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NOAA-OCS Contract No. 81-RA00147

Research Unit 267

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Is Introduction

The shear zone is a concept which has been used for at least the last decade. It appears in published literature as early as 1974, but has not yet been officially recognized by either the World Meteorological Organization or the Joint NOAA/Navy Ice Analysis Center (1981). Early references include Kovacs and Mellor (1974) where ice behavior within the "shear one" is described, and a paper by Hibler, et al. (1974) where the term appears in the title, yet is not defined.

Kovacs and Mellor (1974) use the term in a rather matter-of-fact way following reference to a description of ice behavior in the (apparently then unnamed) zone by Nikolaeva (1970) and Crowder et al. (1973). Kovacs and Mellor quote Crowder (1973) as saying that "the pack ice as a whole is rotating clockwise and slipping within a narrow region (∿50 km) at the boundary" between the seasonal pack ice and the fast ice. Kovacs and Mellor then expand further based on personal experience, mentioning the zone by name for the first time:

> "The ice in the shear zone is subjected to the highest stresses. These occur when the pack ice is driven toward the coast. Unable to overcome the resistance of the more monolithic fast ice, the drift of the irregular floes within the shear zone is arrested and the floes are gradually pushed tighter as more of the outer pack ice comes into play. The stresses developed as these floes impinge upon each other or push against weaker ice that has formed in refrozen leads are often sufficient to cause the failure or crushing of one of the participating ice sheets. The result (spatially) is

a haphazard accumulation of ice blocks of a most irregular and formidable appearance. When high normal and tangential forces are at play between the fast ice and the moving pack ice, extensive shearing and grinding of the ice occur. The result is a ground-up consolidated mass of ice called a shear ridge. These ridges, common along the Alaskan coast, are often tens of kilometers in length and frequently 4m high. At times the shearing stresses are so intense that a sequence of shear ridges develops into a hummock field so formidable that no icebreaker in existence or under construct-ion can penetrate it."

As the term "shear zone" and the concept it implied came into general use, the description developed by Crowder, et al. (1973) come to be taken in what was probably a more literal sense than' had been intended: many personnel involved with Beaufort Sea Outer Continental Shelf matters have spoken to this author as if they expected to find a well defined fracture at all times delineating a boundary between stable shorefast ice and constantly moving shear zone." While the shear zone is a very valuable concept that is quite valid as a long-term description of the interaction between fast ice and pack ice in the Beaufort Gyre, instanteous ice behavior in the offshore region is not always adequately described by the shear zone concept. Consequently, some caution must be exercised in basing decisions and plans concerning development of offshore areas on the mental picture this concept conjures.

Certainly on a long-term average, the Beaufort Sea ice pack is rotating largely as a whole with a rather narrow (50-100 km) peripheral zone where the transition between static shorefast ice and the transiting pack takes place. Observations based on Landsat imagery show that on many specific occasions, there is a pronounced edge of shorefast ice and just beyond, fractured pack ice moving along this edge (usually toward the west in the Beaufort Sea). Often after such episodes considerable shear ridge-building activity can be seen to have taken place along the shorefast ice edge, In terms of differential motion within the ice, the greatest slippage also appears to take place along the very edge of the shorefast ice, and the pack ice fragmentation is greatest there, decreasing with distance into the Arctic pack.

However, on many occasions such slippage between shorefast and pack ice, if it is taking place at all, is occurring far seaward (over 100 km) of the normal edge of the shorefast ice. Observations by Stringer (1974), using Landsat imagery have shown that at times the shorefast ice extends far seaward, well past the normal shear zone during midwinter for periods up to 6 weeks in length. Furthermore, from one occasion to the next, the location of this slippage can change drastically. The well known track of the ice island, T-3, traveling with the arctic pack shows that the rotation of the pack ice is stepwise and not continuous. Hence, the shear zone i-s not a continuous process, but rather a series of stochastic events taking place at various distances from shore.

The shoreward boundary of an active shear zone is easily defined, usually consisting of a line along which the ice has failed under shear stress. This may consist of a series of polynyas and/or shear ridges between two continuous ice sheets or a distinct edge of fast ice with floes surrounded by open water to the seaward. Conversely, the seaward edge of the shear zone is a concept which is difficult to apply to an unambiguous identification. By definition it is the location at which shear stresses within the shear zone ice are reduced to some ambiant pack ice level. But clearly this, too, changes spatially and temporally.

Fortunately, it is the shoreward boundary of the shear zone which is of chief interest from an environmental assessment point of view: this line defines the seaward limit of stable fast ice where under-ice pooling of spilled oil can take place and where fast ice conditions apply to the design and operation of offshore facilities. It is also the extreme landward boundary of possible whale migration routes during the springtime migration period.

II. Data Analysis

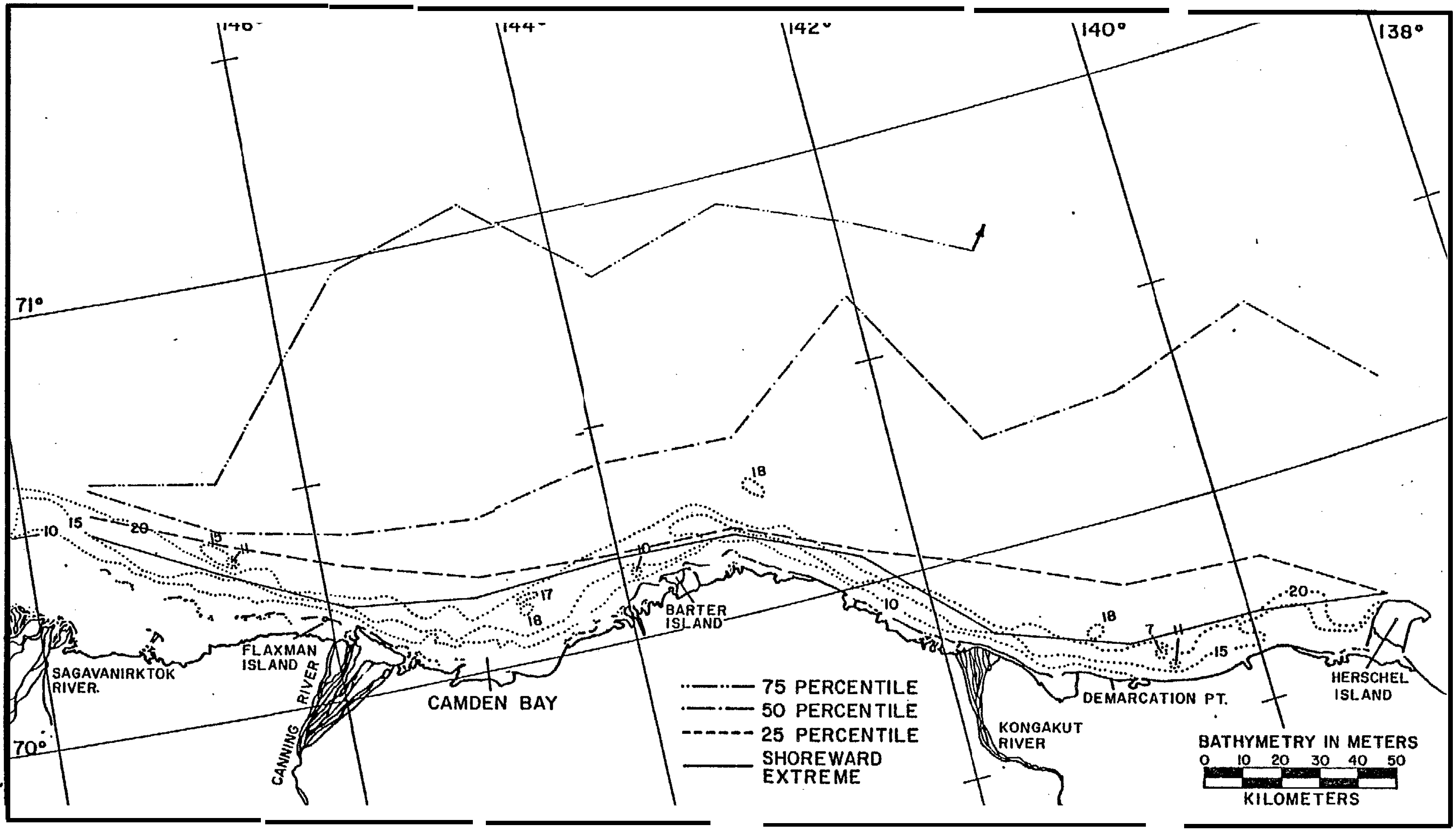
Landsat images obtained between 1973 and 1981 were utilized to measure the shoreward boundary of the shear zone for as many occasions as possible throughout the period of study. Previous experience with similar data suggested that these data could be divided into three seasonal groups: late winter (February 1 to March 15), early spring (March 16 to May 15), and late spring (May 16 to June 15).

