# RATES OF SEDIMENT DISRUPTION BY SEA ICE AS DETERMINED FROM CHARACTERISTICS OF DATED ICE GOUGES CREATED SINCE 1875 ON THE INNER SHELF OF THE BEAUFORT SEA, ALASKA

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## ABSTRACT

Repetitive sidescan sonar and precision bathymetric surveys made between 1975 and 1980 were used to assess seafloor changes due to ice gouging along 8 shore-perpendicular corridors, and to gain insight into the question of when, where, and how gouges are produced on the inner shelf of the Beaufort Sea. The percentage of seafloor area impacted annually by ice keels increases from the coast seaward to at least the 25-m isobath, the offshore limit of repeated surveys. Up to 6.8 % of the total seabed area scanned along the roughly 15 km-long corridors was disrupted in a single year. Total seafloor disruption in single km-long segments ranged as high as 60 %. The maximum new gouge incision depth measured is 1.4 m. High gouge densities are associated with wide, shallow "multiplet" gouging events, where long sections of pressure-ridge keels raked the bottom. Small annual variations in the amount and intensity of new gouges indicate rather consistent reworking of the inner shelf by this process. Where shoals occur within survey corridors our seafloor monitoring has documented the predicted sheltering of seafloor areas on the landward side.

## INTRODUCTION

Ice interaction with the seafloor forms gouges which influence the sedimentary structures, morphology and sediment transport on the shelves off northern Alaska (Reimnitz and Barnes, 1974, Toimil, 1978, Barnes and others, 1984). Ice gouges and the gouging process are important considerations for the safty and design of pipelines (Weeks and others, 1984) and for foundations relying on the seabed for stability (Bea and others, 1985). Pipelines will have to be protected from the impact of ice on the seabed either by burial or by defensive strategies such as berms or armor. Seafloor morphology influences the lateral shear resistance of bottom founded structures such as mobile exploration islands as the bond with the seafloor may occur through discontinuous sediment contact points formed by ice gouge ridges and troughs. The intensity of ice gouging is also an important indication of the rate and intensity of ice/seafloor interaction on the shelf. The size, shape and frequency of gouging is reflected in the size shape and frequency of ice contacts with the bottom. In addition the gouge parameters reflect the creation of ice keels of sufficient draft and strength to form gouges.

In this report we present data on the rate and character of ice gouging in the fast ice and inner stamukhi zone (Reimnitz and others, 1978), from a series of repetitive seabed observations extending over 8 years at 8 different sites (Figure 1 and Table 1).

We detail their numbers, depth, width and orientation. These repetitive observations have allowed us to document the year to year variability of ice gouge processes and to determine the relationship to changes in ice zonation that occur from year to year. The results are discussed in light of sediment reworking and in relation to the ice regime. We also present preliminary speculations on the rates of gouging in relation to other sedimentary processes acting on arctic shelves.

Our data are from the inner shelf where open water conditions are most common and where the limited range of our precise navigation equipment is most useful. Thus our observations are biased toward shallow water by the data base (average water depth-15m). We would expect different results when repetitive data are gathered from deeper water where ice and sediment conditions will certainty be different (Reimnitz and others, 1978, Barnes and Reimnitz, 1974).

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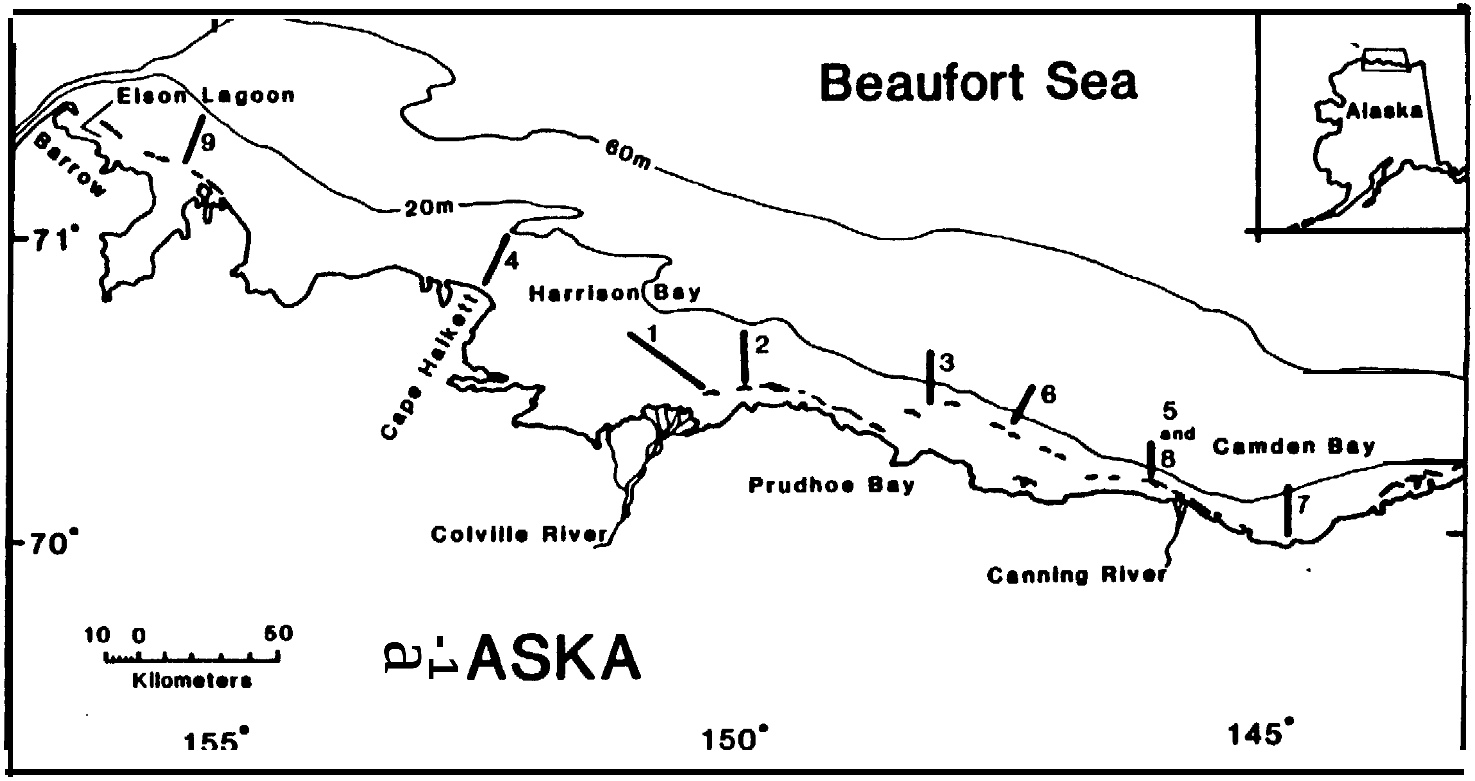


Fig 1 Location map indicating corridor locations and generalized bathymetry for the Alaskan Beaufort Sea.

## TABLE 1.

### Location and timing of corridor surveys - Data documentation

| Corridor | Baseline Length* | Geographical Name | Survey Year | Time Between Surveys | Trackline Number | Sidescan Roll # | Fathometer Roll # |
|---|---|---|---|---|---|---|---|
| 1 | None | Thetis Is. | 1975 | Baae Year | | | |
| | | | 1976 | 1 | | | |
| | | | 1977 | 1 | 35 | 8 | 7 |
| | | | 1978 | 1 | 14,19 | 5 | 8,10 |
| | | | 1979 | 1 | 13,33 | 8,12 | 9,10b |
| | | | 1980 | 1 | 17 | 6 | 12 |
| | | | 1981 | 1 | 27 | 14 | 18,19 |
| | | | 1982 | 1 | 16 | 8 | 10 |
| 2 | None | spy Is. | 1975 | Base Year | | | |
| | | | 1976 | 1 | | | |
| | | | 1977 | 1 | 31 | 6 | 6 |
| | | | 1978 | 1 | 17 | 5 | 9 |
| | | | 1979 | 1 | 31 | 10 | 10a |
| | | | 1980 | 1 | 16 | 5 | 11b |
| | | | 1981 | 1 | 26 | 14 | 18 |
| 3 | 14936m | Cross Is. | 1975 | Inadequate data | | | |
| | | | 1979 | Base Year | 92 | 27 | 33 |
| | | | 1982 | 3 | 12 | 6 | 8 |
| 4 | 12622m | Cape Halkett | 1977 | Base Year | 39 | 12 | 10 |
| | | | 1978 | 1 | 10,11 | 4 | 7 |
| | | | 1980 | 2 | 20 | 7 | 14,15 |
| | | | 1982 | 2 | 4 | 2 | 2 |
| 5 | 16744m | Flaxman Is. | 1979 | Base Year | 44 | 15 | 14 |
| | | | 1980 | 1 | 25 | 9 | 17 |
| 6 | 21926m | Karluk Is. | 1979 | Base Year | 77 | 23 | 27 |
| | | | 1980 | 1 | 24 | 9 | 17 |
| | | | 1981 | 1 | 18 | 10 | 13 |
| | | | 1982 | 1 | 6 | 3 | 3 |
| 7 | 13544m | Camden Bay | 1981 | Base Year | 15 | 9 | 11 |
| | | | 1982 | 1 | 8 | 4 | 5 |
| 8 | 18430m | Flaxman Is. | 1981 | Base Year | 16 | 9 | 12 |
| | | | 1982 | 1 | 7 | 3 | 4 |
| 9 | 17639m | Cooper Is. | 1978 | Base Year | 8 | 3 | 5 |
| | | | 1982 | 4 | 1 | 1 | 1 |

* **Baseline distance is measured between the two** shore breed navigations stations,

## Data Sources (Table 1 continued)

Reports containing **data, locations, log sheets, and methodology (records often on microfilm).**

| Year Collected | Open-File Report No. | Authors |
|---|---|---|
| **1975** | **none** | |
| **1976** | **79-766** | **Reimnitz, Barnes, and Maurer** |
| **1977** | **78-1066** | **Maurer, Barnes, and Reimnitz** |
| **1978** | **79-384** | **Reimnitz, Barnes, and Kempema** |
| **1979** | **80-603** | **Barnes, Reimnitz, Kempema, Minkler, and Ross** |
| **1980** | **81-241** | **Kempema, Reimnitz, and Barnes** |
| **1981** | **82-586** | **Minkler, Reirnnitz, and Barnes** |
| **1982** | **83-493** | **Kempema, Barnes, Reimnitz, Asbury, and Rearic** |

Copies of the Open-files are available at Open Files Semites Section, Branch of Distribution, Box 25425, Federal Center, Denver, CO 80225.

**Complete microfilm copies of all geophysical records, ships log and computer listings of navigational** way ponts, can be obtained from the National Geophysical and Solar-Terrestrial Data Center, NOAA, Boulder CO, 80303.

The original records are archived at the U.S. Geological Survey, Branch of Pacific Marine Geology, 3475 Deer Creek Road, Palo Alto, CA 94304.

Background -

Earlier studies of the rates of ice gouging **based on repetitive observations of the seafloor inshore of 20 meters indicated that sea ice presently interacts with the sea bed forming gouges (Lewis, 1977, Reimnitz and others, Barnes and others, 1978). In these previous studies gouging was ubiquitous in the areas studied although data from one study suggested that sediment reworking by waves and currents is important to gouge morphology on the inner shelf inshore of 13m (Barnes and Reimnitz, 1979).**

**Most ice gouges** form in winter when a large semi-ridged ice sheet integrates atmospheric and oceanic energy over a large area and **allows this** energy **to** be transmitted through the ice canopy for some distance **to** the boundary of the ice **sheandothersng** the continent where ridging **and** grounding occur (Barnes and others, 1978; **Thomas** and Pritchard, **1980)**. This allows **more energy to be focused at grounded ice keels in winter than would be** available **during the summer** when a discontinuous ice **sheet diffuses atmospheric and oceanic energy over smaller areas and distances. In the summer waves and currents are often the only forces acting on isolated grounded ice blocks.**

**The earlier repetitive surveys mentioned above have shown the rates of seabed reworking by ice for the Canadian shelf and the shelf off northern Alaska to be on the order of 2% each year**

with depths of incision ranging up to 120 cm but averaging leas than 20cm.

The ice regime in the study area is discussed by Kovacs and Mellor (1974) and by Reimnitz and others (1978). Briefly, the ice environment is composed of a relatively stable winter 'fast' ice sheet up to 2m thick inshore of a zone of discontinuously grounded shear and pressure ridges called the stamukhi zone. The outer edge of the fast ice and the inner edge of the stamukhi zone forma in water deptha of 15 to 25m. The boundary is typically composed of linear ridges which parallel the isobaths. isolated grounded ridges and grounded ice blocks may occur inside of the stamukhi zone. In particular, a stamukhi zone boundary has, on occasions, developed along the 10 meter isobath in Harrison Bay (Reimnitz and others, 1978).

The stamukhi zone ia significant in that the atmospheric and oceanic energies imparted to moving offshore polar ice pack are, primarily expended against the continent within this zone. In this regard the stamukhi zone could be thought of as the winter "surf" zone of the Beaufort Shelf. The expenditure of energies results in higher numbers of pressure and shear ridges than elsewhere in the Beaufort (Weeks and others, 1980) and an intensely gouged seafloor (Barnes and others 1984). Inshore of the stamukhi zone, gouging is expected to be leas intense and less frequent due to the expenditure of energy by *ridge* building and gouging processes within the stamukhi zone. Our study is focused primarily on the area inshore of the stamukhi zone and provides only a glimpse of the rates and character of gouging at the inner margin of the zone. The expenditure of energy and rate of ice gouging is expected to drastically increase seaward of our data set in the stamukhi zone (Barnes and others, 1978, 1984).

