Pleistocene and Holocene Seismic Stratigraphy between the Canning River and Prudhoe Bay, Beaufort Sea, Alaska

by

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Open-File Report 85-549

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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FIGURES AND ILLUSTRATIONS

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INTRODUCTION

Petroleum development along the shores of the Beaufort Sea, Alaska, particularly in the vicinity of Prudhoe Bay, has led to an increased awareness and concern for the marine and coastal plain environments, for geohazards and engineering problems, for the geologic history, for arctic processes of sediment erosion and deposition, for sea ice movement and its effects, and for permafrost, to mention but a few. This report is primarily concerned with the shallow stratigraphy of the inner shelf between Flaxman Island in the east and Prudhoe Bay, some 50 km to the west. The Branch of Pacific Marine Geology of the U.S. Geological Survey has acquired a large amount of seismic, side-scan sonar and bathymetric data in the region since 1970. These data form the basis for this study. Additionally, bottom samples, cores, temperature and salinity data, and diving programs have provided much information complementary to the research program. Twenty boreholes drilled throughout the study area by Harding-Lawson Associates under contract to the Conservation Division of the U.S. Geological Survey in 1979, (Fig. 1), and several additional ones drilled under the OCSEAP, provide ground truth for the seismic stratigraphy. The stratigraphic and environmental record from these boreholes have been interpreted by David Hopkins, Roger Hartz and Peggy Smith of the U.S. Geological Survey (Hopkins and others, 1978; Hartz and others, 1979; Smith and Hopkins, 1979; and Smith, in press).

The seismic data available for this study are a combination of high resolution geophysical records, obtained with such systems as boomers, minisparkers, and fixed frequency transducers within the range of 3.5 to 7 kHz. The side-scan sonar provided seafloor imagery and the transducers provided bathymetric data. The purpose of the study leading to this report has been to obtain and interpret all available geophysical data, to relate the findings to borehole data both onshore and offshore, to develop an understanding of the geologic framework that operated during Quaternary time, and to describe the recent geologic history of the area.

REGIONAL SETTING

The study area is emcompassed by the Canning River fan delta on the east and the Sagavanirktok delta on the west. The coastal plain in the area is underlain by a series of coalescing alluvial and glacial-outwash fans extending northward from the Brooks Range (Hopkins and Hartz, 1978). The tundra surface is dotted by thousands of shallow thaw lakes, and crossed by shallow river channels both abandoned and presently active. Coastal bluffs along the plain gradually rise in height from 2 m to 6 m to the south, where the plain merges with the Brooks Range. An offshore island chain sub-parallel to the coastline consists of islands that appear to be true constructional barrier islands, whereas the eastern one (Flaxman Island, Fig. 1) is really a coastal plain remnant, capped by tundra as much as six meters above sea level. Seismic data suggest that some of the other islands may have origins similar to Flaxman Island. Although they may appear as true barrier islands, they may in fact consist of erosional debris resulting from destruction of a coastal remmant, later shaped by modern currents to appear surficially as a classical barrier island.

Between the islands and the coastline are lagoons which receive sediment supplied by rivers and coastal erosion. The lagoons are generally protected from large pack ice by the island chain and shallow passes, whereas the shelf seaward of the island chain is severely gouged by sea ice. Sedimentation appears to be low or non-existent and is influenced by coastal currents and by ice drifting from east to west. Coastal erosion, dominated by thermokarst processes, proceeds at an

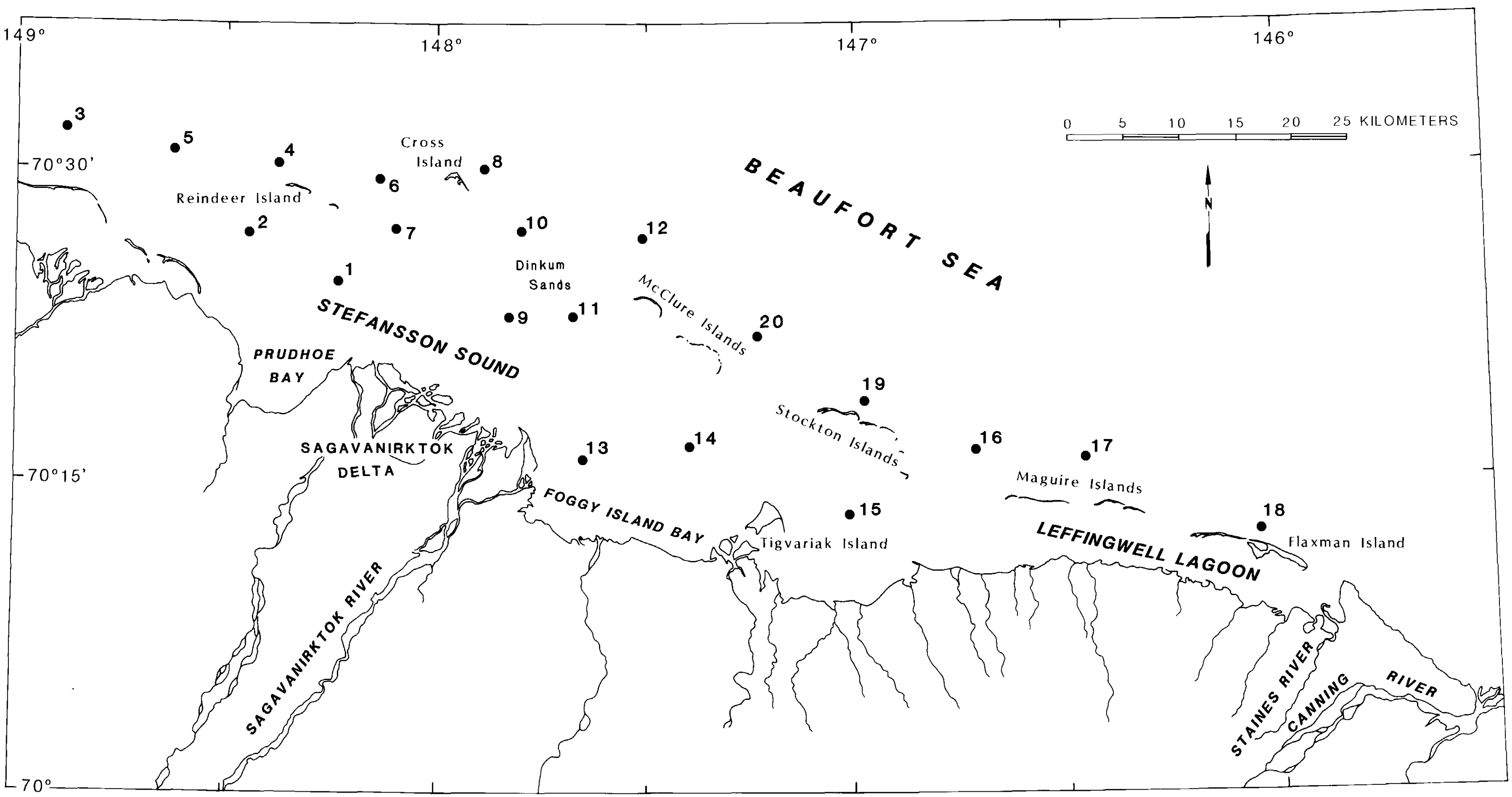


FIGURE 1. Map showing location of study area. Numbers refer to boreholes drilled in 1979 (Harding-Lawson Associates - USGS Conservation Division). Map is composed of Beechey Point to Flaxman Island Quadrangles (USGS).

average rate of 1.6 m/yr (Hopkins and Hartz, 1978). But the high-standing areas of Flaxman Island actually are retreating at a rate of 3.5 m/yr (Lewellen, 1977), demonstrating that the island also will appear as a barrier island in a few hundred years.

Topographic maps and LANDSAT images indicate that the Canning River in the past has shifted back and forth across its subaerial fan, as evidenced by the well developed radial channel pattern. The river's most recent shift has been from discharge points in Leffingwell Lagoon to the eastern fan boundary in Camden Bay .

The acoustic response of the sedimentary sequence to high resolution seismic profiling techniques in the Beaufort Sea is inferior to that of any other Quaternary to Holocene sediments we have studied with similar techniques in other parts of the world. We attribute this poor seismic resolution to a combination of factors unique to high latitudes:

1) Subaerial exposure of a soft sediment section to the cold atmosphere during glacial periods results in permafrost agradation, which in turn results in the formation of large masses of ground ice, in the form of ice wedges and ice lenses, that can be several meters thick. Besides this massive ice, there is excess interstitial ice in the sediments, Totaling as much as 80% or more ice by volume in the upper 5 m of the section (Sellmann, et al., 1975). This ice does not necessarily conform to bedding planes in stratified sections. Thus, where preserved since the last glacial transgression, the ice results in discontinuous or irregular acoustic reflectors where good stratification may actually have existed.

2) Where glacial regression results in the disappearance of the ice in sediments, thaw collapse, small scale slumping, and sediment deformation may result.

3) Transgressive beach sedimentation, during periods of glacial regression, may replace the ice within ice wedges with sand and gravel. In this case, the basal transgressive unit will not be a distinct and continuous unit separating pre-transgressive sediments from post-transgressive ones.

4) The growth process of massive ice results in sediment deformation (cryoturbation). Thus the sediments exposed in coastal bluffs 2 m to 7 m high in the area generally appear unstratified or exhibit small scale crenulated folding.

5) The processes of formation of strudel scour craters to a sub-seafloor depth of 6 m to 7 m, and rapid filling of such craters (Reimnitz and Kempema, 1983), result in deposits at modern delta fronts consisting largely of strudel scour fill. These steep sided sediment pockets can not be resolved with presently available seismic reflection techniques.

6) Slow deposition on a jagged shelf surface that has been rapidly reworked by ice gouging (Reimnitz and Barnes, 1974; Barnes and others, 1984) results in the formation of complex, interfingering shoestring-shaped deposits (Reimnitz and Barnes, 1981). The resulting sediment package appears unstratified in seismic reflection profiles.

7) The presence of permafrost itself, whether partly or fully ice bonded, results in large sound velocity inhomogeneities within the section. A non-homogeneous velocity structure adds further complexities to the seismic stratigraphy. In the Canadian part of the Beaufort Sea, work with high resolution profiles has led to the concept of acoustically defined permafrost with its own, sporadic reflectors of several types (O'Connor, 1981).

8) Gas charged sediments are widespread in the study area (Harding-Lawson Assoc., 1979). Essentially vertically bonded non-stratified acoustic anomalies are produced (Boucher and others, 1981).

BACKGROUND INFORMATION

The first studies of the inner shelf stratigraphy in the study area were those reported on by Reimnitz and others (1972), who used interpretion of mini-sparker data to map the depth to the base of Holocene marine sediments and several underlying reflectors. Although they suspected the presence of offshore permafrost in certain shallow areas, their data did not confirm it. Since then more than 25 widely spaced boreholes have been drilled and numerous probe penetrations were made in the study area, mainly to study offshore permafrost (Harding-Lawson Associates, 1979; Osterkamp and Harrison, 1976, 1982; Osterkamp and Payne, 1981; Miller and Bruggers, 1980; Blouin and others, 1979; Harrison and Osterkamp, 1981; Sellman and Chamberlain, 1979). The information so obtained was extended considerably by the analyses of seismic data (Boucher and others, 1981; Neave and Sellman, 1982, 1983, 1984; Morack and Rogers, 1982, 1984; Rogers and Morack, 1980). From these studies we know that ice bonded permafrost is widespread within 5 to 10 meters or more of the seafloor. But this permafrost is patchy, and the depth to the top of ice bonded materials very irregular. In thick deposits of sand and gravel off Prudhoe Bay the top of ice bonded sediments drops sharply to 100 m or more. This feature has been interpreted as a major paleo-valley emerging from Prudhoe Bay and turning west out of Stefansson Sound. (Hopkins and others, 1979). An area of scattered boulders with prolific kelp growth was mapped from geophysical data, cores, surface samples, and diving off the Sagavanirktok River (Reimnitz and Ross, 1979). Beyond some speculation on the existence of three major paleo-valleys, one east of Flaxman Island, one between the Maguire and Stockton Island, and one off Prudhoe Bay (Hopkins and others, 1979), no stratigraphic interpretation of the borehole data has been published to date. While all inner shelf data, including a recent study of sediment geotechnical properties (Lee and Winters, in press), indicate a thin and patchy cover of Holocene marine sediments, a thick wedge of such Holocene materials has been defined on the central and outer shelf (Dinter, 1982).

SURVEY METHODS

Seismic work by the USGS in this area began in 1970, utilizing an ORE towed vehicle transducer system operating at 3.5 kHz. Data were poor, probably as a result of a combination of factors, such as, poor sediment response, poor equipment performance, and poor environmental conditions. In 1971 the 12 m R/V LOON, the first U.S. Geological Survey arctic vessel, began operating in the area using a 500 joule minisparker with an electrode designed by the first author. Data were recorded on a Gifft Model 4000 graphic recorder. The receiver consisted of a Teledyne model 20 high-resolution hydrostreamer and preamplifier, and a Khronhite passive filter. Data in most cases were acceptable to marginal. Degraded records were often due to marginal sea states for high-resolution profiling, but in particular due to the fine to coarse grained sediments with minimal internal reflectors. Much of the work occurred in shallow water and, therefore, produced multiples which obscured the actual data. A Simrad recorder provided bathymetric data. The acquired data resulted in a report on the surficial stratigraphy of the region between Tigvariak Island and the Colville Delta (Reimnitz and others, 1972). The 1972 operating season utilized the same fathometer, but replaced the sparker with an EG&G Model 230 Uniboom and an EG&G Model 265 Hydrostreamer. We also added an EG&G Model 259, 100 kHz side-scan sonar to record seafloor imagery. Seismic records were greatly improved in resolution, but with some loss of penetration. The side-scan sonar was towed from the bow of the boat off an "A" frame, rather than off the stern, as the vessel commonly surveyed in very shallow water (1m). This towing arrangement also facilitated the towing of other equipment off the narrow stern. Side-scan data, even in very shallow water, were excellent. Additionally, an EDO Model 324, 12 kHz transducer was mounted on the Uniboom catamaran to supplement bathymetric as well as some sub-bottom data in 1972. This bathymetry was recorded on a Gifft 4000 graphic recorder and the seismic data on an EPC 4100 graphic recorder. The 1973 field season operated with the same equipment as in 1972 with the exception of the 12 kHz transducer, and the addition of a second boomer plate to the Uniboom catamaran. This addition resulted in insignificant improvements of penetration and signal to noise ratio, and therefore was discontinued in succeeding field efforts.

In 1975 the R/V LOON was replaced by the newly constructed 13 m R/V KARLUK. No data were taken in this area during the 1974 field season. Aboard the KARLUK , the surveys from 1975 through 1982 were accomplished utilizing the Uniboom and side-scan sonar systems, and occasionally a sparker for site-specific studies. Additionally, a Raytheon RTT 1000, sub-bottom profiling system was added to the instrumentation in 1975. This system operates at 3.5, 7.0 and 200 kHz. Most data were taken at 7 and 200 kHz. A Del Norte Model 502 seismic amplifier and 12-20 hydrostreamer provided improved seismic data quality during this period. An EPC 3200 dual channel graphic recorder replaced the EPC 4100 in 1982. New program requirements and state of the art equipment development brought about instrumentation changes in 1983. The EG&G side-scan sonar system was replaced with a Klein Hydroscan system, consisting of a 531T, three-channel tape-compatible recorder, 100 kHz and 500 kHz side-scan sonars, and a combined sub-bottom (3.5 kHz) and micro profiler (500 kHz) attachment. Expansion of microprofiler data and recording of 7 kHz data were accomplished with the use of an EPC 1600 graphic recorder. The Uniboom was replaced by an ORE Model 5810A (Geopulse) sound source. Seismic data were tape recorded analog through a TSS Model 307 TVG amplifier for processing of the data, such as removal of sea swell distortion and stacking. The Klein 500 kHz side-scan sonar improved the resolution of seafloor images, but at the expense of range capability compared to the 100 kHz system. Bathymetric detail was greatly improved with the microprofiler, as was sub-bottom penetration with the 3.5 kHz transducer.

In general terms, data acquisition can be divided into groups of instrumentation as follows:

1. Seismic data

   a. EG&G minisparker
   b. EG&G Uniboom
   c. ORE (Geopulse)
   d. RTT 1000 at 7 kHz

2. Seafloor imagery

   a. EG&G side-scan sonar (100 kHz)
   b. Klein Hydroscan (100 and 500 kHz)

3. Bathymatric data

   a. Simrad recording fathometer (38 kHz)
   b. EDO (12 kHz)
   c. RTT 1000, (200 kHz)
   d. Klein Hydroscan, (100/500 kHz, 3.5 kHz)

EQUIPMENT CHARACERISTICS AND DATA QUALITY

Typically minisparkers operate at a dominant frequency of approximately 500 Hz within a filter bandpass of 350-900 Hz. The first 1 m to 2 m of sub-bottom data are lost due to the pulse length and reverberation of the outgoing signal. Penetration depths of 100 m and more can generally be achieved with resolution on the order of 1 m to 1.5 m. The dominant frequency of the Uniboom is about 2.5 kHz, with most data recorded between 900 and 2000 Hz. Typically the first .5 m to 1 m of sub-bottom is lost, expected penetration depths of 50 m to 100 m and resolution better than .5 m are appropriate for the uniboom. The ORE Geopulse System has a broader dominant frequency, dependent on power output, but lies generally between 2 and 7 kHz. Tests show that the ORE system has a higher output signal level, a higher frequency content, and can achieve better penetration and resolution than the Uniboom. The better performance of the ORE system in the Beaufort Sea may also be partly due to the common occurrence of sand and gravel, materials in which the ORE gives superior performance. Bandpass filter settings of 1-3 kHz are commonly used. Test runs by the first author have shown that by carrying two uniboom transducers on the same catamaran and pulsing both simultaneously, signal level outputs and broad frequency spectrum similar to those of the Geopulse system can be achieved. However, on small vessels where space is limited, this technique becomes impractical.

Quality of seismic data acquired is also dependent on towing configuration and technique for the source and receiver. In the case of small vessel operations, the source and receiver are towed on opposite sides of the vessel with the hydrophone (receiver) streaming as close to the sea surface as possible. The latter should be short hauled in shallow water and farther from the source in deep water. Degradation of the data often results from rough seas which causes "acoustic noise", from improper towing arrangements, and from inexperience of technical personnel. For example, towing the hydrostreamer too far behind the vessel in shallow water leads to incorrect water depth measurements and placement of multiples on the record. This can make analyses of the records very difficult and reduce the confidence of the interpretation. Quality of the seismic data acquired over the past thirteen years, in this area, has been degraded periodically due to a combination of the preceding causes. Additionally, the data have been degraded more often than not by poor sediment responsiveness to acoustic profiling. Overall, the data are acceptable to marginal, making interpretation and correlation difficult. Level of confidence in interpretation is good between Flaxman and Tigvariak Islands but decreases to questionable north of Prudhoe Bay, largely due to poor profiling conditions in that area. As will be seen later, that area has presented problems in preliminary interpretations of seismic data. The surfical layer of most Holocene sediment does not thicken eastward from Prudhoe Bay into Stefansson Sound, as erroneously interpreted by Reimnitz and others (1972), but rather thins to zero over the area of the Boulder Patch (Reimnitz and Ross, 1979).

Bathymetric and side-scan sonar data are good to excellent, and already have been used extensively for other program objectives.

TRACKLINE COVERAGE

A compilation of all track charts for the 13-year period is shown in Figures 2, 3, and 4 revealing a pattern which appears only partially systematic. However, for the purposes of the present investigation, the line spacing and orientation are adequate. Profiles used to measure depths to different seismic horizons in the study area are labeled with the line number and year on each of the Figures. Almost all of the data recorded along the remaining lines were viewed and used as guides to ensure that our regional correlation of major seismic horizons is correct. A complete listing of seismic lines from 1971 through 1982, including the time of operation of the different geophysical survey equipment and the data roll numbers, is given in the APPENDIX.

