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Introduction

A joint project by four Divisions of the Geological Survey of Canada and the Earth Physics Branch (Project EPB 5.2.1) was planned as a multidisciplinary marine program in the central Arctic, in the area of probable future pipeline and transportation development. The objective was to advance basic knowledge of seafloor and coastal materials and of underlying bedrock structure. The expedition planned to operate from *C.S.S. Hudson* for 30 days in the ice-infested waters of Barrow Strait and adjacnet channels. The proposed investigations related to surficial sediment distribution processes, coastal materials and processes, bedrock structures linking and dividing the Arctic Islands, and subsea thermal regime, with special reference to ice-bonded permafrost. The cruise also was planned to utilize high resolution geophysical techniques in order to determine the physical properties of near-surface seafloor sediments. Two launches, *Gull* and *Fulmar* were outfitted for diving and for sonar/seismic/sampling operations and to conduct nearshore programs in conjunction with *Hudson's* offshore operations. An evaluation of the Differential Omega positioning system was also scheduled by Bedford Institute's Navigation Group to take advantage of *Hudson's* operating location close to Resolute, where an existing ground station monitored variations in VLF radio wave propagation characteristics.

Unfortunately, the locale of the entire program had to be changed and its period cut in half when *Hudson* lost one of its two propellers near Prince Leopold Island en route to Resolute. Although normally capable of limited movement in ice, the research vessel was thereafter restricted to ice-free waters. Because of the abundance of sea ice in 1976 the program was recast in a contingency area — Lancaster Sound — where open water conditions generally prevailed (Fig. 96.1).

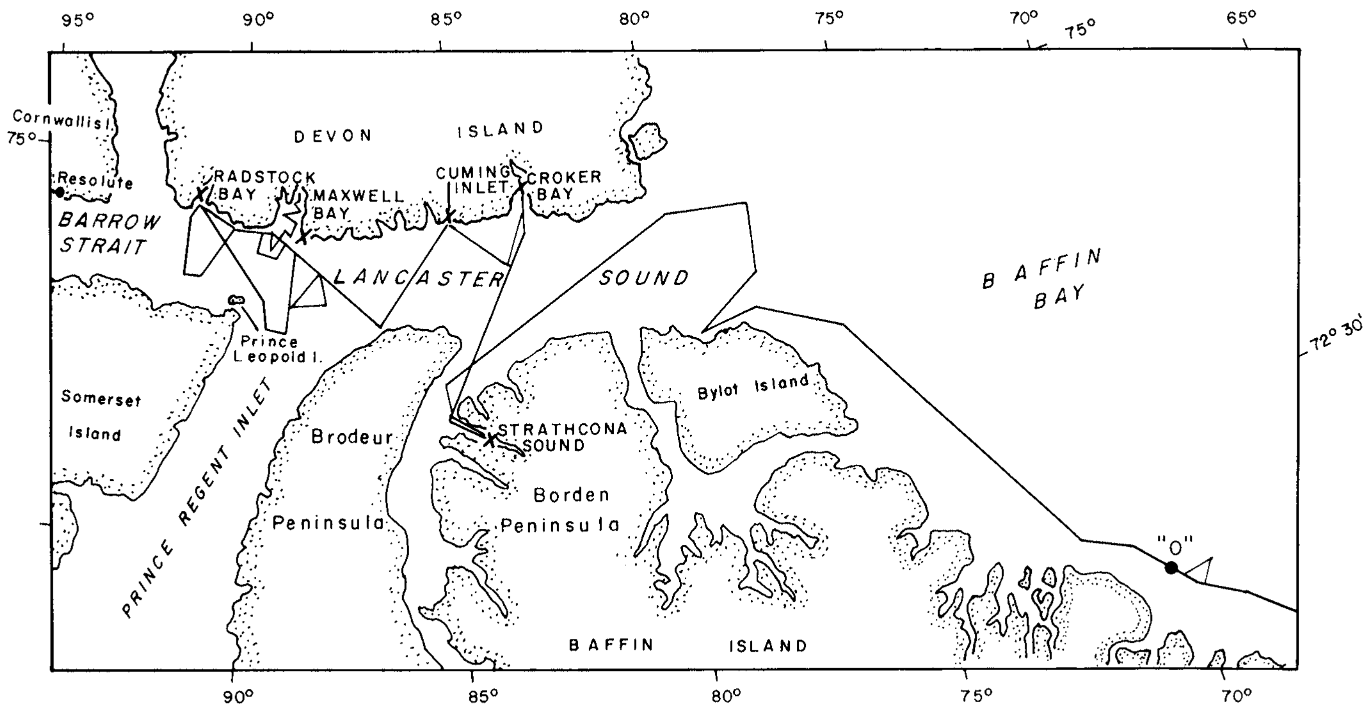

Figure 96.1. Sketch chart of *C.S.S. Hudson* tracks in Lancaster Sound area in 1976. The X's indicate nearshore study sites with the launches *Gull* and/or *Fulmar*.

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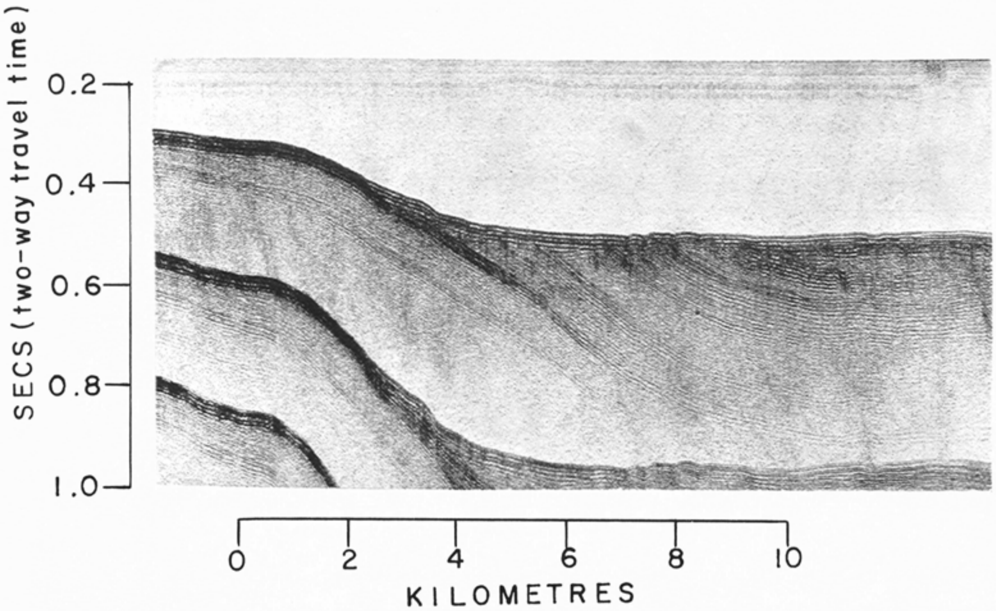

Figure 96.2.

