UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ICE-GOUGE DATA, BEAUFORT SEA, ALASKA, 1972 -1980

by

Douglas M. Rearic, Peter W. Barnes, and Erk Reimnitz

OPEN-FILE REPORT

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INTRODUCTION

The interaction of sea ice with the sea floor is an important factor affecting geologic processes on high latitude shelves. One of the most obvious forms of this interaction is the formation of furrow-like gouges on the sea floor. These gouges are caused by wind- and current-driven ice masses that rake the seabed with their keels. Since the advent of side-scanning sonar about 1970, the morphology and character of these seabed features have been under study. Ice gouges have been reported from the Bering Sea (Thor and Nelson, 1980); from the Chukchi Sea (Rex, 1955; Toimil, 1978); from the Beaufort Sea off Alaska (Brooks, 1974; Carsola, 1954; Reimnitz et al., 1972); from the Beaufort Sea off Canada (Kindle, 1924; Lewis, 1978; Pelletier and Shearer, 1972; Wahlgren, 1979); from the east coast of Canada (Harris, 1974); from the northeast Atlantic (Belderson et al., 1973); and from the Great Lakes (Berkson and Clay, 1973).

We have been collecting ice-gouge data in the form of sonographs and fathograms since 1972, and since 1975 precision bathymetry and navigation have been used as an aid to our studies. Our initial efforts summarized distribution and character of ice gouges (Reimnitz et al., 1973; Reimnitz and Barnes, 1974). Subsequently, we have focused on describing processes and rates of processes (Barnes et al., 1978, Barnes and Reimnitz, 1979; Reimnitz et al., 1977). In this report we outline the field and office techniques, the terminology, and the results of an effort to enumerate ice gouge characteristics from existing sonographic and bathymetric records to form a comprehensive set of data on ice-gouge characteristics on the Alaskan Beaufort Sea shelf.

Over 2000 kilometers of trackline data collected in the Beaufort Sea between 1972 and 1980 have been analyzed for ice-gouge characteristics (Barnes et al., 1973; Barnes et al., 1980; Kempema et al., 1981; Maurer et al., 1978; Reimnitz et al.; 1979a, 1979b). These tracklines were selected in order to obtain nearly continuous detailed ice-gouge data coverage from Smith Bay to Camden Bay, Alaska (Fig. 1). Three major environments were covered by these records: Harrison Bay, the semi-protected lagoons and sounds, and the offshore shelf areas. The division of data into 1-km segments allowed a detailed analysis of ice gouging in sub-environments such as shoals as well a gross characterization of shelf gouging. In the course of the project other seabed features such as strudel scours (Reimnitz et al., 1974), tick marks (Reimnitz et al., 1973), and sediment waves and ripples were recorded and measured where possible.

The comprehensive study of ice gouge characteristics has only recently been attempted and the terminology for these features has not been standardized. In this report the term ice gouge is synomomous with ice score (Kovacs, 1972), ice scour (Lewis, 1978; Pelletier and Sherarer, 1972), ice scour track (Wahlgren, 1979), and ice plow mark (Belderson and Wilson, 1973). The terminology we use here follows the usage of Barnes et al., (1978), Reimnitz and Barnes (1974), and Toimil (1978), and is diagramed in figure 2. A detailed discussion of the range of modifiers for terminology to cover a range of ice-gouge forms is given in Wahlgren (1979).

As we are primarily interested in the effect gouging has on the seabed rather than in the tools that caused the gouging, we consider each seabed incision as a separate gouge even when several parallel gouges may have been

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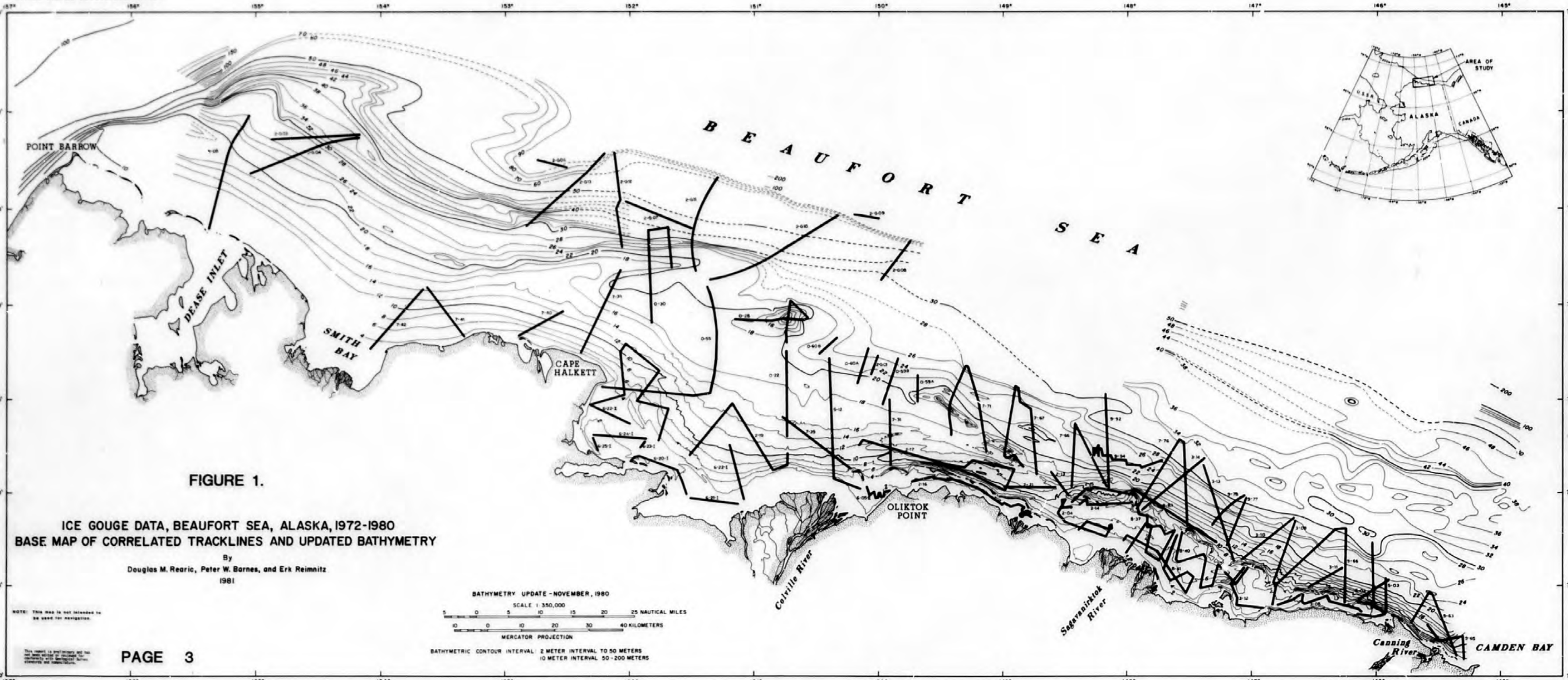