The Landsat image format used was $1:1 \times 10^6$ scale, band 7 (near infrared) photographic prints. Using a coastal overlay keyed to major geographic features, the distance from shore to the active shear zone was measured along eleven azimuths perpendicular to the mean coastline in the study area. These data were retained, together with their date for analysis purposes. A total of 264 ice edge observations were recorded. Figures 1 through 3 show the nearshore extreme, 25-percentile, median (50-percentile), and 75-percentile values of the shoreward edge of the shear zone determined statistically for the periods chosen. The seaward extreme value cannot be shown because it was often so far seaward that it was not only beyond the area mapped, but also beyond the area covered by Landsat imagery. Also included on these maps are the 20-m, 15-m, and 10-m isobaths taken from U.S. Coast and Geodetic Marine Charts so that the values shown here can be compared with this parameter which has frequently been associated with the position of the shear zone in Outer Continental Shelf Environmental Assessment literature.

In order to gain some insight concerning the behavior of the shear zone edge with time, the data have been combined in order to show: the seasonal progression of the extreme shoreward edge of the shear zone (figure 4), the seasonal progression of the 25-percentile shoreward edge of the shear zone (figure 5), the seasonal progression of the median (50-percentile) shoreward edge of the shear zone (figure 6), and the seasonal progression of the 75-percentile shoreward edge of the shear zone (figure 7).

Each map is discussed as it is presented.

F G.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144°
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SAGAVANIRKTOK RIVER.
FLAXMAN ISLAND
CANNING RIVER
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
75 PERCENTILE
50 PERCENTILE
25 PERCENTILE
SHOREWARD EXTREME
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 1: Statistical Location of the Shear Zone in Late Winter (Feb 1-Mar 15)

This figure shows the statistical shear zone edges during late winter. Starting adjacent to shore:

(1) the extreme shoreward edge observed

(2) the 25-percentile shoreward edge

(3) the "median (50-percentile) shoreward edge

(4) the 75-percentile shoreward edge

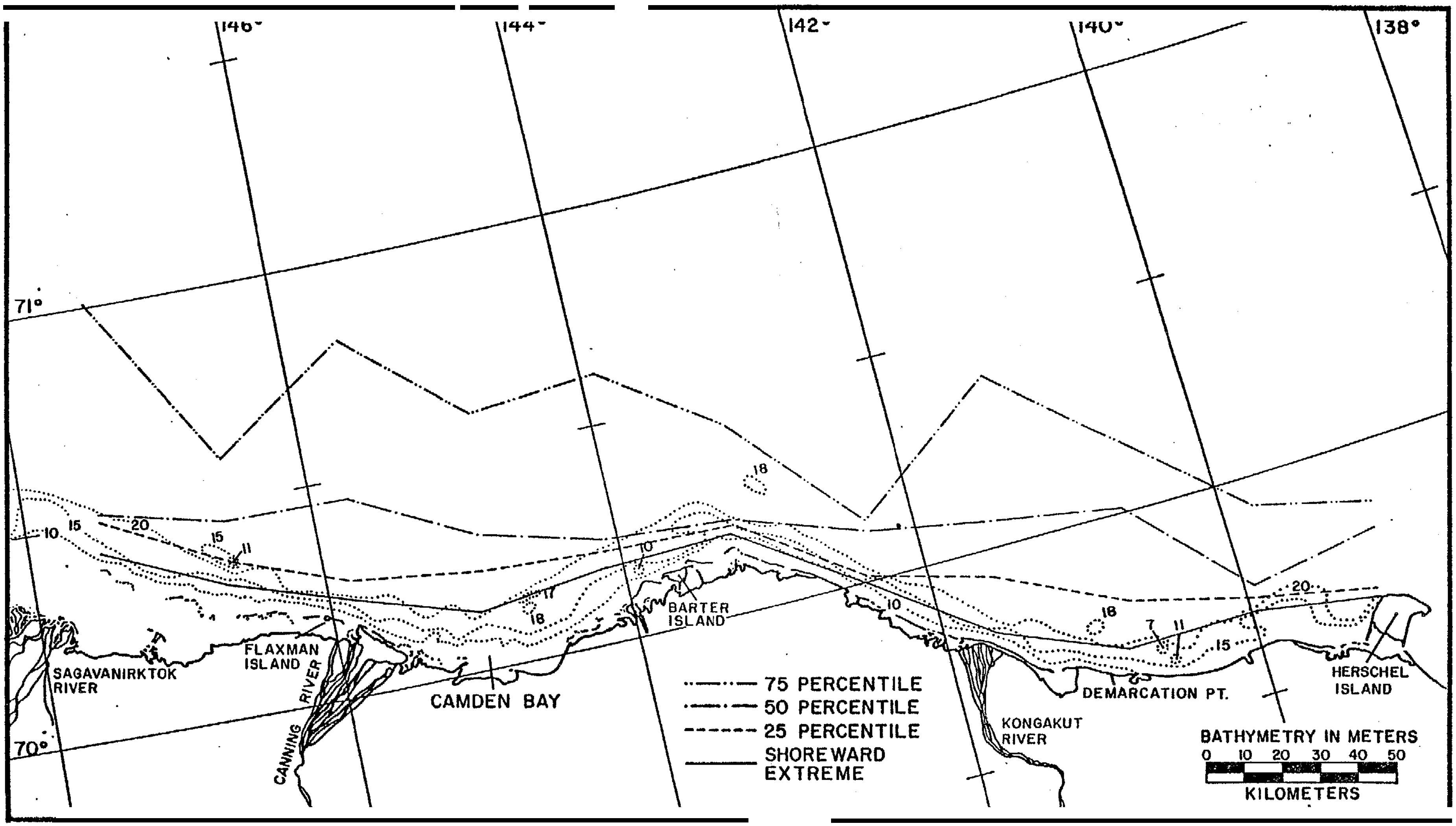
These results show that although the median shoreward edge of the shear zone is located quite far seaward during this season, the 25-percentile and shoreward extreme shear zone edges are both close to and, at some locations, located inshore from the 20-m isobath. This latter observation is chiefly true at the location of the large promontory which includes Barter Island and the extensive shallow region seaward of the barrier islands in the extreme western portion of the study area. A similar "choking down" of these statistical regions appears to occur at Herschel Island at the extreme eastern end of the study area.