Air gun seismic reflection record from western Lancaster Sound south of Radstock Bay. The profile crosses the nothern rim of Barrow Basin and shows Paleozoic carbonate rocks in the north (at left) overlain by Mesozoic-Tertiary clastics in the basin (at right).

All the foregoing planned activities then were undertaken within the abbreviated program in Lancaster Sound, except for seafloor rock drilling and suspended matter sampling. The following programs were undertaken:

(1) An analysis of surficial sediments was made by combining the results of high resolution seismic work with sediment coring. Surficial sediments were cored at selected sites and analyzed in the conventional manner. Physical sedimentary properties were determined remotely using the Huntec '70 Deep Tow seismic boomer (Hutchins *et al.*, 1976), a 20 m seabed seismic refraction array, neutron (porosity) probe, thermal gradiometer probe, gamma-gamma (density) probe, a spectrometer probe (for K, U, Th concentrations), a gamma-ray probe (for natural gamma radiation); and a seawater velocimeter probe.

(2) Representative nearshore sediment facies were examined by scuba divers with particular reference to bottom scouring by drifting icebergs and sea ice. This work will contribute to geological characterization of Arctic coasts and to the development of site selection criteria for future coastal structures.

(3) Determinations were made of seabottom temperatures, sediment and water thermal gradients, and sediment thermophysical properties, primarily for an assessment of the potential for ice-bonded subsea permafrost.

(4) Surficial sediment distribution and offshore bedrock structures were delineated by seismic, magnetic, and gravity profiling. The distribution of Cretaceous-Tertiary sedimentary basins and the fault-bounded margins of Lancaster Sound were of particular interest.

In addition to obtaining specific information about the Lancaster Sound region, the program also contributed to developing techniques and operational expertise for future application in other Arctic areas. The actual field operation in the Lancaster Sound area ran from August 19 to September 3. From September 4 to 13 *Hudson* was directed southwards for repairs with one stop on the Baffin Island shelf (at point '0', Fig. 96.1) to sample an oil slick Loncarevic, and Falconer, 1977).

Lancaster Sound

Seismic reflection profiling was undertaken in Lancaster Sound to: (1) establish the structural framework and its control on Mesozoic, Tertiary, and Quaternary sedimentation and (2) attempt to understand better the nature and history of Quaternary marine environments. Both conventional air gun seismic reflection techniques and the Huntec '70 Deep Tow System were used. The latter provided detailed records of the unconsolidated sediments lying on bedrock.

The main channels in the central Arctic are grabens, and their internal topography generally is controlled by bedrock structure (Kerr, in press). Bedrock structure that developed in a Cretaceous-Tertiary downfaulting episode provided a topographic framework which has been modified by erosion and deposition to give details of present bathymetry. A major Mesozoic-Tertiary basin of this origin occupies part of Lancaster Sound and is bounded on the north by the steep faulted southern margin of Devon Island. It has been identified by Daae and Rutgers (1975) and further defined by Bornhold and Lewis (1976). The basin occupies the northern half of western Lancaster Sound, has an area

