water column
0
5
10
15
meters
1724 hrs
1726
EOL
2
0
0.01
0.02
0.03
0.04
Two-Way Travel Time (Seconds)
Bay Floor
Glaciated Surface
(probably till)
Post Little Ice Age
Sediment
Surface bounce
Multiple Reflection
0
100
200 meters

Figure 4

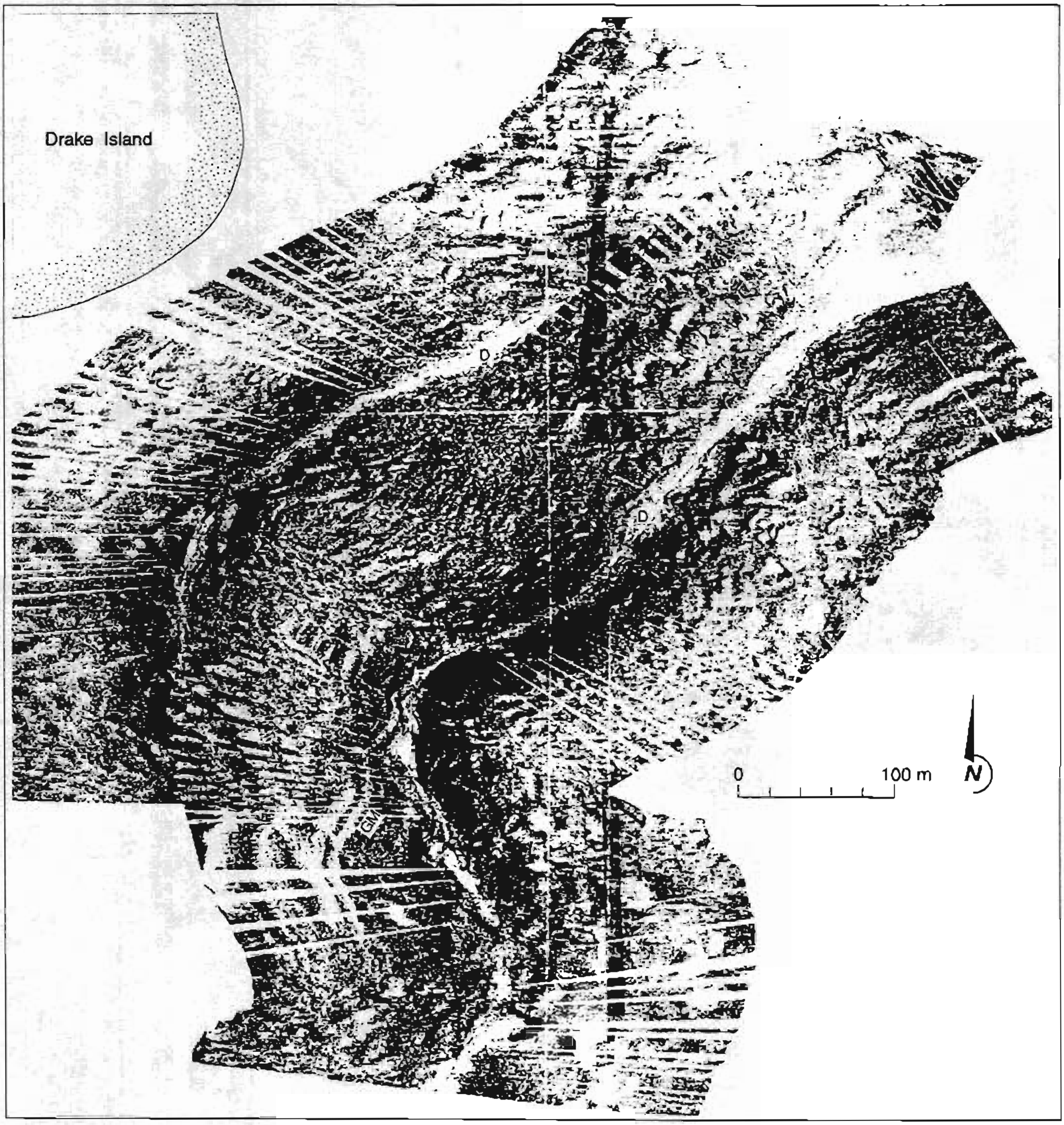
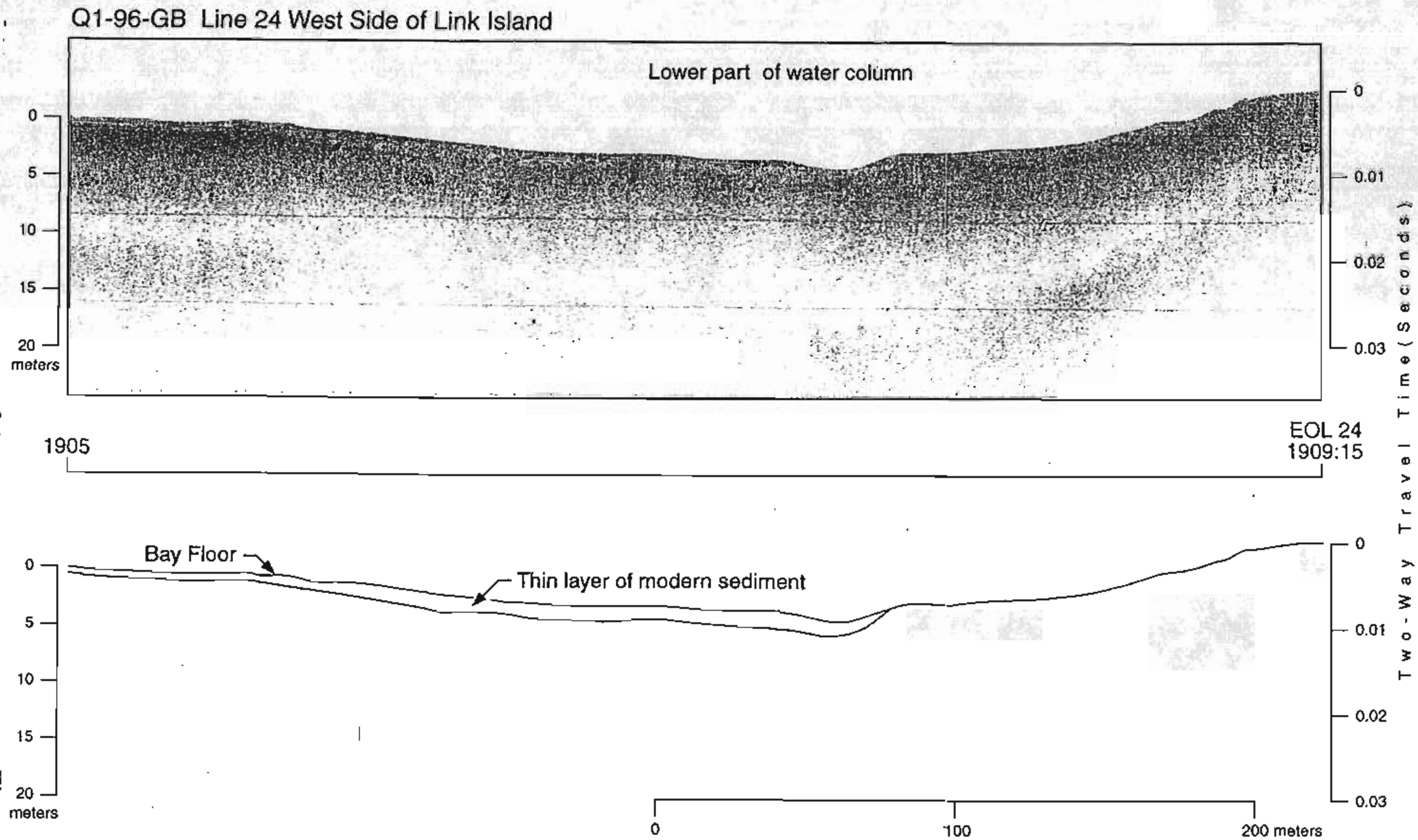


Figure 7


Location of Sidescan Sonar Tracklines
In Beardslee Islands
Approximate Coverage of Tracks
Water
Intertidal Zone
Land
N
E
S
W
1 0 1 Kilometers
1 0 1 Miles
Hutchins Bay
Kidney I.
Link I.
Spider I.
Elder I.
Secret Bay
Beardslee Entrance
58°34'
58°32'
58°30'
135°46'
135°48'
135°50'
135°52'
135°54'
135°56'
135°58'
136°
136°2'
136°4'
Figure 8



Q1-96-GB Line 24 West Side of Link Island
Lower part of water column
0
5
10
15
20
meters
0
0.01
0.02
0.03
Two-Way Travel Time (Seconds)
1905
EOL 24
1909:15
Bay Floor
Thin layer of modern sediment
0
5
10
15
20
meters
0
0.01
0.02
0.03
0
100
200 meters