## METHODS

A 42 foot research vessel was used to run repetitive surveys. The basic objective was to establish tracklines which could be reoccupied in subsequent years. The subsequent trackline observations or line sets from the same or nearly the same corridor forms the basic data for this report. The navigation and depth observations were correlated with sidscan sonar data (Belderson and others, 1972) which covered a swath of seafloor 125 meters wide on either side of the trackline. This resulted in a "corridor" of the seafloor which was resurveyed in subsequent years. We have arbitrarily numbered these corridors depending on the year in which the initial data were collected (Figure 1 and Table 1).

### Navigation

The location of the survey vessel for the initial two survey corridors (1 & 2) was determined by aligning the vessel with two in line range marks several kilometers apart and measuring the vessels distance from one of the ranges (Figure 2). With this technique we were able to carry the line seaward from the islands in excess of 20 kilometers achieving position accuracies of better than 20 meters. The technique was occasionally aided by a thermal inversion which created a "mirage" causing the range markers to appear higher above the horizon and thus visible at greater distances. The common summer fog bas made the routine re-occupation of corridors one and two diffucult and time consuming. Aa a result of this problem and the lack of appropriate range marks, the remainder of the corridors were navigated using precision range-range electronic navigation alone (Table 2). These navigation systems typically give precision ranges to a few meters and repeatable locations within about 10 meters. For simplicity we chose benchmarks and survey lines such that the corridors could be *run* equidistant from the two shore stations. This meant that the boat operator and navigator were required to keep the vessel equidistant from both shore stations by maintaining the same range from each station.

### Ice gouge measurements

The enumeration of new gouges was accomplished through the comparison of sonograph records and fathograms in one kilometer intervals. The starting point for counting began either on

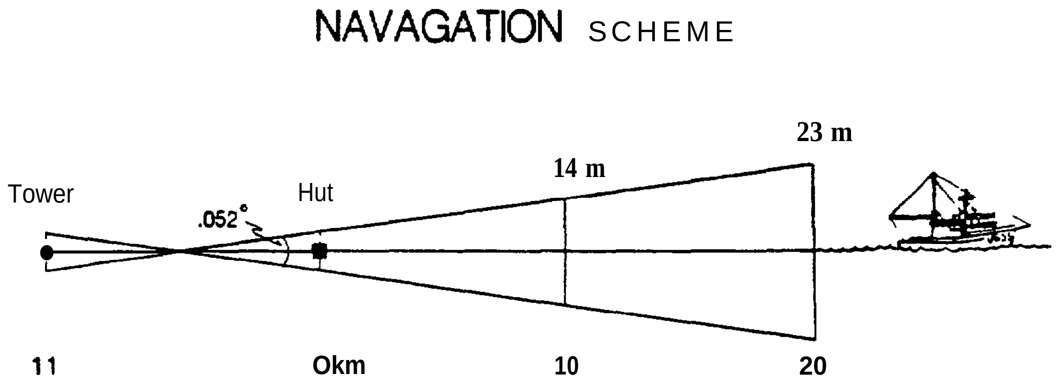


**Fig. 2 Navigation scheme used on corridors 1 & 2 indicating the errors likely to be experienced in aligning the ranges with good visibility.**

## Table 2

### Ranges and benchmarks used for navigating along corridors

| Corridor | Course | Navigation (Shore Stations) | Remarks |
|---|---|---|---|
| 1 | 305 T | 1) Thetis Is. Benchmark ('10m south of hut)<br>2) Oliktok Pt. 300ft. Tower | Range alignment of Oliktok tower and Thetis Island hut. Distance along line is measured from Thetis Is. or Oliktok. |
|  | 358 T | 1) spy Is. benchmark (under 1950's wooden tower)<br>2) Oliktok Pt. 300ft. Tower | Range alignment of Oliktok tower and tower over Spy Island bench mark. Distance along line measured from Spy Island or Oliktok. |
|  | 000 T | 1) Reindeer Is. tower (USGS tower at Humbolt C-1 well- (lat. 79 29'12"; long. 14820' 25")<br>2) Cross Is. (top of USCG RACON tower) | Line is run equidistant from Reindeer and Cross Island. |
| 4 | 027 T | 1) Cape Halkett RACON tower<br>2) Northeast comer of the sod hut at Esook. | Line is run equidistant offshore from the two stations. |
| 5 |  |  | One shore location has been lost and the corridor has not been resurveyed. |
| 6 | 028 T | 1) Pole Is. (USGS 50ft. tower)<br>2) Narwhal Is. (150ft. tower) | Line is run equidistant from Pole and Narwhal Island stations. |
| 7 | 000T | 1) "Collinson Point" benchmark | Line is run equidistant from the two stations. |

| | | |
|---|---|---|
| | 2) Benchmark "Koganak" (13.2km east of "Collinson Point") | |
| 006T | 1) Brownlow Point RACON tower<br>2) Benchmark "Rods" near Point Thompson | Line is run equidistant from the two stations. |
| 020 T | 1) Cooper Is. NOS benchmark<br>2) Igilik Is. NOS benchmark | Line is run equidistant from the two stations. |

the range /range baseline or one kilometer offshore from a barrier island or coast. One kilometer intervals were scaled off seaward on the navigation charts and the time the vessel crossed tbe kilometer points was determined. These times were then used to correlate the sonographs and fathograms with the navigation at the established intervals. Aa pointed out in Wolf and others (1983) systematic errors did occur. Therefore, seabed ice gouge "matches" on monographs were used wherever possible to establish comparisons between records.

Side-scan sonar records from sequential yeara were used to determine the number of new (datable) gouges occurring during the year or more interval since the previous survey. The total number of gouges in each segment was also determined. The percent of new gouges to the total was calculated for each interval. Other measurements taken from the monographs included gouge orientation, gouge width, disruption width of multiplet gouges, and length of gouges (See Barnes and others, 1984, for explanation). The location of each new gouge along the trackline was determined (+/-50 meters) and will allow us to monitor sedimentary processes in the vicinity of the gouge in future years.

Fathogram records were used to determine the maximum depth of the new gouges below the seafloor, maximum height of ridge of plowed sediments from the new gouge, and the water depth at which the new gouge occurred. In the case of multiplet gouges only the deepest incision was measured.

### The problem of small gouges

In many cases we were able to resolve individual gouge features on the monographs that we could not resolve on the fathograms, except to note that the gouge was smaller than we could resolve on most of our fathograms (20 cm). For the large percentage of the new gouges ( >60%) that fell into this unresolvable category, we assumed a depth of 10 cm for purposes of our statistical calculations. The assumed depth is probably less than the actual gouge depth for these gouges as the limit of resolution of the monographs is also near 10cm (based on wavelength), thus the incision depths of the gouges observed on the monographs and not resolved on the fathograms should fall between 10 and 20cm. From the above it follows that there also exist gouges that are smaller than the 10 to 20 cm resolution of our instruments. These gouges are not accounted for in our data.

### Other observations

Observations of interest were noted in the comments column of the data sheets (Appendix). Ice gouge termination directions were determined which indicate the direction of ice keel movement during a gouging event. Sediment wave orientations were determined whenever observed on the monographs as these have a direct application to sediment movement and infilling. On some corridors, older gouges formed in cohesive sediments are reexposed when non-cohesive sediment cover is redistributed by waves and currents (Barnes and Reimnitz, 1979). These gouges could be misinterpreted as new gouges and, counted in the datable gouge population.

## Subjectivity of analysis

Due to many factors, such as record quality, navigational accuracy, ice conditions, etc., enumeration of ice gouge data is a subjective task varying significantly between individuals. In this study, we found that new gouges in water depths of leas than about 15 m were generally easy to resolve on the sonograph records and thus least subjective. Dated gouges in water depths greater than 15 m required more subjective decisions due to increased gouge densities (> 100/km) on the seafloor and resultant complexity of seafloor morphology at these depths.

To keep the subjectivity consistent throughout the data set , the second author enumerated all of the gouge records. Even with this precaution the data exhibit some inconsistencies, particularly with regard to the number of gouges. Examination of the appendix will show segments where the total number of gouges increases from one year to tbe next by a number greater than the “new” gouge count.

Occasionally assumptions were made regarding what constituted a datable gouge. Areas exist where there were poor *matches” between sequential sonographs due to deviations from trackline, an extended time between resurveys (generally 2 years or more), or extensive hydraulic reworking of the bottom. In these areas, other criteria were used to determine what gouges could be dated. Superposition of gouges on older gouges, tbe fresh or crisp appearance of gouge trough and ridge morphology, and gouge orientation parallel to other gouges of the same age were used in determining whether a gouge was considered to have been formed since the last survey of the trackline and was, thus, datable. We estimate that these criteria were used in less than IO% of the 1 km segments and that only 30% of the dated gouges within these segments were accounted for by this method.

## Reality of Year-*year differences in ice gouge parameters

In addition to tbe year to year variability of ice gouge interaction with the seafloor due to the variability of natural processes, artificial factors based on the survey techniques and data quality enter into the comparative analysis. Ice conditions varied from year to year influencing tbe length of the survey lines and the ability to reoccupy these lines without “ice detours”. In addition some datable gouges may have gone uncounted due to poor record quality, or to rapid infilling or to deviations from tbe desired trackline. Data summarized for entire tracklines are not strictly comparable area to area or year to year as differing line lengths represent unequal portions of the ice gouge environment.

Variable record quality leads to uncertain correlation from year to year which may have resulted in calling gouges "new" and datable when in reality they may have been poorly defined on previous records. We estimate that at most about 25% overcounting of the gouges may have resulted but that these gouges would consist primarily of the small short and shallow gouges which are the least clear *on* the monographs and fathograms in all water depths. We also note that since the initiation of the repetitive surveys in 1975 the quality of our records bss improved due to growing skills with the equipment and to advances in equipment design. Thus in recent years seabed morphology was visible in greater detail. This means that the number of “new” features may have increased due to this artificial factor.

## RESULTS - OBSERVATIONS and DISCUSSION

The morphologic environments for each of the corridors varied considerably. The corridors were resurveyed during the open water seasons from 1977 to 1982, although only a few years of record are available in some corridors (Table 1). As other workers may wish to reoccupy these corridors the methods of navigation and the location of the shore stations used in surveying each of the lines is given in Table 2. The corridors are described from west to east (Figure l). The raw data are given in the appendix, and data summaries are shown in Table 3 and Figurea 3 through 11.

**Corridor 9 -** This corridor extends northeast from a chain of sand and gravel islands stretching east from Point Barrow (Figure 1). Depths quickly increase to 5m seaward of the islands then steadily increase seaward such that the 20 m contour is crossed more than 12 km from the islands (Figure 3). There are no noticeable shoals or steps along this trackline. The bottom sediments in this area are muds and muddy sands with the coarser sediments generally occurring further inshore.

Corridor 4- Another northeast trending corridor which starts in shallow water offshore from a coastline with 1 to 2 meter high tundra bluffs. The watera gradually increase in depth to about 15m where a 1 to 2m high sheaf exists (Figure 4). The seafloor continues to deepen seaward from here to depths of 19m, 24 km from shore, then rises a few meters over a broad shoal at the outer end. The sediments along this corridor are characterized as muddy sands and sandy muds, although there is no onshore/offshore pattern.

27

Corridor 1- One of our oldest corridors, originally established in 1973 (Reimnitz, and others, 1977), and one for which we have the most repetitive surveys (Table 2). The trackline extends northwest from Thetis Island on the eastern side of Harrison Bay (Figure 1). The bottom drops quickly to 7 m seaward of the island, then gently and rather uneventfully to water depths of 15 or more meters in the central part of Harrison Bay (Figure 5 and 6). The sediments along this corridor are sands and muddy sand inshore; offshore the porportion of muds increases.

Corridor 2- Extending north from Spy Island in the northeast comer of Harrison Bay, this older corridor (established in 1975) is marked by 2 to 3m high sand shoals in water deptha of 12 to 15m (Figure 6 and 7) before reaching its seaward limit at water depths near 20m. Except for the sand shoals the sediments along this corridor are sandy muds which generally become finer in a seaward direction.

Corridor 3- Although also established in 1975, this corridor has been seldom repeated due to the persistence of ice in this area. The corridor extends north equidistant from Cross and Reindeer Islands, offshore of the Prudhoe Bay area (Figure 1). The bottom profile in this corridor is steeper than on the corridors to the west (above), as are the profiles from here eastward to Camden bay (Figure 8). Proceeding seaward, corridor 3 crosses a mound 4 m high in 13m of water then drops to about 19 m before rising gradually to a small shoal or bench between 18 and 22m water depth (Barnes and Asbury, 1985). The mound is composed of sands and gravels while the sediments elsewhere along the corridor are sandy muds and muds. Just inshore of the break in slope at 18 to 22m the bottom sediments are an over consolidated mud, which is common here and efaewhere on the shelf (Reimnitz and othera, 1980).

Corridor 6- Extending northeasterly from the chain of islands north and east of Prudhoe Bay (Figure 1), this corridor's steep profile crosses a bench at 18m and continues dropping to water depths of more than 25m (Figure 9). The sediments in this area are quite varied and are commonly over- consolidated. Sediment descriptions include pebbly clays and stiff sandy muds. At the innermost end of the corridor boulders up to 50cm in diameter have been observed on underwater TV.

