UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Sand-wave movement on Little Georges Bank

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS or BLM.

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ABSTRACT

A 1-x-1.5-km area on Little Georges Bank (centered at 41°08´N., 68°04´W.) was mapped three times during a ten-month period by sidescan sonar and echo-sounding techniques to assess the morphology and mobility of sand waves on Georges Bank. Sand-wave amplitudes in the survey area ranged from 1-11 m although most were 5-7 m. Wavelengths were not constant as the crests were sinuous and in places, even bifurcated. The sand waves are asymmetrical with their steepest sides facing northwest; however, gradients of their steep sides mostly are 4°-10° which is well below the angle of repose for sand in water. Sand waves tended to have greater relief and a sharper asymmetry during the survey in September than during those in June or April.

During the survey period the sand waves moved but the direction and rate of motion was variable. Even along an individual sand wave some parts moved as much as 60 m between surveys while other parts apparently remained stationary. The sand waves were asymmetrical, but movement was not consistently in the direction that the steep sides faced. Along the same sand wave, parts moved to the northwest while other parts moved to the southeast. Despite the complex pattern of sand motion, the mean displacement of the sand waves was below the resolution of the survey technique; to resolve it, a longer survey is needed.

INTRODUCTION

This report summarizes the results of a pilot study designed to measure the mobility of sand waves on Georges Bank. The study covers a 1-x-1.5-km area on Little Georges Bank (centered at 41°08´N., 68°4´W.) in water 27-45 m deep (figs. 1, 2). Three echo-sounding and sidescan-sonar surveys were conducted in the area over a ten-month period to document the morphology and movement of sand waves.

Previous studies of sand waves show rates of movement up to 150 m/year in marine environments subject to oscillating tidal currents (Stewart and Jordan, 1964; Jones and others, 1965; Langeraar, 1966; Salsman and others, 1966; Ludwick, 1972; Boothroyd and Hubbard, 1975; Bokuniewicz and others, 1977; Langhorne, 1982). Stewart and Jordan (1964) estimated that sand waves on the top of Georges Shoal (fig. 1) in water depths less than 30 m moved at a rate of 12 m/year, but that those in deeper water on the flanks of the shoal did not move and were considered relict. Recently acquired sidescan-sonar images show that megaripples cover all the sand waves on Georges Bank (Twichell, in press). The presence of these smaller bed forms implies that active sand wave movement occurs over the entire top of Georges Bank in water depths less then 60 m and is not restricted just to the shallowest areas as suggested by Stewart and Jordan (1964).

METHODS

In the past, sand-wave movement has been estimated by making repeated echo-sounding measurements across them. However, because sand waves are linear features, the rate of movement may vary from point to point along the crests (Bokuniewicz and others, 1977); a single crossing of a sand wave cannot take this differential movement into account. The approach used in this study was to map repeatedly a relatively large area of sand waves (1 x 1.5 km). In

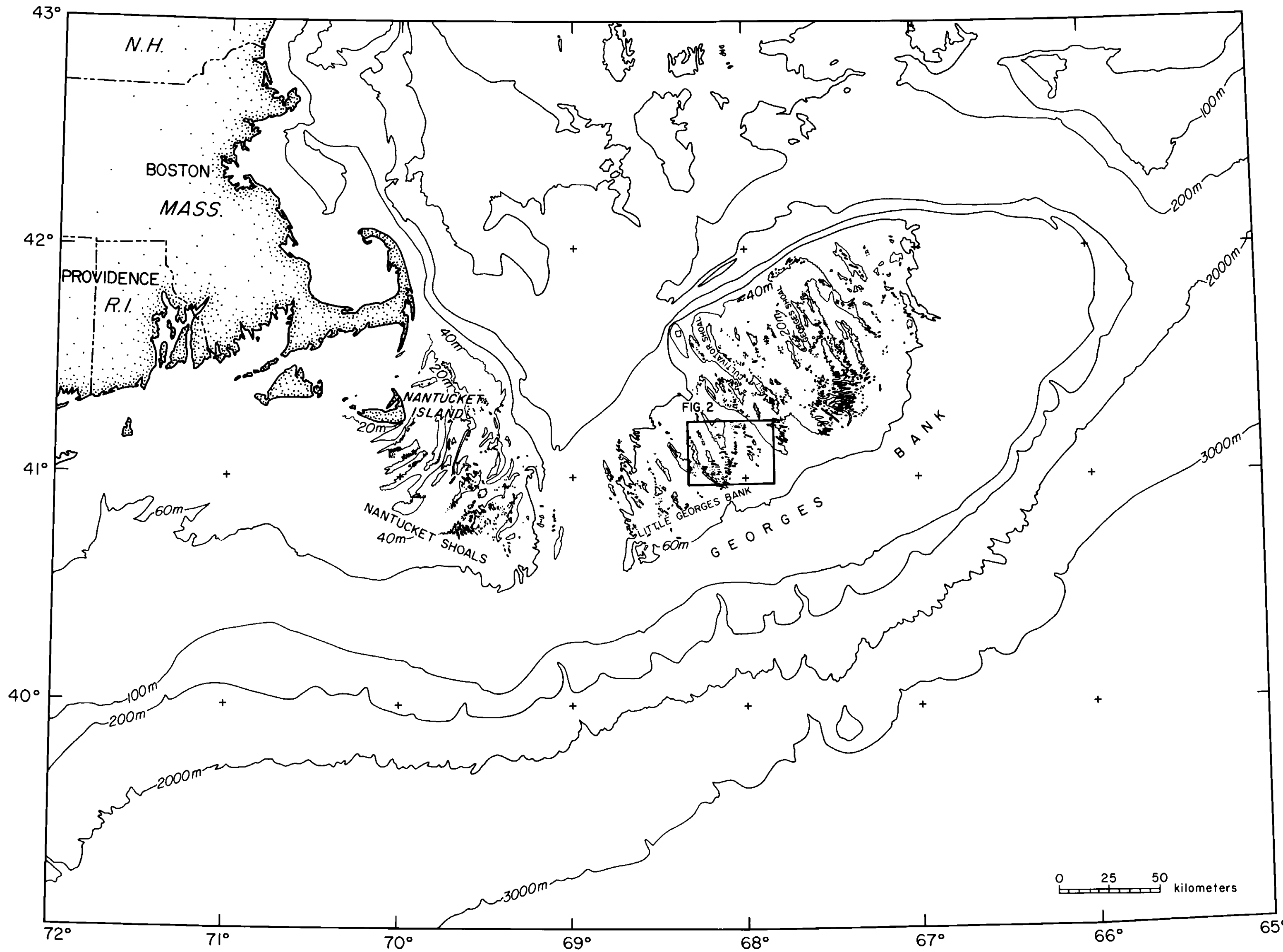


Figure 1. Map showing location of study area and locations of some of the sand ridges (shoals) on Georges Bank.

