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BATHYMETRIC AND SHORELINE CHANGES NORTHWESTERN PRUDHOE BAY, ALASKA

By

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INTRODUCTION

The coastal environment in the vicinity of Prudhoe Bay, Alaska (Fig. 1) is presently being vigorously utilized by petroleum activities. In particular, barges moving freight onshore over the past 8 years, have used the Prudhoe Bay entrance channel almost exclusively. To further facilitate the offloading of supply barges, Atlantic Richfield Company constructed a gravel fill causeway in 1975 between the Prudhoe Bay channel and Stump Island (Fig. 1). As initially constructed, the causeway extended 1.3 km perpendicular to the coast. Subsequently the causeway was extended 1.5 km in a northwesterly direction during the winter of 1975-76 to facilitate the offloading of barges stranded during the fall of 1975.

During July and August of 1976 the R/V KARLUK ran a series of sounding lines across the Prudhoe Bay entrance channel and in the vicinity of the new causeway west of the channel (Fig. 1). A skiff was also used to run lines between Stump Island and the causeway. This data compared with the detailed coastline and nearshore bathymetry from the U.S. Coast and Geodetic Survey smooth sheet (7857) and 1970 U.S. Geological Survey orthophotos, allow us to determine qualitative changes in bathymetry and coastal configurations. Such a comparison provides a baseline to assess natural and man-related changes since 1950.

In addition to the long term variation of bathymetry, knowledge of whether bay and lagoon entrances in the arctic are blocked by fast ice during the course of the winter is of great importance for our attempts to evaluate the modern shallow water environments in the Beaufort Sea. Since the fast ice generally attains a thickness of about 2 meters (6 ft.), one might assume that shallow connections between the open ocean and bays or lagoons are sealed off sometime during the winter. Our studies in Gwydyr Bay and published reports (Schell, 1974), show that salinities below the ice can be twice as high as those in the open ocean. We have also found that the temperature of the high salinity water may be on the order of -5°C. These facts would indicate that the shallow bodies of water indeed are isolated from the ocean. Before the isolation is completed, dense water may spill from the embayment of the lagoon, and flow seaward. The implications are important for the potential dispersal of pollutants, for example.

METHODS

U.S. Coast and Geodetic Survey smooth sheet 7857 was used to derive the 1950 bathymetry. The field data for this sheet was gathered in 1950 at 1:20,000 with trackline spacing of 300 m or less. Soundings were reported to the nearest foot below mean lower low water. As these early charts and our sounding instruments reported in English units, for ease and consistency, we have not interpolated to metric and will use English units for bathymetric measurements in this report (1 m = 3.28 ft).

During the 1976 survey, depths were measured to the nearest 0.1 foot, but were uncorrected for sound velocity, tidal or sea level differences. At the shallow depths (less than 10 ft) in this survey, sound velocity corrections are inconsequential. The tidal range is normally about 0.5 foot, with wind setup and setdowns of several feet during storms. Winds during this survey were not above 10 knots, and were from the northeast which causes a sea level set down. Line crossing from different times during the summer agreeed within 0.3 foot. Thus the 1976 data measured greater depths than the 1950 survey reported but the difference is less than one foot and probably less than 0.5 foot.

Line spacing for the 1950 survey was on the order of 300 m and during the 1976 work the spacing varied greatly (Fig. 1). Sallinger and others (1975) indicated the horizontal control for Coast and Geodetic Survey Charts of the scale used should be less than 50 m. Our navigational control was achieved using a range-range system giving a position accuracy of 20 m or better considering the system errors and the errors involved in locating the shore stations. Thus a detailed comparison of the absolute depth values of the 1976 survey with the 1950 survey is inappropriate, however, the changes in position and form are probably real.

Coastal configuration comparison was based on the 1950 smooth sheet coastline and the 1970, 1:20,000 U.S. Geological Survey Orthophoto maps of the area. The datum for the two surveys was based on mean lower low water and mean sea level respectively. Considering the small tidal range and the fact that the beaches are only a few meters wide, backed by 2 to 3 meter bluffs, and that the island foreshores are rather steep, the absolute difference between the two datums will amount to only a few meters or less.