### Testline 9-COOPER ISLAND

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 6.0 | 7.7 | 8.5 | 9.3 | 10.0 | 10.9 | 11.8 | 12.4 | 13.0 | 13.5 | 14.0 | 14.6 | 15.4 | 16.2 | 17.0 | 18.2 | 18.7 | | | |
| No. of New Gouges (m) | | | | | | | | | | | | | | | | | | Total | avg/Km | |
| 1978-1982 | 7 | 10 | 16 | 1 | 7 | 5 | 23 | 18 | 12 | 2 | 11 | 4 | 7 | 12 | 16 | 7 | | 158 | 9.9 | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | | Deepest | | |
| 1978-1982 | - | - | - | - | | | | | | | | | | | | | | | | |
| (m) | | | | | | | | | | | | | | | | | | Total | avg/Km | % disturbed (in 4 yr) |
| 1978-1982 | 19 | 53 | 71 | 13 | 49 | 51 | 159 | 147 | 132 | 23 | 83 | 43 | 72 | 107 | 142 | 86 | | 1250 | 78.1 | 7.8 |

Total No. of New Gouges = 158
Deepest New Gouge = 1.1 m
Total Disruption Width = 1250 m
Mean % disturbed = 2.0

### Testline 4-CAPE HALKETT

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | x | 3.2 | 5.1 | 6.8 | 7.8 | 8.7 | 9.5 | 10.4 | 11.0 | 11.9 | 12.5 | 13.1 | 14.0 | 14.7 | 15.0 | 15.4 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 17.6 | 17.9 | 17.7 | 17.7 | 18.5 | | | |
| No. of New Gouges | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Total | avg/Km | |
| 1977-1978 | x | 4 | 6 | 7 | 4 | 4 | 6 | 5 | 4 | 6 | 11 | 24 | 5 | 19 | 98 | 45 | 11 | 21 | 13 | 0 | 6 | 7 | 2 | 0 | 6 | 5 | 5 | | 322 | 12.4 | |
| 1978-1980 | x | 5 | 3 | 0 | 4 | 4 | 5 | 9 | x | x | 52 | 20 | 10 | 21 | 31 | x | x | | | | | | | | | | | | 164 | 13.7 | |
| 1980-1982 | x | x | 0 | 0 | 3 | 1 | 1 | 6 | x | x | 8 | 13 | 8 | 17 | 19 | | | | | | | | | | | | | | 76 | 6.9 | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Deepest | | |
| 1977-1978 | x | 3 | .2 | .2 | .1 | .4 | .1 | 2 | .1 | .2 | .4 | .4 | .2 | .5 | 1.2 | .5 | 4 | 5 | .5 | 0 | .4 | .3 | 1.2 | 0 | .1 | 3 | .5 | | 1.2 | | |
| 1978-1980 | x | .1 | .2 | 0 | .1 | .4 | | .1 | x | x | .5 | .6 | .5 | .4 | .8 | x | x | | | | | | | | | | | | .8 | | |
| 1980-1982 | - | - | - | - | - | - | .1 | | | | | | | | | | | | | | | | | | | | | | | | |
| (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Total | avg/Km | %disturbed |
| 1977-1978 | x | 16 | 16 | 13 | 13 | 19 | 16 | 24 | 18 | 36 | 46 | 134 | 24 | 96 | 398 | 321 | 122 | 200 | 68 | 0 | 33 | 34 | 13 | 0 | 29 | 39 | 28 | | 1756 | 67.5 | 6.8 |
| 1978-1980 | x | 11 | 13 | 0 | 22 | 14 | 16 | 22 | x | x | 223 | 77 | 79 | 101 | 212 | x | x | | | | | | | | | | | | 790 | 65.8 | 6.6<br>(2 yrs.) |
| 1980-1982 | x | x | 0 | 0 | 6 | 4 | 5 | 20 | x | x | 46 | 76 | 61 | 134 | 144 | | | | | | | | | | | | | | 496 | 45.1 | 4.5<br>(2 yrs.) |

Total No. of New Gouges = 562
Deepest New Gouge = 1.2 m
Total Disruption Width = 3042 m
Mean % disturbed = 3.6 per year

### Test line 1 - The tie Island

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth | 4.9 | 5.8 | ● | .B | 8.5 | 9.6 | 10 1 | 10.10. 9 | 11.5 | 12.0 | 12.4 | 12.8 | 1 1 | 13.6 | 13. 8 | 14.2 | 14.6 | 14.9 | 15.1 | 15.2 | 15.5 | 15.4 | 16.0 | 16.5 | 16.7 | | | | |
| m.. of New Gouges | | | | | | | | | | | | | | | | | | | | | | | | | | | Total | ● -n= | |
| 1977-1978 | 0 | 2 | 6 | 0 | 0 | 6 | 0 | 0 | 1 | 18 | 5 | 4 | 15 | 21 | 18 | 8 | 4 | 0 | 0 | 0 | 0 | 10 | 4 | 5 | 0 | | 127 | 5.1 | |
| 197.. 1979 | 4 | 4 | 13 | 20 | 12 | 0 | 4 | 1 | 5 | 2 | 2 | 6 | 24 | 8 | 3 | 8 | 1 | 1 | [illegible] | [illegible] | 0 | | | | | | 142 | 6.8 | |
| 1979-1980 | [illegible] | [illegible] | 16 | 30 | 4 | 64 | 51 | 14 | 10 | 5 | 2 | 8 | 0 | 1 | 3 | 40 | 4 | [illegible] | 13 | 1 | 3 | 0 | | | | | 278 | 15.4 | |
| 1980-,981 | . | [illegible] | 9 | 15 | 16 | 9 | 2 | 12 | 14 | 15 | 6 | 11 | 15 | 15 | 22 | 30 | 7 | 9 | | | | | | | | | 207 | 12.4 | |
| 1981-1982 | * | 0 | 2 | 8 | 10 | 3 | 2 | 22 | 20 | * | 6 | 3 | 3 | | | | | | | | | | | | | | 81 | 6.5 | |
| | 5 | 6 | 46 | 73 | 42 | 86 | 57 | 32 | 54 | 65 | 34 | 38 | 35 | 42 | | | | | | | | | | | | | | | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | Deepest | | |
| 1977-1978 | 0 | .1 | .1 | 0 | 0 | .10 | 0 | .3 | .2 | .1 | .1 | .1 | .3 | .2 | .1 | .9 | 0 | 0 | 0 | 0 | .5 | .1 | .3 | 0 | | | .5 | | |
| 1978-1979 | .1 | .1 | .1 | .1 | .1 | 0 | ., | ., | .1 | .2 | .4 | .2 | .1 | .1 | .1 | .1 | .2 | .1 | .2 | .2 | [illegible] | [illegible] | 0 | | | | .4 | | |
| 1979-1980 | [illegible] | [illegible] | .1 | .2 | .1 | .1 | .1 | .1 | .1 | .1 | .4 | .3 | 0 | .1 | .2 | .4 | .2 | [illegible] | .3 | .3 | 0 | | | | | | .4 | | |
| 1980-1981 | * | .1 | * | .4 | .2 | .1 | .1 | .1 | .1 | .6 | .1 | .6 | .1 | .2 | .3 | .3 | .2 | | | | | | | | | | .1 | | |
| 1981-1982 | .1 | 0 | .1 | .1 | .3 | .3 | .1 | .2 | .4 | .3 | .4 | .2 | 1.0 | .5 | | | | | | | | | | | | | .0 | | |
| Total Disruption Width (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | Total | ● q/M9 | % disturbed |
| 1977-1978 | 0 | 18 | 20 | 0 | 0 | 9 | 0 | 0 | 4 | 70 | 3 | 29 | 102 | 92 | 46 | 60 | 37 | 0 | 0 | 0 | 0 | 49 | 24 | 46 | 0 | | 609 | 24.4 | 2.4 |
| 1978-1979 | ● | m 4 2 9 * | 4 5 0 | 3 | 25 | 50 | 24 | 60 | 25 | 6 | 5 | 23 | 101 | 30 | 12 | 33 | 4 | [illegible] | [illegible] | 0 | | | | | | | 563 | 26.8 | 2.7 |
| 1979-1980 | . | m | 71 | 123 | 14 | 174 | 214 | 31 | 43 | 33 | 31 | 62 | 0 | 10 | 27 | 146 | 21 | 0 | 82 | 82 | 0 | | | | | | 1164 | 61.3 | 6.1 |
| 1980-1981 | [illegible] | [illegible] | 30 | 70 | 58 | 36 | 8 | 64 | 62 | 96 | 71 | 51 | 7, | 62 | 105 | 113 | 35 | 40 | | | | | | | | | ● 73 | 60.9 | 6.1 |
| 1981-1982 | 1 | 0 | 10 | 31 | 31 | 29 | 4 | 5 | 58 | 62 | 25 | 42 | 22 | 28 | | | | | | | | | | | | | 340 | 28.9 | 2.5 |
| | ● | 26 | 173 | 283 | 148 | 248 | 229 | 125 | 217 | 285 | 190 | 209 | 204 | ,97 | 201 | 420 | 123 | 52 | 115 | 86 | 0 | 49 | 24 | 46 | | | | | |

Total m . of New Gouges = 845 Deepest New Gouge . ,.0 . Total Disruption Width . 3659 . Mean % dis turbed = 4.0

### Testline 2. - Spy Island

| Kilometers | 0 | 1 | 1 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 6.9 | 10.0 | 11.4 | 11. 5 | 12.2 | 13.3 | 14.2 | 14.9 | 14.4 | 14.1 | 15.1 | 15.4 | 16.3 | 17.3 | 17.9 | 18.5 | | | |
| No. of New Gouges | | | | | | | | | | | | | | | | | Total | ● v/m | |
| 1977-1978 | 12 | 4 | 1 | 22 | 1 | 30 | 17 | 4 | 23 | 0 | 8 | 13 | 11 | 17 | 7 | | 170 | 11.3 | |
| 1978-1979 | 0 | 1 | 25 | 44 | 12 | 1 | 0 | 0 | 20 | 0 | 9 | 0 | 1 | | | | 133 | 10.2 | |
| 1979-1980 | 0 | 0 | 0 | 21 | 0 | 1 | 2 | 1 | 14 | 0 | 2 | 1 | 4 | | | | 46 | 3.5 | |
| 1 980-t 981 | 2 | 5 | 2 | 25 | 7 | 6 | 2 | 0 | 14 | 7 | 7 | 14 | 19 | ● | | | 118 | . . . | |
| | 14 | 10 | 28 | 112 | 20 | 38 | 21 | 5 | 71 | 7 | 26 | 28 | 35 | 25 | 7 | | | | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | Deepest | | |
| 1977-1978 | .1 | .1 | .1 | .1 | .1 | .2 | .2 | .1 | .1 | 0 | .1 | .2 | .4 | .1 | .5 | | .5 | | |
| 1978-1979 | 0 | .1 | .1 | .2 | .1 | .1 | 0 | 0 | .1 | 0 | .2 | 0 | .1 | | | | .2 | | |
| 1979-1980 | 0 | 0 | 0 | .2 | 0 | .1 | .1 | .1 | .2 | 0 | .1 | .1 | .3 | | | | .3 | | |
| 1980-1981 | .1 | .1 | .1 | .1 | .1 | .1 | .1 | 0 | .2 | .4 | .2 | 1.4 | .3 | .3 | | | 1.4 | | |
| Total Disruption Width (m) | | | | | | | | | | | | | | | | | Total | avg/km | % disturbed |
| 1977-1978 | 72 | 19 | 3 | 97 | 9 | 134 | 65 | 20 | 50 | 0 | 44 | 58 | 56 | 139 | 60 | | 826 | 55.1 | 5.5 |
| 1978-1979 | 0 | 4 | 97 | 149 | 30 | 3 | 0 | 0 | 53 | 0 | 18 | 0 | 4 | | | | 358 | 27.5 | 2.8 |
| 1979-1980 | 0 | 0 | 0 | 82 | 0 | 3 | 15 | 3 | 48 | 0 | 4 | 1 | 15 | | | | 171 | 13.1 | 1.3 |
| 1980-1981 | 11 | 13 | 5 | 121 | 21 | 14 | 4 | 0 | 64 | 28 | 49 | 88 | 88 | 34 | | | 540 | 38.6 | 3.9 |
| | 83 | 36 | 105 | 449 | 60 | 154 | 84 | 23 | 215 | 28 | 115 | 147 | 163 | 173 | 60 | | | | |

Total No. New Gouges = 447 Deepest New Gouge = 1.4 m Total Disruption Width = 1895 m Mean % disturbed = 3.4

## Testline 3-CROSS ISLAND

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 11.5 | 12.5 | 12.3 | 12.0 | 15.0 | 17.8 | 20.5 | 21.6 | 22.4 | 22.7 | 22.5 | 22.2 | 21.7 | 21.0 | 24.1 | | | |
| | | | | | | | | | | | | | | | | Total | avg/Km | |
| No. of New Gouges Depth (m) 1979-1982 | 6 | 7 | 6 | 11 | 9 | 2 | 5 | 3 | 0 | 4 | 0 | 22 | 8 | 134 | | 217 | 15.5 | |
| | | | | | | | | | | | | | | | | Deepest | | |
| Maximum Gouge Depth (m) 1979-1982 | .1 | .1 | .1 | .1 | .1 | .2 | .2 | .1 | 0 | .1 | 0 | .2 | .3 | .8 | | 8 | | |
| | | | | | | | | | | | | | | | | Total | avg/Km | %disturbed (in 3 yrs.) |
| Total Disruption Width (m) 1979-1982 | 23 | 22 | 15 | 30 | 25 | 13 | 15 | 9 | 0 | 50 | 0 | 169 | 71 | 600 | | 1042 | 74.4 | 7.4 |

Total No. of New Gouges = 217 Deepest New Gouge = .8 Total Disruption Width = 1042 m Mean % disturbed = 2.5