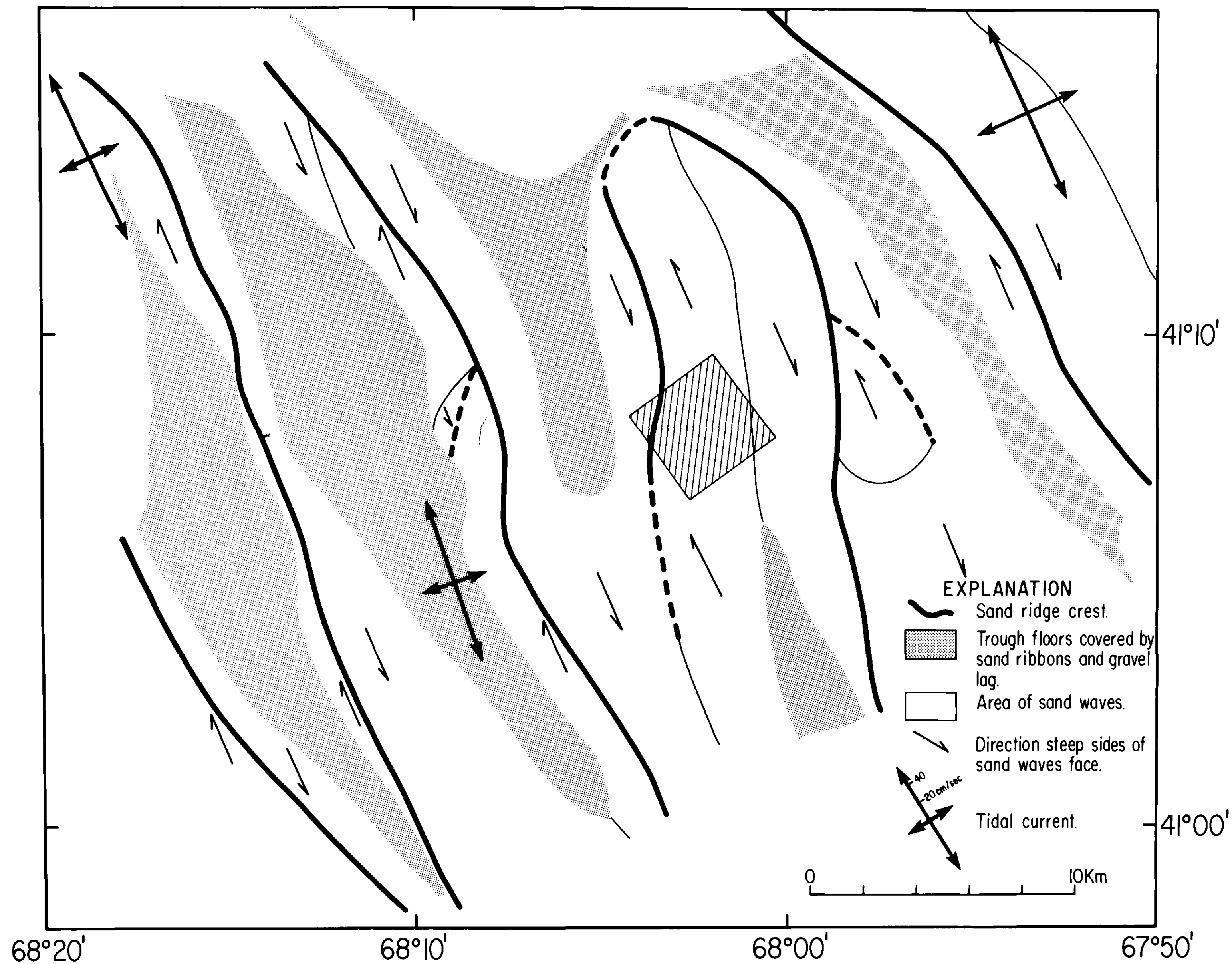


Figure 2. Distribution of sand ridges on Little Georges Bank. The lined box is the site of the sand-wave mobility study. Tidal current data from Haight (1942).

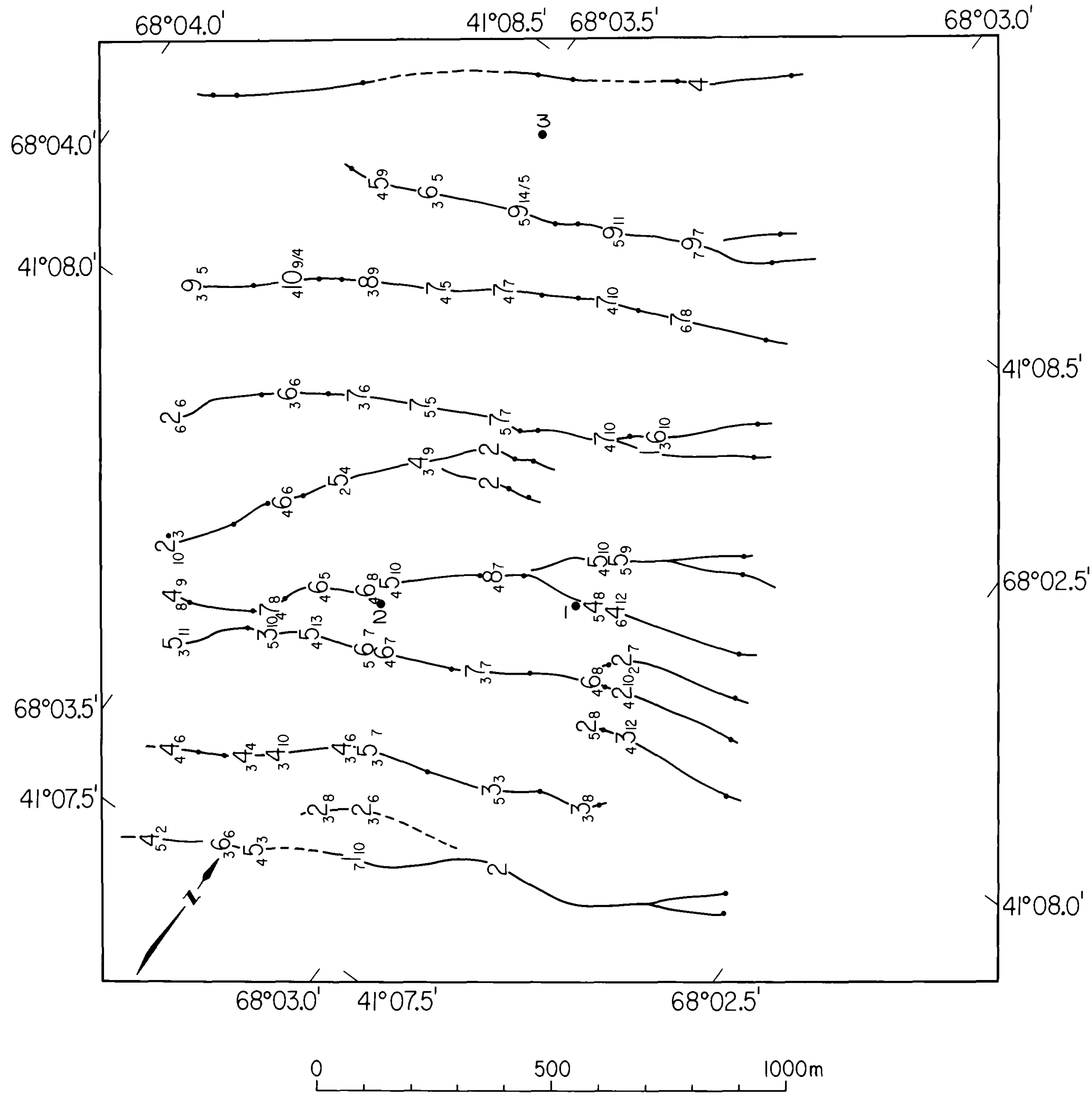
this way it is possible to establish the variability of the movement along an individual sand wave as well as variations in the movement among the sand waves present in the survey area.

Sidescan-sonar and 3.5-kHz echo-sounder surveys were conducted on June 20 and September 23, 1980, and April 3-4, 1981 over the same 1-x-1.5-km area on Little Georges Bank (fig. 1). The timing of the three surveys spans 10 months of the summer and winter and was designed to assess seasonal variations in sand-wave activity.

