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Research Unit 267

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Introduction

Ice ridges are pertinent to environmental assessment analyses because their density is a measure of the frequency of major dynamic ice events which may require consideration in the design of structures or in evaluating the potential fate of spilled petroleum. In general, two types of ridges have been recognized: pressure ridges and shear ridges. Pressure ridges are usually rather local manifestations"of confining pressure within the ice overcoming ice strength and creating piles of ice blocks. Often a ring of pressure ridges can be found surrounding an ice floe. They can also be found along the former route of a lead which had frozen to a thickness less than that of the neighboring ice and then was compressed, forming a pile of ice rubble as the two thicker sheets of ice came together. Pressure ridges are a very common feature of the sea ice landscape.

"Shear ridges", on the other hand, are a different matter. Rather than local in nature, they are generally quite long and usually rather massive. They generally result when one large ice mass grinds against another. The use of the word "shear" in the name has been considered a misnomer by individuals accustomed to the strict physical use of the word which involves the arrangement of forces on a rigid body. Clearly, shear ridges do not result from forces on a rigid ice body, but occur when an ice mass fails under a shearing stress and ice is piled as a consequence of the differential motion between the two resulting ice masses under confining pressure.

The distinction between shear and pressure ridges is not always as clear as the foregoing explanation might make it seem. However, for the most part, major shear ridges are distinguishable because of their linearity. These ridges are often over 100 km long and, although seldom absolutely straight, they exhibit curvatures with radii on the order of tens of km. They often tend to build in width as successive walls of piled ice are added to the seaward side of the ridge.

Very large ridges can be identified on Landsat imagery. Stringer (1980) has performed an analysis of large ridges over the entire Beaufort Sea based on 5 years of Landsat imagery. The work described here builds upon that analysis, extending the temporal coverage to 9 years and performing a more quantitative analysis of the results. However, the study area is confined to the region of the eastern Beaufort Sea.

Data Analysis

Aerial surveys conducted to verify interpretation of Landsat imagery have shown that the size threshhold at which ridges can be identified on winter Landsat imagery is on the order of 200 m in width and tens of kilometers in length (see figure 1). The ability to detect ridges varies with season. Ridges are more easily identified on low sun-angle imagery than on imagery obtained at higher solar elevation angles. This detectability appears to result from the presence of shadows in and extending from the ridge system, creating a modulated gray area against the lighter background of snow-covered ice,

As solar elevation angles increase, ridges become somewhat less detectable. Once snow-melt on the ice surface has taken place, ridges again become apparent because they tend to be better drained and are, therefore, considerably more reflective than their surroundings, particularly in the near-infrared portion of the electromagnetic spectrum.

On winter-time, snow-covered imagery only the very largest ridges can be detected, whereas, on summer-time, snowless imagery many well drained features appear, not all of which are massive ridge systems. Therefore, the direction of interpretive error changes between these two types of imagery. During winter errors are made in the direction of not identifying ridges rather than incorrectly identifying ice features as ridges. However, in the use of summertime imagery many more features become visible and it is often difficult to determine which are truly massive ridges. " Very often large pressure ridge complexes will be interpreted as shear ridges. Hence, this work only claims to identify areas of massive ridges. Whenever possible, early season and late

