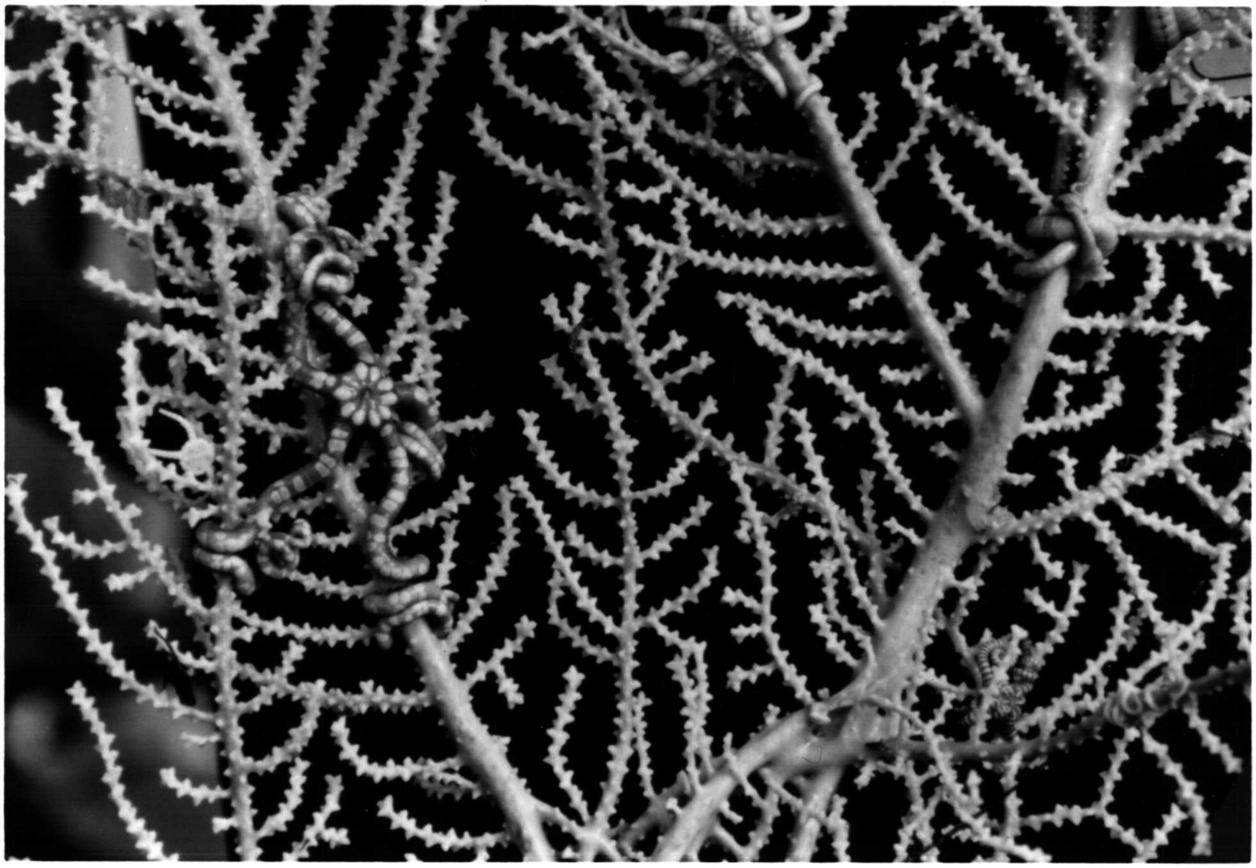
OCS Study
MMS 93-0021

Habitat Impacts of Offshore Drilling: Eastern Gulf of Mexico



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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MMS 93-0021

Habitat Impacts of Offshore Drilling: Eastern Gulf of Mexico

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ABSTRACT

In this survey six offshore exploratory drill sites in a variety of environments and water depths were examined using a small research submersible. Sites varied from locations off northwest Florida to as far west as offshore Alabama. Water depths ranged from 21 m (70 ft) to 149 m (489 ft), and bottom sediments ranged from carbonate mud to shelly quartz sand and silt to hard limestone. The age of the sites (the time between cessation of drilling activities and our observations) ranged from 15 months to 17 years.

In a previous MMS-funded study, Shinn et al. (1989) and Dustan et al. (1991) examined eight sites off South Florida, where the age of the sites ranged from 2 to 29 years. The study documented repeatedly variability of impact from site to site. In the present study, we note a similar wide divergence of impacts. Using the concentration of barium (the major component of drill mud), cuttings, and trace metals as a basis, we found that time is the single most important factor determining the nature of habitat recovery. Older sites, particularly the 17-year-old site, were relatively pristine. At a 7-year-old site, two hurricanes did far more damage than drilling. At other sites, we documented a significant amount of discarded debris, and at two 5-year-old sites, large concentrations of barium and cuttings. Impacts, such as the extent of debris and cuttings, affected the bottom ranging in area from almost negligible (17-year-old site) to as much as 3 acres (4-year-old site). As suspected, those sites with the most debris and/or open boreholes attracted the most abundant and diverse fish fauna.

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EXECUTIVE SUMMARY

The purpose of this report is to present site-specific data concerning the environmental impact of drilling exploratory wells on selected offshore locations in the northeastern Gulf of Mexico. The wells were drilled between 1972 and 1990, as little as 15 months and as much as 17 years before our observations began. All six sites selected were examined using a two-person research submersible. Water depth ranged from 21 to 149 m, and ambient grain size of bottom sediment varied from mud to coarse sand and pebbles. Two of the six sites were on hard-rock bottom with only a veneer of sediment interspersed with scattered hardbottom communities. The data presented here therefore relate to both short- and long-term impacts to a variety of marine habitats. The locations of all sites are shown in Figure 1 and site-specific data are given in Table 1.

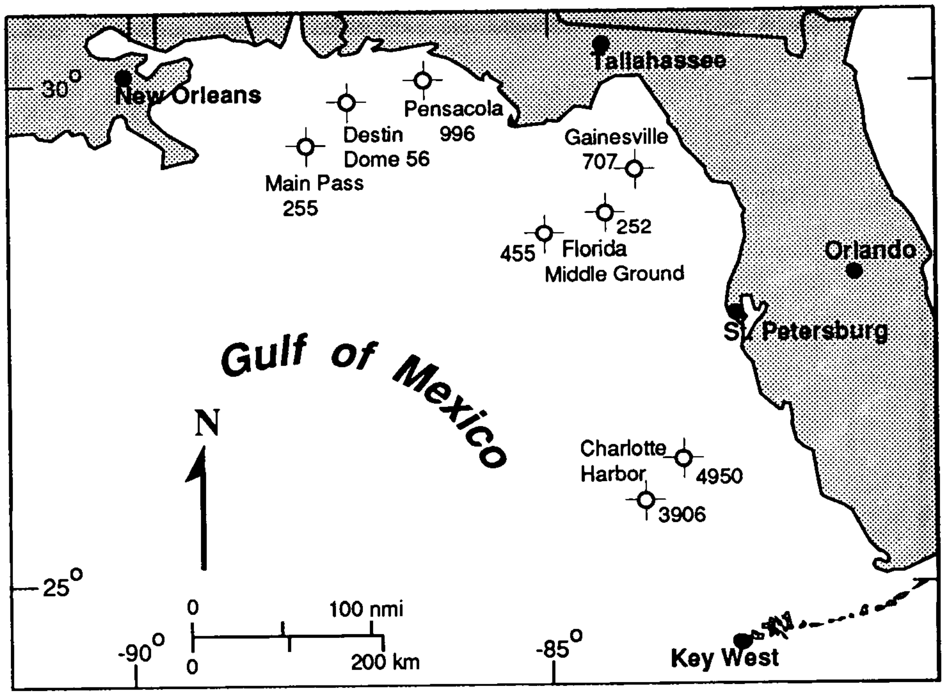


Figure 1. Locations of the six well sites examined in this study. The two Charlotte Harbor wells were described in previous studies (Shinn et al., 1989; Dustan et al., 1991).

This study, in addition to documenting the drill sites visually with video and photography, was principally directed toward determining the spatial distribution of cuttings and drill muds. The distribution of cuttings, drill mud and other discarded debris is thought to provide the best estimation of aerial extent of measurable impact. The need for such data was prompted by public concern over the effects of offshore drilling and by the publication of a National Academy of Sciences panel review report (1989) and a State of Florida Governor's Report (1989), both of which highlighted the lack of site-specific data. The lack of data resulted in enactment of a drilling moratorium off southwest Florida.

Table 1. Essential data for sites examined in this study (*proprietory data not available at this time).

Well Name	GPS Lat. and Long.	Water Depth	Year Drilled	Well Depth	Company	Rig Type	Bottom Type
Pensacola Block 996 No.1	86°23.750 30°01.167	48.8 m	1988	5,430 m	Texaco	Jack-up	Sandy with macroalgae
Destin Dome Block 56 No.1	87°12.758 29°53.579	57.3 m	1989	*	Conoco	Jack-up	Sandy with macroalgae
Main Pass Block 255 No.1	87°48.752 29°19.221	103.6 m	1990	*	Elf Aquitaine	Jack-up	Rock pinnacles w/ thin mud over rock
Gainesville Block 707 No.1	83°57.107 29°14.805	21.3 m	1985	4,860 m	SOHIO/BP Exploration	Jack-up	Limestone w/ thin patchy sediment
Florida Middle Ground 252 No.1	84°19.859 28°41.739	37.2 m	1974	4,644 m	Texaco	Jack-up	Rippled lime sand
Florida Middle Ground 455 No.1	85°09.276 28°30.690	149.4 m	1986	3,790 m	Chevron	Semisubmersible	Mud with burrow mounds

METHODOLOGY

Underwater observation and sample collection were accomplished using the research submersible *DELTA* deployed from the 35-m research vessel *SUNCOASTER* operated by the Florida Institute of Oceanography in St. Petersburg, Florida. The submarine maintains voice communication with the surface vessel and is equipped with a transducer tracking system that allows surface personnel to track and plot location of the submersible at all times.

The MMS Gulf of Mexico Region, Office of Leasing and Environment, New Orleans, Louisiana, selected the sites. Latitude and longitude were converted to decimal format and entered as way points in the ship's Global Positioning Satellite (GPS) receiver. The GPS receiver's video display allowed the captain to proceed directly to the site so that a buoy could be deployed. The submersible was then launched, and the pilot and an observer followed the buoy line to the bottom.

On the bottom, the pilot and observer conducted a visual search for the borehole. After the borehole was located, the buoy's 20-kg anchor was transported to, or immediately adjacent to, the borehole using the mechanical arm of the submersible. In areas of poor underwater visibility, the submersible was skidded along the bottom to make tracks that allowed the pilot to navigate back to the buoy or to any location previously visited. Placing the anchor at the precise location of the borehole saved time by enabling the pilot to descend directly to the borehole during subsequent dives and the ship captain to maintain position of the surface vessel. Usually, the buoy anchor landed within 60 m of the borehole. Finding the borehole with the submersible was aided by visual sightings of fish, short lengths of welding rods and large barnacles. Other objects also provided useful clues. Discarded welding rods invariably surrounded the boreholes and had previously been found to be reliable indicators of drilling activity (Shinn et al., 1989; Dustan et al., 1991). An additional clue consisted of large, 2- to 4-cm-long barnacle shells that do not grow on the bottom at the water depths in which these wells were drilled. The distinctive barnacle shells had been scraped from jack-up drill-rig legs by workers during drilling and possibly incidentally during deployment or retrieval of the jack-up legs. The GPS system for site location proved reliable and even at the deepest site (149 m), the anchor landed within 10 m of the borehole. At all sites, the first dive was devoted to repositioning the buoy anchor and to reconnaissance and photography using both still and video cameras.

Sampling and photography were conducted along north-south and east-west transects originating at the borehole. Orientation of the transects was generally parallel and perpendicular to the current, which was generally from the north. The distal ends of each transect extended beyond visible evidence of drilling activity, i.e., there were no cuttings, barnacles, or drill rods and the bottom appeared typical for the area. Analyses for barium, however, showed that the distribution of drilling mud extended well beyond our most distant sample sites at three of the most recent drill sites. At a location drilled in 1974, four samples were taken approximately 1 km from the drill site using a Peterson grab sampler deployed from the research vessel, and at another site drilled in 1985 the submersible was deployed for quick sampling dives 1 km beyond each transect. Elevated barium levels were not found in these samples at either drill site.

Samples were coded N1, N2, N3, N4, and so forth for the north transect, and S1, S2, S3, S4 for the south transect, with #1 representing the location closest to the borehole. At the Pensacola Block 996 site, 20 samples were collected along the east transect and 12 along the north transect. Together with those taken on the south and west transects, a total of 39 samples was obtained. The sample locations were spaced approximately 5 m apart using the length of the submarine as a measure. This close spacing was labor intensive and time consuming and required a minimum of 10 dives to collect all 39 samples. Thereafter, to utilize the sea time available more efficiently, a smaller number (four samples on each of four transects) of more widely spaced samples was taken. To determine spacing and location, the submersible was piloted outward from the borehole at a uniform speed for either 2 or 4 minutes between collecting sites. The distance (2 or 4 minutes travel time) was determined by the observer on the basis of whether cuttings or other evidences of drilling were visible. Cuttings were clearly visible near the boreholes due to their dark color, elongate angular shape, and size. Cuttings sizes ranged from millimeters to over 1 cm in length. Transects were timed so that sample #4 on each transect was beyond visible evidence of drilling activities. After collecting the most distant sample (#4), the submersible rested on the bottom while the captain positioned the research vessel directly overhead and took a GPS reading. The track-point system, which displays the submersible's transducer position on a video screen, allowed the captain to hover directly overhead. With the location of sample #1 known (marked by a buoy and a GPS reading), it was relatively simple to interpolate the positions of samples #2 and #3. A navigation software program was used to display and plot sample locations. This sampling method evolved during the study and proved most expeditious, given the weather conditions and ship time available.

The "bullseye" sampling plan of north-south-east-west transects was accomplished using the submersible's onboard compass. When sample locations were plotted using the GPS positions, it became clear that either the GPS readings were not precise (commercial GPS signals are deliberately degraded at times for security reasons), or the submersible tracks were more severely affected by bottom currents than were apparent to the observer and pilot while running the transect. The actual sample transect plots lie somewhere between the programmed right angles and the skewed transects produced by the navigation software.

Winds between 15 and 20 knots prevailed throughout most of the study. In spite of marginal sea conditions, the submersible was deployed as many as eight times per day. Due to 25-knot winds and seas approaching 3 m, only one dive was made on the 149-m-deep Florida Middle Ground Block 455 site.

The submersible, *DELTA*, is equipped with a sampling arm that can collect rocks or sediment. For this study, the arm was fitted with a stainless steel clamshell-like collecting device. The observer/scientist, located in the forward part of the submersible, operates the sediment sampler, takes notes, and operates both a 35-mm still camera and 8-mm video camera.

Samples were collected by digging the clamshell into the sediment and then depositing the contents into a four-chamber carousel sample carrier (Fig. 2). Each chamber was numbered. The carousel is attached by a line to the side of the submersible and is lowered into a position visible to the observer each time the submersible stops for sampling. The openings in the top of the four chambers are equipped with inclined clear plastic baffles to prevent winnowing and accidental loss of sediment while the submersible is underway. The operator maneuvers the closed clamshell to the top of the 10- by 10-cm carousel chamber opening and, by opening the clamshell, slowly allows the sediment to spill into the chamber. Some of the fine fraction is lost during transfer, especially in areas of strong current.

Figure 2. Print of a video image taken from within submersible *DELTA* showing the sampling procedure used in this study. Sample was scooped from within 0.25-m^2 frame and transferred to the four-slot carousel sample holder visible in lower lefthand corner of the photograph.

After the submersible was lifted from the water, the carousel was removed, taken to the ship's laboratory, disassembled, and the sediment transferred to numbered, plastic ziplock bags.

At Pensacola Block 996, a 1-m^2 PVC pipe frame was used, but because of difficulty in transporting it with the submersible arm, the frame was cut to 0.25 m^2. Each sediment sample was taken from within the 0.25-m^2 frame (Fig. 2) that was moved from site to site using the collecting arm, and the sample location within the frame was recorded on video. A still photograph was also taken through the porthole by the observer and with an externally mounted 250-frame, 35-mm camera. The purpose of the frame was to allow quantification of biota in the photographs and/or video in order to calculate percent coverage per square meter of bottom. Originally, a computer image-analysis program on the photographic image of the framed area was planned to estimate percent coverage of bottom biota. Difficulties with uneven lighting and the inability of some observers to position the frame properly resulted in this method being abandoned. In retrospect, we feel that the data gained from this method would not have significantly affected the results of the study.

Video and Still Photography

The submersible was equipped with an externally mounted 8-mm video camera that operated continuously during each dive. An onboard computer recorded bottom-water temperature, time and depth directly on the video tape at 2-second intervals. Each evening the temperature and depth data were downloaded to computer disks. Temperature/depth data were printed in table form aboard ship, and at three locations a complete temperature/depth profile was graphically plotted. External video and still cameras were operated and maintained by the submersible pilot. Color film was processed on board ship by a member of the submersible crew.

The scientific observer was able to view and photograph the bottom through six portholes. Voice observations were recorded simultaneously on both the external video-camera tape and the intermittently operated internal video. The sediment-sample sites were thus documented by still photographs, external and internal video, and verbally on the sound tracts of both video recorders. Because the number of video images far exceeded still camera images, many were converted to 8- by 10-inch black-and-white still photographs using an inexpensive video-frame grabber. These images were copied with 35-mm black-and-white film and reduced to form many of the illustrations used in this report.

Sidescan Sonar

Sidescan-sonar surveys were attempted at three of the six sites. The surveys were always conducted in the late afternoon, after the diving had been concluded and the submersible secured on board the ship. Sunlight and visibility were typically waning and the seas were generally rough, making the reference buoy difficult to see. Wind and waves were generally from the east, so the ship had to be piloted east or west (into or away from the seas) to avoid snagging the buoy line with the sonar fish. Ship speed was too fast for sidescan-sonar profiling with both engines running; thus, only one engine could be used, which greatly reduced the ship's maneuverability. Sonar-equipment breakdowns, inability to see the buoy in the waning light, and rough seas provided marginal results. At Main Pass Block 255, where bottom visibility was reduced to a few meters, sidescan imagery revealed the shape and extent of trenches that had been observed from the submersible. The trenches extended in zig-zag fashion for several hundred meters beyond the study area. At Destin Dome Block 56, a metal wellhead cover and two of three jack-up drill-rig leg holes were clearly seen in the sidescan profile.

It was anticipated that cuttings and debris would produce a mappable sonar signature. We detected no mappable image but remain convinced that the newer digital systems, if used in calm seas, would provide mappable data, especially in those areas where the surrounding sediment is finer grained than the cuttings. Such a survey would require about 6 hours at each site. We lacked sufficient time, equipment and the calm seas necessary to conduct such a study.

Grain-Size Analysis

Grain-size analysis was performed on all samples as a way to characterize and map the distribution of cuttings. Cuttings were found to be larger than the median grain size of ambient sediment; thus, plots of grain-size distribution served as useful indicators of drilling impacts. In addition, the sieving process provided the fine fraction necessary for elemental analysis.

To determine grain size, wet samples were weighed and an average of 75 gm of wet sediment was then wet sieved through a 63-µm nylon mesh screen using deionized water. The portion greater than 63 µm was placed in a beaker and dried for further grain-size analysis. The water containing the mud-size fraction (<63 µm) was placed in a 500-ml graduated cylinder and diluted to exactly 500 ml with deionized water. The mixture was stirred vigorously, starting from the bottom, until all the material was uniformly distributed in the cylinder. Twenty seconds after stirring, a pipette was inserted approximately 20 cm into the cylinder and 20 ml were withdrawn. The 20-ml aliquot was then placed in a beaker and dried in an oven at 75°C. The dried mud was weighed and multiplied by 25 (1/25 of the muddy water was withdrawn) to obtain the weight of mud in the total sample. The final weight of mud was based on the assumptions that (1) there was no loss of the fine fraction either from the clamshell during sampling or during laboratory preparation, (2) a homogeneous mixture was achieved during stirring, (3) exactly 1/25 of the original volume was sampled, and (4) there was no moisture uptake by the dry mud during weighing.

The material greater than 63 µm was dried and passed through a series of 18 standard U.S. brass seives. Screen mesh sizes ranged from 63 µm to 2.0 mm. Sediment at each mesh size was placed in vials of known weight and weighed. Figure 3 shows the size fractions in vials compared to a graph depicting the weight of each size fraction. The weight of the 18 size classes was converted to weight percent for all 105 samples. Weight percentage of each size class was originally plotted as simple line graphs (such as shown in Fig. 3) and then converted to three-dimensional figures using a computer program. Raw grain-size data are presented in Tables A1-A6 in the Appendix. The three-dimensional graphs help visualize variations in grain-size distribution relative to distance from the well site. We also prepared simple maps by contouring the weight percent of grains greater than 1 mm, based on visual estimates that most grains in this size range are cuttings rather than natural grains. The exceptions were in those areas of shallow or rocky bottom (Gainesville Block 707 and Main Pass Block 255), where, in addition to cuttings, there were natural grains, mainly rock fragments, greater than 1 mm in size.

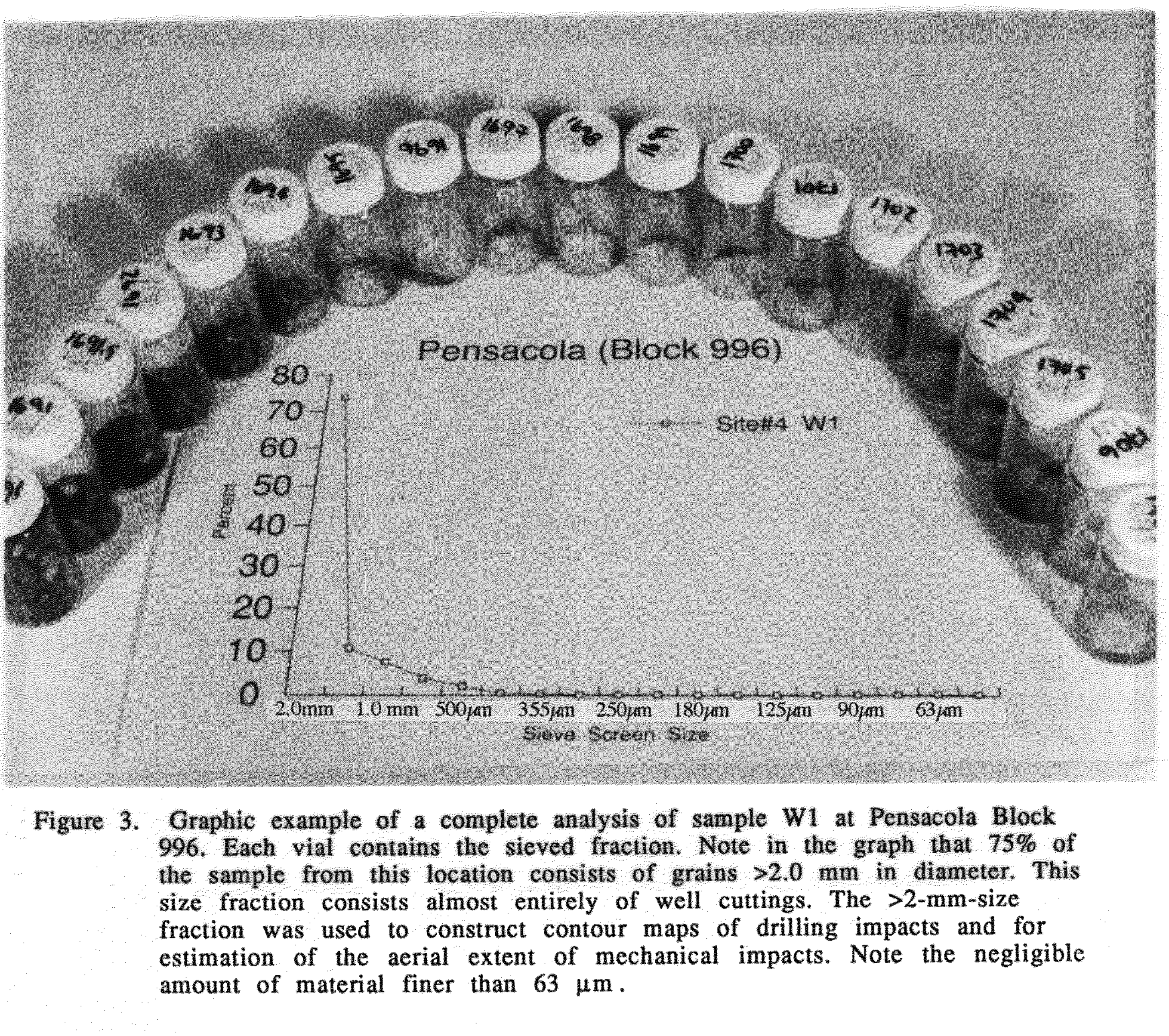


Figure 3. Graphic example of a complete analysis of sample W1 at Pensacola Block 996. Each vial contains the sieved fraction. Note in the graph that 75% of the sample from this location consists of grains >2.0 mm in diameter. This size fraction consists almost entirely of well cuttings. The >2-mm-size fraction was used to construct contour maps of drilling impacts and for estimation of the aerial extent of mechanical impacts. Note the negligible amount of material finer than 63 μm.

X-Ray Diffraction Analysis

X-ray diffraction (XRD) is the most widely used technique for quick semi-quantative analysis of mineral content. The XRD utilizes the principle of refraction of focused X-rays from the crystal lattice characteristic of minerals with crystal structure. The unique spacing and alignment of atoms in the crystal lattice are independent of the mineral grain size; thus, fragments of a large mineral or crystal have the same lattice arrangement as the parent. Calcite crystals, for example, can be ground down to mud-size particles and still be detected as calcite using the XRD method. In fact, the method is most accurate when applied to a large number of mud-size particles. The detection limit of most crystalline minerals is between 1 and 2% and semi-quantitative detection is often as high as 5%. The method, however, is not applicable to elements such as barium (Ba), the metal in the mineral barite ($BaSO_4$), or to all of the other elements of interest is this study, such as chromium (Cr), iron (Fe), nickel (Ni), vanadium (V), or zinc (Zn), because they lack crystal structure.

Barite, the mineral most commonly used as a weighting agent in drilling mud, is readily detected with the XRD method, as are the various clay minerals present in drilling mud. Barite and barium are the most commonly used tracers for drilling muds in the environment (Holmes, 1973; Boothe and James, 1985; Bothner et al., 1985; James and Boothe, 1988; Presley et al., 1992). Clay minerals, the most universal component of drilling muds, are also readily detected with XRD, but they are of limited value as tracers because they are so widely distributed in nature and are invariably part of the formations being drilled in the Gulf of Mexico.

In this study a portion of the mud-size-fraction (<63 μm) water mixture was allowed to settle and form a slurry. The mud slurry was then smeared on a glass petrographic slide and allowed to dry. In most cases drying was accomplished by placing the slide in an oven for 5-10 minutes.