Figure 9

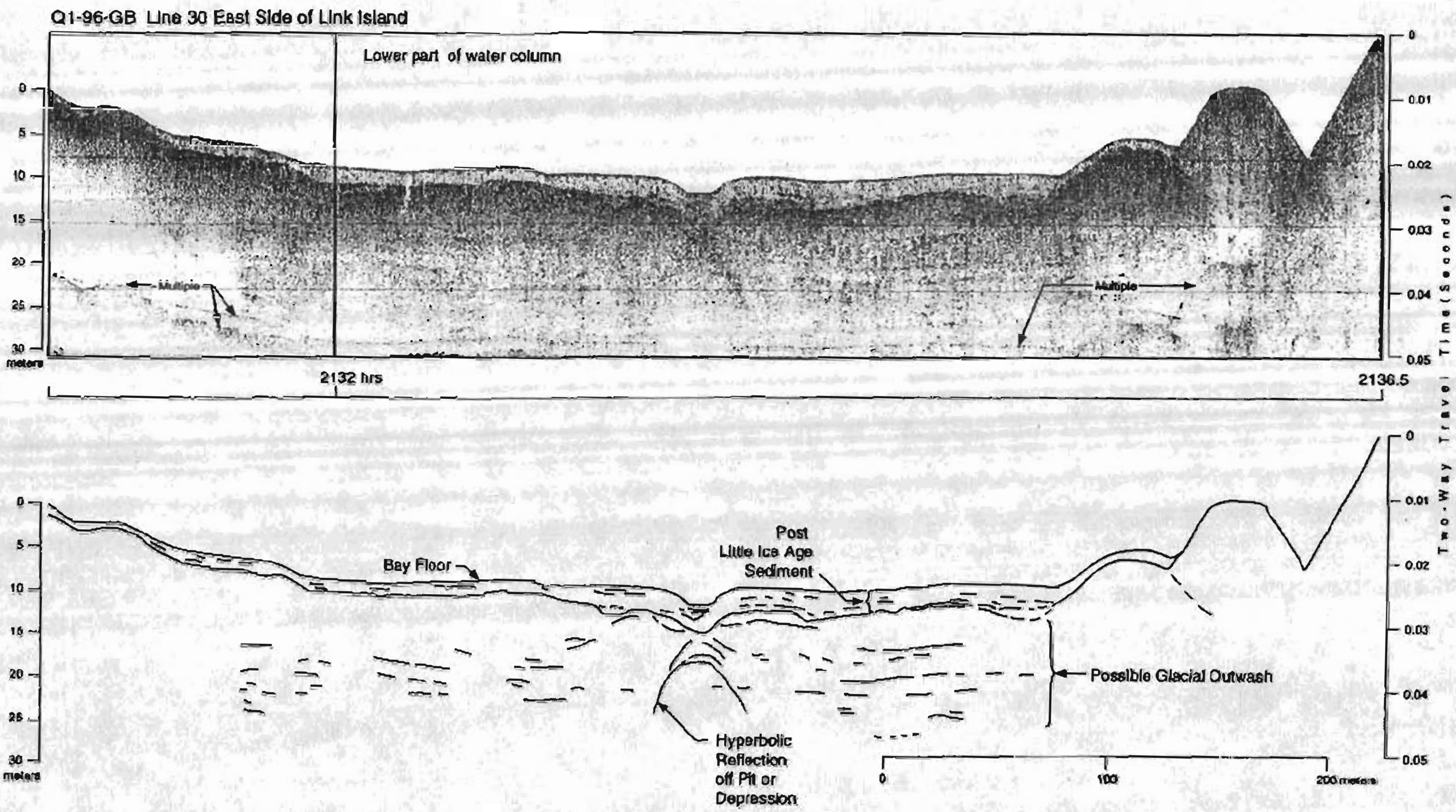

Q1-96-GB Line 30 East Side of Link Island
Lower part of water column
Multiple
Multiple
2132 hrs
2136.5
0
5
10
15
20
25
30
meters
0
0.01
0.02
0.03
0.04
0.05
Two-Way Travel Time (Seconds)
Bay Floor
Post Little Ice Age Sediment
Possible Glacial Outwash
Hyperbolic Reflection off Pit or Depression
0
100
200 meters

Figure 10

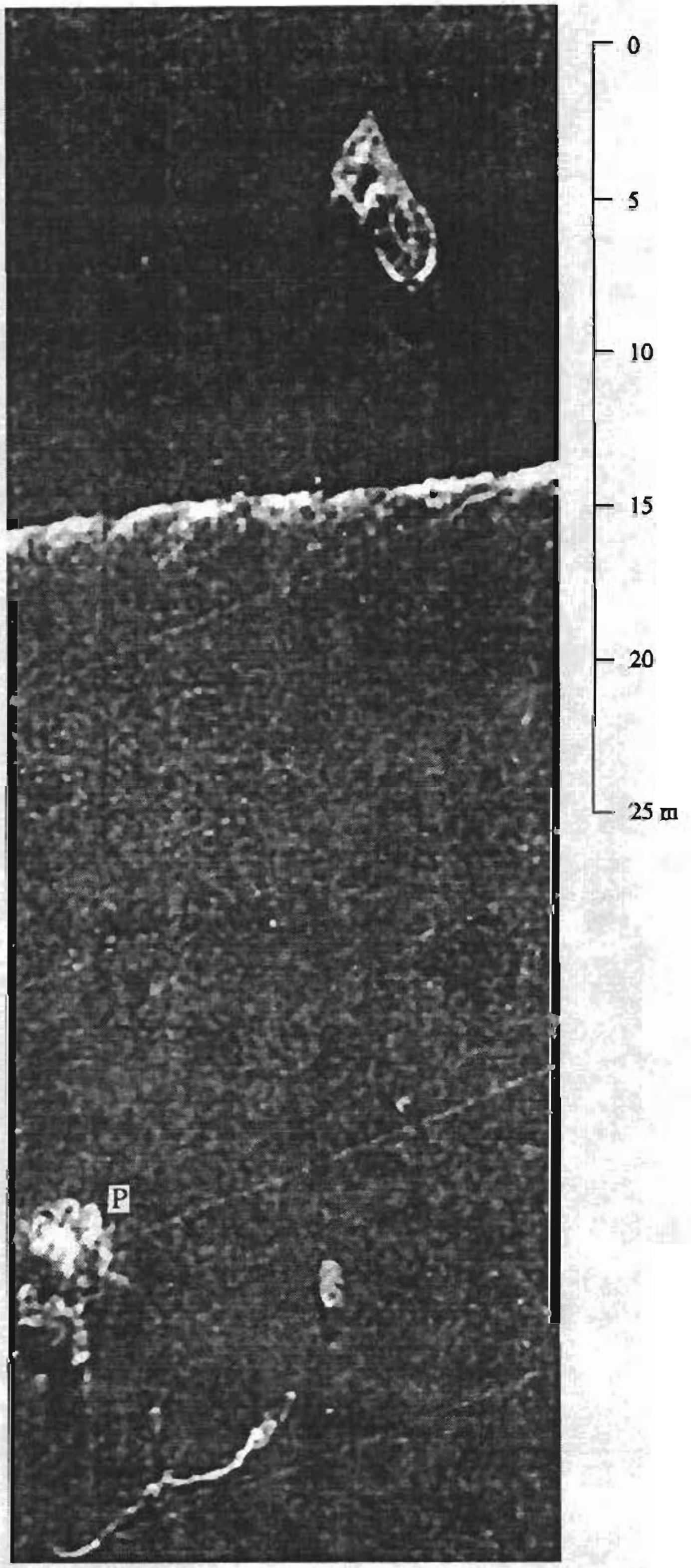
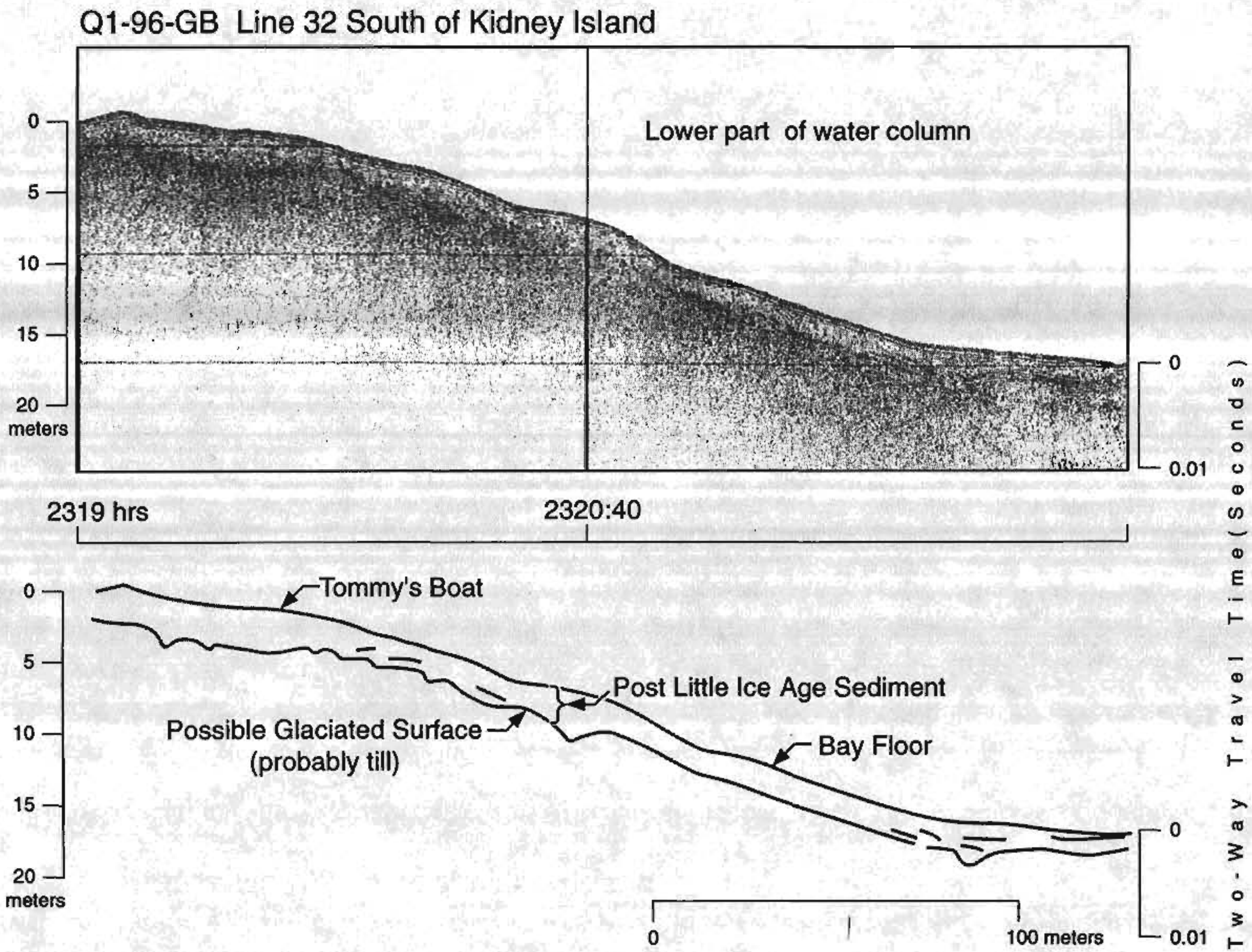
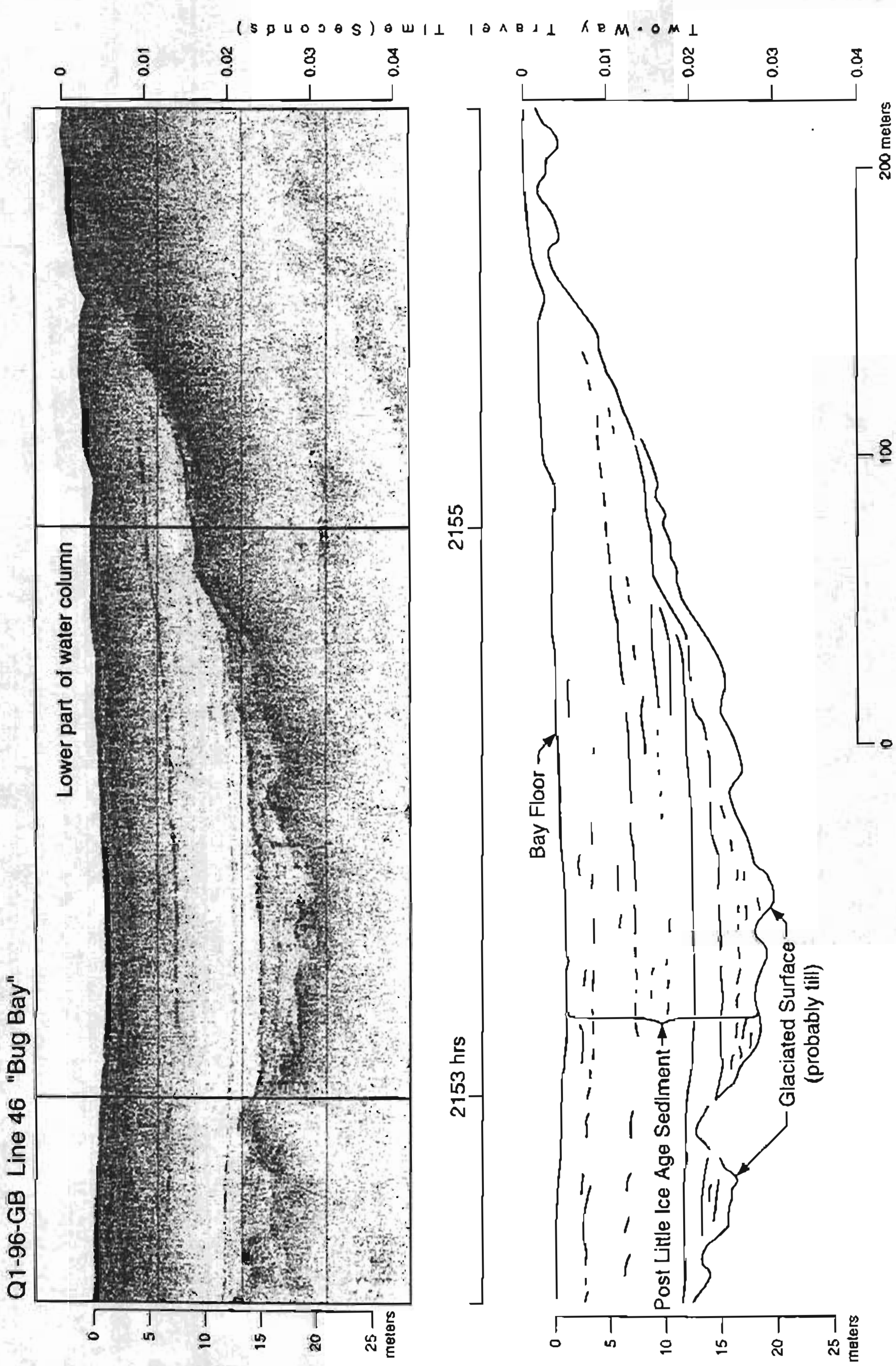