FIGURE 1.

ICE GOUGE DATA, BEAUFORT SEA, ALASKA, 1972-1980
BASE MAP OF CORRELATED TRACKLINES AND UPDATED BATHYMETRY

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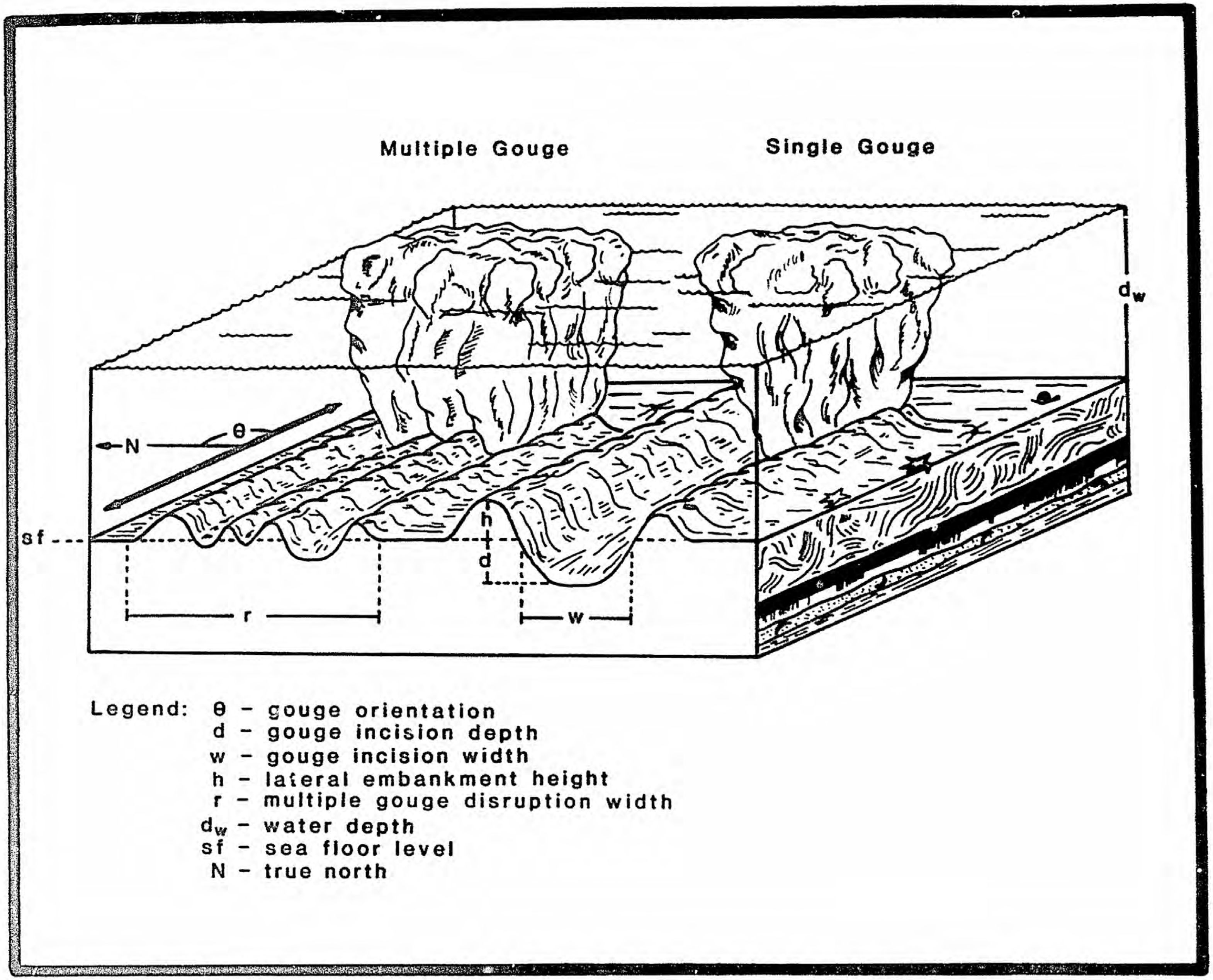

