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CHAPTER 7

TRACE METAL CONCENTRATIONS IN SEDIMENT CORES FROM THE CONTINENTAL SHELF OFF THE SOUTHEASTERN UNITED STATES

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ABSTRACT

The concentrations of 12 metals in sediment cores collected from the Continental Shelf off the southeastern United States are generally uniform with sediment depth. Concentrations are low compared to average crustal abundances and small variations correlate with variations in texture, and in amount of calcium carbonate and organic carbon. No evidence of the accumulation of anthropogenic metals was found in these sediments. The data presented are the first compilation of trace metal concentrations in sediment cores of this area and provide a basis for determining the magnitude of future trace metal deposition in these sediments.

INTRODUCTION

The purpose of this study was to determine the magnitude of changes in trace metal concentrations with depth in sediment cores collected from the Continental Shelf off the southeastern United States. This information is necessary to determine whether or not anthropogenic contamination or natural processes have already contributed trace metals to the surface sediments in sufficient quantities to raise their concentrations above those measured in sediments at greater depth. The data provided in this study also establishes concentrations of trace metals in sediment cores from this area for the first time. Previous studies of trace metals in bottom sediments in this area include only a few analyses of surface samples (Hathaway 1971) although a broad survey of metals in surface samples concurrent with the present work has been completed (Windom and Betzer 1979). The data generated in this study may be used to determine the magnitude of trace metal contributions from future offshore resource development and from other activities that add trace metals to this broad area. Additional work on these sediment cores (Bothner et al in preparation) will add the results of neutron activation analyses and more complete statistical analyses of the data presented in this report.

METHODS

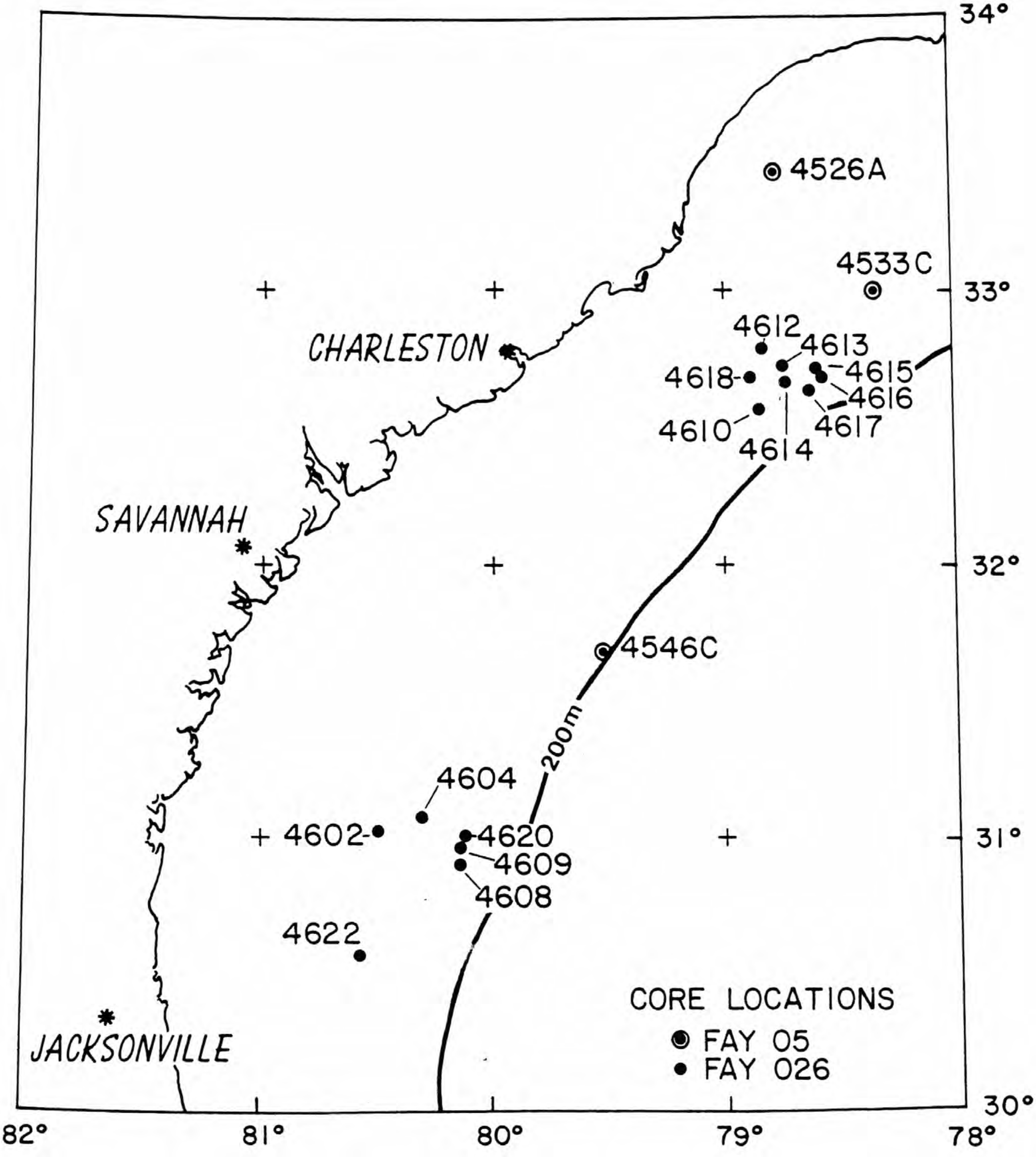
Sampling

We collected sediment cores for this study during October 1975 and 1976 aboard the R/V FAY using a vibracoring apparatus and a hydrostatically-damped gravity corer. Station locations are indicated on Figure 7-1. The vibracorer utilized a pneumatic hammer to drive the core barrel as much as 6 m into the sediment. This penetration was achieved at the expense of disturbing the surficial sediment in some cases. The hydrostatically-damped gravity corer was used to collect short cores (a maximum of 70 cm long) with minimal disturbance of material at the water-sediment interface. Collection of the undisturbed surficial sediment is important because recently added trace metals or other contaminants may be concentrated at the water-sediment interface.

Vibracore samples were collected in plastic core liners. Later, the cores were split, described, and subsampled for sediment texture and trace metals on the basis of textural changes. This work was carried out at Skidaway Institute of Oceanography under the general direction of Dr. O. H. Pilkey.

Hydrostatically-damped gravity cores were frozen in an upright

Figure 7-1. Locations of sediment cores on the Continental Shelf off the southeastern United States.


34°
33°
32°
31°
30°
82°
81°
80°
79°
78°
4526A
4533C
4612
4613
4615
4616
4617
4618
4614
4610
CHARLESTON
SAVANNAH
4546C
200m
4604
4602
4620
4609
4608
4622
JACKSONVILLE
CORE LOCATIONS
FAY 05
FAY 026

position immediately after collection. In the U.S.G.S. laboratory at Woods Hole, Massachusetts, the samples were extruded from the fiberglass core barrels, allowed to thaw, and subsampled at regular intervals for trace metal and texture analysis.

Textural Analyses

Texture analyses were performed on sediments after large shell fragments (>3 mm) had been removed. Conventional techniques used included sieving, settling tube (Schlee 1966) and pipetting. Because of the small size of the hydrostatically-damped gravity core samples in most cases, the settling tube could not be used to resolve the sand fraction, and results are limited to percent ages of gravel, sand, silt and clay.

Trace Metals

At least 5 samples from each of 10 vibracores and 10 hydrostatically-damped gravity cores were analyzed for trace metals. All samples were analyzed for the trace metals chromium, copper, and zinc with a partial-leach technique. Although not specified in the memorandum of understanding, samples from 6 cores (30 samples) were completely dissolved and analyzed for the total content of the same three elements as well as aluminum (Al), barium (Ba), cadmium (Cd), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), and vanadium (V).

The partial-leaching technique involves weighing out a 4 g sample into an acid-washed beaker containing 15 ml of 5 N HNO_3. The covered beakers were swirled for 2 hours at room temperature and the solution was then filtered through a nuclepore filter (0.4 mm pore diameter) held in an all-glass filter assembly. The solution was then diluted to 50 ml and transferred to polypropylene bottles which had been pre-leached with

5 normal HNO_3 at 60°C for 12 hours. The concentrations of Cr, Cu, and Zn were determined by flame atomic absorption spectrophotometry. All analyses were corrected for reagent blanks which were determined by analyzing pure leaching solutions carried through the same procedures as samples. Machine settings, conditions used, detection and sensitivity limits for this method are given in Table 7-1.

The concentration of metals was calculated from calibration curves obtained by the method-of-additions technique, and reported as parts per million (µg/g) dry weight. For Zn and Cu, the slopes of respective calibration curves were essentially the same for about 20 samples. Concentrations in the individual samples were based on these composite curves. Concentrations of Cr were determined from a separate calibration curve for each sample, because of the non-conformity in slopes of these lines. The background corrector was used during all the analyses. In an experiment with Cu without the background corrector, we found considerable interference amounting to about a 2-fold signal increase in some samples.

The 50 samples analyzed for all 12 metals were ground in an agate disk mill until small subsamples would pass a 0.149 mm (100 mesh) sieve. After grinding, these sediments were completely dissolved by heating approximately 0.5 g samples on a hot plate at 150°C for 16 h (overnight) with 5 ml concentrated $HClO_4$, 10 ml concentrated HNO_3, and 15 ml concentrated HF in covered teflon beakers. Then, the beakers were uncovered and solutions were evaporated to dryness. The salts were dissolved in HCl and diluted to 50 ml (final HCl concentration about 1 normal). The resulting solutions were analyzed for all 12 trace metals by atomic absorption or spectrophotometric methods. Instrumental methods and sensitivities are reported in Table 7-1.

Table 7-1a. Analytical conditions for the complete dissolution technique.

Element	Method	Sensitivity*	(ppm) Detection Limit**	Comments
Al	spectrophotometric	13,000	50	1) Alizarin S complex
Ba	Flame AA	0.4	50	1) N_2O Acetylene flame
Cd	Flameless AA	1.5	0.1	1) Separation by solvent extraction (Dithizone)
Cr	Flame AA Flameless AA	0.25 20.	30	1) N_2O Acetylene flame
Cu	Flame AA Flameless AA	0.09 30.	10 2	-- --
Fe	Flame AA	0.12	--	--
Mn	Flame AA	0.055	10	--
Mo	spectrophotometric	24,000	0.1	1) Separation by solvent extraction (Zinc dithiol)
Ni	Flameless AA	100	2	--
Pb	Flame AA Flameless AA	0.5 20.	30 2	-- --
V	Flameless AA	380	5	--
Zn	Flame AA	0.018	2	--

Table 7-1b. Analytical conditions for the partial leach technique.

Cr	Flame AA	0.1	0.66	air-acetylene
Cu	Flame AA	0.1	0.35	air-acetylene
Zn	Flame AA	0.2	0.29	air-acetylene

*For Flame AA (atomic absorption), the sensitivity units are ppm per 1% absorption. For Flameless AA (atomic absorption), picograms per 1% absorption. For Spectrophotometric methods, sensitivities are experimentally determined molar extinction coefficients (cm^2/mole). Deuterium background correction used with all abomic absorption work.

**Detection limits for total decomposition method are given in ppm in the original sediment sample.

Precision for the partial leach method was determined by analyzing 5 aliquots of the original samples and the U.S.G.S. standard rocks, G2 and MAG 1 (Table 7-2). The precision for the analysis of the finely ground rock standards (coefficient of variation for replicate determinations) is less than 7%. One exception is the copper value on sample MAG1 (5-31-77 #2), but this case is probably due to an error in recording original data. We noticed that the levels of Cr measured in 2 g samples are somewhat lower than in 1 g samples, which suggests that the percentage of Cr leached is a function of the amount of sediment used. This finding highlights the importance of standardizing the partial leaching procedure. Precision of replicate samples (Table 7-3) is within 12%. This higher variability is attributed to inhomogeneities in unground natural samples.

The accuracy of the partial-leach technique is difficult to evaluate because standard materials have not been analyzed by numerous independent laboratories with exactly the same procedure. However, 6 samples prepared by Texas Instruments were analyzed by the partial leach technique at the U.S.G.S. for an inter-laboratory comparison of results (Table 7-4). Excepting the problem samples indicated in Table 7-4, the difference between the two laboratories (U.S.G.S./Texas Instruments) averages 27% ±25%.

The analytical precision and accuracy for the complete-dissolution technique was determined during a similar study (Bothner 1976) on surface sediments from the mid-Atlantic continental shelf for all elements except Al, Mo, and Mn. The results of analyzing 5 aliquots from each of two samples are given in Table 7-5. Calculated coefficients of variation are generally less than 10% except for those elements present at concentrations near the detection limit of the

Table 7-3. Precision of replicate samples.

Sample	Weight of Sample	ppm		
		Cr	Cu	Zn
4602B 3cm #1	4g	4.9	.35	2.6
#2		4.6	.37	2.5
#3		4.9	.35	2.6
#4		6.1	.35	2.4
#5		5.0	.37	2.5
Mean		5.1		2.5
Stand. Dev.		.58		.10
Coeff. of Var. %		11.0		4.9

Sample	Weight of Sample	ppm	
		Cu	Cu
		Run #1	Run #2
4610 180cm #1	4g	1.4	1.7
#2		1.2	1.4
#3		1.3	1.4
#4		1.5	1.5
#5		1.1	1.6
Mean		1.3	1.5
Stand. Dev.		.16	.13
Coeff. of Var. %		12.	8.7

Sample	Weight of Sample	ppm	
		Cu	Cu
		Run #1	Run #2
4620 330cm #1	4g	2.4	2.3
#2		2.6	2.5
#3		1.9	2.2
#4		2.4	2.2
#5		2.3	2.4
Mean		2.3	2.3
Stand. Dev.		.26	.13
Coeff. of Var. %		11.	5.7

Table 7-4. Intercalibration of samples between U. S. Geological Survey and Texas Instruments (TI). Concentrations in parts per million (μg/g dry weight).

Sample	Cr (TI)	Cr (USGS)	Cu (TI)	Cu (USGS)	Zn (TI)	Zn (USGS)
1B	10.1	6.5;5.9;5.6	2.98*	.35;.50	5.6	5.1;5.1
2F	8.1	8.4;6.5;7.6	1.9 *	.62;.37	1.4	1.5;1.4
5D	4.4	2.7;2.9	.34	.35	1.3	1.6
5G	7.9	7.8;7.8	.50	.37	3.4	2.0
7A	4.8	5.4;5.7	2.1	1.8	4.2	7.4
7E	.06*	7.2;7.7;8.5	.8 *	3.5;3.1	.12*	7.6;8.8

*In case of 1B and 2F, high Cu values are attributed to possible contamination, and low values of all 3 metals for sample 7E are attributed to difficulties with this fine-grained sediment (T. Ferguson, Texas Instruments, oral communication).

Table 7-5. Precision of trace metal analysis by the complete dissolution technique.

Sample	ppm								
	Ba	Cd	Cr	Cu	Fe[1]	Ni	Pb	V	Zn
A-1 VIMS (Fall 1975)	250	0.35	7*	6	1.4	6	11	25	26
	250	0.45	19	4	1.4	7	10	25	27
	200	0.42	21	5	1.4	7	10	22	27
	250	0.25	21	4	1.4	7	10	26	28
	250	0.25	20	5	1.4	7	9	25	28
Mean	240	0.34	20.3	4.8	1.4	6.8	10	24.6	21.2
Stand. Dev.	22.4	0.09	1.0	0.8	0	0.4	0.7	1.5	0.8
Coeff. of Var. %	9.3	26.5	4.9	16.6	0	5.9	7	6.1	2.9
A-4 VIMS (Fall 1975)	250	<0.1	24	3	2.9	8	12	26	36
	250	<0.06	23	3	2.9	9	10	26	40
	250	<0.06	24	2	3.0	9	10	27	40
	280	<0.06	24	3	2.9	9	9	29	41
	250	<0.06	24	2	2.9	8	10	27	40
Mean	256	<0.1	23.8	2.6	2.9	8.6	10.2	27	39.4
Stand. Dev.	13.4		0.4	0.5	0.04	0.5	1.1	1.2	1.9
Coeff. of Var. %	5.2		1.7	19.2	1.4	5.8	10.8	4.4	4.8

[1]Multiply by 10^4

*This value not used in the calculation of statistics.

technique (Cd and Cu).

Accuracy was determined by the analysis of several U.S.G.S. standard rocks in the same analytical run with samples. Within two standard deviations of mean values reported in Table 7-6, our results agree with published recommended values (Flanagan 1973) for GSP-1, AGV-1, and G2, for all metals except nickel. The lower nickel values obtained for these rocks, however, and all elements listed for BCR-1 are within the range of values determined by other investigators (Flanagan 1969). The values reported by Manheim et al (1976) are within 2 standard deviations of the mean values reported in Table 7-6 for the marine mud standard (MAG-1).

RESULTS AND DISCUSSION

Texture

Sand is the predominant size class of the sediments collected with the hydrostatically-damped gravity corer, making up 99.9% of many of the samples (Table 7-7). Grain size shows no apparent trends within the length of these relatively undisturbed cores, even within the three cores for which more detailed analysis of the sand fraction is available. This suggests that extensive mixing and homogenization has taken place over at least the depth interval sampled. Pilkey et al (1977) found evidence for sediment mixing to a depth of 6 m in some locations; however, the time interval for this deep mixing is unknown. Studies are presently underway at the U.S.G.S., Woods Hole, Massachusetts, to estimate the rate of sediment mixing within the upper 30 cm using ^{210}Pb.

It is noteworthy that a layer of anomalously fine grained sediments or flocculent material at the water-sediment interface is not apparent

Table 7-6. Trace metal concentrations in standard rock materials by the complete dissolution technique.

Sample	ppm								
	Ba	Cd	Cr	Cu	Fe^{1}	Ni	Pb	V	Zn
BCR-1	850	<0.1	14	22	9.3	8	14	400	130
	680	<0.1	11	18	9.1	8	13	400	120
	690		10	13	9.7	7	13	380	130
	750	<0.1	9	16	9.8	7	13	330	125
Mean	742.5	<0.1	11	17.3	9.5	7.5	13.3	377.5	126.3
Stand. Dev.	78.0		2.2	3.8	0.33	0.6	0.5	33.0	4.8
Coeff. of Var. %	10.5		20	22.0	3.47	8.0	3.8	8.7	3.8
GSP-1	1600	<0.1	9	30	3.0	7	59	55	100
	1400	<0.1	14	36	3.0	7	50	55	98
	1480		12	32	3.3	7	51	50	100
	1400	<0.1	9	27	3.2	6	50	45	99
Mean	1470	<0.1	11	31.3	3.1	6.8	52.5	51.3	99.3
Stand. Dev.	94.5		2.4	3.8	0.15	0.5	4.4	4.8	1.0
Coeff. of Var. %	6.4		21.8	12.1	4.84	7.4	8.4	9.4	1.0
AGV-1	1500	<0.1	7	62	4.7	17	39	130	92
	1300	<0.1	11	66	4.7	13	36	120	86
	1300		10	59	4.9	13	34	120	86
	1500	<0.1	8	59	4.9	13	32	110	86
Mean	1400	<0.1	9	61.5	4.8	14	35.3	120	87.5
Stand. Dev.	115.5		1.8	3.3	0.12	2	3.0	8.2	3
Coeff. of Var. %	8.25		20	5.4	2.50	14.3	8.5	6.8	3.4
G-2	2400	<0.1	3	8	1.8	< 2	33	30	87
	2000	<0.1	7	11	1.9	< 2	31	37	84
	2080		8	8	1.8	2	30	37	83
	2100	<0.1	6	7	1.9	2	28	29	83
Mean	2145	<0.1	6	8.5	1.85		30.5	33.3	84.3
Stand. Dev.	175.4		2.2	1.7	0.06		2.1	4.3	1.9
Coeff. of Var. %	8.2		36.7	20	3.24		6.9	12.9	2.3

[1]Multiply by 10^4

Table 7-6. Trace metal concentrations in standard rock materials by the complete dissolution technique (continued).

Sample	ppm								
	Ba	Cd	Cr	Cu	Fe[1]	Ni	Pb	V	Zn
BHVO-1	150	<0.1	260	180	8.7	120	3	340	100
	150	<0.1	260	150	8.4	110	4	280	100
	140		290	150	9.0	120	4	320	100
	140	<0.1	260	150	9.0	110	4	280	100
Mean	145	<0.1	267.5	157.5	8.78	115		305	100
Stand. Dev.	5.8		15	15	0.29	5.8		30	0
Coeff. of Var. %	4		5.6	9.5	3.3	5		9.8	
MAG-1	620	0.15	94	40	4.9	57	35	150	130
	510	0.18	110	35	4.9	52		130	130
	550		130	30	4.9	59	28	120	130
	480	0.10	90	27	4.9	55	24	150	120
Mean	540	0.14	106	33	4.9	55.8	29	137.5	127.5
Stand. Dev.	60.6	0.04	18.2	5.7	0.0	3.0	5.6	15	5
Coeff. of Var. %	11.2	28.57	17.2	17.3	0.0	5.4	19.3	10.9	3.9

[1]Multiply by 10^4

Table 7-7. Grain size analysis of hydrostatically-damped gravity cores from the Southeast Georgia Embayment.

Core No.	Latitude	Longitude	Sediment Depth (cm)	% Gravel	% Sand	% Silt	% Clay	Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand
4526A	33°25.8'N	78°46.9'W	0.5	0.0	98.0	1.4	0.6					
			3	0.0	99.8	0.1	0.1					
			12	0.0	99.8	0.1	0.1					
			21	0.0	99.5	0.3	0.2					
			30	0.0	99.8	0.1	0.1					
			39	0.0	99.8	0.1	0.1					
4533C	32°59.6'N	78°21.8'W	1	0.0	99.9	0.05	0.1					
			7	0.0	99.9	0.05	0.05					
			14	0.0	99.9	0.05	0.1					
			17	0.0	99.9	0.05	0.1					
			23	0.0	99.9	0.05	0.1					
4604A	31°04.6'N	80°19.1'W	1	0.0	99.8	0.1	0.1					
			7	0.0	99.8	0.1	0.1					
			13	0.0	99.9	0.05	0.1					
			19	0.0	99.9	0.05	0.05					
			27	0.0	99.8	0.1	0.1					
4608A	30°54.5'N	80°08.3'W	1	0.0	99.9	0.05	0.1					
			10	0.0	99.9	0.05	0.05					
			20	0.0	99.8	0.1	0.1					
			30	0.0	99.8	0.1	0.1					
			40	0.0	99.7	0.2	0.1					
4612A	32°47.2'N	78°50.7'W	2	0.0	99.8	0.1	0.1					
			7	0.0	99.0	0.05	0.05					
			12	0.0	99.9	0.05	0.1					
			17	0.0	99.8	0.1	0.1					
			21	0.0	99.8	0.1	0.1					
4620A	31°00.5'N	80°07.9'W	1	0.0	99.9	0.05	0.1					
			6	0.0	99.9	0.05	0.05					
			12	0.0	99.9	0.05	0.05					
			18	0.0	99.8	0.1	0.1					
			20	0.9	99.9	0.05	0.1					

Table 7-7. Grain size analysis of hydrostatically-damped gravity cores from the Southeast Georgia Embayment (continued)

Core No.	Latitude	Longitude	Sediment Depth (cm)	% Gravel	% Sand	% Silt	% Clay	Very Coarse Sand	Coarse Sand	Med. Sand	Fine Sand	Very Fine Sand
4622A	30°34.7'N	80°34.5'W	1	0.0	99.9	0.05	0.1					
			5	0.0	99.9	0.05	0.05					
			11	0.0	99.8	0.1	0.1					
			20	0.0	99.8	0.1	0.1					
4546C	31°41.0'N	79°32.9'W	1	6.8	91.1	1.9	0.3	21.9	32.8	20.0	10.9	5.5
			3	12.5	87.1	0.2	0.2	26.1	34.8	17.4	5.2	3.5
			6	7.7	91.8	0.3	0.1	18.4	41.3	24.8	5.5	1.8
			9	13.1	86.4	0.3	0.1	17.3	27.6	24.2	12.1	5.2
			12	9.3	88.0	2.6	0.1	7.0	22.9	33.4	14.1	10.6
			15	8.4	91.1	0.4	0.1	21.9	32.8	18.2	12.8	5.5
			18	7.0	92.5	0.5	0.1	3.7	3.7	51.8	2.8	5.6
			24	13.6	86.2	0.1	0.1	13.8	24.9	26.7	13.8	6.9
4602B	31°18.0'N	80°17.0'W	2	0.0	99.9	0.0	0.0	0.0	22.0	51.9	24.0	2.0
			3	0.0	99.9	0.0	0.0	0.0	24.0	45.9	26.0	4.0
			5	0.0	99.9	0.0	0.0	4.0	45.9	38.0	11.0	1.0
			8	0.0	99.9	0.0	0.0	0.0	32.0	47.9	17.0	3.0
			10	0.0	99.9	0.0	0.0	0.0	18.0	53.9	24.0	4.0
			13	0.0	99.9	0.0	0.0	2.0	22.0	57.9	17.0	1.0
			16	0.0	99.8	0.2	0.0	0.0	42.9	36.9	17.0	3.0
			24	0.0	99.9	0.0	0.0	5.0	48.9	31.0	13.0	2.0
			32	0.0	99.9	0.0	0.0	3.0	38.9	38.0	16.0	4.0
4614B	32°40.4'N	78°43.8'W	1	0.0	99.9	0.0	0.0	2.0	49.9	38.0	7.0	3.0
			5	0.0	99.9	0.0	0.1	2.0	45.9	36.0	12.0	4.0
			6	0.0	99.9	0.0	0.1	4.0	43.9	40.0	10.0	2.0
			7	0.0	99.9	0.0	0.0	4.0	46.9	36.0	11.0	2.0
			10	0.0	99.9	0.0	0.1	4.0	42.9	40.0	12.0	1.0
			12	0.0	99.9	0.0	0.0	5.0	47.9	35.0	11.0	1.0
			13	0.0	99.9	0.0	0.0	1.0	44.9	38.0	15.0	1.0
			16	0.0	99.9	0.0	0.1	7.0	36.9	36.9	15.0	4.0
			18	0.0	99.9	0.0	0.0	2.0	45.9	42.0	9.0	1.0
			20	0.0	99.8	0.2	0.0	7.0	50.9	28.9	12.0	1.0
			24	0.0	99.9	0.0	0.0	5.0	54.9	28.0	10.0	2.0

in the texture analysis of the uppermost 1 cm layer of sediments, nor was it evident from direct observations of the interface immediately after sample collection. This layer, identified in estuaries and other nearshore areas (Rhodes 1973), has been cited as an important vehicle in the transport of trace metals and other contaminants. During the periods when hydrostatically-damped gravity cores were collected in this region this flocculent material was not present.

Trace Metals

The low concentrations of leachable Cr, Cu and Zn (Table 7-8) are characteristic of an area having uncontaminated, coarse-grained sediments. However, the concentrations are somewhat higher than observed in sediments from the Georges Bank area (Bothner et al 1978) probably because of the higher carbonate fraction in the sediments of the Southeast Georgia Embayment which completely dissolves in the partial-leach procedure. Similarly, the concentrations of the 12 metals analyzed by complete dissolution are also low (Table 7-9). Concentration ranges and median levels determined by both the partial-leach and complete-dissolution methods indicate the low concentrations compared to average crustal rocks (Table 7-10).

A comparison was made of the metal concentrations obtained by the partial-leach and complete-dissolution methods. The nitric acid leach removes about 67% ±26% (1 standard deviation) of the total Zn, and 69% ±20% of the total Cr, in 30 samples analyzed. Copper levels were below the detection limits in most cases but within 4 samples an average of 34% ± 13% of the total copper was leachable with the nitric acid technique.

The percentage of metal leachable by this technique from sediments in the Southeast Georgia Embayment is twice as high as that obtained

Table 7-8. Trace metals in sediment cores--partial leach technique.

Core No.	Latitude	Longitude	Sediment Depth (cm)	ppm Cr	ppm Cu	ppm Zn
4608*	30°54.5'N	80°08.3'W	30	6.8	.86	2.0
			60	7.8	.50	2.5
			90	7.3	.50	3.3
			150	6.7	.88	1.8
			180	6.8	< .35	1.8
			300	5.5	1.1	2.8
			360	2.3	.63	1.5
			390	3.4	.75	1.8
4609	30°57.7'N	80°08.4'W	0	7.5	.63	1.8
			30	8.1	.64	2.8
			60	9.2	.62	2.2
			90	7.0	.38	2.3
			120	7.4	.87	2.5
4610	31°34.4'N	78°51.4'W	0	8.8	.69	2.7
			90	9.1	.86	2.5
			150	8.3	.62	2.5
			180	7.2	1.1	3.7
			270	6.7	< .35	3.5
			330	6.1	.62	3.5
			390	5.6	.50	4.5
			480	7.2	.74	4.3
4612	32°47.2'N	78°50.7'W	30	11.3	.94	6.0
4613	32°43.8'N	78°45.0'W	30	8.7	.52	5.3
			90	9.7	.69	3.3
			150	9.8	2.5	4.3
			180	15.5	5.2	6.2
			210	15.7	4.9	6.2
4614	32°40.4'N	78°43.8'W	30	6.7	.75	1.1
			90	7.7	.39	1.4
			150	9.8	.63	1.8
			210	8.5	.50	1.8
			270	11.8	1.6	4.0
4615	32°43.0'N	78°36.5'W	30	5.8	< .35	1.0
			60	7.1	.88	1.1
			120	8.6	.87	2.0
			150	8.2	1.0	1.8
			210	10.5	1.2	1.7

*Core numbers without letter are vibracores.
Core numbers with letter are hydrostatically-damped gravity cores.

Table 7-8. Trace metals in sediment cores--partial leach technique (continued).

Core No.	Latitude	Longitude	Sediment Depth (cm)	ppm Cr	ppm Cu	ppm Zn
4546C	31°41.0'N	79°32.9'W	1	14.5	2.6	9.7
			6	17.3	2.5	9.2
			12	20.5	2.7	10.4
			18	20.1	2.5	9.2
			24	16.8	2.7	9.0
4602B	31°18.0'N	80°17.0'W	3	5.1	< .35	2.5
			5	4.4	.50	2.6
			8	5.3	< .35	2.9
			16	5.1	< .35	2.5
			24	4.6	.37	2.6
			32	5.6	.38	2.6
4604A	31°04.6'N	80°19.1'W	1	3.4	< .35	1.3
			7	4.0	.50	1.6
			13	3.8	.37	1.4
			19	4.1	< .35	1.6
			27	4.8	< .35	1.9
4608B	30°54.5'N	80°08.3'W	1	6.2	.37	1.4
			10	6.3	.37	1.0
			20	6.5	.38	1.5
			30	6.6	.38	1.6
			40	6.2	.88	2.3
4612A	32°47.2'N	78°50.7'W	2	7.7	1.3	3.9
			7	8.4	1.5	3.9
			12	7.8	.66	4.4
			16-17	10.3	.89	4.4
			20-21	9.5	.75	4.1
4614B	32°40.4'N	78°43.8'W	1	7.2	.37	1.2
			6	7.1	< .35	1.1
			12	5.7	.50	1.4
			18	7.2	.50	1.4
			24	7.8	< .35	1.5
4620A	31°00.5'N	80°07.9'W	1	8.5	.62	3.1
			6	7.7	< .35	2.6
			12	10.1	.37	3.0
			18	9.0	.37	2.0
			20	8.3	.75	3.0

*Core numbers without letter are vibracores.
Core numbers with letter are hydrostatically-damped gravity cores.

Table 7-8. Trace metals in sediment cores--partial leach technique (continued).

Core No.	Latitude	Longitude	Sediment Depth (cm)	ppm Cr	ppm Cu	ppm Zn
4622A	30°34.7'N	80°34.5'W	1	6.7	.74	3.0
			5.5	6.0	.62	2.7
			11	7.0	.62	3.0
			16	7.9	.62	3.0
			20	7.0	.86	3.2

*Core numbers without letter are vibracores.
Core numbers with letter are hydrostatically-damped gravity cores.

Table 7-9. Trace metal composition of completely dissolved sediment from the Southeast Georgia Embayment.

Core No.	Core Depth (cm)	Al_2O_3%	Fe_2O_3%	ppm									
				Ba	Cd	Cr	Cu	Mn	Mo	Ni	Pb	V	Zn
4546C	1	0.79	0.93	100	<0.06	21	<2	67	<1	<2	<4	11	8
	6	1.00	1.20	110	<0.06	23	2	65	<1	<2	<4	13	10
	12	1.30	1.40	70	<0.06	38	3	74	<1	<2	<4	14	13
	18	0.97	1.40	120	<0.06	29	<2	74	<1	<2	<4	13	12
	24	0.81	1.00	80	<0.06	25	2	62	<1	<2	<4	14	12
4602B	3	0.77	0.27	< 50	<0.06	5	<2	32	<1	<2	<4	< 5	10
	5	0.71	0.27	< 50	<0.06	5	<2	35	<1	<2	<4	< 5	4
	16	0.67	0.29	< 50	<0.06	6	<2	46	<1	<2	<4	< 5	5
	24	0.55	0.26	< 50	<0.06	5	<2	28	<1	<2	<4	< 5	9
	32	0.59	0.23	< 50	<0.06	5	<2	27	<1	<2	<4	< 5	5
	8	0.74	0.29	< 50	<0.06	11	<2	34	<1	<2	<4	< 5	4
4610	1	0.61	0.26	60	<0.06	11	<2	50	<1	<2	<4	< 5	6
	90	0.79	0.21	100	<0.06	10	<2	41	<1	<2	<4	< 5	4
	150	1.00	0.21	80	<0.06	9	<2	41	<1	<2	<4	< 5	4
	180	1.70	0.39	140	0.14	10	<2	59	<1	<2	<4	< 5	4
	270	1.40	0.31	80	<0.06	16	<2	43	<1	<2	<4	6	6
	330	0.68	0.33	50	<0.06	10	<2	54	<1	<2	<4	< 5	6
	390	0.74	0.34	60	<0.06	8	<2	84	<1	<2	<4	< 5	4
	480	0.77	0.41	70	<0.06	9	<2	84	<1	<2	<4	7	5

Table 7-9. Trace metal composition of completely dissolved sediment from the Southeast Georgia Embayment (continued).

Core No.	Core Depth (cm)	Fe_2O_3%	Al_2O_3%	ppm									
				Ba	Cd	Cr	Cu	Mn	Mo	Ni	Pb	V	Zn
4616	30	0.39	0.36	100	<0.06	18	<2	50	<1	<2	<4	9	4
	60	1.30	0.47	100	<0.06	19	<2	49	3	<2	<4	7	6
	120	0.52	0.34	60	<0.06	23	2	29	<1	<2	<4	7	4
	120	0.52	0.34	60	<0.06	23	2	29	<1	<2	<4	7	4
	150	0.60	0.31	90	<0.06	15	<2	24	<1	<2	<4	9	4
	210	0.61	0.30	100	<0.06	21	<2	29	<1	<2	<4	5	4
	270	0.73	0.18	100	<0.06	11	<2	21	<1	<2	<4	<5	3
4614B	1	0.89	0.15	80	<0.06	11	<2	16	<1	<2	<4	<5	4
	6	0.82	0.15	90	<0.06	12	<2	20	<1	<2	<4	<5	3
	12	0.97	0.23	80	<0.06	10	<2	45	<1	<2	<4	<5	4
	18	0.99	0.21	70	<0.06	16	<2	47	<1	<2	<4	<5	4
	24	1.00	0.17	100	1.00	18	<2	33	<2	<2	<4	<5	4

Table 7-10. Summary of all trace metal concentrations determined in this study.

a. Partial leach technique

	Cr	Cu	Zn
No. of analyses	115	115	115
Range	1.2-20.5 ppm	<0.35-5.2 ppm	1.0-10.4 ppm
Median	7.5 ppm	0.69 ppm	2.7 ppm

b. Complete dissolution technique

	Al_2O_3	Ba	Cd	Cr	Cu	Fe_2O_3
No. of analyses	30	30	30	30	30	30
Range	0.39-1.7%	<50-140ppm	<0.06ppm	5-38ppm	< 2-2ppm	0.15-1.4%
Median	.78%	80ppm	<0.06ppm	11ppm	2ppm	.295%

	Mn	Mo	Ni	Pb	V	Zn
No. of analyses	30	30	30	30	30	30
Range	16-84ppm	< 1-3ppm	< 2ppm	< 4ppm	< 5-14ppm	3-13ppm
Median	46.5ppm	1ppm	< 2ppm	< 4ppm	< 5ppm	4ppm

c. Average abundance of element in the earth's crust (Krauskopf 1967)

Al_2O_3	Ba	Cd	Cr	Cu	Fe_2O_3
25%	425ppm	0.2ppm	100ppm	55ppm	8%

Mn	Mo	Ni	Pb	V	Zn
950ppm	1.5ppm	75ppm	13ppm	135ppm	70ppm

with the same technique from sediments from Georges Bank (Bothner et al 1978). However, the concentrations of trace metals determined on completely dissolved samples are very similar. The difference in leachable metals is probably best explained by a difference in mineralogy; a large soluble $CaCO_3$ fraction exists in samples off Georgia while a large insoluble quartz and feldspar fraction is present in samples from Georges Bank.

Variations in trace metal concentrations as sediment depth increased were examined for evidence of anthropogenic increases or natural processes. Hydrostatically-damped gravity cores undoubtedly give the most accurate trends in nearsurface sediments because these samples are collected with minimal disturbance. Of the 10 hydrostatically-damped gravity cores analyzed, only 2 showed higher concentrations of Zn and Cu, and none showed higher concentrations of Cr in the surface 1 cm than at greater depth in the core. The magnitude of increase was less than a factor of 2. Similarly, in the vibracores, the samples nearest the surface (usually at about 30 cm depth) showed higher concentration than deeper samples in only 2 out of 10 cores. In the remaining cores, the concentrations nearest the surface were similar to or lower than values measured at greater depth in the cores.

The 6 cores analyzed for 12 metals by the complete-dissolution technique also showed no enrichments of these metals in the surface sediments compared to sediments at greater depth.

The uniformity in the concentration of trace metals with depth in these sediments and the low concentration levels (Table 7-10) show that anthropogenic trace metals have not been added to these sediments in sufficient quantity to raise concentration levels above background.

A matrix of linear correlation coefficients was calculated which included all the trace metals having concentrations above the limit of detection and various parameters of sediment texture (Table 7-11). Fe, Mn, Cr, Zn, V, analyzed after complete dissolution, and fine-grained sediment (% finer than fine sand), are all correlated with coefficients >0.6 at a significance level >.02. Intercorrelations of Cu, Cr, and Zn, analyzed by the partial leach technique, and the fine-grained sediment fraction is 0.7. The absence of a strong correlation with the silt and clay fraction is undoubtedly related to the near zero concentrations of this size material.

Although strong correlations alone do not confirm a dependence of one trace metal concentration on the concentration of another, this data suggests that the metals Cr, Zn, and V are associated with Fe and Mn oxides/hydroxides. Confirmations of this relationship require selective leaching and analysis of the Fe and Mn phases in these sediments, work which will be included in future analytical work on these samples.

CONCLUSIONS

The leachable concentrations of Cr, Cu, and Zn, and the total concentrations of Al, Ba, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, V, and Zn in these sediments are low compared to average crustal abundances and are characteristic of an area having uncontaminated coarse-grained sediments (see Table 7-10). No evidence of the accumulation of metals from present-day sources was found in these sediments. In cores collected with a special technique which preserves the sediment at the water-sediment interface, there is no apparent difference between the metal concentrations at the surface and at deeper levels in the core.

Sediment texture also appears to be uniform with depth in the hydrostatically-damped cores, possibly because of considerable mixing by

Table 7-11a. Pearson correlation coefficients for trace metals analyzed after total decomposition.

	Aluminum	Barium	Chromium	Iron	Manganese	Vanadium	Zinc	Less than Fine Sand	Mud	Silt	Clay
Aluminum	1.0000	0.43 25(.02)	0.22 31(.12)	0.28 31(.07)*	0.32 31(.04)	0.18 12(.289)	0.22 31(.115)	0.44 16(.04)	0.27 19(.127)	0.52 16(.019)	0.21 16(.20)
Barium		1.0000	0.09 25(.30)	0.24 25(.128)	0.01 25(.50)	0.29 12(.20)	0.12 25(.280)	-0.12 10(.40)	-0.09 13(.40)	-0.09 10(.40)	0.36 10(.20)
Chromium			1.0000	0.76 31(.001)	0.33 31(.04)	0.77 12(.022)	0.49 31(.003)	0.74 16(.001)	0.42 19(.037)	0.70 16(.001)	0.58 16(.01)
Iron				1.0000	0.65 31(.001)	0.91 12(.001)	0.82 31(.001)	0.74 16(.001)	0.34 19(.08)	0.68 16(.002)	0.64 16(.004)
Manganese					1.0000	0.61 12(.017)	0.49 31(.002)	0.64 16(.004)	0.43 19(.032)	0.66 16(.003)	0.61 16(.006)
Vanadium						1.0000	0.85 12(.001)	0.26 5(.30)	-0.73 8(.02)	-0.20 5(.40)	-0.91 5(.02)
Zinc							1.0000	0.72 16(.001)	0.15 19(.30)	0.53 16(.02)	0.43 16(.05)
Less than Fine Sand								1.0000	0.86 16(.001)	0.86 16(.001)	0.57 16(.01)
Mud									1.0000	0.98 51(.001)	0.53 51(.001)
Silt										1.0000	0.51 51(.001)
Clay											1.0000

*Number of data pairs (level of significance).

Table 7-11b. Pearson correlation coefficients for trace metals analyzed after partial leach technique

	Partial Leach Chromium	Partial Leach Copper	Partial Leach Zinc	Less than Fine Sand	Mud	Silt	Clay
Partial Leach Chromium	1.0000	0.87 50(.001)	0.81 65(.001)	0.74 16(.001)	0.27 54(.03)	0.45 51(.001)	-0.01 51(.50)
Partial Leach Copper		1.0000	0.90 51(.001)	0.74 11(.005)	0.36 41(.01)	0.60 38(.001)	0.21 32(.10)
Partial Leach Zinc			1.0000	0.77 16(.001)	0.34 54(.005)	0.66 51(.001)	0.24 51(.04)
Less than Fine Sand				1.0000	0.86 16(.001)*	0.86 16(.001)	0.57 16(.01)
Mud					1.0000	0.98 51(.001)	0.53 51(.001)
Silt						1.0000	0.51 51(.001)
Clay							1.0000

*Number of data pairs (level of significance)

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CHAPTER 8

DISTRIBUTION AND OCCURRENCE OF REEFS AND HARDGROUNDS IN THE GEORGIA BIGHT

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Chapter 8

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CHAPTER 8

DISTRIBUTION AND OCCURRENCE OF REEFS AND HARDGROUNDS IN THE GEORGIA BIGHT

Vernon J. Henry and Robert T. Giles

ABSTRACT

During cruises in June, July and October 1976 3.5 kHz seismic records were obtained and used to map the distribution and determine the nature of reefs and hardgrounds in the Georgia Bight. Ground truth was provided by vibracore logs from a cruise made in November, 1975.

Three general morphotypes of reefs and hardgrounds are identified. These include: low-relief hardgrounds (<0.5 m relief) which support a sparse faunal community and are difficult to identify; moderate-relief hardgrounds (2 m or more relief) which have a large faunal community; and shelf-edge reefs, discontinuous, yet well-defined, high-relief ridges at the shelf break which also support a large faunal community. Distribution of the hardgrounds is unpredictable and patchy influenced by such factors as thickness of Quaternary sediment cover and distribution of Pleistocene river channels.

A detailed study is made of records obtained in Bureau of Land Management (BLM) Lease Areas A and D.

INTRODUCTION

The primary purpose of this chapter is to discuss the occurrence of reefs and hardgrounds in the Georgia Bight as interpreted principally from side-scan sonar and 3.5 kHz seismic profile records obtained during the U.S. Geological Survey's R/V FAY 026 cruise made in October, 1976, and from 3.5 kHz records from R/V FAY 017 and 018 cruises carried out during June and July, 1976. Important ground-truth information was obtained from vibracore logs from the FAY 026 cruise and from the FAY 005 cruise made in November, 1975. The location of the track lines of these cruises, as well as citations of other data sources used in this report, are given on Map 8-A (in pocket at rear of volume).

Where record quality and vibracore data permitted, the occurrence of reefs and hard bottoms relative to macro-topography, sediment texture and shallow-buried or outcropping rock and/or acoustically hard layers is specifically addressed.

PRELIMINARY CLASSIFICATION OF REEFS AND HARDGROUNDS

Based on the interpretation of sonograms and seismic records available to this study, together with published and unpublished information obtained from visual observations with still and motion picture photography and closed circuit television, the reefs and hardgrounds of the Georgia Bight appear to occur as three general morphotypes.

Low-Relief Hardgrounds

These hardgrounds occur as relatively smooth, flat-lying rock outcrops with less than 0.5 m relief that support sparse to moderately abundant benthic communities. Because of their low relief, the hardgrounds appear subject to cyclic covering and uncovering by a veneer of sand several centimeters or more in thickness. Such features and conditions have been visually observed in depths of 15-20 m off Charleston, South Carolina by Barans (personal communication) and in similar water depths in the vicinity of Grays Reef (see Map 8-A), approximately 30 km east of Sapelo Island, Georgia (Hunt 1974). In both localities, marginal sand-covered areas show evidence of a shallow, hard substrate by the presence of a sparse growth of attaching organisms--principally sponges, alcyonarians, and ascidians, that extend through the flat, sandy bottom.

Low-relief hardgrounds are generally undetected on fathometer records, although the presence of fish signatures is indicative of such features. Also, comparison of 3.5 kHz records with sonograms indicates that hard bottoms with sparse growth and covered by only a thin layer of sand are difficult to identify by side-scan sonar survey. Inferred examples of low-relief hardgrounds are represented on sonograms and 3.5 kHz profiles shown in Figures 8-1 and 8-2. In Map 8-A they are indicated under the term "probable hard bottom."

Moderate-Relief Reefs

Exhibiting relief of 2 m or more, these features support a moderately abundant to abundant benthic and pelagic community. Reefs in this category are commonly referred to as patch reefs, live bottoms, hard bottoms, coral patches, fishing banks, snapper banks, black rocks, and limestone reefs. Such features have been visually observed at mid-shelf depths off Charleston by Barans (personal communication) and at Grays Reef. Hunt (1974) described Grays Reef as an interfingering series of ridges and troughs subtended by a dolomitic, sandy biomicrite. He reported the most abundant large fauna as consisting of numerous species of sponges, alcyonarians and ascidians as well as abundant reef fishes. Rock samples from the South Carolina shelf locality appear very similar to the Grays Reef substrate. On Map 8-A these features are indicated by the term "reef-hard bottom."

Although often difficult to identify on fathometer records by bottom roughness alone, these features are more easily discerned on sonograms, particularly when used in conjunction with 3.5 kHz profiles, as shown in Figures 8-3 through 8-5.

Figure 8-1. Line 9, about 75 km east of Georgetown, South Carolina. 3.5 kHz profile oriented approximately northwest-southeast, left to right, covers a distance of about 2.5 km. The acoustically hard layer is covered by little or no sediment except near (A) where a sediment cover of almost 1.5 m exists. Location of figure is shown on Map 8-A.

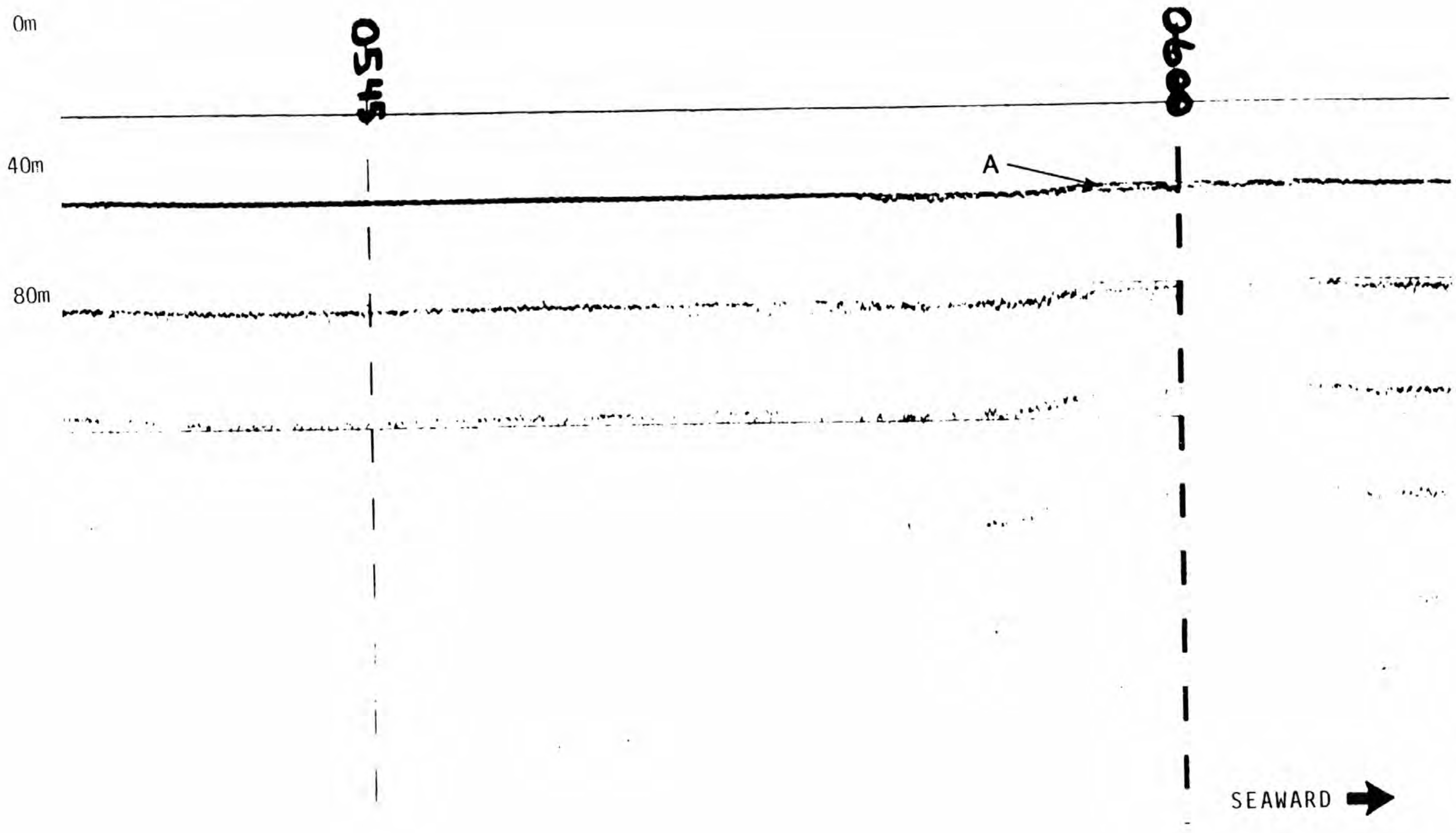


Figure 8-1

Figure 8-2. Area A, Line 1, about 105 km east of Charleston, South Carolina. Sonogram covers a horizontal distance of 1.8 km and lateral distance of 300 m. Outcrop of hard bottom (A) bounded on west by an acoustically finer sediment (B) than on the east (C). Hard bottom is buried under a progressively thicker sediment cover to the east. Location of figure is shown on Map 8-A.

Figure 8-2

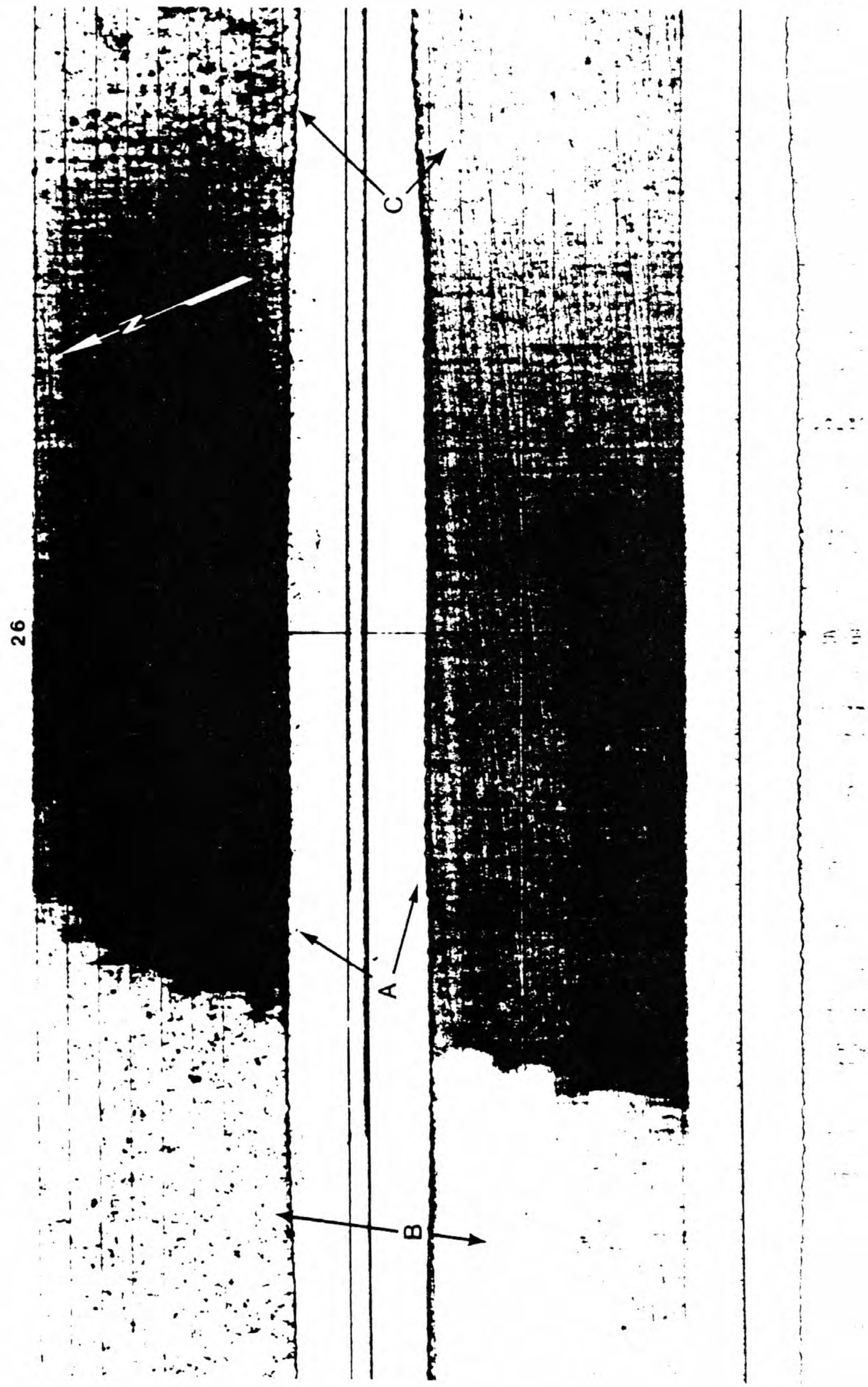


Figure 8-3. Area A, Line 3, about 105 km east of Charleston, South Carolina. Sonogram covers a horizontal distance of 0.9 km and a lateral distance of 150 m. Moderate-relief reef is located in a topographically low area. The area contains a wide range of acoustical sediment sizes. Location of figure is shown on Map 8-A.

Figure 8-3

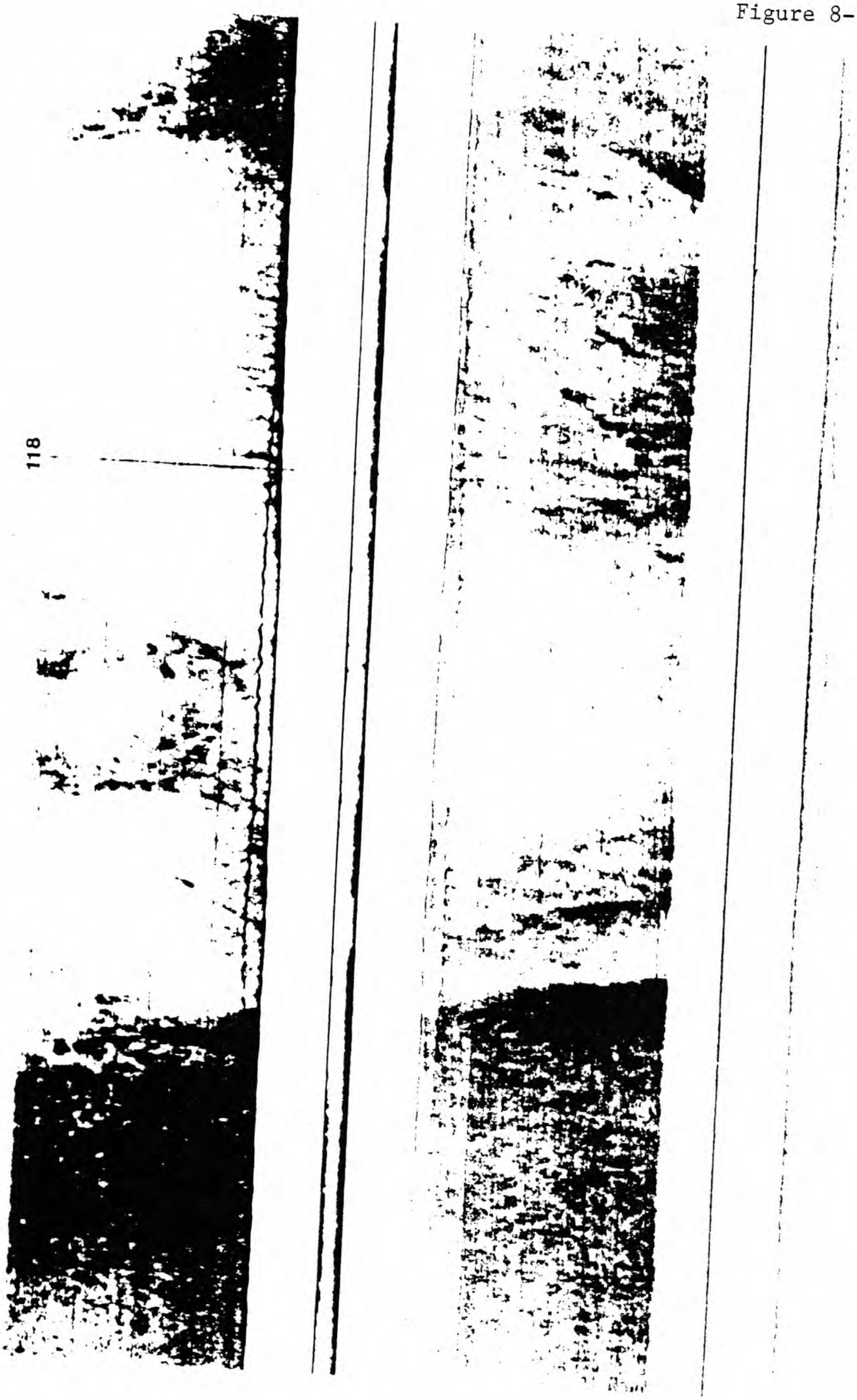
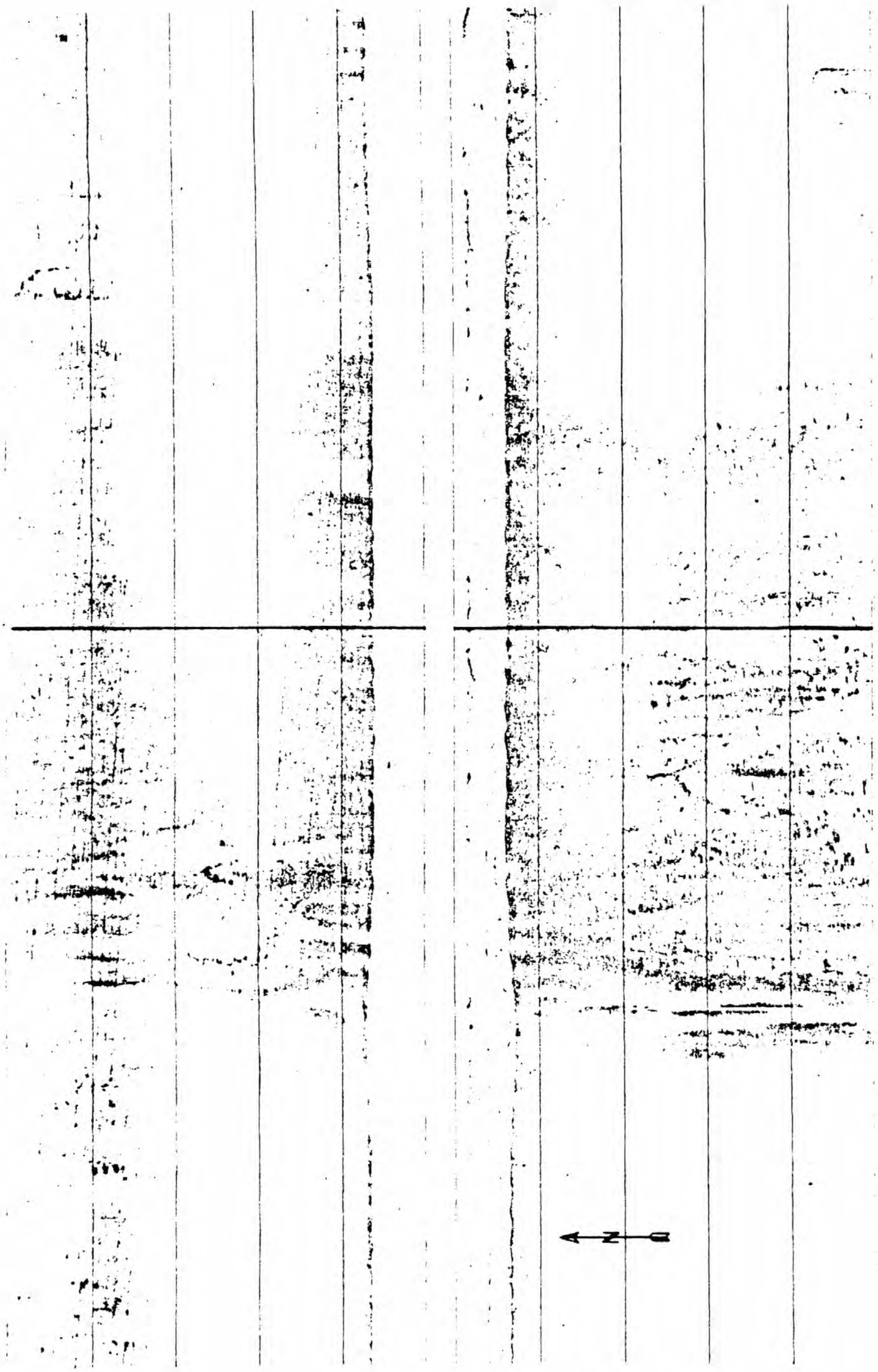


Figure 8-4. Area A, Line 15, about 125 km east of Charleston, South Carolina. 3.5 kHz profile oriented approximately northwest-southeast, right to left, covers a distance of about 2.5 km. The acoustically hard layer (A) crops out (B) and from this point northwestward a moderate-relief reef has developed. Location of figure is shown on Map 8-A.

Figure 8-5. Sonogram of Grays Reef nearly 30 km east of Sapelo Island, Georgia. Transect extends 1 km horizontally and 250 m laterally. This is a moderate-relief reef supporting a varied biological assemblage. Ground truth was obtained by 8nderwater closed circuit television and by diver-held still cameras (Hunt 1974). Location of figure is shown on Map 8-A.

Figure 8-5



Shelf Edge Reefs

These features occur as a discontinuous but generally well-defined, usually high-relief, ridge or ridges from Cape Hatteras to Fort Lauderdale, Florida (Macintyre and Milliman 1970). They are located at or very near the initial break in slope at the edge of the continental shelf in water depths ranging from 20 to 110 m. Off Georgia the ridge has been observed with television at 50 to 70 m depths (Henry and Hoyt 1968). At this locality the reef supports a moderately abundant to abundant benthic and pelagic (Miller, personal communication) community similar to that of Grays Reef. Reef substrate dredged from a location due east of Sapelo Island consisted of a well-lithified oolitic (beachrock?) conglomerate.

The presence of this ridge as defined by R/V FAY cruise and U.S.G.S. Conservation Division (1977) data is shown on Map 8-A. Generally, this type of reef can be clearly seen on fathometer records as well as on 3.5 kHz records and sonograms as shown in Figures 8-6 through 8-10.

GEOLOGICAL IMPLICATIONS

Reefs and hardground occur on the continental shelf of the Georgia Bight from near shore to the shelf edge. However, except for the shelf edge reefs, their distribution is best described as patchy and is presently unpredictable. The occurrence of low- and moderate-relief features appears to be primarily related to one or more near-surface, acoustically hard layers which crop out in low areas that have resulted either from erosion or non-deposition. Outcrops of this hard layer are less common nearer shore probably because of a greater thickness of Quaternary sediments and from partial removal of the hard layer by

Figure 8-6. Line 20, near the shelf break about 135 km east of Tybee Island, Georgia. 3.5 kHz profile oriented approximately northwest-southeast, left to right, covers a horizontal distance of about 2.5 km. A shelf edge reef (A) has developed on, or in association with, an acoustically hard layer. A moderate-relief reef (B) is on an outcrop seaward of the scrap. Location of figure is shown on Map 8-A.

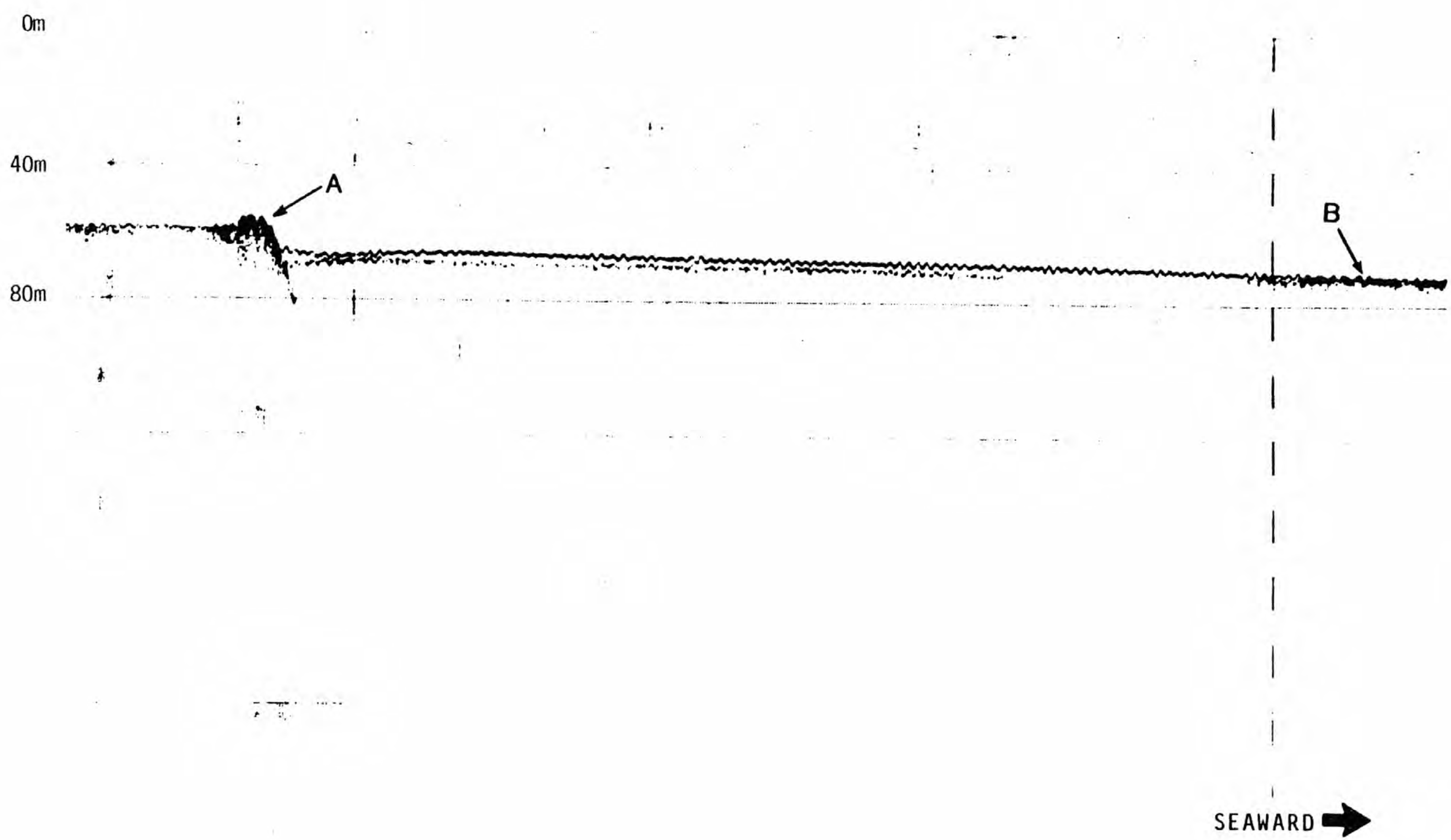


Figure 8-6

Figure 8-7. Line 28, about 125 km east of Jacksonville, Florida. 3.5 kHz profile oriented nearly east-west, left to right, covers a horizontal distance of about 2.5 km. Shelf edge reefs (A) associated with an acoustically hard layer. Location of figure is shown on Map 8-A.