Figure 11



Q1-96-GB Line 32 South of Kidney Island
Lower part of water column
0
5
10
15
20
meters
0
0.01
2319 hrs
2320:40
Tommy's Boat
Post Little Ice Age Sediment
Possible Glaciated Surface (probably till)
Bay Floor
0
100 meters
Two-Way Travel Time (Seconds)

Figure 12



Q1-96-GB Line 46 "Bug Bay"
Lower part of water column
Two-Way Travel Time (Seconds)
0
0.01
0.02
0.03
0.04
2153 hrs
2155
Bay Floor
Post Little Ice Age Sediment
Glaciated Surface
(probably till)
0
5
10
15
20
25
meters
0
100
200 meters

Figure 13

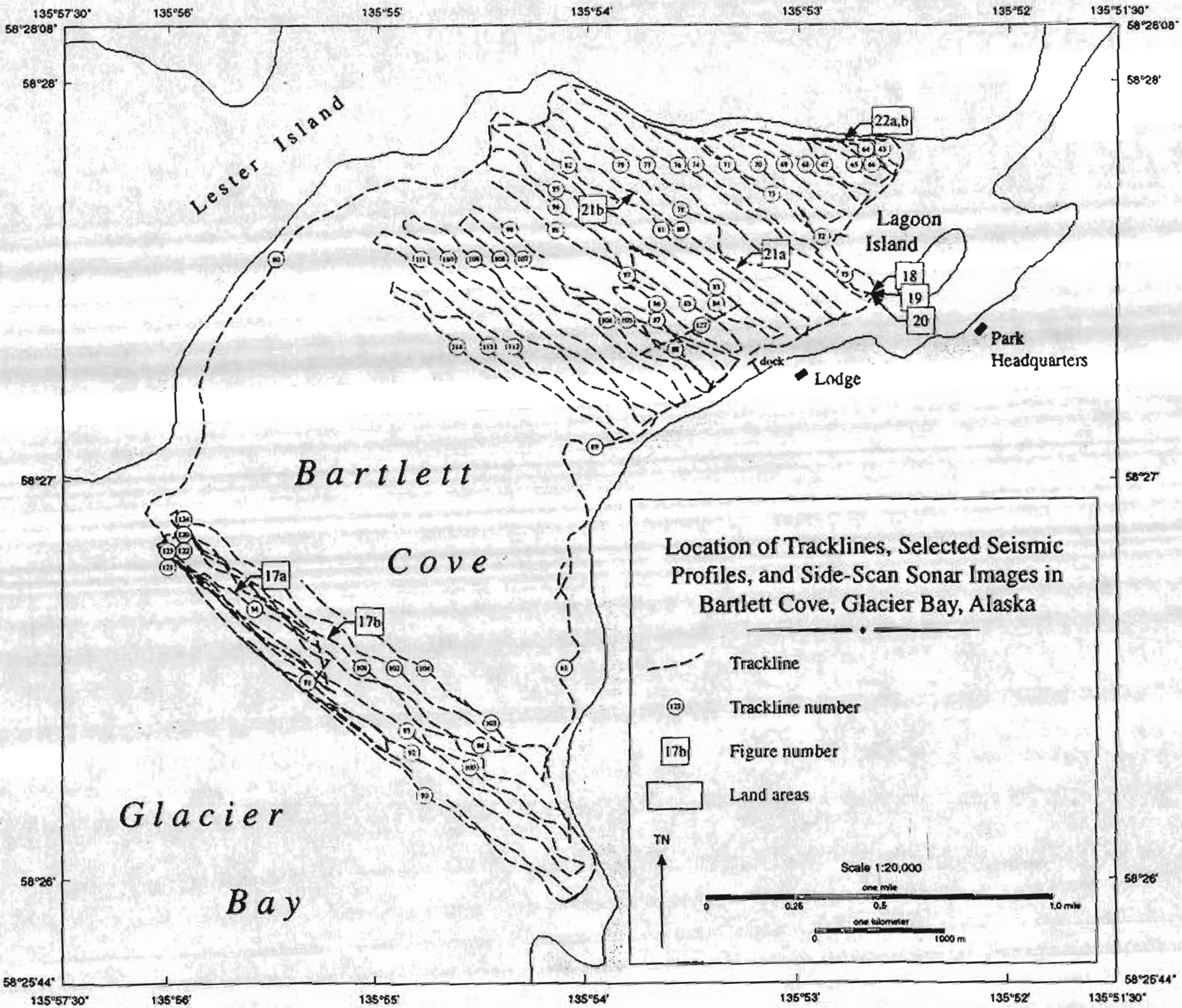

135°57'30"
135°56'
135°55'
135°54'
135°53'
135°52'
135°51'30"
58°26'08"
58°26'
58°27'
58°25'44"
Lester Island
Lagoon Island
22a,b
21b
21a
18
19
20
Park Headquarters
dock
Lodge
Bartlett
Cove
Glacier
Bay
17a
17b
Location of Tracklines, Selected Seismic Profiles, and Side-Scan Sonar Images in Bartlett Cove, Glacier Bay, Alaska
Trackline
Trackline number
Figure number
Land areas
TN
Scale 1:20,000
one mile
0
0.25
0.5
1.0 mile
one kilometer
1000 m