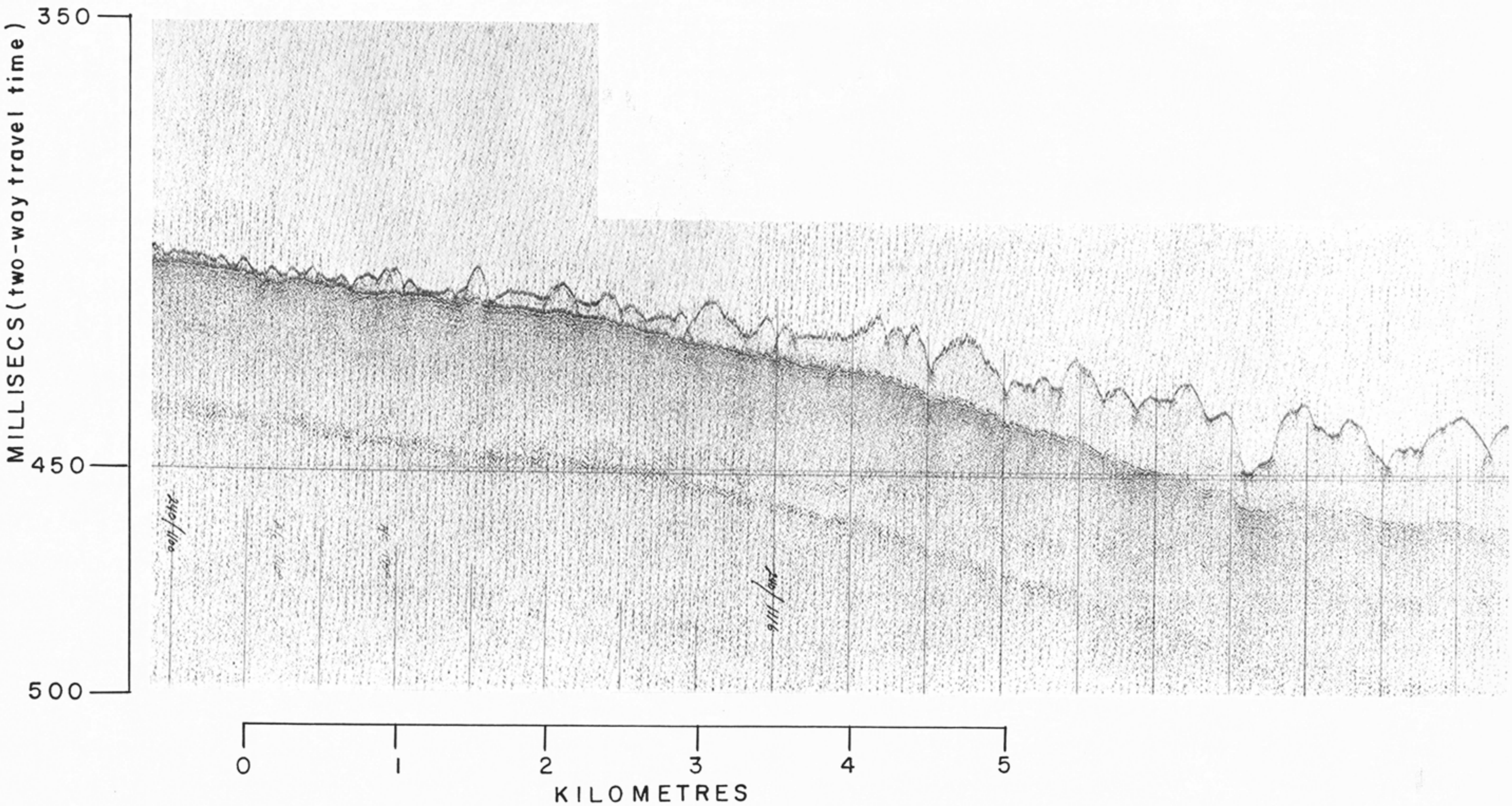

Figure 96.3. Huntec '70 Deep Tow seismic reflection record in western Lancaster Sound (approx. 74°04'N, 89°25'W) showing a thick accumulation of unconsolidated sediments overlying bedrock in deeper water but thinning to less than 5 m in shallower areas.

Figure 96.4. Seafloor photograph from western Lancaster Sound showing pebble-cobble pavement and evidence of strong current flow.

of 2400 km^2, and contains poorly consolidated clastic sediments at least 1300 m thick. Seismic reflection profiles (Fig. 96.2) also were obtained across the northern rim of Barrow Basin (Bornhold *et al.*, 1976; Bornhold and Lewis, 1976), which is a Mesozoic-Tertiary basin and also a prominent modern day topographic depression between Somerset and Devon islands. This basin occupies an area of approximately 700 km^2 and contains about 1000 m of clastic sediments in its deepest parts. The location of Barrow Basin may be controlled by bedrock structure. Its eastern margin may be related to the northward continuation of a fault suggested along the east coast of Somerset Island (Kerr and de Vries, 1977).

Earlier studies of the Quaternary sedimentary history of western Lancaster Sound (Bornhold and Lewis, 1976), based primarily on short gravity cores and seafloor photographs, concluded that net accumulation is occurring at the present time in only a few, small isolated basins, principally off northwestern Baffin Island and northern Somerset Island. Seismic reflection records (Fig. 96.3) obtained by the Huntec '70 System, combined with seabottom photography (Fig. 96.4), grab sampling, and coring, confirm the interpretation that the seafloor in western Lancaster Sound south of Devon Island is primarily undergoing erosion. The seismic profile (Fig. 96.3) shows hummocky topography developed on a thick sequence of unconsolidated sediments near the centre of the Lancaster Sound.

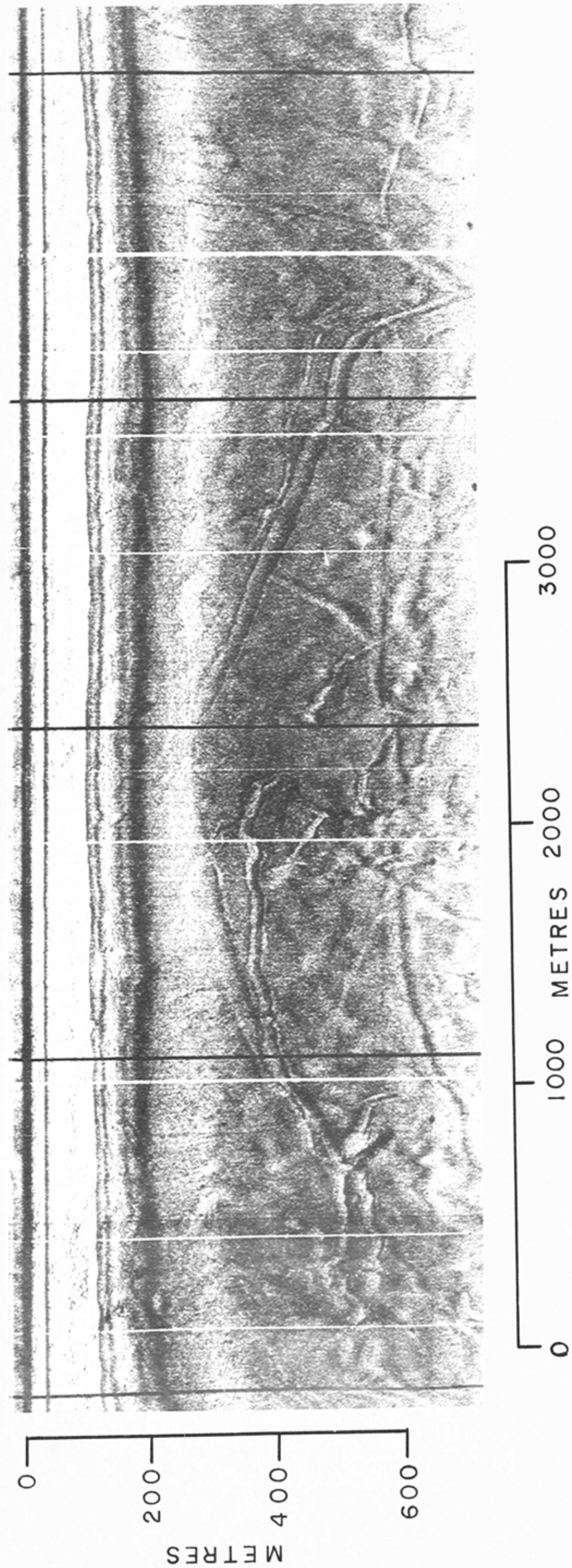

Figure 96.5 (opposite)

Side-scan sonograph off Fellfoot Point, southeastern Maxwell Bay, Devon Island, in approximately 130 m water depth showing numerous intersecting ice-scour tracks.