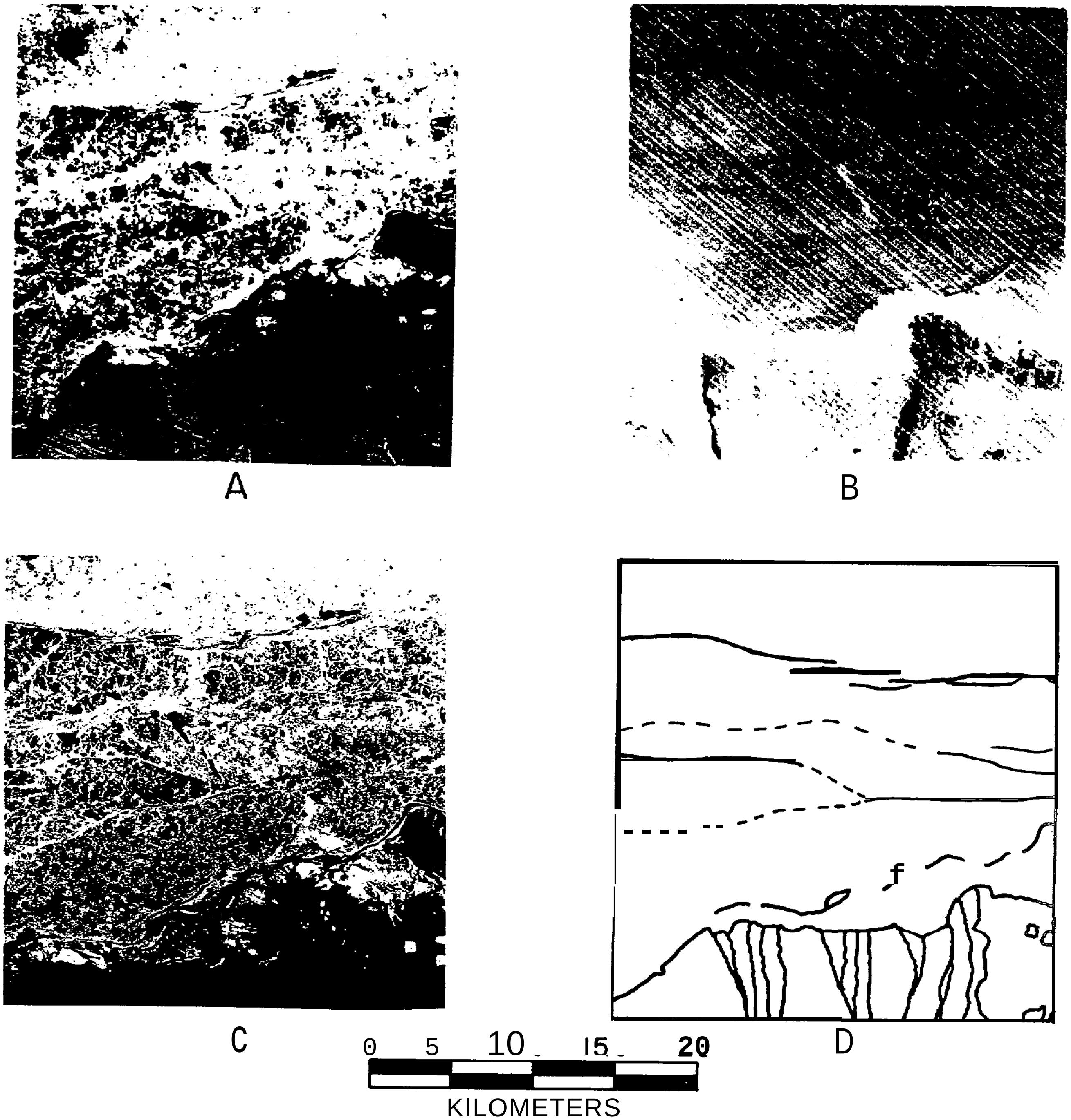

Figure 1. Demonstrating the utility of Landsat imagery to map massive ridge systems. All portions show same region of Alaskan Beaufort coast in vicinity of Barter Island. Shown are (a) portion of Landsat scene obtained June 21, 1974 (b) portion of Landsat scene obtained March 24, 1974 (c) portion of high-altitude aerial photograph obtained June 24, 1974 (d) map of ridge systems identified on the basis of (a) and (b). Solid lines show ridges identified on winter Landsat image, dotted lines show additional ridges identified on basis of spring Landsat image.

season imagery are compared to aid in positive identification of massive ridges (see figure 1), although within the shear zone this is not always possible.

In performing this analysis, Landsat imagery from 1973 through 1981 was used to map large ridges throughout the study area. The combined loci of these ridges have been superimposed on a map of the study area in order to identify the long-term ridging pattern (figure 2). Figure 3 shows the scaled density of ridges in order to provide a quantitative assessment of this pattern, Figures 4 and 5 show the density of ridges within the 20 m isobath and within the minimum extent of fast ice observed within the study period.

