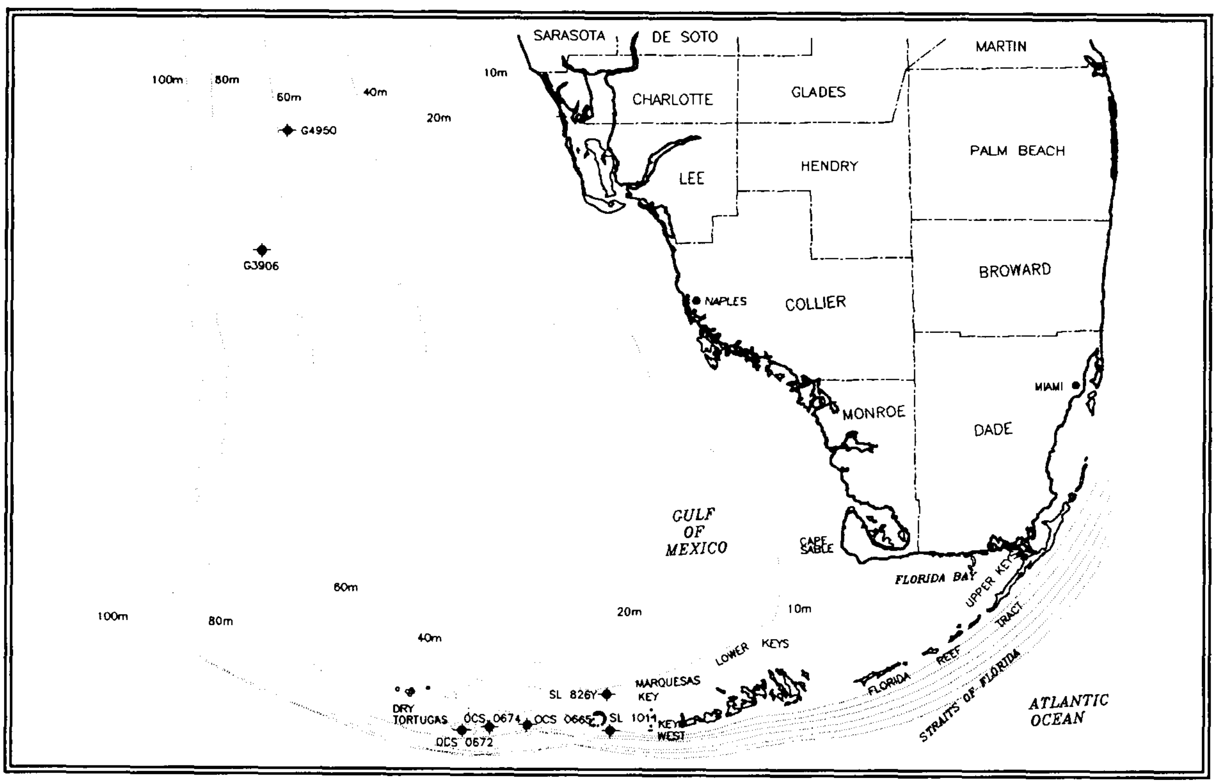
OCS Study
MMS 89-0022

Impact Assessment of Exploratory Wells Offshore South Florida



U.S. Department of the Interior
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Impact Assessment of Exploratory Wells Offshore South Florida

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PREFACE

Concern for environmental effects related to offshore drilling have increased during the past few years as exploration in the Gulf of Mexico has moved southward toward coral reefs, sandy beaches, and mangrove shorelines: environments where the effects of exploratory drilling are little known. Perceived effect is particularly acute in south Florida and the Florida Keys, where the quality of reefs and shores form the base of a proliferating tourist-driven economy. Seven offshore wells were drilled in sensitive environments near Key West, Florida, in the late 1950s and early 1960s; thus, one way to determine the environmental impacts of drilling is to examine the impacts of these past activities. To our knowledge, this site-specific approach has been undertaken only twice in tropical waters; one off the Philippines (Hudson *et al.* 1982) and the other near the Marquesas Keys off Key West (Smith and Hunt 1979).

In the present study, five shallow-water sites, including the one previously examined by Smith and Hunt (1979), and two deep-water sites off the west coast of Florida were examined. Time since drilling ranged from less than 3 to 29 years. Environments ranged from visually barren sand to sea grass to coral reefs and hardbottoms. Water depths ranged from 5 to 70 m (16-230 ft). The five shallow-water sites off Key West were drilled between 1959 and 1962 and could be examined in detail using SCUBA. These five sites were drilled using technology now outdated and before Outer Continental Shelf (OCS) offshore drilling restrictions came into effect. The two deep sites off the west coast of Florida, however, were drilled with modern equipment in 1981 and 1986 (after OCS regulations). A manned research submersible was necessary to examine the deep-water sites.

The focus of this study was to evaluate mechanical and toxic effects on those organisms considered important to the south Florida coral reef ecosystem, namely corals, gorgonians, sea grasses, and fleshy algae. Although observations were made concerning the attraction of fish to artificial reefs created by drilling debris (mechanical effect), no attempt was made to determine toxic effects. Semi-quantitative methods were used at the five sites shallow enough to use SCUBA, and observational data are presented for the two deep sites that required use of a two-person submersible.

Here we describe each of the shallow sites and present observational and statistical data, followed by a discussion of the observations. The deep-water sites are described, then discussed in a similar manner, but without statistical data. The final section is a discussion of the implications of all areas examined.

It should be emphasized that this was a study of the effects of normal exploratory drilling conditions, where there were no blowouts, fires, spills, or other unusual events.

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We thank Jack Kindinger and Harold Hudson of the U.S. Geological Survey, Donna Schroeder of the University of California at Santa Barbara, and Les Dauterive of MMS for their aid during the search phase. We also thank Donna Schroeder for her biological expertise counting and cataloging organisms on the chain transects. Jim Barkuloo of the U.S. Fish and Wildlife Service and Les Dauterive served as observers and helpers during the final phase of study. We were aided on numerous occasions by Murray Brown of MMS, who was our contracting officer's technical representative.

We especially thank Captain Roy Gaensslen of the research vessel ***Captain's Lady***, whose expertise and Loran C equipment were instrumental in finding the drill sites. Harold Hudson designed and constructed search buoys, identified fleshy algae and reviewed early versions of the manuscript. Jennifer Wheaton kindly identified gorgonian specimens.

We thank Captain Joe Newhouse and the crew of the ***R/V Powell***, and Bill Green and Robert Wicklund, Jr., who served as submarine pilots during the submersible diving phase. Robert Wicklund, Sr. of the Caribbean Marine Research Center arranged use of the submersible and the ***R/V Powell.***

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EXECUTIVE SUMMARY

In this investigation, five older and two newer exploration oil well sites were examined to evaluate environmental impacts under tropical conditions. At the time of investigation, elapsed time since drilling ranged from less than 3 years to 29 years and water depths from 5 to 70 m (16 to 230 ft). Environments at the five older sites (two wells were drilled at one site) off Key West (Fig. 1) in the late 1950s and early 1960s (Table 1) ranged from visually barren sand to sea grass and gorgonians to coral reefs. These six wells were drilled before stringent OCS and MMS regulations. The two deep sites examined were drilled in 1981 and 1986 off the west coast of Florida using modern technology and OCS regulations.

Table 1. Well Site Data

Well Name	Loran C TDs	Lat./Long.	Lease Block	Date Drilled	Rig Type	Water Depth (m)	Well Depth (m)	Lessee
SL 1011 No.2	13887.9 43748.5	24.32.07 82.06.25	State 1011	1961	Barge	5	2,354	California Co.
SL 1011 No.3	13887.9 43748.5	24.32.07 82.06.25	State 1011	1962	Pontoon	5	3,917	California Co.
SL 826Y No.1	13905.4 43729.1	24.37.05 82.02.14	State 826Y	1959	Unknown	5	4,481	Gulf Oil Corp.
OCS 0665 No.1	13845.7 43826.8	24.27.06 82.21.40	OCS Block 28	1960	Jackup	11	4,662	Gulf Oil Co.
OCS 0674 No.1	13826.4 43867.9	24.26.01 82.29.18	OCS Block 46	1961	Jackup	23	2,399	Gulf & Calif. Co.
OCS 0672 No.1	13809.8 43903	24.25.13 82.36.02	OCS Block 44	1961	Barge	20	1,429	California Co.
OCS G4950 No.1	13854.67 30348.52	26.18.37.98 83.42.10.99	OCS Block 622	1986	Jackup	70	3,216	Shell Oil Co.
OCS G3906 No.1	13978.88 30587.78	26.49.27.19 83.24.33.20	OCS Block 144	1981	Jackup	53	3,464	Gulf Oil Corp.

Using semiquantitative techniques, we determined whether there had been negative, positive, or no impacts on the various bottom communities with special emphasis on corals, gorgonians, and seagrass beds. We emphasized corals because coral reefs and their associated biota have been considered fragile and threatened by offshore drilling. Quantification of impacts of previous exploration drilling may make impact of future drilling more predictable. For the purpose of prediction, we examined wells drilled at various water depths, on different bottom types under different regulations with a variety of equipment over a variable period of time.

Since evidence of mortality due to drill muds, cuttings, or chemicals could not be detected, our major conclusion is that impacts at both the old and the new sites were mainly mechanical in nature. Obvious mechanical impact occurred at two of the older sites and minor environmental impact occurred at the two more recent deep-water sites (Fig. 3, Table 1) drilled with modern equipment under OCS regulations during the 1980s. Cuttings were not apparent at any site, though traces were detected in the sediment: cuttings did not create a pile that persisted or physically smothered any bottom community. Drill mud was not visually detected and had no apparent long-term effects on the bottom communities.

The sites and environmental impacts are described in brief below.

Site SL 1011 Nos. 2 and 3 (Drilled 1961-1962)

Two adjacent wells were drilled southeast of the Marquesas Keys in 5 m (16 ft) of water. The wells SL 1011 No. 2 and SL 1011 No. 3 were drilled so close together that we treat them as a single site (Fig. 1, Table 1). Well SL 1011 No. 3 was drilled to a depth of 3,917 m (12,850 ft) after well SL 1011 No. 2 was abandoned at 2,354 m (7,723 ft). The type of rig (Fig. 1, Table 1) used to drill well SL 1011 No. 3 required the dumping of many tons of limestone pea gravel to level the bottom. This gravel smothered well SL 1011 No. 2 and approximately one-half hectare (1 acre) of hardbottom gorgonian, sponge, and seagrass community. After well SL 1011 No. 3 reached total depth (TD) and was abandoned, more than 100 cement bags were discarded over the well bore, creating a hardbottom with a geometric complexity and functioning as an "artificial reef." Eight species of coral, 25 species of fish, and numerous invertebrates inhabit the cement-bag pile. The pea-gravel pad away from the cement bags is characterized by fleshy macroalgae and marine grasses, whereas softer sediment that has accumulated on the fringe of the pile supports a *Syringodium/Thalassia* marine-grass community. Because it supports the type of community that likely existed there prior to drilling, the hard bottom (exposed Pleistocene limestone) surrounding the site was examined for comparative purposes. Of all the sites, this one had the largest area affected due to dumping of the pea gravel and cement bags, both of which have permanently altered the substrate. Our methods could not detect evidence of community mortality other than that caused by smothering.

Site SL 826Y No. 1 (Drilled 1959)

This 4,481-m (14,702 ft) well was drilled to the northeast of the Marquesas Keys (Fig. 1, Table 1) in approximately 5 m (15 ft) of water on a rippled sand bottom in an area of strong tidal currents. The thin sand moves with each tide, exposing patches of underlying hard limestone. Due to shifting sand, the bottom supports no obvious biological community. Several tons of drilling debris (metal) and limestone cores had been discarded when the well was abandoned. The debris is encrusted with three species of coral and numerous species of fleshy algae and harbors a reef-fish community typical of that found on shipwrecks and artificial reefs in the area. There was no control area with which to compare this site because it was drilled on visually barren bottom.

Site OCS 0665 No. 1 (Drilled 1960)

This 4,661-m (15,294 ft) well was drilled in 11 m (36 ft) of water on a coral bottom along the outer reef line southwest of the Marquesas Keys (Fig. 1, Table 1). The well was drilled from a large 14-legged jackup rig Fig. 1, Table 1). Each leg crunched into the rock substrate, producing a 4.5-m-diameter (15 ft) depression now filled with coarse-grained rippled sand. In addition, there are two sand-filled anchor scars. Corals have not recruited into either the sand-filled scars or "footprints." The total area of bottom made unsuitable for corals and/or gorgonians by the 14 legs, one well head, and two anchor scars amounts to 406 m^2 (4,365 ft^2), or roughly 10% of an acre.

To determine if coral growth had been affected outside of the foot impact zone, we established two 100-m^2 quadrats and in each identified, counted, and measured species of coral and gorgonians. Both quadrats were situated downcurrent from the well bore (Figs. 8, 9). One was in an area that would have been shaded by the platform, and the other was located immediately adjacent to the well bore but would not have been shaded. During drilling, both quadrat areas should have experienced maximum impact from drill mud and cuttings. All of the 18 species of gorgonians, whose individuals out-numbered corals by 6 to 1, were identified in each quadrat. For controls, two identical quadrats were established in the same water depth on hard bottom approximately 0.4 km (0.25 mi) away. Statistically, the coral and gorgonian fauna, in numbers, size, and species, were essentially the same at both drill and control sites. Species number and diversity were slightly larger in the quadrat adjacent to the well bore, because discarded cables and other debris produced a greater surface area for coral attachment. This site did not function as an artificial reef since it surrounded by natural reef bottom.

Site OCS 0674 No. 1 (Drilled 1961)

This 2,399-m (7,871 ft) well was drilled in 23 m (75 ft) of water on a sandy bottom by the same 14-legged jackup used to drill site OCS 0665 No. 1 (Fig. 1, Table 1). The bottom is a relatively lifeless sandy plain and as such, the rig legs did not produce lasting "footprints" as at site OCS 0665 No. 1. The only debris consisted of a 23-m (77 ft) length of 0.9-m-diameter (36 in.) conductor casing and a cement cube (for a marker buoy).

Any other debris, if present, was undoubtedly buried beneath the sand. Whereas only a few fleshy algae occupy the surrounding sand bottom, eight species of corals and numerous sponges grow on the pipe. The pipe also served as an artificial reef for both fish and lobsters.

Site OCS 0672 No. 1 (Drilled 1961)

This well, which never reached intended depth, was drilled in 20 m (65 ft) of water atop a small coral knoll and was abandoned at a depth of 1,430 m (4,687 ft) because of weather and drilling difficulties. The well was drilled from a floating rig (Fig. 1, Table 1) anchored by large anchors placed on sandy bottom surrounding the coral knoll. The only evidence of drilling was two lengths of 0.9-m-diameter (36 in.) casing and some scattered metal debris. The casings were heavily encrusted and had a higher percentage of coral cover than the surrounding bottom. Mechanical impact to the area was minimal, because the rig was a floater and the large anchors were placed in sand.

Site OCS G4950 No. 1 (Drilled 1986)

This well was drilled from a modern jackup rig in 70 m (230 ft) of water on a flat, sandy bottom populated by a surficial community of coralline algae, small sponges, starfish, and the green alga *Caulerpa* spp. (Fig. 3, Table 1). Grout from the conductor casing produced a mound approximately 1 m (3 ft) high and 10 to 15 m (33-49 ft) in diameter surrounding the well bore. Some debris, including a length of pipe, a piece of grate decking, a chair, two plastic buckets, hundreds of used welding rods, and a pipe wrench lay scattered within a few meters of the grout mound. However, there were no footprints, cuttings pile, or drill muds. Large numbers of sardinelike bait fish, tropical reef fish, and two large groupers lived in and around the well bore. The surficial sand bottom community was permanently buried beneath the grout mound and visual disruption of the community extended out approximately 25 m (80 ft) from the well bore.

Site OCS G3906 No. 1 (Drilled 1981)

This well was drilled from a modern jackup rig in 53 m (175 ft) of water on a visually barren bottom covered with sand (often rippled) only a few centimeters thick (Table 1). Rock outcrops with thick encrusting fauna consisting predominantly of sponges harboring numerous tropical fish protruded through the sand here and there. The well bore consisted of an approximately 1-m-diameter (3 ft) vertical hole in the center of a rock outcrop. Organisms on the rock just centimeters from the well bore appeared similar to those on surrounding natural outcrops. Debris was less obvious than at site G4950 and consisted of metal scraps, small pieces of hose, monofilament fishing line, and a 2-m-long (6 ft) sheet of corrugated steel roofing. Two large groupers, one approximately 36 kg (80 lbs), lived in the bore hole. Schools of unidentified bait fish and large amberjacks up to 30 kg (66 lbs) each hovered over the area. Footprints, cuttings, and evidence of drilling mud could not be found.

Summary and Implications

Of the seven sites (eight wells), three had small-scale but lasting negative impacts. At site OCS 0665 No. 1, the rig legs and anchor scars altered an area of 406 m^2 (4,365 ft^2 or approximately 10% of an acre), an area that could have harbored 520 coral colonies and 2,738 gorgonians, based on their abundance in the measured control quadrats. The surrounding coral and gorgonian communities only a few centimeters away, however, showed no impact.

At site SL 1011 No. 2 and 3, approximately 0.4 hectare (1 acre) of bottom has been permanently altered by the deposition of pea gravel and cement bags and scattered iron debris. Although the bottom communities are different than before drilling, there is today a concentration of fish at the site not found on the surrounding natural bottom.

At the deep-water site OCS G4950 No. 1 drilled in 1986, the 10- to 15-m-diameter grout mound altered the bottom by smothering an algal community. Eventually, a hardbottom community will attach to the grout, whereas the surrounding bottom, which although visually different from the bottom more than 25 m (80 ft) from the site, will recover.

At all other sites, impacts were minimal, and whether impacts were positive or negative depends on point of view. For example, at site SL 826Y No. 1, what was visually barren sand where fish and corals did not grow can now be described as an "artificial reef" composed of encrusted drilling debris. There is now more marine life, including fish, corals, algae, and crustaceans, than exists on surrounding sandy bottom on which the well was drilled. The same statement can be made for site

OCS 0674 No. 1 and the deep-water site at OCS G3906 No. 1. At site OCS 0672 No. 1, impacts whether positive or negative could not be determined.

Our methods failed to detect effects of drilling mud, cuttings, or "chemicals" at any site. There may have been such effects at the time of drilling, but they probably are not measureable at this time. Measureable impacts have been shown to be mainly mechanical and as such can be avoided. By placing rigs on sandy bottom, even if near a reef, no trace of drilling should remain if debris is not thrown overboard.

METHODOLOGY

Location

The first phase of study consisted of locating the five shallow-water sites near Key West, Florida (Fig. 1). These wells were difficult to find because they were drilled before introduction of sophisticated electronic positioning devices, such as Loran C. The Minerals Management Service and the Florida State Bureau of Geology provided copies of drilling permits and well logs as well as latitude and longitude for the sites. Latitude and longitude had been determined at the time of drilling by conventional line-of-sight survey. Latitude and longitude data were converted to Loran C Time Differentials (TDs) and the search conducted from the 50-ft (15 m) vessel ***Captain's Lady***. A flagged buoy was deployed when the presumed site was reached and a magnetometer search then initiated. A grid search pattern was established using the buoy as the focal point. The proton magnetometer was a portable device powered by a 12-volt storage battery. The device printed the degree of magnetic anomaly (expressed as nannoteslas) along with latitude and longitude provided by the Loran C device with which it interfaced. Examples of printouts from four sites are shown in Figure 2. Because several thousand feet of iron casing was left in the earth, a sizeable magnetic anomaly was present at each drill site. When anomalies of the magnitude shown in Figure 2 were detected, buoys were deployed. When an anomaly was consistently encountered on subsequent passes, the bottom was examined using SCUBA. In all cases, anomaly printouts (Fig. 2) proved to be the well sites. Sites were verified by presence of drilling debris: cables, angle iron, drill bits, pieces of casing, and at two sites pieces of discarded rock core. The sites were usually located within 304 m (1,000 ft) of the initial buoy. Bad weather was a recurring problem during this phase of study, which was conducted in the fall.

The two deep-water sites off Ft. Myers (Fig. 3) were drilled in the 1980s; thus, accurate Loran C TDs were readily available. A buoy was deployed when the search vessel reached the proper Loran C TDs and the drill site located by descending along the buoy line in a two-person submersible. In both cases, schools of fish provided cues that led the submersible pilot and observers to the well bore. Sites were located between 30 and 45 m (100-150 ft) of the buoy. The Loran C TDs, latitude and longitude, and other data obtained are shown in Table 1.

Assessment Methods

Chain Transects

No two sites were the same, so methods were frequently modified to suit conditions and time restraints. The basic assessment technique was the so-called chain-transect method, a modification of the traditional line-transect (Loya 1972; Porter 1972). The 10-m-long (33 ft) metal chain used was composed of twisted 1-cm-long wire links. Chain proved superior to line or tape because it sinks, stays in place, and readily conforms to the irregular bottom. The chain is marked with colored tape every 10 cm (4 in.) Once the 10-m chain was placed on the bottom, the genus (and species if known) of coral or algae under each 10-cm mark was recorded on an underwater slate. The raw data for individual species were entered into a personal computer aboard ship and expressed as percent of the number of total counts. Under ideal conditions, 1,000 counts or more are preferable, but limited bottom time often necessitated fewer counts. The chain method was most useful on coral reef sites, where transects were placed as close to the actual drill bore as possible. For control purposes, similar chain counts were made at a distance away from the drill hole, where there was less chance of environmental modification caused by drilling.

