Daniel J. Stanley
and Noel P. James

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ABSTRACT

Stanley, Daniel J., and Noel P. James. Distribution of *Echinarachnius parma* (Lamarck) and Associated Fauna on Sable Island Bank, Southeast Canada. *Smithsonian Contributions to the Earth Sciences*, number 6, 24 pages, 1971.—A combined bottom photographic and sampling survey of Sable Island Bank southeast of Nova Scotia, Canada, reveals locally high densities (to 180 individual/m^2) of the northern sand dollar *Echinarachnius parma*. Populations of this form are closely related to texture of the sea floor and generally concentrated on moderately sorted fine to medium sand surfaces. Topography and current regime are also correlatable factors; depth, time, salinity, and temperature apparently are not. Sand dollars are second in importance, after current activity, in reworking surficial sediments, and these organisms modify at least a third of the total Bank surface in the study area. Bioturbation is particularly intense in the sector north of Sable Island. Associated epifauna and infauna populations occur in two east-west trending areas on the Bank north and south of Sable Island. Absence of conspicuous fauna, save *E. parma*, in an east-west zone along the crest of the Bank and near Sable Island results from extremely strong current activity concentrated in this region.

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Introduction

The present study was conducted as an outgrowth of a sedimentological survey (James and Stanley 1968) of the sand-covered, current-dominated shallow outer banks of the Nova Scotian Shelf off southeastern Canada. It is an attempt to evaluate more precisely than heretofore possible the fauna likely to affect surficial sediments on a shallow platform, Sable Island Bank, located far from the present mainland. It is possible as a result of this investigation to define the regional distribution pattern and density of the northern sand dollar, *Echinarachnius parma* (Lamarck), and associated fauna commonly encountered on Sable Island Bank. Previous investigations (James 1966; James and Stanley 1968) have shown that this circumboreal echinoderm is particularly abundant on Sable Island Bank, the largest of the outer banks on the shelf. Availability of detailed geographic and hydrologic data, together with information on the sediment regimen, suggested that a study of the benthic fauna of this area would be particularly profitable.

Data evaluated are derived mainly from bottom photographs, supplemented by surficial samples collected at numerous stations distributed over most of Sable Island Bank and immediately adjacent areas. The present analyses serve, first of all, to supplement the surprisingly small amount of quantitative data and field information on this common sand dollar (Moore 1966). This echinoid occurs on both margins of northern North America, in the western North Pacific, and in the western North Atlantic the known range of *E. parma* extends from Cape Hatteras to Labrador and Greenland (Mortensen 1948). We relate the distribution of *E. parma* to such parameters as time of observation, depth, topography, sediment type, current regime, and associated fauna. The problem of correlating fauna visually observed on the bottom with that collected in relatively small bottom grabs is also considered.

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Geographic and Hydrologic Setting of Study Area

Morphology.—Sable Island Bank is a sand-covered platform approximately 250 km long with a maximum width of 115 km. The 90 m (50 fms) isobath defines the bank margin (Figure 1). Sable Island, at approximately 60°W longitude and 43°55′N latitude, is located on the eastern margin of the Bank, 334 km southeast of Halifax on the Nova Scotian mainland. Topography and sediments of the island, a low (relief of 1 to 20 m) east-west trending arcuate bar of sand flats and dunes about 39 km long and 1.5 km wide, have recently been described by James and Stanley (1967).

Extremely gentle gradients characterize the bank top east and south of Sable Island (approximately

1:880 and 1:330 respectively) as well as north (1:280) of the island. Along its steep northern edge, the Bank is bounded by the Gully Trough, a depression (90 to 210 m deep) characterized by hummocky and dissected topography. This depression curves southward around the northeast margin of the Bank and deepens to form the southeast trending submarine canyon known as The Gully Canyon (Marlowe 1967). The southeast margin of the Bank is the boundary between the outer shelf and the upper continental slope. The outer margin topography and sediments have been detailed elsewhere (Stanley and Silverberg 1969).

General water mass properties.—Water mass likely to affect sediments and organisms in the study area is composed of Atlantic water diluted by 20% coastal water (Hachey 1961) and covers the outer banks of the Nova Scotian Shelf, including Sable Island Bank. Between this "shelf water" and the Gulf Stream to the south lies a band of "slope water" having intermediate surface salinities and relatively low temperatures at middepth. Shelf water is generally well stratified into three layers during the summer months and less so during the winter. The upper layer may be as much as 40 fms (73 m) thick, with temperatures ranging between 5°C and 20°C and salinities less than 32‰. The intermediate layer ranges between 17 and 80 fms (31 to 146 m) in thickness, with temperatures from 0°C to 4°C and salinities between 32‰ and 33.5‰. Bottom water, occupying depths of 50 to 110 fms (91 to 201 m), has a temperature range from 5°C to 8°C and salinity gradient from 33.5‰ to 35‰.

The intermediate layer is most important in determining the water characteristics of the outer banks including Sable Island Bank (Hachey 1961). The presence of this cold water on the shelf is due to the large volume of water transported from the east and northeast by the Labrador Current, and chilling *in situ* is a continuous feature, at least during part of the year. Incursions of slope water (a mixture of surface, coastal, Gulf Stream, Labrador Current, and upwelling deep Atlantic waters, as described by McLellan et al. 1953) onto the Nova Scotian Shelf results is salinity variations on the outer margin of Sable Island Bank ranging from 33‰ to 33.5‰ and temperature variations from 5°C to 20°C.

Currents, waves, and tides.—The regional distribution of benthic organisms whose feeding burial habits make them dependent on the tex of surficial sediments would almost certainl controlled to a considerable degree by water-movement affecting Sable Island Bank. The ample evidence that bottom currents do, in modify the sedimentary cover of the bank to circulatory pattern centered around Sable Is displays an average rate of drift ranging from to 0.15 knots (5.6 to 7.7 cm/sec) (Trites 19 This surface circulation pattern varies seaso (Bumpus and Lauzier 1965). The northeas and easterly drift along the outer Bank margin stitutes a general off-the-shelf movement an consistent except in spring when there is a wes drift east of Sable Island. Bottom-circulation terns in the study area are modified by ma topographic features including The Gully Ca and Sable Island.

In fall and winter, when the Bank top is likely to be affected by storms, the numbe waves over 20 feet or more are reported 5% o time (*Climatological-Oceanographic Atlas for M ners* 1959). In spring the number and size of w decrease (waves less than 4 feet in height acc for over 45% of all waves), and in summer w over 5 feet in height are rare. Fall and winte times of long period, high waves from the west northwest. In spring and summer the dire changes 90 degrees and the waves set from the ocean to the south.

Tidal currents are particularly importan determining the current circulation around S Island (Cameron 1965) and modifying bed f on the shallow Bank surface. Cotidal lines, tr ing in an ENE-WSW direction across the (Sverdrup et al. 1942), suggest that the predomi tidal flow may be NW-SE. Currents do, in fact, to set westward (*Canadian Hydrographic Se* 1960). The mean range of tides on the bank i feet. The ebb stream sets southward at 1.5 knots (77 to 103 cm/sec) on the submerged te nal bars of Sable Island, and the flood stream 0.5 knots (26 cm/sec) less northward (*Cana Hydrographic Service* 1960). Terminal bar Sable Island directly affect the flow pattern of currents in the study area; the morphology o terminal bars is, in turn, directly molded by currents (James and Stanley 1967).

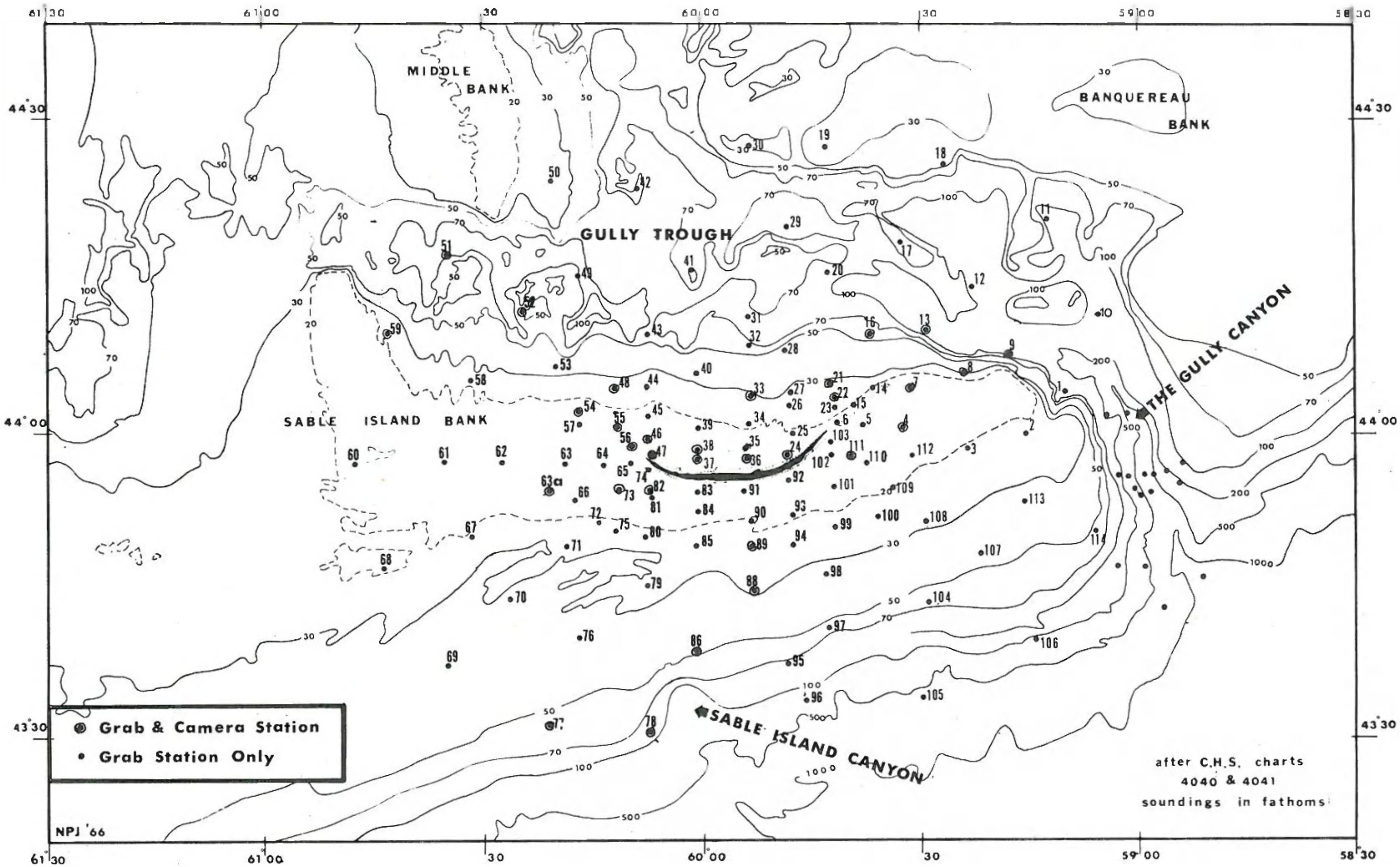

FIGURE 1.—Chart of Sable Island Bank and adjacent area on the outer Nova Scotian continental shelf showing major features discussed in text. Sable Island is a narrow, lunate feature (shown in black) on the Bank crest. Dots represent grab sample stations; circled dots represent stations with camera coverage (Table 1). Unnumbered dots in The Gully Canyon are piston cores collected by Marlowe (1967).