The primary reason for the apparently random line patterns is that field work objectives and priorities varied from one year to another, as did the sea ice distribution. The latter is a factor that commonly dictates where and how a particular line can be run. Furthermore, seismic profiles represent only a fraction of the data gathered. Often specific study topics were pursued, involving such additional techniques as underwater photography and video recording, diving operations, sediment and water sampling, coring, ice gouge studies and repetitive surveys of certain lines with side scan and 7 kHz equipment. Furthermore, many tracklines simply represent transit lines from one study site to another, on which only bathymetric data were taken. These factors have resulted in overlapping coverage with minisparker, Uniboom or Geopulse data in certain areas. For example, in 1979 Uniboom and minisparker lines were specifically placed over each of the 20 HLA boreholes drilled during the preceeding winter for the purpose of tying each hole to the seismic survey net. This use of different survey tools from one line to another, and the low

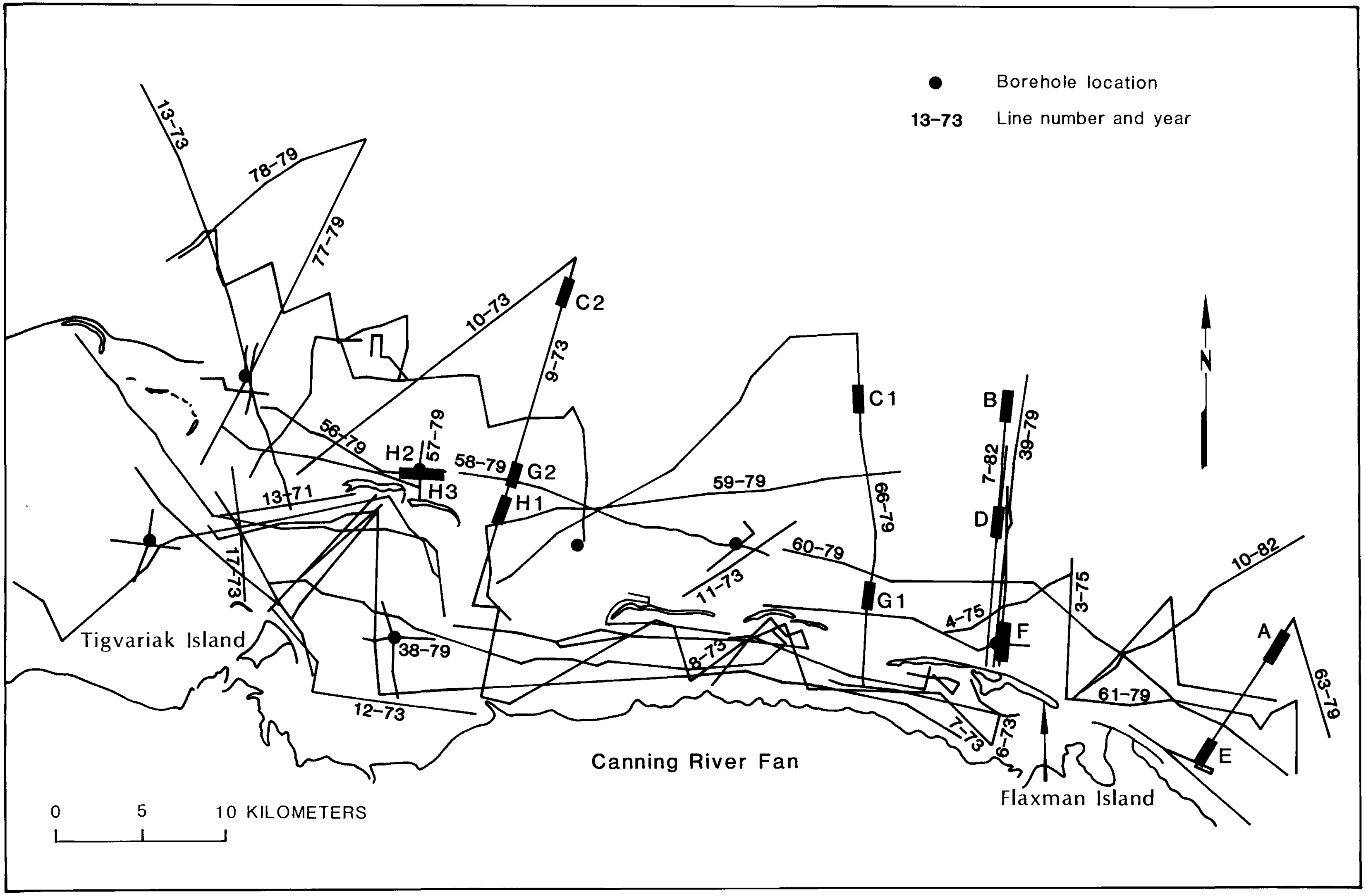


FIGURE 2. Trackline map - Tigvariak Island to Flaxman Island showing tracklines for 1971 - 1982. Tracklines labeled are those along which seismic interpretation was made. Lettered boxes are locations of seismic sections refered to in this report.

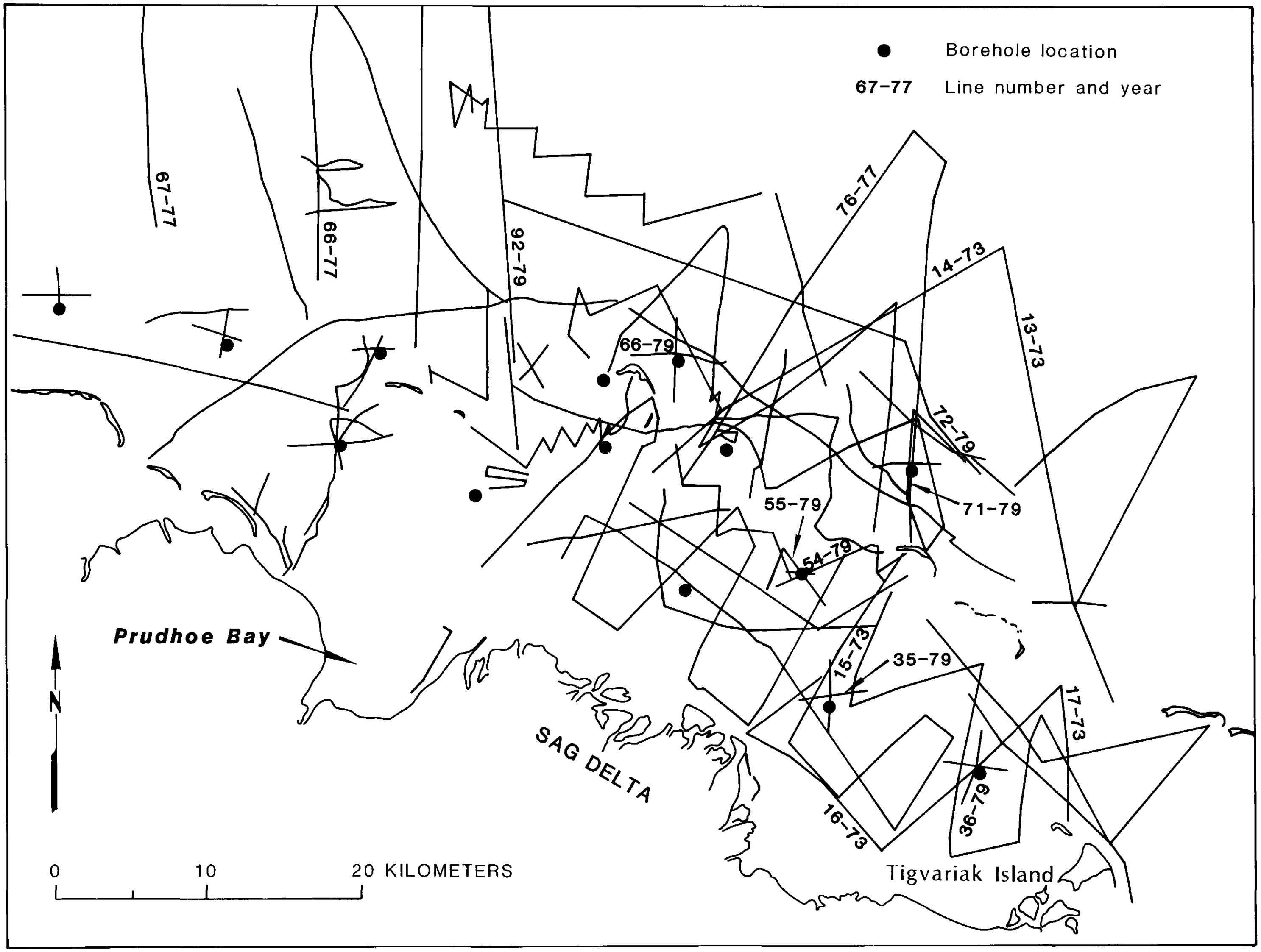


FIGURE 3. Trackline map - Prudhoe Bay to Tigvariak Island showing tracklines for 1973 - 1982. Tracklines labeled are those along which seismic interpretation was made and referenced in this report.

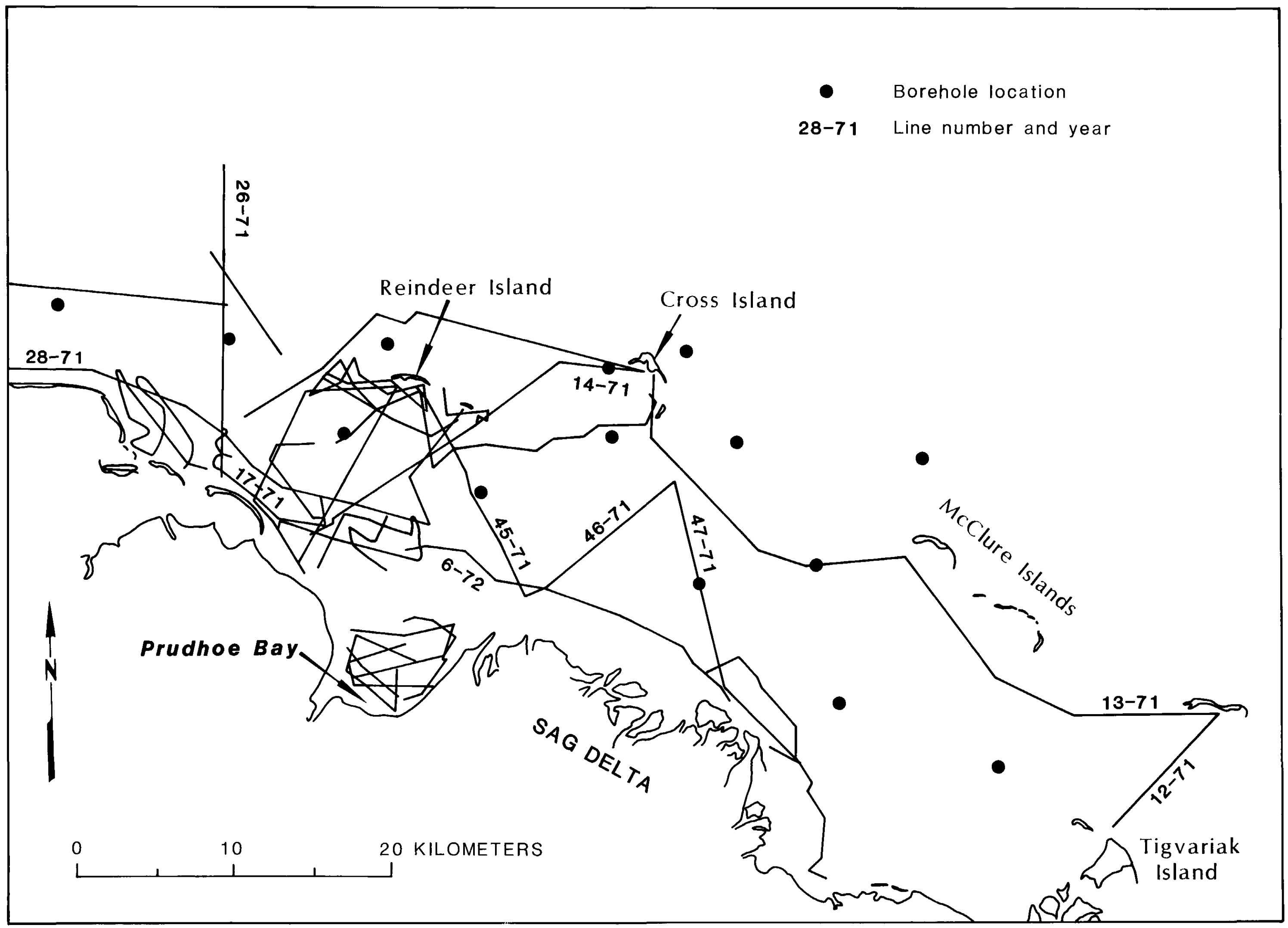


FIGURE 4. Trackline map - Prudhoe Bay to Tigvariak Island showing tracklines for 1971 - 1972. Tracklines labeled are those along which seismic interpretation was made and referenced in this report.

data quality in many places, made correlation between the 20 boreholes a long and difficult project. Lithologic and paleontologic data from the boreholes show a wide variety of sediments and sediment sequences. Prior to the seismic data interpretation, correlation of boreholes was tenuous at best, but a combination of stratigraphic, lithologic, paleontologic, and seismic studies has led to reasonable success in delineating the shallow Pleistocene and Holocene geology throughout most of the area.

SEISMIC DATA ANALYSIS AND RESULTS

Description of Acoustic Reflectors

Eleven seismic profiles, representive of data from the region between Flaxman and Tigvariak Islands are lettered and keyed to Figure 2. The discussion of these samples will serve to introduce the different acoustic surfaces recognized, their characteristics, overall relationships to each other, and their spatial distribution. Seismic sections west of Tigvariak Island are not shown as the data are of poor quality, and the regional seismic stratigraphy is relatively flat lying.

Excluding a very shallow horizon at the base of modern sediment accumulation, we identified seven distinct reflectors, and numbered them 1 through 7. The oldest is number 1. No single profile shows all seven major surfaces as strong reflectors. The key to assigning numbers to these reflectors with a high degree of confidence is a combination of a) traceability from one line to another, b) assumption of an orderly sequence where a particular reflector is not traceable over a long distance, and c) recognition of a strongly developed layer cake stratigraphic model that lacks complexities produced by faulting, tectonic deformation, or interaction of strongly different sediment regimes.

Reflectors 3, 4, and 7 can be traced east-west throughout much of the area, but number 7 occurs only seaward of the barrier islands. It top laps into the present seafloor, dips offshore, and is most likely overlain by additional younger reflectors on the outer shelf beyond the area of our data. Within the lagoons we can trace a shallow reflector, which stratigraphically seems to overlie 7, through the entire region. Because it is so shallow, this surface is traceable only with the 7 kHz records supplemented in places with uniboom where the surface is more than 1 m to 1.5 m below sea floor.

On a regional basis, reflectors 3, 4 and 7 are generally flat lying, whereas intermediate reflectors have slight NE dips. Seaward of the island chain in the central part of the study area, these intermediate reflectors steepen significantly.

Seismic Section A.

This profile (Fig. 5) illustrates surfaces 3 and 4, both with approximately the same reflectivity. Surface 4 is flat lying and conformable to sediments above and below. Surface 3 is overlain by conformable sediments, but truncates a channel-like depression below. On the left side of the profile is a seafloor feature that appears to be a shoal with the steep side to the south. The seafloor on either side of the feature can be traced as a nearly horizontal datum. The orientation of the feature is not known, but it is in all respects, including the water depths of surrounding terrain, so similar to shoals of the stamukhi zone (Reimnitz and Maurer, 1978; Reimnitz and others 1978; Reimnitz and Kempema, 1984), that we interpret the feature as a shore-parallel shoal constructed since the last transgression, and migrating southwestward. Based on acoustic reflectivity, sediments between the sea floor and surface 4 and between 4 and 3 appear to be similar in lithology, and may be sand and silt interbeds.

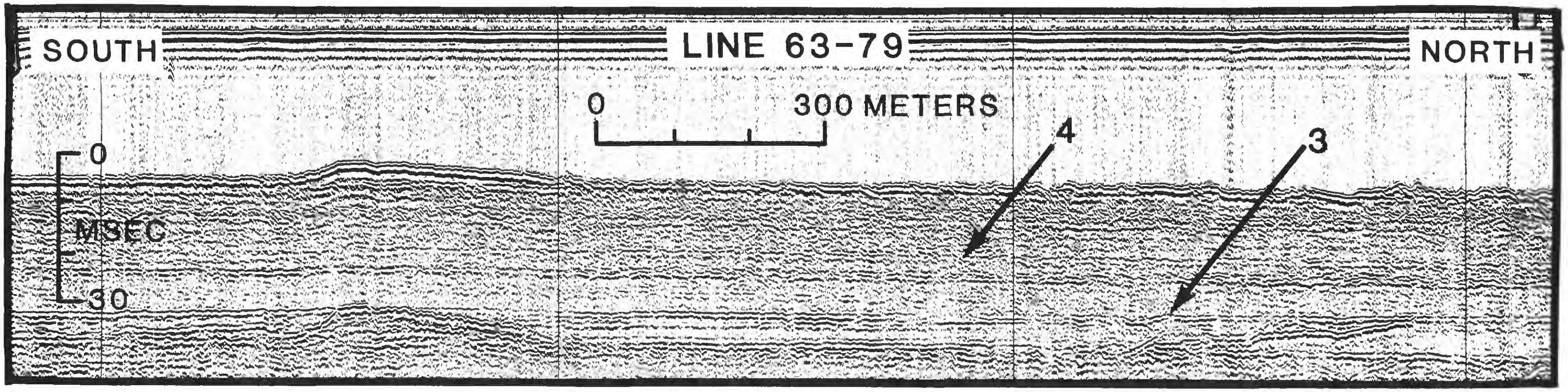


FIGURE 5. Seismic profile near the eastern border of the area taken in approximately 20 m water depth.

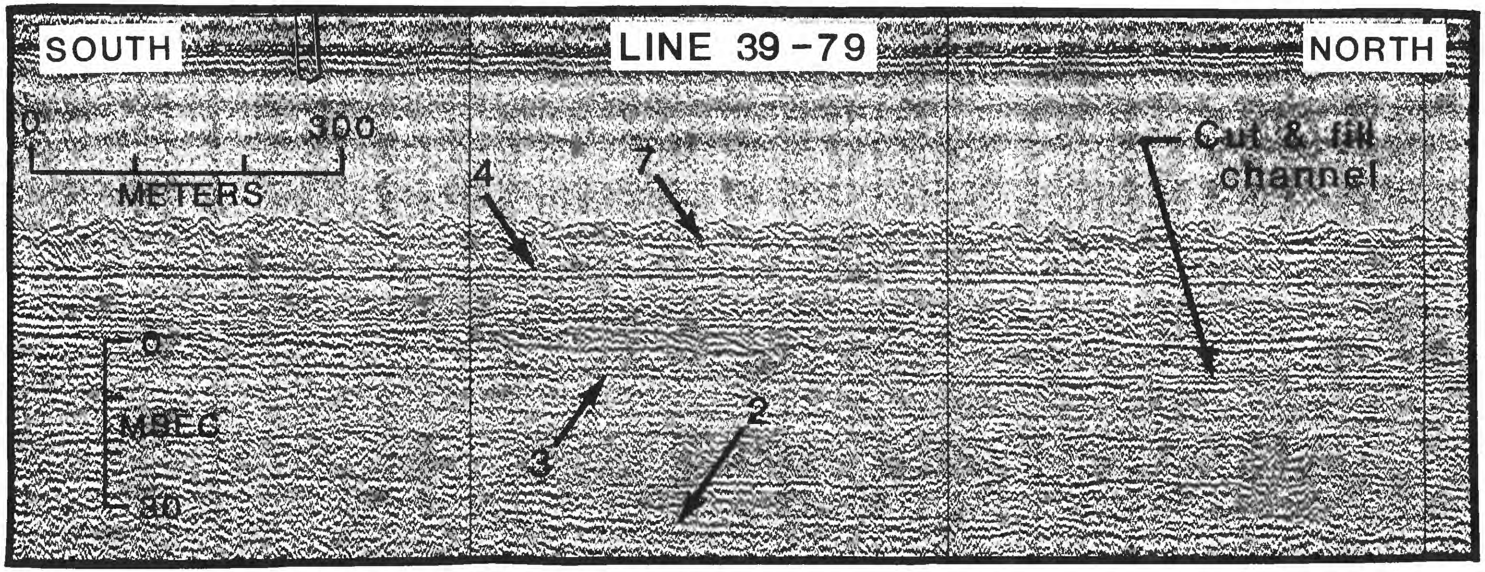


FIGURE 6. Seismic profile taken in 30 m water depth north of Flaxman Island.

Seismic Section B.

This profile (Fig. 6) depicts reflectors 2 and 7 in addition to 3 and 4. All four reflectors are generally conformable to each other. Sediments below 2 and between 3 and 4 appear to be irregularly stratified, with a slight seaward dip. Internal bedding exhibits characteristics of thickening, thinning, pinch outs, and channeling. The irregular seafloor is characteristic of an intensely ice-gouged surface, and in some places, the gouging has cut deeply enough to penetrate surface 7 and remove it entirely. To the south (left) surface 7 outcrops at the seafloor. Surface 3 truncates what may be a small cut-and-fill channel. Sediments between the major surfaces indicated appear less similar in nature and exhibit more varied acoustic reflectivity than those in Figure 5. This might suggest a sediment sequence containing occasional gravel and more sand.

Seismic Section C.

Seismic section C composes two profiles, C-1 and C-2 in which reflectors 3, 4, and 7 can be seen (Fig. 7). In C-1, the acoustic reflectivity of sediments above surface 4 is so similar to that of the sediments below, that it is difficult to differentate. Surface 3 in places is much stronger than it appears laterally. This discontinuous character might be assumed to result from lithologic similarites of the sedimentary facies above and below, and, therefore, the acoustic impedance of the surface is markedly reduced locally. Below this surface, pinch outs and channeling can be observed as in Figure 5. Sediments between 3 and 4, on the basis of acoustic reflectivity, appear to grade upward from sands to interbeds of sand and fine-grained materials. Surface 7 is buried sufficiently deep below ice gouge incision depth to escape reworking. It deepens to the south (left).

In profile C-2, surface 7 is very shallow, weak, and discontinuous. It has been severely destroyed by ice gouging, which suggests that the present seafloor in this part of the offshore region of the area has undergone and is undergoing mechanical reworking. Also, deposition of sediments is not occurring, and the shelf surface may be undergoing erosion. The unit between 3 and 4 shows better seismic stratification in the upper part, suggesting that the sediments may be fining upward as in C-1. However, it should be noted that the upper sediments dip seaward and top lap into reflector 4. Surface 3 is even more discontinuous than in C-1 and most likely for the same reasons.