Figure 14

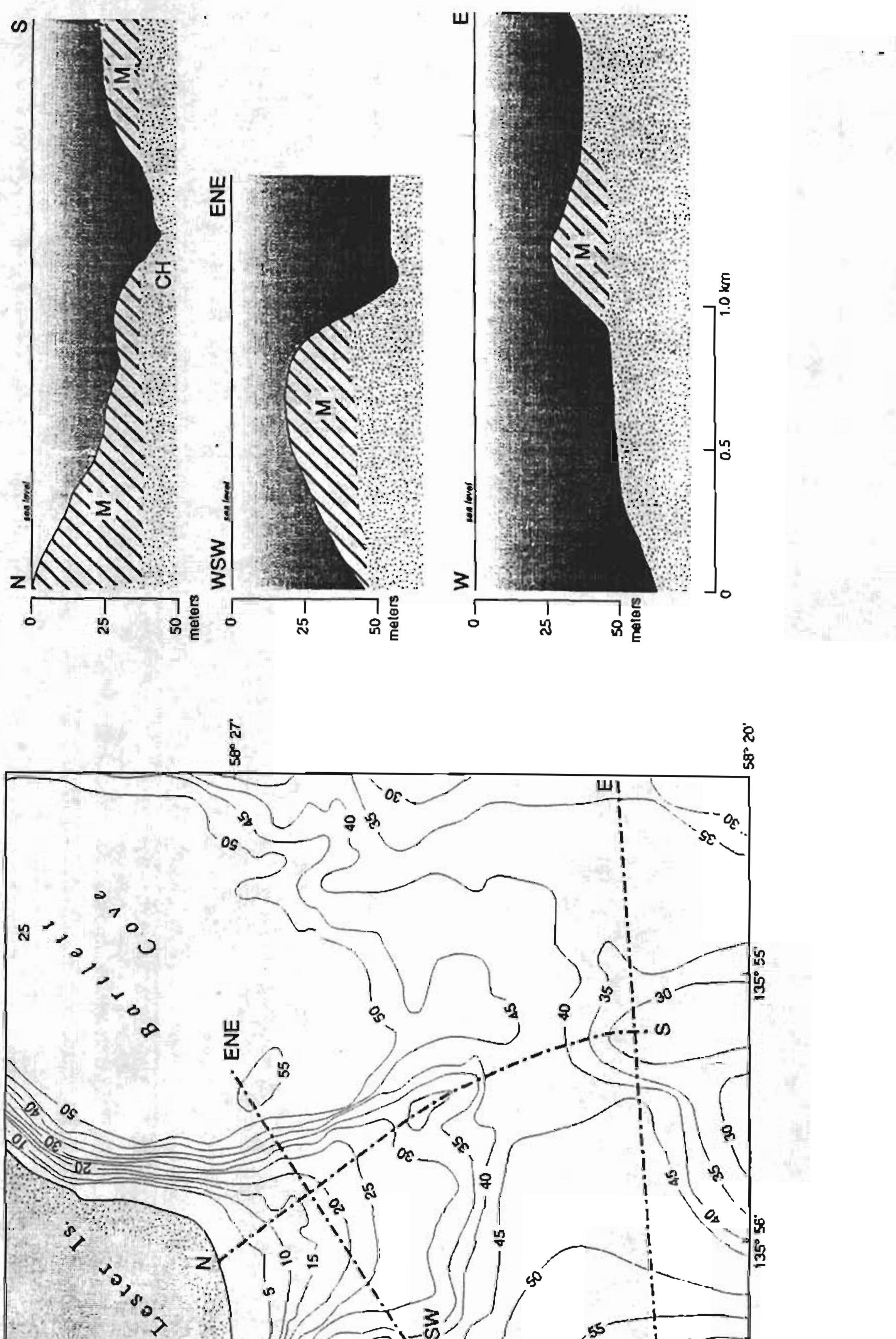

Lester Is.
Bartlett Cove
N
S
WSW
ENE
W
E
M
CH
sea level
meters
0
25
50
0.5
1.0 km
58° 27'
58° 20'
135° 55'
135° 56'

Figure 15a

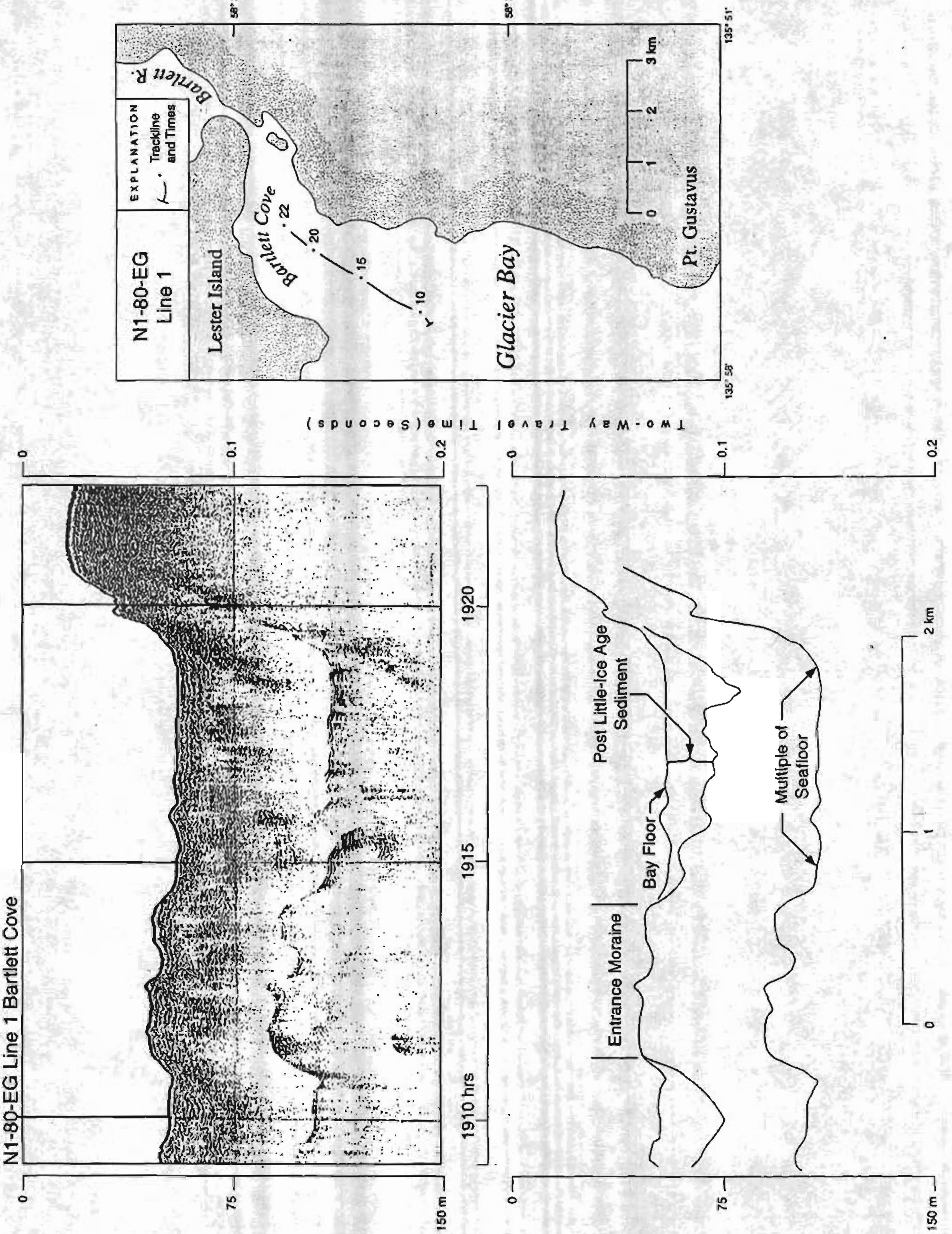

N1-80-EG Line 1 Bartlett Cove
1910 hrs
1915
1920
0
75
150 m
0
0.1
0.2
Two-Way Travel Time (Seconds)
Entrance Moraine
Bay Floor
Post Little-Ice Age Sediment
Multiple of Seafloor
0
1
2 km
N1-80-EG Line 1
EXPLANATION
Trackline and Times
Lester Island
Bartlett Cove
Bartlett R.
Glacier Bay
Pt. Gustavus
10
15
20
22
3 km
58° 28'
58° 25'
135° 56'
135° 51'