TABLE 1. – *Sample stations on Sable Island Bank, Nova Scotian Shelf*

Sample No.	Depth (meters)	Position Longitude	Latitude	Composition %Gravel	%Sand	%Mud	Colour	Sample Equipment Phleger core	Van Veen grab	Ca
1	360	59°03.0'	44°00.8'	small speck mud			5Y5/2	x		
2	39	59°15.5'	44°00.5'	0.00	98.7	1.3	2.5Y6.5/4		x	
3	22	59°23.5'	43°58.5'	0.00	98.8	1.2	2.5Y6.5/4		x	
4	23	59°33.5'	44°01.0'	0.00	97.9	2.1	2.5Y6/3		x	
5	28	59°38.2'	44°01.0'	0.00	98.7	1.3	2.5Y6.5/4		x	
6	2	59°41.5'	44°01.0'	0.00	99.0	1.0	2.5Y7/2		x	
7	20	59°31.5'	44°04.5'	0.00	98.3	1.7	2.5Y7/5		x	
8	52	59°24.0'	44°06.0'	0.00	99.1	0.9	2.5Y6.5/4		x	
9	256	59°18.0'	44°08.0'	0.00	99.4	0.6	2.5Y6/4		x	
10	175	59°07.5'	44°12.0'	96.4	2.7	0.8	/		x	
11	286	59°15.0'	44°21.0'	0.00	38.0	62.0	/		x	
12	231	59°23.0'	44°14.0'	0.00	72.3	27.7	5Y4/2		x	
13	223	59°29.0'	44°10.0'	0.00	60.8	39.2	5Y4/2		x	
14	63	59°37.0'	44°04.5'	0,00	97.8	2.2	5Y6/2		x	
15	4	59°39.0'	44°02.5'	0.00	99,3	0.7	2.5Y 6.5/2		x	
16	128	59°37.5'	44°09.5'	0.00	89.8	10.2	5Y4/2		x	
17	132	59°32.5'	44°18.0'	8.5	85.5	6.0	5Y5/4		x	
18	73	59°26.5'	44°26.5'	18.3	80.6	1.1	5Y6/4		x	
19	40	59°43.0'	44°28.5'	3.3	95.2	1.5	2.5Y6.5/8		x	
20	187	59°43.0'	44°15.5'	0.00	35.2	64.8	5Y4/2		x	
21	50	59°42.0'	44°04.0'	0.00	94.9	5.1	5Y5.5/2		x	
22	52	59°42.0'	44°03.5'	0.00	90.2	9.8	5Y5/2		x	
23	53	59°42.0'	44°02.5'	0.00	97.3	2.7	5Y6/2		x	
24	20	59°48.0'	43°58.0'	1.0	97.7	1.3	2.5Y6/3		x	
25	32	59°47.5'	44°00.0'	2.2	96.3	1.5	5Y6/2		x	
26	44	59°48.0'	44°02.0'	00.0	97.8	2.2	2.5Y6/4		x	
27	52	59°47.0'	44°04.0'	00.0	97.5	2.5	5Y5/4		x	
28	72	59°48.5'	44°08.3'	3.7	95.1	1.2	10YR 6/8		x	
29	148	59°48.0'	44°20.0'	0.00	87.9	12.1	5Y4/2		x	
30	no	sample								
31	128	59°54.0'	44°11.0'	00.0	52.1	47.9	5Y5/4		x	
32	120	59°54.0'	44°07.5'	4.1	90.3	5.5	5Y4/3		x	
33	50	59°53.5'	44°03.5'	0.7	97.0	2.3	2.5Y6/4		x	
34	38	59°54.0'	44°01.0'	00.0	98.8	1.2	2.5Y4.5/4		x	
35	-	59°54.0'	43°59.0'	00.0	98.5	1.5	5Y5/3		x	
36	20	59°54.0'	43°57.5'	00.0	99.0	1.0	2.5Y6/3		x	
37	16	60°01.0'	43°57.5'	00.0	99.2	0.8	2.5Y6/3		x	
38	20	60°01.0'	43°58.5'	00.0	98.8	1.2	2.5Y6/3		x	
39	26	60°00.6'	44°00.5'	00.0	98.8	1.2	2.5Y6/2		x	
40	65	60°01.0'	44°06.0'	4.3	94.4	1.3	2.5Y6/4		x	
41	139	60°01.0'	44°17.5'	0.7	77.3	22.0	/		x	
42	121	60°09.0'	44°24.5'	10.9	86.1	3.0	2.5Y4/4		x	
43	170	60°07.5'	44°10.0'	00.0	4.4	95.6	7.5y4/2		x	
44	51	60°07.5'	44°05.0'	00.0	98.8	1.2	2.5Y6/4		x	
45	29	60°07.5'	44°01.8'	1.9	97.4	0.7	2.5Y6/4		x	
46	20	60°20.0'	44°59.5'	00.0	98.5	1.5	2.5Y6/3		x	
47	15	60°07.0'	43°58.0'	00.0	99.0	1.0	2.5Y6/2		x	
48	44	60°12.0'	44°04.3'	1.7	97.3	0.9	2,5Y6/4		x	
49	90	60°17.0'	44°15.0'	74.7	24.1	1.2	2.5Y4/4		x	
50	37	60°20.5'	44°24.0'	00.0	98.8	1.2	2.5Y6/4		x	
51	146	60°35.0'	44°17.0'	19.1	75.1	5.8	2.5Y4/2		x	
52	90	60°26.4'	44°11.0'	1.0	97.4	1.6	2.5Y5/4		x	
53	65	60°20.0'	44°06.5'	2.1	97.3	0.6	2.5Y6/4		x	
54	37	60°17.0'	44°02.5'	00.0	98.8	1.1	5Y5/2		x	
55	38	60°11.5'	44°01.0'	00.0	98.7	1.3	2.5Y6/3		x	
56	22	60°09.5'	43°59.0'	00.0	99.0	1.0	2.5Y6/4		x	
57	33	60°17.0'	44°01.0'	00.0	98.8	1.2	2.5Y6/4		x	
58	38	60°32.0'	44°05.0'	00.0	99.2	0.8	2.5Y6/4		x	
59	25	60°43.0'	44°09.0'	00.0	98.9	1.1	2.5Y6/4		x	
60	36	60°47.0'	43°57.0'	00.0	98.7	1.3	2.5Y6/4		x	
61	20	60°35.0'	43°57.2'	00.0	98.8	1.2	2.5Y6/4		x	
62	18	60°27.0'	43°57.0'	00.0	99.0	1.0	2.5Y6/4		x	
63	-	60°19.0'	43°57.0	00.0	99.0	1.0	2.5Y6/4		x	
63A	18	60°21.0'	43°54.5'	00.0	98.9	1.1	2.5Y6/4		x	

TABLE 1.—*Sample stations on Sable Island Bank, Nova Scotian Shelf—Continued*

Sample No.	Depth (meters)	Position		Composition			Colour	Sample Equipment		
		Longitude	Latitude	%Gravel	%Sand	%Mud		Phleger core	VanVeen grab	Camera
64	20	60°13.5'	43°57.5'	00.0	99.9	1.0	2.5Y7/4		x	
65	10	60°10.0'	43°57.0'	2.0	97.2	0.8	10YR7/2		x	
66	38	60°17.0'	43°53.5'	00.0	98.8	1.2	2.5Y6/4		x	
67	40	60°31.5'	43°50.0'	00.0	95.6	4.4	2.5Y5/2		x	
68	36	60°43.2'	43°46.5'	00.0	98.8	1.2	2.5Y5/4		x	
69	62	60°35.0'	43°37.0'	00.0	98.0	2.0	5Y5/2		x	
70	53	60°26.2'	43°43.5'	00.0	98.4	1.6	5Y5/2		x	
71	57	60°18.5'	43°49.0'	00.0	98.1	1.9	5Y5/2		x	
72	36	60°14.0'	43°51.3'	00.0	98.8	1.2	2.5Y6/2		x	
73	20	60°11.5'	43°54.5'	00.0	99.0	1.0	2.5Y6/3		x	x
74	10	60°07.5'	43°56.5'	00.0	98.9	1.1	5Y6/2		x	
75	45	60°12.5'	43°49.5'	0.8	96.7	2.5	5Y5/2		x	
76	59	60°17.0'	43°40.0'	00.0	98.0	2.0	5Y5/2		x	
77	105	60°21.0'	43°30.0'	00.0	97.0	3.0	5Y5/2		x	x
78	175	60°07.5'	43°30.6'	00.0	94.5	5.5	5Y5/2		x	x
79	50	60°08.0'	43°45.0'	11.8	87.3	0.9	2.5Y6/4		x	
80	40	60°08.0'	43°50.0'	5.6	92.8	1.6	5Y5/2		x	
81	18	60°07.0'	43°54.0'	00.0	98.8	1.2	2.5Y7/2		x	
82	18	60°07.5'	43°41.5'	00.0	99.0	1.0	2.5Y6/2		x	x
83	20	60°01.0'	43°54.5'	00.0	96.4	3.6	7.5Y3/2		x	
84	27	60°01.0'	43°52.5'	00.0	98.5	1.5	2.5Y6/2		x	
85	46	60°01.0'	43°49.0'	00.0	97.3	2.7	5Y5/2		x	
86	92	60°01.0'	43°37.5'	3.5	95.3	1.2	5Y5/2		x	x
87	320	59°53.5'	43°31.5'	/	/	/	10YR6/2	x		
88	54	59°52.0'	43°46.0'	00.0	97.8	2.2	7.5Y5/4		x	
89	42	59°53.5'	43°49.0'	00.0	96.9	3.1	5Y5/2		x	x
90	37	59°53.5'	43°51.5'	00.0	98.1	1.9	5Y5/1		x	
91	10	59°55.0'	43°54.5'	00.0	98.9	1.1	5Y7/2		x	
92	22	59°48.0'	43°55.0'	1.3	97.8	0.9	2.5Y6.5/4		x	
93	40	59°47.5'	43°52.0'	00.0	98.0	2.0	5Y5/2		x	
94	46	59°47.5'	43°49.0'	00.0	97.1	2.9	5Y5/2		x	
95	120	59°48.0'	43°37.3'	0.4	95.4	4.2	2.5Y5/2		x	
96	440	59°42.0'	43°34.0'	00.0	31.8	69.2	5Y5/1	x		
97	80	59°43.0'	43°41.0'	0.9	97.3	1.8	2.5Y6/4		x	
98	60	59°43.0'	43°46.0'	00.0	96.3	3.7	5Y6/2		x	
99	42	59°42.5'	43°51.0'	00.0	97.5	2.5	5Y5/2		x	
100	40	59°36.5'	43°52.0'	00.0	98.5	1.5	5Y5/2		x	
101	31	59°42.5'	44°55.0'	00.0	98.6	1.4	5Y5/2		x	
102	23	59°42.5'	43°58.0'	12.4	86.5	1.1	2.5Y6.5/4		x	
103	5	59°42.5'	43°59.5'	0.00	98.8	1.2	2.5Y7/3		x	
104	99	59°29.0'	43°43.5'	00.0	80.5	19.5	5Y5/2		x	
105	732	59°30.0'	43°37.5'	00.0	58.6	41.4	/	x		
106	230	59°14.0'	43°40.0'	00.0	94.8	5.2	5Y5/2		x	
107	76	59°24.5'	43°46.5'	20.4	72.2	7.4	10Y5/1.5		x	
108	54	59°29.5'	43°51.5'	00.0	98.0	2.0	5Y5.5/2		x	
109	38	59°34.0'	43°55.5'	7.5	90.1	2.4	5Y6/2		x	
110	26	59°38.0'	43°57.2'	00.0	99.1	0.9	5Y6/2		x	
111	20	59°00.0'	43°58.0'	00.0	98.7	1.3	2.5Y7/3		x	x
112	24	59°31.0'	43°58.0'	00.0	98.9	1.1	2.5Y6/4		x	
113	-	59°16.0'	43°53.5'	00.0	98.9	1.1	2.5Y6/4		x	
114	102	59°06.0'	43°50.5'	00.0	99.2	0.8	2.5Y6/6		x	

SEDIMENT DISPERSAL.—Bottom currents mold the surface of Sable Island Bank in response to water-mass movement of the type described in the previous section. Large sedimentary features, including sand waves and subaqueous dunes in water less than 40 fms (73 m) deep, show that net current movement north and south of Sable Island is in opposite directions: toward the east in the region north of the island, and toward the west, south of the island (James and Stanley 1968). Intensity of current activity increases, as would be expected, in the shallower water close to the island. This circulatory pattern is confirmed by an independent examination of the texture and mineralogy of the sand on the Bank.