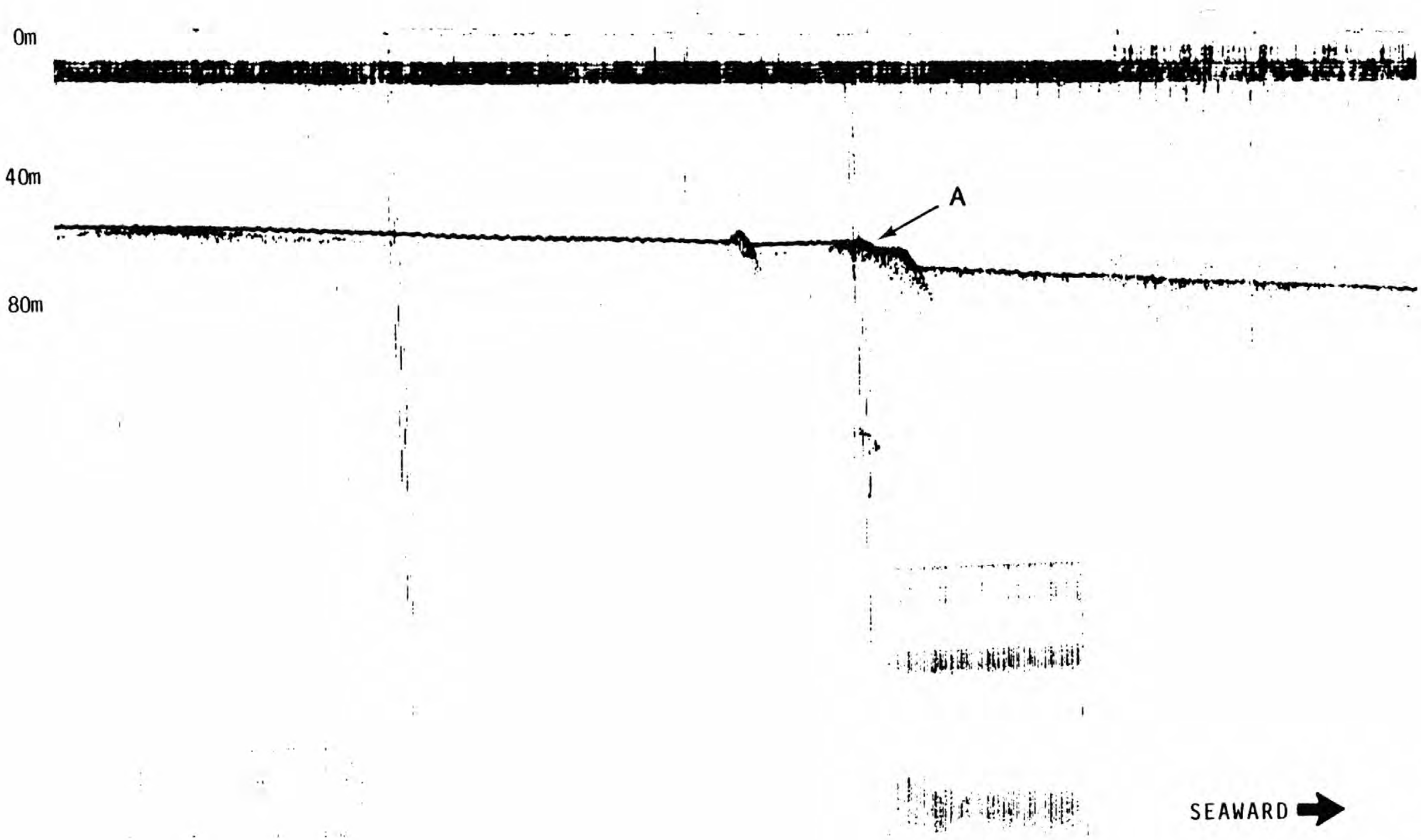


Figure 8-7

Figure 8-8

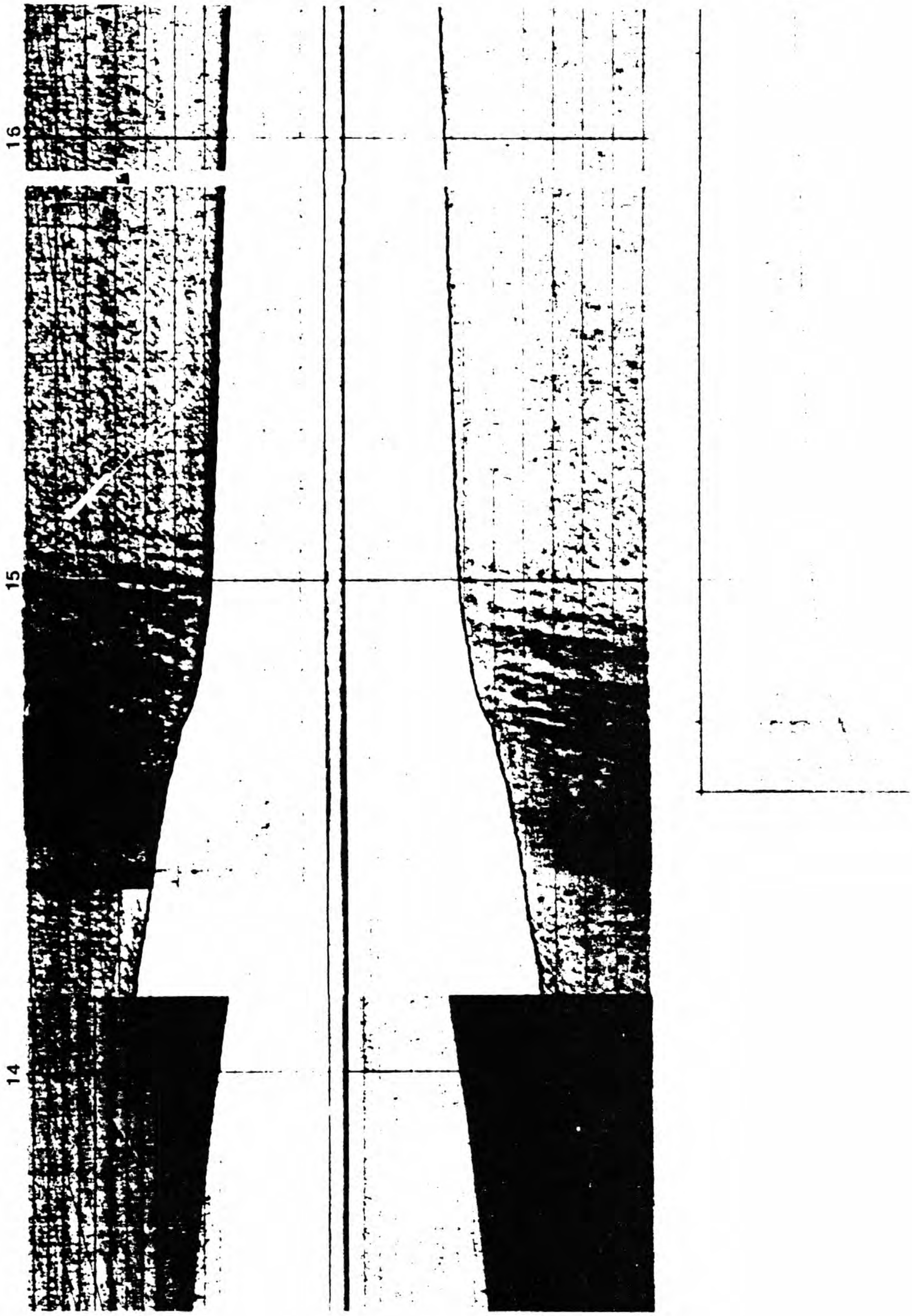


Figure 8-9. Air gun record of shelf edge reef (A) northeast of Line 20, about 140 km east of Tybee Island, Georgia. Transect approximately northwest-southeast, right to left, covers a horizontal distance of about 1.8 km. This reef is a northeastward extension of the reef shown in Figure 8-6. Location of figure is shown on Map 8-A.

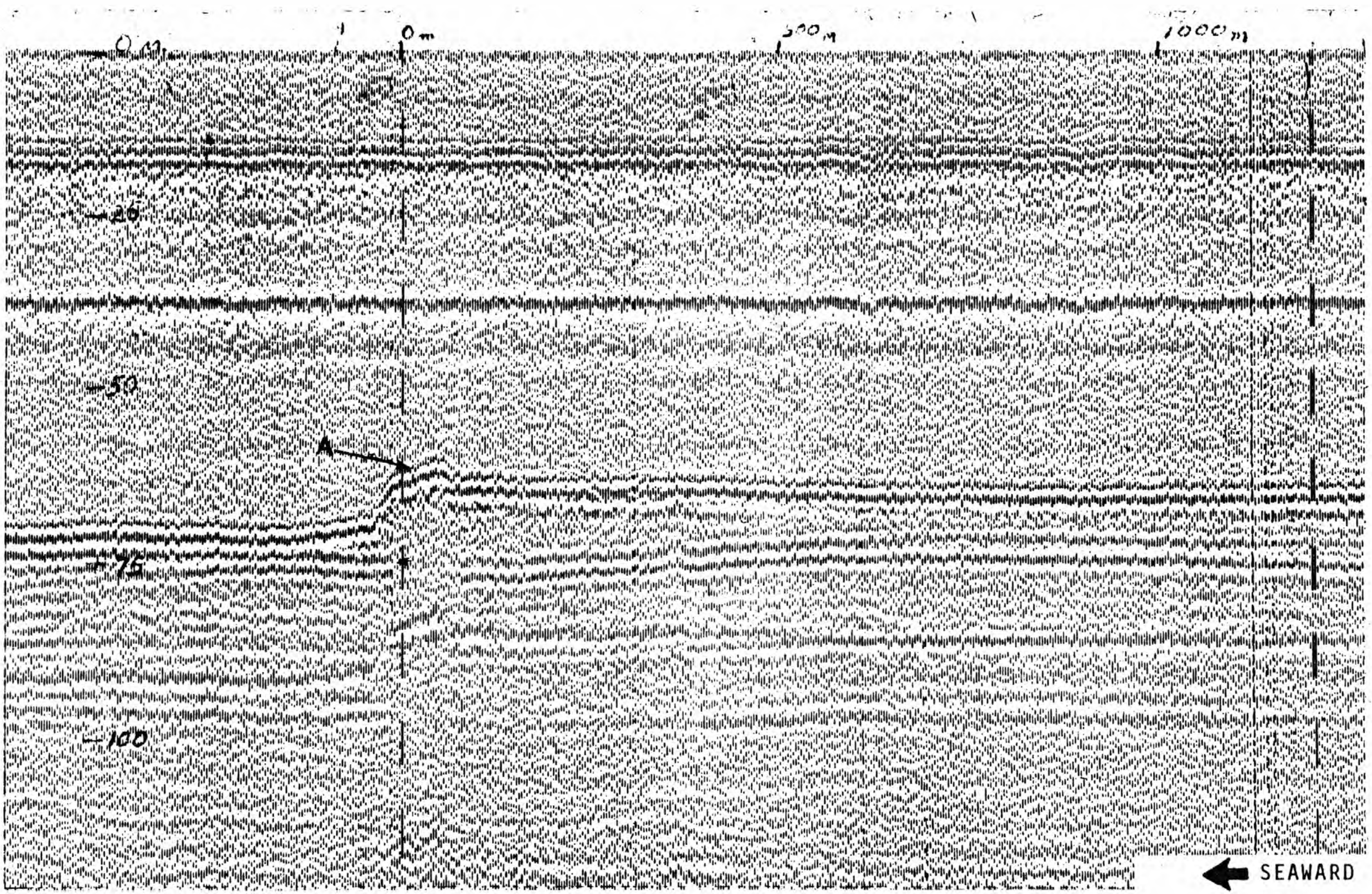


Figure 8-9

Figure 8-10. 3.5 kHz record of the reef shown in Figure 8-9. Location of figure is shown on Map 8-A.

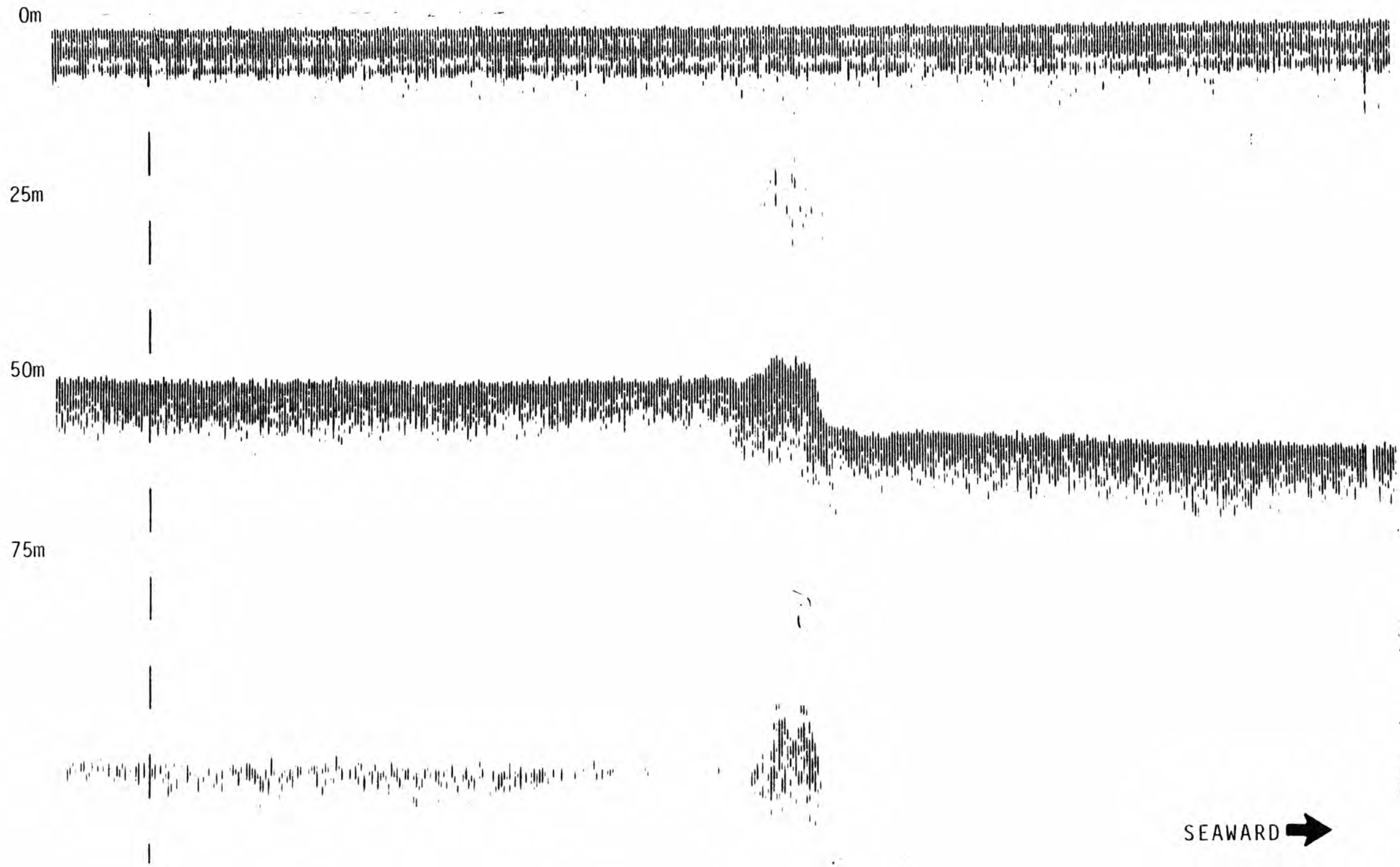


Figure 8-10

Figure 8-11. Line 5C, about 20 km southwest of Cape Fear, North Carolina. 3.5 kHz profile oriented approximately northwest-southeast, right to left, covers a horizontal distance of about 2.5 km. Eroded surface of acoustically hard layer shows irregular surface (A) and incised stream channel (B). Location of figure is shown on Map 8-A.

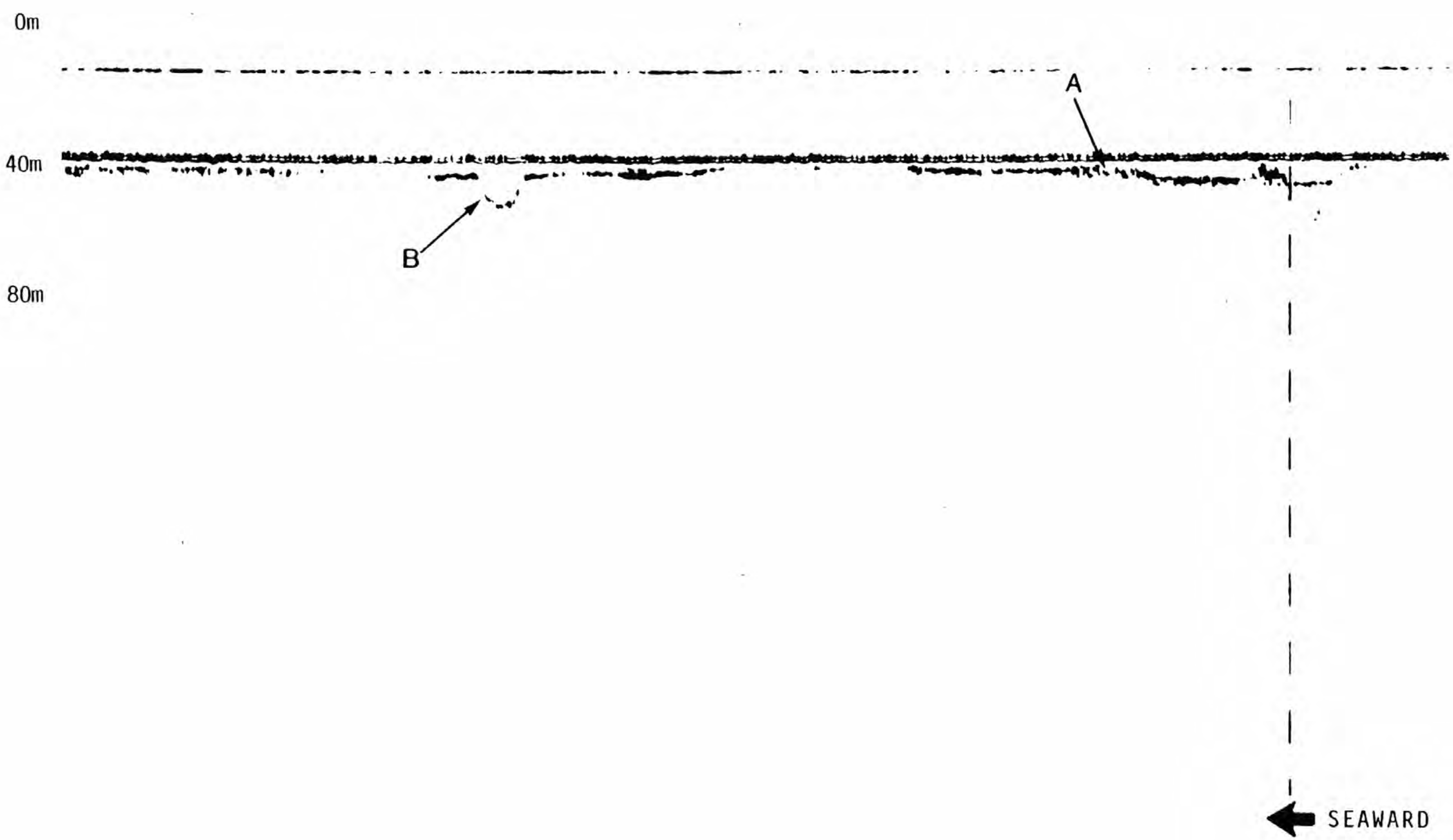


Figure 8-11

Figure 8-12. Line 23, about 60 km southeast of Tybee Island, Georgia. 3.5 kHz profile oriented nearly northwest-southeast, right to left, covers a horizontal distance of 4.3 km. An acoustically hard layer crops out in several topographic lows (A, B, and C) in an area of irregular topography. Location of figure is shown on Map 8-A.

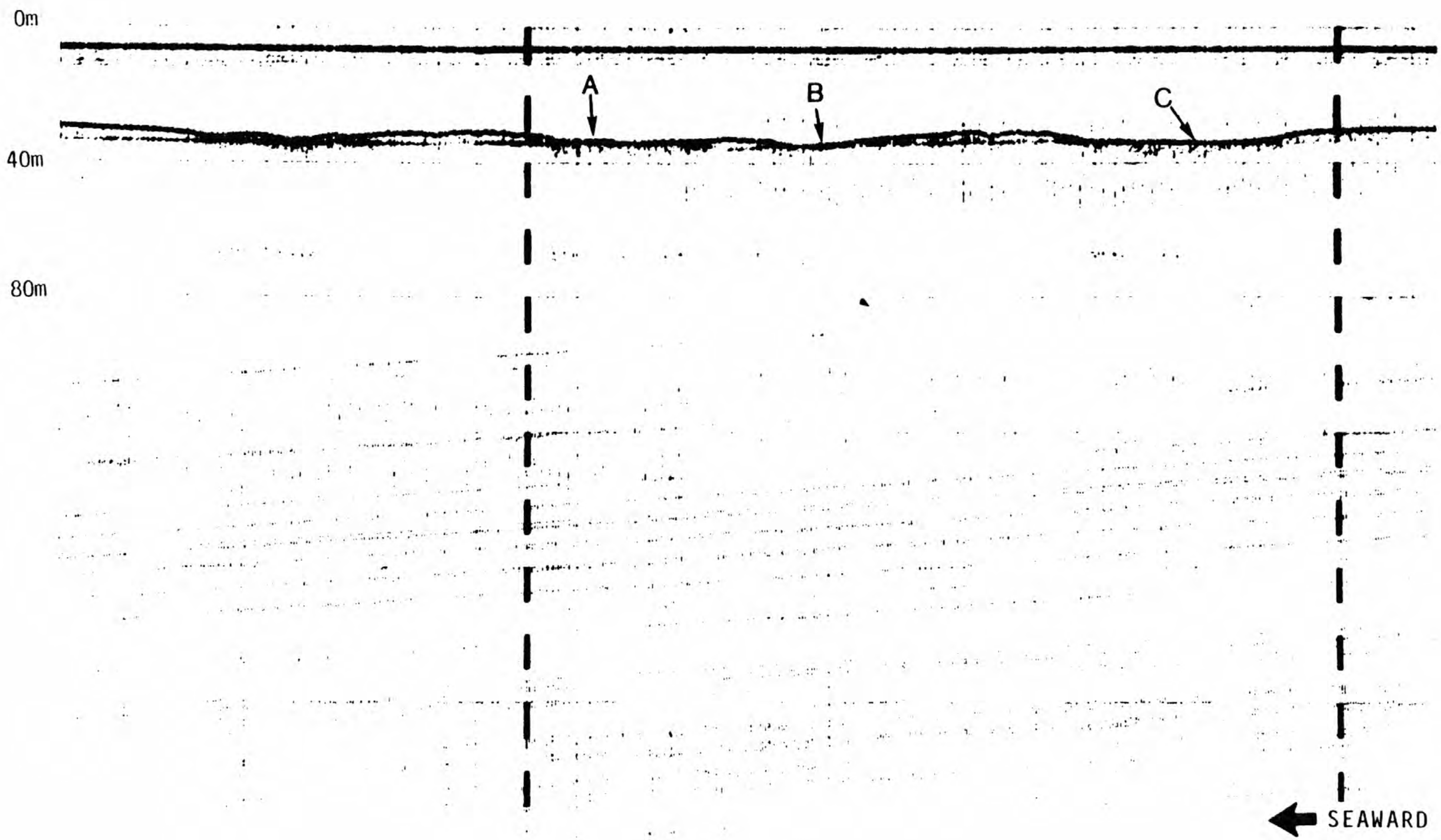


Figure 8-12

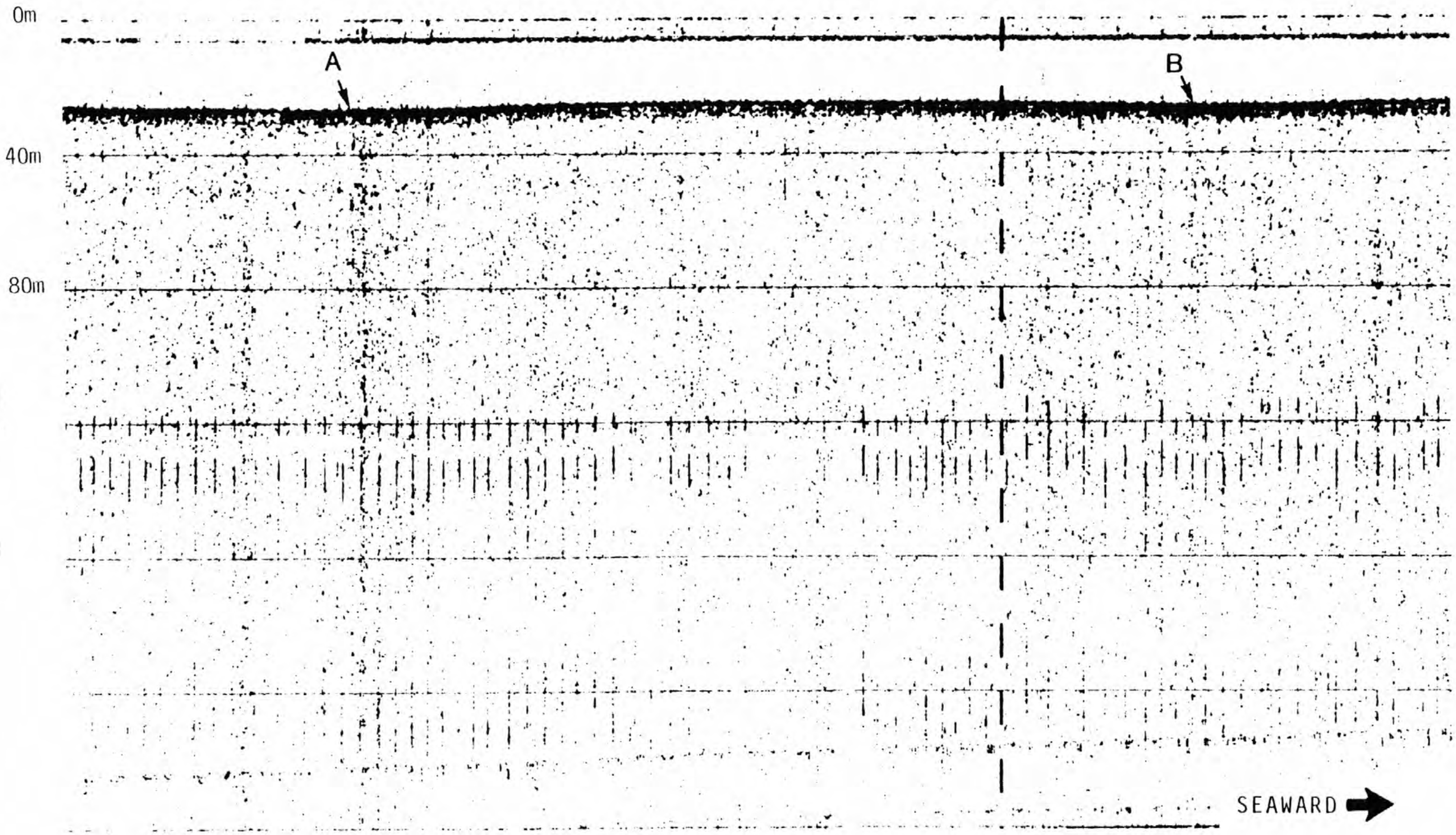


Figure 8-13

Figure 8-14. Percent occurrence of reef/hard bottom and shallow strong reflector in the Georgia Bight.

PERCENT OCCURRENCE OF REEF/HARD BOTTOM AND SHALLOW STRONG REFLECTOR IN THE GEORGIA BIGHT

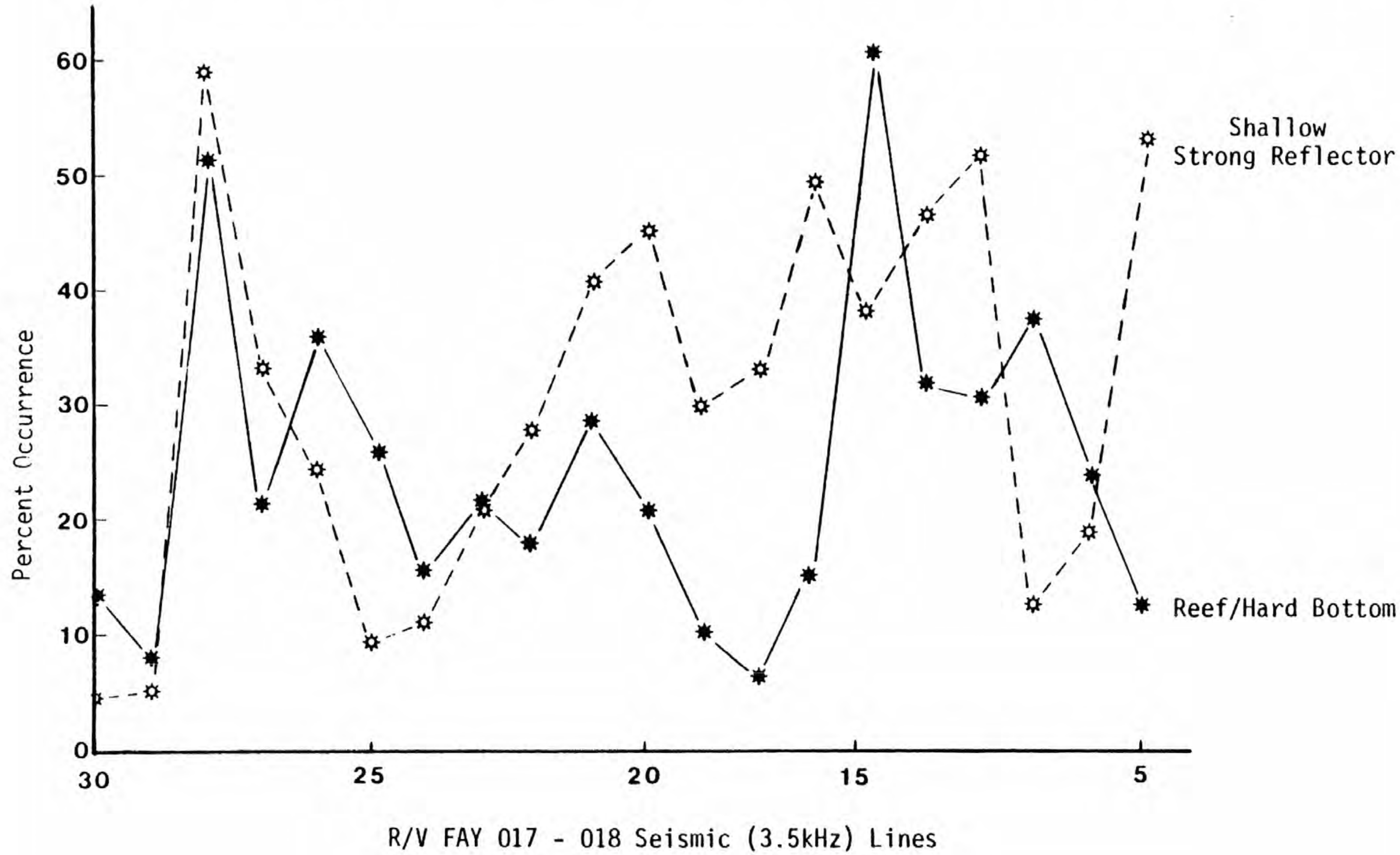


Figure 8-14

Figure 8-15. Line 15, about 130 km east of Charleston, South Carolina. 3.5 kHz record oriented approximately northwest-southeast, right to left, covering a horizontal distance of 4.4 km. Shelf edge reef (A) has developed on outcrop of the acoustically hard reflector. Buried reefs (B) occur to the northwest. Location of figure is shown on Map 8-A.

Figure 8-16. Line 27, about 45 km east of Amelia Island, Florida. 3.5 kHz record oriented west northwest-east southeast, left to right, covers a horizontal distance of 2.5 km. Two buried reefs (A and B) and one outcropping reef (C) are located just landward of midshelf. Location of figure is shown on Map 8-A.

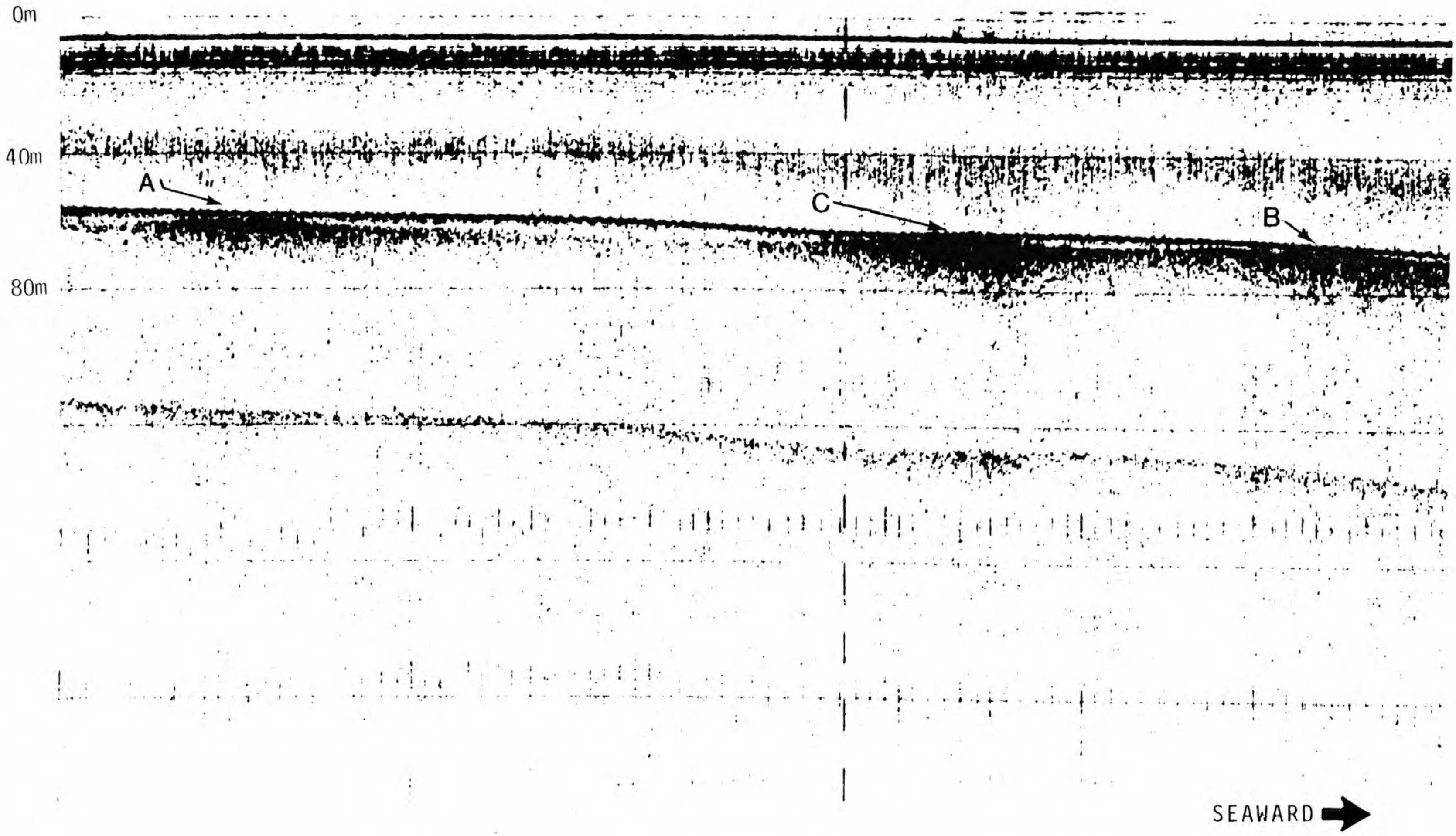


Figure 8-16

tracks, shot points and block numbers are shown in Figure 8-18a.

Nearly 70 percent of Area A is in water depth of 36-40 m (Figure 8-18b). The sea floor slopes to the southeast at nearly 0.5 m per km from a depth of 30 m in Block 197 on the west to the northern margin of Blocks 420 and 421, about 2.5 km from the shelf edge. One major change in slope occurs in the southwest section of Block 287 and in the north-central part of Block 331 between the 32 and 40 m isobaths, increasing from 1.1 m per km on the northwest side to 2.7 m per km on the southwest side, in a distance of about 2.5 km. From the 40 m isobath to the shelf break, which occurs at a depth of about 65 m, the slope averages about 7.6 m per km. The steepest slope, at the shelf break, averages almost 100 m per km over a distance of nearly 400 m.

Broad, nearly flat, almost symmetrical ridges and swales averaging nearly 1 km in wave length with an amplitude of less than 2 m trend southwesterly through the area. Small sand waves with wave lengths in the 10 m range are commonly superimposed on the larger features, occurring with about equal frequency on ridges and in troughs.

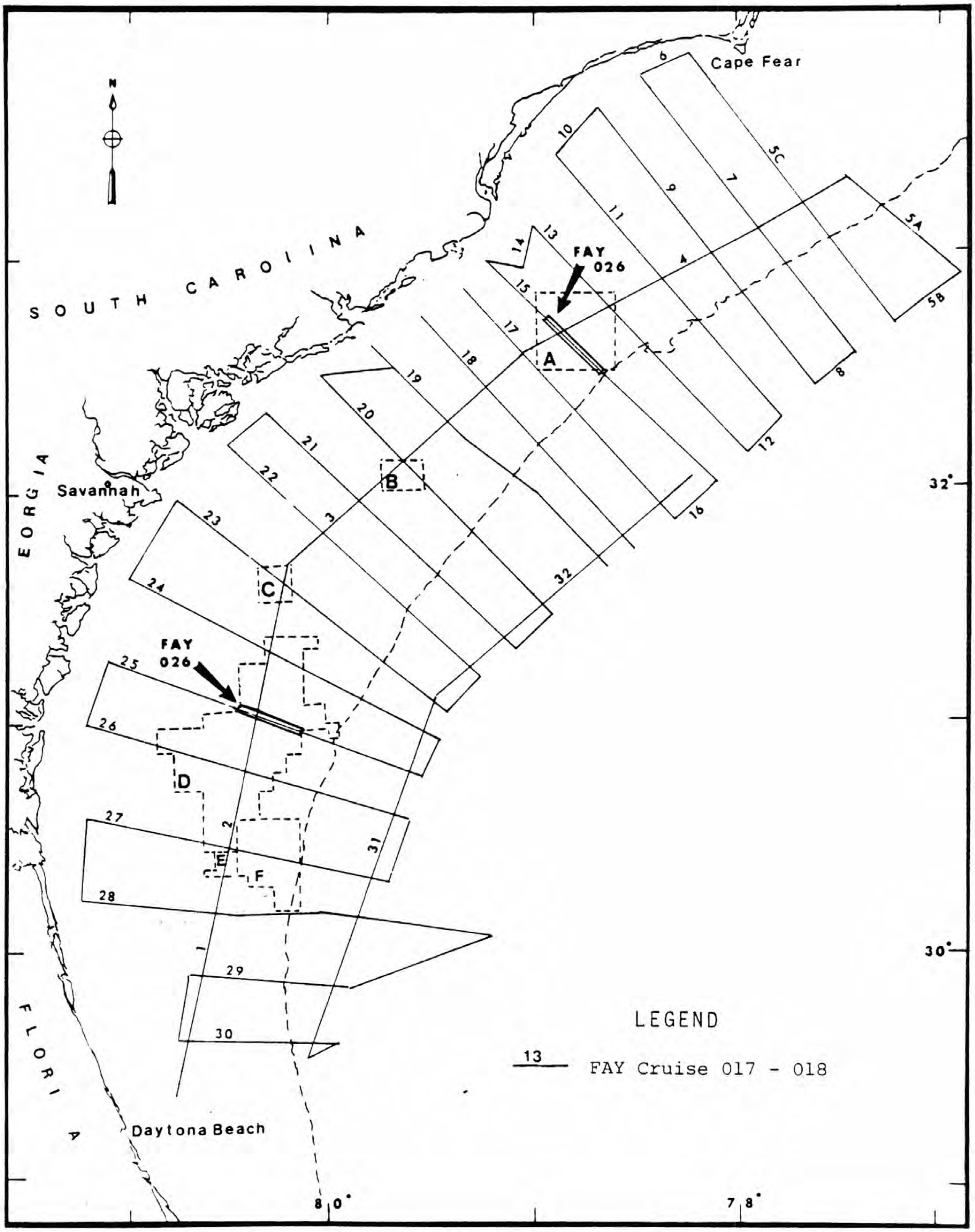
Sonar signatures of uncertain origin, best described as representing reticulated bottom, are found from the extreme south part of Block 287, through Blocks 331, 332, 376 and into Block 337 (Figure 8-19). These features may have been caused by refraction or interference within the water column.

Shelf sediment cover of post-Pliocene age has been found by Pilkey (1976) to average less than 5 m.

Several areas of moderate-relief reefs are found from the beginning of the transects on the west side of Area A through Block 377 on the east. Blocks 196, 197, 241, 242 and the northern part of 286 contain an area reef overlain, for the most part, by a thin cover of sediments

Figure 8-17. Cruise track lines, R/V FAY Cruise 17, 18, and 26 showing the location of track lines used in Figure 8-18.

Figure 8-17



Cape Fear
SOUTH CAROLINA
GEORGIA
FLORIDA
Savannah
Daytona Beach
FAY 026
FAY 026
A
B
C
D
E
F
32°
30°
80°
78°
LEGEND
13 FAY Cruise 017 - 018

Figure 8-18. Interpretation of the distribution of reefs and hard bottoms, outcrop and subcrop areas, acoustic texture of bottom sediments, and bathymetry along three R/V FAY-26 track lines from Lease Block Area A.

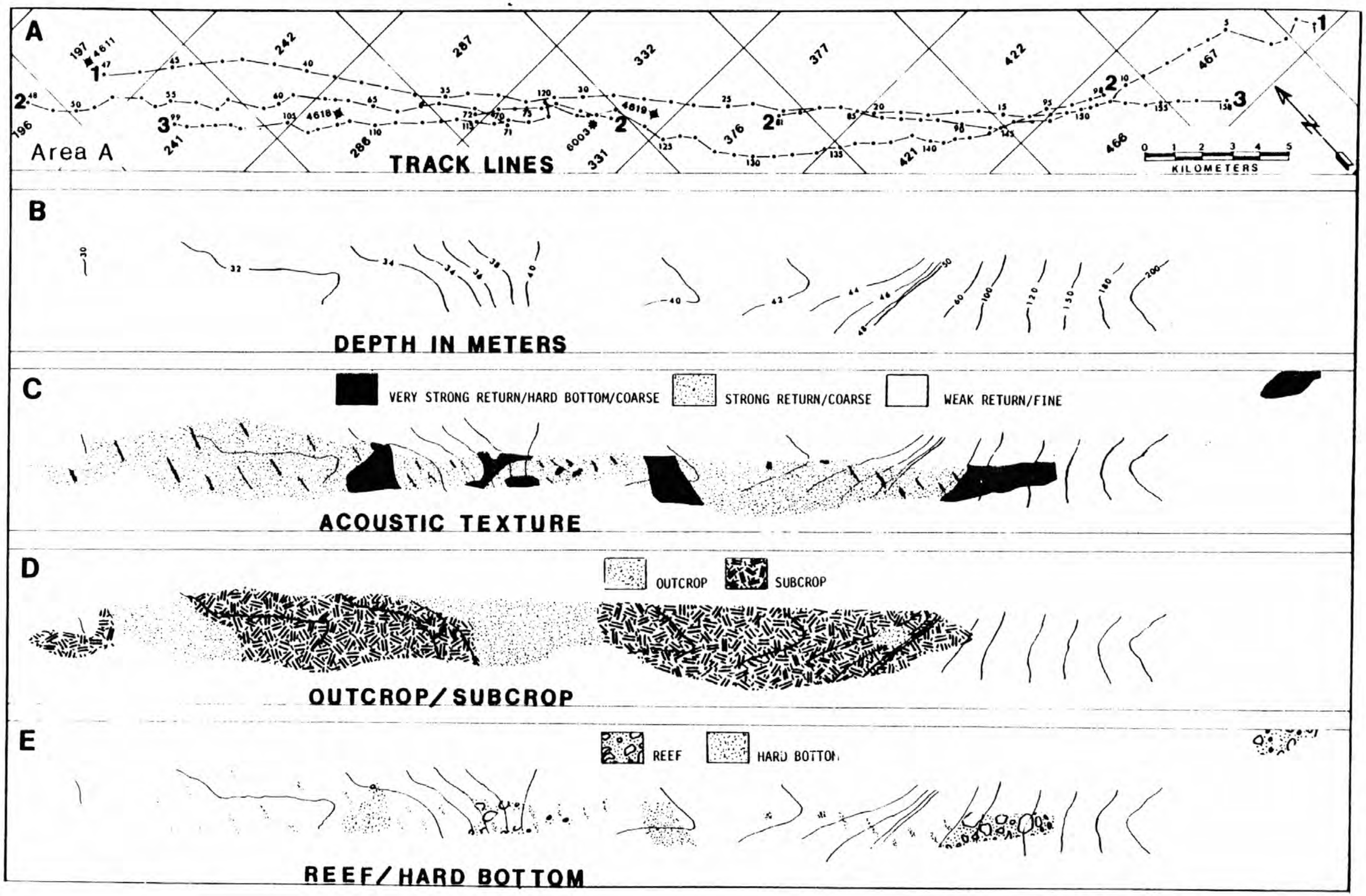
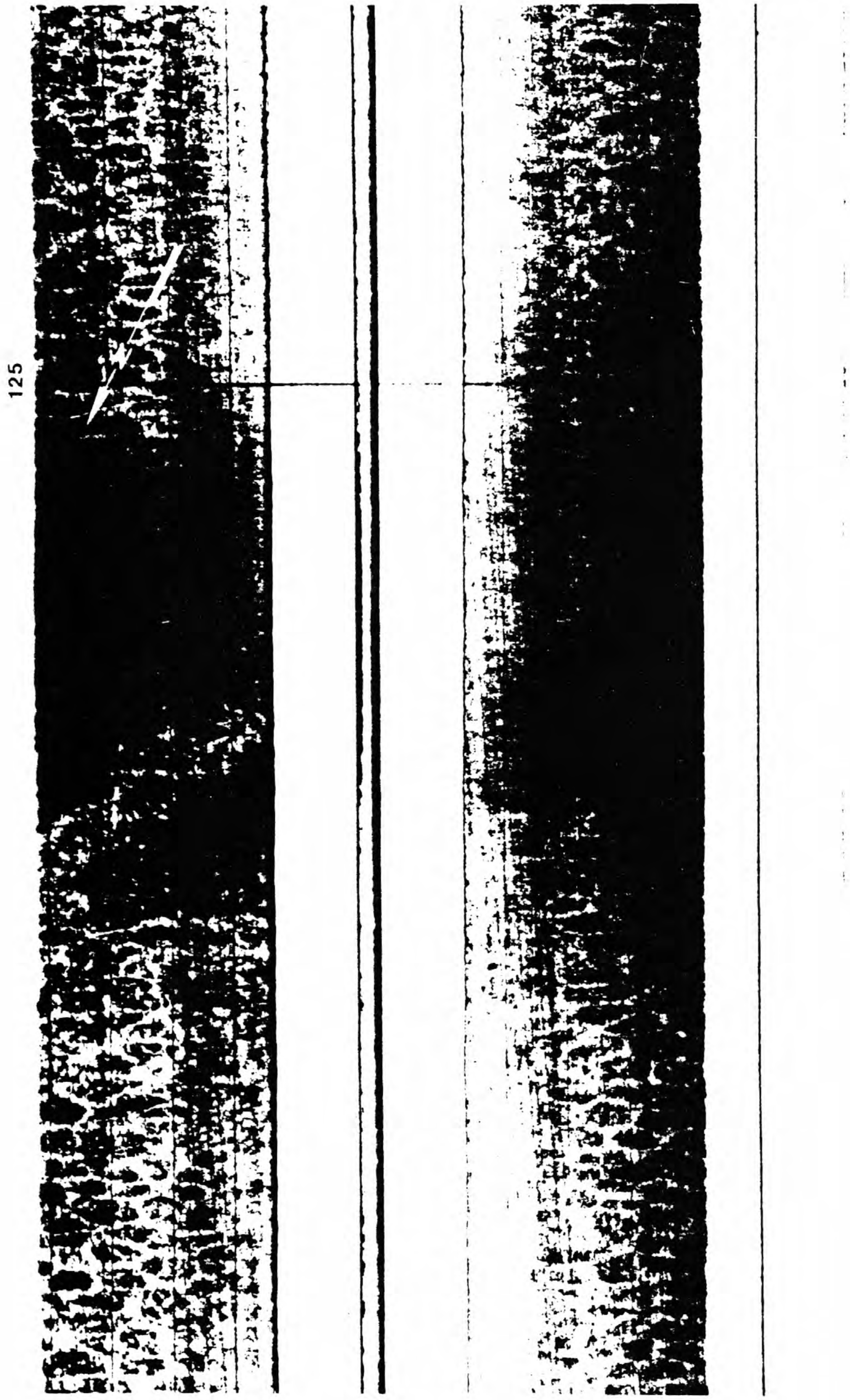

A
Area A
TRACK LINES
KILOMETERS
B
DEPTH IN METERS
C
VERY STRONG RETURN/HARD BOTTOM/COARSE
STRONG RETURN/COARSE
WEAK RETURN/FINE
ACOUSTIC TEXTURE
D
OUTCROP
SUBCROP
OUTCROP/SUBCROP
E
REEF
HARD BOTTOM
REEF/HARD BOTTOM

Fig.18

Figure 8-19. Area A, Line 3, about 105 km east of Charleston, South Carolina. Sonogram covers a horizontal distance of about 1 km and a lateral distance of 150 m. Well developed network of reticulated bottom structures of unknown origin are present. Location of figure is shown on Map 8-A.

Figure 8-19



through which narrow, irregular outcrops of reef occur (Figure 8-20). Two other relatively large reef areas occur in Blocks 286, 332 and 376.

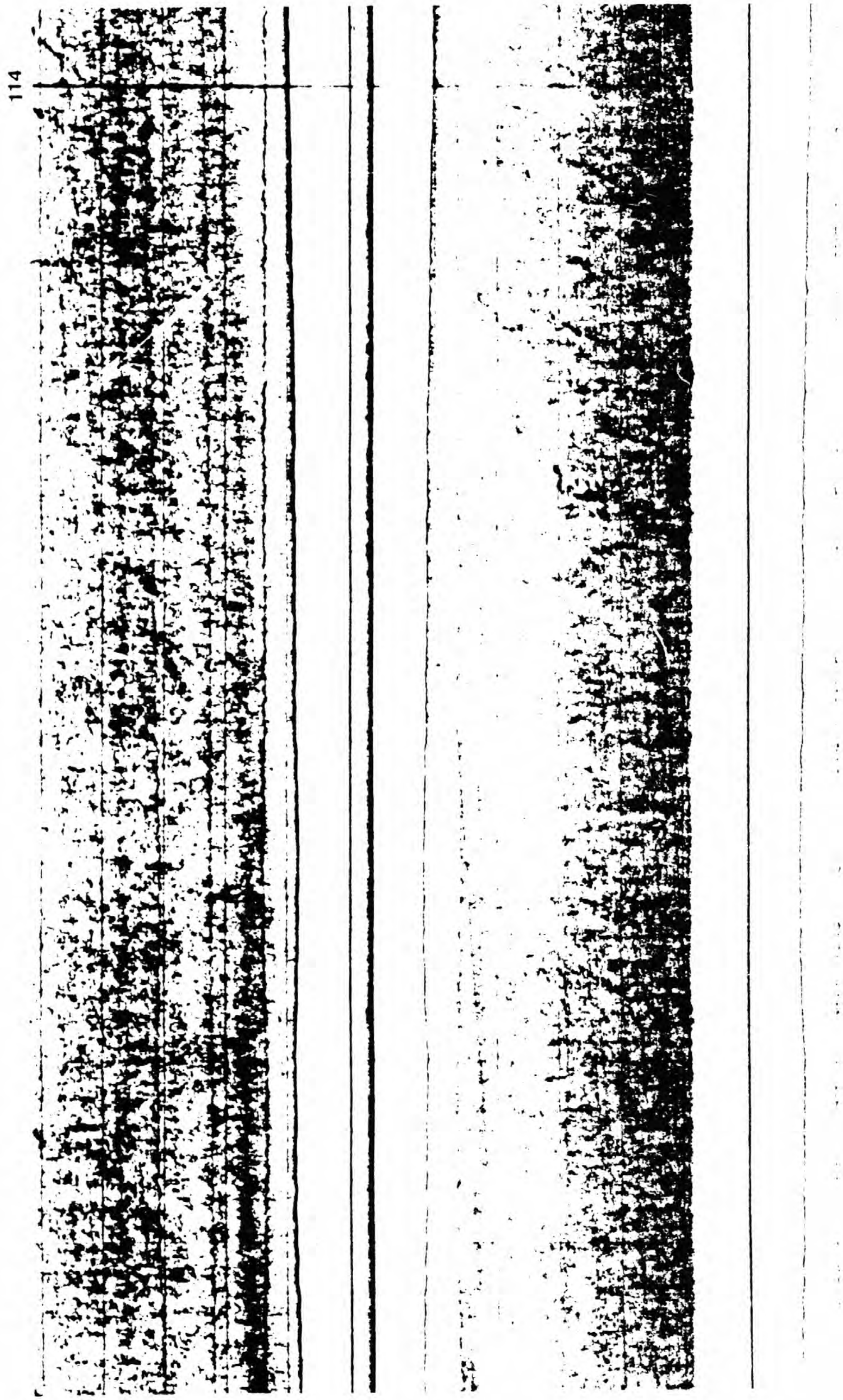
Areas of reef/hard bottom are shown in Figure 8-18e. Although outcrop areas showing topographic expression were uncommon, three areas with well-developed reefs were identified in Blocks 287 and 331, with the greatest concentration near the northern boundary of Block 331. A third, smaller area is located in the northeast sector of Block 286. These all appear to be of the moderate-relief, patch reef variety described earlier. A well-expressed shelf edge reef is found in Blocks 421, 422 and 466, which extends from near the 110 m isobath up to the shelf edge where it gradually merges with the bottom and becomes covered by sediments (Figures 8-8 and 8-15). Much of the sediment on the slope is probably reefal debris, as indicated by the strong signature. However, on the slope side of the reef, the acoustic sediment size becomes abruptly finer near the base of the reef in Block 466, and continues to the end of the record. This agrees with the observations of Pilkey (1966) who reported that the transition from medium or coarse sand to fine sand and silt occurs rapidly on the uppermost slope, at depths from 100-300 m and in all cases at depths greater than the shelf break.

While predominately within a size range interpreted as being medium sand, rapid textural changes appear to occur in Area A. This patchiness was first reported to be shelf-wide by Gorsline (1963) and has been subsequently confirmed by Pilkey (1976) and others.

Figure 8-18d shows the outcrop/subcrop pattern of a shallow, strong reflecting layer. The data is a composite of 3.5 kHz tuned transducer records from FAY 017, 018, and 026 cruises. Much of the reflector outcrop is covered by a thin layer of sediment, as indicated by

Figure 8-20. Area A, Line 3, about 100 km east of Charleston, South Carolina. Sonogram covers horizontal distance of 0.8 km and a lateral distance of 150 m. Narrow irregular ridges of a hard substrate crop out through the thin sediment cover. Location of figure is shown on Map 8-A.

Figure 8-20



sonograms, but is too thin to be resolved by the seismic profiler. The outcrops are generally associated with topographic lows. Whether the lows are related to mobile bedforms or result from scour is conjectural.

Ground truth is generally unavailable for assessing the validity of these interpretations. Just north of Shot Point 47 in Block 197, in an area interpreted to be thin sediment discontinuously covering a hard layer, hard bottom was encountered at 0.5 m in vibracore No. 4611 (Block 197) as described by Pilkey (1976).

In Block 286 an acoustically hard layer was indicated beneath an acoustically, relatively coarse sand. Near Shot Point 108 (Block 286) rock was encountered at about 3 m in vibracore 4618 (Pilkey 1976).

Farther to the southeast in Block 331, both sonar and shallow seismic data indicate a hard bottom. Hathaway et al (1976) reported that Atlantic Margin Coring Project Hole No. 6003 near Shot Point 79 (Figure 8-18a) was abandoned after an hour and 40 minutes of drill rotation because no bottom penetration had been achieved and that the anchor tended to "skate" on the bottom, suggesting a hard surface with little sediment cover. They suggested that the hard bottom is a siliceous zone of either the Santee limestone or Duplin marl.

In Block 332, an area underlain by a weak to moderately strong acoustical reflector, vibracore 4619 penetrated to a depth of about 2 m, but recovered no core, presumably resulting from coarse sand which flowed from the core barrel (Pilkey 1976).

It is interesting to note that considerable disparity exists between our interpretation of the occurrence of reefs and hardgrounds in Area A and that described in the U.S.G.S. Conservation Division's report. Whatever the reason, this condition points out the need for ground truth capability.

Area D

Located approximately 80 km east of St. Simons Sound, Area D extends east-southeast for about 40 km from near the northwestern boundary of Block 912 near midshelf to the center of Block 39 (Figures 8-7 and 8-21). Cruise tracks, shot points, and BLM Lease block numbers are shown in Figure 8-21a.

The bottom, which ranges from irregular to undulatory, slopes generally to the east at an average of about 0.2 m per km (Figure 8-21b). Water depth ranges from 22 m in the southwestern corner of Block 912 in the western portion of the area to 40 m in Blocks 1004-1006 and 37-39 in the eastern portion.

Two distinct types of bottom topography are evident. The boundary between Blocks 959-960 and 1003-1004, passing through the center of the area, separates an irregular topography to the west from a low relief, slightly undulating topography to the east. The irregular topography is characterized by ridges and depressions with a maximum relief of 16 m.

As shown in Figure 8-21c, two basic acoustic textures occur in Area D--a generally medium textured sediment which is present west of Block 1005 and a generally coarse sediment to the east. Superimposed on this pattern are several reef/hard bottoms in association with acoustically coarser sediment, presumably reefal debris or hard substrate (Figure 8-22). Areas such as these are common west of the center of Block 1005. The sediment cover appears to be thinner than the less than 5 m average thickness of post-Pliocene sediment reported by Pilkey (1976). Although the presence of hard bottom/coarse texture is indicated by sonograms over much of Area D (Figures 8-21c and 8-23), a shallow hard reflection, indicated by 3.5 kHz records, occurs only in the extreme eastern and western portions of the transects (Figure 8-21d). This contrasting

Figure 8-21. Interpretation of the distribution of reefs and hard bottoms, outcrop and subcrop areas, acoustic bottom texture, and bathymetry along four closely-spaced traverses, Lease Block Area D.

Figure 8-22. Area A, Line 6, about 100 km east of Jekyll Island, Georgia. Sonogram covers a horizontal distance of 2.8 km and a lateral distance of 300 m. A large area of hard bottom (A) is covered on the west by a layer of sediment (B). Location of figure is shown on Map 8-A.

Figure 8-22

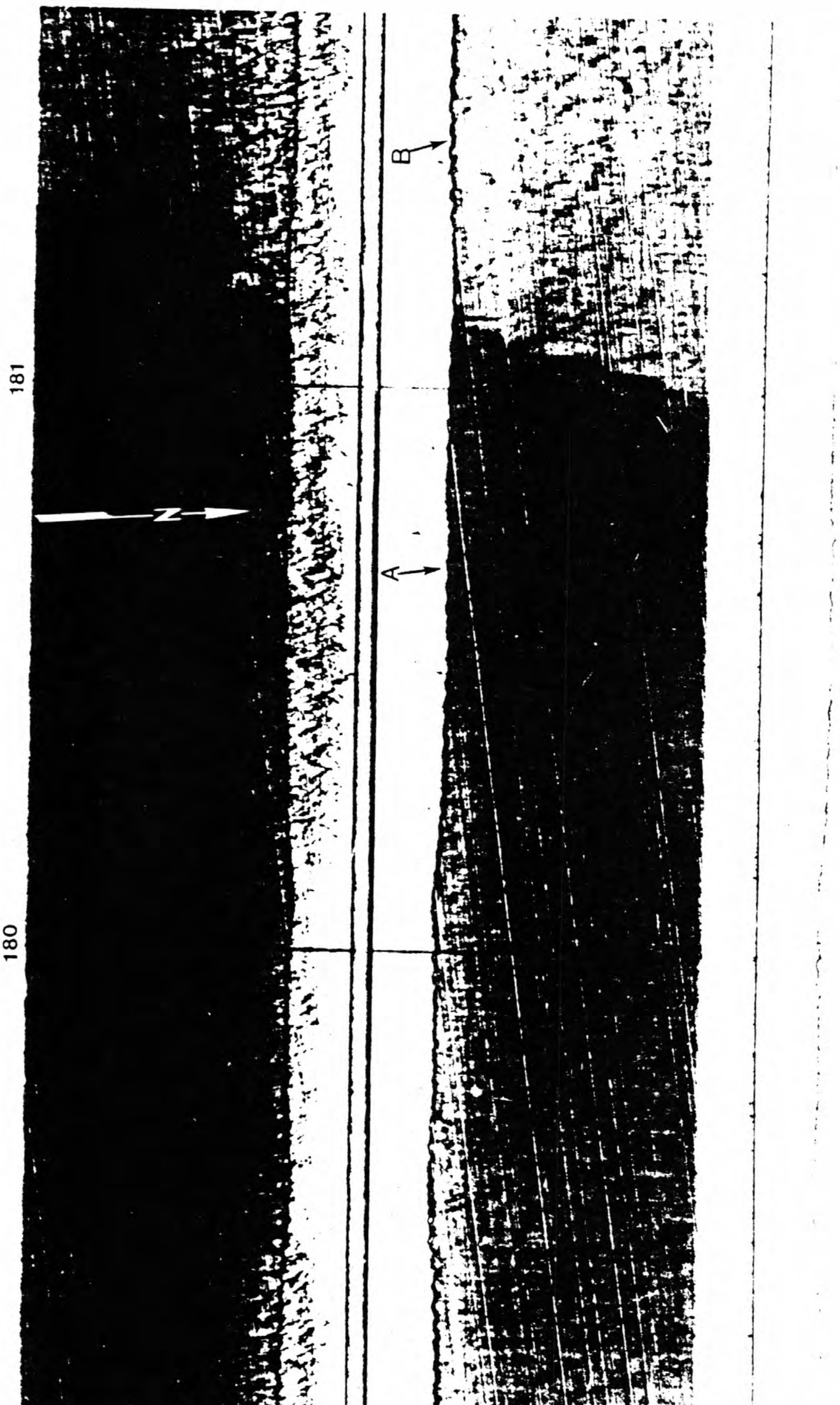
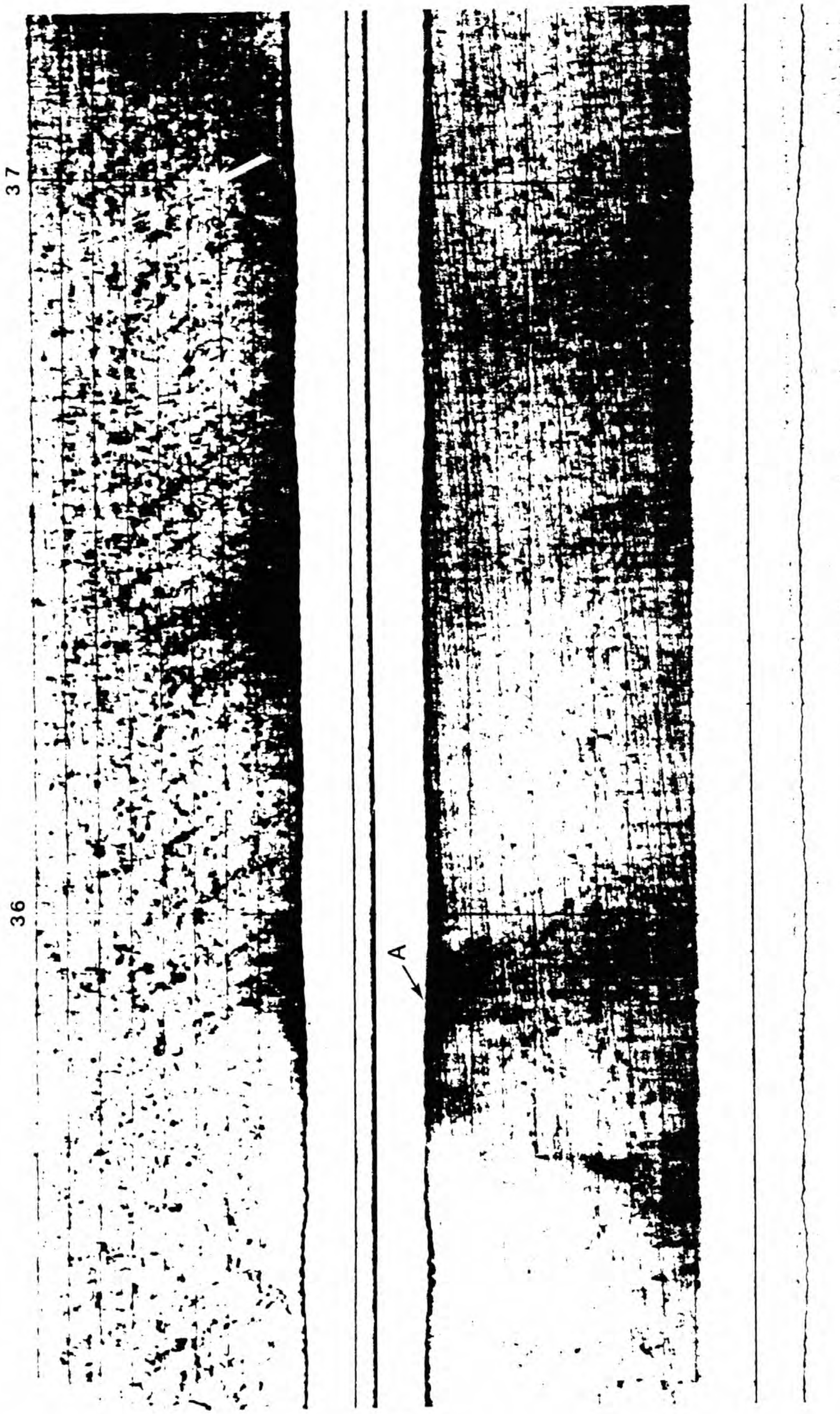


Figure 8-23. Area D, Line 4, about 100 km east of Jekyll Island, Georgia. Sonogram covers a horizontal distance of about 1.2 km and a lateral distance of 300 m. This area of hard bottom (A), partially covered by a thin layer of sediment with a patchy grain size distribution, is the northern end of the hard bottom area shown in Figure 8-22. Location of figure is shown on Map 8-A.

Figure 8-23



relationship could result from the inability of the 3.5 kHz to resolve a very thin sand layer overlying an acoustically hard layer. Otherwise, it is very difficult to explain the hard bottom inferred by the sonograms.

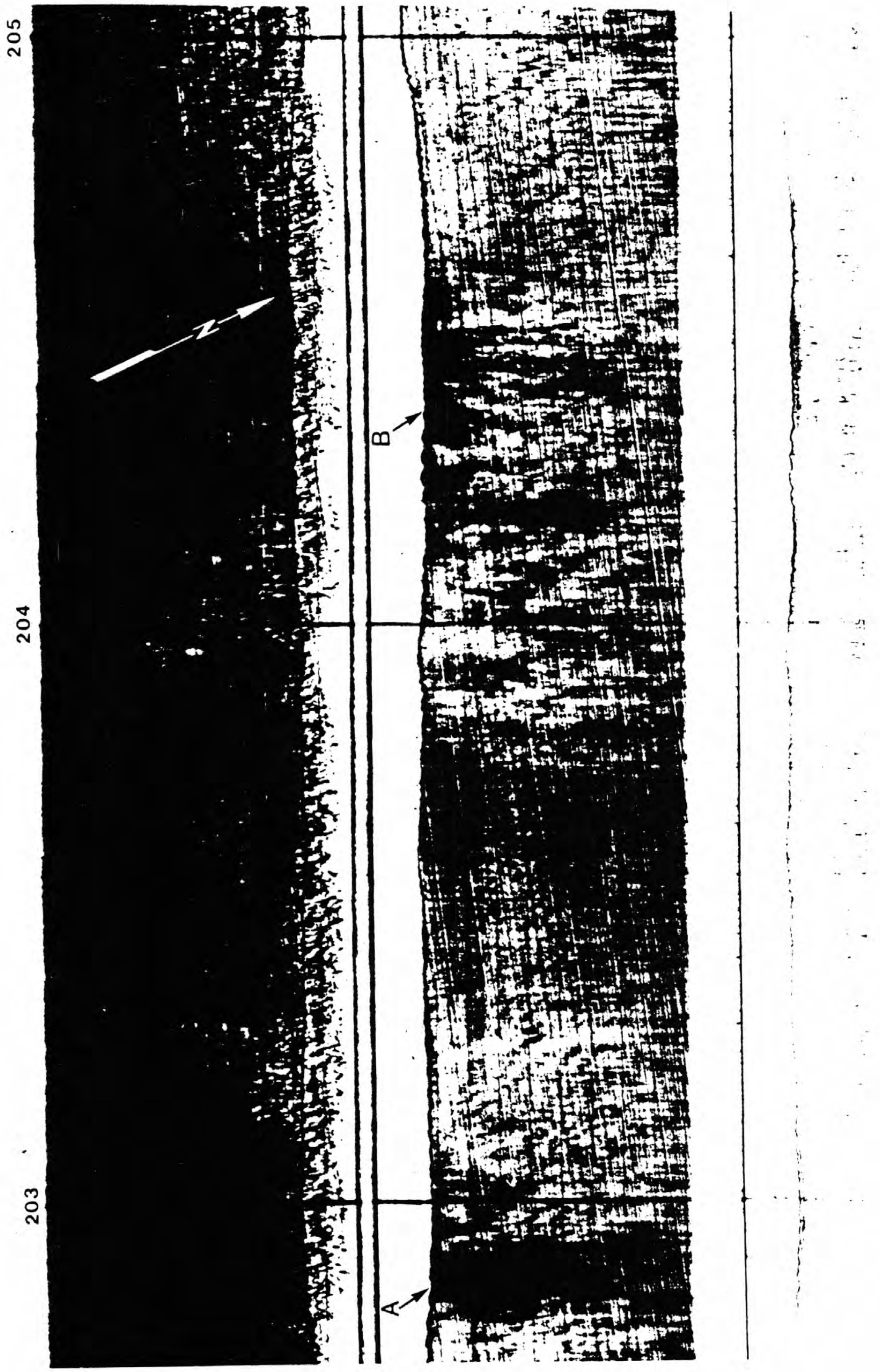
As shown in Figure 8-21e, two areas of moderate-relief reef are present in Area D. The first is located in the southeast corner of Block 912 (Figure 8-24) and the southwest corner of Block 913, the occurrence of which was also reported in the U.S.G.S. Conservation Division's report (1977). The second area of reef occurrence is located at the eastern end of the transect in Block 39. Both reefs are closely associated with outcrops or shallow subcrops of a strong reflecting layer. Although inferred hard bottoms, with essentially no topographic relief, are found in nearly all of the blocks, only those at the ends of the transect appear on the 3.5 kHz tuned transducer records as outcrops of a strong reflector. Presumably the other areas are outcrops of a reflector buried too shallow to be resolved in the seismic records.

