U.S. DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

BED FORM DISTRIBUTION AND INFERRED SAND TRANSPORT ON GEORGES BANK

By David Twichell

Open-File Report 81-764

1981

Table of Contents

Illustrations

BED FORM DISTRIBUTION AND INFERRED SAND TRANSPORT ON GEORGES BANK

by David Twichell

ABSTRACT

Four bed-form provinces have been identified on Georges Bank using sidescan sonar and echo-sounding techniques: large sand waves, small sand waves, megaripples, and featureless sea floor. The large sand waves are found on the bank crest where the surface tidal currents are strongest, and are bordered, north and south, by areas of small sand waves and/or megaripples, formed where tidal currents are moderate in strength. Featureless sea floor is found farthest from the bank crest where surface tidal currents are weakest.

Bed-form asymmetry and surface-sediment texture have been used to infer bedload transport paths on the bank. In the large sand-wave area, bed forms converge on linear northwest-striking ridges from both sides implying erosion from the troughs and growth of the ridges. The asymmetry of the small sand waves along the south side of the bank indicates that sand is also transported southward away from the bank. Though the bed-form asymmetry of megaripples could not be determined in this study, the occurrence of megaripples between the sand-wave provinces and areas of featureless sea floor suggests a decreasing effectiveness of sand transport away from the bank crest. This sand transport pattern is further supported by surface-sediment texture which becomes progressively finer both to the north and southwest away from the crest of Georges Bank.

INTRODUCTION

Sand waves are large bed forms indicative of intense sediment movement, normally found in areas with strong tidal or unidirectional currents. These bed forms can reach 20 m in height, have wave lengths of as much as 1,500 m (Langhorne, 1978), and are either symmetrical or asymmetrical. Asymmetrical sand waves have steeper sides facing the direction of net sediment transport (Stride, 1963). Because of their large size and relatively rapid migration rates (as much as 150 m/y, Ludwick, 1972), they have proven to be hazards to navigation (Langhorne, 1977) and to pipeline and oil rig emplacement (Caston, 1974). The largest area of sand waves on the eastern United States Continental Shelf is on Georges Bank (fig. 1), an area of interest for oil and gas exploration. Because of this interest, this study was undertaken to evaluate the size, orientation, and distribution of sand waves and to make some inferences as to the net sediment transport paths of the area.

Previous work on Georges Bank has dealt with its structure (Emery and Uchupi, 1965; Knott and Hoskins, 1968; Uchupi, 1970; Oldale and others, 1974; Lewis and others, 1980), bathymetry (Uchupi, 1968), sediment texture (Wigley, 1961; Schlee, 1973), and, to a lesser extent, sediment mobility (Stewart and Jordan, 1964; Sanders and others, 1969; and Belderson and others, 1978). Seismic-reflection profiles show that the bank is cored by Tertiary material which is overlain on its western flank by a wedge of Pleistocene sediment (Lewis and others, 1980). Lewis and others identified a smooth unconformity unevenly covered by late Pleistocene drift; the drift having been reworked first by waves when sea level was lower and presently by storms and strong tidal currents.

The morphology of Georges Bank has been described by Uchupi (1968).

Figure 1. Bathymetric map of the Georges Bank area compiled from National Ocean Survey Bathymetric Charts NK 19-11, NK 19-12, and NK 19-18 and Canadian Hydrographic Service Natural Resource Charts 15116-A and 15126-A. Inset shows location of study area.

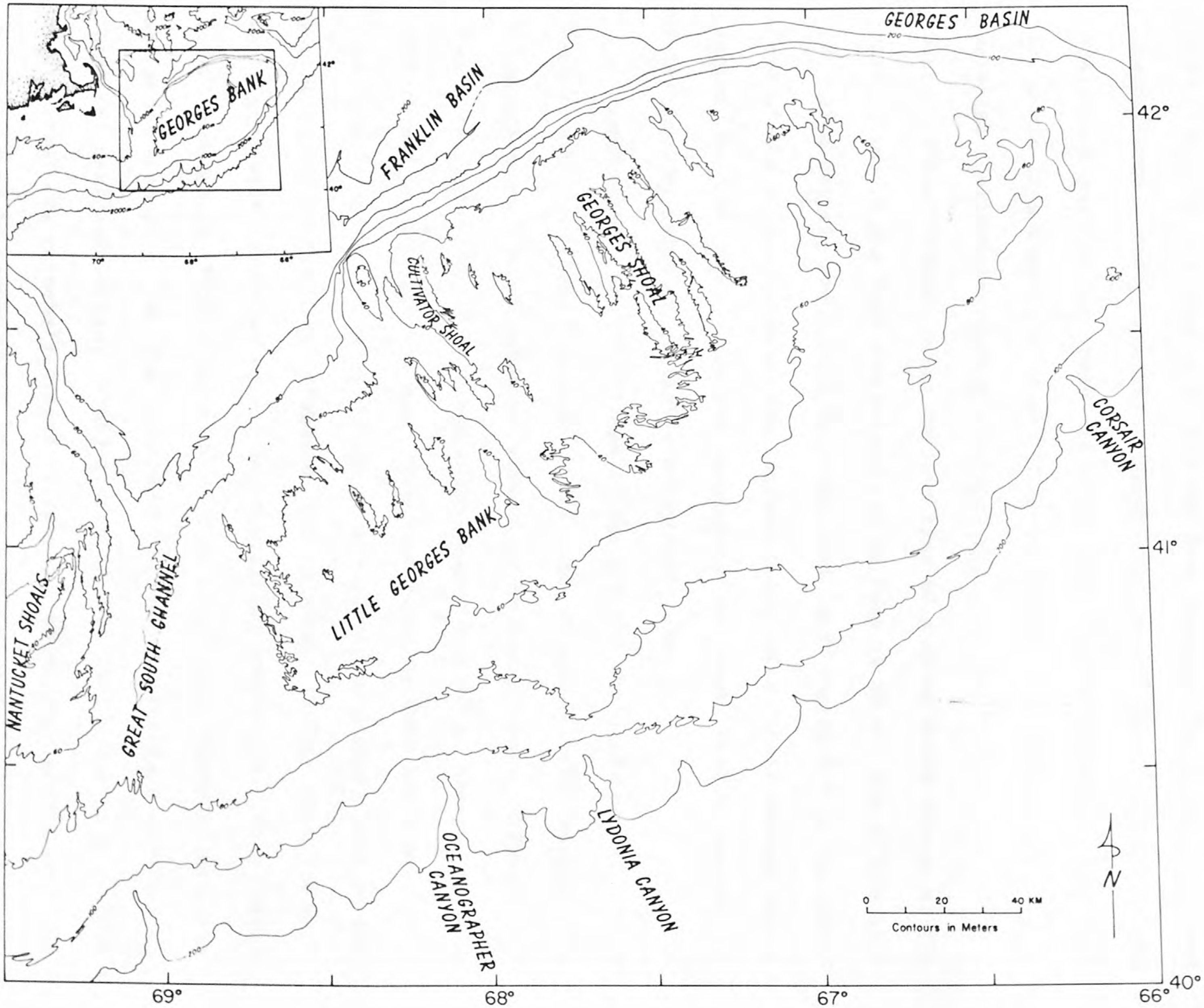

GEORGES BASIN
FRANKLIN BASIN
GEORGES BANK
GEORGES SHOAL
CULTIVATOR SHOAL
LITTLE GEORGES BANK
NANTUCKET SHOALS
GREAT SOUTH CHANNEL
CORSAIR CANYON
OCEANOGRAPHER CANYON
LYDONIA CANYON
42°
41°
40°
69°
68°
67°
66°
0 20 40 KM
Contours in Meters
N

Figure 1

In general, the bank is a broad shallow area bounded to the north by the Franklin and Georges Basins and to the south by the Continental Slope (fig. 1). It is separated from the Nova Scotian Shelf by Northeast Channel and from Nantucket Shoals by Great South Channel. The shallowest part of the bank is near its northern edge where several areas are less than 5 m deep (Uchupi, 1968). A series of roughly parallel northwest-trending ridges extend over the shallow part of the bank. These ridges occur in less than 60 m water depth except at the eastern end of the bank where they are as deep as 80 m. The ridges have 10 - 35 m relief, are 5 - 30 km long, and are spaced 2 - 15 km apart. Some of the largest ridges are asymmetrical with their steeper sides facing to the west, but the asymmetry of most ridges cannot be determined by means of available bathymetric charts.