## Testline 6-KARLUK ISLAND

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 5.4 | 8.0 | 9.5 | 10.2 | 11.1 | 12.0 | 13.5 | 14.6 | 15.7 | 16.2 | 19.3 | 21.7 | 23.2 | 25.2 | 26.0 | 26.5 | 27.4 | | | |
| No. of New Gouges | | | | | | | | | | | | | | | | | | Total | avg/Km | |
| 1979-1980 | * | * | * | * | 3 | * | 5 | 4 | | | | | | | | | | 12 | 4.0 | |
| 1980-1981 | 0 | 0 | 2 | 5 | 1 | 2 | 0 | 0 | | | | | | | | | | 10 | 1.3 | |
| 1981-1982 | 1 | 5 | 1 | 0 | 1 | 18 | 1 | 1 | 1 | 15 | 15 | 0 | 6 | 0 | 0 | 1 | | 66 | 4.1 | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | | Deepest | | |
| 1979-1980 | * | * | * | * | .1 | * | .1 | .1 | | | | | | | | | | .1 | | |
| 1980-1981 | 0 | 0 | .1 | .1 | .1 | .1 | 0 | 0 | | | | | | | | | | .1 | | |
| 1981-1982 | .1 | .7 | .5 | 0 | .1 | .1 | .1 | .1 | .1 | .1 | .2 | 0 | .2 | 0 | 0 | .1 | | .7 | | |
| Total Disruption Width (m) | | | | | | | | | | | | | | | | | | Total | avg/Km | % disturbed |
| 1979-1980 | * | * | * | * | 11 | * | 16 | 8 | | | | | | | | | | 35 | 11.7 | 1.2 |
| 1980-1981 | 0 | 0 | 3 | 16 | 3 | 4 | 0 | 0 | | | | | | | | | | 26 | 3.3 | 0.3 |
| 1981-1982 | 3 | 15 | 4 | 0 | 6 | 83 | 1 | 5 | 3 | 57 | 56 | 0 | 25 | 0 | 0 | 6 | | 264 | 16.5 | 1.7 |

Total No. of New Gouges = 88 Deepest New Gouge .7 m Total Disruption Width = 325 m Mean % disturbed = 1.1

### Testline 5 & 8-FLAXMAN ISLAND

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 7.1 | 10.6 | 11.9 | 14.1 | 16.8 | 19.8 | 20.5 | 22.5 | 24.3 | 25.8 | 27.0 | 27.7 | | | |
| No. of New Gouges | | | | | | | | | | | | | Total | avg/Km | |
| 1979-1980 (TL5) | 1 | 0 | 12 | 12 | x | | | | | | | | 25 | 6.3 | |
| 1981-1982 (TL8) | 0 | 0 | 12 | 1 | 12 | 2 | 2 | 4 | 1 | 5 | x | | 39 | 3.9 | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | Deepest | | |
| 1979-1980 (TL5) | .1 | 0 | .1 | .1 | x | | | | | | | | .1 | | |
| 1981-1982 (TL8) | 0 | 0 | .1 | .1 | .1 | .1 | .1 | .3 | .1 | .8 | x | | .8 | | |
| Total Disruption Width (m) | | | | | | | | | | | | | Total | avg/Km | % disturbed |
| 1979-1980 (TL5) | .1 | 0 | 29 | 25 | x | | | | | | | | 55 | 13.8 | 1.4 |
| 1981-1982 (TL8) | 0 | 0 | 54 | 4 | 58 | 10 | 6 | 10 | 4 | 29 | x | | 175 | 17.5 | 1.8 |

(TL5) Total No. of New Gouges = 25 Deepest New Gouge = .1m Total Disruption Width = 55m Mean % disturbed = 1.4

(TL8) Total No. of New Gouges = 39 Deepest New Gouge = .8m Total Disruption Width = 175m Mean % disturbed = 1.8

### Testline 7-CAMDEN BAY

| Kilometers | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Depth (m) | 5.5 | 6.7 | 7.1 | 7.4 | 8.2 | 9.0 | 9.5 | 10.2 | 10.8 | 11.7 | 12.5 | 13.0 | 14.3 | 15.0 | 15.9 | 16.8 | 17.7 | 18.6 | | | |
| No. of New Gouges | | | | | | | | | | | | | | | | | | | Total | avg/Km | |
| 1981-1982 | 2 | 2 | 2 | 7 | 2 | 15 | 8 | 8 | 4 | 9 | 14 | 23 | 15 | 9 | 18 | 12 | 1 | | 151 | 8.9 | |
| Maximum Gouge Depth (m) | | | | | | | | | | | | | | | | | | | Deepest | | |
| 1981-1982 | .1 | .1 | .1 | .1 | .1 | .2 | .1 | .3 | .1 | .1 | .1 | .1 | .3 | .2 | .7 | .4 | .1 | | .7 | | |
| Total Disruption Width (m) | | | | | | | | | | | | | | | | | | | Total | avg/Km | % disturbed |
| 1981-1982 | 4 | 9 | 4 | 20 | 5 | 50 | 30 | 40 | 14 | 38 | 32 | 68 | 71 | 28 | 95 | 66 | 3 | | 577 | 33.9 | 3.4 |

Total No. of New Gouges = 151 Deepest New Gouge = .7 m Total Disruption = 577 m Mean % disturbed = 3.4

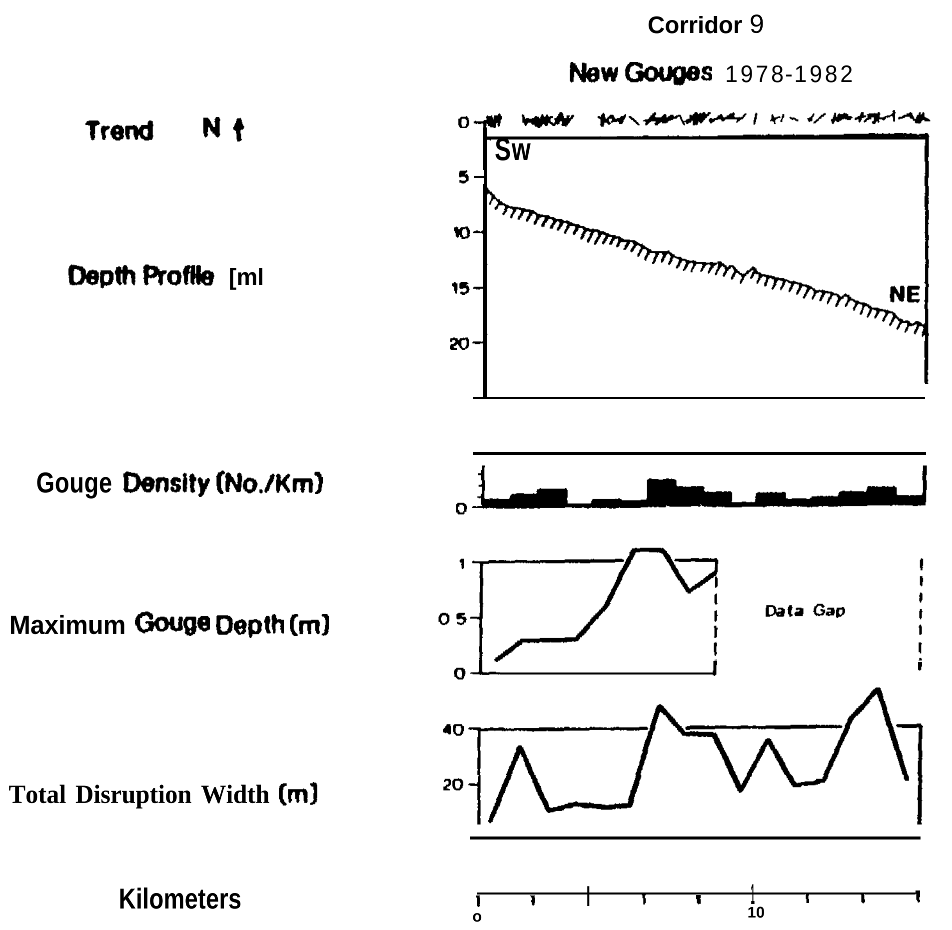


Fig.3 Graph of dated gouge characteristics and bathymetry profile vs. length of trackline for corridor 9. Vertical exaggeration is 1:400 for figures 3 through 11, except Figure 6. There is a 4 year time span between the compared data sets. See Figure 1 for corridor location.

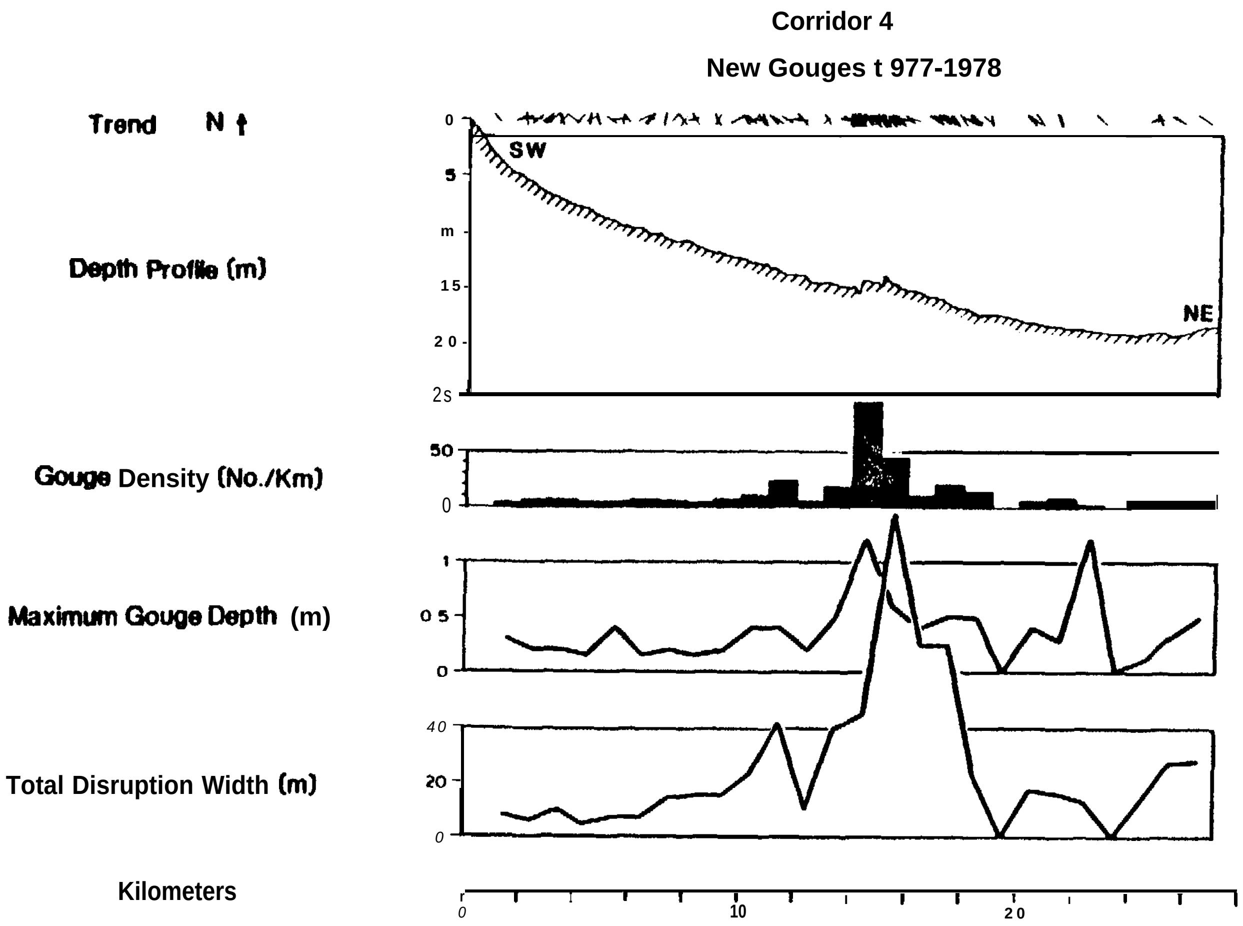
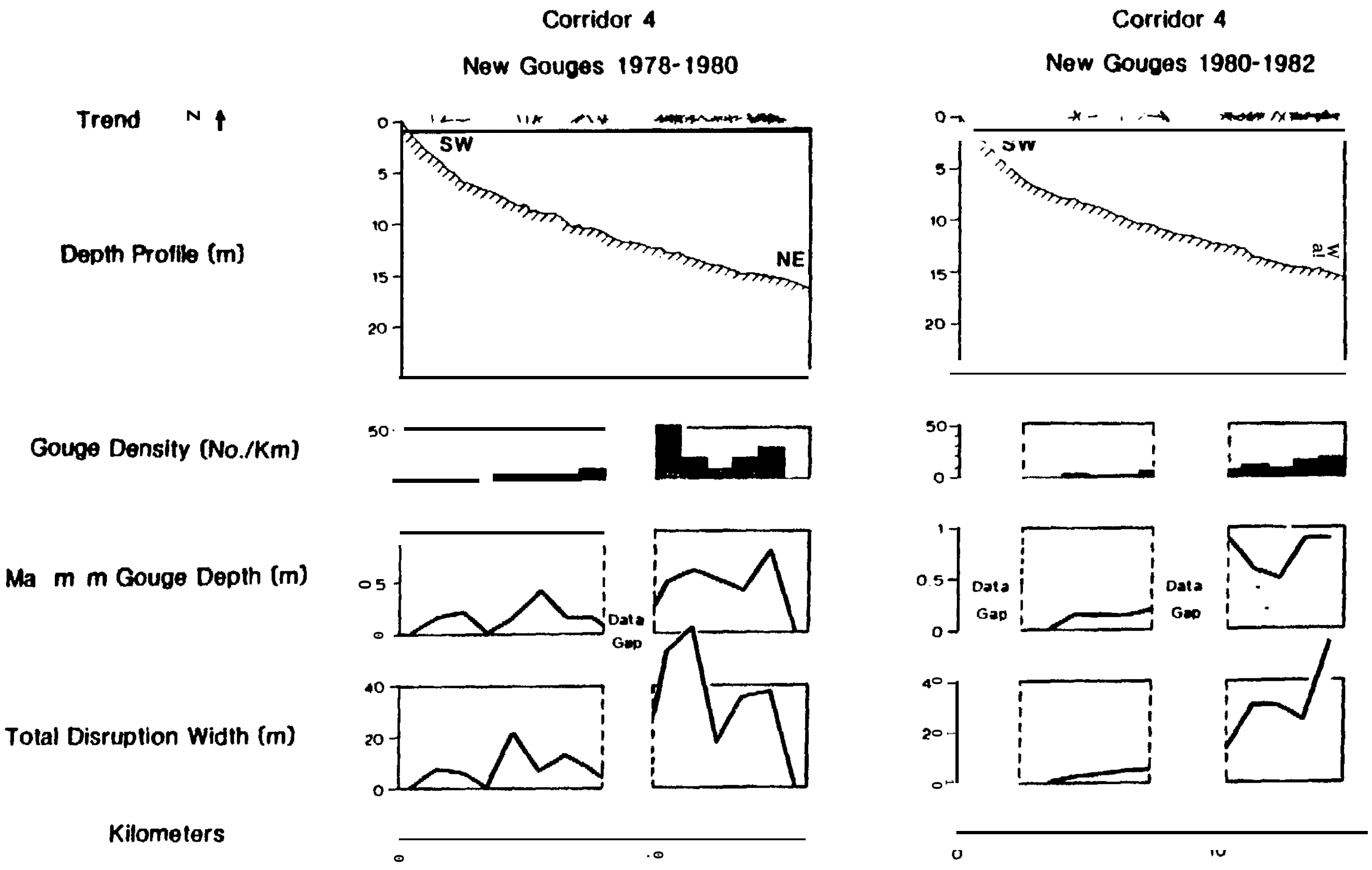


Fig. 4 a. Graph of dated gouge characteristics and bathymetry profile vs. length of track line for corridor 4 (1 year span between surveys). See Figure 1 for corridor location.