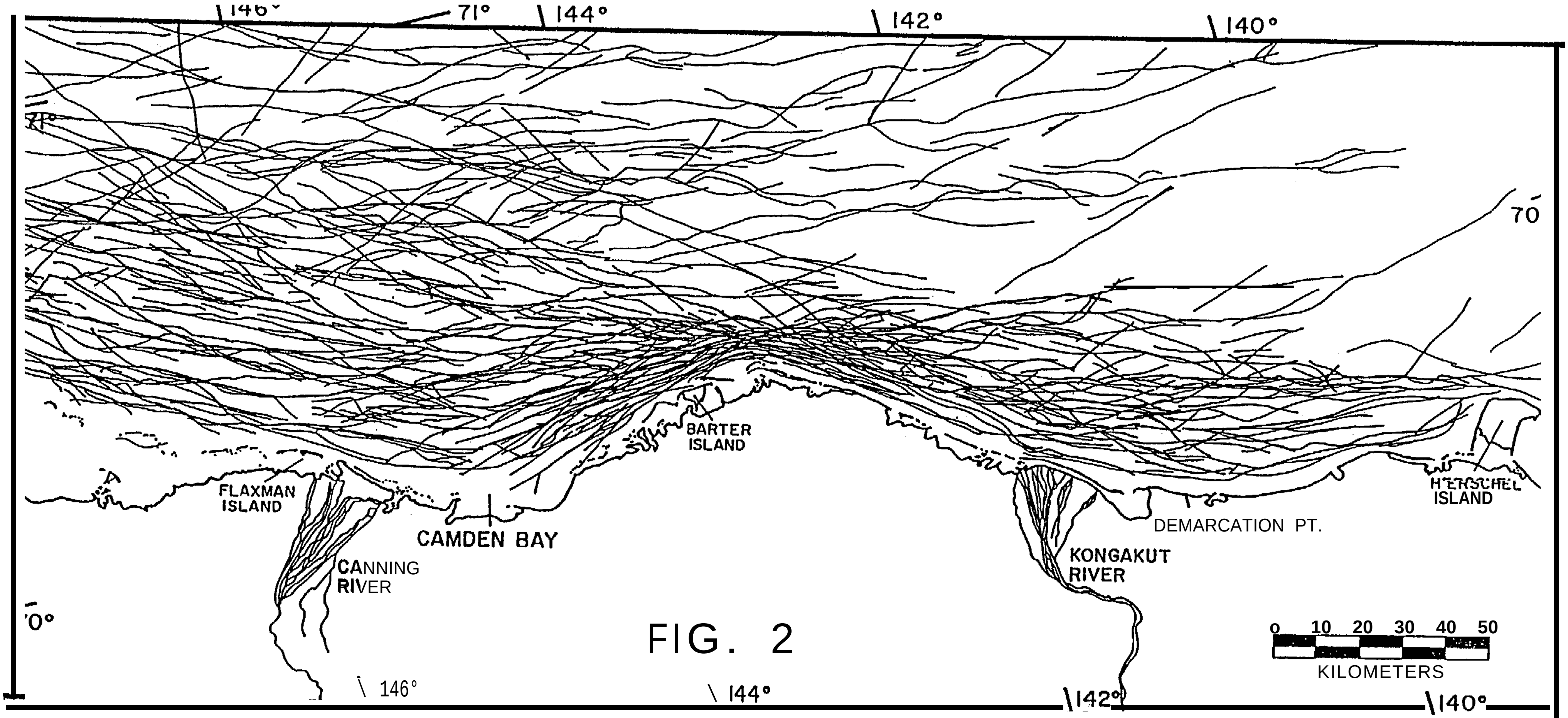

FIG. 2

Figure 2. Composite map of all massive ridges observed in the eastern Beaufort Sea study area during the period 1973 through 1981.