Figure 2. Diagram of the typical gouge measurements made from side scan sonar and fathometer records.

caused by the same ice movement event or even by the multiple tools of a single ice keel. This, along with the fact that we counted gouges in the area covered by our sonographs rather than only those crossed over by the ship, makes our density values generally higher and unfortunately incomparable to Canadian data (Lewis, 1978; Wahlgren, 1979) or Bering Sea data (Thor and Nelson, 1980).

Methods of Data Collection

The records used in this project were collected from on board the U.S.G.S. R/V Karluk and R/V Loon and the U.S.C.G. icebreaker Glacier. Bathymetry data collected in 1972 and 1973 were recorded by either a fathometer or a high-resolution seismic system. On the best of these fathograms we could resolve depth changes as small as 30 - 40 centimeters. Bathymetry records collected between 1975 and 1980 were obtained with a Raytheon RTT-1000 dry paper recording fathometer using a 200 kHz transducer for bottom profiling and a 7 kHz transducer for subbottom observations to 10 m below the sea floor (Fig. 3).. Under ideal conditions this system can resolve features as small as 15 cm. Sonar coverage was accomplished using a model 259-3 EG & G Side-scan sonar recorder and a model 272 EG & G sonar fish using a 105 kHz pulse (Fig. 4). The availability and quality of the sonographs were major determinants in trackline selection.

Data collection was subject to many types of problems both internal and external. The variation in data sources from year to year controlled the overall resolution. The variation in quality of records depended on two major factors: enviromental factors affecting the bathymetric and sonographic records, and ship and system operational variabilities. Many of the factors influencing the quality of sonographs in general have been presented by