Caution was taken to insure a mud layer of uniform thickness. A layer too thin produces weak diffraction angles and incorrect intensities below some low-incidence angle value (Moore and Reynolds, 1989). A thick sample insures that the incident beam energy is absorbed by the diffraction process within the sample.

The slides were prepared in the USGS laboratory and the analyses accomplished on the University of South Florida's Scintage XDS 2000 X-ray diffractometer using CuKα radiation. Samples were run at 40 kV and 35 mA at angles from $2^{o}2\theta$ to $40^{o}2\theta$. These angles are optimum for the minerals targeted in this investigation. The approximate mineral abundance for each sample was determined by integration of peak areas. Calculated values (expressed as counts per second, CPS) are presented in Table 2.

The XRD data for barite were found to be useful but of less value as a tracer of drill mud than elemental analysis for barium. Apparently, the barite tends to disintegrate into its individual elements Ba, S, and O in the presence of other drill-mud components. Although high barite content generally correlated with high barium content, this was not always the case. We therefore relied more heavily on barium content as a tracer for drill mud.

Elemental Analysis

Analyses for the elements Ba, Cr, Fe, Ni, V, and Zn were performed on all samples that contained sufficient mud fraction (5 gms were required) using Induction Coupled Neutron Activation Analysis (INAA). These analyses were performed by a contract laboratory (XRAL). The analyses were performed because (1) XRD was found to lack sensitivity, (2) the method is only applicable for the mineral barite, which may dissolve after discharge into the marine environment, and (3) "neutron activation has become the method of choice for determining sediment Ba levels" (Boothe and James, 1985).

We had expected to find a good correlation between XRD-barite values and INAA-determined barium analysis; however, a poor correlation (r=0.69) was found only in those samples with extremely high barite and barium content. Samples of less than 380 ppm barium were found to contain no detectable barite using XRD.

Barium levels between 50 and 400 ppm have been considered background for the eastern Mississippi bight area, whereas levels averaging around 400 ppm are considered background for the western Gulf of Mexico due to extensive drilling activities and Mississippi River runoff (Presley et al., 1992). We used the values for Ba, Cr, Fe, Ni, V, and Zn, published by Presley et al. (1992), as a background to compare our data. These trace elements have been the most commonly used elements to track the presence of drill mud in the environment. Barium, for

Table 2. Chemical data, based on induction coupled neutron activation analyses (generally referred to as either INAA or NA) of the fine fraction (<63 µm) of samples collected during this study. X-ray diffraction (XRD) values, expressed as counts per second, are also provided for barite ($BaSO_4$), the mineral that contains barium (Ba). All values for elements determined by INAA are expressed as parts per million (ppm) except for iron (Fe), which is expressed as percent. Detection limits for the method are provided at the bottom of the table.

Site & Station	Ba INAA	Ba XRD	Cr (ppm)	Fe (%)	V (ppm)	Zn (ppm)
Pensacola Block 996:						
N3	35,000	13.93	50	1.6	56	170
N5	9,400	4.21	30	1	36	60
N7	15,000	0.00	40	1.1	39	100
N9	13,000	0.00	50	1.4	38	<50
N11	7,500	0.00	50	1.4	46	80
E1	9,300	83.00	30	1	36	80
E3	10,000	34.99	70	2.6	85	330
E5	12,000	9.42	70	2.4	68	240
E7	19,000	44.70	80	2.4	69	230
E9	25,000	12.86	90	2.5	56	500
E11	22,000	13.86	60	1.8	52	440
E13	22,000	32.41	40	1.4	44	140
E15	30,000	27.03	50	1.4	46	150
E17	22,000	26.10	50	1.3	43	100
E19	43,000	14.82	50	1.5	44	60
S1	30,000	24.04	110	2.5	69	570
S2	15,000	6.60	50	1.7	53	120
S3	11,000	2.30	50	1.4	48	50
S4	6,300	16.37	50	1.6	52	<50
W1	4,100	0.00	40	1.3	59	70
W2	150,000	5.04	30	1.3	33	230
W3	800	0.00	10	0.3	43	<50
W4	1,800	0.00	50	1.3	45	<50
Destin Dome Block 56:						
N1	17,000	7.60	70	4.1	110	150
N2	94,000	91.03	40	4.4	55	210
N3	36,000	33.82	50	2.1	56	190
N4	130,000	89.09	40	1.6	48	200
E1	2,200	0.00	60	2.8	110	120
E2	69,000	43.43	60	2.5	81	90
E3	55,000	87.41	40	1.7	49	90
E4	31,000	18.43	60	2.3	81	90
S1	77,000	42.76	40	3.1	79	80
S2	66,000	30.97	50	2	76	70
S3	59,000	50.21	40	1.9	48	140
S4	63,000	54.61	30	1.3	47	50
SW1	150,000	80.65	20	1	34	<50
SW2	77,000	69.33	40	1.5	52	70
SW3	51,000	125.24	50	1.8	47	60
SW4	34,000	62.73	30	1.3	48	50
W2	110,000	32.49	20	1.6	48	170
W4	74,000	219.71	50	1.7	50	170
Detection limit=	100 ppm	0.5 wt.%	10 ppm	0.10%	1 ppm	50 ppm

Site & Station	Ba INAA	Ba XRD	Cr (ppm)	Fe (%)	V (ppm)	Zn (ppm)
Main Pass Block 255:						
N1	800	0.00	40	1.8	63	60
N2	2,200	0.00	50	2.1	69	60
N3	5,700	5.21	60	2.5	87	100
N4	2,900	0.00	50	1.9	65	60
N6	1,200	0.00	50	2.2	85	80
E1	24,000	3.35	80	3.1	93	120
E2	15,000	17.07	60	2.1	79	90
E3	4,000	5.89	40	1.8	76	70
E4	7,700	5.28	60	2.5	93	100
S1	12,000	18.24	40	1.8	70	<50
S2	22,000	16.42	80	2.9	96	80
S3	17,000	26.21	50	1.7	68	60
W1	1,100	0.00	40	2	67	70
W2	4,900	0.00	80	2.9	96	110
W3	1,800	0.00	50	2.4	85	200
W4	4,900	0.00	70	2.8	100	110
WH	14,000	3.58	80	3.4	96	160
Gainesville Block 707:						
N5	200	0.00	20	0.5	22	<50
E1	1,600	0.00	40	1.3	36	80
E5	200	0.00	20	0.5	20	<50
S5	100	0.00	30	0.6	25	50
W5	100	0.00	20	0.4	15	<50
Florida Middle Ground Block 252:						
N5	<100	0.00	20	0.6	22	<50
E1	500	0.00	40	1.2	37	60
S5	200	0.00	40	0.9	23	270
W1	200	0.00	30	0.7	20	50
Florida Middle Ground Block 455:						
WH	6,300	14.97	30	0.7	21	60
N	1,600	14.14	20	0.4	17	<50
S	500	0.00	10	0.5	18	70
Detection limit=	100 ppm	0.5 wt.%	10 ppm	0.10%	1 ppm	50 ppm

example, is used as a weighting agent and may constitute as much as 90% of most drill muds. Chromium is often used as a bacteriacide and to preserve starches and other organics used as emulsifiers in drill muds. Vanadium is present in some crude oils, and its presence may be the result of oil in the geologic section. Nickel and zinc are present in various metals used during drilling, especially Zn, which is used in anodes to prevent oxidation of the rig structure. Iron is present in clays but can be elevated in cuttings as pipe scale scraped from the drill string and casing during drilling. Results of the elemental analyses are presented in Table 2.

OBSERVATIONS AND RESULTS

Pensacola Block 996

The first site examined was Texaco Well No. 1 in Pensacola Block 996, drilled in 1988 and located 37 km (20 nmi) southeast of Pensacola Bay, Florida (Fig. 1, Table 1). The water depth is 49 m (160 ft) and visibility at the bottom was approximately 10 m. The surrounding area consists of a flat sandy substrate with scattered 3- to 4-cm pelecypod valves, small sponges and surficial fleshy algae. Figure 4 is a view looking into a large hole thought to represent the wellbore, and Figure 5 is a typical view of cuttings-rich sediment as seen inside the 1-m^2 frame near the borehole. Figure 6A shows the location of 39 sediment samples relative to the assumed borehole, and Figure 6B is a contour map of grains >2 mm in size. Figure 7 shows the distribution of grain size along each individual transect. Data from which the grain-size graphs and contour map were constructed are presented in

Figure 4. View into pit at Pensacola No. 1. Sediment in foreground is composed of cuttings and pit is lined with cuttings. Anchor for site buoy was placed in center of pit and forms center point for all sample locations shown later.

Figure 5. Photo at Pensacola No. 1 taken with external camera showing 1-m^2 PVC frame with sampling scoop in lower left. Sediment is a mixture of cuttings and natural sediment. Note clump of fleshy algae near right bottom and large pelecypod shell beneath fish.

Table A1 in the Appendix. Figure 8 is a contour map of the well site showing distribution of barium expressed in ppm. The data are from Table 2.

Cuttings were widespread and formed a mound approximately 0.5 m high near a 4-m-diameter, 2- to 3-m-deep depression lined with cuttings. The depression (Fig. 5) was assumed to be the wellbore rather than a jack-up leg footprint because there was only one. The depression was designated as center point for the four transects. Grain-size distribution of the samples closest to the depression in the south, east, and west transects confirms the abundance of cuttings. In sample W1 (Fig. 7), more than 70% of the grains are >2.0 mm in size, and at S1 the >2.0-mm-size fraction comprises more than 60% of the sample. Note that the dramatic reduction in the size class between the 1.4-mm and >2.0-mm fraction in nearly all samples is an artifact of the method. The >2.0-mm fraction also contains larger grains (up to pebble size), whereas the 1.4-mm fraction contains only those grains between 1.4 and 2.0 mm.

In all samples from Pensacola Block 996, including those well away from the borehole, the median grain size is between 500 µm and 1 mm. The ambient median grain size for the area is therefore considered to lie between 500 µm and 1 mm.

Sample E1 (Fig. 7) contains a slightly greater percentage of fines, especially in the range between 63 and 150 µm, than all other samples from this location. This increase in finer grains adjacent to the borehole reflects an increase in drill mud relative to the natural sediment in that size range. Barite and barium values (Fig. 8, Table 2) confirm the presence of drilling mud in sample E1 as well as in all samples from the drill site.

On the other hand, samples W1 and S1 (both close to the borehole; see Fig. 7), contain the highest percentage of cuttings but relatively less of the finer grain sizes than at any other location. This area was probably directly beneath the point

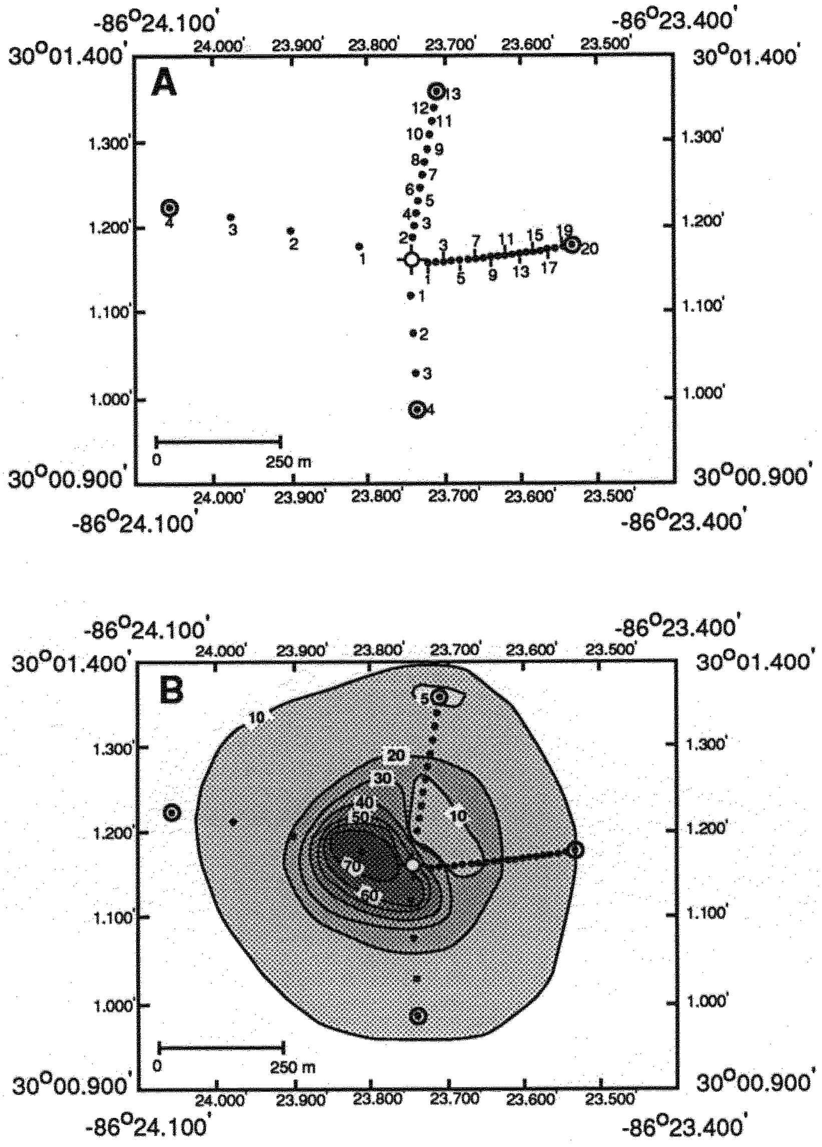
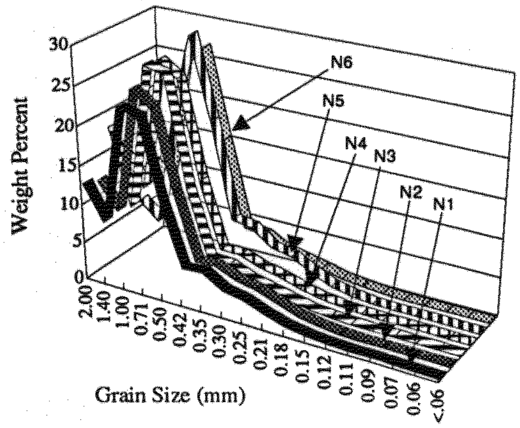
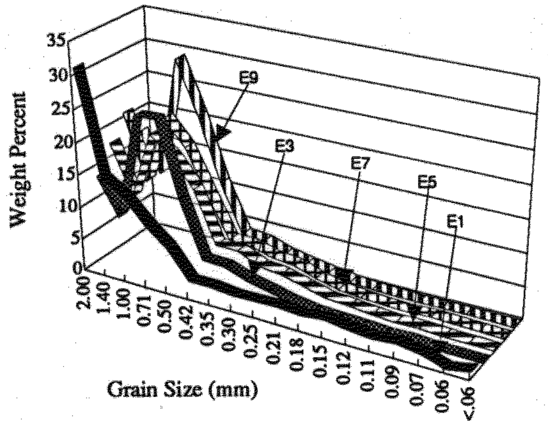


Figure 6. (A) Site map at Pensacola Block 996 showing location of four sampling transects. Points with circles are where GPS readings were taken. North and east sample sites were determined using submersible's length as a measuring stick, which was too time consuming. Thus, the west and south transect sample locations were interpolated after timed runs between central buoy anchor and GPS locations. (B) Sediment-size contours based on percent of grains >2 mm. The highest value (75%) came from the sample (W1) closest to the center on the west transect (Fig. 3).

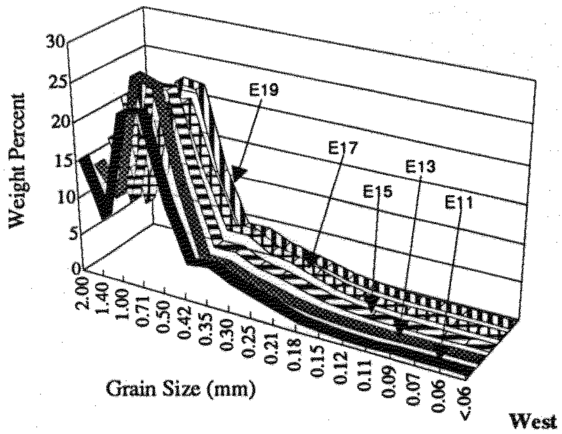
North Transect



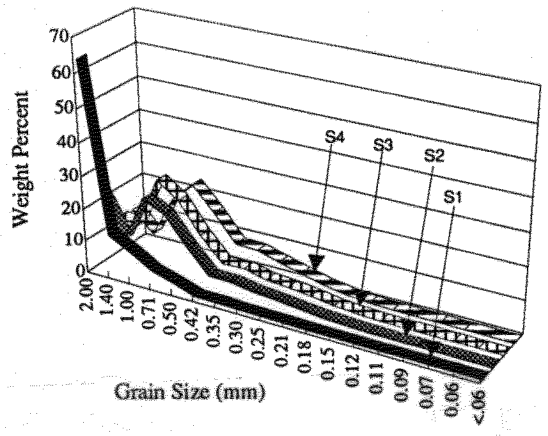
East Transect (1 of 2)



East Transect (2 of 2)



South Transect



West Transect

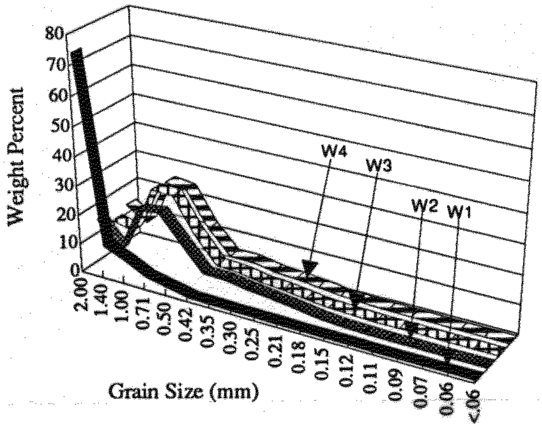


Figure 7. Three-dimensional representation of grain-size distribution in samples along north, south, east, and west transects at Pensacola Block 996. Not all samples along north and east transects were analyzed due to close spacing of locations and similarity of samples. Raw data for these graphs are provided in Table A1 in the Appendix.

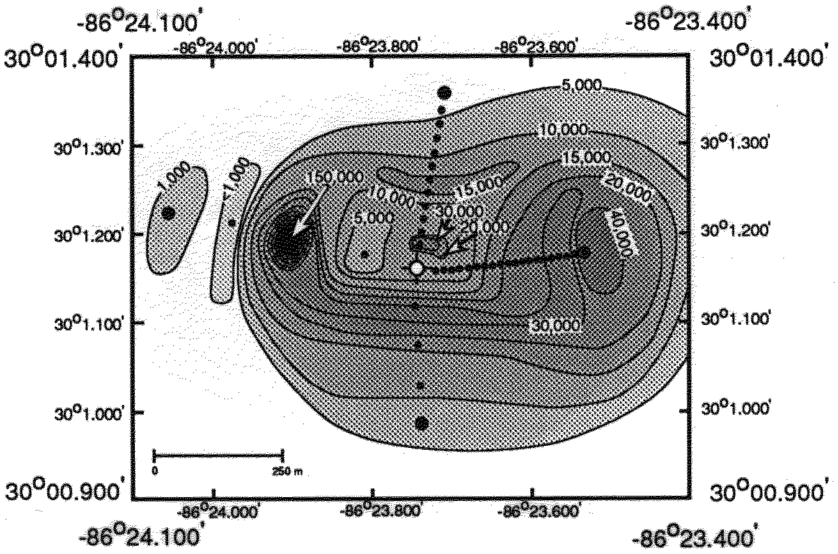


Figure 8. **Site map showing contours of barium concentrations at Pensacola Block 996.** Concentrations were determined by neutron activation analyses of the fine fraction (<63 µm), expressed in parts per million (ppm). Data are given in Table 2.

of cuttings and mud discharge. Cuttings, because of their size and weight, would tend to fall directly to the bottom, whereas drill mud drifts farther before settling (Ray and Shinn, 1975). The high percentage of fine sizes at E1 is not fully understood. The E1 location was either downcurrent during discharge or directly beneath the massive discharge that sometimes occurs when a well is completed, or when cuttings and mud are shunted directly to the bottom.

Although the bottom current was from the north during our dives, cuttings were visually more abundant along the north and east transects, as were various discarded objects. Refuse included welding rods, small flanges, lengths of pipe, buckets, rib bones from food waste and various bits and pieces of metal and rubber (Figs. 9A-C). At this and at the Destin Dome site (discussed later), a discarded bucket full of barnacles and other encrusting organisms was found.

Fish were not as abundant at the Pensacola site as at other sites, but tended to concentrate around the wellbore and discarded objects. Triggerfish, wrasses, sand perch and two species of butterfly fish occupied nooks and crannies within discarded debris. Mid-water pelagic fishes such as amberjacks and barracuda hovered over the area.

Based on the contour map of percent grains >2.0 mm (Fig. 6B), we interpreted the diameter of bottom significantly impacted by drilling to be approximately 2,539 m^2 (27,320 ft^2) or a little more than one-half an acre. The distribution of barium, however, shows the influence of drill mud over an area larger than that sampled. Sediment throughout the affected area, including that most heavily impacted, contains an infauna of worms and crustaceans. Bottom fish followed the submersible and fed on organisms stirred from the bottom during sampling.

Figure 9. Debris at Pensacola Block 996 well site. (A) Piece of grating. Segments are approximately 2.5 cm apart. (B) Discarded mop wringer. (C) Pipe flange approximately 25 cm in diameter. Fish were hiding in and around such objects.

Destin Dome Block 56

Conoco Well No. 1 in OCS Destin Dome Block 56 was drilled in 1989 on a flat sandy bottom in 58 m (188 ft) of water approximately 54 km (29 nmi) south of Pensacola Bay. The wellhead is covered with a 3- to 4-m-high steel pyramid with an opening approximately 30 by 30 cm at the top (Fig. 10B). Three depressions, 1 to 2 m deep and 3 to 4 m in diameter, were equally spaced on the north, east and south sides of the pyramid-shape wellhead protector. The pyramid and two of the depressions were clearly visible in a sidescan-sonar image (Fig. 10A). Spacing of the depressions suggests the imprints of a three-legged jack-up rig. An interpretive sketch of the site is shown in Figure 11.

The pyramid was used as the center point of the five radiating transects sampled at this site (Fig. 12A-B). Cuttings were abundant and were concentrated close to the pyramid (Figs. 13, 14A-B). Both cuttings and natural bottom sediment were coated with a white mucous-like film thought to be of bacterial origin (Fig. 15A-B). The coating was most noticeable on the south side of the pyramid.

In addition to the usual concentrations of welding rods (Fig. 16A) and other debris (Fig. 16B-C), there were many large barnacle shells scattered about the bottom (Fig. 17A). A plastic bucket filled with barnacles was found along the north transect (Fig. 16D). Other objects included a shovel, various small lengths of rubber hose, wire, tape, gloves, burlap bags, a brush, and a cargo lifting strap. The most surprising discovery was natural debris consisting of large (>12 m across) patches of skate egg cases (Fig. 17B). The 8- by 4-cm egg cases had a leathery consistency and were piled one atop the other, often 4 to 6 deep. One large patch of cases was observed amid drilling debris and cuttings along the north transect and another far from obvious drilling impacts along the southwest transect. Several cases were collected and examined for juveniles. Because the cases were on top of sediment containing cuttings, we conclude that spawning had occurred sometime after the well was drilled 2 years earlier.

Fish were abundant. Schools of large amberjack continuously circled the pyramid and the submersible. Several groupers (gags and broomtail) along with red snapper, grey snapper, queen angels and black drums were observed swimming in and out of the pyramid. Fish and/or turtles had burrowed under one corner of the pyramid, resulting in an opening large enough for 2- to 5-kg fish (5-10 lb) to enter and exit (Fig. 15A). A large loggerhead turtle was observed near the pyramid on one collecting dive.

Grain-size distribution shows an increase in the percentage of cuttings (grains >2 mm) at all four sample sites closest to the wellhead (Figs. 13, 18). Except for sample W1, the transect with samples least visually affected by drilling was to the west. The ambient median grain size for this area falls between 212 and 355 µm, about half the median grain size of the Pensacola 966 area. This reduction in ambient median grain size is probably related to greater water depth and distance from shore.

Surprisingly, samples with the most cuttings contained relatively less barium than samples farther from the wellhead. Although all samples contained substantial amounts (Table 2), sample N1, for example, contained 17,000 ppm barium, E1 had 2,200 ppm barium, but SW1 was the highest with 150,000 ppm barium. Even the farthest sample from the well (SW4), where there was no visual effect of drilling, contained 34,000 ppm barium. Apparently, currents, in the case of N1, swept the fine-grained drill muds away but allowed cuttings to settle near the wellhead. All samples from near the wellhead contained more cuttings and fine-grained material than those farther away. Elemental analysis for barium, in a

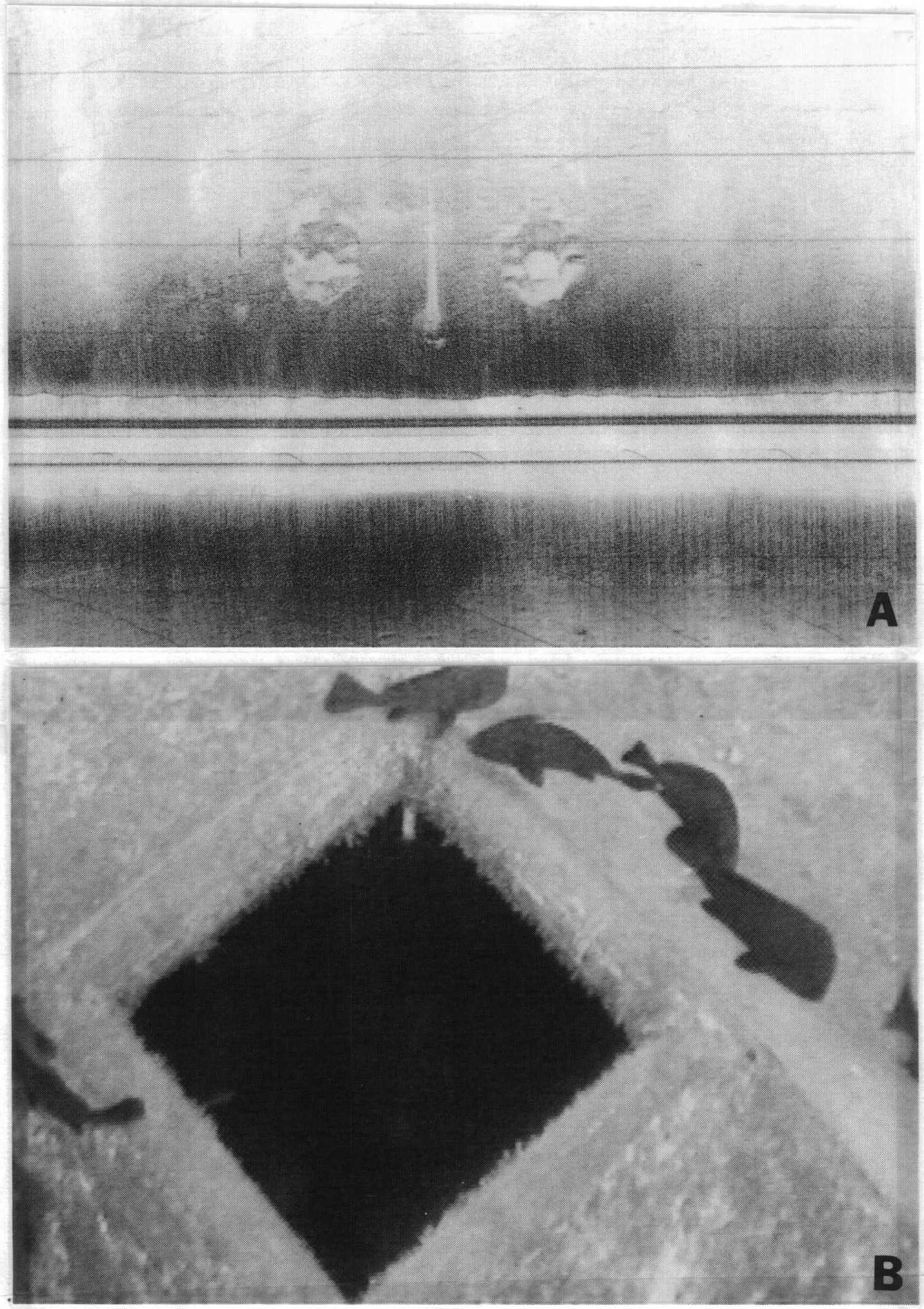


Figure 10. (A) Portion of sidescan-sonar image at Destin Dome site showing iron pyramid-shape wellhead protector and two of the three prominent seafloor depressions. The third depression is hidden beneath central track line of image. Depressions are interpreted as shallow holes made by three legs of a jack-up drill rig. (B) Nearly vertical view from a video frame of the wellhead protector with square opening in top. Fish swam in and out of opening.