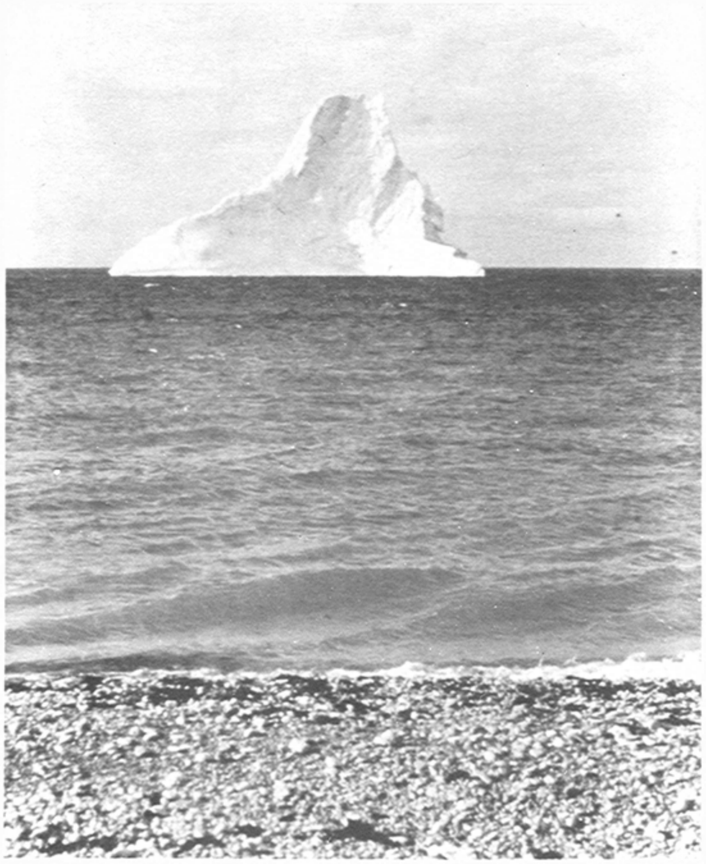

Figure 96. 6. Grounded iceberg observed off Fellfoot Point, Maxwell Bay, in August 1973.

Farther north on the same profile, these sediments thin rapidly and finally are left as small, isolated, pebble- and cobble-mantled mounds on the underlying bedrock. The ubiquitous pebble and cobble pavements are remnants of older unconsolidated sediments from which the fine material has been winnowed by seafloor currents. The original sediments are presumed to have been glacial tills, overlain by pebbly marine muds which were deposited in an ice shelf environment during the early stages of deglaciation. Circulation in western Lancaster Sound and Barrow Strait at the present is too vigorous for fine sediments to accumulate, except in isolated depressions and in easternmost Lancaster Sound where water is deep.

Side-scan sonar studies were carried out in several areas off the south coast of Devon Island in an effort to determine the significance of ice scour. Sonographs off Fellfoot Point (southeastern Maxwell Bay) revealed scours (Fig. 96. 5) in water depths of 50 to 130 m. A grounded iceberg was observed in this area in August 1973 (Fig. 96. 6). Side-scan sonographs in water depths more than 150 m off southwestern Devon Island also showed long, curved, and sinuous scour tracks (Fig. 96. 7) of unknown age. It is possible that these deep-water scour tracks are old, possibly relict, since they may be inscribed onto a nondepositional seabed and would not be obliterated by normal sedimentation.

The question of scourage, particularly in these relatively deep waters, is extremely relevant to engineering design of seabed pipelines; if relict, the scours represent no threat, but if they are modern, future ice scouring poses a distinct hazard to pipeline integrity.

Devon Island Fiords

Marine geological and geophysical studies were carried out from *C.S.S. Hudson* and the launches *Fulmar* and *Gull* in several fiords — Radstock Bay, Maxwell Bay, Cuming Inlet, and Croker Bay. Seismic reflection profiling by both air gun and the Huntec '70 Deep Tow System extended work done from *C.S.S. Baffin* in 1973 (Lewis *et al.*, 1974) and from *C.S.S. Hudson* in 1974 (Blake and Lewis, 1975). The objectives were: (1) to determine the structure of the fiords and relate this to larger structural elements in the Arctic Islands and (2) to determine the thickness, age, and character of unconsolidated sediments accumulating in the bays. The bays and inlets of southern Devon Island are dominated by north-south trending linear ridges and depressions, presumably horsts and grabens. At most, only a few metres of sediment have accumulated on the

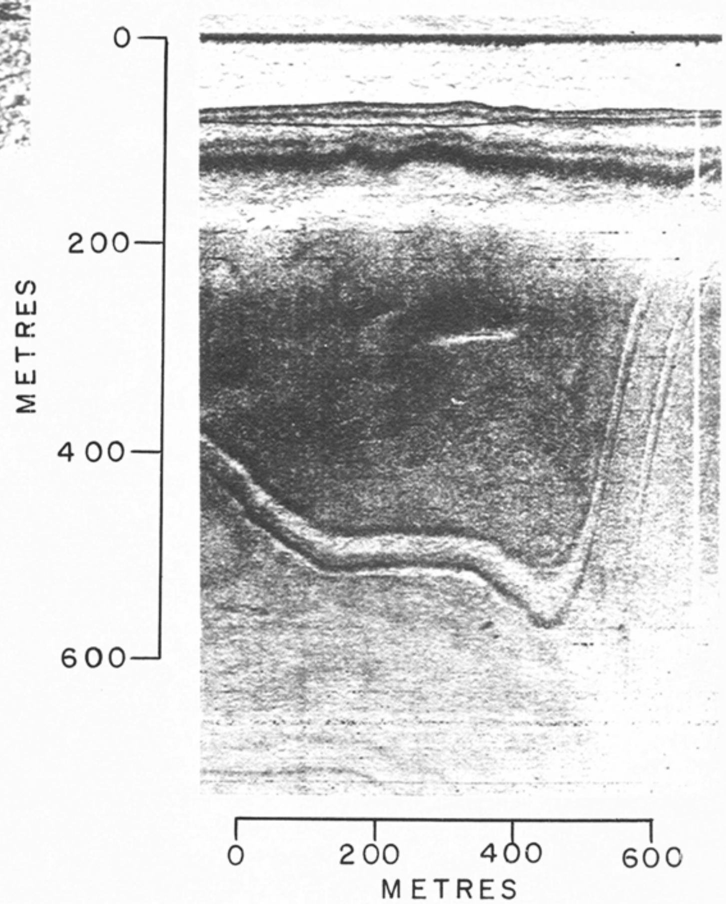

Figure 96. 7. Side-scan sonograph in 145 m water depth in Lancaster Sound (74°31'N, 91°16'W) south of Radstock Bay. The record shows several ice-scour tracks.