Atlantic Richfield Company kindly permitted the use of data gathered for them on the thickness of the fast ice and the depth of the water beneath the ice in a reconnaissance study of the channel done in May and June of 1969. This data should closely represent conditions during the maximum thickness of the fast ice during the year. The report contains measurements of ice thickness and bottom depth along a track paralleling the axis of the channel (Fig. 1) and on cross-sections perpendicular to the axis. The initial survey of the axis and cross-sections was conducted in May using the top of the ice as the datum. The axial trackline was resurveyed in early June using the Prudhoe Bay benchmark as datum, which takes into account the irregular topography of the ice surface. When the correction for the datum level was made for the May data, the three sets (2 axis profiles and 1 cross-section profile) of ice thickness and depth curves agreed within .25 foot except for one point which seems to be in error.

RESULTS

Prudhoe Bay Channel

The most apparent bathymetric changes which have occurred in the 26-year interval between the 1950 and 1976 surveys, are the relative depth and location of the channel (Figs. 2 and 3). Within this time interval, the axis of the deepest part of the channel has shifted shoreward 50 to 175 m, the greatest onshore movement occurring near the midpoint of the channel. In addition to the onshore movement, the channel has been displaced seaward along with the shallows on either side of the channel, as evidenced by displacement to the northwest of the 1976 4-foot contour relative to its location in the 1950 contour.

Depth of the channel axis is 1 to 1.5 feet greater in 1976 than in the 1950 data. The 1976 fathograms also show local depressions up to 8 feet in depth. These deep holes may be related to seasonal changes in the maximum depth of the channel or to propellor wash from barge traffic. The 2-foot shoal in the central section of the channel has remained since the 1950 survey.

The study of the channel conducted in May and June of 1969 states that a general description of the channel would be approximately 4 feet of ice on top of 2 feet of water. This is significantly less ice than the normal 6-8 feet (2 m) seasonal ice growth found elsewhere. Using the data for the depth to the bottom and the ice thicknesses calculated from the drill hole logs, an isopach map of the thickness of water beneath the ice in the channel was constructed which showed water beneath the ice in all parts of the channel (Fig. 4). The assumption was made that the ice bottom was essentially flat along the length of the cross sections perpendicular to the channel axis.

The greatest water gap beneath the ice in the channel is three feet, and the least is 1.5 feet. This would indicate that water should have been able to flow in and out of Prudhoe Bay throughout the winter of 1968-1969 via this sub-ice channel although the pathway is much restricted compared to that of the open season.

Causeway and Vicinity

A comparison of the 1950 and 1976 bathymetry shows a number of marked changes in bathymetry in the vicinity of the causeway. The 6, 7, 8 and 9 foot contours on the east side of the causeway are displaced shoreward up to several hundred meters (Figs. 2 and 3). Southeast of the causeway, towards the entrance channel, the 4 and 5 foot contours are displaced offshore from the 1950 data.

Along the northeast side of the causeway extension our fathograms indicate a very irregular and disturbed bottom with depths of 3 to 15 feet. Field observations suggest that in part these features are due to dredging operations during causeway construction and completion. Furthermore, the aerial photographs show that the intense tug and barge activity in October, 1975 during freeze-up occurred along a corridor just to the northeast of the causeway extension. Propellor wash during this period could have created cut and fill structures.

Stump Island Area

Stump Island has undergone dramatic changes in shape and position during the twenty-year interval. The Island has moved onshore (southwest) 75-100 meters while both ends have extended in a northeasterly direction. In effect, this has changed the shape from lunate to almost linear. In addition, the area of the island has increased about 120,000 square meters between 1950 and 1970 (Figs. 2, 3, & 4).

The eastern tip of Stump Island has moved approximately 275 meters to the northeast of its 1950 location. The 1976 location from our studies and the 1970 location of the island terminus from U.S. Geological Survey orthophoto maps are essentially the same, indicating that the changes occurred prior to 1970 and that this end of the island has been essentially stationary since 1970. Our bathymetric survey crossed a shoal of less than 2 feet somewhere east of the present end of the island at a position which coincides with the 1950

Considering the earlier work on the movement of islands and spits on the Arctic Coast (Short, A.D., 1973; Barnes and others 1976) the onshore movement of Stump Island is to be expected. However, the earlier reports and our own data show that these islands typically migrate in a westerly direction as exhibited by the westward extension of Stump Island. The enlargement and offshore movement of the eastern spit is unique. Perhaps the funneling of water from occasional westerly storms down the coastal lagoon system, which extends some 50 km westward, has operated to maintain the eastern extremity of Stump Island.