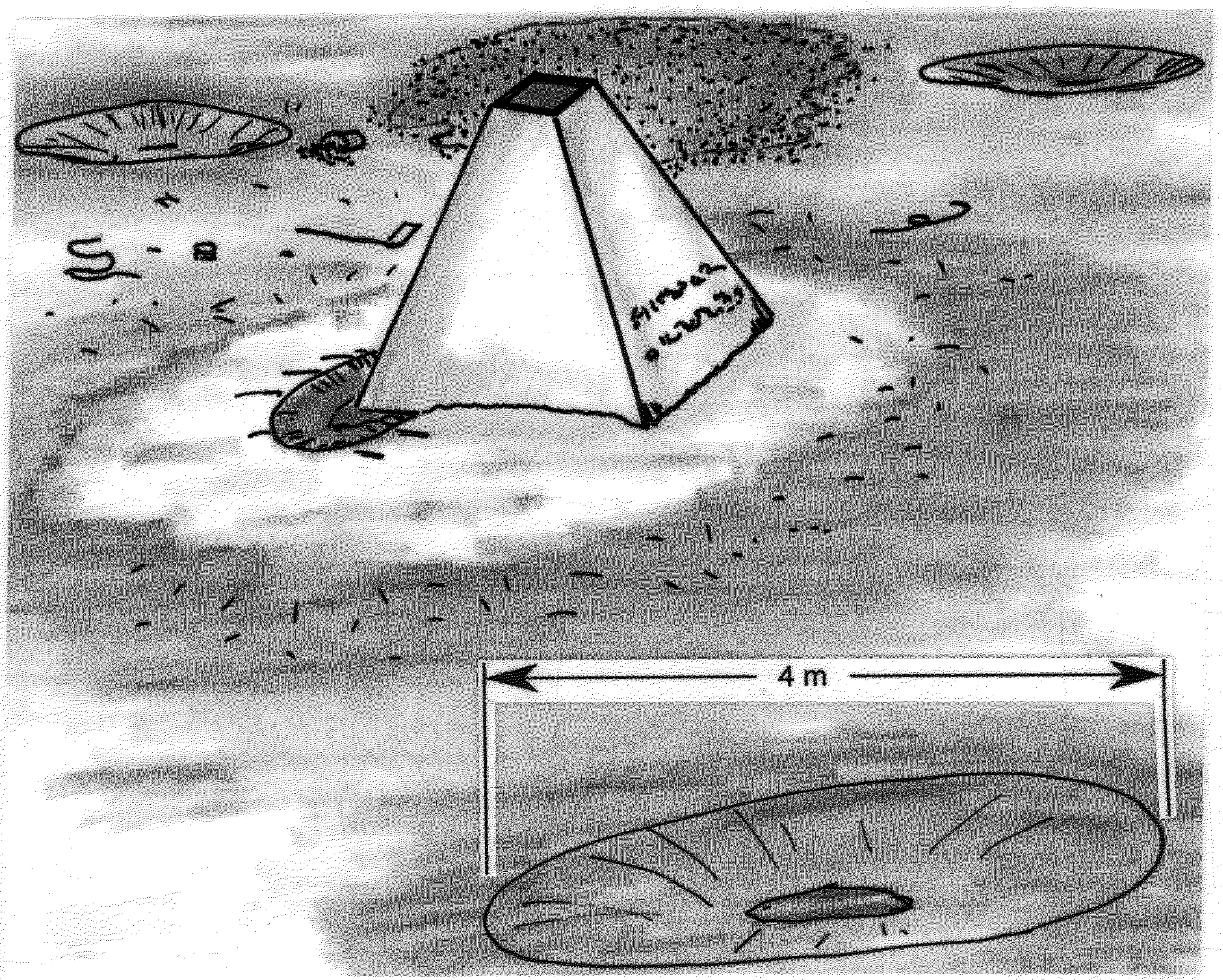


Figure 11. An interpretive sketch of the Destin Dome site showing pyramidal wellhead protector, three depressions, debris, and large patch of skate egg cases behind pyramid. White area around base of pyramid is a bacterial or fungal mat. The mat is missing where fish have burrowed under lower left corner of pyramid.

general way, supports the XRD analysis for barite, except at sample site E1, which contained 2,200 ppm barium but no detectable barite. The highest amounts of barium were found at N4, SW1 and W2 (Fig. 19, Table 2). Barium content at E1 closest to the well was three times less than at E3 or SW3, and seven times less than at N4. The processes that preferentially concentrate drill mud in some areas around the site and not in others are not understood, but are likely a result of tidal-current and weather interactions during drilling and whether or not a shunt was used to funnel cuttings to the bottom. During the approximately 12 hours spent at this site, the bottom current was from the north and visibility was excellent (10 m).

Using the maps of cuttings distribution (grains > 2 mm) and barite distribution (Figs. 13, 18), we estimate the area of bottom impacted by cuttings and muds to be 13,352 m^2 (143, 668 ft^2) or a little more than three acres. The area containing above-normal amounts of barium, however, is much larger and cannot be evaluated with our data because above background levels extend beyond our sampling area (Fig. 19). It should be remembered that the barium is present only in the fine fraction, which represents only a small fraction of the total range of grain sizes present in each sample (see Table A2 in the Appendix). For example, if 1% of the sample is <63 µm and contains 100,000 ppm barium, the total ppm for the entire sample is ~1,000.

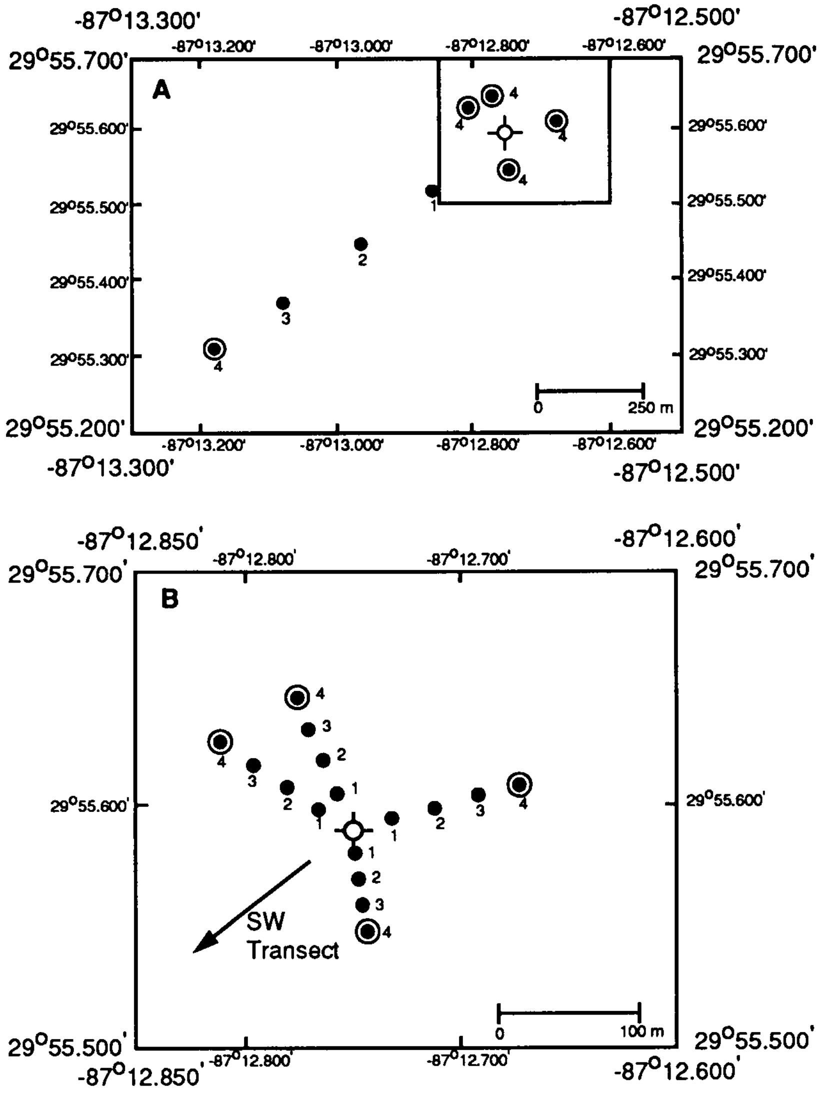
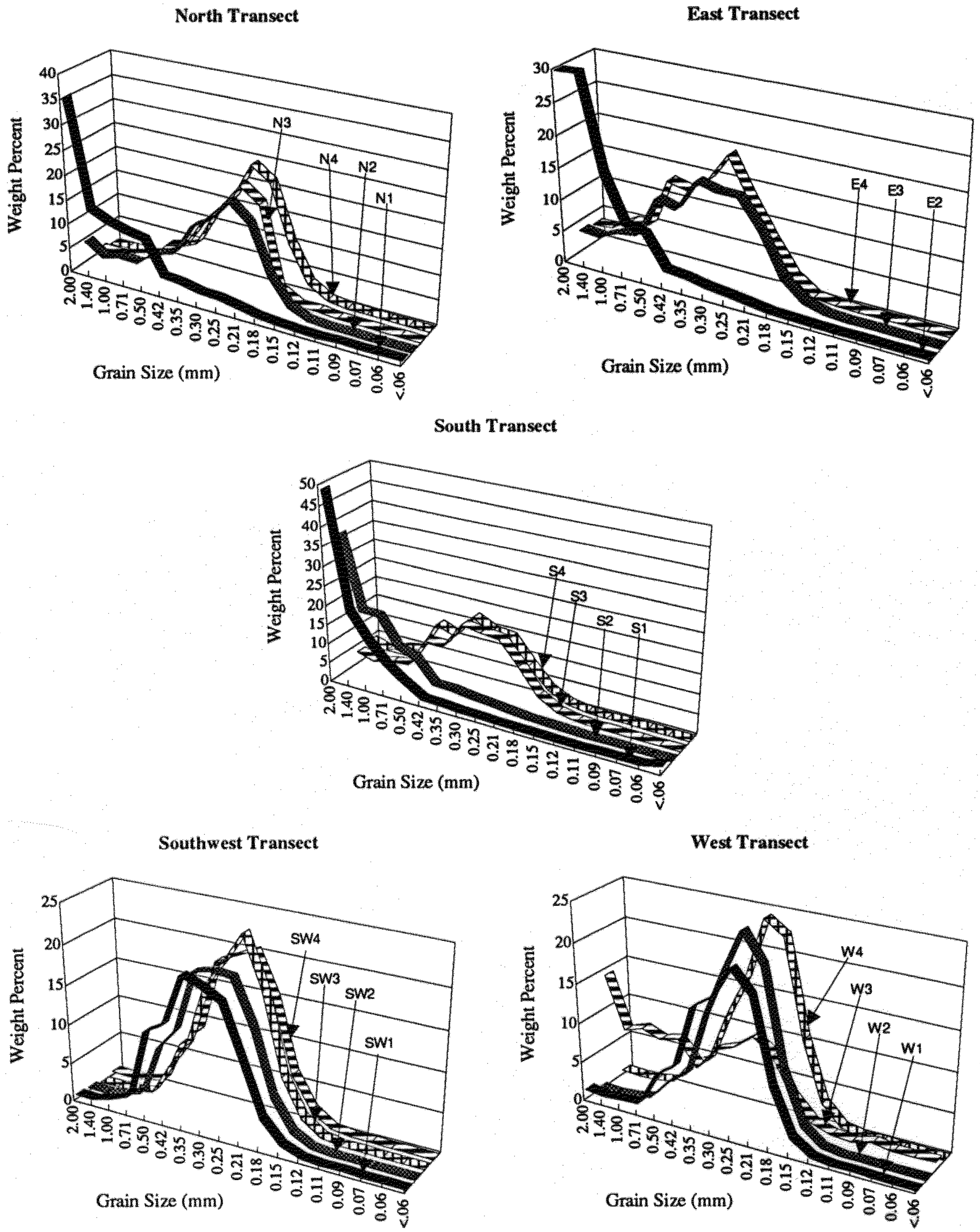


Figure 12. (A) Map showing sample locations at Destin Dome site. Note long southwest transect. Circled dots indicate GPS locations. (B) Enlargment of inset in (A) showing closely spaced sample locations around borehole.


North Transect

East Transect

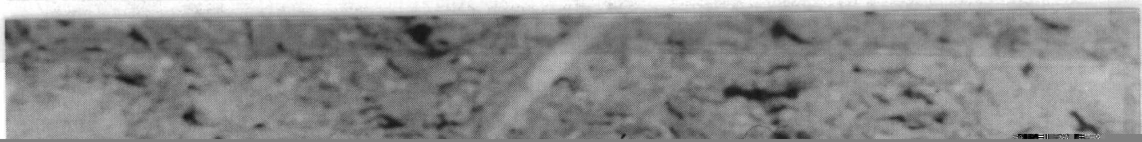
South Transect

Southwest Transect

West Transect

Figure 13. Three-dimensional representation of grain-size fractions in Destin Dome samples from transects shown in previous figures.


A
2 1_3 2_3



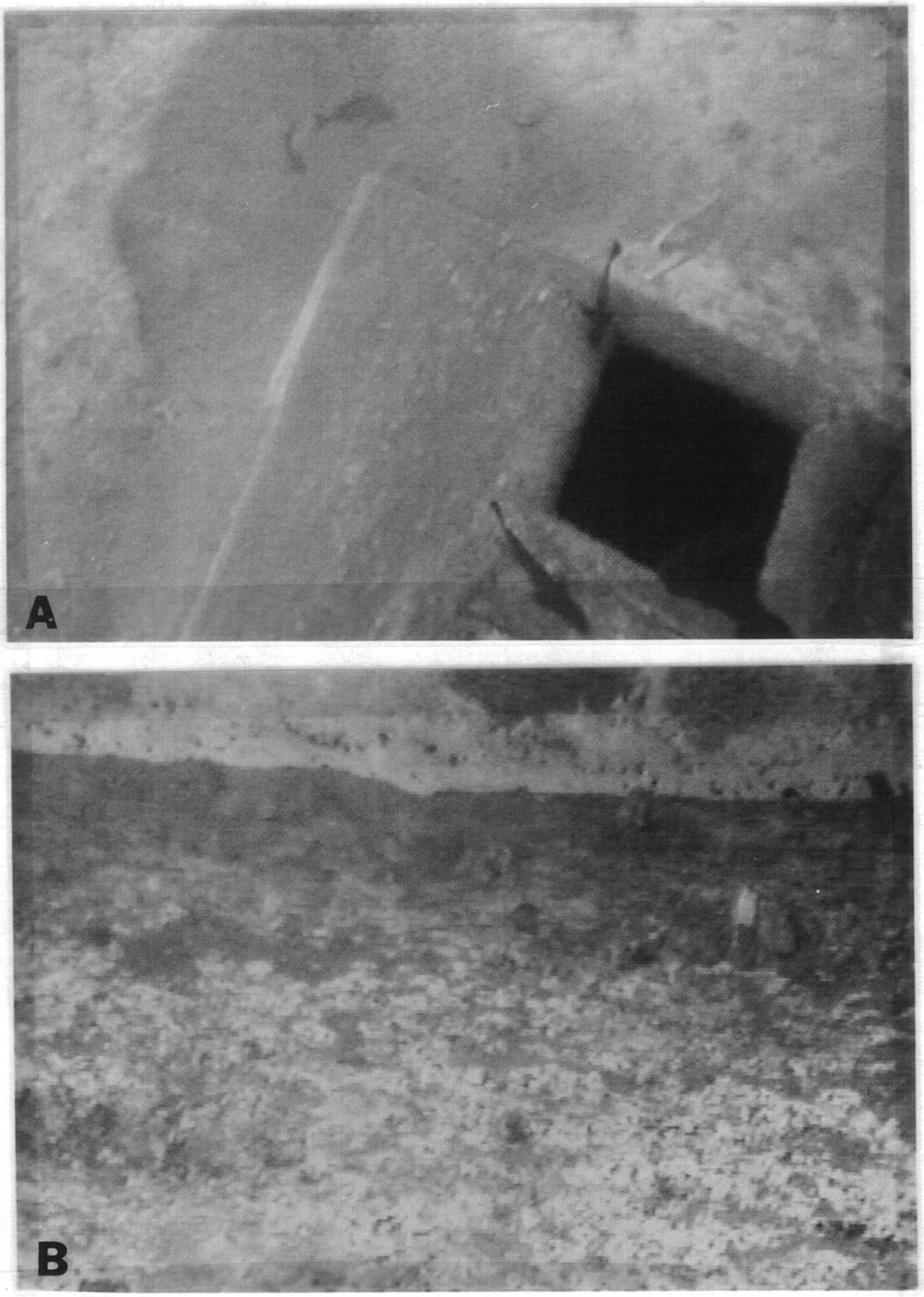


Figure 15. (A) Vertical view (from video) of pyramid at Destin Dome showing excavated area at base where white bacterial mat has been removed. Large groupers swam in and out of excavation. (B) Closeup of patchy white mat with base of pyramid in upper background. Black spots in white areas are cuttings fragments.

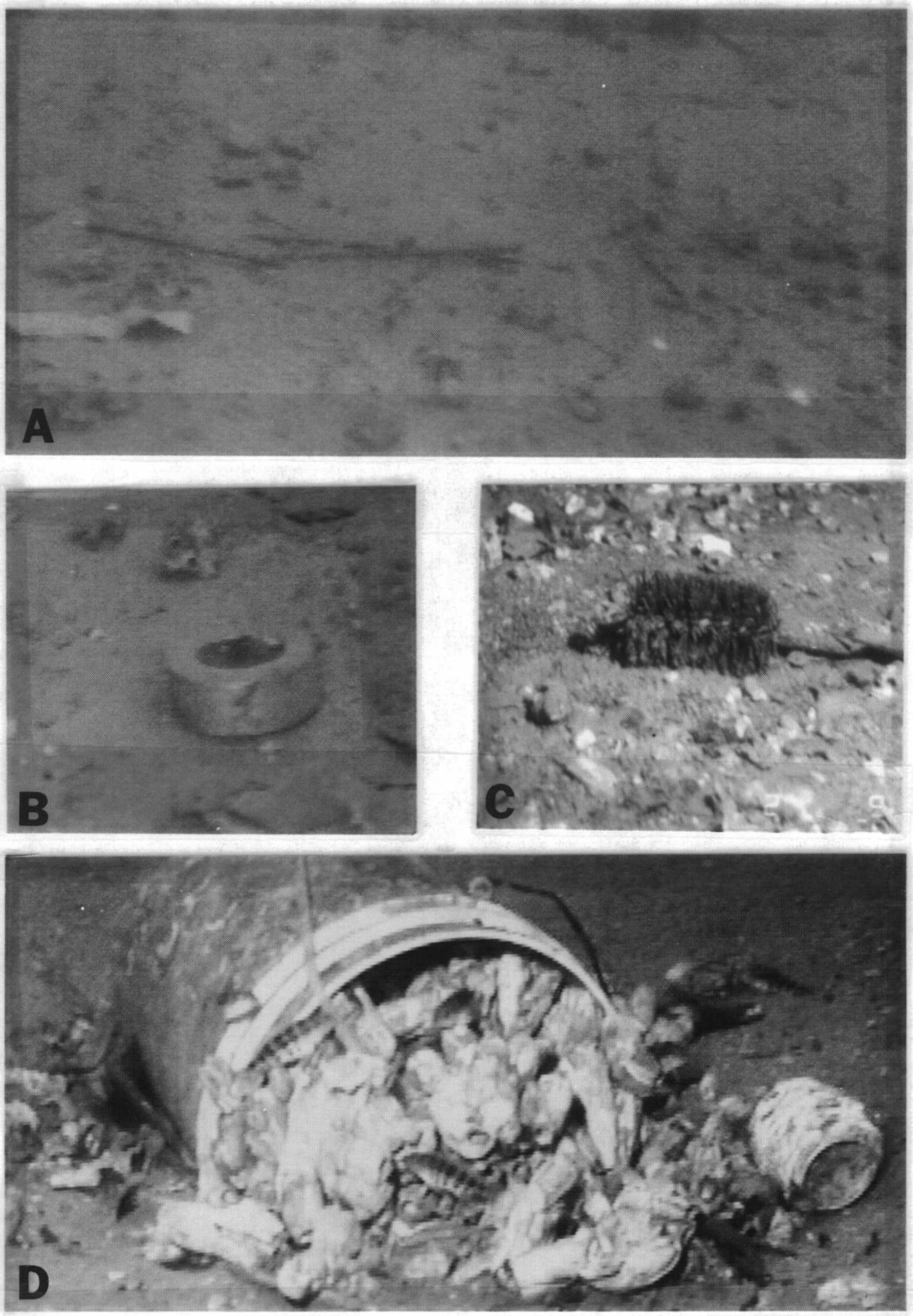


Figure 16. Typical views of discarded objects at Destin Dome site. (A) Welding rods. (B) Roll of duct tape. (C) Brush with large white barnacles in background. (D) Discarded bucket full of barnacles, oysters and an aluminum beverage can. Numerous striped blennies lived in and among the barnacle debris. A similar bucket full of barnacles was photographed at the Pensacola site.

Figure 17. Destin Dome site. (A) Discarded barnacles and clam shells. (B) Closeup view of large patch of leathery skate egg casings. Egg casings were overlying drilling debris and thus post-date drilling of well. Another large patch of casings was observed along the southwest transect far from any visible drilling debris.

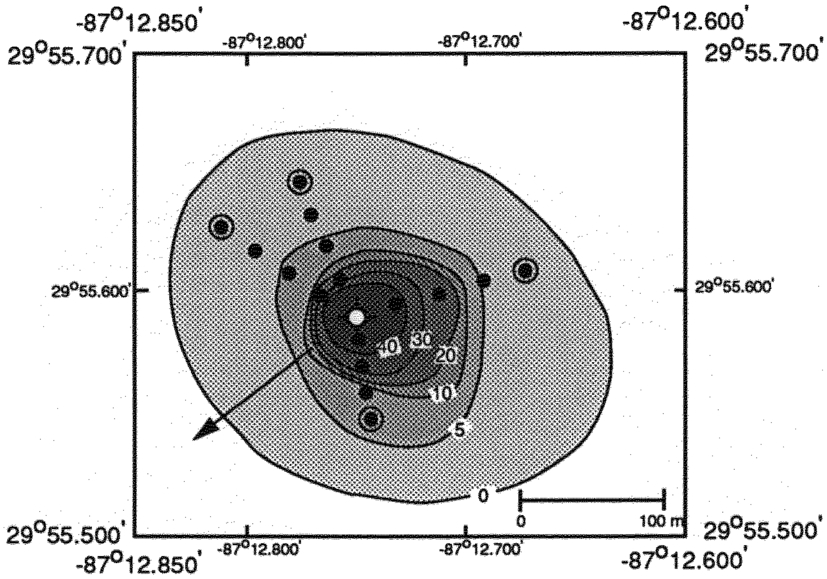


Figure 18. Contour map showing percentage of grains (mainly cuttings) >2 mm in diameter at Destin Dome site.

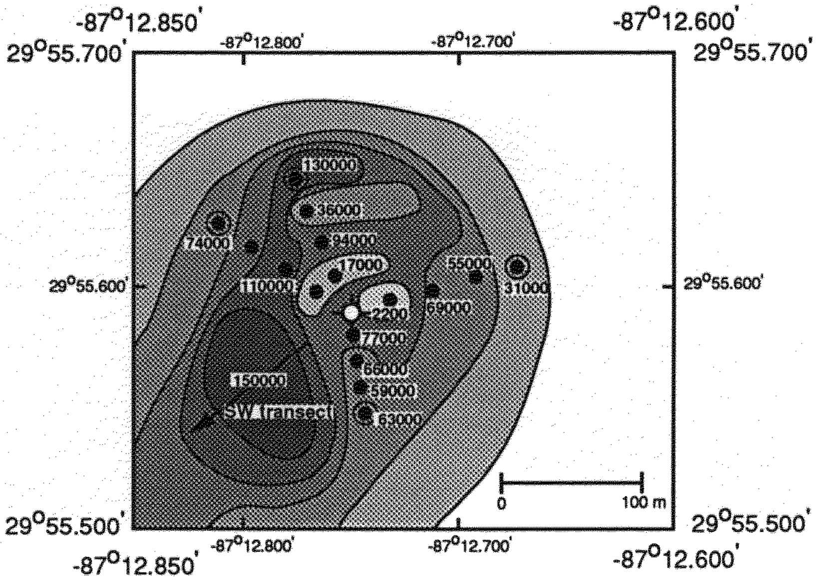


Figure 19. Contour map showing barium concentrations in the <63-µm-size fraction at Destin Dome (expressed in ppm). Note patchiness of barium (also related to amount of fine material in sample). See Table 2 for values along southwest transect.

Main Pass Block 255

Elf Aquitaine Well No. 1, drilled in 103 m (338 ft) of water in 1990, is in a region of rocky pinnacles supporting hardbottom communities typical of this water depth. In spite of poor bottom visibility (3 to 4 m), an attached fauna could be seen and photographed (Figs. 20, 21, 22A-B). The diverse community included gorgonians, sponges, non-reef-building corals such as *Oculina* spp., a species of horn coral, and abundant meter-long whiplike antipatharians characteristic of tropical hardbottom communities in water 30 m or more in depth. There were some large groupers, but the fish community was not noticeably diverse. The site is 123 km (66 nmi) south of Mobile Bay, Alabama, and along the south border of the area known as the Pinnacle Reef Trend (Fig. 1). The 20-km-long by 1.5-km-wide (10.8 by 0.8 nmi) Pinnacle Trend has been mapped in detail as part of an earlier MMS-funded study (Laswell et al., 1990). Our observations suggest the rocky pinnacles are relect, highly eroded features that formed during a time of lowered sea level.