Figure 15b

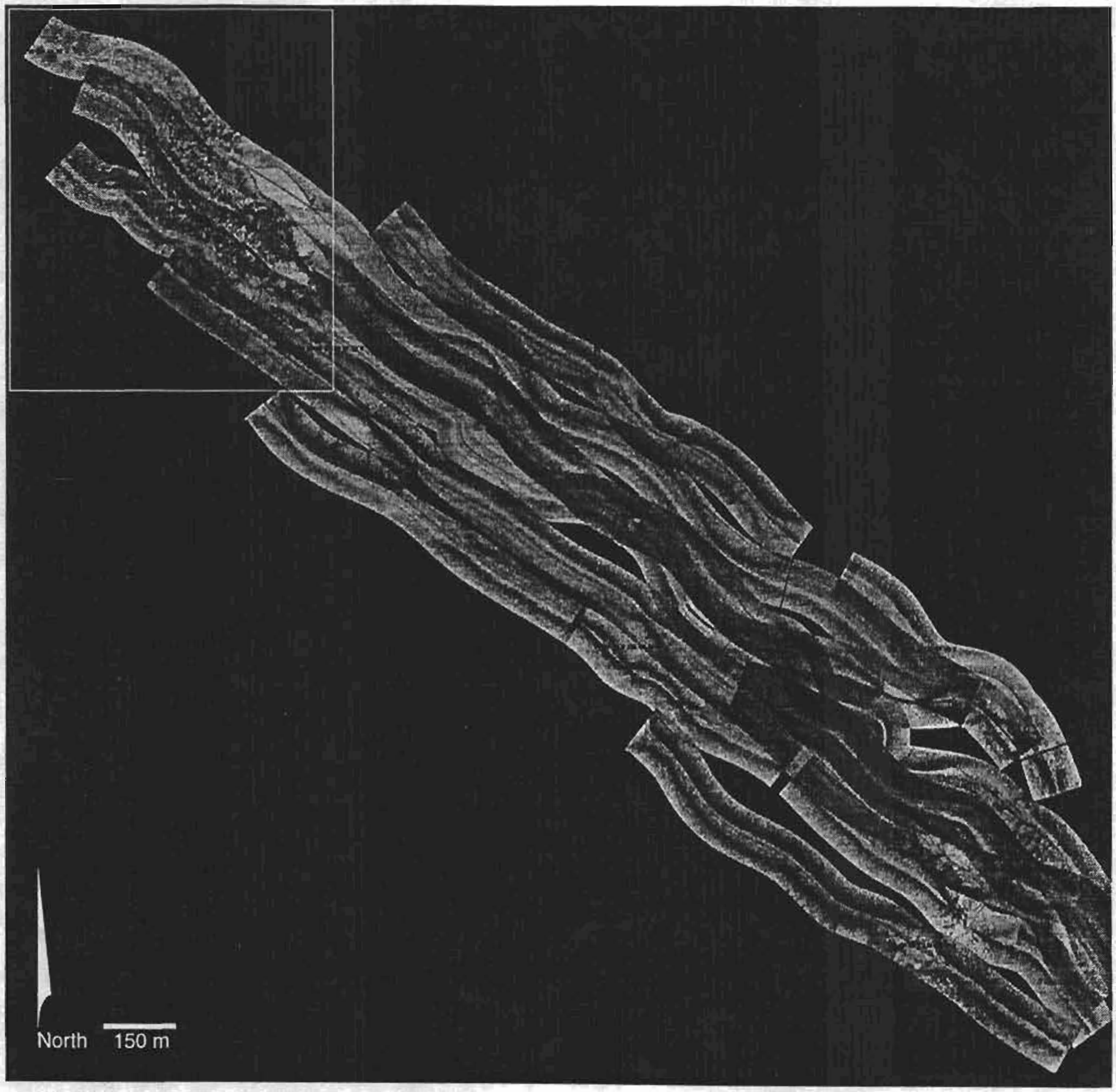


Figure 16a

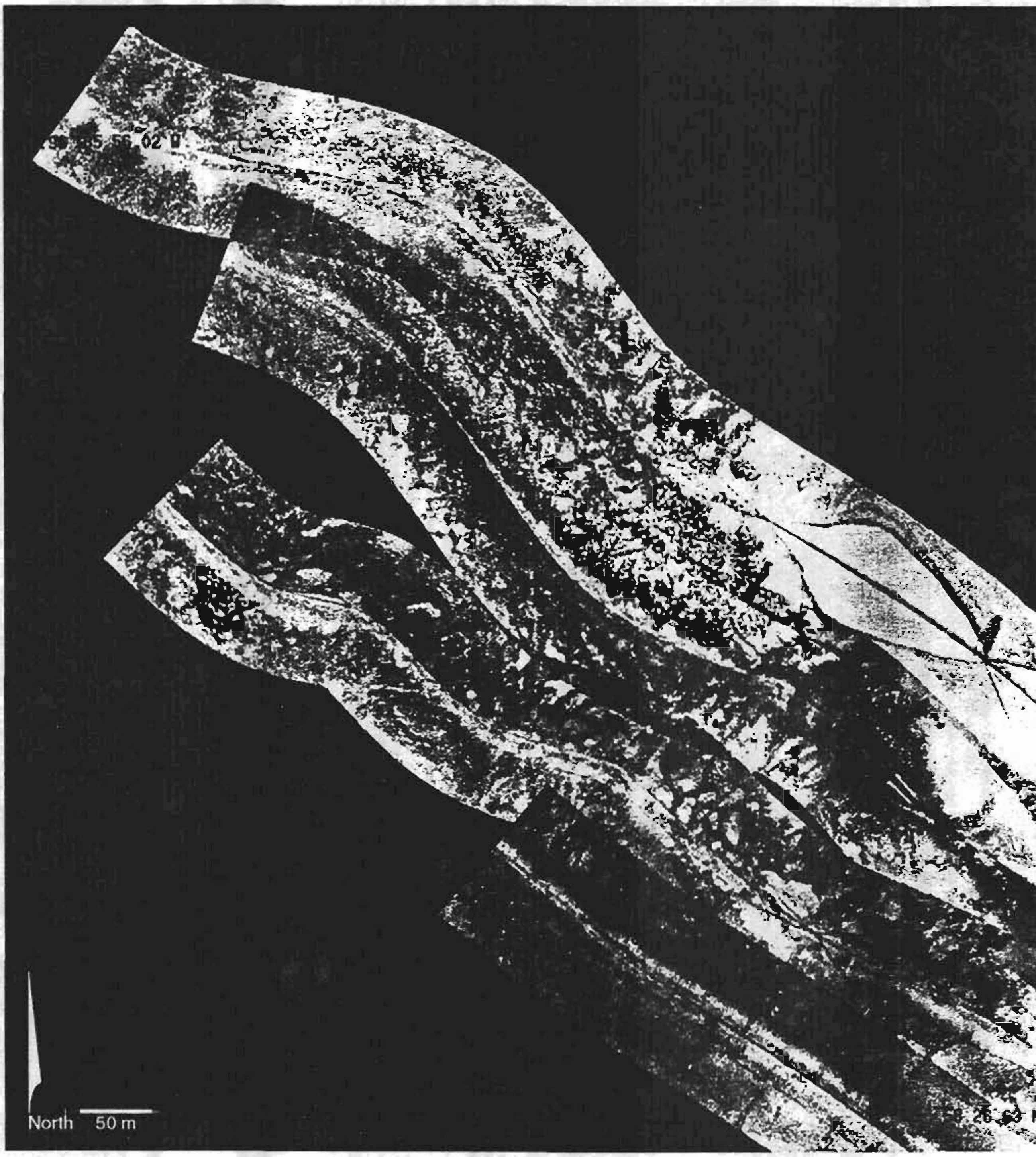


Figure 16b

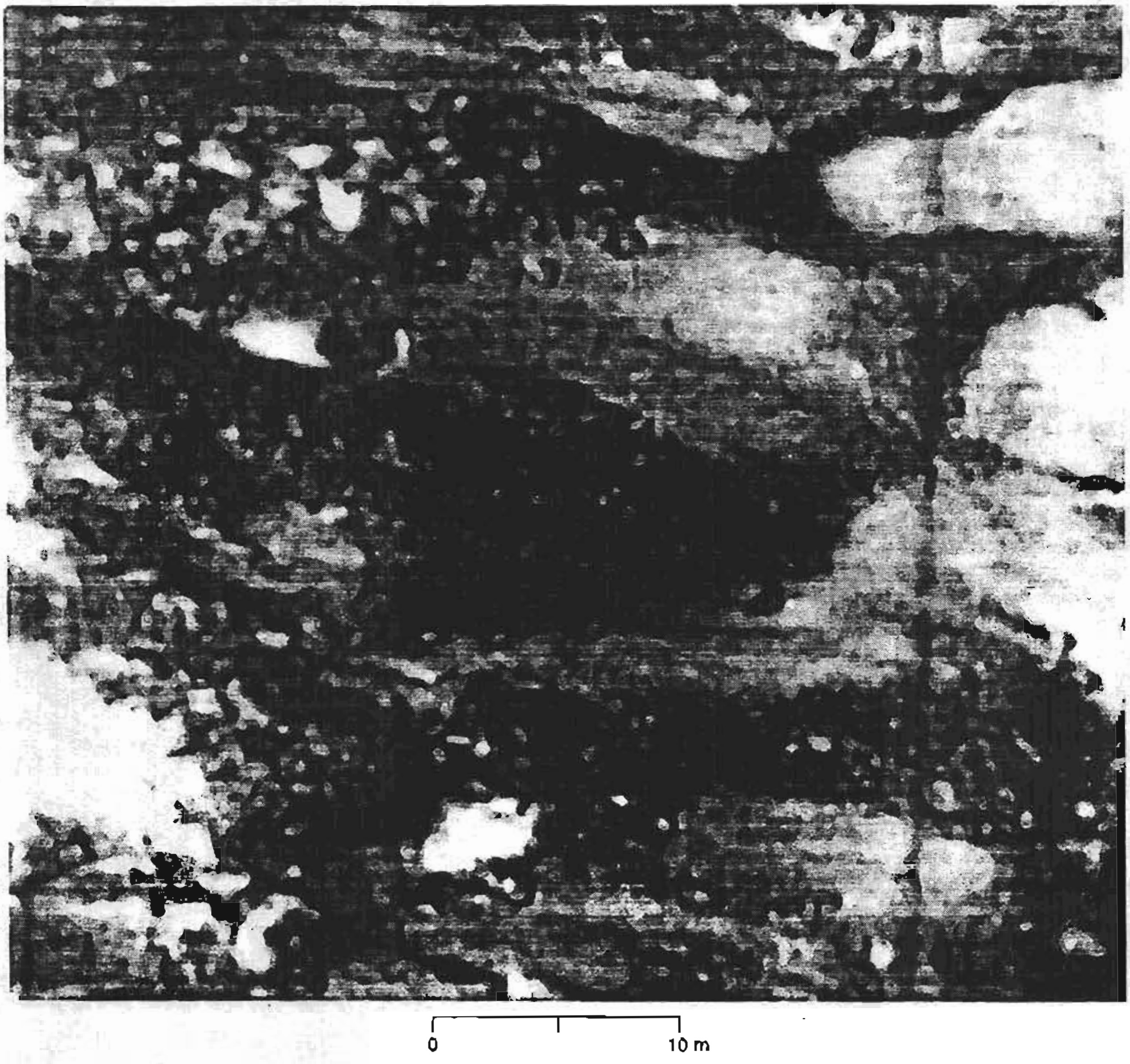


Figure 16c

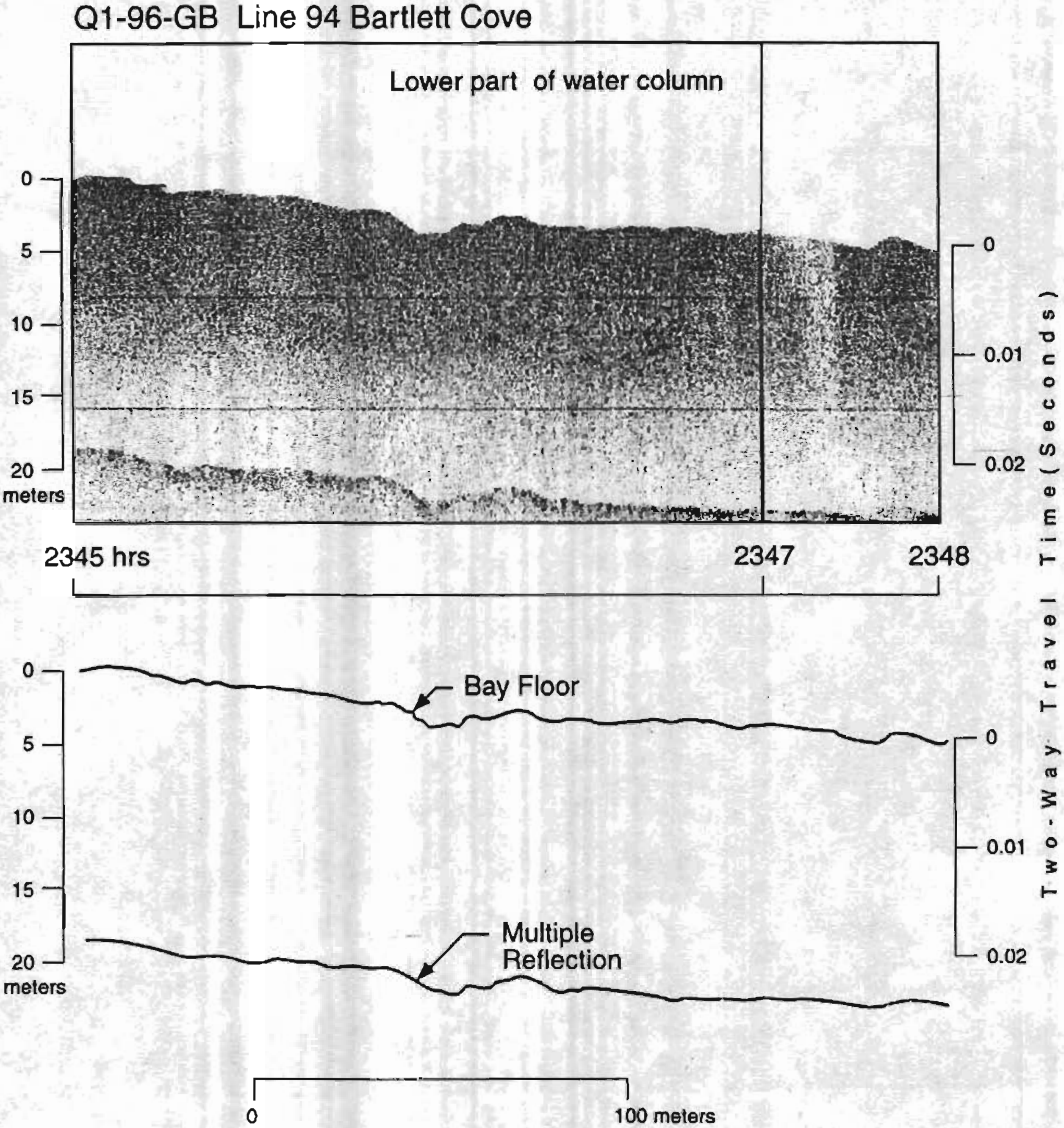

Q1-96-GB Line 94 Bartlett Cove
Lower part of water column
0
5
10
15
20
meters
2345 hrs
2347
2348
0