Data from the 1950 survey did not cover much of the inshore area southwest of the causeway and across the eastern entrance to Gwydyr Bay, thus changes in this region cannot be evaluated. Our data shows a channel in excess of 5 feet deep along the mainland side of the channel between Stump Island and the coast. This channel shoals to the east and probably shoals to the west in Gwydyr Bay as we know this end of the bay is impassable to a vessel of 4-foot draft.

Coastal Erosion

A comparison of the 1950 and 1970 coastlines shows erosional changes on the mainland coast along with the marked change in the configuration of Stump Island (Fig. 4). The northeast-facing coasts east of Gwydyr Bay have been eroded up to 60 meters. The most pronounced erosion occurs at Point McIntyre. From here eastward the coast is uniformly eroded from 10 to 20 meters. Rates of erosion calculated for the 20-year interval range up to more than 3 meters per year, but average about 1 meter per year. Within Gwydyr Bay erosion has been restricted to the coastal promintory west of Point McIntyre. On this point maximum coastal retreat of 50 meters was measured.

The coastal retreat reflects the pattern of dominant winds and waves. On the exposed coast east of Point McIntyre, erosion is noted all along the coast while within the protected environment of Gwydyr Bay only the coastal promintory exposed to the considerable fetch of westerly waves has marked erosion. It is interesting to note erosion even in the region of coast somewhat protected by Gull Island shoal. Coastal retreat in the lee of the new causeway will probably decrease.

DISCUSSION

Prudhoe Bay Channel

The onshore movement of the channel axis is probably a result of the coastal retreat and the southwestward extension of the Gull Island shoal under the influence of the dominating northeasterly winds and waves. Apparently, however, the channel has moved more than the coastline has retreated. Furthermore, there is an apparent shoaling of the channel during the open water season. Personnel of the tug and barge operations report that the channel seems to become more difficult to traverse as the open water season progresses (July to September) due to shoaling. During the 1976 season with the KARLUK we noted that in late July and early August we could transit the channel easily with a draft of 4 feet, while in late September, even lightly loaded (3.5 foot draft), we had to grind along the bottom over much of the central portion of the channel.

One possible explanation for these changes is apparent when the entire yearly cycle of events is considered. During the fall and early winter when the sea ice canopy is growing in thickness, tidal and barometric changes in sea level must move in and out of Prudhoe Bay through smaller and smaller cross sections. Ultimately, when Gull Island shoal and the openings between Gull Island and Heald Point are sealed off by bottom fast ice, the only opening remaining for the flow of water in and out of the bay is the entrance channel. Data taken from channel cross sections by drilling through the ice in May and June, show that the channel may be hydraulically maintained all year below the ice (Fig. 4). The shallowest section of the channel in this survey was 5.5 feet. Thus each spring the channel could be scoured to a depth somewhat near the thickness of the seasonal ice cover (about 6 feet).

During the open-water season, the prevailing northeasterly winds and waves would tend to move sediments from the Gull Island shoal into the channel.

This would explain the shoaling noted by the tug and barge operators and the shallower depth of the August 1950 Survey of the Coast and Geodetic Survey. Our 1976 channel survey was accomplished in late July right after the ice had cleared and would explain why we observed a deeper channel. The southwesterly extension of the Gull Island shoal is further evidence that sediments are moving onshore. With the onset of freezeup, channel scour would be initiated with the newly infilled sediments being the most susceptible to erosion.

Coastal Erosion

The predominant winds and waves during the open water season on the arctic coast are from the northeast. Elsewhere along the coast this has resulted in longshore drift to the west as seen in the westward movement or extension of insular spits on many of the coastal islands (Short, A. D.,1973; Barnes and others, 1976) Furthermore, the eastern parts of these same islands show erosion. The rare late summer and fall storms usually are accompanied by westerly winds and a significant rise in sea level (up to 3 meters in 1970).

In the area of this study, longshore transport and accompanying erosion have been noted. At the dogleg in the causeway, sheet piling and weighted barrels are being used to retard and prevent erosion on the eastern side. Further inshore The Alaska Department of Fish and Game personnel experienced burial of their fish trap due to longshore transport of gravel (T. Bendock, pers. commun.).