Although the water was clear at the surface, visibility on the bottom was limited to between 2 and 4 m due to a region-wide nepheloid layer. Bottom water was brown, contained visible suspended particles, and the bottom was coated with a veneer of rusty-brown mud that was easily stirred into suspension by movement of the submersible. These conditions, including limited light due to water depth, made

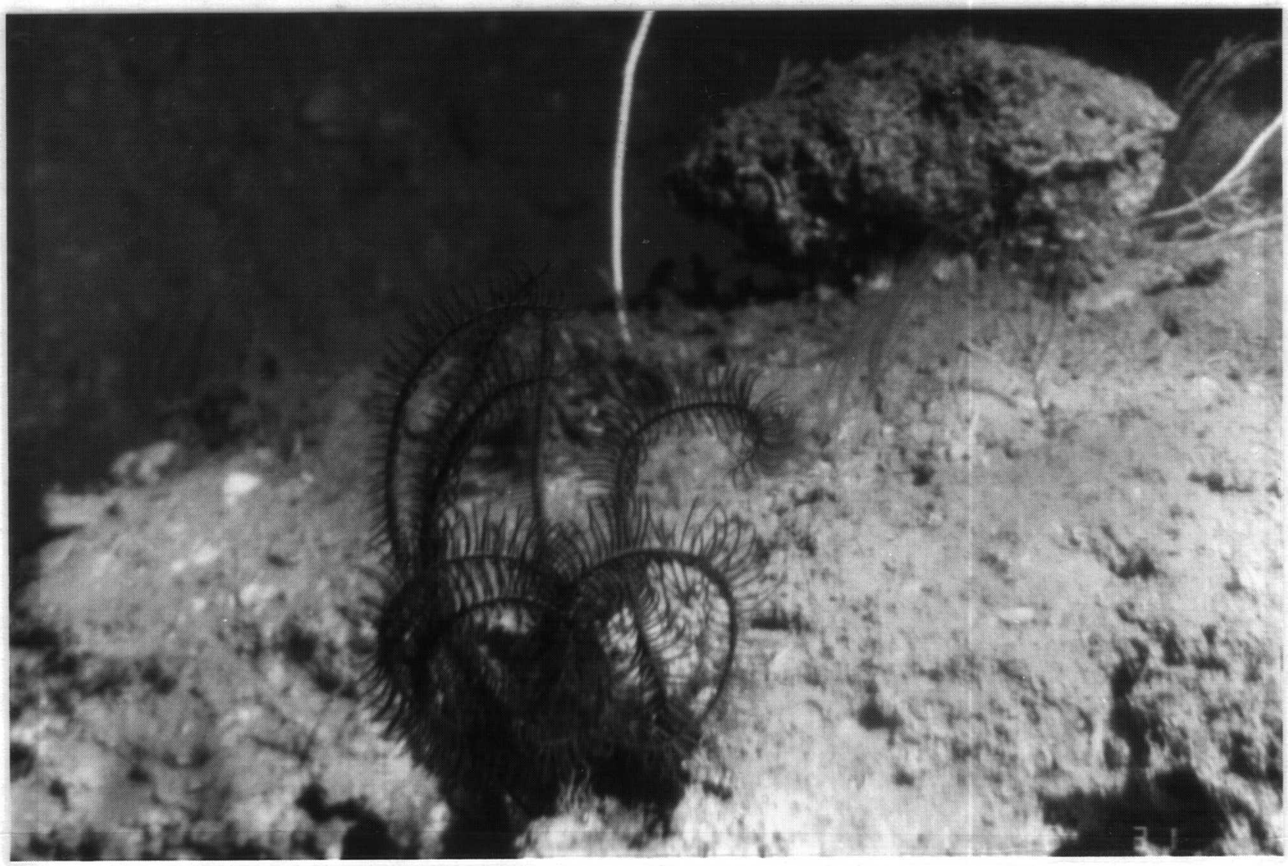


Figure 20. Photograph near Main Pass site showing mobile crinoid in foreground and a portion of a whip-like antipatharian in background next to a rock fragment. Darker area in background is view into a long trench scoured into bedrock.

Figure 21. View from within trench near Main Pass site showing fresh exposure of limestone encrusted with feathery gorgonians in background. White branching corals are visible in lower right corner.

underwater observation and photography difficult. The top of the nepheloid layer was observed to be associated with a noticeable thermocline (Fig. 23).

The well site was found to be about 1 m south of the base of a nearly vertical 4- to 5-m-high rock pinnacle. The site consisted of four vertical conductor pipes protruding from a large steel template. Photographs showing selected portions of the template and conductor pipes are shown in Figure 24A and B, and an interpretive sketch is depicted in Figure 25. The tallest uncapped conductor extended approximately 13 m above the sea floor. The others were shorter and were capped. This elaborate device suggests that a discovery had been made and that as many as four wells will be completed upon installation of a production platform.

Debris, such as hose, wire, cuttings and welding rods, was found on and adjacent to the pinnacle near the wellhead (Figs. 26A-B, 27B). Two buckets and a plastic funnel were found on more level bottom near the site (Fig. 27C-D).

Two trenches, generally 2-3 m wide and in places more than 1 m deep, originated a few meters from the site and were followed for approximately 1 km northward with the submersible (Fig. 21A-B). The total length of these scars is not known. The two scars, along with others, were later identified on sidescan-sonar images (Fig. 27A). The bedrock had been scoured along either side of the trenches. The trenches were probably made by the legs of a jack-up rig during emplacement of the rig. The zig-zags noted in the sidescan-sonar image suggest that seas and/or currents changed while the legs were dragging. It seems likely that the rig drifted and the

Figure 22. (A) Sea-fan-like octocoral (upper center) growing on smooth cavernous surface of rock pinnacle adjacent to wellhead at Main Pass site. Dark areas to right and left of sea fan are 30- to 40-cm-high natural caverns extending back into the rock. Note dust-like coating of rusty-brown mud that covers entire area. (B) Three white cone-shape solitary corals (each approximately 2.5 cm high), lacey gorgonians, and a white antipatharian at left growing next to a piece of debris. This layering is visible in rock surface near bottom center of video image.

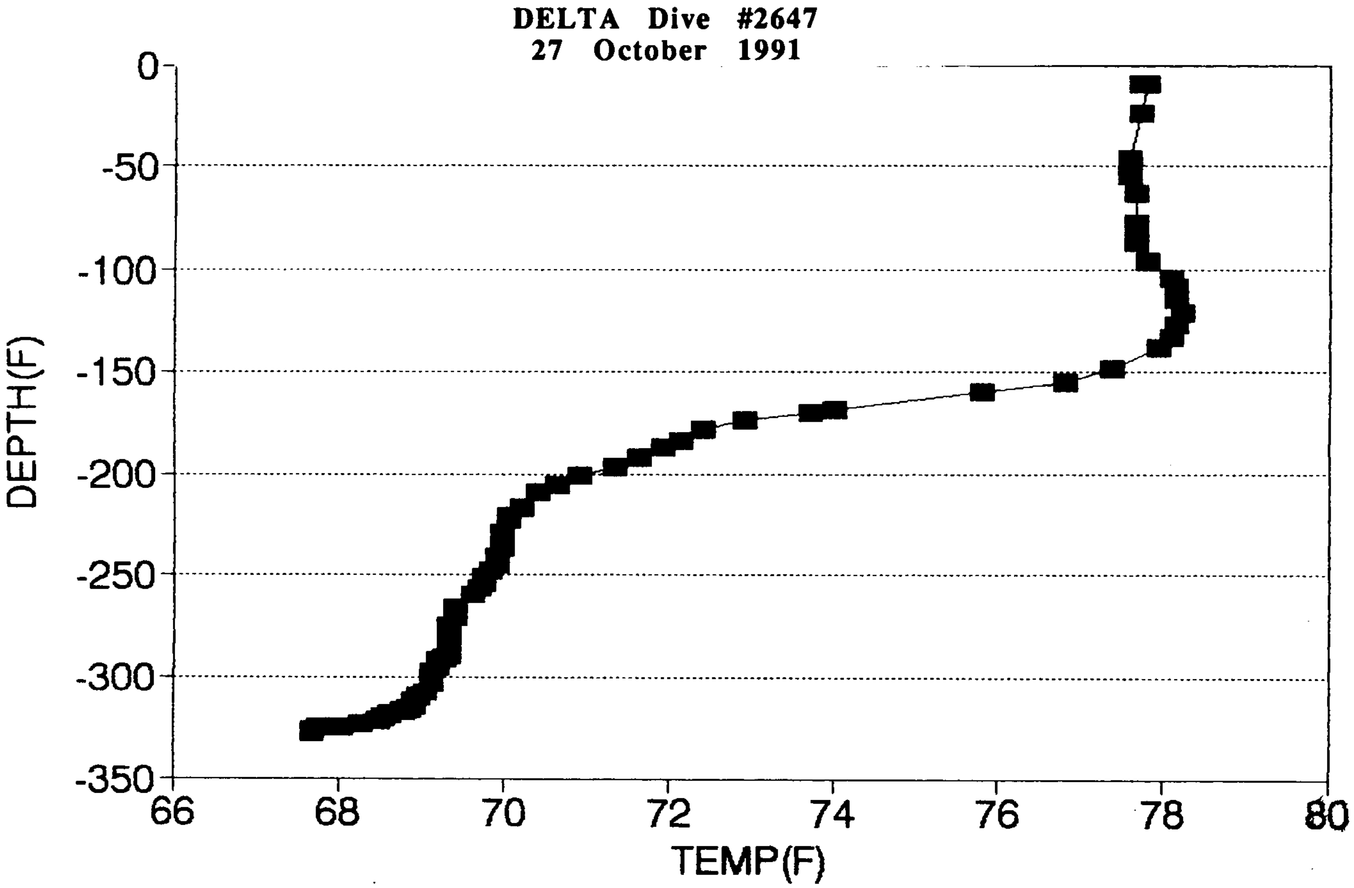


Figure 23. Depth/temperature curve for Main Pass site showing position of thermocline and top of the nepheloid layer at approximately 45 m. Underwater visibility above thermocline exceeded 30 m but was reduced to less than 4 m near the bottom.

legs dragged the bottom until coming to rest against the pinnacle shown in Figures 25 and 27A.

Schools of amberjack hovered over the site, but demersal fish life was not particularly diverse. Bright-red "bigeyes" were fairly abundant and large groupers had taken up residence among the conductor pipes and template (Fig. 24A). The well had been drilled 15 months before our observations.

The grain sizes of collected sediments differed significantly from those at the previous sites and clearly reflect the unique nature of the bottom. The bottom away from the large rock pinnacles consists of a flat limestone substrate with numerous holes and small centimeter-size protrusions. The surface is covered with an approximately 1-cm-thick coating of fluffy brown sediment containing sand- and pebble- and boulder-size fragments of the underlying limestone. Drill cuttings were mixed with natural rock pebbles near the wellhead. The sediment here was poorly sorted with the median grain sizes between 500 µm and 1.4 mm but contained a significant quantity of fines (Table A3). Figure 28 shows the location of sample sites, including a long northerly transect, and Figure 29 shows graphs of the grain-size distribution. Notice that some samples near the wellhead contained a high percentage of grains larger than 2 mm. These larger grains consisted predominantly of drill cuttings and possibly grout (Fig. 30).

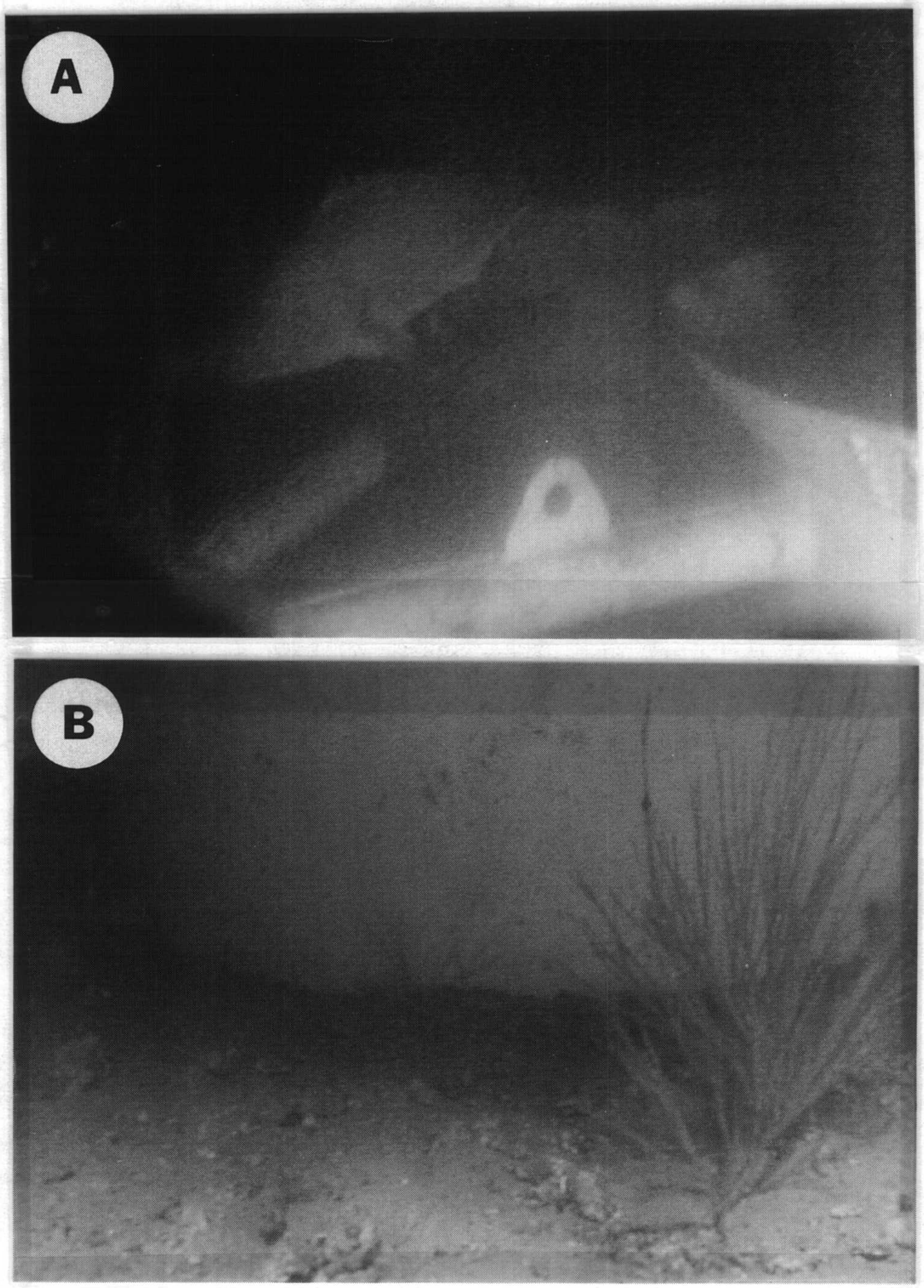


Figure 24. (A) Video image of a portion of the wellhead template at Main Pass site with one of several large groupers that had taken up residence there. (B) Video view of base of wellhead template. Note living gorgonians next to conductor pipe and rock and cuttings scattered in foreground.

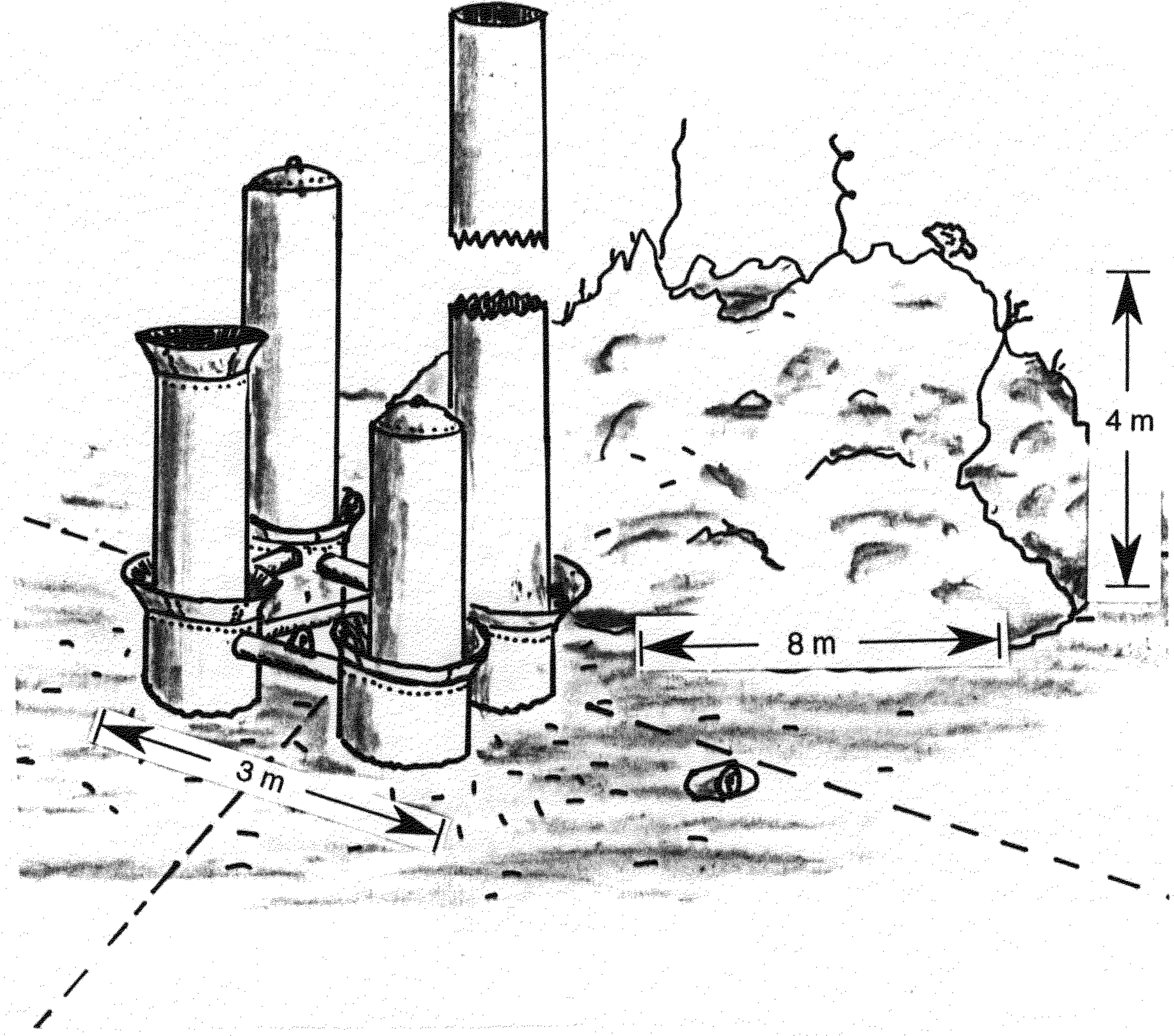


Figure 25. Sketch of four 1-m-diameter conductor pipes and well template resting against rock pinnacle at Main Pass site. Longest conductor pipe extended approximately 12 m above bottom and was open at top. Two conductors were capped and the other was fitted with a funnel-shape re-entry cone. Dashed lines represent directions of radiating transects.

The abundance of fine-grain sizes is not unexpected at this depth. The nepheloid layer, containing suspended strings of mud and mucus, was present throughout the area. The muddy nepheloid layer and a fine dusting of mud over flat rocky bottom were equally present along a long northward transect intended for observation and collection of unaffected bottom sediment. Bottom current was undetectable during all dives and the dusting of fine mud everywhere suggests strong bottom currents there are rare events. It seems likely there had been no strong currents during the 15 months since the well was drilled. Not surprisingly, elemental analysis revealed significant amounts of barium in all samples (Fig. 31, Table 2), including N6 taken approximately 1.5 km north of the drill site.

Figure 26. (A, B) Two views of cuttings scattered about wellhead template at Main Pass site. The larger fragments in (A) consist of natural limestone bottom that occurs beneath a thin cover of sediment throughout the area.

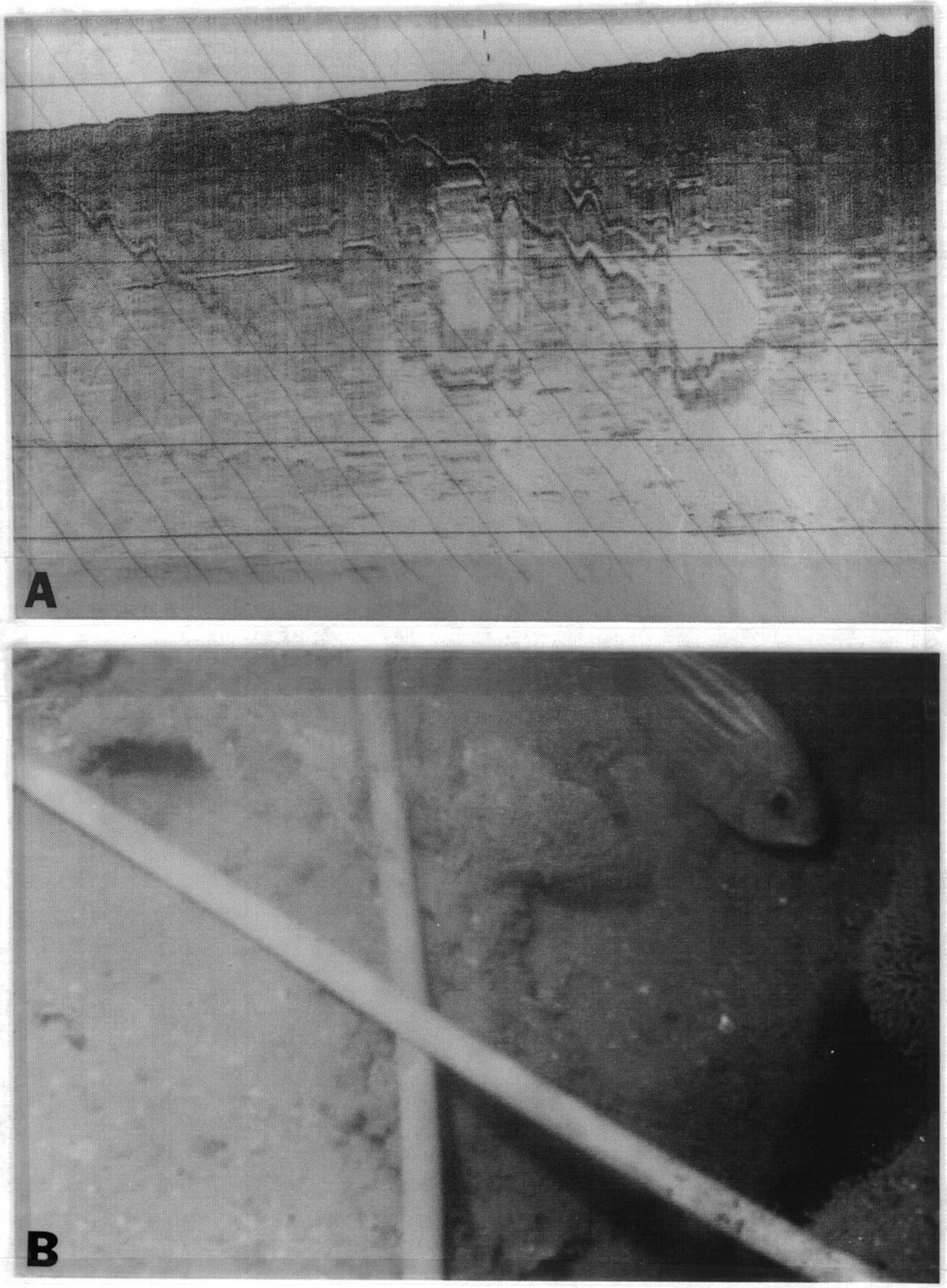


Figure 27. (A) Portion of sidescan-sonar image showing two rock pinnacles and two prominent zig-zag trenches that lead to base of pinnacle, Main Pass site. Also note two other trenches closer to pinnacle at left. Trenches are oriented roughly north-south and extend well beyond view of this image. (B) Closeup view of 2-cm-diameter hoses resting on top of pinnacle adjacent to wellhead. Note small fish at upper right. Gorgonian beneath the vertical hose was alive in spite of thin coating of rusty-brown sediment and scattered cuttings.

Figure 27 (cont.). (C) Yellow plastic funnel fitted with screening device and (D) encrusted bucket were found near wellhead.

Sampling transects revealed a relatively flat sloping bottom to the east and south, as well as to the north. The sidescan image clearly shows, however, that the well was drilled adjacent to one of the only two prominent pinnacles in the area.

The area with mappable cuttings and drill debris (Fig. 30) is approximately 6,440 m^2 (69,294 ft^2), or about one and one-half acres. The area above background levels of barium in the fine fraction extends beyond our area of investigation (Fig. 31). Note the local variations of barium in Figure 31 and the heavy concentration to the southeast of the well site. The widespread distribution of drilling mud is probably related to the thick nepheloid layer and lack of bottom currents, which would tend to disperse fine-grained sediment. Background levels of barium for this region of the slope, measured in March 1988, ranged from 45 to 400 ppm (Presley et al., 1992).