A Klein sidescan-sonar system and an ORE 3.5-kHz echo-sounder were run over a grid of lines parallel and perpendicular to the sand-wave crests. Line spacing was intended to be 150 m to give overlapping coverage on sidescan sonographs. Deviations from this spacing are due primarily to the effects of strong tidal currents. The sonographs were used to map sand-wave crest locations and the distribution and orientation of secondary bed forms such as megaripples. The 3.5-kHz profiles were used to make bathymetric maps and to map the crest locations, heights, and slopes of the gentle and steep sides of sand waves.

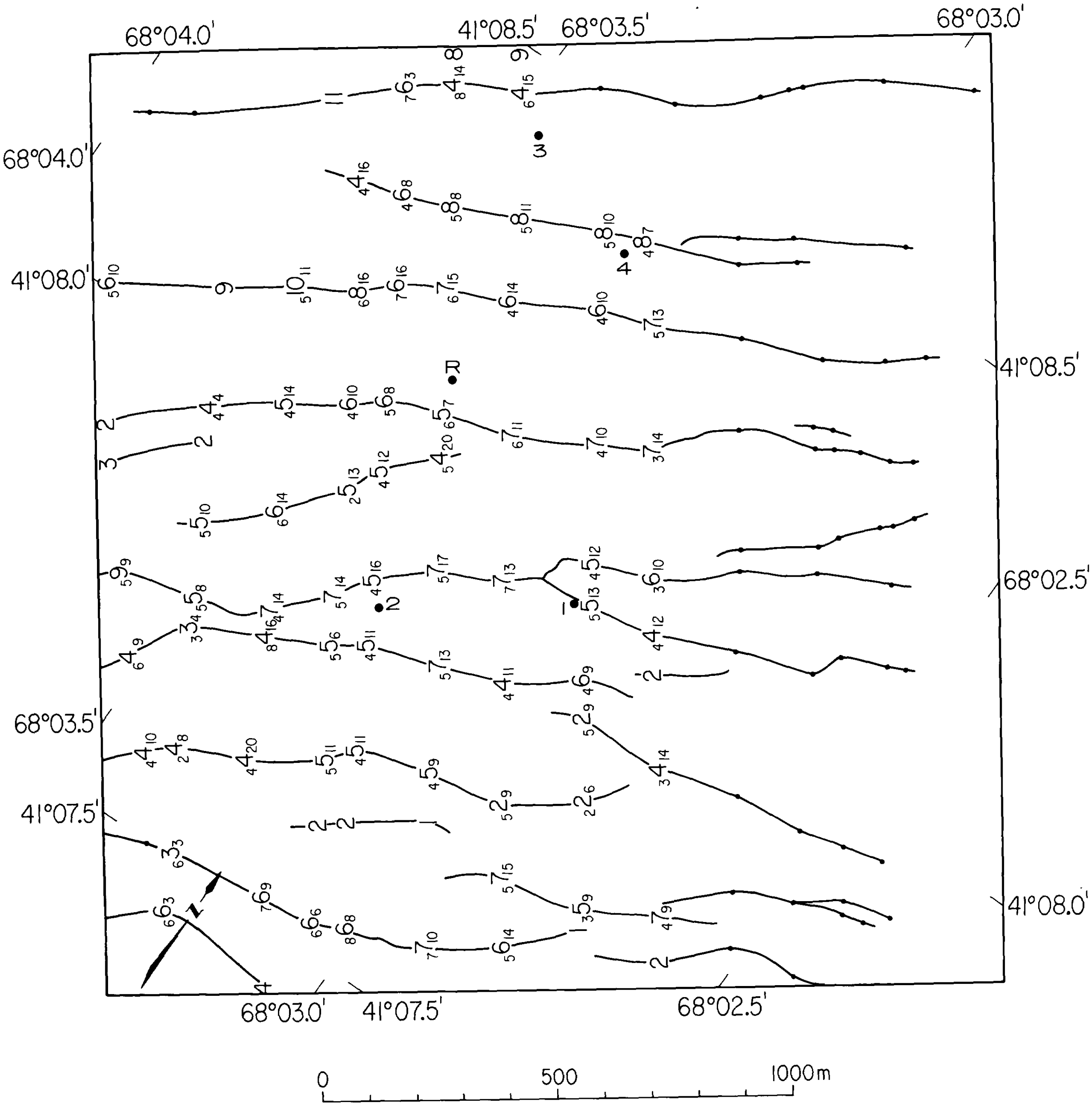
Navigational precision was of the utmost importance and for this reason, an acoustic transponder navigation system was used. Three transponders tethered 2-4 m above the sea floor were used for each survey. Water temperature was measured and corrections made to obtain the proper velocity of sound. Sound velocity was 1,482 m/s in June, 1,510 m/s in September, and 1,465 m/s in April. The transponder net was surveyed to obtain the locations of the transponders and then the sand-wave survey was conducted with fixes collected every 30 s. The northern transponder (transponder 3) was recovered after the June survey, but the other two (1 and 2) were left to fix the navigation grid for the next two surveys (figs. 3, 4, 5). In September, two sidescan-sonar reflectors and a transponder (4) were deployed, and these were left at the survey site until April. Only one of the sidescan reflectors is shown because the second one was not seen in the spring; presumably it was buried by a moving sand wave (figs. 4, 5). The eastern transponder (1) did not function in April, so another was deployed to the southeast of transponder 1 to take its place. Two transponders remained fixed between each set of surveys which made it possible to align the three surveys for comparative purposes.

The transponders and the sidescan-sonar reflectors showed on the sonographs and provided a check on the quality of the navigation. During each survey most transponders and reflectors were recorded by the sidescan sonar several times. Corrections were made for slant-range distance on the sonographs, for the distance of the sidescan fish behind the navigation transducer, and for the difference between ship's heading and actual course over the bottom. With these corrections, the positions of a transponder or sidescan reflector as determined from the different survey lines all fell within 20 m of each other. The best case showed positions within 3 m of each other, and all but the sidescan reflector showed positions within 10 m of each other. Errors probably were due to insufficient data on ship heading, minor variations in the distance of the sidescan fish behind the ship due to variations in ship speed, and the fact that the transponders were tethered 2-4 m off the bottom and were swaying in the strong tidal currents. Presumably differences larger than 10 m in sand-wave locations are real.



SURVEY 1 (JUNE)

Figure 3. Summary map of survey 1 (June 1980) showing the location of the top of the steep slopes of the sand waves (solid line), the height in meters relative to the trough on the steep side of the sand wave (large numbers along sand waves), and the slopes of the two sides of the sand waves (smaller numbers to either side of the sand-wave height). Numbered dots refer to transponder locations.



SURVEY 2 (SEPTEMBER)

Figure 4. Summary of map survey 2 (September 1980) showing the location of the top of the steep slopes of the sand waves (solid line), the height in meters relative to the trough on the steep side of the sand wave (large numbers along sand waves), and the slopes of the two sides of the sand waves (smaller numbers to either side of the sand-wave height). Numbered dots refer to transponder locations.