Superimposed on this ridge topography are the sand waves. From bathymetric profiles, Jordan (1962) and Uchupi (1968) mapped the orientation and distribution of sand waves on Georges Bank. They found them restricted to water depths shallower than 60 m except at the eastern end of the bank where they are found as deep as 70 m. Their data and results of a sidescan-sonar survey in a small area on the southern side of the bank (Sanders and others, 1969), show the sand waves generally have east or northeast striking crestlines. Both Jordan (1962) and Uchupi (1968) concluded that sand wave asymmetry suggests sediment transport to the southwest. Diver observations on Georges Shoal (Stewart and Jordan, 1964) indicated that sand waves on the crest of the shoal are extremely active in response to strong tidal currents whereas those in deeper water at the base of Georges Shoal appear to be inactive. Repeated echo-sounding surveys suggest that the bed forms on the crest of Georges Shoal may be moving at a rate of 12 m/y (Stewart and Jordan, 1964).

Tidal currents, which are considered the mechanism responsible for moving sand waves on the open shelf (Kenyon and Stride, 1970), are strong on Georges Bank. Haight (1942) measured the surface tidal currents over the bank and found maximum currents exceeding 75 cm/s over most of the area shallower than 60 m. The path of the rotary tidal currents is elongated with the major axis oriented north-northwest-south-southeast. In the deeper water on the southern side of the bank, surface tidal currents decrease to 40-60 cm/s and the path of the current is more nearly circular.

METHODS

Four hundred fifty-six km of sidescan sonar and 12 kHz echo-sounding profiles and 185 km of Uniboom profiles were collected on selected parts of Georges Bank (fig. 2) during three cruises aboard the R/V ATLANTIS II (cruise 103, September 26-October 2, 1978) and the R/V OCEANUS (cruise 056, March 6-15, 1979 and cruise 067 August 6-13, 1979). A Klein sidescan sonar set to scan either 100 m or 150 m to each side of the towed fish was used to map the bottom character and the orientation of bed forms. A 12 kHz echo sounder measured bed form height and asymmetry. The Uniboom data was filtered at 400-4,000 Hz, was recorded at a 0.5-s sweep rate, and was used to map the shallow stratigraphy of part of the study area. Navigation was done by Loran-C. 3.5 kHz echo-sounding profiles collected aboard the R/V FAY (cruise 003 October 2-17, 1975) during a regional survey of Georges Bank have also been used to map sand wave location, height, and asymmetry.

Rough weather during the OCEANUS 056 cruise affected the quality of these data, making them less useful than the data collected during the

Figure 2. Location of tracklines used in this study, and the different types of data that were collected. Heavy line segments refer to illustrations shown in other figures.

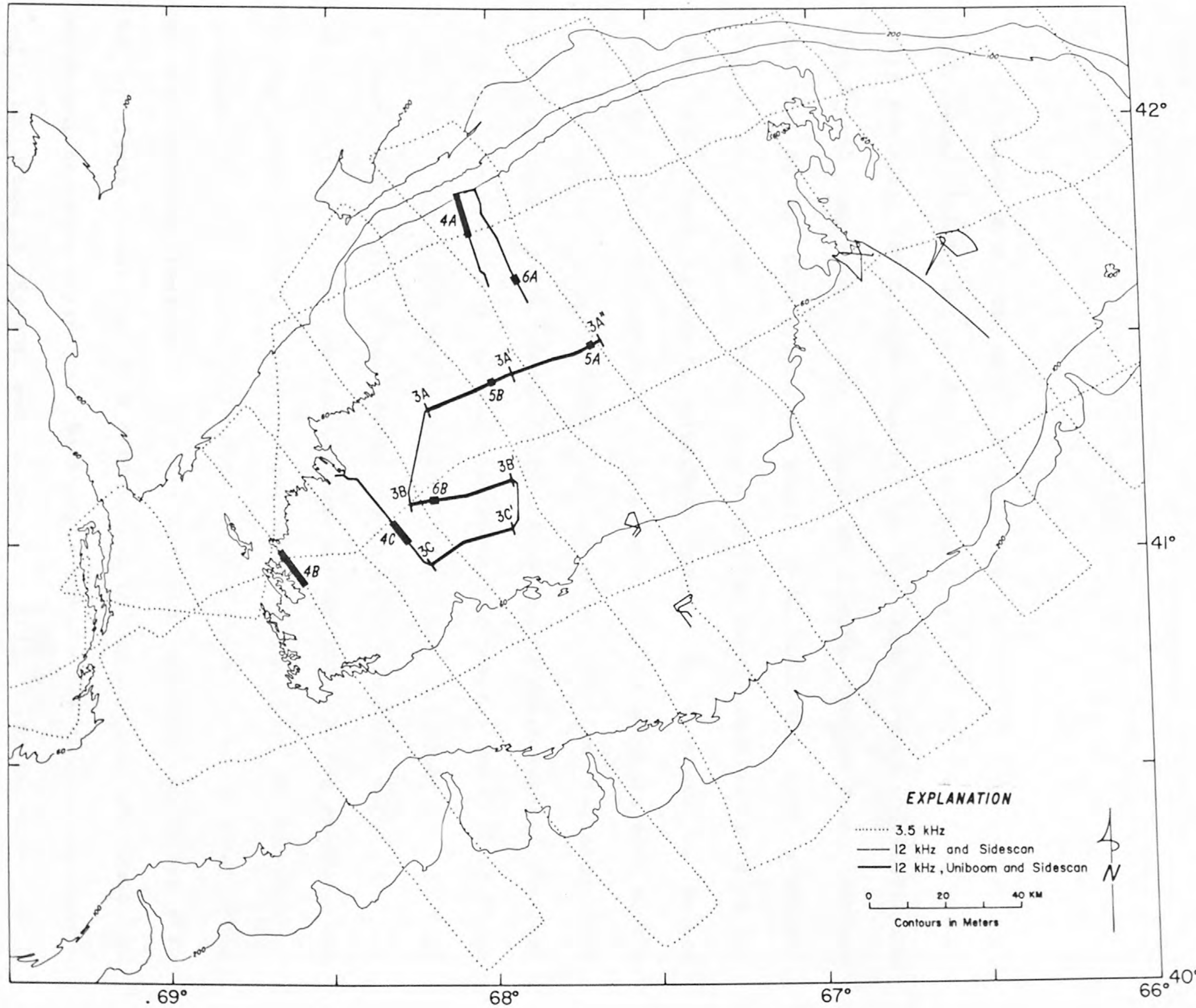

42°
41°
40°
69°
68°
67°
66°
4A
6A
3A
3A'
3A"
5A
5B
3B
6B
3B'
3C'
4C
3C
4B
EXPLANATION
3.5 kHz
12 kHz and Sidescan
12 kHz, Uniboom and Sidescan
0
20
40 KM
Contours in Meters
N

Figure 2

two other cruises. Because of large seas, sand wave asymmetry and height could not be accurately determined from much of the OCEANUS 056 data.