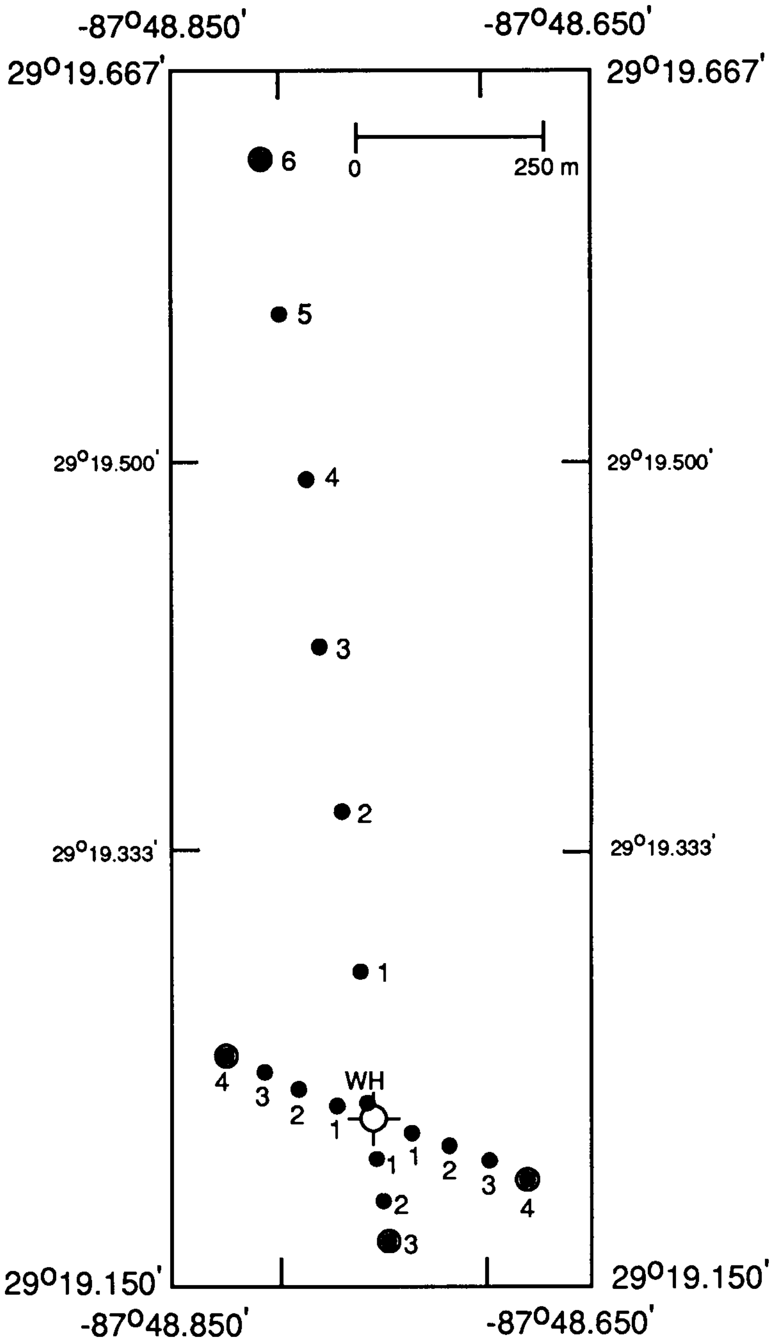
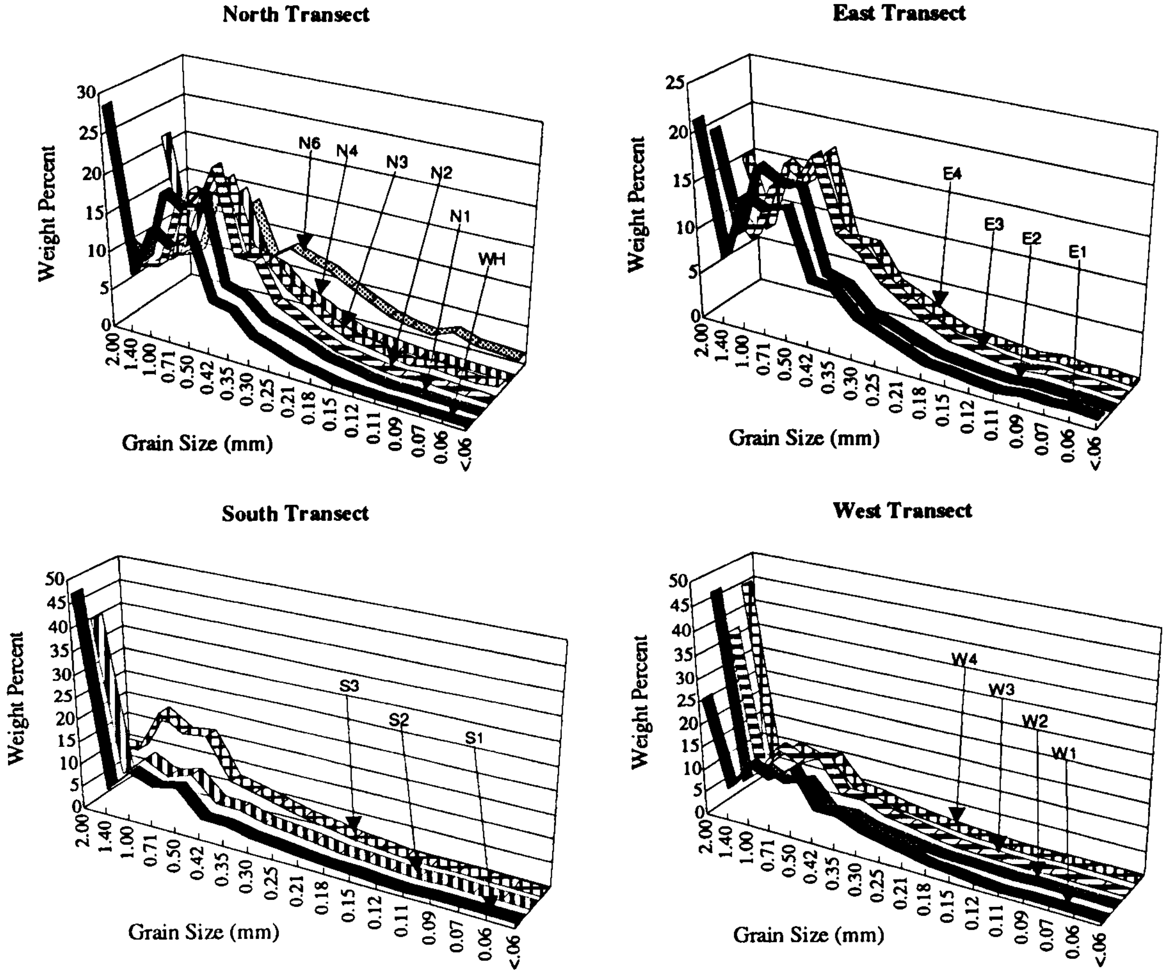


Figure 28. Site map showing location of sample transects relative to wellhead template, Main Pass site. Note wide spacing of samples along north transect.


North Transect

East Transect

South Transect

West Transect

Figure 29. Three-dimensional graphs of grain-size distribution of samples taken along all four transects at Main Pass site. Only significant difference is in the percent of grains >2 mm along west and south transects.

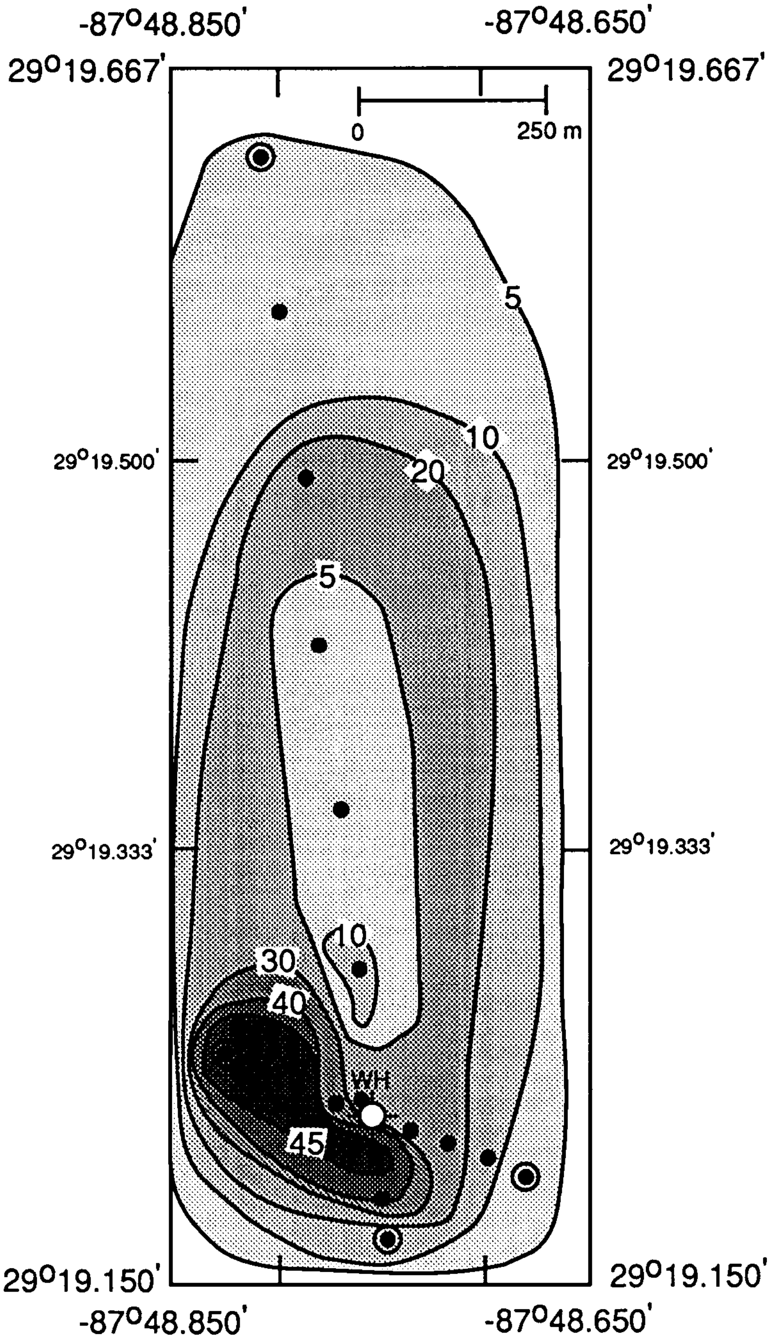


Figure 30. Contour map based on percentage of grains >2 mm at Main Pass site. Note concentration of cuttings south and west of wellhead. Natural rock fragments comprise a significant portion of all samples taken at this study site.

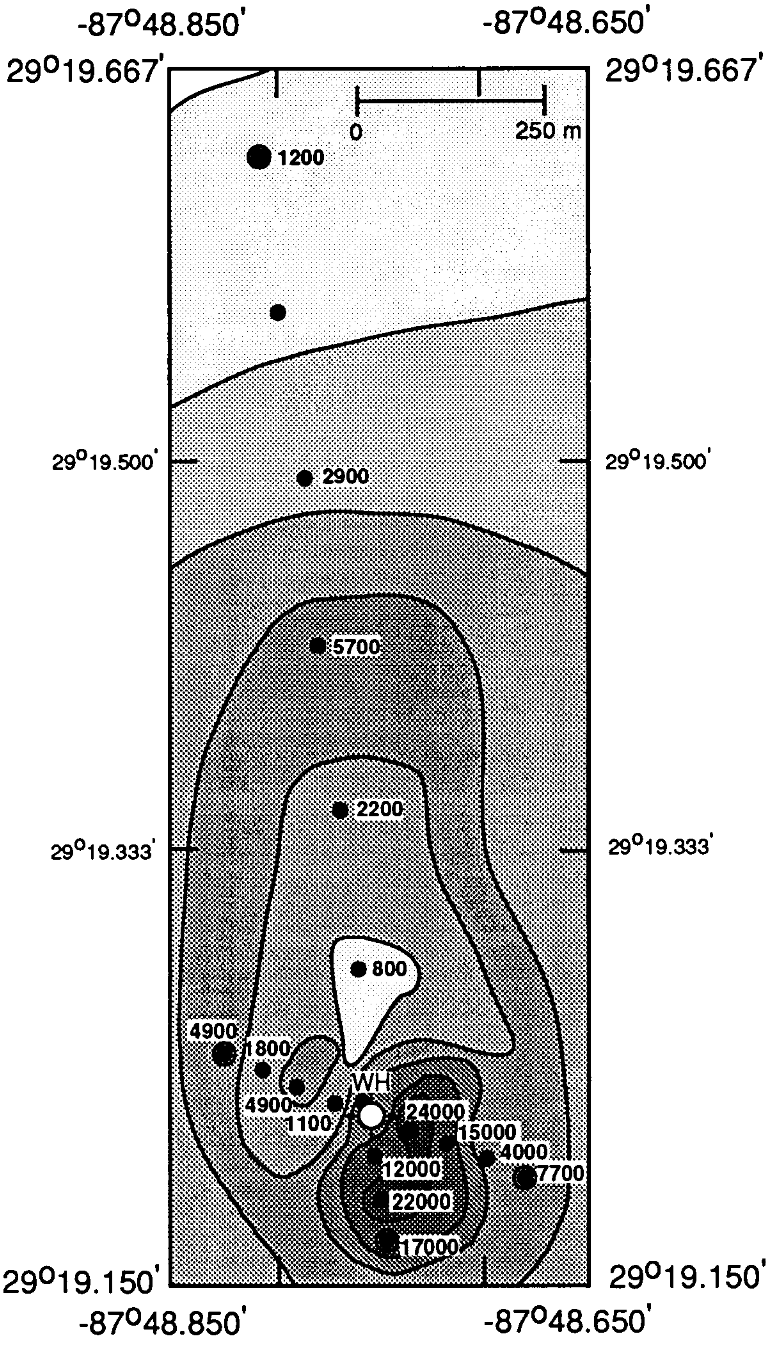


Figure 31. Contour map of barium values (ppm) for Main Pass Block 255 site. Note that although ppm values are above background 1.5 km away from the wellhead, maximum values near the wellhead (the most recently drilled site examined) are six times less than maximum values measured at the older sites at Pensacola and Destin Dome.

Gainesville Block 707

Gainesville Well No. 1, drilled in 21 m (70 ft) of water in 1985 by SOHIO (now British Petroleum) and located 67 km (37 nmi) east of Apalachicola, Florida, was the shallowest site examined (Fig. 1, Table 1). The well was drilled on hard bottom with interspersed patches of sandy sediment. Broad rock ridges only a few centimeters high support abundant gorgonians, mainly *Pseudopterogorgia* spp. and *Eunicea* spp. (Fig. 32A-B), fleshy algae (Fig. 33B), loggerhead sponges, finger sponges, ascidians commonly called "seasquirts" (Fig. 33A), and occasional head corals, mainly species of *Solenastrea*. The rocky bottom and the wellbore itself supported the most diverse benthic communities of all the sites examined. The sandy areas, slightly rippled, contained sand dollars and at least one large Bahamian starfish (*Oreaster reticulatus*). The fauna was clearly more tropical than at any of the other sites examined, and ripples proved the bottom is occasionally affected by wave-generated currents.

The wellbore consisted of two side-by-side unlined holes (Fig. 34A-B). The larger of the two holes is approximately 1.5 m across. Exposed bedded limestone was visible in the side of the larger hole. Sponges and species of the coralline alga *Lithothamnion* encrusted edges of both holes. Even the green alga *Halimeda* spp., an important lime-sand producer in the Florida Keys and Caribbean, was observed growing along the edge of the holes.

The two holes joined just below the surface and a mooring line visible in Figure 34B had been secured around the bridge between the two holes. Surrounding the site were 1-m lengths of construction reinforcing rods (commonly called "rebar") that had been driven into the bottom by divers to mark the corners of several 1-m^2 biological monitoring stations. Also nearby were the remains of several PVC sediment-trap clusters (Fig. 35A-B). Each cluster consisted of three approximately 75-cm-long by 80-mm-diameter PVC pipes attached to a metal base. Each PVC pipe was fitted with a grill-like plastic screen to reduce eddies around the entrance. These items were the remnants of an extensive pre- and post-drilling monitoring project sponsored by SOHIO. The results of this extensive biologic and sedimentologic study were rendered questionable when Hurricanes Danny (1985) and Elena (1985) scoured the bottom throughout the area. The data from that study are available in three reports (Continental Shelf Associates, 1984, 1988a, and 1988b). The only refuse from the drilling operations besides cuttings was the ubiquitous welding rods.

The borehole (two holes side by side) was often almost totally obscured by clouds of small "bait fish," which attracted various jacks including amberjacks and barracuda. Groupers were abundant, and during one dive eleven 2- to 5-kg (5-10 lb) groupers were counted within the larger borehole (Fig. 34A-B). Queen angelfish, grunts, butterfly fish, snakefish and schools of jackknife fish were also abundant around the site.

Cuttings adjacent to the boreholes were readily apparent and formed a thin layer over the rock (Fig. 32A). Sediment was thin in the area and sampling was difficult, requiring numerous scoops to obtain sufficient material. The location of samples, including locations more than 1 km from the wellbore, are shown in Figures 36A and B. Grain-size distribution graphs (Fig. 37) show the median grain size ranges between 180 and 250 µm. Variability in grain size is also apparent (Table A4). Sample N1 (Fig. 37) clearly shows the presence of cuttings (500- to 1.0-mm-size fraction). Figure 38 is a contour map showing distribution of grains (mainly cuttings) larger than 2 mm. Sample N1 was so dominated by coarse-grained material

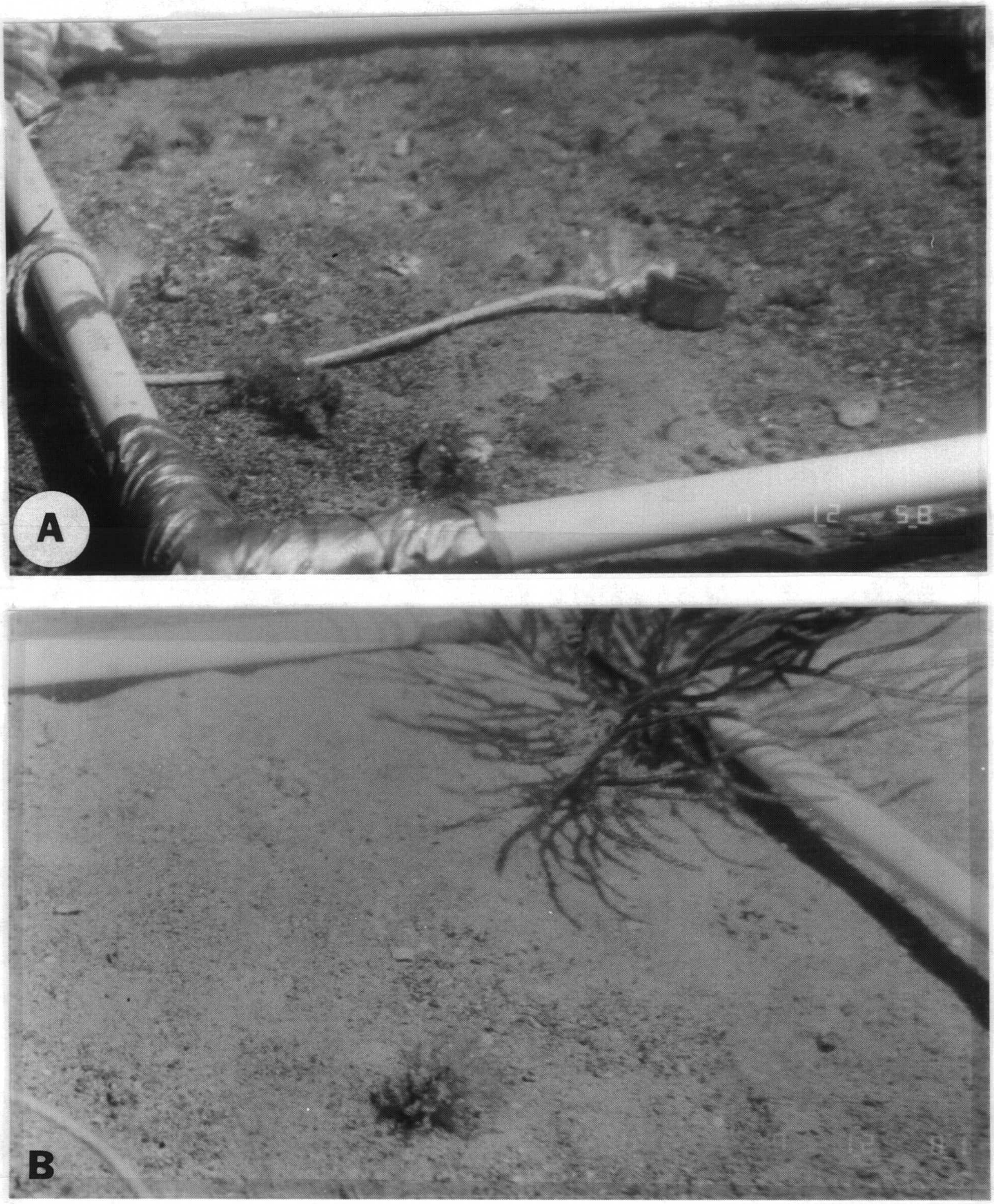


Figure 32. Typical views of the bottom surrounding the Gainesville Block 707 site. (A) thin layer of cuttings over exposed limestone (rock is exposed just under large nut attached to string). (B) Thicker sediment containing cuttings than in (A). Note live gorgonian under upper righthand corner of frame.

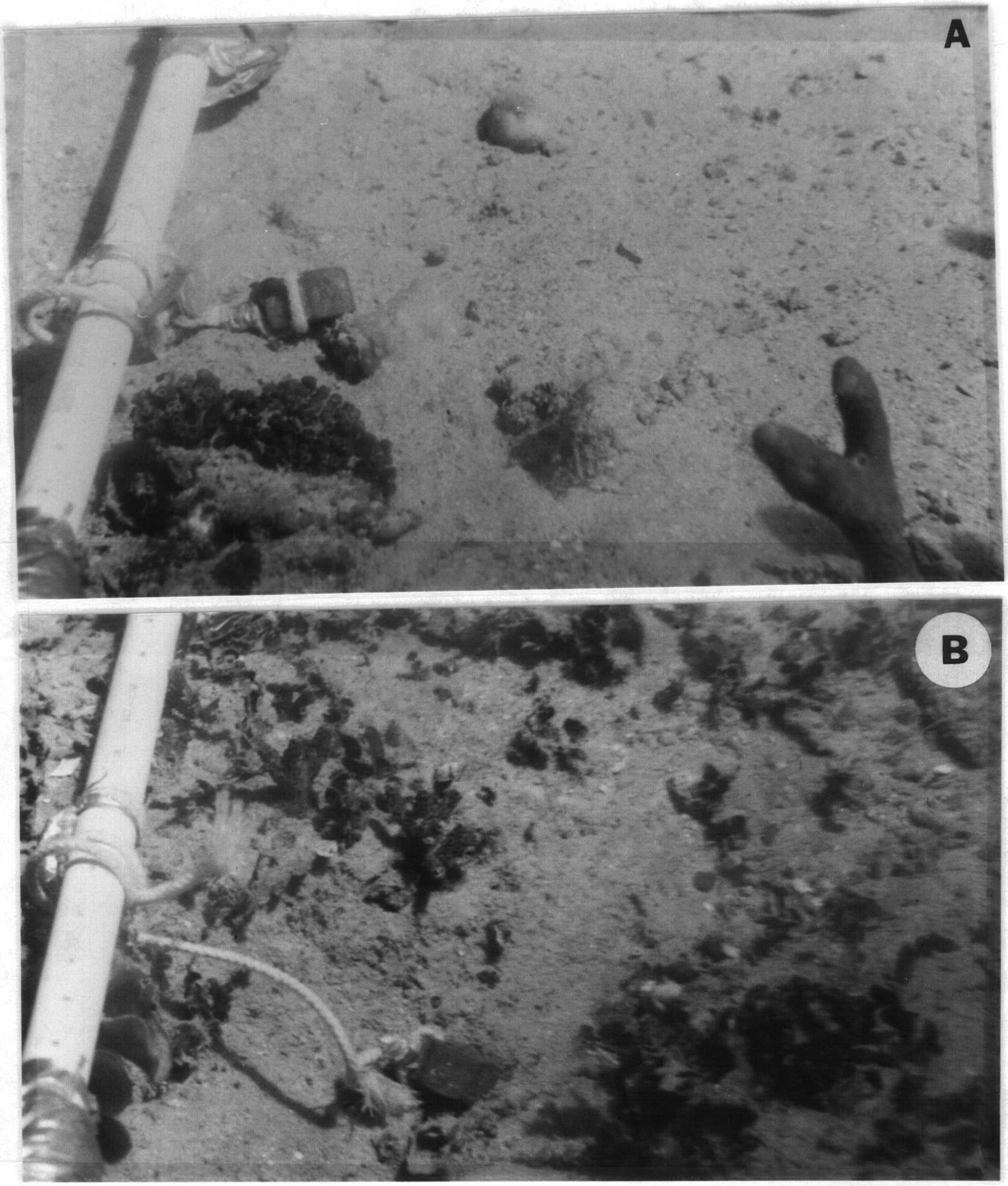


Figure 33. (A) View of sampling site at Gainesville Block 707 showing branching sponge at lower right, ascidians attached to rock fragment at lower left, and numerous small rock fragments and cuttings. Sediment layer approximately 1 cm thick. (B) View similar to that in (A) showing codiacian alga *Halimeda* spp. at upper left and fleshy algae at lower right.

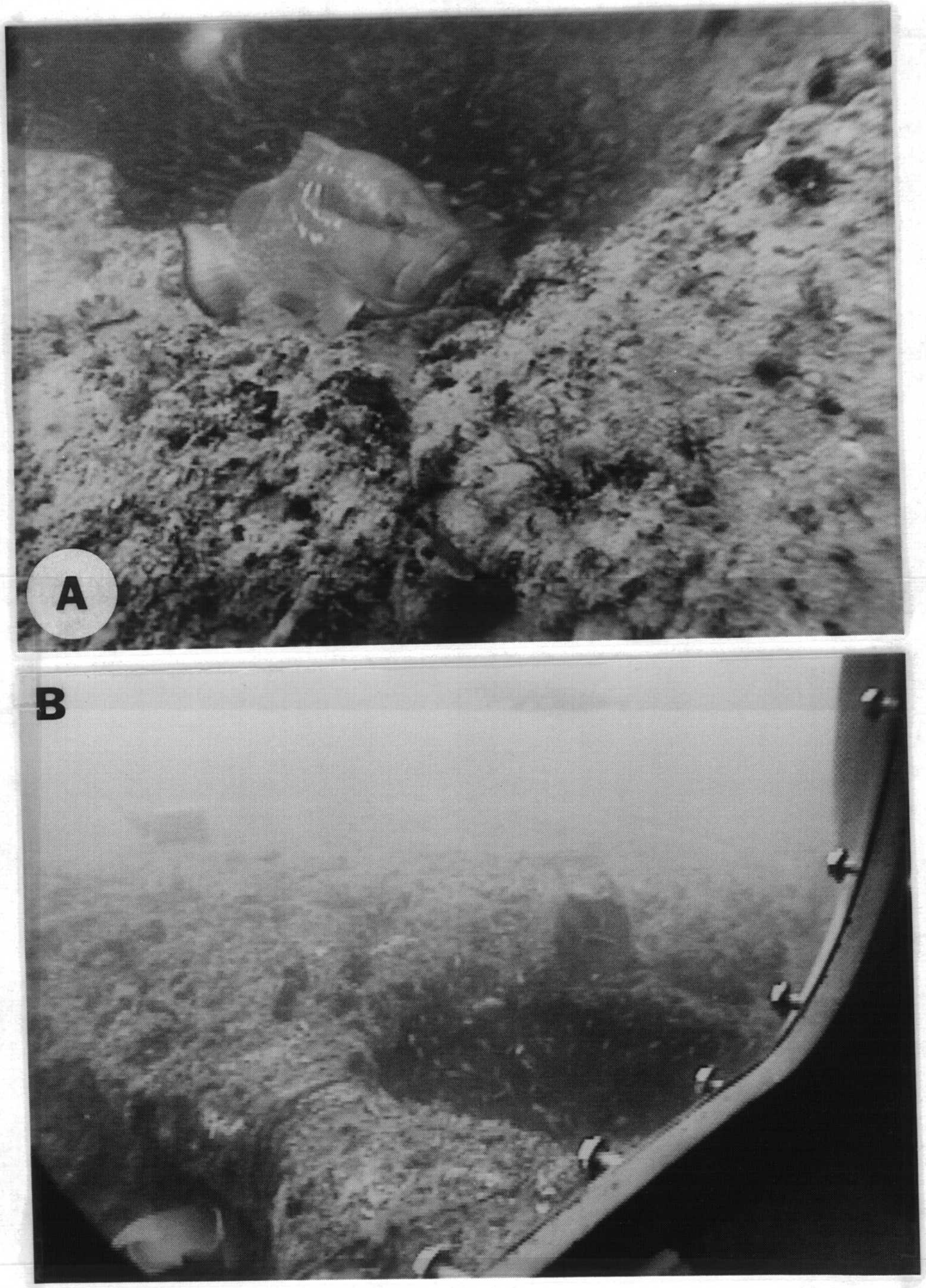


Figure 34. (A) Edge of borehole at Gainesville site with red grouper at margin. Rock surrounding hole is encrusted with species of *Lithothamnion*, *Halimeda* and other fleshy algae. Minnows obscure vision into hole that contained 11 groupers at time of observation. (B) View showing small hole separated from main borehole by a bridge of limestone. Rope tied around bridge was apparently used for a buoy. Grouper hovers above small hole and an angelfish is visible in lower left corner.