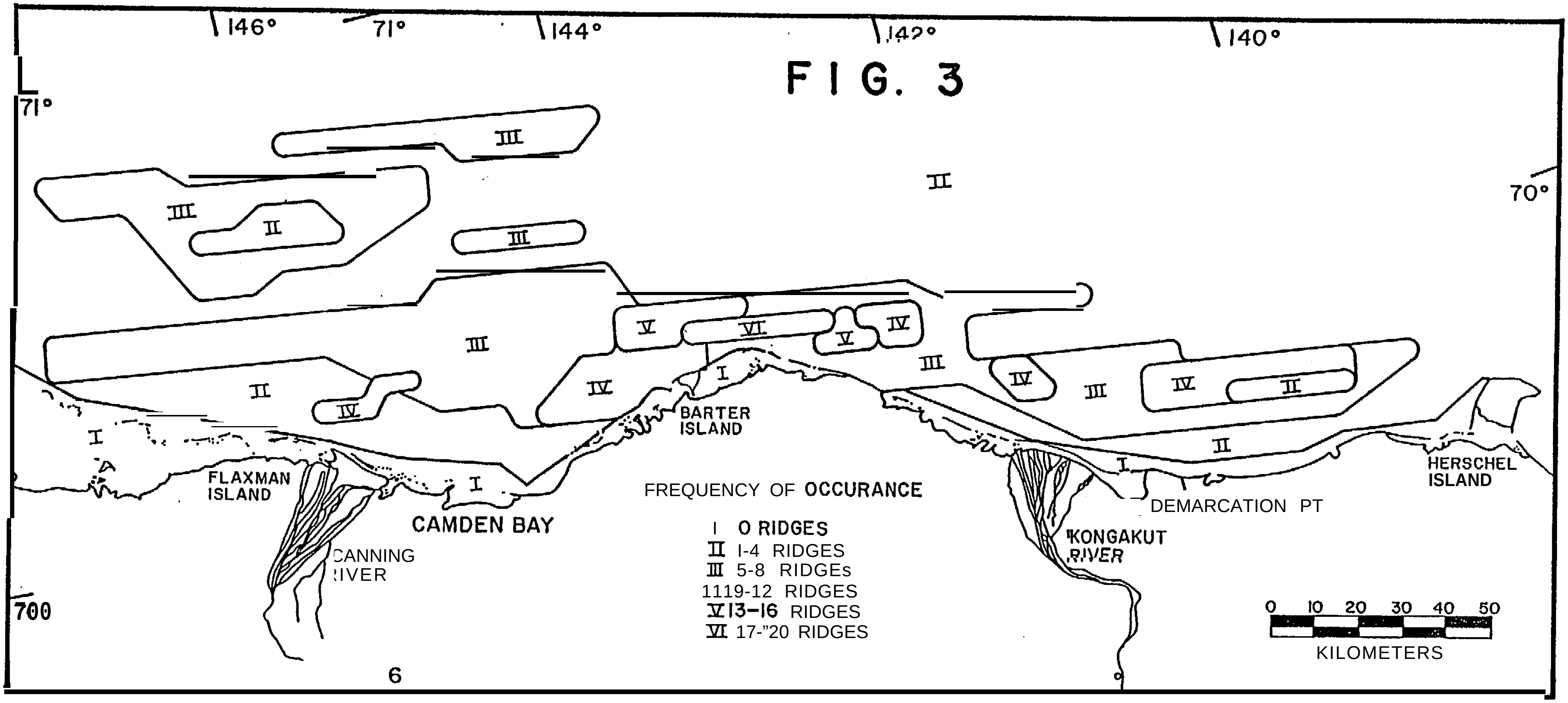

Figure 3. Map of isopleths of ridge density scaled from figure 2. Density is in terms of ridges counted in 25 km^2 over a 9year period.

Discussion

Figure 2 is a composite of all massive ridges observed within the study area during the period 1973 through 1981. Two general trends appear on this figure: (1) in the offshore region (30-40 km from the coast) there is a marked increase of ridging from east to west and (2) in the nearshore region there is a pronounced increase in ridge density off the large promontory containing Barter Island.

The general east-to-west decrease in ridge density offshore suggests a trend toward less dynamic ice events in the eastern portion of the Beaufort Sea. However, no such trend is apparent in the nearshore region.

The increase in ridge density immediately adjacent to Barter Island is apparently related to the local concentrating effect of the large promontory in that region. This geographic feature is the most pronounced , feature along the entire U.S. Beaufort coastline (see figure 6) and has been found to have a significant impact on the location of the shear zone as well (Stringer, et al., 1982). Just as these ridges are compressed in this region, the shear zone is also compressed toward shallower waters here. Although the location of the shoreward edge of the shear zone generally follows the 20-m isobath in the Beaufort Sea region, at this location it is found even inshore from the 15-m isobath.

The number of ridges located between shore and a straight line parallel to the mean shore is relatively constant. In other words, the number of ridges remains fairly constant along the coast, but they are compressed in the vicinity of Barter Island by the shoreline configuration. “ Therefore, the promontory does not result in increased ridging but in increased ridging density. This suggests that ridge-building events are regional in character, each event causing one or more ridges along large portions of the coast.

Figure 3 is a map of isopleths of scaled ridge density. The density values given are in terms of number of ridges per 25 km^2 per nine year period. Since most ridges tend to cross each square of the grid in a generally east-to-west direction, this number can also be taken as the number of massive ridges to be encountered per 5 km transect over a nine year period. In terms of annual ridging frequency, these numbers have the following implication: the zone of greatest ridging density (zone VI, offshore from Barter Island) has a density of 17-20 ridges. This translates to roughly 2 massive ridges per year per 5 km transect or roughly one massive ridge per 2.5 km per year.