On the other hand, the shoreward extreme shear zone and the 25-percentile shear zone become more separated in the two large embayments: Camden Bay and the coastal indentation created by Herschel Island and the Barter Island Promontory. Furthermore, both of these statistical isopleths are found in deeper waters off these coastal embayments. The extreme shear zone edge is located as far seaward, and in some locations, slightly farther than the 20-m isobath while the 25-percentile shear zone edge is located in even deeper waters.

This map shows that while the median shoreward edge of the shear zone is located considerably farther seaward than the 20-m isobath during late *winter,* the extreme shoreward shear zone edge has been found generally between the 20-m and 15-m isobaths. Furthermore, these extreme events are not too rare. One quarter of the late winter shear zone edges have been observed between the extreme and 25-percentile isopleths. Therefore, conclusions based on median or average shear zone edges might be misleading in terms of predictions concerning ice conditions to be encountered by an oil spill in the nearshore area of this region.

The arrow on the eastern end of the segment denotes that the 75-percentile shear zone edge was located somewhere beyond the seaward limit of the Landsat imagery available for this sector and that location was somewhere seaward of the arrow shown.

F G. 2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SAGAVANIRKTOK RIVER
FLAXMAN ISLAND
CANNING RIVER
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
75 PERCENTILE
50 PERCENTILE
25 PERCENTILE
SHOREWARD EXTREME
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 2. Statistical Location of the Shear Zone in Early Spring (Mar 16-May 15)

This figure shows the statistical shear zone edges during early spring. Starting adjacent to shore:

(1) the extreme shoreward edge

(2) the 25-percentile shoreward edge

(3) the' median (50-percentile) shoreward edge

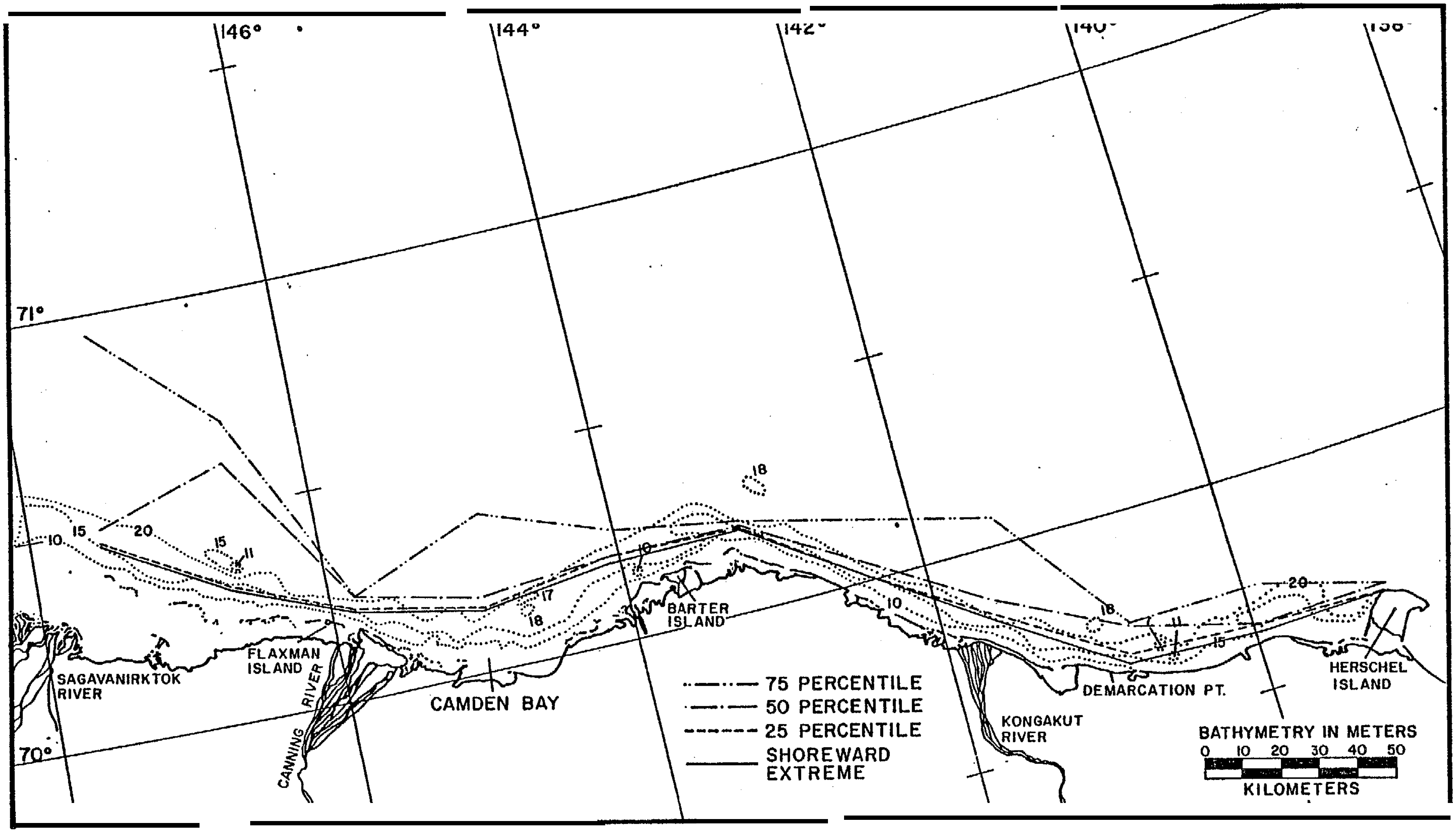
(4) the 75-percentile shoreward edge

Although later direct comparisons will be made of the seasonal locations of corresponding statistical zones with season, it is immediately obvious that the 75-percentile and median shoreward edges of the shear zone are considerably closer to shore in early spring than during the late winter season. Particularly interesting is the observation that during this season the median shear zone edge is located shoreward of even the 15-m isobath offshore from the large promontory containing Barter Island.

Again, the extreme shoreward shear zone location is often found along the 15-m isobath, occasionally along the 20-m isobath, and rarely seaward of the 20-m isobath (where it crosses coastal embayment). Also similar to the late winter map, the 25-percentile edge of the shear zone is generally located closer to the extreme shear zone edge than to the median isopleth. This 25-percentile delineation is found in a similar configuration to that of the previous season: running along or inshore from the 20-m isobath at locations where that isobath juts seaward from the average coast, and bridging embayments of that isobath.

Clearly, 25% of the observed shoreward shear zone edges were located between the extreme shoreward shear zone edge and the 25-percentile isopleth. Because of the small width of this region, it is not. reasonable to refine the statistical shear zone parameters to a higher degree with any confidence. Therefore, any location seaward of the extreme shoreward edge of the shear zone during this season should be regarded as having a reasonable probability of being located within the shear zone. Or, from an environmental assessment point of view, there is a significant chance that petroleum spilled seaward of the extreme shoreward observed shear zone will be introduced into shear zone ice conditions. In other words, there is no buffer zone of very low probability adjacent to the extreme observed shear zone position. In fact, because of the relatively short period of observation (11 years) the probability that even further shoreward shear zone edges will be observed on any given year is about 9%.