RESULTS

Structure

Uniboom profiles were collected on the OCEANUS 067 cruise near Cultivator Shoal and on Little Georges Bank (fig. 1, 2). The profiles were run along two troughs parallel to the ridges east of Cultivator Shoal, and transverse to the ridges on Little Georges Bank. Maximum penetration by this system was about 50 m, and the most prominent horizon seen on the profiles was a shallow nearly continuous reflector (fig. 3). This surface is relatively smooth in contrast to deeper reflectors which are commonly channelled. On the southern side of the bank (on Little Georges Bank) the prominent shallow reflector dips gently seaward; on the two profiles across the northern edge of the bank it dips more steeply in the opposite direction towards the Gulf of Maine (fig. 4A). Under most of the ridges the shallow reflector is a flat surface, but a few of the ridges are cored by subdued highs in the shallow reflector. At the southwestern end of line 4, for example, two of the ridges sit on a surface elevated about 8 m above the surrounding horizon (fig. 3). Some of the other ridges may be cored by older highs as well, but with reliefs of only 1-4 m, these apparent highs may also be artifacts resulting from differences in the velocity of sound in different sediment types. In the troughs between the ridges, the smooth reflector often is exposed, and in one place (fig. 3 southwestern end of line 4) it is truncated on a ridge flank suggesting that locally the ridge-forming process involves or involved the older surface. The

Figure 3. Line-drawing interpretations of sonographs (upper part of set) and seismic-reflection profiles (lower part of set). Sonographs show sand wave locations and orientations, and hatch marks point in direction steep side is facing. On seismic-reflection profiles, the heavy line marks a shallow nearly continuous horizon interpreted to be the late Pleistocene unconformity identified by Lewis and others (1980). Profile locations shown in figure 2.

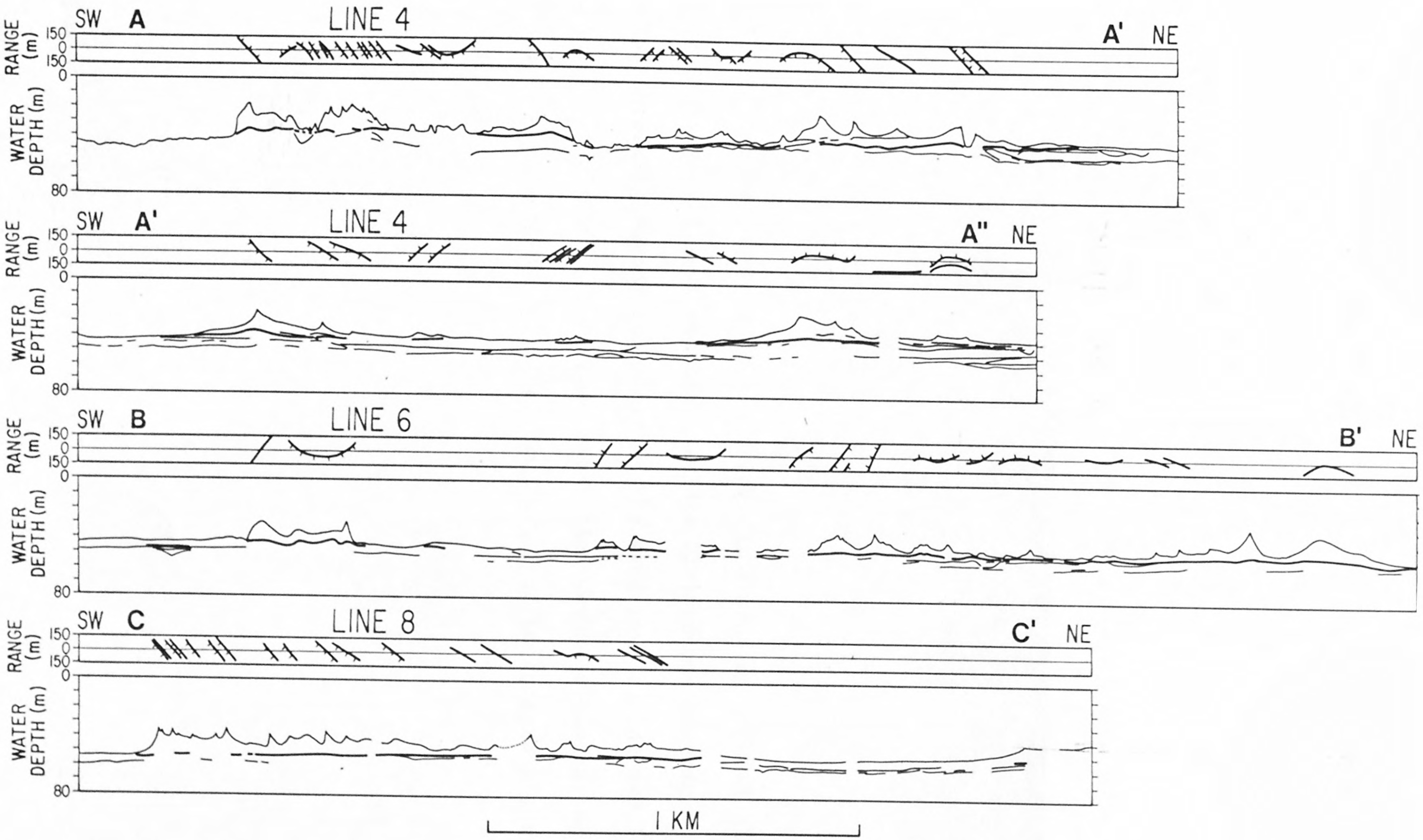
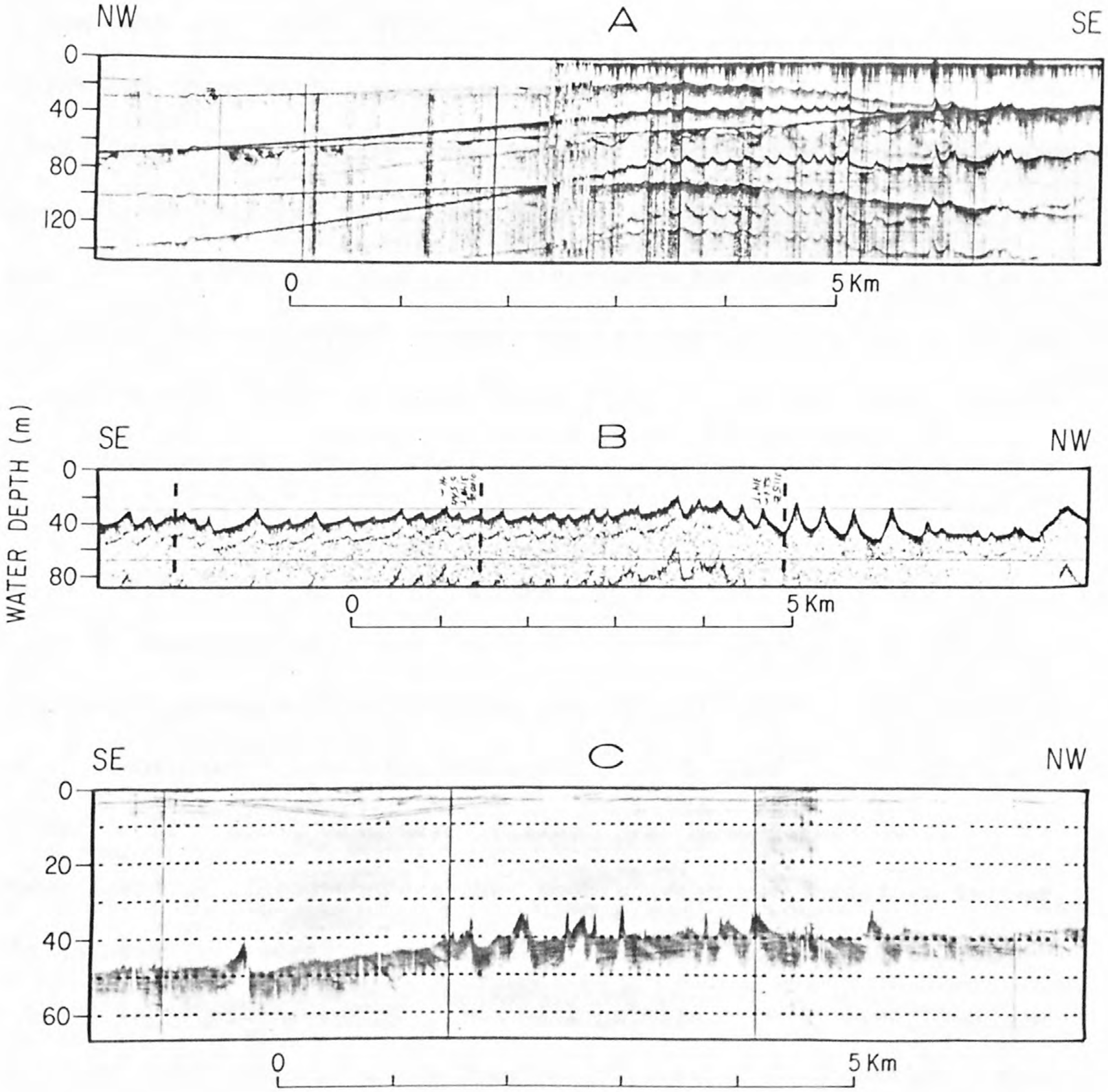