At site OCS 0674 No. 1, the only evidence of drilling was a 24-m (77-ft) length of 0.9-m-diameter (36 in.) casing bent at the drill bore so that it lay on a relatively bare sand bottom. Chain transects were run along the entire length of the pipe and the coral species identified. For comparison, similar transects were conducted in the surrounding sand bottom.

The same method was used at site SL 826Y No. 1 near the Marquesas, where there was abundant debris. However, transects were not run on the surrounding bottom there because it was visually barren.

Where there were sufficient chain-count data, such as at site OCS 0665 No. 1, the Shannon Diversity Index (Shannon and Weaver 1949) was calculated both for coral species and coral cover. Shannon Diversity Index numbers are provided at the bottom of Tables 7 and 9-12.

Quadrats

At the coral reef site, labeled OCS 0665 in Figure 1 and Table 1, two 10-m quadrats were established by stretching polypropylene line a few centimeters above the bottom to form a square 10 m (33 ft) on a side. Every coral and gorgonian was identified in each quadrat. The two quadrats were established on opposite sides of the well bore, in areas that would have had maximum exposure to drill mud and cuttings with each tidal change. One quadrat was situated where it was both downcurrent during flood tide and in shadow under the drilling platform. The other quadrat was downcurrent during ebb tide but not shadowed. In addition, two identical 10-m^2 quadrats were established and examined in the same depth of water approximately one-quarter of a mile away. Location of the two control sites was selected by throwing overboard from the starboard and port sides of the boat a 40-m (130 ft) length of line attached to a lead weight. The floating polypropylene line trailed out downcurrent from the weight. The trailing line formed one side of the quadrat. The line was tied to the bottom 10 m downcurrent from the lead weight and stretched for 10 m perpendicular to the current and tied to the bottom again. The remaining 10 m of line was placed parallel to the first and tied to the lead weight to form a nearly perfect 10-m square. The same procedure was used for both control sites.

Radial Transects

Radial-transect lines were established at site SL 1011 Nos. 2 and 3 near the Marquesas. In Table 1, the wells are listed separately. Well SL 1011 No. 2 was abandoned at 2,350 m (7,723 ft), then redrilled (well SL 1011 No. 3) from another drill rig very close to site SL 1011 No. 2. Underwater visibility varied from 2 to 5 m (6 to 16 ft), and tidal currents were strong (approximately 100 cm/sec) except at slack tide. At this site, well SL 1011 No. 3 had been covered with several dozen hardened cement bags, each shaped like standard bed pillows. In addition, pea gravel covering approximately an acre had been dumped to level the bottom. Eight radial transects were established using 50-m-long (164 ft) polypropylene lines marked with tape every 1 m (3.3 ft). The lines were centered at a point in the middle of the cement bag pile thought to be above the well bore. Transect lines were established in the following manner. First, a 50-m line was attached to the center of the bag pile and allowed to trail out with the outgoing tide. The free end was then fixed to the bottom with a lead weight. This line was designated "A." We assumed that in this shallow water where 100-cm/sec tidal currents predominate, effluents from drilling would have taken the same path. The second line, designated "B," was deployed in the opposite direction because this was the path of effluents during the incoming tide. The next two lines were placed perpendicular to the first two transects and designated "C" and "D," and four more were equally spaced between the other four to make a total of eight evenly spaced radial transect lines. The four additional radials were designated "AC," "CB," "BD," and "DA." The layout is shown in Figure 6A. Some lines did not reach beyond the area impacted by pea gravel, so an additional 50 m of line was attached and surveys extended outward until bottom unaffected by pea gravel was reached. The maps in Figures 5 and 6A were prepared from data collected along these survey lines.

Video Surveying

Using SCUBA, we swam each radial transect line at SL 1011 Nos. 2 and 3 and recorded on video and underwater slates those points where epifaunal community changes occurred. Continuous video transects were run along each line in such a way that the bottom community and the meter marks were clearly visible throughout each of the eight transects. Tapes were reviewed aboard the boat and compared with visual data previously recorded on underwater slates. Video was used in a less controlled fashion at all other sites as a way of verifying observations. Fish, which were abundant on and around the bag pile, were visually identified.

Probing

Probing was conducted at site SL 1011 Nos. 2 and 3 to determine a possible relation between grass communities and substrate. The gravel pile was probed every 5 m (16 ft) along each radial transect line using a 1.5-m (5 ft) stainless steel shaft driven with a mallet. In areas away from the epicenter, where changes in sediment thickness were less frequent, probes were made every 10 m. Over 400 probes were made. Gravel and sediment thicknesses (the accumulation is underlain by relatively hard limestone) were recorded to the nearest centimeter. These data allowed the construction of a gravel thickness or isopach map (Fig. 6A).

Photography

Underwater photographs were taken at all sites to document communities, and at site SL 1011 Nos. 2 and 3 overlapping plan view underwater photographs were made to construct a photomosaic of the cement pile. Color aerial photographs and video of sites SL 1011 Nos. 2

and 3 and OCS 0665 No.1 were taken from a small airplane with 35-mm cameras.

Manned Submersible

A PC14 submersible was used at the deep sites off Ft. Myers where water depth precluded use of scuba. The submersible is owned by the Caribbean Marine Research Center and deployed from the 48-m (168 ft) ***R/V Powell***, a converted offshore supply boat. Both sea state and bottom time were limiting, so quantitative methods could not be used. Instead, the area was documented with color video and 35-mm underwater photography. The amount of area affected by drilling was visually estimated.

Sediment Samples

Sediment samples were taken at all sites and examined under a binocular microscope for presence of cuttings. Because much of the geologic section drilled consists of dolomite, dilute HCL could be used to detect dolomite cuttings: dilute HCL does not dissolve dolomite as rapidly as limestone. Cuttings were in the same size range as natural sediment so they were not visually obvious. There was no attempt to quantify their presence. Our estimates show their presence within natural sediment was minimal.

OBSERVATIONS AND RESULTS

Locations of the drill sites are shown in Figures 1 and 3. The companies, kinds of drill rigs, dates, depth of hole, and other data are listed in Table 1. Site SL 1011 Nos. 2 and 3 (Fig. 1, Table 1) is actually the site of two exploratory wells. The first, well SL 1011 No. 2, was drilled to a depth of 2354 m (7,723 ft) using the same floating drill ship used to drill at site OCS 0672 No. 1 but was abandoned because of drilling problems. Later, well SL 1011 No. 3 was successfully drilled to 2,850 m (13,917 ft) at approximately the same location. The rig used to drill SL 1011 No. 3 required leveling of the bottom with a layer of pea gravel. The gravel layer, we believe, covers site SL 1011 No. 2, which could not be visually located but produced a strong magnetic anomaly (Fig. 2). After plugging and abandonment, well SL 1011 No. 3 was covered with several dozen cement bags; thus, although discussed as a single site, two wells were actually drilled there.

Site SL 1011 Nos. 2 and 3

Description of the Site

Four principal community types were identified.

1. Cement bag community, consisting of eight species of corals and a diverse fish population (Fig. 4A, B);
2. Pea-gravel fleshy algae community with one coral species (*Manicina areolata*) and few fish (Fig. 4C);
3. Seagrass community consisting of *Thalassia* spp., *Syringodium spp.*, and *Halodule spp.*, the coral *Manicina areolata*, and

few fish (Fig. 4D);

4. Hardbottom gorgonian community consisting of gorgonians, sponges, corals, and some small tropical fish distinctly different from those of the cement bag community.

The distribution of bottom communities is shown in Figure 5 and thickness of the pea gravel is shown in Figure 6A and B. The percentage coverage of major hardbottom communities on the cement bags and on the hardbottom control area away from the drill site is shown in Table 2.

Table 2

Percent Coverage at Site SL 1011 Nos. 2 and 3 and Control Site

Community Category	Site DE-1 Cement Bags	Control
Corals	26.4	0.2
Gorgonians	0.0	6.9
Sponges	1.3	1.9
Macroalgae	40.7	59.4
Substrate	30.8	31.4

Gorgonians were not growing on the bags or in the general vicinity of the drill site with the exception of a few very small colonies found on some debris scattered about 40 m (131 ft) from the cement pile. They were abundant on the natural hard bottom away from the well site.

Reef-building corals identified on the cement bag pile appeared healthy and are listed in Table 3.

Table 3

Corals on Cement-Bag Pile, Site SL 1011 Nos. 2 and 3

Oculina diffusa
Siderastrea siderea
Porites astreoides
Isophyllastrea rigida
Favia fragum
Millepora alcicornis
Porites furcata
Stephanocoenia michelinii

Data from individual chain-count transects are listed in Appendix A under the heading "Chain Transect Data for Site SL 1011 Nos 2 and 3 and Controls." Chain transects were run only on the cement bags and the pea-gravel bottom immediately adjacent, as well as on the hardbottom surrounding the pea-gravel pile. The location code given as A-c-C or B-c-D indicates the chain was laid parallel to the radial transect lines described in the methods section, which are labeled A, B, C, D, AB, BC, CD, and DA (Fig. 6A). The "-c-" in the location code means the chain transect passed over the center point from which all the plastic radial lines radiated. The four chain transect controls are labeled D/E/1 DSE through D/E/4 DSE. These data were obtained by making four random chain counts on the hardbottom surrounding the pea-gravel pile.

Manicina areolata was the only species observed growing in the sediment or pea-gravel drill pad. *Diploria strigosa, Solenastrea hyades,* and *Porites astreoides* were observed on a piece of cable debris in the seagrass community. Many of the colonies were small and presumed juvenile.

A diverse assemblage of fish was observed on or in the vicinity of the cement-bag pile and is listed in Table 4.

Table 4

Fish on or near Cement-Bag Pile, Site SL 1011 Nos. 2 and 3

Juvenile blue tang - *Acanthurus coeruleus*
Yellow jack (9) - *Caranx bartholomaei*
Nassau grouper - *Epinephelus striatus*
Gray triggerfish - *Balistes capriscus*
Grunts (abundant) - *Haemulon* spp.
Red grouper (7 kilos) - *Epinephelus morio*
French angelfish (12) - *Pomacanthus paru*
Gray snapper - *Lutjanus griseus*
Cleaning goby - *Gobiosoma genie*
Black grouper (2) - *Mycteroperca bonaci*
Porkfish - *Anisotremus virginicus*
Slippery dick (abundant) - *Halichoeres bivattatus*
High-hats (abundant) - *Equetus acuminatus*
Surgeon fish (abundant) - *Acanthurus bahianus*
Beaugregory - *Pomacentrus leucastictus*
Queen angelfish (small) - *Holacanthus ciliaris*
Butterflyfish (2 kinds) - *Chaetodon* spp.
Hogfish - *Lachnolaimus maximus*
Porgy - *Calamus calamus*
Puffer (juvenile) - *Canthigaster rostrata*
Spotted moray - *Gymnothorax moringa*
Green moray - *Gymnothorax funebris*
Nurse sharks (2 under cement slab) - *Ginglymostoma cirratum*

Observations on the Algae

A fleshy algal community dominated the pea-gravel pile substrate surrounding the cement bag pile. Similar species of algae, but in lesser numbers, were observed growing attached to the bedrock in the natural hard substrate gorgonian community. No sea grasses were observed living on the pea gravel in the immediate vicinity of the cement bag pile but occurred sparsely mixed with fleshy algae on the gravel pile farther away. The fleshy macroalgae community is listed in Table 5.

Table 5

Fleshy Macroalgae Community, Site SL 1011 Nos. 2 and 3

Penicillus capitatus
Penicillus dumetosus
Caulerpa ashmeadii
Acetabularia crenulata
Rhipocephalus phoenix
Codium spp.
Dicthyota cervicornis
Laurencia poitei
Heterosiphonia gibbessi
Ceramium rubrum
Cymopolia barbata
Udotea spinulosa
Padina vickersiae
Batophora oerstedi
Stypopodium sp.
Halimeda opuntia
Halimeda discoidea
Halimeda incrassata
Cyanophyte algal mats
Avrainvillea sp.
Lobophora variegata

Twelve species of octocorals were identified on the gorgonian-sponge hardbottom community surrounding the pea-gravel and sediment pile. They are shown on the octocoral species list in Appendix A. Forty-two species have been identified from southeast Florida in water less than 30 m (98 ft) deep. The terms "gorgonians" and "octocorals" are used interchangeably throughout the text.

The most common sponges were the large loggerhead sponge, *Specioasperia verparia*, and various vase or basket sponges.

Discussion of Site SL 1011 Nos. 2 and 3

The placing of many tons of pea gravel and the cement bags, rather than the actual drilling, permanently altered the environment at this site. Alteration of the original substrate by pea gravel and cement bags resulted in a biological community considerably different from the hardbottom gorgonian community that existed before drilling. The four principal community types we recognized at the site are substrate specific and, whereas all the species can be found in the neighboring natural hardbottom community, the dominance of different groups varies. The cement bags provide a stable substrate for coral and sponge colonization, and the resultant geometric complexity results in increased fish diversity. The cement bags therefore act as an artificial reef attracting a diverse community of fish, in marked contrast to low diversity and numbers of fish in the surrounding pea-gravel, seagrass, or natural hardbottom gorgonian community. The absence of gorgonians on the cement bags is not understood but may result from fish predation as fish were continually observed nipping at the bags.

The near golf ball-size pea gravel in the vicinity of the cement bag pile supports the community of fleshy algae listed previously. Away from the cement bag pile, the pea gravel becomes slightly finer. The finer grained substrate supports a *Thalassia/Syringodium/Halodule* seagrass community, which becomes quite dense and thick (up to 50 cm high; see Fig. 4D). Perhaps the establishment of these vascular plants is prevented near the bag pile because their roots cannot "penetrate" the pea-gravel "soil," whereas farther away the gravel is finer and has more sediment in the pore spaces. There is no stable hard substrate in the grass to support corals. However, one species of sediment-dwelling coral (*Manicina* sp.) was observed. Farther off the pea-gravel pile, where the sediment becomes thin or absent (3-0 cm), the gorgonian-sponge hardbottom community predominates. The dominant organisms (gorgonians and sponges) rise almost a meter off the hard-rock substrate and greatly increase geometric complexity of the environment. The gorgonian community includes a large number of sponges, in contrast to those few found on the bags.

An "ecological halo" was observed at the edge of the cement bag community: a thinning of the vegetation, presumably from grazers which range out from the bag pile to forage. Such halos are common features of tropical patch-reef environments (Randall 1961), and the presence of a halo supports the suggestion that the pile of hardened cement bags serves as an "artificial reef." We also observed a "reverse ecological halo," or transition zone, at the edge of the gorgonian hardbottom community, suggesting that members of the hardbottom community forage into the edges of the seagrass community. Observation and underwater photographs taken prior to the Caribbean-wide die-off of the herbivorous urchin *Diadema* spp. show a much more barren bottom surrounding the cement-bag pile. Before 1983, the crevices between bags were densely populated by *Diadema* spp. *Diadema* are herbivores that range into the open at night to graze on algae.

From a recovery/recolonization point of view, the site will never return to pre-drilling conditions, because the pea gravel, although it may shift slightly during storms, has permanently altered the physiography and substrate.

Site SL 826Y No. 1

Description of the Site

This site is located in approximately 5 m (16 ft) of water on the Gulf side of the Marquesas (Fig. 1, Table 1). The site is on bedrock covered by a thin veneer of mobile sand. The location is littered with drilling debris (Fig. 7A, B) overgrown by a variety of organisms, mostly fleshy algae and turf algae. Horizontal underwater visibility is seldom greater than 3 m (10 ft), often much less, and tidal currents are severe.

Chain transects were conducted on the debris in an attempt to characterize the encrusting community (see Table 6 and tables in Appendix A). Chain transects were not made outside the debris-littered area due to the limited epifaunal community of the sandy substrate. Several dead corals attached to debris had apparently been killed by accumulation of shell hash and shifting sand. Octocorals were not present. To determine the extent of debris coverage, a 360^0 sweep of the area was made by three divers. Between a distance of 40 and 50 m from the center of the debris field, no debris was seen, only sand and exposed rock. Calcrete-coated Pleistocene bedrock was sporadically exposed within and outside the debris field and could be found everywhere by digging in the sand by hand.The actual drill hole was not found. Numerous pieces of Cretaceous limestone core among the debris proved this was the drill site. The percent coverage of communities derived from chain-transect data in Appendix A is given below in Table

6. Five individual chain counts (Appendix A) provided a total of 345 "counts."

Table 6

Percent Coverage on Debris at Site SL 826Y No. 1

Community Category	Well Site Debris Area
Corals	2.2
Sponges	16.6
Macroalgae	50.7
Algal turf	15.6
Substrate	14.9

Discussion of Site SL 826Y No. 1

This site was not studied as extensively as other sites because of bottom conditions and paucity of the natural community. The natural bottom at 826Y is subjected to strong tidal currents and shifting sands. Sand ripples were observed to be moving with each tide, sporadically covering and uncovering the bedrock. Shifting sand had prevented attachment of sessile organisms; thus, macroepifauna was not observed on the bottom. There were few macroepifauna or fish in this area that would have been affected by drilling. The encrusting biomass observed is dependent on the hard substrate provided by the scrap iron and the rock cores. Although a species list was not compiled, there were abundant fish. The fish community was dominated by grey snapper, grunts, and triggerfish. Lobsters were also observed hiding in the debris. Macroalgae were basically of the same species identified at site SL 1011 Nos. 2 and 3.

Site OCS 0665 No. 1

Description of the Area

By far the most interesting, significant, and thoroughly studied site was OCS 0665 No. 1 (Fig. 1, Table 1). The well at site OCS 0665 No. 1 was drilled on the reef tract in 11 m (36 ft) of water. Although the reef cannot be considered lush or thriving, all the common reef-building corals, except *Acropora palmata*, were present (see table of Florida reef corals in Appendix). Other studies (Jaap 1984; Shinn 1988; Shinn *et al.* 1989) have noted that coral growth deteriorates progressively from Sand Key Reef off Key West to the Dry Tortugas. The paucity of reef development is attributed to sporadic chilling from central and northern Gulf of Mexico waters, which often inundate the area (Shinn *et al.* 1989). The relative lack of reef development in the area was demonstrated by core drilling. By using a diver-operated hydraulic coring device, we drilled to a depth of 6.1 m (20 ft) at well site OCS 0665 No. 1. Recovered core showed the Holocene reef sediments to be 4 m (13 ft) thick at this site. Most major Holocene reef accumulations in the Florida Keys are more than 10.6 m thick (35 ft) (Shinn *et al.* 1977; Shinn *et al.* 1989).

The majority of corals living in the area are of small size. However, scattered in this region are *Montastraea annularis* heads 1 to 2 m (3-6 ft) high. They are usually situated hundreds of meters apart. Growth-band measurements (Hudson 1981) show heads of this size are between 100 and 200 years old. For the most part, however, head and branching corals throughout this area are seldom more than 30 cm (12 in.) high, and massive species are on the order of 4 to 10 cm (1.5-4 in.) in diameter. Our measurements in four different 10-m^2 quadrats show that living corals cover only 1 to 3% of the surface, whereas coral cover on reefs off Key Largo may exceed 50%. These observations of small coral size, especially that of the rapidly growing branch coral *Acropora cervicornis,* indicates sporadic mortality. Death may be related to incursions of colder Gulf waters (an extensive die-off of *A. cervicornis* was documented during the unusually cold winter of 1977 at the Dry Tortugas; Porter *et al.* 1982) or the effects of hurricanes. *Acropora cervicornis* easily attains a height of 1 m in 10 years off Key Largo (Shinn 1966), but in this area colonies more than 30 cm (12 in.) high were not found. *Acropora cervicornis* colonies observed during this study were probably not more than 3 years old. This background is considered important for interpreting the significance of data collected at site OCS 0665 No. 1 and nearby control areas.

Description of the Site

The 4,662-m (15,294-ft) well drilled to the Lower Cretaceous Sunniland Zone at site A was drilled from Offshore 52, a jackup rig supported by 14 legs. Each leg was fitted with a 4.5-m-diameter (15 ft) foot pad. When the platform was jacked out of the water, these pads crunched into the reef, producing circular depressions 5 to 30 cm (2-12 in.) deep and 15 ft in diameter. When the rig was removed, the depressions partially filled with coarse carbonate sand. Corals have not become established in the sand-filled holes during the 28 years since the well was drilled. Because of the white circular sand holes, the site is clearly visible from the air (Fig. 8). Configuration of the circular sand-filled depressions matches exactly a photograph of the rig published in the Oil and Gas Journal (1960). An additional 15-ft-diameter sand-filled hole is located at the exact position of the drill derrick in the Oil and Gas Journal photograph and can be seen in Figure 8, 9, 10E. Excavation at the well bore to a depth of 0.6 m (2 ft) did not reveal casing, but a large 2.54-cm-diameter (1 in.) cable fitted with an 20-cm-diameter (8 in.) black rubber bushing extended downward into the center of the sand hole. The sand surrounding the well bore indicates the conductor pipe for the drill string was fitted with a pad similar to that on the legs. Debris surrounds all the sand-filled depressions, including the well bore, which themselves are free of debris (Fig. 10E).

In addition to the 15 circular sand-filled "footprints," there are two linear scars located approximately 30 m (98 ft) from the main site. The sand-filled scars are clearly visible in the aerial photograph in Figure 8. Because of their shape, we concluded they are not natural, and underwater examination showed that the scar closest to the drill site contained a cement buoy anchor (Fig. 10C). The cement anchor is identical to the one found at site OCS 0674 No. 1, which was drilled with the same rig (see Figs. 11 and 12A). We suspect the features are anchor scars created by supply boats. According to the well log, the platform was in place during Hurricane Donna; thus, scarring may have occurred then. Scars may have been made by the platform legs during the jacking up process; however, our measurements show the scar width to be variable, unlike the circular footprints, which are uniformly the same diameter.