F G. 3



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SAGAVANIRKTOK RIVER
FLAXMAN ISLAND
CANNING RIVER
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
75 PERCENTILE
50 PERCENTILE
25 PERCENTILE
SHOREWARD EXTREME
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 3. Statistical Location of the Shear Zone in Late Spring (May 16-June 15)

This figure shows the statistical shear zone edges during early spring. Starting adjacent to shore:

(1) the extreme shoreward edge

(2) the 25-percentile shoreward edge

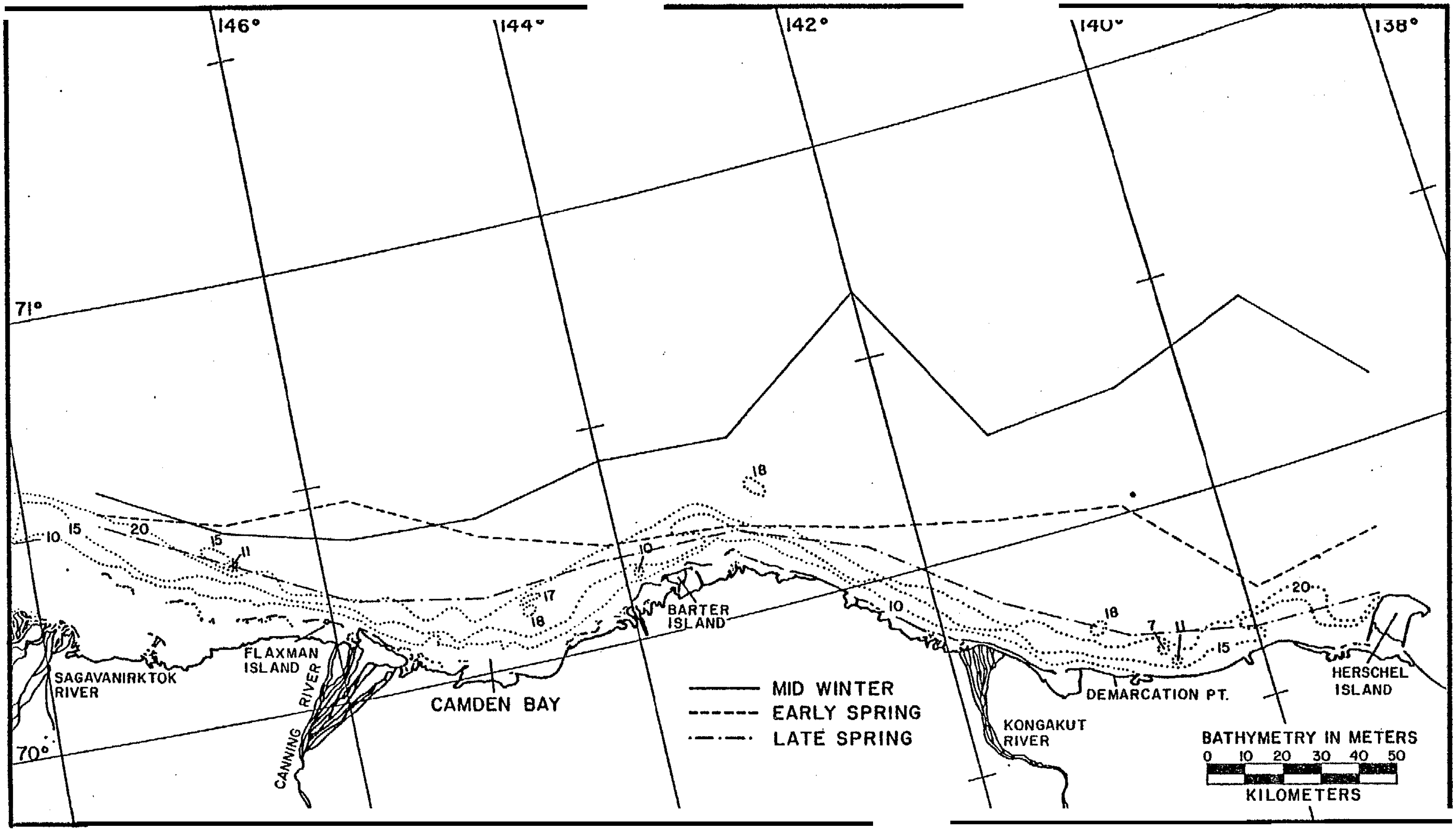
(3) the median (50-percentile) shoreward edge

(4) the 75-percentile shoreward edge

Because of extreme cloudiness during this period, there was not a large quantity of data available for preparation of these statistics. On the average, 5 observations were made along each coastal azimuth. Admittedly this is a small sample, but these data are all that are available at this spatial resolution and, therefore, must be considered.

As might be anticipated, at all percentiles the shear zone edge is located closer to shore than during the previous two seasons. Furthermore, the shoreward extreme and 25-percentile shear zone edges are nearly coincident throughout the study area and are found between the 20-m and 15-m isobaths. The proximity of these shear zone edge percentiles indicates that the shear zone edge is frequently very close to shore.