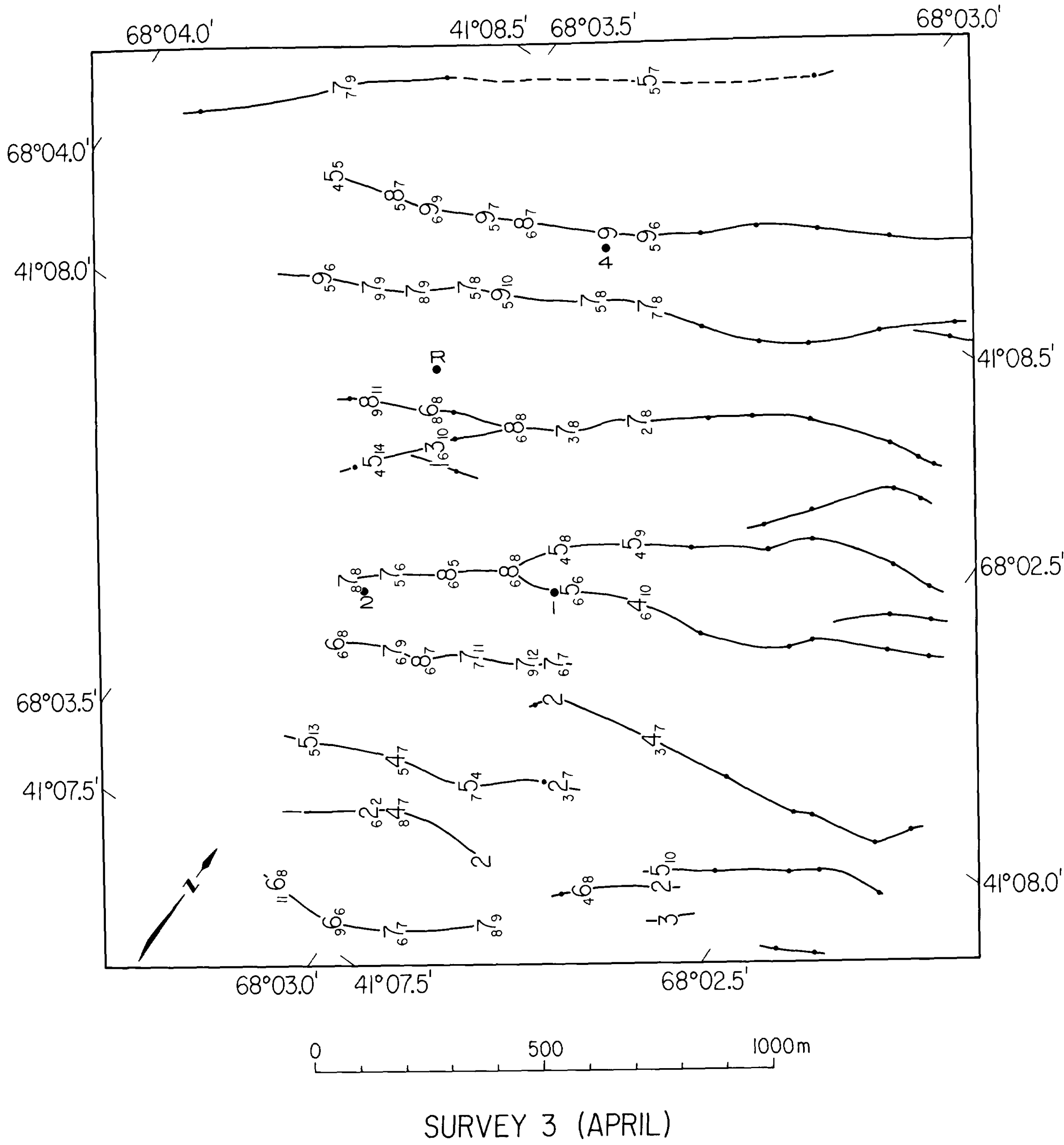


Figure 5. Summary map of survey 3 (April 1981) showing the location of the top of the steep slopes of the sand waves (solid line), the height in meters relative to the trough on the steep side of the sand wave (large numbers along sand waves), and the slopes of the two sides of the sand waves (smaller numbers to either side of the sand-wave height). Numbered dots refer to transponder locations and R is the sidescan reflector.

RESULTS

Little Georges Bank is covered by northwest-trending sand ridges that are spaced 1-10 km apart. The study area was located on the eastern side of one of these ridges (fig. 2). Here, the flank of the sand ridge was shaped by asymmetrical sand waves with their steep sides facing mostly towards the northwest (figs. 3, 4, 5). Sand wave amplitudes were 1-11 m, but were mostly 5-7 m (fig. 6). Height was measured relative to the trough floor on the side of the sand wave having the steeper slope. The height of an individual sand wave could vary by as much as 7 m along the length surveyed, and most varied 2-4 m in height along their lengths (figs. 3, 4, 5). The tops of the sand waves were in 27-42-m water depths.

The trough floors were mostly 40-45 m deep and were deepest in the southeastern corner of the survey area and shallowest in the northwestern corner. Trough floor depths did not change appreciably between the three surveys.

Sand waves had the greatest relief and were most sharply asymmetrical in September and slightly lower and more nearly symmetrical in April (figs. 3, 4, 5). Although not consistently, the surveys in June and April tended to show the sand waves 1-2 m lower than in September. Their steep sides consistently faced northwest, but the gradients of the steep sides were less than the angle of repose of sand. The steep sides of the sand waves were concave during all three surveys (fig. 9); their slopes ranged from 4^{o}-24^{o} but most were between 7^{o} and 15^{o}. Slopes of the steep sides were steepest in September (fig. 4) and gentlest in April (fig. 5). Slopes of the gentle sides had gradients of 2^{o}-9^{o}. Gradients generally were less than 5^{o} for the June and September surveys and were mainly between 5^{o}-8^{o} for the April survey.

Sand waves were spaced as much as 400 m apart; however, because they were sinuous and in places bifurcated, their spacing was not uniform (figs. 3, 4, 5). The bed forms were slightly more sinuous in September than during the other two surveys.

The sand waves did move during the ten-month period and movement involved the entire bed form, not just the crests (figs. 9, 10, 11, table 1). Measurements of the bases of the sand waves showed that the motion of the bases parallelled that of the crests (fig. 9).

The direction and amount of displacement varied along the length of individual sand waves as well as among sand waves. For example, between the first two surveys the sand wave immediately northwest of transponders 1 and 2 was displaced 30 m to the southeast to the east of transponder 1 and 25 m to the northwest at transponder 2 (figs. 10A, 11, table 1). The part of the sand wave at transponder 1 showed no movement during this same time interval (fig. 11, table 1). Between the first two surveys (three months apart), displacement ranged from 35 m (giving a rate of 137 m/yr) to the northwest to 35 m to the southeast; between the second two surveys (six months apart), displacement ranged from 65 m (123 m/yr) to the northwest to 40 m (76 m/year) to the southeast. Parts of many sand waves showed no displacement between the three surveys. Those parts that did move often moved in one direction between the first two surveys and in the opposite direction between the second two surveys (fig. 10C). Thus, the displacement between the first and second