For the most part, there is little coral growth in the scars. However, isolated growths were seen on rocky debris scattered randomly within the sand-filled features. To determine the surface area of the scars, we measured the width at 1.5-m (5 ft) intervals. Length was measured with a fiberglass tape. Scar number 1 (closest to the drill site) is 27.4 m (90 ft) long and covers 71 m^2 (764.5 ft^2); scar number 2 is 42.7 m (140 ft) long covers 93 m^2 (1,000.5 ft^2). The total area affected by both scars is 164 m^2 (1765 ft^2), or roughly 40% of the total foot-pad scar area, which is 242 m^2 (2,600 ft^2). Thus, the total bottom area at this site that has not recovered in the 28 years since drilling is 406 m^2 (4,365 ft^2).

Biological Assessment

Two quadrats, described earlier in the methods section, were established at site OCS 0665 No. 1. The location of the 10-m^2 quadrats is shown in Figure 9. Note in Figure 9 that quadrat A-l immediately adjacent to the well bore is located downcurrent when the tide is flowing from the Gulf, and A-2, located farther from the well bore, was in the shade of the platform and downcurrent when the tide was flowing from the Atlantic. That diurnal tides flow in these directions was confirmed while working at the site. These two quadrats therefore are located where drill mud and cuttings would have had maximum impact on the bottom. Quadrat A-2 would have experienced both shade and drilling effects.

Three 10-m chain transects were conducted within each quadrat, and the maximum and minimum diameters of all corals within the quadrats were measured. Individual chain-count data are presented in tabular form in Appendix A. The coral measurement data were used to calculate the area covered by coral (cm^2), based on the assumption the coral colonies approximate an ellipse (A = XY * Pi). This tends to overestimate the aerial coverage of branching corals but otherwise seems to be a reasonable approximation.

The total number of gorgonians in each quadrat was counted, except in quadrat A-1 where a subsample of the area was measured and the total number calculated based on counts from a 1- x 10-m section within the quadrat. Gorgonians were photographed, and a voucher sample was taken by cutting a tip for later species identification. Gorgonian species are listed in the octocoral faunal list in Appendix A. Eighteen different species were identified at well site OCS 0665 No. 1 and 13 species were found at the nearby control quadrats.

Two control quadrats were examined using identical methods approximately 0.4 nautical miles west of site OCS 0665 No. 1 in the same water depth. Selection and establishment of the quadrat sites is described in the methods section. At both control sites, coral populations and colony sizes were similar, and the gorgonian communities looked to be the same as that at the well site.

Summary data from quadrats A-1 and A-2 and control site quadrats C-1 and C-2 are given in Table 7, and a species list of corals and fish is given in Table 8.

Table 7

Percent Coverage at Site OCS 0665 No. 1 and Control Site

	Well Sites		Controls	
Hardbottom Community Category	A-1	A-2	C-1	C-2
Coral	8.7	4.1	8.9	3.4
Sponges	5.3	1.2	0.9	3.5
Gorgonians	3.5	15.9	7.8	5.4
Sediment/Substrate	77.8	78.4	82.3	86.0
Debris (Cable, etc.)	4.0	0.0	0.0	0.0

Summary of Quadrat Survey for Site OCS 0665 No. 1 and Control Site

Number of Coral Species	20.0	11.0	19.0	14.0
Percentage Coral Cover	2.3	1.1	2.9	2.0
Number of Coral Colonies	123.0	73.0	147.0	111.0
Shannon Species Diversity:				
Based on Number of Colonies	2.64	1.85	2.17	1.95
Based on Species Coverage	2.16	1.71	1.82	1.78
Number of Gorgonian Colonies in Each Quadrat	739	569	668	690

Table 8

Species of Corals in Area of Site OCS 0665 No. 1

Acropora cervicornis
Porites porites
Meandrina meandrites
Porites astreoides
Helioseris cucullata
Montastraea annularis
M. cavernosa
Mussa angulosa (baby)
Siderastrea siderea
Dichocoenia stokesii
Millepora alcicornis
Stephanocoenia michelinii
Diploria clivosa
Solenastrea sp. *(hyades?)*
Manicina areolata
Colpophyllia natans

Corals on Debris near Wellhead Site

Colpophyllia natans
Diploria clivosa
Eusmilia fastigiata
Porites furcata
Isophyllastraea rigida
Siderastrea siderea
Oculina diffusa
Montastraea cavernosa
M. annularis
Acropora cervicornis
Porites astreoides

Fish on and around Well Site

Queen angelfish - *Holacanthus ciliaris*
Gray angelfish - *Pomacanthus arcatus*
Bicolor damselfish - *Pomacentrus partitus*
Honey damselfish - *Pomacentrus mellis*
Trunkfish - *Lactophrys trigonus*

Yellow stingray - *Urolophus jamaicensis*
Spotted goatfish - *Pseudopeneus maculatus*
Spotfin butterflyfish - *Chaetodon ocellatus*
Blue tang - *Acanthurus coeruleus*
Yellow jack - *Caranx bartholomaei*
Mackeral - *Scomberamorus regalis*
Barracuda - *Sphyraena barracuda* (2 large, with juvenile barjacks -*Caranx ruber*)
Blue chromis - *Chromis multilineatus*
Parrotfish - *Scarus* spp.
Hogfish - *Lachnolaimus maximus*
Bluehead wrasse - *Thalassoma bifasciatum*
Yellowhead wrasse - *Halichoeres garnoti*
Harlequin bass - *Serranus tigrinus*
Black grouper - *Mycteroperca bonaci* (2 15-lbs)
Beaugregory - *Pomacentrus leucostictus*
Yellowhead jawfish - *Opistognathus auraifrons*
Wrasse (2 unidentified spp.)
Porgy - *Calamus calamus*
Surgeon fish - *Acanthurus bahianus*
Damselfish (2 unidentified spp.)
Blenny (unidentified sp.)
Puffer - *Canthigastera rostrata*
Neon goby - *Gobiosoma oceanops*
Gray snapper - *Lutjanus griseus*

Specific data regarding coral species, number, size, and percent cover for quadrats A-1 and A-2 and control sites 1 and 2 are shown in Tables 9-12.

Table 9

Coral Summary Data for 10-m^2 Quadrat A-1

Species	N. Col. (n)	Size (cm^2)	Cover (cm^2)
Isophyllastrea rigida	3	108.9	326.7
Eusmilia fastigiata	1	47.1	47.1
Porites astreoides	16	202.2	3235.1
P. furcata	2	42.4	84.8
Agaricia agaricites	11	57.4	631.5
Porites porites	5	56.4	282.0
Siderastrea siderea	23	54.7	1257.4
Acropora cervicornis	9	949.5	8545.1
Colpophyllia natans	4	23.0	91.9
Meandrina meandrites	6	276.5	1658.8
Diploria labyrinthiformis	1	125.7	125.7
Oculina diffusa	3	95.3	285.9
Montastraea annularis	2	204.2	408.4
Favia fragum	7	10.1	70.7
Solenastrea spp.	1	1099.6	1099.6
Stephanocoenia michelinii	2	132.3	264.7
Dichocoenia stokesii	10	203.3	2032.6
Montastraea cavernosa	11	122.7	1349.3
Diploria clivosa	4	192.8	771.3
Cladocora arbuscula	2	42.4	84.8

Total Surface Area of Colonies (cm^2) = 22,653.24
Percentage Coral Cover in 10-m^2 Quadrat = 2.3
Total Number of Species of Corals = 20
Total Number of Colonies = 123
Coral Species Diversity (Number) = 2.636
Coral Species Coverage (Coverage) = 2.163

Table 10

Coral Summary Data for 10-m^2 Quadrat A-2

Species	N. Col. (n)	Size (cm^2)	Cover (cm^2)
Dichocoenia stokesii	16	240.6	3849.2
Montastraea cavernosa	10	200.8	2008.2
Siderastrea siderea	25	114.3	2858.7
Porites porites	1	37.7	37.7
P. furcata	1	113.1	113.1
P. astreoides	10	102.1	1021.0
Oculina diffusa	2	66.4	132.7
Isophyllastrea rigida	2	16.1	32.2
Solenastrea spp.	1	219.9	219.9
Acropora cervicornis	2	392.7	785.4
Stephanocoenia michelinii	3	65.2	195.6

Total Surface Area of Colonies (cm^2) = 11,253.72
Percentage coral cover in 10-m^2 Quadrat = 1.1
Total Number of Species of Corals= 11
Total Number of Colonies = 73
Coral Species Diversity (Number) = 1.847
Coral Species Diversity (Coverage) = 1.708

Table 11

Coral Summary Data for 10-m^2 Quadrat, Site OCS 0665 No. 1, Control 1

Species	N. Col. (n)	Size (cm^2)	Cover (cm^2)
Dichocoenia stokesii	32	262.3	8394.1
Porites astreoides	23	72.2	1660.7
Manicina areolata	6	75.7	454.0
Montastraea cavernosa	26	178.1	4630.9
Meandrina meandrites	1	131.9	131.9
Siderastrea siderea	32	62.	2009.6
Oculina diffusa	6	376.5	2258.8
Scolymia cubensis	2	9.8	19.6
Isophyllastrea rigida	1	10.2	10.2
Madracis decactis	1	47.1	47.1
Stephanocoenia michelinii	3	8.1	24.3
Colpophyllia natans	4	2137.9	8551.4
Mussa angulosa	2	9.8	19.6
Eusmilia fastigiata	2	15.7	31.4
Acropora cervicornis	2	483.8	967.6
Agaricia agaricites	1	75.4	75.4
Unidentified	1	4.7	4.7
Porites furcata	1	12.6	12.6
P. porites	1	50.3	50.3

Total Surface Area of Colonies (cm^2) = 29,354.38
Percentage Coral Cover in 10-m^2 Quadrat = 2.9
Total Number of Species of Corals = 19
Total Number of Colonies =147
Coral Species Diversity (Number) = 2.171
Coral Species Diversity (Coverage) = 1.820

Table 12

Coral Summary Data for 10-m^2 Quadrat, Site OCS 0665 No. 1, Control 2

Species	N. Col. (n)	Mean Size (cm^2)	Cover (cm^2)
Mussa angulosa	1	848.2	848.2
Acropora cervicornis	1	37.7	37.7
Favia conferta	2	17.3	34.6
Porites furcata	5	30.8	153.9
Manicina areolata	1	47.1	47.1
Eusmilia fastigiata	1	18.8	18.8
Stephanocoenia michelinii	2	25.5	51.1
Solenastrea spp.	2	1137.3	2274.5
Montastraea cavernosa	18	335.1	6031.9
Oculina diffusa	3	23.0	69.1
Agaricia agaricites	1	314.2	314.2
Porites astreoides	17	153.5	2608.7
Dichocoenia stokesii	28	204.9	5737.3
Siderastrea siderea	29	78.0	2263.3

Total Surface Area of Colonies (cm^2) = 20,490.38
Percentage Coral Cover in10-m^2 Quadrat = 2.0
Total Number of Species of Corals = 14
Total Number of Colonies = 111
Coral Species Diversity (Number) = 1.947
Coral Species Diversity (Coverage) = 1.776

Of the 41 species previously identified off Key Largo and the 39 at Dry Tortugas (Appendix A), 30 were present in the vicinity of drill site OCS 0665 No. 1. A list of octocorals present at this site is compared with those for the entire reef tract in Appendix A. Gorgonians outnumber corals approximately six to one (Table 7).

Fish

Site OCS 0665 No. 1 is located on the reef tract and therefore did not offer more geometric complexity than the surrounding bottom except locally around piles of cable. There was no noticeable artificial reef effect for fish. Site OCS 0665 No. 1 does not offer a central debris pile surrounded by visually barren bottom, as at sites SL 826Y No. 1 or SL 1011 Nos. 2 and 3. The list of fish species (Table 8) was therefore compiled by identifying fish in the general area - within approximately 50 m (165 ft) of the well bore. A similar list for fish was not compiled for control sites AC-1 and AC-2, but visual observation suggests the same numbers and species as at the drill site.

Discussion of Site OCS 0665 No. 1

Other than physical effects caused by the legs and bore hole casing, and the coral-, algal-, gorgonian-, and sponge-encrusted debris, the area at and around site OCS 0665 No. 1 supports a hardbottom community essentially the same as that in the surrounding area. Data from the two control quadrats confirm similarity of species, number, and percent coral, sponge, and gorgonian cover. Corals at both control and drill sites cover between 1 and 3% of the substrate. The community is visually similar to the deeper water coral community seaward of the major reefs off Key Largo in the Key Largo National Marine Sanctuary.

Some of the most striking organisms in the area are large, brown, basket sponges (Xestospongiae spp., Fig. 10E). It was thought these 1-m-high sponges would serve as sediment traps and thus contain drill mud or cuttings trapped in their basal tissues. Two specimens were dissected in a search for cuttings, but none were found. Further investigation revealed many of the larger specimens growing on drilling debris (cables, etc.), suggesting that all the sponges in the area had grown since drilling and thus could not contain drill cuttings. Sponges growing on debris therefore are 28 years old or younger.

Lack of coral colonies greater than 30 cm (12 in.) high both at the drill and control sites suggests that all the corals and possibly all other organisms are less than 28 years old (Figs. 10B-E). One might argue that the entire community was killed by drilling and therefore all the organisms grew since the rig moved away. Our data do not disprove this supposition because most all of the organisms are younger than 28 years old. What we can say is that size and species composition at both control quadrats are essentially the same as those at the drill site. It is possible that many small heads and branch corals were killed during drilling. However, for this to be valid, the dead corals would have to have been bioeroded and/or encrusted over, while new corals were being recruited. There is slightly greater coral species diversity at the drill site quadrat A-1 simply because debris, mainly cables, provides additional attachment area not provided by the natural bottom (Fig. 10D; Table 7). Clearly, the debris left by drillers was not toxic to corals, gorgonians, sponges, or fish.

Hudson *et al.* (1982) examined a drill site on coral bottom in the Philippines 18 months after drilling and found little mortality directly attributed to drill mud and cuttings. At the Philippine site (Hudson *et al.* 1982), as at site OCS 0665 No. 1 in Florida, the most devastating effects were physical. The drill rig foot pads and, more significantly a heavy anchor chain holding a marker buoy, caused the most damage. The anchor chain had made 360^0 sweeps of the bottom during heavy weather and completely scoured the bottom free of live corals, creating a visually barren zone approximately 15 m (49 ft) in diameter. Similar coral-free chain-swept areas can be observed under navigational buoys on the Florida reef tract.

Mechanical damage at site OCS 0665 No. 1 is clearly recognizeable and easily measured (Figs. 8, 9, 10A, E). The 15 circular sand-filled depressions, each 4.56 m (15 ft) in diameter, amount to a total of 242 m^2 (2,600 ft^2), and the two scars total 164 m^2 (1,765 ft^2), making a grand total of 406 m^2 (4,365 ft^2), or approximately 10% of an acre that has not been recolonized by coral and gorgonian growth in the past 28 years. Based on the average number of corals and gorgonians in both control areas, each of which is 100 m^2, we calculate that 520 coral colonies and 2,738 gorgonians were killed in the 406-m^2 area of the sand-filled footprints and anchor scars. Eventually, corals may colonize the depressions, but when that might occur is impossible to determine. In an area of vigorous coral growth, recolonization would occur faster than at site OCS 0665 No. 1, which, as discussed earlier, is one of marginal growth punctuated sporadically by widespread mortality.

We are unable to explain fully the fate of cuttings that should have accumulated during drilling. Typically, a well of this depth (4,662 m) would produce several thousand barrels of cuttings. Because the geological section in south Florida is basically limestone and dolomite with very little shale, cuttings should be similar to the natural lime sand and resistant enough to prevent degradation. In predominately sand-and-shale areas, such as the northern Gulf of Mexico, cuttings are soft and readily degraded to silt and mud sizes easily removed by currents. Microscopic examination of sediment from the well-bore scar revealed a few percent dolomite cuttings, but they are in the same size range as the natural reef sand. The general lack of cuttings accumulation at all sites will be discussed later.

Site OCS 0674 No. 1

Description of the Site

Well site OCS 0674 No. 1 is in 23 m (75 ft) of water and located beyond sight of land (Fig. 1, Table 1). The 2,399-m (7,871 ft) well was drilled with Offshore 52, the same rig used to drill site OCS 0665 No. 1. At site OCS 0674 No. 1, however, the bottom is coarse carbonate sand and any "footprints" made by the 14 legs could not be discerned from surrounding bottom. Debris also was not observed but may exist buried beneath sand. A sketch of the site is shown in Figure 11. Only two objects mark the site. A cement cube approximately 0.6 m (2 ft) on a side was completely buried in sand (Fig. 12A). The cube has a steel eye to which was attached approximately 13 m (10 ft) of algae-encrusted light chain and 30 m (100 ft) of 1.3-cm (0.5 in.) nylon line. Next to the cement cube is a 91-cm-diameter (36 in.), 23.5-m-long (77 ft, 2 in.) piece of casing lying on the sand bottom oriented in a northeast-southwest direction (Fig. 12B). The northeast end is bent and turns downward into the sediment. Shallow digging by fanning away sediment and probing with a rod showed the pipe continued downward. The southeast end of the pipe is cut square and contains an inner pipe 51 cm (20 in.) in diameter. The annulus between the 91- and 51-cm-diameter pipes is filled with cement (Fig. 12C). Two 5-cm-diameter (2 in.) "eye" holes are located opposite each other on this end of the inner pipe. Because of the large magnetic anomaly and mention of 91-cm-diameter conductor pipe with cemented 51-cm-diameter inner casing, described in the drilling report, we conclude this was without question the drill site. Apparently, when the site was abandoned, the pipe had been partially severed with explosives near the sediment/water interface, allowing it to bend and fall to the bottom. The cement cube within a few feet of the bore hole was undoubtedly a buoy anchor.

As would be expected, numerous fish had concentrated around the pipe since it is surrounded by visually barren sand. No attempt was made to compile a complete fish species list due to depth and limited bottom time.

Data Collection

Chain transects were conducted along the length of pipe and on sandy bottom approximately 10 m from the pipe. Percent cover data are summarized in Table 13 below and species abundance is provided in the Appendix tables. A partial species list of fish is provided in Table 14.

Table 13

Percent Coverage at Site OCS 0674 No. 1

Community Category	Site C Pipe	Control Sediment
Corals	13.9	0.0
Sponges	22.3	0.5
Macroalgae	0.0	37.0
Sediment/Substrate	62.9	62.5

Table 14

Fish in or near Pipe, Site OCS 0674 No. 1

Gobies (white, on sand) - ?
Hogfish - *Lachnolaimus maximus*
French angelfish - *Pomacanthus paru*
Grunt - *Haemulon album* (regular, white)
Rock beauties - *Holacanthus tricolor*
Small tropicals (several species)
Lobster - *Panularis argus* (in pipe)
Slipper lobster - *Seyllarus americanus*
Cubera snapper - *Lutjanus analis*
Queen angelfish - *Holacanthus ciliaris* (juvenile)

Discussion of Site OCS 0674 No. 1

From an ecological perspective, the pipe functions as an artificial reef, both for sessile and swimming organisms. Although there was no cuttings pile, we did detect dolomite cuttings (less than 5%) and up to 30% grey to black limestone chips, many of which are probably cuttings. How far they extend outward from the site is not known. Snorkeling over several thousand meters of surrounding bottom during the initial search on a day when the bottom was visible from the surface indicated sandy-bottom conditions throughout the area. Even at this depth, severe waves, especially those caused by hurricanes, would be capable of spreading sediment.

The cement cube was completely buried, as indicated by at least 0.6 m (2 ft) of sedimentation since the well was drilled. Sandy bottom and rapid sedimentation would explain why drill-rig footprints or drilling debris were not detected. Had sediment burial not occurred, any debris from drilling may have enhanced the "artificial reef" effect.

Site OCS 0672 No. 1

Description of the Site

Well site OCS 0672 No. 1 is located in the approximate center of a coral knoll surrounded by sandy bottom (Fig. 14). Depth at the top of the knoll is 20 m (65 ft), and the surrounding sandy bottom ranges from 24 to 30 m (80 to 100 ft) depth . Site OCS 0672 No. 1 is the westernmost drill site on the Florida reef tract (Fig. 1, Table 1) and is located approximately 65 km (40 mi) west of Key West. The unsuccessful well was drilled from the same floating drill ship used at site SL 1011 No. 2, described earlier. Because the drill rig was on a ship, anchors held it in position. The wide spread of the anchors required for this depth apparently resulted in their being placed on the sandy plain surrounding the knoll. According to well log records, the rig was forced off location several times because of inclement weather. The well never reached planned total depth and was abandoned at 1,429 m (4,687 ft) because of numerous problems.

A large magnetic anomaly like those shown in Figure 2 identified the site. Two lengths of 91-cm-diameter conductor pipe (one 3 m in length and the other approximately 10 m long) along with scattered pieces of encrusted debris confirmed the location (Fig. 15A). However, the exact well bore could not be located by diving. Abundant coral and gorgonian growth most likely obscured the actual bore hole, and because there were no scars from legs, such as at site OCS 0665 No. 1, visual clues for locating the precise bore hole were lacking. The bottom surrounding the conductor pipes appeared typical of other reefs in the area. The major changes in bottom community were caused by increasing depth near the outer fringe of the knoll, where the bottom gradually turns to a sandy plain.