FIG. 4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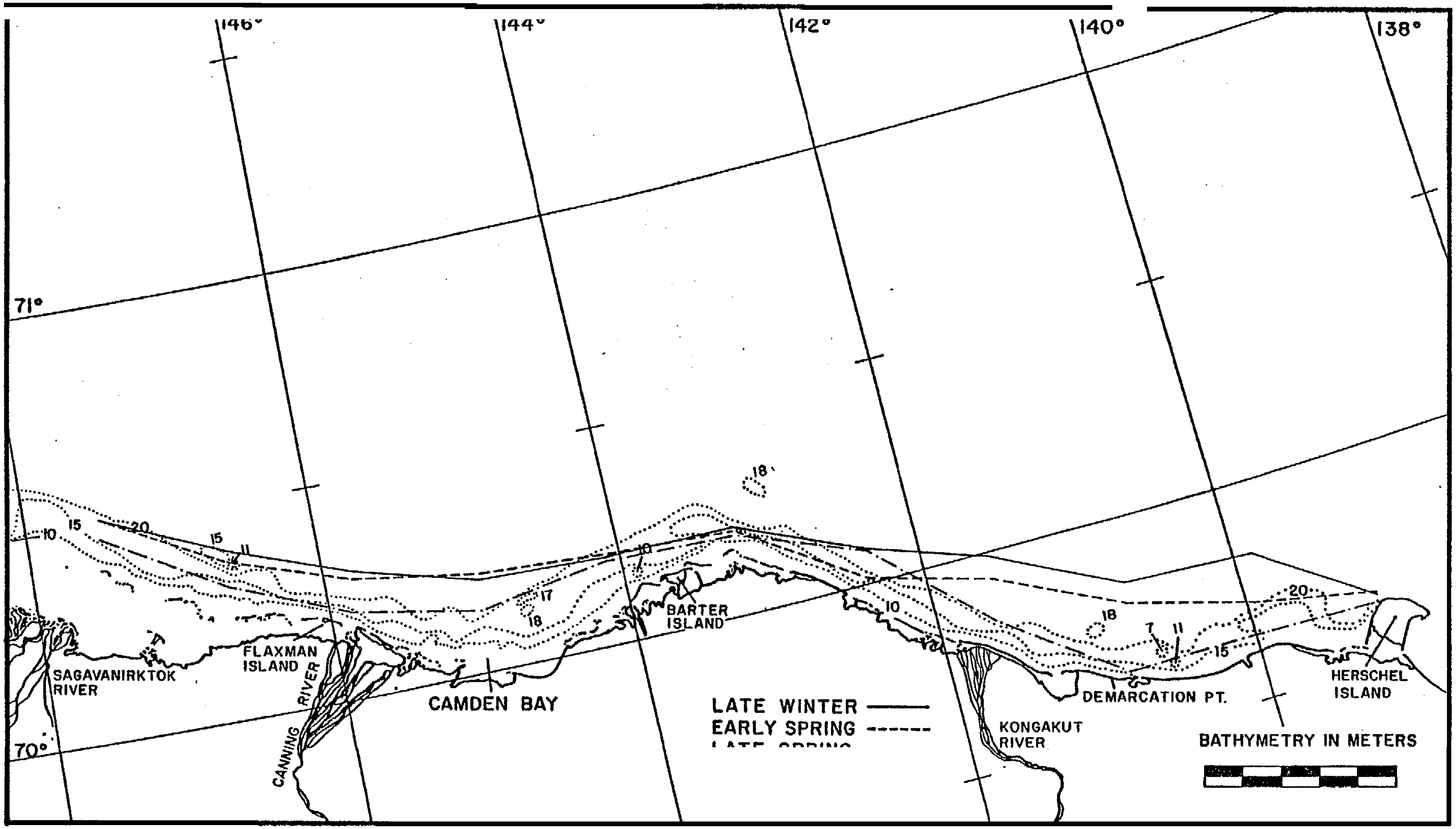
CANNING RIVER
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
MID WINTER
EARLY SPRING
LATE SPRING
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 4. Comparison of the Seasonal Median Shoreward Edges of the Shear Zone

This figure shows that median shoreward edges of the shear zone for the three seasonal analysis periods. East of central Camden Bay these data behave in a systematic fashion, being farthest offshore in midwinter and progressing toward shore as the season advances. To the west of central Camden Bay, this systematic behavior breaks down offshore from the Canning River, then returns to predicted order at the western edge of the study area.

F G. 5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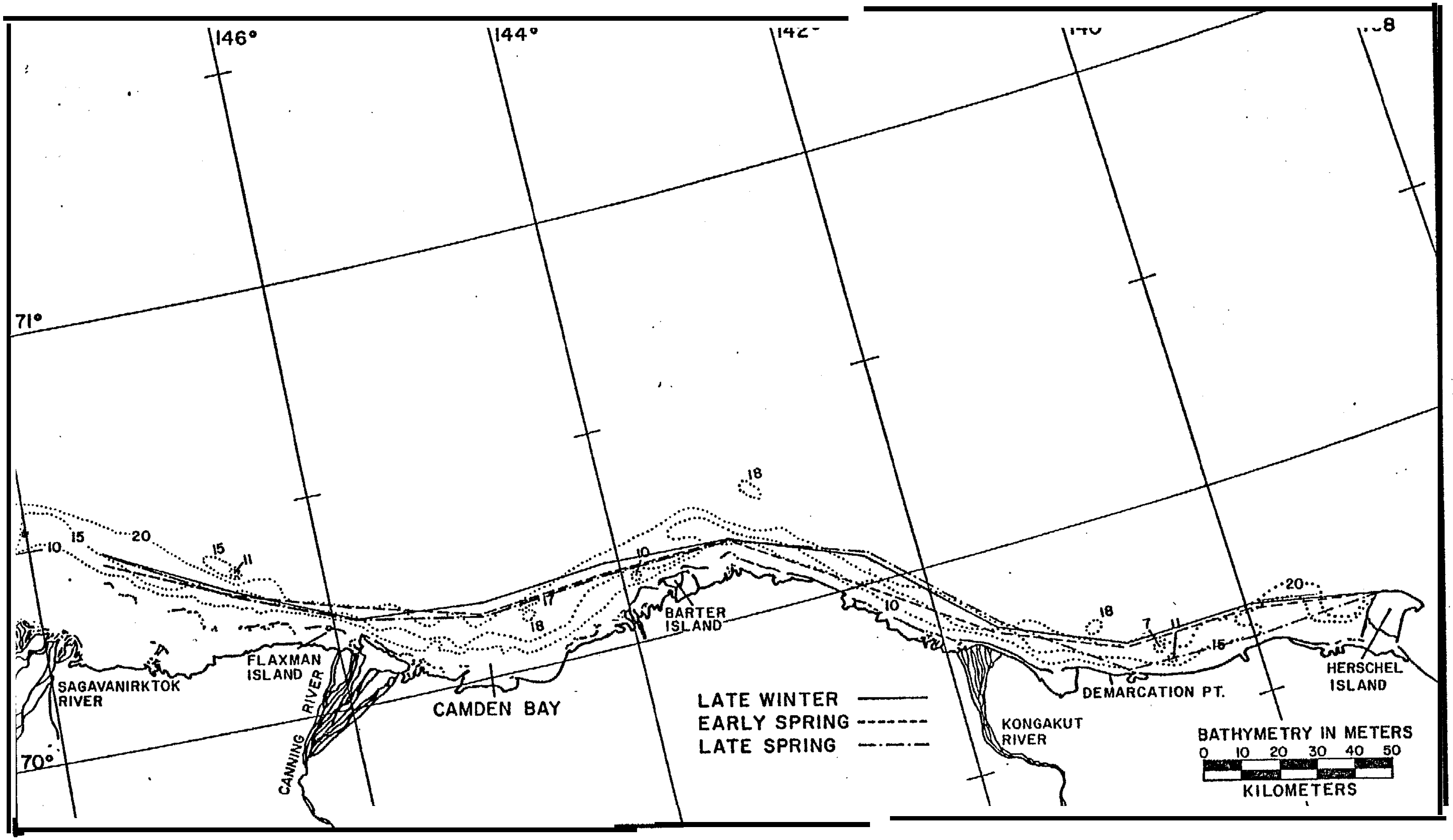
FLAXMAN ISLAND
CANNING RIVER
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
LATE WINTER
EARLY SPRING
BATHYMETRY IN METERS
10
15
20
15
11
17
18
10
18
10
18
7
11
15
20

Figure 5. Comparison of the Seasonal Shoreward 25-Percentile Edges of the Shear Zone

This figure shows the locations of the 25-percentile shoreward edges of the shear zone for each of "the three analysis periods, East of Barter Island, there is a systematic trend with shear zone edge location becoming closer to shore with advancing season, while at Barter Island and to the west this variation with season is generally weaker. In the center of Camden Bay where the late spring shear zone edge is considerably inshore from the late winter and early spring shear zone edges.

It would appear significant that all these seasonal 25-percentile ice edges are coincident offshore from the Barter Island promontory. Furthermore, they are largely coincident with the 15-m isobath, well inshore from the 20-m isobath often considered the seaward limit of stable fast ice, and therefore the shoreward limit of the shear zone. This result indicates that regardless of season, 25% of the shoreward edges of the shear zone will be shoreward of this location and seaward of the extreme shoreward edges of the shear zone displayed on Figure 4. (This envelope is actually quite small - on the order of 1 or 2 km at this location.)