Reflectors 3 and 4 can be traced westward through the area for which we show no samples to the region off Prudhoe Bay. Reflectors are generally flat lying and have similar characteristics as the examples shown in Figures 5 - 7. However, the two reflectors rarely truncate channels in the western part of the the study area except for an area NE of the Sagavanirktok River where channeling again is observed at similar distances seaward of the island chain.

Seismic Section D.

Two additional reflectors, 1 and 6 can be observed on section D (Fig. 8). Reflector 1 is conformable to surfaces 2, 3, and 4 but has a slight seaward dip. This is the deepest reflector observed throughout the area and was observed only on this seismic trackline. It is important to note that the entire stratigraphic sequence from reflector 1 to the sea floor exhibits relatively flat lying to slightly seaward dipping units and are generally conformable to each other. Surface 6, although difficult to impossible to see in some regions, downlaps onto 4 farther to the north. On many seismic profile crossings, surface 6 apparently top laps or crops out to the south at the juncture of the smooth and heavily gouged seafloor, as seen in this profile. Few profiles show surface 6 extending landward beyond the heavily gouged area and cropping out under the smooth floor. When viewed with side scan sonar, gouges are seen south of the juncture between smooth and jagged seafloor (Barnes and Asbury, in press). This pronounced boundary has been noted in numerous publications and has been described as the "18 meter bench" (Barnes and Reimnitz, 1974; Reimnitz and Barnes, 1974; Reimnitz and others, 1978; Barnes and others, 1980; Reimnitz

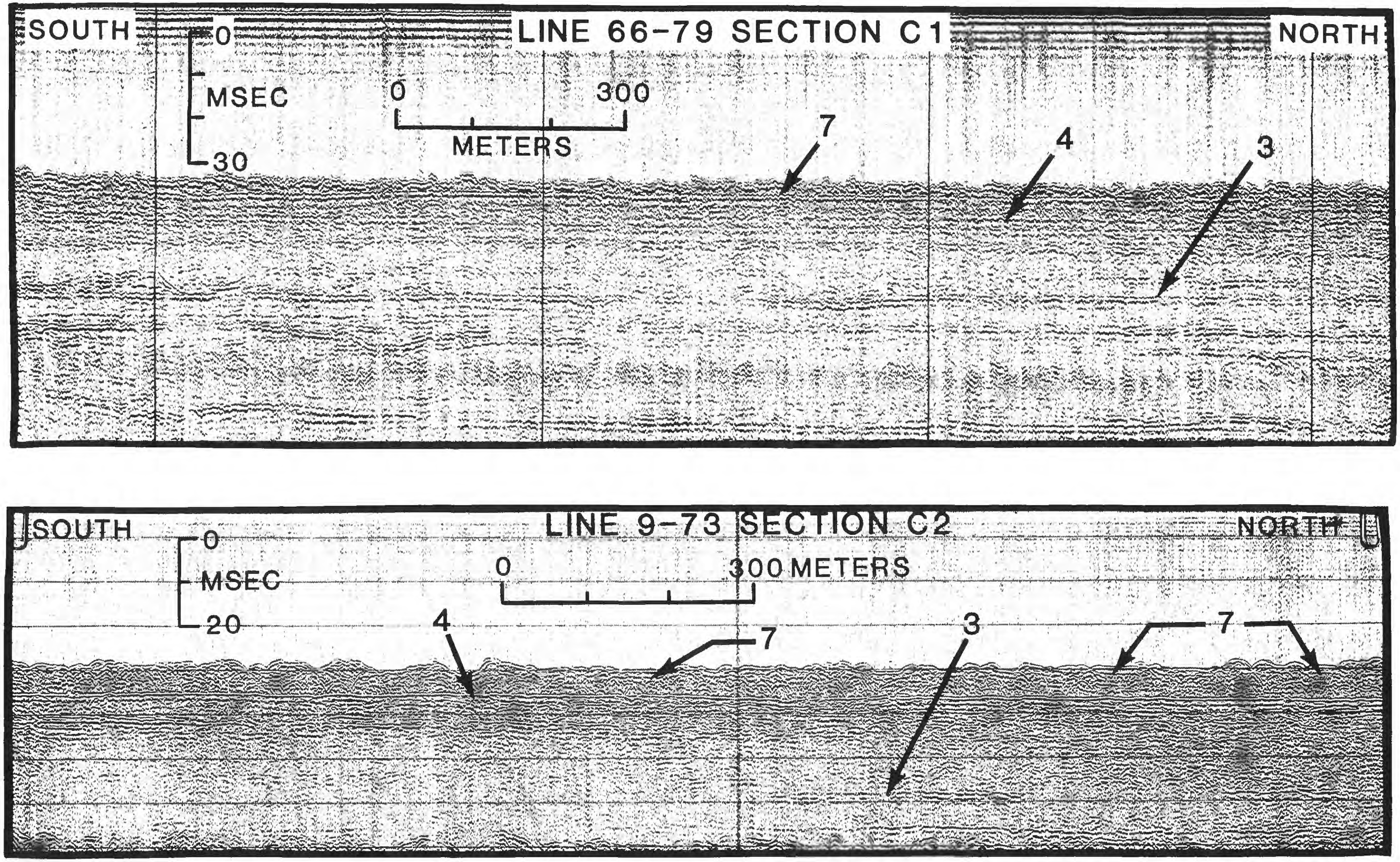


FIGURE 7. Seismic profile taken in 30 m water depth north of the Maguire Islands.

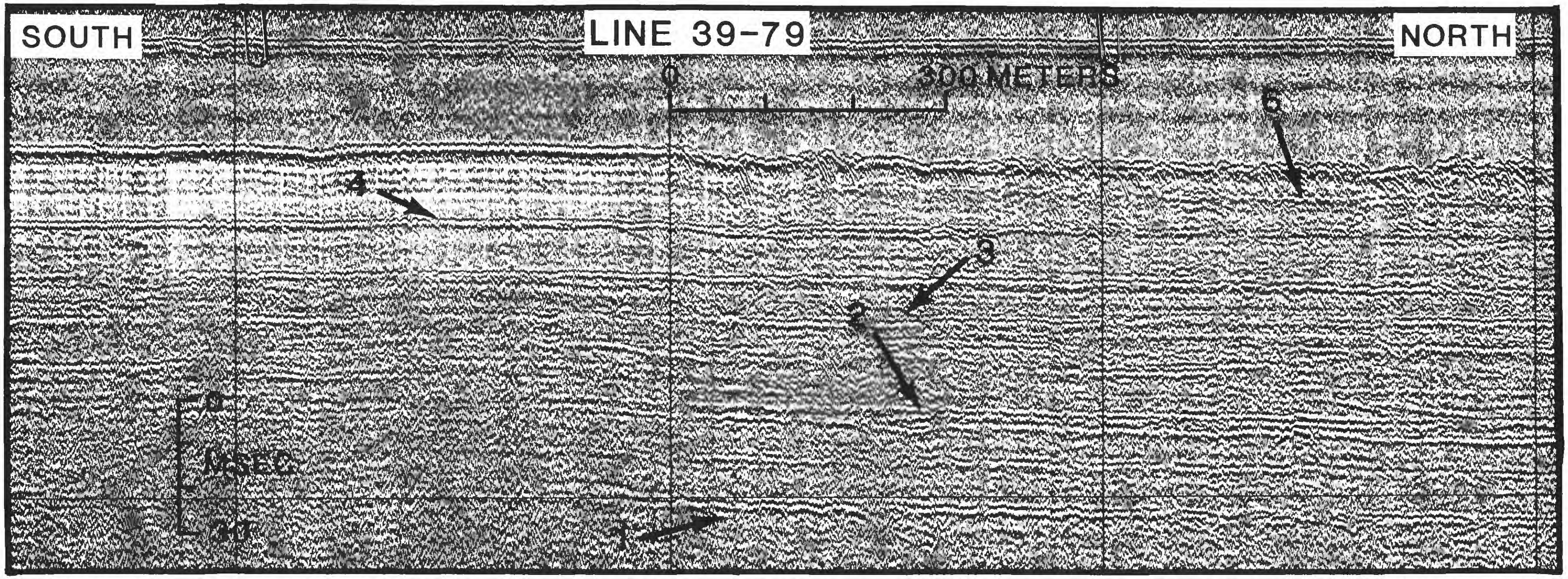


FIGURE 8. Seismic profile taken in approximately 20 m water depth north of Flaxman Island.

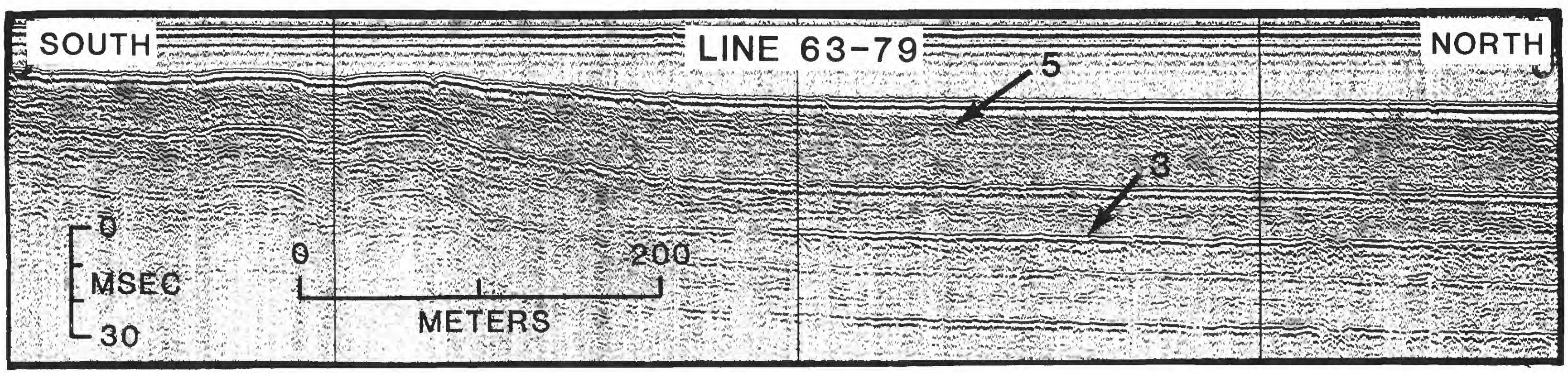


FIGURE 9. Seismic profile taken in approximately 10 m water depth at the eastern margin of the area.

and Kempema, 1984), but a total understanding of its nature, or origin still is lacking.

As is the case with remnants of surface 7, the 2 m to 3 m relief between the smooth seafloor surface and the gouged areas may also represent a combination of mechanical destruction of the sediments by gouging and removal of sediments by currents. In essence the "18 meter bench" is slowly retreating shoreward as intense gouging continues. Sediments below surface 3 and 4 show evidence of pinch-outs and channeling.

Seismic Section E.

Surface 5 can be observed on section E (Fig. 9). This surface has a hummocky, irregular appearance. This characteristic is best seen on the 7 kHz subbottom profiler data. Other profiles show 5 bottom lapping offshore onto 4, and it generally crops out at the sea floor near the barrier islands. Analysis of the 7 kHz records shows the surface to have relief of 2-4 meters, with peak-to-peak distances of 20 to 40 meters. In Figure 9, and elsewhere near the barrier islands, reflector 5 is the first reflector below the sea floor. This stratigraphic postion suggests a possible basal transgressive origin and a Holocene age for the overlying sediments. However, due to its top- and bottom-lapping nature, the overall geometry rules out an early Holocene age. Surface 4 is difficult to see in Figure 9, primarily due to interference by seafloor and underlying multiples. Surface 3 is very pronounced and can be seen to rise slowly to the south, somewhat independent of the present sea floor gradient. Sediments between 5 and what we interpret as 4 have slight seaward dips toward the south end of the seismic profile.

Seismic Section F.

This profile (Fig. 10) passes directly over borehole 18 and illustrates surface 5 and 3. In Figure 9, and other proflies, surface 3 gradually rises to the south and passes under the shoal region surrounding Flaxman Island, unaffected by the stratigraphy and seafloor morphology above. This lack of relationship to the present island chain is characteristic for both surfaces 3 and 4 throughout much of the study area. Surface 5 crops out at the seafloor between borehole 18 and Flaxman Island, and dips in a seaward direction. Also in Figure 9, the internal stratification of the unit between 4? and 5 dip seaward near the island. The internal structures also are very irregular, suggesting disruption by such processes as mass wasting, slumping, or sliding during deposition, particularly at the base of the unit. The seaward dip of this unit seen in Figure 10 is characteristic for units seen in other seismic profiles as far west as the Stockton Islands (Figure 11).

Seismic Section G.

Surface 4 is clearly defined on profile G-1 seaward of the point where it is obscured by multiples, and less well defined on profile G-2 (Fig. 11), an example from a still more westerly region. The bedded, and seaward dipping sedimentary sequence above 4 is truncated at the sea floor. This is analogous to the setting off Flaxman Island shown in Figure 10.

Seismic Section H.

Cut-and-fill channels can be observed on many seismic profiles in the vicinity of the island chain. These old channels all have been filled by sediment in transit on the inner shelf, thereby smoothing over the originally rough seafloor. Section H-1 (Fig. 12) is a profile across the shallow water region in the western half of the island chain. Multiple sequences of cut-and-fill channels can be seen. The smaller, narrow features could be tributary channels feeding into a larger system. This sequence has been truncated, the channels filled, and a very thin younger sequence was deposited on top. The relief of the erosional surface is quite varied and suggests incomplete planation before a following transgression deposited new sediment. Profile H-2 (Fig. 12) is another example, a transverse section across one of the larger channels, in which borehole 19 was sited

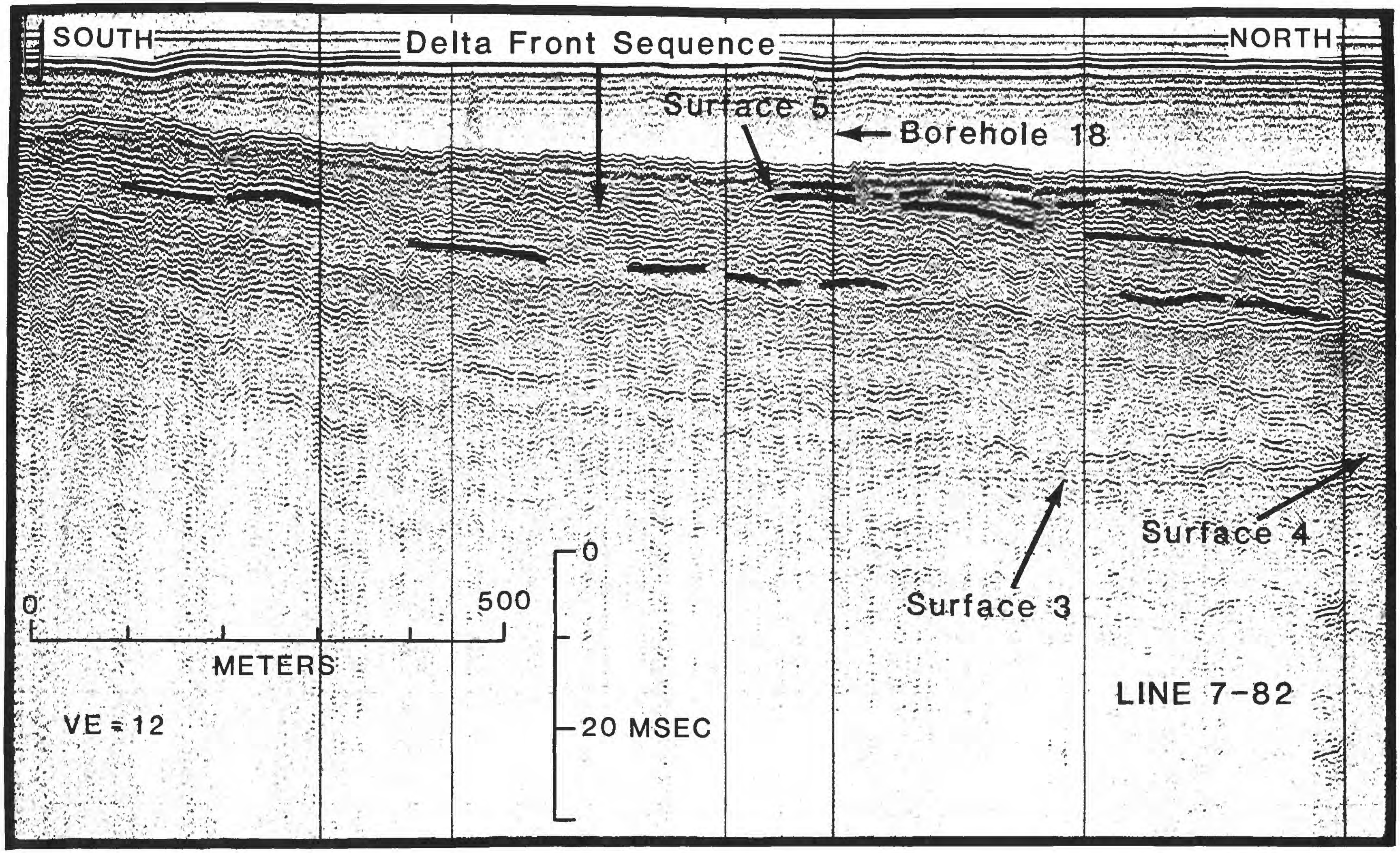


FIGURE 10. Seismic profile taken north of Flaxman Island through borehole 18.

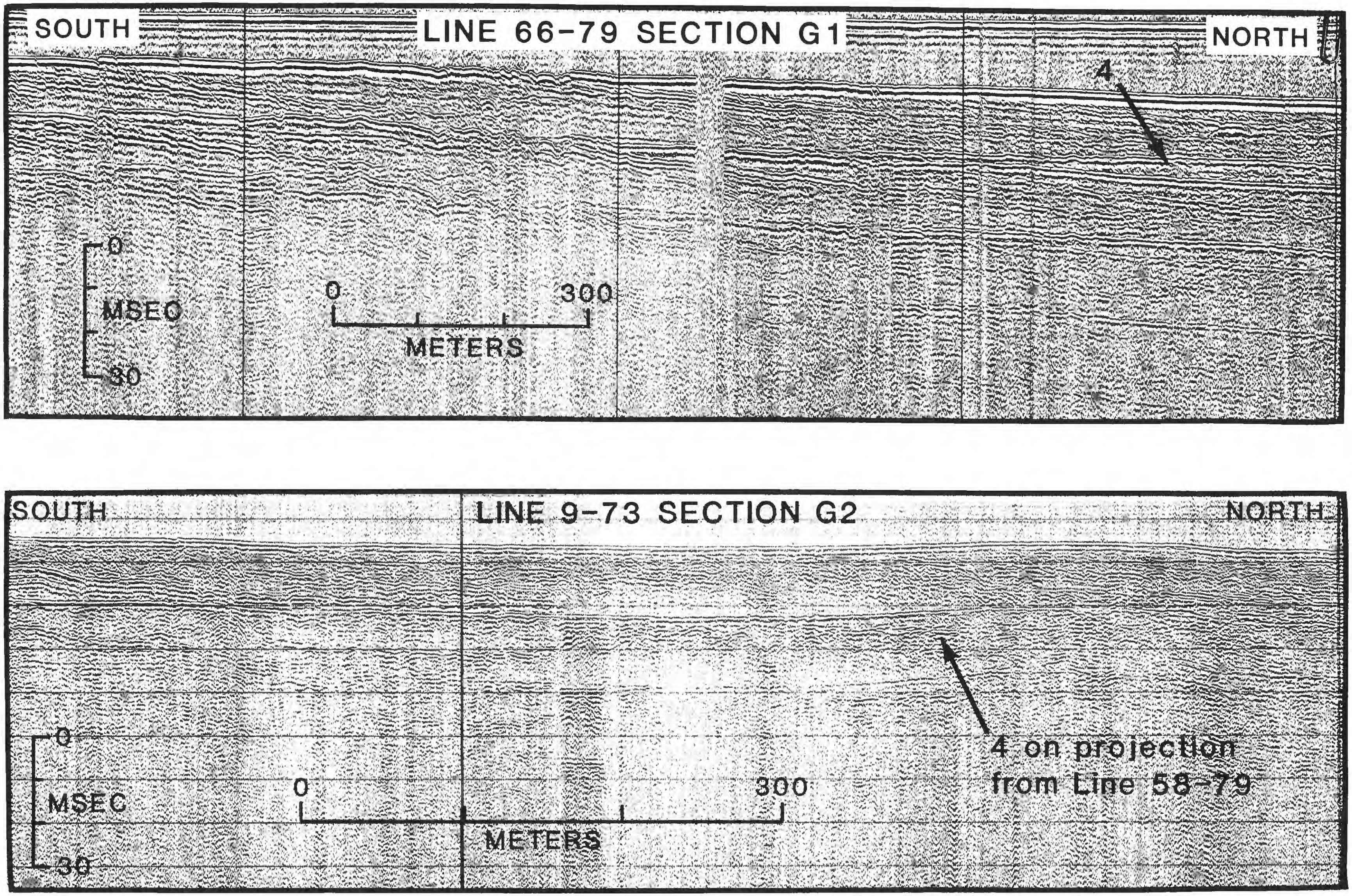
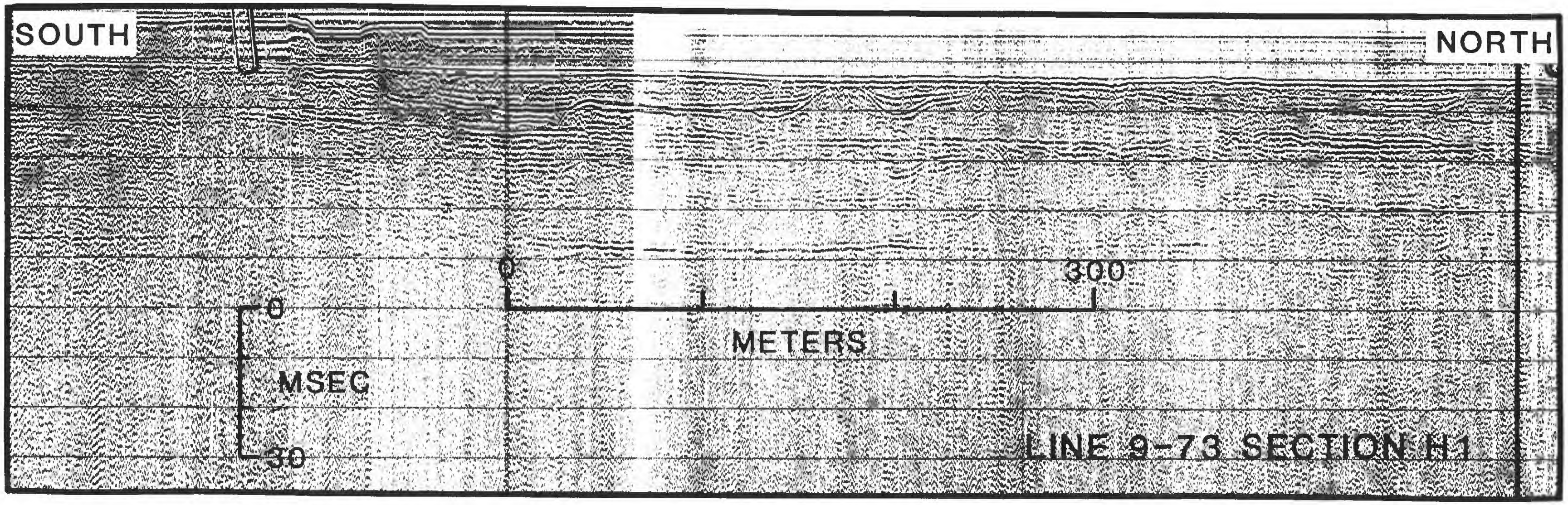


FIGURE 11. Seismic profiles taken on the seaward edge of the barrier island shelf (G1, north of Maguire Island; G2, north of Stockton Islands).