Most of the sediment on the Bank surface is now (or in the recent past) being moved by bottom currents. Winnowing and bypassing of finer sediment would explain the absence of fine silt and clay on the Bank surface (Stanley and Cok 1968). Although much of the Bank is undergoing active erosion, several zones of probable sediment accumulation are on the Bank margins (shelf-break) south, east, and northeast of Sable Island (James and Stanley 1968, their Figure 10).

Methods

A total of 114 bottom grab sample stations were taken on the Bank and surrounding area during the period from 5 to 9 May 1965 (Table 1 and Figure 1). The sample grid was planned so that the density of stations increases toward Sable Island. A Van Veen type grab sampler, which covers approximately 0.15 m^2 of surface area and when full recovers about 20 kg of sediment, was used on 110 of these stations. Small Phleger cores were collected at 4 of the deeper stations. Camera lowerings were made at 32 of these stations with an EG&G bottom camera rig, below which was suspended at 7.6-cm-diameter compass for orientation of physical and biogenic features. The camera was automatically triggered (not bottom-activated) and photographs were taken every 12 to 15 seconds while the camera rig was about 1 to 4 meters above the sea floor. The camera rig remained near the bottom for approximately 5 to 10 minutes as the ship drifted on station. The direction of drift on station is indicated by a 25-cm-long vane attached to the compass.

A total of 307 (1 to 30 per station) usable bl and white 35-mm photographs were obtained 28 of the 32 camera stations. A small clock sh ing the exact time when photographs were ta and a number recording the frame sequence, nc in the data chamber, were also photograpl Depth of stations ranged from 10 to 250 met Position, water depth, and textural compositior bottom sediment of each sample station are li: in Table 1. Complete cruise data and results mineralogical analyses of the bottom samples lected at the 114 stations are detailed in Ja (1966). Negatives of all photographs are m: tained in the bottom-photograph collection in Division of Sedimentology, National Museum Natural History. Data obtained at each of the camera stations are listed in an extensive tε available from the National Oceanographic D Center, Washington, D.C. (NODC Accession nı ber 70–1010). From each usable photograph area photographed was calculated and the foll ing information recorded: quality of photograj presence of compass in photo frame, presence ripple marks, sand waves and other current ii cators, mottling, bioturbate structures (tracks : burrows), and fauna. Where one particular spe was abundant (e.g., *E. parma* or anemones), total number of individuals was counted. In case of *E. parma*, apparently stationary, parti: buried and moving individuals were counted se rately. The occasional white, often overturned, s: dollar was interpreted to be dead. Finally, the nı ber of individuals per square meter was calcula

Sediment Texture and Evidence of Current Acti

Bottom photographs supplement information tained from the mineralogical and textural a yses (Figure 5). Distinctly different types of floor microtopography and texture were nc (Plate 1): clean sand, generally rippled; sh sand with granular texture; silt and silty sand l tom; and sea floor completely modified by burr ing organisms (bioturbation). A light and d mottled bottom was observed at a number of tions. The dark material is almost certainly ganic; the patchy distribution is produced by l rowing organisms and bottom-current activity ı disrupt this bottom veneer.

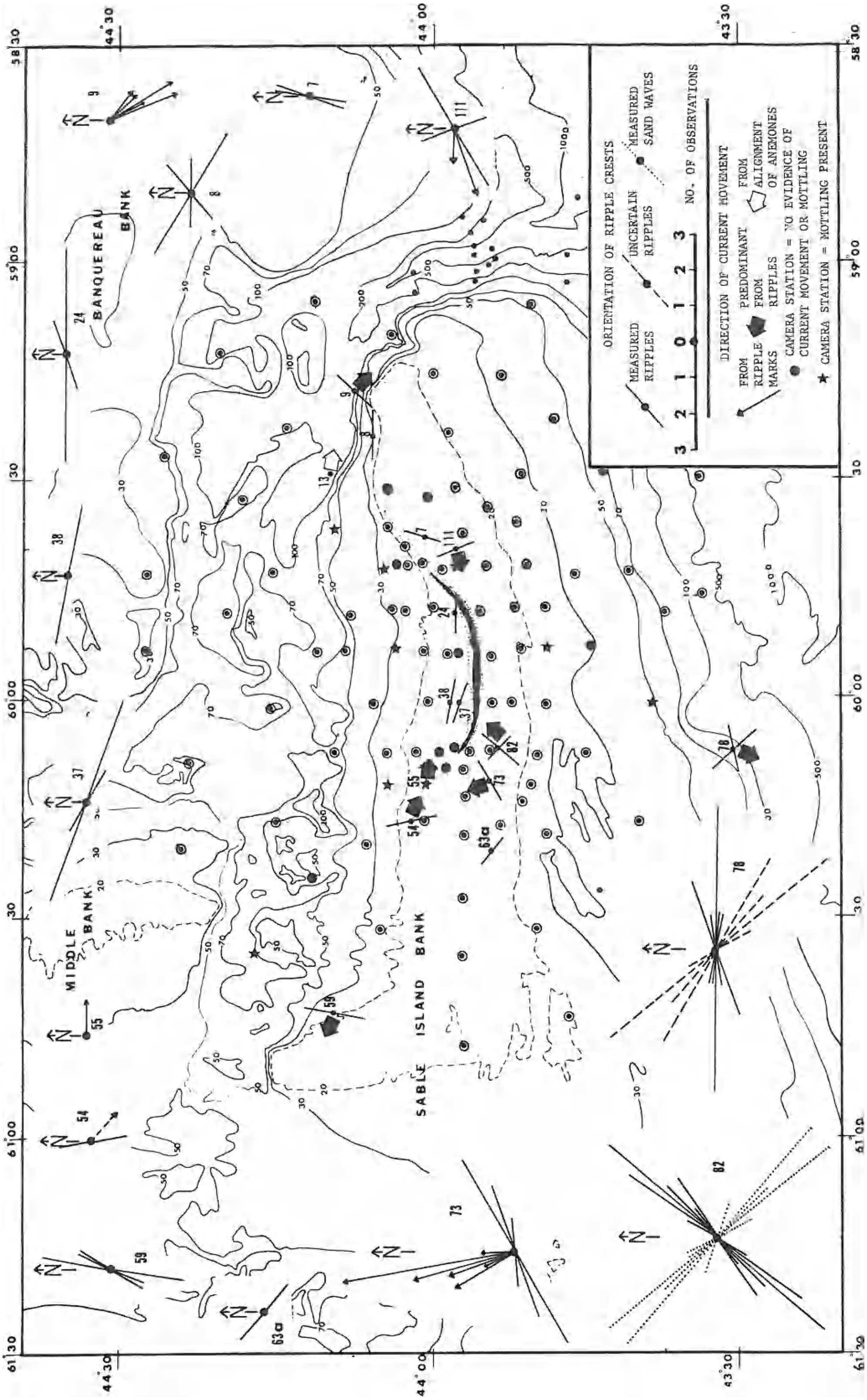

FIGURE 2.—Bottom current information from camera stations on Sable Island Bank. Current direction ascertained from bed forms (sand ripples and waves) and orientation of organisms. Note circulatory clockwise pattern of bottom currents immediately adjacent to Sable Island. The presence of mottling is also depicted. Current evidence and mottling are generally mutually exclusive.

Bottom photographs also provide evidence of short-term bottom-current activity (Plate 2). Most useful in detailing current direction are sand ripples noted at 14 camera stations (Figure 2). In one instance, the predominant orientation of anemones, presumably bending in the current direction (Station 13), was also noted. The NW-SE trending crests at Station 82 are those of larger sand waves. The ripple-crest orientation was recorded at all 14 stations, and the sense of bottom-current movement determined at 8 of these (Figure 2).

In shallow water surrounding Sable Island, the orientation of ripple marks confirms the circulatory pattern described earlier. Northeast of the island, at Station 59, a NW trend off the Bank is suggested. Current directions recorded in the head of The Gully Canyon (Stations 9 and 13) indicate a movement seaward, generally parallel to the canyon axis. A predominant downslope current movement is also noted at the shelf-break near the head of Sable Island Canyon (Station 18).

It is noteworthy that areas presenting evidence of strong current activity and those illustrating mottled sediment are generally mutually exclusive (Station 55 is an exception). At Station 9, what appears to be eroded algal matter has been concentrated in ripple troughs by bottom-current activity.

Echinarachnius parma on Sable Island Bank

Population density.—The northern sand dollar *Echinarachnius parma* (Lamarck) was observed in 13 of 28 camera stations. Where present, the density ranged to as many as 185 individuals per square meter (at Station 21). The number of photographs showing this species varied from 5 to 22 at any one station. The photo-to-photo variation in density at each station is depicted on the histograms shown in Figure 3.

Immediately apparent is the irregularity of concentration (Plate 3) caused by clustering of individuals. From comparison of the number of animals counted within the area covered by the photograph (shown in black on histograms in Figure 3), it appears that if the area covered exceeds one square meter, the number counted is relatively close to the mean for that particular station (see Stations 8 and 21). Only a few photographs suffice then to give a reasonably close proximation to the overall distribution at any position on the bank.

It is noteworthy that correlation between ind uals photographed at the surface and individ retrieved in a small grab at the same statio poor (Figure 3). Those areas that contain n than 50 sand dollars per m^2 yielded two or n individuals in the accompanying small Van V grab sample. This low retrieval reflects the sı area covered by the grab but also suggests that many sand dollars were buried at the time of survey.

Regional distribution.—A chart showing distribution and density of *E. parma* on Sabl land Bank is given in Figure 4. This chart is piled from both bottom photographs and samples (the presence of at least 2 individual more retrieved in a grab sample at a station w no photos are available indicates the prob abundance of at least 50 individuals/m^2). northern sand dollar is present over one thir the total Bank surface. Highest densities are fc in an arcuate trending belt north of Sable Is as earlier postulated in a sedimentological s of the Bank (James and Stanley 1968). Concen tions of up to 180 individuals per m^2 are fc just north of the two terminal submerged bar tending from Sable Island. High densities (> m^2) are rarely found in water deeper than 30 (55 m).

While a large area of relatively few sand do is found on the Bank southeast of Sable Isl the crests of the island's two submerged term bars, nearshore stations, and the area southeas the island appear devoid of sand dollars as Sand dollars do occur, however, in two restri areas southeast of the island: (a) a linear NE trend in shallow water just south of Sable Isla eastern submerged bar, and (b) at depths of meters on the eastern margin of the Bank adja to The Gully Canyon.

The deepest stations where individuals are countered are near the heads of Sable Island yon (Station 78, 175 m) and The Gully Car (Station 9, 256 m).