Corridor 4
New Gouges 1978-1980

Corridor 4
New Gouges 1980-1982

Fig 4 b. Graph of dated gouge characteristics and bathymetry profile vs. length of trackline for corridor 4 (2 year spans between surveys).

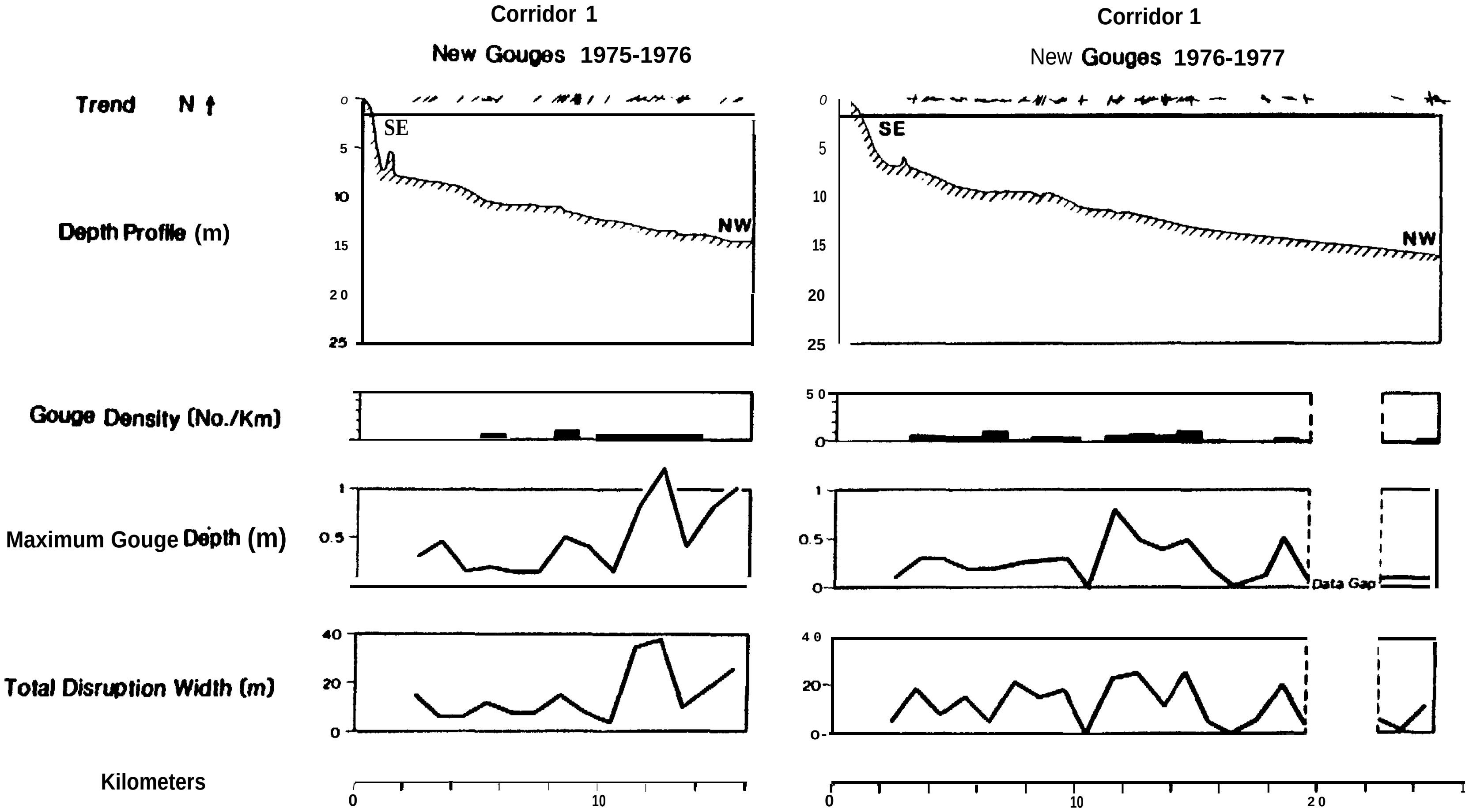


Fig. 5 Graph of dated gouge characteristics and bathymetry profile vs. length of trackline for corridor 1 between 1975 and 1977 (1 year spans between surveys). See USGS Open-File Report #78-730 for data tables for these survey years.

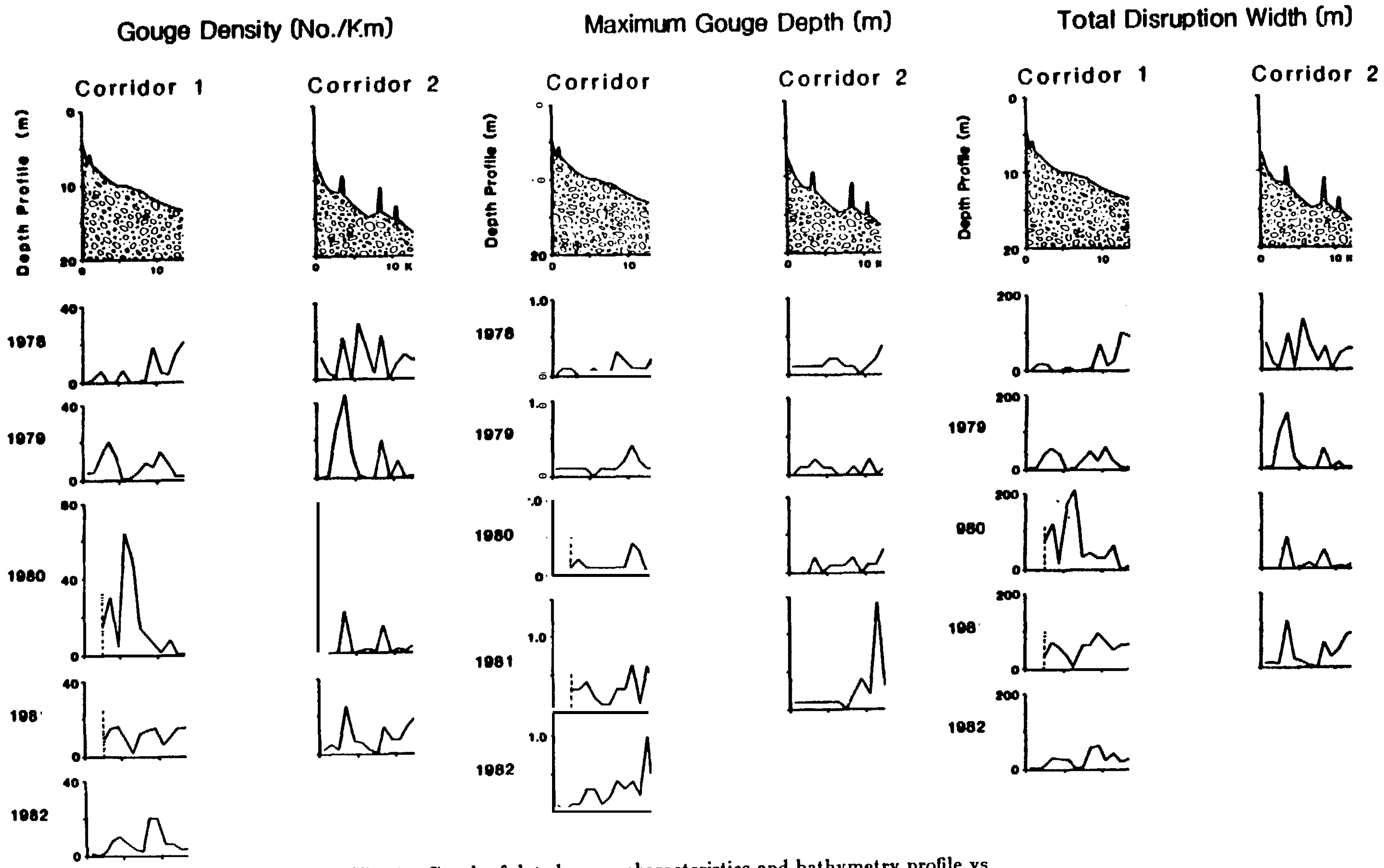


Fig. 6 Graph of dated gouge characteristics and bathymetry profile vs. length for corridors 1 and 2 between 1978 and 1982. 1 year time span between surveys). See Figure for location of corridor. Vertical exaggeration is 1: 000 in this figure.

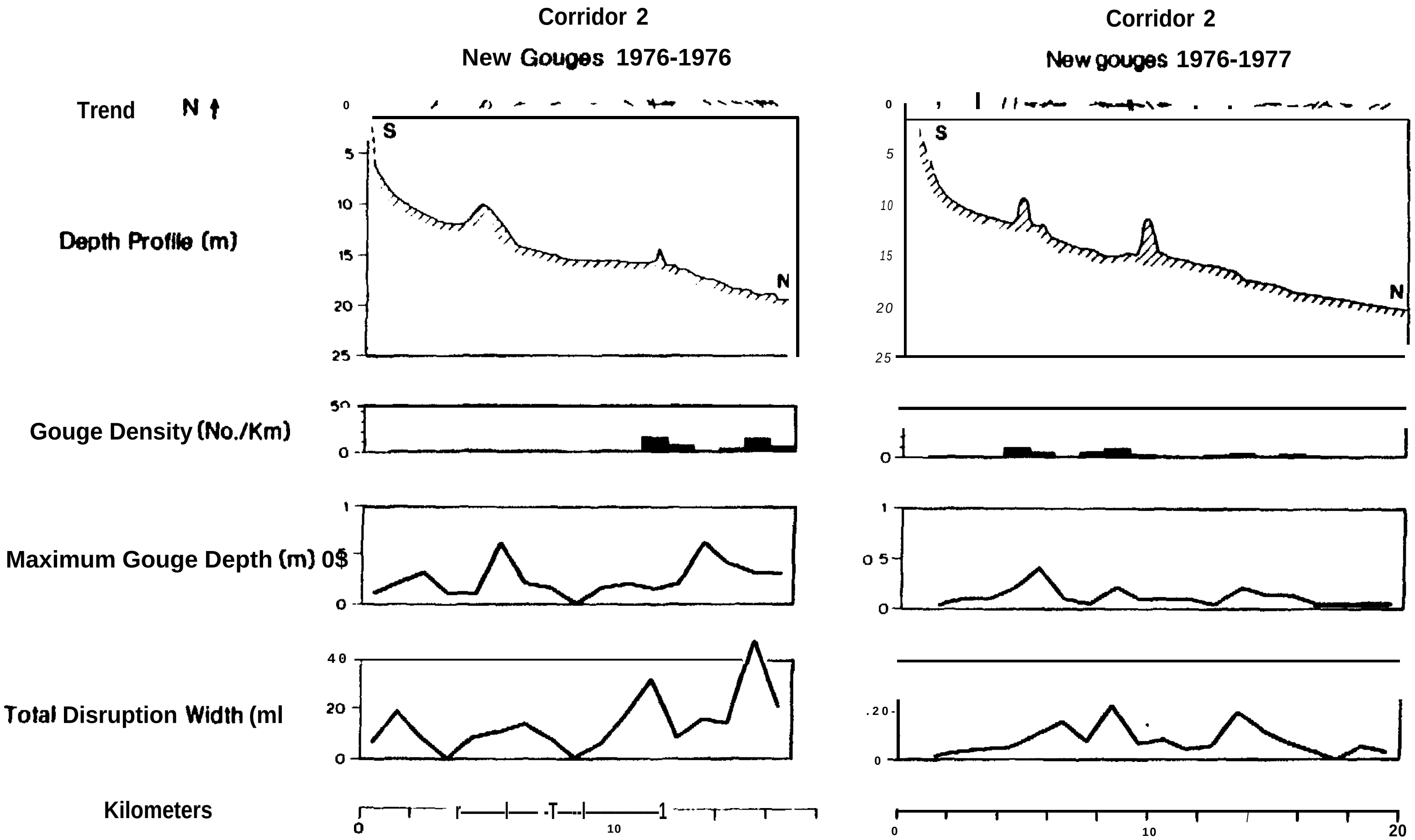


Fig. 7 Graph of dated gouge characteristics and bathymetry profile vs. length of trackline for corridor 2 between 1975 and 1977.