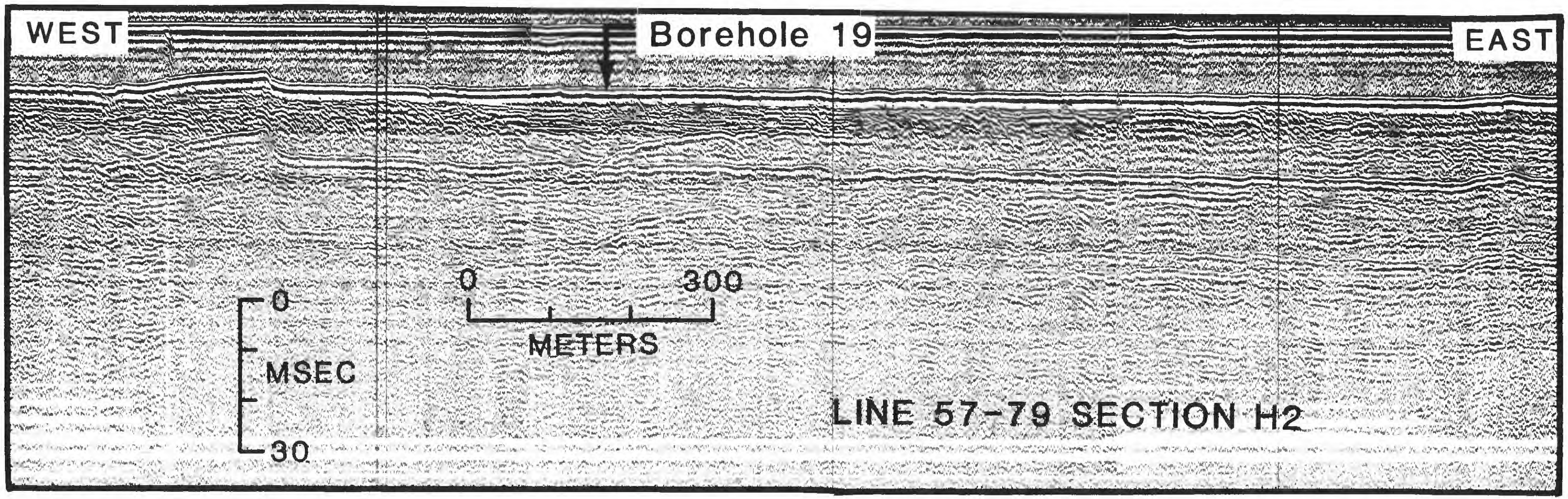


FIGURE 12. Seismic profiles taken in shallow water north of the Stockton Islands.

(Fig. 2). As in profile H-1 (Fig. 12), a shallow erosional surface can be seen east of the channel. The seafloor was again smoothed by sediments filling depressions. An enlargement of the channel is shown on section H-3 (Fig. 13). This channel was approximately 12 meters deep and 600 meters wide, and seems to trend NE-SW. Successive cutting and filling can be seen, with sediment supply originating from the west or south, as indicated by the apparent bedding plane dip of channel fill. This fill possibly originated from erosion in the Stockton Islands area. The materials below the uncomformity into which the channel was cut are nondescript and may consist of sands and gravels intermixed. The knowledge gained from borehole 19 provides ground truth for seismic records that penetrate similar channel fill in other areas. These combined data were very important for the interpretation of the geologic history during Quaternary time in the study area..

Seismic Section I.

Seismic profiles crossing the locations of boreholes 16 and 17 (Fig. 2) reveal that these also were inadvertently drilled into channel fill. The profile in Figure 14 shows that at the precise location of borehole 17, a channel more than 10 meters deep and 800 meters wide is located. This channel, like the one in borehole 19, also is positioned between two present day islands. Although less obvious, this channel reflects several periods of cut-and-fill prior to smoothing of the present surface by movement of recent sediments on the seafloor. In each case, the channel apparently maintained its position through successive transgressions and regressions, spanning considerable time. Seismic data do not suggest additional channels north of the subaerial portions of the Maquire and Stockton Islands. One might speculate that these channels were confined to their positions as a result of the presence of the islands during cutting and filling. This also suggests that the barrier islands are relatively stationary and not moving in time nor constructional in nature.

SUMMARY OF ACOUSTIC REEFLECTORS

Seven distinct surfaces have been identified on the high resolution seismic records and described. The essential features of the seven surfaces are:

Surface 7: Seen in seaward, deeper region only. Partially destroyed by ice gouging, slight seaward dip.

Surface 6: Central parts of study region, in places downlaps onto 4, top laps at the smooth shelf shoreward of the 18 m bench, may in part be equivalent to a mechanically formed surface which represents maximum incision depth of ice gouges over long term as the "18 meter bench" retreats shoreward.

Surface 5: Central parts of study region and near the island chain, hummocky relief, downlaps seaward onto 4, crops out at or near the island chain.

Surface 4: Erosional surface, relatively flat in outer regions, rises in attitude near and under the island chain.

Surface 3: Same description as surface 4, but deeper.

Surface 2: Deep reflector in middle and outer portions of eastern area.

Surface 1: Same description as for surface 2, except that it lies deeper in the section.

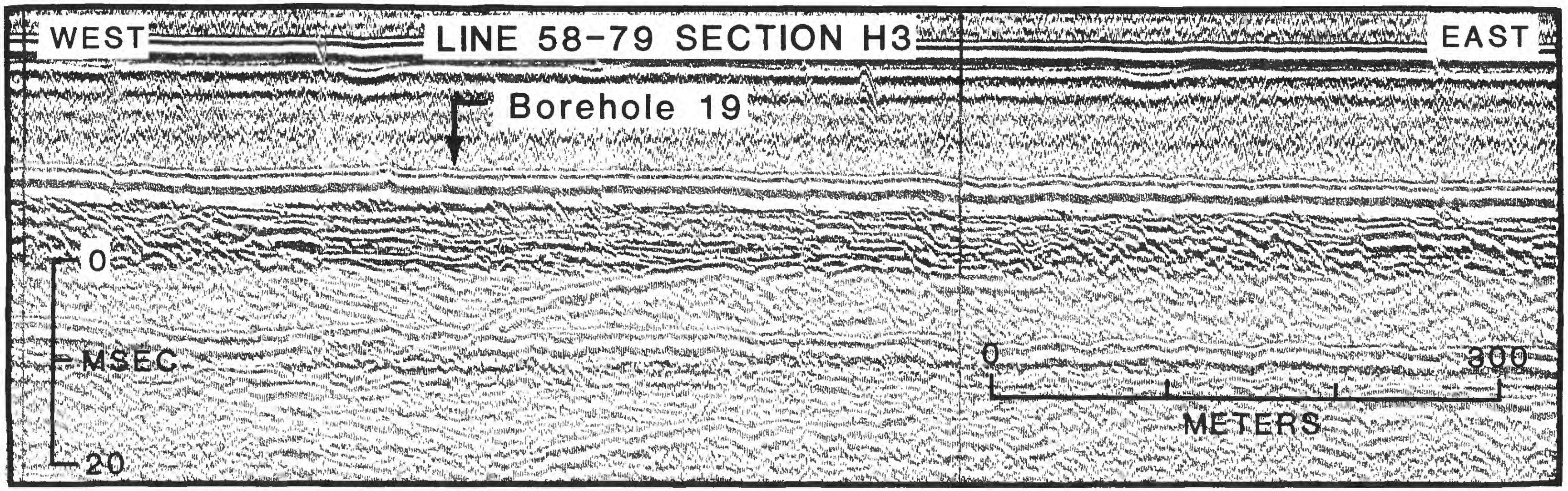


FIGURE 13. Seismic profiles taken through a cut and fill channel located at borehole 19 north of Stockton Islands.

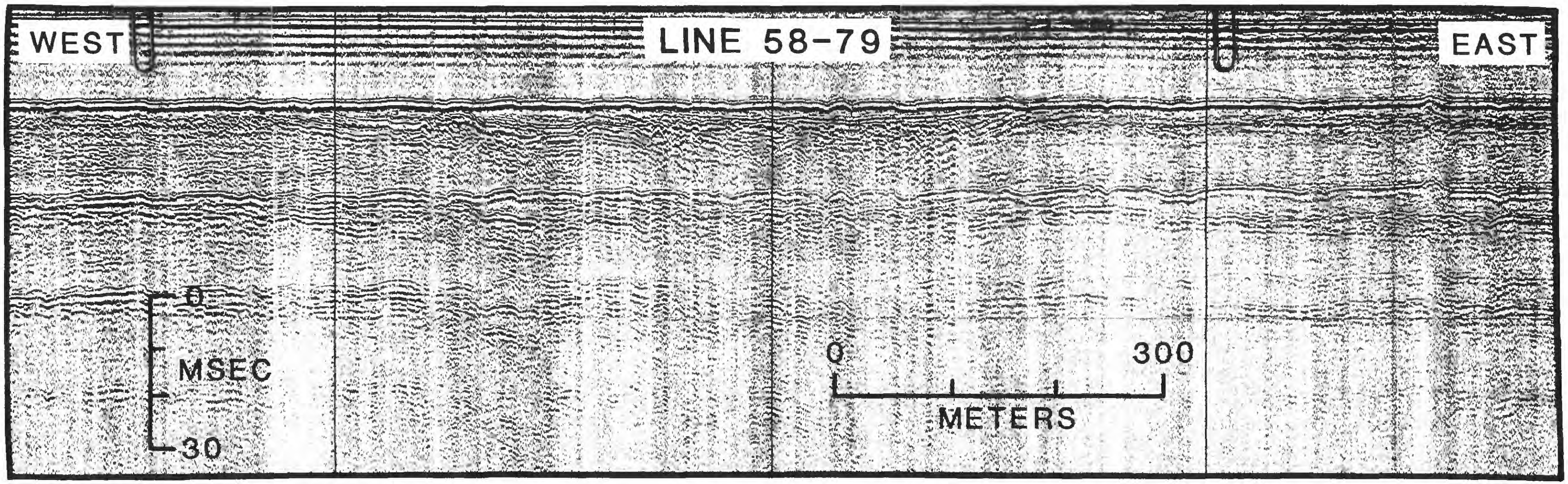


FIGURE 14. Seismic profile taken through a cut and fill channel located at borehole 17 north of Maguire Islands.

AREAL DISTRIBUTION OF MAJOR SEISMIC REFLECTORS AND INTERVENING SEDIMENT PACKAGES

Surfaces 1, 2, 6, and 7

Seismic reflectors 1 and 2 are observed north of Flaxman Island along seismic line 39-79 and reflector 2 alone on the seaward end of line 66-79 north of the Maguire Islands. The significance of these reflectors is that when projected southward into the Alaska State A-1 drill hole on Flaxman Island they lie within a non-marine sequence of sediments. Also, in both areas of occurrence these surfaces have a slight seaward dip, suggesting sediment sources in the Brooks Range, perhaps in a setting similar to that of the present Canning River Fan onshore. Little else can be said about these reflectors, as additional data are lacking. Surfaces 6 and 7 are not significant enough to warrant lengthy discussions of each. However, one should keep in mind their stratigraphic positions relevant to the surfaces discussed below, their seaward dip, and the fact that each crops out at the sea floor.

Sufficient data and seismic line intersections permit contouring of surfaces 3 and 4 and also a "pre-Holocene" reflector from Flaxman Island to Prudhoe Bay.

Surface 3

Figures 15 and 16 define the depth of surface 3, and show the spatial characteristics of sediments which overlie the surface. The contours are dashed where questionable. There is a dominant WNW-ESE trend which generally subparallels the present coastline and island chains. The hachured area north of Prudhoe Bay and southeastward to Tigvariak Island across the Sagavanirktok delta (Fig. 16) represents an area where surface 3 is equal to surface 4. Reflector 3 probably was removed during the erosional cycle which formed surface 4 The area defined as PBT (Fig. 16) refers to a region where seismic records exhibit numerous hyperbolics throughout the section. The significance of these hyperbolics, already mapped and discussed by Reimnitz and others (1972) is still in question; but the restricted occurrence of the hyperbolics in the area near Prudhoe Bay and the "Sag" delta is rather striking. This pattern may represent a broad topographic low that was filled by a sedimentary sequence near the surface and at depth similar to the formation of the Prudhoe Bay area and the subsequent infilling of perhaps an ancestral "Sag" River channel. This topographic low would be a much broader feature than the Paleo Valley postulated by Hopkins to exit from the present Prudhoe Bay and turning westward away from the present "Sag" Delta (Hopkins and others, 1979). Some hyperbolics have also been observed on seismic records around Cross Island to the northeast.

The NE-SW trend of surface 3 contour lines (Fig. 15, 16) may suggest the past existence of a broad flood plain of which the old "Sag" River was a part. Insufficient data exist to substantiate coexistence of an old channel, thus the existence of a low relief flood plain is more appropriate. The convex curvature of the contours north of the Canning fan-delta is also striking. The gradient of that surface steepens as it nears the coast and suggests that surface 3 may crop out south of the shoreline on the present Canning River fan. Two embayments with NE-SW linear trends can be observed on surface 3, one through borehole 17 (Fig. 15) north of the Maguire Islands and the other north of the McClure Islands near borehole 12 (Fig. 16). These embayments may mark an old Canning River drainage in the former case and old "Sag" River drainage in the latter. But the relief across the features is only four meters, and their side slopes are gentle.

The configuration of surface 3 suggests that these two major river systems may have played a part in forming the erosional unconformity during a period of lowered sea level. As transgression resumed, sediments were apparently distributed more or less conformably to surface 3 over the area. However, dips of 8 and 13 minutes can be observed in the outer region between the two embayments previously mentioned. These dips suggest that deposition may have first occurred in this area during the first stages of transgression followed by wider distribution as topographic

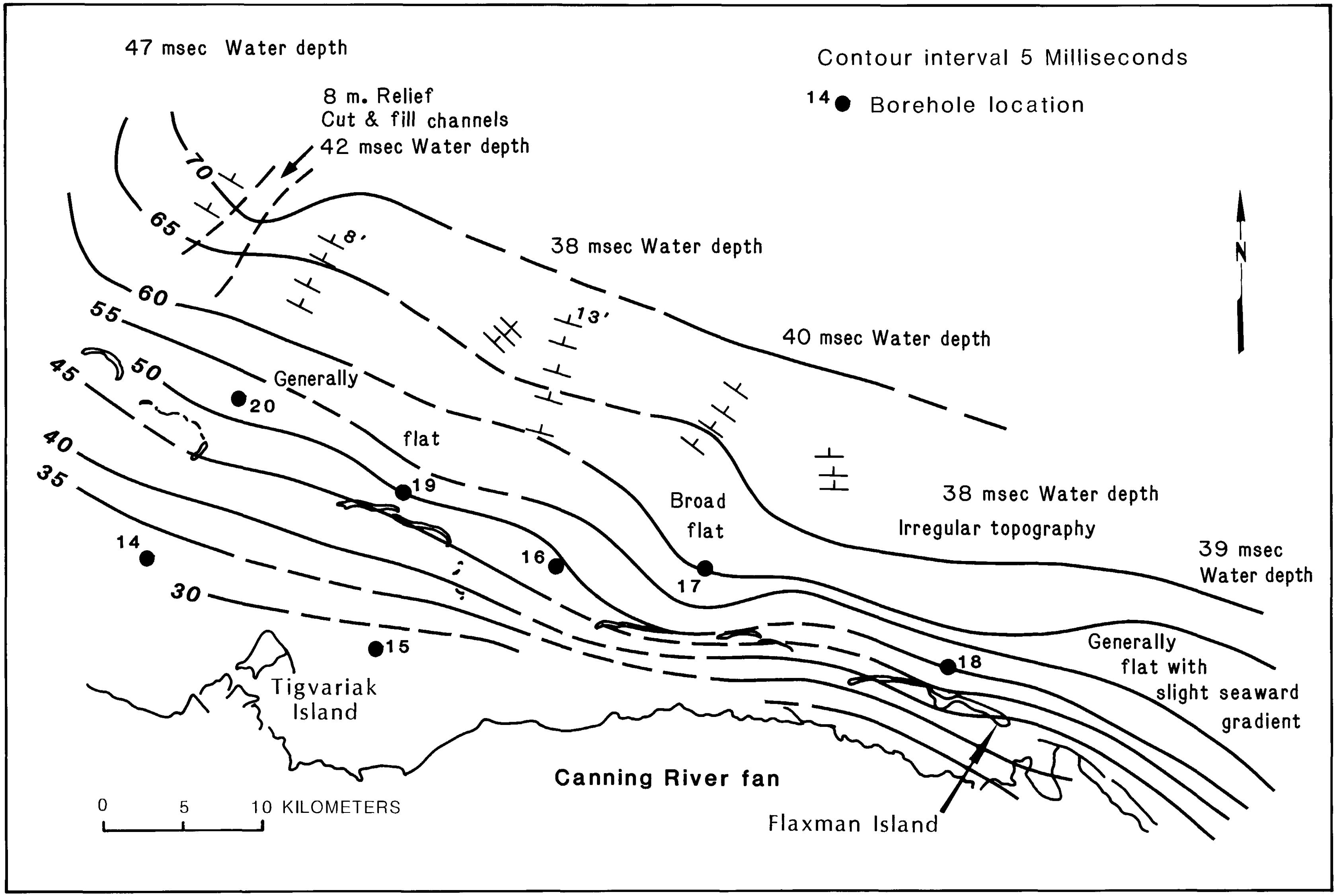


FIGURE 15. Contour map showing depth of surface 3 between Tigvariak and Flaxman Islands.