FIG. 6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FLAXMAN ISLAND
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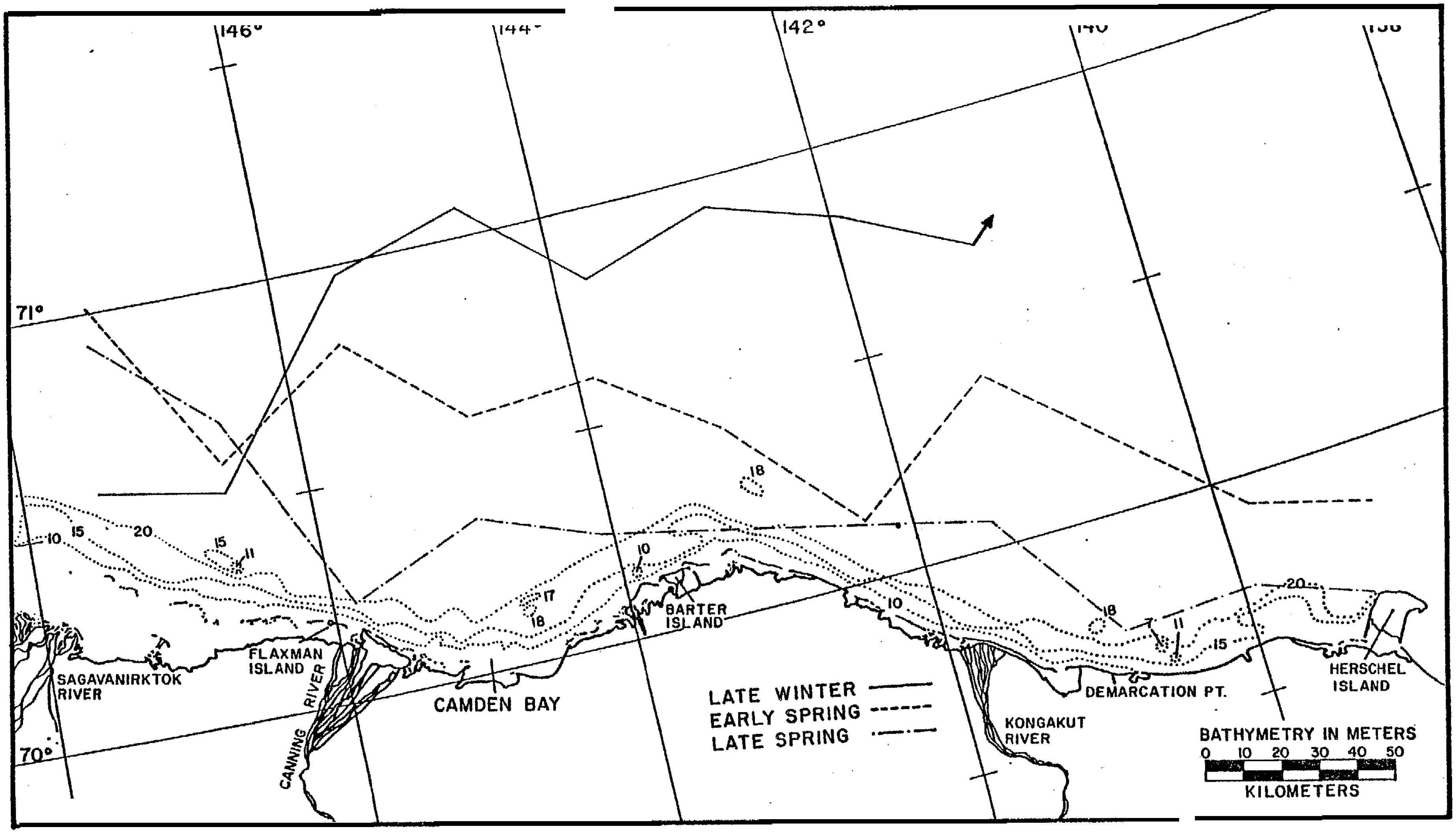
CAMDEN BAY
BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
LATE WINTER
EARLY SPRING
LATE SPRING
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 6. Comparison of the Extreme Seasonal Shoreward Edges of the Shear Zone

This figure shows the extreme shoreward edges of the shear zone observed in each of the three seasonal analysis periods. For the most part, these extreme cases agree quite closely. This result and figures 4 and 5 illustrate that while generally speaking, the 75-percentile, median and 25-percentile edges of the shear zone migrate toward shore with advance of season, the extreme shoreward position which can be attained remains roughly the same for all seasons. Furthermore, while agreeing in some cases with the frequently used 20-m isobath generalization for the seaward limit of fast ice, there are geographic regions with significant departure from this generalization. The most pronounced of these is off the Barter Island promontory where for all seasons the shoreward edge of the shear zone has been located not only inshore from the 20-m isobath, but inshore from the 15-m isobath as well, and at one point, coincident with the 10-m isobath.

In addition, during all three periods studied here, the extreme shear zone edge has been observed along the 15-m isobath parallel to the barrier island group west of Flaxman Island.

FIG. 7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BARTER ISLAND
KONGAKUT RIVER
DEMARCATION PT.
HERSCHEL ISLAND
LATE WINTER
EARLY SPRING
LATE SPRING
BATHYMETRY IN METERS
0 10 20 30 40 50
KILOMETERS

Figure 7. Comparison of the 75-Percentile Seasonal Shoreward Edges of the Shear Zone

This figure shows the 75-percentile shoreward edges of the shear zone observed in each of the three seasonal analysis periods. Although the 75-percentile edge is not of great interest in terms of environmental assessment, the seasonal behavior of this statistical measure gives some idea of the wide variation in shear zone location which can occur as a function of season. Overmuch of the study area, the 75-percentile shoreward shear zone edge advances toward shore with season just as the other statistical measures of shear ’zone location. Comparison with figures 4, 5, and 6 shows that this variation in distance from shore is clearly greatest for the 75-percentile measure. This result demonstrates that the envelope of shear zone edges is broadest in late winter and decreases with season.