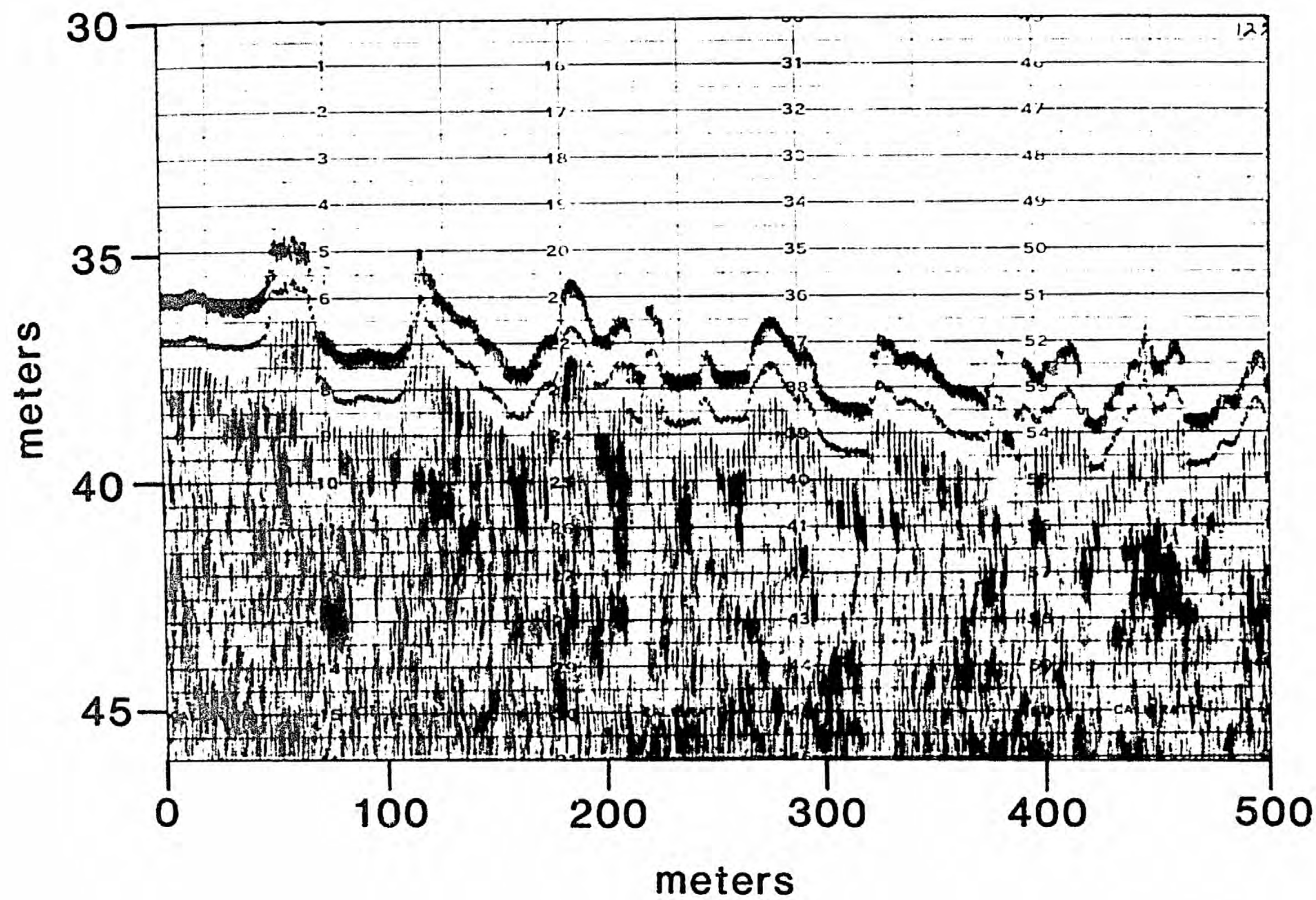

Figure 3. Fathogram of an ice gouged seafloor from which the measurements of gouge depth, ridge height, water depth, and subbottom depth were made. Water depth is 36 meters.

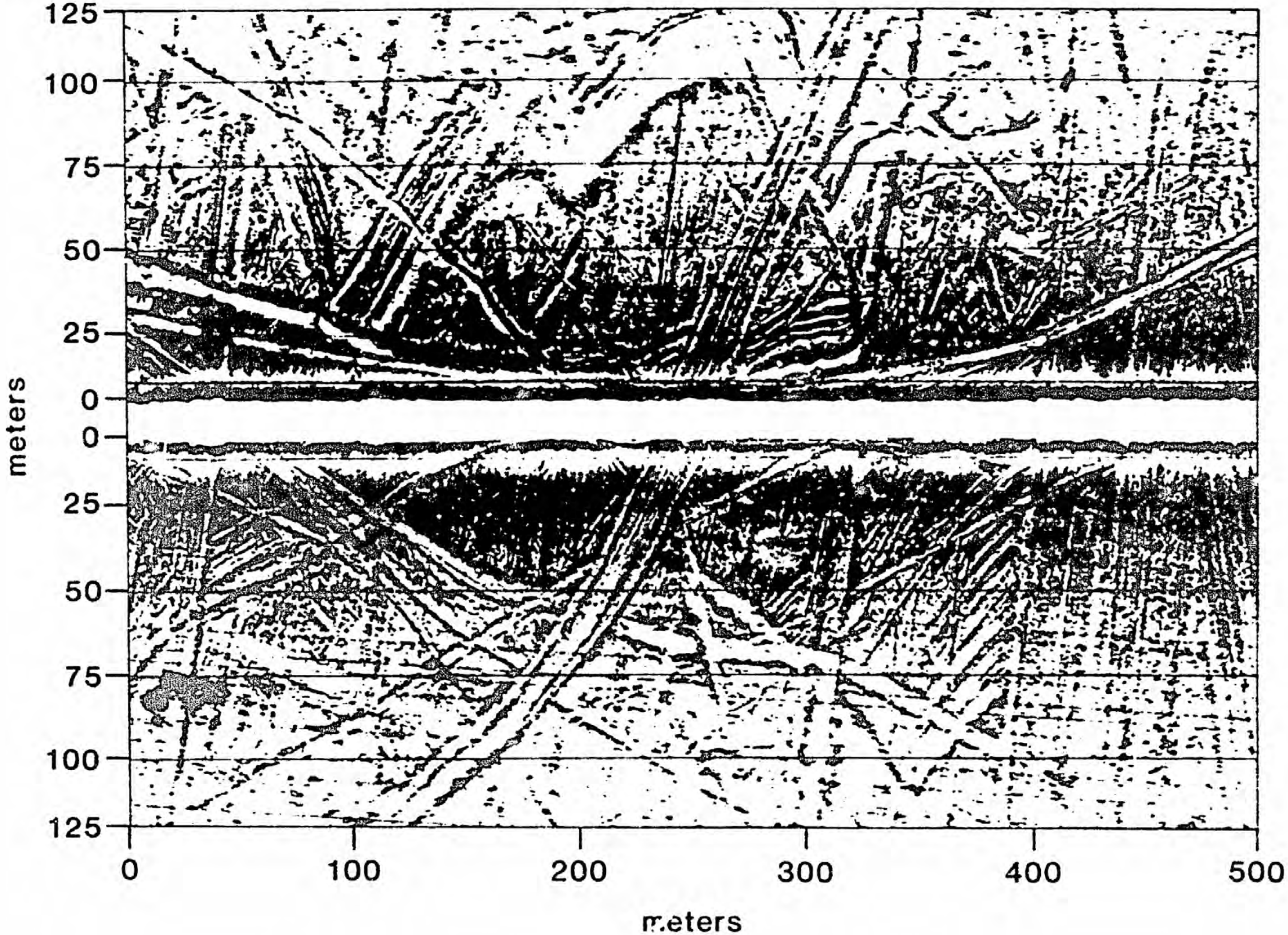

Figure 4. Sonograph of an ice gouged seafloor from which the measurements of gouge density, gouge orientation, and gouge width were made. Water depth is 20 meters.