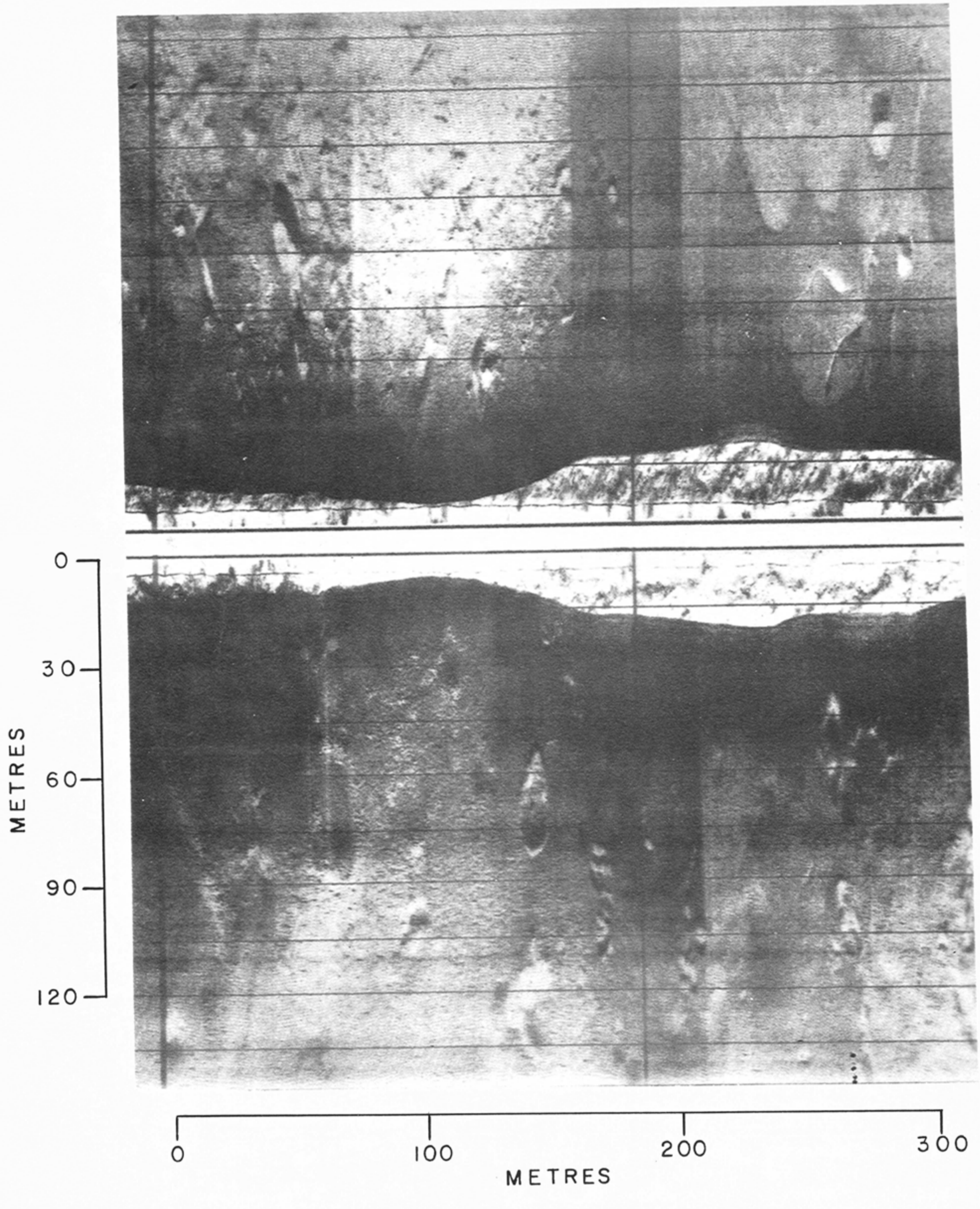

Figure 96.8. Side-scan sonograph in Radstock Bay (74°44'N, 91°10'W) in water depths between 10 and 40 m. The record shows numerous isolated crater scours presumably the products of periodic impact of ice in the shallow nearshore area.

Figue 96. 9.

Cobble pavement in nearshore region of Radstock Bay. Water depth approximately 15 m. Length of scale is 30 cm.

Figure 96. 10.

View of the interior of an ice scour at Dealy Point in Radstock Bay. The boulder and cobble debris has slumped down from the unstable oversteepened sides which are sloping at approximately 50 degrees. Water depth is approximatley 20 m.

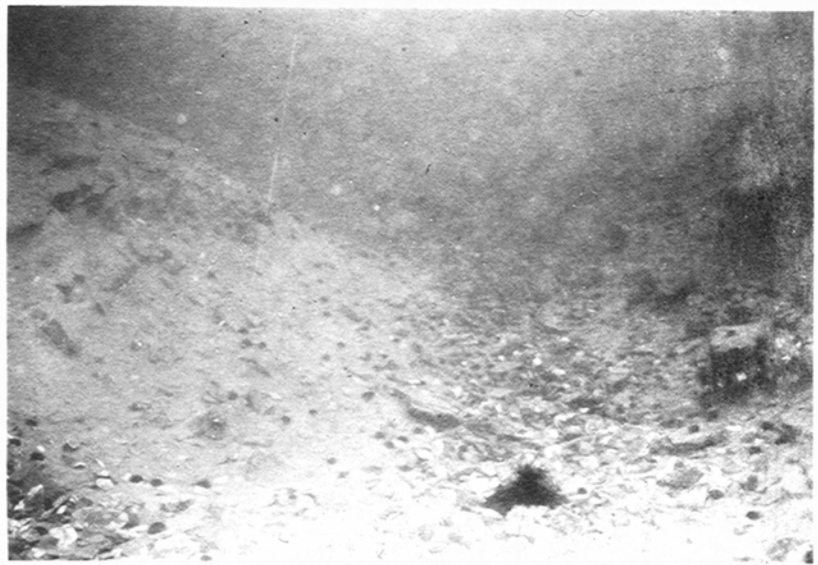

Figure 96. 11.