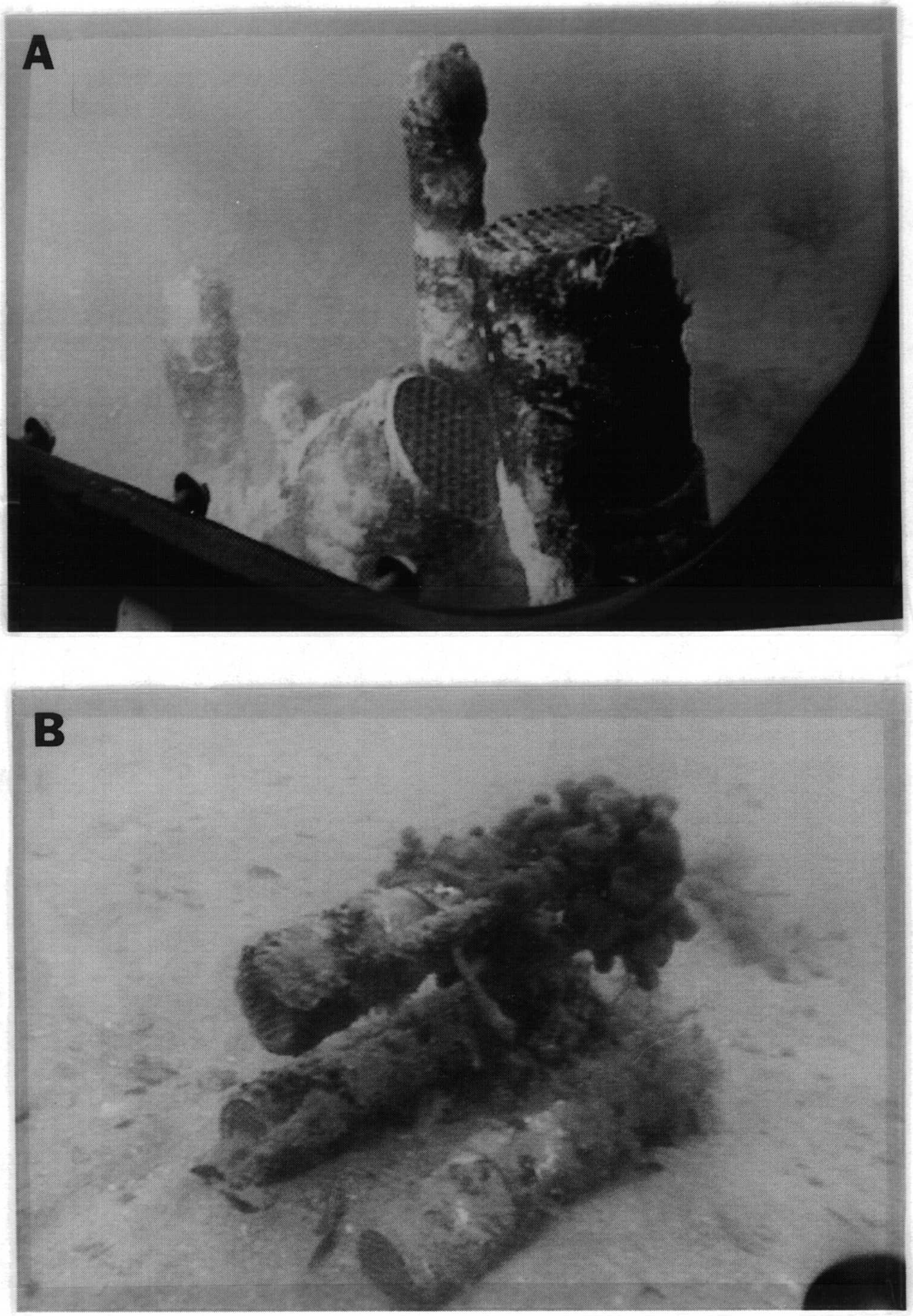


Figure 35. (A) Scientific sediment traps found on bottom near Gainesville Block 707 borehole. Note gorgonians growing in background. (B) Similar traps overturned near borehole.

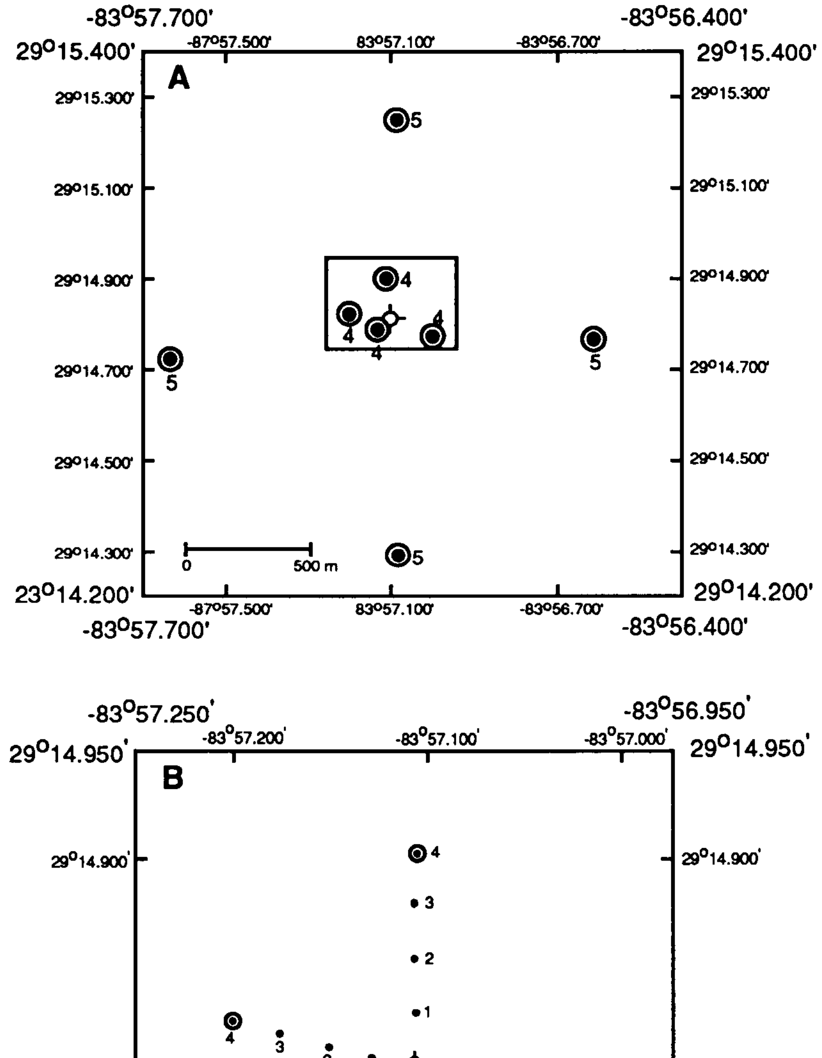
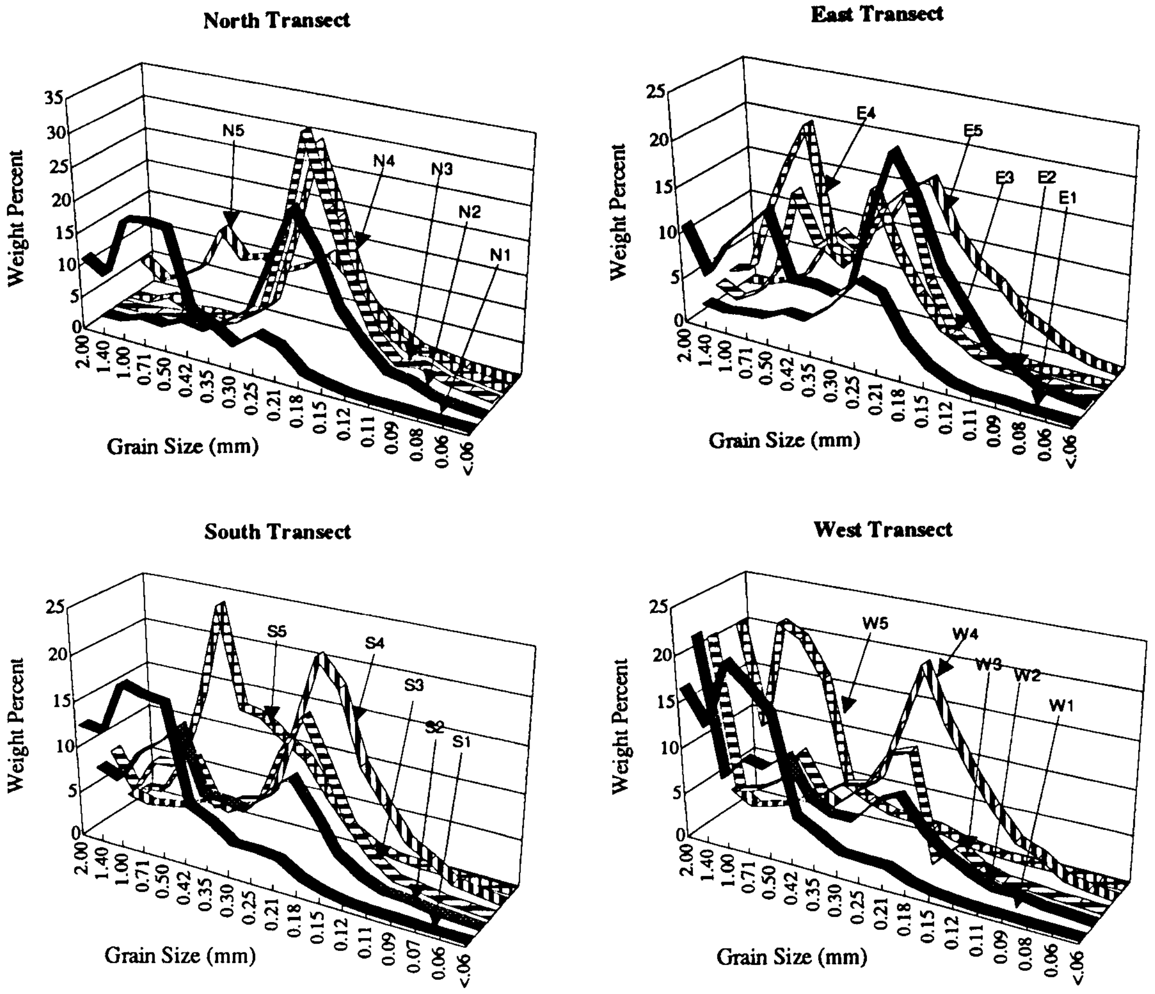


Figure 36. (A) Samples where GPS readings were taken, including distant samples close to 1 km from borehole at Gainesville site. Inset (B) shows closely spaced samples near borehole.



North Transect

East Transect

South Transect

West Transect

Figure 37. Three-dimensional graphs of grain-size distribution within samples taken along all four Gainesville transects, including locations approximately 1 km from the wellhead. See previous figure for locations.

that there was insufficient fine-grained material for either XRD or neutron activation analysis.

The XRD analysis revealed that those samples with a sufficient amount of fine material had no detectable barite. Elemental analysis (Table 2), however, detected only one sample (E1) with barium above background levels. The high level in sample E1 was 1,600 ppm. Barium concentrations up to 200 ppm are considered background values for natural sediment in the Gulf. These analyses indicate that the initial drill-mud contamination reported by Continental Shelf Associates (1988a and b) has been significantly reduced. When analyzed in 1985 during drilling, barium content of fines was reported to be as high as 247,457 ppm at a distance of 65 m from the discharge site. At the same time, a high of 48,628 ppm was detected 300 m from the discharge point. By August 1986, the highest barium content had fallen to 2,920 ppm at 65 m and 1,112 ppm at 300 m from the discharge point. Pre-drilling levels in June of 1985 were reported at 55 ppm 65 m from the site and 72 ppm 300 m from the site (Continental Shelf Associates, 1988a and b). The two hurricanes that swept the area during drilling and while studies were underway had clearly resuspended and dispersed much of the drilling mud that had accumulated, as evidenced by the more than 80 times reduction in barium at the 65-m site just one year later.

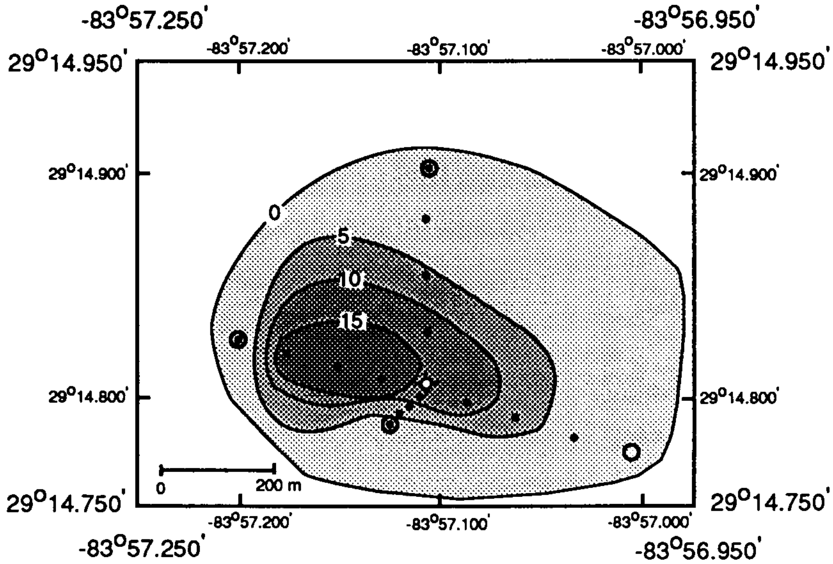


Figure 38. Contour map showing distribution (in percent) of grains >2 mm that are composed mainly of cuttings, Gainesville site. Layer of cuttings over underlying limestone bedrock is thin (1 to 4 cm at most).

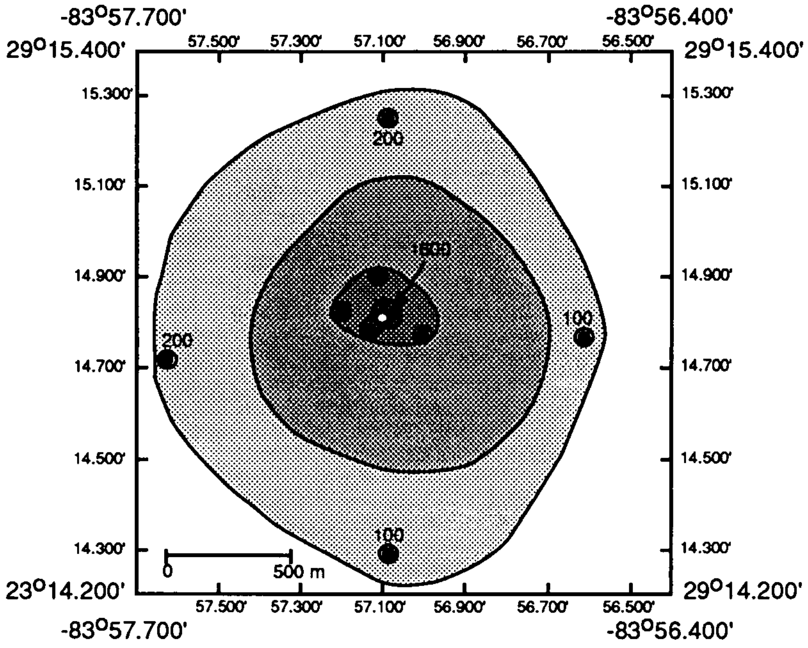


Figure 39. Contour map of barium (ppm) in fine fraction at Gainesville site. Only five samples contained sufficient fine fraction for analysis. All are considered to be background levels except for that in sample E1, which contained 1,600 ppm.

Because of shallow-water depth and reduced "fall time" through the water column, there should have been a substantial buildup of cuttings while the well was being drilled. Indeed, Continental Shelf Associates (1988a and b) reported significant cuttings and a 500-m-diameter zone of total decimation of seagrasses, mainly *Halophila* spp. The area of seagrass denuded by drilling was reported to be 74 acres and the area sub-lethally impacted was 10,475 acres. The amount of seagrass bottom denuded by Hurricane Elena in the area spanned by reference stations was estimated at 288,059 acres (Continental Shelf Associates, 1988a and b). Absence of a thick pile of cuttings when we examined the site in November 1991 suggests that the two 1985 hurricanes and those that have occurred since had not only reduced barium content to essentially background levels, but also had dispersed most cuttings, leaving only a thin (approximately 1 cm thick) layer adjacent to the borehole. The area visually affected in 1991, i.e., by the presence of cuttings, welding rods, and the two boreholes, was only about 20 m^2 (215 ft^2) or about 1/200 of an acre. Although the contour map of barium (Fig. 39) shows one sample location with 1,600 ppm barium, the remainder of the values contoured is considered to be background level. We considered this site to be one of the cleanest and least disturbed sites examined in this study.

Florida Middle Ground Block 252

The Florida Middle Ground Well No. 1 was drilled by Texaco in 37 m (121 ft) of water 130 km (70 nmi) south-southeast of Apalachicola, Florida, in 1974 (Fig. 1, Table 1). The bottom is flat and varies from patches of coarse lime sand with long-period 30-cm-high ripples, to flat, more muddy bottom with occasional patches of species of the alga *Caulerpa* (Fig. 40A-B). The actual wellbore was impossible to locate because there were no schools of fish, no visible borehole, and only a few pieces of debris and partly buried welding rods. After an extensive bottom search, a spot with visible cuttings was selected to serve as the center point for the four radiating sampling transects (Fig. 40C-D).

Sampling transects were begun after running the submersible for 1 minute from the selected center point where we placed the buoy. Subsequent samples were 3 minutes apart. Transects extended north, east, west, and south from the arbitrary center point. In addition, a large sample was taken 1 km beyond the end of each transect with a Peterson grab deployed from the surface (Fig. 40C). These samples are labeled N5, E5, S5 and W5 in Table A5 in the Appendix and Figure 41. The north transect clearly followed an area of coarse sediment, and the samples contained both cuttings and fragments of coralline algae. Coralline algae were observed living, forming popped popcorn-like aggregations, some of which were encrusting cuttings. The median grain sizes along the north transect fall between 500 µm and >2.0 mm, reflecting the presence of coralline algae and cuttings. Samples N5, E5, S5, and W5 did not contain cuttings. Compared to the north transect, the south, east, and west transects had a median particle size between 125 and 250 µm. Only samples E1 and W1, however, show the presence of cuttings and coarse coralline algal grains. We therefore feel confident that the arbitrary center point was very close to the actual wellbore.

Samples with median grain size between 500 µm and >2.0 mm barely contained enough mud for XRD analysis and were insufficient (5 gm required) for elemental analysis. Only in samples N5, E1, S5 and W1 could we separate enough mud for XRD and INAA analysis. We therefore lacked sufficient data to make a contour map of barium concentrations. The barium data are presented in Table 2. Notice that XRD

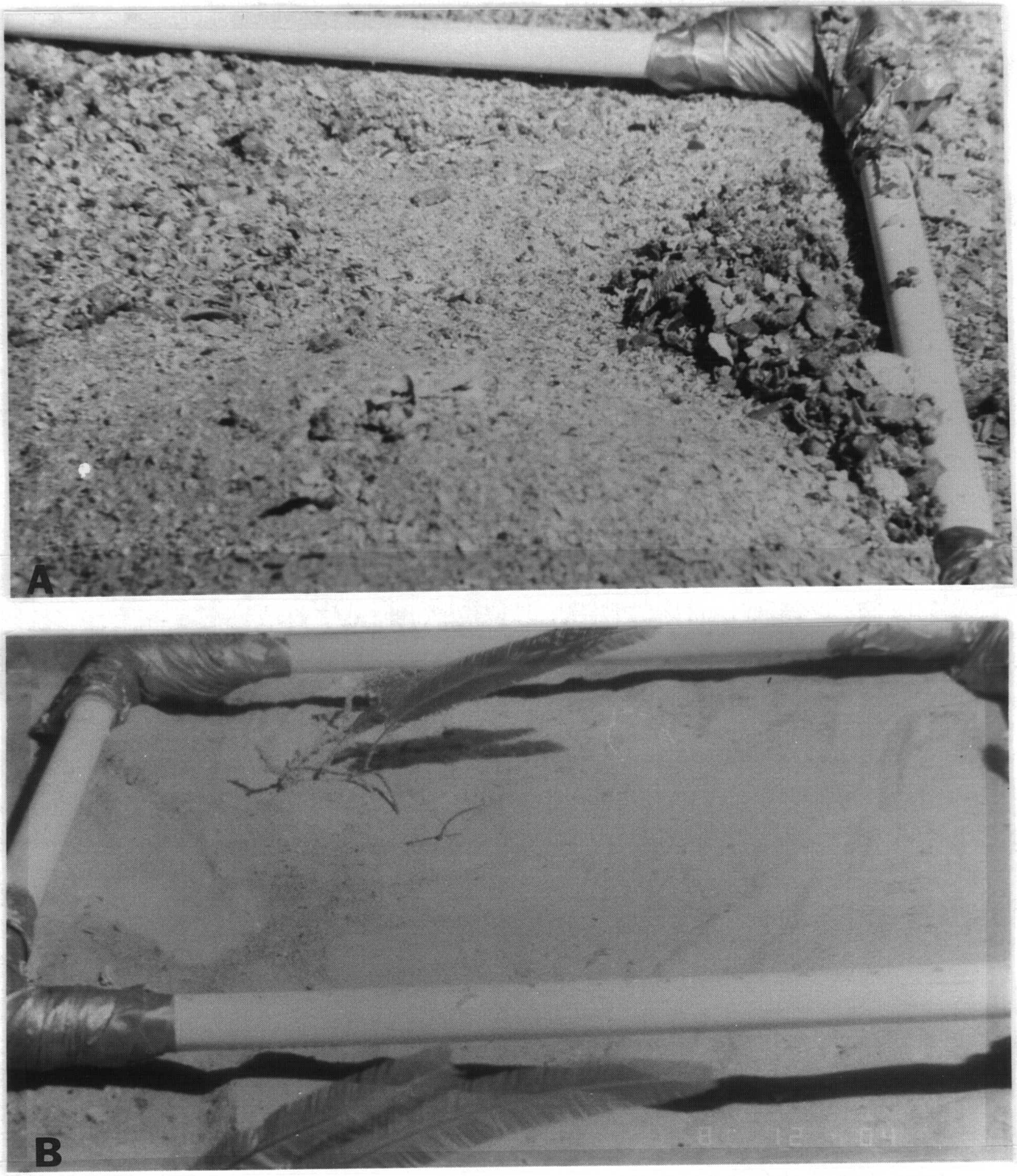


Figure 40. (A) Coarse, rippled, shelly sediment containing cuttings at Florida Middle Ground Block 252. See Figure 2 for distant view of ripples in this area. (B) View of finer sediment along east transect with scattered species of the green alga *Caulerpa*.

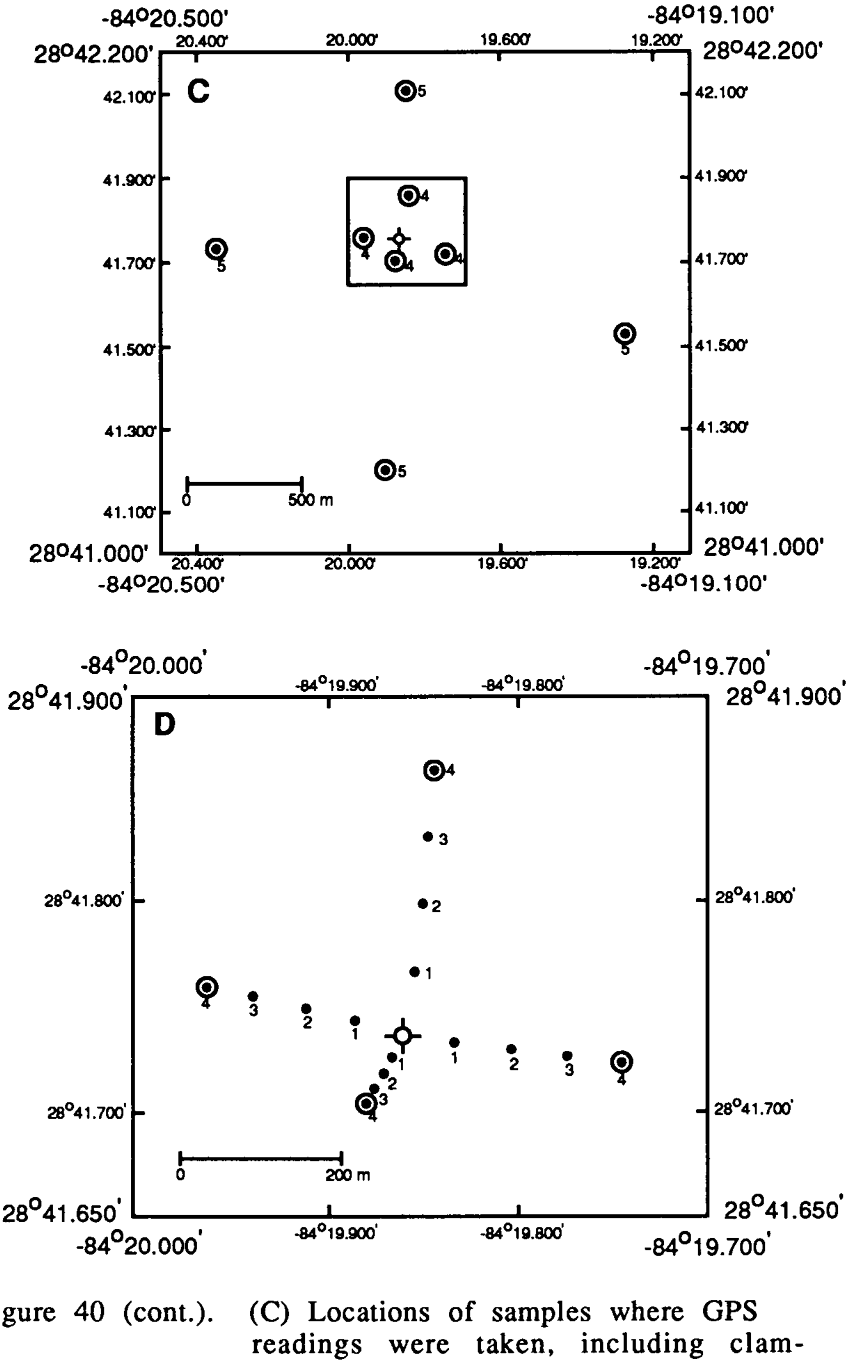


Figure 40 (cont.). (C) Locations of samples where GPS readings were taken, including clamshell grab samples collected from surface vessel. (D) Enlargement of inset in (A) showing closely spaced sample locations around borehole.

analysis detected no barite in any samples. Elemental analysis (INAA) for samples that contained sufficient fines provided values ranging from <100 to a high of 500 ppm barium. We consider these amounts to represent essentially background levels for sediment in the eastern Gulf. Drill mud undoubtedly had settled here during drilling but has subsequently been dispersed during the 17 years since drilling took place.