(1 year spans between surveys). See Figure 1 for corridor location and USGS Open-File Report #78-730 for data tables for these survey years.

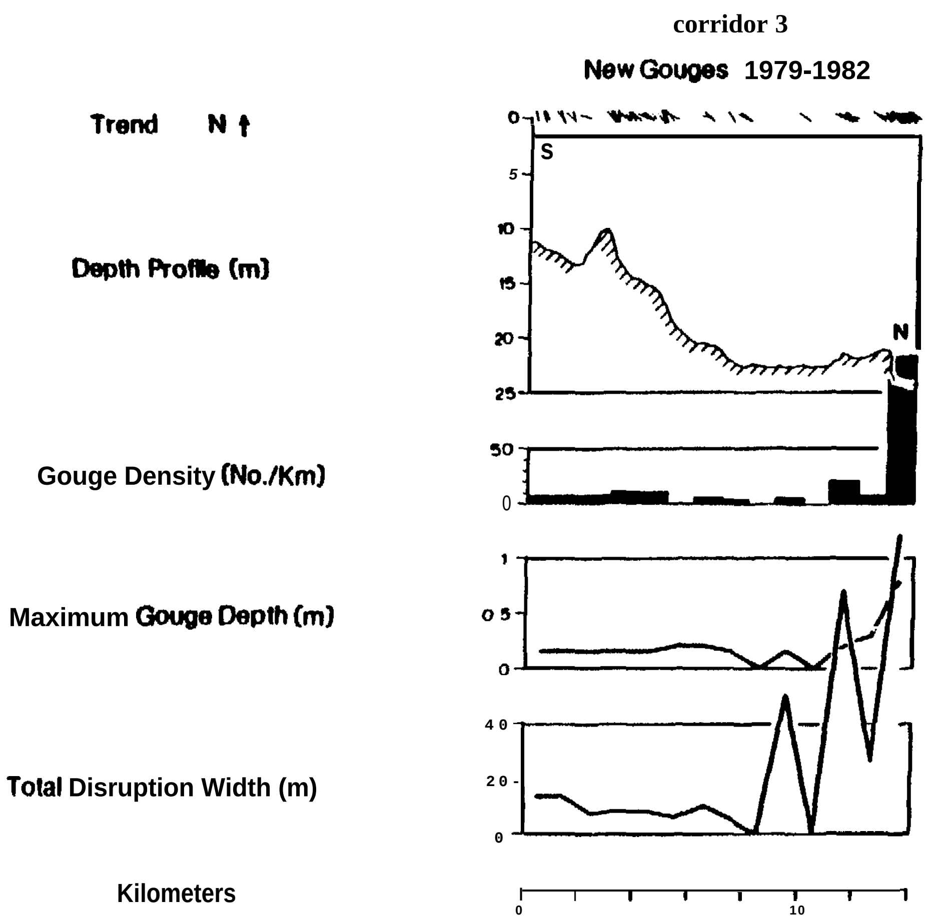


Fig. 8 Graph of dated gouge characteristics and bathymetry profile vs. length of track line for corridor 3 (3 year spans between surveys). See Figure I for corridor location.

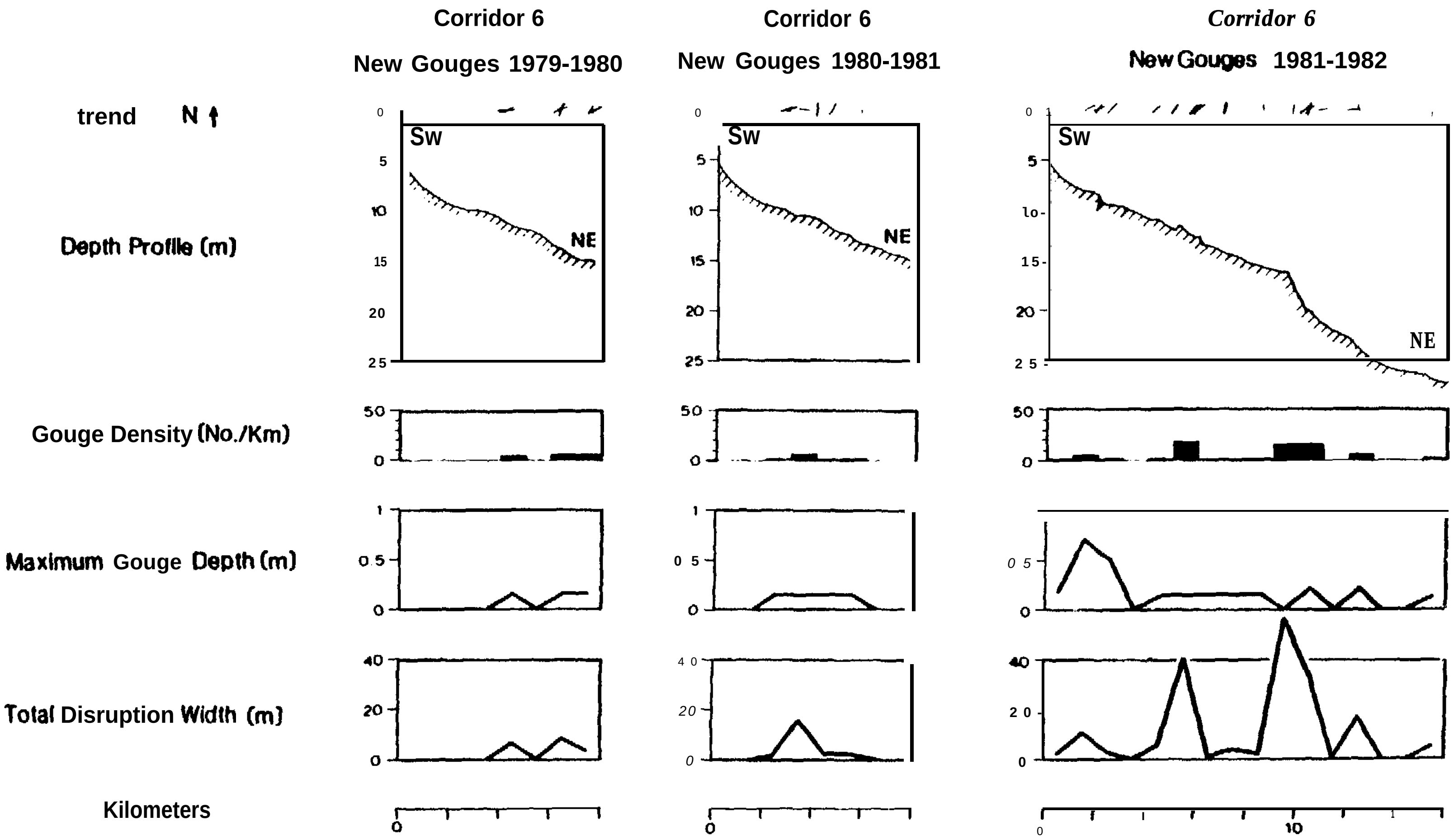


Fig. 9 Graph of new gouge characteristics and bathymetry profile vs. length of trackline for corridor 6 (1 year spans between surveys). See Figure 1 for corridor location.

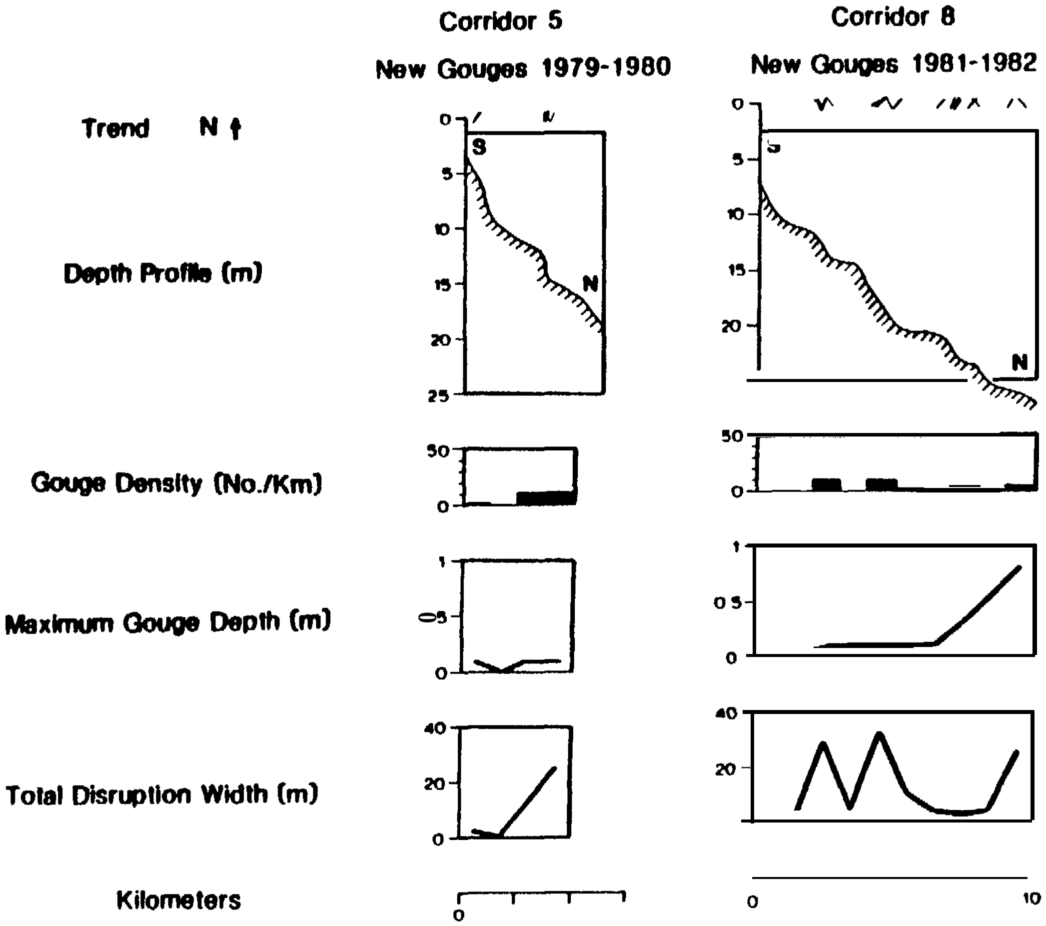


Fig. 10 Graph of new gouge characteristics and bathymetry profile vs. length of trackline for corridors 5 and 8 (1 year spans between surveys). See Figure 1 for corridor location.

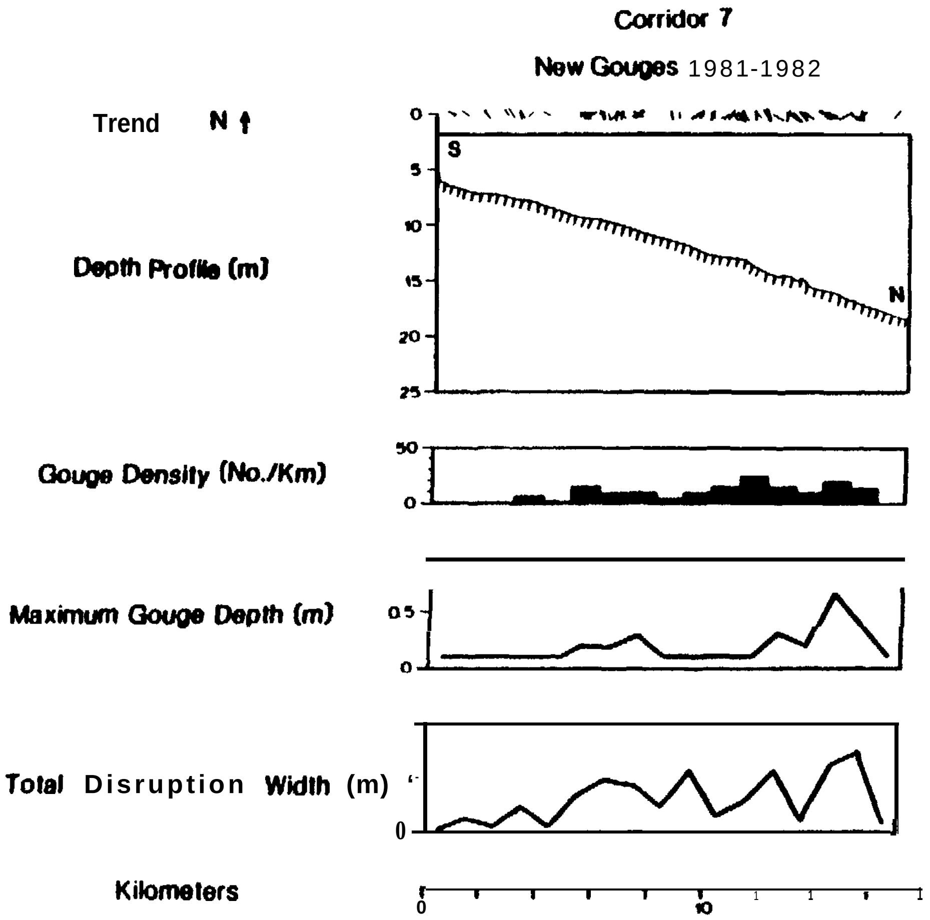


Fig.11 Graph of new gouge characteristics and bathymetry profile vs. length of trackline for corridor 7 ( 1 year spans between surveys). See Figure 1 for corridor location.