0.01
0.02
Two-Way Travel Time (Seconds)
Bay Floor
Multiple Reflection
0
100 meters

Figure 17a

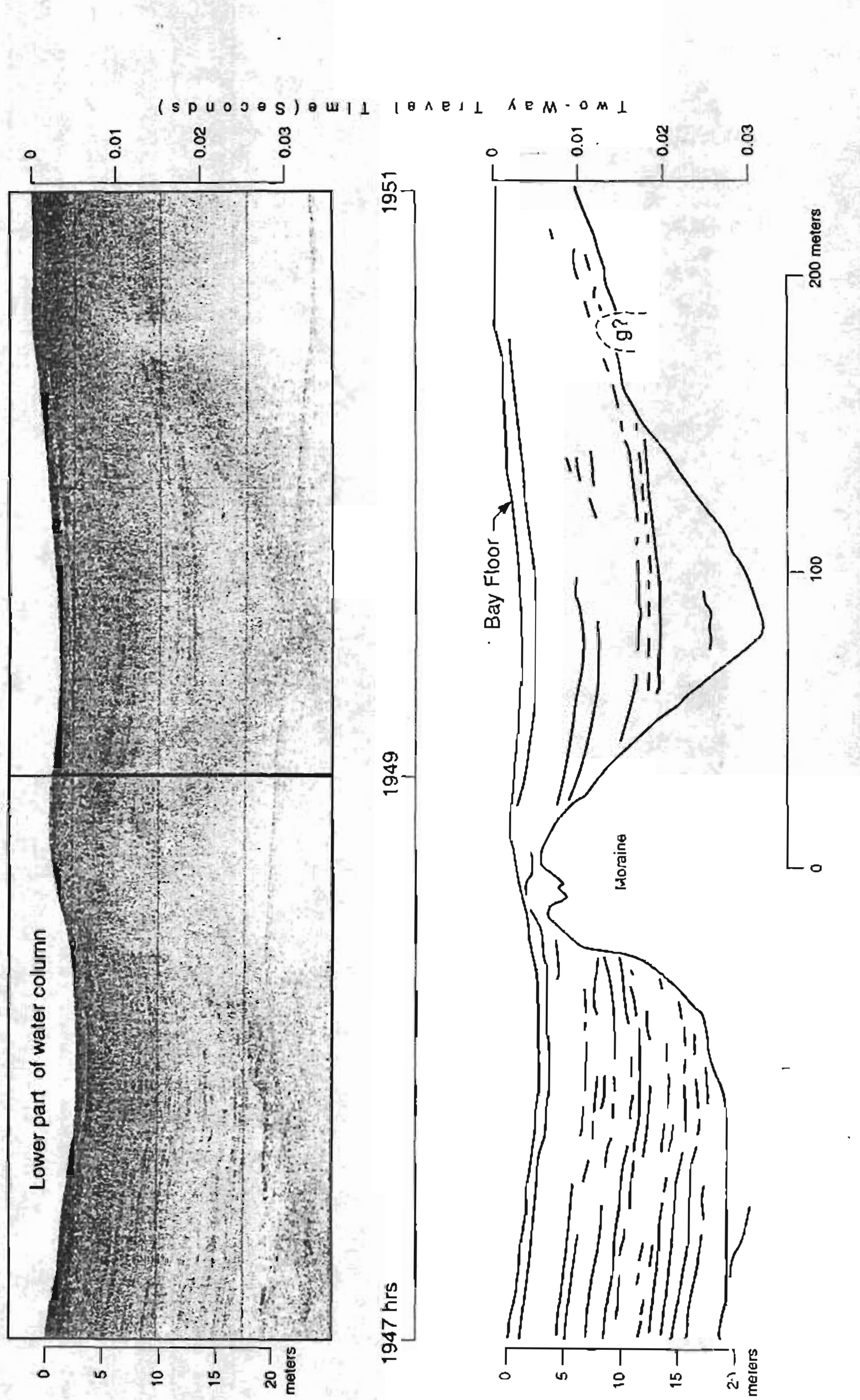

Q1-96-GB Line 101 Bartlett Cove
Lower part of water column
Two-Way Travel Time (Seconds)
0
0.01
0.02
0.03
1947 hrs
1949
1951
0
5
10
15
20
meters
Bay Floor
Moraine
g?
0
100
200 meters