A number of trends were observed in the det photographic analysis. Comparison of sand do with the known compass diameter indicates tha

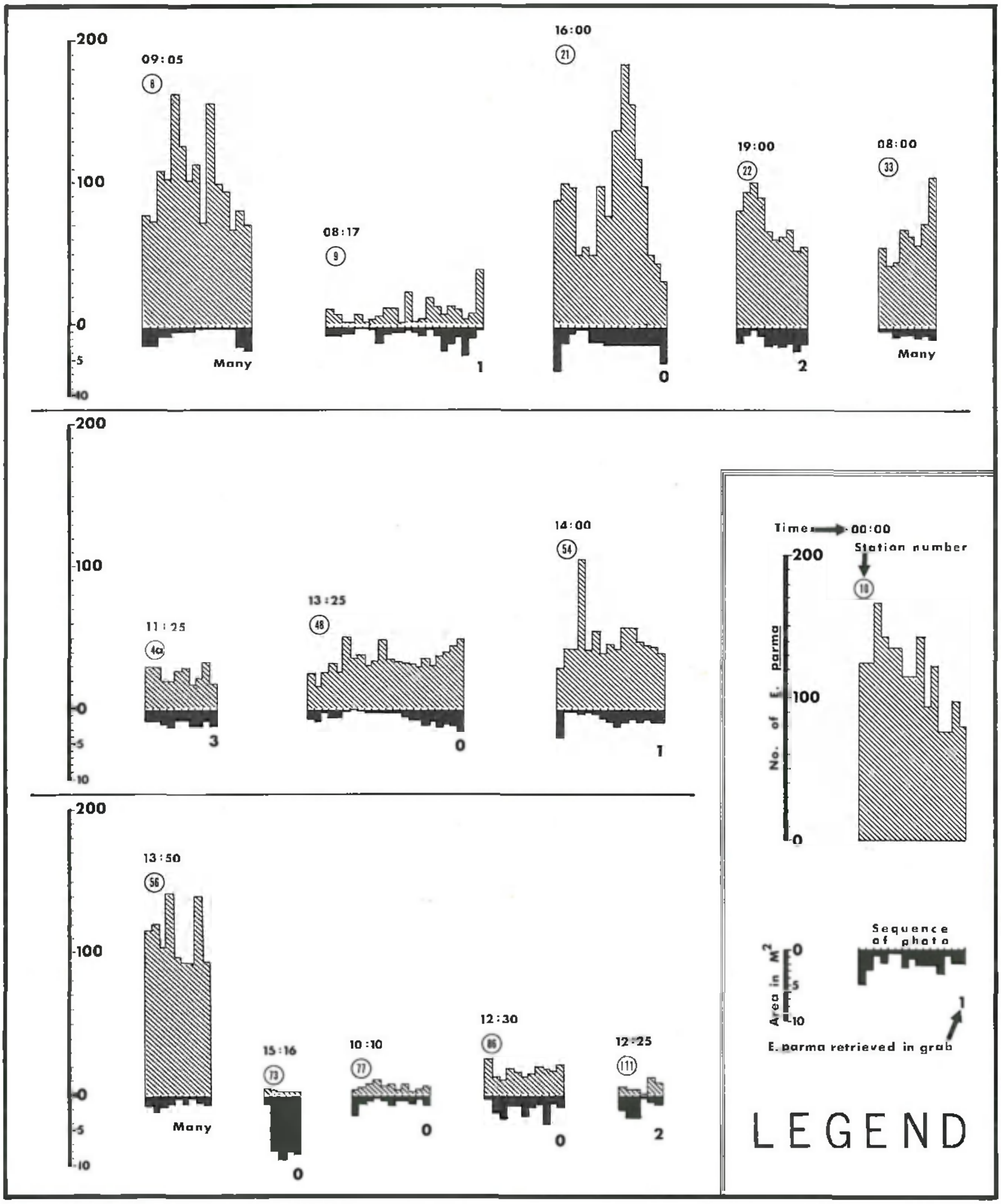

FIGURE 3.—Histograms showing photo-to-photo variation in concentration of the northern sand dollar *Echinarachnius parma* (Lamarck) (density in m^2) as observed at camera and grab stations on Sable Island Bank. The area covered in each photograph and time of sampling is also shown.

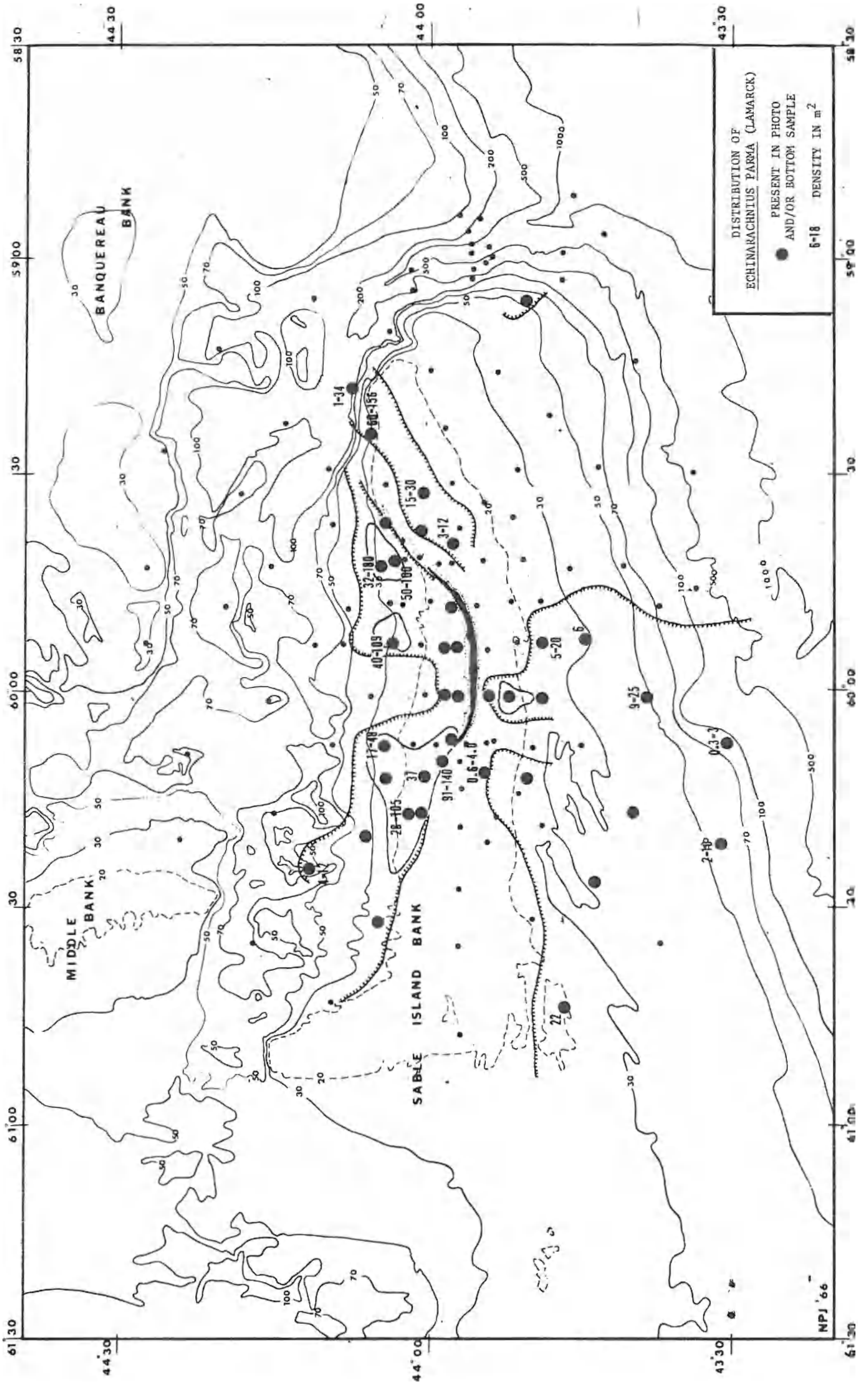

FIGURE 4.—Regional distribution and concentration in numbers per m² of *Echinarachnius parma* on Sable Island Bank.

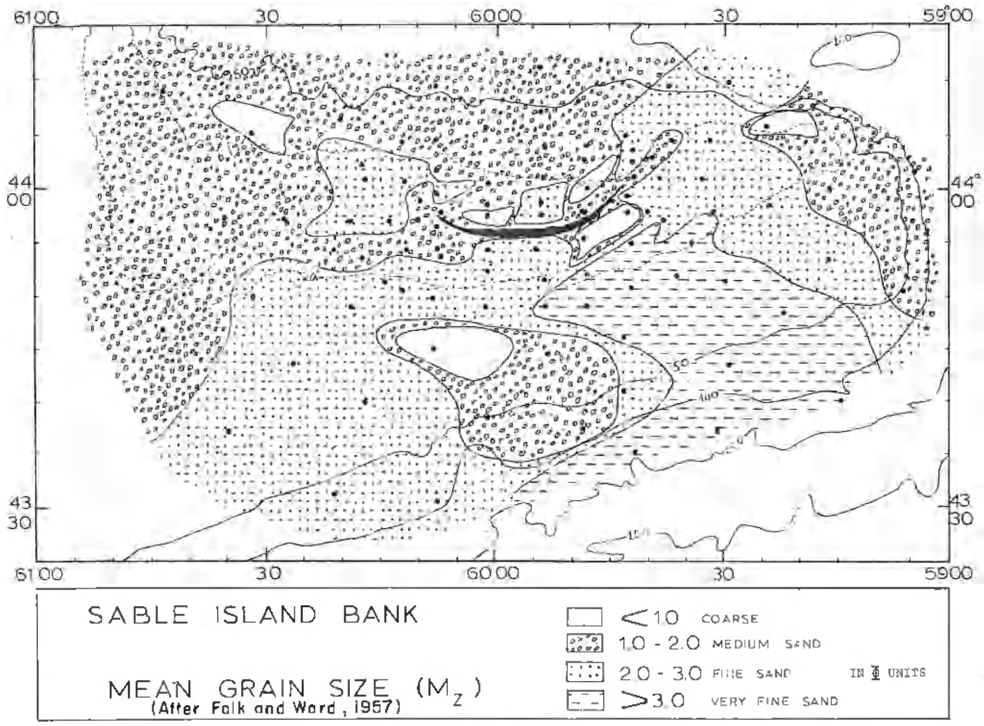

FIGURE 5.—Distribution of mean grain size (in ϕ units) on Sable Island Bank (after James and Stanley 1968). Note close relation between the presence of *E. parma* (see Figure 4) and that of fine to medium sand grade.

predominant size of *E. parma* observed in photos is between 5 and 6 cm. This is in close agreement with dimensions of this form found off New England (Lohavanijaya and Swan 1965). It is difficult to estimate the amount of movement of individuals in some photographs due to the absence of reworked sand markings. In many cases, however, partially buried forms and those having left a trail are noted (Plate 4).

There appears to be no relation between numbers of individuals and time of day or in the tidal cycle (Figure 3). Only in a few cases were individuals found in concentrations such as those observed by Zenkevitch (1963) in the northwest Pacific. With the possible exception of Station 56 (Plate 4) individuals appear to be moving in a random pattern, confirming the observations of Weihe and Gray (1968) and Boehmer (1970) on southern United States species of sand dollars. In areas of high density this movement is responsible for modifying physically produced bottom structures, and the effect of this bioturbation can be seen on Plate 4. The movement, by rotation and progression, as described by Parker (1927) in response to feeding and burying, modifies both rippled and nonrippled surfaces. The broad, flat, generally arcuate tracks made by the sand dollars are characteristic and may be recognized in the fossil record.

At Station 9 (256 m) located in the head of The Gully Canyon, sand dollars were observed on a rippled sand bottom in which organic matter, probably algal detritus, was noted in ripple troughs (Plate 2f).

Other Epifauna

In addition to *E. parma* the presence of other organisms living on the sea floor as noted in bottom camera stations and grab recoveries include starfish, brittle stars, anemones, gastropods, and fish (hake and cod). Their distribution is shown in Figure 6 and examples are illustrated in Plate 5. Starfish [*Henricia sanguinolenta* (O. F. Müller) and others] are found at 8 camera stations from depths of 20 to over 200 m and appear more numerous north of Sable Island. Brittle stars (*Ophi-*