Coastal erosion along the north coast of Alaska is a result of permafrost degradation of the low 1 to 3 meter high tundra bluffs. Rates of erosion are commonly around 1 meter per year with the greatest erosion occuring on headlands and the eastern ends of the offshore islands where rates of 10 to 40 meters per year have been reported (Short, A.D., 1973; Lewellen, R., 1970). The values we report here of up to 2.5 meters per year average for the 20-year interval between 1950 and 1970, are in keeping with the earlier observations. Furthermore, the northeast facing shores appear more susceptible to erosion from the prevailing northeasterly wind, even though these winds are not associated with the meteorological rise in sea level.

Conclusions:

1. The Prudhoe Bay channel is migrating shoreward at 1-2 meters per year and possibly experiences seasonal infilling and erosion which results in open season variations in channel depth.

2. Coastal retreat under the influence of the northeast winds averages 1-2 meters per year but may average more than 3 meters.

3. The construction of the causeway and the attendant ship traffic is affecting the bathymetry in the immediate vicinity, although it is too soon to see any established trends.

4. Stump Island has moved onshore and has undergone an apparently episodic change resulting in an increase in size and change in shape.

5. The nearshore environments in this area are influenced by long and short term changes in coastal configuration, bathymetry and island morphology which are and will continue to be influenced by man's activities.

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Short, A. D., 1973, "Beach dynamics and nearshore morphology of the Alaskan arctic coast," Unpublished Ph.D. dissertation., Louisiana State Univ. Baton Rouge, LA., 140 p.

Figure Captions

Figure 1. Location and trackline map showing the location of the study area of this report and the tracklines occupied in July and August, 1976. Section A-A' is the channel survey line occupied by the industry survey in 1969.

Figure 2. Bathymetric contours from the 1950 survey east of Stump Island, U.S. Coast and Geodetic Survey smooth sheet 7857. Contours at one foot increments.

Figure 3. Bathymetric contours from the 1976 U.S. Geological Survey KARLUK data. The inner causeway segment was constructed in spring 1975 and the outer segment in the winter of 1975-76. Contours at one foot increments.

Figure 4. Isopach map in feet of the water beneath the ice in late May 1969. The + indicate the bore holes and the center lines for the channel cross sections from the industry report.

Figure 5. Coastal erosion and Stump Island re-configuration from 1970. 1950 data from U.S. Coast and Geodetic Survey smooth sheet 7857. 1970 data from U.S. Geological Survey Orthophoto map, Beechy Point B-4 NW, Scale 1:20,000. The coastal retreat and changes in island morphology from 1950 to 1970 are shown as solid black.