Little ground truth is available along this transect. Near Shot Point 74 on line 5 U.S.G.S. vibracore No. 4601 was unable to penetrate a hard layer at a depth of 3.8 m. Between Shot Points 28 and 29 on line 5, vibracore No. 4605 penetrated to a depth of 4.5 m and was unable to go deeper as a result of a bent core barrel, probably resulting from encountering a hard layer. At the end of the transect, just east of Shot Point 163, vibracore No. 4609 could not penetrate deeper than 1.5 m, indicating the presence of a hard layer. Sediment samples collected near this transect (Kingery 1973) were found to be predominately in the medium sand size range, ranging from near the fine-medium to medium-coarse size boundaries.

Essentially the same reef/hard bottom distribution in this area was

Figure 8-24. Area D, Line 6, about 80 km east of Jekyll Island, Georgia. Sonogram covers a horizontal distance of 2.2 km and a lateral distance of 300 m. Two areas (A and B) of moderate-relief reef crop out in a topographically low area. Location of figure is shown on Map 8-A.

Figure 8-24



reported by U.S.G.S. Conservation Division (1977).

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CHAPTER 9

SOUTHEAST GEORGIA EMBAYMENT HIGH-RESOLUTION SEISMIC-REFLECTION SURVEY

Douglas W. Edsall[1]

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CHAPTER 9

SOUTHEAST GEORGIA EMBAYMENT

HIGH-RESOLUTION SEISMIC-REFLECTION SURVEY

Douglas W. Edsall

ABSTRACT

A high-resolution seismic survey of the offshore part of the Southeast Georgia Embayment on about a 30 km spacing was completed in 1976. A stratigraphic analyses of the data shows that the largest controlling factor in the depositional history of the shelf has been the Gulf Stream. These currents have shifted back and forth across the shelf, at times incising into shelf sediments, and at all times blocking much of the accumulation of Cenozoic sediments seaward of the Florida-Hatteras Slope. In the southern region the Gulf Stream maintained its present position since Miocene time, blocking the accumulation of Pliocene and younger rocks on the Plateau. Northward, in the middle, region the currents turned slightly to the northeast. The inner portion of the Blake Plateau has been scoured of sediments since the Paleocene, although scouring has also occurred in this area on the shelf from time to time. In the northern part of the survey area a more easterly flow of the Gulf Stream has allowed Eocene and younger rocks to be deposited on the Plateau. Line drawings and a geologic map show the distribution of the various Cretaceous and Cenozoic units.

A number of potential environmental hazards or constraints to petroleum development seen in the reflection data are identified. Besides current scour and erosion features, these include gravity faults on the slope, a slump, faulting on the inner Blake Plateau, the shelf edge reef, and deep water reefs on the Blake Plateau.

INTRODUCTION

During June and July of 1976, the U.S. Geological Survey conducted a high-resolution seismic-reflection survey of the offshore part of the Southeast Georgia Embayment. The embayment is an east-plunging depression recessed in the Coastal Plain between the Peninsular Arch of Florida and the Cape Fear Arch of North Carolina (Figure 9-1). The embayment opens seaward onto the Blake Plateau Trough.

Data were collected on the Continental Shelf, Florida-Hatteras Slope, and western portion of the Blake Plateau between 29°30′ and 33°31′ N (Figure 9-2). This survey represents the most complete coverage of the Southeast Georgia Embayment to date, allowing a careful regional analysis of geologic hazards. In addition, the minisparker records have provided a much more detailed understanding of the Cenozoic development of the area.

A 600-joule minisparker was used to penetrate the first half-second of subbottom strata. The data were filtered between 280 and 1060 hertz. Excellent records were obtained in all areas except on the shallowest portions of the continental shelf, where the interference of bottom multiples prevented the positive identification of deeper reflecting horizons. An integrated navigation system was used. It included a Teledyne Loran C, Magnavox Satellite receiver, Sperry Mark 29 gyro, and a Chesapeake speed log integrated with a Hewlett Packard HP-21 MX, and a data acquisition computer with dual 9 track magnetic tape recording. Range-Range Loran was the primary system. Hyperbolic Loran and the gyro were used as secondary systems. Reliable satellite fixes were generally within 150 m of either Range-Range or hyperbolic Loran positions.

This report deals with the analysis of minisparker records in terms of acoustic units. An acoustic unit, as observed on the minisparker

Figure 9-1. Location map showing the major structural elements of the southeastern U. S. Coastal Plain.

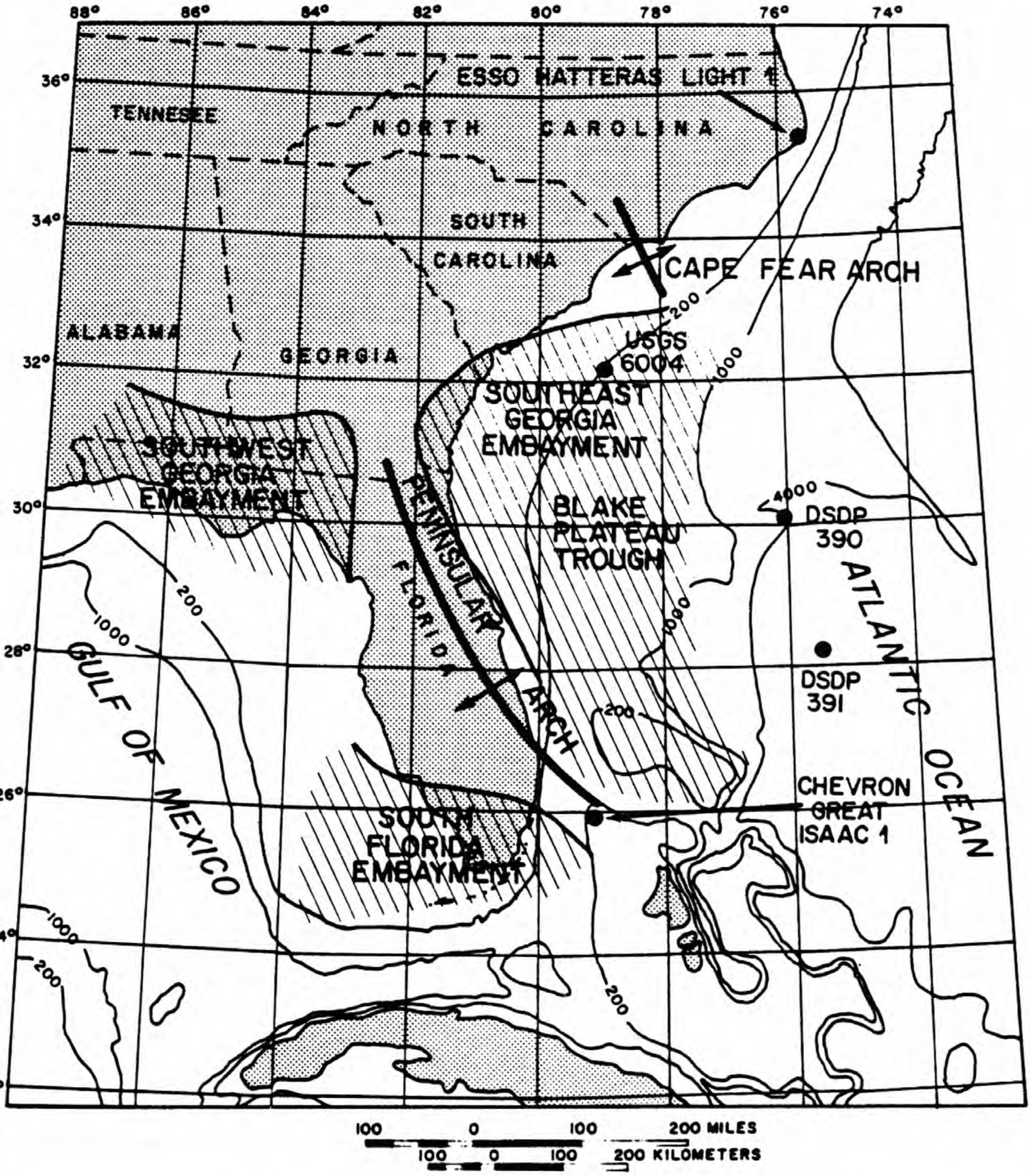

Figure 1

SOUTHEAST GEORGIA EMBAYMENT

from Dillon and others
(in press, Figure 1)

Figure 9-2. Location of track lines and offshore wells for the high resolution seismic survey.

records, is a relatively comformable sequence of related strata (Vail et al 1976). Each unit is separated from sequences above and below by unconformities or their correlative conformities. In most instances, the acoustic impedence contrast is larger between units than within units, showing on the record as a stronger reflector. Eight major acoustic units were identified within the study area. Reflections bounding these units were traced around the grid network of 21 NW-SE lines and 3 NE-SW tie lines. Geologic ages could be assigned to the acoustic units based on dated materials recovered at several drill sites and from published and unpublished descriptions of vibracores, piston cores, and dredge samples from the area. Depths to unconformities observed on the minisparker records were correlated with stratigraphic horizons established at drill sites by assuming seismic velocities between 1.5 and 1.8 km/sec. Once the age for a particular acoustic unit was established in this manner, the continuity and age equivalency of this unit were verified elsewhere on the grid network.

Tracings of reflections observed on the minisparker records were converted to true depth cross sections, assuming sound velocities of 1.5 km/sec in water and sediments. Approximate vertical exaggeration is X20 on the line drawings (Appendix 9-B).

GEOLOGIC STUDIES IN THE SOUTHEAST GEORGIA EMBAYMENT

The continental margin in the Southeast Georgia Embayment differs from the typical shelf-slope-rise transition because of the presence of the Blake Plateau, which interrupts the slope at a depth of several hundred meters. The Continental Shelf and Florida-Hatteras Slope landward of the Blake Plateau consist of a gently southeasterly dipping sequence of Tertiary and Quaternary sediments that have upbuilt the

Shelf and outbuilt the Slope. Erosion has modified the Blake Plateau and the Florida-Hatteras Slope since early Cenozoic times. The Southeast Georgia Embayment lies in the transition zone between the calcareous province of Florida and the Bahamas and the clastic province north of Cape Hatteras. U.S. Geological Survey Open File Report 75-411 (Dillon et al 1975) summarizes the geology of this region. Several articles (Hersey et al 1959; Ewing et al 1966; Emery and Zarudzki 1967; and Uchupi 1967) discuss interpretations of seismic reflection records across the continental margin.

Many hundreds of wells drilled onshore in Florida, Georgia, and South and North Carolina have provided detailed information on the structure and stratigraphy of the sediments and rocks underlying the Atlantic Coastal Plain. McCollum and Herrick (1964) have reported on the stratigraphy of a drill hole in 17 m of water on the continental shelf at 31°56′53.5" N, 80°41′00" W. In 1965, six holes were drilled east of Jacksonville, Florida by the Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) Program. However, until the summer of 1976, no drill sites were available on the main part of the Continental Shelf in the embayment. The JOIDES holes (Figure 9-2) revealed a continuity in age and lithologic character of the onshore and offshore sequences at the south end of the embayment (Bunce et al 1965; Schlee 1977). The three United States Geological Survey (U.S.G.S.) Atlantic Continental Margin Coring Project Holes (AMCOR) (6002, 6004, and 6005) (Figure 9-2) drilled in the embayment have provided dating control for the major acoustic units observed on the minisparker records (Hathaway et al 1976). Furthermore, these sediments have provided samples for determining the geotechnical and engineering properties of the materials and information useful in determining paleodepositional environments.

Due to the anchoring requirements of the D/V GLOMAR CONCEPTION, this drilling program was limited to a maximum of 305 m of penetration at a maximum water depth of 460 m. Other information available for the offshore areas came from piston and vibracores, grab and dredge samples, and from CALDRILL C-5 drill hole, located on line 5A.

DISCUSSION OF DATA

General Description

Acoustic penetration up to 0.5 second two-way time (375 m) was obtained from the Blake Plateau on the high-resolution seismic records. Less penetration was observed beneath the Continental Shelf and Florida-Hatteras Slope due to interference of bottom multiples. The pulse length of the minisparker system usually obscures the uppermost 5 to 7.5 m of the section, and commonly prevents a detailed look at the Holocene section on the Shelf and Slope. On the Blake Plateau the presence of Holocene sediments could not be documented in the profiles, although bottom cores from this area usually include a thin Holocene sequence (Pilkey 1977, personal communication).

Bottom topography on the Continental Shelf is generally smooth. Irregularities arise from buried or partially buried algal and coral reefs, sand waves, wave-cut terraces, and other erosional and constructional features associated with changes in sea level during Quaternary time. Such bottom irregularities have been discussed by Stetson _et al_ (1962), Uchupi and Tagg (1966), and Pilkey _et al_ (1971). Examples of these various features are presented in Appendix 9-A (photographs 2, 3, 4, 6, 10, 12, 13, 15, 17, 19 and 20). The approximate 30 km spacing between the NW-SE track lines does not permit good correlation between tracks, but pronounced features such as shelf edge reefs and large erosional forms can be traced between the lines. There is good correlation between the features observed on the two sets of closely spaced lines (15, 15A, and 15B; and 25, 25A, and 25B). Subbottom reflections can be traced for long distances beneath the shelf. Buried erosional valleys, as much as 75 m deep and 4 km wide, are common on the shelf. In general, the NW-SE cross-shelf lines show seaward-dipping Tertiary and Quaternary beds, often in the form of foreset bedding near the shelf edge. Most of the Tertiary units pinch-out beneath the Quaternary veneer north of 32° and northwest of the present shelf break. The subaerial exposure of a large portion of the shelf during the Pleistocene resulted in the removal of some older units. In addition, the acoustic pattern of Pleistocene and Pliocene sediment in the southern portion of the embayment suggests that these sediments were deposited primarily on the slope. For these reasons, as well as minor amounts of recent sediment accumulation, older Tertiary units are close to the present sea floor. In the embayment, several unconformities occur beneath the shelf. The U.S.G.S. AMCOR holes (6002, 6004, and 6005) provide ages for the sediments above and below them, and in most cases, it is relatively easy to trace these acoustic units from line to line. However, north of 32° the shelf has undergone extensive erosion which makes the tracing more difficult. As a result of the cut and fill stratigraphy, the units are discontinuous and complicated by apparent dip reversals and chaotic bedding. It is possible that age assignments of some of these units may change as more cores become available in this area.

The most distinctive features on the Florida-Hatteras Slope are reefs, two major faults on line 29, and a major slump on line 19. No submarine canyons were observed.

Figure 9-3. Interpretive map of the shallow subcrop geologic units. This map is also presented as Map 9-A in the pocket at the rear of this volume.

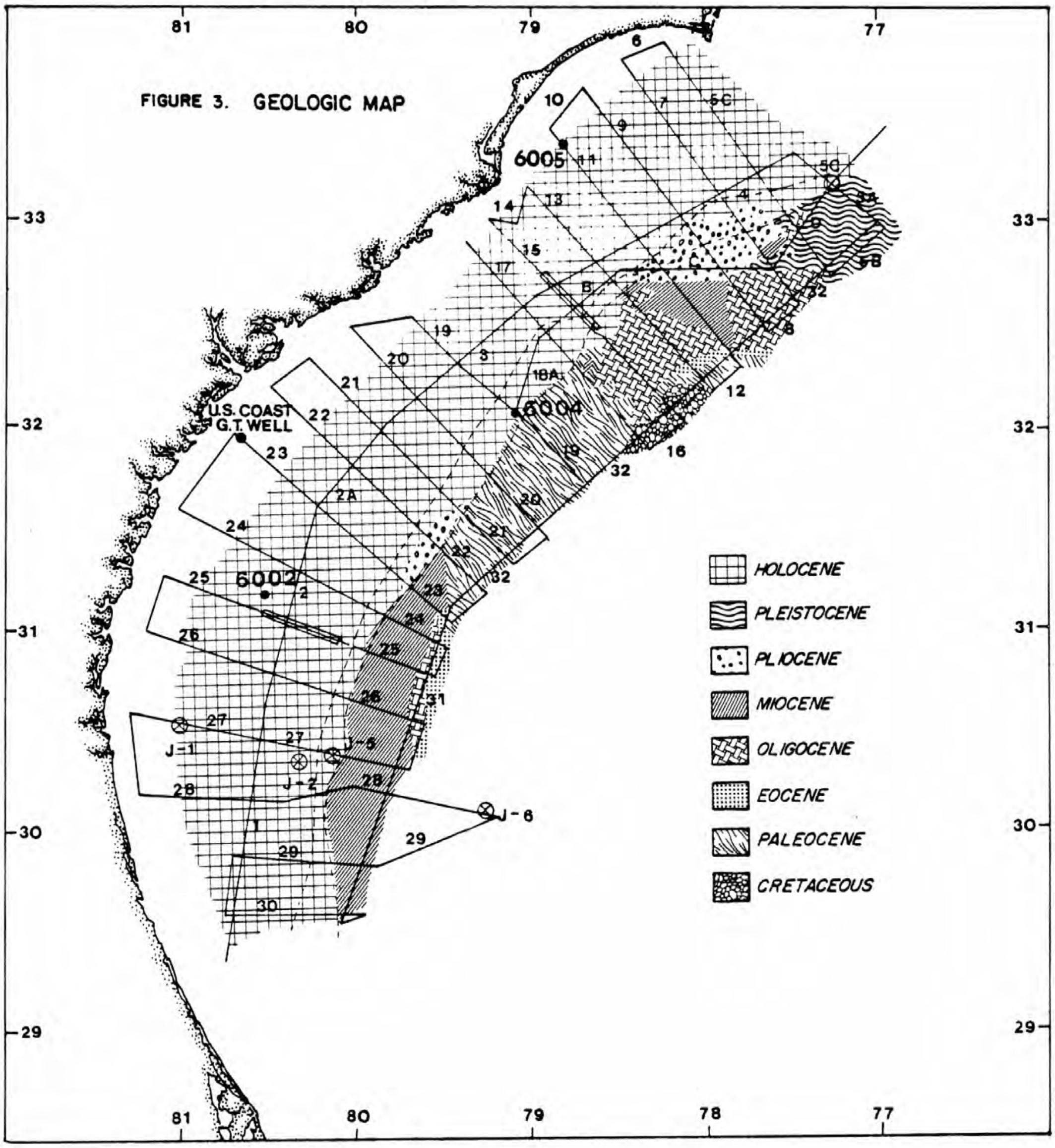
FIGURE 3. GEOLOGIC MAP
81
80
79
77
78
33
32
31
30
29
U.S. COAST G.T. WELL
6005
6004
6002
J-1
J-2
J-5
J-6
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS

of sediment distribution by age (Appendix 9-C) form the basis of this report. The line drawing interpretations of the minisparker records appear as Appendix 9-B. Appendix 9-D presents the variations in sediment thickness and structure in each epoch of the Cenozoic.

Upper Cretaceous

Figure C-1 represents the inferred distribution of Upper Cretaceous sediments in the Southeast Georgia Embayment. This is based on the correlation of the depth to the top of the Upper Cretaceous recovered in U.S.G.S. AMCOR 6004 with the depth to the top of the appropriate acoustic unconformity on line 19. This deepest unconformity was traced throughout the embayment where possible, or inferred on the basis of the age of the overlying sequence. The assumed Upper Cretaceous sequence was observed in the southern region on lines 25 and 29 (Figures B-1 and B-2). It is presumably present throughout the area, but was not readily observed on all records. It is overlain by the Paleocene sequence throughout the southern region as drilled at Site J-6 (Figures B-1 through B-3). The Upper Cretaceous in the middle region was drilled at Site 6004 on line 19 and was extrapolated to lines 17-22 (Figures B-3 through B-5). Due to insufficient penetration on lines 20-22, it was not possible to observe internal stratification in the Upper Cretaceous sequence. An unconformity is observed within the Upper Cretaceous sequence on line 17. The lower unit consists of gently southeast—dipping strata, while the upper unit contains truncated foreset bedding. The thickness of this unit decreases to the southeast. The top of the Upper Cretaceous is too deep beneath most of the slope and all of the shelf to appear on the minisparker records. The Upper Cretaceous boundary was extrapolated from drill site 6004 on line 19 into the northern region (lines 5A-15), and was observed on all transects except line 5A, where the correlation was made from the tie line. The Upper Cretaceous is believed to crop out on the surface of the Blake Plateau (Figures B-5, B-10, and B-11) where it appears to dip gently northeastward.

Paleocene

Figure C-2 represents the inferred distribution of Paleocene sediments. Paleocene sediments were recovered by drilling at Sites 6004, 6005, J-6, and CALDRILL C-5 and thus related to the appropriate unconformities on minisparker lines 19, 11, 28, and 5A which passed through these drill sites. This unconformity was traced throughout the embayment where possible or inferred to be the top of the Paleocene on the basis of the age of the overlying sequence. In the southern region (lines 23-30), the Paleocene was observed to crop out on tie line 31, northeast of the crossing with line 24 (Figure B-2). Evidence of erosion is observed beneath the plateau on lines 23-26 (Figures B-2 and B-3). The middle region (lines 17-22) is characterized by the cropping out of southwest-dipping Paleocene sediments on the Blake Plateau. In addition, the highly eroded Paleocene sequence is very obvious beneath the shelf and slope on lines 17 and 19. The eroded appearance of the Paleocene beneath the shelf and slope differs greatly from that on the Blake Plateau. Beneath the shelf and slope the erosional features have resulted from the downcutting of streams into the Paleocene sediments during the subaerial exposure of this region during post-Paleocene, but pre-Miocene time. Although the track spacing is too great to be certain of correlations from one line to another, these stream channels on the shelf are thought to strike in a northeasterly direction parallel to the shelf edge. The appearance of the Paleocene sequence on the surface of the Blake Plateau reveals that erosion has truncated the gently southeasterly dipping beds and produced isolated outliers rising above its surface.

In the northern region (lines 5A-15), the Paleocene sequence was recovered at drill sites 6004 and 6005 and crops out on the southeastern ends of lines 13 and 15 and on tie line 32. It overlies the Upper Cretaceous and is present beneath the shelf, slope, and Blake Plateau. Whereas, evidence of severe erosion on the top of the Paleocene is absent, minor channels have been cut into it beneath the Plateau on lines 11 and 13, beneath the slope on line 7, and beneath the shelf on lines 15B, 15, and 15A. Evidence of channelling is lacking on the top of the Paleocene sequence beneath the present shelf on lines 13, 11, 9, 7, and 5C. However, the Paleocene unit shows a drop of approximately 75 to 100 m, indicating the position of the Paleocene shelf edge. Its distance from the present shelf edge increases to the north (Figure D-1).

Eocene

Figure C-3 represents the inferred distribution of Eocene sediments. Eocene sediments were recovered at drill sites J-1, J-2, J-5, J-6, and 6002, and CALDRILL C-5. The distribution of Eocene sediments is determined from the correlation of depth of the cored Eocene sequence with the depth of the unconformity observed on minisparker lines 5A, 25, 27, and 28 which pass through or close to the drill sites. In some instances Eocene sediments were inferred to be present because of the age of the overlying sequence.

Eocene sediments were observed in the southern region (lines 23-30) on all lines except 23 (Figures B-1 through B-3). In the southern region these sediments crop out on the southeastern end of lines 24 and 25, and on line 26 they appear as an outlier resting on the Paleocene.

Eocene sediments do not appear to have been deposited, or were possibly removed by subsequent erosion, in the middle region (lines 17-23) beneath the slope and Blake Plateau. This is confirmed by their absence in AMCOR hole 6004, by a thin section in J-4, and by their decrease in thickness on the acoustic records as the middle region is approached (Figure D-2). It is possible that subsequent drilling and dating of recovered sediments from beneath the shelf may prove that the greater thickness of sediment apparent on lines 17, 19, and 21 considered to be Miocene, may also contain Eocene and Oligocene materials. However, it is obvious that vigorous current activity impinged against the continental margin near the approximate position of the slope, curtailing the seaward deposition of these sediments. The eroded Paleocene sequence beneath the outer shelf and slope on lines 15-21 may have acted as a barrier restricting the seaward distribution of Eocene sediments.

The Eocene sequence in the northern region (lines 5A-15) overlies the Paleocene sequence on lines 13 through 5C. It is absent on 15 and was not identified on line 5A, although it was seen on tie line E, which crosses line 5. The Eocene sequence is seen beneath the shelf, slope, and Blake Plateau on lines 11, 9 and 5C, but is quite thin. It is restricted to the Blake Plateau on lines 13 and 7. Some evidence of erosion is seen on line 11. Eocene crops out on the southeastern end of lines 13 and 11 and on line 32. A large area of Eocene sediments beneath the Plateau has been removed by erosion on line 11.

Oligocene

The inferred Oligocene sediment distribution is presented in Figure C-4. Oligocene sediments were recovered at drill sites J-1, J-2, J-5, J-6, 6002, and CALDRILL C-5. The Oligocene sequence in the southern region overlies the Eocene sequence on lines 24-30 and the Paleocene sequence on line 23 (Figures B-1 through B-3). The Oligocene sequence reaches its maximum thickness beneath the Florida-Hatteras Slope (Figure D-3). A reversal in dip on line 29 is related to a fault beneath the slope. The Oligocene sequence crops out on lines 24-26 (Figures B-2 and B-3) and lines 28 and 29. Evidence of major post-Oligocene current erosion is visible on lines crossing areas where the Oligocene is exposed, but where the Oligocene is buried erosion is less extensive. The Oligocene sequence on line 23 pinches out towards the southeast beneath the plateau.

In the middle region (lines 17-22), Oligocene sediments may or may not be present beneath the shelf and slope as indicated above. Oligocene sediments apparently extend northward only as far as line 22, although small remnants are preserved as outliers on line 17. These outliers overlie a major unconformity, below which Paleocene sediments have been identified. It appears that Oligocene sediments were deposited on the plateau and have subsequently been removed by erosion with the exception of the few remnants on line 17. The Oligocene sequence in the northern region (lines 5A-15) has been highly eroded by bottom currents on lines 15, 13, 11, and 9. The channels produced have been filled by younger sediments (Figures B-5 through B-9).

<u>Miocene</u>

Figure C-5 shows the distribution of Miocene sediments. They were recovered at drill sites J-1, J-2, 6002, 6004, and CALDRILL C-5. The inferred distribution was determined in the same manner as previously mentioned. Several unconformities are observed within the Miocene, and the distribution of these sediments is the result of a continual balance between sedimentation and erosion (Figure D-4). In the seaward parts of lines 23-26 (Figures B-2 and B-3), the Miocene sediments either pinch out or have been totally removed by erosion, thus exposing older sequences. The pattern of Miocene sedimentation in the area of lines 29 and 30 indicates an episode of upbuilding and outbuilding on a previously existing southeast-ward dipping sequence of Oligocene sediments. Lines 23-28 (Figures B-1 through B-3) show extensive erosion of the Miocene sediments beneath the present slope and outer portion of the shelf, producing a rather abrupt notch beneath the present slope. Note the truncation of southeastward-dipping Miocene beds on lines 24-28. Erosion in Miocene time apparently concentrated in this area beneath the present-day shelf and slope.

In the middle region (lines 17-22) the Miocene is present beneath the shelf and slope and has filled eroded channels (see tie line ABCDE/FAY 025, Figures B-14 and B-15). Several unconformities are observed within the Miocene sequence. Miocene does not exist on the plateau except as an outlier on line 17. This indicates Miocene sediments were eroded or were not deposited due to vigorous current activity. On the plateau in the northern region (lines 5A-15) Miocene sediments have filled the channels cut into the Oligocene sequence (see lines 15, 13, 11 and 9). It exists below Pliocene sediments on line 5A, and is present as an erosional surface on the eastern portion of line 11. Some of the Miocene on the plateau has subsequently been removed by erosion shown on lines 9, 7 and 5C. Noticeable outbuilding and upbuilding of the continental shelf in Miocene time is demonstrated by lines 9 and 7, and is less noticeable on lines 5C and 5A. The Miocene on the plateau in the northern region, as seen on line 32 (Figures B-10 and B-11) appears to dip in a northeastward direction.

Pliocene

The distribution of Pliocene sediments is shown in Figure C-6. Pliocene sediments were recovered at drill sites J-1, J-2, J-5, 6004 and CALDRILL C-5 and their distribution was traced in the manner previously described. Pliocene sediments in the southern region (lines 23-30) are found beneath the present day shelf and slope on all lines (Figures B-1 through B-3), but they do not appear to extend onto the Plateau. The pattern of the Pliocene sediments (Figure D-5) shows increased thickness towards the northeast (lines 23-26), corresponding with the areas of greater erosion of the underlying Miocene sequence.

Pliocene sediments in the middle region appear as a thin sequence beneath the shelf and slope. The Pliocene sequence in the northern region (lines 5A-15) is present beneath the shelf and slope on lines 15 and 13 and beneath the shelf, slope, and Blake Plateau on lines 11, 9, 7, 5C and 5A. The Pliocene on the plateau has been subjected to varying degrees of erosion; small channels have been cut into the Pliocene on lines 11 and 9, and part of the Pliocene sequence have been totally removed by erosion on lines 5C and 5A. The Pliocene crops out on the surface of the slope and plateau on lines 11, 9, 7 and 5A (Figures 9-3 and C-6). Foreset bedding is obvious in the Pliocene sequence beneath the present shelf north of line 19. Changes in dip within the Pliocene sequence on alongshelf profiles (Figures B-16 through B-21) are observed, probably representing deposition from different source locations.

Pleistocene

The distribution of Pleistocene sediments is shown in Figure C-7. Pleistocene sediments were recovered at Sites 6004, 6005 and CALDRILL C-5 and traced to adjacent lines.

waves can act as shallow water waves anywhere on the continental shelf; their refraction by capes and underwater topographic features may result in the concentration of wave energy in localized areas, causing high energy breaking waves. This particular hazard cannot be assessed from the seismic reflection data.

High-Velocity Currents

The Gulf Stream skirts the edge of the continental shelf and has a maximum flow of about 180 cm/sec (3.5 knots). It flows north across the Southeast Georgia Embayment and meanders and gyres have been observed, particularly north of the bathymetric high on the northern Blake Plateau. Reverse flows of the Gulf Stream may occur near the surface (counter currents) and on the bottom (undercurrents). The Gulf Stream and associated currents are key factors in determining the outcome of drilling operations. This is exemplified by the drilling problems encountered by the JOIDES group in 1965 and by the U.S.G.S. aboard the GLOMAR CONCEPTION in 1976 (Site 6003, Hathaway et al 1976) while drilling in Gulf Stream currents. Large areas of scour on the Blake Plateau also attest to the strength of the Gulf Stream through a large span of geologic time.

Bottom Conditions

Bottom-supported structures on the outer continental shelf would be subject to damage by scour and mass movement of bottom sediments. Additional hazards could be posed by solution cavities or shallow, high pressure gas pockets which may be present in subbottom formations, by possible movement on subsurface faults, and seismicity. Variations in the physical properties of the bottom sediments are important in determining the stability of any bottom-supported structures.

Scour by Storm-Generated Waves and Currents

The mid- and outer shelf sediments are sands which appear to be in textural equilibrium on the shallow shelf. Active deposition or redeposition is indicated by the presence of such primary structures as cross bedding, ripple marks, and graded bedding. Near the high-energy zones of the capes, current and wave action transport the sediments across the shelf and deposit mud and sand on the slope. Between the various capes, the central and outer shelf sediments migrate shoreward. Thus, the movement of currents and sediments in varying directions across the shelf could result in scour around the support structures of platforms. Scour would also present a severe problem on the inner portion of the Blake Plateau where the Gulf Stream flows along the bottom with velocities on the order of 40 cm/sec (400 to 800 m depth). The only evidence of mobile sediments observed on the seismic records were sand waves present in the northern portion of the Southeast Georgia Embayment (Figure A-3), however sand waves are undoubtedly present on other areas of the shelf. The effects of strong current on the Florida-Hatteras Slope are especially obvious on lines 5A, 13 and 17. Scour and depositional features are also seen on the Blake Plateau and examples are presented in Figures A-6, A-9, A-12, and A-13.

Mass Movement of Sediments

The medium to coarse sand typical of the continental shelf is relatively dense due to reworking by oceanic currents and thus should provide good platform support, although it will also be resistive to pile penetration. Zones on the shelf characterized by differing sediments, such as lagoonal muds and peats and stream-channel fill, would possess lower supportive capabilities since static bearing capacity and stability against sliding can be drastically reduced by the presence of even thin layers of clay.

Slumping would be unlikely on the continental shelf as the average bottom slopes are only on the order of 1^{o}. Slumping on the Florida-Hatteras Slope would be likely to occur in areas where fine-grained sediments are accumulating, in areas of truncated foreset bedding near the shelf edge, and where erosion by the Gulf Stream has removed sediments farther down on the slope. The only slumping observed in the Southeast Georgia Embayment was on line 19 (Figure A-16).

Collapse Caused by Cavernous Limestones

Many of the limestone formations of the Florida Peninsula and Bahamian Banks area are known to contain extensive networks of caves which may present serious problems in drilling and completing wells. This seismic survey did not detect any cavernous limestones, but they may be present in the shallower Tertiary sections where subsurface erosion occurred during the Pleistocene when sea level was lower. Cavernous porosity was encountered during the drilling of the Bahamas Oil No. 1 Andros Island well and the Esso No. 1 Hatteras Light well. A serious threat to bottom-mounted platforms and structures will exist in the Southeast Georgia Embayment if cavernous limestones exist at depth.

Faulting

The only large fault detected by the seismic survey was observed on line 29 (Figure A-21) beneath the Florida-Hatteras Slope. It is a normal fault, with the downthrown side to the east. Miocene and lower Pliocene sediments are displaced, while the Pleistocene and Holocene sediments do not appear to have been affected. Other faults are apparent on lines 18A, 19 and 24.

Large faults beneath the continental shelf are unknown, although numerous minute faults with displacements of 1 m or less appear to be common in some areas (see Chapter 11 this volume).

On the minisparker line connecting lines 24 and 25 (Figures A-23 and A-24) and on lines A-16 and A-21, disrupted reflectors can be seen at depth. They may represent strata broken by faulting or the effects of differential compaction and draping on a buried unconformity within the Cretaceous (Paull and Dillon, Chapter 10 this volume). A more detailed look at this area is needed before a conclusion can be made.

Seismic Activity

Although the Eastern U.S. is an area of generally low earthquake activity, a narrow northwest trending zone of historical seismicity extends across the emerged Coastal Plain in the central part of the Southeast Georgia Embayment. The 1886 Charleston, S.C. earthquake, the largest historical earthquake in the eastern United States, occurred along this zone. Numerous investigators have proposed that the seismicity reflects a landward extension of the Blake Spur Oceanic Fracture Zone. The recurrence of weak seismicity in the Southeast Georgia Embayment indicates that stronger seismicity in the future must not be discounted although the reflection survey indicates that structural type faulting is rare to nonexistent on the shelf. The major danger to structures on the shelf from a large seismic event would probably be from liquifaction of sediments.

Drilling Hazards

Gas and oil leaks during petroleum exploration and development could occur as the result of accidents, severe weather, strong currents, seismic activity, or by the encountering of high pressure gas-charged reservoirs. Drilling areas located near faulting or channel fill would be more prone to these latter dangers. In deeper water clathrates

Figure 9-4. Map showing the updip limit of water column anomalies reflecting deep-water reefs on the inner Blake Plateau.

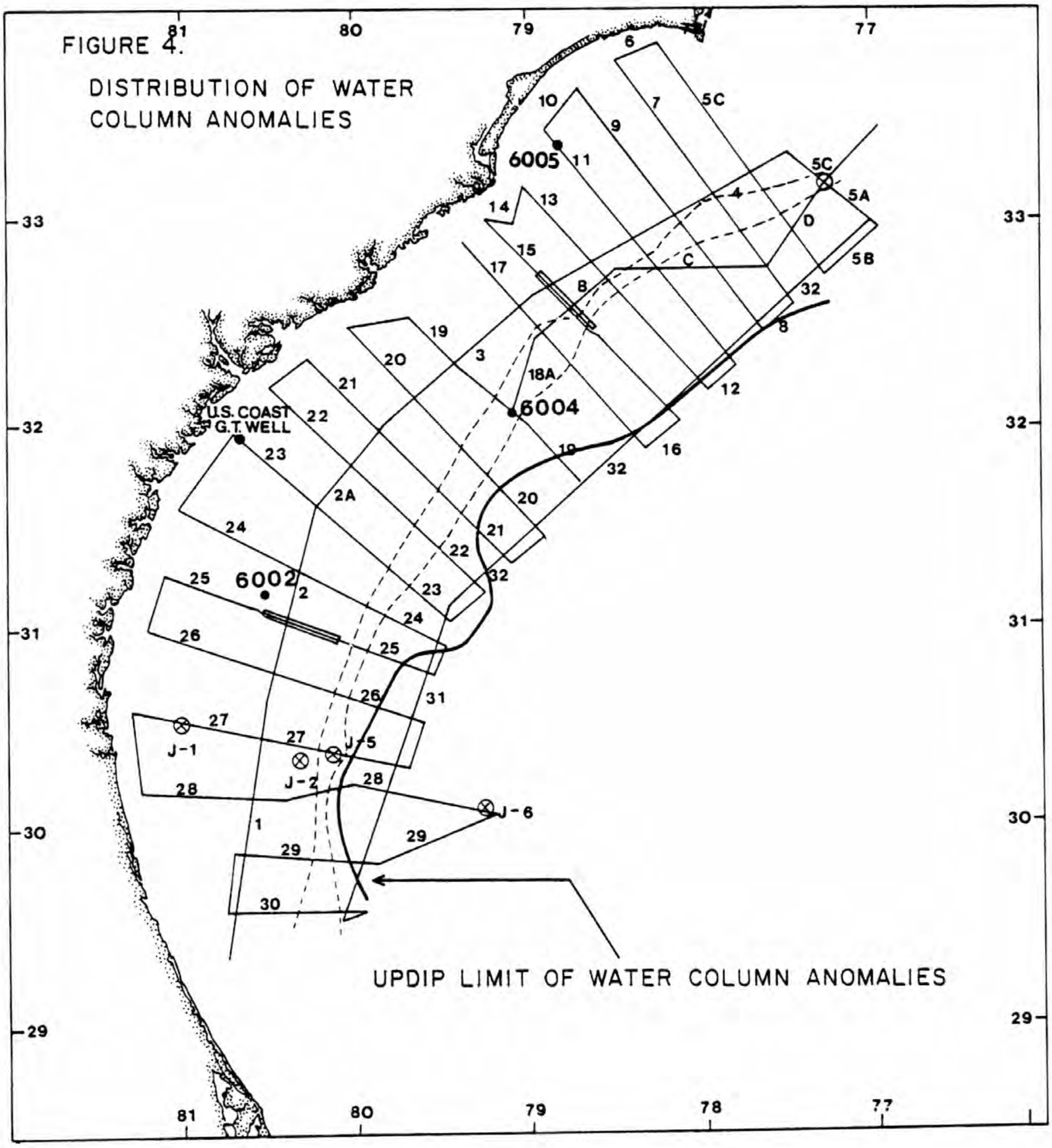
FIGURE 4.
DISTRIBUTION OF WATER
COLUMN ANOMALIES
U.S. COAST G.T. WELL
6005
6004
6002
J-1
J-2
J-5
J-6
UPDIP LIMIT OF WATER COLUMN ANOMALIES

originate from large schools of fish. Therefore, the most logical cause appears to be deep-water coral banks. John Milliman (personal communication, 1978) suggests that these are deep-water coral banks similar to ones he has seen in this area from the ALVIN and which are discussed by Stetson et al (1962). The linear pattern of several sequences of hyperbolas (Figure E-1) suggests that their source is nearly linear, like many of the coral banks Milliman observed. The reefal features in the other Figures (Figures E-2 through E-5) appear to be individual or patch-type. The lack of reef-type reflectors beneath the surface reefs suggests that they have grown above the floor of the plateau in recent times and do not have a substantial base of older reefal materials.

CONCLUSIONS

Acousto-stratigraphic units, ranging in age from Upper Cretaceous to Holocene have been identified and dated by extrapolation of paleontologic ages assigned to samples recovered from four JOIDES, three U.S.G.S. drill sites, CALDRILL C-5, and from vibracore, piston core, and dredge samples. The post-Upper Cretaceous sequence is thin and exhibits a complex history of erosion and deposition with numerous unconformities. The Southeast Georgia Embayment has been subjected to erosion by north to northeast flowing currents since at least Paleocene time. These currents have shifted back and forth across the continental margin and have effectively blocked the seaward accumulation of the various Cenozoic sequences. In addition, currents have incised into Cenozoic sequences, producing numerous channels. The Southeast Georgia Embayment can be divided into three distinct regions. The southern region (lines 23-30) has had the Gulf Stream and its predecessors flowing northward along the margin near the base of the present Florida-Hatteras Slope since Miocene time. Pliocene and younger sequences have been unable to bypass the currents and reach the Plateau. In the middle region (lines 17-22), these currents have turned slightly to the northeast. The lack of sediments younger than Paleocene on the Plateau in the middle region attests to the strenuous activity of currents since that time. The northern region (lines 5A-15) demonstrates that these currents have turned in a more easterly direction, thus allowing Eocene and younger sediments to reach the Blake Plateau. Minor channels are locally present in the younger sequences which suggests that major current activity in the northern region (lines 5A-15) has not occurred since post-Oligocene time.

The distribution of the Cenozoic sequence suggests that the Continental Shelf, Slope, and Blake Plateau have formed in an area where dynamic equilibrium has been established between sediment supply and the erosional activities of the Gulf Stream and its predecessors.

A number of potential environmental hazards have been identified in the previous section. It is reasonable to expect that problems associated with severe weather conditions and the Gulf Stream and its associated flows would be the most consistent problems to be encountered. Problems related to bottom conditions, other than scour of bottom sediments, can probably be avoided by detailed site surveys before drilling. The collapse of material above solution cavities or the presence of shallow gas pockets may be more difficult to predict. The only unpredictable event, other than weather-generated phenomena, which could create major difficulties, would be seismic activity in the embayment. There is no way at present of predicting these events, except for the historical record, which does not indicate seismicity on

vol. 55, pp. 110-115.

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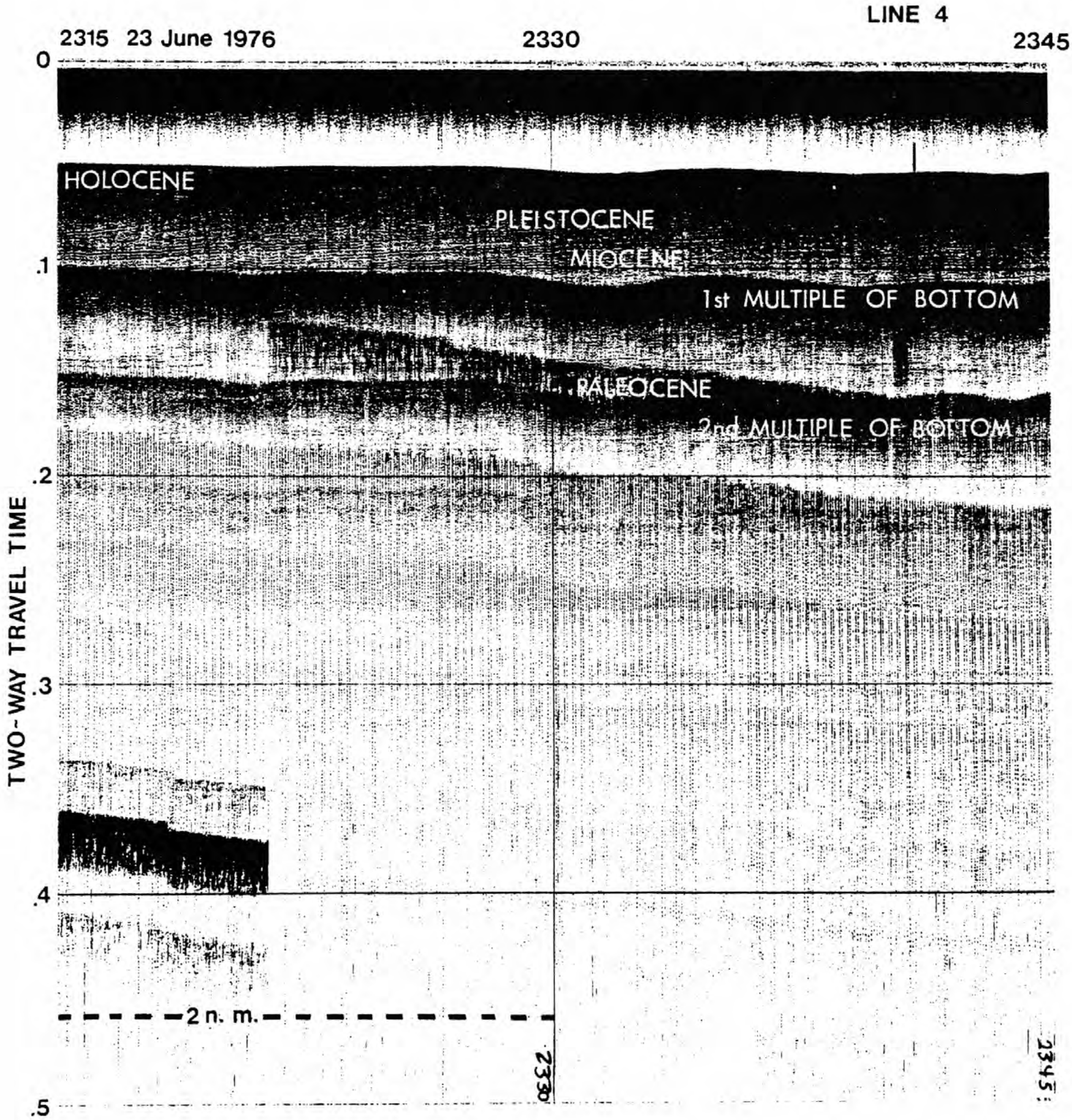
APPENDIX 9A

Features Demonstrated on Minisparker Records

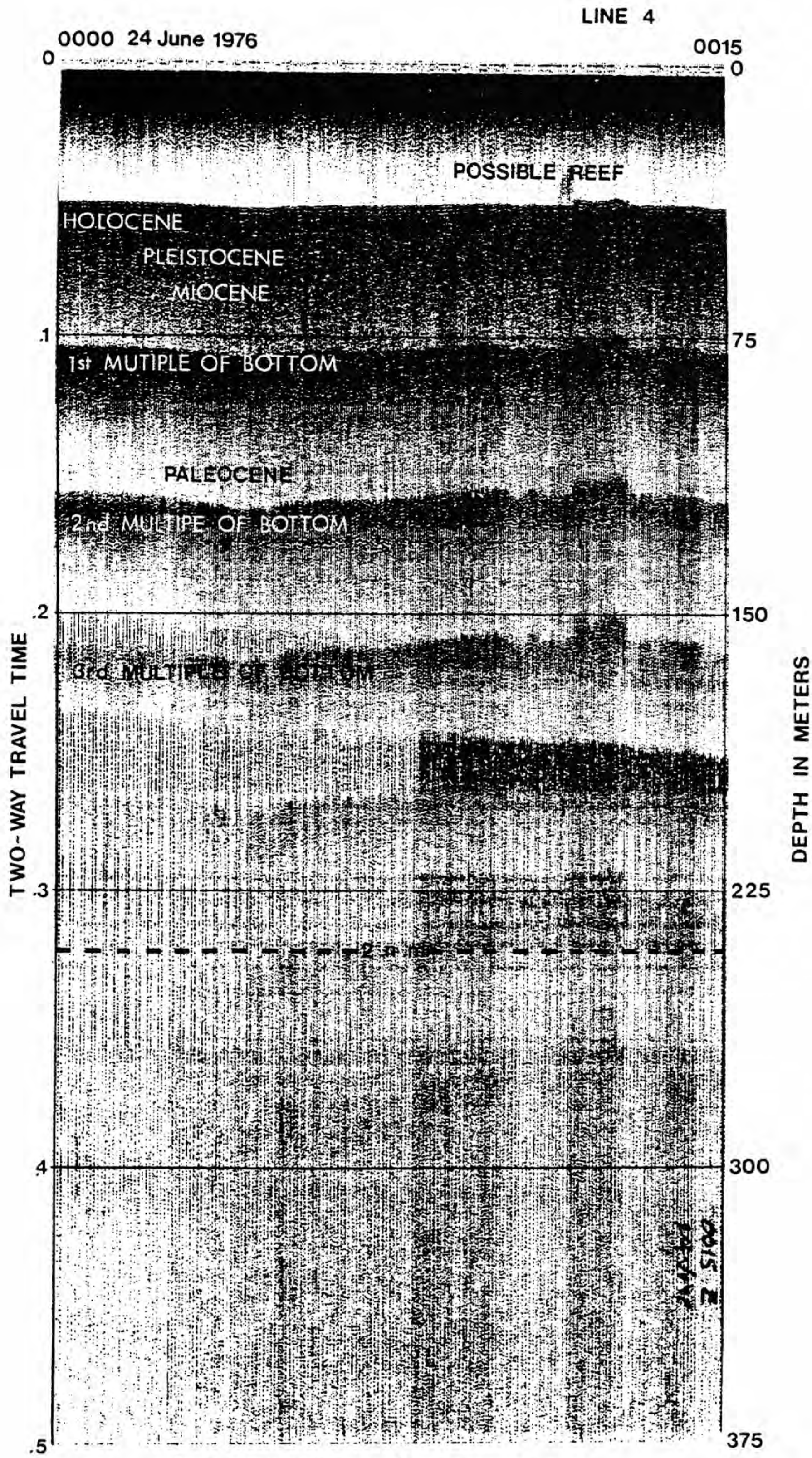
Photograph No.	Line No.	Time	Date	Feature
A- 1	4	2315-2345	23 June	Continental Shelf, minimum penetration
A- 2	4	0000-0015	24 June	Continental Shelf, possible reef
A- 3	5A	0115-0145	24 June	Continental Shelf, sand waves
A- 4	5A	0230-0245	24 June	Shelf Break, reef
A- 5	5A	0300-0330	24 June	Florida-Hatteras Slope, CALDRILL C-5 location and dating control
A- 6	5A	0400-0430	24 June	Blake Plateau, erosional channel
A- 7	5C	1445-1515	24 June	Florida-Hatteras Slope, pinchout of sedimentary sequences at base
A- 8	11	1530-1545		Line 11 crossing drill site 6005
A- 9	7	1430-1500	25 June	Blake Plateau, channel fill
A-10	9	2230-2300	25 June	Blake Plateau, erosional appearance of Oligocene sediments
A-11	11	2115-2145	26 June	Continental Shelf-Florida-Hatteras Slope transition
A-12	11	0030-0100	27 June	Blake Plateau, erosional detail on Miocene sequence
A-13	13	0930-1000	27 June	Blake Plateau, Oligocene outliers
A-14	15	0630-0700	28 June	Continental Shelf-Florida-Hatteras Slope transition
A-15	17	0400-0430	29 June	Florida-Hatteras Slope, subbottom structures
A-16	19	0400-0430	15 July	Florida-Hatteras Slope, slump
A-17	22	0015-0045	6 July	Florida-Hatteras Slope, recent reefs
A-18	27	1515-1530	10 July	Florida-Hatteras Slope, vicinity of drill site J-5

Appendix 9A - Features Demonstrated on Minisparker Records (continued)

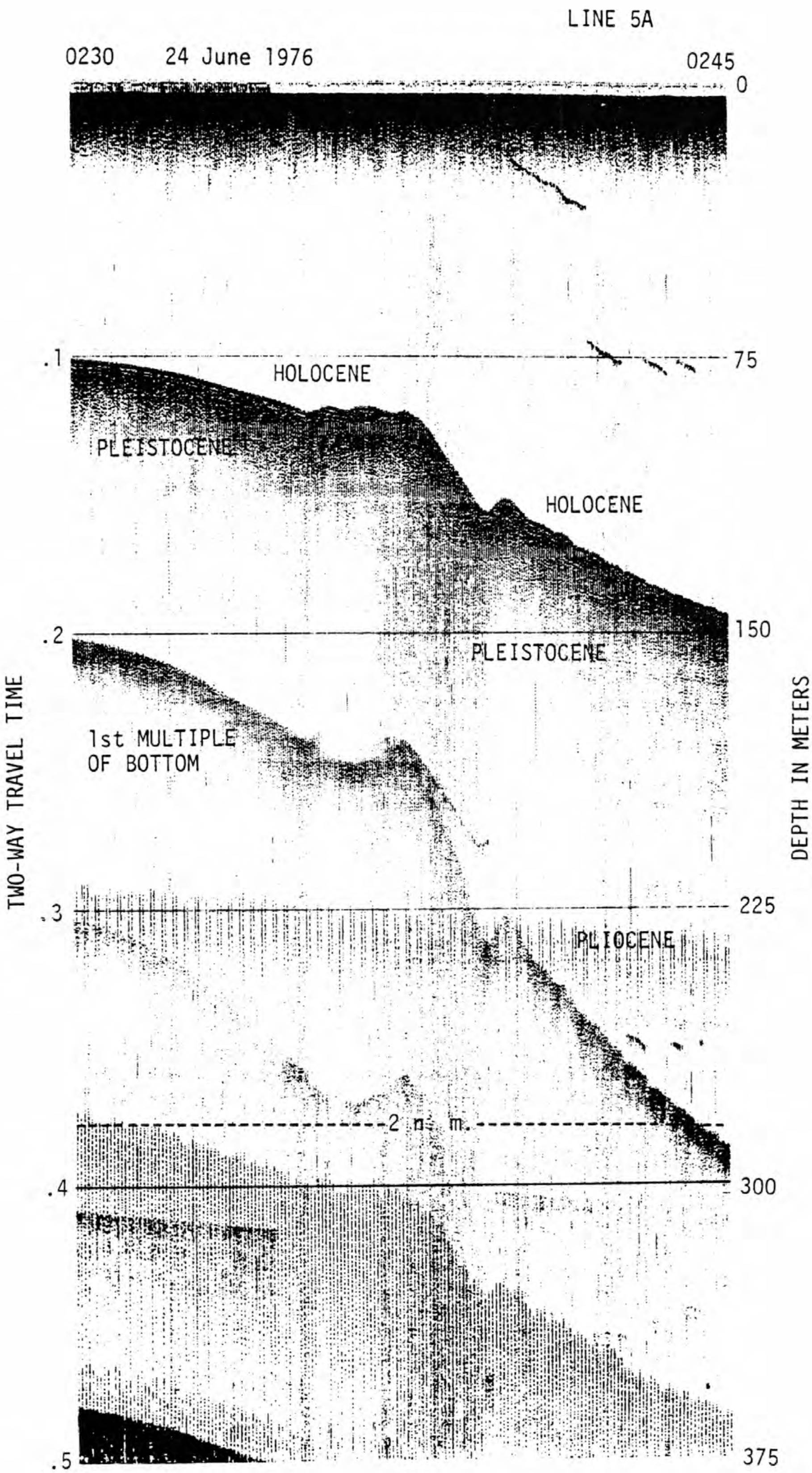
Photograph No.	Line No.	Time	Date	Features
A-19	27	1415-1450	10 July	Florida-Hatteras Slope, erosion
A-20	29	1100-1130	12 July	Continental Shelf-Florida-Hatteras Shelf transition, reefal feature
A-21	29	1030-1100	12 July	Florida-Hatteras Slope, shallow fault
A-22	32	0815-0900	14 July	Blake Plateau, pinchout of Pleistocene, Pliocene, and Miocene
A-23	24-25	2030-2115	7 July	Blake Plateau, subsurface faulting
A-24	24-25	2230-2300	7 July	Blake Plateau, subsurface faulting



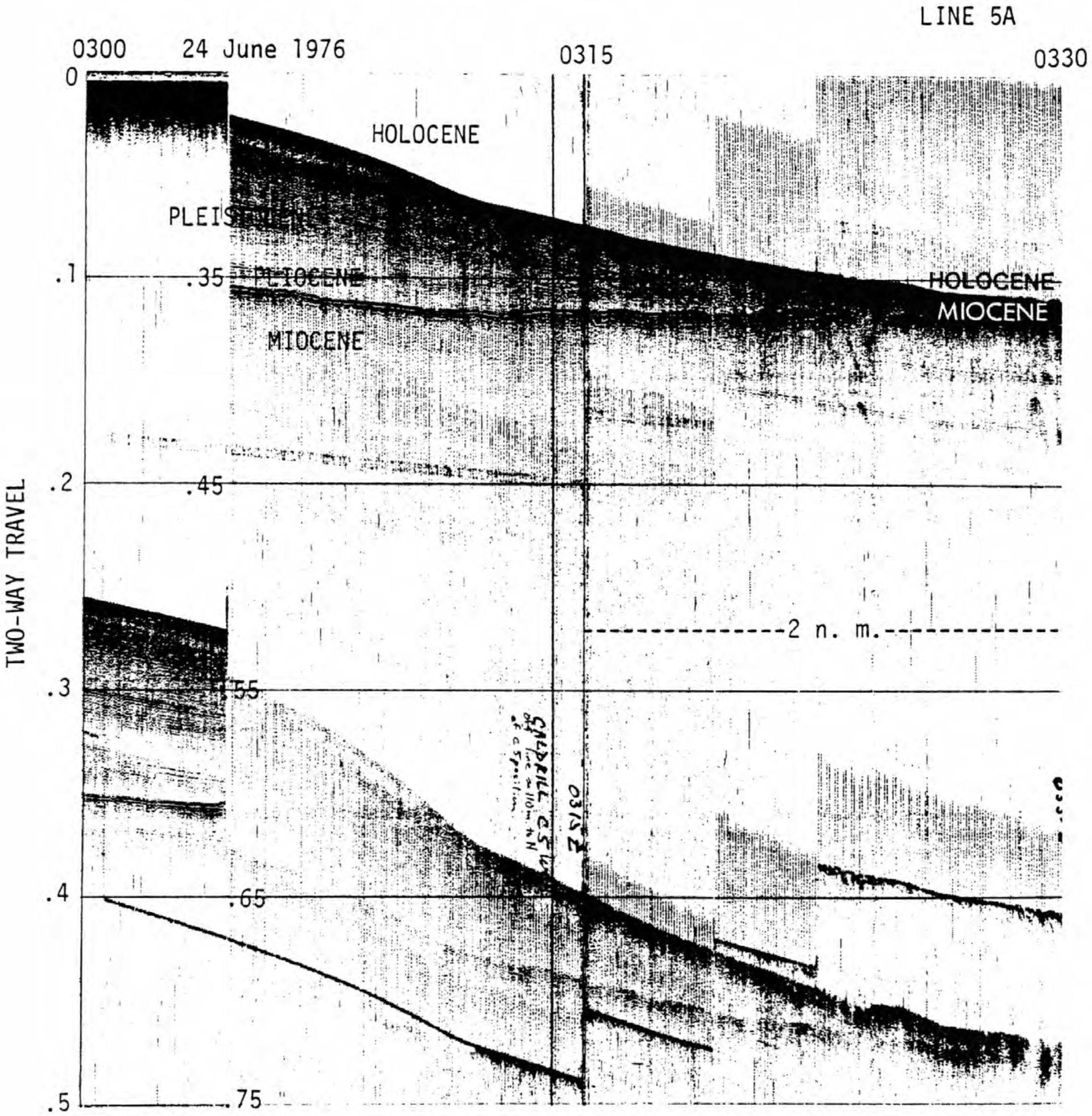
A 1 Crossing of Line 4 and Line 5C
Note minimum amount of penetration and interference of bottom multiples.