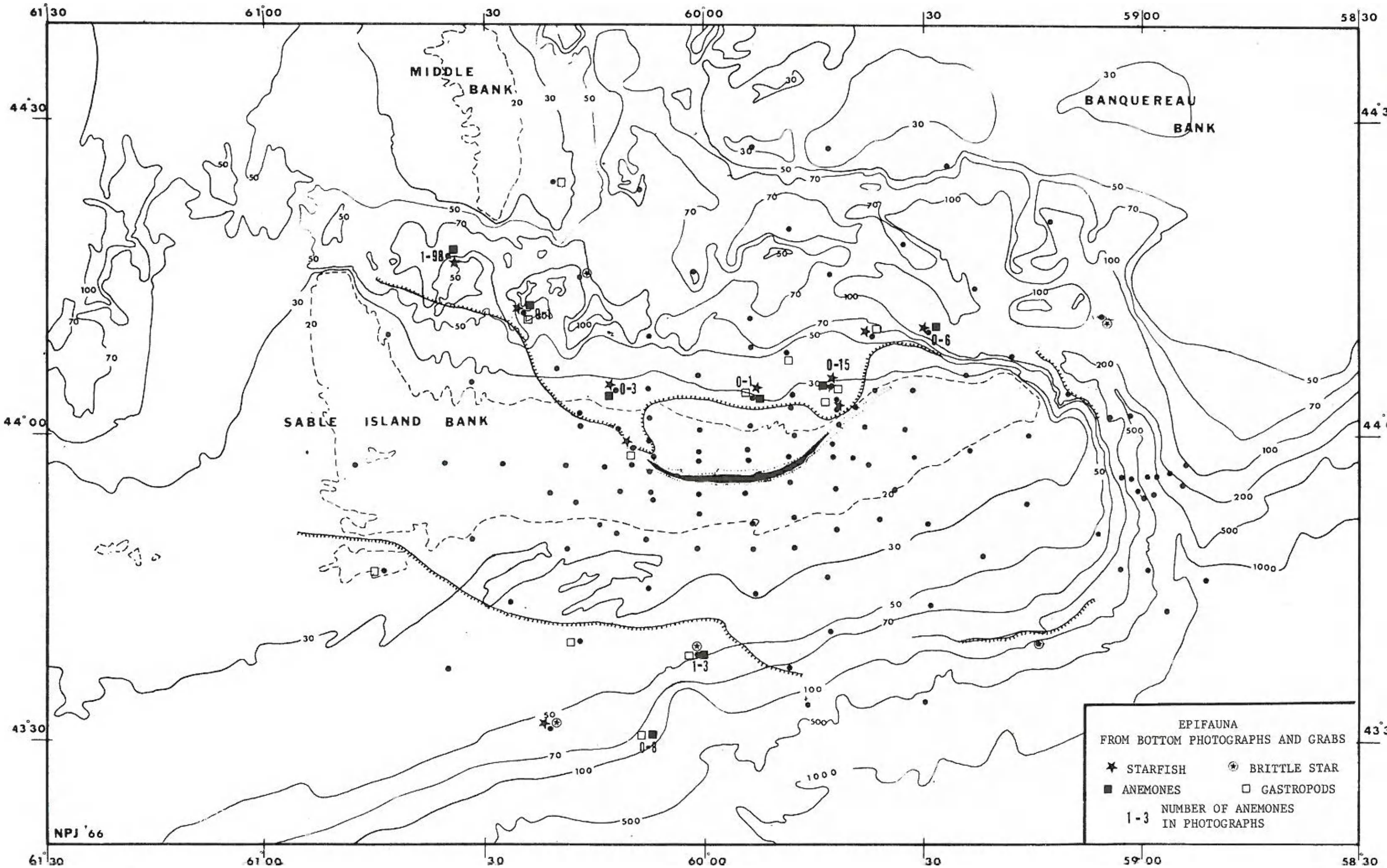

FIGURE 6.—Regional distribution of epifauna on Sable Island Bank. Note area barren of organisms (except *E. parma*) north and south of Sable Island.

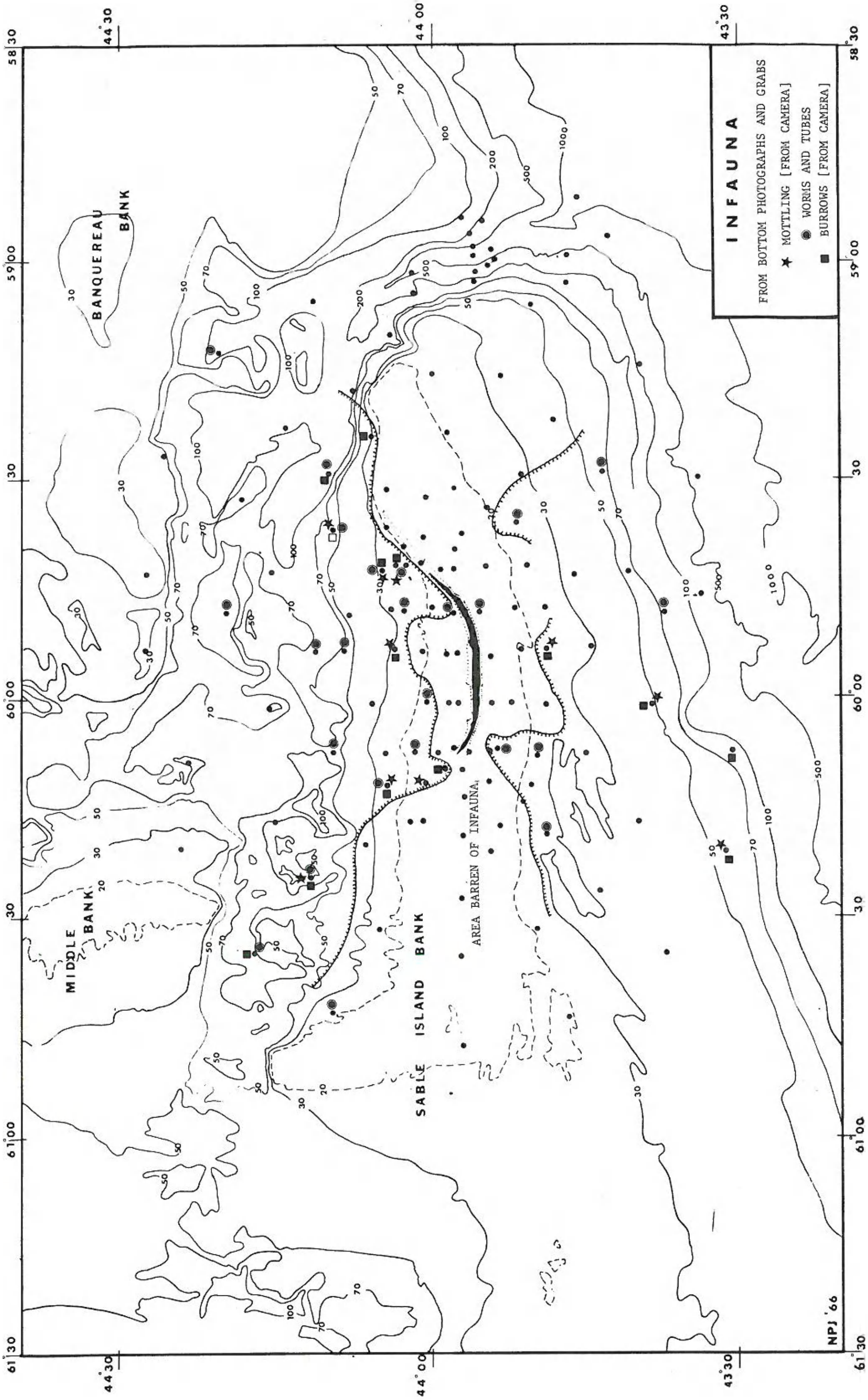

FIGURE 7.—Regional distribution of infauna on Sable Island Bank. The east-west area barren of infauna is considerably narrower than the area devoid of epifauna shown in Figure 6.

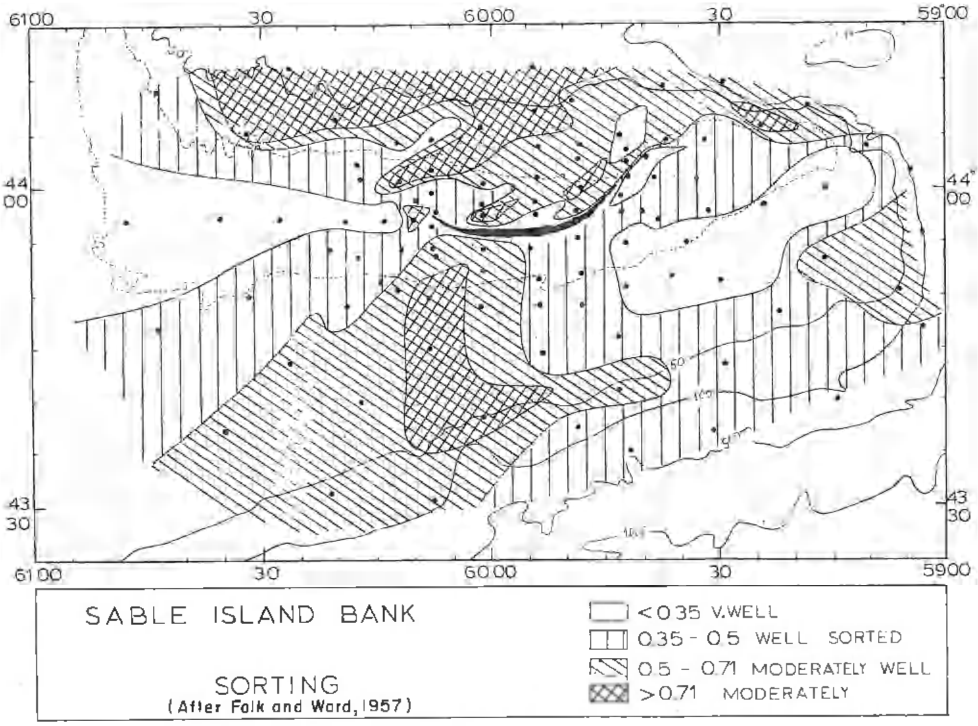

FIGURE 8.—Regional distribution of sorting of sand on Sable Island Bank. The zones generally devoid of fauna north and south of Sable Island are very well sorted sands coinciding with areas of high current activity (Figure 2).

omusium lymani Wyville Thomson at 2 camera stations and in 3 grab samples), on the other hand, were not recorded above 90 m. These ophiuroids appear not to be restricted geographically but are rather limited to deeper water (for example, Gully Trough, The Gully Canyon, and outer shelf near the shelfbreak).

Numerous attached anemones were observed at 6 deep water camera stations (>90 m); north of Sable Island, at Station 33 (50 m), several anemones were attached to shells. At Station 51 in the Gully Trough (depth of 146 m) as many as 98 (26/m^2) were counted in a single photograph.

Gastropods, including the species *Aporrhais occidentalis*, were recognized at 8 camera stations and recovered in 7 grab samples. These mollusks are more common north of Sable Island. Gastropods occur in water deeper than 55 m on the southern part of the Bank, while north of Sable Island they are found in depths over 35 m and in even shallower water in the lee of the submerged terminal bars of the island.

The organisms cited above generally occur together. The regional distribution of this epifau assemblage occurs in east-west trending zone depicted in Figure 4. A belt 34 to 40 km wide parallels the shallow crestal axis of the Ban generally devoid of conspicuous epifauna.

Infauna

The regional distribution of organisms li within the surficial sediments cover of Sable land Bank, evaluated from both photographs grab recoveries, is shown in Figure 7. Include this assemblage are tubes and polychaetes f grab recoveries and burrows and tubes obse in photos. Actual examples are shown in F 6. The regional distribution pattern of this ass blage is similar to that of the epifauna (Fi 6). The zone devoid of infauna, however, is rower (12 to 22 km) than that devoid of epifa and is more symmetrically oriented along the of the Bank.

Infauna is generally associated with a mot sediment surface. Small mounds of light-col sand surrounding burrow openings (Plate 6) are separated by darker areas, suggesting that this patchy coloring results, in some cases, from bioturbation (i.e., disruption of an originally continuous dark veneer).

Recognizable pelecypod shells, including *Cyrtodaria siliqua*, *Pecten magellanicus*, and *Arctica islandica*, are observed in bottom photographs. Fragments of shell, or shell hash, are ubiquitous. Bottom photographs are generally unreliable in estimating the density of pelecypods because of the large number of buried individuals. Bottom grab samples reveal a concentration of shell fragments in southeast, northeast, and northwest belts trending away from Sable Island toward deeper water on the Bank (in James and Stanley 1968, their Figure 6B). Shells are also abundant near the south shore of the island, at ends of both bars, and in shallow water surrounding submerged offshore terminal bars.

Discussion

INTERPRETATION OF *E. parma* DISTRIBUTION.—There does not appear to be any recognizable correlation between density and regional distribution of *E. parma* and time of observation or depth of water on the Bank. The tolerance of this species to significantly large seasonal variations of temperature and salinities cited earlier is apparent. The salinity and temperature of bottom water north and south of Sable Island are not significantly different and cannot explain the remarkable faunal difference in these two regions (i.e., extremely large number of sand dollars north of the island as opposed to low densities south of the island). Predators that may affect regional distribution are unknown. The distribution pattern of the northern sand dollar (Figure 4) can, on the other hand, be closely related to that of the mean grain size of sand (Figure 5) which in turn reflects local conditions of bottom current agitation and topography.