Belderson et al. (1972). Ice influenced the record quality in two unique ways: (1) floating or grounded ice acts as a strong reflector, printing a strong signal on the sonograph and often blocking the view of the seabed beyond the ice, (2) on many track lines the presence of ice required the helmsman to steer left and right of the track to avoid the ice, thereby causing the side-scan sonar sensors to veer back and forth resulting in an unreal sinuosity to linear features on the sonographs. Additional factors influencing the sonographic records are depth of tow-fish (insufficient tow depth decreases resolution of small features such as gouges) and system-tuning variability from operator to operator and from year to year. Because side-scan sonar records represent the acoustic reflection properties of the sea floor, it is possible that some gouges, infilled by fine sediments, may be visible because of textural differences between the gouge fill material and the surrounding sea floor sediments. This problem, however, was not encountered except with gouges observed in the deeper offshore areas (usually greater than 50-m depth). Again, due to the reflection process of sonar, the orientation of gouges relative to the trackline had an effect on the clarity and resolvability of gouges (Fig. 5).

Typical factors affecting the quality of bathymetric records are sea state and water depth (decreasing signal strength and increasing sound cone coverage combine to decrease record quality and resolution).

Navigational accuracy varied greatly within the data set. Techniques ranged from dead reckoning to radar to precision range-range techniques on the innermost shelf. An evaluation of the error has not been made on a line-to-line basis but in general the records obtained closer to shore and more recently are more accurate. We estimate, at worst, location errors on the order of 1 kilometer, and, at best, errors of only a few meters.

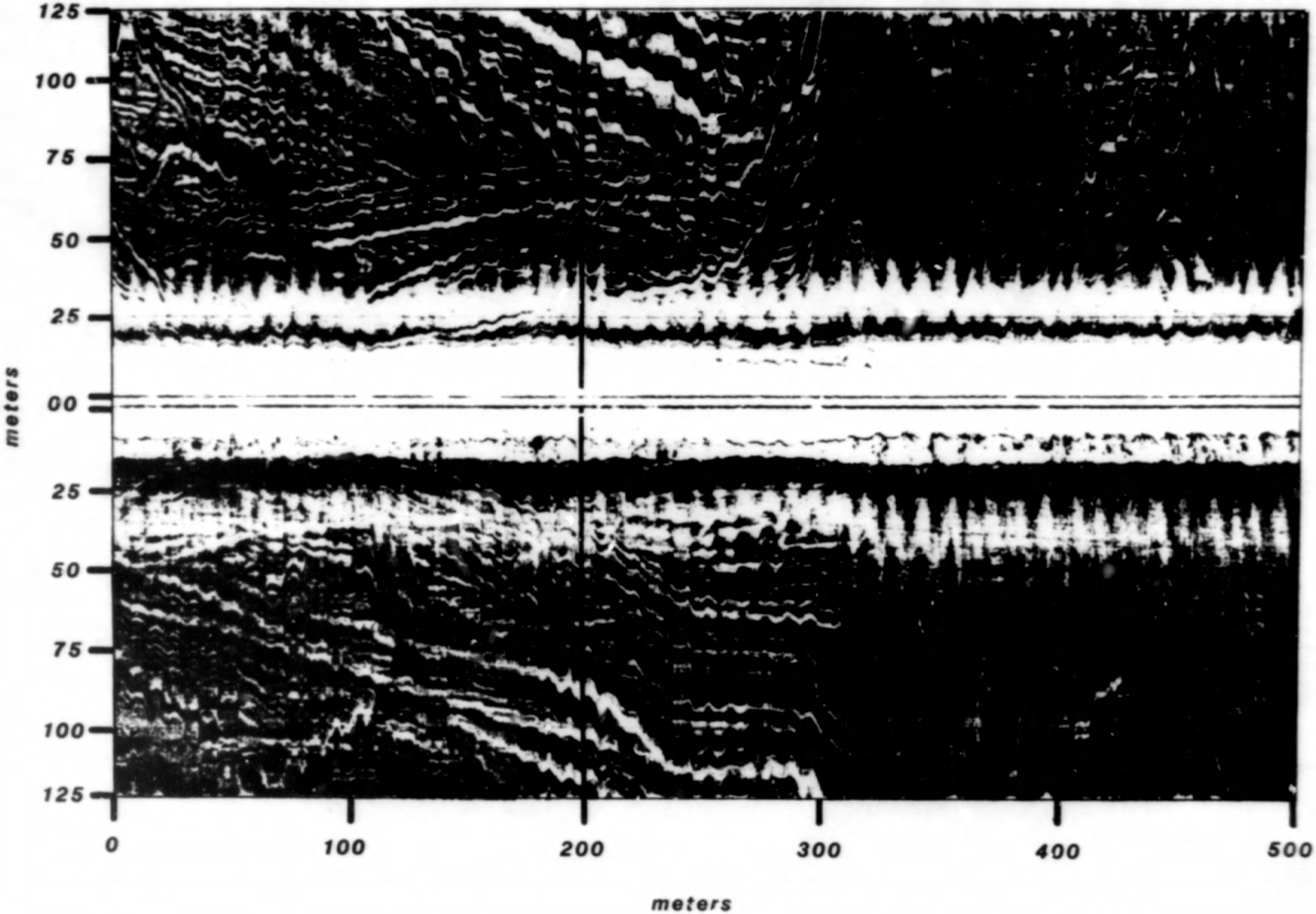

Figure 5. Effects of a one meter swell and change in gouge orientation (due to a 90 degree course change at the 300 meter mark) on the side scan sonar quality.