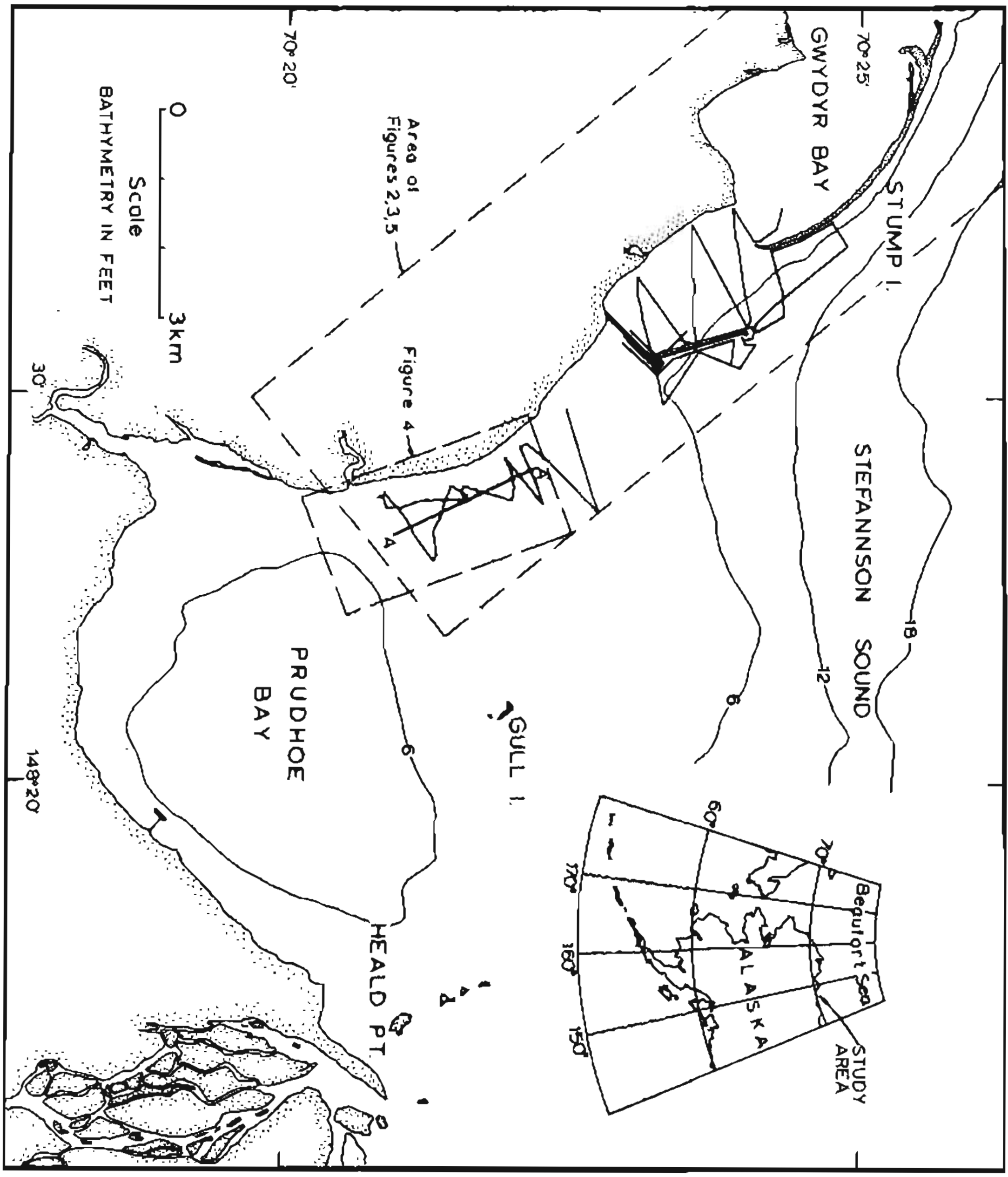
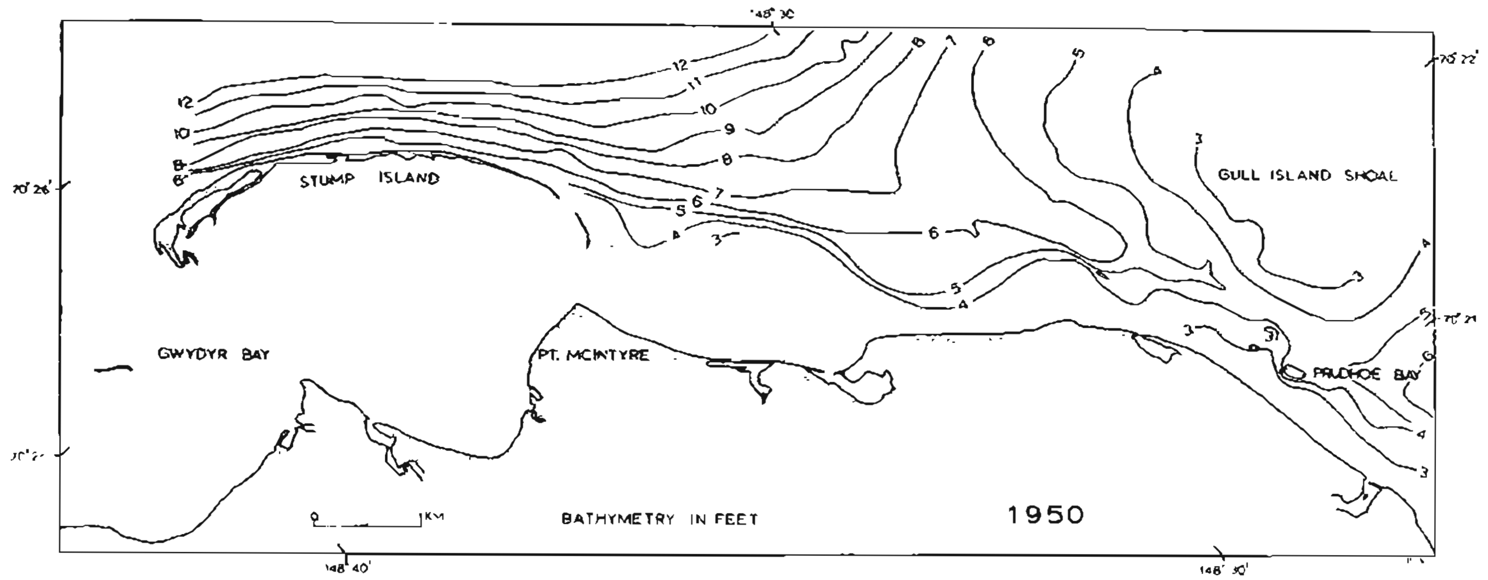
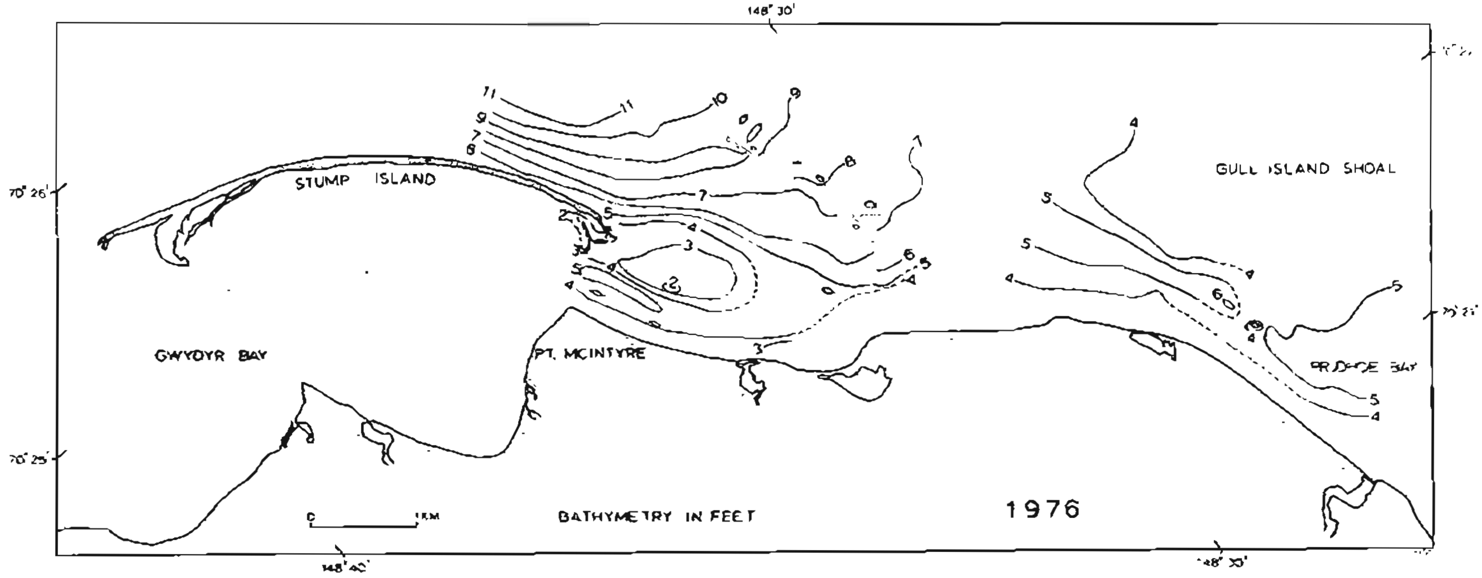