We cannot provide an estimate of area impacted because of the pristine appearance of the site. The two or three welding rods and a piece of pipe and a small piece of grating would not have been noticed had we not been specifically looking for such clues. Absence of fish, present at all the heavily impacted sites, is indicative of the relative lack of debris at this site.

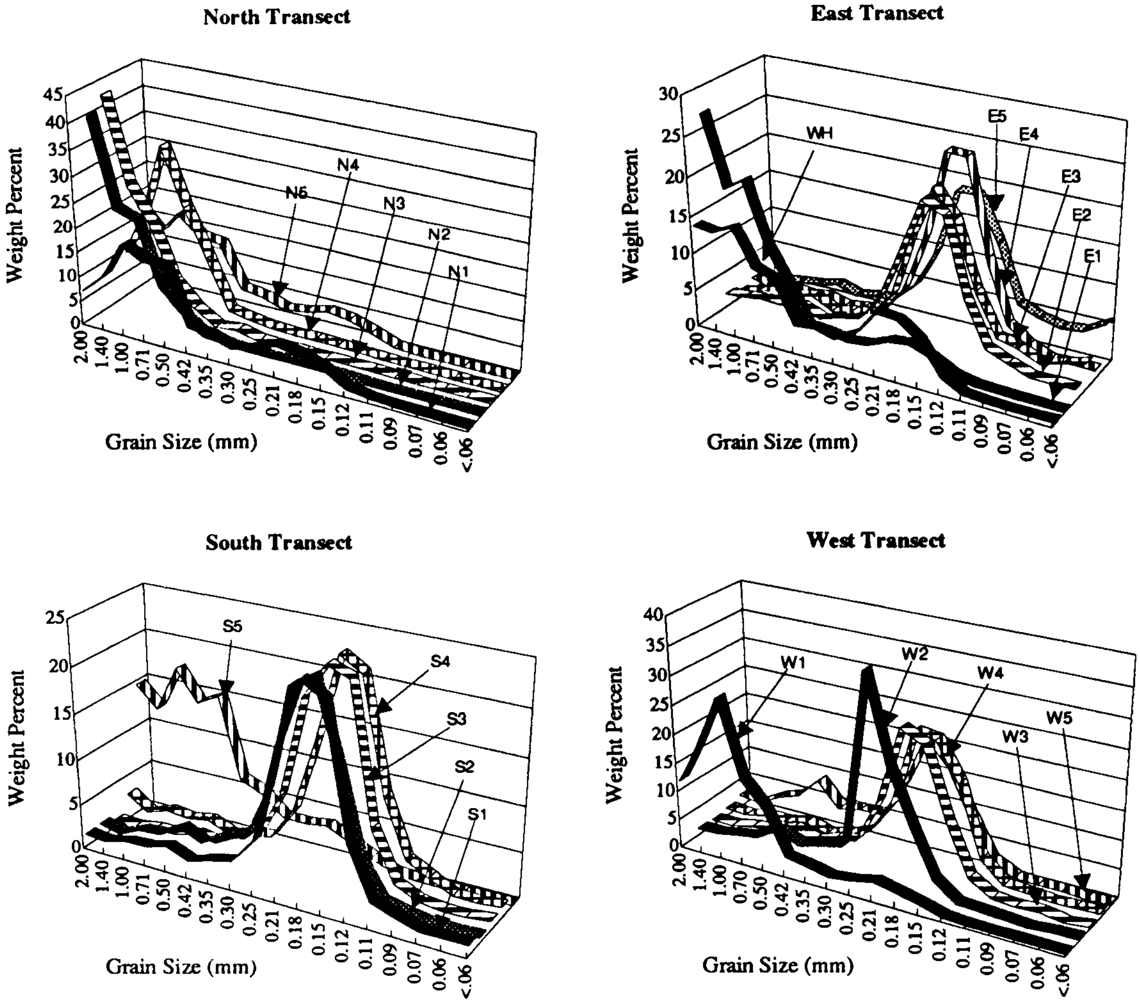


Figure 41. Three-dimensional graphs showing grain-size distribution of samples along all four transects at Florida Middle Ground Block 252 site. Note abundance of coarse grains in samples along north transect and abundance of fine-sand size along east transect.

Florida Middle Ground Block 455

The last well site examined was drilled by Chevron in 1986 in 149 m (489 ft) of water 136 km (73 nmi) south of Apalachicola (Fig. 1, Table 1). The bottom was composed of white lime mud with conspicuous 1-cm-diameter burrows and 5- to 10-cm-high mounds made by burrowers. There were no grasses or bottom faunas other than an occasional starfish. Infrequent snakefish and bright-red shrimp were observed buried with only their eyes showing.

Because seas and winds were increasing due to onset of a cold front, only one dive was possible. Three samples were collected, however, one north, one south, and one about 2 m from the borehole.

Water visibility on the bottom was less than 4 m and artificial lighting was necessary. The wellbore was discovered by following large Warsaw groupers, which immediately surrounded the submersible whenever it stopped. The wellhead was located in the center of a 30-cm-thick hexagon-shape steel frame (Fig. 42A), which apparently served as a template for multiple reentry. The wellbore consisted of a funnel-shape central hole about 1 m in diameter. The bottom of the hole could not be seen, but large groupers (Fig. 43A) continually swam in and out, disappearing each time they entered. The movement of fish stirred up bottom sediment, making observations difficult. Short lengths of heavy cable with which the template had been lowered to the bottom were still attached to eyes welded to the frame (Fig. 42A). The cables had been cut. Excavation, apparently made by fish, made corners and the thickness of the template visible. Had the template not been excavated, only the central wellbore would have been visible.

Several meters to the north was a half-buried steel cargo loading basket. The basket was in a depression apparently made by the groupers that resided in and around the basket's steel frame (Fig 43B). When approached by the submersible, fish repeatedly swam into the depression, stirring up sediment and obscuring vision.

Fish fauna, other than bright-red bigeyes, was restricted almost entirely to large Warsaw groupers. One fish (Fig. 43A) was estimated to be 2 m long and weigh well over 200 kg (440 lb).

Drill cuttings were barely visible around the wellbore and welding rods, though present, were not abundant. The only other debris observed was a hardened broken bag of cement, several meters of acetylene welding hose, a wad of half-buried cable, and large barnacles (Fig. 44A-C). Any other debris was likely buried in the mud. Grain-size analysis of the sample taken at the wellbore (WH in Fig. 45) clearly indicates the presence of cuttings (Table A6). Compare the graph for sample WH with those for samples taken north and south of the borehole. The median grain size in samples along the north and south transects falls between 63 and 95 µm. In the wellbore sample, median grain size is between between 180 and 500 µm. These were the muddiest samples taken from any of the sites.

The XRD analysis showed that all three samples contain barite, and sample WH was shown by neutron activation to contain 6,300 ppm barium, about 20 times the background level for eastern Gulf of Mexico sediments. At these depths, hurricanes and winter storms are not likely to remove drill mud that is in the same size range as the predominant natural sediment. Continued sedimentation by fine-grained mud and reworking of sediment by burrowing organisms, however, will eventually bury the drill mud and all traces of drilling at this site.

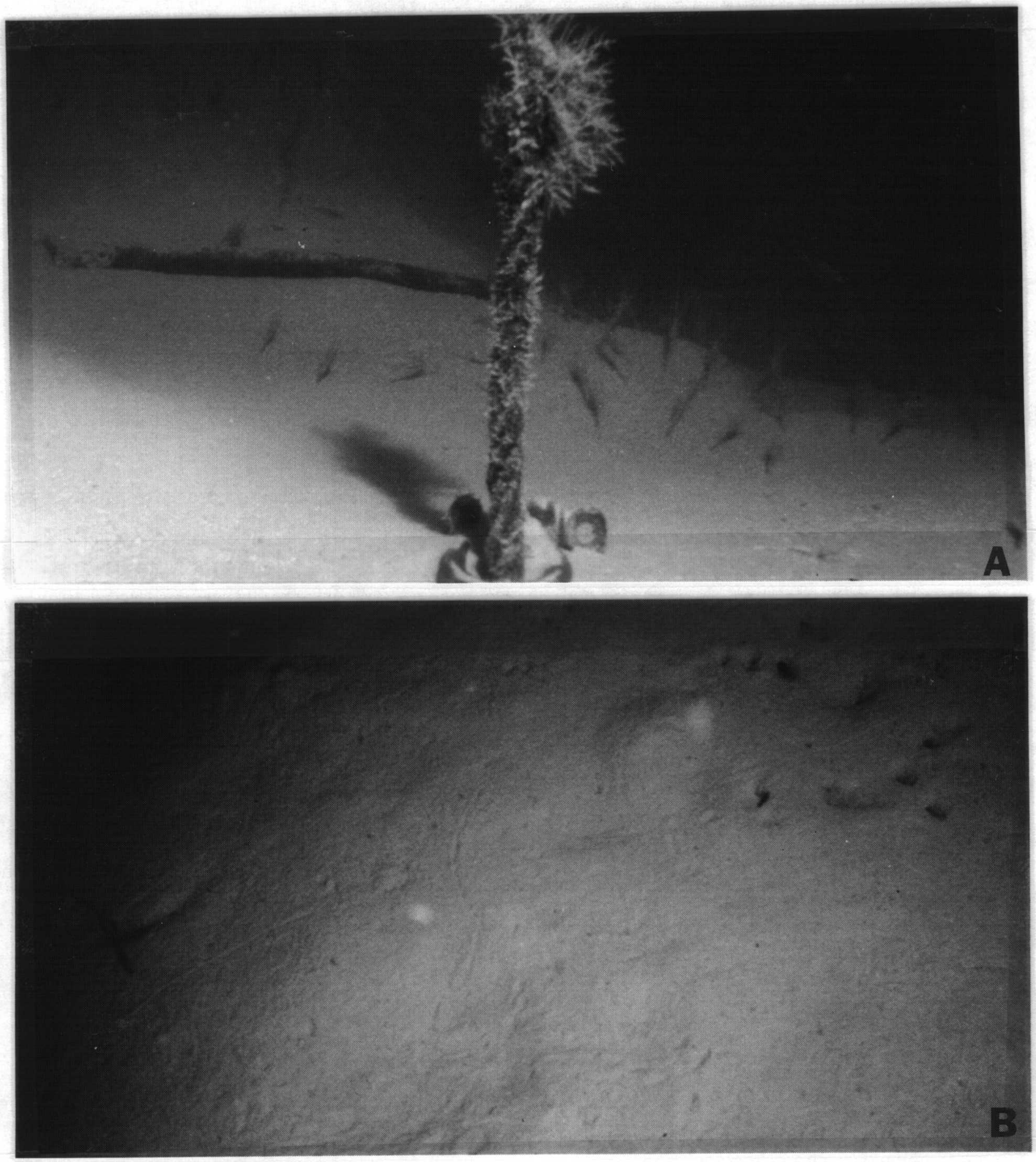


Figure 42. (A) Edge of metal-lined borehole at Florida Middle Ground Block 455 visible at upper right. Small organisms are shrimp. The vertical cable with shackle at base is one of several attached to the sediment-covered hexagonal metal frame that surrounded borehole. Large groupers swam in and out of dark hole. (B) Typical view of lime-mud-burrowed bottom with worm and snail trails crisscrossing surface. Burrow holes are approximately 1 cm in diameter.

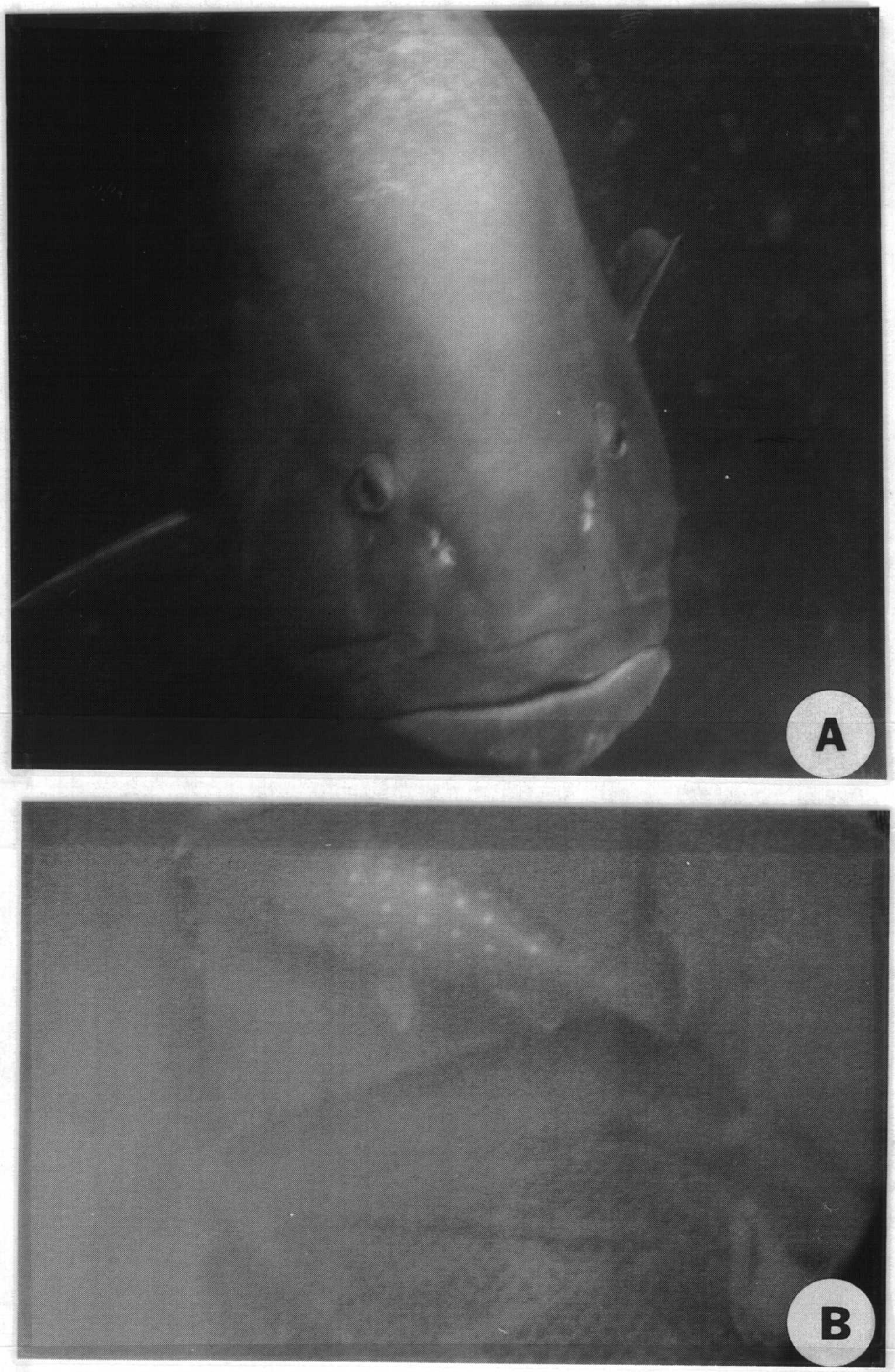


Figure 43. (A) Extremely large Warsaw grouper that occupied Florida Middle Ground Block 455 site. Many smaller groupers in the 59-kg range swam in and out of borehole. (B) Spotted snowy grouper occupying cargo cage that had been excavated from sediment by fish.

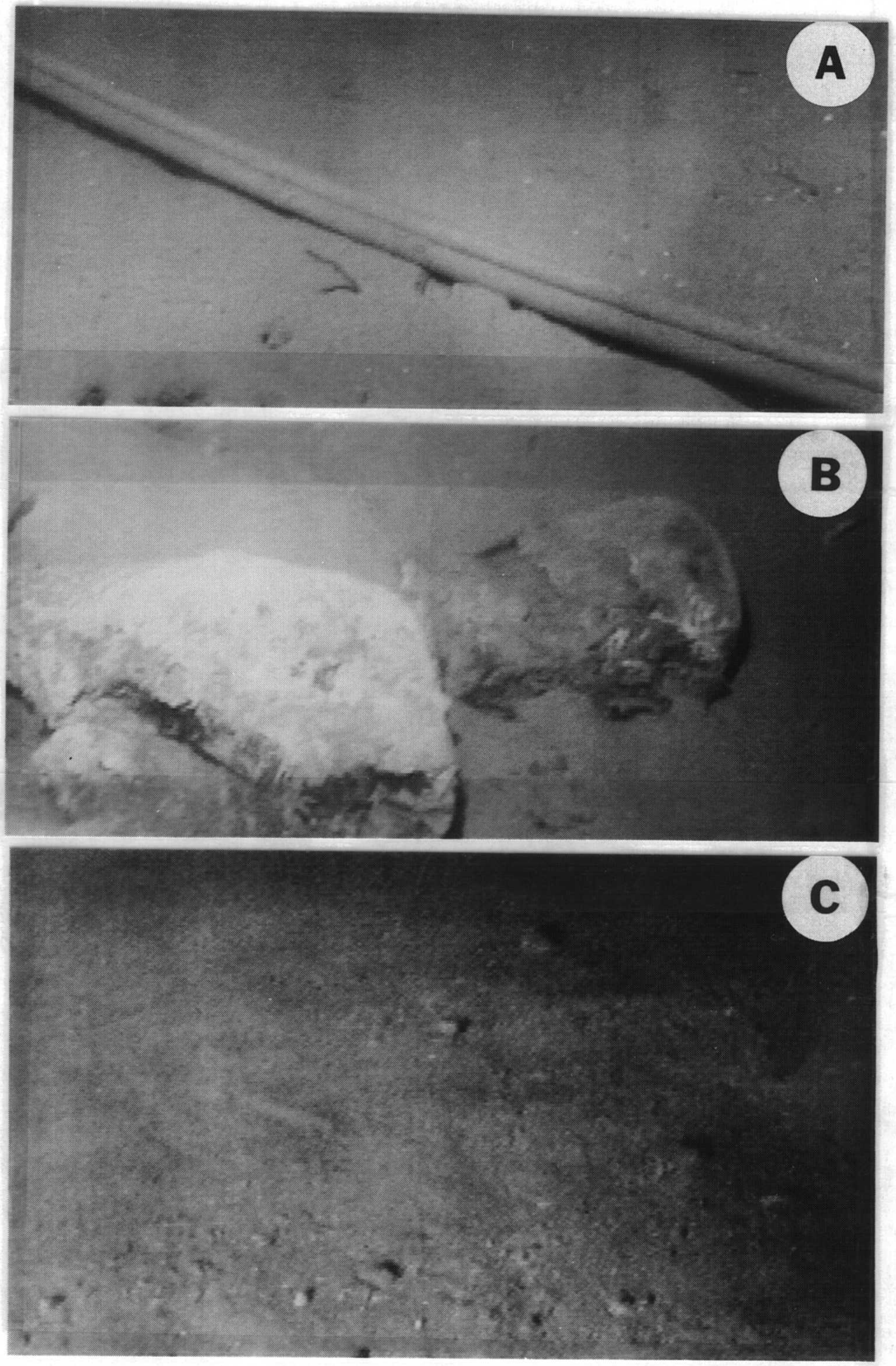


Figure 44. (A) Length of paired red and green acetylene gas welding hose at Florida Middle Ground Block 455 site. (B) Fragments of hardened bag of cement. (C) Cuttings and grout fragments on surface a few meters from the wellhead (sample WH).

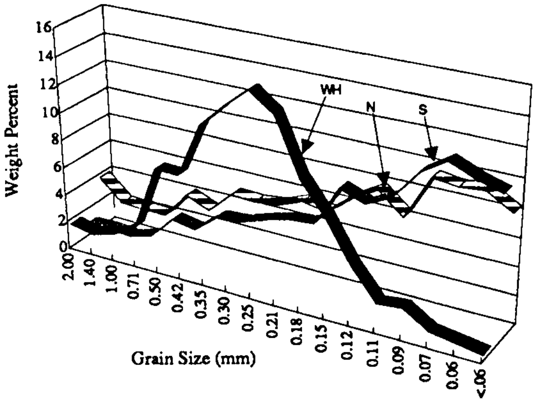


Figure 45. Three-dimensional graph of grain-size distribution of the only (three) samples taken at Florida Middle Ground Block 455 site. Note preponderance of fine grains in north and south transects compared to those at WH, which contain cuttings.

SUMMARY AND IMPLICATIONS

The geologic setting, hydrographic setting, water depth, sediment composition, drill crew, and type of drill rig, as well as the period of time since drilling, were different at every site examined. Not surprisingly, impacts varied greatly from site to site. At least one variable, time, clearly has had a large effect on the ultimate condition of the bottom: this study shows that impacts diminish with time. At the oldest site, Florida Middle Ground Block 252 (drilled in 1974), the lack of obvious debris and fish made the site difficult to locate. Drilling-mud components, at least the most commonly used weighting agent barite ($BaSO_4$), were not detectable using XRD, and barium (Ba) was detected at what is considered as essentially background levels. This 4,644-m-deep test well should have produced several thousand barrels of cuttings, yet what remains today is so thoroughly mixed with natural sediment that cuttings are very difficult to distinguish.

The next least affected site studied was that at Gainesville Block 707, which was drilled only 6 years before our study. There, the shallow-water depth (21 m) had accelerated the normal effects of time, and the bottom therefore had been affected by numerous winter-storm-generated waves and currents, as shown by oscillatory sand ripples near the wellhead. Furthermore, the area had been affected by two hurricanes while the well was being drilled and has probably been affected by the fringe winds of several more recent hurricanes and numerous winter storms. Cuttings at this site were obvious, but the accumulation was thin and only a small area around the borehole was affected. This well was drilled 216 m (710 ft) deeper than the well at Florida Middle Ground Block 252 and therefore should have produced a greater quantity of cuttings. How and where the cuttings went we do not know. The cuttings and mud that blanketed the area when studied by Continental Shelf Associates in 1984 had been considerably reduced by the time they reexamined the site in 1986 and 1987. In 1988, they reported the following: "The MMS-funded survey of the Florida Big Bend seagrass beds in August 1986 detected no long-term hurricane impacts (Continental Shelf Associates, Inc., 1988a, p. 118). Likewise, data collected in October 1987 indicated that recovery of the seagrasses had occurred. Passage of Hurricane Elena destroyed virtually all the deep seagrass beds in this area of the west Florida continental shelf. Whether or not the seagrass recovery observed at Gainesville Block 707 was from drilling impacts alone cannot be determined because the effects of the drilling and the hurricane were confounded--the seagrass recovered from both the hurricane and drilling."

Fish were abundant and diverse when we examined the site. Gainesville Block 707 was the most tropical of all the sites examined. Clearly, fast-growing tropical flora and fauna can more quickly overgrow insults to their communities than can deeper more slowly growing temperate-water organisms.

The dispersion of drill mud in these shallow depths is not surprising. Because our samples did not contain detectable barite, and barium was at background levels except in one sample adjacent to the borehole, we therefore assume there is now insufficient contamination of the bottom to affect marine life significantly. Analyses for barium both during drilling in 1985 and after passage of the two hurricanes showed a significant reduction in barium levels (Continental Shelf Associates, 1988a and b). When we analyzed the sediments six years after drilling, barium levels had been further reduced.

Interestingly, the well at Gainesville Block 707 had been the subject of much controversy when it was drilled. Though not in State waters, the State of Florida attempted to discourage the drilling of this well. Because there was so little documentation on the aerial extent of drilling impacts, an agreement was reached between State and lease holder; an extensive study would be funded by the lease holder. The principle organism of concern at that time was a species of *Halophila*, a seasonal surficial seagrass that, during certain months, covers extensive areas of the sea bottom off west Florida. Changes in seagrass cover associated with drilling were indeed documented during the drilling (Continental Shelf Associates, 1984) and decimation of the grass community occurred around the drill site while the well was being drilled. Ironically, the two 1985 hurricanes, Danny (August 16) and the stronger Elena (Aug. 31-Sept. 3), swept away all of the seagrasses over thousands of acres of bottom. Data to support a Governor's report highly critical of offshore drilling were derived from Continental Shelf Associates (1988a and b) initial reports on barium levels and disappearance of the seagrass *Halophila* sp.

Other areas examined in this study showed significantly more severe impacts. The areas most affected were at Pensacola Block 996 and Destin Dome Block 56. These wells had been drilled only two and three years (Table 1) before our examination. The layer of cuttings at both sites was still quite thick (possibly as much as 1 m thick) and drill mud (barite and barium) was present in substantial quantities. Though the ambient sediment is in the sand-size range, water depth at these two sites makes it unlikely that any event, short of a hurricane, will cause currents strong enough to winnow the mud.

Trace metals were also significantly elevated above background levels at both sites (Table 2). Zinc ranged from less than 50 ppm to as much as 570 ppm in one sample, and both chromium and vanadium were slightly elevated. Iron ranged from less than 1% to as much as 2.6%. All the samples with elevated metals were those closest to the borehole and contained significant quantities of cuttings. Iron is most likely from pipe scale, a universal component of well cuttings.

Burrowing infaunas, present at all sites including those with elevated levels of barium and metals, will in time rework the sediment sufficiently to remove much of the drill-mud and cuttings components. Above background levels, however, will probably remain for decades.

At both sites, barnacles had been scraped from the rig, placed in buckets, and thrown overboard. We found an assortment of items ranging from shovels, spoons, brushes, gloves, bags, various flanges, lengths of pipe, tubing, hose, wire, and cable, to the ubiquitous stubs of used welding rods. Although such items do not appear harmful to fish life (in fact, they clearly attract fish), they can be snagged in shrimpers nets. At the very least, such items are generally considered aesthetically displeasing.