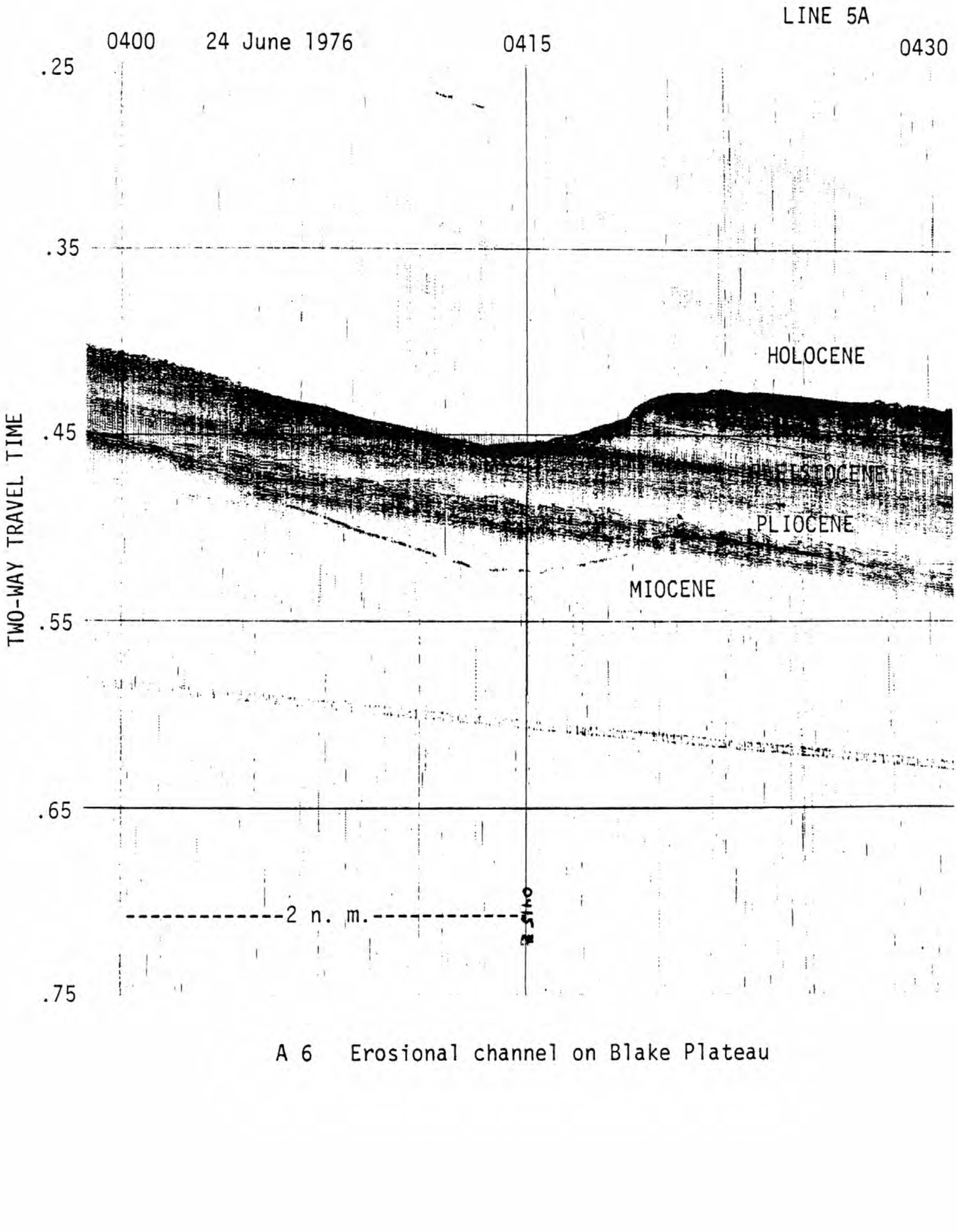
A 2 Possible reef or gas seep



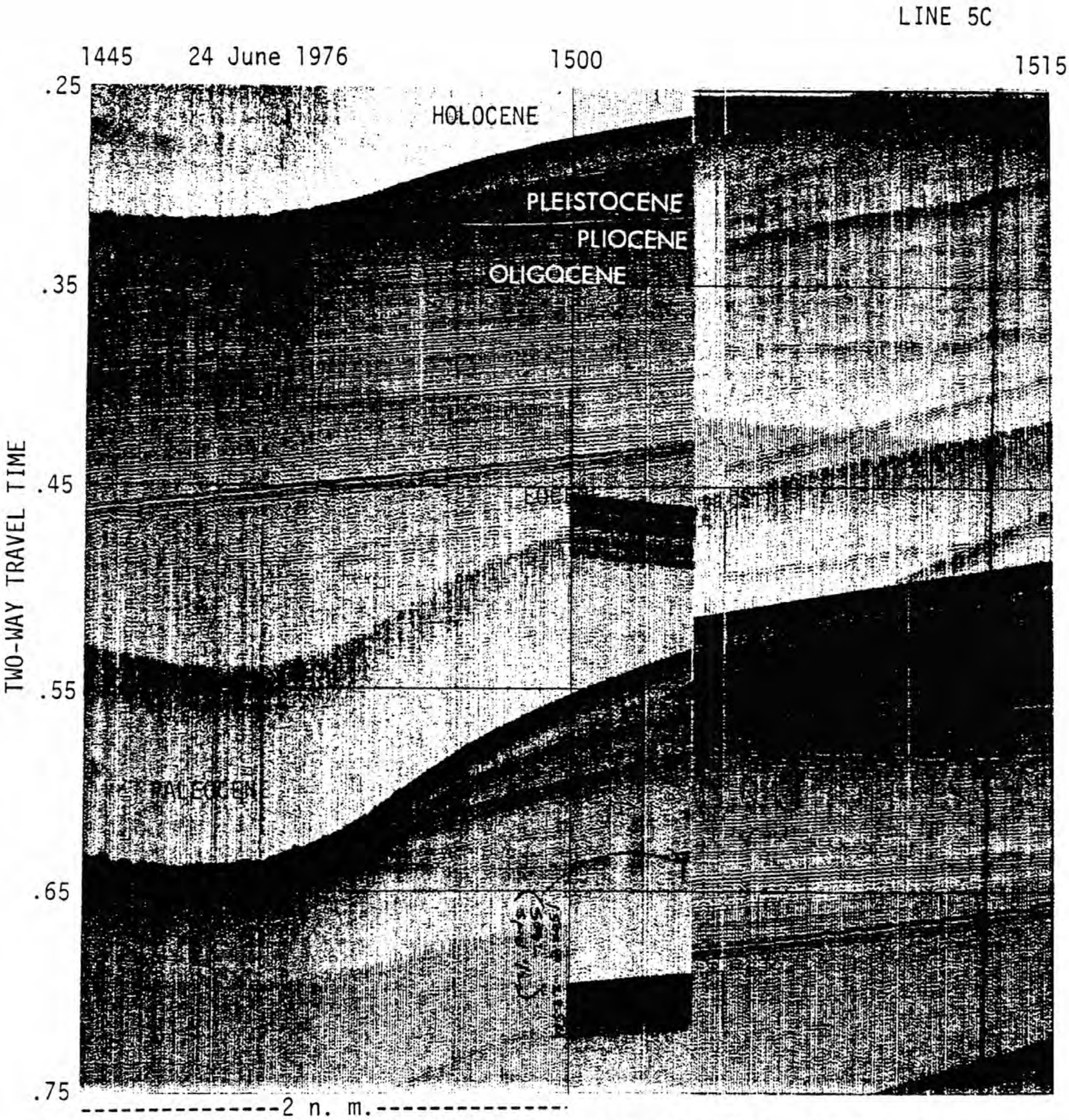
A 4 Shelf edge reef



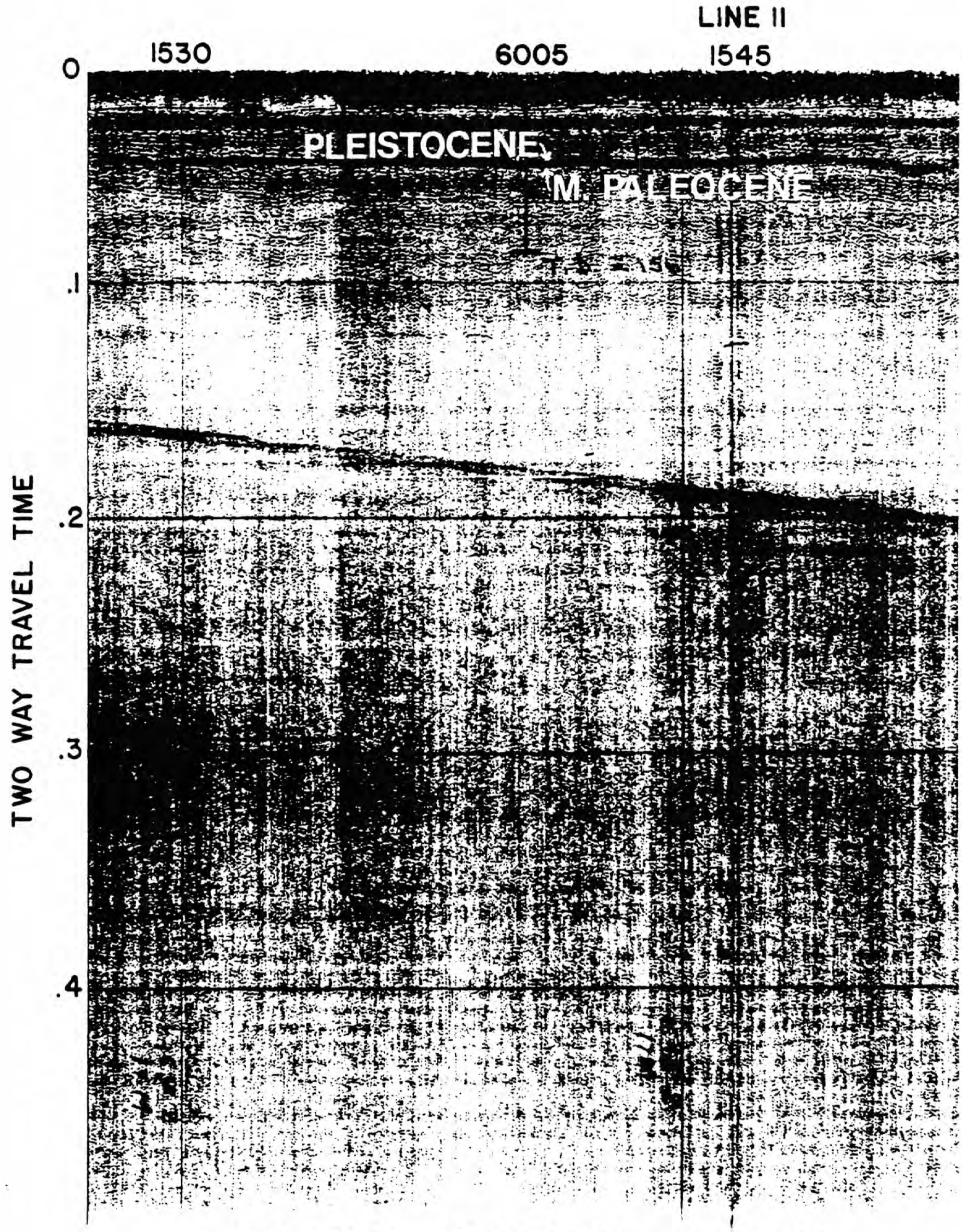
A 5 Florida Hatteras Slope-Blake Plateau transition
Dating control provided by Caldrill C-5 well



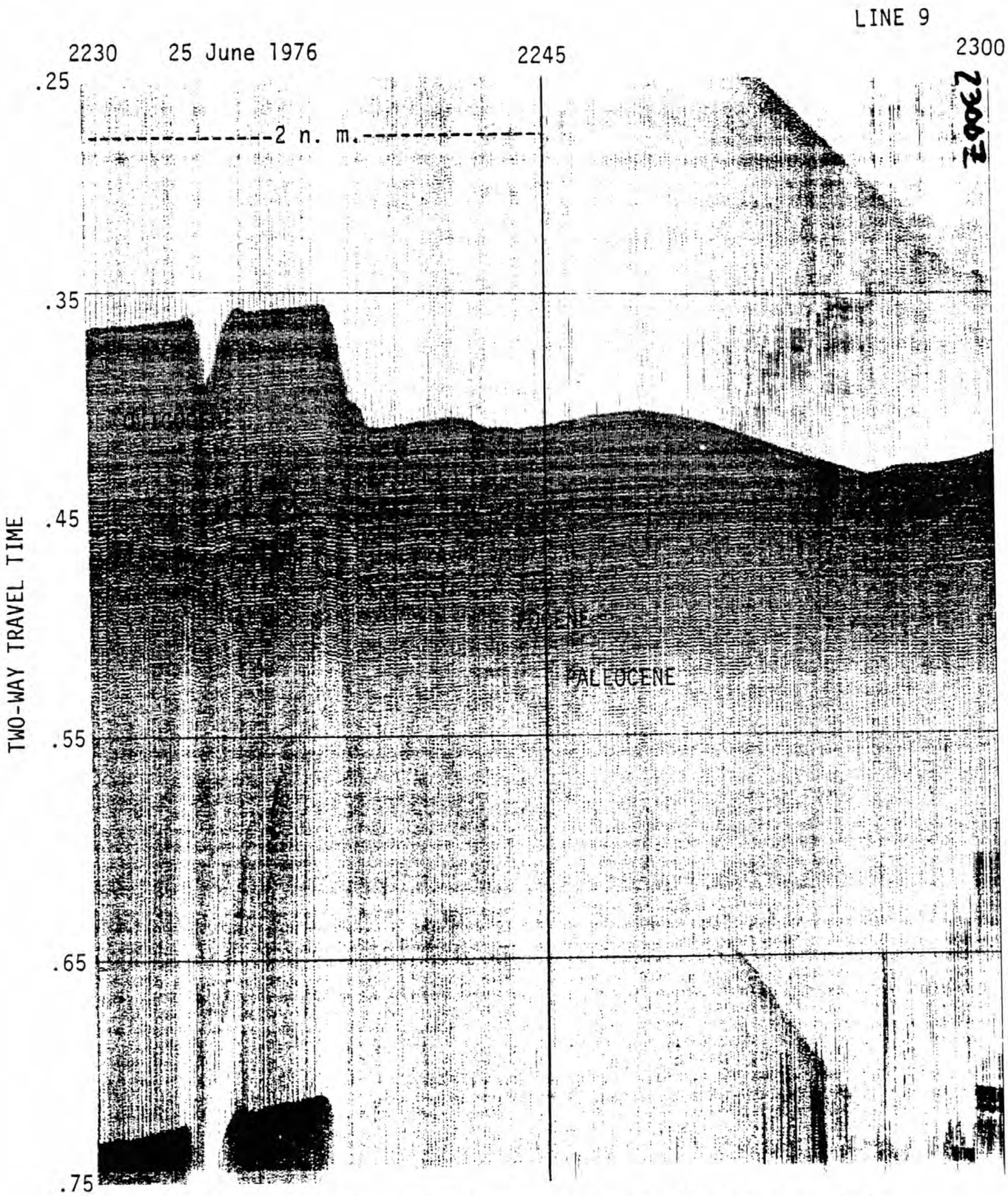
A 6 Erosional channel on Blake Plateau



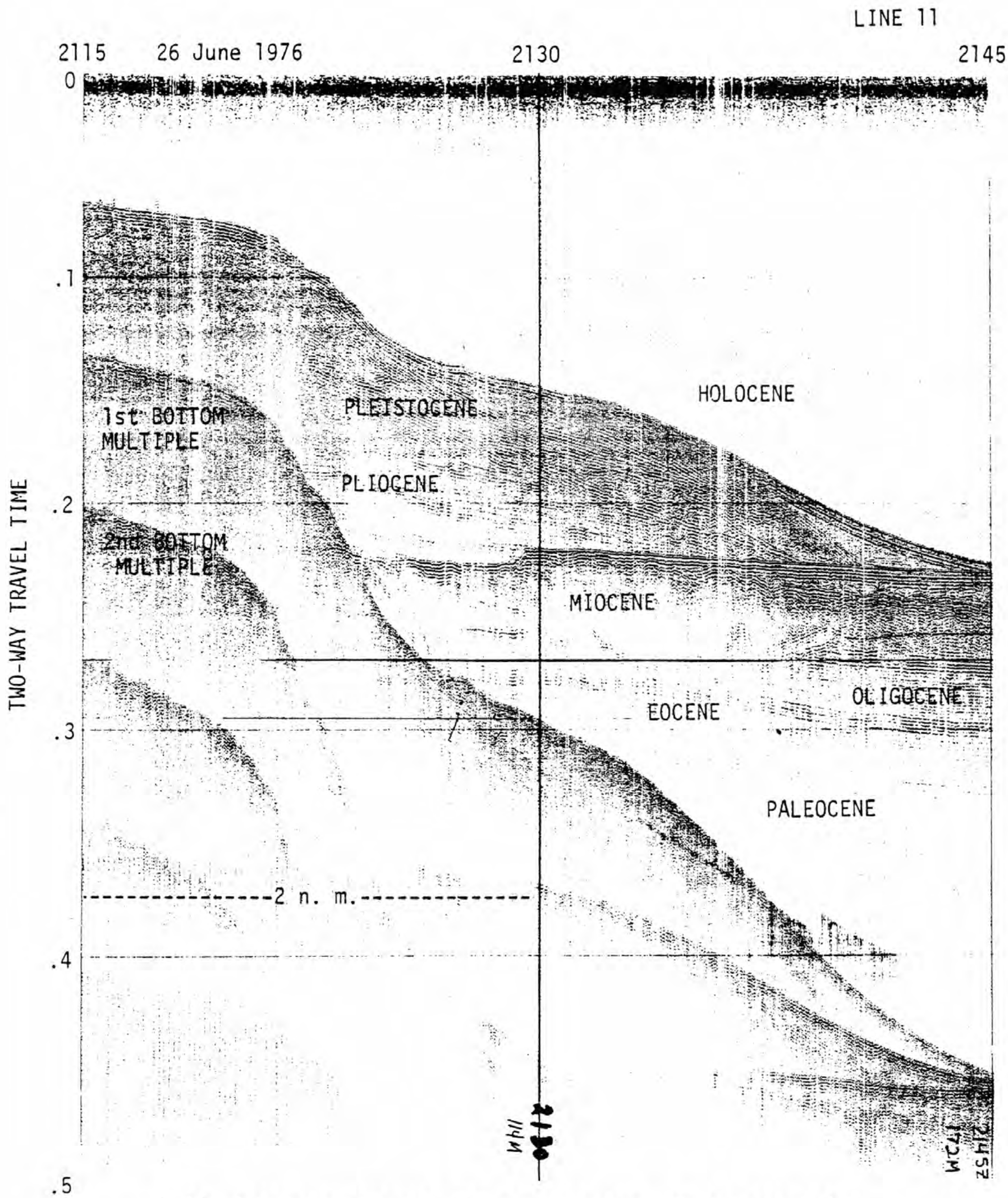
A 7 Pinchout of sedimentary sequences at base of Florida-Hatteras Slope



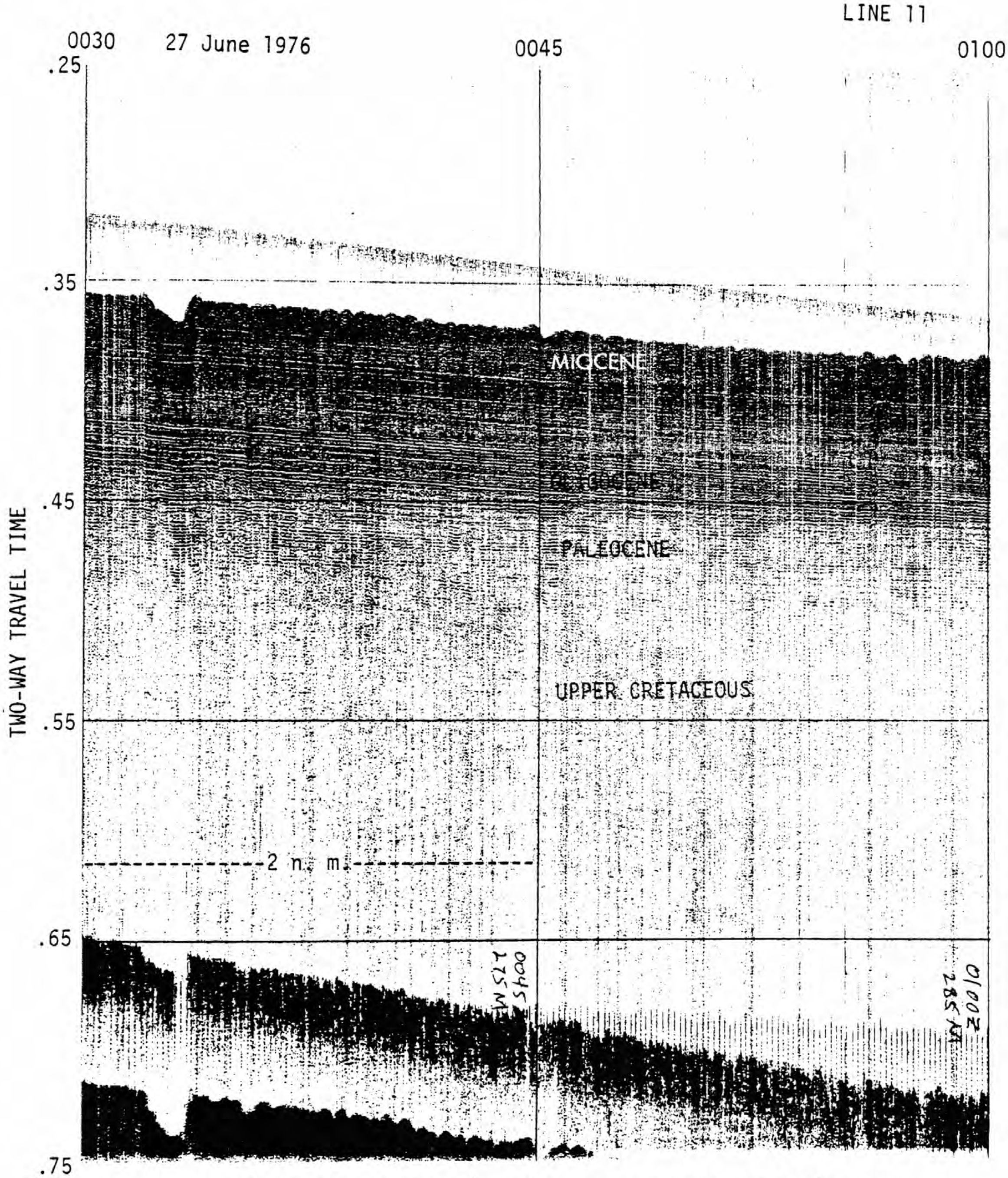
A-8 LINE 11 CROSSING DRILL SITE 6005



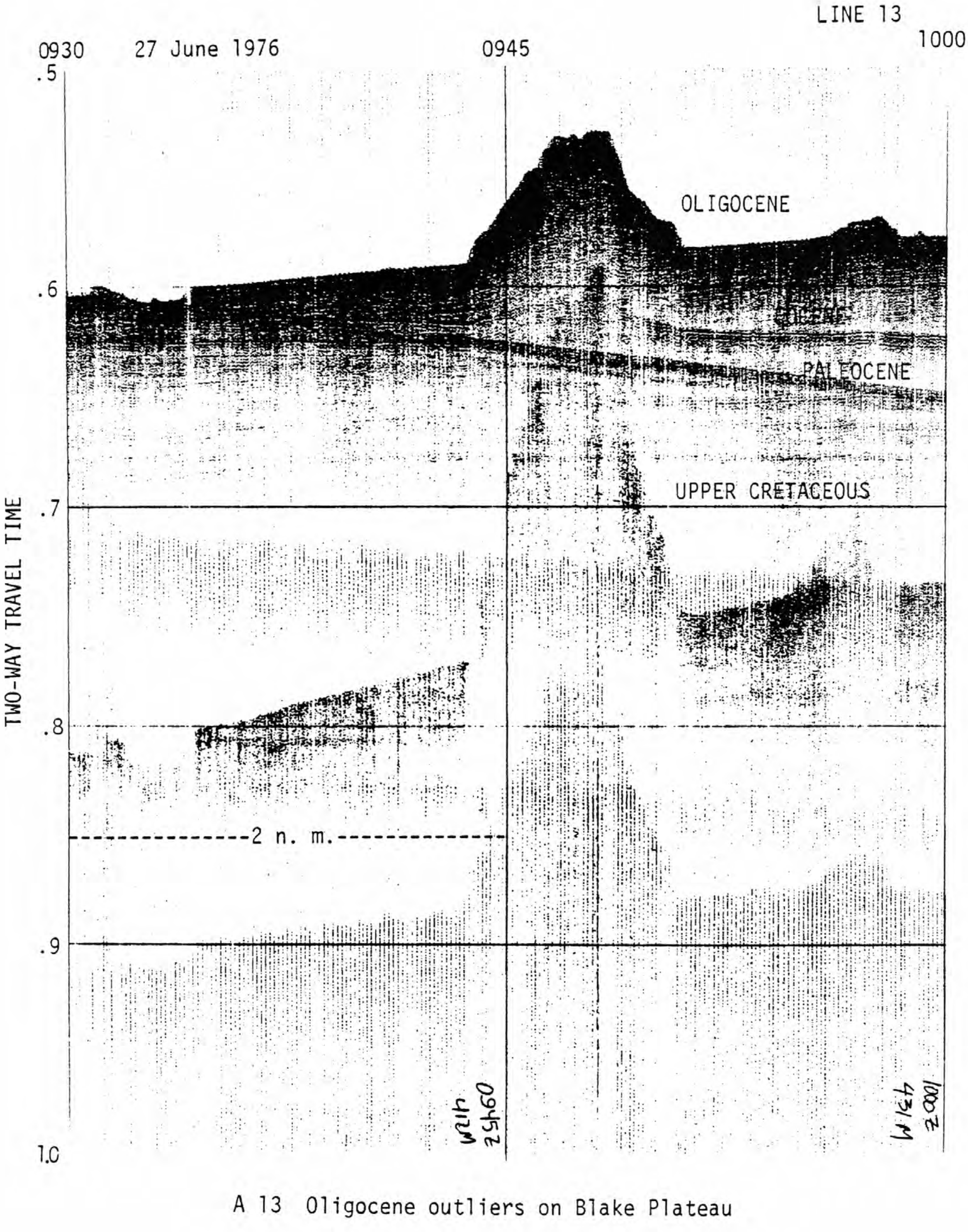
A 10 Typical erosional appearance of Oligocene sequence on Blake Plateau in northern region



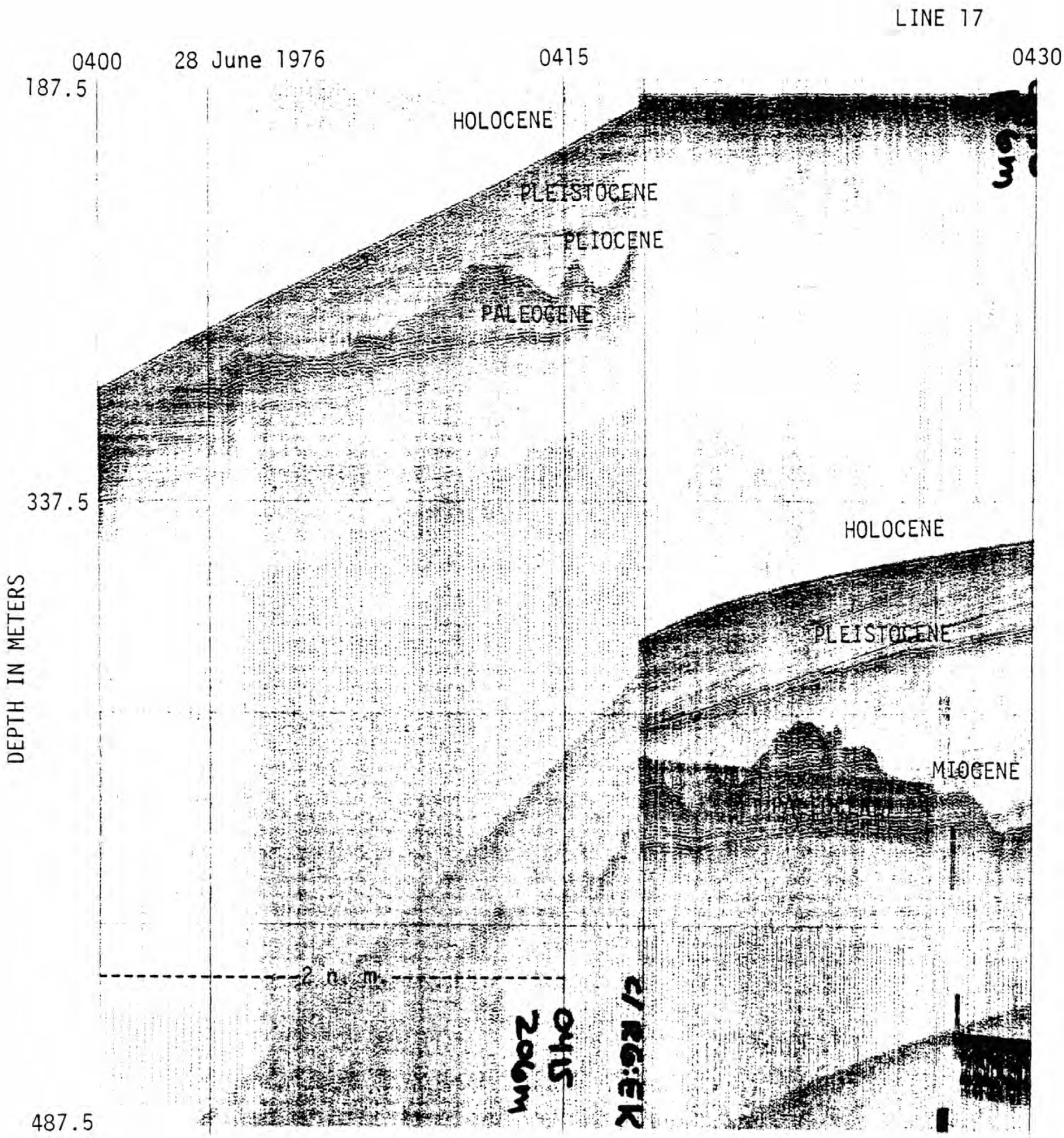
A 11 Continental Shelf-Florida-Hatteras Slope transition



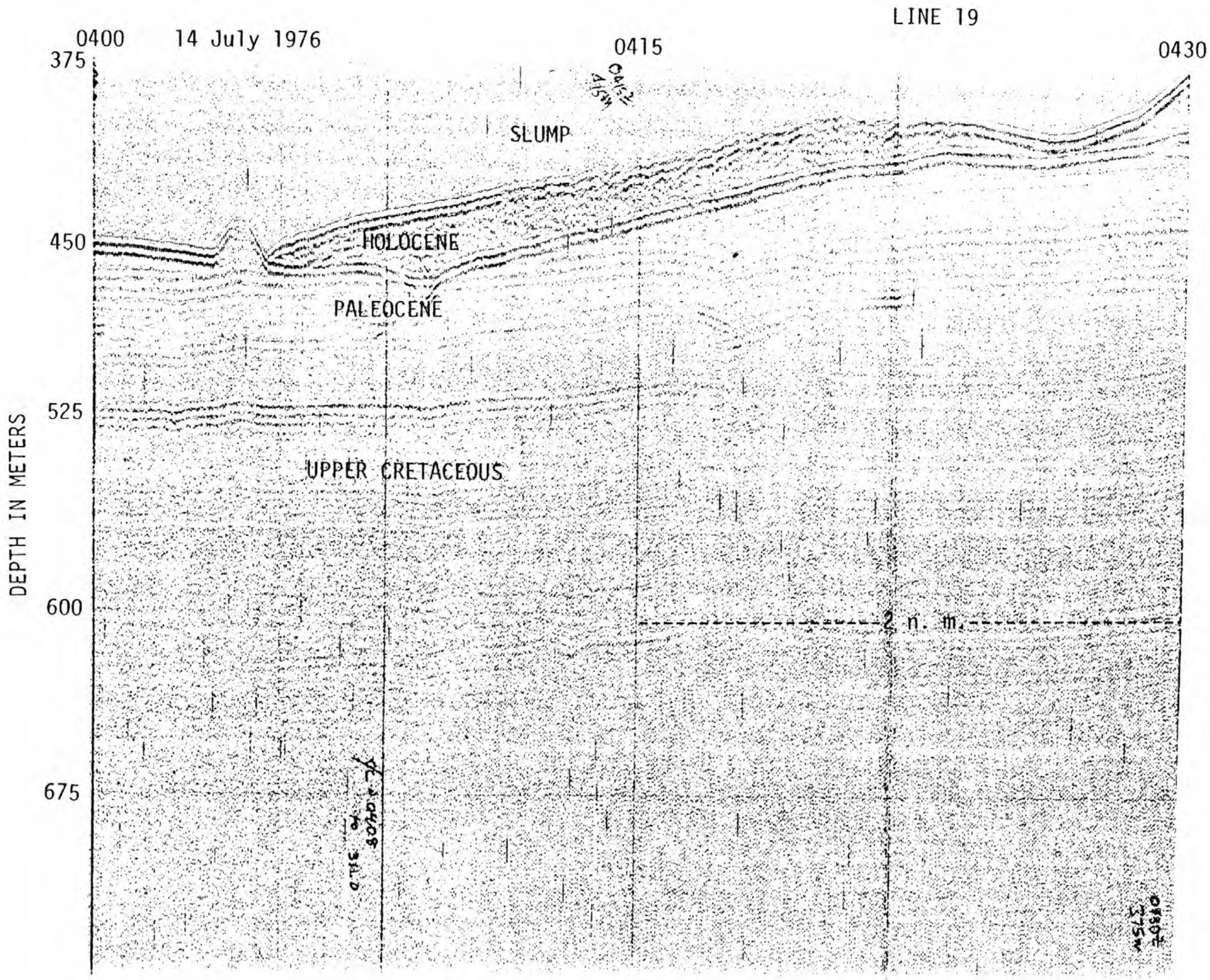
A 12 Erosional detail on Miocene sequence exposed on Blake Plateau



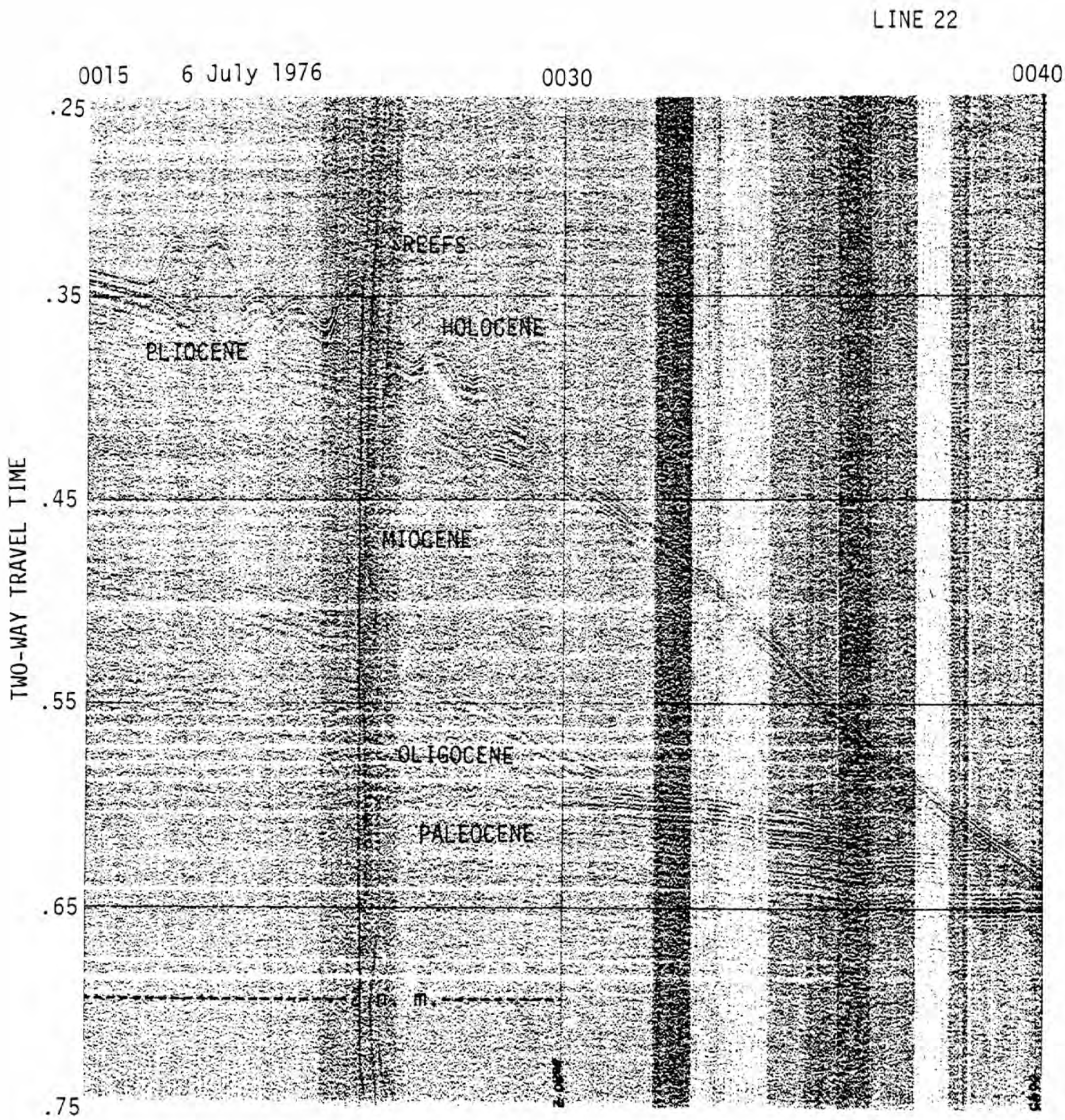
A 13 Oligocene outliers on Blake Plateau



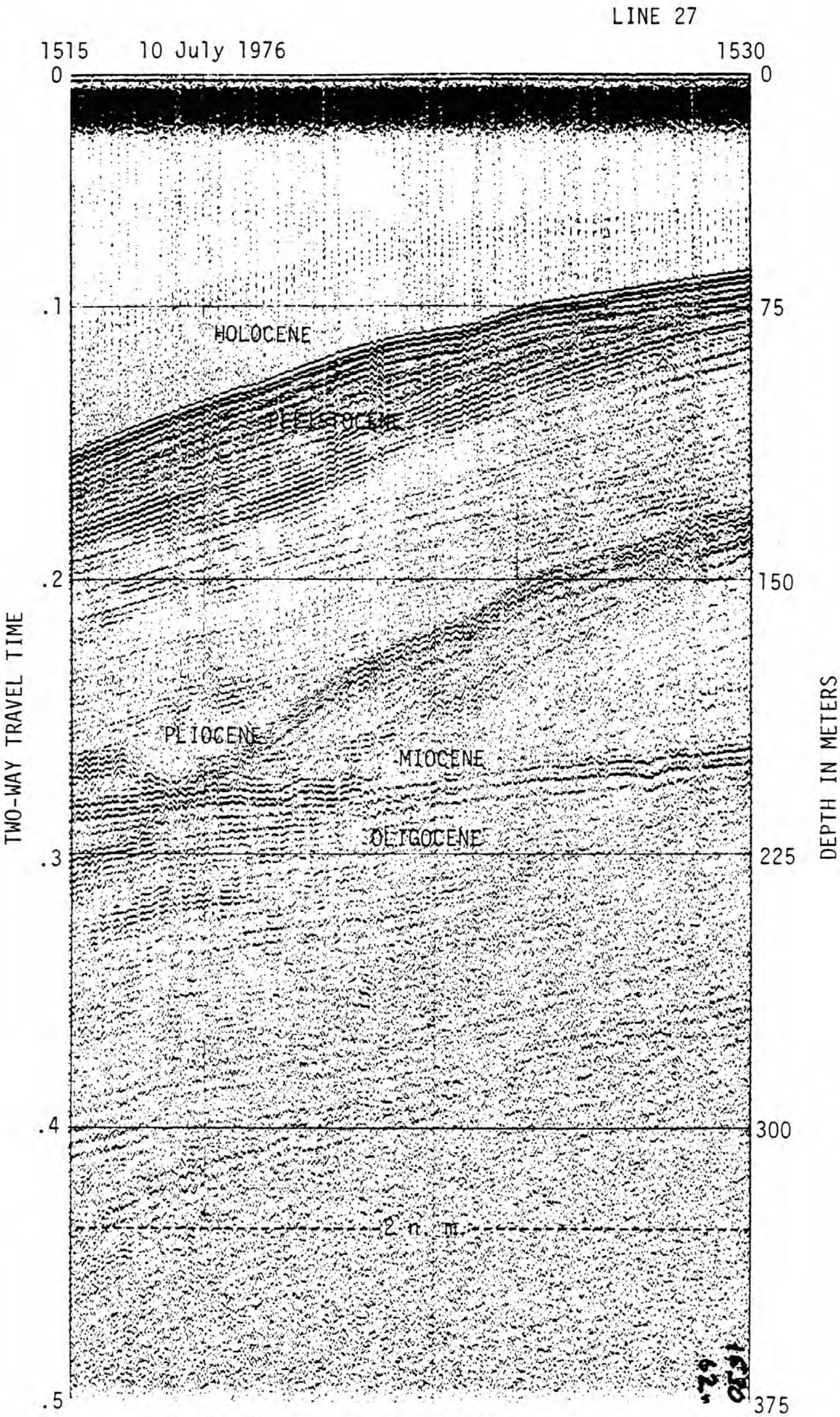
A 15 Sedimentary sequences beneath Florida-Hatteras Slope. Note prominent Paleocene shelf-edge which has effectively blocked Pliocene and older sediments from reaching Blake Plateau



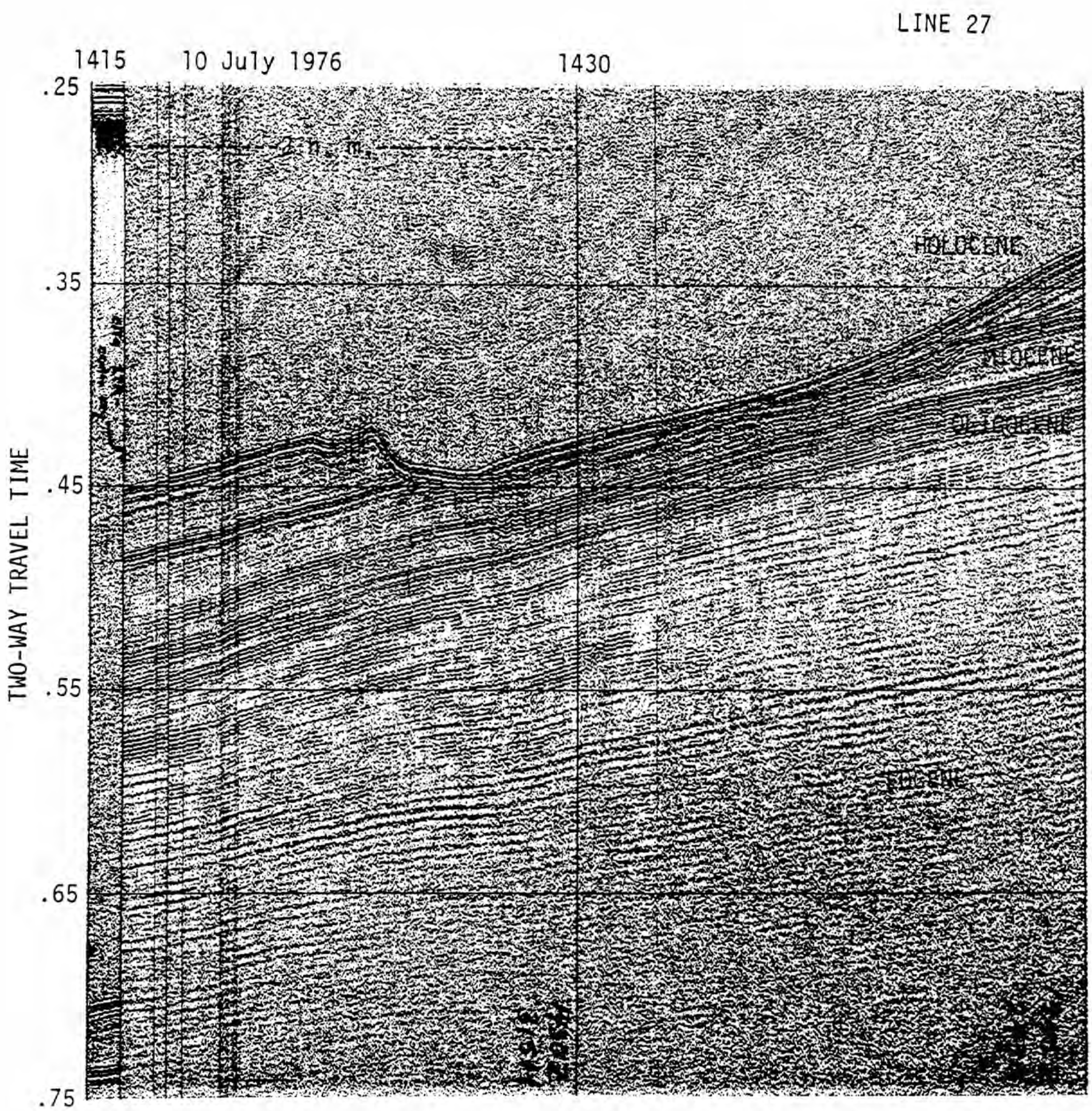
A 16 Slump sheet at base of slope



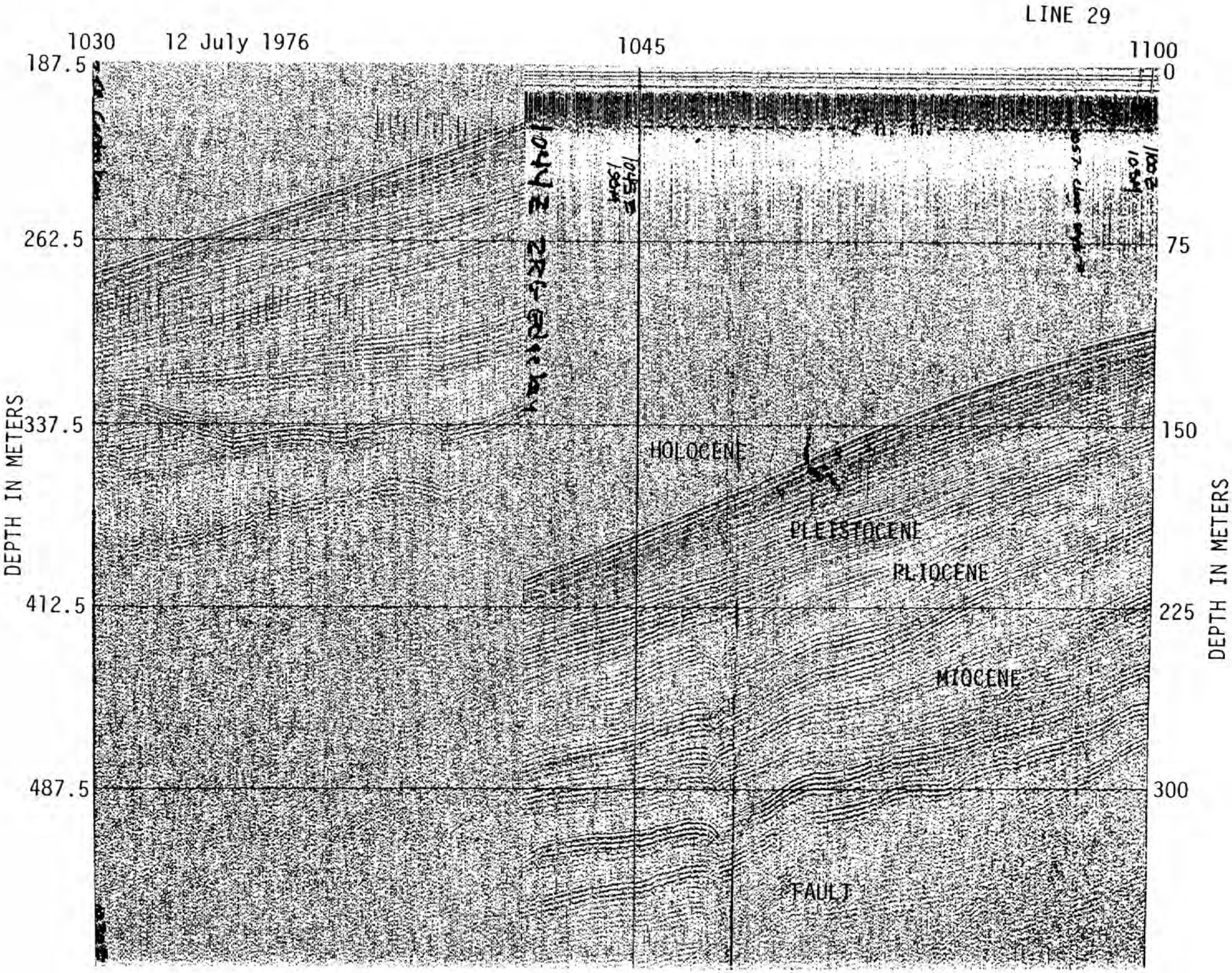
A 17 Recent reefs on Florida-Hatteras Slope



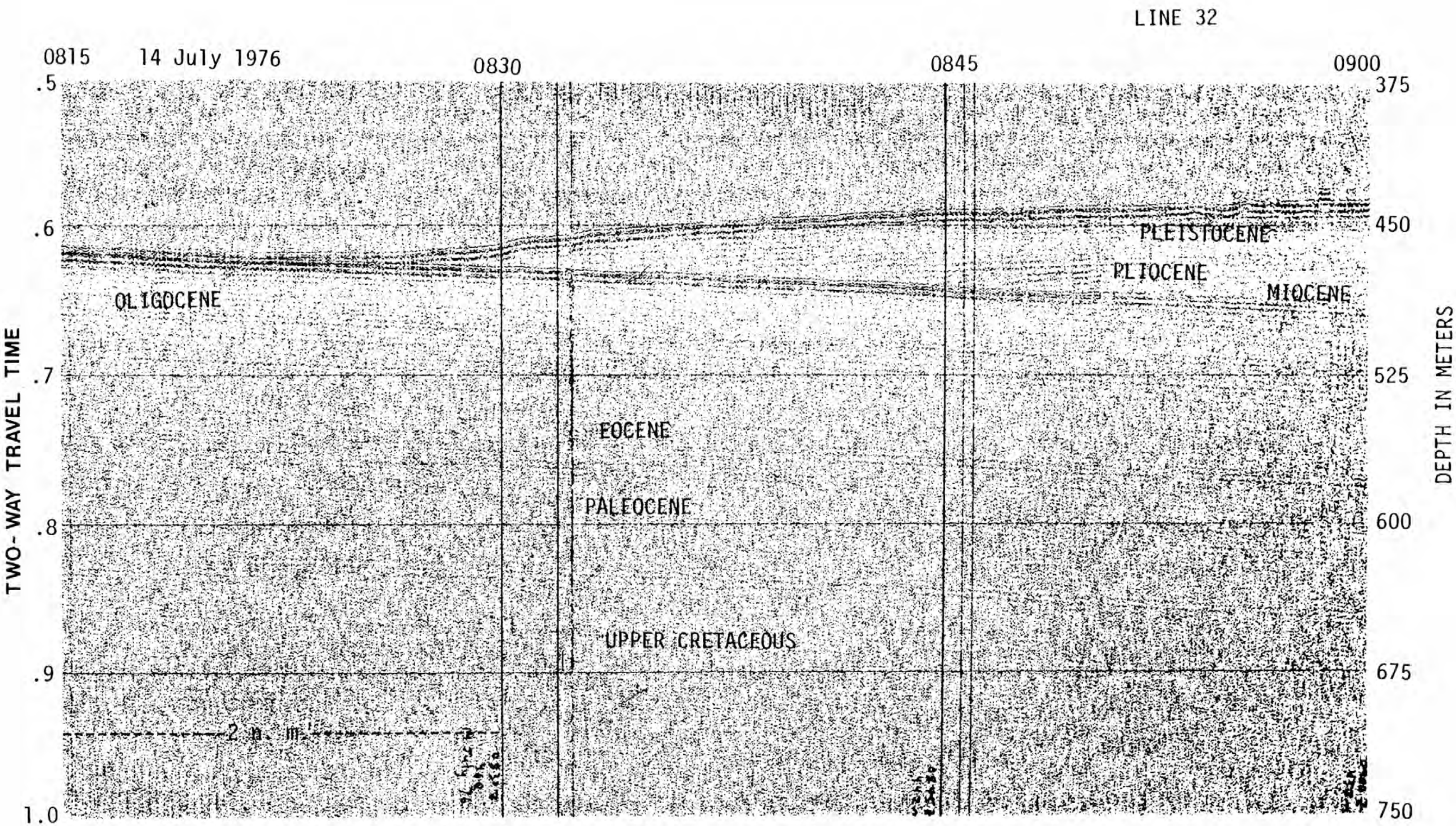
A 18 Northwest of drill hole J-5



A 19 Erosion at base of Florida-Hatteras Slope

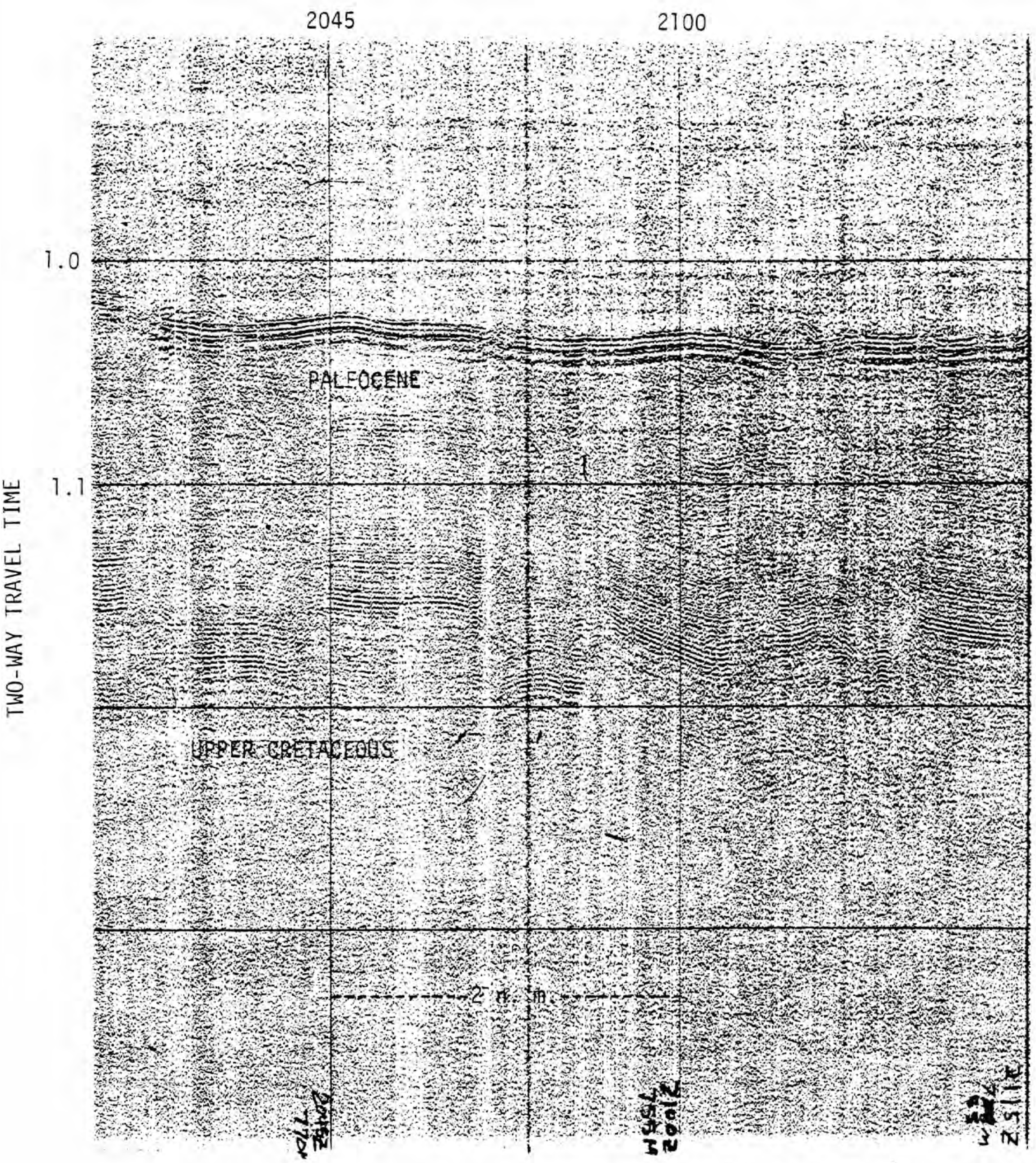


A 21 Shallow fault on slope

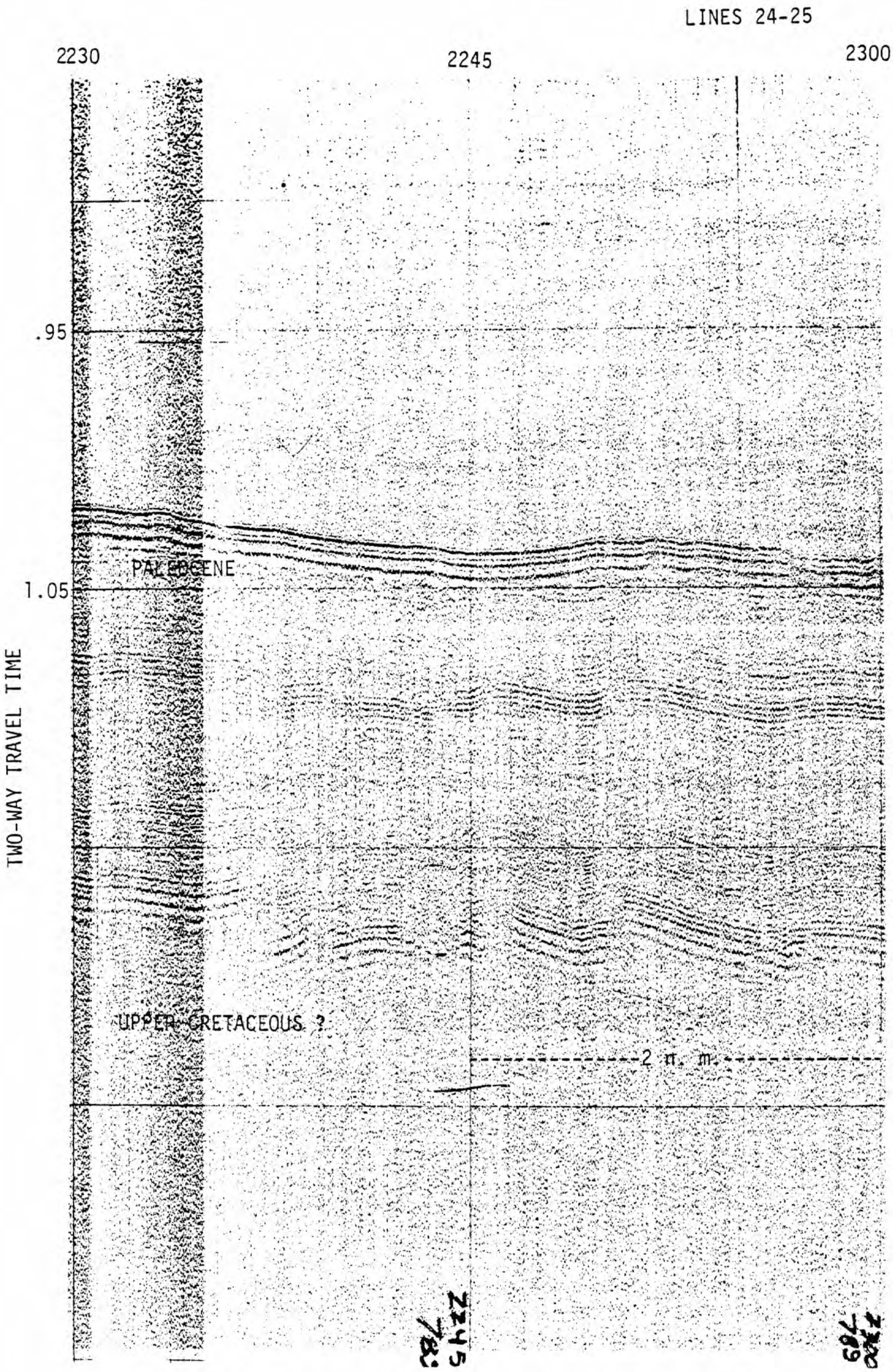


A 22 Pinchout of Pleistocene, Pliocene, and Miocene sequences between lines 5C and 5

LINES 24-25



A 23 Possible subsurface faulting or draping of sediments across buried unconformity



A 24 Possible subsurface faulting or draping of sediments over buried topography

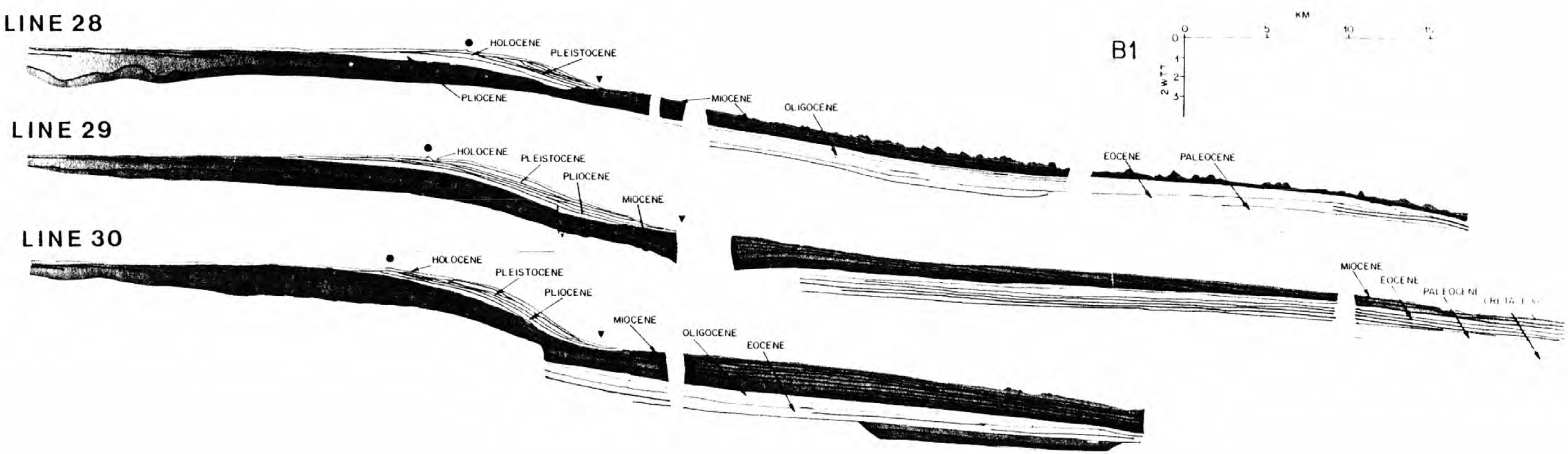
APPENDIX 9B

Line Drawings of Minisparker Record Interpretations

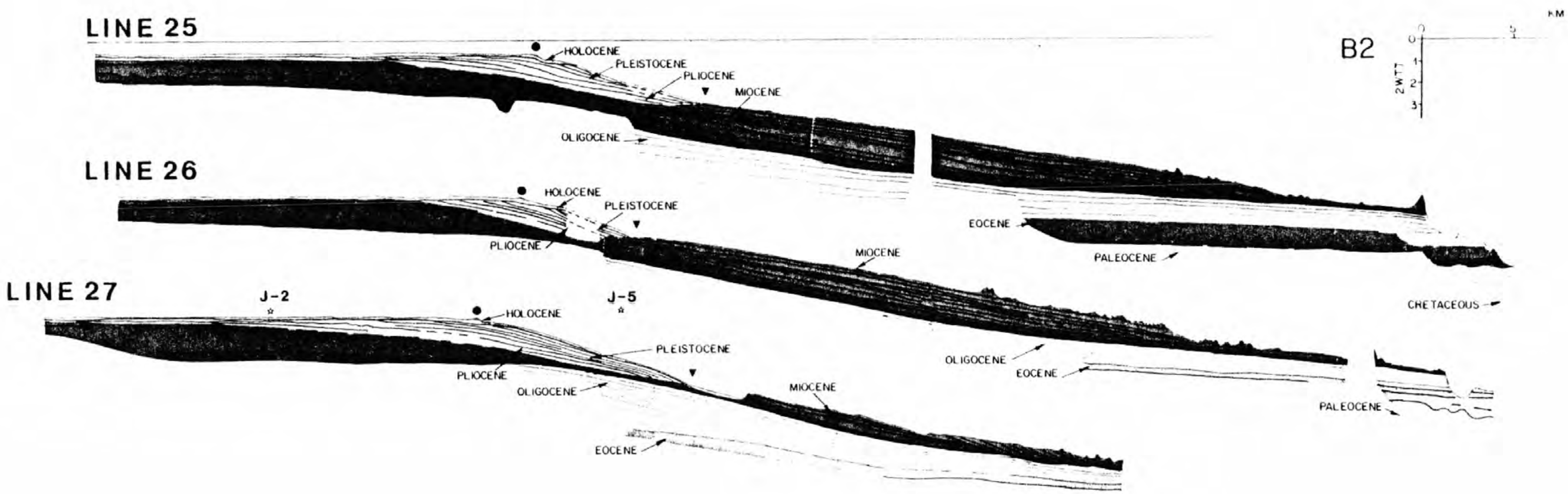
B- 1	lines 30, 29 and 28
B- 2	" 27, 26 and 25
B- 3	" 24, 23 and 22
B- 4	" 21, 20 and 19
B- 5	" 17, 15B, 15 and 15A
B- 6	" 13, 11 and 9 - part 1
B- 7	" 13, 11 and 9 - part 2
B- 8	" 7, 5C and 5 - part 1
B- 9	" 7, 5C and 5 - part 2
B-10	tie lines 32 and 31
B-11	tie line 18
B-12	tie lines 1, 2, 2A, 3 and 4

△ location of base of slope

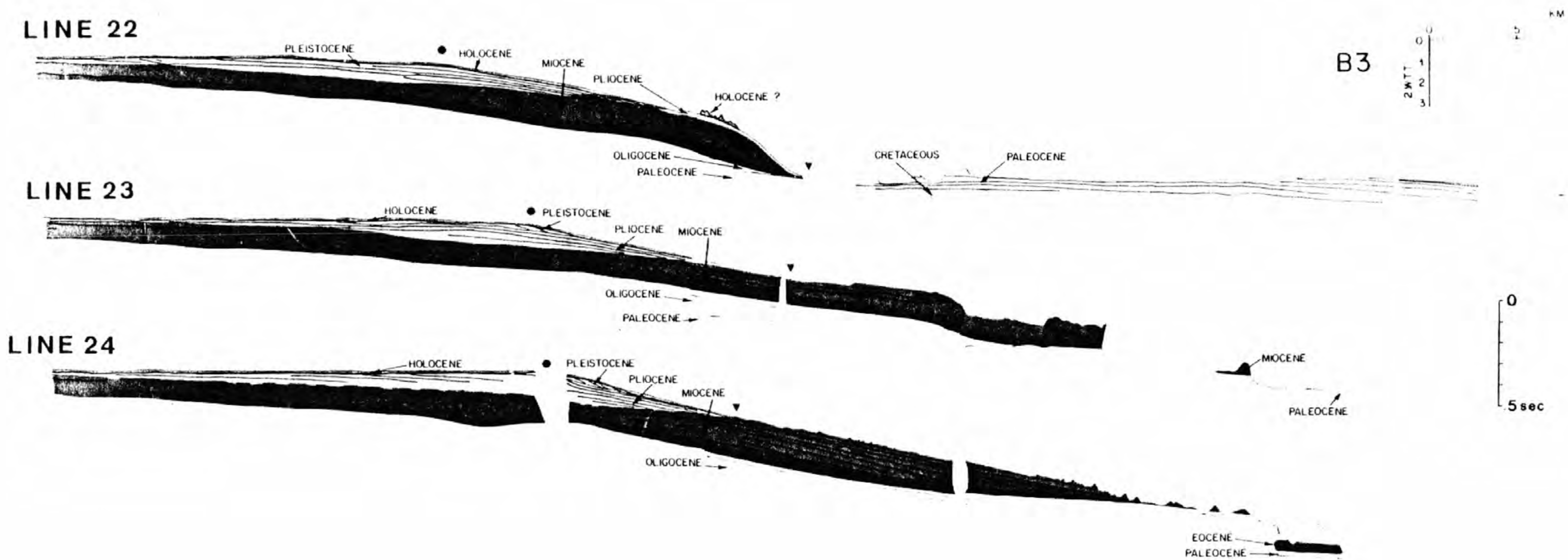
○ location of shelf break



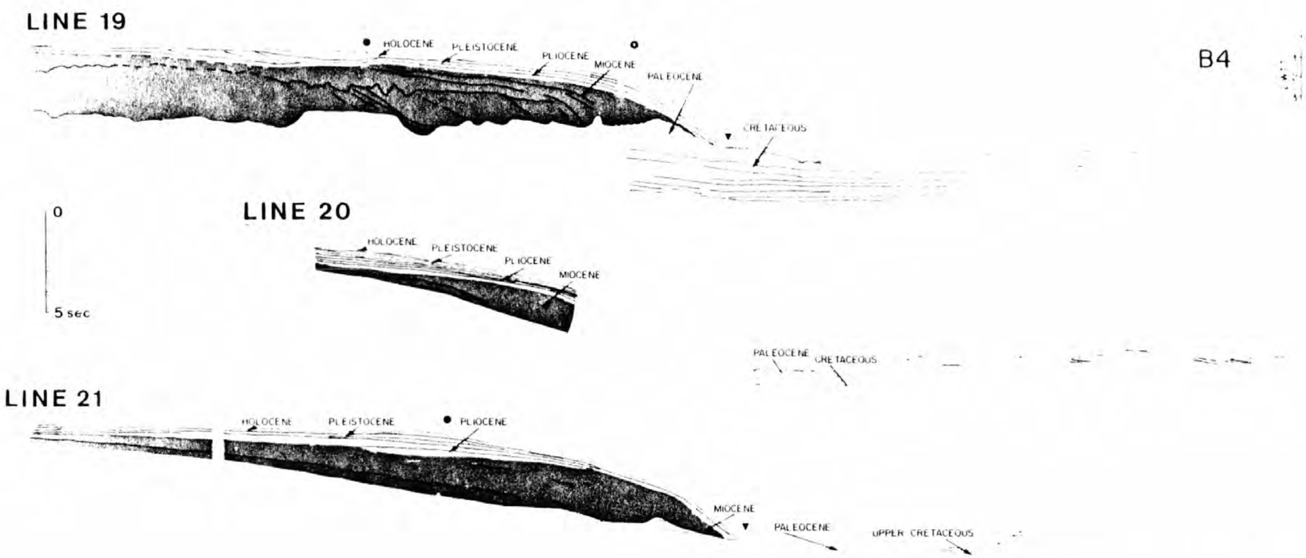
LINE 28
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
B1
KM
LINE 29
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
EOCENE
PALEOCENE
LINE 30
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
MIOCENE
EOCENE
PALEOCENE



B2
KM
2WTT
0
1
2
3
LINE 25
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
LINE 26
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
EOCENE
PALEOCENE
LINE 27
J-2
J-5
HOLOCENE
PLEISTOCENE
PLIOCENE
OLIGOCENE
MIOCENE
EOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS

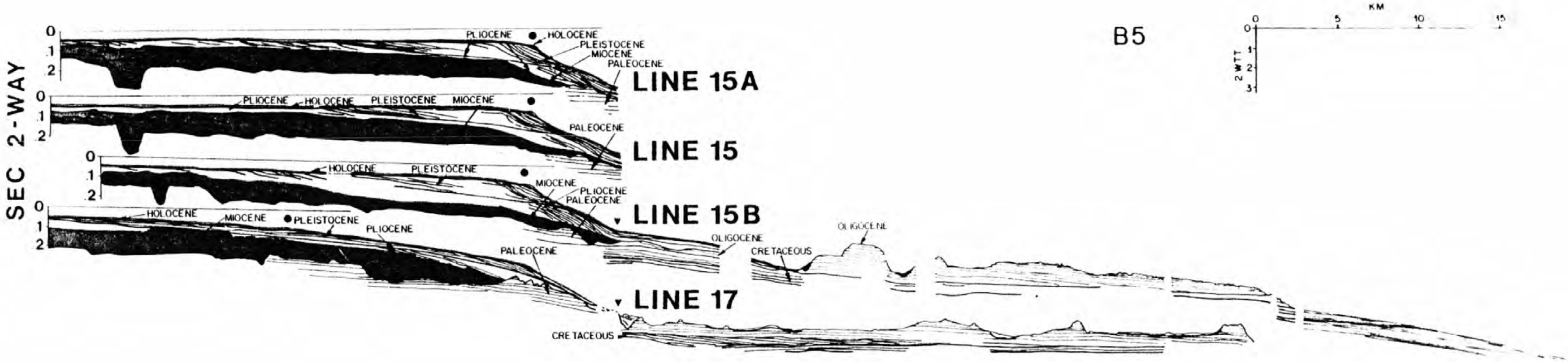


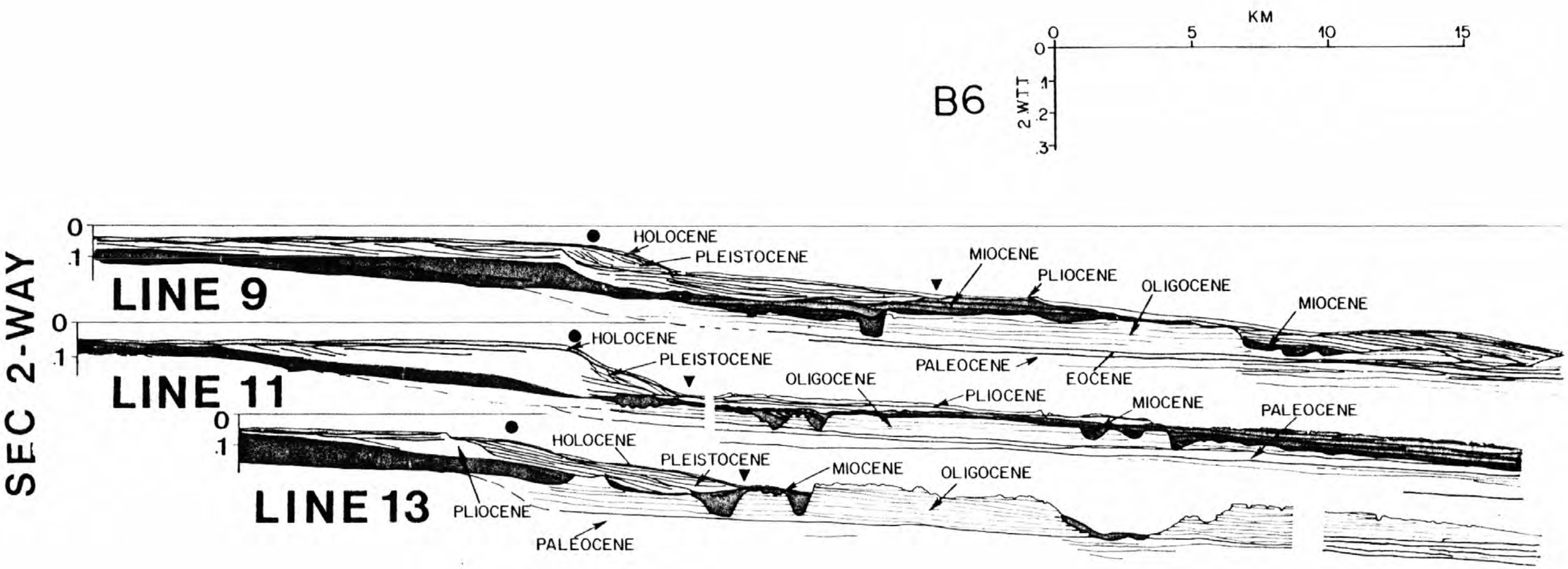
LINE 22
PLEISTOCENE
HOLOCENE
MIOCENE
PLIOCENE
HOLOCENE ?
OLIGOCENE
PALEOCENE
CRETACEOUS
PALEOCENE
B3
KM
0
5
10
0
1
2
3
TWTT
LINE 23
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
PALEOCENE
0
5 sec
LINE 24
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
MIOCENE
PALEOCENE
EOCENE
PALEOCENE