Figure 17b

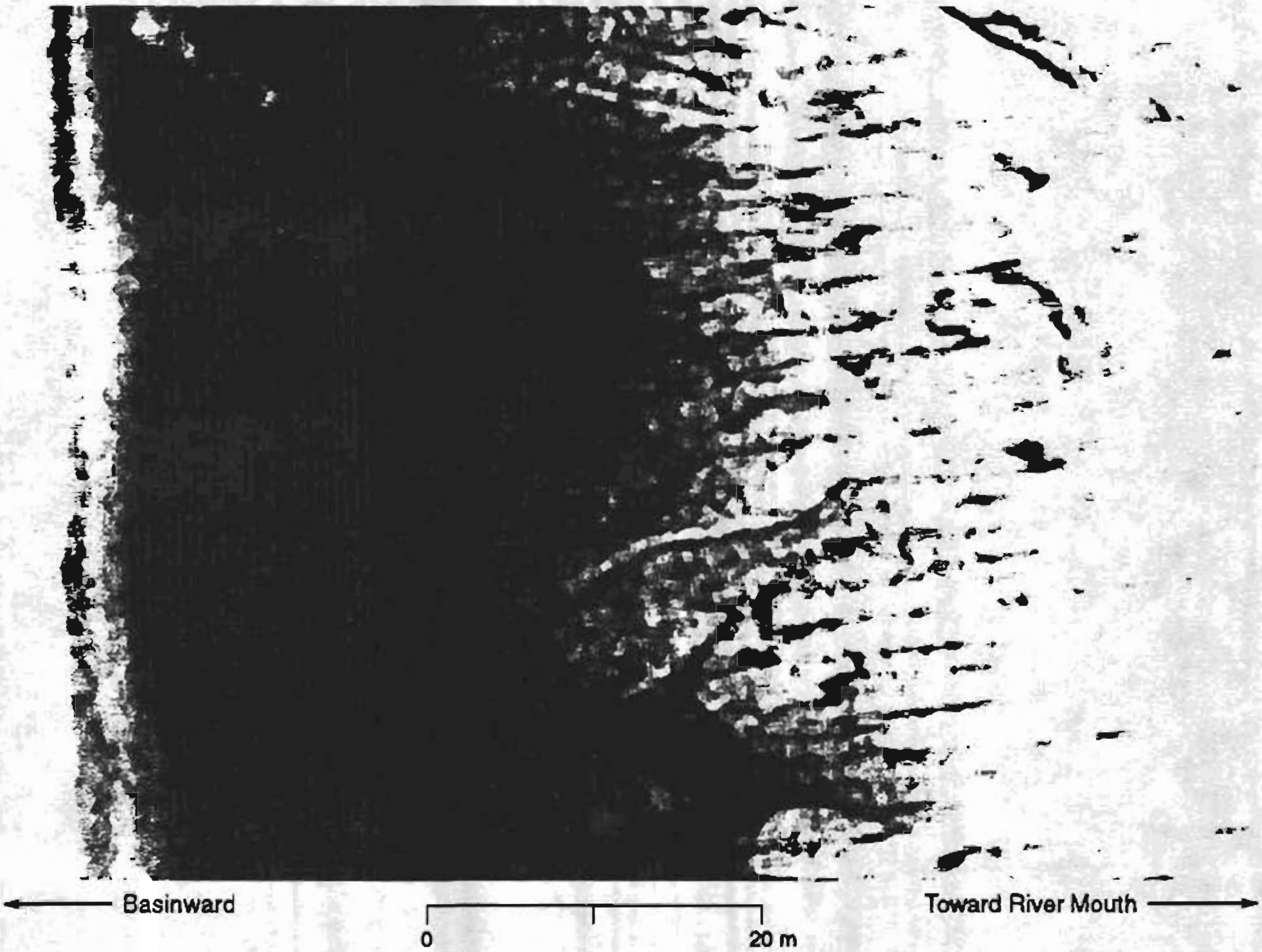


Figure 18

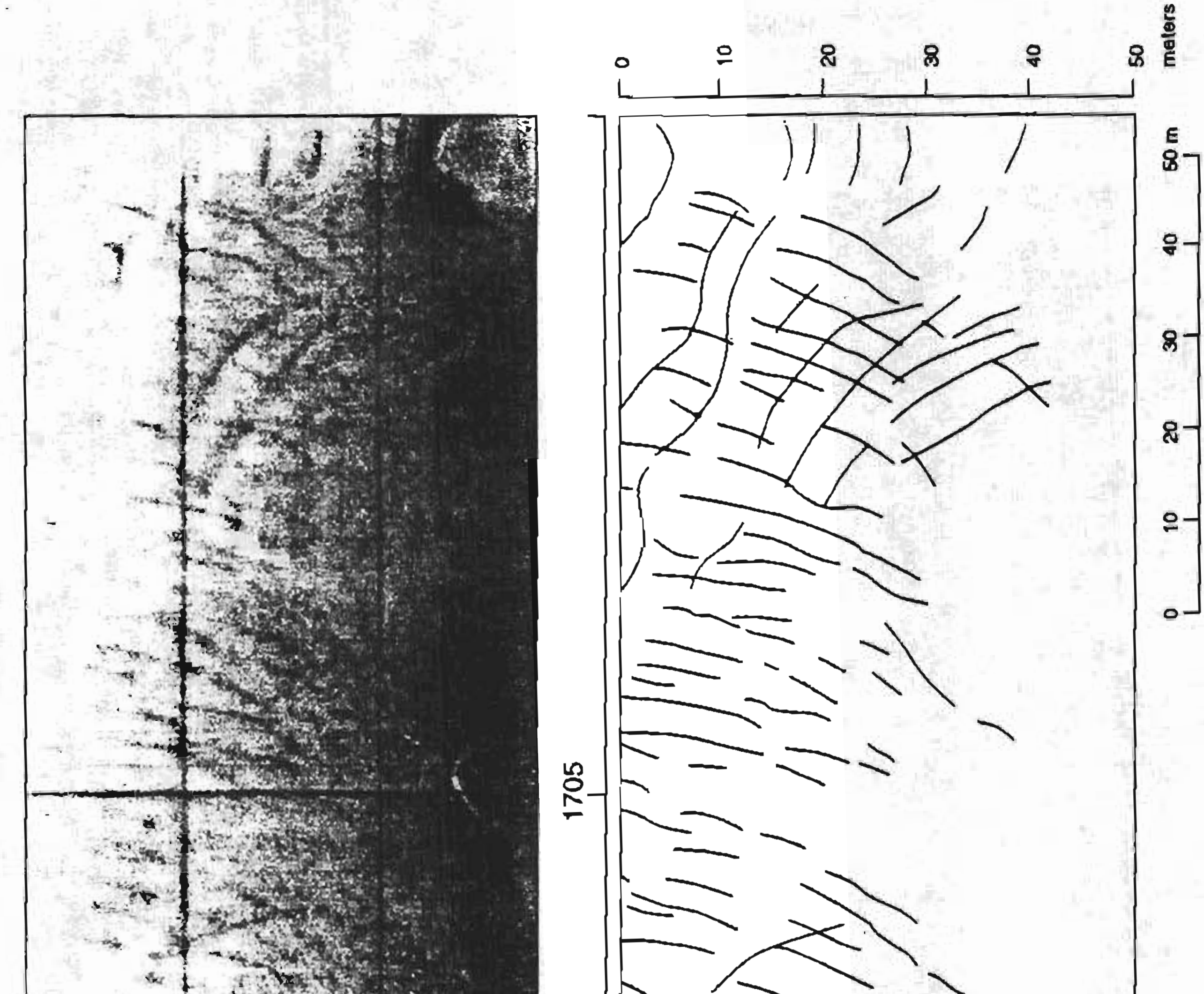

Interpretive Map of Sand Wave Crests
1704 hrs
1705
0
10
20
30
40
50
meters
0
10
20
30
40
50 m

Figure 19

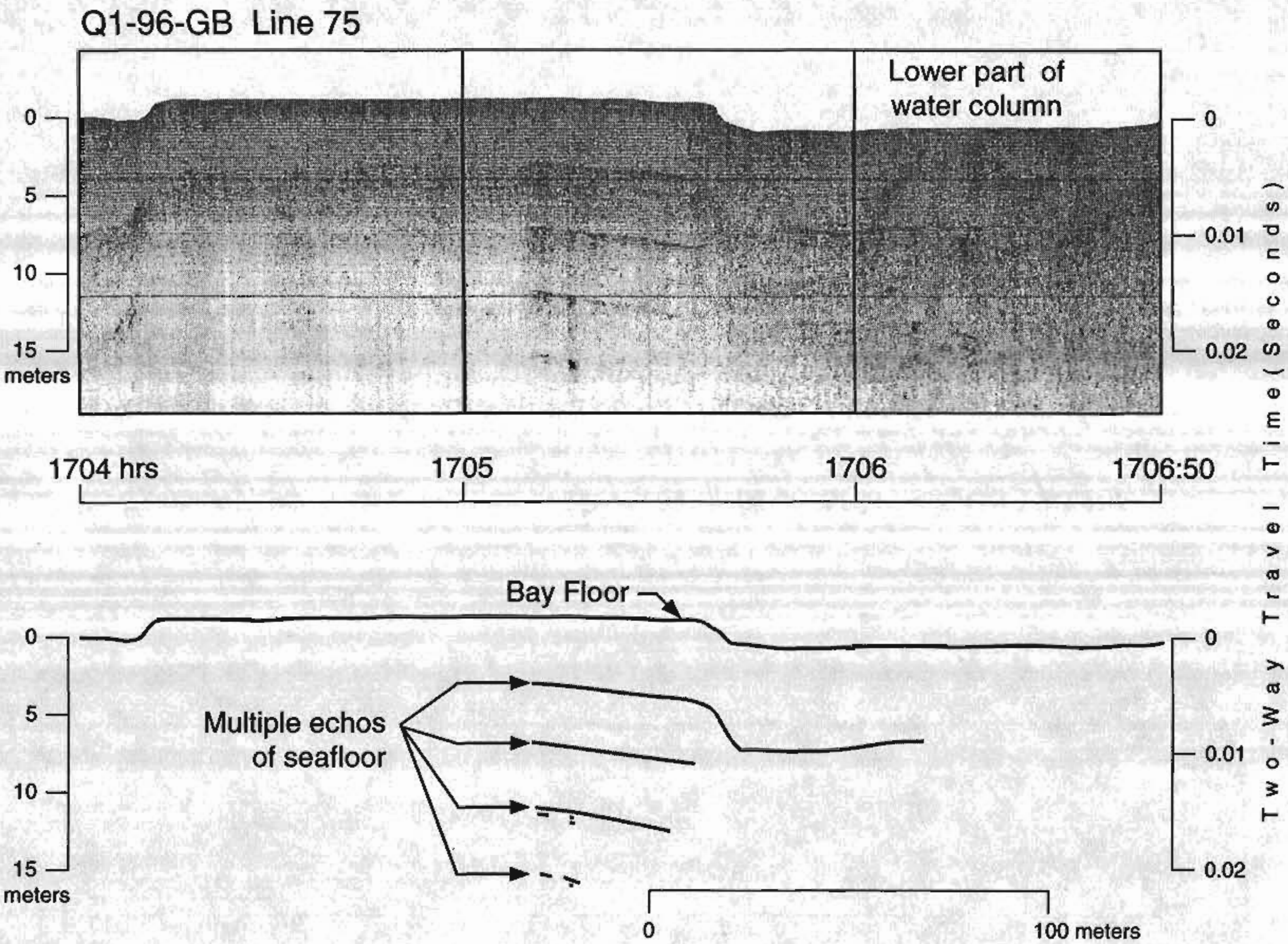

Q1-96-GB Line 75
Lower part of water column
0
5
10
15
meters
0
0.01
0.02
1704 hrs
1705
1706
1706:50
Bay Floor
Multiple echos of seafloor
0
5
10
15
meters
0
0.01
0.02
0
100 meters
Two-Way Travel Time (Seconds)