SW
A
LINE 4
A'
NE
RANGE (m)
150
0
150
0
WATER DEPTH (m)
80
SW
A'
LINE 4
A"
NE
RANGE (m)
150
0
150
0
WATER DEPTH (m)
80
SW
B
LINE 6
B'
NE
RANGE (m)
150
0
150
0
WATER DEPTH (m)
80
SW
C
LINE 8
C'
NE
RANGE (m)
150
0
150
0
WATER DEPTH (m)
80
1 KM

Figure 3

Figure 4. Seismic-reflection profiles showing (A) a lens of acoustically transparent sediment overlying a late Pleistocene unconformity and extending beyond the limit of the sand wave field; and (B and C) fields of large asymmetrical sand waves demonstrating bed form convergence on ridge crests. Profile locations shown in figure 2.

Figure 4A-C



NW
A
SE
0
40
80
120
0
5 Km
WATER DEPTH (m)
SE
B
NW
0
40
80
0
5 Km
SE
C
NW
0
20
40
60
0
5 Km

Uniboom profiles showed that the ridges are composed of acoustically transparent material having no internal structure.

<u>Sand waves and megaripples</u>

In addition to the northwest-trending ridges, two other types of bed forms were seen: sand waves (fig. 5) and megaripples (fig. 6). Sand waves are bed forms with wavelengths greater than 10 m and megaripples are bed forms with wavelengths between 0.6 and 6 m (Boothroyd and Hubbard, 1975). Ripples (less than 0.6 m wavelength) are too small to be resolved by sidescan sonar. The sidescan-sonar data and additional echo-sounding data collected during the FAY 003 cruise (fig. 2) showed that sand waves, like the sand ridges, are found in water depths shallower than 60 m except at the eastern end of the bank where they are recognized to depths of 90 m (fig. 7). On the basis of these data, the extent of the sand waves is in accord with the extent based on the findings of Jordan (1962) and Uchupi (1968). Sand waves are not uniformly distributed over wide areas, but occur in fields separated by tracts of smooth sea floor. Echo-sounding profiles and sonographs show that most of the sand-wave fields are associated with the northwest-trending ridges whereas the smooth areas are localized in the troughs between the ridges (figs. 3, 6B). Sonographs showed that sand waves found in troughs occur only in small patches, have less than 2-m relief, and less than 50-m wavelengths (fig. 6A). In contrast, the ridge-associated sand-wave fields are large, covering entire ridges, and the sand waves themselves are larger having heights of 1-10 m and wavelengths mostly between 100 and 300 m (figs. 4B and C, 5). Generally sand waves are largest on the shallowest part of the bank, whereas in water depths greater than 50 m along the southern edge of the sand-wave area sand waves are typically smaller, having less than 4 m relief

Figure 5. Sonographs showing large sand waves and associated megaripples. Example locations shown in figure 2.