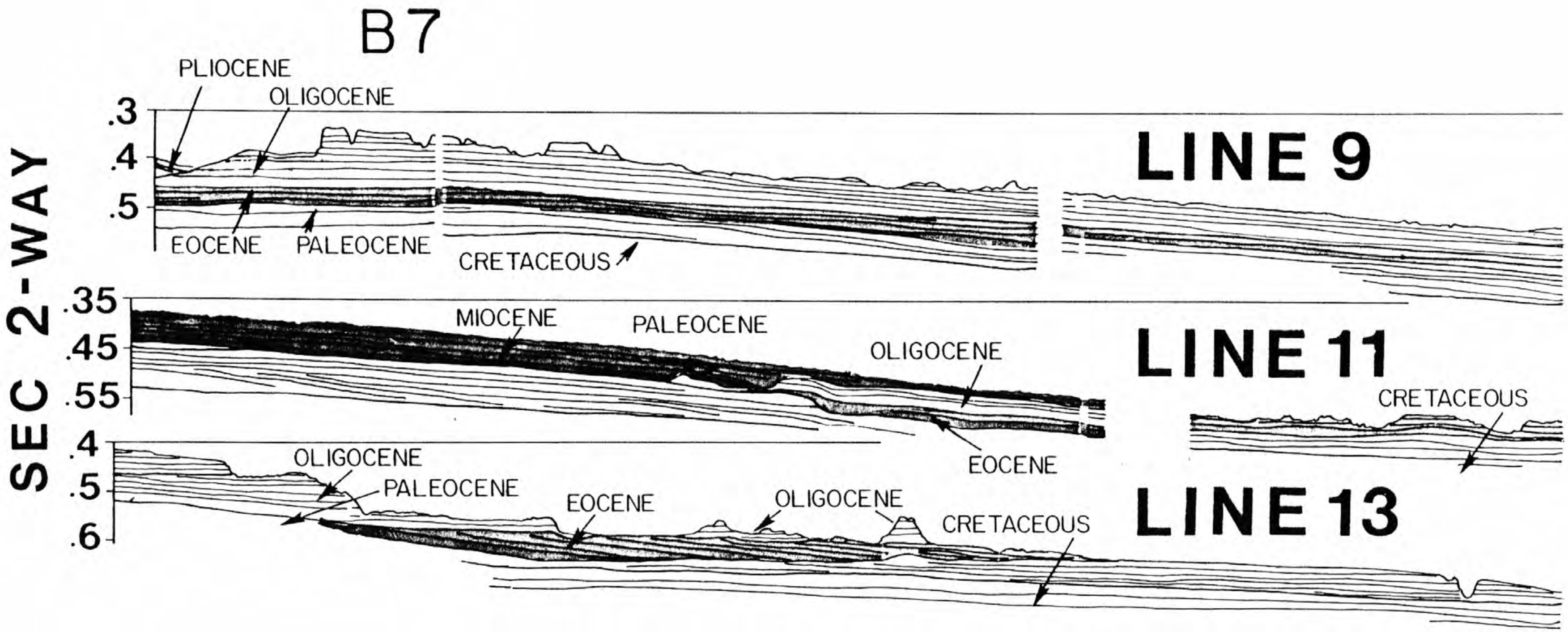
LINE 19
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
CRETACEOUS
0
5 sec
LINE 20
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
CRETACEOUS
LINE 21
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
PALEOCENE
UPPER CRETACEOUS

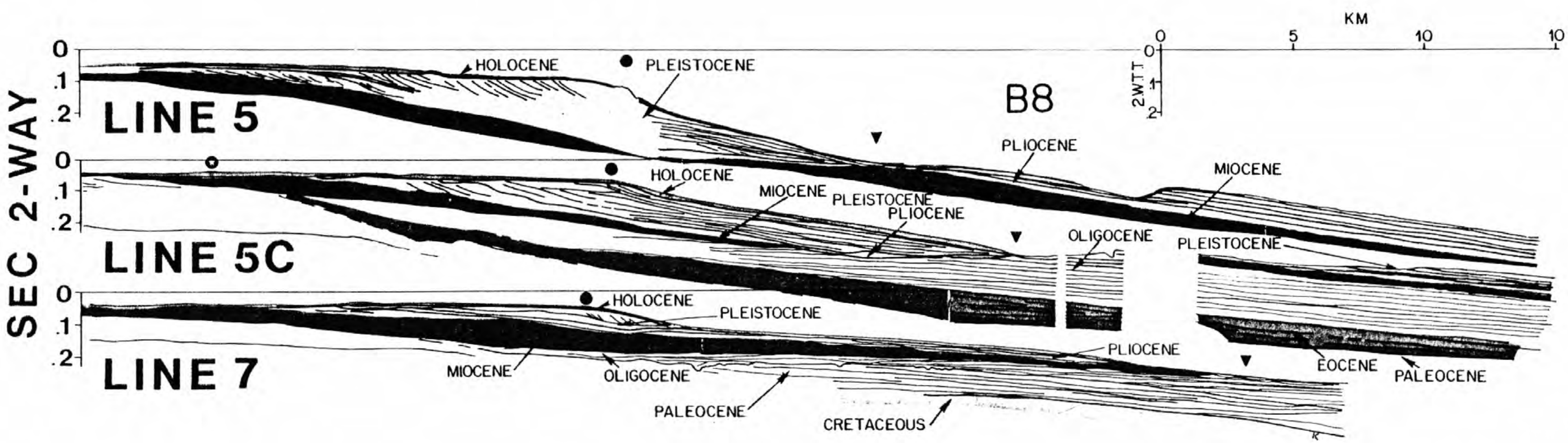
B4


B5
KM
0
5
10
15
2 WTT
SEC 2-WAY
LINE 15A
LINE 15
LINE 15B
LINE 17
PLIOCENE
HOLOCENE
PLEISTOCENE
MIOCENE
PALEOCENE
OLIGOCENE
CRETACEOUS

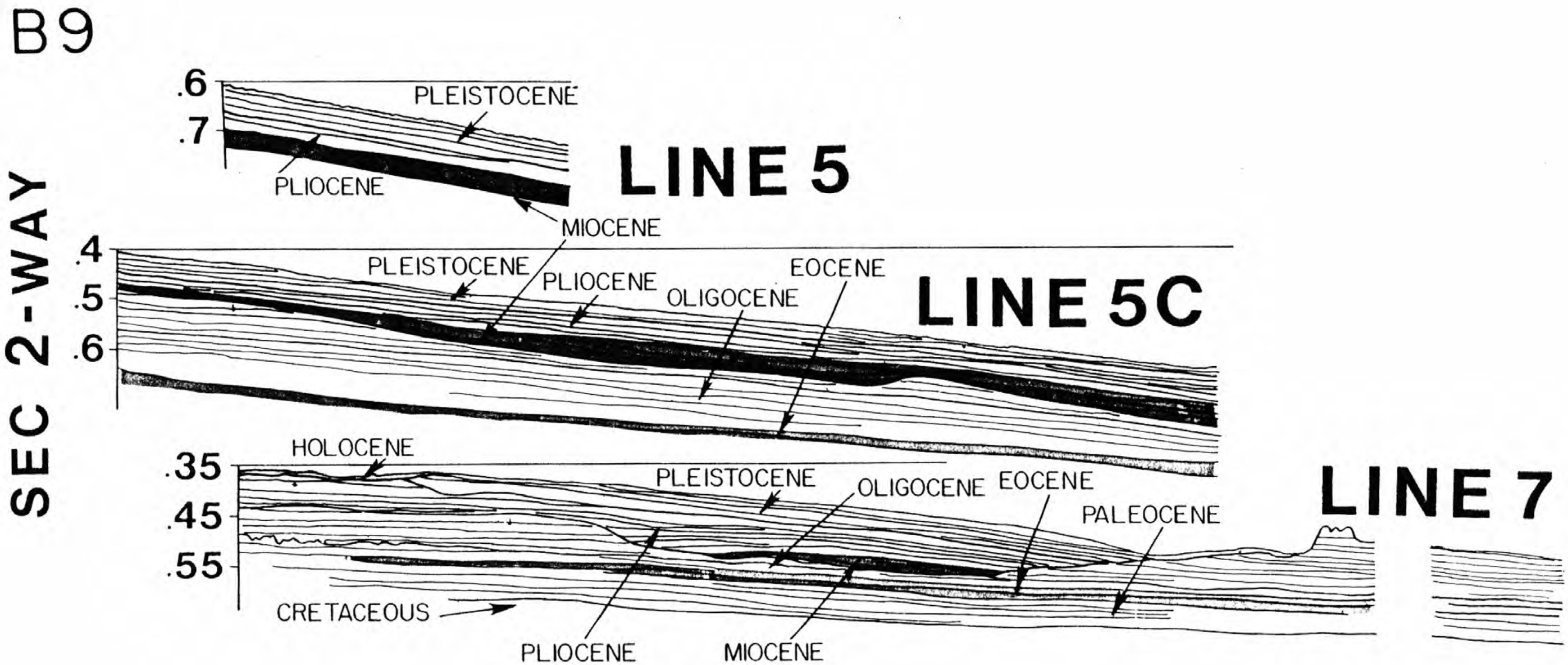


B6
KM
0
5
10
15
0
.1
.2
.3
2 WTT
SEC 2-WAY
LINE 9
LINE 11
LINE 13
HOLOCENE
PLEISTOCENE
MIOCENE
PLIOCENE
OLIGOCENE
PALEOCENE
EOCENE


B7
SEC 2-WAY
.3
.4
.5
PLIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS
LINE 9
.35
.45
.55
MIOCENE
PALEOCENE
OLIGOCENE
EOCENE
CRETACEOUS
LINE 11
.4
.5
.6
OLIGOCENE
PALEOCENE
EOCENE
OLIGOCENE
CRETACEOUS
LINE 13

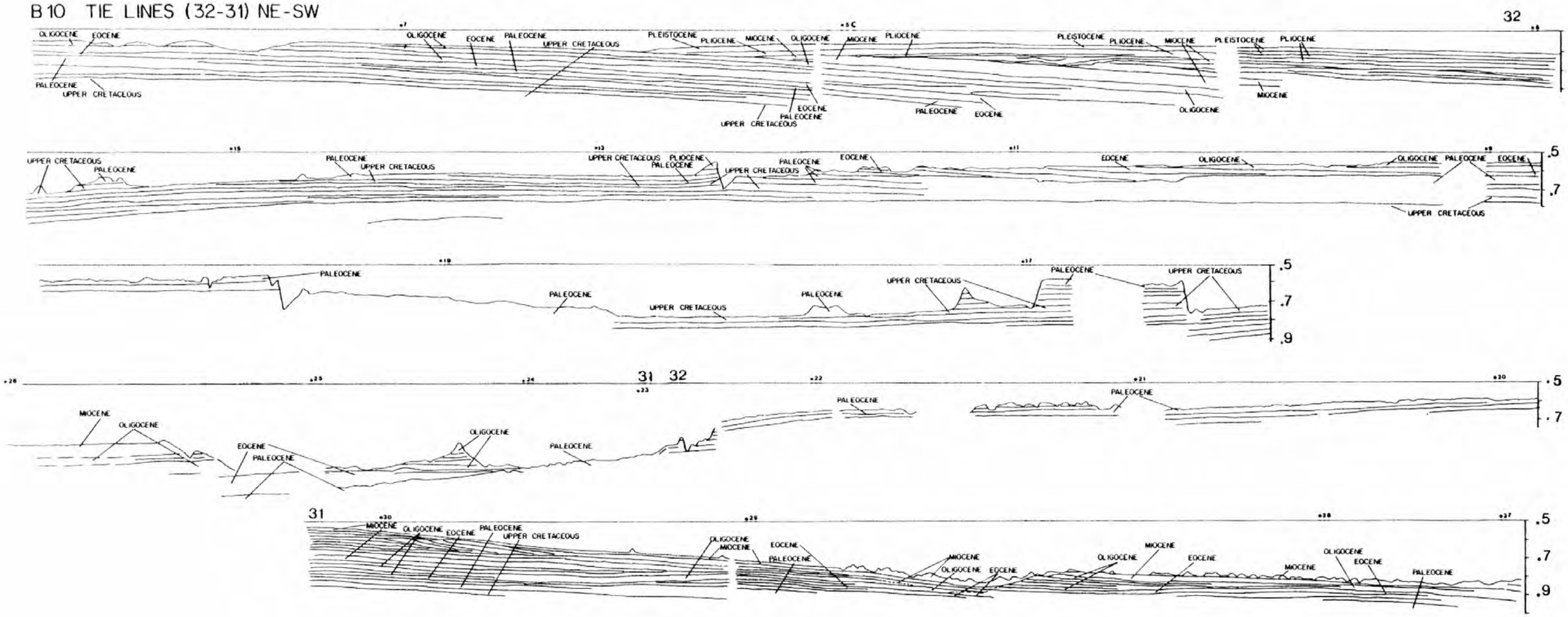


SEC 2-WAY
LINE 5
LINE 5C
LINE 7
B8
KM
0
5
10
2WTT
HOLOCENE
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
CRETACEOUS

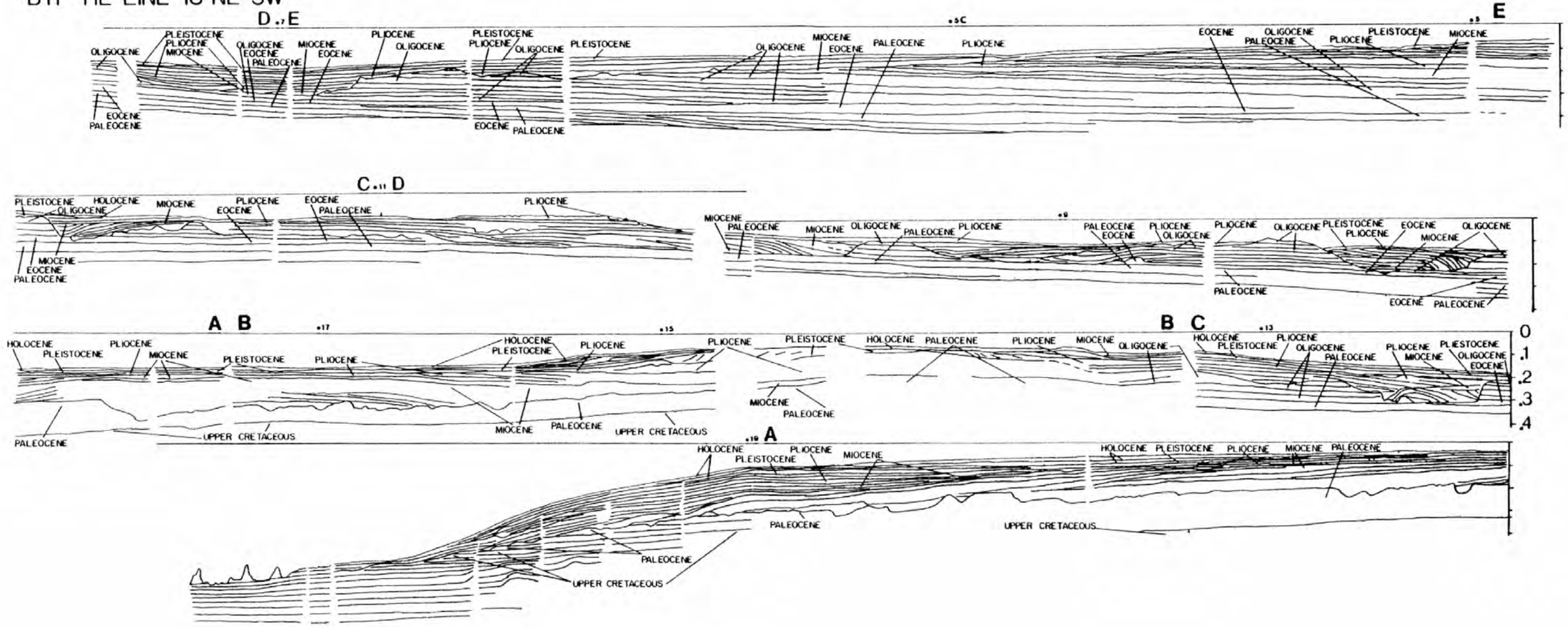


B9
SEC 2-WAY
.6
.7
PLEISTOCENE
PLIOCENE
MIOCENE
LINE 5
.4
.5
.6
PLEISTOCENE
PLIOCENE
OLIGOCENE
EOCENE
LINE 5C
.35
.45
.55
HOLOCENE
PLEISTOCENE
OLIGOCENE
EOCENE
PALEOCENE
LINE 7
CRETACEOUS
PLIOCENE
MIOCENE

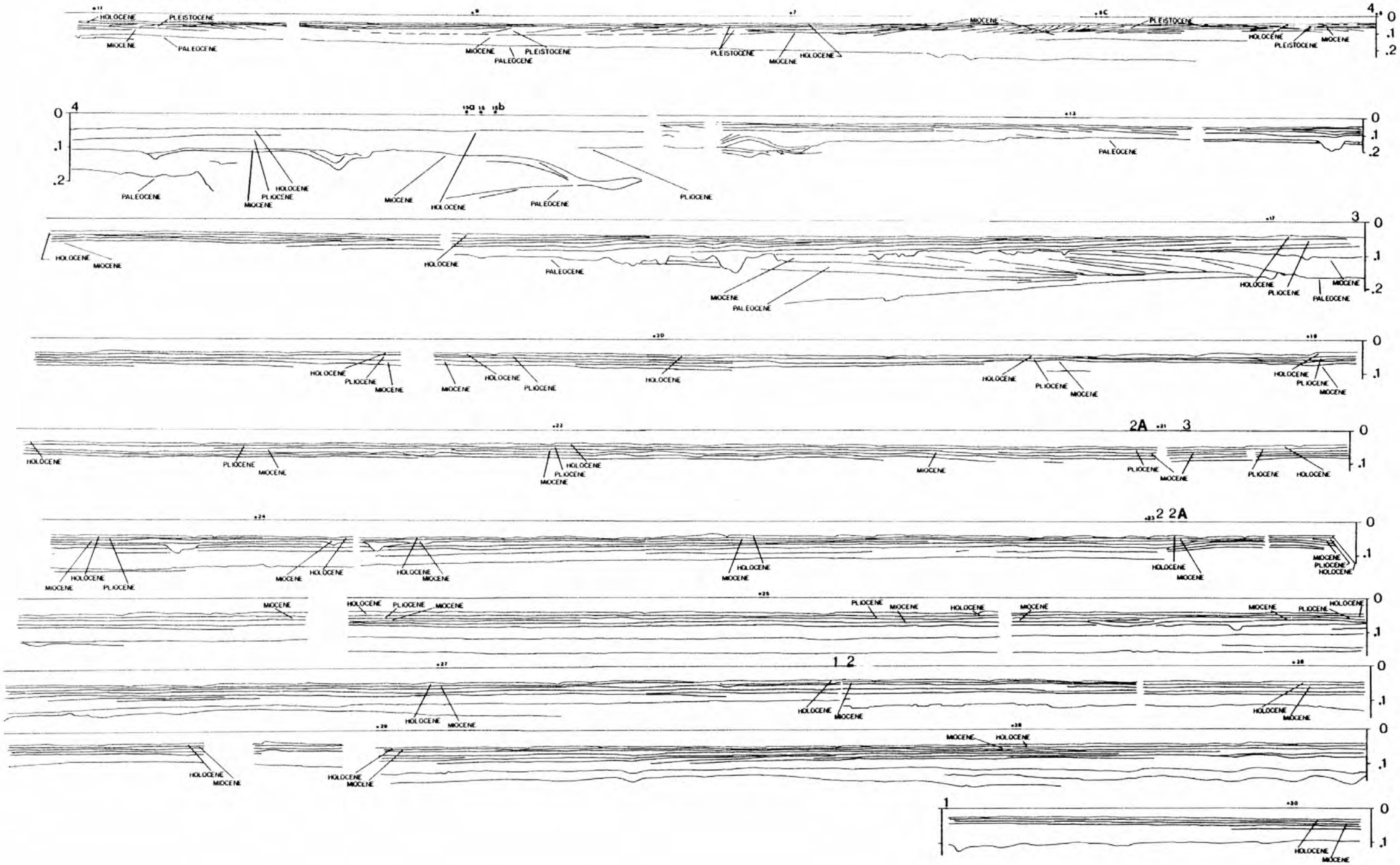
B 10 TIE LINES (32-31) NE-SW



B11 TIE LINE 18 NE-SW

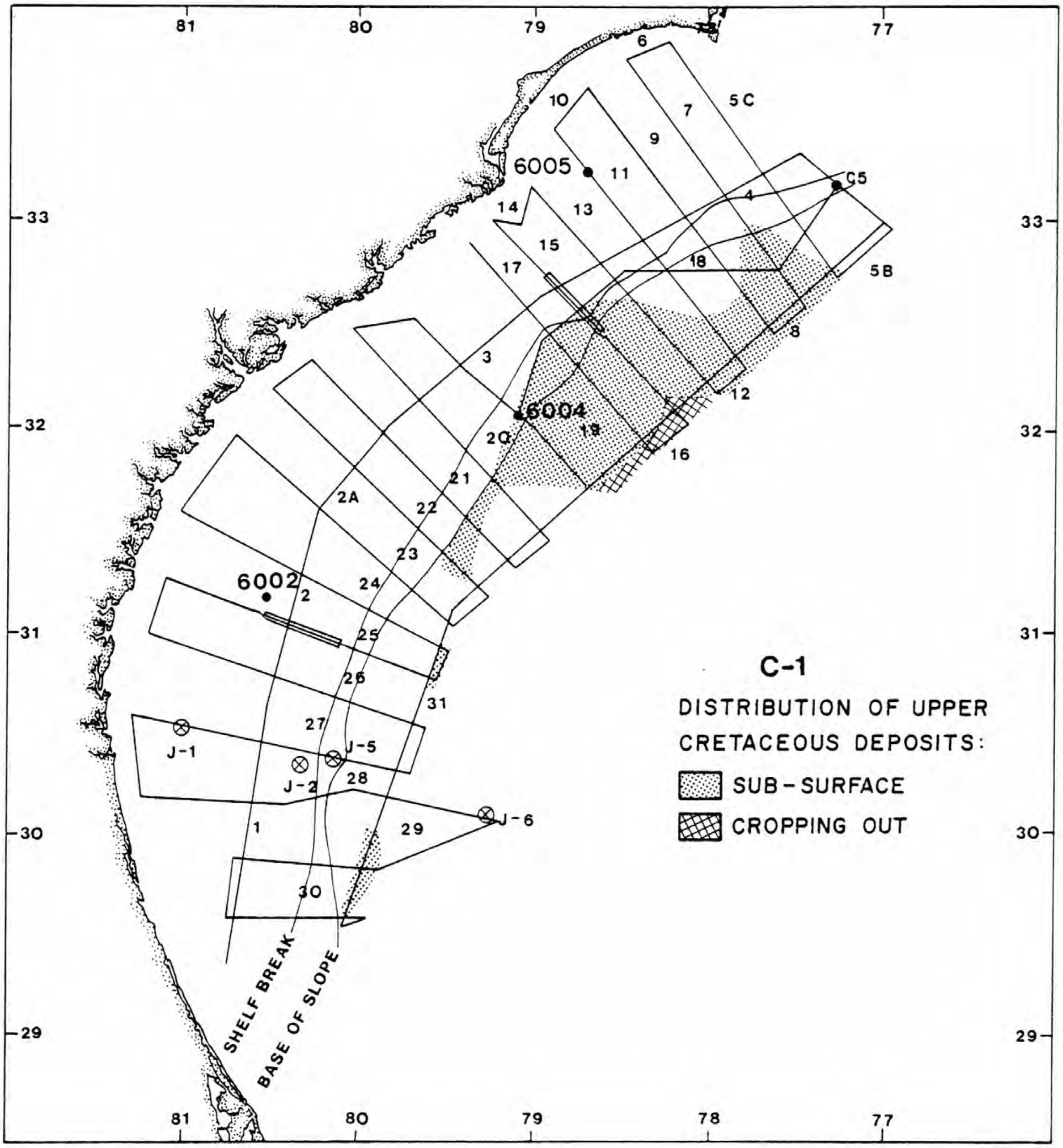


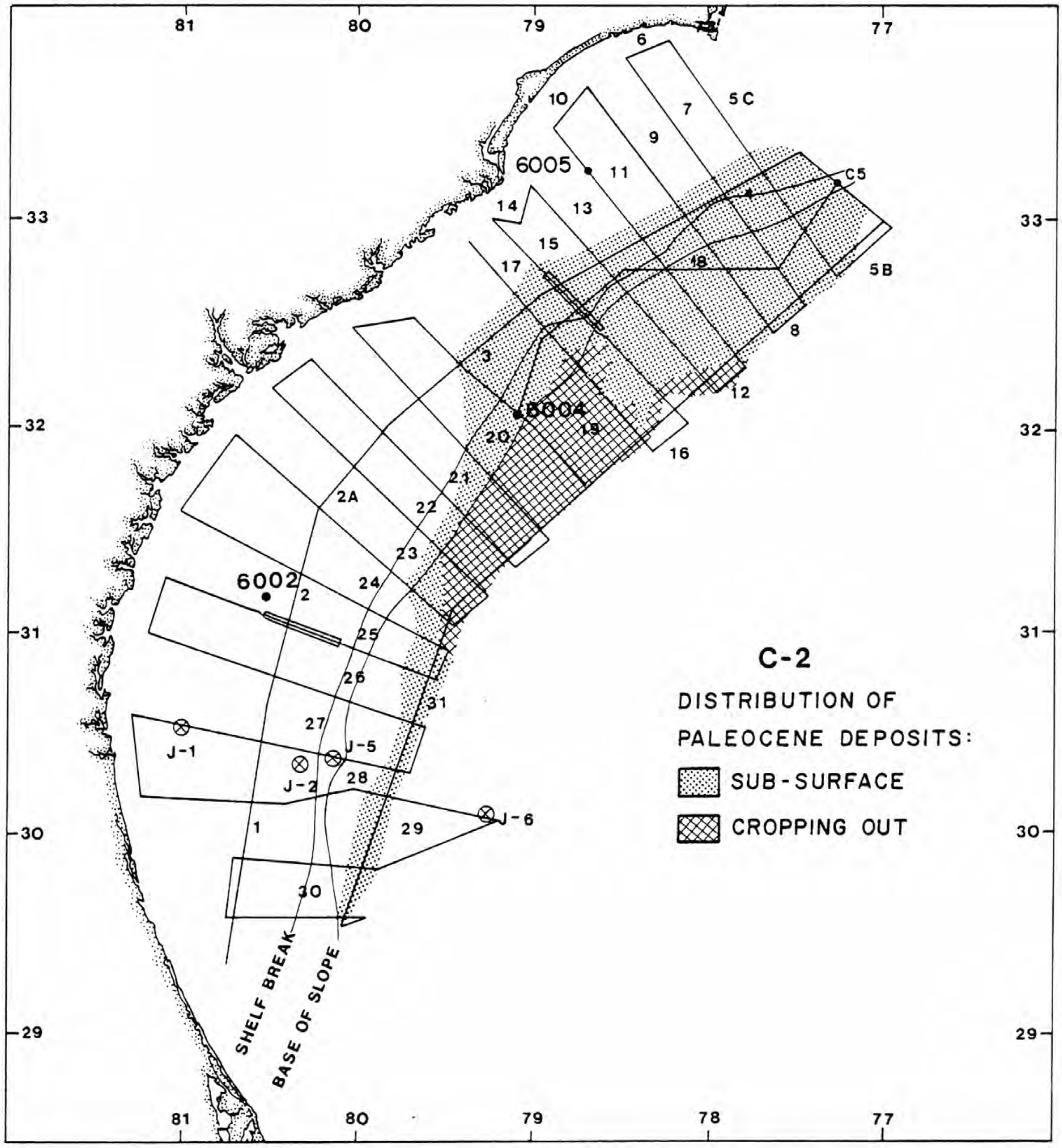
B 12 TIE LINES (4-1) NE-SW



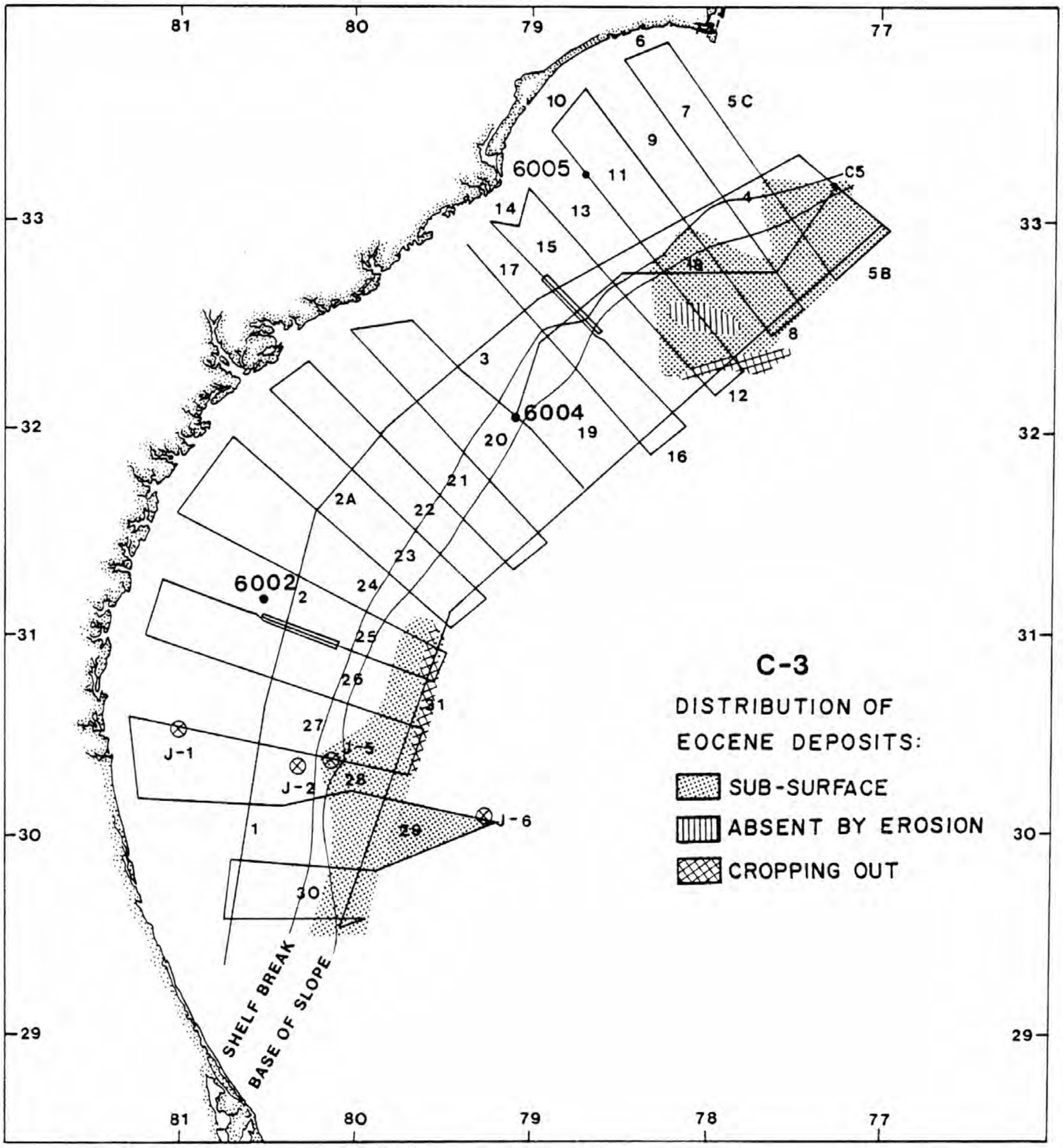
APPENDIX 9C

Maps Showing Sediment Distribution by Epoch

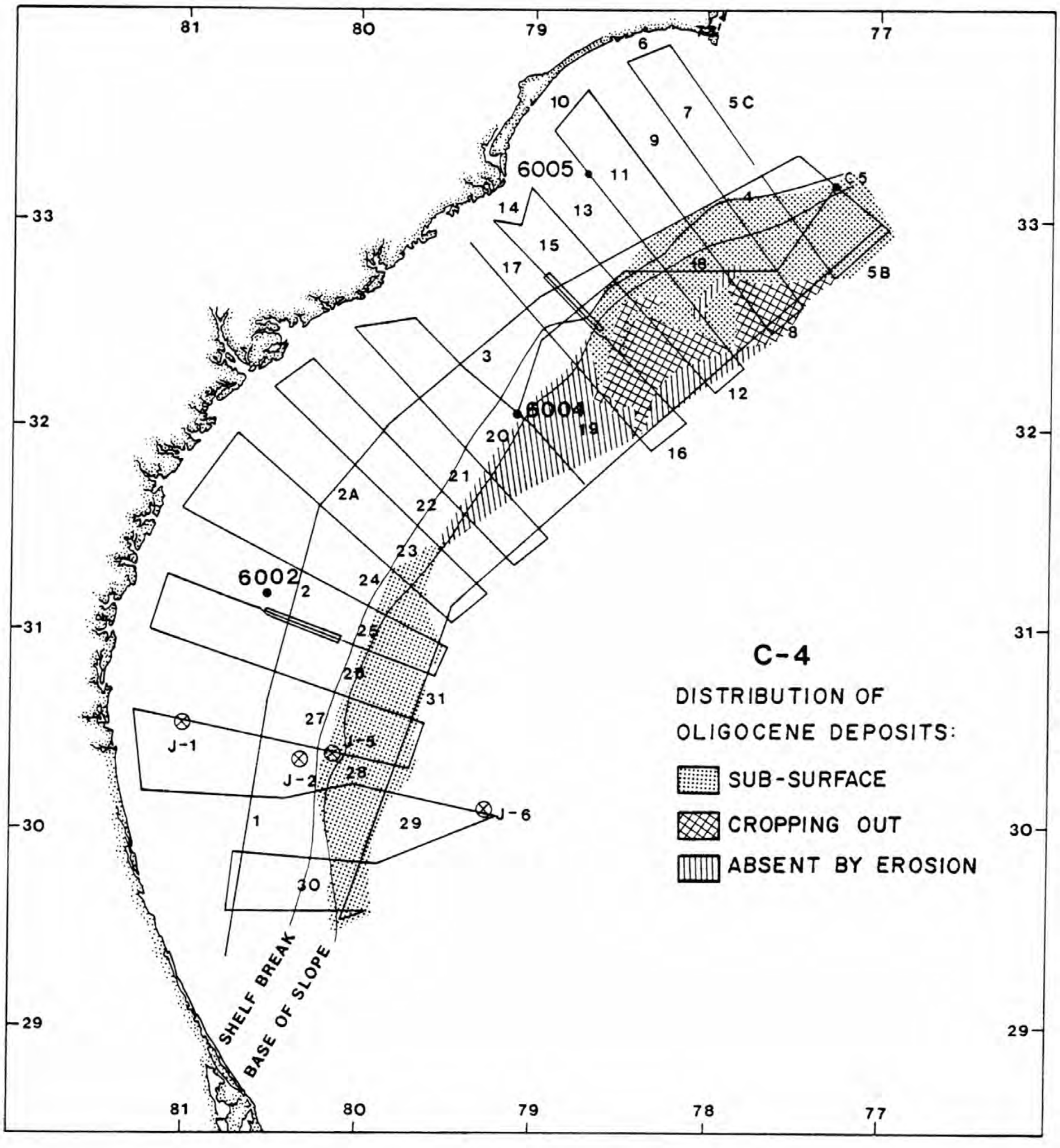

C-1
DISTRIBUTION OF UPPER CRETACEOUS DEPOSITS:
SUB-SURFACE
CROPPING OUT
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
C5
5B
5C



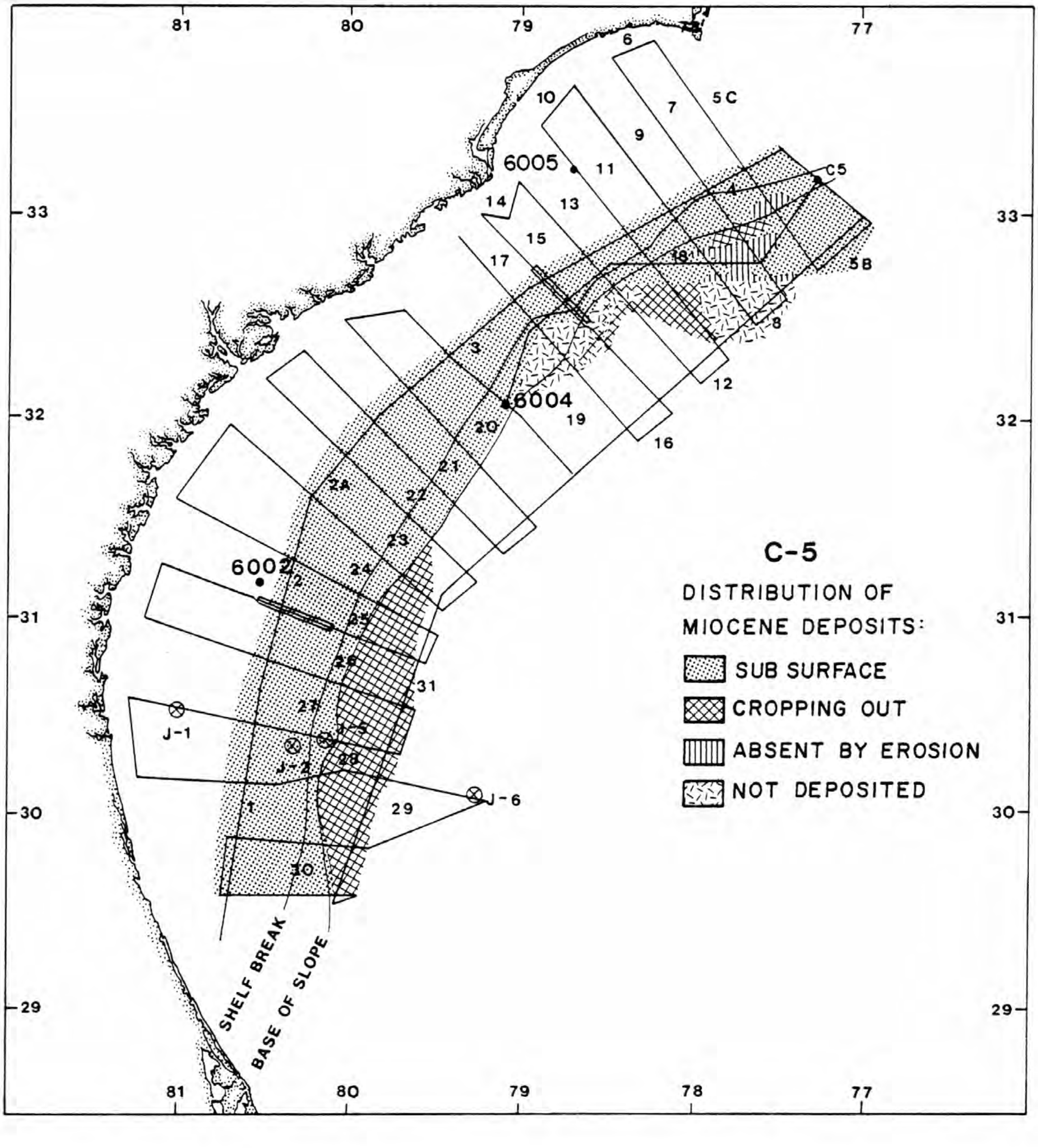
C-2
DISTRIBUTION OF
PALEOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
6005
6004
6002
C5
J-1
J-2
J-5
J-6
SHELF BREAK
BASE OF SLOPE
81
80
79
78
77
33
32
31
30
29

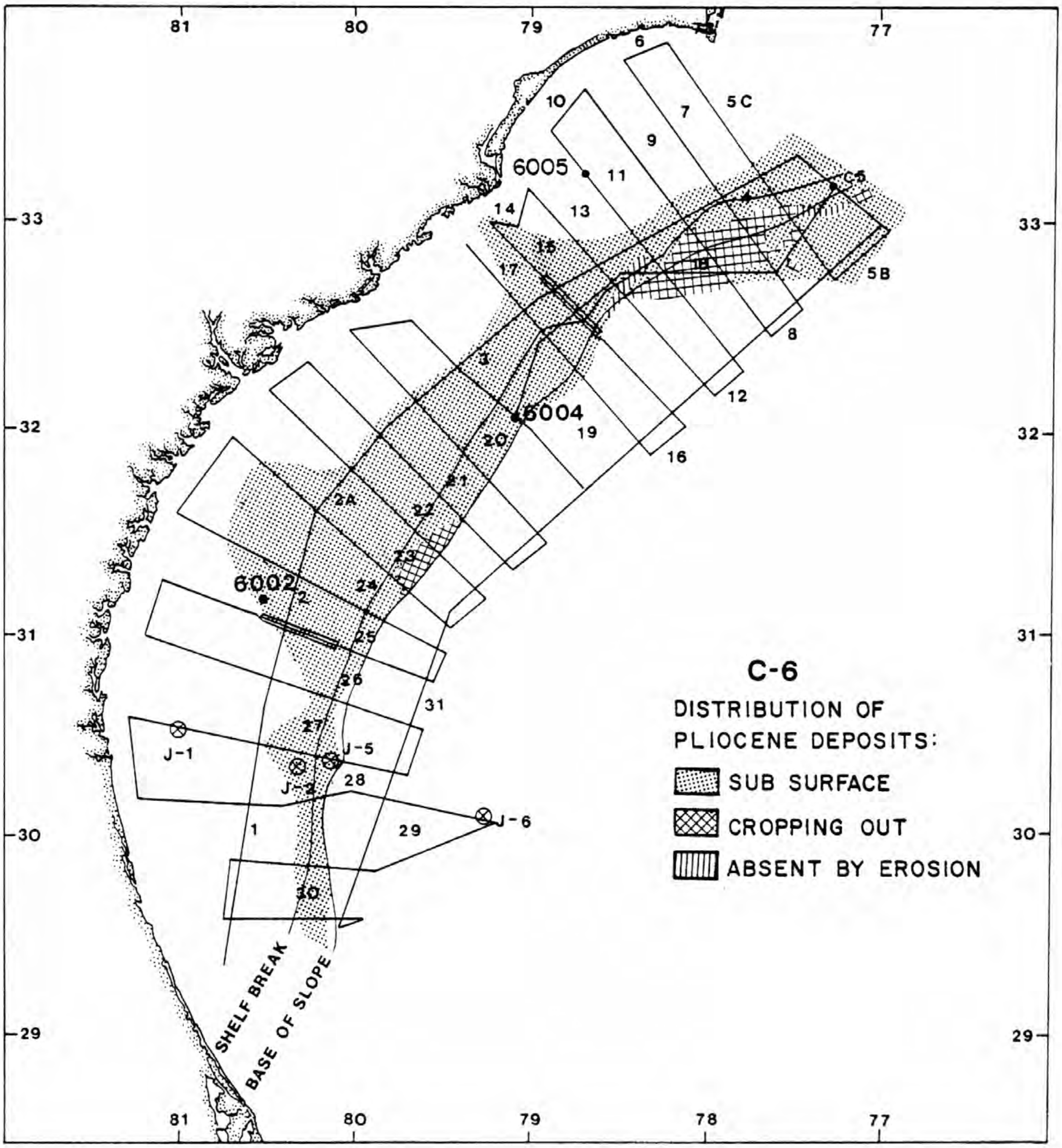


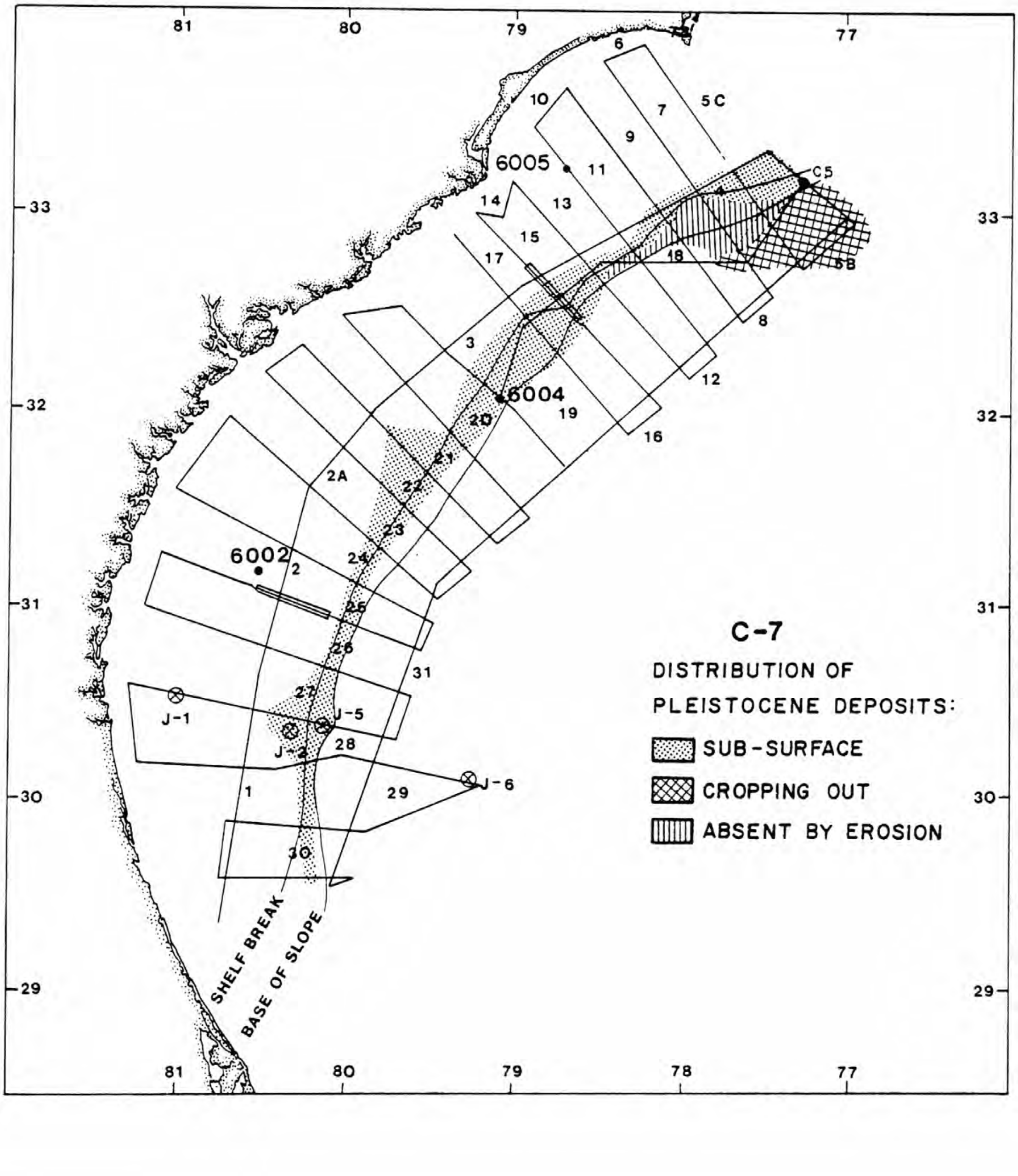
C-3
DISTRIBUTION OF
EOCENE DEPOSITS:
SUB-SURFACE
ABSENT BY EROSION
CROPPING OUT
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
C5
5C
5B
2A

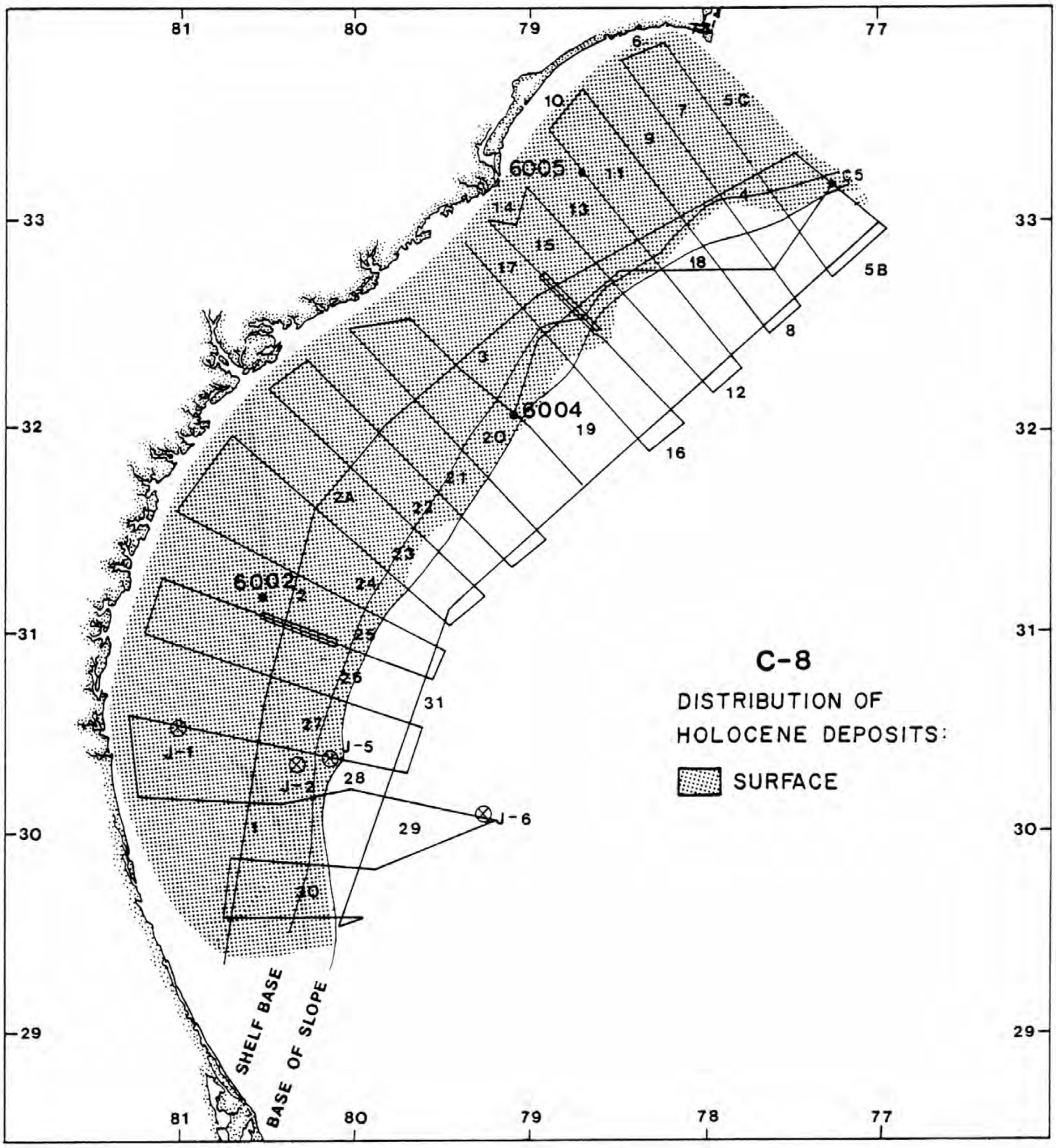


C-4
DISTRIBUTION OF
OLIGOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29


C-5
DISTRIBUTION OF
MIOCENE DEPOSITS:
SUB SURFACE
CROPPING OUT
ABSENT BY EROSION
NOT DEPOSITED
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-6
C5
5C
5B
81
80
79
78
77
33
32
31
30
29


C-6
DISTRIBUTION OF
PLIOCENE DEPOSITS:
SUB SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29

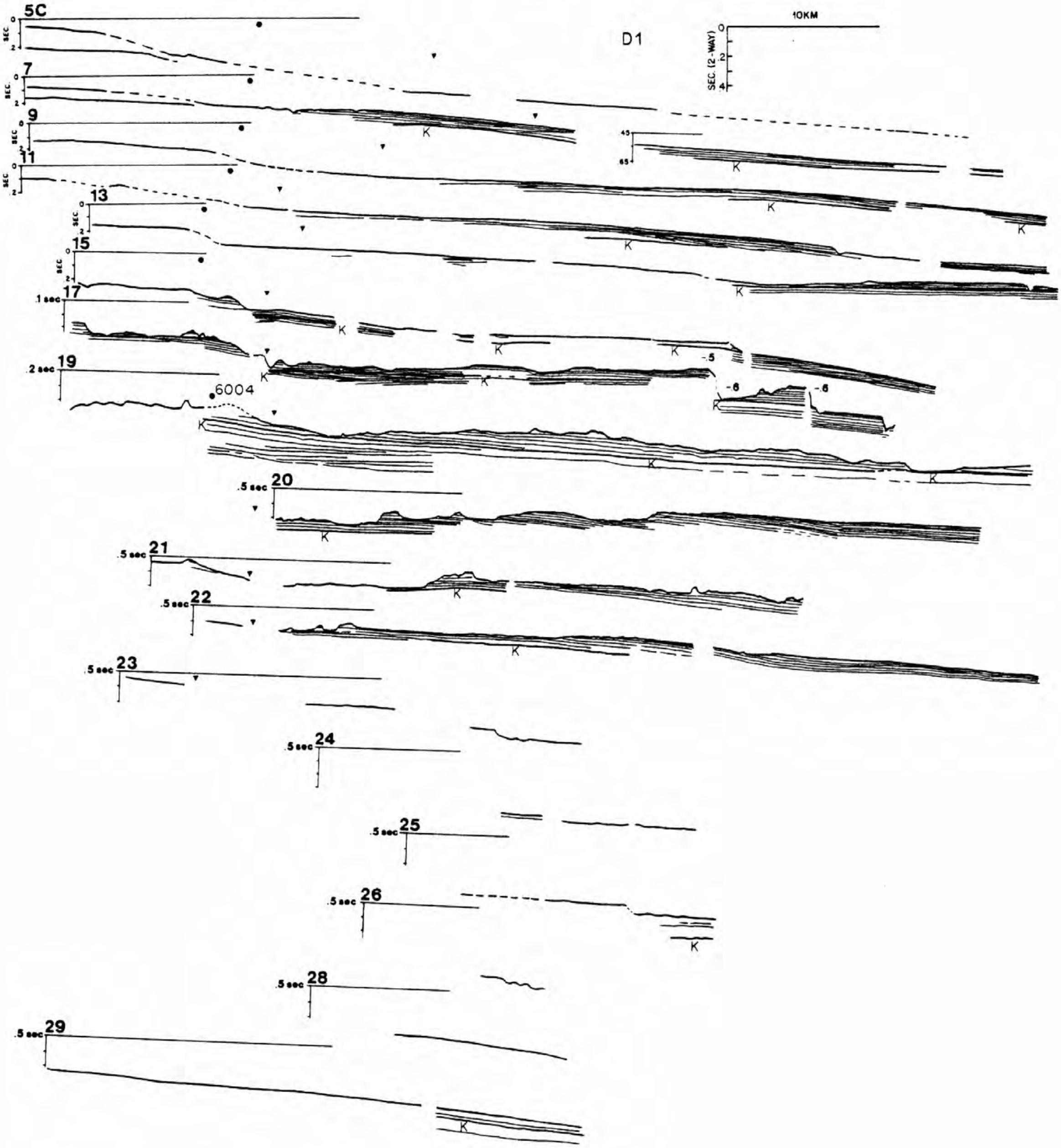

C-7
DISTRIBUTION OF
PLEISTOCENE DEPOSITS:
SUB-SURFACE
CROPPING OUT
ABSENT BY EROSION
SHELF BREAK
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
C5
5B
5C
2A
81
80
79
78
77
33
32
31
30
29


C-8
DISTRIBUTION OF
HOLOCENE DEPOSITS:
SURFACE
SHELF BASE
BASE OF SLOPE
6005
6004
6002
J-1
J-2
J-5
J-6
81
80
79
78
77
33
32
31
30
29

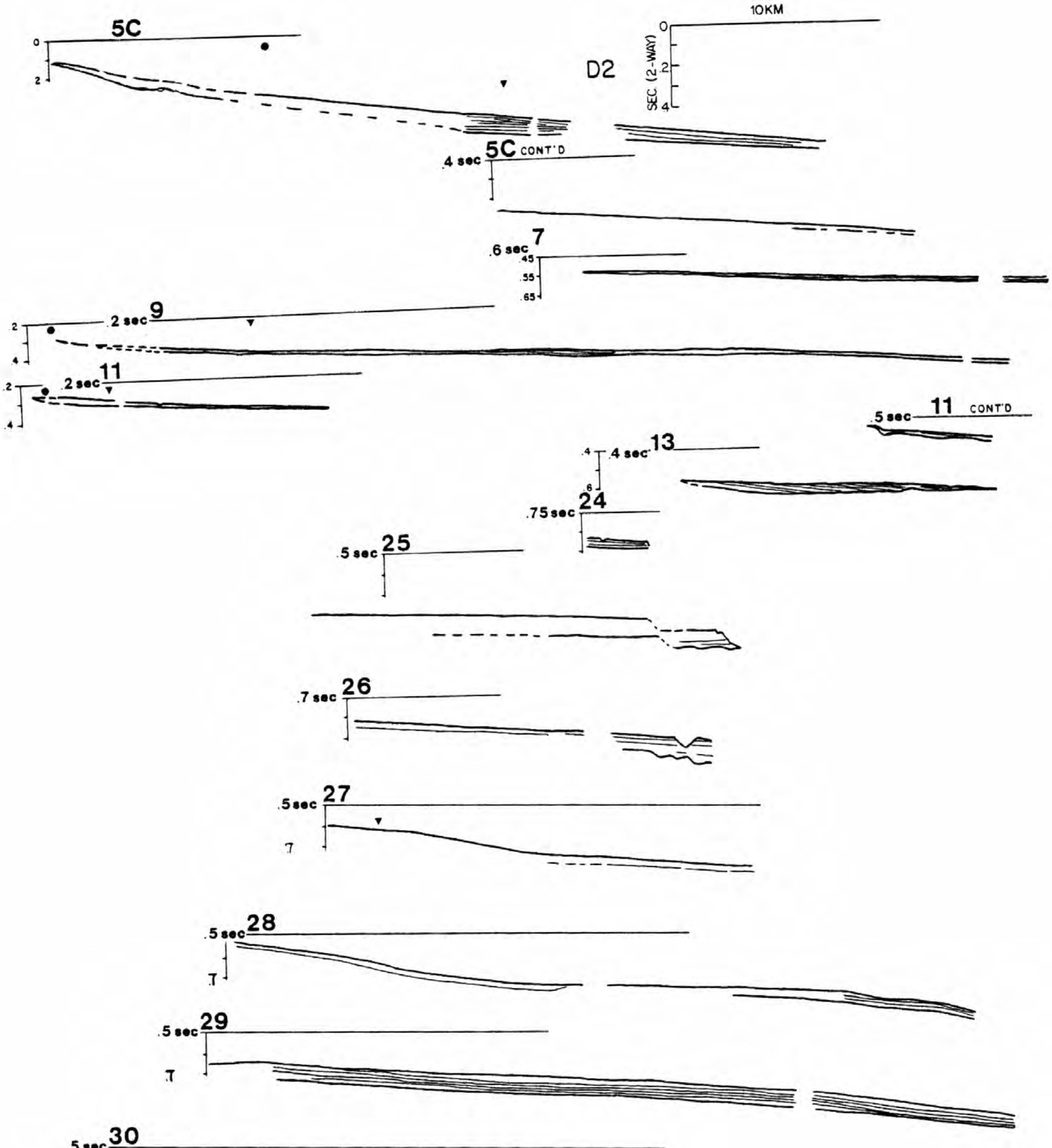
APPENDIX 9D

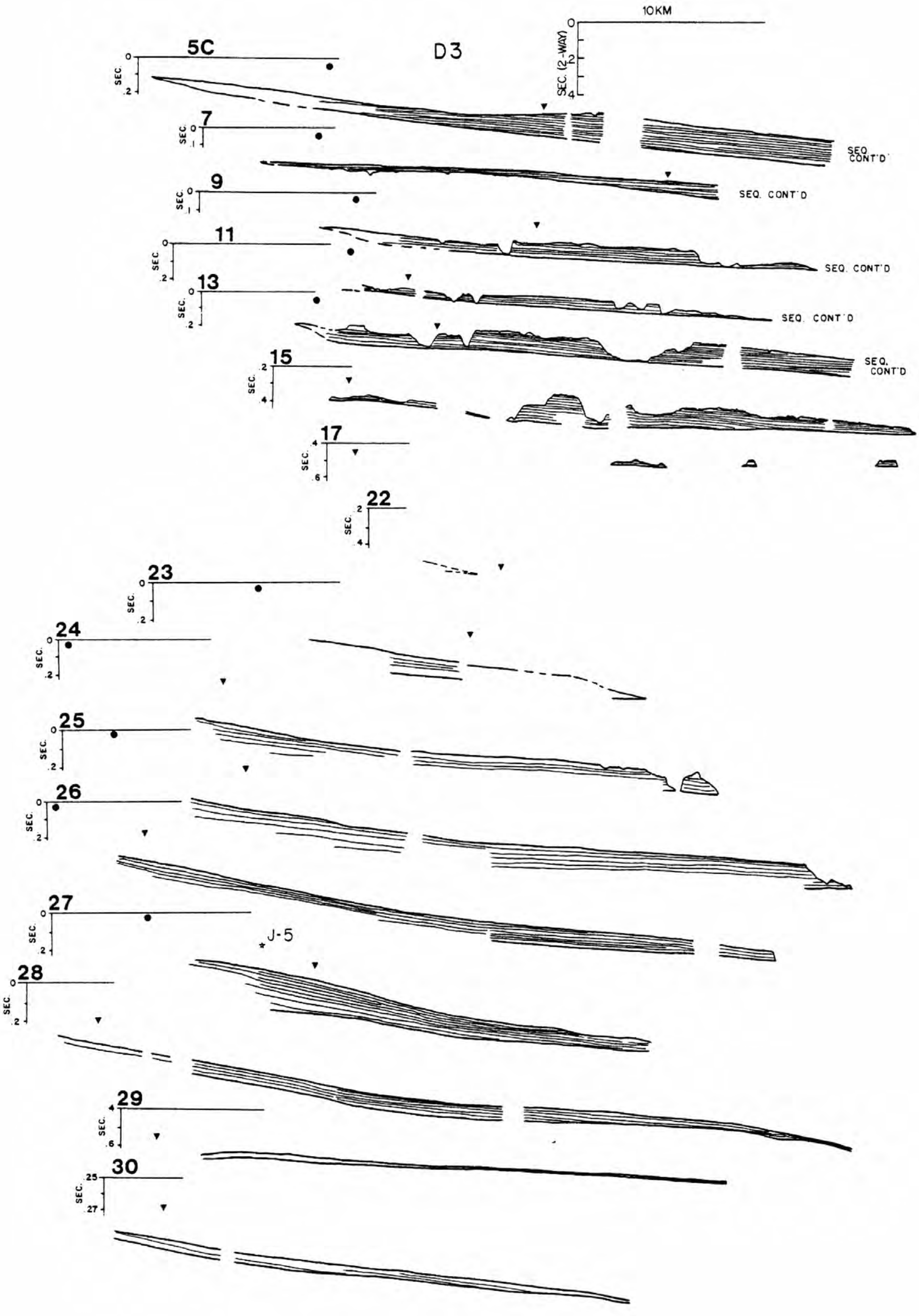
Line Drawings of Minisparker Records Showing Distribution of Sediments of Each Geologic Epoch within the Cenozoic and Upper Cretaceous

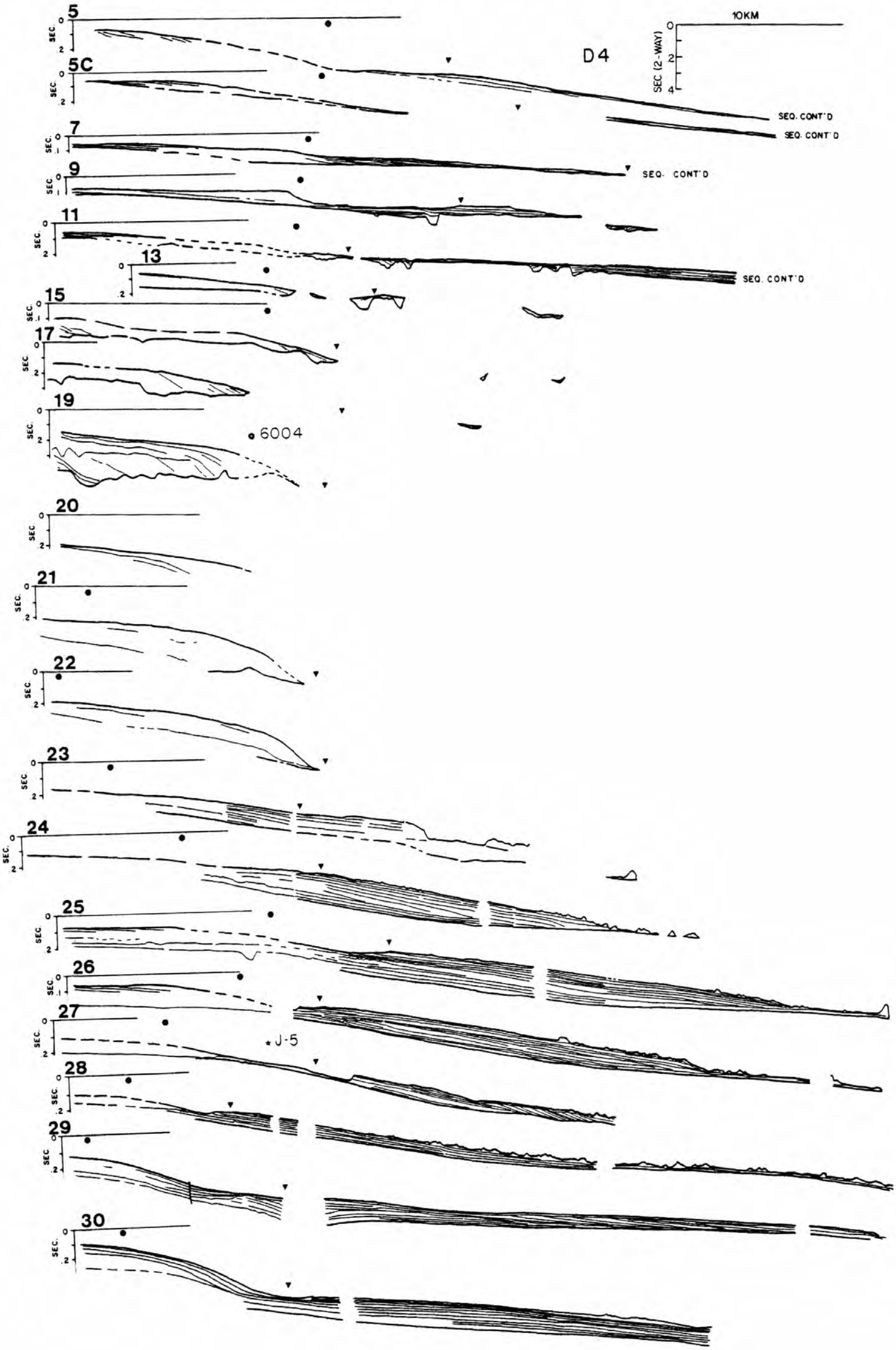
D-1	Upper Cretaceous and Paleocene
D-2	Eocene
D-3	Oligocene
D-4	Miocene
D-5	Pliocene
D-6	Pleistocene



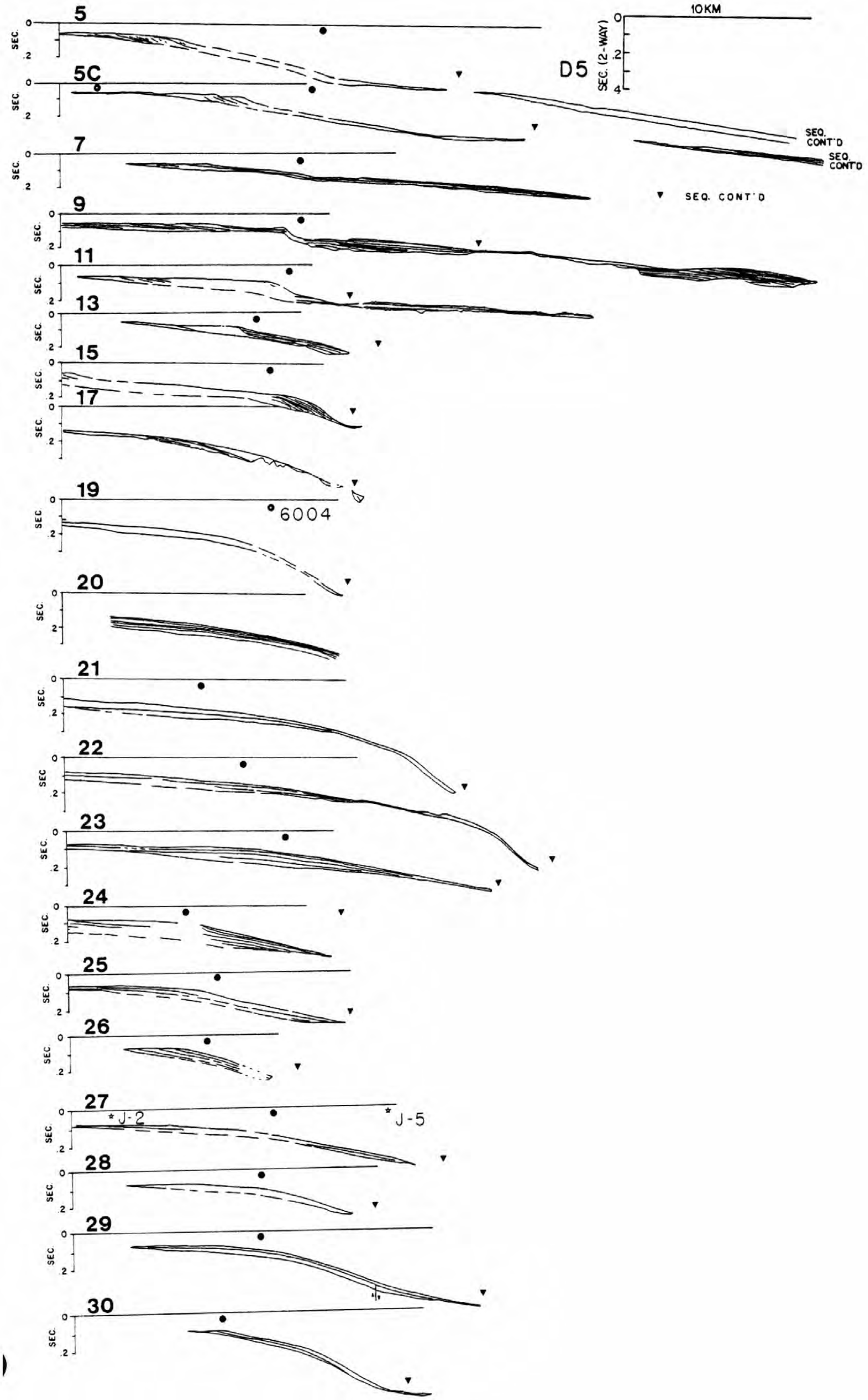
D1
10KM
SEC. (2-WAY)
5C
7
9
11
13
15
17
19
20
21
22
23
24
25
26
28
29
6004
K