Diver using a Sonardyne Mark IV Underwater Rangemeter positioning system. A transponder held in its frame is in the foreground, and the diver is measuring the distance of a base line to a second transponder 200 m away.

ridges, but up to 30 m of fine muds and interstratified coarse sandy turbidites are common in the deep basins of these fiords. A rectilinear pattern of normal faults exists on southern Devon Island (Thorsteinsson, pers. comm., 1976). Thus structure, sculptured by erosion, may control the pattern of inlets on southern Devon Island.

A small embayment on the southwest coast of Radstock Bay and nearby parts of Barrow Strait were studied in greater detail using *C.S.S. Hudson* and both launches to investigate a potential harbour site. Echo sounding, seismic refraction, side-scan sonar, grab sampling, and coring were done from the *Fulmar*. Launch navigation was controlled by a Trisponder

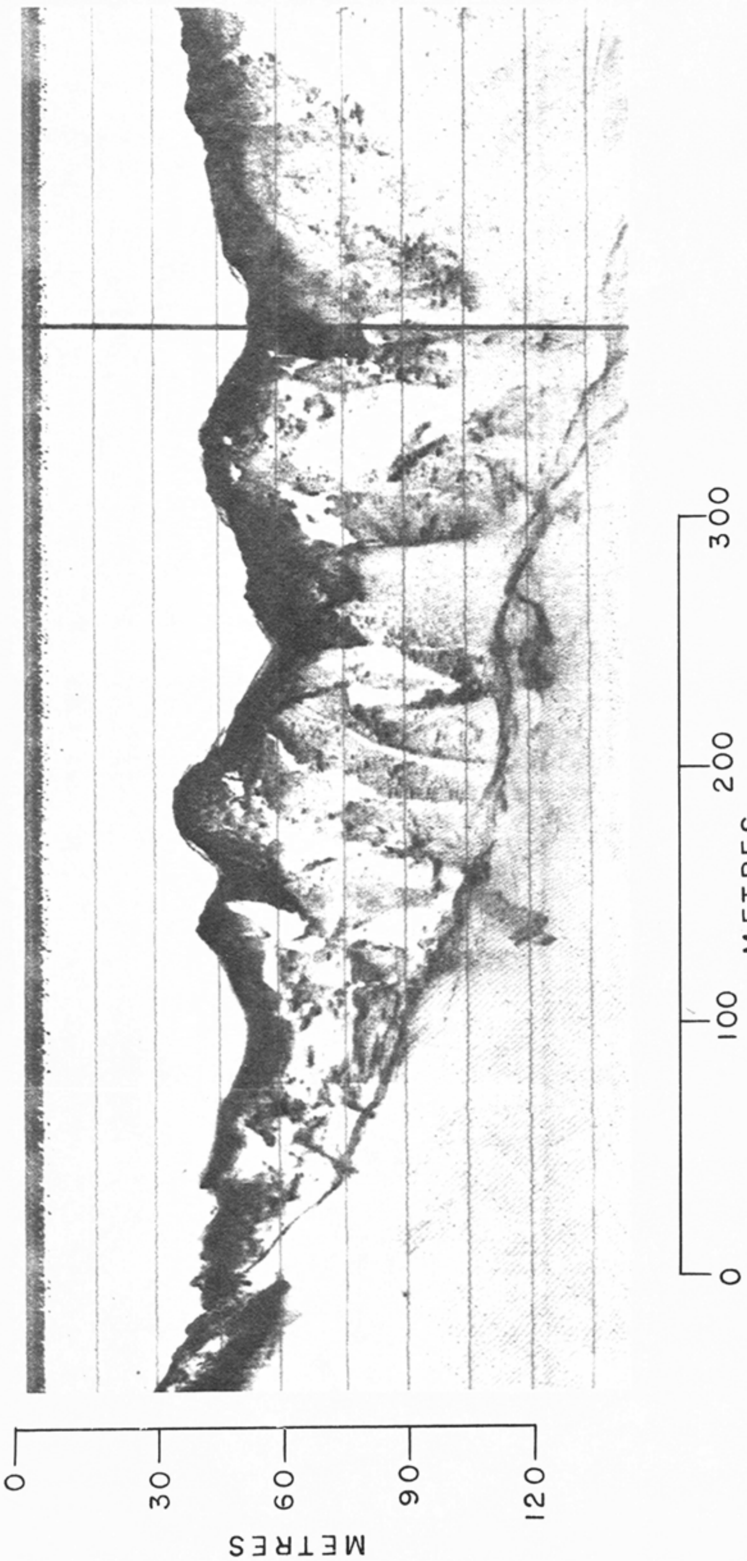

Figure 96.12.

Side-scan sonograph of the glacier in northwestern Croker Bay, Devon Island (74°53'N, 83°30'W) showing ledges and fissures in the glacier front. The seafloor was beyond the range of the side-scan sonar. The sonograph shows the morphology of only the underside of the ice.

range-range positioning system. Side-scan sonar records revealed a 'cratered' seafloor in nearshore waters believed to be caused by the impact of sea ice (Fig. 96.8).

Diving investigations, carried out from the *Gull*, at the potential port site at Radstock Bay included photography, coring, and biological sampling. In general, the nearshore bottom consisted of 80 to 100 per cent gravel and cobble pavement (Fig. 96.9) resting on steep slopes (30 to 45 degrees). Boulders were common, particularly adjacent to cliffed coastlines. The sedimentary matrix beneath the pavement contained a poorly sorted sandy mud, possibly till. It was difficult to obtain cores, and this would be done only after the surficial cobble pavement was removed. Ice scour was developed spectacularly on the seaward side of shoals and on exposed headlands (Fig. 96.10). The scours were observed to be approximately 3 m deep, 6 m wide, and 30 m long.

A Sonardyne, Mark IV Underwater Rangemeter and transponder system (Kelland, 1975) for positioning divers was used successfully. This instrument is a diver-operated acoustic range-range system that presents two way travel time between diver and transponder as a digital readout to a maximum of five different transponders (Fig. 96.11). The system range resolution is 0.1 ms or 150 mm at a propagation velocity of 1500 m/s; the useful range is approximately 300 m. This type of instrument is considered essential for future detailed underwater mapping. Three cores were located accurately with respect to two transponders.