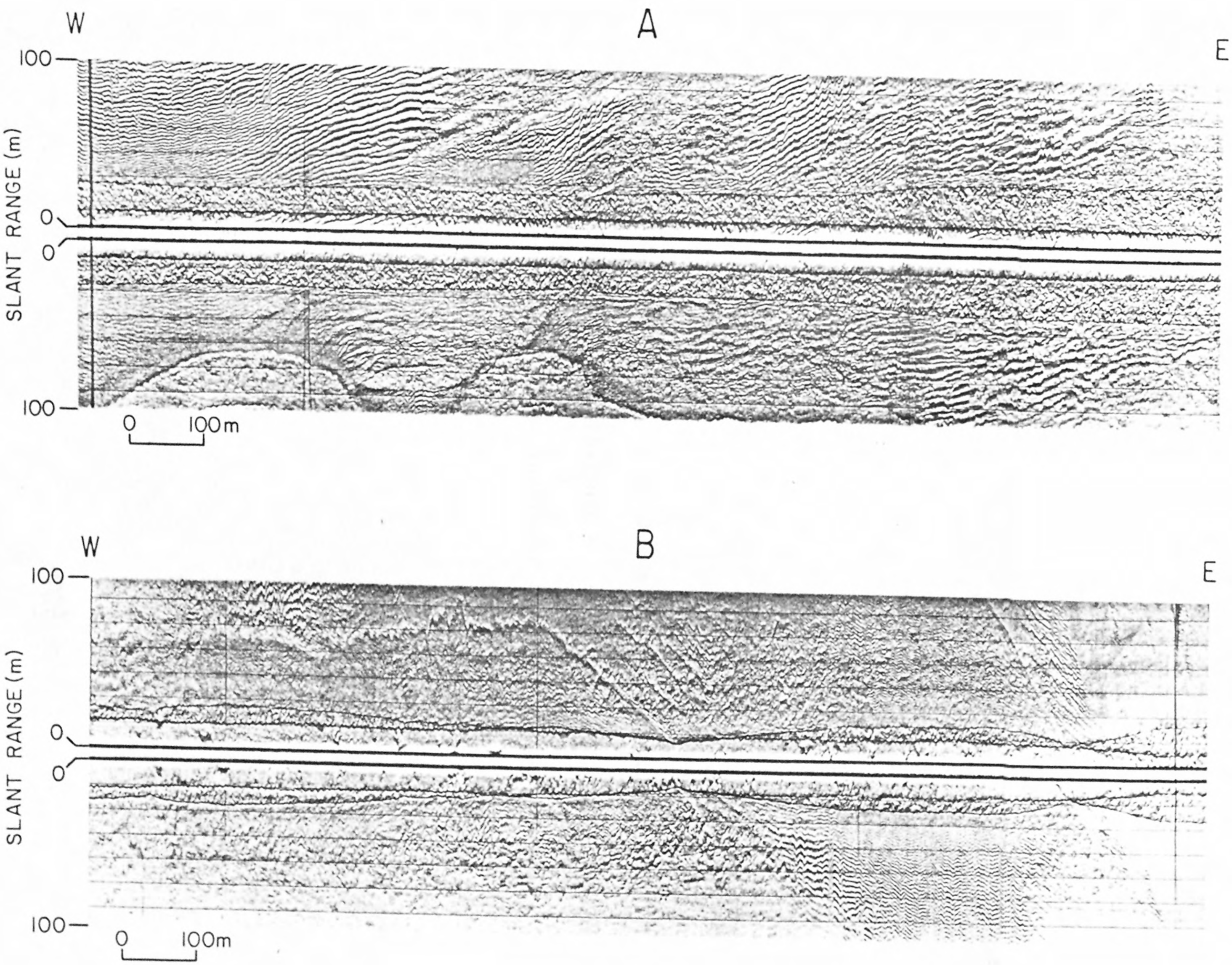

W
A
E
100
SLANT RANGE (m)
0
0
100
0
100m
W
B
E
100
SLANT RANGE (m)
0
0
100
0
100m

Figure 5

Figure 6. Sonographs showing (A) small sand waves in a trough east of Cultivator Shoal and (B) featureless sea floor with some patches of megaripples in a trough on Little Georges Bank. Sonograph locations shown in figure 2.

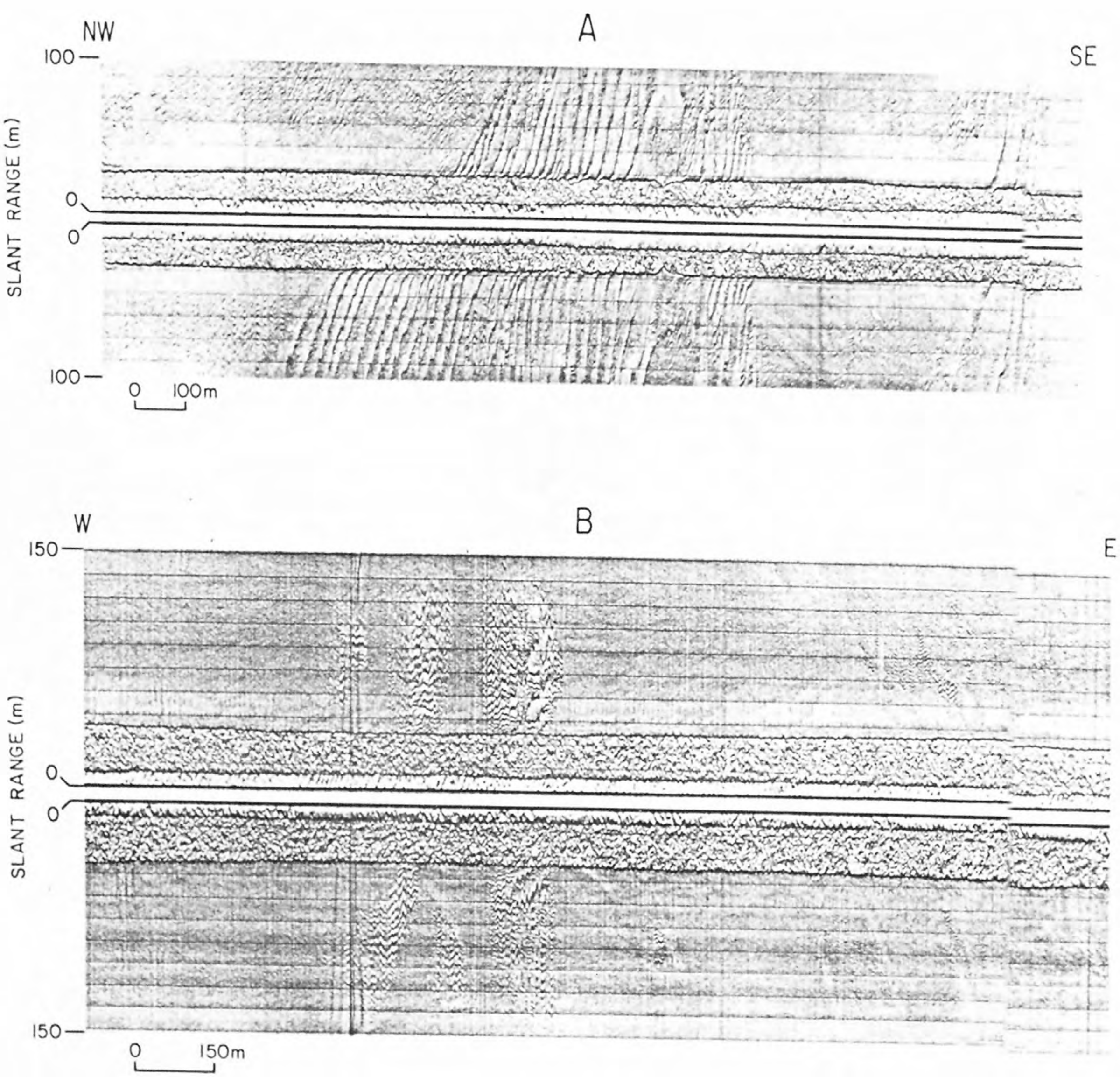

A
NW
SE
100
0
0
100
SLANT RANGE (m)
0 100m
B
W
E
150
0
0
150
SLANT RANGE (m)
0 150m

Figure 6A-B

Figure 7. Map showing distribution of large sand waves, small sand waves, megaripples, and featureless sea floor and direction in which sand waves are interpretated to be moving.