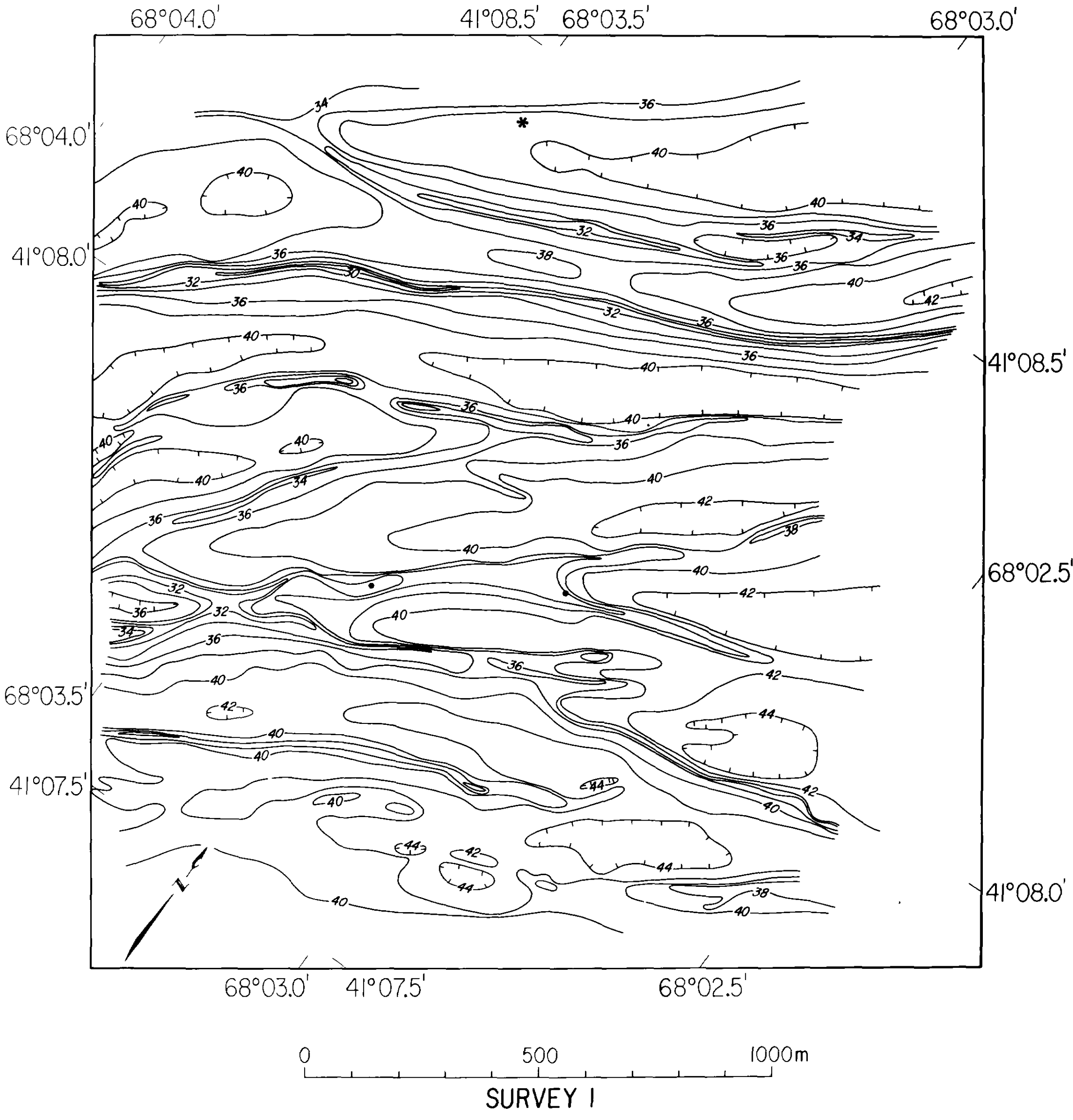


Figure 6. Bathymetry compiled from the first survey in June 1980. Depth in meters. Dots and asterisk show locations of transponders.

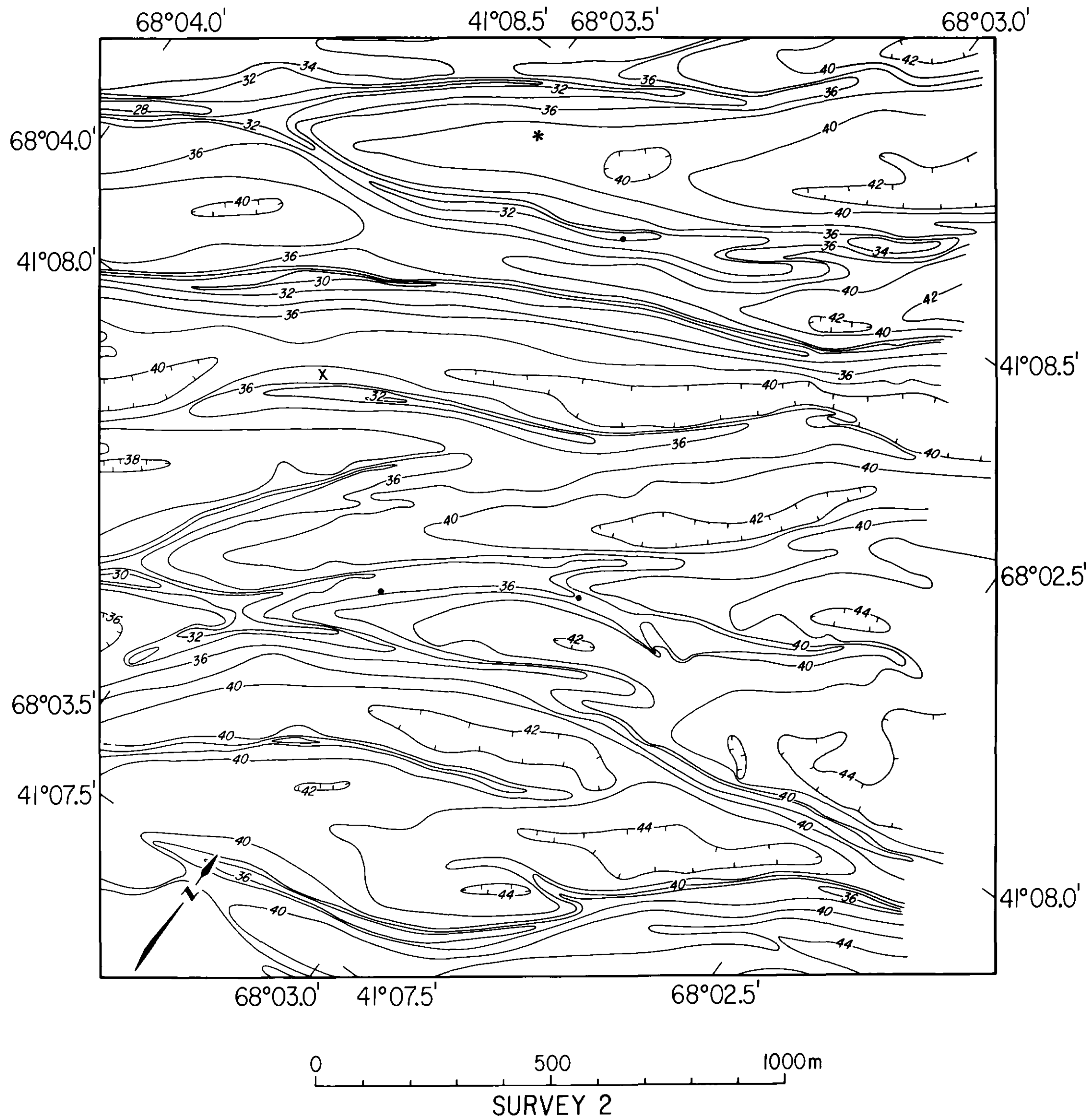


Figure 7. Bathymetry compiled from the second survey in September 1980. Depths in meters. Dots and asterisk show locations of transponders, and X shows location of the sidescan reflector.