D2
10KM
SEC (2-WAY)
0
.2
.4
5C
0
2
5C CONT'D
.4 sec
7
.6 sec
.45
.55
.65
9
.2 sec
.2
.4
11
.2 sec
.2
.4
11 CONT'D
.5 sec
13
.4 sec
.4
.6
24
.75 sec
25
.5 sec
26
.7 sec
27
.5 sec
.7
28
.5 sec
.7
29
.5 sec
.7
30
.5 sec
.7


D3
10KM
SEC. (2-WAY)
0
2
4
5C
SEC.
0
.2
SEQ. CONT'D
7
9
SEQ. CONT'D
11
SEQ. CONT'D
13
SEQ. CONT'D
SEQ. CONT'D
15
17
22
23
24
25
26
27
J-5
28
29
30



D4
10KM
SEC (2-WAY)
SEQ. CONT'D
6004
J-5

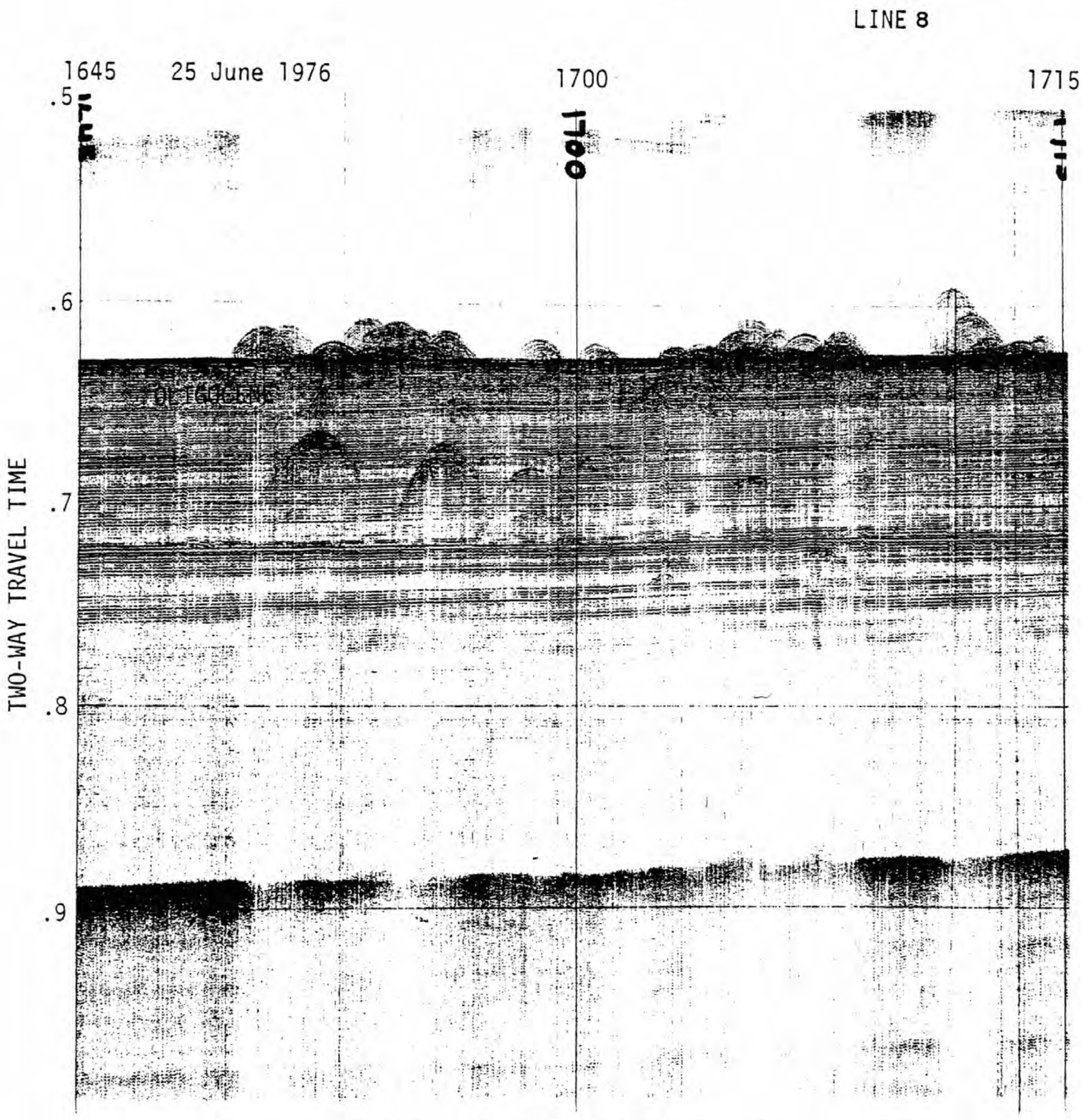


10KM
SEC. (2-WAY)
D5
5
5C
7
9
11
13
15
17
19
6004
20
21
22
23
24
25
26
27
J-2
J-5
28
29
30
SEC.
SEQ. CONT'D

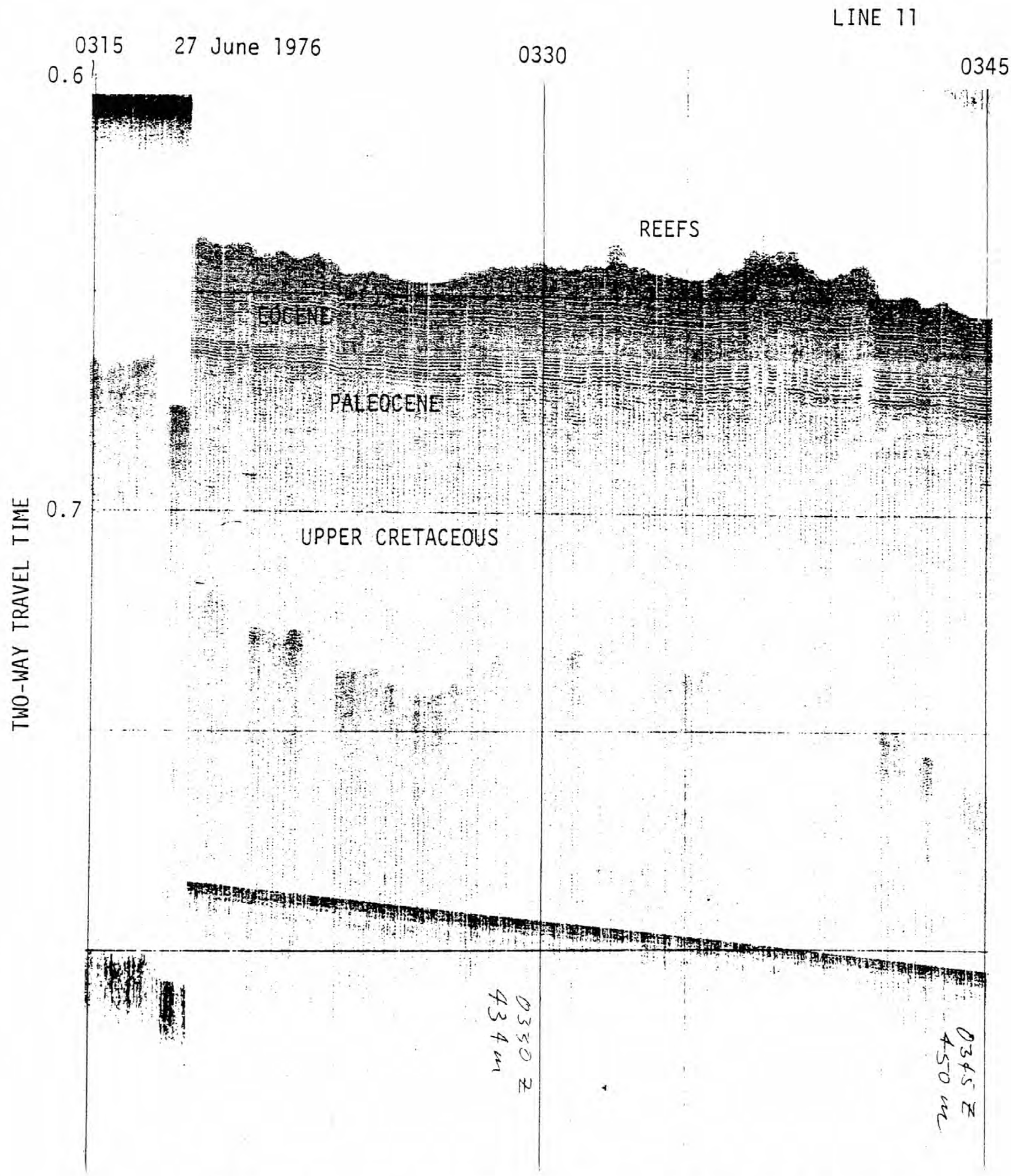
APPENDIX 9E

Water Column Anomalies on the Blake Plateau

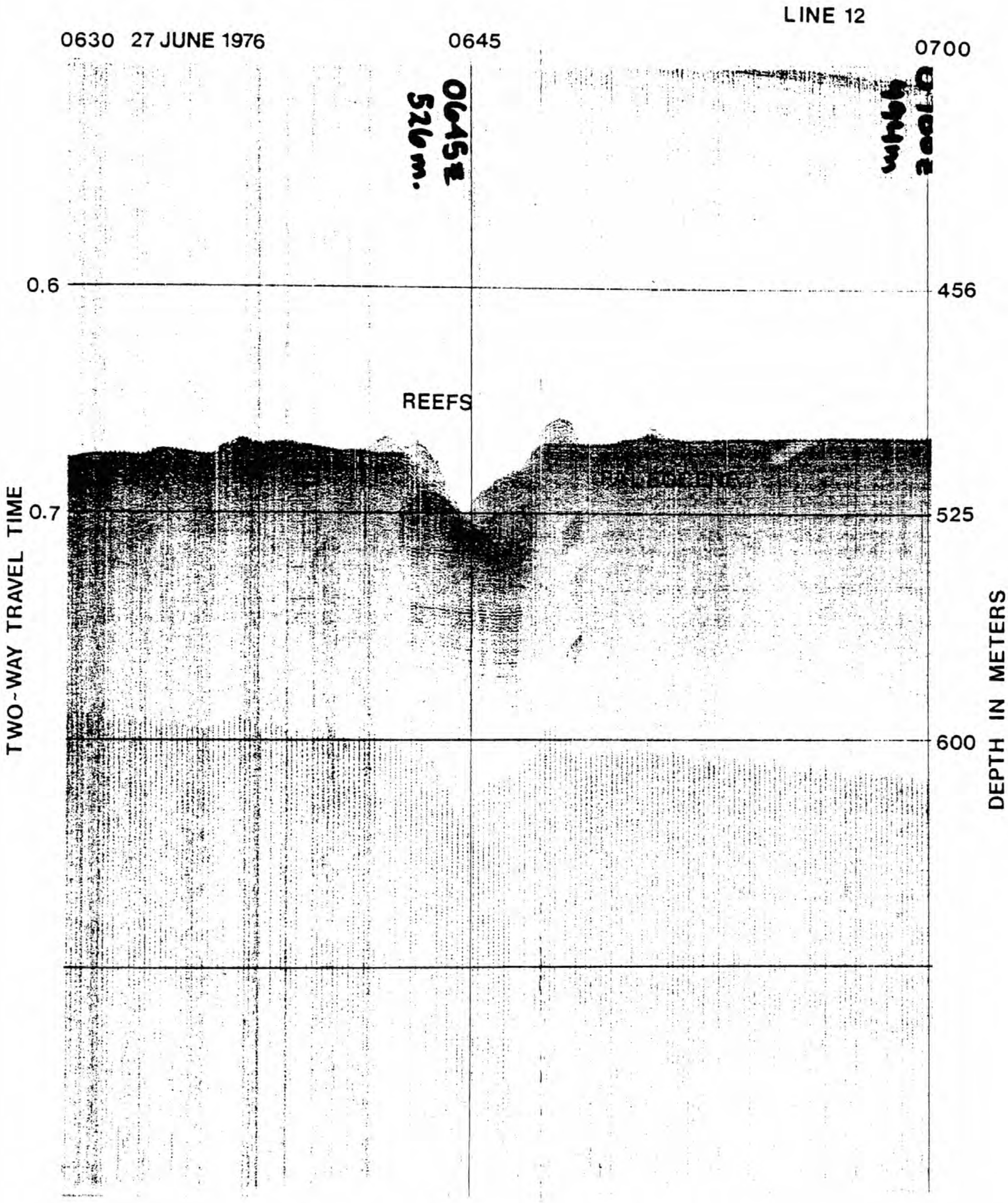
Photograph	Line No.	Time	Date
E-1	8	1645-1715	25 June
E-2	11	0315-0345	27 June
E-3	12	0630-0700	27 June
E-4	15	1915-1945	28 June
E-5	17	2230-2315	28 June
E-6	24	1830-1900	7 July



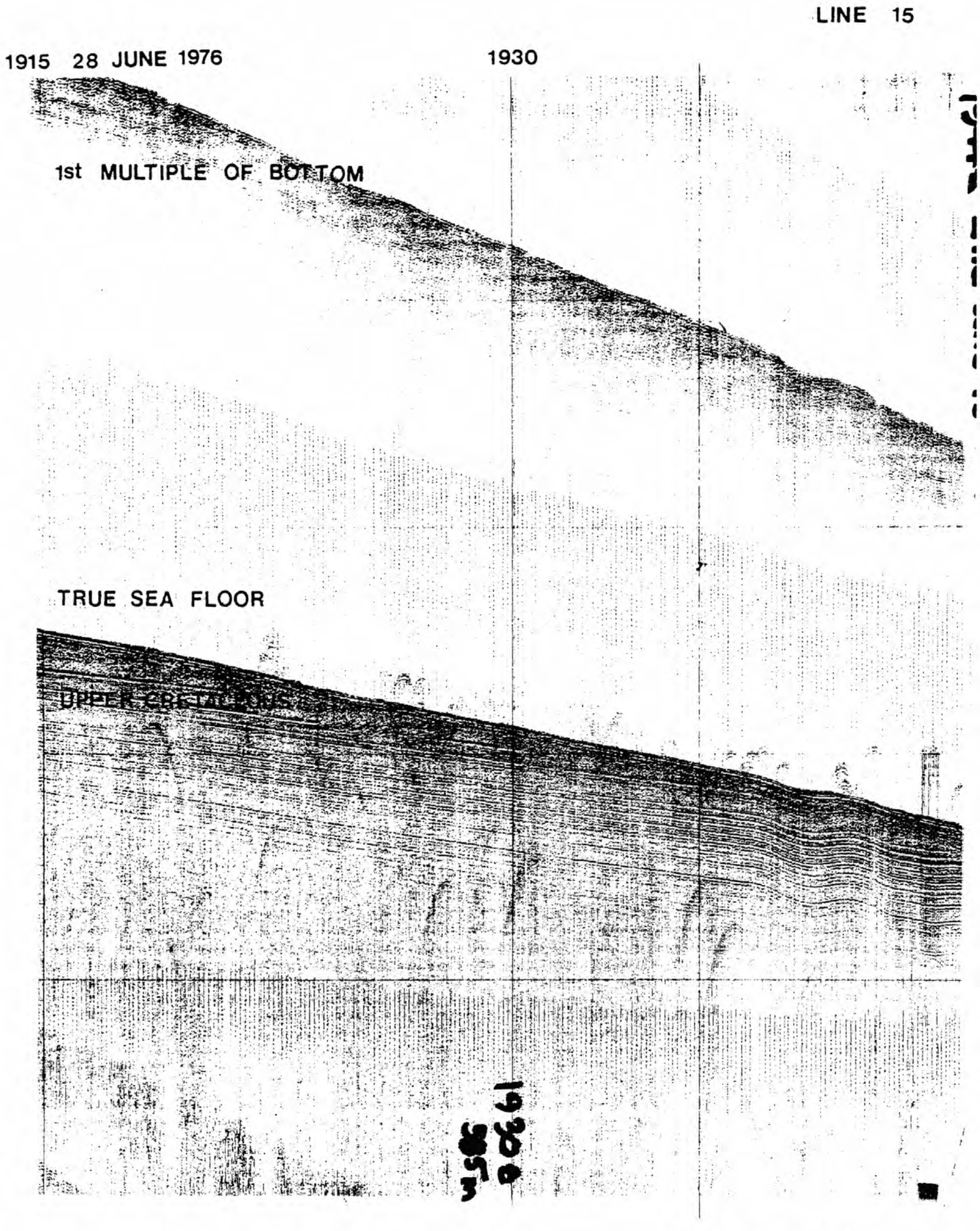
E 1 Hyperbolas from Blake Plateau in northern region
Note hyperbolas beneath present sea floor, their source is within cone of sound but off to side



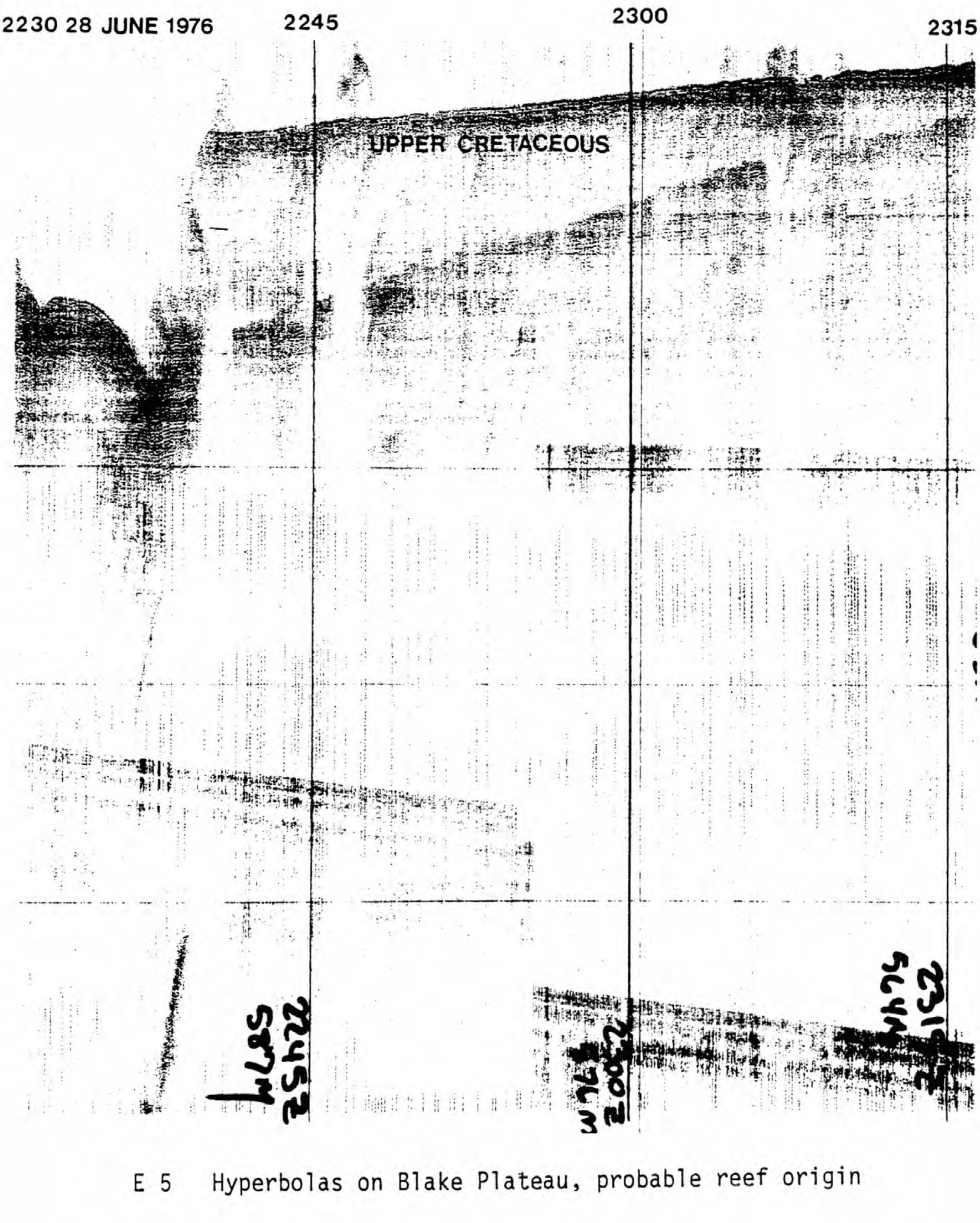
E 2 Hyperbolas on Blake Plateau, probably due to reefs



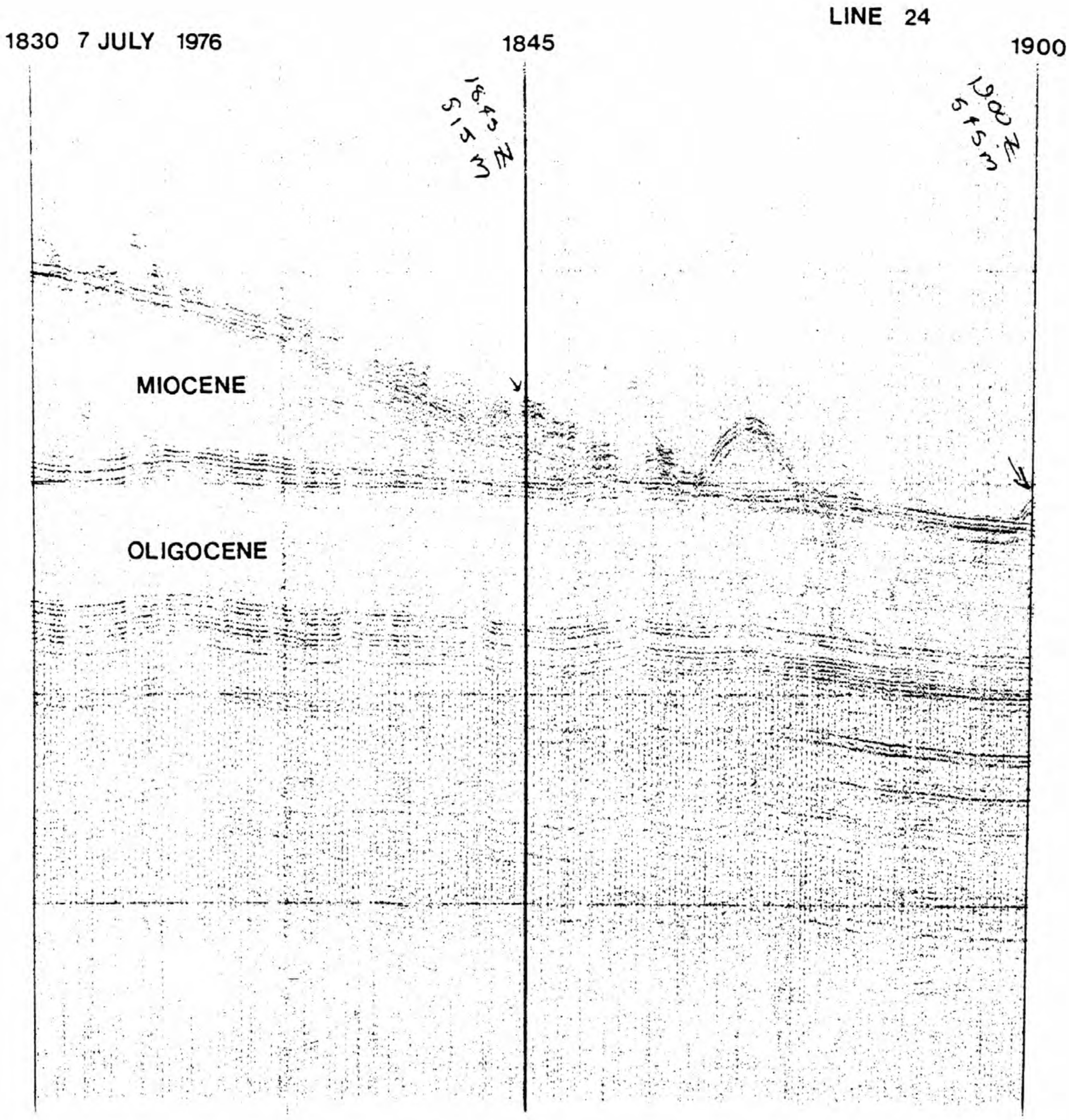
E 3 Hyperbolas on Blake Plateau, generated by reefs



E 4 Hyperbolas on Blake Plateau, some above the bottom, others below, suggestions of linearity



E 5 Hyperbolas on Blake Plateau, probable reef origin



E 6 Hyperbolas on Blake Plateau, probably of reef origin

CHAPTER 10

THE GEOLOGY OF THE FLORIDA-HATTERAS SLOPE AND INNER BLAKE PLATEAU

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Chapter 10

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CHAPTER 10

THE GEOLOGY OF THE FLORIDA-HATTERAS SLOPE AND INNER BLAKE PLATEAU

Charles Paull and William Dillon

ABSTRACT

The structure and stratigraphy of the Florida-Hatteras Slope and inner Blake Plateau was studied by means of 4,780 km of single-channel air gun seismic reflection profiles. Control for the seismic stratigraphy is provided by correlating reflecting units and paleontologically dated stratigraphic units identified in offshore wells and dredge hauls. Many Tertiary unconformities exist, and major regional unconformities at the end of the Oligocene and in the late Paleocene are mapped. Reflecting surfaces believed to represent the tops of the Cretaceous, Paleocene, and Oligocene extend throughout the region. Upper Cretaceous (pre-Maastrichtian) rocks on the southeastern side of the Carolina Platform form a large seaward-facing progradational wedge. The Upper Cretaceous rocks in the Southeast Georgia Embayment, are seismically transparent and on the inner Blake Plateau are cut by numerous small faults, perhaps due to compaction.

Within the survey area relatively flat-lying Maastrichtian and Paleocene strata show no evidence that a feature similar to the present Florida-Hatteras Slope existed at the beginning of the Tertiary. Late Paleocene erosion, related to the initiation of the Gulf Stream flow, probably developed this regional unconformity. Eocene and Oligocene sediments landward of the present Gulf Stream form a thick sequence of seaward-dipping progradational beds. A seaward progradational wedge of Miocene to Holocene age covers a regionally traceable unconformity,

which separates the Oligocene from the Miocene sediments. Under and seaward of the present Gulf Stream, the Eocene and younger sediment supply was much smaller and the buildup is comparatively insignificant. The difference in accumulation rates in the Eocene and younger sediments, landward and seaward of the Gulf Stream, is responsible for the Florida-Hatteras Slope. Tertiary isopach maps suggest that there is a well developed triangular depocenter under the shelf. The edges of the depocenter correspond with magnetic anomalies and it is suggested that the depocenter is related to differential subsidence during the Tertiary across older crustal structures. The Eocene and Oligocene units contain the aquifer onshore, and the aquifer probably remains in these units offshore. With this assumption the potential aquifer has been identified and traced under the shelf and slope.

INTRODUCTION

This study was undertaken to trace the continuity of stratigraphic units on the Florida-Hatteras Shelf and Slope between bore holes and to determine the relation of the Continental Shelf to the inner Blake Plateau. Forthcoming oil development has stimulated interest in determining structural patterns which might be environmentally significant. In order to make decisions concerning the environmental hazards of an area, the geological development of the region must be understood. In pursuit of this understanding, the United States Geological Survey (U.S.G.S.) collected 4,780 km of single channel seismic data. The analysis of these data is reported in this study.

Physiography

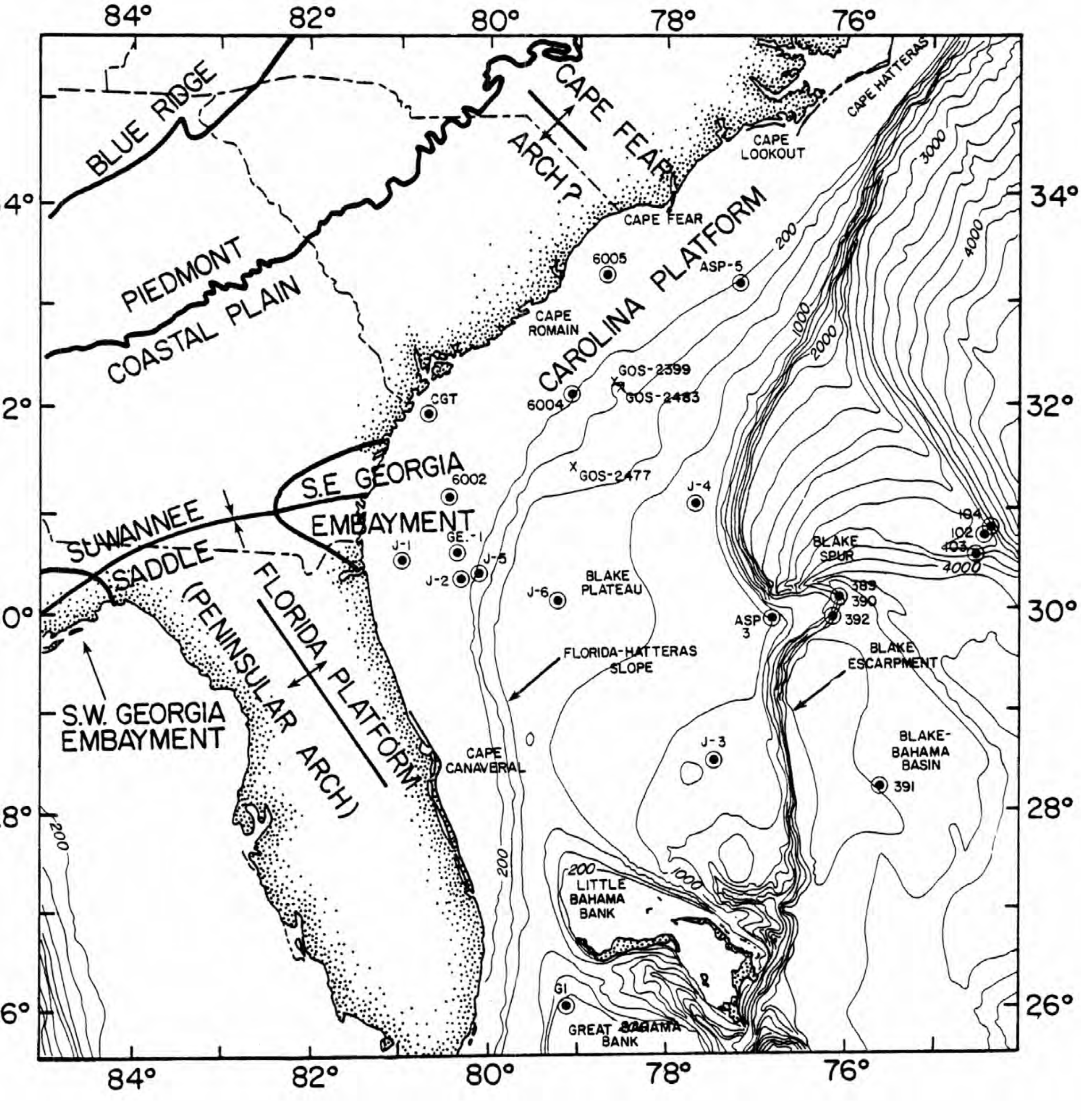
The Atlantic Continental Margin between Cape Fear and Cape Canaveral can be divided into two physiographic regions: the Continental

Shelf and the Blake Plateau. The Continental Slope connects these two features and is known as the Florida-Hatteras Slope (Figure 10-1). Depths on the Continental Shelf are less than 100 m. The Blake Plateau is a broad platform at about 600-1000 m depth; an unusual feature since most continental margins do not have similar intermediate depth plateaus seaward of the shelf break. This plateau extends from the Straits of Florida to Cape Lookout. The Blake Plateau attains its greatest width of over 300 km south of the Blake Spur, while north of 31^{o} N it becomes progressively narrower. The Plateau ends at Cape Lookout where the Florida-Hatteras Slope merges with the seaward edge of the Plateau. The rise of the Little Bahama Bank forms the southern end of the Blake Plateau (Uchupi 1968; Pratt and Heezen 1964).

Previous Work

The general geology of the Coastal Plain is well known. Over five hundred wells have been drilled in Florida, Georgia, and South Carolina. The Paleozoic and Pre-Cambrian rocks of the Appalachian Piedmont dip gently seaward and are overlain on the Coastal Plain by Triassic through Holocene sediments. The Southeast Georgia Embayment and offshore Georgia Bight is a region of transition from the predominantly terrigeneous province at Cape Hatteras to the predominantly carbonate province of southern Florida. The boundary between these provinces oscillated across the region since at least the lower Cretaceous. The Coastal Plain displays three prominent structural features between southern North Carolina and eastern Florida: the Southeast Georgia Embayment, the Cape Fear Arch (on the Carolina Platform), and the Peninsular Arch (on the Florida Platform). The Southeast Georgia Embayment, bordered to the north by the Cape Fear Arch and to the south by the Peninsular Arch, is an east-plunging basin on the coastal plain

Figure 10-1. Physiography of the continental margin and major structural features of the coastal plain off the southeastern United States. Locations of offshore wells and stratigraphically significant dredge hauls are indicated with circles (o) and Xs (X) respectively.


BLUE RIDGE
PIEDMONT
COASTAL PLAIN
CAPE FEAR ARCH?
CAPE FEAR
CAPE LOOKOUT
CAPE HATTERAS
CAROLINA PLATFORM
CAPE ROMAIN
6005
ASP-5
GOS-2399
GOS-2483
6004
CGT
S.E GEORGIA EMBAYMENT
6002
GOS-2477
J-4
SUWANNEE SADDLE
J-1
GE.-1
J-5
J-2
J-6
BLAKE PLATEAU
BLAKE SPUR
104
102
403
389
390
392
ASP 3
FLORIDA PLATFORM
(PENINSULAR ARCH)
FLORIDA-HATTERAS SLOPE
BLAKE ESCARPMENT
S.W. GEORGIA EMBAYMENT
CAPE CANAVERAL
J-3
BLAKE-BAHAMA BASIN
391
LITTLE BAHAMA BANK
G1
GREAT BAHAMA BANK
84°
82°
80°
78°
76°
34°
32°
30°
28°
26°
200
1000
2000
3000
4000

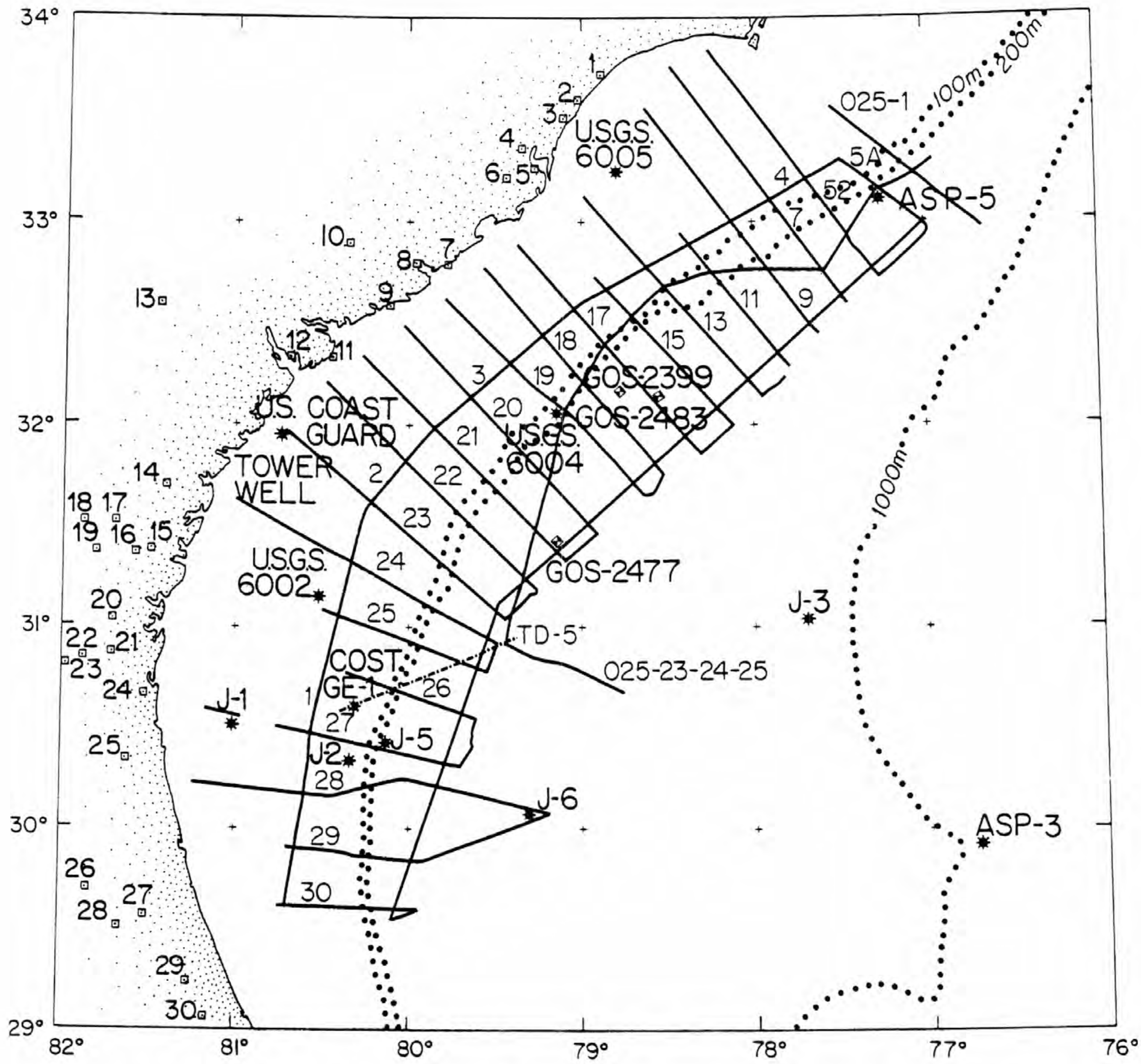
of Georgia, South Carolina, and northeast Florida (Figure 10-2). The Cape Fear Arch extends from the Piedmont Uplands southeastward under Cape Fear, North Carolina, whereas the Peninsular Arch extends from central Georgia southeastward down the Florida Peninsula (Applin and Applin 1944; Pressler 1947; Applin 1952; Toulmin 1955; Murray 1961; Herrick and Vorhis 1963; Maher 1971).

Before the 1960's, no information was available regarding the subsurface geology of the offshore region. It was assumed that coastal plain stratigraphy could be extrapolated onto the Continental Shelf. Since that time, geophysical and drilling techniques have been employed to obtain direct data on the subsurface of the region which permits us to delineate the region's geological features.

In 1965, the Joint Oceanographic Institute Deep Earth Sampling (JOIDES) program drilled six holes off the northern coast of Florida, two on the shelf, one on the Florida-Hatteras Slope, and three on the Blake Plateau. Data from these bore holes contributed greatly to the knowledge of the Tertiary stratigraphy. The first two were drilled on the shelf and demonstrated that stratigraphy from the land could indeed be extrapolated out onto the shelf. The faunas encountered in holes J-1 and J-2 indicated that the environments of deposition were at shelf depths. The three wells on the Blake Plateau had much thinner Tertiary units than those on the shelf. Two of them penetrated the Paleocene where the faunas indicated that the material on the Plateau was deposited in deep water (JOIDES 1965). Environments of deposition for all samples were found to correspond with the present water depths, suggesting the general physiography probably was the same throughout most of the Tertiary.

In the 1960's continuous seismic profiles were run across the

Figure 10-2. Locations of single channel seismic profiles discussed in this report are shown by the solid lines. Multichannel profile TD-5 which crosses the COST GE-1 drill site is indicated by the broken line. The names of the wells onshore, numbered 1-30, are listed in Appendix A.



Track Lines of Fay 017, 018, & 025 where interpretable data were collected

- Location of offshore wells
- Location of dredge hauls of Cretaceous age
- Location of land wells with good stratification information

Southeast Georgia Embayment and Blake Plateau. Ewing, Ewing, and Leyden (1966) published a delineation of major reflection trends on the Plateau. With 12 lines extending from the shelf break seaward over the edge of the Plateau they obtained up to a kilometer of penetration with poor resolution. Since multiples prevented collecting data in shallow water, the coverage of the western portions of the Plateau and Florida-Hatteras Shelf was limited. They demonstrated that reflections on the Blake Plateau, although nearly horizontal, tend to rise to the east and converge near the seaward edge of the Plateau. Based partly on refraction velocities they extrapolated the stratigraphy from land before the early information from JOIDES wells on the Blake Plateau was available.

Between 1967 and 1970 a series of publications which dealt with seismic reflection profiles on the Blake Plateau (Emery and Zarudzki 1967; Uchupi 1967; Uchupi and Emery 1967; Uchupi 1970) delineated many of the near surface features of the shelf, slope and Blake Plateau. These data, taken with a 10,500 joule sparker, provided good resolution but often less than 0.3 seconds of penetration. The distance between lines averaged 65 km. Most of the lines started about 20 km west of the shelf break and extended seaward approximately 60 km across the Florida-Hatteras Slope onto the Blake Plateau. The slope was shown to be formed by an irregular wedge of Tertiary sediments, while the surface of the Plateau was found to be highly eroded and covered by a thin veneer of Tertiary sediments.

Ages were assigned to seismic reflectors where they crop out near coring or dredging sites. Although strata on the Blake Plateau tend to be nearly horizontal, some older sediments are present at the surface as a result of erosion or nondeposition. Four dredge hauls produced

Cretaceous material (Uchupi 1970, p. 321) and several cores on the Plateau have contained samples dated as pre-Quaternary. Most of these are catalogued by either Saito et al (1974) or by Hathaway (1971). Three wells were drilled on the southern U. S. Atlantic Shelf as part of the U.S.G.S.'s Atlantic Margin Coring Project (AMCOR) in 1976 (Hathaway et al 1976). Of the two wells located on the middle shelf (6005 and 6002), one bottomed in the Paleocene and the other in the Eocene. The third well (6004), located near the shelf break at 32° N latitude, encountered upper Cretaceous calcareous clay at 290 m, the deepest strata penetrated by any hole on the southern U. S. Atlantic OCS prior to the drilling of the COST GE-1.

The Consortium Offshore Stratigraphic Test Georgia Embayment 1 (COST GE-1) hole was drilled in the center of the Southeast Georgia Embayment at 30°37′ N latitude and 80°18′ W longitude. It penetrated more than four km of material and ended in Paleozoic metamorphic rocks. The upper 1,800 m of the hole contained fossiliferous sediments which could be dated paleontologically down to the Turonian. Below this, the section changed from a lime mud into an unfossiliferous fluvial sandstone. Albian pollen grains have been found in this section (Poag 1978; Valentine 1979; Amato and Bebout 1978; Poag and Hall 1979). This is the only offshore hole in the embayment which penetrates all the units with which this study is concerned.

In 1965 there were a series of shallow wells drilled on the east coast by private industry. Recently, data from them have been released. The Atlantic Sampling Program (ASP-5) hole on the Florida-Hatteras slope at about 33°N latitude bottomed in Paleocene sediments at 293 m depth (Poag 1978). The new wells and the older JOIDES wells provide good stratigraphic control throughout the survey area (Figure 10-2).

The structure, stratigraphy, and development from the time of continental rifting to the present, of the Southeast Georgia Embayment and Blake Plateau have been outlined based on Common Depth Point (CDP) multichannel seismic data (Dillon et al 1979a). Buffler et al (1978) published an interpretation of a CDP seismic line off Jacksonville, Florida. The portion of this line which crosses the Florida-Hatteras Slope is also described by Dillon et al (1979a). Dillon and Paull (1978) published interpretations of three CDP lines which extend seaward from the Carolinas, including calculated true depth sections and photographs of selected portions of the lines. These lines were previously discussed by Dillon et al (1979a). A CDP seismic line (TD-5) which passes through the COST GE-1 well site and seaward to ASP-5 and DSDP 390 has been discussed by Dillon et al (1979b). This is the first published seismic line on the U.S. South Atlantic continental margin which has solid stratigraphic control for most of the sedimentary section.

Data Collection and Processing

The data presented in this study consist of a grid of single-channel seismic reflection profiles, which were collected on three different cruises. The bulk of the data was collected on two cruises of the R/V FAY (FAY 017 and FAY 018) during June and July 1976. Twenty-one dip lines were run across the shelf and inner Blake Plateau at an average spacing of 30 km (Figure 10-2). Two tie lines were also run; one was on the shelf and one on the plateau. In September and October of 1976 the R/V FAY returned to the Blake Plateau with the same seismic system and collected two additional seismic lines, one dip line and one tie line. This grid was designed for the collection of several types of data. Unfortunately, the airgun lines which were shot on the shelf are difficult to interpret due to the interference of multiples and a long outgoing pulse. The data improve at the shelf break, and on the Plateau are of excellent quality.

The R/V FAY had a Western Geophysical integrated navigation system (INS) that consisted of a satellite navigation receiver, rho-rho Loran-C, hyperbolic Loran-C, a gyrocompass, a speed log, and a Cesium vapor time standard, all interfaced with a Hewlett Packard 2100 computer. The prime mode of navigation was rho-rho Loran-C with periodic updates from satellite fixes. The system position and most of the navigational parameters were recorded every two seconds. The INS had the capability to trigger the guns at a specified distance interval. About ninety percent of the data were obtained with the guns firing at a shot point interval of 30 m. When the INS Shot Point routine was not being used the guns were fired every 12 seconds.

The seismic source consisted of four Bolt airguns of 20, 40, 80, and 160 cubic inches fired at 2,000 psi. Wave shapers were used on all guns. The three smaller guns were used continuously, but the 160 cubic inch gun was periodically removed. Although the 160 cubic inch gun did increase the signal it did not markedly affect the signature. The guns were equipped with blast monitors and delay boxes which allowed the firing of the guns to be synchronized. However the array was not "tuned" and the resulting signature was long and complex.

The hydrophone streamer was made by Seismic Engineering Company. The streamer has a 91.5 meter (300 foot) active section and was towed on a 243.9 meter (800 foot) lead-in-section. The active section was composed of two groups, with 12 MD-5 phones over the first 84 feet of active length and 28 MD-5 phones over the remaining 196 feet. At six knots the streamer was at a depth of about 5 m.

The analog signal was recorded on two channels of a magnetic tape, one filtered and one unfiltered. The average filter setting was for a band between 32 - 205 Hz. The filtered signal was also sent to an EPC Labs flat bed recorder where a paper record was made on a 5 second sweep.

Data Playback

Since the seismic data were recorded on tape, post cruise playback was possible. All the tapes were run at the same settings with a 2 second sweep and a band pass filter of 85 - 115 Hz. These parameters were selected because the water was never much more than one second of two-way travel in depth and the signature was long and complex. Serious ringing occurred in shallow water (shelf depths) and in deeper water interpretable information beneath the multiple was uncommon. The higher frequency band pass helped to suppress the multiple although a significant amount of energy was lost. Original and taped records of the same line were compared. The taped records in nearly all cases were of significantly better quality.

Interpretation

Major reflectors and those reflectors believed to be stratigraphically significant were traced on the records. Line drawings are shown in Figures 10-3a through 3d. Not all primary reflections are shown, but enough to show the general reflection style. Depths to surfaces considered stratigraphically significant were converted from time to depth and structure and isopach maps produced. Interval velocities were determined from the root-mean-square (RMS) velocities of the common depth point (CDP) multichannel seismic data in the region (Dillon et al 1979a and b; Dillon and Paull 1978). Refraction seismic velocities were not used because they give the velocities at a

Figure 10-3. Line drawing of seismic profiles. Selected reflections are shown to indicate inferred trends of reflectors.

a. Shows the northern groups of dip lines.

b. Shows the middle groups of dip lines.

c. Shows the southern groups of dip lines.

d. Shows strike lines.

Locations of lines within a section of the figure are shown in the associated small insert map.

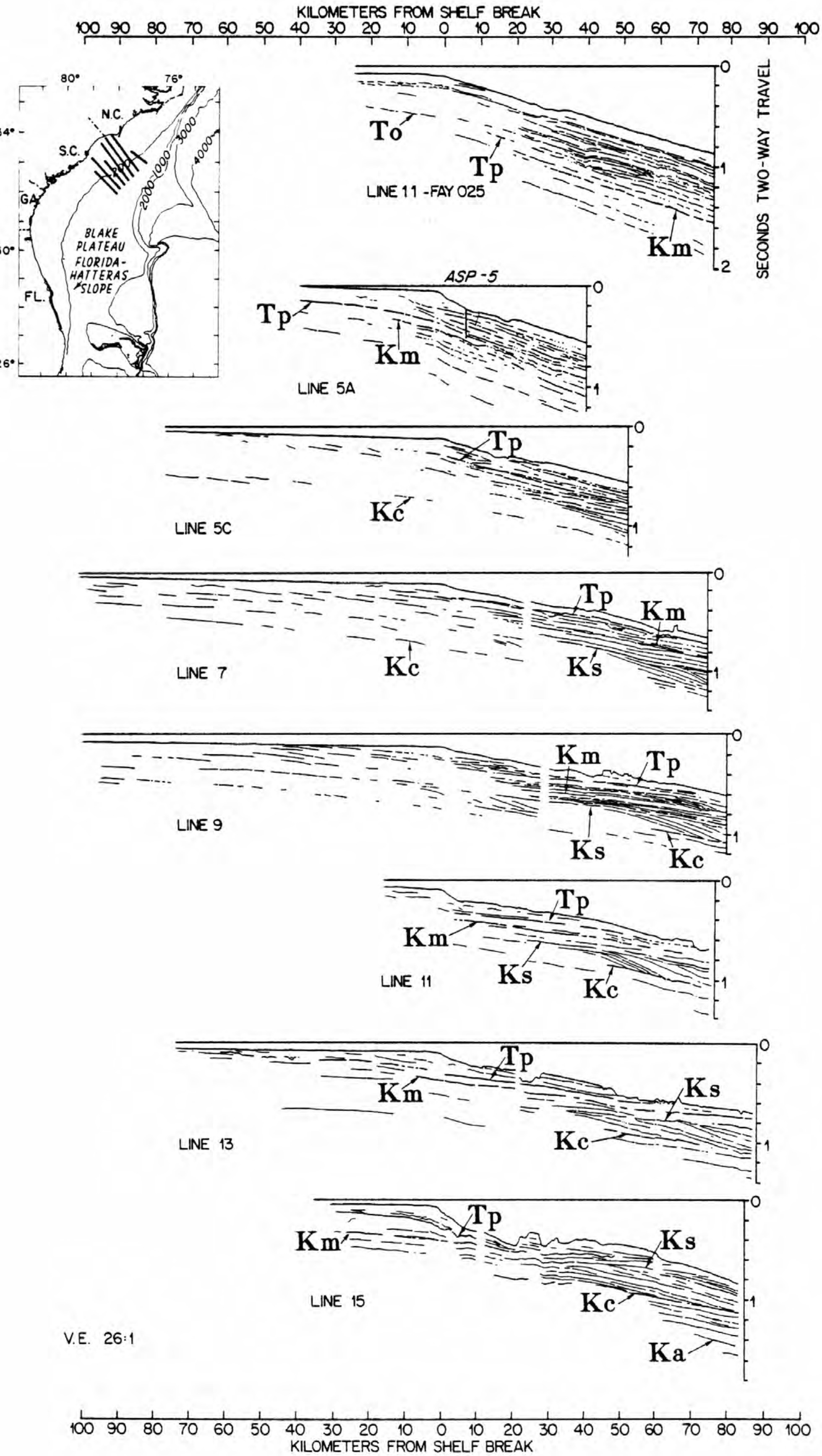
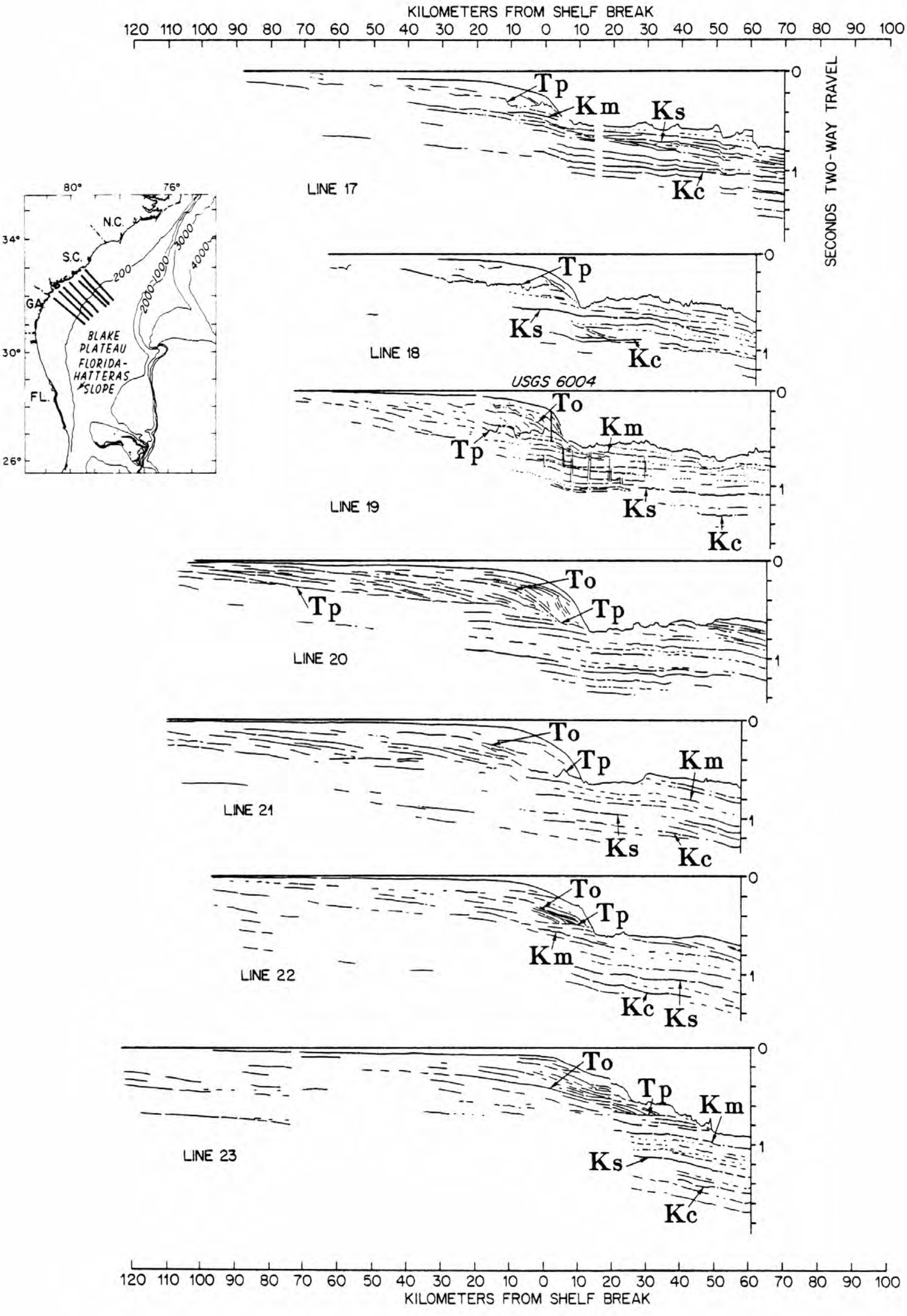
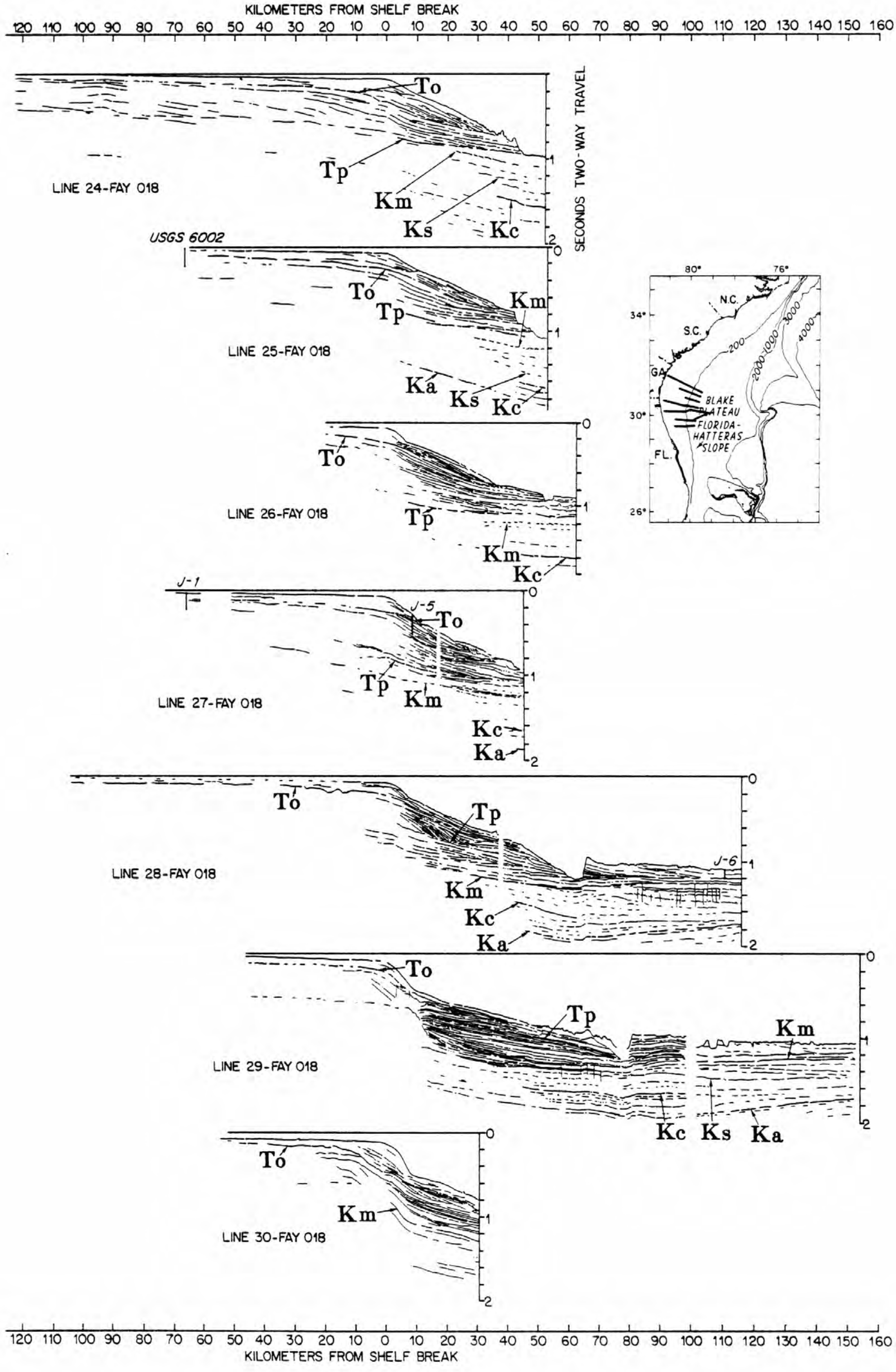

KILOMETERS FROM SHELF BREAK
100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100
SECONDS TWO-WAY TRAVEL
80°
76°
34°
30°
26°
N.C.
S.C.
GA.
FL.
BLAKE PLATEAU
FLORIDA-HATTERAS SLOPE
2000
1000
3000
4000
LINE 11 -FAY 025
To
Tp
Km
ASP-5
LINE 5A
LINE 5C
Kc
LINE 7
Ks
LINE 9
LINE 11
LINE 13
LINE 15
Ka
V.E. 26:1

Figure 10-3 b


KILOMETERS FROM SHELF BREAK
120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100
SECONDS TWO-WAY TRAVEL
LINE 17
Tp
Km
Ks
Kc
LINE 18
Tp
Ks
Kc
USGS 6004
LINE 19
To
Km
Tp
Ks
Kc
LINE 20
To
Tp
Tp
LINE 21
To
Tp
Km
Ks
Kc
LINE 22
To
Tp
Km
Kc
Ks
LINE 23
To
Tp
Km
Ks
Kc
80°
76°
34°
30°
26°
N.C.
S.C.
GA.
FL.
200
2000
1000
3000
4000
BLAKE PLATEAU
FLORIDA-HATTERAS SLOPE
0
1
120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100
KILOMETERS FROM SHELF BREAK


KILOMETERS FROM SHELF BREAK
120 110 100 90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
SECONDS TWO-WAY TRAVEL
LINE 24-FAY 018
To
Tp
Km
Ks
Kc
USGS 6002
LINE 25-FAY 018
Ka
LINE 26-FAY 018
J-1
J-5
LINE 27-FAY 018
LINE 28-FAY 018
J-6
LINE 29-FAY 018
LINE 30-FAY 018
N.C.
S.C.
GA
FL.
BLAKE PLATEAU
FLORIDA-HATTERAS SLOPE
80°
76°
34°
30°
26°
200
1000
2000
3000
4000

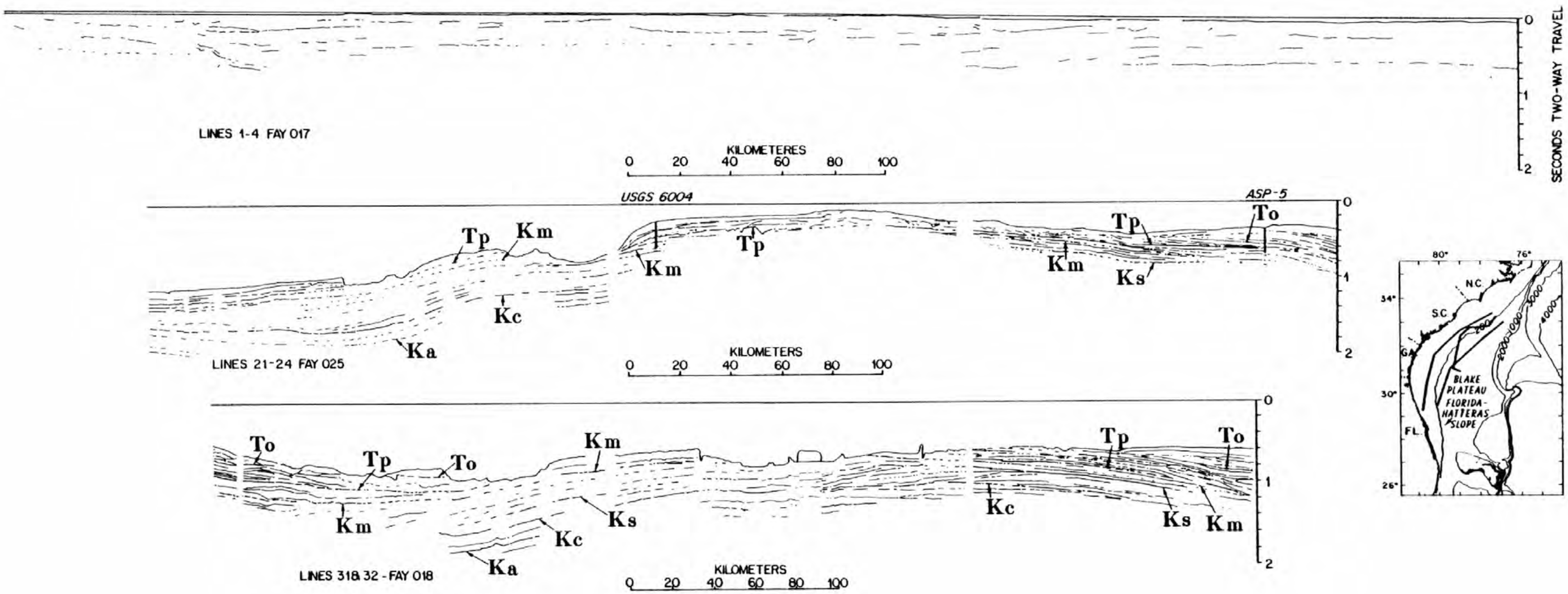

SECONDS TWO-WAY TRAVEL
LINES 1-4 FAY 017
KILOMETERES
0 20 40 60 80 100
USGS 6004
ASP-5
Tp
Km
Tp
Km
Tp
To
Km
Ks
Kc
Ka
LINES 21-24 FAY 025
KILOMETERS
0 20 40 60 80 100
To
Tp
To
Km
Tp
To
Km
Ks
Kc
Ka
Kc
Ks
Km
LINES 31& 32 - FAY 018
KILOMETERS
0 20 40 60 80 100
80°
76°
34°
30°
26°
NC
SC
GA
FL
BLAKE PLATEAU
FLORIDA-HATTERAS SLOPE

Figure 10-3 d

particular horizon or layer rather than being an average velocity for a finitely thick layer. RMS velocities down to the top of the Cretaceous and the Santonian were used in the calculation of the interval velocities (Dillon et al 1979a and b; Dillon and Paull 1978; Taner and Koehler 1969). Interval velocities between these surfaces were contoured at 200 m/sec intervals. These generalized contours were then projected onto a Fay 017, 018 and 025 track chart, providing interval velocities for converting the single channel seismic data from time to depth. Arrival times were multiplied by the appropriate velocity to convert to distance.

Stratigraphic control was provided by marine wells, coastal wells and dredge hauls. Locations of the wells and dredge hauls are shown in Figure 10-2. The names of the land wells and references for their published descriptions are listed in Appendix A.

DISCUSSION

The evolution of the Atlantic Margin is profoundly affected by subsidence. Substantial thermal uplift and rifting of the east coast occurred in the Triassic and Jurassic, and in the Jurassic the continents began to drift apart. Subsequent thermal activity was restricted to the ridge crest which moved farther away from the margin. Cooling of the margin resulted in subsidence, which presumably decreased logarithmically with time (Sclater and Francheteau 1970). Sediment loading resulted in additional subsidence near the continent. This study shows various aspects of the sedimentation accompanying the late stages of this subsidence with the superimposed effects of the relative changes in sea level, local tectonics, and current activity.

The strata indicated by the airgun seismic data are divided into three groups--the Lower Cretaceous, the Upper Cretaceous and Paleocene, and the rest of the Tertiary. Each of these units is acoustically distinct both on the basis of reflection intensities and by structural and depositional characteristics. The correlation between the various acoustic units and the stratigraphic units is controlled by the crossings of the holes COST GE-1, J-1, J-2 J-5 and J-6, AMCOR 6004, ASP-5 and dredge hauls GOS-2399, GOS-2477 and GOS-2483 by our grid of single channel lines and the multichannel line TD-5 (Figure 10-2). The correlation of chronostratigraphic units and the major reflectors is shown in Figure 10-4.

Lower Cretaceous

A thin layer (less than 100 m) of nonmarine red arkosic sandstone and micaceous vari-colored clay and shale overlie pre-Triassic basement beneath the eastern Coastal Plain of Georgia and South Carolina (Maher 1971; Herrick and Vorhis 1963; Cramer 1974; and Applin and Applin 1967). These authors identify the continental unit as Lower Cretaceous in age, although it contains no microfossils and could be Jurassic or Triassic in age. Down dip in Franklin County Florida, a unit inferred to be an extension of the continental strata, changes from a marginal clastic facies into a shallow marine facies which contains microfossils of Washita (Early Cretaceous) age (Applin and Applin 1967).

The only location where Lower Cretaceous rocks have been sampled offshore is at the COST GE-1 well. Here there is a distinct lithologic difference between the Upper and Lower Cretaceous. The Upper Cretaceous is an essentially monotonous sequence of argillaceous chalks and limey shales which ranges in age from Maastrichtian to Turonian. Although no Cenomanian sediments are identified in the COST GE-1 well, the rocks identified as being uppermost Albian were not fossiliferous

Figure 10-4. Chart correlating major reflectors as observed in profiles (Figure 10-3), progradational wedges, and geologic time. Reflectors To, Tp, Kc, and Ka are correlated with unconformities in bore holes. No holes have been drilled in the region where reflectors Km and Ks are strong, but they are interpreted as also being unconformities.