Many offshore operating criteria have been developed based on the concept that the winter and spring locations of the shear zone are associated with the 20-m isobath. In particular, severe dynamic ice events have been assumed to occur generally beyond 20-m during that period, the nearshore area being protected by the shorefast ice. The data developed here demonstrate that this is not always the case. First, it has already been shown (Stringer, et al., 1982) that the extreme edge of the shear zone in many-locations is located inshore from the 20-m isobath. Figure 4 shows that many massive ridges are also located inshore from the 20-m isobath. Clearly, many dynamic. ice events responsible for construction of massive ridges occur shoreward of this location.

Furthermore, and perhaps more importantly, massive ridges are found inshore from the extreme shoreward location of the mid-winter and spring-time shear zone (see" figure 5). Without question, these ridges were created as-part of the freeze-up process of the fast ice zone.

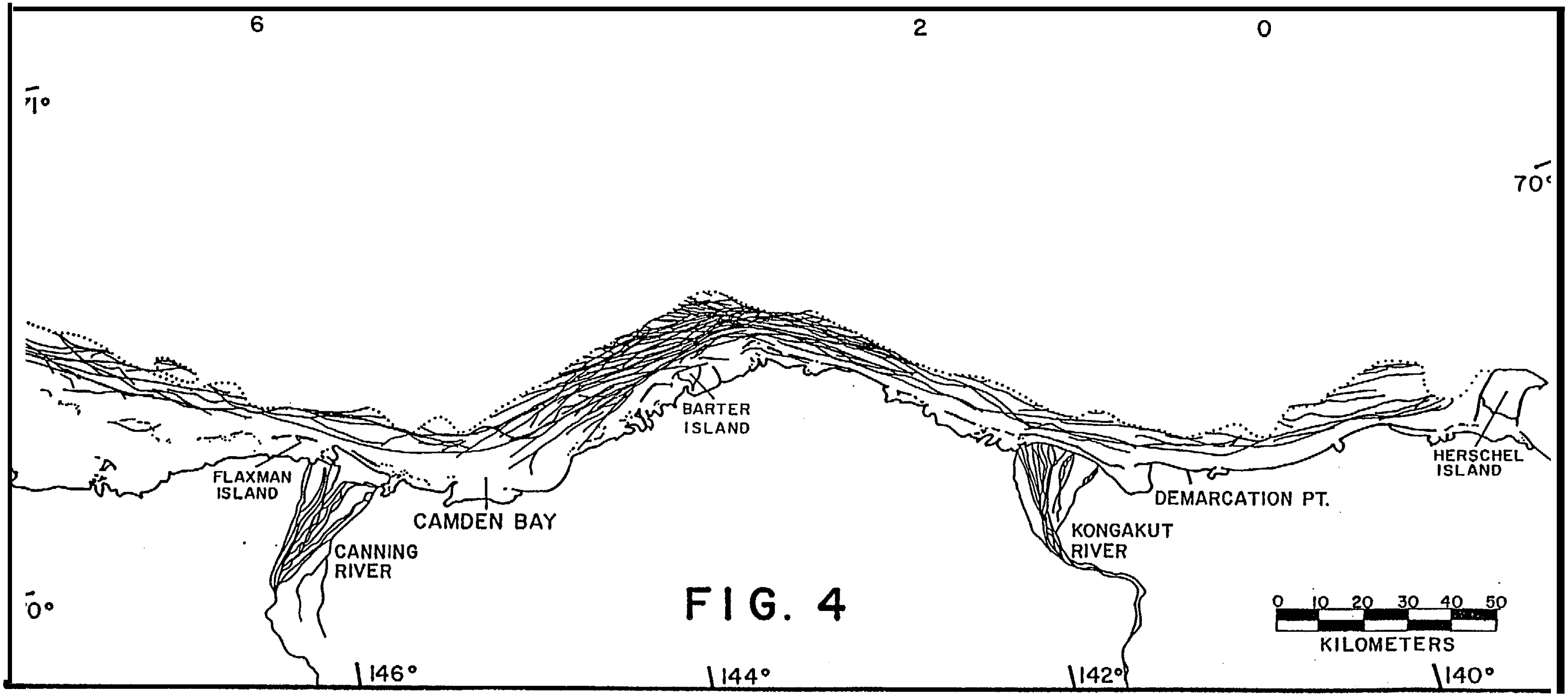

Figure 4. Map of mass ve ridges from figure 2 which were located shoreward of the 20-m isobath.