70°25'
GWYDYR BAY
STUMP I.
STEFANNSON SOUND
70°20'
Area of Figures 2,3,5
Figure 4
4
0
3km
Scale
BATHYMETRY IN FEET
30'
148°20'
18
12
6
6
GULL I.
PRUDHOE BAY
HEALD PT.
Beaufort Sea
ALASKA
STUDY AREA
70°
60°
170°
160°
150°

Figure 1



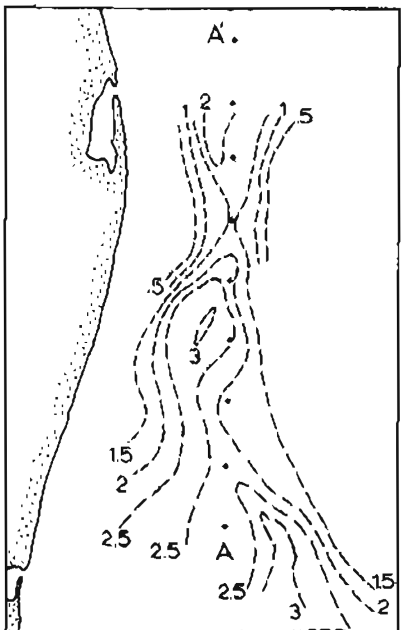
148° 30'
70° 22'
70° 26'
70° 21
GULL ISLAND SHOAL
STUMP ISLAND
GWYDYR BAY
PT. MCINTYRE
PRUDHOE BAY
12
11
10
9
8
7
6
5
4
3
0
1KM
BATHYMETRY IN FEET
1950
148° 40'
148° 30'