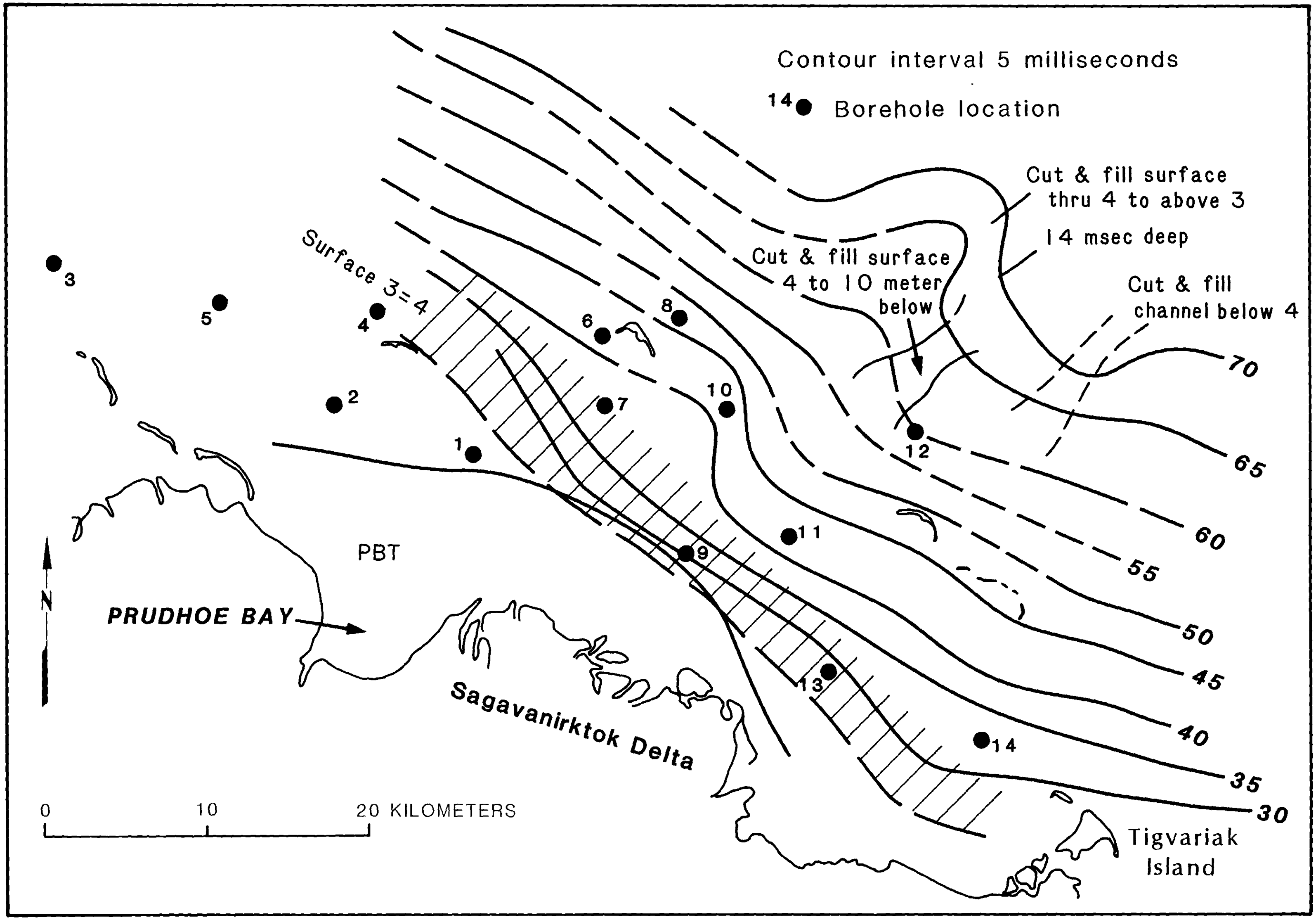


FIGURE 16. Contour map showing depths of surface 3 between Prudhoe Bay and Tigvariak Island.

irregularities were reduced. The cut-and-fill channels in the central region probably were cut at the close of this depositional transgression and at the initiation of the next erosional cycle, which led to the formation of surface 4.

Data from the West Mikkelsen Unit 2 drill hole on Tigvariak Island show loose gravel, sands, and conglomerates of non-marine origin below surface 3. Borehole 15 (Fig. 15) also shows sand and gravel of a non-marine origin below surface 3 in conjunction with fresh water fossils and gravel in the sediments above surface 3 and below surface 4 (Peggy Smith, Oral Commun. 1984). Alaska State A-1 drillhole on Flaxman Island also shows the non-marine characteristics of the sediments below surface 3. The presence of (marine?) shell fragments near surface 3 suggests close proximity to a beach-like environment. Seaward in borehole 18 (Fig. 15), nearshore and beach sediments are indicated above and below surface 3 (Peggy Smith, Oral Commun. 1984). These data suggest that an ancestral shoreline lay somewhat north of the present shoreline at the time of initiation of surface 3. Using a sound velocity of 1600 m/sec for the sediments penetrated acoustically, approximately 10-25 meters of sediment remain between surfaces 4 and 3 in the outer central region, little to none near Prudhoe Bay and approximately 10 m along the Flaxman-Maquire Island chain.

Surface 4

The depth to surface 4 is contoured in Figures 17 and 18, dashed where the surface cannot be clearly seen on the seismic profiles as was the case with surface 3 contours. Those of surface 4 strikes WNW-ESE, and have a gentle offshore slope. The previously existing embayment north of the McClure Islands is no longer evident. The embayment north of the Maquire Islands still existed at the time of surface 4 erosion; but the present embayment is somewhat larger than its predecessor and has shifted somewhat west of its previous position. This suggest that the old Canning River continued to play a role throughout the depositional cycle between surfaces 3 and 4 and was an active agent in forming surface 4 topography. We see no evidence for the existence of an old "Sag" River at this time. A topographic high now exists north of Flaxman Island, where underlying surface 3 had only slight topographic irregularities.

The convex curvature of the contours nearest the coastline of the Canning fan-delta is again evident. Surface 4 is at or near the sea floor near Prudhoe Bay and like surface 3, may crop out south of the coastline on the modern Canning River fan. North and west of Tigvariak Island, sediments overlying surface 4 are conformable, are relatively flat lying, and have a slight seaward dip. A region of cut-and-fill channels and more steeply dipping internal strata than noted above surface 3 exist along the island chain between Stockton and Flaxman Islands (Fig. 17). Direction of dips suggest a crenulated, prograding delta front cut by small channels. This delta-like subsurface feature is clearly related to the present Canning River fan-delta. The 35 to 45 minute dips are, in fact, in agreement with dips characteristic of classic low-latitude "delta front sediments" of other delta systems (Coleman and Prior, 1980). They are, however, much steeper than those of modern Arctic deltas. The position of channels near the modern Canning River suggests that an old Canning River played an active role in the progradation of the postulated delta across erosional surface 4. The orientation of small channels between the Stockton and McClure Islands suggest increased activity of the Shaviovik River, south of Tigvariak Island, during the same time. Most of the larger channels, including those along a NE-ward extension from the "Sag" delta exhibit repeated cycles of cutting and filling. These data suggest that the old Canning and "Sag" Rivers have been maintaining positions throughout the depositional/erosional cycles from pre-surface 3 to post-surface 4 time.

Our interpretation also suggests that following surface 3 time, both the old Canning and old "Sag" Rivers have shifted eastward to new positions as indicated on figures 17 and 18. Currently available data indicate that all channels are located on the seaward side of the present islands, between groups of islands, or between islands within a group. The present island chain and associated zone of shoal water extending as an almost continuous ridge from Flaxman Island to Cross

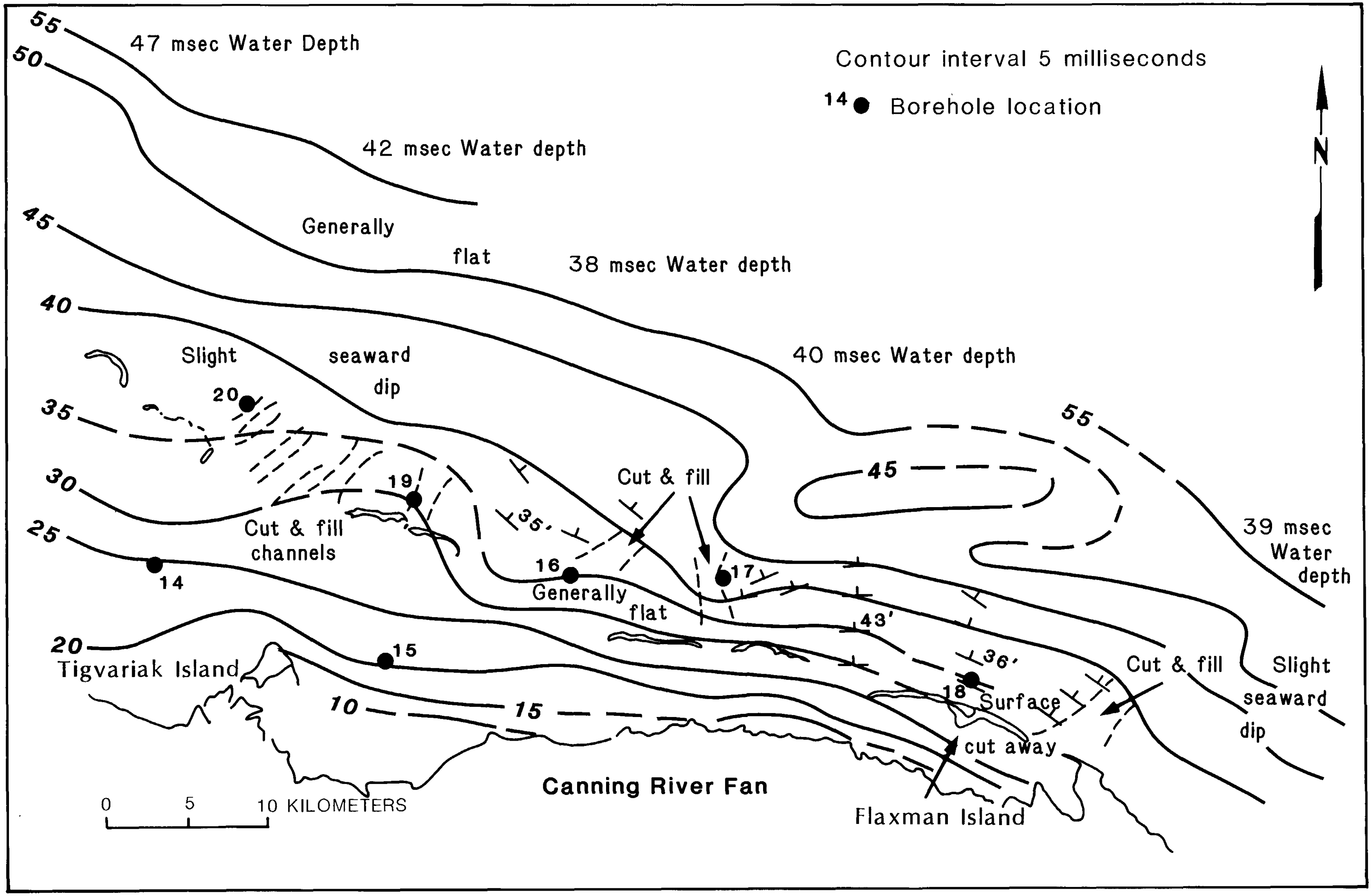


FIGURE 17. Map showing contours drawn on surface 4 between Tigvariak and Flaxman Islands.

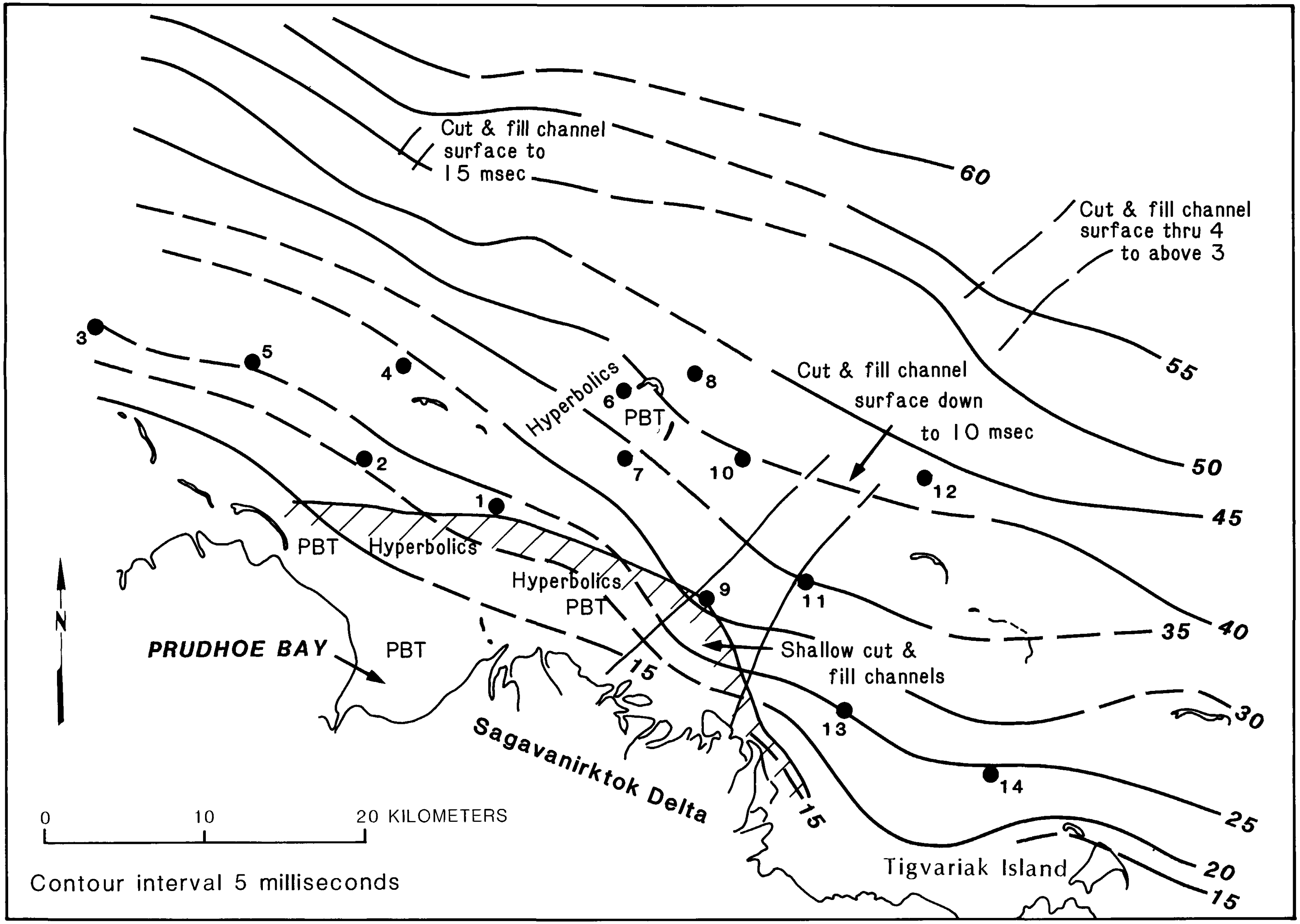


FIGURE 18. Map showing contours drawn on surface 4 between Prudhoe Bay and Tigvariak Island. Numbers by dots indicate borehole number and location.

Island marks a major break in the underlying stratigraphy. Landward of this ridge are flat lying strata, whereas offshore strata dip seaward, implying progradation. The overall geometry is similar to that of a classical delta sequence with topset and foreset beds. The channels in this sequence mark the positions of river distributaries along the delta front.

Borehole data indicate that most sediments between surfaces 3 and 4 are of marine origin (Peggy Smith, Oral Commun., 1984) suggesting that deposition of these sediments was in a predominantly subaqueous shallow water environment. The position of the shoreline at that time is somewhat in doubt, but areas of subaerial depositon most likely existed along the island chains and southward. Sediments seaward of the delta front have slight seaward dips which are comparable to those of pro-delta sediments in other delta systems. Overall, sedimentation in the "Sag" River region was relatively slow and quiet during the period when active deltaic progradation was occurring off the Canning River fan-delta. Although sediments are sand size and finer, boulders have been found in the Flaxman Formation in coastal bluffs from Prudhoe Bay to the Canning River, in adjacent shallow water regions, and in an area defined as the "Boulder Patch" (Reimnitz and Ross, 1979). This Boulder Patch covers extensive areas off the "Sag" River delta between Cross and the McClure Islands, suggesting that these boulders were introduced into this area by ice rafting during accumulation of the fine-grained marine sediments and became incorporated in the sediments as the ice melted.

The location of the Boulder Patch suggests that a shallow open embayment existed during that time, thus allowing ice to enter and become stranded. The islands and parts of the coastline acted as obstacles to penetration of ice into the upper reaches of the then existent delta system. Ice grounding and daming may also account for the fixed positions of some cut-and-fill channels, particularly those between islands and island groups.

Surface 5

Surface 5 is not a continuous surface similar to surfaces 3 and 4. Offshore it downlaps onto surface 4 and crops out near the island chain. Seven kHz, bommer seismic records and side-scan sonographs were obtained along identical tracks across borehole 20 in two different years (1980 and 1981). Partial sections of these records were analyzed and compared to learn about the nature of the hummocky relief so typical of surface 5 (Wolf and others, in press). The side-scan sonographs made possible the relocation of identical targets on the seafloor and confirmed the nearly precise match of the two lines. An example of such targets is shown in Figure 19-I, point B. This analysis revealed lateral trackline offset of approximately 20 meters. The 7 kHz subbottom reflector appears as a very jagged surface with broad highs and lows (Fig. 19-II). The sawtooth pattern has an approximate relief of one to three meters and as much as four to five meters when measurements on both profiles are combined. However, removal of the 20:1 vertical exaggeration inherent in these records shows the subbottom surface to represent "swells and swales" of 20 to 40 meters wavelengths from peak to peak. Superimposing the two profiles, and considering the up to 20 m lateral offset between the two records, revealed no clear match of individual peaks and troughs. This demonstrates that the hummocky relief is not elongated at right angles to the two semi-parallel tracklines. However. this does suggest that broad scale highs and lows with wavelengths possibly of hundreds to thousands of meters, and the general distribution of jagged relief, does match. For different reasons, neither the 7 kHz nor the boomer system permits tracing the details of the hummocky surface to the seafloor.

Both the boomer and the 7 kHz records (Fig. 19-II) show a transparent, nonreflective sediment layer above surface 5. The transparency of the sediment may be a result of intensive mixing by ice gouging, making the unit entirely homogeneous to seismic methods. Thus, the reflector, like surface 6 farther offshore, may in places represent maximum depth of ice gouging nearer shore. This in turn implies that the term "Holocene sediments" may be improper to use to describe the thin surficial sediment layer that consists of intermixed older Pleistocene materials with Holocene fauna in an area believed to nondepositional.

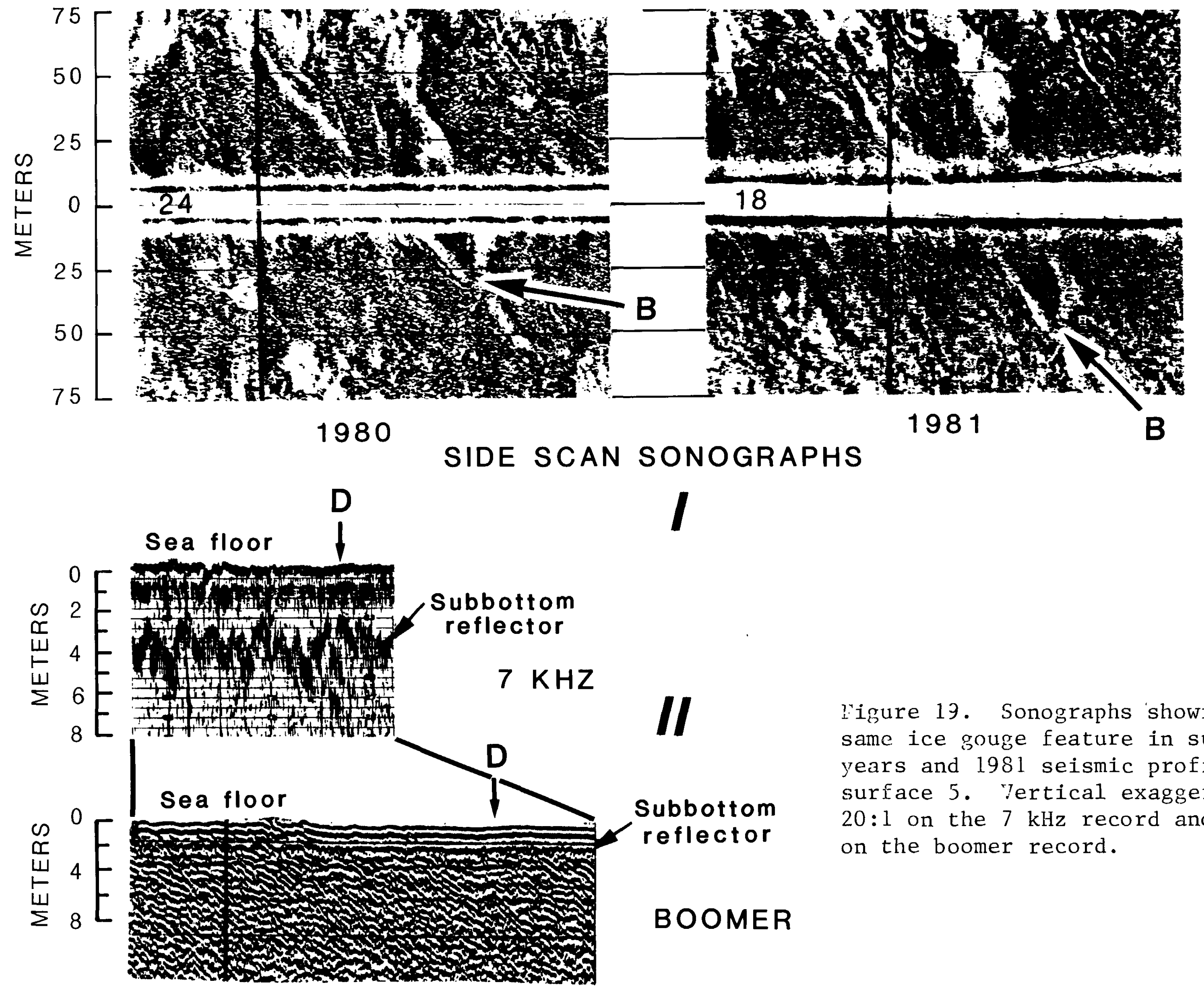


Figure 19. Sonographs showing the same ice gouge feature in succeeding years and 1981 seismic profiles for surface 5. Vertical exaggeration 20:1 on the 7 kHz record and 6.6:1 on the boomer record.