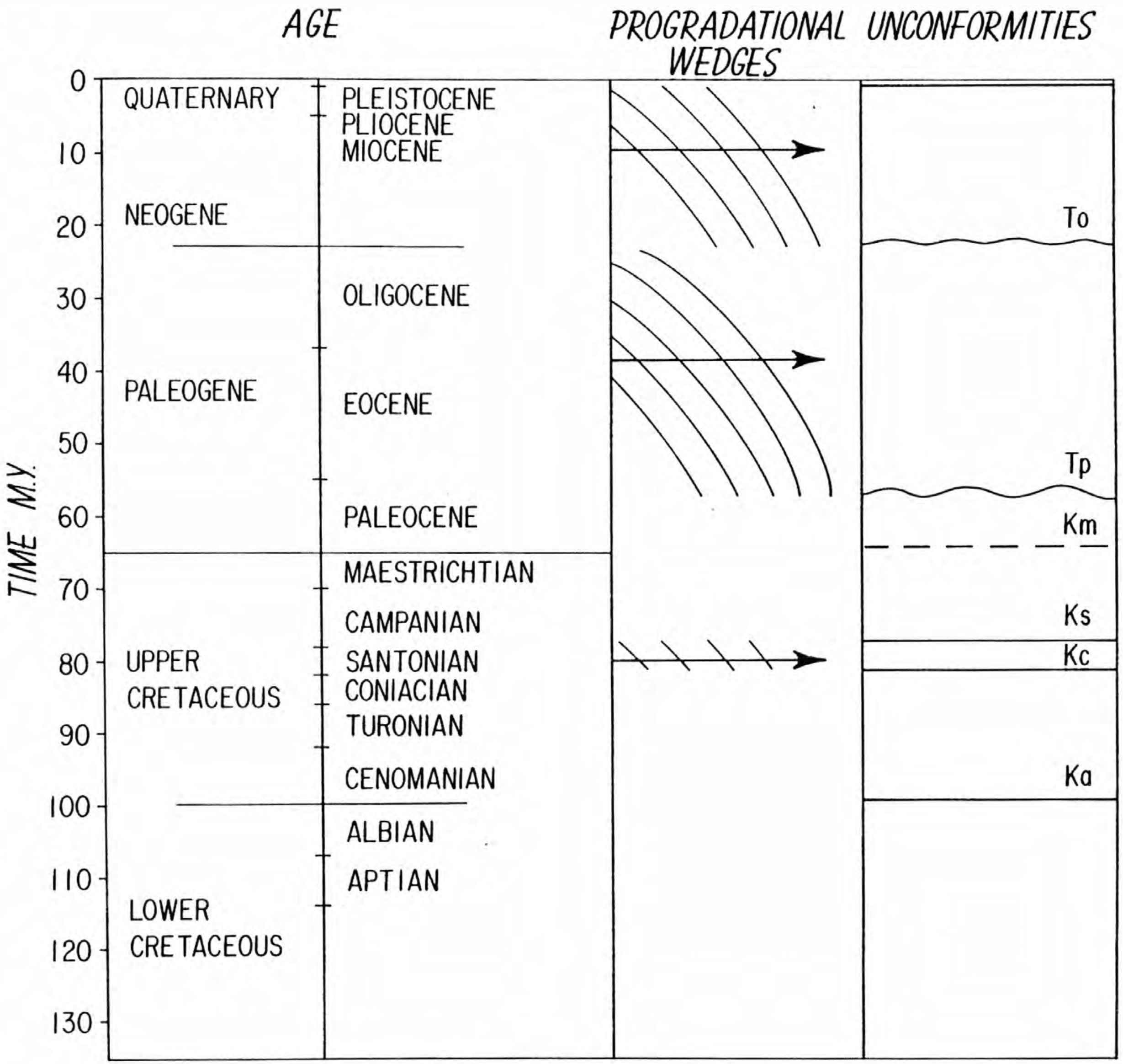

AGE
PROGRADATIONAL WEDGES
UNCONFORMITIES
TIME M.Y.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
QUATERNARY
NEOGENE
PALEOGENE
UPPER CRETACEOUS
LOWER CRETACEOUS
PLEISTOCENE
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
MAESTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
To
Tp
Km
Ks
Kc
Ka

Figure 10-4

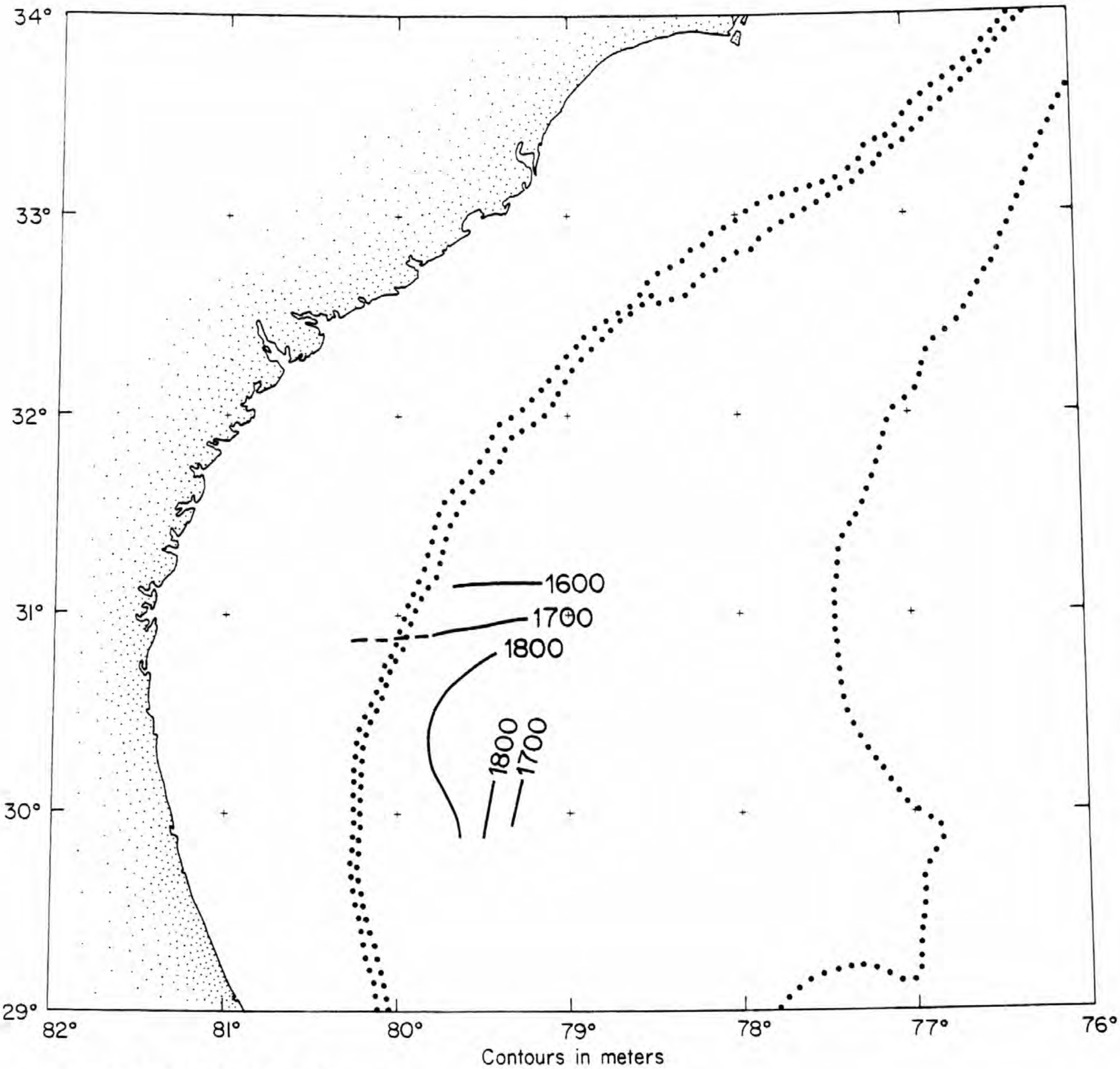
and some of this unit could be Cenomanian (Valentine 1979). The Aptian and Albian sediments are largely red continental sandstone but contain beds of limestone, limey shale, anhydrite, and coal (Halley 1979).

The break between the variable Albian sequence and the uniform Upper Cretaceous sequence has been correlated with a strong reflector (K_A) which is very obvious when it occurs above the first water column multiple (Figure 10-3c). Reflections beneath the inferred Albian top (K_A) are strong, parallel, and appear to be laterally continuous. The reflector at the top of the Albian has been traced throughout the southern portion of the survey area where the multiple does not interfere. To the north reflector K_A runs beneath the multiple and becomes untraceable. The position of the Albian reflectors can be seen at the seaward ends of lines 24-29 in Figure 10-3c. Figure 10-5 is a structure contour map of the top of Albian sediments. The Lower Cretaceous units are discussed in Dillon et al (1979a); Dillon et al (1979b); Dillon and Paull (1978); and Shipley et al (1978) where multichannel seismic techniques were used.

Upper Cretaceous

Rocks of Late Cretaceous age have been penetrated in many wells along the coast between southern North Carolina and northern Florida. They consist of marine carbonates and clastics about 600 m thick in Georgia and thin to about 400 m on the Cape Fear Arch (Maher 1971; Herrick and Vorhis 1963). These rocks grade down dip toward Florida into marine carbonates. Up dip to the northwest near the Fall Line they outcrop as nearshore marine and continental clastic deposits (Maher 1971, p.47). Apparently the Upper Cretaceous rocks grade northwestward into progressively shallower water facies. Offshore rocks of Late Cretaceous age have been sampled in three dredge hauls where they crop

Figure 10-5. Structure contours on reflector Ka which is correlated with the top of Albian sediments.



Depth to Albian Sediments

out on the surface of the plateau and in two wells. The AMCOR 6004 well penetrated only 17 m of Maastrichtian fine silty calcareous clay, whereas the COST GE-1 well penetrated a complete sequence 680 m thick. In the COST GE-1 well the Upper Cretaceous is a nearly uniform sequence of calcareous mudstones (Halley 1979).

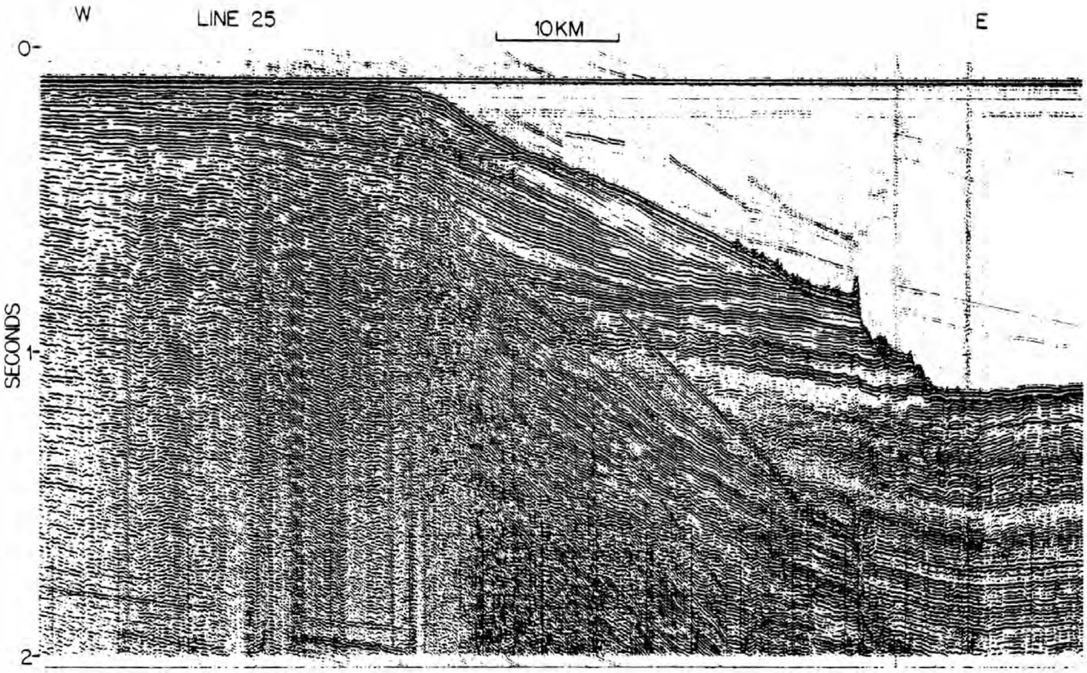
Near the COST GE-1 well the Upper Cretaceous sequence is relatively transparent as it is throughout the southern region. Here the Upper Cretaceous is a nearly uniform sequence of calcareous mudstones. The down hole velocity and density logs for GE-1 show little variation in either parameter. Since there is little change in the velocity and density (and thus of acoustic impedence) of the Upper Cretaceous sediments, few reflections would be expected (Sheriff 1977). Vague zones of slightly increased reflectivity occur but they are probably a result of gradual lithologic changes rather than distinct horizons. The contrast between the transparent Upper Cretaceous units and the more reflective Tertiary units above can be seen in line 25 (Figure 10-6a). The uppermost Cretaceous (Maastrichtian) is somewhat better stratified and has several weak reflectors. The acoustic character of the Upper Cretaceous strata changes to the north. Reflectors become better defined north of about 32^{o} in the vicinity of line 19, and two reflectors (K_C and K_S) can be traced within the Upper Cretaceous section throughout the northern portion of the survey area. Although the Upper Cretaceous near the COST GE-1 well is quite transparent, reflectors K_C and K_S can be traced to the well. Both reflectors are correlated with stratigraphic changes which occur in the COST GE-1 well and in the coastal wells of the Carolinas.

The lower regionally traceable Upper Cretaceous reflector (K_C) is believed to correspond with a stratigraphic break between sediments of

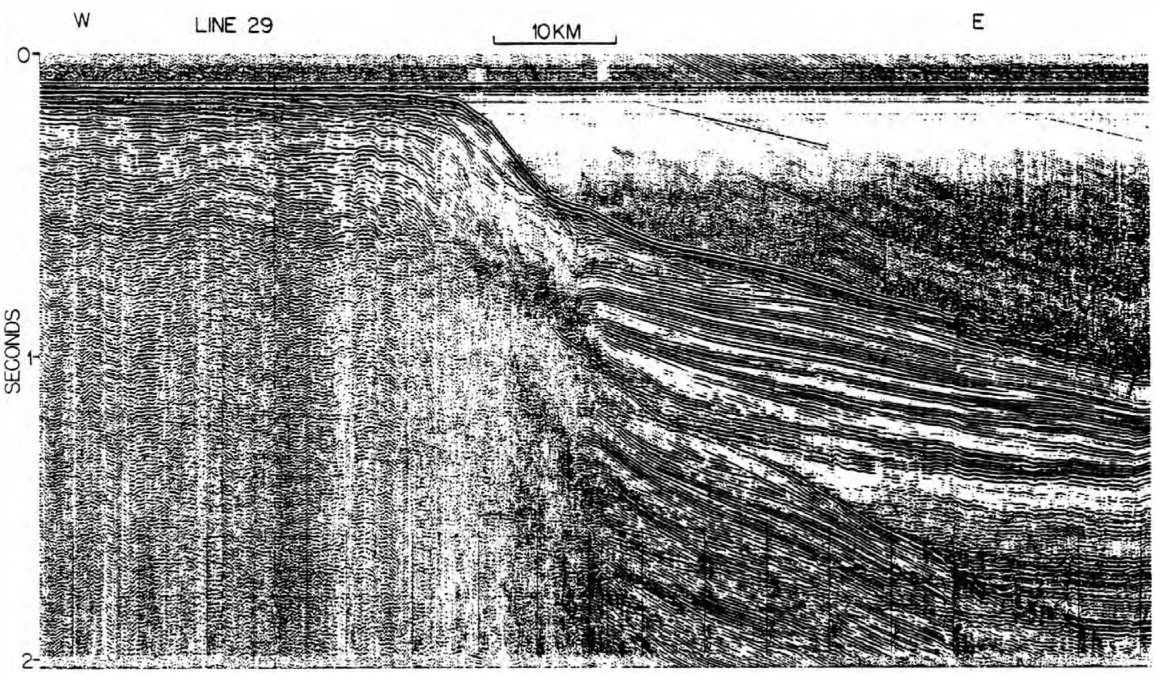
Figure 10-6. Photographs of reflection profiles that extend from the Florida-Hatteras Shelf, across the Slope, and onto the inner Blake Plateau.

a. Line 25 between 30°57'N, 80°07'W to 30°46'N, 79°33'W. The terminations of reflectors at the toe of the Florida-Hatteras Slope indicate major erosion. The units which are exposed are of Eocene and Oligocene age.

b. Line 29 between 29°54'N, 80°32'W to 29°51'N, 79°54'W. Under the shelf and slope below .6 seconds, there are no coherent reflectors. This zone has been interpreted as being a Cretaceous reef or carbonate complex.



a



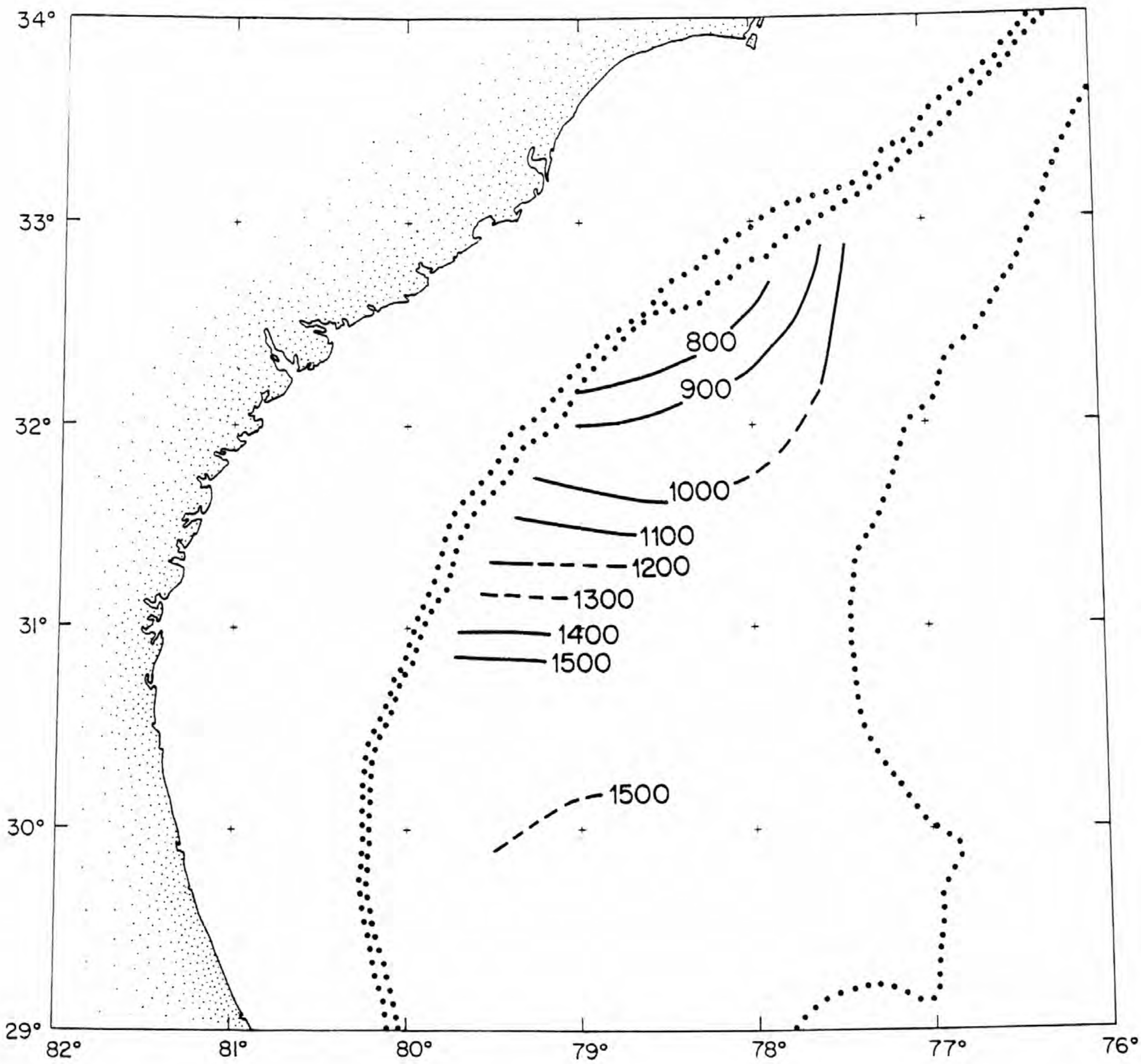
b

Santonian and Coniacian age at the COST GE-1 well as dated by International Biostratigraphers Inc. (1977); Poag and Hall (1979); and Valentine (1979). This reflector can be seen on the seaward ends of the majority of lines but it cannot be traced very far landward (Figures 10-3a through 3d). Coniacian and Turonian sediments may not exist under the Coastal Plain of the Carolinas (Hazel et al 1977, and Gohn et al 1978b) although both Coniacian and Turonian sediments exist in the COST GE-1 well (International Biostratigraphers Inc. 1977; Poag and Hall 1979; and Valentine 1979). A large unconformity is believed to separate the Santonian and Cenomanian onshore. Correlations between the reflectors which correspond with the top of the Coniacian sediments at the COST GE-1 well and the hiatus between the Santonian and Cenomanian onshore noted by Gohn et al (1978b), imply that K_C is the same surface. Since the Coastal Plain of the Carolinas is farther up dip, it is reasonable that an unconformity would have removed more of the section in the Coastal Plain than at the COST GE-1 well. The structure contour map of the portion of this surface below the Blake Plateau is shown in Figure 10-7.

The upper regionally traceable reflector (K_S) within the Upper Cretaceous, although strongest in the northern half of the survey area, may be traced to the vicinity of the COST GE-1 well, where it corresponds with the top of Santonian sediments identified by Poag and Hall (1979) and by Valentine (1979). This reflector (K_S) is correlated with an unconformity which occurred at the end of the Santonian or possibly in the lowest Campanian in the coastal wells of the Carolinas as noted by Gohn et al (1978b). Figure 10-8 is a structure contour map of this surface.

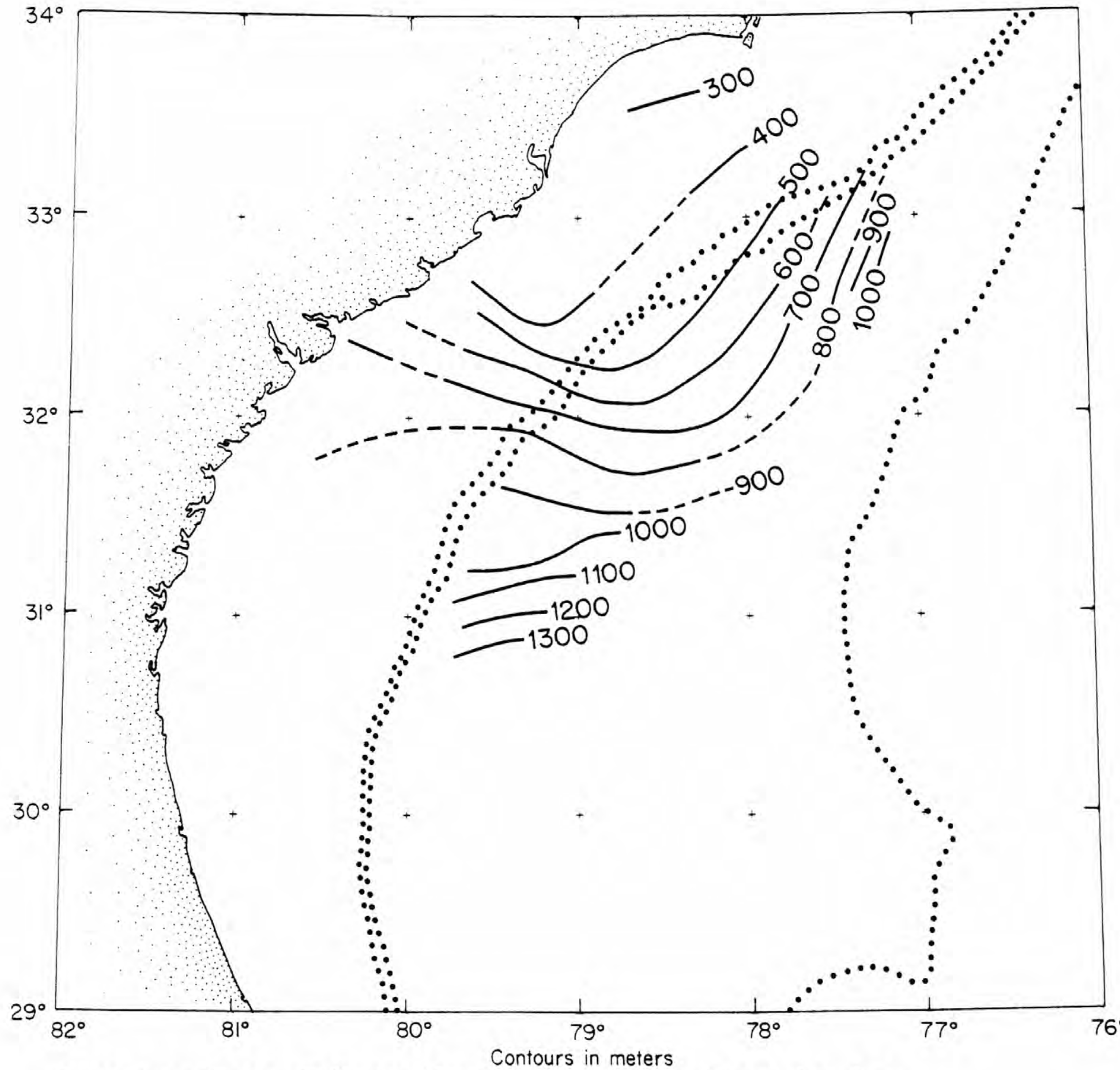
The sediment, between K_C and K_S is assumed to be of Santonian age.

Figure 10-7. Structure contours on reflector Kc which are correlated with the top of Coniacian sediments. Contours are in meters.



Depth to Coniacian Age Sediments

Figure 10-8. Structure contours on reflector Ks which are correlated with the top of Santonian sediments. Contours are in meters.



Depth to a Strong Reflector Presumably of Late Santonian Age

In the northern third of the survey area, the Santonian sediments form a wedge showing strong seaward dipping internal stratifications. Reflectors have toplapping and downlapping relationships at their upper and lower ends. Presumably this pattern was produced as a result of a seaward progradation which occurred during the Santonian. This pattern can be seen in Figure 10-9a. It is best developed in the northern lines 7 and 9 (Figure 10-3a), whereas toward the south in lines 13, 15, and 17 the seaward dips are more gentle. South of line 18 at about 32^{o} N there is no appreciable difference in dips between the Santonian reflections and those of the units directly above or below the Santonian. Also south of 32^{o} N, the Santonian interval becomes increasingly transparent. Such transparent and therefore presumably uniform sediments would not accumulate on a progradational wedge.

The Santonian interval (K_C to K_S) is uniformly about 200 m thick, both in the northern area where it is a progradational wedge and farther to the south where it is less reflective (Figure 10-10). Because the material in the southern area must lap up onto material of the progradational wedge, the wedge portion of the Santonian must be older than the uniform Santonian sediments in the vicinity of the COST GE-1 well.

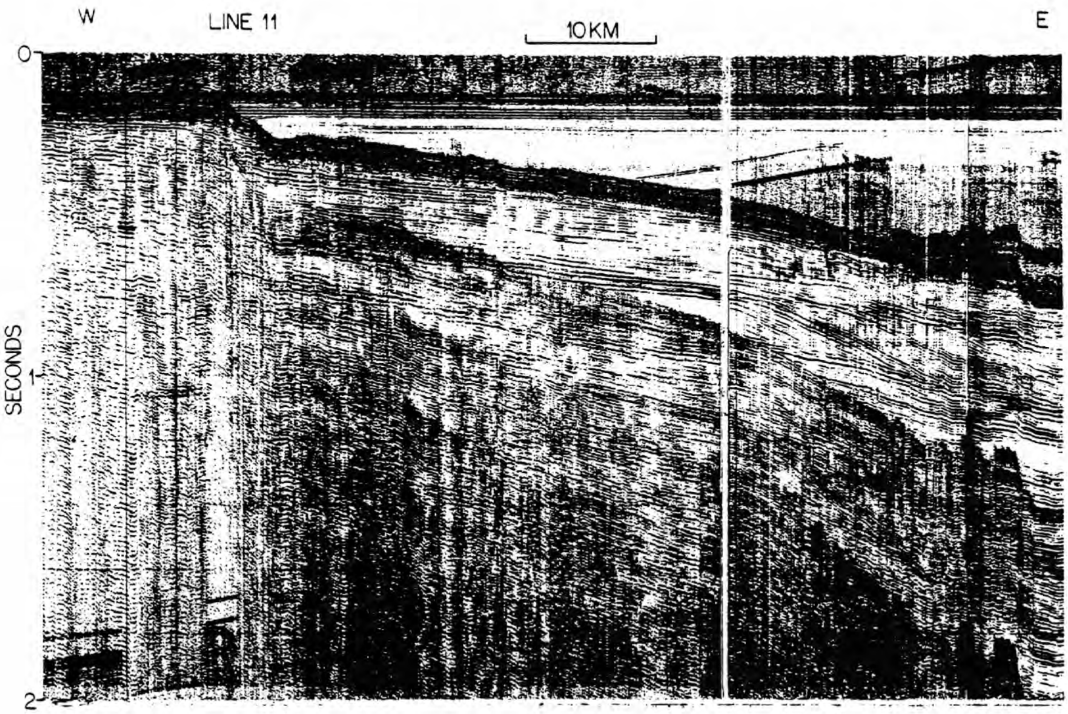
Maastrichtian and Campanian sediments overlie the Santonian unit. These sediments produce horizontal parallel reflectors, presumably indicating deposition on a broad subsiding plateau. The plateau edge was east of the survey area and probably coincided with the edge of the Blake Plateau. A shallower shelf might have existed at this time closer to shore, but at present its location is unknown and presumed to be landward of our survey area. An isopach of these sediments (Figure 10-11) shows southward thickening between lines 15 and 19 near 32^{o} to

Figure 10-9. Photographs of reflection profiles which extend from the Florida-Hatteras Slope, across the Shelf, and onto the inner Blake Plateau.

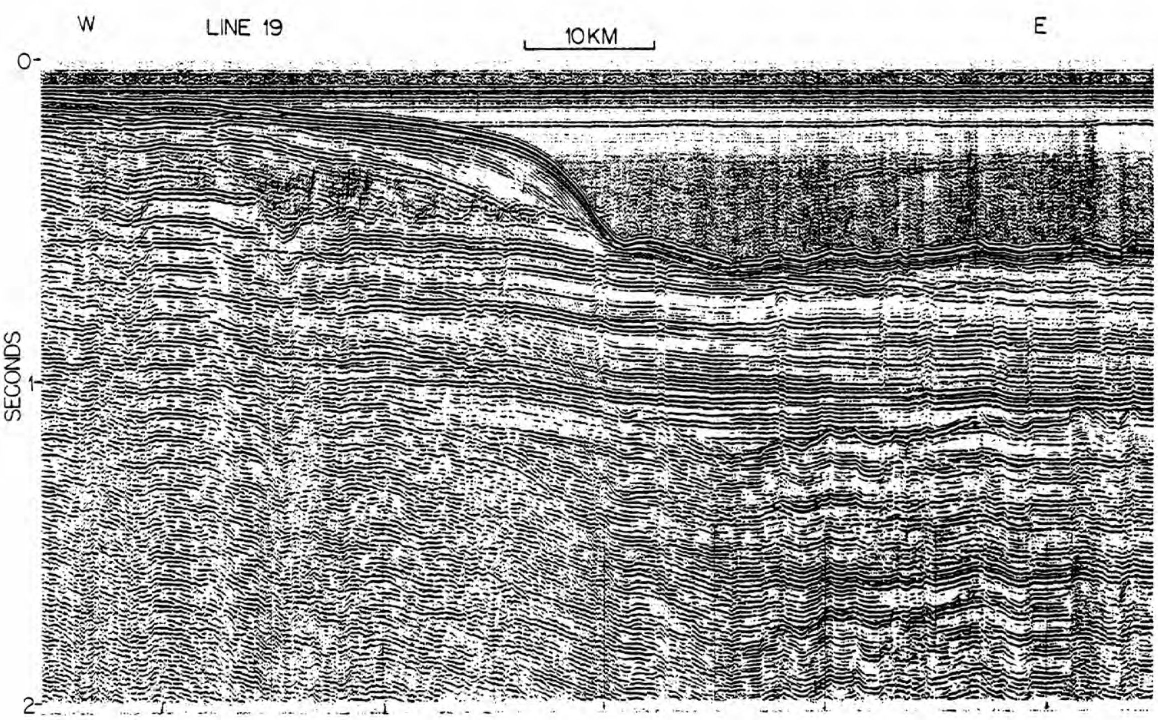
a. Line 11 between 32°38'N, 78°06'W to 32°18'N, 78°47'W where a buried seaward progradational wedge can be seen under the Blake Plateau. This wedge developed during the Santonian. Note that the reflectors above and below the wedge are parallel.

b. Line 19 between 32°11'N, 79°17'W to 31°52'N, 78°50'W. The irregular unconformity under the shelf is related to late Paleocene erosion. Small buried faults are visible under the Blake Plateau.

Figure 10-9

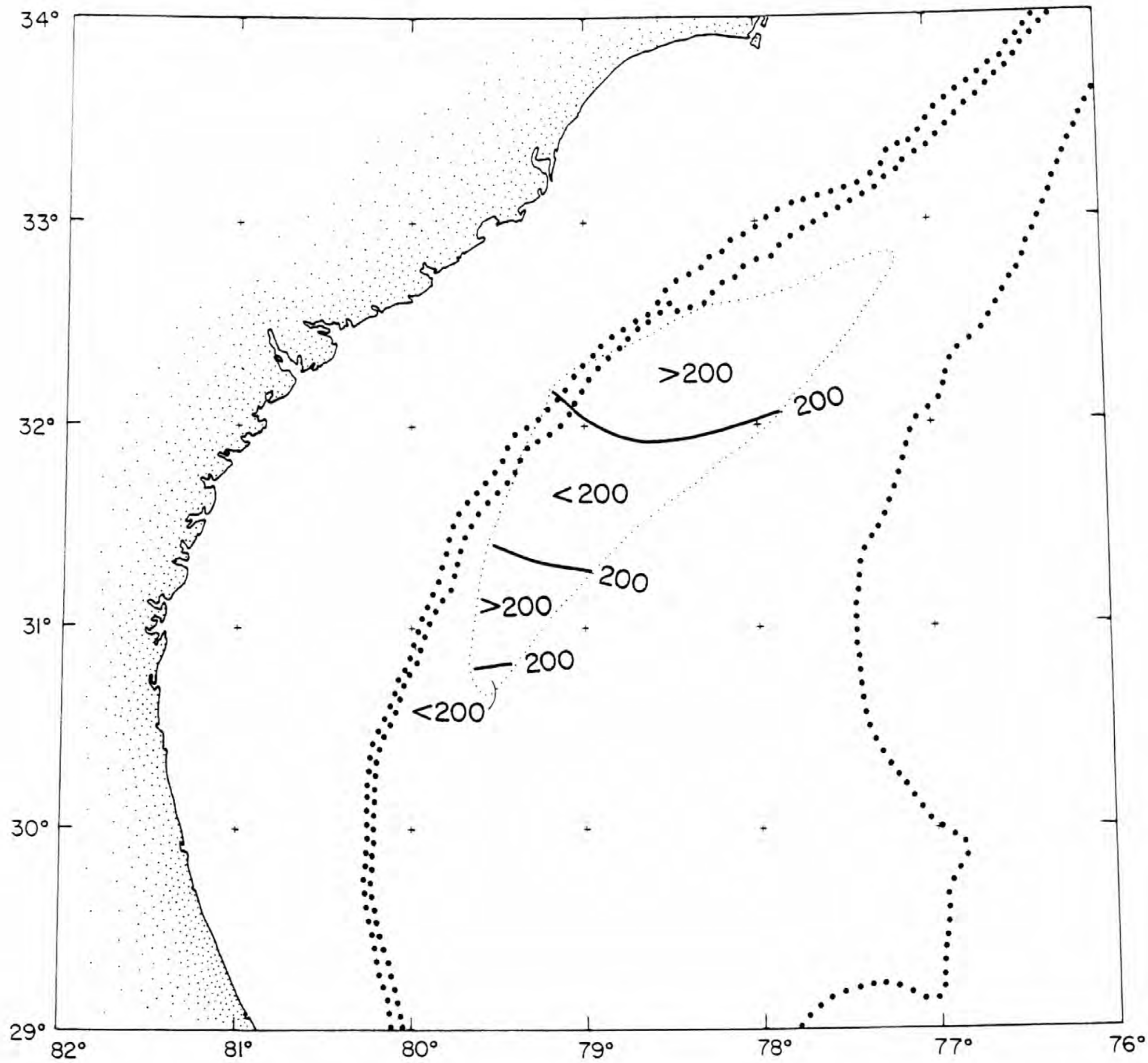


a



b

Figure 10-10. Isopach map of the unit between reflectors Kc and Ks. This unit is inferred to be of Santonian age. Contours are in meters.



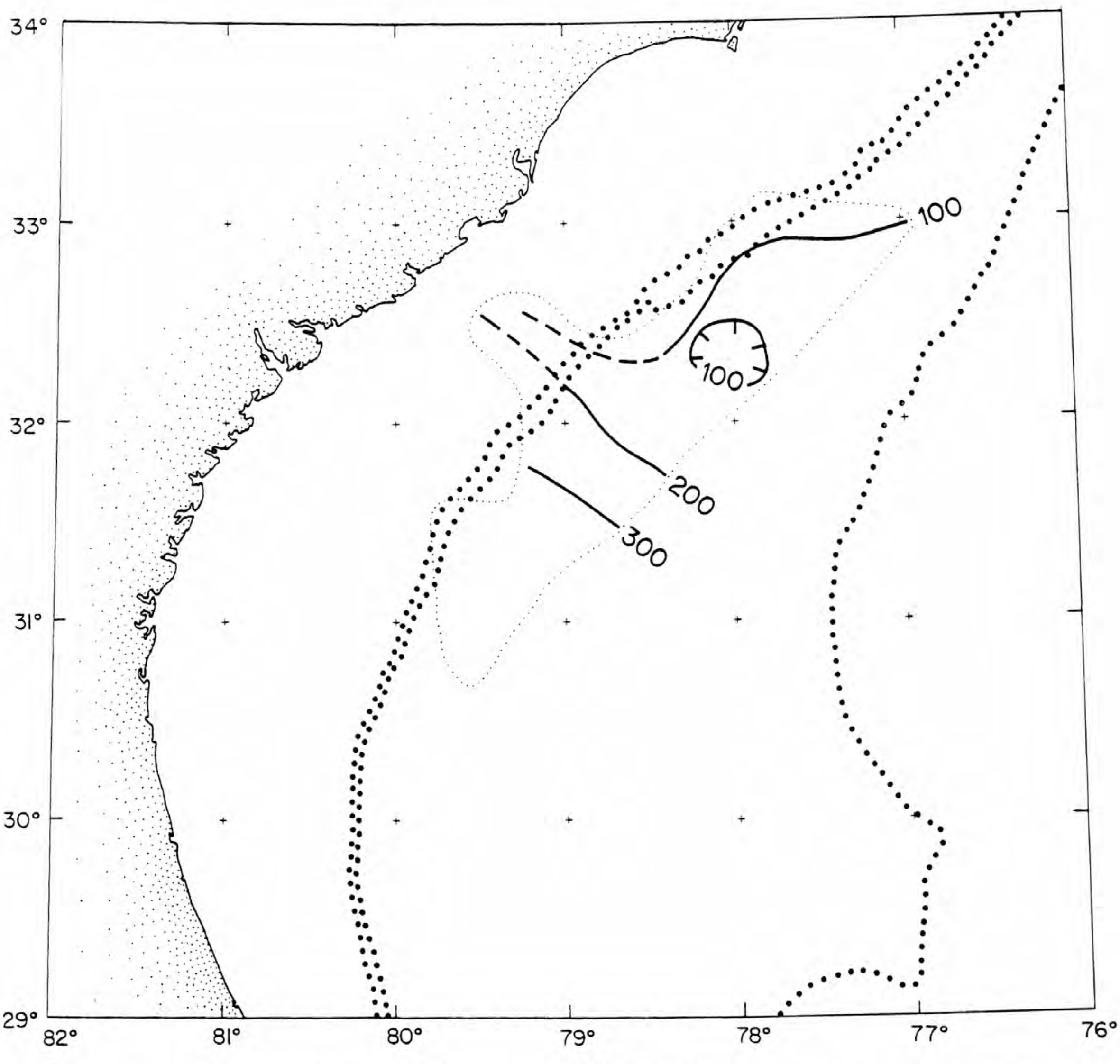
Isopach of Santonian Sediments

32.5° N. This thickening occurred over the area where the Santonian depositional wedge appears to have ended and may result from the infilling with Campanian and Maastrichtian sediments of an area which was sediment starved during the Santonian. The Campanian-Maastrichtian isopach pattern may also result in part from differential subsidence toward the center of the Southeast Georgia Embayment.

Under the shelf, on lines 29 and 30 (Figures 10-3c and 10-6b), there are no coherent reflectors below about .6 seconds. This zone is seen on other seismic lines in the area, and is explained by Shipley _et al_ (1978) as being an "irregular karst surface on top of a lithified carbonate bank" at which essentially all seismic energy is dispersed. Dillon _et al_ (1979a) and Uchupi (1967) called this feature a buried reef. From the north, reflectors lap up onto this feature the way a fore-reef talus slope would lap up on a reef. Both explanations are mutually consistent and to some extent the existence of one would imply the other. The main difference would be in whether the reflecting unit was irregular at deposition, or was rendered so by weathering.

The depth to the base of the reef or carbonate bank complex is not accurately known because of the difficulty in penetrating the unit seismically. Some suggestions of deeper reflectors in CDP data indicate that this reef probably did not start until well into the Upper Cretaceous. A topographic high could have existed in this area during the the late Upper Cretaceous simply by upward growth of the bank. Reefs or carbonate banks typically start growing on pre-existing topographic highs and it is possible that this area was a relative high due to differential subsidence of the surrounding region in the Upper Cretaceous. This will be discussed further in the section on the Eocene and Oligocene. The reef-carbonate bank complex apparently stopped

Figure 10-11. Isopach map of the unit between reflectors Ks and Km. This unit is inferred to consist of sediments of Maastrichtian and Campanian age. Contours are in meters.



Isopach of Maastrichtian and Campanian Sediments growing near or at the end of the Cretaceous.

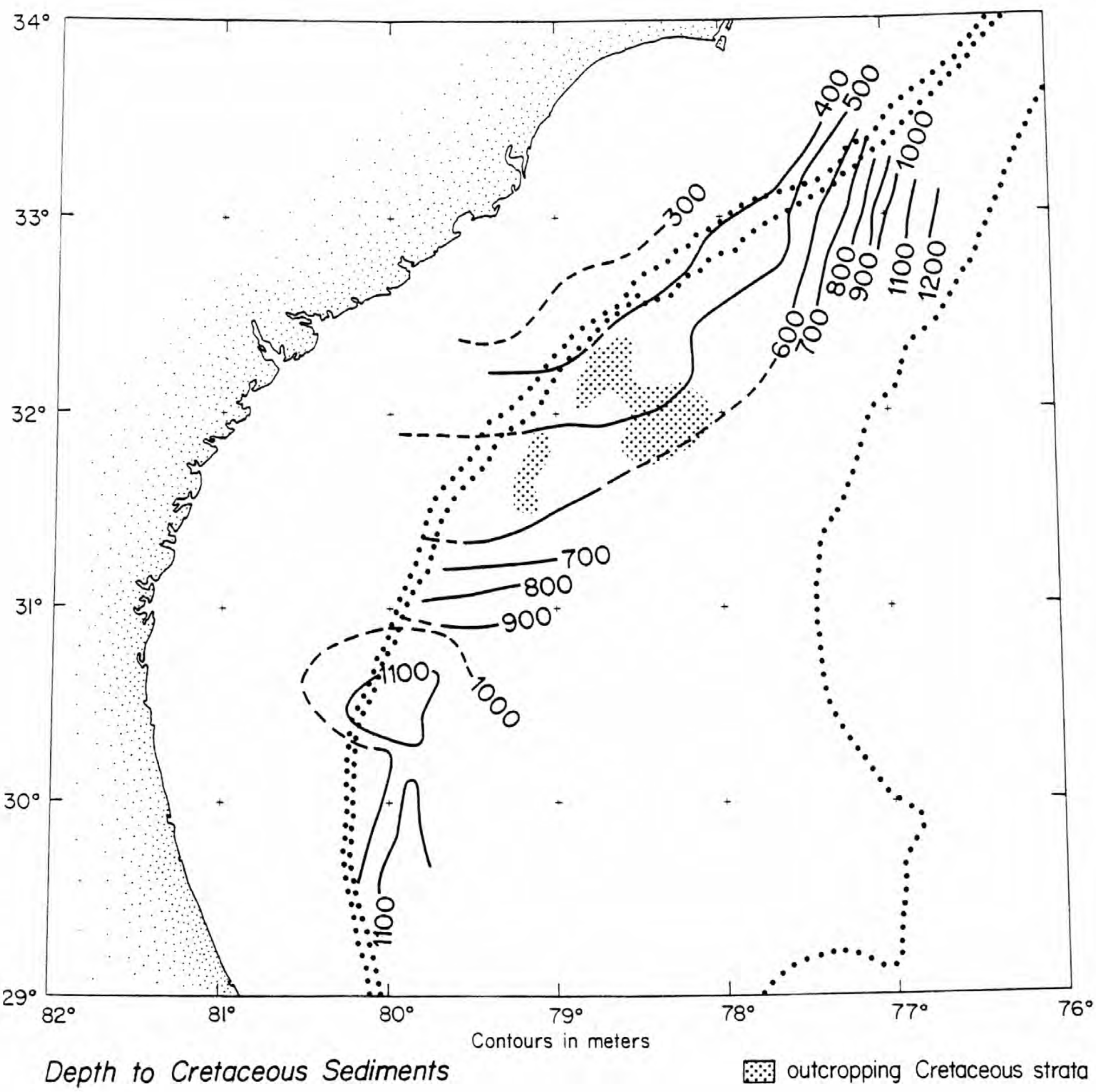
The reflecting surface correlated with the top of the Cretaceous (K_M) is not a strong consistent reflector. A surface considered to represent the top of the Cretaceous has been traced (Figure 10-12) with the assistance of additional stratigraphic information from wells and dredge hauls.

At the U.S.G.S. well 6004, 17 m of fine, gray, calcareous, silty clay were encountered and dated as being Late Cretaceous. Three dredge hauls on the surface of the Plateau produced Late Cretaceous rocks. These dredge hauls occurred in an area on line 32 where reflectors crop out from both the north and south (Figure 10-3d). Paleocene age sediments were encountered in ASP-5 and J-6. Although these sediments do not provide accurate Cretaceous tops, they do at least confirm that our interpretation is reasonable. Only a few closely spaced reflectors that crop out before reaching the area where Cretaceous rocks are exposed can be traced from beneath ASP-5. Therefore the top of the Cretaceous is quite narrowly defined.

Cenozoic

The Cenozoic section is dominated by two major unconformities (T_P and T_O), each of which is overlain by a progradational wedge (Figure 10-4). The deeper unconformity (T_P) was produced at the end of the Paleocene and is covered by a thick Eocene progradational wedge. During the Eocene, major subsidence occurred in the middle of the embayment. The second major Tertiary unconformity (T_O) was produced at the end of the Oligocene and is covered by a progradational wedge of Miocene age. There is evidence that several additional cycles of erosion followed by progradation may have occurred during the Miocene and post-Pleistocene but they were smaller in scale.

Figure 10-12. Structure contours on reflector Km which is correlated with the top of Cretaceous sediment.



Depth to Cretaceous Sediments

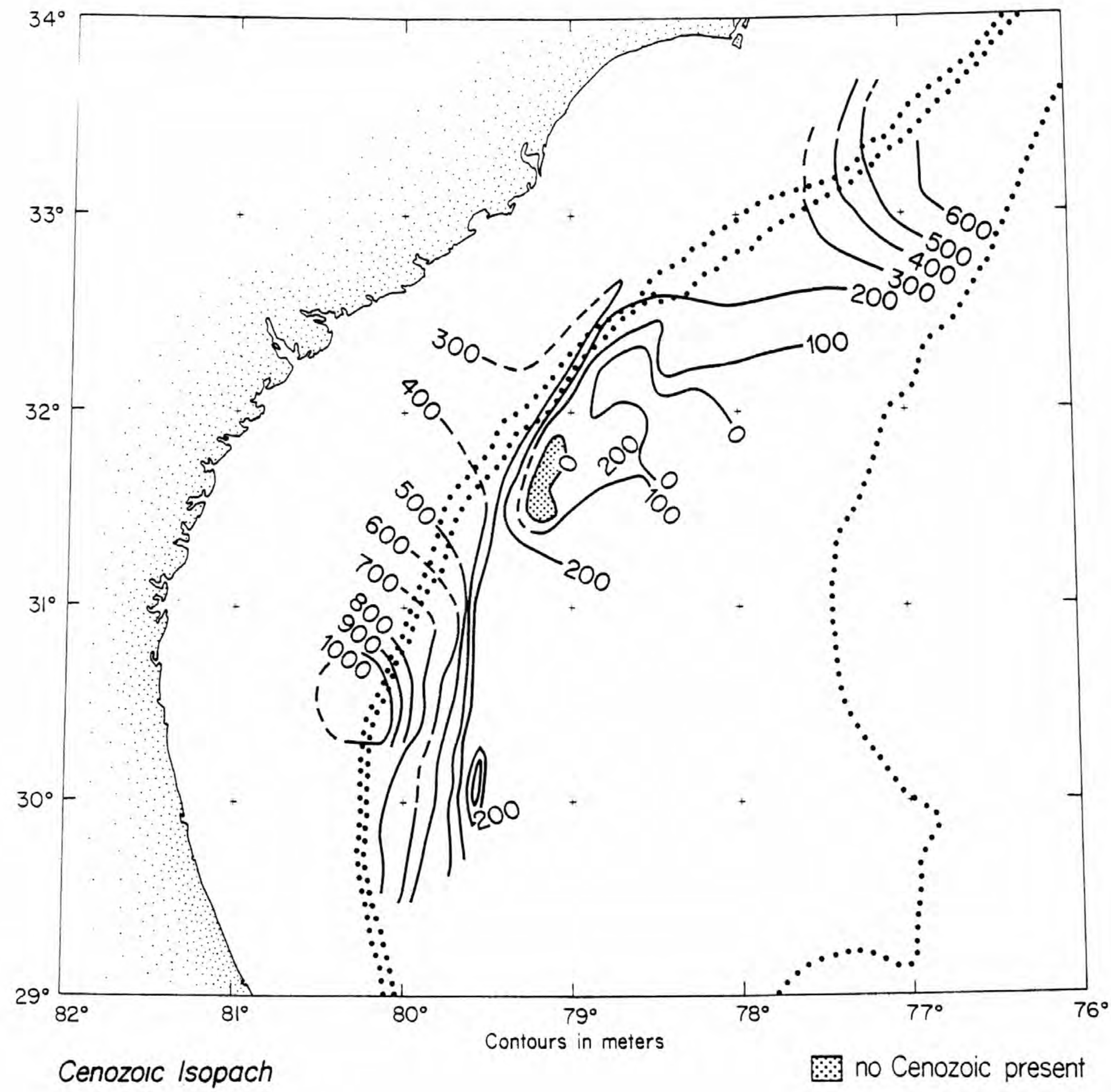
The thickness of Cenozoic sediments is shown in Figure 10-13. In the vicinity of the Florida-Hatteras Slope the bathymetric and Cenozoic isopach contours are parallel. On the shelf, the Cenozoic sediments range to over 1,000 m in thickness while on the Plateau, the Cenozoic is typically 200 m or less. The wells which have been drilled on the Plateau (J-3, J-4, J-6, and ASP-3, Figure 10-1) penetrated sediments of all Cenozoic epochs at one place or another. Cenozoic sediments on the Plateau are deep water oozes which are relatively free of terrigenous inputs and had slow accumulation rates. Sediments on the Florida-Hatteras Shelf are typically shallow water carbonates with accumulation rates much greater than on the Plateau (Schlee 1977; Uchupi 1970).

Seismically the Cenozoic-Mesozoic Boundary does not correspond to a major event in the Southeast Georgia Embayment. A small unconformity was apparently produced at this time as the uppermost Maastrichtian is missing in AMCOR 6004 (Hathaway et al 1976). A traceable, but not particularly strong or distinct, reflector is associated with this boundary.

Paleocene

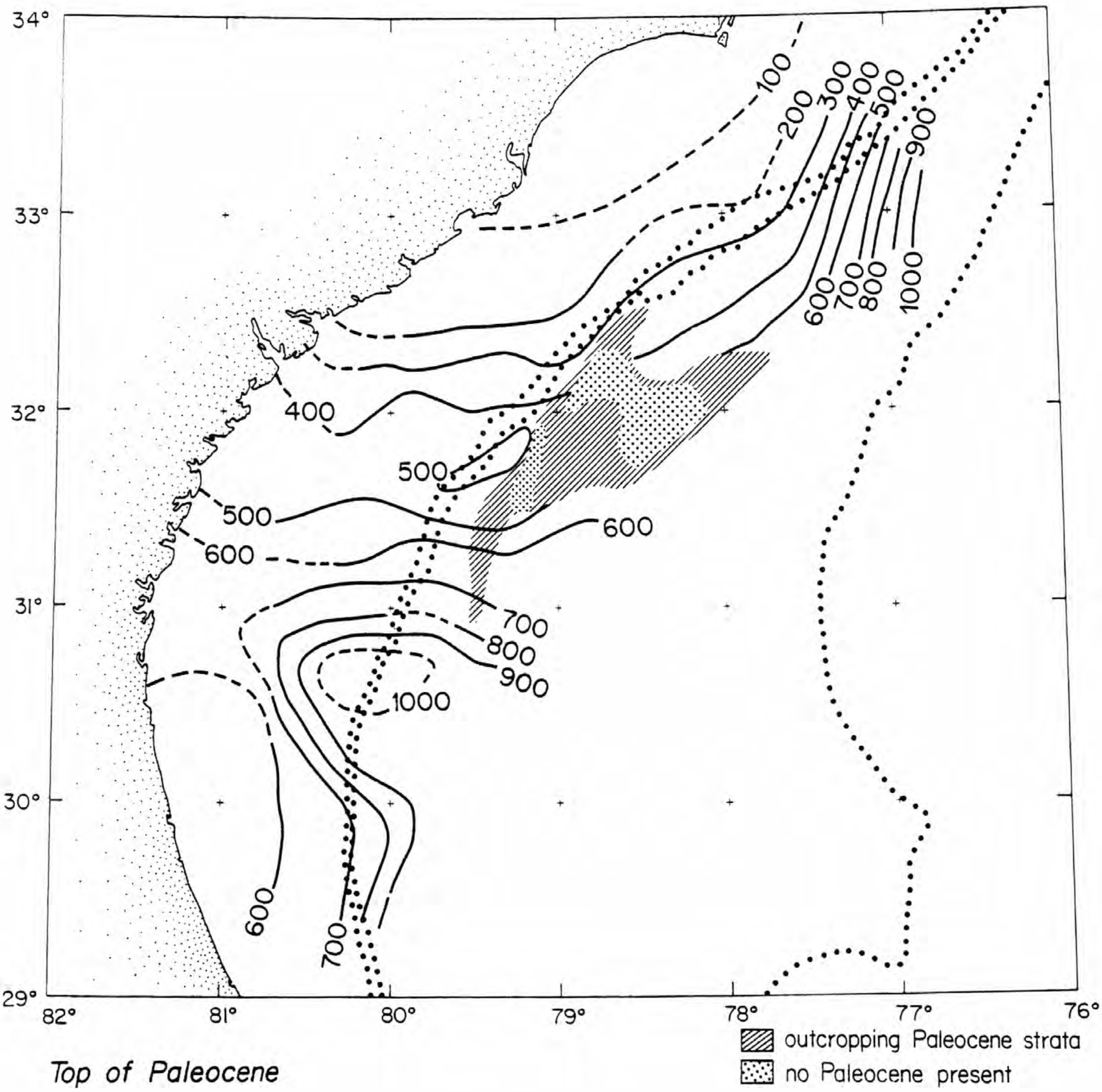
Paleocene sediments, which are parallel to the Cretaceous reflectors, have similar reflection characteristics to the underlying Upper Cretaceous except that the Paleocene reflectors are generally stronger. At the end of the Paleocene, a large regional unconformity (T_p) was formed (Figure 10-14). This unconformity is clearly shown on lines 13, 15, 17, 18, 19, and 20, where it is seen as a surface of appreciable relief (See Figures 10-3a, 10-3b, and 10-9b). On lines 13 to line 30, overlying reflectors lap down onto this surface. North of line 13, the reflectors show the same relation in minisparker data

Figure 10-13. Isopach map of the unit between reflector Km and the sediment-water interface. This unit corresponds with the Cenozoic section.



Cenozoic Isopach

Figure 10-14. Structure contours on reflector Tp which is correlated with the top of Paleocene sediments. Contours are in meters.



Top of Paleocene

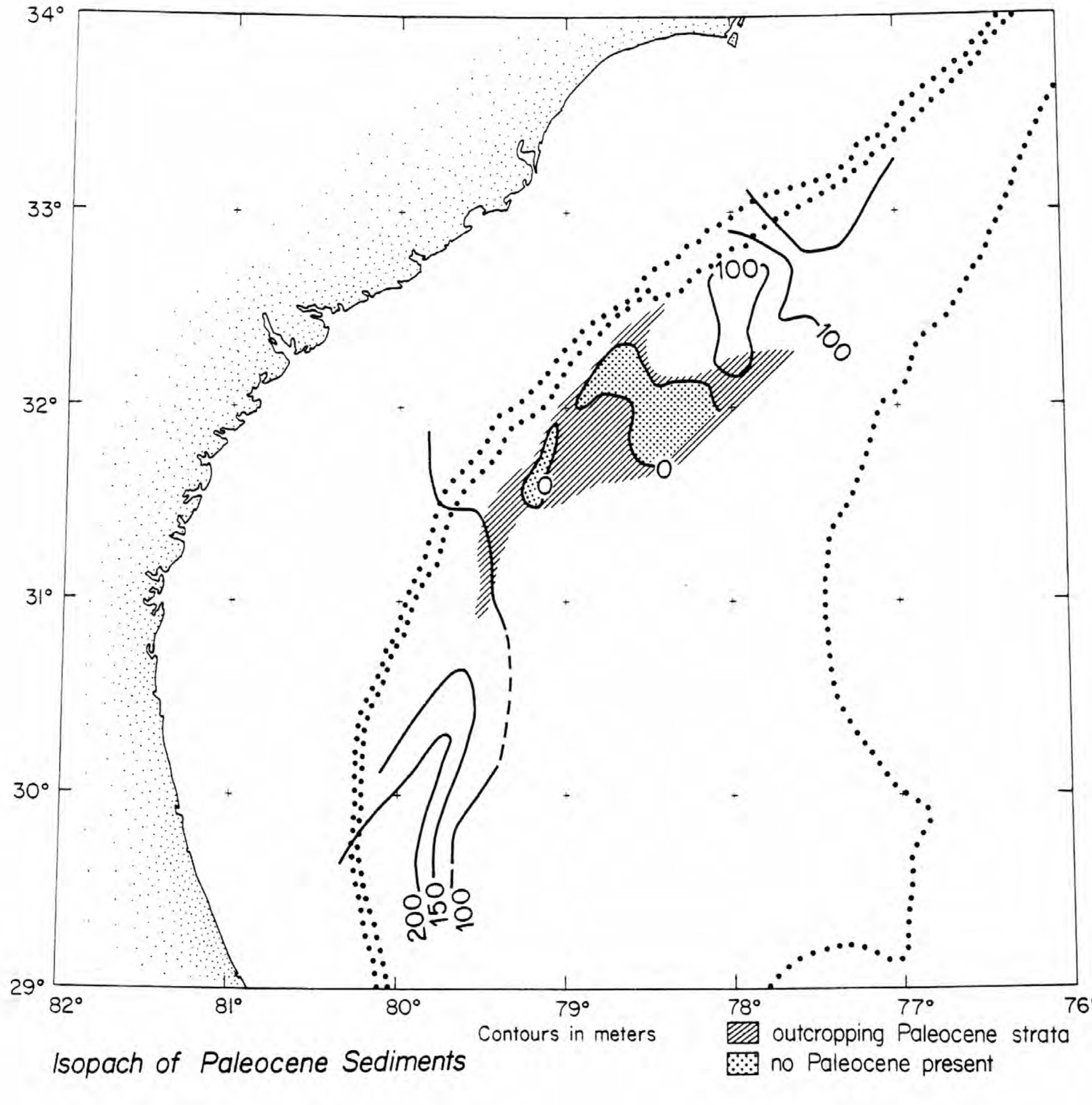
(Edsall this volume). Control as to the age of this surface comes from well ASP-5, AMCOR 6005, AMCOR 6004, J-6, and COST GE-1 (Figure 10-1) where Paleocene sediments have been drilled offshore. Comparison to wells on land confirms that the contours are reasonable (Gohn et al 1978a; Herrick and Vorhis 1963; Cramer 1974; and Maher 1971).

The Paleocene surface, unlike other Cenozoic surfaces, does not mimic the position of the present day Florida-Hatteras Slope, north of 30.5° N. Structure and isopach maps (Figures 10-14 and 10-15) of Paleocene sediments show no consistent tendency (north of 30.5° N) for a thickening of the Paleocene under the present slope. This lack of thickening indicates that the Florida-Hatteras Slope was not in existence in the Paleocene. All other Cenozoic structure and isopach maps (Figures 10-16, 10-17, and 10-18), show a clear concentration of parallel contours in the position of the present Florida-Hatteras Slope, demonstrating that a topographic feature similar to the present slope has been in existence since the Eocene. South of 30.5° N there is a thickening of Paleocene sediments under the present slope. This is interpreted as being the result of infilling to reduce a very steep pre-existing slope, possibly a Cretaceous reef-front, as seen in Figure 10-19.

Eocene and Oligocene

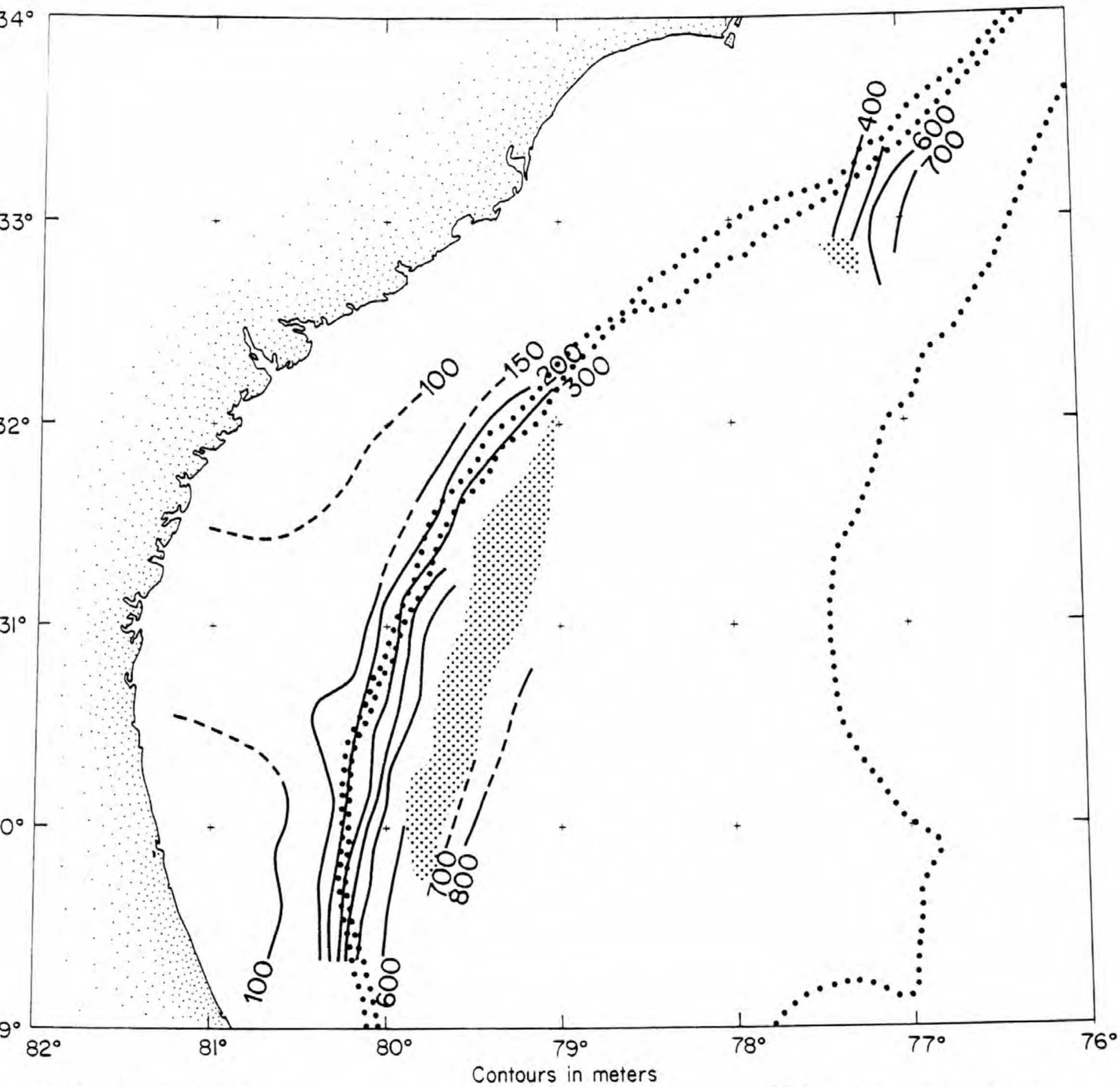
A large progradational wedge overlies the Paleocene unconformity. This can be seen on line 20 in Figure 10-3b. Reflectors within this wedge terminate against reflectors T_P. The upper surface of the wedge (reflector T_O) is the second major unconformity of the Cenozoic, believed to have occurred at the end of the Oligocene. It is regionally traceable south of about 32° N. North of 32° N the Cenozoic section is thin and contains too many crosscutting unconformities to distinguish

Figure 10-15. Isopach map of the unit between reflectors Km and Tp which bound sediments of Paleocene age.



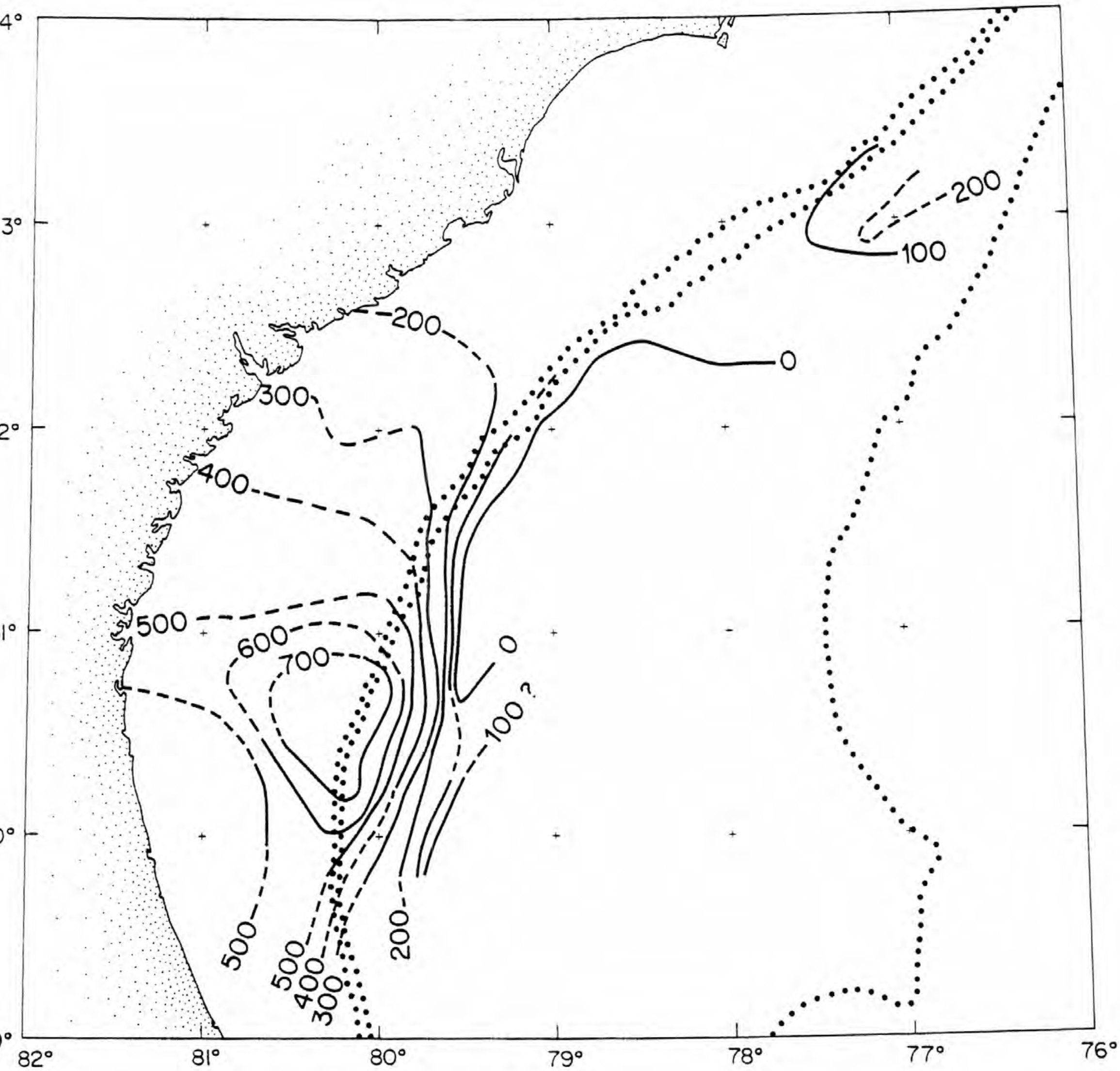
Isopach of Paleocene Sediments

Figure 10-16. Structure contours on top of reflector To which correlates with an unconformity between Oligocene and older sediments, and Miocene and younger sediments.