Because of the rugged relief, a meter or more, the two pipes and scattered debris did not provide any more geometric diversity for fish than the surrounding natural bottom, although one 20- to 25-kg (44-55 lbs) black grouper occupied the larger conductor pipe.

Site OCS 0672 No. 1 is near the Gulf Stream, and large ships pass in close proximity. The surrounding sandy bottom area is large, as indicated by shrimpers observed dragging nets at night. Shrimp boats occasionally anchor on the coral knoll, and one lost anchor of the type used by shrimpers was observed lodged in coral.

Tidal currents of approximately 10.3 cm/sec were common, and visibility fluctuated from 5 to 20 m (16-65 ft). Colder, turbid, green water generally blanketed the bottom, while water above was clear, blue, and warmer. The colder green water appeared typical of Gulf of Mexico coastal areas, whereas surface waters were similar to those of the nearby Gulf Stream.

Data Collection

The community was surveyed by conducting chain transects on the encrusted pipe and surrounding natural substrate. Gorgonians, algae, and fish species were observed. A species list for fish was not prepared, but those observed appeared typical of those usually found on tropical coral reefs.

Data on percent cover by organisms are given in Table 15, and a breakdown of species is provided in tables in Appendix A.

Table 15

Percent Coverage at Site OCS 0672 No. 1

Community Category	Well Site B Pipe	Natural Control
Corals	22.2	12.0
Gorgonians	0.8	8.3
Sponges	0.8	10.4
Macroalgae	2.5	39.9
Substrate	73.5	30.3

Discussion of Site OCS 0672 No. 1

Although corals tended to be larger at site OCS 0672 No. 1 than at site OCS 0665 No. 1, we observed fewer species (18 as compared to 25 at site OCS 0665 No. 1). This may be the effect of deeper water (20 m, or 65 ft) at the shallowest point compared to 11 m (36 ft) at site OCS 0665 No. 1. Between site OCS 0672 No. 1 and the Gulf of Mexico to the north, the water for the most part is 15 m (50 ft) deep or deeper, whereas an east-west shelf, called the Quicksands, which for the most part is less than 6 m (20 ft) deep, separates site OCS 0665 No. 1 from the Gulf. Site OCS 0672 No. 1, therefore, is more likely to be flushed by unimpeded Gulf coastal waters than site OCS 0665 No. 1. Colder water, which we observed on all dives, tends to blanket the bottom. On one occasion, the tide changed and flowed toward the Straits of Florida; the water was noticeably colder than that at the beginning of the dive and visibility was much reduced. On a diving excursion away from the drilling debris down to a depth of 23 m (75 ft), the water became uncomfortably colder and more turbid. Areas not occupied by coral were coated with lush growths of the brown alga *Dictyota* spp. We conclude that the reduced numbers of coral species and thick growth of algae are a result of deeper, colder waters and reduced light penetration, rather than any effects of drilling that took place 28 years earlier. In view of the depth and poor water quality, we were nevertheless impressed with the richness and relatively larger size of corals (Fig. 15B). *Acropora cervicornis,* generally restricted to warm shallow waters, was present.

Had the coral knoll been larger, the drill ship's anchors would have been placed on coral bottom and mechanical damage undoubtedly would have occurred. Because of the small size of the knoll, we believe the anchors were placed in the sand surrounding the knoll.

Neither cuttings nor natural sediment blanketed the bottom at site OCS 0672 No. 1. Coarse, poorly sorted carbonate sand was found only in natural low areas or pockets, and a sample collected from one of these accumulations contained traces of dolomite (less than 1% and approximately 40% gray to black grains), indicating that some drill cuttings were present. Again, as noted elsewhere, the cuttings are in the same size range as the natural reef sand. During drilling, cuttings undoubtedly blanketed portions of the bottom, as they probably did at the other sites, but at some time were redistributed into low areas. We conclude there were no lasting mechanical impacts of the drilling at site OCS 0672 No. 1, such as that documented at site OCS 0665 No. 1, and if there were impacts from drill fluid and cuttings, we do not know how they could be measured.

DEEP-WATER WELL SITES OFF WEST FLORIDA

The locations of two well sites examined west of Ft. Myers, Florida, are shown in Figure 3 and Table 1. Because of depth and distance from shore, examination necessitated use of a large vessel and a two-person submersible (Fig. 16A). Due to expense and weather conditions, time was limited and precluded use of semi-quantitative analyses, although an attempt was made to deploy the measuring chain from the submersible's articulated arm. In lieu of semi-quantitative methods, still photographs and continuous color video were taken from the forward submersible ports at both sites. Description of the sites is therefore based on visual impressions, notes, and review of video and still photographs.

Site OCS G4950 No. 1

The level bottom community at this site in 70 m (230 ft) of water consists of *Caulerpa* spp., bright red star fish, coralgal nodules and plates, and scattered golf ball- to tennis ball-size bright orange sponges (Fig. 17A,B). It is basically an algal community. Water visibility was greater than 20 m (65 ft) at the surface. At a depth of approximately 45 m (150 ft), the clear blue water turned greenish brown and visibility dropped to a little over 10 m (33 ft). Bottom water contained numerous small particles visible with the naked eye.

The community (shown in Figure 17A and B) is unattached, surficial, and easily disturbed. The submersible keel and propwash made a noticeable trail in the bottom community, which allowed the pilot to backtrack and navigate the site more efficiently. During one of three dives, an attempt was made to deploy the chain and obtain statistical measurements. Although using the chain proved unworkable, it showed how easily the surficial community can be disrupted. Note in Figure 17B that the biological community was swept clear simply by dragging the chain laterally.

The sediment that supports the mainly algal community is at least 60 cm (2 ft) thick. Bedrock was not exposed in the bottom of several 60-cm-deep depressions observed near the site. The depressions were oval-shaped, 1 to 2 m (3-6 ft) in longest dimension, and contained an accumulation of transported algae and sponges in their conical-shaped bottom. The origin of the depressions, which were observed as far as 50 m (164 ft) from the well bore, could not be discerned. A 15-cm-deep (6 in.) furrow originated at one depression and was traced for several tens of meters. If the furrow was made by a dragging anchor, it would have been a small anchor (in the 20 to 40 kg, or 44 to 88 lbs range) probably not associated with the drilling operation. The trail may have been made by the anchor or a towed underwater-camera sledge deployed from a small vessel during an unpublished post-drilling survey. Although the well was drilled from a jackup rig, footprints could not be found.

The drill site was found by following several large amberjack and a dense school of unidentified sardinelike fish usually referred to as "bait fish." The first positive signs of drilling activity were short lengths of used welding rods. Other evidence included a length of yellow painted pipe (Fig. 16C), a 1-m-long (3 ft), 50-cm-wide (20 in.) yellow steel grate, two plastic buckets, and a short piece of coiled hose (see Fig. 18 for a sketch of the area). The well bore (Fig. 16B) was located in the center of a 10- to 15-m-diameter (33-49 ft) mound of white sediment approximately 2 m (6 ft) high. Due to murky water, a panorama photograph of all the objects was not possible. The sketch in Figure 18 depicts the mound and surrounding well site area.

The well head consisted of a 1-m-high cement column, or mushroom-like donut (Figs. 16B, 18). The well bore is approximately 1 m in diameter. The walls of the donut were approximately 30 cm (1 ft) thick and water currents had scoured sediment away from the base at one side (see Figs. 16B and 18). A large school of sardinelike bait fish hovered over the well bore and two groupers (weighing approximately 10 kg, or 22 lbs) periodically swam in and out of the hole. The bottom of the hole could not be seen and fish would disappear for several minutes into the opening.

The mound of fine plaster-of-Paris-like sediment contained pebbles and fist-size lumps, which easily crushed in the collecting-arm claw (Fig. 17C). A large pipe wrench lay on the flank of the mound, which was littered with hundreds of used welding rods. Some of the lumps may have been well cuttings, but most appeared to be semi-consolidated clumps of grout used to cement casing. A cuttings pile, which should have accumulated within 50 m 164 ft) of the well bore, could not be found.

Discussion with petroleum engineers has confirmed that the donut-mushroom-shaped mound (Figs. 16B, 18) was indeed grout. When a casing or conductor pipe is first spudded in, cement is pumped down the hole and allowed to flow back up the annulus on the outside of the pipe to form a seal. After the grout sets, drilling commences and grout in the pipe is drilled out. In this case, the cement flowed back to the surface and formed a mound surrounding the conductor casing. When the well was abandoned and plugged, the casing was pulled, leaving only the cement donut and circular mound.

Effect on the Bottom Community

The algal/sponge community, like that shown in Figure 17A and B, was covered by the cement donut and grout pile. The diameter of the covered area is estimated to be 10 to 15 m (33-50 ft). The natural community surrounding the mound was less dense than 25 m (82 ft) away from the mound. The area of visual disturbance extended radially approximately 25 m from the grout mount. Beyond 25 m and as far away as at least 200 m (656 ft), the bottom community appeared the same and looked much like that in Figure 17A. Organisms partially blanketed by sediment or drill mud were not observed, even within the disturbed area close to the grout mound. The total area visually affected was approximately 50 m in diameter. Within the 50-m-diameter area, the bottom community was completely obliterated only in the 10- to 15-m-diameter area of the central grout mound. The debris mentioned earlier was scattered within the 50-m-diameter area affected as depicted in Figure 18.

Discussion of the Site

Lack of a cuttings pile or observable cuttings in the sediment was not anticipated, and we cannot fully explain their absence from a site drilled less than 3 years earlier. Tidal currents apparently dissipated cuttings and drill mud during drilling. In this depth, drill muds would probably drift several or even dozens of kilometers before reaching the bottom. Cuttings, however, should fall nearby. It should be noted that at least two hurricanes have passed the area since the well was drilled. However, storms strong enough to disperse cuttings would have also dispersed the surficial bottom community. An unpublished study using remote cameras conducted at the site 24 hours after the rig departed failed to locate the well bore, debris, or to show conclusive evidence of cuttings. Thin layers of mud were seen in that study but were less than predicted by numerical dispersion models. As noted earlier, the community there is an unattached surficial one lying on coarse, poorly sorted carbonate sand and is easily disturbed.

Site OCS G3906 No. 1

The location of this well site is shown in Figure 3 and Table 1. The site is closer to shore, the water shallower 53 m (175 ft) than at site OCS G4950, and the bottom conditions totally different. Visibility at the bottom was good; however, the well bore was considerably more difficult to locate.

The bottom consists of a thin layer of medium grain-size carbonate sand, in some places rippled, on flat, highly bored and solution-riddled limestone. Sporadic patches of rock 5 to 20 m (16-65 ft) wide protrude 15 to 30 cm (6-11 in.) above the sand. All the rock highs observed were populated by a diverse, brightly colored sponge community. Tropical fish were abundant and concentrated on the rock highs, especially in and around the numerous solution holes. However, limited bottom time precluded taxonomic study and preparation of a fish species list. The surface appears karstic and was probably leached by fresh waters when world-wide sea level was more than 100 m (328 ft) lower than present, approximately 15,000 years ago (Curray, 1965; Milliman and Emery, 1968). Similar karstic limestones have been documented on and offshore west Florida and are summarized in Davis and Hine (1989).

The well bore at this site was located directly in the center of a low-lying rock area (Fig. 19). There were various small bits of metal (Fig. 19C), a few welding rods, small pieces of hose, monofilament fish line, and a sheet of corrugated roofing metal around the well bore.

There was no cement donut or grout mound at the well bore. The well bore consisted of an approximately 1-m-diameter circular hole surrounded by sponge-covered bedrock (Fig. 19A, B). Two groupers, one weighing at least 36 kg (80 lbs), occupied the well bore and large amberjacks hovered over the site and occasionally swam in and out of the hole. Clouds of small sardinelike fish and tropicals made it difficult to see down into the hole. However, the bottom of the sediment-plugged hole was visible 4 or 5 m (13-16 ft) down. The two large groupers occupied a side tunnel or solution hole, which led off to one side near the bottom of the hole. Several welding rods littered the immediate area but were not in the well bore.

Discussion of the Site

Negative impact on the biological communities was not apparent at this site. Most of the bottom was visually barren sand before drilling, and there was no grout mound or cement donut to cover and smother hardbottom communities. Because of the hard limestone, less grouting may have been required to set casing. Drilling debris was less apparent, possibly because the drilling occurred 5 years earlier than at the other deep-water site (Table 1). Welding rods, which are abundant around active drill and production platforms, had probably oxidized. The community that occupied the bedrock into which the well had been drilled appeared visually the same as that on undrilled rock highs in the area.

There was no sign of a cuttings pile or evidence of drill mud. This was clearly an area of higher energy than at OCS Lease No. 4950, Well No. 1. The sandy sediment was rippled, indicating the presence of currents. Thus, drill mud would not be expected to settle or remain on the bottom. Tidal currents were noticeable but not strong enough to move sediment ripples during our period of observation. Footprints were again searched for but not found. The area of drill activity, i.e., debris including welding rods, did not cover an area larger than 50 m in diameter. Any biological effect on bottom communities, even those on the rock community just centimeters from the well bore, was not detectable 6 years after drilling took place. Fish biomass at this site, as at the previous site, is probably greater than before drilling took place due to the artificial reef effect of the well bore. At this, as well as the previous site, fish took refuge in the well bore when approached by the submersible.

SUMMARY AND IMPLICATIONS

At all seven sites examined, including those drilled in the 1980s, measureable environmental perturbation was limited to mechanical effects. Mechanical effects include crushing of reef substrate by drill rig legs and anchor scars at OCS site 0665, smothering of communities by grout as at OCS site G4950, or pea gravel as at SL site 1011, or presence of debris, such as at OCS sites 0665, 0672, 0674, and SL sites 1011, and 826Y. Debris was also present at OCS sites G4950 and G3906 but in minor amounts. In no area was there evidence of corals, gorgonians, or algae killed by drilling fluids or cuttings. There were no conspicuous dead coral heads present at any site. Had organisms been killed by drill fluids or cuttings during drilling at the older sites off Key West, there is probably no way to detect it today. At present, the communities at those sites are similar to those at control areas, except at SL site 1011, where tons of pea gravel permanently altered the bottom, and at OCS site 0665, where drill rig legs and anchors scarred the reef rock, thereby making 406 m^2 of bottom unsuitable for coral and gorgonian growth. At OCS site G4950, the mound of grout smothered an algal community 10 to 15 m in diameter and an area approximately 50 m in diameter was temporarily altered. Only in the grout mound area, however, is the effect permanent. The surrounding area is little affected. There was no permanent damage detectable at OCS site G3906.

At two sites, SL 826Y and OCS site 0674, drilling took place on sand bottom, where pre-drilling epifaunal communities were minimal at best. In both areas, drilling debris created a artificial reefs; thus, a much larger biomass, including corals, exists there now than before drilling.

The same statement can be made for fish at both deep sites, OCS G4950 and OCS G3906. The surrounding level bottom at OCS G4950 is not a suitable habitat for bottom fish and few were seen. At the well head and surrounding debris, however, fish were abundant, so abundant that they were detected on fathometer traces.

We were most astounded by the lack of drill cuttings mounds at all sites, especially at the more recent sites in deep water. At shallow sites on or near reefs off Key West, their absence was anticipated because the effect of storms in such shallow water periodically redistributes natural sediment (Perkins and Enos 1968; Ball *et al.* 1967). Likewise, the absence of drill mud at the shallow sites was also expected. Mud will settle only during the calmest of conditions on a reef and would be quickly removed by day-to-day wave action and tidal currents.

Drill mud and cuttings were expected, however, at the deep-water sites, especially at OCS G4950 drilled less than three years before our study. As noted earlier, the sandy bottom there supports a fragile surficial algal commuunity that could not exist in shallower areas where normal wave oscillatory currents would cause frequent disruption and redistribution. Thus, we fully expected to find an accumulation of cuttings at this site since a 3,216-m-deep (10,500 ft) well should produce several thousand barrels of cuttings. Undoubtedly, cuttings were present (they are in the same size range as the natural sediment), but they clearly did not form a mound. The only mound observed was the grout mound surrounding the well bore. A localized cuttings mound would probably form only if "shunted" through a pipe to the bottom. Apparently, cuttings were not shunted and normal currents dispersed them before they reached the bottom 70 m (230 ft) below. Since cuttings had not accumulated, then clearly drill mud composed of particles in the micromillimeter range would be widely dispersed.

Documentation of the artificial-reef effect of drilling debris highlights a curious sociological aspect of offshore drilling. That operational platforms in the Gulf of Mexico accumulate vast numbers of fish and support a multimillion-dollar sports fishing industry is well known, but the effects of debris left by drilling were not anticipated. Monroe, Dade, and Broward Counties in Florida, along with other counties in the state, spend large amounts of money to support artificial reef-building activities in which derelict ships, culverts, road-building materials and even old oil well platforms are discarded in designated areas to attract fish. When the older wells were drilled off Key West before adoption of stringent dumping regulations, drillers inadvertently produced artificial reefs similar to those being constructed today. The artificial-reef effect was most noticeable where debris had been dumped on visually barren sand. Even at site SL 1011 Nos. 2 and 3, where the pea gravel has permanently altered local ecology, the combination of pea gravel and the dozens of hardened cement bags supports a larger and more diverse fish community than exists on the natural bottom.

With present technology and stringent dumping regulations, however, drilling can be accomplished without leaving a trace. For example, the well at site OCS 0665 No. 1, if relocated 100 m (328 ft) to the north (see Fig. 8), would have been on sand bottom similar to that at site OCS 0674 No. 1. On sand (as shown by study of site OCS 0674, which was drilled with the same rig), the jackup rig would leave no lasting footprints, and if no metal debris was discarded, only a well bore would be left. The well bore would fill with sand, leaving only a magnetic anomaly to mark the spot.

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APPENDIX A

This Appendix contains, in tabular form, both chain counts and percentage data. The last line in each table provides the total number of "points" or "counts" from which the data are derived.

Two tables are provided at the end. One is a coral species list for Florida and shows which species were observed at each of the shallow-water sites. A similar table shows gorgonians found in the Keys and at two of the shallow-water sites.

Table A-1

Chain Transect Data for Well Site OCS 1011 Nos. 2 and 3 and Controls

Coral Species or Community	Counts	Percent Cover
Transect A-c-C Cement Bags		
Favia fragum	1	1.05
Siderastrea siderea	3	3.16
Porites furcata	1	1.05
Millepora alcicornis	16	16.84
Oculina diffusa	1	1.05
Pea gravel	4	4.21
Cement bag	16	16.84
Fleshy macroalgae	53	55.79
Total Number of Points	95	
Transect B-c-D Cement Bags		
Favia fragum	1	1.06
Siderastrea siderea	1	1.06
Porites astreoides	4	4.26
Millepora alcicornis	20	21.28
Pea gravel	5	5.32
Sponge	4	4.26
Cement bag	12	12.77
Fleshy macroalgae	47	50.00
Total Number of Points	94	
Transect DA-c-B Cement Bags		
Siderastrea siderea	5	4.85
Porites astreoides	1	0.97
Millepora alcicornis	24	23.30
Pea gravel	5	4.85
Sponge	1	0.97
Cement bag	42	40.78
Fleshy macroalgae	25	24.27
Total Number of Points	103	

Transect DC-c-A Cement Bags		
Siderastrea siderea	3	2.88
Stephanocoenia michelinii	2	1.92
Porites astreoides	1	0.96
Millepora alcicornis	21	20.19
Pea gravel	23	22.12
Cement bag	20	19.23
Fleshy macroalgae	34	32.69
Total Number of Points	104	
Transect D/E/1-DSE Control		
Millepora alcicornis	2	1.82
Sediment/substrate	34	30.91
Sponge	2	1.82
Gorgonian	11	10.00
Fleshy macroalgae	61	55.45
Total Number of Points	110	
Transect D/E/2-DSE Control		
Sediment/substrate	35	32.71
Sponge	4	3.74
Gorgonian	7	6.54
Fleshy macroalgae	61	57.01
Total Number of Points	107	
Transect D/E/3-DSE Control		
Sediment/substrate	28	26.42
Sponge	2	1.89
Gorgonian	6	5.66
Fleshy macroalgae	70	66.04
Total Number of Points	106	
Transect D/E/4-DSE Control		
Millepora alcicornis	1	0.93
Sediment/substrate	38	35.51
Gorgonian	6	5.61
Fleshy macroalgae	62	57.94
Total Number of Points	107	

Table A-2

Chain Transect Data for Well Site SL 826Y No. 1

Coral Species or Community	Counts	Percent Cover
Transect PD-1 Debris		
Siderastrea siderea	3	4.35
Algal turf	31	44.93
Sponge	24	34.78
Fleshy macroalgae	11	15.94
Total Number of Points	69	
Transect PD-2 Debris		
Algal turf	1	3.70
Sponge	3	11.11
Fleshy macroalgae	23	85.19
Total Number of Points	27	
Transect PD-3 Debris		
Siderastrea siderea	2	4.44
Millepora alcicornis	1	2.22
Algal turf	9	20.00
Sponge	1	2.22
Fleshy macroalgae	32	71.11
Total Number of Points	45	
Transect DS-1 Debris		
Algal turf	31	32.29
Sessile invertebrates	3	3.13
Sediment/substrate	12	12.50
Sponge	12	12.50
Fleshy macroalgae	38	39.58
Total Number of Points	96	
Transect DS-2 Debris		
Algal turf	16	14.81
Sessile invertebrates	10	9.26
Sediment/substrate	13	12.04
Sponge	24	22.22
Fleshy macroalgae	45	41.67
Total Number of Points	108	