Certain trends of features on surface 5 are, however, notable. Near the island chain, reflector 5 crops out at a sharp boundary between heavily gouged seafloor to the north and an irregularly rough seafloor with scattered boulders and ledges of stiff silty clay to the south. This latter bottom type has been studied with side scan sonar, television, and direct diving observations. The outcrop extends landward through the opening between Karluk and Narwhal Islands north of Foggy Bay (Fig. 1). A similar type of bottom has been identified by similar techniques in an area about 30 km to the east, seaward of Flaxman Island and exhibits the same hummocky reflector. North of Flaxman Island, a 7 kHz seismic profile passes directly over borehole 18, whose stratigraphy has been studied (Hartz and others, 1979; Smith, in press). Stratigraphic and paleontologic data from borehole 18 indicate a boundary at the level of reflector 5, with Holocene above and the Flaxman Formation below (Wolf and others, in press). The Flaxman Formation is generally described as a bedded sandy silt and clay unit containing ice rafted boulders up to 3 m in diameter (Hopkins and others, 1978). This correlation suggests that reflector 5 may identify the top of the Flaxman Formation and the occurrence of seafloor boulders may reflect a non-depositional, perhaps an erosional surface at the present-day seafloor. The boulders, therefore, may represent a lag deposit of the Flaxman Formation which lies below and/or a unit that which has already been eroded away.

The more regional morphology of surface 5 may have analogs in the present day coastal plain and island chains. The broad highs may be buried counterparts of the high areas presently seen as islands and raised areas of the present tundra surface. Inshore from some of the islands are shallow lagoons. Broad lows on the profiles perhaps represent similar features offshore.

The small scale hummocky morphology of reflector 5 could be ascribed to a number of causes, as listed below:

1) The present coastal plain surfaces have similar, although somewhat lower, relief features largely related to the pattern of tundra polygons in permafrost. At times when the advancing sea of the last transgression moved across the coastal plain rapidly enough to prevent the formation of erosional bluffs, the underlying surface may have been buried by the younger sediment and preserved. Because of the different scales of the two relief types, but mainly because of the destructive action of ice keels plowing inro the sea floor, we discard this theory as a cause.

2) The reflector could represent a modified former onshore tundra surface as it would appeaer after thaw collapse of massive ice, particularly ice wedges, that occur in the upper 5 m of coastal plain deposits. We discard this theory as a cause mainly because the spacing is not right, and because our analysis indicates the depressions are not linear features.

3) The reflector could represent an erosional surface with cut-and-fill features, such as incised delta front channels. We discard this theory as a cause because the scale of the relief is too small.

4) The surface could represent the former land surface modified by ice gouging (Reimnitz and Barnes, 1974; Barnes and others, 1984). However, as in 2 above, the features are not linear, and the features under question are too large.

5) The relief in surface 5 could represent the effects of strudel scour in a deltaic environment (Reimnitz and Kempema, 1983) during the last transgression. We do not favor this interpretation because such a process generates only depressions and could not account for the peaks seen in the relief on the 7kHz record (Fig. 19-II).

6) The relief may not be related to a stratigraphic unit but to a gas boundary within the section, or to sound velocity inhomogeneities in the transition zone between non-

bonded surficial sediments and ice bonded underlying sediments. Elevation changes in the top of the bonded permafrost over short distances have been reported from the Canadian Beaufort Shelf, but we do not have enough information to properly evaluate this possibility.

At this stage of the analysis, we are as yet unprepared to ascribe a cause for the hummocky relief, but it does appear that this regional reflector may be one of many reflectors which are part of the large subsurface old Canning delta described earlier. There are sufficient data to suggest that the present seafloor is an erosional surface. Thus, parts of the top-set units above surfaces 5 and (6) are most likely missing from the section due to erosional processes still operating.

As outlined above, surface 5 crops out along the seaward margin of the island chain. From this point of outcrop to the islands themselves, we have not seen other shallow reflectors that would indicate the islands are constructional features on top of an older surface. This suggests to us that not only Flaxman, but also Maguire, Stockton, McClure, and possibly even Cross Islands are remnant highs of a once very broad, fluvial plain or larger deltaic system consisting of the Canning and "Sag" Rivers as the major sources of sediment supply. Ongoing destruction of these islands will eventually lead to the formation of shoals and small "moving islands" such as Dinkum Sands and Reindeer Island. Tigvariak and Flaxman Islands on the east end of the chain are the least advanced in this cycle, whereas Reindeer Island, north of Prudhoe Bay at the west end of the island chain is the oldest and most nearly destroyed. Many of the islands between the ends of the chain have curved spits and other beach-nearshore features which are concentrations of sands and gravels resulting from erosion of the island cores. As discussed earlier, there are many large and small buried channels with histories of cutting and filling along the island chain, some cut as deeply as 15 m. Thus, the channels have remained in place for extended periods of time and their positions may in fact be due to confinement by the islands.

Surface 5? - Lagoonal Areas

Shoreward of the island chain another surface, about as shallow below the seafloor as reflector 5 can be widely traced on the 7 kHz records. Although this surface may not be equivalent to surface 5 seaward of the island chain, for discussionary purposes, it will be referenced to as surface 5? Lagoonal Areas. Figures 20 and 21 are isopach or maps of the overburden thickness contoured from the 7 kHz data inshore of the island chain. These figures also show the locations and incision depths of buried channels. Surface 5 was selected on the basis of being the deepest, most continuous and acoustically strongest reflector on the 7 kHz records. Many less obvious, discontinuous reflectors, some of which crop out at the seafloor are seen above this surface. In those areas where borings are available, the isopached surface for the most part, matches with the base of Holocene marine sediments. This trend combined with a variety of background information from the area (see for example the section titled, Sea Floor Characteristics) gives us considerable confidence that the sediments isopached in figures 20 and 21 are Holocene marine sediments. The pattern suggests a possible connection between the presumably erosional surface along the island chain and the buried channels. This correlation may be further evidence that the paleogeography of the region was rather similar to the present configuration of the island chain and lagoons, and that the location of the island chain marks a topographic ridge made up of older fluvial or deltaic deposits. Between Flaxman and Tigvariak Islands (Fig. 20), the isopach pattern shows a convex trend very similar to that of surfaces 3 and 4. Westward toward Prudhoe Bay (Fig. 21), the Holocene sediments are thinnest. That area may have been too shallow for sediment accumulation during the time when deposition predominated in the eastern part of the area. Areally restricted accumulations occur only locally between Reindeer and Cross Islands and NW of Tigvariak Island at borehole 14 (Fig. 1). Slightly landward of the Reindeer-Argo Island topographic ridge, and parallel to it, is what appears to be a buried remnant of an older island. Internal structures of that feature consist of steep foreset bedding dipping south, implying southward migration during the island's last stages. Data are sketchy, but we believe that this feature is not part of the Holocene marine section but lies below it. The base of the Holocene(?) section shows

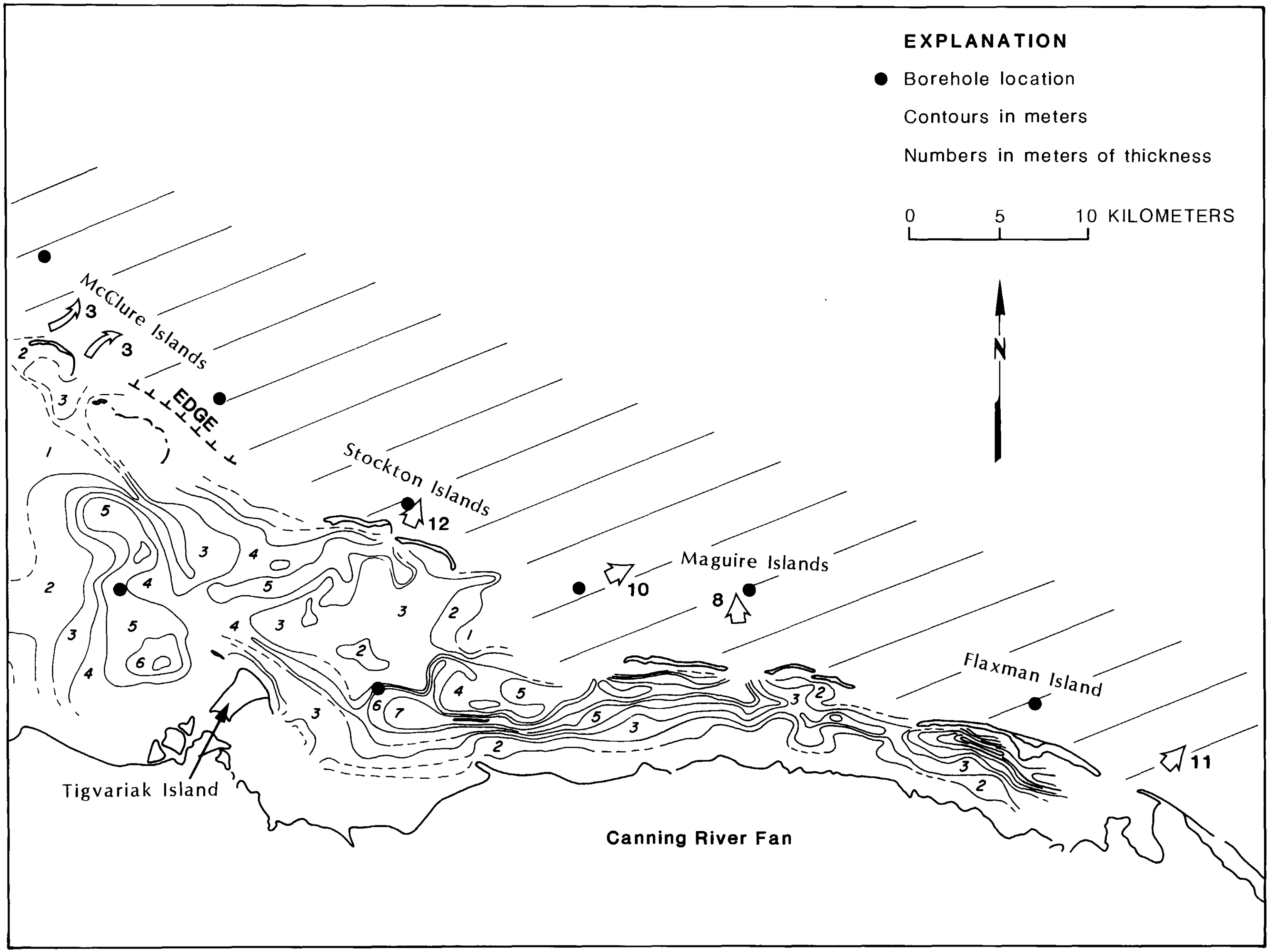


FIGURE 20. Isopach map of thickness of sediment between surface 5? and the seafloor in Leffingwell Lagoon between Tigvariak and Flaxman Islands.

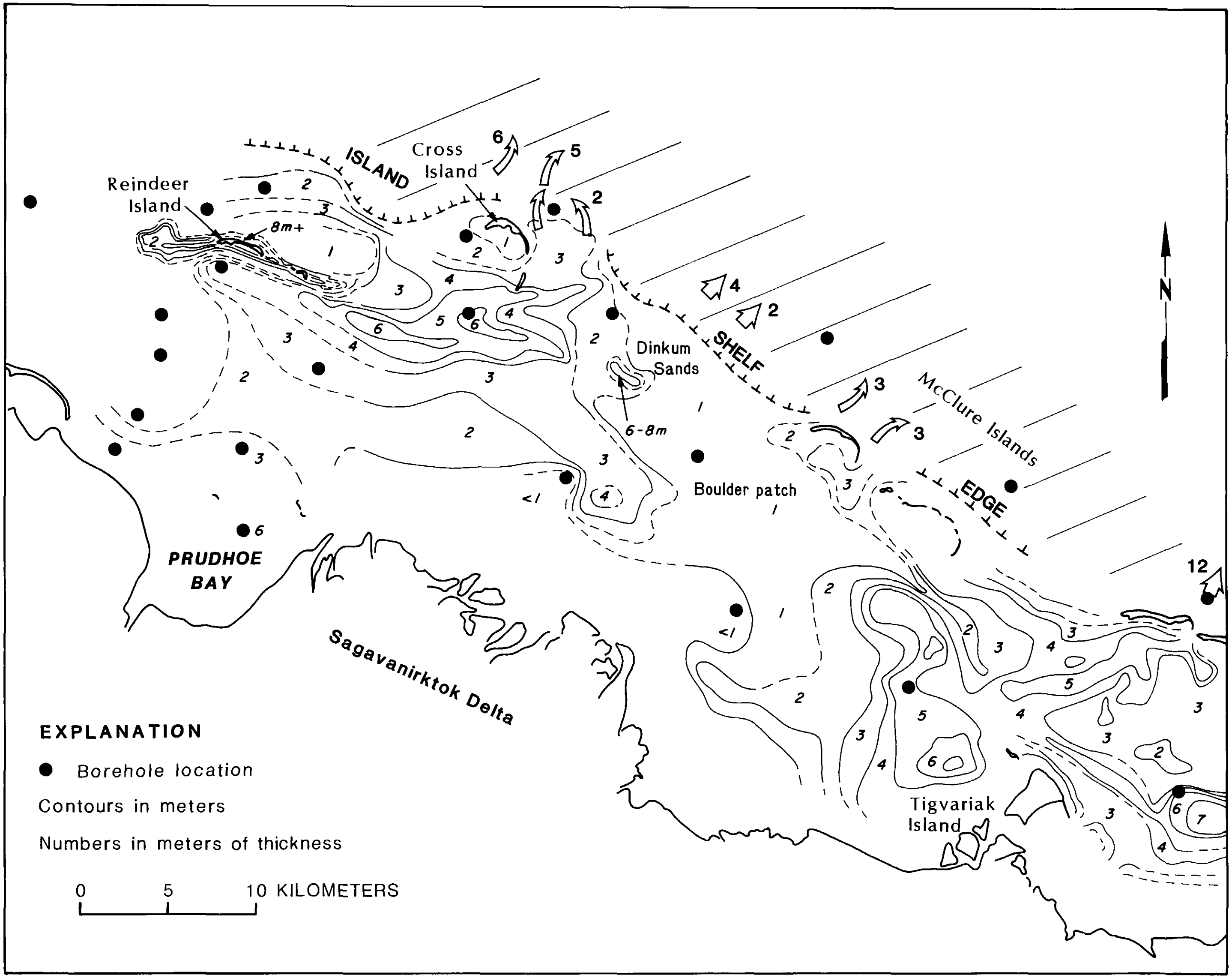


FIGURE 21. Isopach map of thickness of sediment between surface 5? and the seafloor between Prudhoe Bay and Tigvariak Island.

up as a rather widespread, flat reflector, 8 to 10 m below the top of Reindeer Island. The reflector extends to Argo Island and beyond. Thus Reindeer Island today is migrating southwestward (Reimnitz and Kempema, 1982a) over the old island which seems to have migrated in a similar direction. The fate of these two islands suggests that the sediment source is to the NE, and that during the wasting away of one island, a new island may again be formed, and the cycle will repeat itself. Similar to Reindeer and Argo Islands, but possibly different from Cross Island, Dinkum Sands to the E of the latter also seems to represent a constructional feature that rests on top of a flat reflector that crops out landward at the Boulder Patch.

The thinning of Holocene sediment from the center of Stefansson Sound toward the delta front of the "Sag" River is notable. As pointed out by Reimnitz and others (1979), a Holocene lack of delta accretion is an arctic enigma. This is strongly supported by the isopachs of Holocene sediment thicknesses at the "Sag" River delta (Fig. 21), fed by the second largest river of the North Slope (Reimnitz and others, 1979).

Sea Floor Characteristics

Areas without Holocene sediment cover should be marked by outcrops of older sediments that possibly differ from modern ones and therefore give the seafloor a different texture. In an attempt to verify the isopach maps of Holocene sediment thickness (Figs. 20, 21), we made a brief analysis of side-scan sonar records obtained along most of the lines in the eastern half of the study area where seismic coverage is available. In the western half of the study area, delineation of the Boulder Patch (Reimnitz and Ross, 1979) involved an analysis of all available data to define the windows in Holocene sediment cover. The results for the eastern half are discussed here.

Figure 22 is a composite of all side-scan sonar data and illustrates seafloor characteristics from Flaxman Island to Tigvariak Island. The line along which reflector 7, present only in the seaward part of the study area, terminates at the seafloor is shown by the heavy line with slashes on the seaward side. Seaward of the 10 meter isobath, the seafloor is jagged from ice plowing, but shows little evidence of the presence of ledges of overconsolidated sediments. Within the lagoons, the floor is generally smooth, indicative of quiet water deposition and ponding of Holocene sediments. The seaward flank of the topographic ridge underlying the island chain, however, has a mottled seafloor with streaks and patches due probably to alternating sand and gravel accumulations. Scattered boulders are recognized near Tigvariak and Flaxman Islands, and along the coast east of the eastern entrance to Leffingwell Lagoon. The somewhat convex trend of the mottled seafloor parallels that of the present coastline. It also coincides with a belt in which we interpret the Flaxman Formation to crop out or a zone that reflects a lag deposit of the Flaxman Formation.

The deflection in trend of the mottled seafloor area to the northwest , i.e., north of Tigvariak Island, suggests the influence of the Sag delta to the west. The overall trend of outcropping reflector (7) , of the 10 m isobath, and the NW-SE trend of ice gouges support the interpretation that the present seafloor is undergoing mechanical destruction and erosion, and that the seaward flank of the topographic ridge marking the island chain is not being spared from destruction. Whatever originally formed the lagoons, the Holocene sediments they presently contain can only be temporary accumulations to be removed, at least in part, as the sea advances in the present erosive cycle. The present seafloor will become the next surface in the sequence of unconformities on the inner shelf, above surfaces 3 and 4.

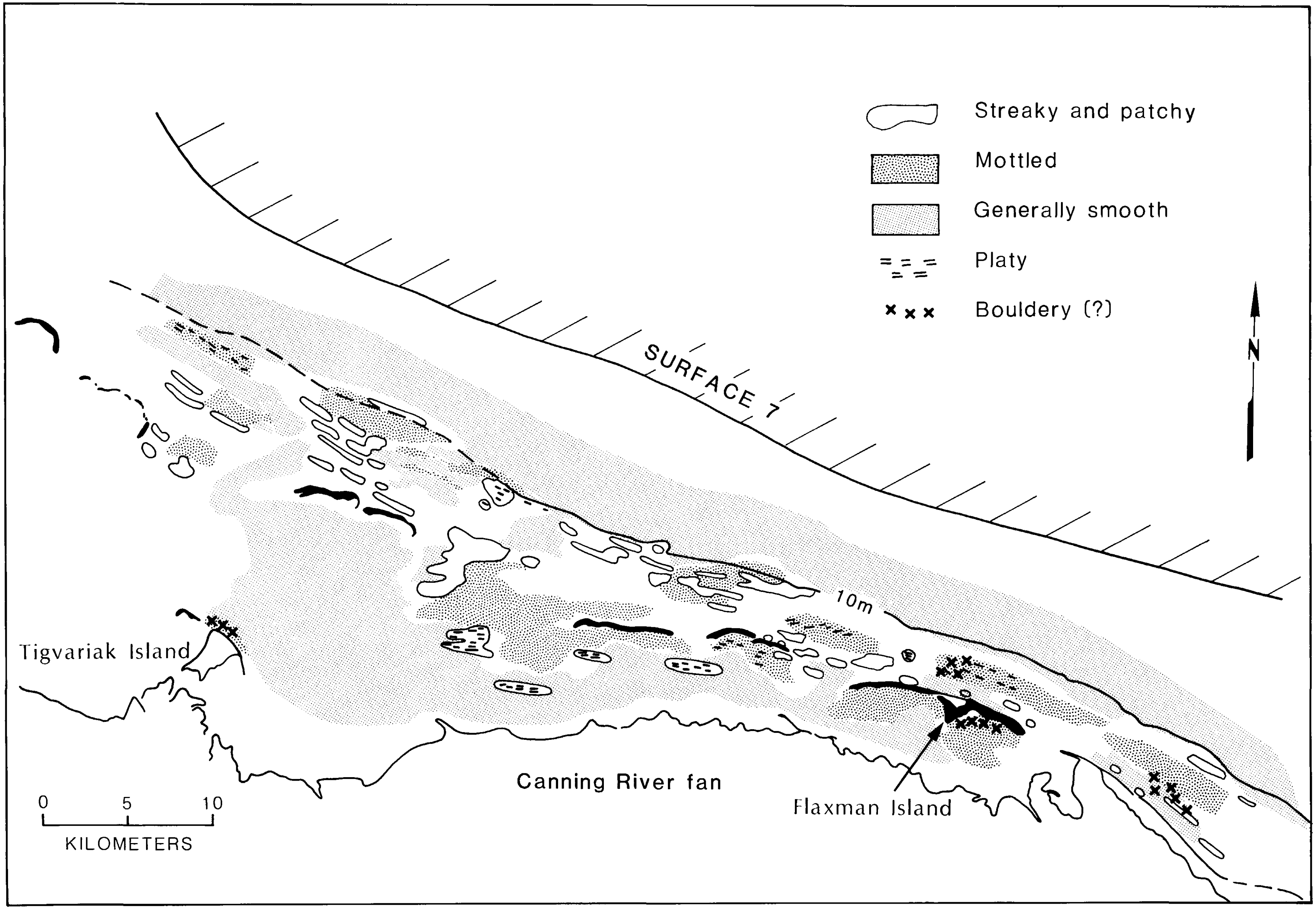


FIGURE 22. Seafloor textural characteristics between Tigvariak and Flaxman Islands.