Methods of Data Analysis

At the beginning of this project we decided to collect as much data at one time as was possible from our records. After the selection of suitable tracklines, navigation records were used to divide tracklines into 1-km segments (Fig. 6). Using time ticks keyed to navigation, the same 1-km segments were marked on the sonographs and fathograms (Rearic and Barnes, 1980). A data sheet was used to tabulate gouge characteristics in each segment (Fig. 7). The major ice gouge characteristics of interest are shown in figure 2. In order to minimize the admittedly subjective factor in the observation and measurement of gouge characteristics, the analysis was performed by one individual (D. R.). Observations and counts from early in the study were repeated in an effort to keep the observations consistent. The following are the data gathered, the units, and the source of information:

1. Segment identification (km) (navigation)
2. Distance from the coast (km) (navigation)
3. Average orientation (°T) (sonographs)
4. Orientation variability (sonographs)
5. Observed number of gouges per segment (sonographs)
6. Correction factor and gouge density
7. Gouge depth (m) (fathograms)
8. Maximum gouge depth (m) (fathograms)
9. Maximum ridge height (m) (fathograms)
10. Maximum gouge width (m) (sonographs)
11. Multiple gouge incisions (sonographs)
12. Depth to the first reflector (m) (fathograms)
13. Other measurements and remarks

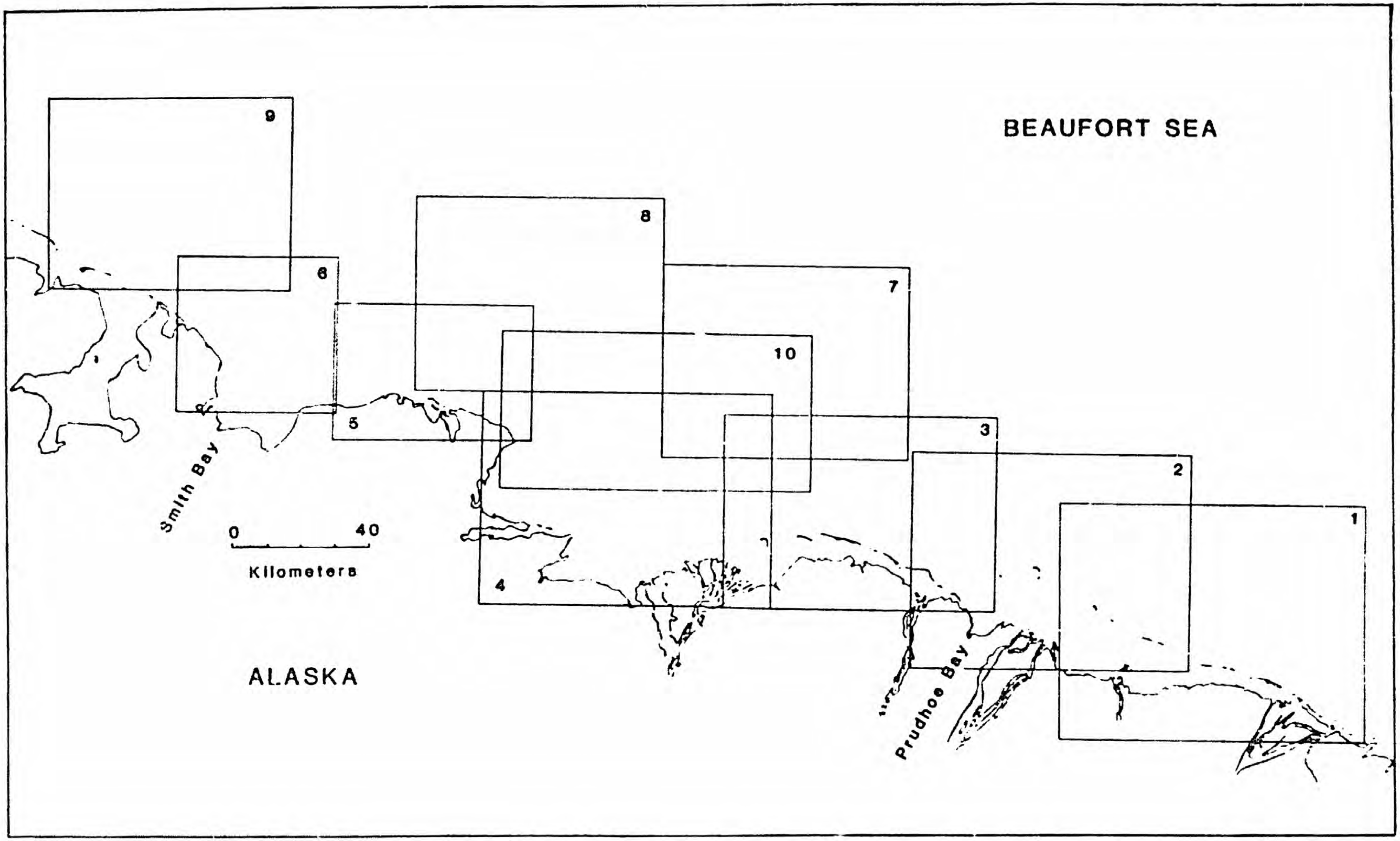

Figure 6. Location map of the ten navigation plates which were developed to correlate sonar and bathymetric records to the trackline navigation at one kilometer intervals. The navigation plates are included with the data set.