Table A-3

Chain Transect Data, Well Site OCS 0665 No. 1 and Controls 1 and 2

Coral Species or Community	Count	Percent Cover
Transect 1-A1		
Porites astreoides	1	0.86
Millepora alcicornis	1	0.86
Sediment/substrate	94	81.03
Sponge	10	8.62
Gorgonian	3	2.59
Debris, cables, etc.	5	4.31
Fleshy macroalgae	2	1.72
Total Number of Points	116	
Transect 2-A1		
Acropora cervicornis	2	2.99
Montastraea cavernosa	1	1.49
Diploria clivosa	1	1.49
Isophyllastrea rigida	1	1.49
Porites porites	1	1.49
P. astreoides	3	4.48
Millepora alcicornis	2	2.99
Sediment/substrate	47	70.15
Sponge	2	2.99
Gorgonian	3	4.48
Debris, cables, etc.	4	5.97
Total Number of Points	67	
Transect 3-A1		
Solenastrea spp.	2	1.77
Diploria clivosa	1	0.88
Porites astreoides	1	0.88
Millepora alcicornis	3	2.65
Meandrina meandrites	2	1.77
Sediment/substrate	93	82.30
Sponge	5	4.42
Gorgonian	4	3.54
Debris, cables, etc.	2	1.77
Total Number of Points	113	

Transect Control 2-1

Montastraea cavernosa	1	0.95
Siderastrea siderea	2	1.90
Dichocoenia stokesii	1	0.95
Porites astreoides	2	1.90
Millepora alcicornis	1	0.95
Sediment/substrate	90	85.7l
Sponge	2	1.90
Gorgonian	6	5.71
Total Number of Points	150	

Transect Control 2-2

Solenastrea spp.	3	2.83
Porites astreoides	2	1.89
Sediment/substrate	95	89.62
Sponge	3	2.83
Gorgonian	3	2.83
Total Number of Points	106	

Transect Control 2-3

Montastraea cavernosa	2	1.94
Porites astreoides	1	0.97
Millepora alcicornis	1	0.97
Sediment/substrate	85	82.52
Sponge	6	5.83
Gorgonian	8	7.77
Total Number of Points	103	

Transect 1-A2

Porites astreoides	1	0.89
Sediment/substrate	102	91.07
Gorgonian	9	8.04
Total Number of Points	112	

Transect 2-A2

Siderastrea siderea	1	0.94
Dichocoenia stokesii	1	0.94
Millepora alcicornis	4	3.77
Sediment/substrate	76	71.70
Gorgonian	24	22.64
Total Number of Points	10	

Transect 3-A2

Montastraea cavernosa	2	1.90
Siderastrea siderea	1	0.95
Dichocoenia stokesii	1	0.95
Millepora alcicornis	2	1.90
Sediment/substrate	76	72.38
Sponge	5	4.76
Gorgonian	18	17.14
Total Number of Points	105	

Table A-4

Chain Transect Data from Well Site OCS 0674 No. 1

Coral Species or Community	Counts	Percent Cover
Transect C/1-PDC Pipe		
Solenastrea spp.	1	0.93
Siderastrea siderea	3	2.78
Millepora alcicornis	1	0.93
Oculina diffusa	8	7.41
Cladocora arbuscula	2	1.85
Sediment/substrate	67	62.04
Sponge	24	22.22
Gorgonian	2	1.85
Total Number of Points	108	
Transect C/2-PDC Pipe		
Stephanocoenia michelinii	3	3.19
Millepora alcicornis	1	1.06
Oculina diffusa	9	9.57
Sediment/substrate	60	63.83
Sponge	21	22.34
Total Number of Points	94	
Transect C/1-DSC Control		
Sediment/substrate	65	65.00
Algal mat	34	34.00
Red crustose algae	1	1.00
Total Number of Points	100	
Transect C/2-DSC Control		
Sediment/substrate	61	60.40
Sponge	1	0.99
Fleshy macroalgae	11	10.89
Algal mat	26	25.74
Dictyota spp.	2	1.98
Total Number of Points	101	

Table A-5

Chain Transect Data for Well Site OCS 0672 No. 1 and Surrounding Substrate

Coral Species or Community	Counts	Percent Cover
Transect B/1-PDB Pipe		
Siderastrea siderea	3	10.34
Stephanocoenia michelinii	1	3.45
Porites astreoides	1	3.45
Oculina diffusa	1	3.45
Sediment/substrate	23	79.31
Total Number of Points	29	
Transect B/2-PDB Pipe		
Siderastrea siderea	3	5.08
Porites astreoides	2	3.39
Millepora alcicornis	8	13.56
Oculina diffusa	1	1.69
Sediment/substrate	40	67.80
Sponge	1	1.69
Gorgonian	1	1.69
Fleshy macroalgae	3	5.08
Total Number of Points	59	
Transect B/1-DSB Natural Substrate		
Montastraea annularis	5	5.26
Montastraea cavernosa	3	3.16
Siderastrea radians	1	1.05
Millepora alcicornis	1	1.05
Sediment/substrate	15	15.79
Sponge	11	11.58
Gorgonian	7	7.37
Fleshy macroalgae	52	54.74
Total Number of Points	95	

<u>Transect B/3-PDB Natural Substrate</u>

Mycetophyllia aliciae	2	2.08
Montastraea cavernosa	2	2.08
Siderastrea siderea	1	1.04
Madracis decactis	4	4.17
Millepora alcicornis	3	3.13
Meandrina meandrites	1	1.04
Sediment/substrate	43	44.79
Sponge	7	7.29
Gorgonian	9	9.38
Fleshy macroalgae	24	25.00
Total Number of Points	96	

Table A-6

Coral Species in Areas of Study

Species	Dry Tortugas	Key Largo	Well Sites SL 1011 Nos. 2, 3	 OCS 0665	 OCS 0672	 OCS 0674	 SL 826Y
Acropora palmata	*	*					
A. cervicornis	*	*	-	*	*	-	-
Mycetophyllia lamarckiana	*	*					
M. ferox	*	*					
M. danana	*	*					
M. aliciae	*	*	-	-	*	-	-
Solenastrea hyades	*	*	*	*	*	*	-
Agaricia agaricites	*	*	-	*	*	*	-
A. lamarcki	*	*					
A. fragilis	*	*					
Helioseris cucullata	*	*	-	*	*	-	-
Colpophyllia natans	*	*	-	*	*	-	-
C. breviserialis	*	*					
Scolymia cubensis	*	*	-	-	-	*	-
S. lacera	*	*					
Mussa angulosa	*	*	-	*	-	-	-
Montastraea annularis	*	*	-	*	*	-	-
M. cavernosa	*	*	-	*	*	-	-
Dendrogyra cylindrus	-	*					
Manicina areolata	*	*	*	*	-	-	-
Favia fragum	*	*	*	*	-	-	-
Siderastrea radians	*	*	-	-	*	-	-
S. siderea	*	*	*	*	*	*	*
Dichocoenia stokesii	*	*	*	*	*	*	-
D. stellaris	*	*	-	-	*	-	-
Stephanocoenia michelinii	*	*	-	*	*	*	-
Deploria strigosa	*	*	*	-	-	-	-
D. clivosa	-	*	-	*	-	-	-
D. labyrinthiformis	*	*	-	*	-	-	-
Isophyllia sinuosa	*	*					
Isophyllastraea rigida	*	*	*	*	-	-	-
Porites porites	*	*	-	*	-	-	-
P. astreoides	*	*	*	*	*	-	*
P. furcata	-	*	*	*	-	-	-
Madracis spp.	*	*					
M. decactis	*	*	-	*	*	-	-
Millepora alcicornis	*	*	*	*	*	*	*
M. complanata	*	*					
Eusmilia fastigiata	*	*	-	*	-	*	-
Oculina diffusa	*	*	*	*	*	*	-
Cladocora arbuscula	*	-	-	*	-	-	-
Meandrina meandrites	*	*	-	*	*	*	-
* = Present; - = absent	39	41	11	25	18	10	3

Table modified after Dustan (1985)

Table A-7. Octocoral Spp.

Species	SE Florida <30 m	SL 1011 Control*	OCS 0665 Quadrat 1	OCS 0665 Quadrat 2	OCS 0665 Control 1	OCS 0665 Control 2
Briareum asbestinum	x	x				
Iciligorgia schrammi	x					
Erythropodium caribaeorum	x					
Plexaura homomalla	x		x			x
P. flexuosa	x			x	x	x
Pseudoplexaura sp.		x				
Pseudoplexaura porosa	x					
P. flagellosa	x					
P. wagenaari	x					
P. crucis	x					
Eunicea sp.		x	spp.	x	x	spp.
Eunicea palmeri	x					
E. pinta	x					
E. mammosa	x	x	x		x	
E. succinea	x		x		x	x
E. fusca	x					
E. laciniata	x					
E. tourneforti	x					
E. asperula	x					
E. clavigera	x					
E. knighti	x	x				
E. calyculata	x	x			x	x
Muriceopsts flavida	x		x	x		
Plexaurella sp.		x				
Plexaurella dichotoma	x			x		
P. nutans	x	x				
P. grisea	x		x	x		
P. fusifera	x			x	x	x
Muricea sp.		x	x			
Muricea muricata	x					
M. atlantica	x	x	x	x		
M. laxa	x					
M. elongata	x			x	x	x
Lophogorgia hebes	x					
Pseudopterogorgia sp.		x	x			
Pseudopterogorgia bipinnata	x					
P. kallos	x					
P. rigida	x					
P. acerosa	x				x	
P. americana	x		x	x	x	x
P. elisabethae	x					
P. navia	x					
Gorgonia ventalina	x		x			x
Pterogorgia sp.		x				
Pterogorgia citrina	x		x		x	
P. anceps	x		x	x	x	x
P. guadalupensis	x			x		
Nicella schmitti	x					

x = present
spp = >1 species

*From hardbottom community surrounding drill site. No octocorals on cement bag or pea-gravel pile.

Table modified from Bayer (1961), Opreske (1973), Jaap (1984), and Wheaton (1987)

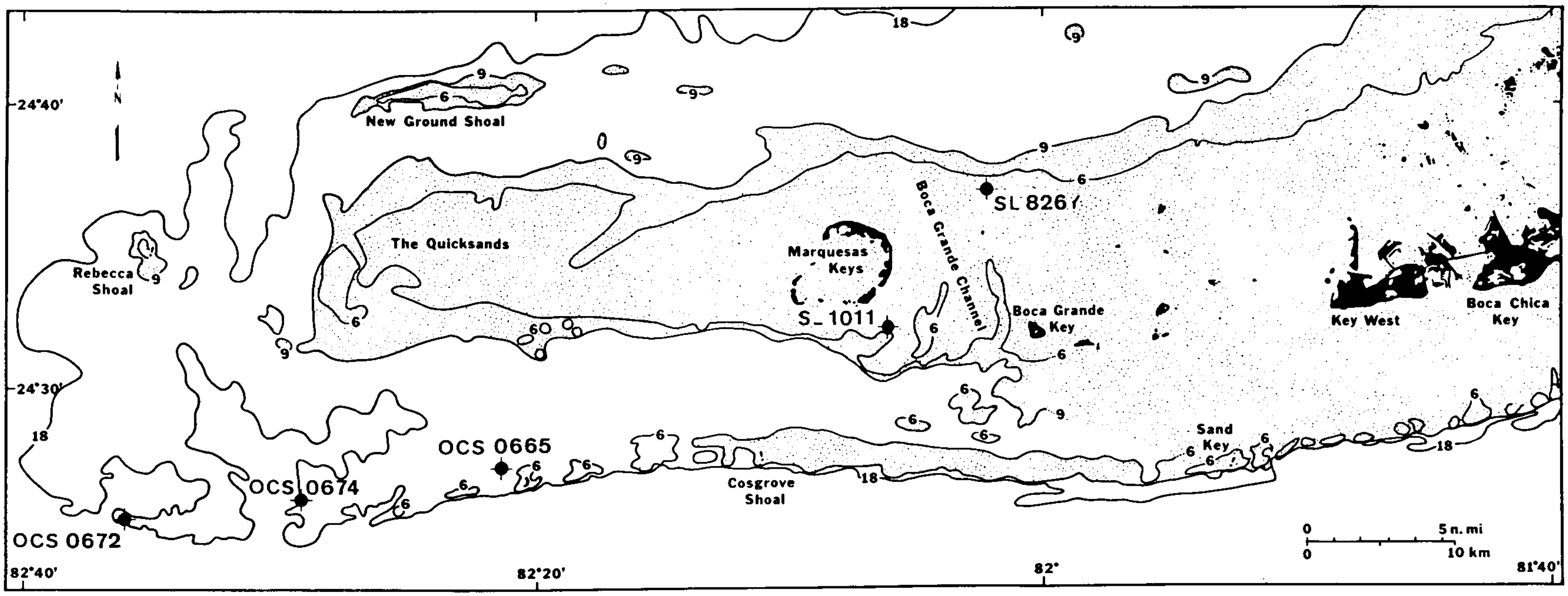


Figure 1. Bathymetric map of Marquesas Keys and reef tract area west of Key West, Florida, showing locations of wells drilled between 1959 and 1962. SL 1011 represents two wells drilled adjacent to each other 2 km (1.2 mi) southeast of the Marquesas and SL 826Y was a single well drilled 7 km (4.3 mi) northeast of the Marquesas. Site OCS 0665 was drilled from a jackup rig on coral bottom in 11 m (36 ft) of water. OCS 0674 was drilled on sandy bottom in 23 m (75 ft) of water, whereas OCS 0672, a few kilometers to the west, was drilled atop a coral knoll in 20 m (65 ft) of water. Contours in meters.

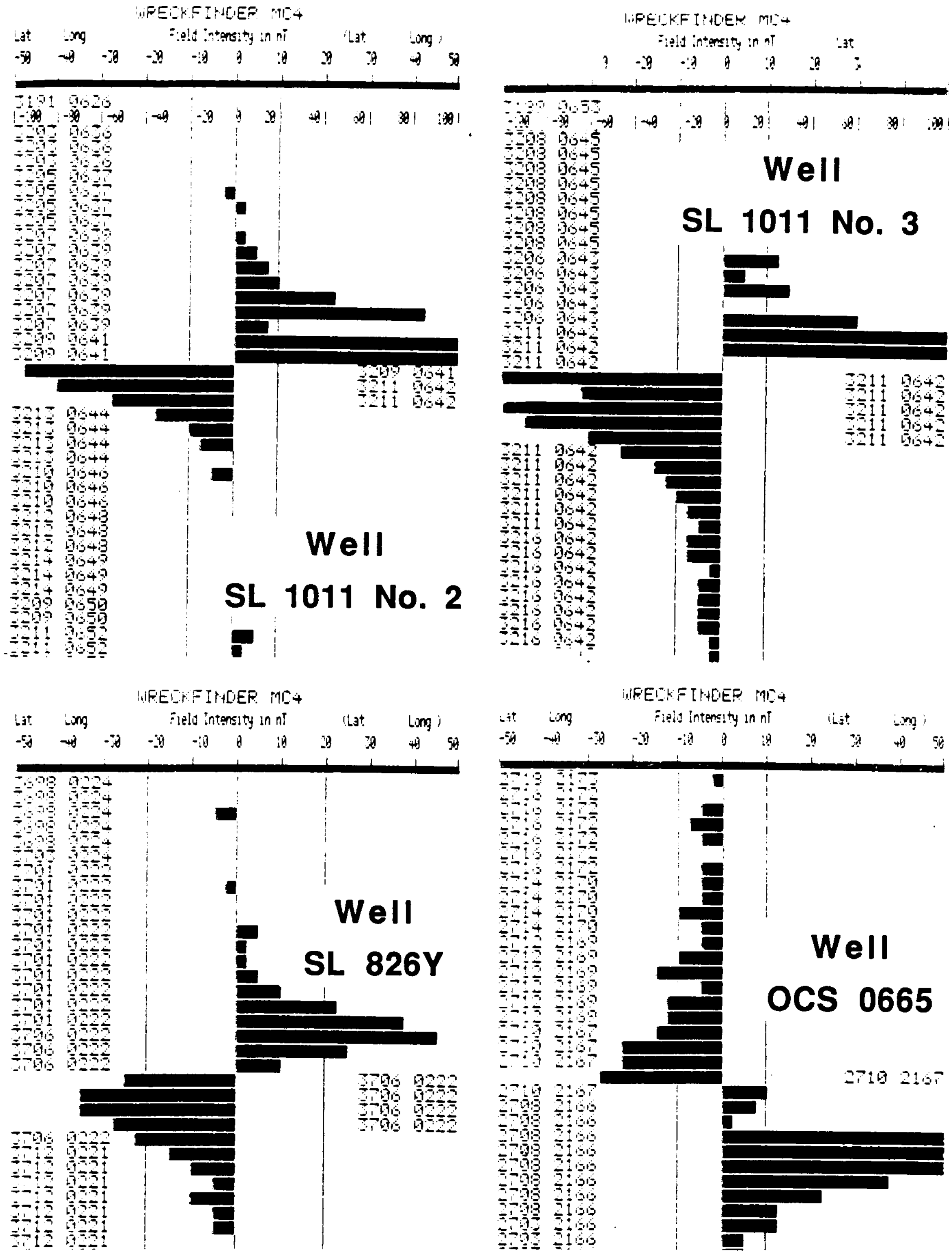


Figure 2. Typical examples of magnetic anomaly printouts from old well sites. Several hundred meters of iron casing, which was left in the earth (not visible at the surface), produces the large anomaly. Printout is calibrated in nannoteslas. Well bore, is located closest to the point where anomaly printout shifts from negative (left) to positive (right). Latitude and longitude from Loran C navigation unit are printed next to each reading.

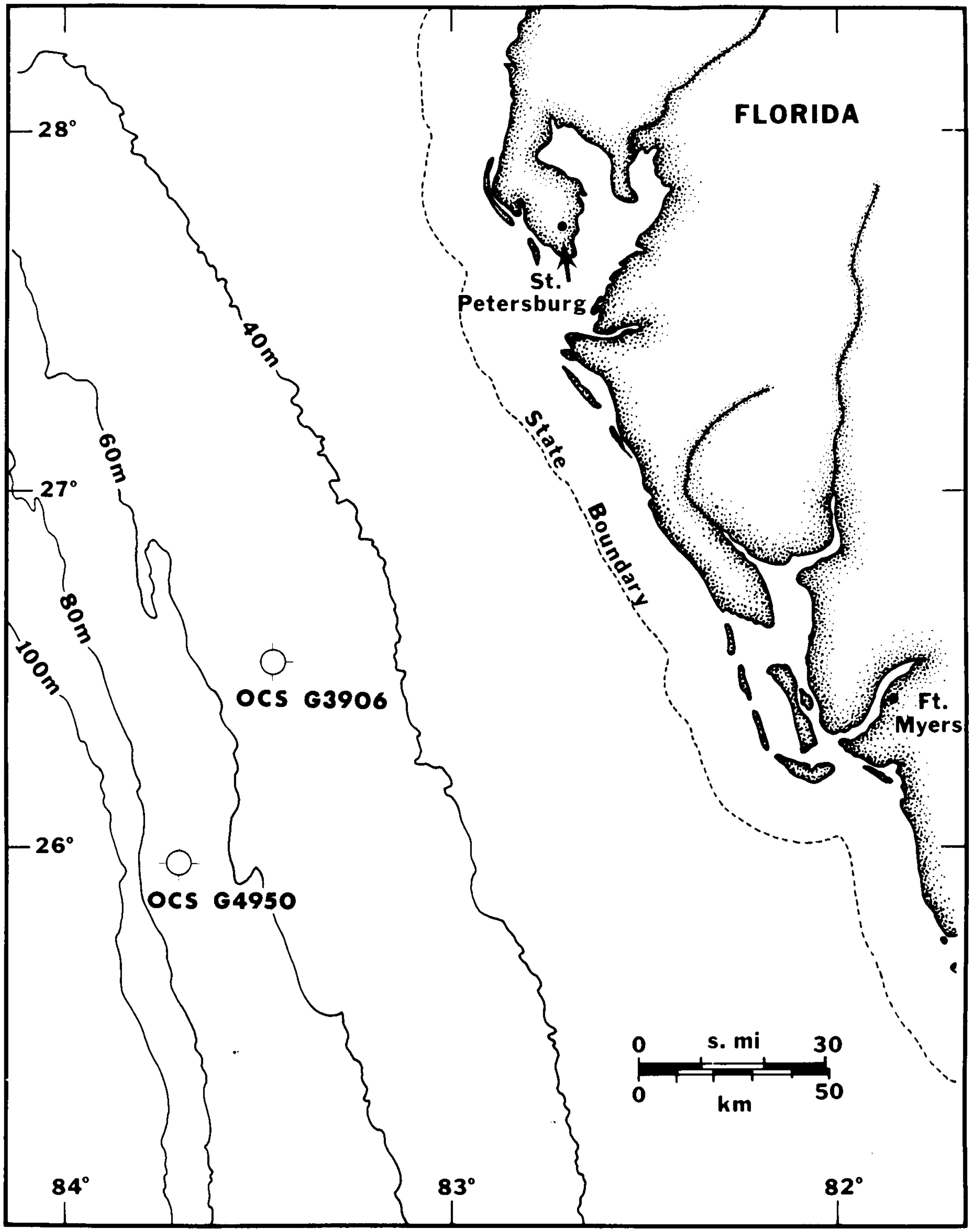


Figure 3. Map showing locations of two deep wells drilled in 1980s off west coast of Florida.