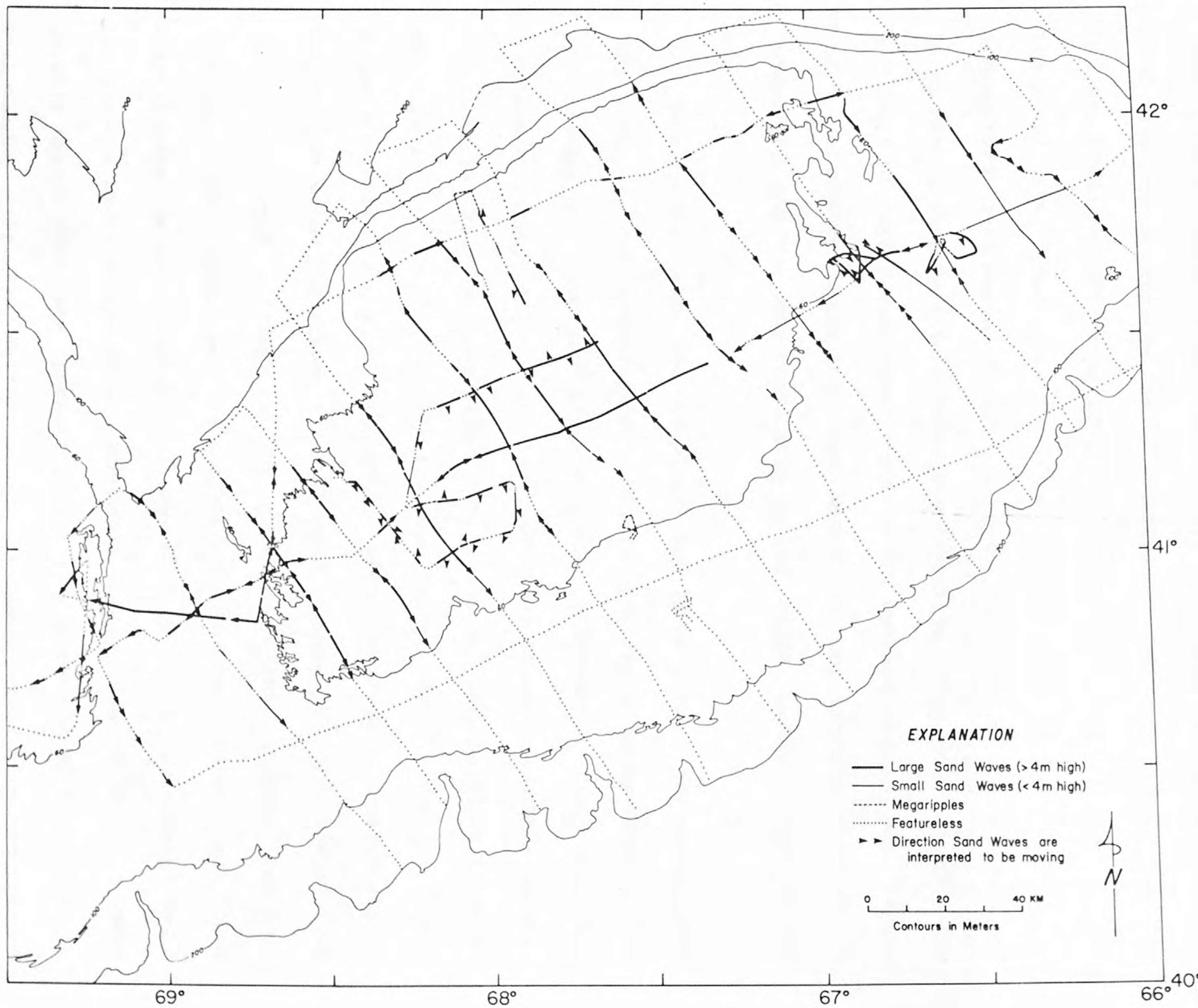

42°
41°
40°
69°
68°
67°
66°
EXPLANATION
Large Sand Waves (> 4m high)
Small Sand Waves (< 4m high)
Megaripples
Featureless
Direction Sand Waves are interpreted to be moving
0 20 40 KM
Contours in Meters
N

Figure 7

(fig. 7).

Sonographs showed that throughout the entire sand wave area the wave crests are oriented 030°-120°. The range in strike of the sand-wave crests reflects the sinuosity of the bed forms, but the average trend of the crests is approximately 045°, roughly normal to the trend of the ridge crests. Echo-sounding profiles showed that the asymmetrical sand waves do not all have steep sides facing southwest; a large number also face in a northerly direction (fig. 4). Usually the northward migrating sand waves occur on the western sides of the ridges and the southward migrating sand waves on the eastern sides of the ridges with the two sets converging on the ridge crests (figs. 4B and C).

Megaripples were the smallest bed forms seen on the sonographs. They have 1 - 7 m wavelengths, heights too low to be resolved by the echo sounder used, and crestlines trending 045°-090°. Their crestline trends are slightly offset from the sand waves except near the sand wave crests where the megaripple crestlines bend until they parallel those of the sand waves (fig. 5). Within the area where sand waves are found, megaripple distribution coincides with sand-wave distribution. Megaripples occur throughout the sand-wave fields on the ridges, but only in scattered patches in the troughs between ridges (fig. 6B). Although the megaripple distribution closely follows sand wave distribution in water depths shallower than 60 m, they also were found in greater water depths where sand waves are absent (fig. 7). Near Corsair Canyon they are present near the 90-m contour where the survey line ended (fig. 7). Farther to the southwest megaripples are present where sand waves are absent in 60 m water depth, but in the same general area are absent themselves in 80-90 m water depth (fig. 7). Along the northern edge of the bank they are found beyond the limits of the sand-wave distribution at least to depths of 60-70 m.

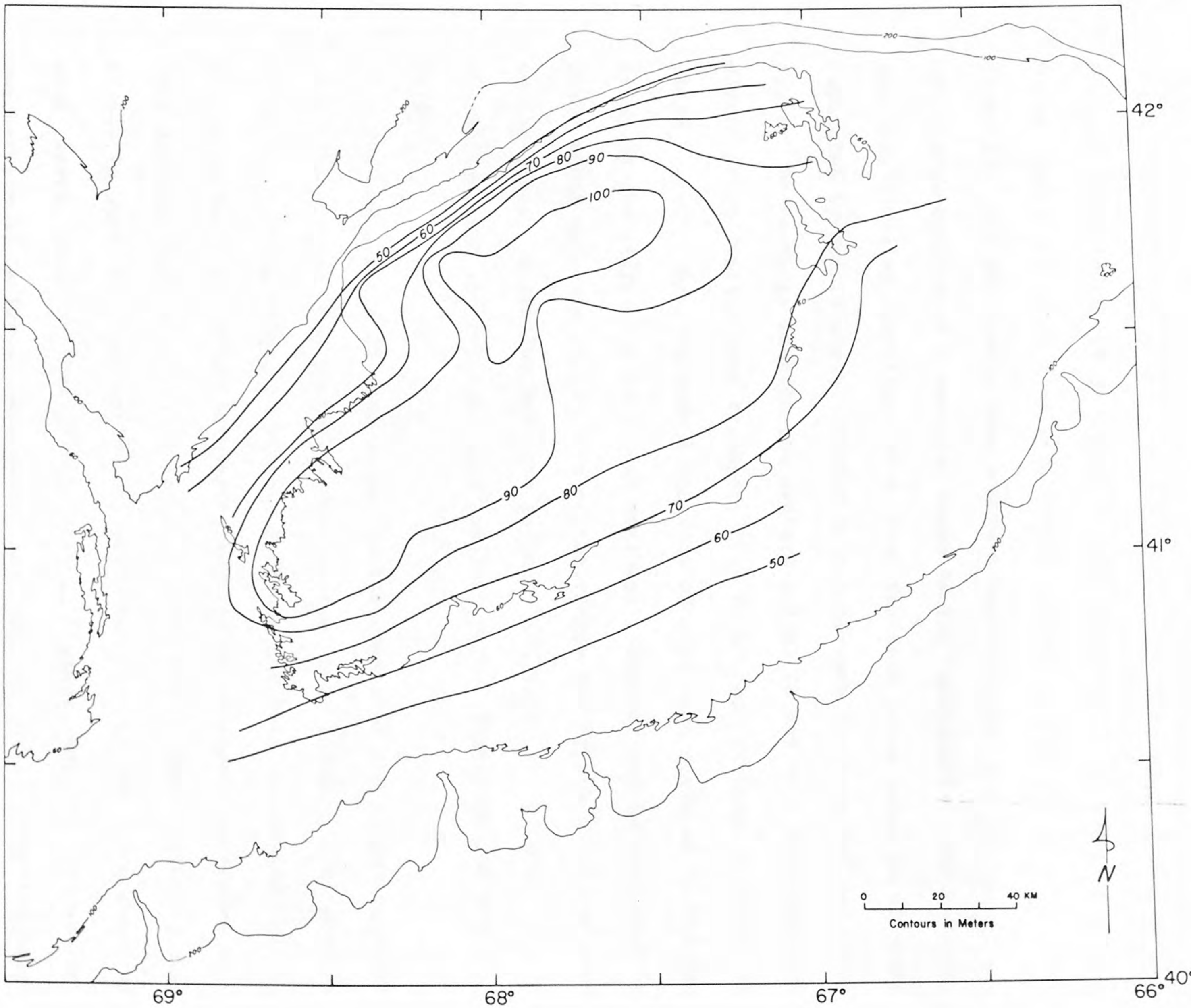
DISCUSSION

Two types of bed forms were found on Georges Bank, megaripples and sand waves. The sand waves can be divided into two groups based on height; namely large (greater than 4 m high) and small (less than 4 m high). Large sand waves occur near the top of the bank in an area covered by northwest-trending ridges (fig. 7). Superimposed on these sand waves are megaripples. Small sand waves occur in patches in some of the troughs between the ridges and in a discontinuous band seaward of the area covered by the large sand waves. These bed forms too are covered by megaripples which have the same orientations. Megaripples also occur by themselves (fig. 7). Beyond the megarippled area the sea floor is featureless except for trawl marks.