RELATIONSHIP OF THE CANNING FAN-DELTA TO OFFSHORE STRATIGRAPHY

To understand the relationship between the offshore seismic stratigraphy and the modern Canning fan-delta, we refer to the topographic map of the latter (Fig. 23). This map shows the locations of 5 topographic profiles (Fig. 24) that delineate the fan-delta system. North-south profiles A, B, and C delineate the fan-surface from the Brooks Range to the coast, and the slight relief northward across the lagoon, island chain, and beyond. Profile D is a transverse profile across the main body of the fan, and Profile E defines the floodplain of the Canning River where it exits from the Brooks Range. The subsurface expression of surfaces 3 and 4, angles of dip along section, and attitude of intermediate reflectors are shown below the seafloor.

The NS profiles of the fan surface show two pronounced steps or knickpoints, one at about 7-1/2 meters and another at 50 meters elevation. Traced on the map (Fig. 23) these two steps delineate small lobes between the radial channel pattern on the fan surface. Fan growth occurs as lobes and channel beds agrade at a site until sufficient elevation is achieved to shift the drainage to a lower level area on the fan. Judging from the large overall transverse relief of the fan shown by profile D (Fig. 24) when compared to that of individual channels and lobes, these channels must have switched back and forth numerous times during the construction of the fan. The apex of the radial channel pattern is approximately at the point where the Canning River emerges from the Brooks Range. The regionally convex seaward pattern of the fan contours, as delineated by the two heavy lines that mark the knickpoints in figure 23, the arcuate shape of the present-day coastline, the positions of the barrier islands and shelves, and the arcuate shape of the subsurface stratigraphy all seem to be related to the Canning River as the sediment source. This drainage system, therefore, has been active in the same area through several transgressions and regressions of the sea.

The locus of most recent progradation may have been in the very eastern part of Leffingwell Lagoon, where the lower contour in figure 23 defines a major topographic bulge at the Staines River. Since Leffingwell Lagoon is sediment starved by an eastward shift of the river into Camden Bay, the front of the fan is retreating by coastal erosion at a rate of 1 to more than 4 m/yr (Lewellen, 1977). This retreat is revealed by the highly crenulated coastline (Fig. 25) and erosional bluffs. The shift into Camden Bay must have occurred long enough in the past to allow construction of a small delta bulge at its present mouth (Fig. 25, Point A).

The radial stream pattern, shape, and relief of the present Canning Fan-Delta can be best observed with LANDSAT imagery (Fig. 25). On this image, the eastern 1/3 of the surface has few lakes compared to the western 1/3. This probably reflects more recent flood plain development on the eastern part of the fan. Also evident are the masses of sea ice which come into contact with the island chain and continue to cut into and erode away the Islands and associated topographic ridges. Although somewhat obscured by thin clouds, a westerly drift of suspended sediment emerging from Leffingwell Lagoon is evident.

This entire fan-delta system and its relationship to the marine and non-marine environment is not uncommon to the coastline of northern Alaska. Figure 26 illustrates a LANDSAT image of a series of fan deltas near Demarcation Bay well to the east. Note the head locations of the major rivers, the radial distribution and in particular the sediment being trapped in the lagoon behind the barrier islands. Small amounts of sediment escaping between the islands is picked up by longshore currents and can become attached to the ice which in turn takes it out of the area. Perhaps, as is the case with the Canning fan-delta, there are subsurface deltaic sequences here also.

Computer enhancement of LANDSAT data reveals an old rather wide river floodplain on the Canning River fan, following a line from the apex toward Flaxman Island, where subsurface

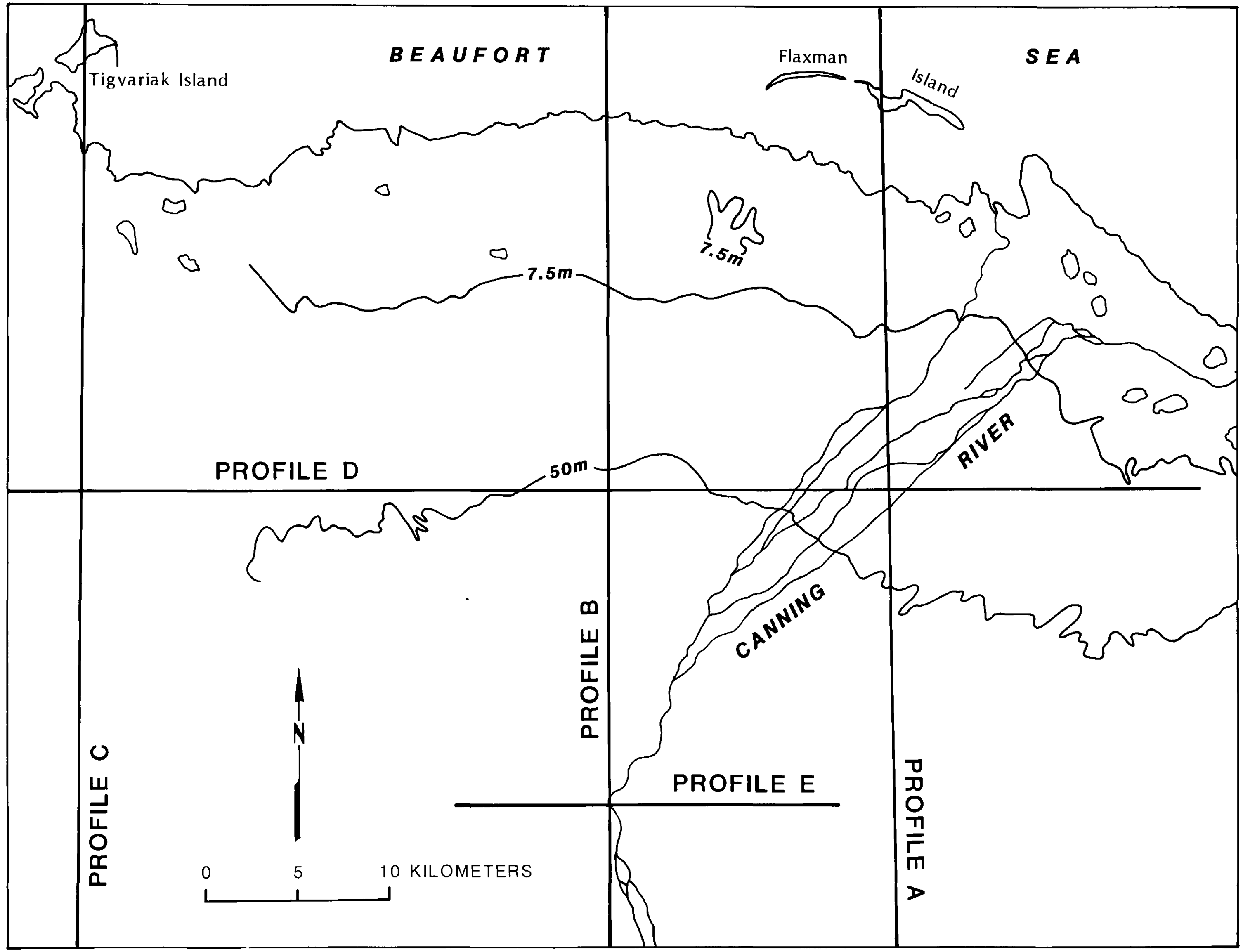


FIGURE 23. Topographic map of the Canning River Fan-Delta showing the location of profiles A through E (Fig. 24).

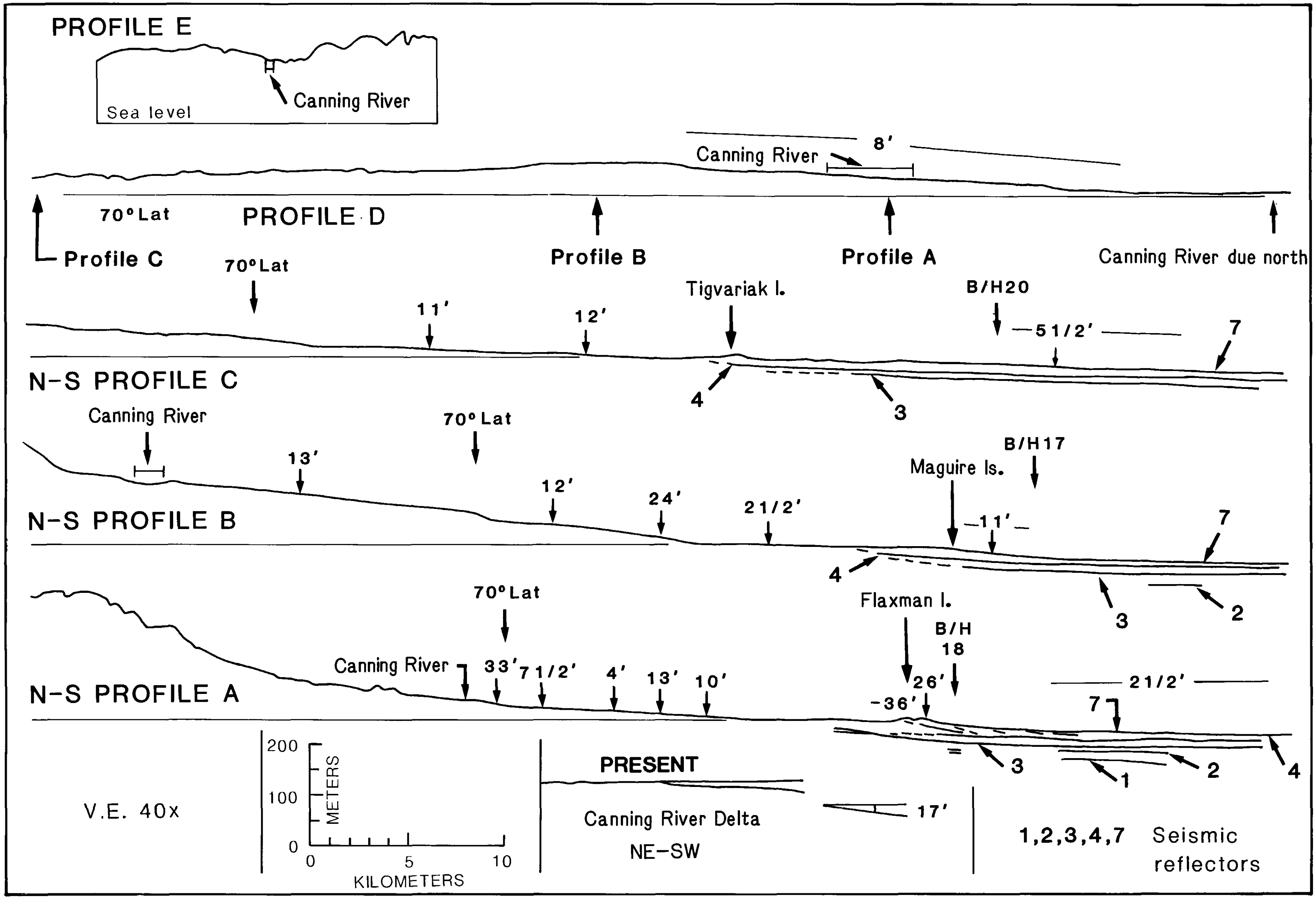


FIGURE 24. Profiles A through E across the Canning River Fan-Delta and seaward.

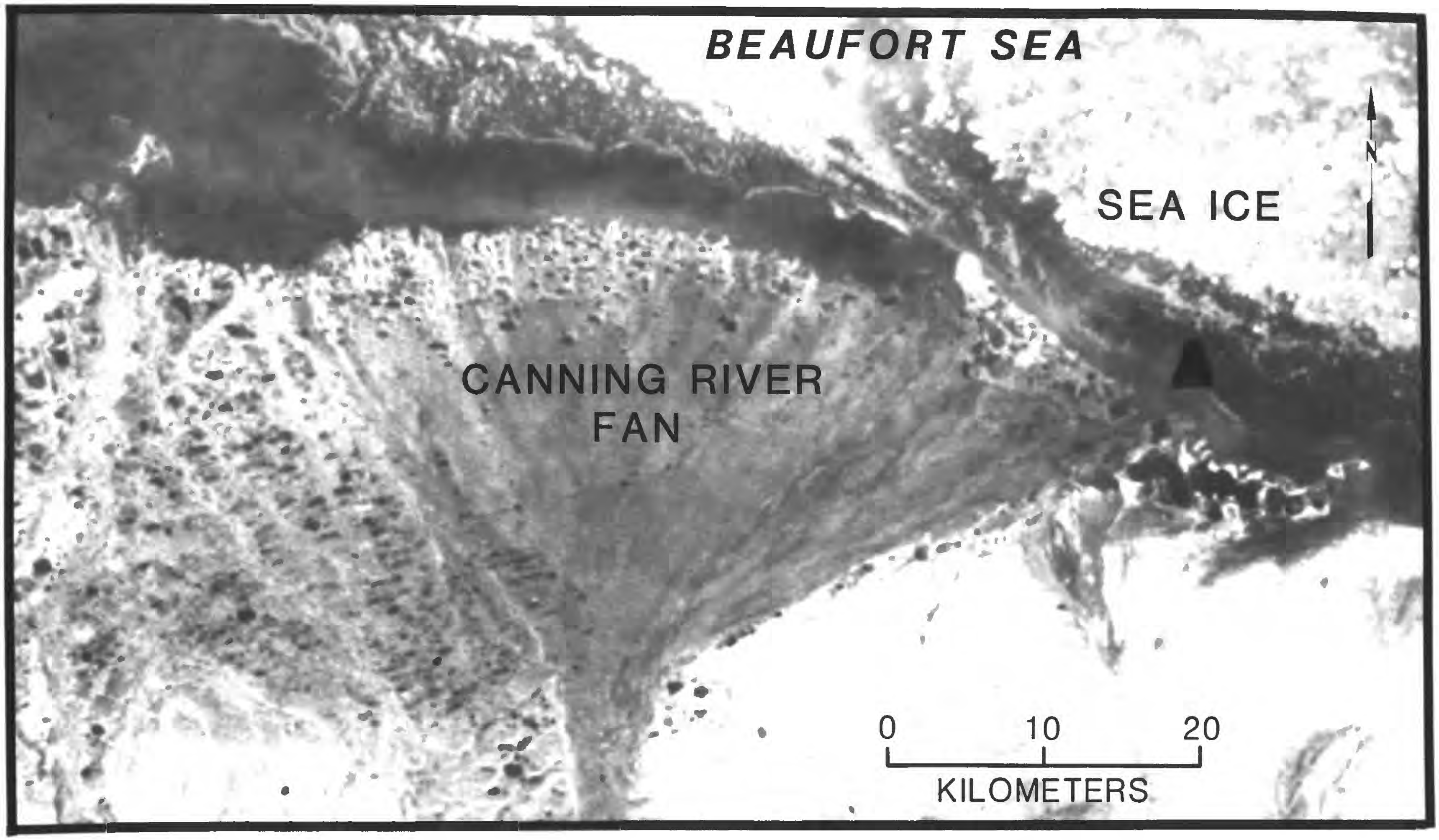


FIGURE 25. LANDSAT imagery of the Canning River Fan-Delta system.

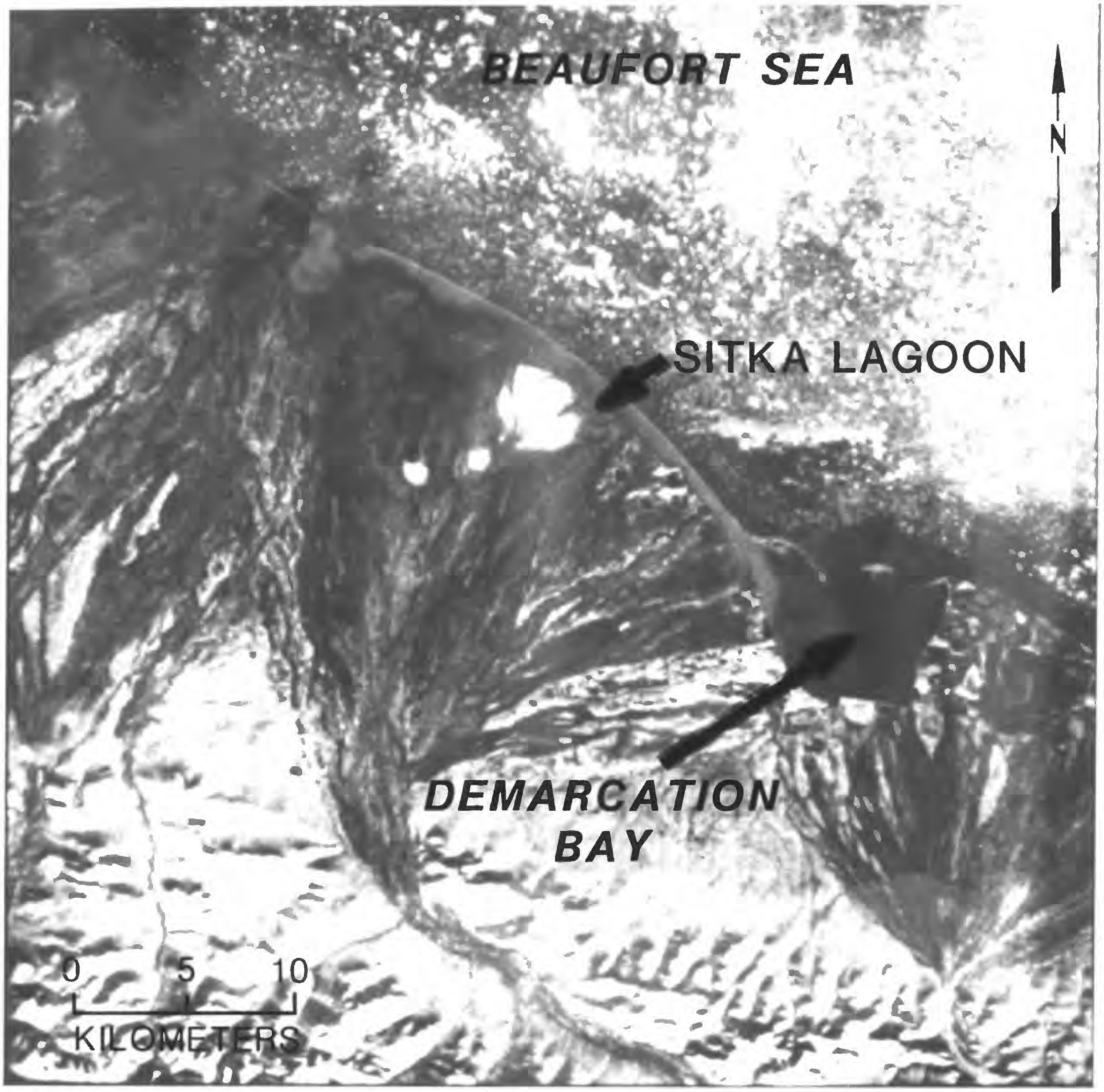


FIGURE 26. LANDSAT imagery of Demarcation Bay, adjacent fans, and barrier islands.

reflector 4 was eroded away at some time prior to accumulation of Holocene sediment. These data suggest that at a lower stand of sea level, the Canning River incised into the fan-delta, cut away at the old erosion surface, and then backfilled as sea level rose.

Surfaces 1 through 4 all have seaward dips. Fan slopes and features that appear to be delta top-set beds in the subsurface from the coast to beyond the island chain have dips varying from 2 to 13 minutes (Fig. 24). Foreset slopes in the subsurface, and surface slopes near the knickpoint have dips of 24 to 36 minutes whereas slopes in the pro-delta sequences offshore are approximately 2 to 5 minutes. These slopes are similar to those of other deltas (Coleman and Prior, 1980). Even the 17 minute delta front slope of the modern Canning River delta bulge in Camden Bay fits well.