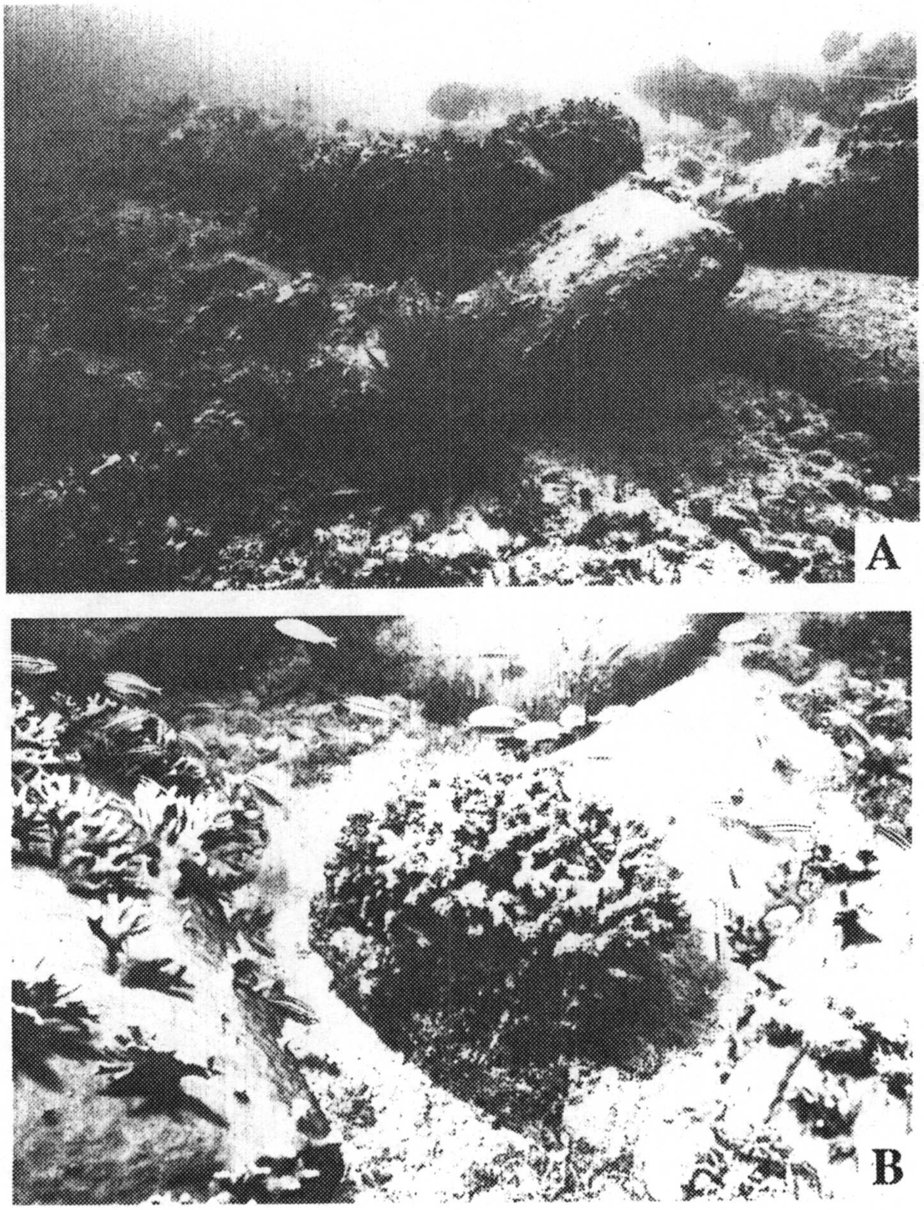


Figure 4. (A) Underwater view of cement-bag pile at site SL 1011. Note fish, including large red grouper, encrustation by the fire coral *Millepora* spp., and large anemone in foreground. Golf ball-size pea gravel on which cement bags rest is visible in right foreground. Well bore is buried beneath bags. (B) Closeup of cement showing *Millepora* spp. (to left) and colony of coral *Oculina diffusa* (center). Small fish are predominantly wrasses and juvenile grunts.

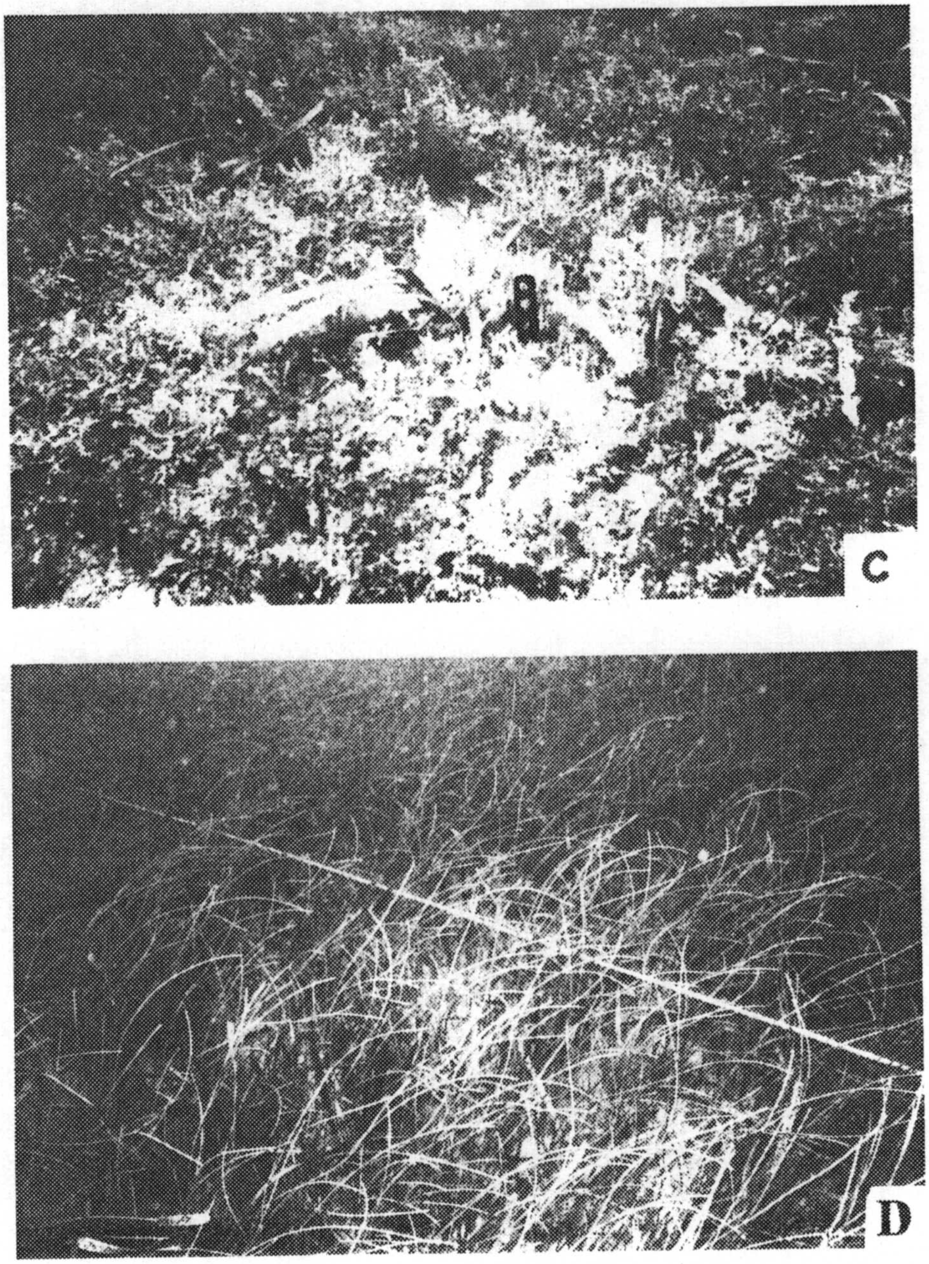


Figure 4 (continued). (C) Fleshy macroalgae *Laurencia* spp. covering pea-gravel area surrounding cement-bag pile. Photographs taken before the *Diadema* spp. urchin die-off in 1983 show this area was relatively barren of algae. Ten-cm-long tall handle near center provides scale. (D) *Syringodium* spp. and *Thalassia* spp. grass zone as seen along radial-transect line away from cement-bag pile. Substrate here is mostly natural sediment with an admixture of pea gravel. See Figure 5 for distribution of communities.

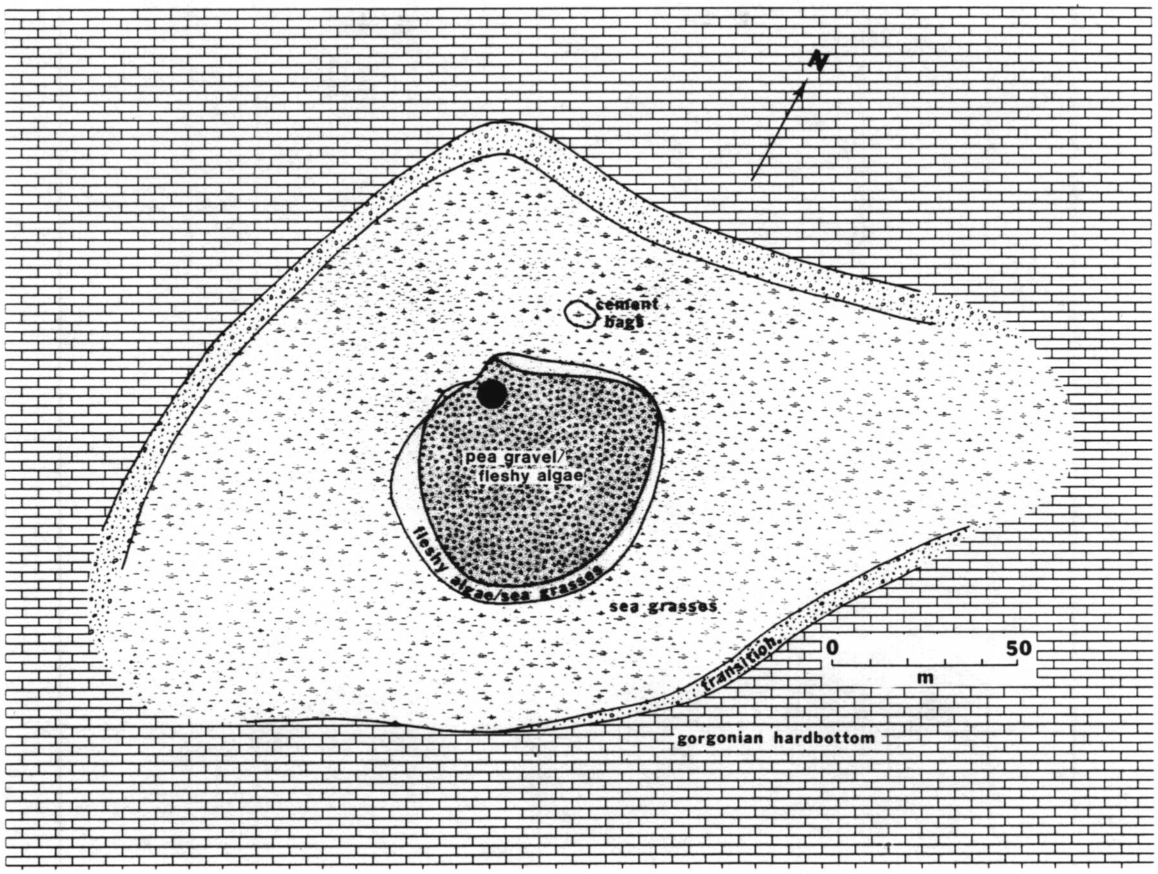


Figure 5. Map of biological communities based on eight transects radiating from main cement-bag (>100) pile, which is represented as large black dot. A smaller pile consisting of 8 to 10 bags is located to the northeast of main pile. Location of radial lines is shown in Figure 6A. Well SL 1011 No. 3 is thought to be under main cement-bag pile, whereas well SL 1011 No. 2 is under pea-gravel pile to south of No. 3. Area is surrounded by mostly exposed Pleistocene bedrock populated by gorgonians, sponges, and scattered corals. Turtle grasses grow in local sediment-filled depressions throughout the area.

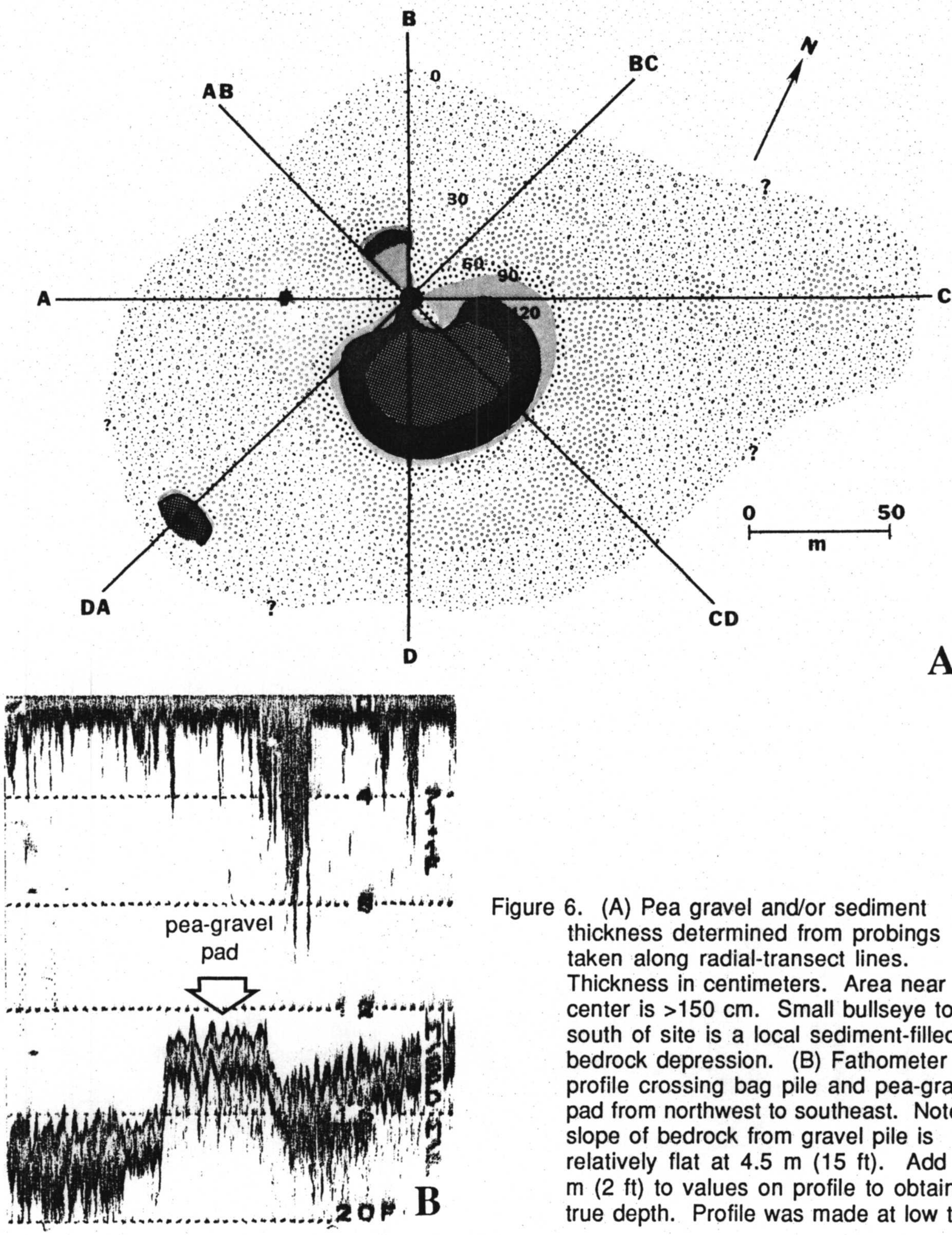


Figure 6. (A) Pea gravel and/or sediment thickness determined from probings taken along radial-transect lines. Thickness in centimeters. Area near center is >150 cm. Small bullseye to south of site is a local sediment-filled bedrock depression. (B) Fathometer profile crossing bag pile and pea-gravel pad from northwest to southeast. Note slope of bedrock from gravel pile is relatively flat at 4.5 m (15 ft). Add 0.6 m (2 ft) to values on profile to obtain true depth. Profile was made at low tide.

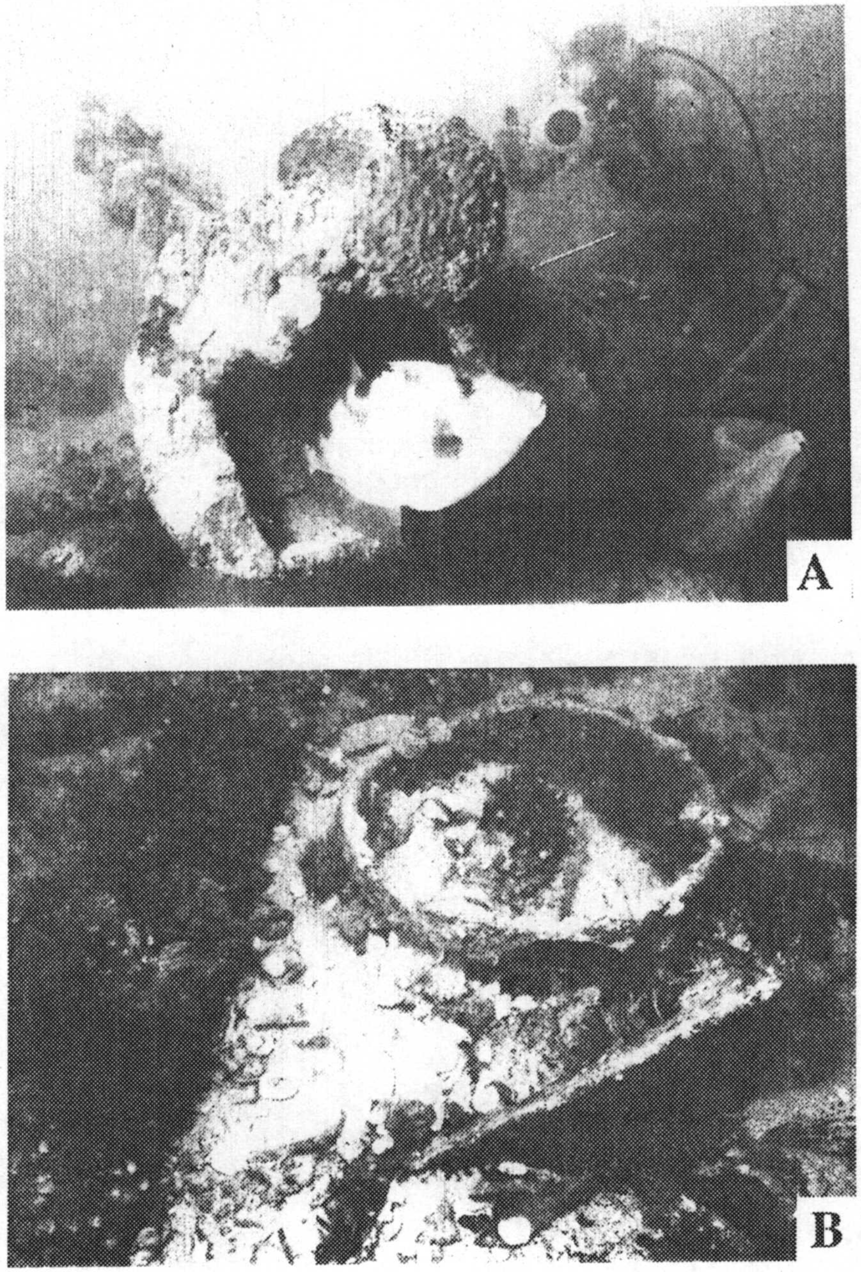


Figure 7. (A) A large piece of sponge- and algae-encrusted drilling debris at well site SL 826Y. Triggerfish emerges from interior of pipe as diver uses underwater video camera. (B) A short length of casing and other algae-encrusted debris at site SL 826Y. Debris is concentrated over an area approximately 30 m (98 ft) in diameter with a few scattered bits extending as far as 40 m (130 ft) from center of pile. Site is surrounded by several centimeters of rippled carbonate sand over smooth Pleistocene limestone.