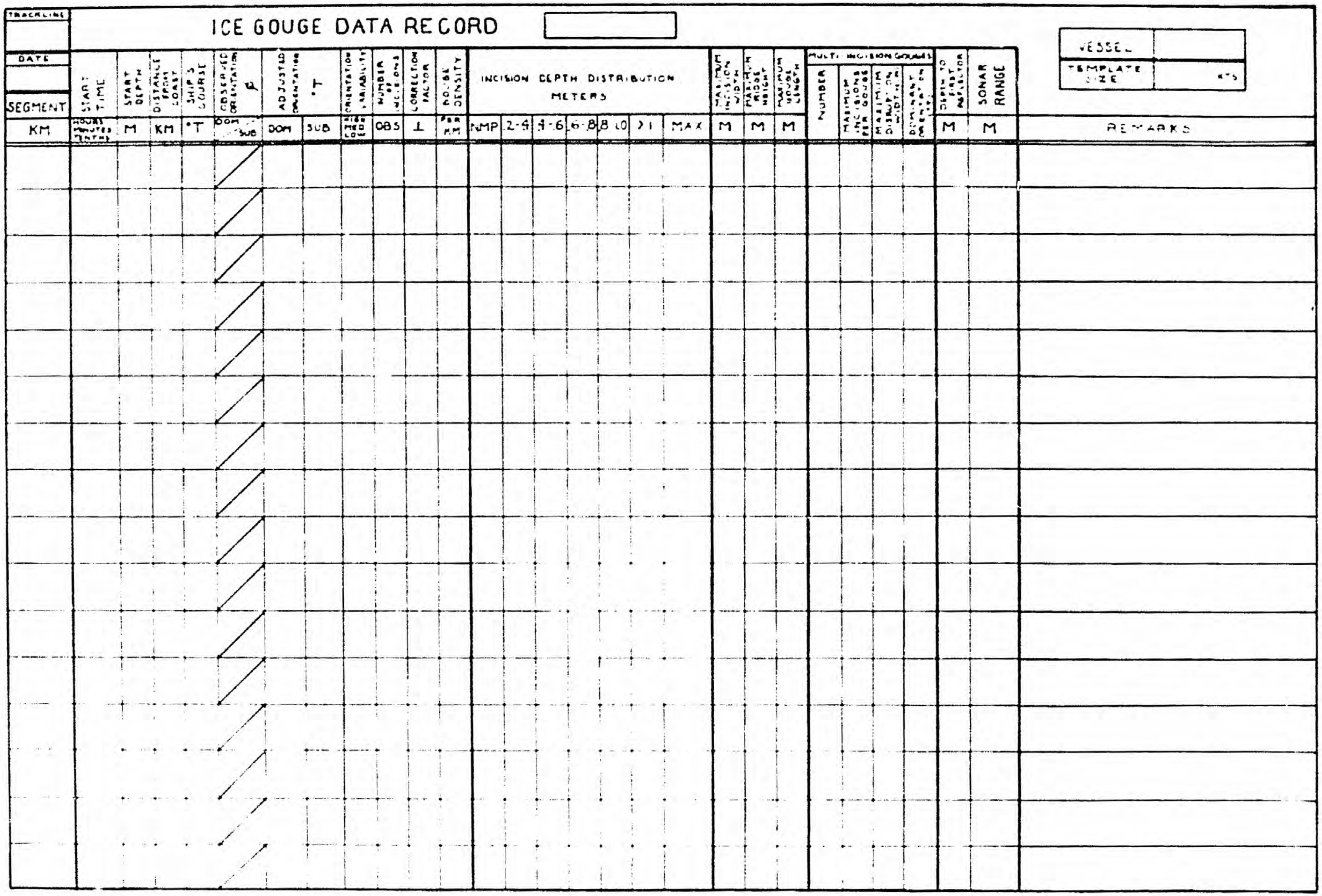

Figure 7. Ice gouge data sheet developed for the recording of ice gouge measurements. See text for an explaination of the column headings.

Explanation of Data Categories

1. Segments (Km) (navigation).- The segments of each trackline are 1 km long. Segment designation letters are references to points spaced 1 km apart with point A being the position of the start of the trackline. Point B is then plotted 1 km along the trackline from point A. The measurements of Start Time, Start Depth, Distance From the Coast, and Depth to the First Reflector refer to the first point of the segment designation letters in that 1-km segment. All other measurements pertain to data acquired between the segment points. In segments where less than 1 km of sonar record was available (due to machine malfunction, paper roll change, etc.), the number of observed gouges counted was adjusted to a 1-km estimate by simple proportion. Line numbers are keyed to year of record, then to trackline within that year (e.g. 7-39 = trackline No. 39 in 1977).

2. Distance from The Coast (km) (navigation).- The measurement was taken normal to the coast or a barrier island. No measurements were taken on tracklines (or portions of them) run in areas between the coast and barrier islands. These areas included Simpson Lagoon, Steffanson Sound, Leffingwell Lagoon, and Harrison Bay (Fig. 1).