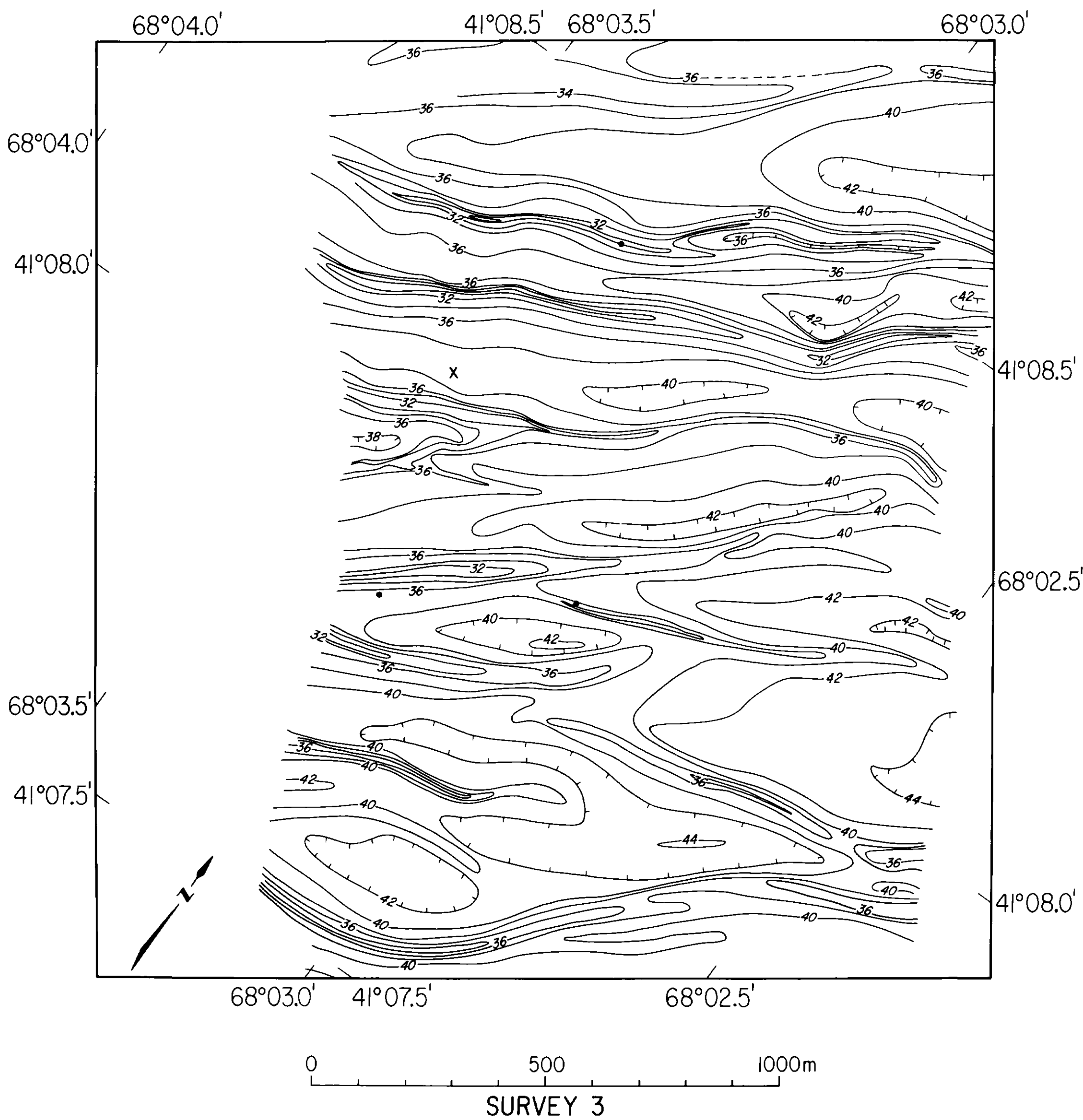


Figure 8. Bathymetry compiled from the third survey in April 1981. Depths in meters. Dots show locations of transponders, and X shows location of the sidescan reflector.

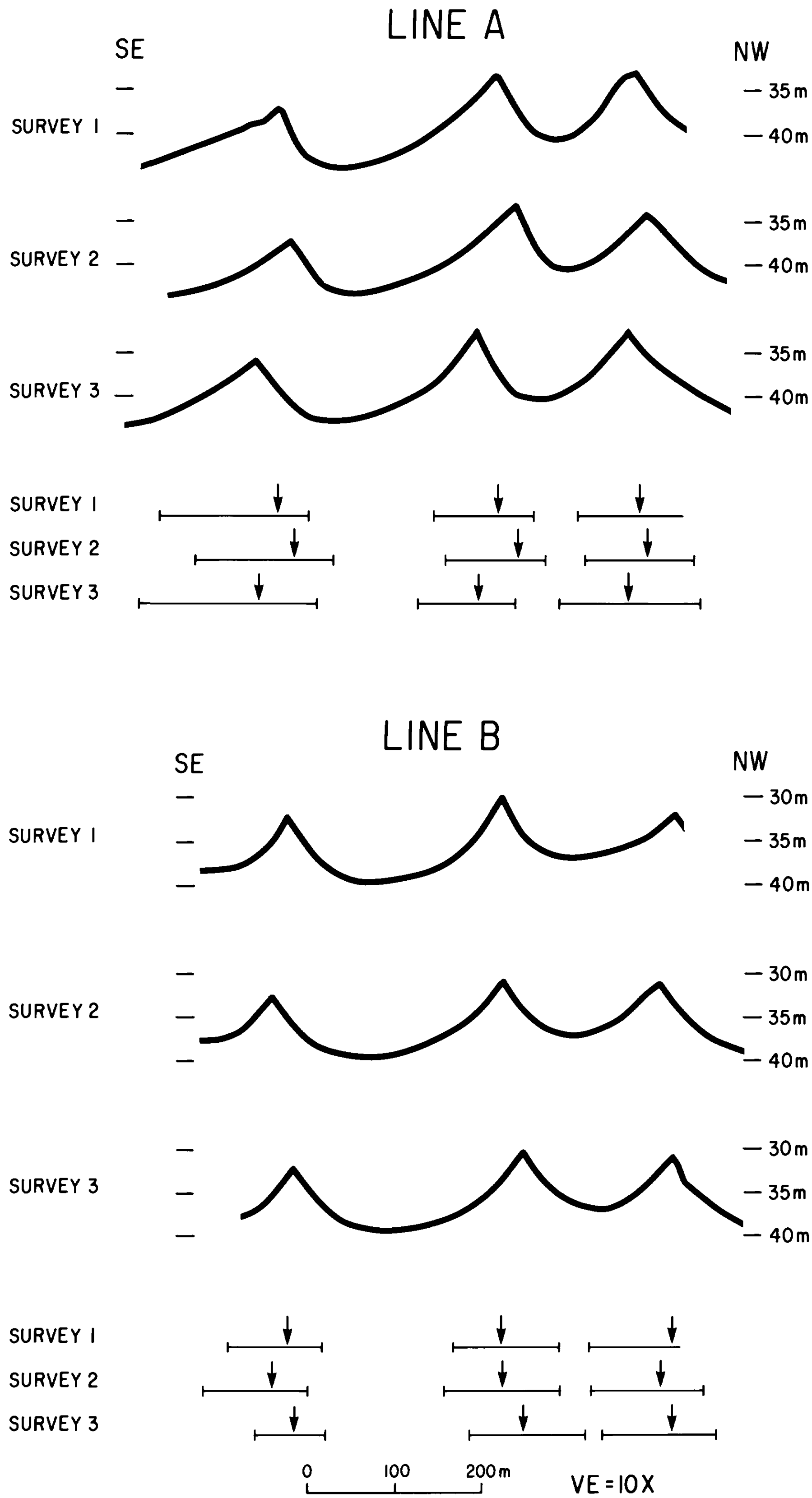


Figure 9. Profiles run along nearly the same lines showing changes in the relative location of the sand waves between the three surveys. Arrows and bars below the profiles show the locations of the sand-wave crests and bases, respectively. Note that movement of the crests and bases parallel each other. Profile locations shown in figure 10C.