Launch studies in Cuming Inlet and Croker Bay focused on the marine margins of three glaciers. Side-scan sonar, echo sounding, grab sampling, coring, suspended particulate matter collection, and diving observations were carried out on and near the ice fronts and on nearby shoal areas. Side-scan sonar profiles (Fig. 96-12) parallel to the ice fronts revealed the submarine morphology of the glaciers. Fissures extending more than 75 m into the ice and ledges of ice several tens of metres in length could be mapped readily using this technique.

Figure 96.13.

Proximal side of boulder moraine near margin of calving glacier front; depth is approximately 25 m.

Figure 96.14.

Prolific fauna and flora on a boulder-covered shoal. Depth approximately 7 m. Length of scale is 15 cm.

Poor visibility (less than 1 m) and water depths beyond the capabilities of SCUBA, precluded making abundant observations of the glacier margins. In all cases a very steep ridge of unstable boulder moraine was parallel to the ice front (Fig. 96.13). The slope on both proximal and distal sides was approximately 45 degrees. The seaward slope was mantled with silt derived from the release of rock flour from the melting glacier ice. The area of active sedimentation, however, was very limited; this conclusion followed from diving observations on a shoal less than 50 m from the glacier front, which contained an area of prolific fauna and flora in a nondepositional environment (Fig. 96.14).

Strathcona Sound

Piston coring, grab sampling, sea floor photography, physical oceanography, and geophysical studies in Strathcona Sound continued work begun in 1975 (Bornhold, 1976). Seismic reflection records (Fig. 96.15) permitted the delineation of several sedimentary basins. These basins are separated by northwest-southeast trending, linear bedrock ridges, for the most part devoid of sediments. Unconsolidated sediments up to 90 m thick and consisting of alternating red-brown muds and sandy turbidites were found to be accumulating in the intervening basins.

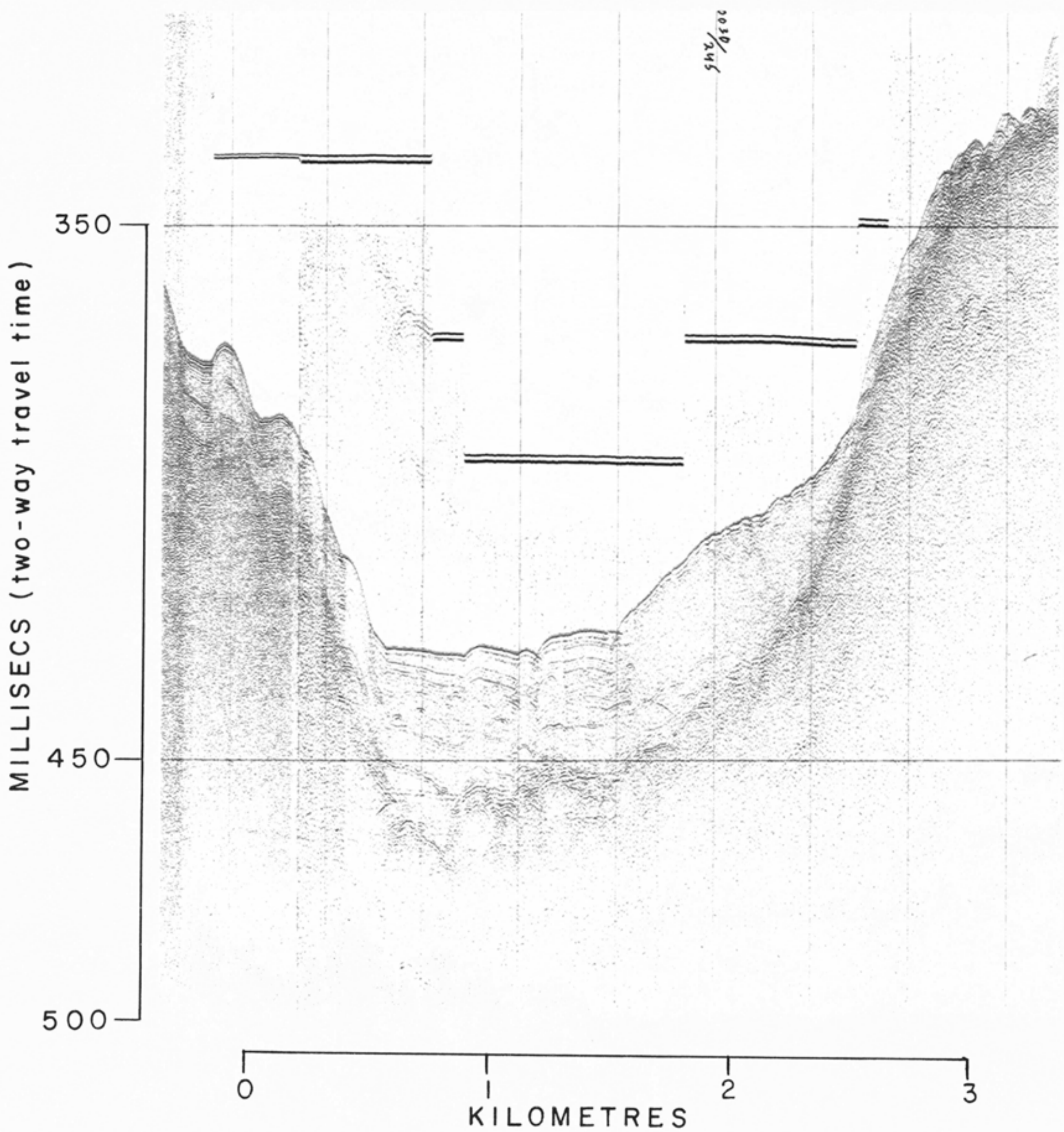

Figure 96.15. Huntec '70 Deep Tow seismic record in Strathcona Sound (73°06'N, 84°40'W) showing an accumulation of more than 35 m of muds and highly reflective sandy turbidites in the deepest part of the basin, structureless slumped sediments near the foot of the fiord wall, and nearly sediment-free valley walls.