The most abundant faunas appear in the fine (2.0 to 3.0 ϕ) and medium (1.0 to 2.0 ϕ) sand grades. An exception is Station 8 on the northeastern margin of the Bank where high densities occur on a coarse sand base. Sand dollars are absent in a large area southeast of Sable Island, an area covered by very fine (3.0 ϕ) sand. Sand dollars also tend to be absent from regions of very well sorted sand (Figure 8). Areas of well sorted sand on the Bank crest and shallow region adjacent to Sable Island coincide with zones of most intense current activity as shown in Figure 2. Although sand dollars do occur in rippled areas (such as Stations 54, 55, 111) reflecting moderate to intense water movement above the bottom, they are more commonly encountered on mottled covered bottoms indicative of somewhat less intense current activity.

The preference for clean sand by *E. parma* (Parker 1927) and other species of sand dollars (Kier and Grant 1965; Bell and Frey 1969) is well known. The preference for a distinct sand size related to its burrowing behavior, by *Mellita quinquiesperforata* (Salsman and Tolbert 1965; Bell and Frey 1969) is also clearly exhibited by *E. parma*. This selection of sand that is frequently mottled and not very well sorted is undoubtedly related to the detrital feeding habit of *E. parma*, a detritus feeder. The apparent relationship of population density with intense current agitation should not be overlooked. As has been suggested by others (Sokolova and Kuznetsov 1960; Zenkevitch 1963; Reese 1966), *E. parma* may obtain some of its food from suspension. Strong current activity like that near Sable Island would not be conducive to either substrate stability or successful suspension feeding.

Furthermore, there is some relation between density and topography. Like the species *Mellita quinquiesperforata* (Weihe and Gray 1968), *E. parma* aggregates in the lee of sand bars, in this case the large terminal bars of Sable Island. Similarly, the "clumping" response of this species is similar to that reported for *M. quinquiesperforata* (Weihe and Gray 1968).

Population densities calculated in the study area are somewhat less variable than those of *M. quinquiesperforata* whose concentrations range from 44 to 821 per m^2 (Salsman and Tolbert 1965). Concentrations of the northern sand dollar on the Bank are also less dense than those depicted by Sokolova and Kuznetsov (1960) and Zenkevitch (1963), whose photographs show extremely high densities of *E. parma*, with individuals actually overlapping.

The observation by Emery et al. (1965, their Figure 9) that more sand dollars were recovered in grab samples than were counted in bottom photographs on the continental shelf southwest of the study area (suggesting that most forms are buried and not detectable) is not confirmed by the present study. Our investigation shows that by far more individuals occur on the surface (as revealed in bottom photographs) than in grab samples, indicating that most individual sand dollars were living on or just at the surface at the time of the survey (May 1965), and that photographs in this instance are a more valid means of estimating population (Figure 3).

The distribution of medium and fine moderately sorted sand bottom selected by *E. parma* is closely related to the present near-bottom current regime on Sable Island Bank. This texture probably traps an optimum amount of particulate matter and grains covered by organic films that tend to sustain high populations. Coarser grain sizes, representing lag deposits in stronger eroded regimens, are probably depleted of sufficient organic matter by abrasion. Finer grain sizes, on the other hand, trap perhaps too much organic matter thus producing conditions unsuitable to *E. parma*. The high number of sand dollars on the surface may, in fact, be due to higher concentrations of organic matter in the sand just below the sediment-water interface. It has been suggested that the dislike by *E. parma* of "foul" (lacking oxygen) sand due to decomposition of organic matter causes it to remain on the surface (Parker 1927). At Station 21, an area containing as many as 180 individuals per m^2 on the surface, a dark malodorous layer of organic matter was recovered just below the thin light-colored sand veneer.

The importance of sand dollars as modifiers of the surficial sediment of Sable Island Bank is clearly evident. *Mellita quinquiesperforata* has been known to level completely a rippled field 6 to 10 cm in height in a single night (Salsman and Tolbert 1965). As the activity of *E. parma* is the same as this southern species, bioturbation must be regarded as almost as important as current activity in molding the microtopography and reworking the sediment of at least one third of the Bank surface.

Distribution of associated fauna.—Other organisms living on the sea floor show a dominant distribution pattern that, like that of *E. parma*, displays a predominant east-west trend. When abundant, the epifaunal and infaunal associations resemble faunas on other shallow outer banks o continental shelves of northeastern North A ica (Wigley 1961; Emery et al. 1965). The barren of epifauna (except *E. parma*) appear dependent of mean grain size (Figure 5) but cides with the well to very well sorted sand ure 8) and areas of abundant sand ripples waves. This would suggest that currents are strong in this area for typical northern shelf tom dwellers. The general absence of Foramin in this barren east-west area adjacent to Sable Is (James and Stanley 1968) tends to confirm above conclusion.

Organisms living within the sediment also req a reasonably stable bottom and consequently not found on the crest of the bank or close to S Island, areas of strongest current activity and ing sediment. The close association of conspic infauna and mottling (the latter suggesting a tranquil current regime) is significant in respect.

The northern limit of the infauna zone sout Sable Island is located closer to the island than of the epifauna zone. The narrower barren of infauna would suggest that buried or part buried organisms are, as a group, somewhat tolerant to current activity than those living on Bank surface.

Summary of Observations

This investigation of faunal associations on S Island Bank on the outer margin of the N Scotian Shelf shows the following:

1. The distribution of *Echinarachnius parm* more closely associated with mean grain size sorting of the surficial sand cover (in respon current activity) and with local topography with any other measured factors.
2. Densities of *E. parma* reach to a maximum o individuals per m^2 and are highest in moder sorted fine- to medium-grained sand.
3. After current activity, sorting and bioturba as a result of feeding and movement b *parma* are the most important factors modi the surficial sediment cover of the Bank (than one third of the total Bank surface including the entire sector north of Sabl land).

4. Absence of *E. parma* from regions of strongest current activity and also from areas of well sorted and very fine sand grades is probably related to feeding and burial habits.
5. Underwater photography applied to northern sand dollar population studies in environments such as broad, shallow outer banks proves to be considerably more reliable than bottom sampling surveys.
6. The shallow, east-west trending axis of Sable Island Bank, subjected to intense current activity, is devoid of the typical neritic northwest Atlantic epifauna and infauna. Population of typical shelf benthic organisms (other than *E. parma*) appear in the deeper, somewhat less agitated waters beyond this shallow axis and, consequently, their regional distribution shows a good correlation with sorting independent of mean grain size.
7. The regional population distribution shows that conspicuous infaunal assemblages on Sable Island Bank are somewhat more tolerant of strong near-bottom current agitation and related sediment movement than are epifauna.

Acknowledgments

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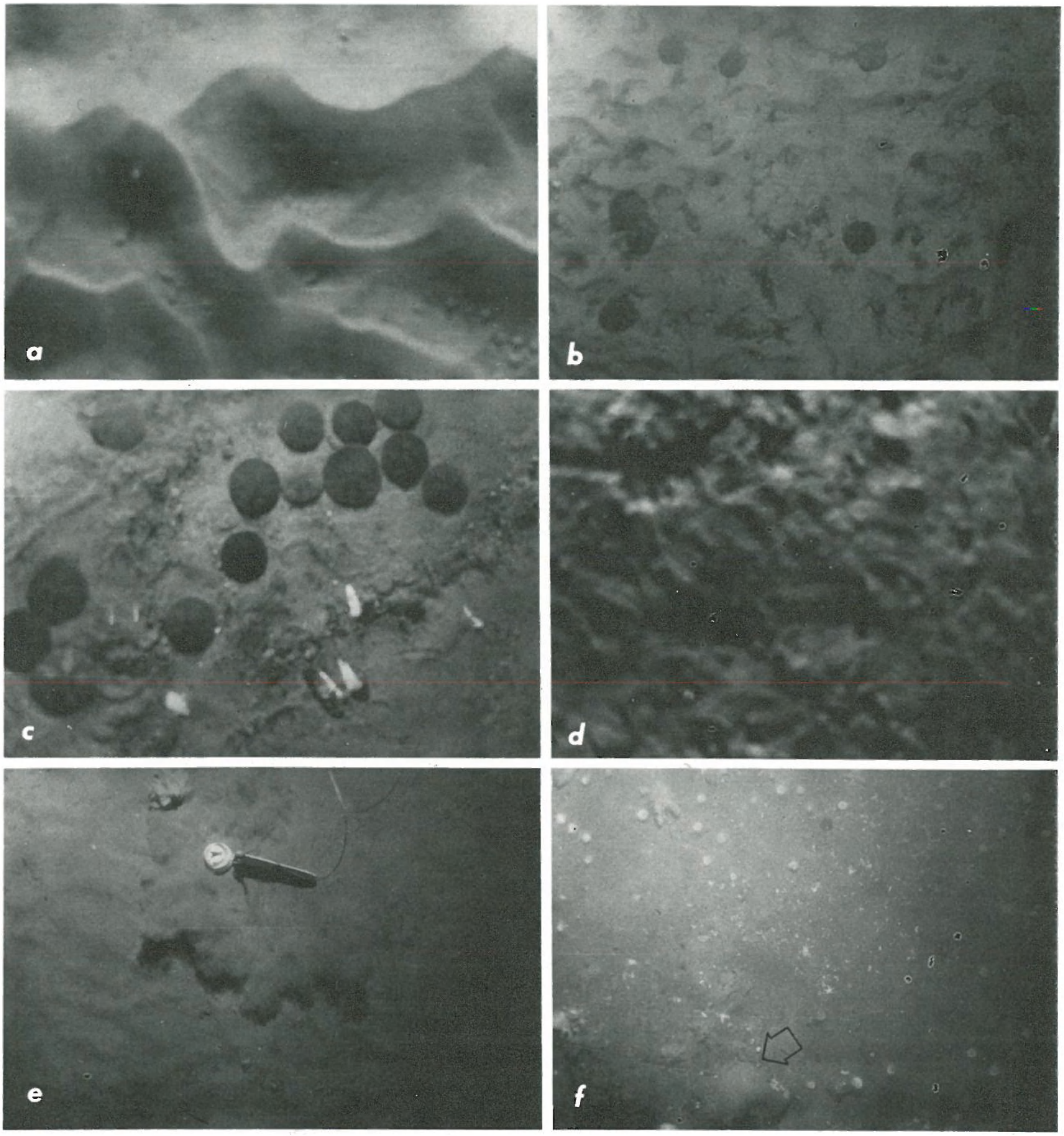

PLATE 1.—Variation of sediment texture and microtopography on Sable Island Bank: *a*. Station 59, on northwest margin of Bank, depth 25 m. Coarse, sinuously rippled sand with granules in trough. Some granular material in ripple troughs may be organic in origin. Wave length of ripple approximately 6 to 12 cm. *b*. Station 9, in head of The Gully Canyon, 256 m. Dark patchy nature of sand bottom referred to as mottling in text. Unlike the sea floor at this station, mottling and current activity are generally mutually exclusive (see Figure 2). *c*. Station 8, on northeast margin of Bank, 52 m. *Echinarachnius parma* (Lamarck) on a shelly granular sand bottom. Individual and articulated valves and current concentrated shell hash are noted. *d*. Station 13, on eastern part of Gully Trough, 223 m. Silty sandy sea floor completely modified (bioturbation) by benthic organisms. Note worm tube in upper-right corner of photo. *e*. Station 78, on southern margin of Bank near head of Sable Island Canyon, 175 m. Silty sandy (note cloud produced by compass striking bottom) sediment covered by old rounded ripples, indicating past current activity. Ripple crests are oriented NNE-SSW. Compass is 7.6 cm in diameter; compass vane is 25 cm in length. *f*. Station 51, in Gully Trough between Middle and Sable Island Banks, 146 m. Boulders (arrow) on a silty shelly sand bottom. Note profusion of anemones and other benthic organisms at this locality. Boulders are glacially transported (Stanley and Cok 1968).