3. Average Orientations ($^{\circ}$T) (sonographs).- The average orientation was measured to the nearest five degrees relative to the trackline by constructed templates (Fig. 2). Using the ship's course, these relative orientations were converted to true orientations between 0 - 360°T. As the sense of ice motion is generally unknown, the orientations are not vectors. They can be represented as either bidirectional or unidirectional, as can the

strike of a bed. That is, a gouge with a "measured" orientation of 270°T is equivalent to an orientation of 090° T or is oriented 270°-090°. Both a dominant and subordinate orientation was measured when more than one trend was distinguishable.

4. Orientation variability (sonographs).- Low, medium, and high variability of gouge orientation (L, M, H) has been estimated using the following criteria:

L - The dominant orientation is virtually the only orientation. Subordinate orientations may be observed rarely or not at all.

M - The dominant and subordinate orientations are approximately evenly distributed in the segment.

H - The dominant and subordinate orientations exist but are not exclusive and may be only a best estimate of many orientations.

5. Observed Number of Gouges (sonographs).- The number of individual gouge lineations identified from the sonar records was recorded for each segment.

6. Correction Factor and Gouge Density.- In order to determine the gouge density normal to the trackline, a correction factor has been applied to the observed number of gouges (Barnes et al., 1978; Reimnitz and Barnes, 1974).

$$N = \frac{i}{i \sin \emptyset + R \cos \emptyset}(N_{obs})$$

where: N = corrected number of gouges in counting interval (gouge density)

N_{obs} = number of observed gouges in the segment

R = recorded width of sonograph, in meters

(both sides of record i.e. 125-m scale = 250-m record width)

i = length of segment, in meters

Ø = dominant trend angle of gouges relative to ship's track

(90° = perpendicular to track)

The normalizing of the gouges in each segment allows us to compare segments on an equal basis and also to evaluate a number per unit area value for that segment. The normalizing assumes all gouges are parallel and infinitely long. Other investigators have counted only those gouges crossed over by the ship (Lewis, 1978). We count all gouges on a sonograph segment, yet gouge length is often short and orientation varies. Therefore, the estimates of density we obtain from this technique may be high.

7. Gouge Depth (fathograms).- The depth of penetration ("Gouge Incision Depth," Barnes et al., 1978) of ice keels into the seabed (see Fig. 2) was measured along the trackline from fathograms and enumerated in 20-cm increments for each segment. The maximum incision depth was also recorded. In many cases the resolution of the fathograms was not good enough to accomplish this enumeration. In areas of considerable seafloor relief due to the abundance of ice gouge ridges and troughs, it was often necessary to subjectively estimate the level of the undisturbed sea floor (Fig. 3). Gouges less than 20 cm in depth or those that were observed on the sonar but not on the fathogram were placed in a category of No Measurement Possible (NMP).

8. Maximum Gouge Depth (m) (fathogram).- The maximum gouge incision depth was recorded for each segment.

9. Maximum Ridge Height (m).- A measurement was made of the highest ridge in each segment from the fathograms. The measurement was made from the adjacent seafloor depth to the highest point of the ridge (Fig. 2). Summing the

maximum ridge height and maximum gouge depth in each segment gives the maximum seabed relief from ice gouging in each segment.

10. Maximum Gouge Incision Width (m) (sonographs).- A measurement of the maximum width of a single gouge in each segment was made from the sonographs (Fig. 2). The template used for orientation corrections was scaled in meters for 10° incremental orientations to allow distance measurements at all orientations. The gouge incision was measured from inside the bounding ridges at seafloor depth, as opposed to a disruption width (Barnes et al., 1978) which would include the width of the bounding ridges. As with orientation, width measurements are distorted by horizontal exaggeration on most records and are corrected for the sonograph distortions.

11. Multiple Gouge Incisions (sonographs).- (1) The number of multiple incision gouges (Fig. 2) in each segment was noted along with (2) the maximum number of incisions formed by any one event. (3) The maximum disruption width (Fig. 2) for the widest multiple gouge was measured across the gouge from the furthest edge of the disrupted sediments outside the bounding ridges. (4) The dominant orientation for multiple gouge incisions in each segment may be different than that for single incisions and therefore was also recorded.

12. Depth to the First Reflector (m) (fathogram).-When possible, the depth to each subbottom reflector was recorded from the 7 kHz record of the Raytheon RTT-1000 fathograms. On tracklines using only a Simrad Fathometer this measurement was not possible.

13. <u>Other Measurements and Remarks</u>.- Pressure ridge gouging, tick marks (Reimnitz et al., 1973) strudel scours (Reimnitz et al., 1974), shoals and terrace measurements, and other observations of seafloor morphology were recorded.

Off Cape Halkett (Trackline 7-39) two additional data measurements were made to obtain more information regarding orientation distributions and gouge spacing. For each segment of this trackline the orientation of every individual gouge was noted and the center line distance between individual gouge troughs was measured.

CONCLUSION

With the completion of this data analysis an ice-gouge data set exists which gives a reasonable estimate of gouge characteristics in the different environments on the Alaskan Beaufort Sea shelf. The format created for the organization and storage of gouge data will allow us to incorporate new data as it becomes available and to increase our data coverage and comparisons to other areas of the Arctic Seas.

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The report, navigation plates, and ice-gouge data are contained on eight (8) microfiche cards.

Report and figures	1	microfiche card
Navigation plates	2	microfiche cards
Ice-Gouge data	5	microfiche cards