III. Discussion

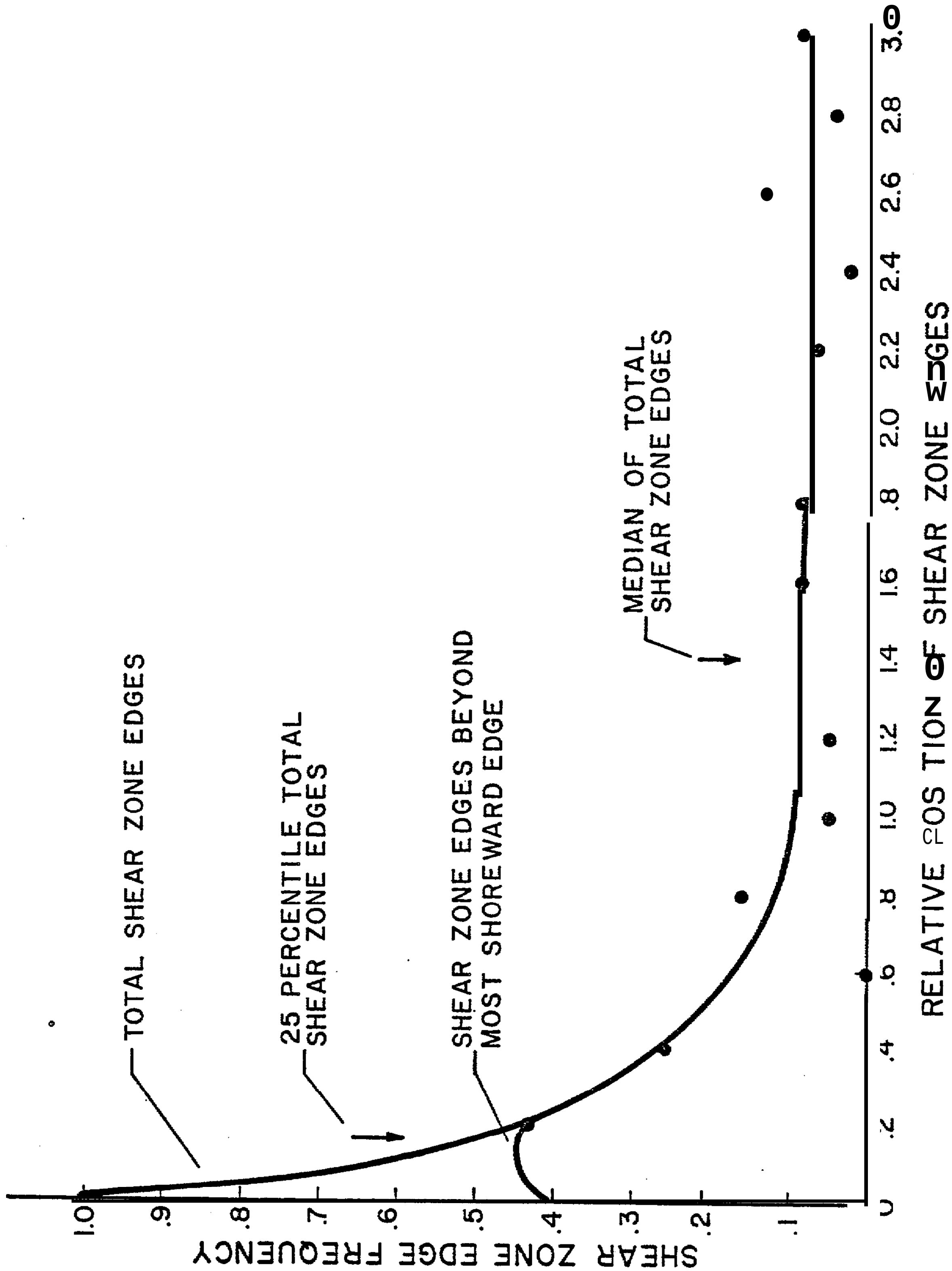
The extreme shoreward edge of the shear zone has been found to be located in general proximity to the 20-m isobath in the eastern Beaufort Sea study area during the entire period Feb 1 to June 15. Local variations from this general rule appear to result from local bathymetric configurations: it is found inshore of the 20-m isobath in exposed regions and it tends to bridge embayments of the 20-m isobath.

In some locations such as off Barter arid Flaxman Islands, this extreme measurement is even found as far inshore as the 10-m isobath. These observations would appear to be at variance with the 20-m figure often quoted as the depth at which the seaward edge of stable fast ice (and hence the shoreward edge of the shear zone) is encountered. The statistical data presented here suggest that for these locations perhaps the average depth at which the 25-percentile edge occurs would be characterized as 20 m. The apparent disagreement can be explained in terms of comparing extreme observed values with central tendency values. Twenty meters is a good overall value for a likely depth at which to encounter the shear zone. It has always been expressed as a generalization and not as an extreme expected value. Therefore, care must be taken for those locations where systematic violations of the rule are found.

For environmental assessment considerations, extreme observed values are important, particularly if they have some chance of recurring within the period for which an activity is planned. ‘In this case, as was pointed out in the discussion of statistical ice edges for each season, the 25-percentile isopleth is closer to the extreme ice edge than to the median isopleth. Therefore, one would expect the shear zone edge frequency distribution to be skewed toward the shoreward side of the distribution. In order to demonstrate this further, figure 8 has been prepared showing the overall normalized frequency of shear zone edge occurrence as a function of normalized distance from shore to the shear zone edge. Normalization was made to the distance from shore to the extreme shoreward shear zone edge for each coastal measurement azimuth. See Appendix A for a detailed description of figure 8 and its preparation. The shoreward peak of this distribution illustrates that in general the shoreward extreme shear zone edge is not a spatially isolated event and that the probability of the shear zone edge being located nearby is not extremely low. Furthermore, the period of study was only 10 years. Therefore, the extreme ice edges observed have a recurrence frequency on that order. This means that there is a 10% chance that the extreme values observed here would recur during any one given year. Over a period of 20 or 30 years, it is likely that an more extreme shoreward value would be experienced.

Although perhaps not as valuable for environmental assessment considerations, the statistical seasonal movement of the median shoreward edge of the shear zone is another useful measure of shear zone behavior. In general, this location moves progressively shoreward with season, being located quite far seaward of the 20-m isobath in late winter, at intermediate depths in early spring and near the 20-m isobath in late spring. It is not immediately obvious why this should be the case, since the ice is thicker, and Presumably stronger, in early spring than in late winter. On the other hand, the freezing rate of leads is much greater in late winter than in early spring, due to the lower temperatures customarily found during that time. As a result, the overall strength of the ice may, on the' average, be strongest at that time rather than

FIG. 8



TOTAL SHEAR ZONE EDGES
25 PERCENTILE TOTAL SHEAR ZONE EDGES
SHEAR ZONE EDGES BEYOND MOST SHOREWARD EDGE
MEDIAN OF TOTAL SHEAR ZONE EDGES
SHEAR ZONE EDGE FREQUENCY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
.8
2.0
2.2
2.4
2.6
2.8
3.0
RELATIVE POSITION OF SHEAR ZONE EDGES

later. In other words, it is the thickness of ice in newly-formed leads which determines the strength and, in particular, the shear strength of the ice pack, not the thickness of the floes. If this is the case, then during midwinter the nearshore ice would tend to be stronger since fractures and leads which did occur would regain strength rather quickly. With the overall strength of the pack increased, one might expect the shear stress failure to tend to occur at greater distances from shore, "where greater stresses could accumulate.

An interesting point is that for all seasons, at least 25% of the shoreward observed edges of the shear zone were well inshore from the 20-m isobath at the tip of the large promontory containing Barter Island. Furthermore, the most shoreward observed edges were coincident with the 10-m isobath, and starting in early spring, even the 50-percentile shoreward shear zone edges were within the 20-m isobath. At no other point along the U.S. Beaufort coast east of Point Barrow is the shear zone boundary so consistently close to shore. However, as figure 9 shows, not only is this promontory the most pronounced seaward departure from the mean Beaufort coastline, but it carries with it the most seaward projection of the U.S. Beaufort 20-m isobath. In this respect, this bathymetric feature is unique among those of the U.S. Beaufort coast, and correspondingly, ice behavior observed here occurs at no other location along this coast. Similar bathymetric configurations do occur along the Chukchi coast south of Barrow at Icy Cape and Point Franklin, where somewhat similar ice behavior has been documented (Stringer, et al., 1978). Hence, the behavior of the shear zone edge near Barter Island is not as unusual as it may seem.