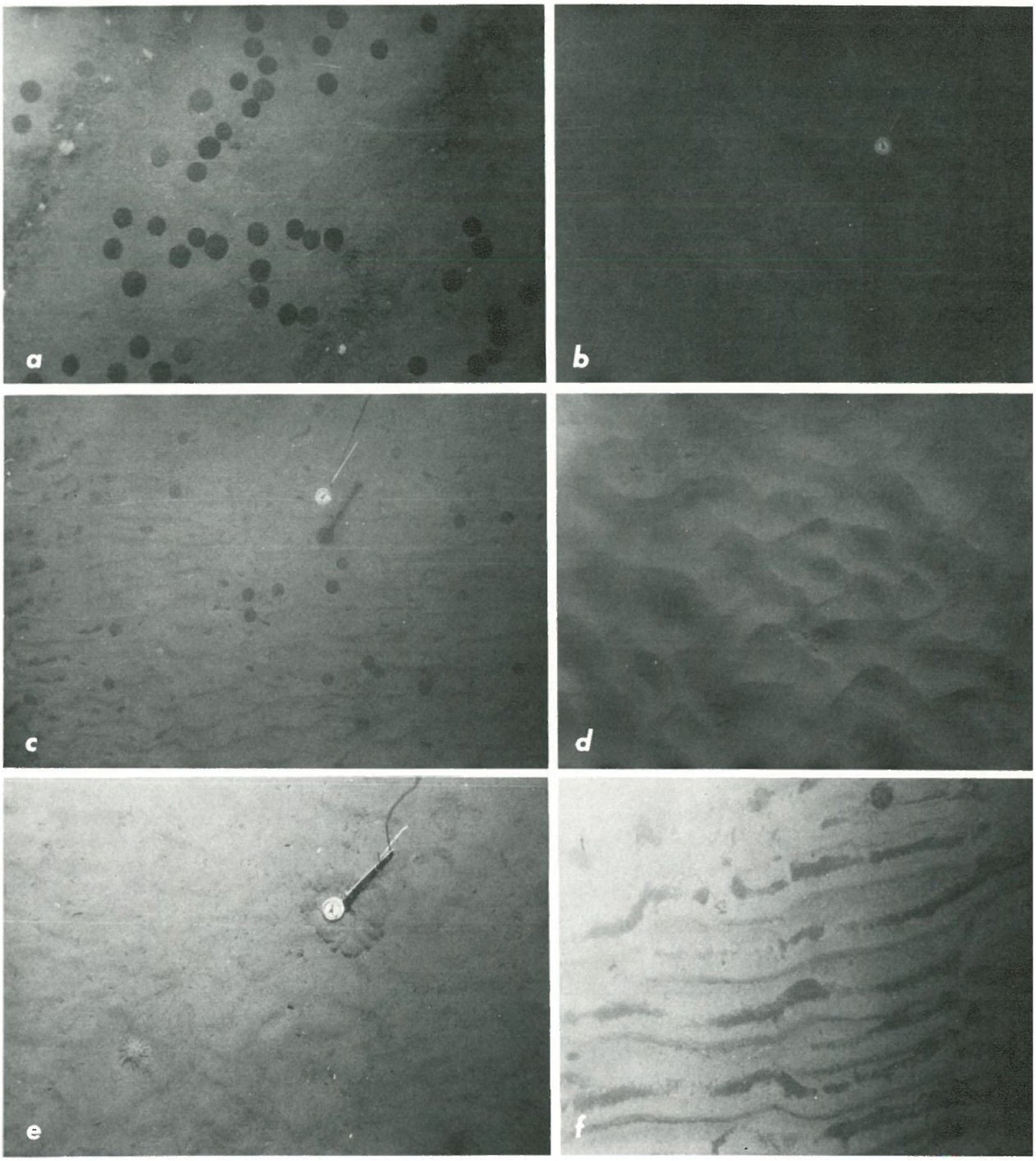

PLATE 2.—Evidence of current activity on Sable Island Bank: *a*. Station 8, on northeast margin of Bank, 52 m. Sand waves (scale provided by *Echinarachnius parma*) with shell hash granules and organic detritus concentrated in linear troughs. *b*. Station 82, on Bank just south of the western tip of Sable Island, 18 m. Two sets of current ripples on an essentially sand bottom: predominant sand wave crest orientation of NW–SE; secondary ripple crests oriented NE–SW. *c*. Station 59, on northwest margin of Bank, 25 m. Straight asymmetric sand ripples showing predominant current direction toward the southeast. Compass and *E. parma* provide scale. *d*. St 9, in head of The Gully Canyon, 256 m. Sinuous and ference sand ripples showing somewhat variable current tions. *e*. Station 78, on southern margin of Bank near of Sable Island Canyon, 175 m. Somewhat vague "r ripples veneered with silt indicative of current activity time in recent past. *f*. Station 9, in head of The Gully yon, 256 m. Dark material, possibly of algal origin, co trated in ripple troughs.

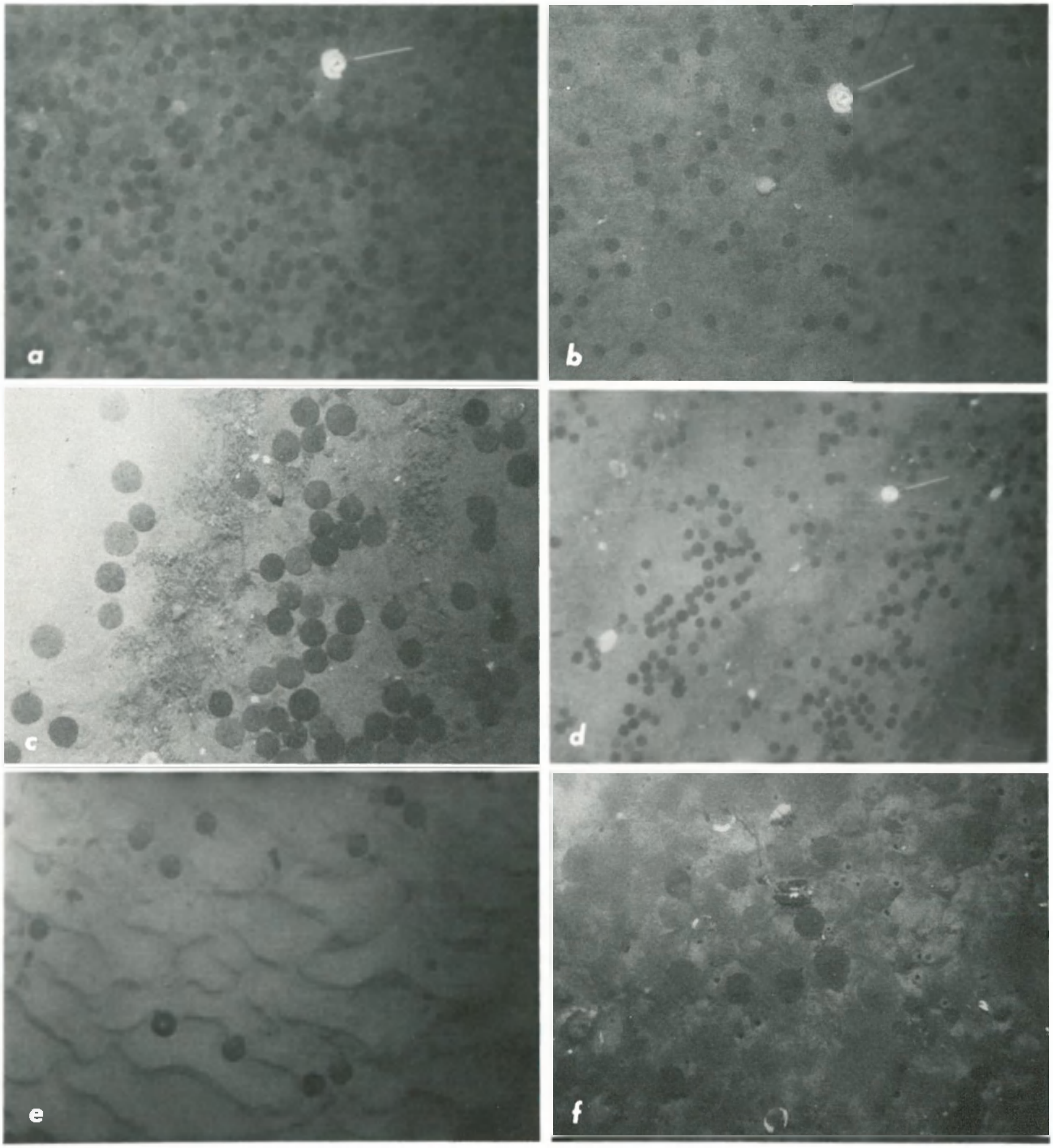

PLATE 3.—Distribution pattern of the northern sand dollar *Echinarachnius parma* (Lamarck) on Sable Island Bank: *a.* Station 21, on Bank north of eastern margin of Sable Island, 50 m. High density of northern sand dollar covering nearly entire sandy sea floor surface. Note starfish below compass. See also Station 21 in Figure 3. *b.* Station 21, same as Figure 1. Much lower concentration of *E. parma*. *c.* Station 8, on northeast margin of the Bank, 52 m. Tendency of sand dollars to cluster on sand wave crests is shown. Shelly and organic matter and granules are concentrated in troughs. *d.* Station 8, same as in Figure 3. Clustering of *E. parma* in linear belts trending parallel with sand wave crests. *e.* Station 9, in the head of The Gully Canyon, 256 m. Relatively low sand dollar population on an asymmetrically rippled sand bottom. Sand is moving parallel with the major downslope trend of canyon. *f.* Station 33, on margin of Bank north of Sable Island, 50 m. Population of *E. parma* on a mottled and burrowed sand bottom, suggesting tranquil bottom conditions. Note articulated pelecypod valves concave down and gastropod shell in upper center.