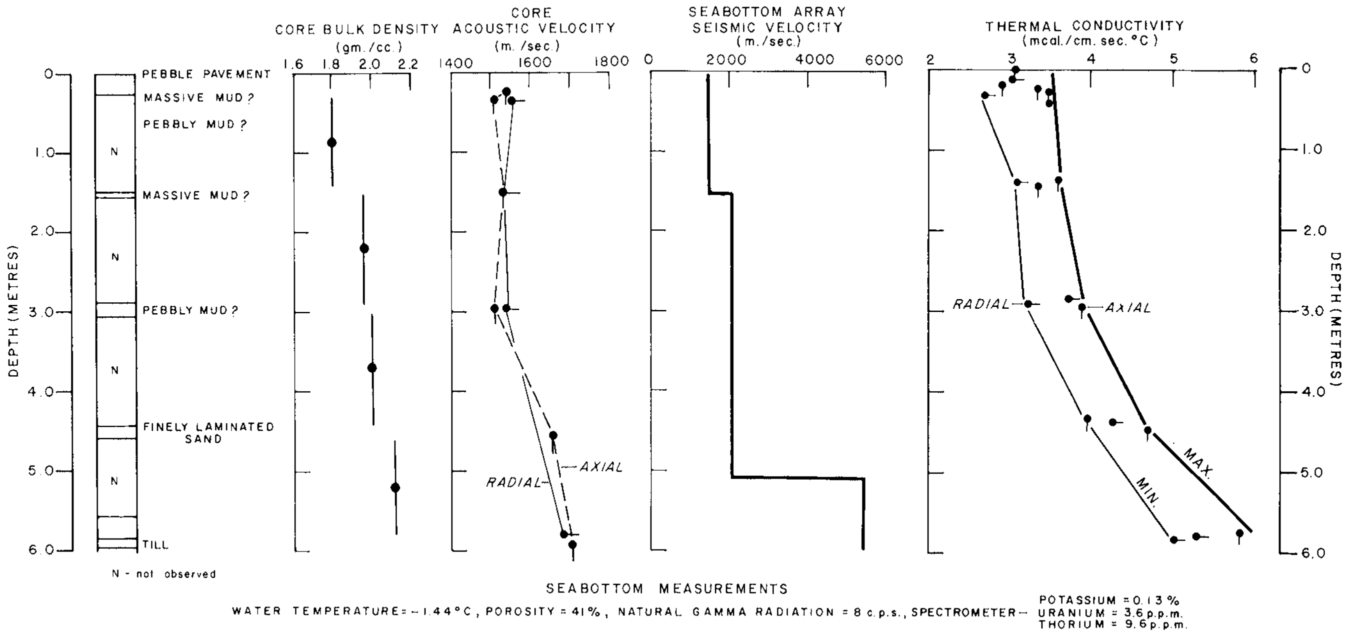

Figure 96.16. Seabottom properties and profiles of some physical parameters of a piston core from Maxwell Bay, Devon Island (74°35.6'N, 88°51.0'W). The core lithology is interpreted from X-radiographs of selected core segments. Values are preliminary and subject to revision.

Side-scan sonographs in the shallow water along the sides of the fiord reveal a few ice-scour tracks, ripple marks and bedrock outcrops. Channels, sediment dunes, and ripples were seen on the front of a small delta on the north side of the sound.

Bottom diving observations and coring attempts on both sides of the sound showed an impenetrable boulder and cobble pavement. The steep sides of the fiord continue underwater at slopes of 30 to 40 degrees in the nearshore. The nature of the fauna and flora is indicative of a nondepositional environment, but no ice scour was seen in the limited area of observation.

Physical Properties of Arctic Sediments

Co-ordinated study of the geotechnical, geological, and geophysical properties of Arctic marine sediments is one of the unique benefits of this multidisciplinary cruise. Nineteen piston cores representing a variety of surficial, glacial, and marine sedimentary environments were collected throughout the Lancaster Sound area including all the fiords visited. Sediment structure was given preliminary appraisal through on board radiography of unopened core liner tubes (Wahlgren and Lewis, 1977). Geological and geophysical samples and data were collected simultaneously at 6 of the 19 core locations to investigate the relationship between remotely sensed acoustic/seismic parameters and sediment geotechnical attributes. The ultimate goal is to improve the potential for high-speed prediction and mapping of sediment properties from analysis of reflected acoustic signals. A second goal, achieved through the measurement of thermophysical properties at the same locations, is to increase understanding of the subsea thermal regime and its relation to the sediments. The equipment deployed at these six test sites was that previously listed in the introduction.

An example of information generated aboard ship is given by the 6 m core from Maxwell Bay which is composed at the top of a pebble lag-veneer above silty mud and at the base of a compact pebbly grey till (Fig. 96.16). An obvious general increase with depth exists in the curves of each of the measured parameters: bulk density, sound velocity, and thermal conductivity (Fig. 96.16). Detailed analysis has yet to be made, but, for example, the consistent difference between axial and radial thermal conductivities suggests a horizontal rather than vertical preference in the orientation of sedimentary particles similar to that in a bedded sediment. Such large differences are not apparent in the acoustic velocity measurements made to date. This in itself may suggest that some geophysical tools are more effective in resolving certain fabric and lithological characteristics of sediment. Much data, however, remain to be analyzed and the differences in sediment parameters, as measured by different methods, require detailed study.

Axial and radial thermal properties were determined on board ship for up to 13 samples from each of 8 cores representing a range of sediment lithologies. Very few measurements of thermal properties of seabottom sediments in the Arctic Islands exist in the literature and yet these values are essential in the performance design of any seabottom or subseabottom structure. The measurements themselves require sample recovery and are tedious to do in large numbers; hence any extended correlations of, for example, the acoustic velocity to thermal conductivity as suggested by Goss and Combs (1974) could provide a useful saving in survey time since acoustic velocities can be measured underway. New data on the water temperature profile and the water/sediment temperature gradient were obtained in at least 12 stations throughout the work area. Many of these sites fill major gaps in the distribution of oceanographic summer bottom-water temperature data, thus assisting in the appraisal of both thermal and hydrodynamic bottom conditions.

Acknowledgments

The Atlantic Geoscience Centre at Bedford Institute of Oceanography supported this cruise in many ways: by arranging for ship time and by providing many of the scientific support personnel and equipment on the *C.S.S. Hudson.* Dr. D.I. Ross, K.S. Manchester, Dr. R.K.H. Falconer and their staff generously managed much of the pre-cruise preparatory work.

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