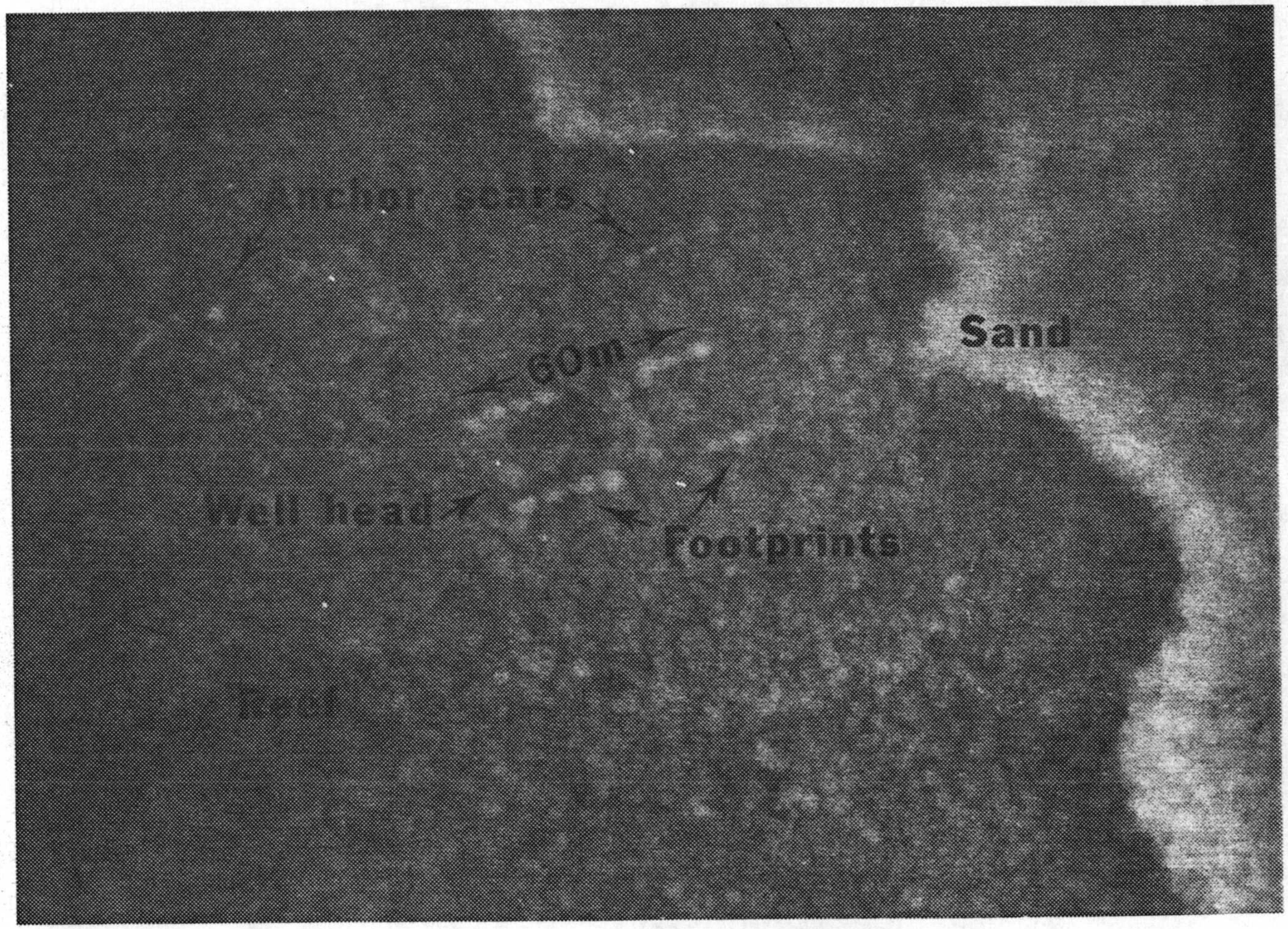


Figure 8. Low-level oblique aerial photograph of site OCS 0665 No. 1 showing 4 sand-filled footprints, well head, and two anchor scars. Area to right of site is carbonate sand lacking coral or gorgonian growth.

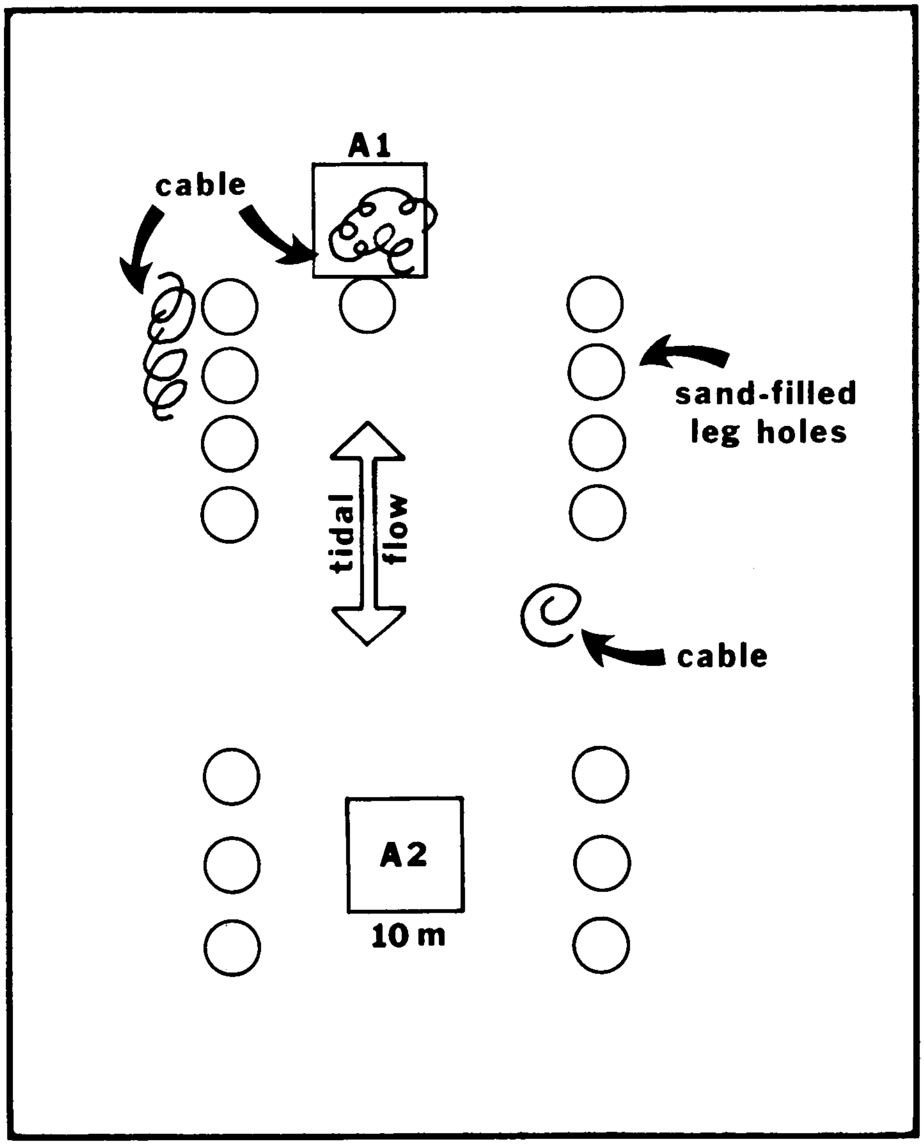
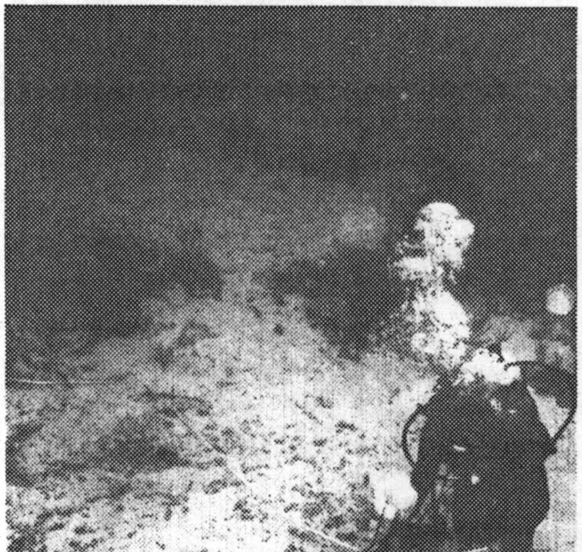


Figure 9. Map of site OCS 0665 No. 1 showing location of quadrats, tidal-flow direction, and distribution of debris, which consists mainly of discarded cable. Quadrat A-1 is situated downcurrent and adjacent to sand hole around well bore and includes cable debris. A-2 is situated downcurrent and beneath the platform, where organisms would be subject to both drill effluents and shade. Bottom is flat. There is no cable debris in A-2.



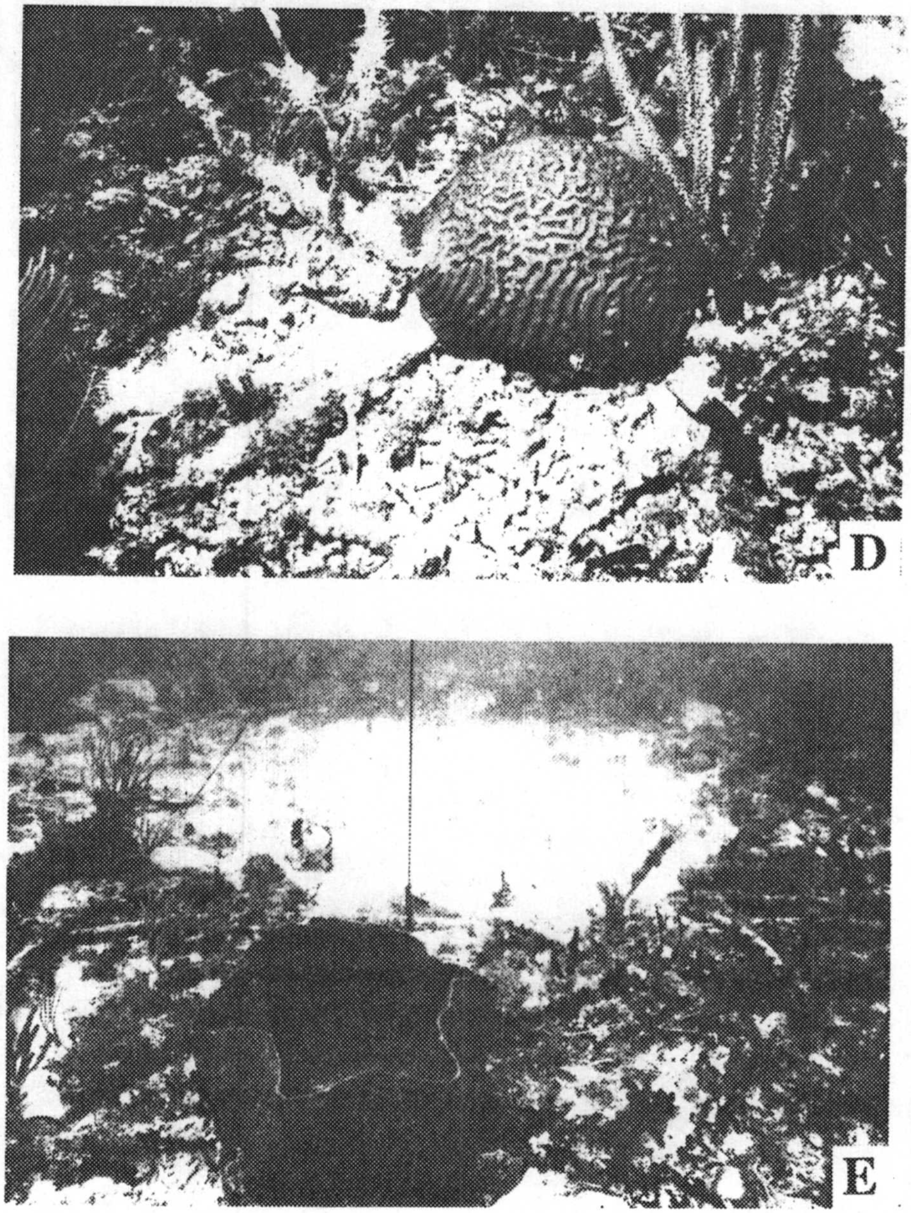


Figure 10 (continued). (D) Brain coral growing on intersection of two pieces of cable within quadrat A-1. (E) Large basket sponge growing on cable debris in quadrat A-1. View is toward circular sand hole, where well bore is buried. Vertical black line attached to piece of cable is tied to marker buoy.

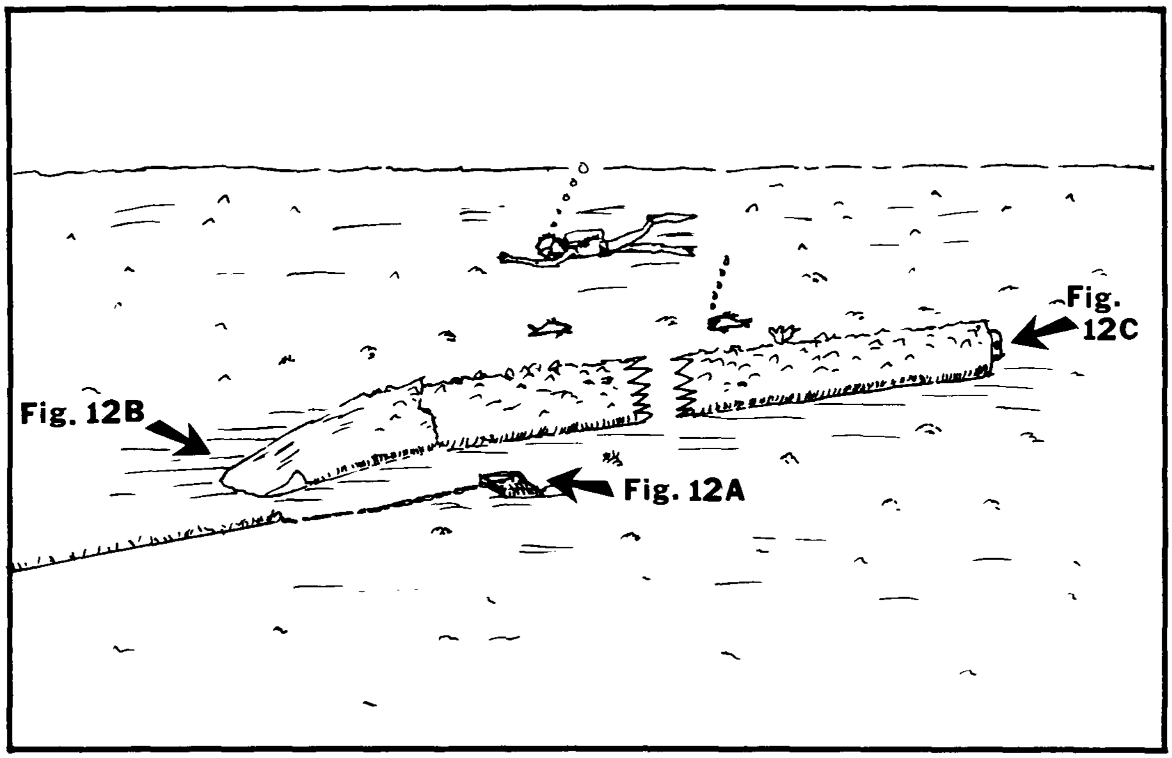


Figure 11. Sketch of 23-m-long (77 ft) conductor pipe casing at site OCS 0674. Well bore is at left, where pipe bends into bottom. Angles of view of underwater photographs in following figure are indicated by directions of arrows. Clumps of brown fleshy algae litter the surrounding sandy bottom.

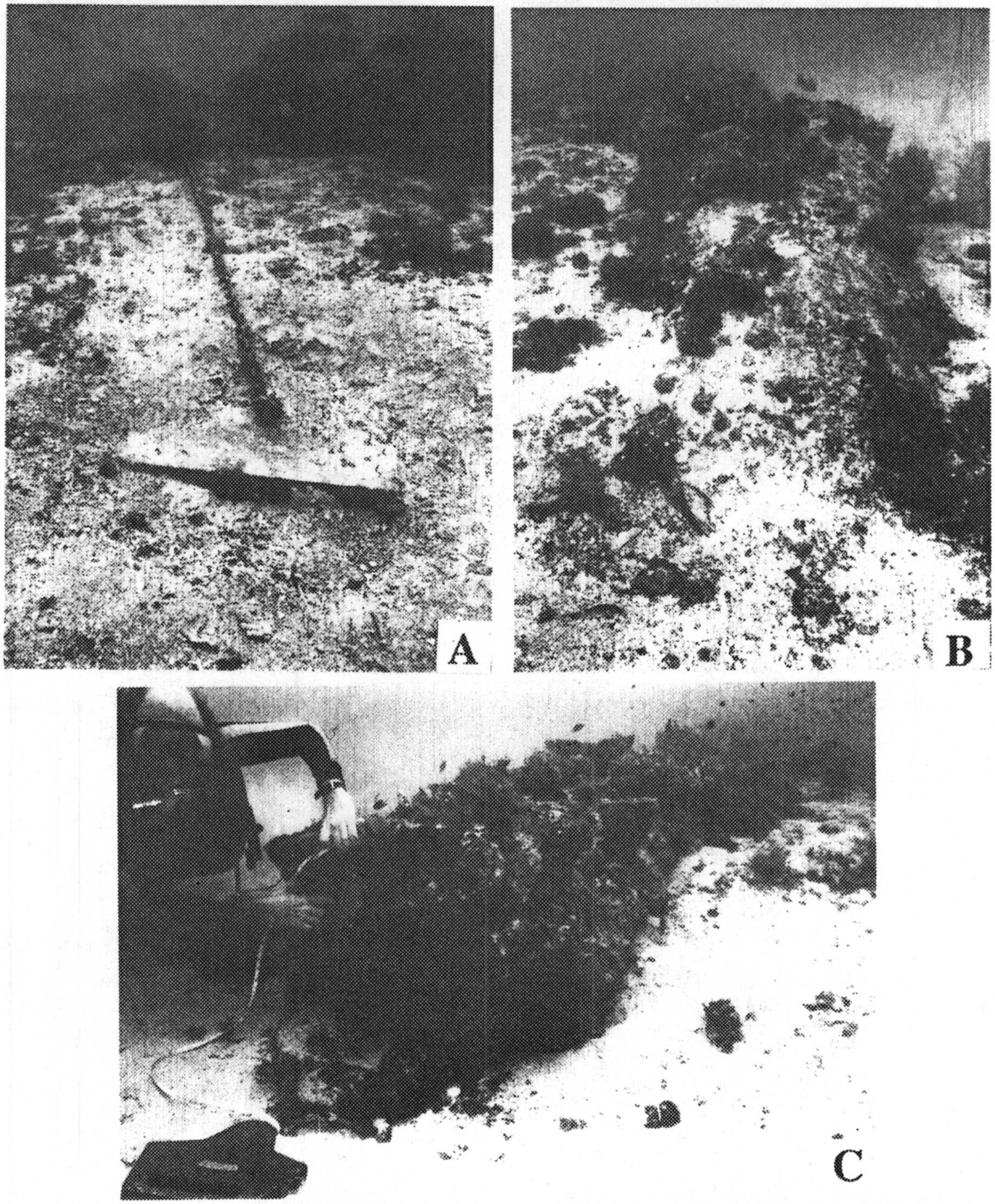


Figure 12. (A) Cube of cement with chain and nylon line attached. Angle of view is indicated in previous figure. Note fleshy algae growing on chain and rope. Pipe at upper right. (B) End view of conductor pipe where it bends into bottom. See previous figure for orientation. (C) View of cut end of pipe showing inner casing. Diver points at cement, visible only after knocking off encrustations with a hammer. Pipe contained lobsters and fish. A large sea anemone lives in annulus at right side of pipe.

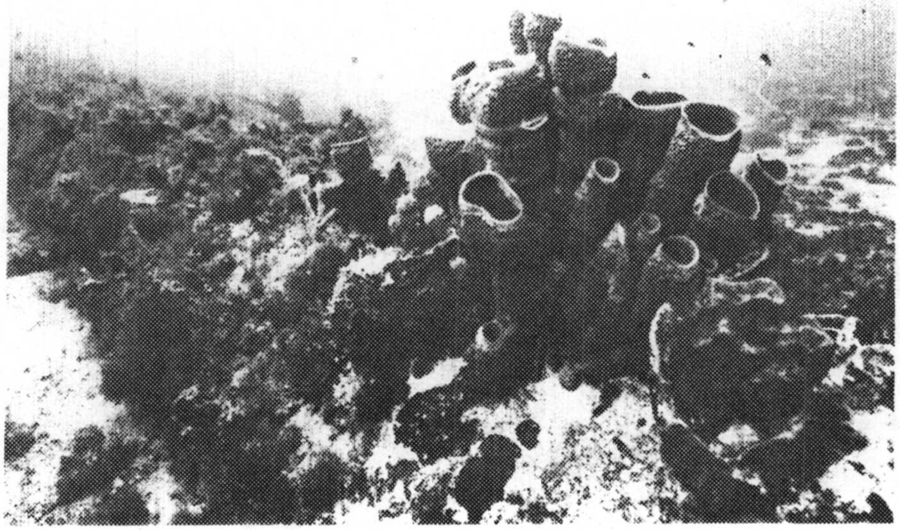


Figure 13. (A) View of sponges and other encrusters on pipe at site OCS 0674. Eight species of coral were identified. No corals lived on sand bottom surrounding pipe.

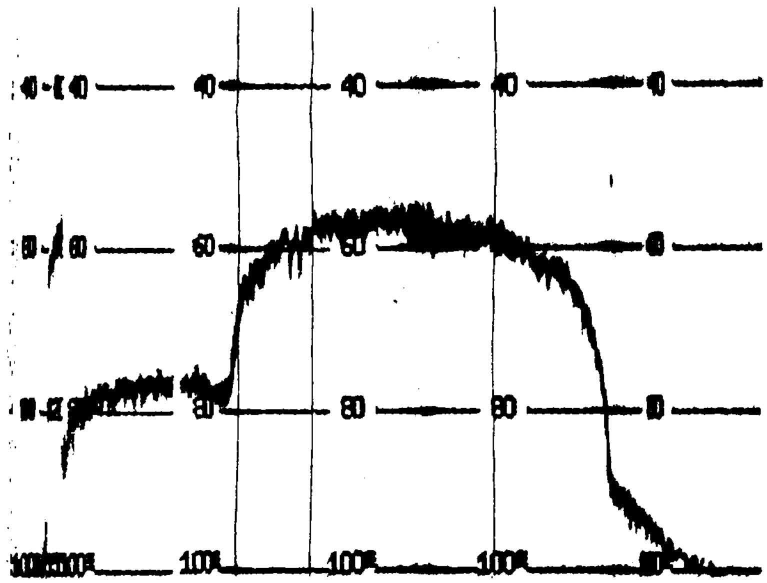


Figure 14. North-south fathometer profile across coral knoll, where well OCS 0672 No. 1 was drilled at shallowest point (20 m, or 65 ft). Knoll is surrounded by sandy bottom similar to that at site OCS 0674.