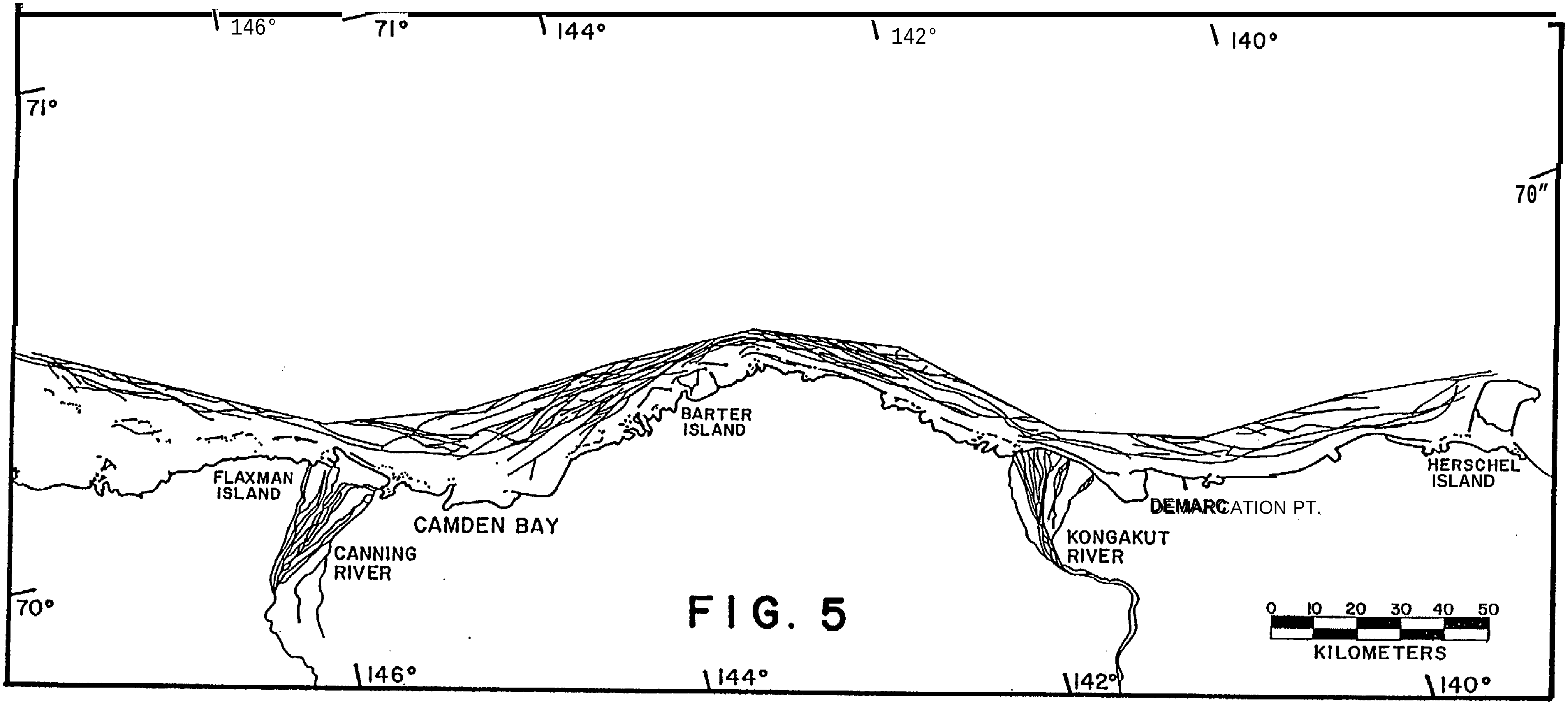

FIG. 5

Figure 5, Map of massive ridges from figure 2 which were located shoreward of the observed extreme minimum extent of wintertime shorefast ice.