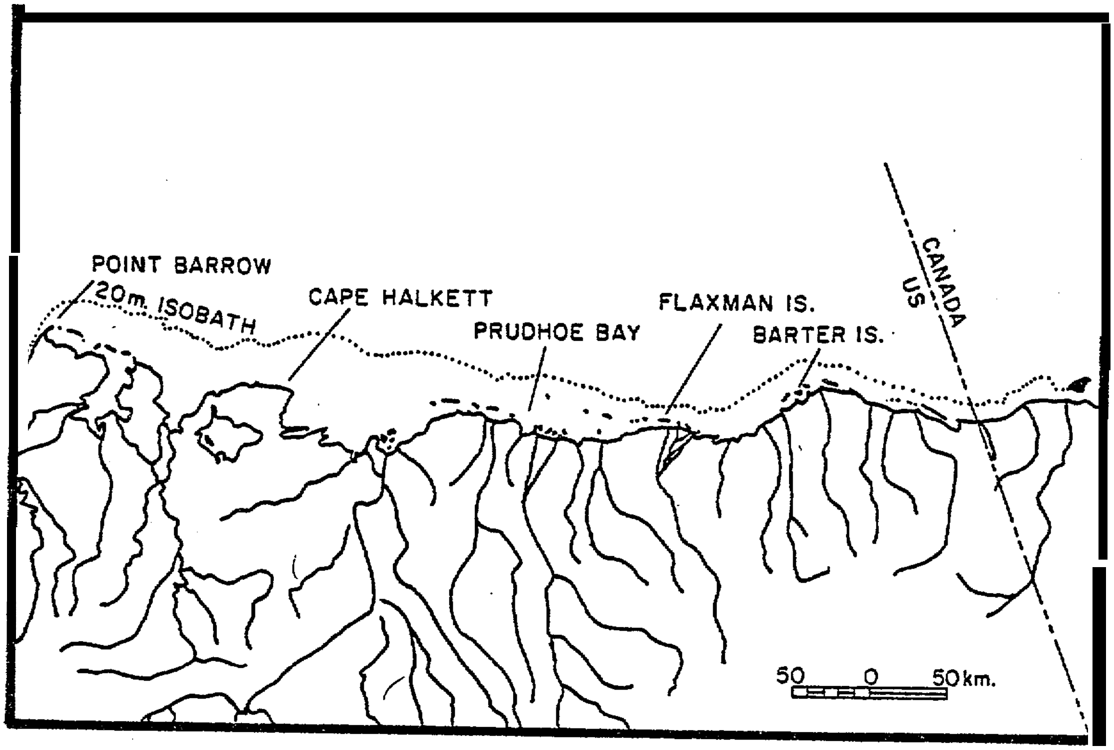


Figure 9.

This figure has been prepared to show the general configuration of the U.S. Beaufort Sea coastline and 20-m isobath. The purpose of this map is to show that the 20-m isobath is farthest from its mean value in the vicinity of the large geographical promontory containing Barter Island. This information is presented to explain the observation that the 0, 25, and 50-percentile shear zone edge isopleths are all found considerably closer to shore there than at any other location along the U.S. Beaufort coast. The explanation is that this location is exposed relative to the balance of the coast and its extent is so sufficiently small that forces *within* the pack ice can be greater than the cumulative strength of the ice anchored farther offshore than the 15-m isobath where the stable ice edge is frequently found.

IV. Conclusions

Further principal conclusions found in this work are as follows:

(1) The isopleths of shoreward shear zone edge frequency do not follow bathymetric contours. Hence, environmental assessment considerations based on shear zone occurrence should be made pointwise and not on a blanket bathymetric generalization.

(2) Although clearly half of the observed shear zone edges occur on either side of the median location, the distribution of shear zone edges is not peaked at the median location, but is skewed toward the shoreward extreme observed values. Twenty-five percent of the observed shear zone edges occur in a narrow region just seaward of the extreme shoreward shear zone edge observation. On the average, the width of this narrow region is .2 times the distance from shore to the extreme shoreward observed shear zone edge while the median value lies at 1.4 times this distance.

Appendix A. Construction of Figure 8

This figure was compiled in order to give a generalized picture of the distribution of shear zone edges as a function of distance from shore. Examination of the percentile isopleth maps for each season showed that, in general, the 25-percentile isopleth was closer to the extreme shoreward shear zone observation (O-percentile) than to the median shear zone edge observation (50-percentile). However, it is not as easy to generalize this phenomenon over the whole study area as it might seem: the width of the shear zone isopleth envelope varies considerably along the Beaufort coast (off Barter Island, for instance, it can be very narrow), but as a general rule, the relationship described above still holds. Hence, the isopleth envelope can be thought of expanding and contracting, yet retaining the relative distance ratios between isopleths. Hence, an attempt to generalize this phenomenon must somehow standardize the scale factor of this relative expansion.

Furthermore, the distance from the coast to the O-percentile isopleth also varies from place to place along the coast. As a result of this, an attempt to generalize the phenomenon described must standardize the distance from shore to this isopleth, or the concentration of shear zone edges near the O-percentile isopleth will be blurred.

Several attempts were made to meet these requirements. The results were illuminating, particularly in terms of dealing with the statistic's of small data sets. For instance, the most obvious approach would be to standardize distance between the O-percentile isopleth and 50-percentile isopleth along each measurement azimuth, adjusting all shear zone edge measurements accordingly, summing all the observations and then sorting the results into bins for preparation of a histogram. This approach would be reasonable for summing a series "of continuous distributions or discrete data sets, each containing many more observations than histogram bins. However, in a case like this, when the number of observations along each azimuth (data subset) is on the order of the number of bins, an interesting phenomenon occurs: the process of normalizing to the 50-percentile observation insures that each data subset will contribute at least *one* count to the population of the 50-percentile bin. Because this is not generally true for all bins due to the limited data set, the 50-percentile bin becomes heavily populated relative to adjacent bins, creating an artifical "peak" in the histogram.

Similar problems arose from other normalization attempts. Finally, the distance between shore and the extreme shoreward shear zone edge was used as a scale factor for normalizing each data subset. This was reasonable because, as was noted above, in general the subsets with the greater distance from shore to the extreme edge are expanded, while the subsets with the extreme edge close to shore are contracted.

After normalizing all data subsets by this procedure, the subsets were summed, producing the histogram shown in figure 8 as a continuous function. The population of each bin has been normalized to the total population of the bin containing the extreme shear zone edges. The horizontal scale is such that a value of 1 corresponds to a distance seaward of the extreme shear zone edge equal to the distance from the extreme shear zone edge to the shore. In order to show that the bin containing the extreme shear zone edges also contains other observations, two values were shown for this bin: the total number and the number exclusive of the extreme edge count. This value was nearly equal to the population of the next bin. Hence, the value here is not totally an artifact of the standardization process.

The 25-percentile shear zone edge is reached close to the end of the second bin count and, therefore, has been shown here as a point within that bin at a position proportional to the point within the bin that the 25-percentile is reached. Similarly, the median shear zone edge has been identified. This figure clearly shows that the distribution of shear zone edges is skewed toward the extreme shoreward shear zone edge.

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