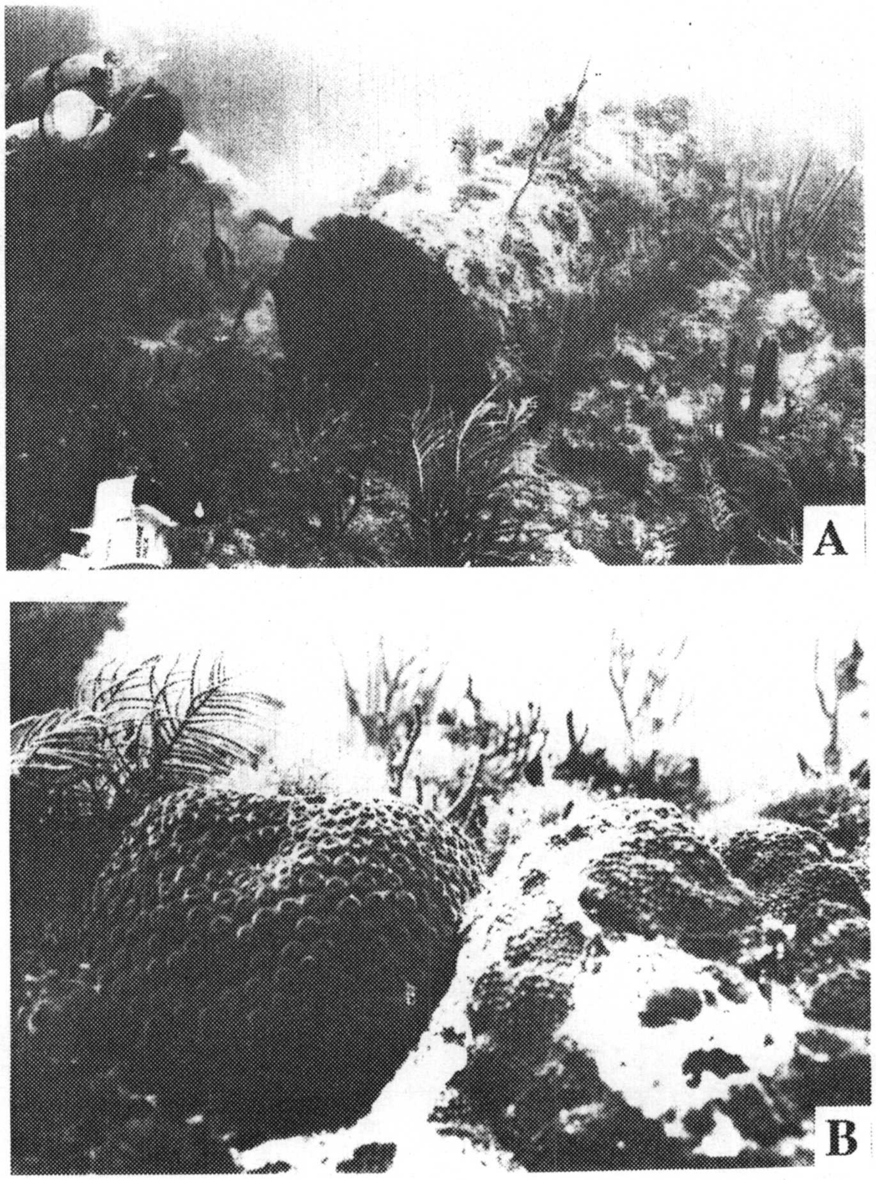


Figure 15. (A) Length of 3.3-m-diameter (36-in.) conductor pipe lying on crest of coral knoll at site OCS 0672. A longer length of casing was located about 50 m (165 ft) away. (B) *Montastraea cavernosa* and *M. annularis* growing on bottom near pipe in (A). Note abundance of gorgonians in (A) and (B).

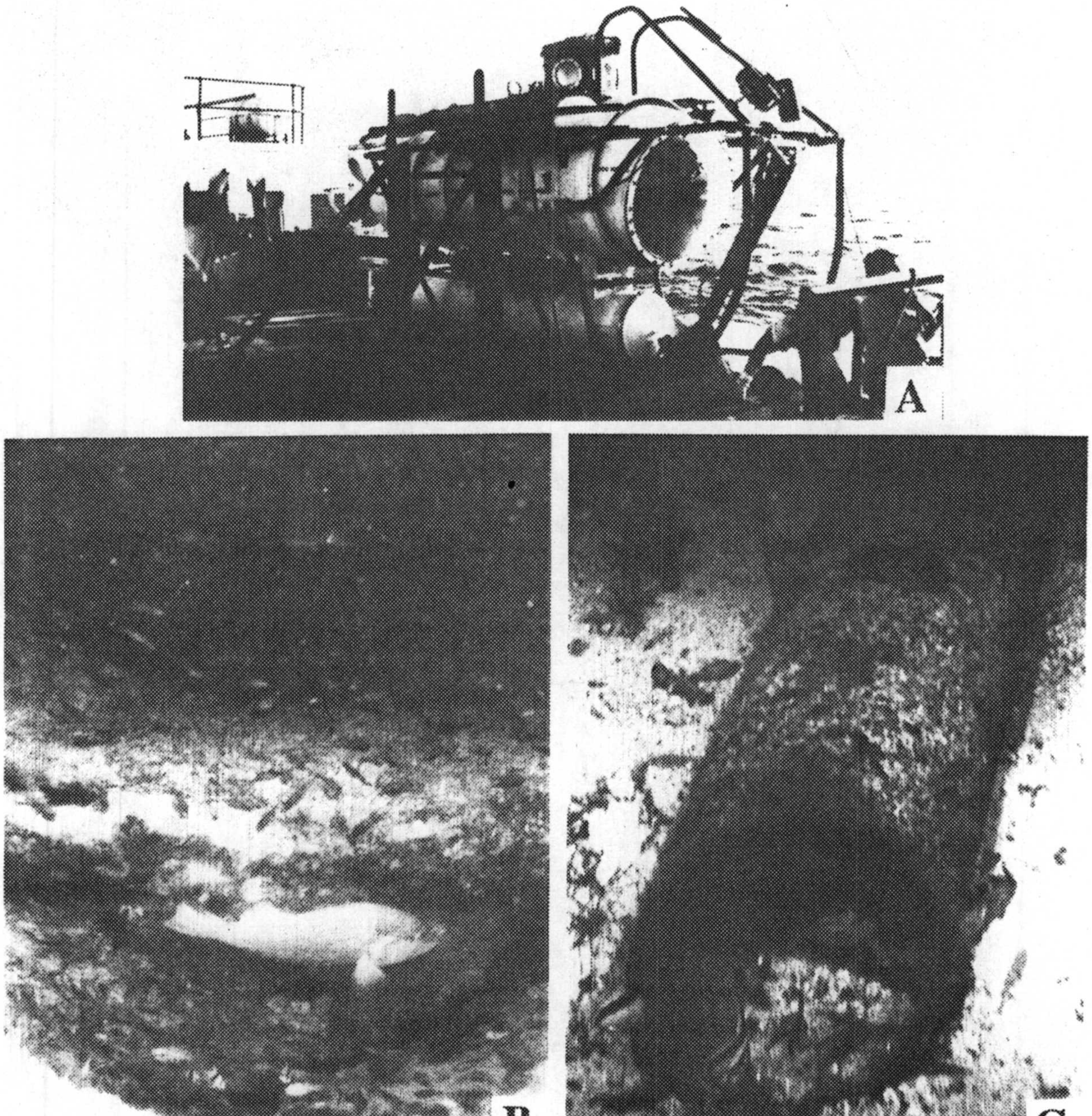


Figure 16. (A) PC 14 submersible aboard ***R/V Powell*** during investigation of deep-water sites. (B) View of cement donut around well bore at OCS G4950 No. 1. Red grouper hovers over open hole; smaller one swims outside with numerous small fish. Both groupers repeatedly disappeared and emerged from well bore. View is of scoured side of donut, which is at right in Figure 18. (C) Length of pipe near well bore. Pipe is inhabited by cardinal fish, jacknife fish, butterflyfish (left foreground), and Queen angelfish (not visible in this view).

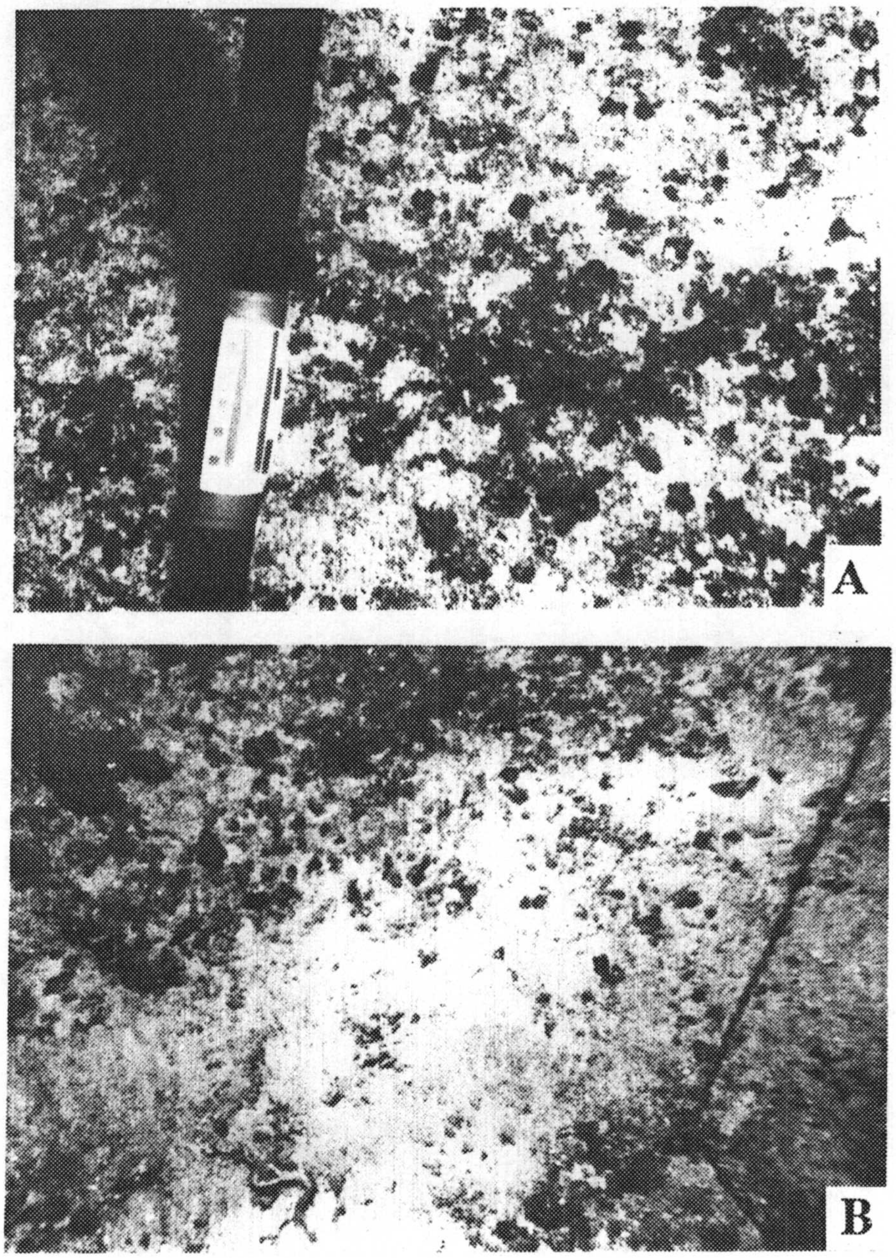


Figure 17. (A) View of undisturbed bottom more than 50 m (165 ft) from well bore. Community is mainly red algal nodules and plates. The green alga *Caulerpa* spp. was common but not visible in this photograph. Scale taped to pipe at left in centimeters. Pipe is approximately 3.5 m (1.4 in.) in diameter. (B) Light measuring chain accidentally dragged laterally (left to right), disrupting bottom community and demonstarting its superficiality. Measuring chain at right composed of 1-cm-long inks formed from 1-mm-diameter wire.

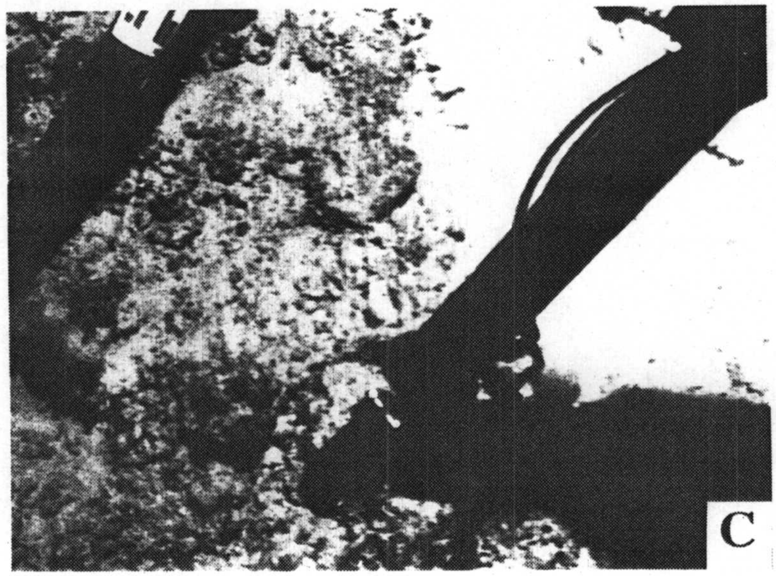


Figure 17 (continued). (C) Lump of semi-consolidated grout on flank of grout mound (near pipe wrench shown in Fig. 18). A clump of grout is in grasp of mechanical claw at bottom center. Grout crushed in claw and could not be collected.

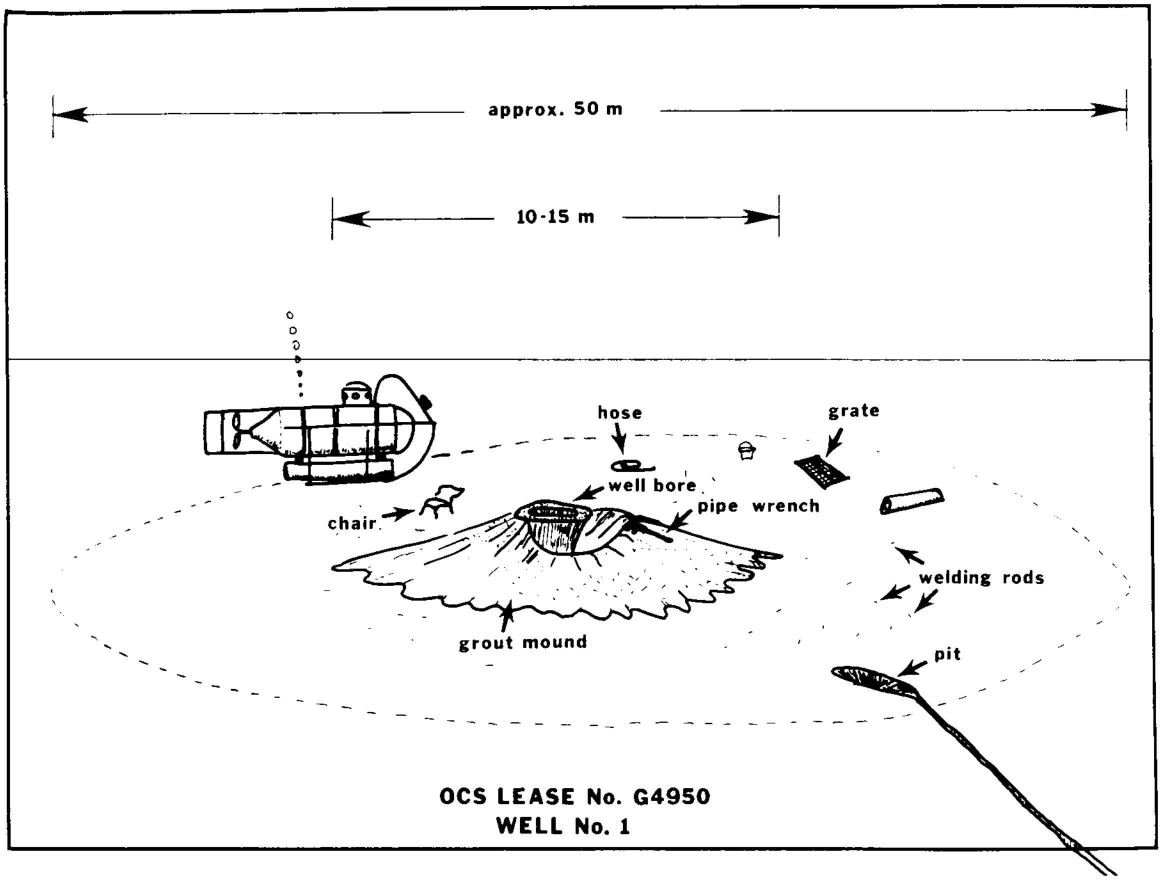


Figure 18. Sketch of well site OCS G4950 showing approximate position of various debris objects. Pipe to right is one shown in Figure 16C. Long furrow leads from 60-cm-deep (2 ft) pit at lower right. Dotted line shows approximate limit of zone of visual disturbance. Water depth is 70 m (230 ft).

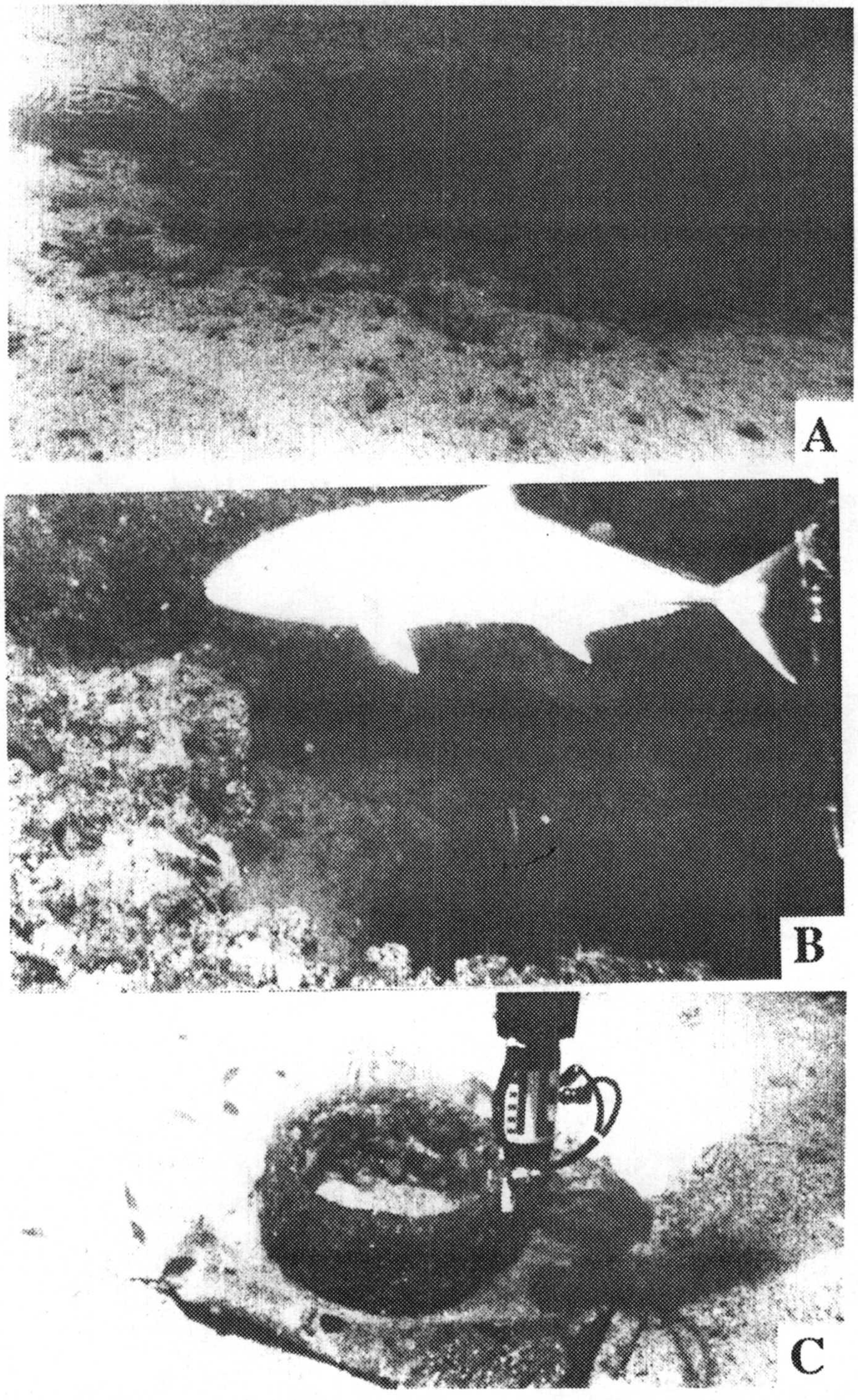


Figure 19. (A) Underwater view of well bore OCS G3906 in 53 m (175 ft) of water showing large black grouper at left and larger (30 kg) grouper peering out of well bore. Dark area is naturally occurring rock through which well was drilled. Surrounding bottom has no algal community. Crest of sand ripple is visible in lower lefthand corner. (B) View into well bore below large amberjack, which was part of a school patrolling the area. (C) Piece of metal debris in submersible's claw near well bore.

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 the wisest use of our land and water resources, protecting our fish and wildlife, 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 assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.