**Corridors 5 and 8- Corridor** 5 **was** established using navigation stations that ultimately could **not** be reoccupied and thus we subsequently established corridor 8 nearby using more permanent benchmarks (Figure **1 and Table** 2). The bottom profile of these two corridors is steeper in comparison **to** the three further west **and** show an irregular profile so **that a bench or shoal at 18 to 22m is difficult to discern (Figure 10). Inshore sediments are sands and gravels while at about 20 meters and seaward over consolidated sandy muds and pebbly sandy muds are found.**

Corridor 7- Located in the **eastern** part of Camden Bay, corridor 7 extenda northward from a coast of tundra **bluffs (Figure 1). Starting in water depths of about 6m the profile** gradually drops **to** depths of more than **16m** (Figure 11] similar **to** the profiles from Harrison Bay westward (Figure 4). Sediments are sands and muddy sands on the inner part of the line while in water depths of about 18m **overconsolidated** sandy muds and clays are found.

## DATED GOUGES

### General Characteristics

**The present data set consists of 146 kilometers of corridor. Because many of the corridors have been resurveyed more than twice, 308 one kilometer segments of repetitive observations are compared. The observations consist of over 2500 dated sea bed gouges. These gouges accounted for over 12 km of seabed disruption, to a maximum depth of 1.4 meters. Over 85% of these gouges were less than one year old when entered into the data set.**

An **"average"** dated gouge **can be defined using the data. We wish to stress that this gouge is not representative e of the undated gouge population because of erosion and infilling of the older gouges. Nor is this average gouge representative of the group of datable gouges that exist in toto on the Beaufort shelf as the data set is limited to the inner shelf insbore of 25m. Barnes and others (1984) have suggested that the highest intensity of gouging occurs within tbe stamukhi zone in water depths of 30 to 40 meters. Thus, the *average" gouge we describe is representative of the gouges leas than a year old inshore of the stamukhi zone. This average gouge occurred in water 14 .3m deep and incised the bottom to a depth of 19cm.** ***An*** **average of 8.2** datable gouges occurred per kilometer, disrupting 27m or almost **3%** of the seabed. Tbe data set indicate that this **3%** is a major portion of the the gouges present on the seafloor in the corridors at any one time. Eighteen percent of the 56 gouges per kilometer in the corridors were **less** than a year old (Table 4).

**Considering a larger gouge population (Barnes and others, 1984) from slightly deeper water (18 m) gives an average gouge density of 70 per kilometer or roughly 9 times tbe average number of datable gouges. This suggests that on tbe average** something more than **10%** of the gouges observed on the inner shelf are **less** than a few **years** old.

### Gouge depth

The logarithmic distribution of dated gouge frequency versus gouge depth is similar to the distribution shown by the entire gouge population (Barnes and others, (1984). There are very few deep gouges and very many **shallow ones (Figure 12). The set of dated multiplet** gouge depths are deeper than the population of all dated gouges which is contrary to tbe suggestion by Barnes **and** others (1984) that **multiplet** gouging is associated with first year ice ridges in contact with the seafloor which results in shallow gouge features. Possibly **multiplet** gouging forms the deeper gouges inshore of tbe **stamukhi** zone **where our** data on gouges is concentrated.

**There does not appear to be a relationship between the number of datable gouges and the depth of those gouges. In one case a few gouges were deep (Corridor 9; Figure 3), elsewhere** there were many new shallow gouges (Corridors 1,2,& 7; Figures 5,6,7 & **11**), while in corridor 4 in 1978 there **were many new datable gouges and many of these were deep [Figure 4).**

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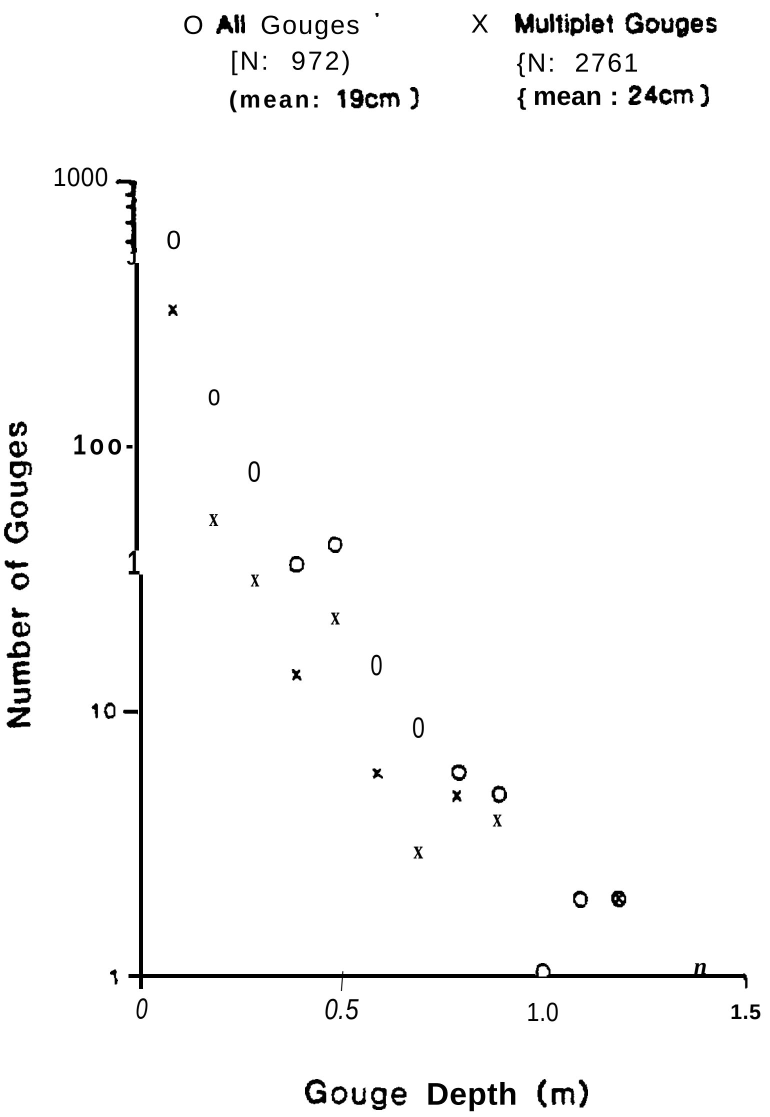

Fig. 12 Distribution of dated gouged versus the observed depth of those gouges. N is the number of gouges in the population.

## TABLE 4

Number Of Gouges

| Line Number | Water Depth (m) | Average no. Gouges . | Seafloor Disruption % per year | Percent of Gouges less than 1 yr. old |
|---|---|---|---|---|
| 1 | 416 | 64 | 4.0 | 22 |
| 2 | 7-17 | 14 | 3.4 | 47 |
| 3 | 11-21 | 62 | 2.5 | 14 |
| 4 | 3-20 | 81 | 3.6 | 10 |
| 5 & 8 | 7-26 | 76 | 1.6 | 11 |
| 6 | 5-26 | 63 | 1.1 | 13 |
| 7 | 6-20 | 76 | 3.4 | 12 |
| 9 | 6-18 | 13 | 2.0 | 18 |
|  |  | 56 ave. | 2.7 ave. | 18 ave. |

### Age

The data for this study was gathered during the open water season, usually in August. This means that nominally a year passes between successive surveys. We have suggested that most gouging occurs during the winter ice covered period (Barnes and others, 1978, and Barnes and others, 1984). Thus the age of "new" gouges on our records is dependent on the number of winter seasons between successive surveys. In most cases this is 1 year and most of the datable gouges were less than one year old when detected. In a few cases 2,3 and 4 years elapsed between surveys in which case we can only say that the gouging occurred sometime during the 2,3 or 4 years since the last survey,

In addition to the age at time of detection, dated gouges can be assigned to time internal during which they were formed. Thus the gouges that occurred during the winter of 1980-81 can be said to be 4 yearn old in 1985.

The ratio of the dated gouge population to the total population was computed for each corridor. These data indicate that the dated gouges commonly make UP a major percentage of the 32 gouges present on the seafloor, particularly on the inshore segments of the corridors (Table 5). This is best illustrated on corridor 1 where we have the longest dated gouge record (Figure 13). There is also some indication that the decrease is reversed at the inner edge of the stamukhi zone in 20m of water(Corridor 3, in Table s). We believe this distribution is due to the higher rates of wave and current reworking infilling gouges and obliterating their surface expression (Barnes and Reimnitz, 1978).

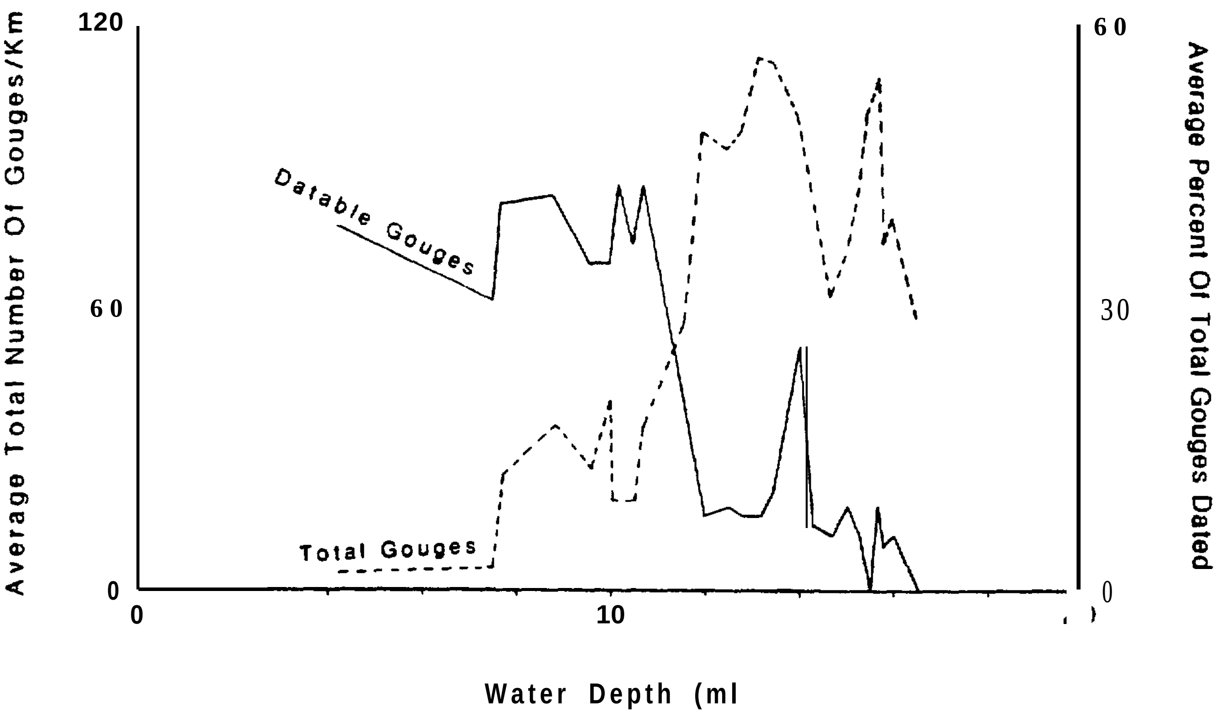

Fig. 13 Comparison of the total gouge population with the percent of that population that was **dated (ie. that was generally less than a year old) for corridor** 1. **Data from Table 5. See Figure 1 for location of corridor 1**.

## AREAL VARIABILITY

Despite the variability in geographic, sedimentologic, and ice environments of the different corridors, ice gouging occurs ubiquitously in all areas and in all water depths studied. Ice gouging is uniformly distributed inside the 15 meter contour (Figures 3 to 11 and Table 3). Given a random distribution of ice keels in, the ice canopy inside the stamukhi zone, a steep rather than gently sloping bottom should be impacted by more ice keels per unit distance. This is not borne out in the overall profiles of the corridors, but is seen where shoals interrupt the profiles (corridor 2, Figure 6 & 7). The steeper profiles of the corridors near Prudhoe Bay (3, 6, 5 and 8 and Figures 8, 9 & 10) do not have noticeable increases in the number of gouges when compared to the more gently sloping corridors to the east and west.

On a smaller scale the concentration and size of newly formed ice gouges is controlled by bottom morphology. Where seafloor slopes are gradual and unbroken by shoals, gouging appears to be evenly distributed in all water depths along the corridors (Corridors 1,7,& 9; Figures 3,5,6, & 11)., When shoals occur within the corridor, their abrupt increase in seafloor slope concentrates newly formed gouges on the seaward flanks of these features and partially shelters the inshore areas from gouging (Corridors 2,3,4, & 6; Figures 4,6,7,8 & 9).

Gouge depths and disruption widths of the dated gougea increase slightly in deeper water, although this trend is not clear cut (see corridors 6 and 9; Figures 3 & 9). An increase in disruption widths with increasing water depths is ascribed to the presence and/or development of larger and more massive ice ridges.

34

The average disruption per kilometer of corridor for different water depths is a further indicator of the increase in amount of disruption in an offshore direction (Figure 14). These data also show a decrease in the amount of disruption between 17.5 and 22.5m. A similar decrease in this gouge parameter was noted by Barnes and others(1984) at these water depths and was linked to the fact that the inner boundary of the stamukhi zone and an associated step or shoal are located here and serve to protect the seafloor inshore for some distance.

Areas that contain higher numbers of dated, shallow gouges and large disruptions widths are associated with multiplet gouge events (See for example corridor 1, 1978 and 1979, Figure 6; Table 3). As multiplet gouging has been associated with first year ice ridging (Barnes and others, 1984) the areas of high multiplet density should mark areas of frequent first year ridging of sea ice.