The distributions of the three bed-form groups correspond with variations in the surface tidal current strength and with sand availability. The large sand waves are found where surface tidal currents exceed 70-80 cm/s (fig. 8). Within the small sand wave region tidal current strength is 60-80 cm/s. In the megaripple area, both along the north and on the south side of the bank, maximum surface tidal current strengths have decreased to 40-70 cm/s. The featureless sea floor coincides with areas where surface tidal currents do not exceed 40-50 cm/s.

Sand supply also contributes to bed-form distribution. The distribution of large sand waves coincides with the ridge locations. It appears that large sand waves develop on the ridges because the ridges are large, loose sand deposits whereas the troughs are areas of outcrop

Figure 8. Map showing speed of surface tidal currents on Georges Bank. Contours in cm/s. Data modified from Haight (1942).



42°
41°
40°
69°
68°
67°
66°
50
60
70
80
90
100
0
20
40 KM
Contours in Meters
N

Figure 8

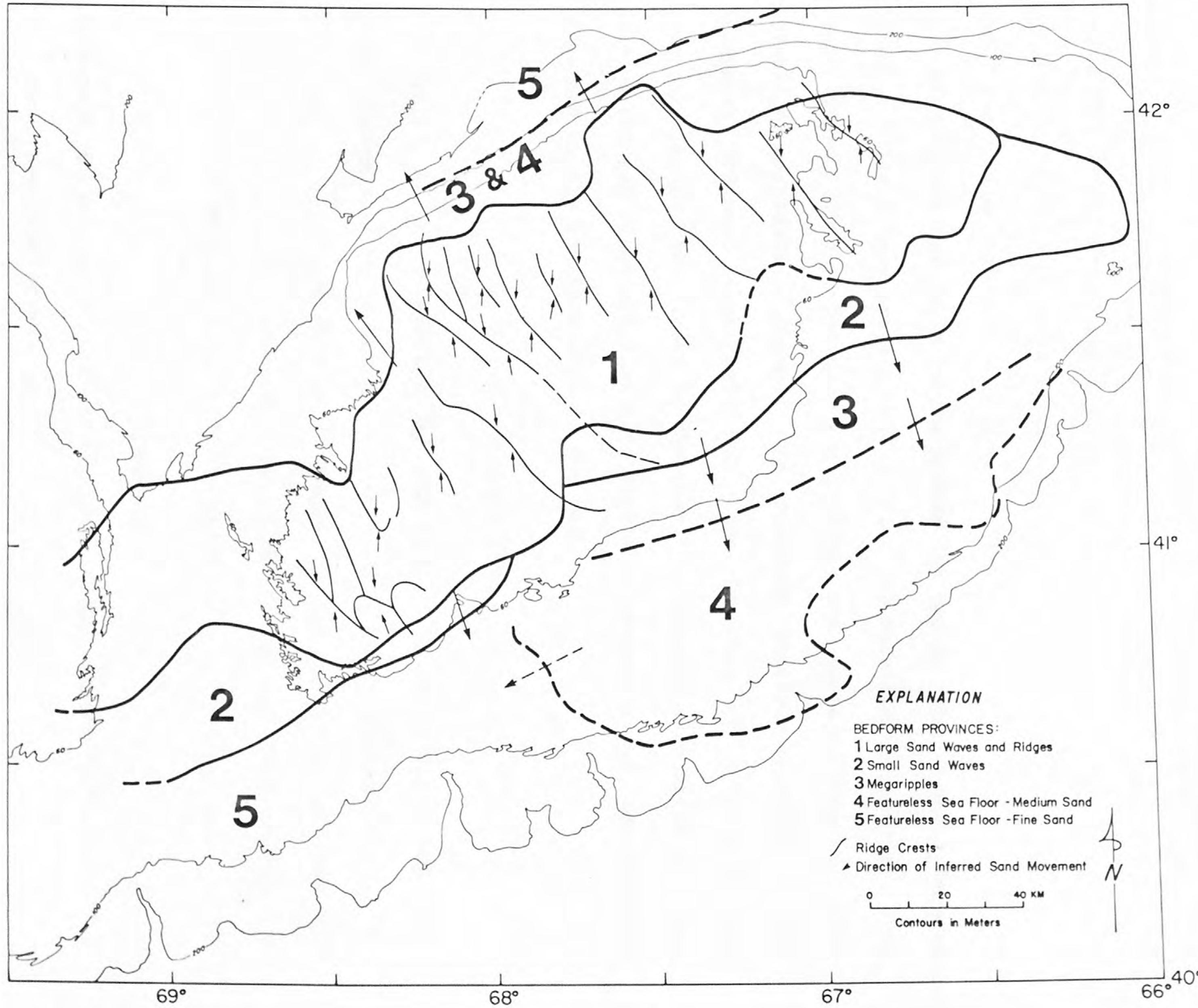
where available sand has been swept away.

The steep faces of asymmetric sand waves have been shown by Belderson and Stride (1966) to indicate their transport directions. Jordan (1962) and Uchupi (1968) suggest that net sand transport on Georges Bank is to the southeast because this is the direction that the steep sides of most sand waves face. However, echo-sounding profiles from the FAY 003 cruise show a more complex facing pattern (fig. 7), with large numbers of asymmetric waves facing northeast. Furthermore, the echo-sounding profiles show that the sand waves occur in clusters separated by smooth areas. Within most sand-wave clusters the bed forms appear to converge towards the centers (figs. 4B and C). This bed form distribution implies sand transport away from the troughs towards the ridge crests. The different directions of sand wave movement on the two sides of the ridges suggests that sediment transport may be dominated by flood tidal currents on one side of the ridges and by ebb tidal currents on the other. A similar bed-form pattern is seen in estuary mouths where flood and ebb currents have separate paths (Boothroyd and Hubbard, 1975).

The convergence of sand waves on the crests of the ridges suggests that the ridges may themselves be active bed forms. The present mobility of these ridges on Georges Bank has not been documented, but in the North Sea, repeated bathymetry surveys of similar ridges show that they do move (Caston, 1972) albeit at a slow rate. The origin of these ridges is unknown. Apparently they are maintained by the convergence of sand waves towards their crests from both sides, but it is unclear whether the migration of sand waves has entirely built these ridges or whether the ridges were created by some other process and presently have sand waves concentrated on them because they are the only areas of available sandy sediment.