In the three north-south profiles of figure 24, landward projections of surfaces 3 and 4 would intercept the present fan surface. This suggests that the present surface may be a very old surface that has experienced multiple cycles of erosion and progradation. The knickpoints themselves, suggest that perhaps at least three major episodes of progradation have occurred, one of which is the subsurface delta defined by seismic stratigraphy.

approximately 7-1/2 meters altitude of Tigvariak and Flaxman Islands, the isolated high areas on the present coastal plain, and the 7-1/2 meter knickpoints just described are a rather striking set of data points. If meaningful, this correlation implies that there may have been a regional fluvial or deltaic plain at a 7-1/2 m elevation and that the relief we see today is all that is left after severe periods of excessive erosion and little deposition. In fact, it appears that the only deposition occurring today is in the quiet lagoons and at the mouths of some rivers.

Figure 27 is a generalized cross section from the Canning fan-delta northward through Flaxman Island and borehole 18. Sedimentary sequences between the fan-delta and Flaxman Island are rather flat lying whereas those north of the island steepen seaward toward borehole 18. The section illustrates the flat lying sequences as topset units and the seaward sequence as delta-front units in a deltaic system. The loose gravels under Flaxman Island are overlain by micaceous shales and siltstones whereas corresponding sediments throughout borehole 18 are mixtures of sandy and clayey silts. The fine-grained sequence that overlies the gravels suggests a depositional history of low terrigenous influx during a transgressive rise in sea level (Vail and others, 1977). The Flaxman Formation likewise is flat lying and rests on the fine-grained topset sequence. Overlying the Flaxman Formation is a non-marine sequence consisting of eolian and coastal plain sediments which contain thaw lake deposits (L. David Carter, oral commun., 1985). The dashed line connecting the top of Flaxman Island with the coastal plain to the south represents the surface of the hypothetical, formally broad fluvial-deltaic plain. Excessive erosion has, for the most part, destroyed this surface leaving Flaxman and Tigvariak Islands, coastal plain highs, and the low relief barrier islands as remnants. Based on all data presented, this illustration depicts one large fluvial-deltaic system consisting of the Canning fan-delta, associated barrier islands, and the subsurface delta.

Earlier discussion focused on the Flaxman Formation, as identified in borehole 18, projecting southward and equivalent to the Flaxman Formation outcrop on Flaxman Island and in the coastal bluffs to the south. The top of the Flaxman Formation is bounded by an unconformity and the base of the unit is thought to be likewise (L. David Carter, oral commun., 1985). In all areas where the formation is known to outcrop, it does so at or near sea level and is thought to be only a few meters thick. This suggests that the unit was deposited on a very broad, nearly horizontal, erosional surface. Assuming this to be true, it would be theoretically impossible to project the Flaxman Formation from Flaxman Island into borehole 18 because to do so would require that the Flaxman extends as a continuous unit diagonally through an unconformity. The unit described in borehole 18 as "Flaxman," (Kris McDougal, 1982) has been shown to be a part of the subsurface delta described earlier and thus rests below the unconformity at the base of the "Flaxman" on Flaxman Island. This line of reasoning suggests that the "Flaxman" cannot be found in borehole 18 and that the topographic highs and barrier islands are remnants of a fluvial or deltaic plain

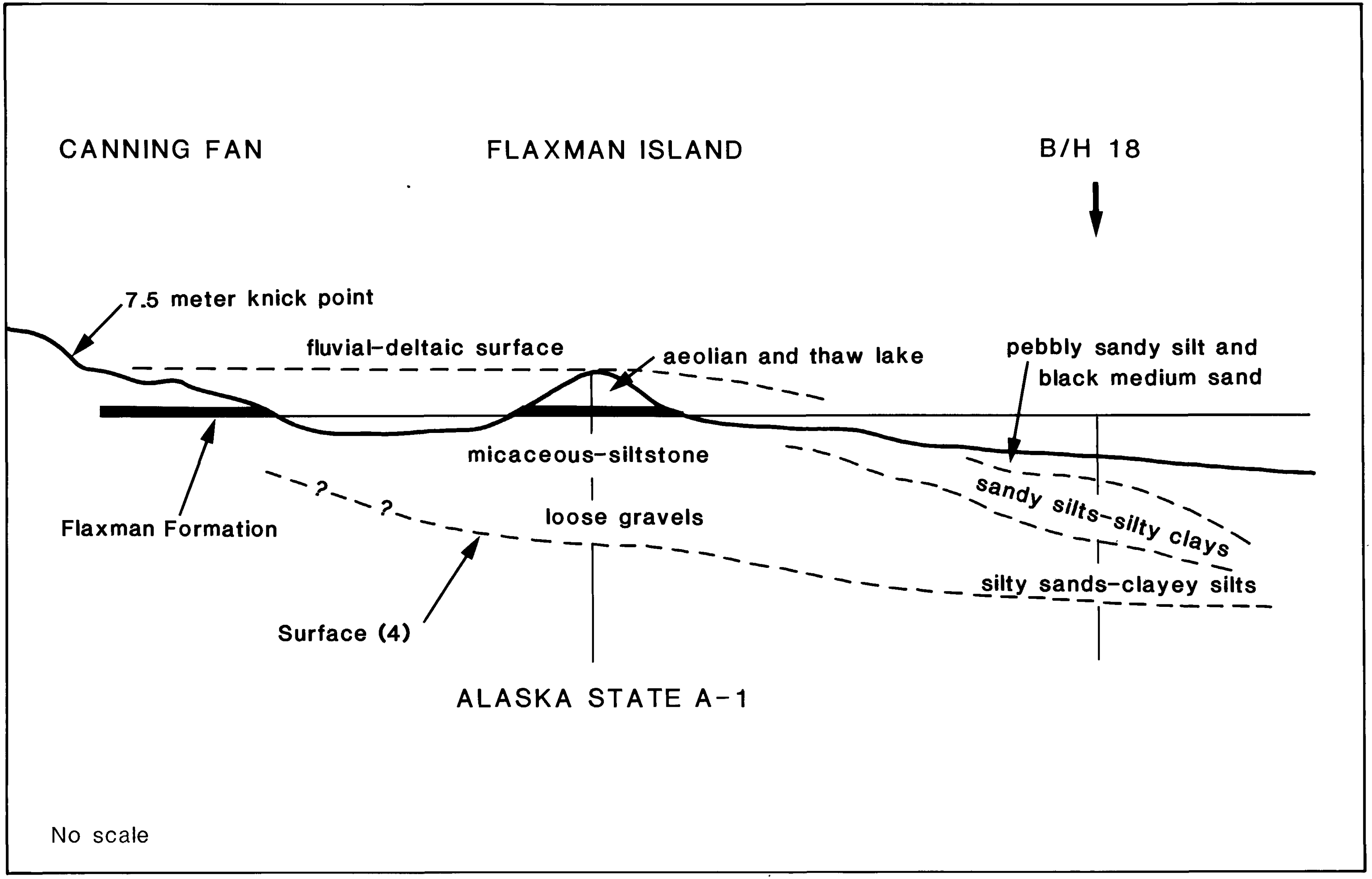


FIGURE 27. Generalized cross section from Canning River Fan-Delta through Flaxman Island to borehole 18.

which is not related to the subsurface delta. In essence two progradational sequences are separated by the Flaxman Formation. Additionally, it is suggested that no "Flaxman" will be found below the lagoonal floors or offshore because the "Flaxman" at or near sea level has been eroded away.

The Boulder Patch, the pebbly unit at the top of borehole 18, and other similar deposits are essentially lag deposits of the eroded Flaxman Formation. These lag deposits will continue to be located near the seafloor as the finer grained sediments below them are removed from the area by erosion.

Based on this analysis and data described earlier, there appear to be five unconformities, 1) surface 3; 2) surface 4; 3) bottom of the Flaxman Formation; 4) top of the Flaxman Formation; and 5) the present sea floor and isolated areas within the lagoons. Transgressive sequences are represented by the large progradational subsurface delta and the Flaxman Formation. The uppermost fluvial-deltaic plain (?) represents a non-marine progradation over "Flaxman" deposits perhaps occurring during a period of high terrigenous influx (Vail and others, 1977) to the area followed by an excessive erosional cycle. An important consideration is that the "Flaxman" is a marine mud accumulation into which "Flaxman boulders" have been deposited and should not be considered to be of deltaic origin (L. David Carter, oral commun., 1985). This point supports reasoning that discounts the presence of "Flaxman" in borehole 18, except perhaps as a lag deposit at or near the sea floor, and provides an environment for quiet deposition of a marine mud, represented by "Flaxman," upon a flat erosional surface which caps an older deltaic sequence which abuts into an ancestral subaerial Canning fan to the south of present Flaxman outcrops along the coast.

Other conclusions can be drawn from all the data presented in this report. They are as follows:

(1) Bonded permafrost throughout the area was not observed on the seismic records. Borehole data indicated permafrost at, above ', or below surfaces 3 and 4 at various locations (Harding-Lawson Assoc., 1979). Using a sound velocity of approximately 1800 m/sec made reasonable correlation of acoustic reflectors with borehole stratigraphy possible. One can conclude therefore that if permafrost does exist in the stratigraphic section described, it has little or no influence on the seismic interpretations.

(2) Geohazards related to slumping and faulting are essentially nonexistent. On seismic records, internal deformation was noted during deposition of what was thought to be the "Flaxman Formation" in borehole 18. This unit and other possible slumping occurrences are at subsurface depth and are related to pre-Holocene deposition and, therefore, are considered to be inactive. Unstable sediments may be encountered in the lagoonal accumulations interpreted to be Holocene deposits. The relatively uniform seaward gradients of surfaces 3 and 4 and the regional parallelism of surface contours to the present coastline suggest that the entire area has been relatively stable throughout the period since the formation of surface 3 and, therefore, deformation or warping of the stratigraphic section is minimal to nonexistent. Gas anomalies were not readily observed throughout the area, but this should not rule out the presence of gas.

(3) Economic gravel deposits probably do not exist. Gravel deposits are known to be present below the Maquire and Flaxman Islands and below the Canning River Fan onshore. These deposits, however, are subsurface and not readily accessible. For the most part, the superficial sediments are fine-grained sands and silts. Gravels or pebbly units near the sea floor are more than likely lag deposits and do not reflect gravel accumulations below. Cut and fill channels described in the area characteristically contain sands and fine-grained deposits associated with minor amounts of gravel.

(4) Historically it appears that after each transgression, i.e., the subsurface delta and the "Flaxman," an extended period of erosion occurred that destroyed much of the sediments that were deposited. If the non marine fluvial-deltaic plain at the top of the stratigraphic sequence had marine depositional counterparts on the inner shelf, the present erosional cycle has removed them completely, is destroying the fluvial-deltaic plain, is incising into the subsurface delta, and reflects a period of erosion of greater intensity than most previous cycles.

(5) Holocene deposits in the lagoons contain reflectors within the section above the pre-Holocene surface. Holocene sediment offshore, if present, should also have reflectors like those on other shelves, however, ice gouging and intermixing by ice processes may destroy their basic characteristics. As an end result, offshore Holocene sediment may actually appear to be homogenous and acoustically transparent. The base of this homogenous sequence may reflect the maximum depth to which ice gouging has been active in Holocene time. This basal surface may in fact be, in part, a mechanically formed surface as a result of subsurface smearing by ice keels as they passed through the area.

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APPENDIX - Trackline dates, 1971 - 1982

Year	Month	Day	JD	Line	Uniboom (Minisparker)	Roll #	7 kHz	Roll #
1982	Sept	18	261	20	--	--	1102-1126	11
1982	Sept	1	244	6	1147-1520	1	1302-1520	3
1982	Sept	2	245	7	1404-1533	2	--	--
1982	Sept	5	248	10	1545-1655	3	--	--
1982	Sept	7	250	12	1500-1815	3	--	--
1981	July	19	200	5	1335-1740	1	1335-1740	2
1981	July	19	200	6	--	--	1757-1830	2
1981	July	20	201	7	--	--	0813-0830	3
1981	July	20	201	8	--	--	0830-1150	3
1981	July	27	208	16	1153-1415	5	1153-1415	12
1981	July	28	209	17	--	--	1509-1640	12
1981	July	29	210	18	1250-1520	5	1250-1520	13
1981	July	30	211	20	--	--	0845-1110	14
1980	July	19	201	1	--	--	1245-1530	2
1980	July	27	209	12	--	--	0819-1115	8-9
1980	July	28	210	13	1130-1520	4	1220-1520	9
1980	July	28	210	14	1520-1638	4	1520-1638	9-10
1980	July	30	212	15	--	--	0850-1435	10-11
1980	Aug	9	222	24	--	--	1659-1814	17
1980	Aug	11	224	25	--	--	1618-1701	17
1980	Aug	12	225	26	0923-1332	5	0923-1332	18
1979	July	23	204	1	(1709-1752)	1	1709-1752	1
1979	July	29	210	5	--	--	1259-1450	3
1979	Aug	1	213	8	--	--	1526-1558	5
1979	Aug	9	221	14	1600-1727	1	--	--
1979	Aug	9	221	15	(1818-1900)	1	--	--
1979	Aug	9	221	17	(2043-2138)	1	--	--
1979	Aug	10	222	19	1323-1505	1	--	--
1979	Aug	10	222	20	(2126-2206)	2	--	--
1979	Aug	12	224	26	0714-0835	3	--	--
1979	Aug	12	224	27	0918-1052	3	--	--
1979	Aug	12	224	28	1127-1155	3	--	--
1979	Aug	12	224	29	1536-1800	4	--	--
1979	Aug	13	225	30	1401-2100	4	--	--
1979	Aug	15	227	35A	--	--	1523-1618	10b-11
1979	Aug	16	228	35B	1430-2148	5	--	--
1979	Aug	17	229	36	1209-1444	5	--	--
1979	Aug	18	230	38	1935-2145	5	--	--
1979	Aug	19	231	39	1613-2008	5-6	1613-2008	12

1979	Aug	20	232	40	--	--	0827-0850	12
1979	Aug	20	232	41	--	--	1139-1235	12
1979	Aug	25	237	43	--	--	1239-1345	13
1979	Aug	26	238	44	--	--	1505-1730	13
1979	Aug	26	238	45	--	--	2049-2146	14
1979	Aug	27	239	46	--	--	1229-1345	14-15
1979	Aug	27	239	47	--	--	1353-1508	15
1979	Aug	27	239	48	--	--	1535-1647	15
1979	Aug	29	241	50	--	--	1044-1154	16
1979	Sept	1	244	54	0853-1026	7	0853-1026	18
1979	Sept	1	244	55	(1027-1125)	7	1027-1125	18
1979	Sept	1	244	56	1321-1520	7	1321-1520	18
1979	Sept	1	244	57	(1545-1616)	7	1545-1616	18
1979	Sept	1	244	58	1645-1452	7	1645-1452	18-19
1979	Sept	1	244	59	(2018-2055)	7	2018-2055	19
1979	Sept	2	245	60	0824-1440	7-8	0824-1440	19-20
1979	Sept	2	245	61	1445-1713	8	1445-1713	20
1979	Sept	3	246	62	1447-1535	8	1447-1535	20
1979	Sept	3	246	63	1617-2037	.8	1617-2037	21
1979	Sept	5	248	66	1120-1810	9-10	1120-1810	22-23
1979	Sept	6	249	67	0830-1520	10	0830-1520	23
1979	Sept	8	251	69	0816-1440	10	0816-1440	24
1979	Sept	9	252	71	0734-0938	10	0734-0938	24
1979	Sept	9	252	72	0942-1027	10	0942-1027	25
1979	Sept	10	253	77	0920-1215	11	0920-1215	27
1979	Sept	10	253	78	1215-1402	11	1215-1402	27
1979	Sept	10	253	79	1431-1614	11	1431-1614	28
1979	Sept	11	254	82	(1220-1257)	12	1220-1257	29
1979	Sept	11	254	83	(1313-1726)	12	1313-1726	29-30
1979	Sept	11	254	84	(1727-1937)	12	1727-1937	30
1979	Sept	11	254	85	(1937-2110)	12	1937-2110	30
1979	Sept	18	261	88	--	--	1213-1318	32
1979	Sept	20	263	92	1414-1910	13	1414-1910	33
1979	Sept	20	263	93	--	--	1938-2135	34
1979	Sept	21	264	94	--	--	0905-1515	34-35
1979	Sept	21	264	95	--	--	1521-1614	35
1979	Sept	21	264	96	--	--	1630-1720	35
1979	Sept	23	266	99	--	--	0750-1000	36-37
1979	Sept	23	266	100	--	--	1116-1452	37
1978	Aug	29	241	21	--	--	1557-1730	11
1978	Aug	30	242	24	--	--	0715-1230	11-12
1978	Aug	30	242	25	--	--	1530-1625	12
1978	Aug	31	243	27	1108-1255	3	1108-1255	12-13
1978	Aug	31	243	28	1345-1437	3	1345-1437	13
1978	Aug	31	243	29	--	--	1754-1915	13
1978	Sept	1	244	30	--	--	0855-1130	13
1978	Sept	13	256	37	--	--	0848-2000	18-19
1978	Sept	14	257	38	--	--	0724-0930	20
1978	Sept	14	257	39	--	--	1252-1435	20

1978	Sept	14	257	40	--	--	1540-2015	20
1978	Sept	15	258	41	--	--	0730-1240	21
1978	Sept	16	259	43	--	--	0954-1046	23
1977	Sept	19	262	74	--	--	0737-1145	31
1977	Sept	19	252	75	--	--	1430-1745	31
1977	Sept	21	264	76	0913-1933	9-10	0913-1933	32-33
1977	Aug	23	235	53	--	--	1400-1509	17
1977	Aug	23	235	54	--	--	1700-1825	18
1977	Aug	24	236	55	--	--	1557-1625	18
1977	Sept	8	251	66	1441-2040	5-6	1441-2040	24-25
1977	Sept	9	252	67	1148-2020	6-7	1148-2020	25-26-27
1976	July	24	205	1	--	--	1340-1450	1
1976	July	24	205	2	--	--	1500-1610	1
1976	July	24	205	3	--	--	1615-1730	2
1976	July	27	208	15	--	--	0940-1318	3
1976	July	27	208	16	--	--	1548-1727	3
1976	Aug	14	226	34-37	West Dock Sur. 7 kHz			
1976	Aug	16	228	40	--	--	0742-0844	12
1975	Sept	2	245	2	1205-1820	11	--	--
1975	Sept	8	251	7	--	--	1240-1348	10
1975	Sept	11	254	8	--	--	1101-1456	11
1975	Sept	5	248	3	1155-1730	11	1155-1730	9
1975	Sept	5	248	4	1753-2000	12	1753-2000	9
1973	Aug	20	232	6	1642-1730	--	--	--
1973	Aug	20	232	7	1735-1915	--	--	--
1973	Aug	20	232	8	1923-2240	--	--	--
1973	Aug	21	232	9	0858-1215	--	--	--
1973	Aug	21	232	10	1217-1500	--	--	--
1973	Aug	21	232	11	1734-1837	--	--	--
1973	Aug	22	233	12	0752-1100	--	--	--
1973	Aug	22	233	13	1224-1619	--	--	--
1973	Aug	22	233	14	1619-1926	--	--	--
1973	Aug	23	234	15	0720-0920	--	--	--
1973	Aug	23	234	16	0920-1340	--	--	--
1973	Aug	23	234	17	1340-1455	--	--	--
1972	July	17	198	1	1415-1600	--	--	--
1972	July	17	198	2	1700-1855	--	--	--
1972	July	18	199	3	1121-1222	--	--	--
1972	July	18	199	4	1700-2150	--	--	--
1972	July	19	200	5	1333-1625	--	--	--
1972	July	19	200	6	1740-2155	--	--	--
1972	July	20	201	7	1003-1250	--	--	--
1972	July	20	201	8	1743-1850	--	--	--
1972	July	21	202	10	1248-1607	--	--	--

1972	July	22	203	11	0935-1235	--	--	--
1972	July	22	203	12	1341-1506	--	--	--
1972	July	23	204	13	0958-1105	--	--	--
1972	July	23	204	14	1400-1813	--	--	--
1972	July	24	205	15	0928-1315	--	--	--
1972	July	27	208	16	0842-1615	--	--	--
1972	July	--	--	17-20	Nav. chart missing			
1972	July	31	212	21	1745-2045	--	--	--
1972	Aug	1	213	22	1000-1527	--	--	--
1971	Sept	2	245	12	(0610-0722)	--	--	--
1971	Sept	2	245	13	(1605-2025)	--	--	--
1971	Sept	4	247	14	(0618-0949)	--	--	--
1971	Sept	4	247	15	(1602-1732)	--	--	--
1971	Sept	4	247	16	(1740-1904)	--	--	--
1971	Sept	4	247	17	(1905-1937)	--	--	--
1971	Sept	5	248	18	(1654-1725)	--	--	--
1971	Sept	5	248	19	(1729-1737)	--	--	--
1971	Sept	5	248	20	(1738-1822)	--	--	--
1971	Sept	5	248	21	(1823-1836)	--	--	--
1971	Sept	5	248	22	(1836-1918)	--	--	--
1971	Sept	6	249	25	(0830-0904)	--	--	--
1971	Sept	6	249	26	(1217-1420)	--	--	--
1971	Sept	6	249	28	(1553-1925)	--	--	--
1971	Sept	6	249	29	(1936-2029)	--	--	--
1971	Sept	12	255	45	(0712-0850)	--	--	--
1971	Sept	12	255	46	(0856-1030)	--	--	--
1971	Sept	13	256	47	(1031-1305)	--	--	--