At water depths of 15 to 20 meters, almost all of the records show a sharp increase in all parameters - numbers of gouges, disruption widths, and incision depths (See especially corridor 3; Figure 8). The inner edge of the stamukhi zone commonly occurs in these water depths each year (Kovacs, 1976; Reimnitz, and others, 1978). The increase in new gouging in this zone is in keeping with the vastly increased ice ridging that occurs here (Tucker and others, 1979) and confirms our earlier postulations that gouging would be more intense in this zone (Reimnitz and Barnes, 1974; Barnes and others, 1978; and Barnes and others, 1984). In contrast to the data of corridor 3 and Figure 14, corridors 6 and 8 cross the inner edge of the stamukhi zone and do not reflect the increase in gouging we expect in this region. Either gouging in the stamukhi zone is episodic and intense or the boundary does not mark a major change of ice gouge recurrence rates. At present we prefer to believe the former.

## TIME VARIABILITY

The year to year variability of the movement and vigor of deep keeled ice ridges should be reflected in the intensity of fresh seafloor gouging, Ice conditions on the inner shelf can vary from season to season due to timing and intensity of storm events and to ice distribution patterns at

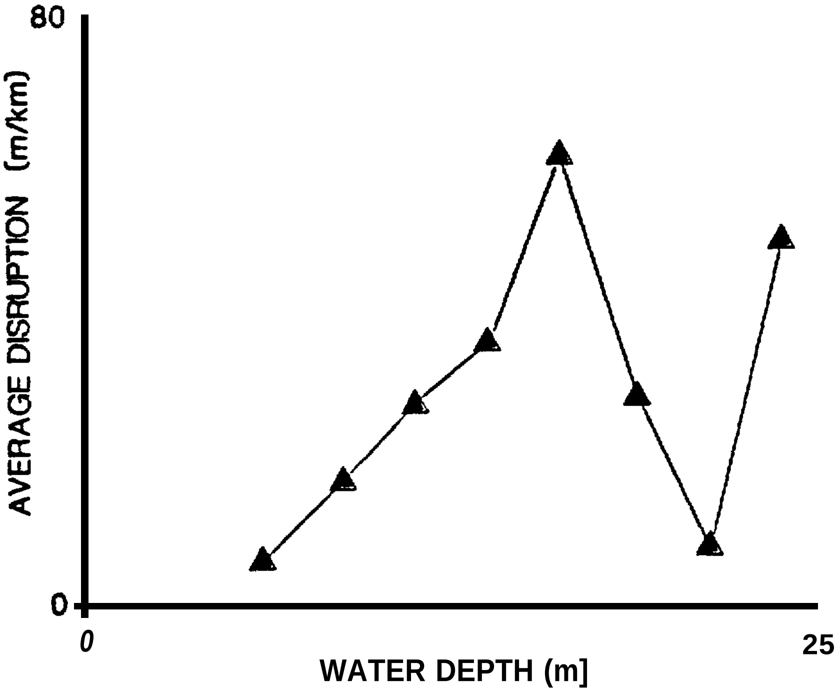

**Fig. 14 Comparison of the average amount of seafloor disruption per** kilometer **and** water depth. All corridors were divided into 2.5m depth increments, and the average computed.

36 freeze up. In 1975, at the end of summer, a large percentage of ice from tbe previous winter remained on the inner shelf which was incorporated in the 1976 ice canopy. These older "welded" ice blocks (Kovacs and Mellor, 1974) would carry solid ice keels within a moving ice canopy and could form a nucleus for grounded ice ridges (Kovacs, 1976). Gouges formed under such an ice canopy could be dominated by individual gouges and by the 2 to 4 keel multiples from the "welded" keels. Furthermore these gouges should be deeper due to the more competent older ice keels.

In contrast the inner shelf during the summer of 1980 was essentially free of older ice by the time of freeze up and the 1981 ice canopy in the study area was formed primarily from first year ice. As first year ice is dense, keels will be deeper for first year ridges than multiyear ridges with sails of equal height. (Kovacs and Mellor, 1974). However, first year keels would be less competent in their ability to gouge not having undergone extensive welding from successive freeze-thaw cycles, although, they may be responsible for extensive shallow multiplet gouging, commonly with many more than 5 gouges per multiplet (Barnes, and others, 1984). Thus we might expect gouging from the winter of 1980-81 to result in a dominance by shallow multiplet gouges.

The time series data we have to examine is rather limited, consisting of 7 yearn of records in one corridor and 6 and 2 years of records at only two other corridors (Table 3). Tbe remainder of tbe data are averaged over several years or represent only a single year. The data indicate no obvious correlation exists between corridors from year to year when comparing trends in average number of dated gouges (Figure 15) or average disruption width (Figure 16). The data do show that tbe number and width of datable gouges in any year vary by a factor of 5 or more. An attempt to correlate tbe ice gouge variability with tbe severity of winter ice conditions by examining tbe wind record at Barrow has thus far been unsuccessful. Tbe lack of correlation is perhaps due to the short length of record we have in light of the fact that the bottom is only gouged a few percent per year and on the fact that tbe severity of ice ridging and the seasonality of ridging is poorly known.

## CONCLUSIONS

1. The intensity of new gouging is related to water depth and bottom morphology, and indistinctly increases offshore at least to water depths of about 25m. Inshore of the stamukhi zone the amount of gouging and the depth of gouging is rather uniform even into waters less than 10 m deep.
2. No correlation exists between the numbers of new gouges and tbe depth to which new gouges have penetrated the sea floor. This results because large numbers of new gouge are associated with wide shallow multiplet gouging ( first-year pressure ridges )
3. Areas that have high gouge densities and large disruption widths are due to multiplet events. A few large multiplet events may account for extensive but shallow disruption of the seafloor.
4. Annual variations in tbe number of individual verses multiplet gouges may be related to the presence or absence of multi-year ice ridges on tbe inner shelf during winter.
5. The annual variations in the data indicate that year to year gouging on this part of the Beaufort shelf is ubiquitous. The year to year intensity of gouging can vary by a factor of 5.

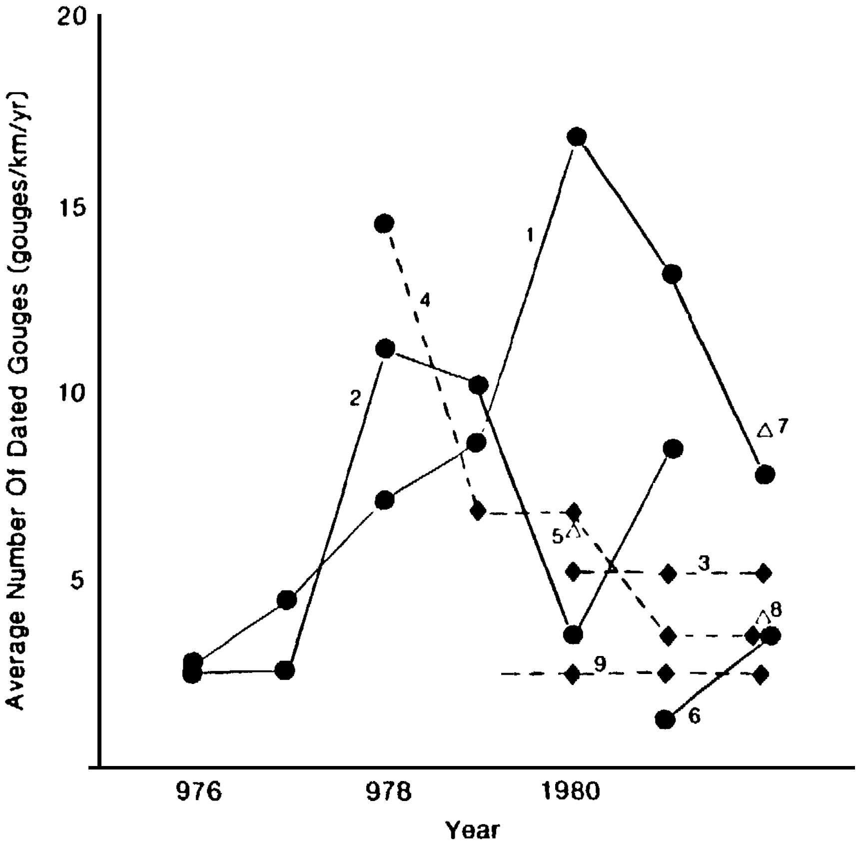

Fig. 5 The yearly variation in the average number of dated gouges per kilometer observed in each of the corridors.

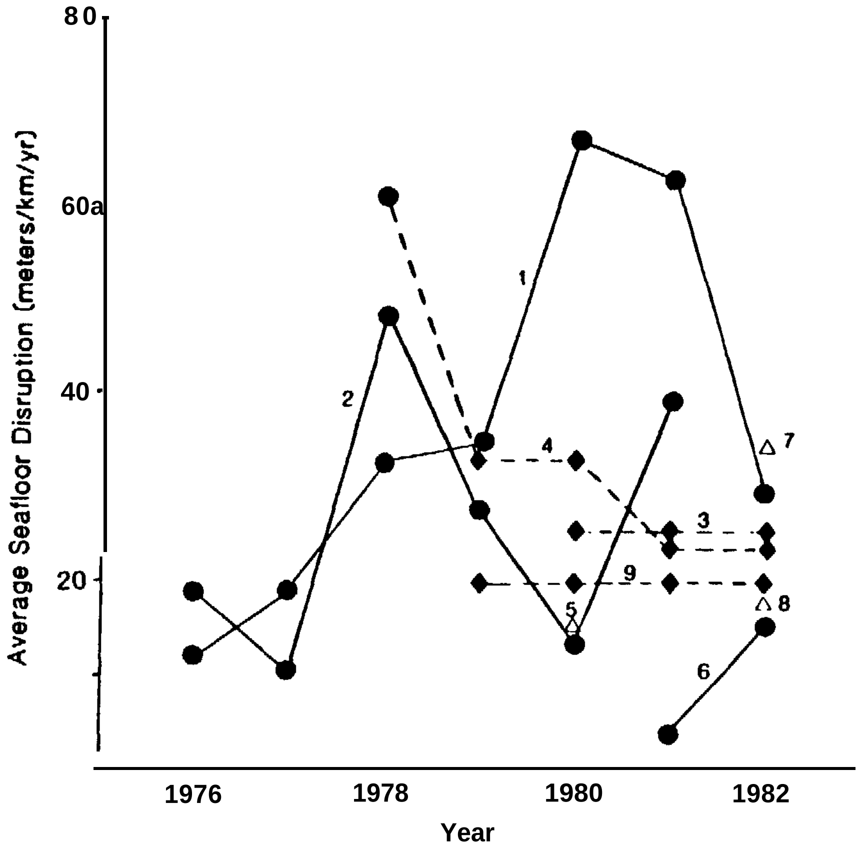

Fig. 16 The yearly variation in the average disruption width per kilometer observed in each of the corridors.

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## KEY TO APPENDIX

**Testline** - refera to corridor number to which the data apply

**Julian Date, Year** - Year and date of survey

**Template Identification** - Template used to correct orientation distortion cause by variable ship speed and recorder paper speeds - expressed as the ratio of the along track distance to the slant range distance.

**Trackline Number** - Field number used to ‘organize field data within each years field effort - not used in analysis.

Additional explanation and usage of many of the following terms is given in Barnes and others, (1984) and in Figure A1 taken from that reference.

**Single Gouges** - Gouges generated by a single tool indenting the bottom leaving a single furrow.

**Multiple gouges** - Gouges generated by a tool with 2 or more indenters leaving one or more adjoining furrows on the seafloor.

**Segment** - Corridora were divided into 1 kilometer segments starting at A, thus the first segment is AB with a starting point at 0km (AB/0). Further along the corridor segment DE starts at 3km (DE/3). Within a segment the distance from the inshore end of the corridor to the occurrence of a dated gouge is given in hundreths of a kilometer (eg. within segment BC/1 a dated gouge was located at 1.50km from A).

**Water Depth** - Water depth at the inner end of a segment at at the location of each dated gouge.

**Total Gouges** - Total number of seafloor furrows observed in a segment. Each furrow in a multiple gouge is counted separately.

**Total New Gouges** - Total number of dated seafloor gouges in a segment. Each furrow in a dated multiple gouge is counted separately.

**Length of new single gouges** - Total length in meters of the dated gouges as observed on the monographs. NL - gouge traversed the entire sonograph and the length was not ascertained: usually a gouge length greater than 250m is indicated based on the scan width of the monographs.

**Gouge depth** - The distance in meters from the “average” seafloor to the bottom of a gouge as measured on the fathograms. This depth is entered ss < .2m when the gouge was not resolvable *on* the fathogram.

**Gouge width** - The distance in meters across the width of a gouge at the measured at the level of the “averaged” seafloor measured on the fathogram.

**Ridge height** - The distance in meters from the “average” seafloor to the top of the highest ridge flanking a dated gouge. This height is assumed to be < .2m when the ridge is not resolvable on the fathogram.

**Φ ( “ T)-** refers to the uncorrected and corrected orientations of the dated gouges relative to true north. The orientations are uniformly reported entered as an angle

**between O and 180° and should not be read as the direction of ice motion during gouging. 160/105 is a gouge oriented at 160’ to the right of a ships course of 305” which results in a 105” orientation for the gouge relative to true north.**

**Length of new Multi. gouges - See Length of single gouges above.**

**Number of incisions - Refers to the number of parallel adjoining furrows that comprise a multiple gouge feature.**

**Deepest incision - The distance in meters from the “average” seafloor to the bottom of the deepest furrow in each multiple gouge as measured from the fathograms.**

**Disruption Width - The distance im meters measured at right angle to a multiple gouge from one bounding ridge to the other, ie the total width of seafloor disrupted by a multiple gouge.**

**Φ {‘ T) - Refers to the orientation of the multiple gouges. See this same entry above.**

**Comments - Includes additional observations on monographs and fathograms. Note - CS= Ships course, SS# - Side scan sonar roll numbers, Bats# - Fathogram roll number, Termination direction - direction of implied ice motion determined** from the termination **of an ice gouge and could have an orientation from O to 360°.**