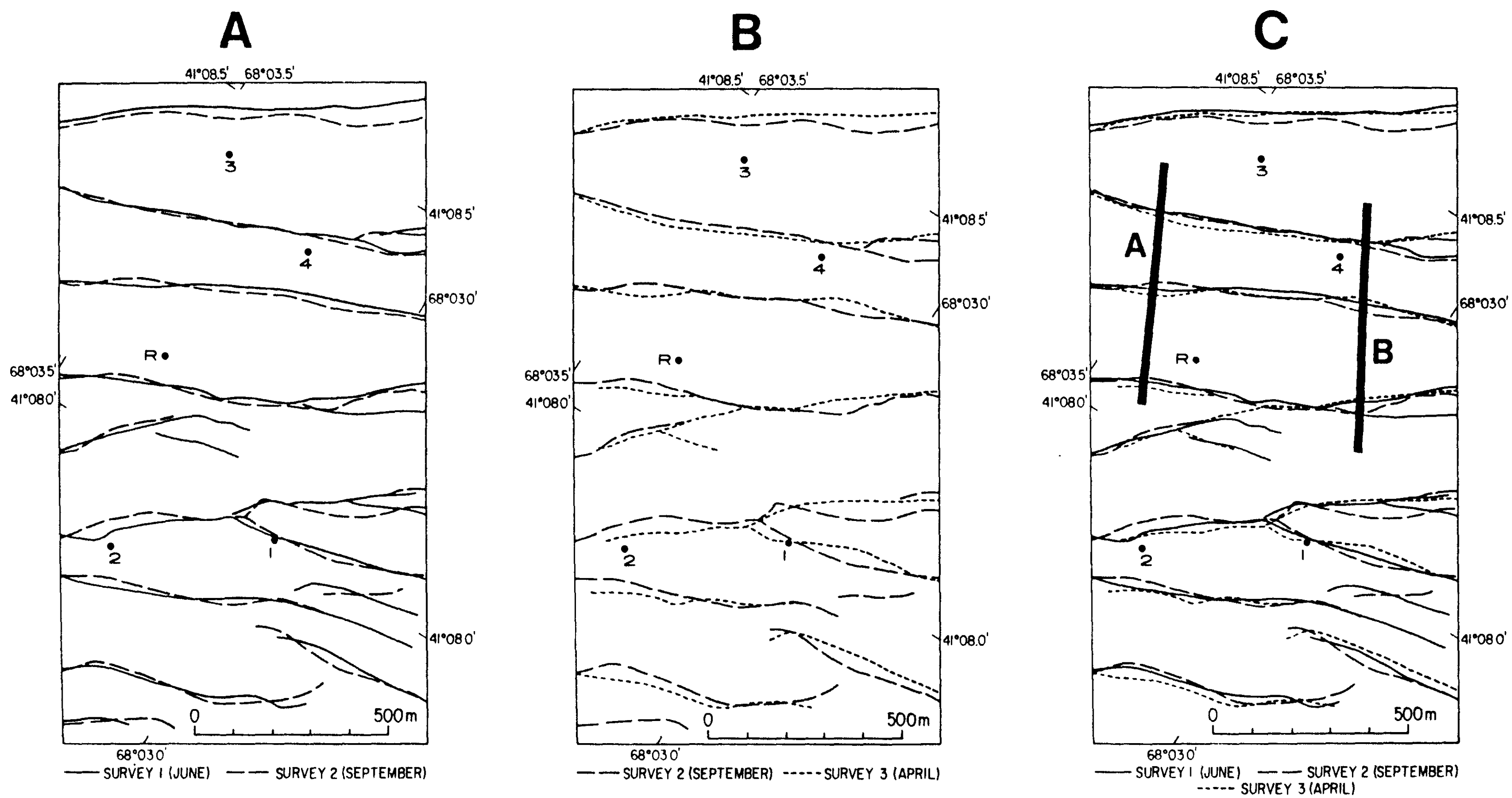


Figure 10. Summary of sand-wave movement: (A) Locations of tops of steep slopes of sand waves in June and September; (B) locations of tops of steep slopes of sand waves in September and April; (C) locations of tops of steep slopes of sand waves during all 3 surveys. Dots refer to transponder locations (numbered) and sidescan-reflector location (R). Lines A and B are locations of profiles shown in figure 9.

Figure 11. Sonographs showing transponders 1 and 2 and the sand wave immediately north of them. Note the megaripples covering the sand waves. Bars show the distance from the transponders to the crest of the sand wave in meters. SB marks the chain and anchors for the surface buoys. Sonographs are not slant-range corrected, but the distances between the transponders and sand-wave crests have been corrected for slant range.

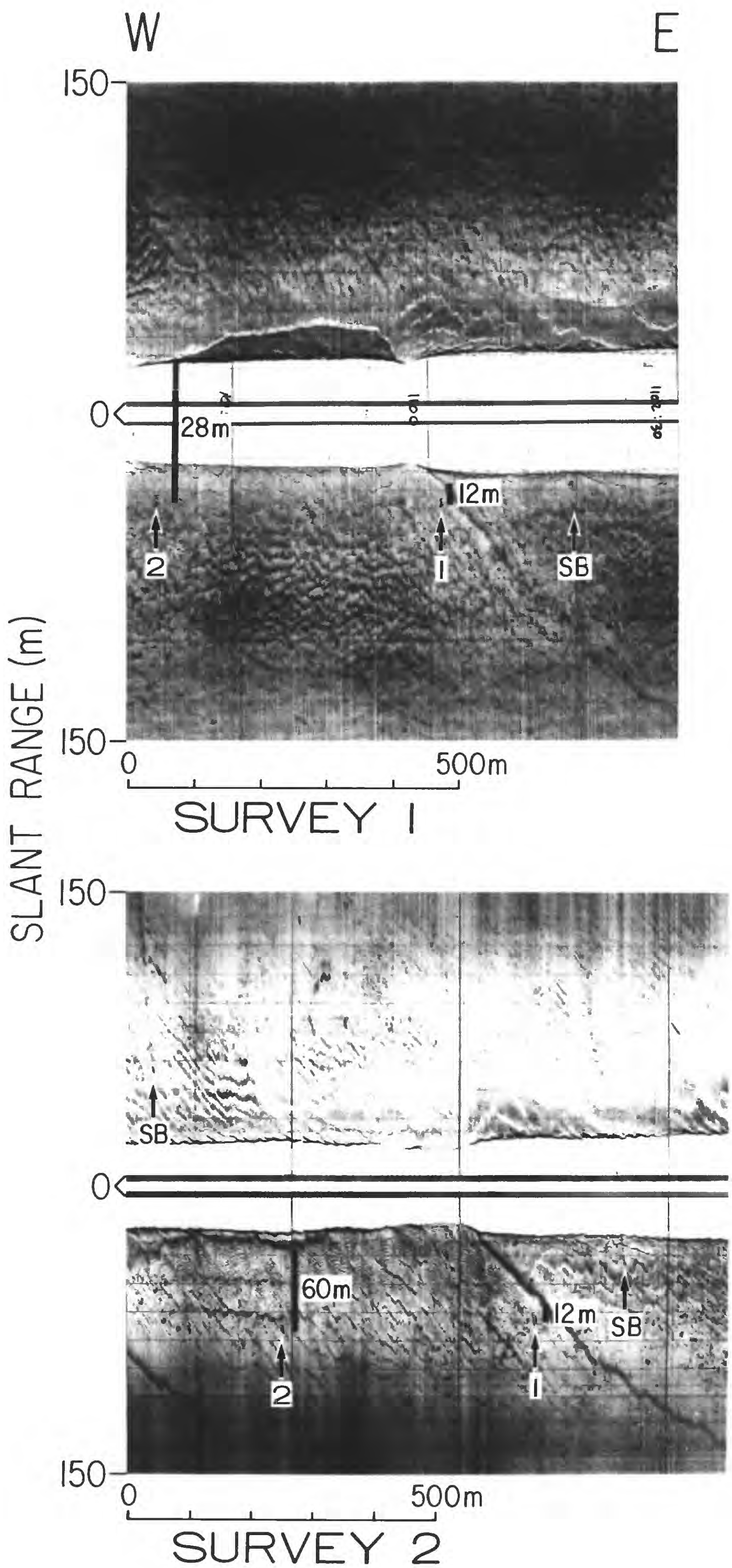

W
E
150
0
150
SLANT RANGE (m)
28m
12m
2
1
SB
0
500m
SURVEY 1
150
0
150
SB
60m
12m
SB
2
1
0
500m
SURVEY 2

Table 1. Sand-wave movement relative to fixed markers

Marker	Sand wave	Distance - marker to sand wave Survey 1	Survey 2	Survey 3	Relative movement (m) (+ = northwest; - = southeast) Survey 1 to 2	Survey 2 to 3
1	South of 1	181	178	160	+3	+18
1	North of 1	6	5	0	-1	-5
2	South of 2		78	117	--	-39
2	North of 2	28	60	30	+32	-30
3	South of 3	173	178	--	-5	--
3	North of 3	116	89	--	-27	--
R	South of R	--	37	30	--	-7
R	North of R	--	189	173	--	-16

See figure 10 for location of the reference marks.

surveys and the second and third surveys tended to cancel each other, and a smaller net displacement was recorded for the ten-month period than between individual surveys.