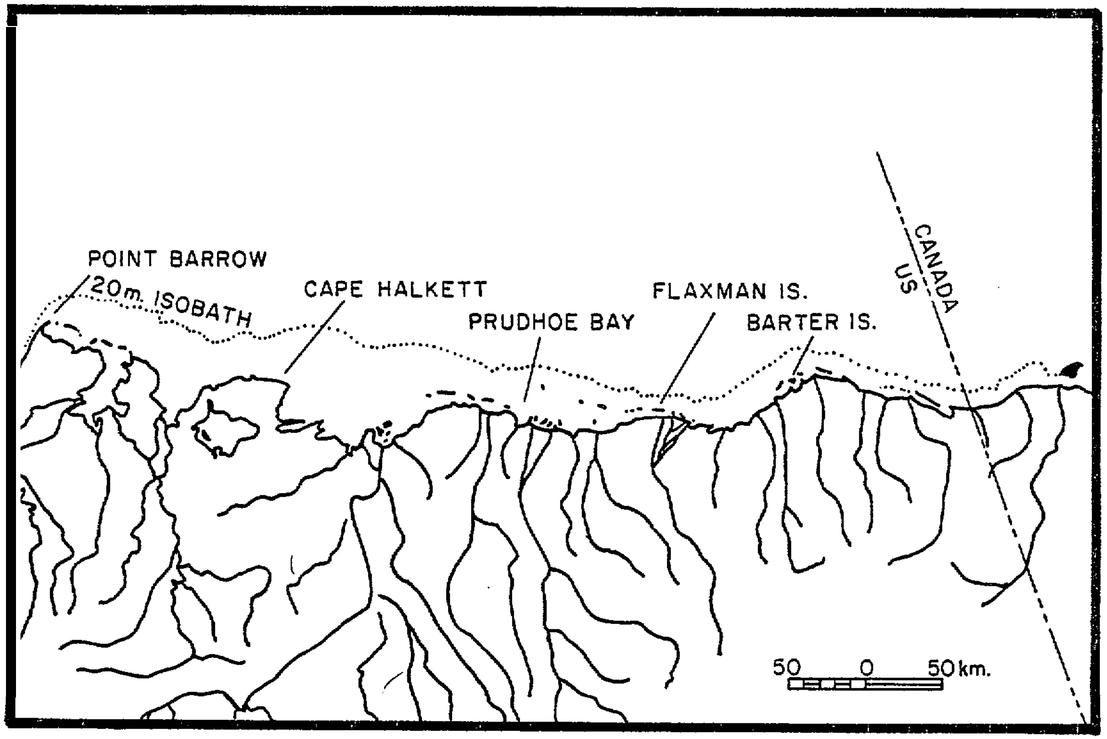

Figure 6. Map showing the U.S. portion of the Beaufort Sea coastline and the 20-m isobath. Note that the large promontory containing Barter Island is the most pronounced seaward variation in this region of the coastline.

The implications of figures 4 and 5 to an environmental assessment of the eastern Beaufort Sea study are:

(1) the 20-m isobath does not delineate the shoreward 1 imit of dynamic ice events creating massive ridge systems

(2) some massive ridges are created within the fast ice zone as part of the freeze-up process. Therefore, locations within the fast ice zone are not necessarily free from dynamic ice events which can create massive ridge systems.

Conclusions

The results presented here suggest the following collusions:

(1) The events responsible for creating massive ice ridges are regional in character, creating ridges which follow the general trend of the coastline, concentrating offshore from headlands and spreading across embayments.

(2) The 20-m isobath does not delimit the shoreward boundary of the zone where dynamic ice events responsible for creation of massive ridges takes place. These events can take place in considerably shallower waters.

(3) Massive ridges are created within the shear zone as part of the freeze-up process. Therefore, man-made structures located within the fast ice zone must be prepared to withstand this sort of event during this period. (It might be noted that this is the period of most harsh environmental conditions: extreme darkness, low temperatures, and high winds.) It might be further noted that active defensive mechanisms (diagonal slits in the ice created to induce ridging beyond man-made structures) would be quite difficult to construct and maintain during this period.

References

Stringer, W.J., S.A. Barrett, and L.K. Schreurs, Nearshore Ice Conditions and Hazards in the Beaufort, Chuckchi, and Bering Seas, Geophysical Institute, University of Alaska-Fairbanks, UAGR#274, May 1980.

Stringer, W.J., J.E. Groves, R.D. Henzler, L.K. Schreurs, and J. Zender-Romick, Location of the Shear Zone in the Eastern Beaufort Sea, prepared for NOAA-OCS, contract No. 81-RA00147, Research Unit 267, September 10, 1982.

Acknowledgements

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