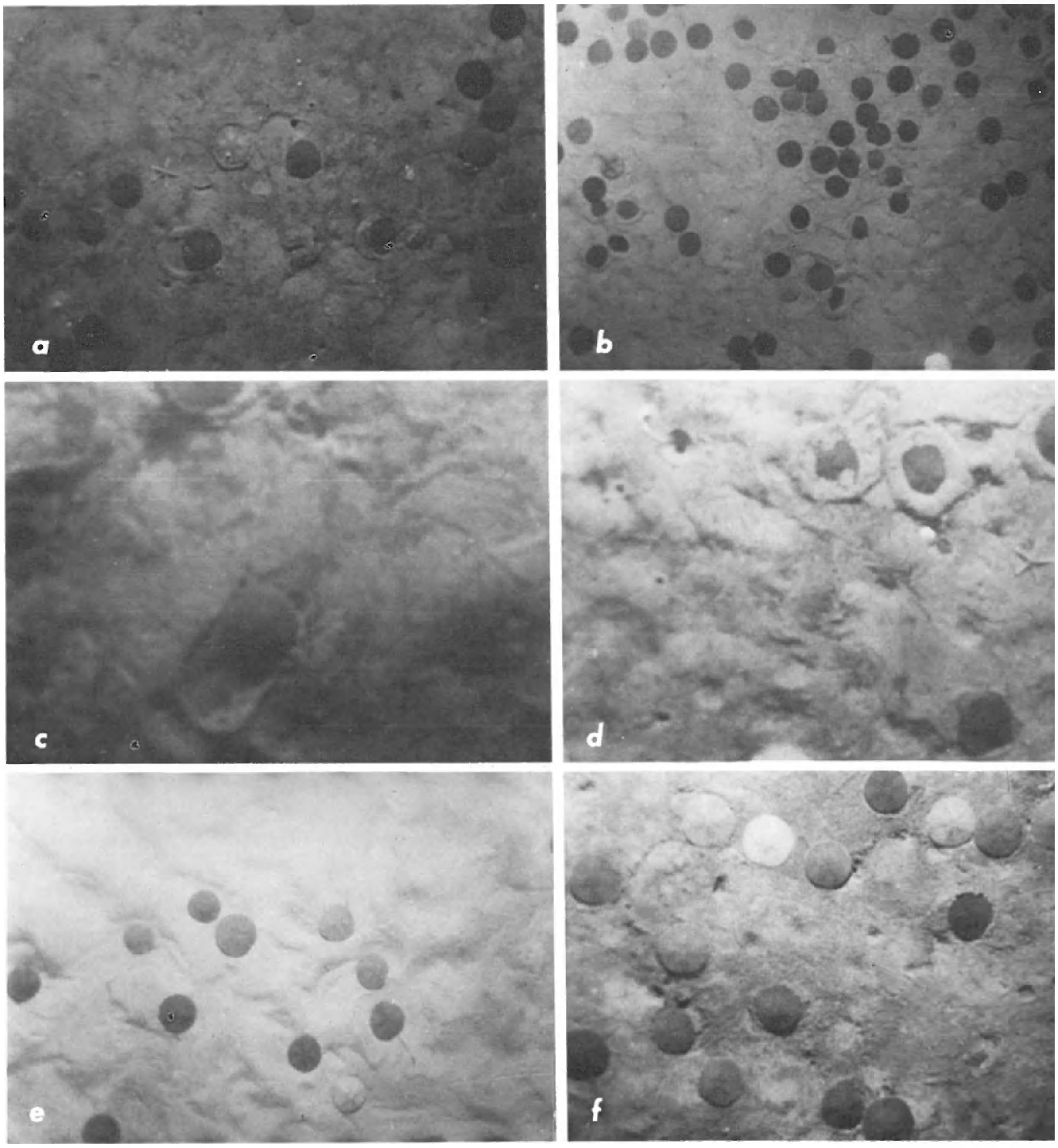

PLATE 4.—Bottom markings produced by *Echinarachnius parma* on the sandy surface of Sable Island Bank: *a*. Station 21, on margin of Bank north of the eastern sector of Sable Island, 50 m. Evidence of bioturbation produced by the northern sand dollars on a mottled sand surface. Evidence of markings produced by rotation and by progression and combinations of both are noted. Partially buried forms are visible. *b*. Station 56, on the Bank adjacent to the submerged western terminal bar of Sable Island, 22 m. Sand dollars completely modifying sand surface of Bank. A possible preferential orientation of individuals moving toward the lower part of photograph is suggested. *c*. Station 88, on Bank south of Sable Island, 54 m. Close view of shallow paralle made by moving *E. parma* on sand surface. *d*. Stati near margin of Bank north of western sector of Sable 44 m. Close view of partially buried individuals ind movement by rotation. Note starfish *Henricia sanguii* (O. F. Müller) in right of photograph, and also in *a*. *e*. 54, on Bank northwest of Sable Island, 37 m. Biotu by *E. parma* on rippled sand bottom. Note curved p track of individual in lower center part of photo *f*. Station 22, on Bank north of east terminal bar o Island, 52 m. Sand dollars on silty bottom covered b organic film. Evidence of burrowing also present.

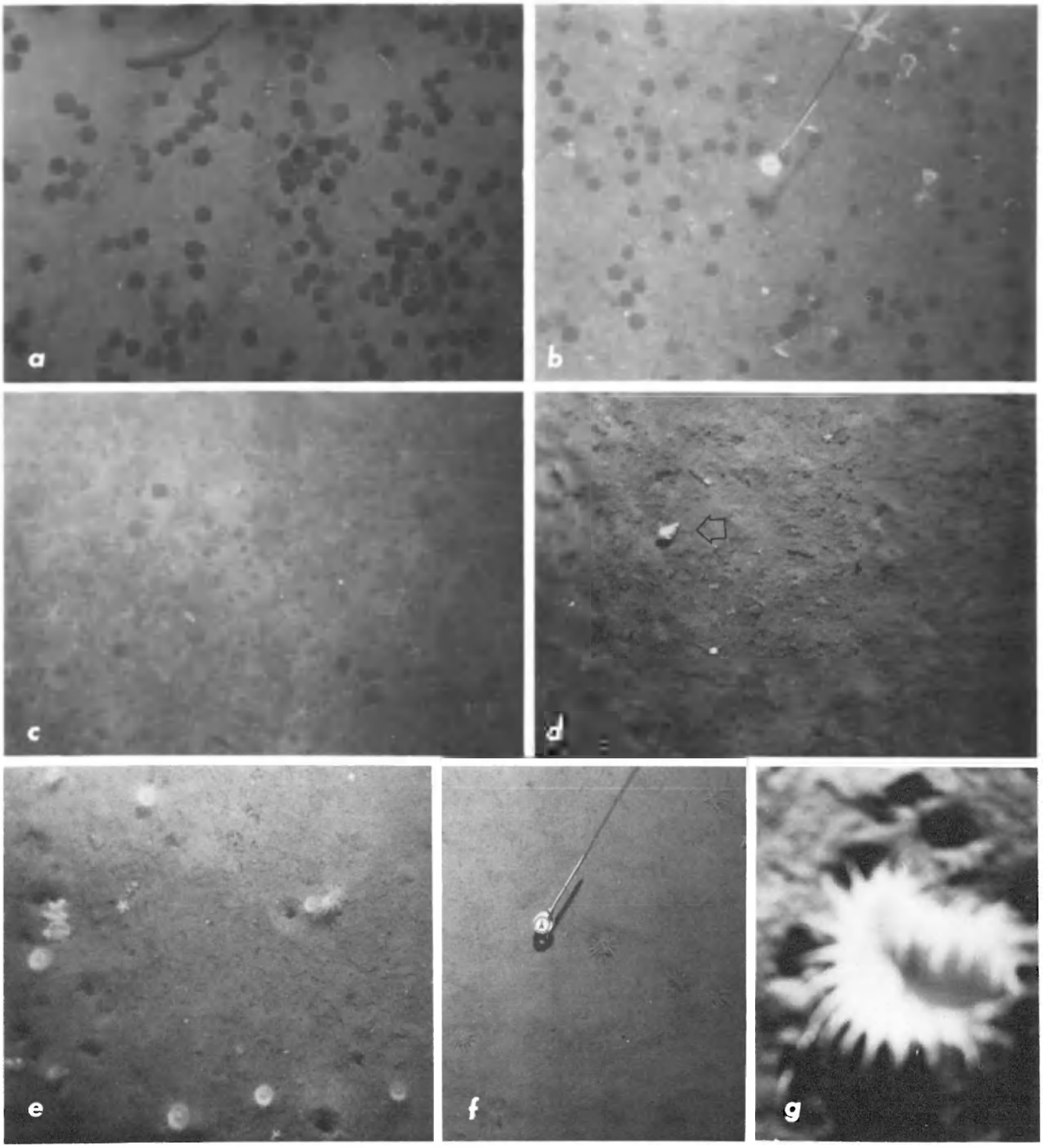

PLATE 5.—Association of organisms living on the surface of Sable Island Bank: *a*. Station 8, on northeast margin of the Bank, 52 m. Benthic fish resting on sand wave trough. Note clustering pattern of *E. parma*. *b*. Station 48, near margin of Bank north of western part of Sable Island, 44 m. Large starfish in upper part of photograph. Note abundant individual valves of pelecypods concave up and partially buried. *c*. Station 86, on margin of Bank south of Sable Island, 92 m. Abundant brittle star (probably *Ophiomusium lymani* Wyville Thomson) on mottled sand surface. Sand dollars give scale. *d*. Station 16, in Gully Trough north of Sable Island, 128 m. Gastropod (see arrow) on a bioturbate silty sand bottom. Granular texture is probably organic in origin. *e*. Station 51, in Gully Trough, 146 m. Large population of small anemones on gravely silty sand bottom. *f*. Station 78, on southern margin of Bank near head of Sable Island Canyon, 175 m. Large anemones on gently rippled sand. *g*. Station 13, in Gully Trough near the head of The Gully Canyon, 223 m. Close-up of small anemone on sandy silt bottom.

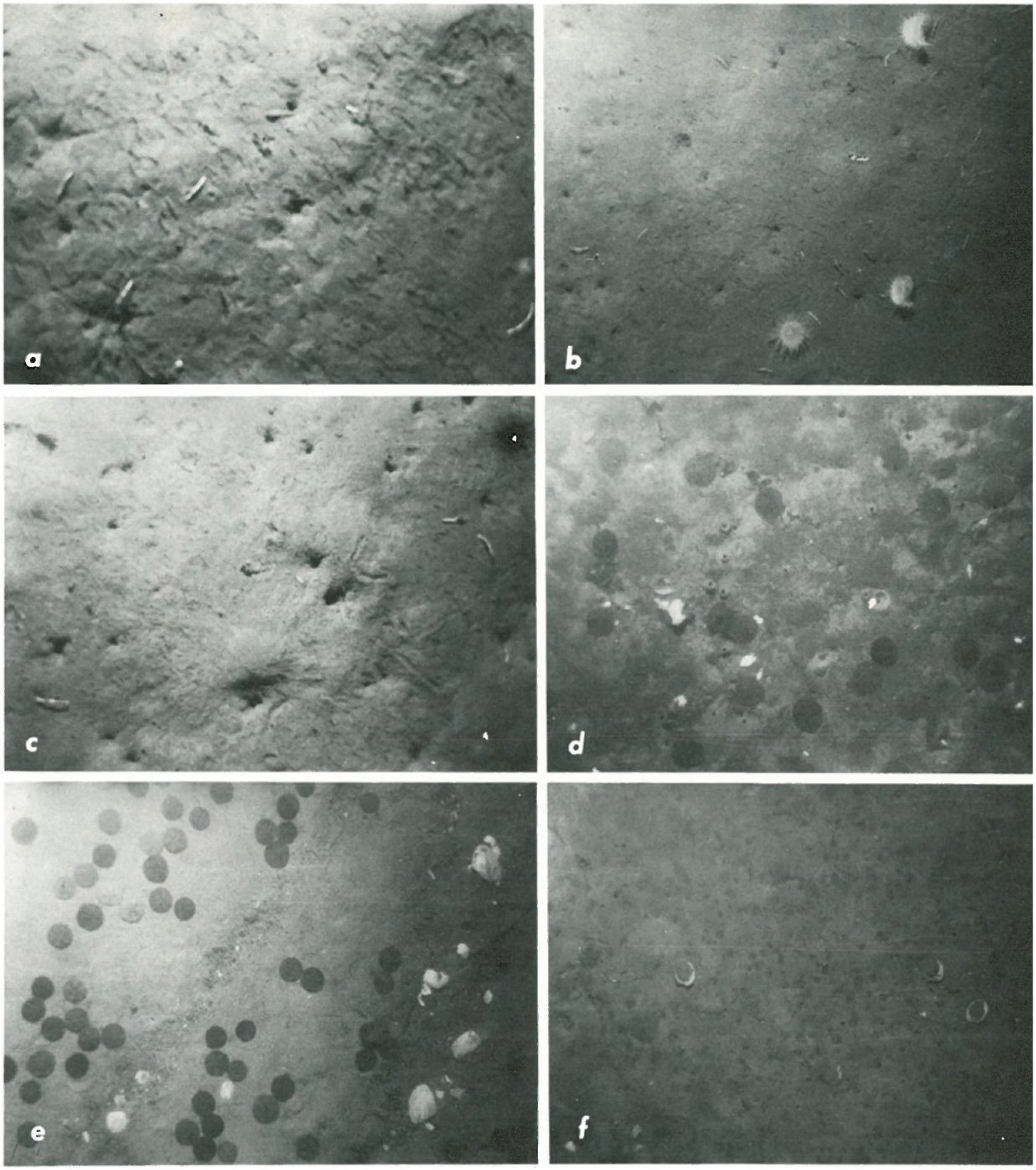

PLATE 6.—Association of organisms living within and on the sediment on Sable Island Bank: *a*. Station 13, in Gully Trough near the head of The Gully Canyon, 223 m. High concentration of worm tubes on a sandy silt bottom. *b*. Station 13, same as Figure 1. Large number of worm tubes and anemones on a burrowed sandy silt bottom. *c*. Station 13, same as Figures 1 and 2. Trails of benthic organisms, probably worms, on burrowed sandy silt bottom. *d*. Station 33, on margin of Bank north of Sable Island, 50 m. Small raised burrows on a mottled shelly sand bottom covered with *E. parma*. Reworking by wormlike organisms probably re in patchy dark and light-colored bottom. Sand dollar vide scale. The associated features suggest relatively tr condition on the sea floor. *e*. Station 8, on northeast n of the Bank, 52 m. Partially buried shell, for the mos individual valves concave down, concentrated in trou sand waves. *f*. Station 77, on southern margin of Ban m. Large individual valves concave up and partially b Mottled surface produced by burrowing organisms.

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