The mean displacement of the sand waves, determined by averaging the displacement of the crests measured every 100 m along the sand waves, was mostly less than 10 m between surveys. Between the first two surveys, mean displacement of the sand waves ranged from 6 m to the northwest to 26 m to the southeast. The mean displacement for all the sand waves in the study area was 7 m to the southeast. Between the second and third surveys, mean displacement of individual sand waves ranged from 29 m to the northwest to 15 m to the southeast, and the mean displacement for all the sand waves was 3 m to the northwest. Displacement of all the sand waves for the entire survey period averaged 4 m towards the southeast. Although the movement of many parts of the sand waves was easily resolvable by the surveying techniques, the net displacement was below the resolution of the navigation system.

DISCUSSION

This study shows that sand waves on Little Georges Bank do move significant distances (up to 60 m) in periods of 3-6 months, but the net movement is small. Their occurrence in waters 45 m deep contradicts Stewart and Jordan's (1964) conclusion that active sand-wave motion takes place only on the crests of the ridges. Sand waves are found in water depths less than 60 m on Georges Bank (Jordan, 1962; Uchupi, 1968; Twichell, in press). Whether all of these sand waves presently are mobile cannot be answered by this study; however, the presence of mobile sand waves in 45 m of water indicates that a much larger section of Georges Bank presently is being reworked by the movement of sand waves than just the tops of the sand ridges.

Slopes of the steep sides of the sand waves are well below the angle of repose of sand (figs. 3, 4, 5). The gentle slopes suggest that these sand waves behave differently from those found under a unidirectional flow regime such as in a river or a flume. There, sand waves move by erosion of sediment from the gentle (upstream) side, and transport to the crest where it either is carried in suspension or avalanches down the steep slope (Yalin, 1972). Flow separation often occurs at the crest of the sand wave. Under the oscillating current of a tidal regime such as on Georges Bank, sand waves have a different geometry, presumably because the mechanism of movement is different. Sand movement occurs during both the ebb and flood of the tide so that the sand shifts back and forth across the sand wave with each reversal of the tide. Presumably the internal structure of these tide-generated sand waves is different from the foreset-bedded structure seen in sand waves generated by a unidirectional flow.

Variations in height and asymmetry of the sand waves between the three surveys indicate that the processes shaping them vary with time. Two conditions known to affect sand-wave geometry are storms and changes in tidal current strength between the spring and neap tides (Ludwick, 1972; Langhorne, 1982). Storm waves tend to lower the relief of sand waves and to round their crests (Ludwick, 1972) by erosion of sand from the crests and deposition in the troughs. Langhorne (1982) observed that sand waves have steeper lee slopes during times of spring tides than during times of neap tides. Also, the crests of sand waves often moved backwards during times of neap tides, although the bases remained stationary. The greater relief and sharper asymmetry of the sand waves on Georges Bank during the second survey (fig. 4) may in part reflect a difference in tidal current strength. The first survey was conducted during a neap tide and the second during a spring tide. However, this change in sand-wave geometry may also reflect the long period of fair weather during the summer. The generally lower relief and the gentler slopes of the sand waves during the third survey (fig. 4) are consistent with changes due to storms. The relative importance and the net effect of these two processes (and possibly others) on sand-wave dynamics will need to be addressed by a longer study period with a more frequent sampling interval than was possible in this pilot study.

Monitoring sand-wave activity within a relatively large area rather than along a single line as was done in many earlier studies (Jones and others, 1965; Salsman and others, 1966; Ludwick, 1972; Langhorne, 1982) provides new insight to sand-wave dynamics. Observations from this study that sand waves do not move at a constant rate, that the movement is not consistently in the direction that the steep sides of the sand waves face, and that movement of different parts of the same sand wave can be in different directions at the same time all need to be considered in the assessment of how sand waves move.

Despite other studies which show that sand-wave asymmetry reflects the direction of net sand transport (Jones and others, 1965; Salsman and others, 1966; Ludwick, 1972; Langhorne, 1973; Pasenau and Ulrich, 1974), this study shows that sand waves move both forward and backward relative to the direction that their steep sides face (figs. 9, 10, 11, table 1). Thus, here the importance of sand-wave asymmetry as an indicator of the direction of sand transport could not be resolved by this study. As Langeraar (1966) reported in the North Sea, a study of at least two years duration probably is necessary to demonstrate net movement.

Between surveys the displacement of parts of some sand waves was as much as 60 m, yet the net displacement of the sand waves was below the resolution of the navigation system. This observation suggests a significantly slower net rate of sand-wave movement than has been found in many other studies (Salsman and others, 1966; Ludwick, 1972; Boothroyd and Hubbard, 1975; Bokuniewicz and others, 1977). Most of the cited studies that show rapid sand-wave movement were conducted in estuaries; however, other surveys of sand waves on the open shelf show net movement ranging from undetectable (Langeraar, 1966) to 36 m/yr (Jones and others, 1965). The oscillatory flow generated by storm waves is destructive to sand waves (Ludwick, 1972; Langhorne, 1977), and may thus contribute to the generally slow migration rate of sand waves on the open shelf. The larger size of the sand waves found on the open shelf compared to those in estuaries may affect their rate of movement as well.

The opposed movement of two parts of the same sand wave at the same time suggests extremely localized variations in the hydraulic regime. Although motion along an individual sand wave is variable, there does appear to be some consistency among sand waves. In general, coherent forward or backward motion of sand waves occurs in aligned narrow stripes perpendicular to the sand-wave crests (fig. 10). Many of the sand waves in the western half of the study area tended to move forward between the first two surveys and backwards between the second two surveys, while in the eastern half of the study area the opposite occurred. Perhaps storms, subtle variations in the hydraulic regime due to the slight change in depth across the study area, or secondary perturbations of the flow around this sand ridge (fig. 2) are responsible for the apparently systematic variations in sand-wave movement.

CONCLUSIONS

Although more questions were raised than answered, several conclusions can be drawn from this pilot study:

1) The movement of sand waves can be measured by this survey technique.

2) Sand waves on Georges Bank do move. Although the net movement is low, parts of some sand waves moved as much as 60 m during the ten-month survey period. The mobility of these bed forms, many of which are greater than 6 m in height should be considered in the siting of platforms and the routing of pipelines.

3) Although the sand waves are asymmetrical, the direction of sand-wave movement is not always in the direction that the steep sides face. A longer term study is necessary to assess the processes responsible for sand-wave movement and the correlation of sand-wave asymmetry with the direction of net sand transport.

4) There is a spatial coherence to the direction of movement from crest to crest that suggests extremely local variations in the hydraulic regime.

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