Figure 20

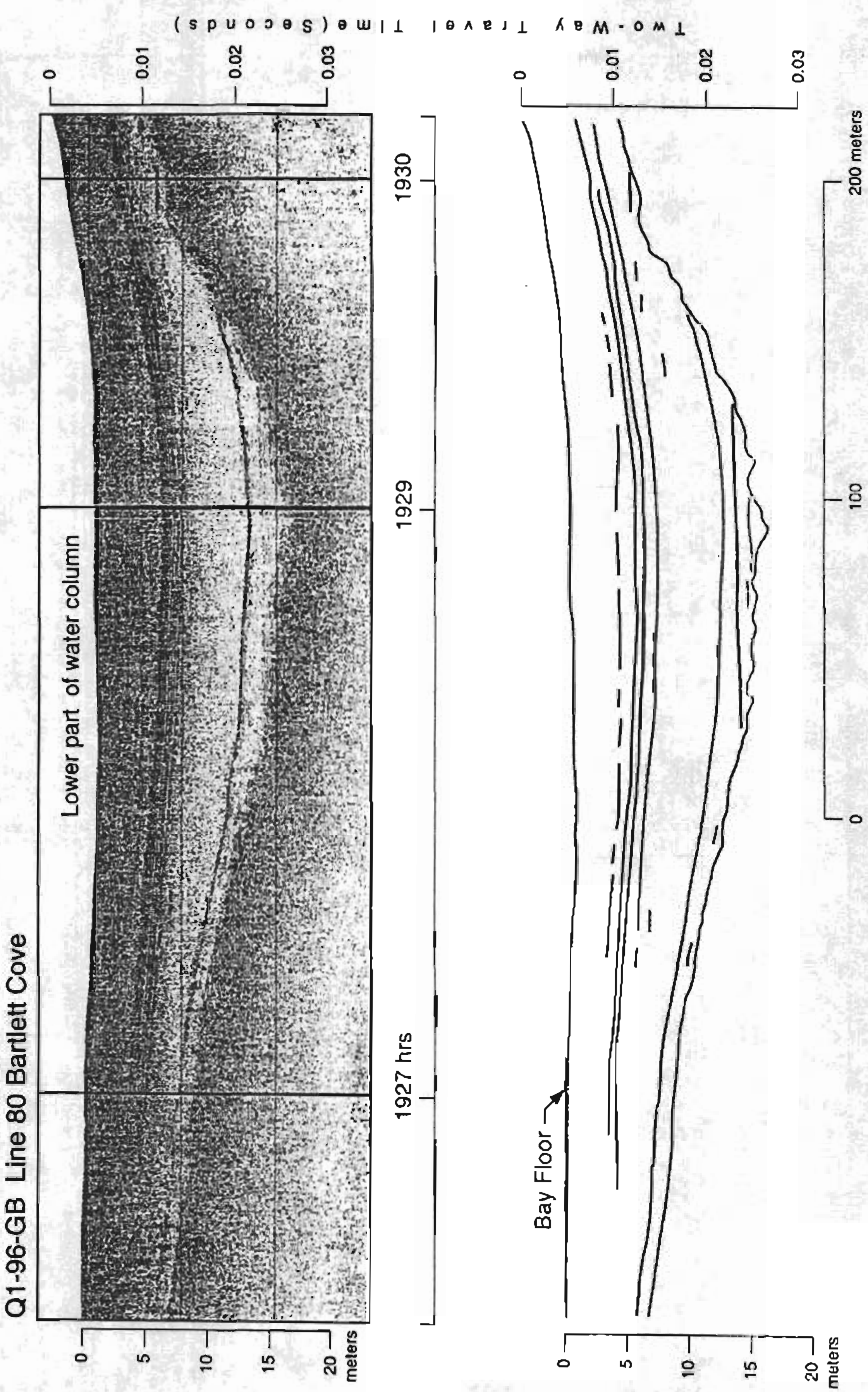

Q1-96-GB Line 80 Bartlett Cove
Lower part of water column
Two-Way Travel Time (Seconds)
0
0.01
0.02
0.03
1930
1929
1927 hrs
Bay Floor
0
5
10
15
20 meters
0
100
200 meters

Figure 21a

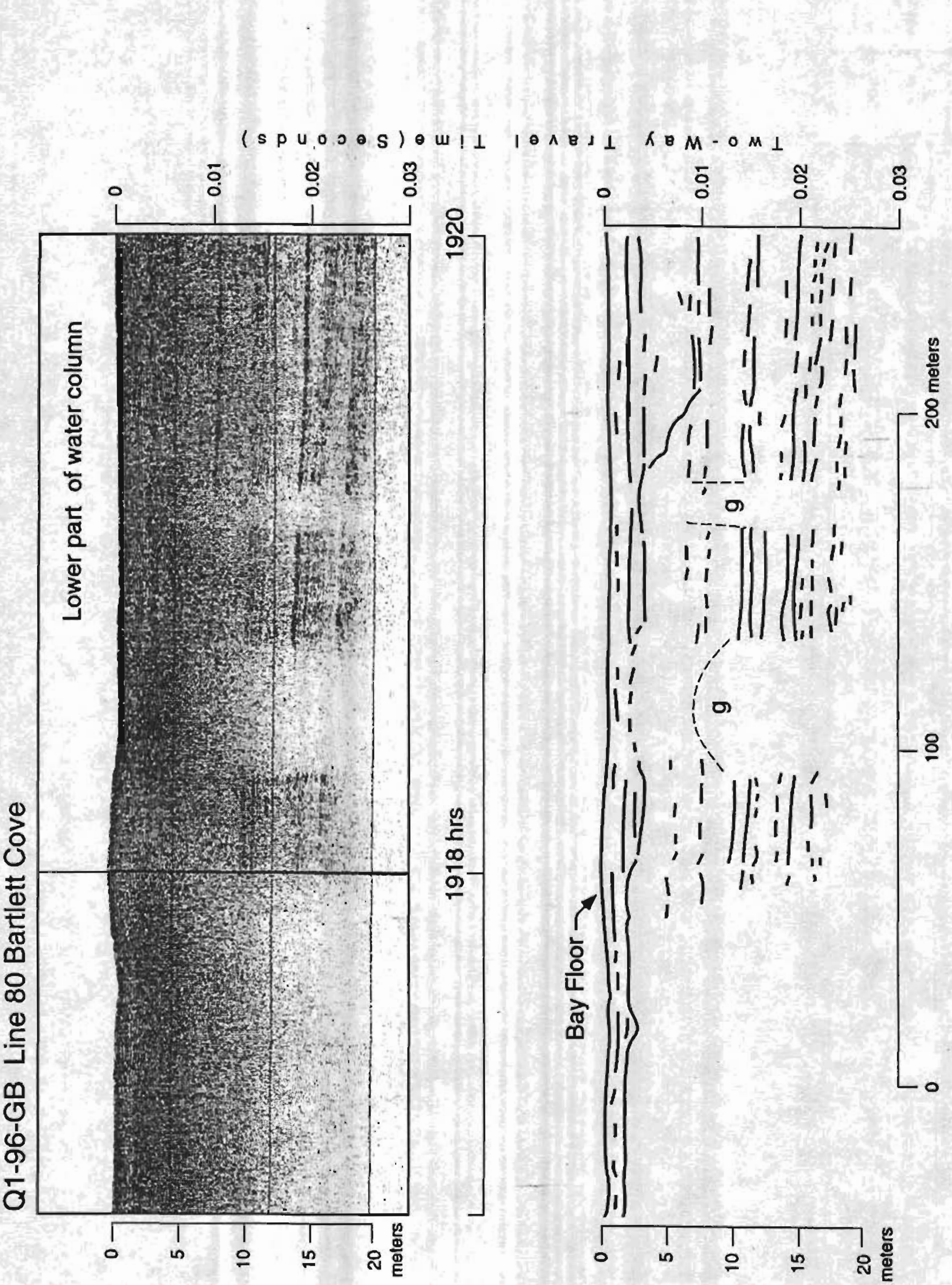

Q1-96-GB Line 80 Bartlett Cove
Lower part of water column
1920
1918 hrs
Two-Way Travel Time (Seconds)
0
0.01
0.02
0.03
0
5
10
15
20
meters
Bay Floor
g
g
0
100
200 meters

Figure 21b

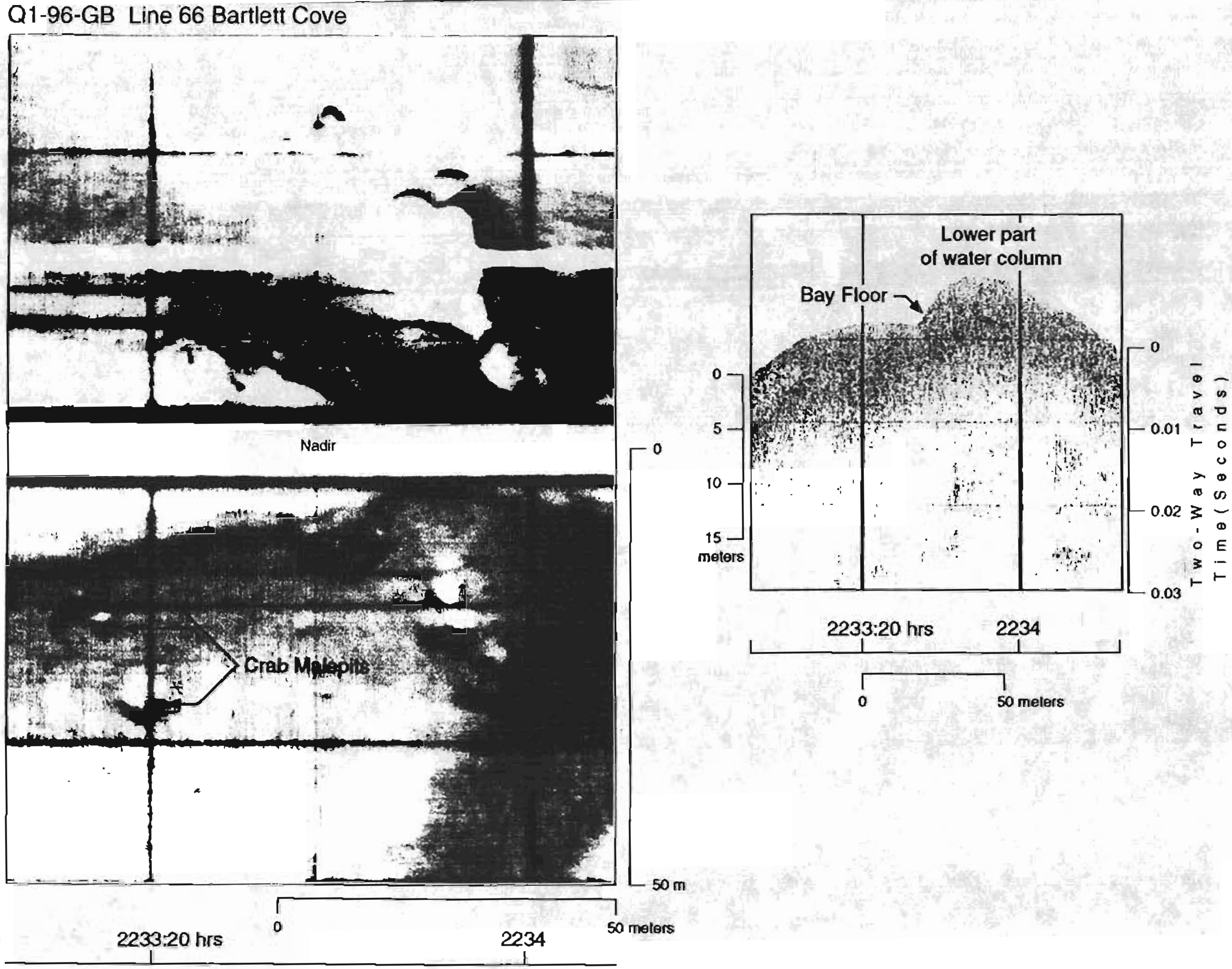

Q1-96-GB Line 66 Bartlett Cove
Nadir
Crab Malepits
0
50 m
0
50 meters
2233:20 hrs
2234
Lower part
of water column
Bay Floor
0
5
10
15
meters
0
0.01
0.02
0.03
Two-Way Travel
Time (Seconds)
2233:20 hrs
2234
0
50 meters

Figure 22a

Figure 22b