One should keep the aerial extent of such impacts in perspective, however. At the Pensacola site, the area affected by discarded debris was less than 1 acre, whereas at Destin Dome a little more than 3 acres of bottom was affected. The Pensacola well was drilled to a subbottom depth of about 786 m (2580 ft) deeper than the old Florida Middle Ground Block 252 well, and although the depth of the Destin Dome well is confidential, we suspect it to be deeper as well. These two wells, therefore, should have produced even more cuttings than those at the other sites under study. Deeper wells also require a greater volume of drilling mud. Drill mud and its components from these two wells must have been dispersed over many square kilometers of adjacent ocean bottom. We have no way to evaluate the total aerial distribution on the bottom. Quantities of particulates suspended in drill-mud plumes have been the subject of numerous investigations (Geyer, 1980; Symposium, Research on Environmental Fate and Effects of Drilling Fluids and Cuttings, 1980). Results of these studies generally show levels approaching background less than 500 m away, even though optically visible plumes are readily apparent. A study by Shinn et al. (1980) of seven different exploratory drilling sites showed levels approaching background less than 100 m downplume. Apparently, organic emulsions, composed of materials such as starches that are not detectable on the sub-micron filters commonly used to quantify the amount of particulates, account for the persistant turbidity of most drill-mud plumes. Though plumes have been observed to extend for considerable distances from the active well, we conclude that there was no clearly visual evidence of damaging effects to the biota beyond the zones of obvious impact, including areas away from the boreholes where analyses showed barium levels in the sediment to be above background. This study did not attempt quantitative assessments, however, of the impact of barium and trace metals on the benthic biota. Barite does precipitate naturally from sea water, so clearly marine organisms can cope with it in small quantities. The complex details of barium and barite toxicity to marine organisms is beyond the scope of this study.

The deep pinnacle-reef site at Main Pass Block 255 was the most recently drilled site examined. The well or wells had been drilled only 15 months before our examination, and the wellhead template was relatively free of marine growth. One would have expected extreme care in site selection and disposal in this hardbottom area. We did, in fact, find relatively fewer discarded items than at the Pensacola and Destin Dome sites but were surprised by the well and template placements. Acres of level bottom existed around the well site, yet the conductor casing had been placed against a 4- to 5-m-high rock pinnacle. The trenches (Fig. 27A) and their zig-zag traces suggest considerable difficulties before or after drilling. The jacking-up process is slow, requiring hours, and can be critically affected by sudden weather changes. We suspect that the trenches were made by spikes that extend below the pads on the platform legs during the jacking-up process, when the rig was only partially afloat. The pinnacle served to stop the rig until jacking up was completed.

From our grain-size data, we estimate the area of mechanical impact by cuttings and debris at this site to be around 6,440 m^2 (69,298 ft^2), or close to 2 acres. Barium-distribution data show the entire area, including samples taken as much as 1.5 km to the north of the site, to contain above-normal concentrations. Barium was present in all samples in the thousands of ppm range.

Iron was consistently higher (2.4-3.1%) at the Main Pass site than at other sites, possibly because of the short interval of time since drilling and the relative lack of bottom current in the nepheloid layer that blankets the area. Sediment throughout the area was rusty brown in color. We suspect the prevailing color was imparted by iron associated with the clays that dominate the nepheloid layer. We are unable to evaluate the impact of drilling on bottom fauna at this site fully. Gorgonians, antipatharians, crinoids, and non-reef-building corals (Figs. 20, 21, 22A-B) attached to the pinnacle adjacent to the drill site as well as nearby rock bottom did not visually appear to be affected. Large fish such as groupers (Fig. 24A) have been attracted to the site.

The deepest site examined, at Florida Middle Ground Block 455, was drilled 5 years earlier on mud bottom in what was the most depauperate of all the environments examined. Light levels at this depth (150 m, or 500 ft) are poor, and there are no natural topographic features to concentrate fish. There were only two significant debris objects visible, a loading basket and the metal template surrounding the wellbore. These objects attracted the largest fish observed at any site during the study (Fig. 34A-B). The relative lack of smaller objects such as welding rods suggests a rate of burial sufficiently fast to cover the observed objects completely within a few years. The three samples collected at this site contained both barite and barium, but cuttings were only visible at the wellhead. There was no rusty-brown coating here as was observed at the Main Pass site closest to the Mississippi River delta. At 150-m depths, bottom currents are not likely to winnow and disperse drill muds and cuttings. Continued sedimentation and the reworking of sediment by burrowing infaunas will likely lead to complete burial of all evidence of drilling.

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APPENDIX

Data from Grain-Size Analyses

A1: Pensacola Block 996

Sample No.	N3*	N5	N7	N9	N11	N13
Sediment Weight (gm)	52.35	48.22	54.78	50.45	52.51	49.29
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	12.56	11.89	17.76	13	5.85	10.11
1.40	8.13	8.48	7.92	9.37	3.61	8.02
1.00	23.35	24.61	26.74	26.42	18.71	24.1
0.71	22.78	22.79	26.08	24.67	29.24	26.8
0.50	12.47	12.8	12.19	12.09	18.79	15.3
0.43	4.78	4.46	3.63	3.64	6.48	4.22
0.36	4.98	4.56	3.37	3.59	6.06	3.91
0.30	3.38	3.43	2.26	2.55	4.06	2.56
0.25	2.86	2.89	1.70	1.99	3.54	1.98
0.21	1.83	1.93	1.07	1.22	2.02	1.34
0.18	0.96	0.93	0.51	0.65	0.92	0.68
0.15	0.59	0.47	0.24	0.32	0.41	0.42
0.12	0.37	0.18	0.10	0.11	0.12	0.17
0.11	0.23	0.09	0.06	0.06	0.04	0.08
0.09	0.29	0.14	0.09	0.09	0.07	0.10
0.07	0.17	0.11	0.08	0.08	0.05	0.07
0.06	0.15	0.12	0.09	0.07	0.05	0.07
<0.06	0.12	0.11	0.08	0.07	0.05	0.06

*Samples collected at sites N2, N4, N6, N8, N10, and N12 were not analyzed. No sample was collected at site N1.

Sample No.	E1*	E3	E5	E7	E9	E11	E13	E15	E17	E19
Sediment Weight (gm)	41.78	47.18	46.96	50.50	50.51	47.86	48.42	49.62	49.72	49.72
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	31.02	13.16	17.05	20.52	16.20	15.07	13.26	15.66	20.02	20.35
1.40	15.01	7.47	9.29	10.38	10.20	7.70	9.20	7.44	6.05	8.23
1.00	13.01	24.04	19.92	21.09	28.99	22.20	25.75	23.35	20.08	22.06
0.71	9.50	24.53	17.31	17.31	20.94	22.83	24.87	23.60	20.90	21.65
0.50	6.77	12.85	12.93	10.64	11.01	11.96	12.71	12.70	12.24	10.98
0.43	2.52	4.21	5.04	4.34	3.61	4.60	3.73	4.24	5.18	4.08
0.36	2.54	4.07	4.99	4.26	3.36	4.93	3.67	4.33	5.23	4.09
0.30	2.18	2.84	3.45	3.25	2.19	3.49	2.45	2.96	3.62	2.90
0.25	2.23	2.12	3.06	2.87	1.48	2.60	1.74	2.38	3.02	2.27
0.21	2.31	1.35	2.21	1.76	0.91	1.65	1.03	1.54	1.90	1.59
0.18	1.95	0.74	1.30	0.95	0.41	0.81	0.50	0.76	0.96	0.76
0.15	2.31	0.58	0.98	0.62	0.24	0.53	0.25	0.38	0.49	0.38
0.12	1.88	0.44	0.59	0.39	0.13	0.29	0.13	0.15	0.21	0.14
0.11	1.55	0.31	0.37	0.28	0.08	0.19	0.09	0.08	0.11	0.07
0.09	1.90	0.47	0.51	0.45	0.12	0.32	0.14	0.12	0.19	0.12
0.07	1.28	0.28	0.33	0.31	0.09	0.26	0.14	0.10	0.16	0.10
0.06	1.22	0.28	0.34	0.33	0.09	0.31	0.16	0.11	0.18	0.12
<0.06	0.85	0.23	0.27	0.25	0.08	0.25	0.16	0.09	0.16	0.09

*Samples collected at sites E2, E4, E6, E8, E10, E12, E14, E16, E18, and E20 were not analyzed.

Sample No.	S1	S2	S3	S4	W1	W2	W3	W4
Sediment Weight (gm)	43.67	47.06	52.16	51.59	44.01	40.23	50.54	50.30
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	63.59	20.89	11.04	10.48	73.68	14.55	10.80	12.98
1.40	12.88	8.39	10.14	4.28	10.53	4.19	8.86	8.51
1.00	9.35	23.07	25.94	17.02	7.33	21.55	25.25	24.72
0.71	5.24	19.91	21.21	23.34	3.60	22.61	25.08	23.79
0.50	3.26	11.4	11.91	16.17	2.01	13.81	13.36	12.22
0.43	0.95	4.15	4.71	7.85	0.51	5.34	4.61	4.42
0.36	0.89	4.06	5.00	7.56	0.39	5.30	4.23	4.46
0.30	0.58	2.88	3.37	5.64	0.26	4.12	2.94	2.89
0.25	0.42	2.35	2.87	3.84	0.21	3.27	2.37	2.50
0.21	0.36	1.47	2.06	2.11	0.17	2.27	1.37	1.70
0.18	0.26	0.67	0.93	1.01	0.13	0.99	0.56	0.83
0.15	0.30	0.31	0.38	0.34	0.14	0.45	0.24	0.38
0.12	0.27	0.11	0.10	0.09	0.13	0.14	0.07	0.13
0.11	0.21	0.06	0.05	0.04	0.10	0.07	0.04	0.07
0.09	0.36	0.09	0.07	0.06	0.17	0.10	0.05	0.11
0.07	0.29	0.07	0.07	0.05	0.16	0.08	0.04	0.09
0.06	0.40	0.08	0.07	0.05	0.23	0.09	0.06	0.10
<0.06	0.37	0.06	0.06	0.04	0.23	0.08	0.05	0.06

A2: Destin Dome Block 56

Sample No.	N1	N2	N3	N4	E2	E3	E4	S1	S2	S3	S4
Sediment Weight (gm)	24.13	37.91	43.87	40.98	44.53	48.46	51.02	35.64	42.00	47.80	44.10
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	35.13	4.26	0.92	0.16	29.67	3.41	2.96	48.68	36.11	3.01	3.97
1.40	13.57	1.69	0.81	0.45	29.82	3.12	3.24	19.16	17.28	1.61	2.48
1.00	11.84	2.66	1.43	0.36	15.24	4.55	4.99	12.46	17.10	2.69	4.51
0.71	10.88	2.65	1.97	0.72	8.03	4.99	5.24	7.54	9.90	3.36	5.16
0.50	10.21	5.66	5.75	3.57	7.42	11.57	13.07	4.21	8.18	10.87	13.13
0.43	3.73	6.66	6.73	5.27	2.52	10.60	12.32	1.26	2.74	10.87	11.26
0.36	3.40	13.26	12.53	12.08	2.25	15.73	14.65	1.06	2.63	17.50	17.41
0.30	2.56	15.48	16.72	16.56	1.58	14.88	19.20	0.70	1.98	16.69	14.92
0.25	2.37	20.02	21.67	24.21	1.25	14.88	13.04	0.58	1.53	16.25	14.45
0.21	1.69	16.71	18.96	21.47	0.81	10.36	7.63	0.38	1.00	10.56	8.58
0.18	0.94	7.38	2.78	10.37	0.38	3.98	2.80	0.34	0.48	4.22	3.51
0.15	0.59	2.20	0.52	3.20	0.25	1.23	0.48	0.32	0.29	1.35	1.10
0.12	0.42	0.52	0.57	0.80	0.16	0.32	0.16	0.25	0.16	0.37	0.30
0.11	0.32	0.21	0.16	0.25	0.09	0.11	0.04	0.19	0.09	0.15	0.12
0.09	0.60	0.27	0.15	0.27	0.13	0.12	0.07	0.38	0.13	0.18	0.16
0.07	0.48	0.17	0.07	0.13	0.10	0.06	0.06	0.37	0.09	0.10	0.07
0.06	0.60	0.17	0.06	0.10	0.12	0.05	0.00	0.43	0.12	0.10	0.09
<0.06	0.66	0.17	0.04	0.07	0.16	0.04	0.00	1.67	0.19	0.08	0.07

Sample No.	SW1	SW2	SW3	SW4	W1	W2	W3	W4
Sediment Weight (gm)	40.64	50.22	54.15	55.55	33.89	43.79	42.18	47.97
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	0.61	0.44	0.05	0.46	14.09	1.25	0.31	0.48
1.40	0.61	0.33	0.12	0.29	7.58	0.92	0.17	0.35
1.00	1.25	0.76	0.25	0.56	8.40	11.12	0.45	0.48
0.71	2.25	1.50	0.59	1.14	7.50	1.31	0.96	0.92
0.50	11.18	8.02	4.66	6.52	8.16	5.57	3.61	3.94
0.43	12.56	10.88	8.00	8.87	5.04	7.25	5.25	4.92
0.36	19.14	18.63	16.12	18.17	8.00	15.15	13.03	11.13
0.30	18.28	19.22	19.46	19.32	8.90	16.79	18.93	16.17
0.25	16.92	18.93	23.25	20.39	10.79	20.84	24.27	24.11
0.21	10.60	13.45	17.05	15.09	9.01	18.24	20.79	22.39
0.18	3.98	5.41	7.00	6.18	4.40	7.97	8.76	10.57
0.15	1.32	1.62	2.35	2.15	1.85	2.23	2.47	3.18
0.12	0.37	0.35	0.56	0.47	0.97	0.54	0.51	0.70
0.11	0.16	0.11	0.15	0.13	0.77	0.20	0.14	0.20
0.09	0.24	0.12	0.17	0.13	1.40	0.25	0.16	0.21
0.07	0.15	0.07	0.07	0.05	0.98	0.13	0.07	0.08
0.06	0.18	0.06	0.07	0.06	1.01	0.12	0.07	0.07
<0.06	0.17	0.05	0.05	0.00	1.13	0.11	0.07	0.07

A3: Main Pass Block 255

Sample No.	N1	N2	N3	N4	N6	E1	E2	E3	E4
Sediment Weight (gm)	43.26	38.69	38.12	41.76	45.34	31.21	34.50	33.80	31.86
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	9.79	5.57	4.93	20.94	3.58	21.16	19.30	9.79	14.69
1.40	8.09	6.26	6.01	6.51	4.58	7.02	8.60	7.27	7.31
1.00	17.71	14.81	15.85	14.00	13.17	14.35	16.56	13.60	15.08
0.71	15.88	14.91	15.51	13.43	11.13	13.31	15.33	13.88	13.36
0.50	19.14	21.10	18.57	15.91	13.28	14.09	15.44	17.75	17.28
0.43	7.51	10.18	9.70	7.75	6.55	6.87	6.60	10.15	8.32
0.36	6.60	10.19	9.04	7.05	8.53	6.59	5.92	8.56	8.27
0.30	4.32	5.40	6.11	4.71	7.48	4.15	3.53	5.92	4.57
0.25	3.52	4.11	4.51	3.56	6.86	3.16	2.74	4.26	3.42
0.21	2.64	2.50	2.86	2.16	5.42	2.19	1.76	2.75	2.14
0.18	1.59	1.34	1.59	1.11	4.05	1.29	1.02	1.49	1.17
0.15	1.20	0.94	1.31	0.79	2.87	1.07	0.73	1.14	0.92
0.12	0.58	0.56	0.82	0.45	2.24	0.74	0.47	0.67	0.63
0.11	0.29	0.36	0.53	0.27	1.82	0.56	0.34	0.44	0.44
0.09	0.39	0.63	0.94	0.49	2.94	0.94	0.62	0.78	0.78
0.07	0.28	0.45	0.70	0.36	1.99	0.81	0.50	0.61	0.56
0.06	0.26	0.40	0.58	0.29	1.85	0.96	0.54	0.55	0.59
<0.06	0.19	0.26	0.43	0.20	1.66	0.73	0.34	0.35	0.42

Sample N5 was not analyzed.

Sample No.	S1	S2	S3	W1	W2	W3	W4	Well Head
Sediment Weight (gm)	35.51	30.43	42.10	18.11	36.93	35.07	36.59	47.03
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	46.92	39.77	9.40	25.29	46.10	36.26	44.38	28.35
1.40	5.31	6.44	9.42	6.47	5.92	5.58	5.87	7.57
1.00	10.49	11.05	19.03	13.24	10.01	12.49	10.34	14.06
0.71	8.36	8.45	15.78	10.87	7.91	10.26	9.08	12.08
0.50	9.56	10.22	16.44	14.57	9.77	12.64	10.15	14.65
0.43	4.04	5.08	7.61	6.76	4.23	5.63	4.82	6.62
0.36	3.86	4.99	6.30	6.79	4.52	5.72	4.24	6.09
0.30	2.68	3.40	4.84	4.69	2.95	3.48	2.87	3.37
0.25	2.22	2.77	3.56	3.64	2.25	2.60	2.15	2.51
0.21	1.59	2.14	2.65	2.72	1.59	1.68	1.58	1.56
0.18	1.14	1.31	1.59	1.59	0.95	0.94	0.95	1.10
0.15	0.90	1.02	1.11	1.15	0.82	0.71	0.82	0.48
0.12	0.54	0.60	0.54	0.56	0.54	0.43	0.50	0.36
0.11	0.35	0.38	0.29	0.30	0.36	0.26	0.36	0.26
0.09	0.54	0.69	0.44	0.43	0.64	0.46	0.59	0.29
0.07	0.52	0.57	0.37	0.34	0.51	0.34	0.50	0.22
0.06	0.51	0.61	0.35	0.34	0.50	0.31	0.45	0.20
<0.06	0.44	0.47	0.27	0.24	0.41	0.21	0.33	0.20

A4: Gainesville Block 707

Sample No.	N1	N2	N3	N4	N5	E1	E2	E3	E4	E5
Sediment Weight (gm)	53.16	44.25	34.76	41.50	47.66	41.94	37.02	46.44	46.39	49.99
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	10.92	0.16	0.11	0.00	4.57	10.64	0.71	1.88	2.42	0.00
1.40	8.94	0.20	0.22	0.06	2.04	5.70	0.36	0.66	3.13	0.27
1.00	18.22	1.38	0.59	1.58	3.59	9.59	0.71	2.00	10.48	1.13
0.71	18.69	1.06	1.02	0.22	5.81	11.87	0.94	5.19	16.06	2.35
0.50	18.44	2.61	1.82	0.65	12.73	14.46	2.07	14.43	20.82	6.24
0.43	6.66	2.09	1.22	0.70	8.75	7.59	1.88	9.09	7.87	4.58
0.36	5.30	4.23	2.72	2.02	9.83	7.60	3.78	11.12	6.87	8.45
0.30	3.25	6.91	5.32	4.79	8.36	7.02	6.49	9.49	15.38	10.52
0.25	5.86	15.30	16.95	16.33	10.04	9.25	14.97	14.73	9.22	14.68
0.21	4.86	23.91	33.40	30.53	12.66	8.40	22.09	17.15	4.91	16.45
0.18	1.66	18.54	22.91	20.60	9.53	4.27	17.82	8.04	1.78	11.32
0.15	0.85	10.56	12.96	10.02	5.74	1.87	11.31	3.07	0.57	8.39
0.12	0.39	6.43	5.84	5.07	3.28	0.73	7.58	1.24	0.21	6.73
0.11	0.20	3.03	2.46	2.79	1.38	0.31	4.14	0.63	0.13	3.89
0.09	0.22	2.49	3.07	3.04	0.90	0.31	2.63	0.54	0.03	2.73
0.07	0.15	0.99	1.77	1.44	0.40	0.16	1.20	0.30	0.05	1.25
0.06	0.14	0.57	1.25	1.05	0.24	0.13	0.79	0.25	0.04	0.51
<0.06	0.10	0.28	0.74	0.55	0.12	0.09	0.51	0.18	0.02	0.29

Sample No.	S1	S2	S3	S4	S5	W1	W2	W3	W4	W5
Sediment Weight (gm)	45.20	46.18	47.65	41.91	46.06	49.11	49.94	46.19	45.98	46.85
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	12.34	6.61	7.40	1.32	0.91	16.41	21.14	20.18	2.03	20.04
1.40	12.07	5.72	3.47	0.71	1.18	12.69	6.00	3.48	0.53	8.83
1.00	17.81	9.31	7.30	1.11	5.29	20.13	8.65	4.20	1.15	20.90
0.71	17.04	10.88	7.49	1.57	12.84	18.10	8.24	5.69	1.99	19.65
0.50	16.73	13.40	8.75	3.15	23.77	15.53	10.10	9.38	4.34	15.66
0.43	6.26	6.45	3.87	2.24	12.97	4.98	6.01	5.32	3.01	4.21
0.36	5.01	6.34	5.31	3.67	12.50	3.63	4.70	7.07	5.18	2.97
0.30	3.31	5.80	5.92	5.54	10.59	2.25	4.67	7.59	6.97	2.05
0.25	3.31	8.72	12.00	13.24	9.05	2.08	7.56	11.40	13.66	1.82
0.21	2.97	10.84	16.28	21.54	5.50	2.02	8.72	12.32	20.51	1.60
0.18	1.53	7.45	11.24	18.73	2.33	1.03	5.48	6.70	14.70	0.86
0.15	0.75	3.60	5.62	11.15	1.05	0.52	3.35	3.19	10.44	0.51
0.12	0.31	1.98	2.78	7.48	0.43	0.22	2.02	1.43	6.86	0.22
0.11	0.16	1.01	1.13	4.13	0.20	0.10	1.06	0.67	3.89	0.12
0.09	0.16	0.85	0.82	2.65	0.17	0.12	1.02	0.64	2.82	0.16
0.07	0.09	0.45	0.32	0.96	0.09	0.07	0.57	0.30	1.04	0.12
0.06	0.07	0.35	0.19	0.56	0.07	0.06	0.46	0.25	0.58	0.14
<0.06	0.05	0.21	0.08	0.23	0.04	0.04	0.25	0.16	0.28	0.12

A5: Florida Middle Ground Block 252

Sample No.	N1	N2	N3	N4	N5	E1	E2	E3	E4	E5
Sediment Weight (gm)	42.01	35.49	37.84	39.32	36.79	50.28	39.19	38.99	46.05	39.26
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	6.78	39.56	42.11	8.99	17.12	26.80	1.80	0.98	1.69	0.51
1.40	10.75	22.77	25.58	18.96	12.41	17.96	2.07	1.59	1.01	0.78
1.00	18.13	21.29	18.99	32.62	17.53	19.56	2.43	2.51	1.60	1.18
0.71	16.00	8.90	7.94	21.45	13.64	11.55	2.31	2.44	1.32	1.50
0.50	15.97	4.63	3.57	11.94	12.98	7.14	2.84	3.02	1.66	2.18
0.43	4.81	0.91	0.68	2.10	4.59	2.03	1.72	1.64	0.99	1.29
0.36	4.18	0.53	1.09	1.21	4.04	1.80	2.64	2.17	1.44	1.84
0.30	2.89	0.28	0.13	0.61	2.67	1.39	3.23	2.64	1.82	2.05
0.25	4.05	0.24	0.13	0.50	3.16	1.75	6.91	5.85	5.28	4.62
0.21	5.92	0.29	0.13	0.55	4.38	2.93	13.66	14.41	12.75	9.84
0.18	5.26	0.24	0.10	0.49	3.70	3.27	20.80	21.29	24.53	18.71
0.15	3.60	0.16	0.08	0.36	2.17	2.29	19.41	17.75	24.39	18.74
0.12	1.03	0.06	0.03	0.10	0.59	0.72	9.44	9.10	12.20	13.02
0.11	0.34	0.02	0.02	0.02	0.19	0.20	3.69	3.74	4.11	5.60
0.09	0.12	0.02	0.02	0.02	0.18	0.14	2.49	3.06	2.07	4.41
0.07	0.04	0.02	0.01	0.01	0.14	0.07	1.48	1.76	0.95	3.78
0.06	0.05	0.02	0.02	0.02	0.18	0.08	1.52	2.61	1.09	4.13
<0.06	0.06	0.04	0.03	0.04	0.30	0.10	1.55	3.41	1.09	5.80

Sample No.	S1	S2	S3	S4	S5	W1	W2	W3	W4	W5
Sediment Weight (gm)	44.82	53.19	55.32	40.19	33.33	42.25	43.74	45.96	41.08	47.67
Size Fraction (mm)	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %
2.00	1.46	1.50	0.82	2.85	14.53	11.53	1.26	1.05	1.50	2.17
1.40	1.26	0.97	0.67	1.31	12.27	18.95	1.34	0.97	1.21	1.72
1.00	1.89	2.03	1.07	2.11	17.26	27.68	2.13	1.77	1.97	3.76
0.71	1.96	2.23	1.09	1.80	13.99	14.56	2.72	2.17	1.97	5.03
0.50	2.58	3.59	1.79	2.24	15.24	10.67	5.01	3.59	2.84	8.65
0.43	1.63	2.56	1.39	1.25	6.41	3.10	3.22	2.48	1.87	4.64
0.36	2.39	4.05	2.72	1.88	5.41	2.44	4.30	3.87	2.93	5.47
0.30	2.99	4.34	3.66	2.25	3.32	1.70	5.30	4.49	4.35	5.63
0.25	5.91	10.23	8.54	5.77	3.28	2.23	35.67	12.34	9.84	11.63
0.21	16.38	21.60	19.43	13.95	3.64	3.13	20.98	25.78	23.65	21.27
0.18	23.56	23.03	23.31	23.49	2.49	2.25	11.96	23.67	23.05	16.81
0.15	22.12	14.93	22.37	22.00	1.27	1.31	3.72	12.07	16.57	9.12
0.12	8.26	5.25	7.54	9.87	0.33	0.27	0.70	3.27	4.64	2.45
0.11	2.69	1.41	2.18	3.57	0.10	0.05	0.51	0.76	1.14	0.53
0.09	1.79	0.83	1.00	2.35	0.10	0.03	0.33	0.44	0.81	0.39
0.07	0.98	0.46	0.64	1.04	0.07	0.01	0.00	0.71	0.49	0.39
0.06	1.04	0.41	0.73	0.99	0.10	0.02	0.38	0.00	0.56	0.04
<0.06	1.10	0.56	1.03	1.26	0.19	0.04	0.44	0.54	0.76	0.27

Sample No.	Well Head
Sediment Weight (gm)	36.37
Size Fraction (mm)	Wt. %
2.00	13.67
1.40	13.25
1.00	14.54
0.71	9.88
0.50	8.88
0.43	3.41
0.36	3.74
0.30	3.13
0.25	4.46
0.21	8.04
0.18	7.73
0.15	5.81
0.12	1.88
0.11	0.49
0.09	0.28
0.07	0.19
0.06	0.24
<0.06	0.36

A6: Florida Middle Ground Block 455

Sample No.	N	S	Well Head
Sediment Weight (gm)	19.59	19.24	30.98
Size Fraction (mm)	Wt. %	Wt. %	Wt. %
2.00	3.70	0.88	1.68
1.40	2.18	0.95	1.34
1.00	2.11	0.86	1.77
0.71	2.06	1.30	2.74
0.50	3.99	2.95	7.39
0.43	3.31	2.67	7.34
0.36	4.88	3.98	11.21
0.30	4.79	4.10	12.92
0.25	5.01	4.67	14.36
0.21	5.68	5.15	13.05
0.18	5.33	5.31	9.12
0.15	6.73	8.16	6.89
0.12	7.73	7.54	4.08
0.11	6.28	8.37	1.95
0.09	9.39	10.48	2.13
0.07	9.18	11.62	0.95
0.06	9.33	10.85	0.67
<0.06	8.29	10.31	0.40

*U.S. G.P.O.:1993-301-078;80407

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.