Fig 2



148° 30'
70° 26'
70° 25'
GULL ISLAND SHOAL
STUMP ISLAND
GWYDYR BAY
PT. MCINTYRE
PRUDHOE BAY
11
10
9
8
7
6
5
4
3
2
0
1KM
BATHYMETRY IN FEET
1976
148° 40'
148° 30'

Fig 3



ISOPACH MAP OF WATER UNDER FAST ICE, IN FEET LATE SPRING 1969

Fig 4

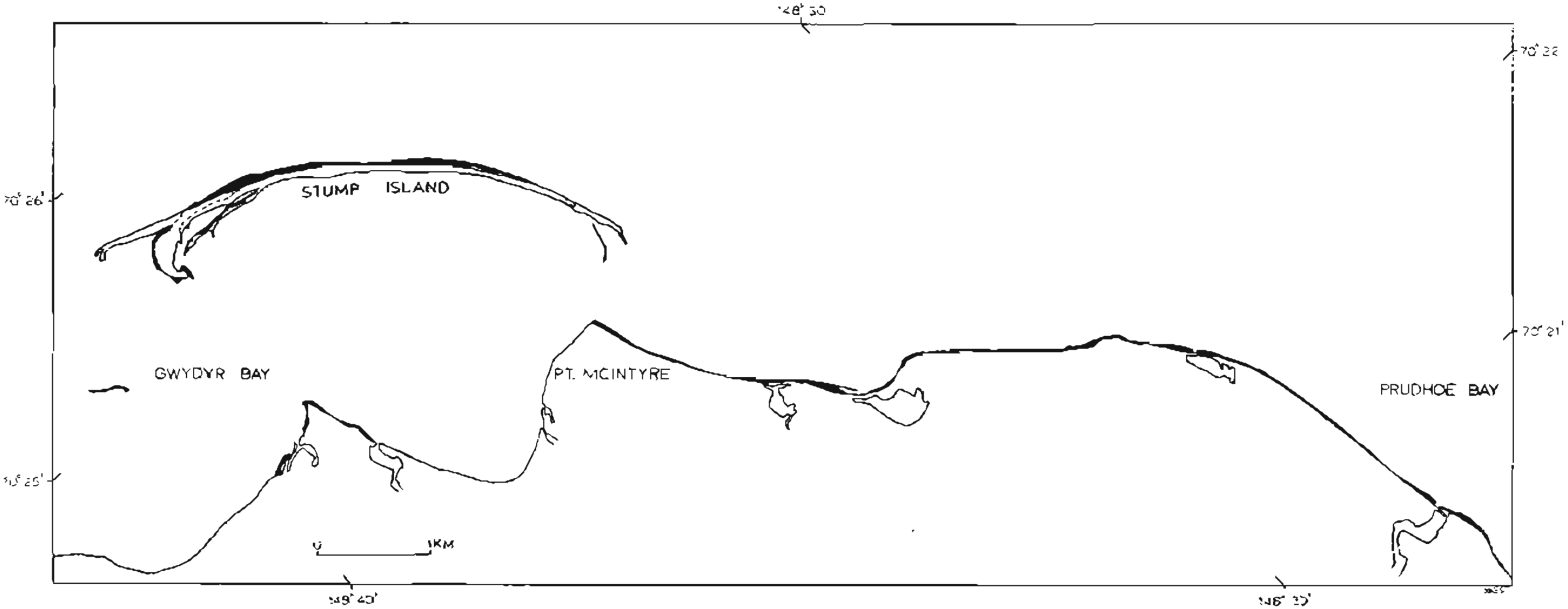

148°30'
70°22'
70°26'
STUMP ISLAND
70°21'
GWYDYR BAY
PT. MCINTYRE
PRUDHOE BAY
70°25'
0
1KM
148°40'
148°20'

fig 5