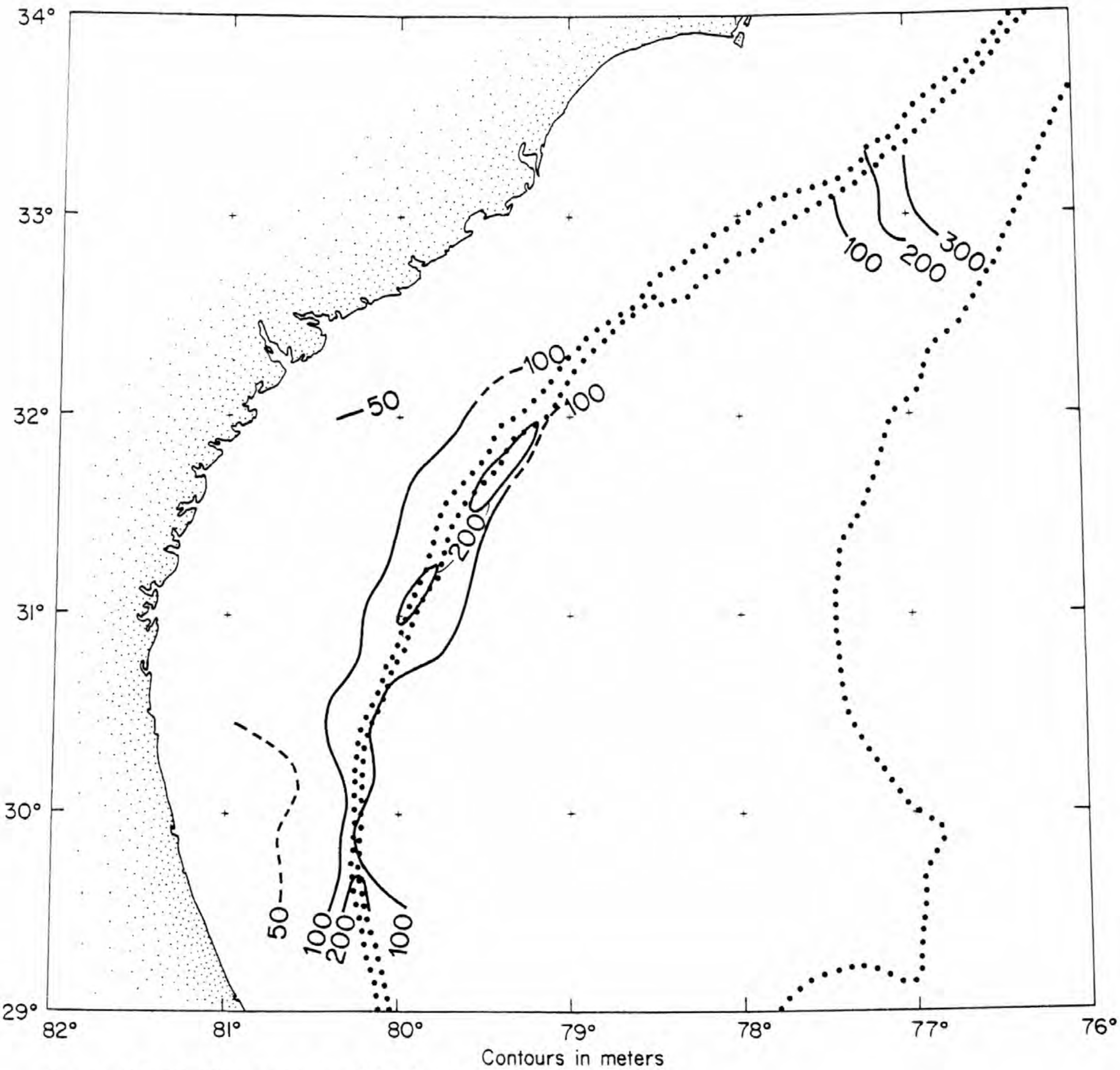
Base of Neogene

Figure 10-17. Isopach map of the sediments between reflectors Tp and To. This unit is inferred to consist of Eocene and Oligocene sediments.



Isopach of Oligocene and Eocene Sediments

Figure 10-18. Isopach map of the unit between reflector To and the sediment-water interface. This unit is inferred to consist of Neogene and Holocene sediments.



Isopach of Neogene and Holocene Sediments this surface. The stratigraphic control comes from J-1, J-5, J-6, AMCOR 6002, AMCOR 6004, AMCOR 6005, COST GE-1, ASP-5, and the Coast Guard Tower Well (Figure 10-1). In these wells, the break between the Miocene and the Oligocene or older sediments corresponds with reflector T_O. Apparently the unconformity was produced at the end of the Oligocene and in places the Oligocene deposits were entirely eroded away. The Oligocene series is never thicker than 100 m on the shelf or Coastal Plain. The thickest Oligocene sequence penetrated is on the slope in J-5 where 162 m were encountered. This exceptionally thick Oligocene accumulation appears to be a pod of sediment deposited on the slope front (Figure 10-3c).

On lines 15-22, the similarity in appearance between the major unconformity at the end of the Paleocene (T_p) and the present surface of the Blake Plateau is striking. The present surface of the Florida-Hatteras Slope is highly irregular with horizontal sub-bottom reflectors truncated at the sea floor (Figures 10-3a through 3d), presumably the result of erosion by the Gulf Stream (Pratt and Heezen 1964; Pratt 1966; Uchupi and Emery 1967; and Uchupi 1970). AMCOR 6004 penetrated this unconformity and there was no evidence that it was produced by subaerial exposure. Because the present surface of the Blake Plateau is the result of erosion by the Gulf Stream and associated currents, it is reasonable to assume that the buried surface was formed by earlier Gulf Stream erosion. As the material covering the unconformity is of Eocene through Miocene age, the erosion on the surface of the plateau must have occurred during the late Paleocene or early Eocene, followed by a seaward progradation of the shelf across the Plateau during the Eocene and Oligocene. In the vicinity of lines 18 and 19, Eocene and Oligocene sediments prograded at least 50 km seaward across the irregular unconformity. The Paleocene top remains traceable as an unconformity all the way to the shoreward end of the lines (less than 10 km from the coast), although it becomes smoother to landward (Figures 10-3a and 10-3b).

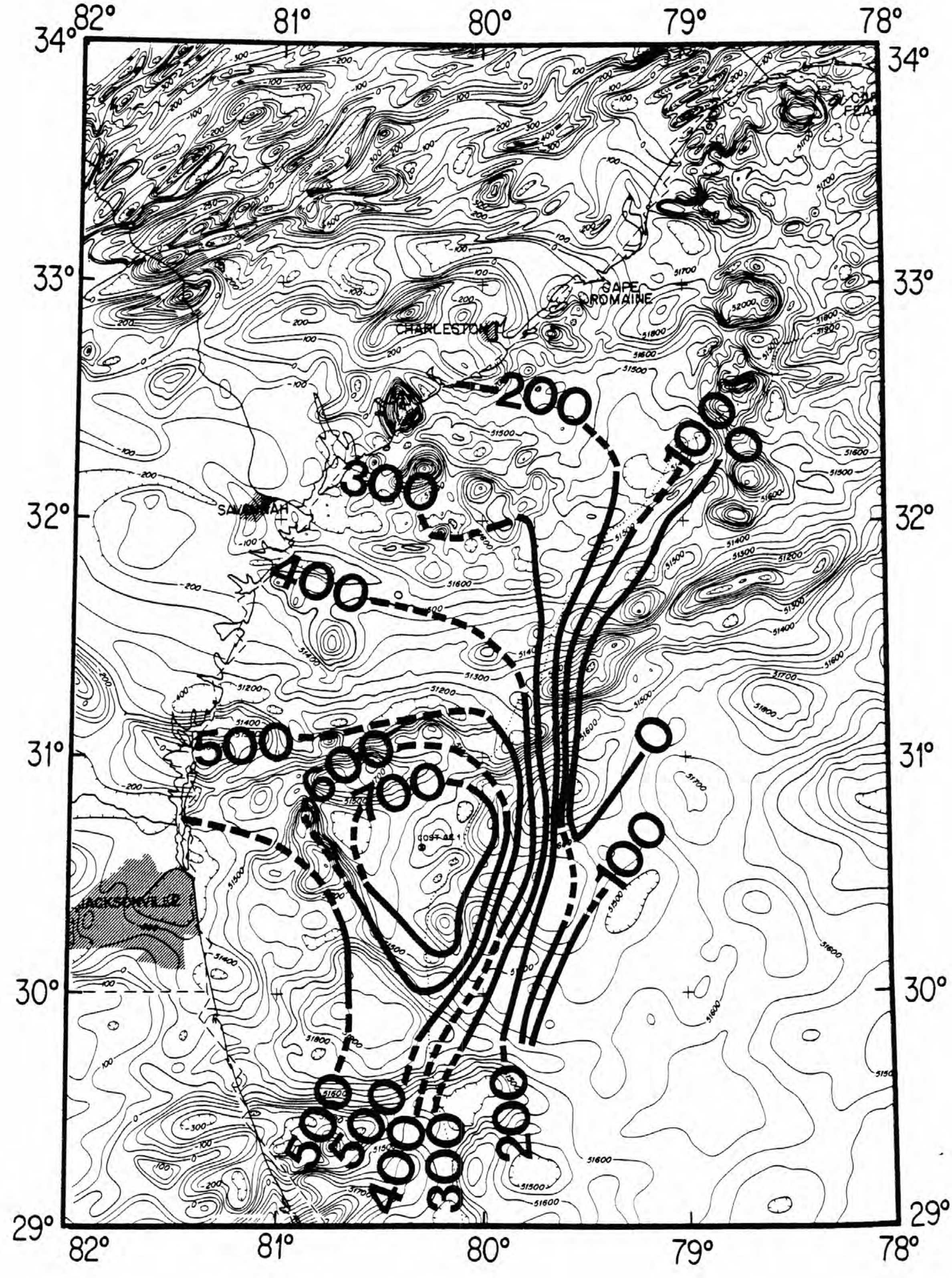
Few if any unconformities appear within the large seaward progradation of Eocene and Oligocene sediments (Figures 10-3b and 10-3c), suggesting that the shelf was prograding out into relatively calm water. The Oligocene and Eocene shelf edge formed about 50 km landward of the present Gulf Stream axis. Whether the Eocene-Oligocene progradation stopped here fortuitously and the Gulf Stream just occupied the area to seaward, or whether the shelf could only prograde to the edge of the stream is unclear. However, there is no evidence that the ancestral Gulf Stream was affecting deposition/erosion under the axis of the present Gulf Stream during the Eocene and Oligocene.

The second major unconformity (T_0) corresponds with the break between the Eocene-Oligocene section and the Miocene section. This is a surface of minor relief but definitely eroded in places. The fact that it is a good reflector results, in part, from a lithologic change at this boundary. The sediments above the unconformity are predominately clastic while those below it are carbonate.

Figure 10-17 is an isopach map of the sediment between the two major Cenozoic unconformities (T_P and T_0). However, since the Oligocene is thin and likely to be absent in many spots, the isopach map is substantially an isopach of Eocene sediments. The thickness of this unit is 100 m or less at 33° N and thickens to over 700 m in the center of a well defined depocenter between 30° and 31° N and between 80° and 81° W. The thickest portion of this depocenter forms a triangle. The Florida-Hatteras Slope forms the eastern boundary of the depocenter, where Eocene and Oligocene sediments thin to less than 100 m, typical of their thickness on the Blake Plateau. The other two edges of the triangular depocenter meet at a well defined apex. These edges correspond with areas of sharp magnetic gradients on the Klitgord and Behrendt (1977) aeromagnetic map of the region, with the northern edge of the depocenter corresponding with the Brunswick magnetic anomaly. The interior of the triangle has a uniformly flat magnetic field (Figure 10-20). The correspondence of the edges of the depocenter with magnetic anomalies which are caused by basement structure (Klitgord and Behrendt 1979) would imply that this depocenter is related to structure in the pre-Jurassic basement.

Eocene sediments in both land and marine wells are primarily carbonate. Under Florida, the Eocene is limestone and marl, grading into sandy limestone and sandstone in the Carolinas, and becoming more clastic up dip toward the Piedmont (Maher 1971; and Cramer 1974). Offshore, the Eocene was encountered in J-1, J-2, J-3, J-4, J-5, J-6, ASP-5, AMCOR 6002, COST GE-1, and the Coast Guard Tower Well (Figure 10-1). In these holes, Eocene sediments vary from calcareous silty clays and carbonate sands to fine grained limestones. Faunal evidence shows that the Eocene sediments were deposited on a shallow carbonate shelf (Poag and Hall 1979; and Valentine 1979). Oligocene sediments of the subsurface of the southeast are primarily calcareous shallow water deposits, with a tendency for more carbonate sand than the Eocene sediments. The Oligocene sequence is absent in southeastern Georgia (Herrick and Vorhis 1963; and Cramer 1974). Where the Oligocene is sampled on the shelf (J-1, J-2, J-3, J-4, J-5, J-6, ASP-5, AMCOR 6002, COST GE-1, and the Coast Guard Tower Well), it remains a shallow water calcareous unit. Near the shelf edge and on the slope, the Oligocene

Figure 10-20. The Eocene and Oligocene isopach contours are superimposed on the Klitgord and Behrendt (1977) magnetic map of the East Coast. The Eocene and Oligocene units form a triangular depocenter. The northern and southwestern edges of this depocenter correspond with areas of strong magnetic gradients, while the center of the depocenter is an area of uniformly low magnetic gradient.


82°
81°
80°
79°
78°
34°
33°
32°
31°
30°
29°
CAPE ROMAINE
CHARLESTON
SAVANNAH
JACKSONVILLE
COST GE 1
200
300
400
500
600
700
100
0

deposits thicken and become a calcilutite or silty clay (Poag 1978).

The depocenter of Oligocene and Eocene sediments narrows towards southern Georgia and connects with the Suwannee saddle, a broad gentle syncline which extends from southeastern Georgia to northwestern Florida. It was originally described by Dall and Harris (1892, p. 132) as being the Suwannee Straits,

> "a wide, and even in Miocene time a moderately deep body of water, the general trend of which did not differ much from that of a line drawn from Savannah to Tallahasse, and which probably had a width of more than 50 miles."

Since this time, a number of articles have refined our knowledge of this feature (Cooke 1945; Hull 1962; Babcock 1962; Chen 1965; Applin and Applin 1967; Cramer 1969; and Cramer 1974). Two schools of thought as to the origin of this feature exist and are best represented by the positions of Chen (1965) and Applin and Applin (1967).

In 1965, Chen proposed the existence of a seaway called the Suwannee Channel across northern Florida and southern Georgia during the Paleocene and Eocene. In a study of wells, he found a thinning in the Upper Cretaceous sediments and a thickening in the Paleocene and Eocene sediments which run along this feature in a belt across northern Florida and southern Georgia. From the Upper Cretaceous to the Eocene, this belt corresponds to a pronounced boundary between carbonate and clastic depositional provinces. Chen suggested that a shallow seaway may have existed in this area and would have been a barrier for terrigenous sediments.

Applin and Applin (1967, p. 631) favored another interpretation for the origin of this feature which they renamed the Suwannee saddle;

> "the area of thinning in the rocks of the Gulf Series that extends southwestward from southeastern Georgia into north-central Florida is interpreted by us as an upwarped barrier that during Navarro time separated the shallow-water marine depositional environment in

southern Georgia and the partly restricted marine-shelf environment in the Florida Peninsula. During the Tertiary widespread tectonic movements in the Florida Peninsula and the Coastal Plain of Georgia brought about a relative depression of the barrier and uplift of the area north and south of it, forming the synclinal feature now known as the Suwannee saddle. Paleocene and younger Tertiary beds unconformably overlie the Cretaceous rocks in the Suwannee saddle and the surrounding area".

As the early Cenozoic depocenters onshore and offshore connect, it is reasonable to assume that they are related features. Data from offshore would suggest that this depocenter was the result of subsidence (Applin and Applin 1967) rather than the filling of a Paleogene channel (Chen 1965). The 700 m of shallow water carbonates which fill the depocenter offshore (Poag and Hall 1979; and Valentine 1979a and b) are unlikely to be purely due to the infilling of a 700 meter deep channel, for there should then be bathyal environments for the early Tertiary faunas. However Chen's (1965) suggestion that a barrier to sedimentation existed across a strait in this area is compatible with the concept that the depocenter was due to subsidence. Presumably an actively subsiding area would be a bathymetric low, which would act as a sediment trap. The result of such a sediment trap caused by subsidence is what Chen's (1965) lithologic data indicate.

Klitgord and Behrendt (1979), on the basis of magnetics, relate these anomalies to crustal sutures. The Brunswick anomaly separates Paleozoic crust to the north from stretched and thinned transitional crust to the south and east. The anomaly which forms the southwestern edge of this depocenter also separates Paleozoic crust which underlies much of northern Florida from the transitional type of crust underlying the depocenter. Differential subsidence across these older crustal sutures has continued into the Tertiary.

Neogene and Quaternary

Reflector T_0 is interpreted as being a major unconformity which separates Oligocene and older sediments from Miocene and younger sediments (Figure 10-16) and is covered by a gently seaward dipping progradational wedge of Miocene and younger sediments. No stratigraphic subdivisions in the Neogene and Quaternary are made in this study. Wells on the shelf and away from the shelf break (AMCOR 6002, J-1, and Coast Guard Tower Well) show that the Miocene makes up the greater portion of the post-Paleogene sediment. The greatest accumulation of Neogene and Quaternary sediments are present at the Florida-Hatteras Slope (Figures 10-3a through 3c and Figure 10-20) where the unit forms progradational pods which thicken to 200 m. The isopach map of Neogene sediments (Figure 10-18) suggests that the embayment is subsiding faster than its flanks, but the late Cenozoic subsidence was more gentle than the early Cenozoic subsidence.

Miocene sediments in the Southeastern Coastal Plain and on the Florida-Hatteras Shelf are composed of terrigenous silts and clays, and quartz sands. The Miocene also shows an unusual concentration of phosphatic pebbles. The clastic lithologies of the Miocene are in sharp contrast to the predominantly carbonate lithologies of the Oligocene and Eocene (Herrick and Vorhis 1963; JOIDES 1965; Maher 1971; Cramer 1974; Poag 1978; Poag and Hall 1979; and Valentine 1979a and b).

After the deposition of the Eocene-Oligocene wedge, major erosion occurred on the surface of the Plateau. Lines 28 and 29 (Figure 10-3c) show a deep erosional channel cut into the seaward toe of the Eocene-Oligocene progradational wedge. Lines 24 and 25 (Figure 10-3c and 10-6a) show gently dipping Eocene and Oligocene beds abruptly terminated by erosion. Nowhere in the survey area does an appreciable thickness of Neogene sediments cover the surface of the heavily eroded Eocene-Oligocene section on the lower slope. On lines 17 and 22 Neogene and Quaternary sediments are thickest at the shelf break, but bedding dips steeply seaward and no strata of this age are found on the Blake Plateau under the present Gulf Stream. It is assumed that the Neogene progradation was terminated by a sedimentation barrier formed by the Gulf Stream's strong northward flowing currents which swept away sediments that would otherwise have been deposited on the inner Blake Plateau.

The present surface of the Blake Plateau shows signs of relatively recent erosion throughout the survey area except for the two northernmost lines (5 and 5A, Figure 10-3a). These two lines occur in a region of more normal shelf - slope - rise topography, where Neogene sedimentation rates have been greater, presumably because of reduced effect of the Gulf Stream.

RELATED FEATURES

Through the study of the shelf and slope sediments several additional features have been observed. The Gulf Stream has influenced deposition leaving a signature of its movements. Also as this area has been considered for petroleum development, occurrences of faults and the offshore extent of the aquifer is discussed.

Gulf Stream History

The Gulf Stream has affected the development of the Florida-Hatteras Slope, thus recording part of its history in the sedimentary record. The first evidence for the existence of an ancestral Gulf Stream is the erosion which occurred on the top of the Paleocene sediments producing an unconformity with relief up to 100 m.

Presumably this is the result of submarine erosion, which covered a broad area, extending westward beneath the present shelf. No evidence was found which suggests that the Gulf Stream existed during the Eocene and Oligocene. This was a time of progradation of the shelf into relatively quiet water with seaward dipping strata being deposited on top of the irregularly eroded Paleocene surface. The change in sediment facies and different volumes of Neogene sediments across the axis of the present Gulf Stream suggest that the Gulf Stream has existed in essentially its present position and has acted as a sedimentation barrier throughout the Neogene and Holocene. Little or no Neogene sediments exist under the present Gulf Stream, implying that they either were not deposited or were eroded away. Where the shelf edge has prograded during the Neogene, the wedge does not extend under the present Gulf Stream, but terminates abruptly on the down dip ends, as seen in Figure 10-19.

Faults

All the faults found in this survey are believed to be related to either compaction or gravity faulting. No faults were identified which appear to extend down to basement.

Figure 10-9b shows small near vertical faults of a style which are found throughout the inner Blake Plateau. Figure 10-21 shows the distribution of these faults, which are common in the southern portion of the survey area. They generally occur in groups or clusters of several faults in zones of about 10 km, but their orientation could not be determined. They are not necessarily associated with bathymetric features and do not extend to the surface. Throws on this style of faulting do not exceed 10 m and the faults do not offset beds younger than Cretaceous. The offsets of the uppermost Cretaceous reflections

Figure 10-19. Cartoon showing the latitudinal variations in structure of the Florida-Hatteras Slope. At 30°N the Upper Cretaceous section is dominated by the presence of a reef-like feature. At 30° and 31°N the reflectors within the Upper Cretaceous section are weak and horizontal; however at 32° and 33°N the reflectors are stronger and show a Santonian progradational wedge within the Upper Cretaceous section. Paleocene sediments are similar in reflection characteristics to the Cretaceous sediment and are typically about 100 meters thick except at 30°N where they form a wedge in front of a pre-existing Cretaceous high, probably a reef. Eocene and Oligocene sediments form a large seaward dipping progradational wedge. The Neogene cap thickens at the shelf break, but at 31° does not completely cover the Eocene and Oligocene units.

Figure 10-19

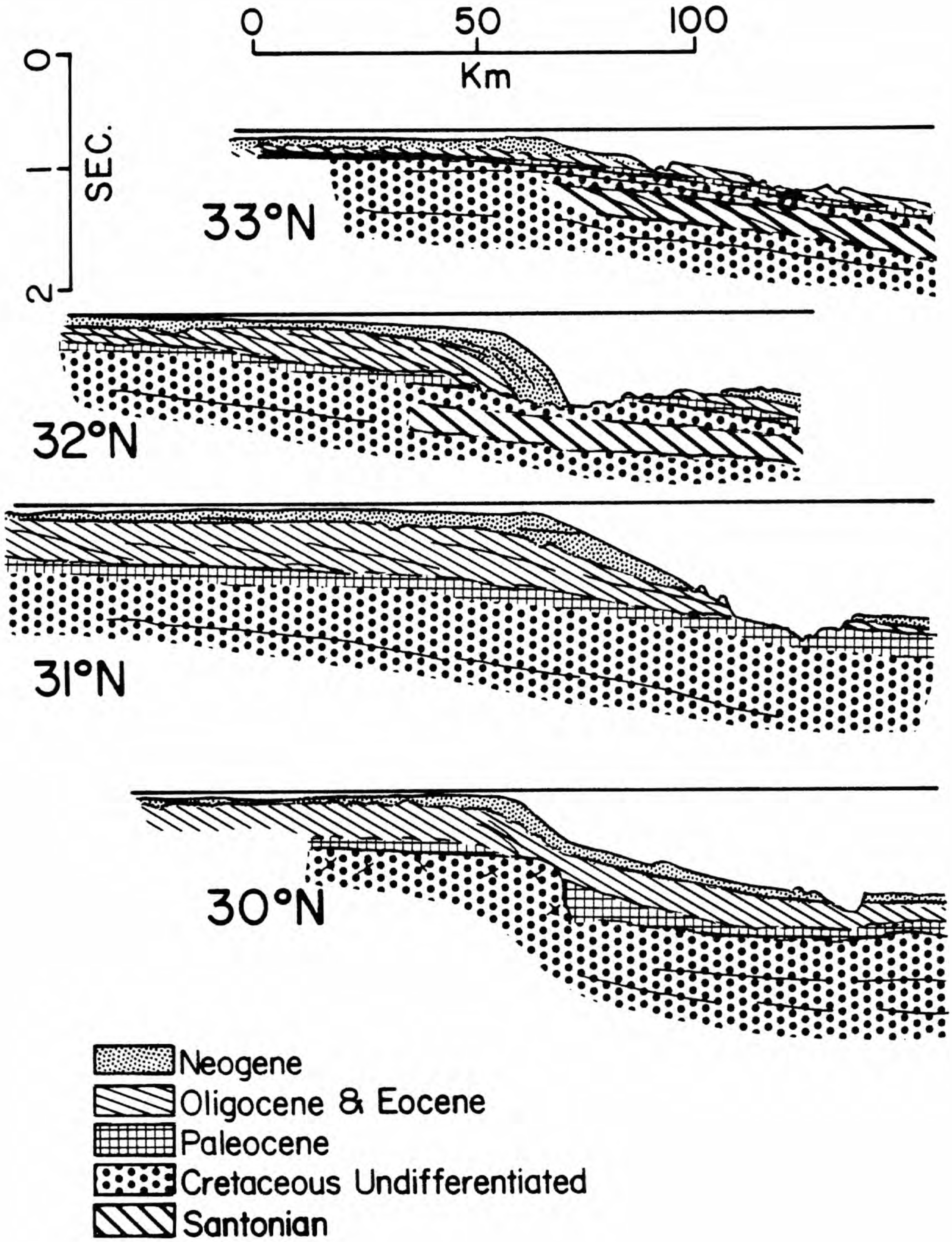
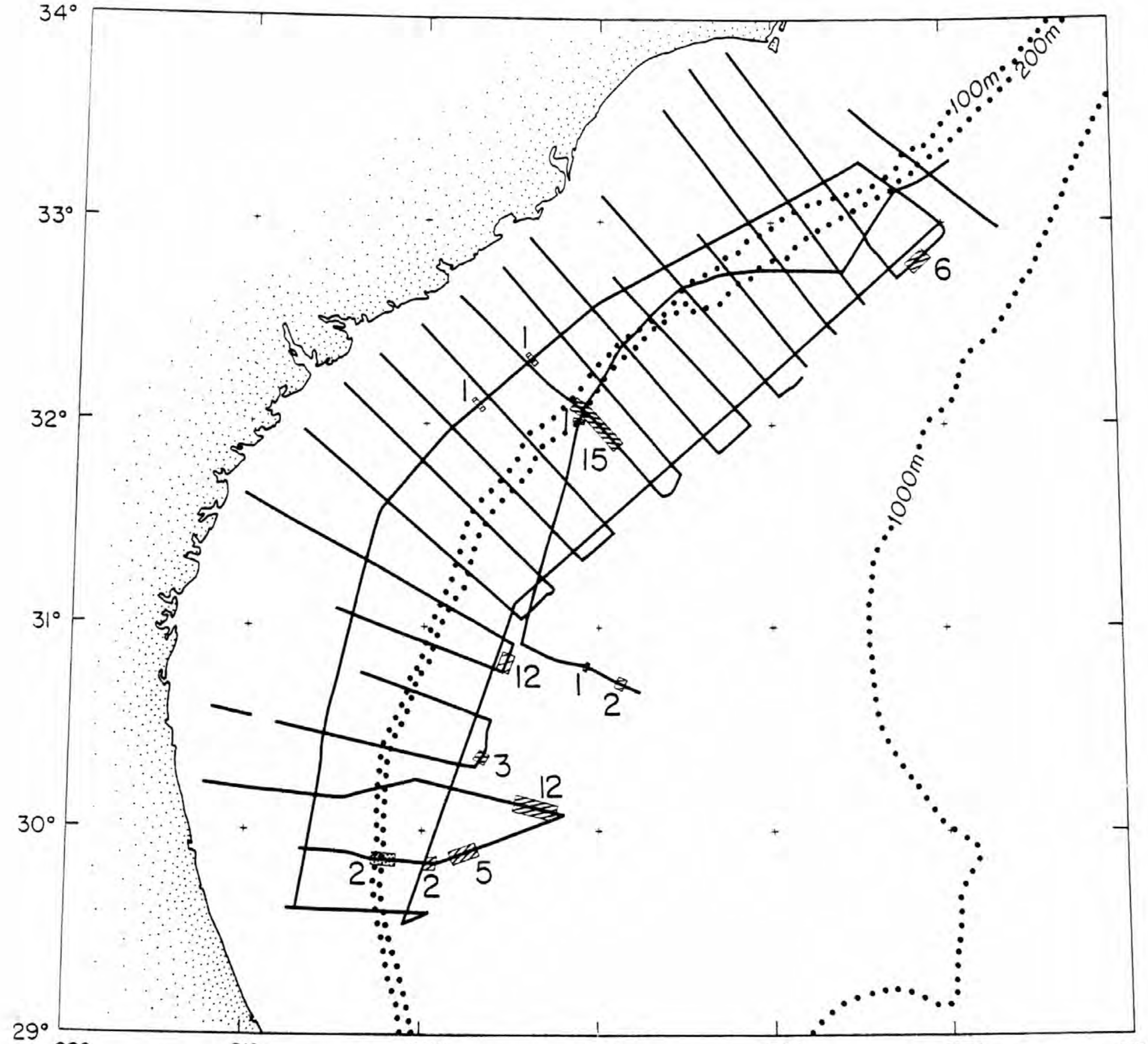

0
50
100
Km
0
1
2
SEC.
33°N
32°N
31°N
30°N
Neogene
Oligocene & Eocene
Paleocene
Cretaceous Undifferentiated
Santonian

Figure 10-21. Locations of possible faults identified in the survey.



Fault Map

Zone of faulting in rocks of upper Cretaceous age
Zone of normal gravity faults
Features probably due to burried channels but possibly faults

continue down into the seismically transparent zone below. No effects are seen in the deeper reflections below the transparent zone. In places where the Upper Cretaceous is not transparent, throws diminish with depth. Paleocene sediments may drape over the faults but do not seem to be offset by them. Although this style of faulting was not observed in the Cretaceous rocks beneath the shelf, the multiples in such shallow water make it unlikely that features of such small scale would be resolved if they were present.

These Upper Cretaceous faults are believed to be the result of compaction. They occur in a unit which corresponds with a thick sequence of chalk at the COST GE-1 well, and in which post-depositional compaction would certainly have occurred (Shinn et al 1977). The loading on these units would be different between the shelf and the inner Plateau, leading to differences in the amount of compaction which perhaps explains the faulting. A gradient in the interval velocities in the Upper Cretaceous unit indicates that differential compaction may have occurred. On the USGS TD-5 seismic line the interval velocities for the Upper Cretaceous change from 3.2 km/sec to 2.4 km/sec under the inner Blake Plateau (Dillon et al 1979b). This pattern continues but the difference in velocities appears to decrease in lines to the north (Dillon and Paull 1978). The differential between Cenozoic loads on the shelf as opposed to loads on the surface of the Plateau also decreases toward the north (Figure 10-13). The southern section of this survey area has the greatest differential between Cenozoic loads, the strongest increase in velocities in the Upper Creteceous between the shelf and the Plateau, and the most frequent occurrence of this type of fault.

Two shelf break normal faults were observed on line 29 (Figure 10-3c). One of these faults extends to near the surface. It is impossible to discern from the airgun records whether or not it reaches the surface of the sediment, but minisparker data (Edsall _et al_ this volume) suggest that the faults do not. The second fault is covered by Miocene sediments. Both faults dip seaward and presumably end in bedding planes.

At the base of the slope on line 19 (Figures 10-3a and 3b) there is a pod of sediment which has been interpreted as being a small slump mass on the basis of minisparker data (Edsall _et al_ this volume). It is .05 seconds thick and about 4 km long. No slump scarp has been observed.

Two additional features were seen on the shelf in the vicinity of Charleston which are probably small buried stream channels (Figure 10-16). They occur at about .3 seconds subbottom and show disruptions which are propagated throughout the rest of the record. These features occur several multiple cycles down into the record, which was of poor quality, and therefore it is not possible to eliminate all possibility that these features are due to faulting. The location of these features are shown in Figure 10-21.

Aquifer

The aquifer known as the "principal artesian aquifer" in the Carolinas and Georgia and as the Floridan Aquifer in Florida, is one of the major resources of the Coastal Plain in the Southeastern United States. In general, the confining beds which overlie the aquifer range in age from Miocene to Oligocene. Although the aquifer is primarily developed in Eocene rocks, its boundaries may overlap into Oligocene and Paleocene rocks over its entire geographic range (Counts and Donsky 1963; Stringfield 1966; Siple 1969; Dillon _et al_ 1975).

The hydrologic characteristics of the Upper Cretaceous rocks of the Coastal Plain are poorly known. However, in northeastern Georgia and

South Carolina they yield large quantities of fresh water, while in Florida and southeastern Georgia they yield salty water (Stringfield 1966). The aquifer is not utilized extensively because of its depth (600-1,000 m below sea level in South Carolina and Georgia). A Cretaceous aquifer may extend offshore and underlie the southeastern Atlantic Shelf and Blake Plateau.

Evidence as to the extent of the aquifer offshore is sparse. There are many reports of submarine discharges off the southeastern Atlantic Coast (Manheim 1967), mostly off Florida, especially southern Florida. Four features or accounts of features occur near or within this survey area.

Counts and Donsky (1963, p. 54-56) summarized the type of natural feature which is likely to contaminate the aquifer.

> "Prior to the development of ground water in the Savannah area the configuration of the piezometric surface was controlled chiefly by the hydrologic characteristics of the aquifer and intervening confining beds and the topography and altitude of the outcrop areas. The original piezometric surface was reconstructed by Warren (1944a, p.26) using the elevation of the static water levels of the first wells drilled into the principle artesian aquifer in each locality. The map indicates that the hydraulic gradient in the Savannah area sloped eastward at the rate of about 1 foot to the mile. ... Estimates based on the slope of the hydraulic gradient and the convergence of flow lines suggest that the natural discharge area was about 30 to 35 miles northeast of Savannah, near St. Helena Island, S.C. This means that ground water discharges through the limestone into the Atlantic Ocean as submarine springs or into streams in the area through thin places in the confining layer. Old time residents report that during years past submarine springs had been noted in the Beaufort River near Port Royal. Assuming that ground water discharged in this area until recent years, then salt water can and will move into the principal artesian aquifer when the artesian head in this area declines to or below sea level."

In the early sixties a large sinkhole was discovered on the shelf off Jacksonville, Florida at 29° 44′ N and 80° 45′ W. This is near the tie line which connects line 29 and 30. It is known as Red Snapper Sink and is 50 m in diameter and 150 m deep. High oxygen content in the seawater of the sink hole implies nonstagnant water and dye dispersion tests indicate downward flow, suggesting that this could be a point where seawater is entering the Floridan Aquifer (Brooks 1961; Manheim 1967; and Kohout et al 1977).

An anecdotal account of a feature on the Blake Plateau in the vicinity of the seaward ends of lines 20 and 21 was related by Manheim (1967, p. 844).

> "A remarkable discovery by the deep submersible, "Aluminaut", during 1966 heightens interest in the flow of fresh and brackish water from the continent. While moving along the manganese-phosphate paved portion of the Blake Plateau off Georgia and South Carolina (Pratt & McFarlin, 1966) the 80-ton "Aluminaut" suddenly lost an estimated 1/2 ton of buoyancy as it passed over an approximately 50 meter deep depression. The general depth of the bottom in the area was about 510 meters, and the water temperature was about 10^{o} C compared with 12^{o} C normal bottom water temperature in the vicinity. The loss of buoyancy under these circumstances can only be explained by the outflow of water substantially less salty than seawater. Mr. Markel commented that similar depressions were present in the area, but were not investigated."

This submarine dive was near an area of the Blake Plateau where Cretaceous rocks have been dredged from the surface (Uchupi 1967; Hathaway 1971; and Valentine 1979a and b), implying that if this incident were the result of fresh water discharge it would have been from the Cretaceous aquifer.

In 1965 three JOIDES wells were drilled on the shelf and slope off Jacksonville, Florida. Wells J-1 and J-2 encountered relatively fresh water, and J-5 encountered brackish water. J-1 and J-2 penetrated through the Upper Eocene into the middle Eocene rocks. Unfortunately J-5 was lost because of drilling difficulties shortly after the upper Eocene was encountered, where chlorinities of the sediments started dropping abruptly. It is likely that fresh water would have been encountered in more porous sections below.

In 1976 three wells were drilled on the shelf off the southeastern United States during the U.S.G.S. Atlantic Margin Coring Project (Figure 10-1). In two of these wells, 6002 and 6004, down-hole salinity increased to over 40 PPT (parts per thousand). Wells 6002 and 6004 ended in the Upper Eocene and Upper Cretaceous respectively. Why these interstitial salinity values exceeded those of normal salt water (35 PPT) is unclear. Hathaway et al (1976) suggest that this might be due to diffusion from hypersaline brines at greater depth. At well 6005 a salinity profile was observed for the 48 m hole which passed directly from Pleistocene sand into Paleocene clay and limestone. The salinity decreased from 35 to 25 PPT, indicating a fresh water influence (Hathaway et al 1976).

Seismic surveys do not produce any direct information about an aquifer. Since the principal artesian aquifer is generally contained within the Oligocene and Eocene units onshore, it would likely remain in these units if it extended offshore. The extent and thickness of these units has been traced seismically. The contour of the top of these units is shown in Figure 10-16. An Oligocene and Eocene isopach, which may correspond to an aquifer isopach, is shown in Figure 10-17.

If the assumption is made that the principal artesian aquifer remains in the Oligocene and Eocene strata offshore, it is possible to identify areas of potential aquifer outcrops. Eocene rocks are exposed at the base of the slope on lines 24-25 (Figure 10-3c), where on lines 24 and 25 the Oligocene-Eocene section shows an abrupt seaward truncation at an erosional scarp of about 10° true dip. Lines 26 and 27 (Figure 10-3c) show that some of the Oligocene-Eocene strata are exposed but the erosion did not cut completely through the sequence. On lines

28 and 29 (Figure 10-3c) there is a deep erosional channel cut through nearly the entire Eocene section. However there is a drape of Neogene and younger sediments which extends down the slope and cover some of the Eocene sediments. In all lines north of line 24 the Oligocene and Eocene section is entirely covered and sealed by the Neogene and Holocene section on the slope. This is seen in line 19 where AMCOR 6004 was drilled (Figure 10-3b). No Eocene and Oligocene sediments were encountered in AMCOR 6004 as they pinch out just landward of the drillsite, lines 19-23 (Figure 10-3b). North of line 19 it was not possible to trace the Oligocene unconformity so the Oligocene-Eocene units could not be identified. However the drape of Neogene sediments in the northern lines (with ASP-5 as control) and the general lack of erosion on the bottom would tend to indicate that no Eocene-Oligocene sediments crop out at the shelf break. Eocene and Oligocene sediments may be exposed on the surface of the plateau in places north of line 19 but they probably would not be hydrologically connected with the major part of the aquifer.

Our knowledge of the offshore extent of the fresh water aquifers of the southeast is quite limited. There is enough solid evidence from the JOIDES wells J-1 and J-2 to show that at 30° the aquifer remains fresh almost to the shelf break. JOIDES J-5 indicates that fresh water may extend down beneath the shelf break in the Eocene units. To the north the bore holes AMCOR and 6004 contain interstitial water above the salinity of sea water. If the Neogene caps the aquifer offshore in this area, it is quite thin as is shown in Figures 10-18 and 10-19. Sink holes like Red Snapper Sink could easily penetrate the confining beds and be places of potential aquifer contamination. At other places where the confining bed is penetrated, discharge may occur. Areas where the aquifer crops out on the slope are also possible sites of fresh water discharge. Care should be taken in any future development of the Florida-Hatteras Shelf to assure that the units corresponding to the aquifer on shore are not contaminated until the actual extent of the fresh water aquifer is better understood.

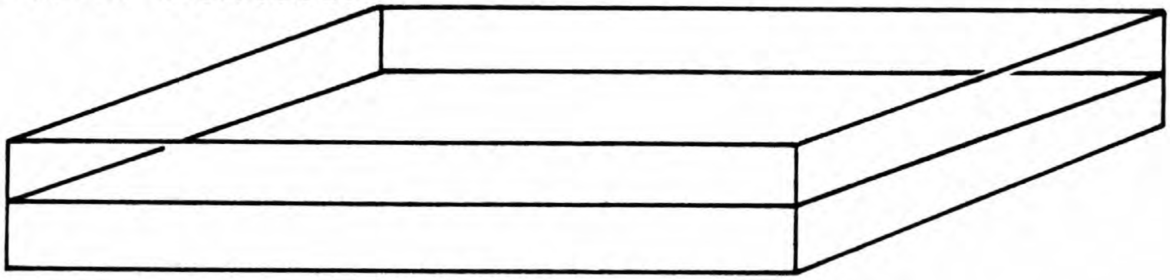
CONCLUSIONS

The Upper Cretaceous has been divided into three units. The Turonian to the Coniacian was a time when sediments were deposited which produce nearly level parallel reflectors. This represents deposition on a broad submerged shelf which presumably extended to the seaward end of the Blake Plateau. An unconformity separates the Coniacian from the Santonian sediments. Then during the Santonian, sea level was higher and a shelf prograded out across the northern portion of the survey area. On top of the Santonian progradational wedge another interval was deposited which produced level reflectors of Campanian and Maastrichtian age. This is interpreted as corresponding to another interval when there was a broad shelf. Sometime in the Upper Cretaceous, a reef - carbonate bank developed and formed a topographic high in the southern portion of the survey area. This reef died in the uppermost Cretaceous. Elsewhere in the embayment the Upper Cretaceous conditions remained stable into the Tertiary.

Cenozoic history is summarized in Figure 10-22. Paleocene sediments were deposited on a broad submerged plateau, conformable over the Cretaceous. At the end of the Paleocene there was a major erosive event which left an irregular unconformity in a linear belt 100 km wide to the west of the present Gulf Stream, which is believed to have been caused by the initiation of the Gulf Stream. This unconformity was

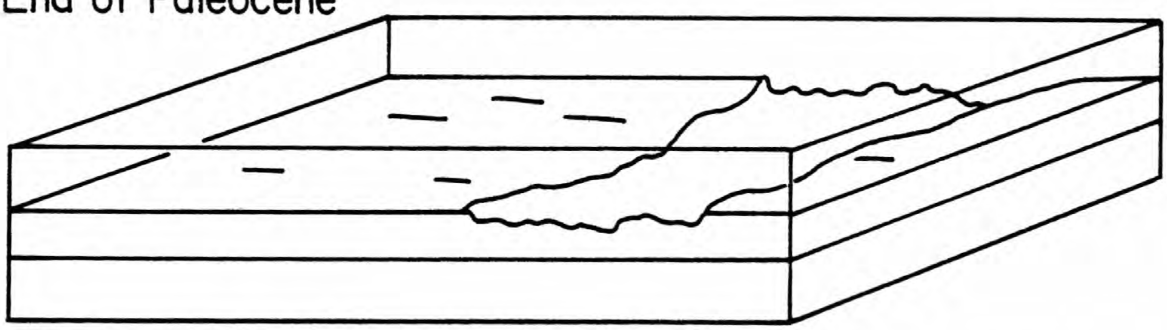
Figure 10-22. a. and b. Idealized block diagrams showing inferred Tertiary development of the Florida-Hatteras Slope.

End of Cretaceous

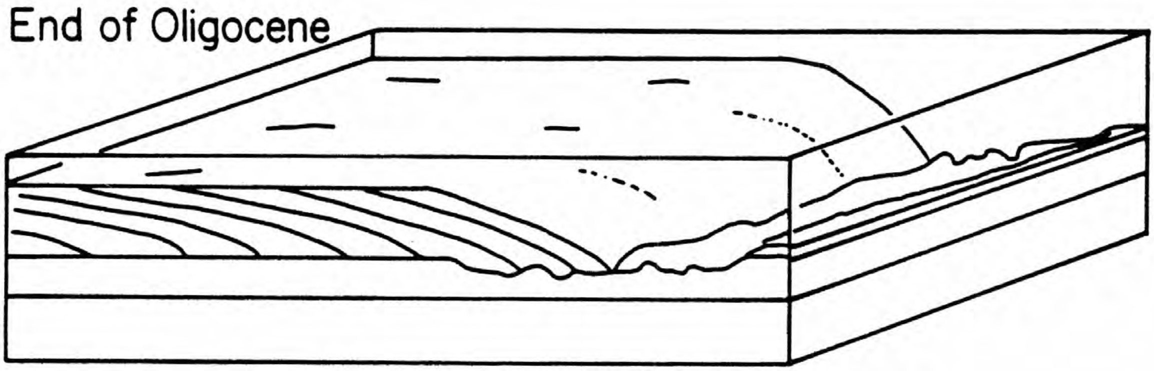


At the end of the Cretaceous this area was a broad, level, submerged platform. There was no appreciable distinction between the eastern and western portions of the surveyed area. The Cenozoic-Mesozoic boundary is marked by a small but not particularly distinct unconformity.

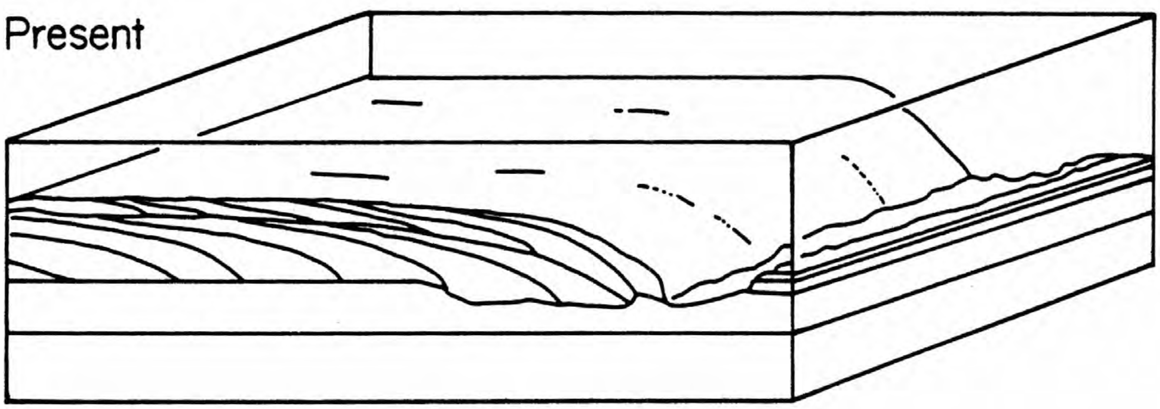
End of Paleocene



A sequence of Paleocene strata about 100 meters thick overlay the Cretaceous units. The top of the Paleocene section is irregularly eroded. Reliefs on this surface are up to 100 meters. This erosion is related to the initiation of the Gulf Stream in this area.



The late Paleocene unconformity is buried by a large seaward progradational wedge of Eocene to Oligocene age. This progradation was terminated by an erosional event at the end of the Oligocene.



The late Oligocene erosion surface was buried by an additional progradation of the shelf and slope from Miocene to recent times. The Tertiary accumulations under the shelf are much greater than on the Blake Plateau.

buried in the Eocene by a seaward progradation of the shelf. The shelf progradation ended in the Oligocene with another regional erosive event. The Oligocene erosion was not as intense as the earlier Paleocene erosion. Miocene and younger sediments cover the late Oligocene erosion surface with a second Tertiary shelf progradation. This progradational wedge was smaller than the Eocene-Oligocene wedge. The post-Paleocene accumulation on the Blake Plateau is quite thin because the areas under and seaward of the Gulf Stream have been sediment starved since the initiation of the Gulf Stream.

The offshore part of the Southeast Georgia Embayment is a basin which resulted from differential subsidence across pre-existing crustal structures. The center of the embayment has subsided over 500 m more than its flanks during Cenozoic time.

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APPENDIX A

Key to Land Wells for Figure 10-2

1.	Myrtle Beach	(Gohn *et al*, 1978a and b)
2.	Carolina Utilities	" "
3.	Litchfield	" "
4.	Penny Royal	" "
5.	Esterville Plantation	" "
6.	Hampton Plantation	" "
7.	Isle of Palms	" "
8.	Charleston	" "
9.	Kiawah Island	" "
10.	U.S.G.S. Clubhouse Crossroads	" "
11.	Hilton Head Island	" "
12.	Parris Island	" "
13.	GSS-855	(Cramer, H., 1974)
14.	GSS-363	"
15.	GSS-719	"
16.	GSS-52	"
17.	GSS-651	"
18.	GSS-3146	"
19.	GSS-1197	"
20.	GSS-153	"
21.	GSS-1199	"
22.	GSS-1198	"
23.	GSS-876	"
24.	W-890	(Florida Bureau of Geology Well Library)*
25.	W-3869	" "
26.	W-1514	" "
27.	W-1838	" "
28.	W-1746A	" "
29.	W-1118	" "

*Data obtainable from Florida Bureau of Geology, 903 West Tennessee Street, Tallahassee, Florida 32304.

CHAPTER 11

SOUTH ATLANTIC OUTER CONTINENTAL SHELF HAZARDS MAP

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Chapter 11

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CHAPTER 11

SOUTH ATLANTIC OUTER CONTINENTAL SHELF HAZARDS MAP

Mahlon Ball, Peter Popenoe, Michael Vazzana, Elizabeth Coward,
William Dillon, Thomas Durden, Jack Hampson, and Charles Paull

ABSTRACT

This report contains a narrative description of the attached map. Four hundred and thirty-seven faults have been picked on the Florida-Hatteras Shelf, and adjacent continental slope and inner Blake Plateau. These features are predominantly normal, down to the east and south. Most faults are believed to be related to compaction. Five slump faults have been located on the slope. The faults appear to be buried and inactive at the present time. The largest faults have throws of 10-20 m and occur in clusters confined to Upper Cretaceous sediments beneath the slope and inner Blake Plateau.

Cut and fill structures from submarine erosion are concentrated on the Blake Plateau, slope, and outer shelf off Cape Romain. Cut and fill probably related to Pleistocene river channels is concentrated in Lease Block Area D. Water column anomalies on the slope probably stem from coral pinnacles, and on the shelf are probably due to bottom growth such as patch reefs. Possibly some may reflect fields of gas seeps. Reef types within the study area include deep water bioherms rising up to 100 m above the adjacent bottom in water depths over 400 m, a shelf edge carbonate ridge-type reef and patch reefs on the shelf. No active sand waves or slump masses have been located on the shelf or slope.

INTRODUCTION

This report presents a map (Map 11-A) of possible hazards to or constraints on petroleum exploration and production on the continental shelf off the southern United States. The map supplements an accompanying report: Southeast Georgia Embayment High-Resolution Seismic-Reflection Survey (Edsall, Chapter 9, this volume). Together, these reports fulfill a part of the U. S. Geological Survey's commitments under the Bureau of Land Management's Memorandum of Understanding: AA550-MU6-56. According to the Memorandum, a hazards map based on high resolution seismic data was to be constructed and accompanied by an interpretative narration discussing the extent and age of shallow seismic features and their potential effects on resource recovery activities. This report's purpose is to complete the fulfillment of these requirements.

An extensively referenced discussion of studies pertinent to seismic measurements off the southeastern United States is presented in Dillon and others (1975). Up-to-date summaries are included in companion papers in this volume (Edsall, Chapter 9; Paull, Chapter 10). Readers are referred to these papers for discussions of previous work.

The report begins with definition of potential hazards and constraints and a description of seismic techniques used to identify these features. Then, specific instances of the various hazards noted on the U. S. South Atlantic shelf are described and conclusions are drawn. The main conclusion based on our studies is that, with proper precautions, the U.S. South Atlantic shelf is a relatively safe place for drilling operations.

IDENTIFICATION OF HAZARDS AND CONSTRAINTS

High resolution reflection seismic measurements provide the primary basis for recognition of a number of geologic features that constitute possible dangers in marine resource evaluation operations. Faulting is an obvious example. Terminations and dip changes of reflections are indicative of faulting. Where correlation of terminated reflections can be made across the disrupted zone, the vertical component of fault offset can be estimated and a measure of magnitude can be assigned. In addition to terminations and dip changes, edges of beds displaced by faulting are often excellent reflectors that continue to return energy for some time after the seismic energy source crosses the fault location. These reflections appear as upward convex hyperbolas known as diffractions whose apices mark the fault plane. An interpretation team of Geological Survey personnel marked reflections on all minisparker and 3.5 kHz records at the same time noting terminations and diffractions. Interpreters marked locations where these features occurred in steeply dipping alignments. Places where such alignments were encountered are shown as inferred faults on Map 11-A.

Seismic reflections may also reveal sediment body geometries and internal structures. Features like slump masses, reefs, karst surfaces and solution cavities, channels and channel fills, scoured bottoms, sand waves, ridges, and shoals are often readily discernible on reflection records. Our interpreters examined the records attempting to identify sedimentary and diagenetic structures. A number of these features are noted on Map 11-A.

Seismic data may also expose gas seeps where sufficient gas is present in the water column to cause reflections. Bubble train reflections may be associated with bottom craters or mud volcanoes. The interpreters scrutinized the records for indications of seeps and related bottom features. A number of possible examples are marked as water column anomalies on Map 11-A.

Knowledge of sediment body shape and internal structure derived from reflection geometries and character may lead to identification of shallow gas reservoirs. Reflection whiteouts, wipeouts, or translucent zones have been shown in some instances to be related to gas accumulations in sediments. Sediment bodies that exhibit this reflection character are often unstable due to high gas pressures in pore spaces. Reflection intensity variations coupled with velocity anomalies resulting from gas filled pore spaces can be used to directly infer gas accumulations. This technique comprises so-called "bright spot" analysis.

Reflecting records may aid in recognition of highly porous intervals that could cause loss of fluids in drilling operations. This is sometimes the case where permeable conglomerates are concentrated on unconformities in terrigenous clastic material or where solution features are the result of erosion and corrosion associated with unconformities in carbonate rocks. The tendency for unconformities to be strong reflectors has a number of other applications in reflection interpretation. Both Paull (Chapter 10) and Edsall (Chapter 9) make use of unconformities in seismic stratigraphic applications. Paull (Chapter 10) maps the offshore extension of the Paleogene aquifer of Florida and Georgia by following early and mid-Cenozoic unconformities that bound the stratigraphic interval that contains the aquifer.

It is hoped that some inferences may be drawn regarding wave and current action from indications of erosion, transportation and deposition visible in high resolution records. Evidence of bottom scour and sand wave formation may perhaps contribute something to our knowledge of Gulf Stream and hurricane activities. Reflection data may also record ship wrecks and sites of archaeological interest such as submerged Indian mounds. Location of such man-made objects are of course rare.

U. S. SOUTH ATLANTIC HAZARDS AND CONSTRAINTS

Faulting

A number of small faults with throws measured in meters are inferred on the basis of terminations and dip changes noted in the Cenozoic sediments beneath the shelf (Map 11-A). These small faults occur mainly in Miocene and Oligocene age rocks and appear to diminish with depth. In several areas sea floor irregularities occur in conjunction with terminations and dip changes, and these features on Map 11-A are mapped as surface faults. Interpreters were encouraged to mark minute reflection dip changes and offsets as faults in keeping with our aim to identify all potential dangers to drilling operations in this region. As lateral velocity inhomogeneties may appear as faults on seismic records many of the small displacements faults picked on the shelf are considered conjectural, however it is our opinion that most of the faults shown are real.

The orientation of the shelf faults is difficult to discern from the regional data, but within the lease block areas the interpretation of the faults is based on seismic track coverage on rectangular grids with line spacings of 800 x 3,200 m (U. S. Geological Survey Hazards Study for the Secretarial Issue Document, Lease Sale 43). This data shows that although many of the faults are discontinuous and have random orientation, the predominant orientation is to the northeast and the predominant dip is into the deeper part of the sedimentary basin. This, and the fact that the faults diminish with depth suggests that these small displacement faults are compactual or are related to subsidence in the Southeast Georgia Embayment.

We searched for concentrations of recognizable faults on the shelf opposite the Charleston earthquake area. Such concentrations of possible faulting are not well defined. Two faults, one near lease block area B and one on line 3 north of line 19, were large enough to be recognized by Paull (Chapter 10) in airgun reflection data indicating displacements of more than 10 m. These faults may reflect tectonic activities that are manifested by earthquake occurrences in the Charleston, S.C. region (Dillon and others 1975, p. 166); however the style of observed faulting does not shed new light on the active earthquake site.

As pointed out by Edsall (Chapter 9, Figure A-21), two obvious faults, revealed in the high-resolution data of this study, occur on the upper Florida-Hatteras Slope on line 29 in the southern part of the survey area. Terminations, dip changes and diffractions defining these faults are visible over a relief of about 150 m. The throw appears to be about 10 m. The faults have normal displacement, down to the east, and are buried beneath 45 m of undisturbed sediment. This style of faulting is common on slopes. The faults have corrected apparent dips of approximately 50^{o} and as such closely approximate true dips commonly noted on near surface normal faults. It follows from the dip directions that the faults strike approximately north-south. A third fault of smaller displacement occurs below the faults pointed out by Edsall, and two other possible slump faults occur on the slope on lines 5A and 11, however the evidence for these faults is not conclusive.

A large slump mass approximately 5 km long and 50 m thick occurs at the base of the slope on line 19 (Edsall, Chapter 9, Figure A-16). Two other possible slump masses occur on lines 5A and 11. Attempts to core the line 19 feature (Mark Ayers, R/V EASTWARD Cruise Report, April 1978) resulted in bent core barrels and no recovery of sediment. It appears that this sediment mass has been in place long enough to have been armored by phosphorite and manganese nodules. Certainly the feature is older than the 1886 Charleston, S.C. earthquake.

The fact that there are so few slump faults along the slope or slump masses at the base of the slope probably reflects relatively stable slope sediment conditions. Conditions necessary for slumping include rapid deposition of semi-consolidated fine-grained sediments on slope areas. Sediments are further weakened by organic decay leading to natural gas generation. Work by Pilkey and others (Chapter 5), Doyle and others (Chapter 2), and Butman and others (Chapter 4) all indicate that fine-grained sediments are rare on the shelf as the fines have been winnowed out of the sediment cover by reworking and current action. River derived fine-grained materials that are not trapped in the estuaries are transported across the shelf to become entrained in the Gulf Stream and swept north. Thus, they are not deposited on the upper slope. This and the low angle of declivity of the slope (approximately 3^{o}) probably explain the relatively stable slope conditions.

Paull (Chapter 10) describes clusters of faults visible as terminations, dip changes and diffractions in the Upper Cretaceous rocks of the Florida-Hatteras Slope and Blake Plateau. Essentially all of the faults shown by long bars on the outermost shelf, slope, and inner Blake Plateau shown on Map 11-A are of this type. Throws are measured in a few tens of meters. These faults are unusual in that their displacements die out with increased depth and they also terminate upward against Paleocene age rocks. From this, Paull (Chapter 10) infers that they are a result of compaction in the chalky Upper Cretaceous sediments. Failure to recognize these features buried beneath the Cenozoic section on the mid and inner shelf may be due to poor record quality caused by reverberating sea floor multiples.

The orientation of the faulting in Upper Cretaceous age rocks is difficult to predict from regional data, therefore a statistical approach is used. Approximately 60% of the Upper Cretaceous offsets are seen on strike lines whereas strike coverage very nearly equals dip line coverage. Seventy percent of the strike line faults have apparent dip components to the south and 80% of the dip line faults have apparent dips to the east. These observations are consistent with the generalization that most of these faults trend SW-NE and are down to the SE, toward the deepest part of the Southeast Georgia Embayment.

On the basis of observations of fault patterns, it seems clear that the study area is predominantly a region of extension. This is consistent with its setting as part of a passive continental margin. No reverse faulting or faulting that may be indicative of tectonism was observed with the possible exception of the two 10 m displacement faults previously mentioned on line 3 near Lease Block Area B (Map 11-A).

Cut and Fill Structures

Cut and fill structures are potential hazards to drilling for the following reasons. First, where exposed at the surface of the sea floor, they imply bottom current conditions that could undermine platforms. Second, at the surface or buried in the subsurface, channel fills possibly contain materials contrasting in grain size, porosity and engineering properties to adjacent materials. Such contrasts could result in differential settling of structures straddling the contrast or could result in pods of material that might trap shallow gas. Shallow gas represents potential problems both as a contributor to structural instability and as a source of blow outs with attending fire and pollution hazards.

Cut and fill features observed in this study are divided into channeling of probable stream origin and channeling of probable submarine current origin. The origin of the cut and fill may be reflected in the grain size of the channel fill material as that of stream origin would probably be coarser-grained than that of submarine origin. Thus, origin would probably also reflect differences in engineering properties or porosity. The identification of origin is based on a judgment of the appearance of the unconformity on which the channeling occurs, the shape of the channel, the probable age of the channel fill material or its depth, and its areal location relative to the slope. Cut and fill channels were observed at several horizons in depth but generally only the shallowest are classed as being of stream or river origin. Thus, all those shown as of stream origin probably reflect stream positions during lower stands of sea level during the Pleistocene.

Cut and fill channels of stream origin are concentrated on the inner and middle shelf. Where detailed data is available in Lease Block Area D the channeling is shown to be discontinuous and striking approximately northeast. This strike suggests remnant estuarine stream channeling behind then existing barrier islands during lower sea levels of Pleistocene Time.

Cut and fill channeling of probable submarine current origin is concentrated on the Blake Plateau, the slope, and outer shelf. The most extensively channeled area on the shelf is in and around Lease Block Area A, east of Cape Romain. Here the seismic profiles show a long history of submarine cut and fill dating from the Paleocene when this area approximately occupied the shelf edge. The area appears to have been reworked by strong Gulf Stream currents into Pliocene time. Pliocene and Holocene sediments are not channeled. The extensive cut and fill channeling in this are may be due to the structural bathymetric high east of the area on the Blake Plateau (Edsall, Chapter 9) which probably has deflected and interfered with the Gulf Stream flow from the Eocene to the present. Similarly, the extensive channeling on the slope to the east of lease block area A shares this history.

A large channel on line 9 is marked on the map as possibly gas filled. This interpretation is based on a "white-out" of the seismic data in the area of the channel.

Extensive areas of the inner Blake Plateau and lower slope are marked by submarine cut and fill and by severe submarine scour and scour topography. This topography reflects erosion and cut and fill by the Gulf Stream. Both scour channeling and steep erosional topography are marked by the same symbol. Examples of these features are shown by Edsall (Chapter 9) in Figures A-6, A-9, A-10, A-12, A-13, A-19 and in the detailed topography shown in the line drawings in Chapter 9, Appendix 9-B.

Reefs and Water Column Anomalies

Three types of inferred reefs are discernible from the high resolutions reflection data. On the shelf prominant hardground areas of moderate to high relief are marked on Map 11-A as marine habitats. These features include the reefal structures on the shelf edge (Edsall, Chapter 9, Figures A-4 and A-20) and the more prominant moderate-relief hardgrounds (Edsall, Chapter 9, Figure A-2). Also included in this category is a moderately shallow reef (depth 260 m) on the slope (Edsall, Chapter 9, Figure A-17). Henry and Giles (Chapter 8) present a more comprehensive summary of the shelf reefs and hardgrounds.

A second category of reefs is discernible on the seismic data as attached and unattached hyperbolas on the lower Florida-Hatteras Slope and inner Blake Plateau beneath the Gulf Stream. Edsall (Chapter 9, Figure 9-4 and Appendix 9-E) describes these features and refers to them as hyperbolas of unknown origin. He observed that these hyperbolas are restricted to areas of water depth greater than 420 m, i.e., well down the Florida-Hatteras Slope and on the Blake Plateau. Edsall does not make a strong distinction between unattached hyperbolas and diffractions that appear to originate from pinnacles attached to the sea floor (Edsall, Chapter 9, Figures A-17, 1, 2, 3, 5 and 6).

Stetson and others (1962) describe diffractions of an attached nature in water depths of 800 m, centered at 31°50′ N and 77°30′ W, just east of the north-central part of the study area. With observations from cores, bottom photos and reflection records, Stetson and his colleagues make a strong argument for concluding that the rough bottom topographic features giving rise to the diffractions are deep-water coral bioherms. Relief above the bottom for some of these features exceeds 100 m. Areas of attached hyperbolic returns on slope records in the southern third of this survey were cored during April 1978 (Pilkey and others 1978) and fresh hermatypic corals were recovered. Also the appearances of these features in our airgun records are very suggestive of reefs (Paull, Chapter 10, Plate 1). For this reason, these attached diffractions are mapped as coral reefs (R) on Map 11-A.

On the shelf a number of attached and unattached pinnacles with relief measured in meters are seen in the seismic data. These are indicated on Map 11-A as water column anomalies, and as such may represent bottom growth, patch reefs, fish schools, or gas seeps. Examples of these features are shown by Edsall (Chapter 9) in Figure

A-11 at the top of the slope and in Figure A-2 near the possible reef. With the exception of that shown in Figure A-2 most of these features appear on the seismic records as attached isosceles triangles with an apparent height more or less equal to their base dimension. When the vertical exaggeration of the seismic records is taken into account it is clear that the base widths exceed the height by more than an order of magnitude, therefore we believe that most of the features shown as water column anomalies on the shelf represent patch reefs, although the possibility of other origins cannot be discounted.

Sand Waves

Sand waves are seen on lines 5A, 5C, 9, 11, 27A and 28. With the exception of the sand waves on line 5A off Cape Fear (Edsall, Chapter 9, Figure A-3) the sand waves are not well developed. On line 5A the face slopes are directed toward the west, the wavelengths are hundreds of meters and the heights are meters, so that dips are negligible. It seems probable that these features are relict, particularly in view of low storm-generated current speeds of less than 1 knot measured by bottom instruments (Butman and Pfirman, Chapter 4 Part II, this volume) on the mid- and outer shelf.

SUMMARY AND CONCLUSIONS

At this stage of our studies, a number of potential hazards to resource assessment operations have been identified for the U. S. South Atlantic shelf and slope. However, if proper precautions are taken and site surveys are made this region should be relatively safe for exploration and exploitation of mineral resources.

The small faults inferred in the Cenozoic sediments beneath the shelf are conjectural and are probably related to compaction or subsidence in the Southeast Georgia Embayment, which is suggested by their strike and dip. The lack of well developed faults opposite the Charleston, S.C. area is puzzling in that we had expected some correlation between faults in the marine environment and the active earthquake zone onshore. The two faults identified in the mid-shelf area southeast of Charleston may be related to this activity since they are the largest displacement faults that we observed on the shelf, but these two faults are the only suggestion that an earthquake has ever occurred in the area.

The lack of slumps and faulting on the Florida-Hatteras Slope probably results from low sedimentation rates, a lack of fine-grained sediments being deposited, and the low angle of declivity of the slope. Phosphorite nodules overlay the slump mass seen on line 19 which were probably winnowed and precipitated onto its surface by Gulf Stream currents. This suggests that the slump has been in position at the base of the Florida-Hatteras Slope for a considerable amount of time, and no doubt preceeds the 1886 Charleston, S.C. earthquake. The overall lack of slumps and faulting on the slope suggests that sediment stability will be only a minor problem in petroleum development of the area.

On the inner Blake Plateau faults are confined to the Upper Cretaceous section and believed to be due to compaction of that chalky unit (Paull, Chapter 10). These faults may persist beneath the shelf but poor record quality precludes testing this speculation.

Cut and fill structures from submarine erosion are concentrated on the slope and inner Blake Plateau. The orientation of slope channels tends to be parallel to the strike of the slope. Channels on the mid and inner shelf are with few exceptions buried and appear to meander with no well defined orientation.

A number of reefs are identified. These areas on the shelf support an abundant benthic community of sponges and carbonate-producing organisms and provide a habitat for reef-type fishes. Areas where these reefs are well developed are environmentally sensitive and should be protected during petroleum exploration or development phases. Deep reefs on the Blake Plateau will probably not be a constraint to development as any resultant pollution from exploration activities will probably be swept north by the Gulf Stream before reaching bottom depths. In addition, these reefs support only a sparse benthic community (Stetson and others 1962).

Different types of water column anomalies have been observed on the shelf and slope. On the slope apparently unattached diffractions are believed to originate from coral pinnacles, but other possibilities are concentrations of fish or gas seeps. On the shelf, low relief clusters of deltoid shaped attached anomalies probably also originate from bottom growth including patch reefs.

A major constraint to exploration on the lower slope and inner Blake Plateau will be combatting strong currents associated with the Gulf Stream. These currents have scoured the bottom into a series of channels, plateaus, and cut and fill areas. It follows that drilling in these strong currents and scour around bottom structures and pipelines will be a major problem.

FUTURE WORK

The full utilization of seismic measurements on the southeastern U. S. Atlantic Shelf and slope represents both a formidable task in terms of synthesis and a tremendous opportunity for scientific accomplishment. A start has been made with the cooperative analysis of high resolution and airgun seismic data. These studies have been coordinated with the high density, high resolution work in nominated lease tracts by the U. S. Geological Survey's Conservation Division and the regional network of multichannel reflection coverage obtained by the U. S. Geological Survey's Atlantic and Gulf of Mexico Marine Branch. Both data bases were used to compile Map 11-A. Regional sidescan sonar and towed television surveys are being conducted by University of Georgia scientists as another part of this overall program. All these studies are in progress. High resolution and airgun data have been extended over the Blake Plateau. The amount of multichannel coverage is in the process of being more than doubled and plans are to fill in high resolution and airgun data by additional dip lines spaced at about 10 km on the shelf during the next field season.

Full advantage in the seismic interpretations has been taken of available offshore subsurface control provided by JOIDES wells, the Atlantic Slope Project, the Atlantic Margin Coring Project and the Continental Offshore Stratigraphic Test. Onshore subsurface studies under the auspices of the Georgia Geological Survey, the South Carolina Geological Survey, the Florida Geological Survey, and the U. S. Geological Survey's Charleston Earthquake Study Group are being tied into the marine geophysical measurements and subsurface control. The U. S.Geological Survey's Marine Branch has initiated a sea floor seismometer study in cooperation with the onshore earthquake study group. Coring, geotechnical properties investigations, and analyses of gas in cored sediments are being planned in conjunction with the seismic studies.

The synthesis of all these undertakings will result in an unparalleled understanding of the nature of the sedimentary wedge expanding seaward from its pinchout on the onshore Appalachian Piedmont to the thick sediment accumulation beneath the continental rise.

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