With this reconnaisance understanding of the distribution and asymmetry of sand waves and with information on surface-sediment texture (Wigley, 1961; Schlee, 1973), some predictions can be made of the net sediment transport paths on Georges Bank (fig. 9). Sediment movement on the top of the bank, where tidal currents are strong, appears to be intense with any available sand in the troughs transported towards the linear ridges. Convergence of sand waves on ridge crests implies sand storage in the ridges, however, this storage system is not "leak proof" because on the southern side of the bank, outside the area of ridges and large sand waves, the southeast-facing asymmetry of most of the small sand waves indicates transport away from the bank crest. Along the north edge of the bank, sand may be accumulating outside the area of large sand waves as seismic-reflection profiles show an acoustically transparent lens of sediment overlying the same unconformity which underlies the ridges (fig. 4A). Megaripples veneer the surface of this deposit (fig. 7), but, unfortunately, their asymmetry cannot be resolved to confirm sand transport away from the top of the bank. Where bed forms are absent or are too small for these data to define their asymmetry the progressive fining of the surface sediment texture away from the bank crest (Wigley, 1961; Schlee, 1973) supports an inference of continued transport away from Georges Bank. Medium to coarse sand is found on top of the bank whereas fine sand covers the northern and southern flanks and becomes finer with distance from the bank crest. Mud deposits are at the ends of the transport paths in Georges and Franklin Basins and on the shelf south of Martha's Vineyard. In these areas, tidal currents have become weak enough to permit even the fine-grained suspended sediment to be deposited (Twichell and others,

Figure 9. The location of five bed form and textural provinces and inferred sand transport paths on and around Georges Bank.



5
3 & 4
1
2
3
4
2
5
42°
41°
40°
69°
68°
67°
66°
EXPLANATION
BEDFORM PROVINCES:
1 Large Sand Waves and Ridges
2 Small Sand Waves
3 Megaripples
4 Featureless Sea Floor - Medium Sand
5 Featureless Sea Floor - Fine Sand
Ridge Crests
Direction of Inferred Sand Movement
0 20 40 KM
Contours in Meters
N

Figure 9

1981; Bothner and others, 1981).

IMPLICATIONS

In light of possible oil exploitation on Georges Bank two findings from this study may be significant. First, these admittedly preliminary findings suggest that sand waves are concentrated in fields associated with the northwest-oriented ridges. In the event of oil production in the area, pipelines might be run across the top of the bank. Because sand wave fields may present difficulties in maintaining pipelines over sand ridges, troughs between the ridges may serve as less hazardous pipeline corridors. Second, the proposed bedload transport model suggests sediment transport away from the top of the bank and accumulation on the flanks of the bank. Pollutants associated with the sand-sized and finer material then should accumulate along the northern edge and on the southern side of the bank.

ACKNOWLEDGMENTS

This work was supported by the U.S. Bureau of Land Management under Memoranda of Understanding with the U.S. Geological Survey AA551-MU9-4 and AA551-MU0-18. Thanks is extended to the crew and scientific personnel aboard the R/V OCEANUS 056 and 067 cruises for their skillful help in collecting the data.

REFERENCES

Belderson, R. H., and Stride, A. H., 1966, Tidal current fashioning of a basal bed: Marine Geology, v. 4, p. 237-257.

Belderson, R. H., Johnson, M. A., and Stride, A. H., 1978, Bed-load partings and convergences at the entrance to the White Sea, U.S.S.R., and between Cape Cod and Georges Bank, U.S.A.: Marine

Geology, v. 28, p. 65-75.

Boothroyd, J. C., and Hubbard, D. K., 1975, Genesis of bed forms in mesotidal estuaries, in Cronin, L. E., ed., Estuarine research: New York, Academic Press, v. 2, p. 217-234.

Bothner, M. H., Spiker, E. C., Johnson, P. P., Rendigs, R. R., and Aruscavage, P. J., 1981, Geochemical evidence for modern sediment accumulation on the Continental Shelf off Southern New England: Journal of Sedimentary Petrology, v. 51, p. 281-292.

Caston, V. N. D., 1972, Linear sand banks in the southern North Sea: Sedimentology, v. 18, p. 63-78.

Caston, V. N. D., 1974, Bathymetry of the northern North Sea; knowledge is vital for offshore oil: Offshore, p. 76-84 (Feb. 74).

Emery, K. O., and Uchupi, E., 1965, Structure of Georges Bank: Marine Geology, v. 3, p. 349-358.

Haight, F. J., 1942, Coastal currents along the Atlantic coast of the United States: U.S. Coast and Geodetic Survey Spec. Publ. v. 230, p. 73.

Jordan, G. F. 1962, Large submarine sand waves: Science, v. 136, p. 839-848.

Kenyon, N. H., and Stride, A. H., 1970, The tide-swept continental shelf sediments between the Shetland Isles and France: Sedimentology, v. 14, p. 159-173.

Knott, S. T., and Hoskins, H., 1968, Evidence of Pleistocene events in the structure of the continental shelf off northeastern U.S.: Marine Geology, v. 6, p. 5-44.

Langhorne, D. N., 1977, Consideration of meteorological conditions when determining the navigational water depth on a sandwave field: International Hydrographic Review, v. 54, p. 17-30.

Langhorne, D. N., 1978, Offshore engineering and navigational problems; the relevance of sandwave research: Society for Underwater Technology and Institute of Oceanographic Sciences Technical Notes, 21 p.

Lewis, R. S., Sylwester, R. E., Aaron, J. M., Twichell, D. C., and Scanlon, K. M., 1980, Shallow sedimentary framework and related potential geologic hazards of the Georges Bank area, in Aaron, J. M., ed., Environmental Geologic studies in the Georges Bank area, United States Northeastern Atlantic Outer Continental Shelf, 1975-1977: U.S. Geological Survey Open-File Report 80-240, Ch. 5.

Ludwick, J. C., 1972, Migration of tidal sand waves in Chesapeake Bay entrance, in Duane, D. B., Swift, D. J. P., and Pilkey, O. H., eds., Shelf sediment transport: Process and Pattern: Stroudsburg, Pa., Dowden, Hutchinson, and Ross, p. 377-410.

Oldale, R. N., Hathaway, J. C., Dillon, W. P., Hendricks, J. D., and Robb, J. M., 1974, Geophysical observations on northern part of Georges Bank and adjacent basins of Gulf of Maine: American Association of Petroleum Geologists Bulletin, v. 58, p. 2411-2427.

Sanders, J. E., Emery, K. O., and Uchupi, E., 1969, Microtopography of five small areas of the continental shelf by sidescanning sonar: Geological Society of America Bulletin, v. 80, p. 561-572.

Schlee, J., 1973, Atlantic continental shelf and slope of the United States-Sediment texture of the northeastern part: U.S. Geological Survey Profesional Paper 529, p. 64.

Stewart, H. B., and Jordan, G. F., 1964, Underwater sand ridges on Georges Shoal, in Miller, R. L., ed., Papers in Marine Geology - Shepard Commemorative Volume, p. 102-114.

Stride, A. H., 1963, Current swept sea floors near the southern half of

Great Britain: London, Quarterly Journal Geological Society, v. 119, p. 175-199.

Twichell, D. C., McClennen, C. E., and Butman, B., 1981, Morphology and processes associated with the accumulation of the fine-grained sediment deposit on the Southern New England Shelf: Journal of Sedimentary Petrology, v. 51, p. 269-280.

Uchupi, E., 1968, Atlantic continental shelf and slope of the United States-Physiography: U.S. Geological Survey Professional Paper 529-C, 30 p.

Uchupi, E., 1970, Atlantic continental shelf and slope of the United States-Shallow structure: U.S. Geological Survey Profesional Paper 529-I, 43 p.

Wigley, R. L., 1961, Bottom sediments on Georges Bank: Journal of Sedimentary Petrology, v. 31, p. 165-188.