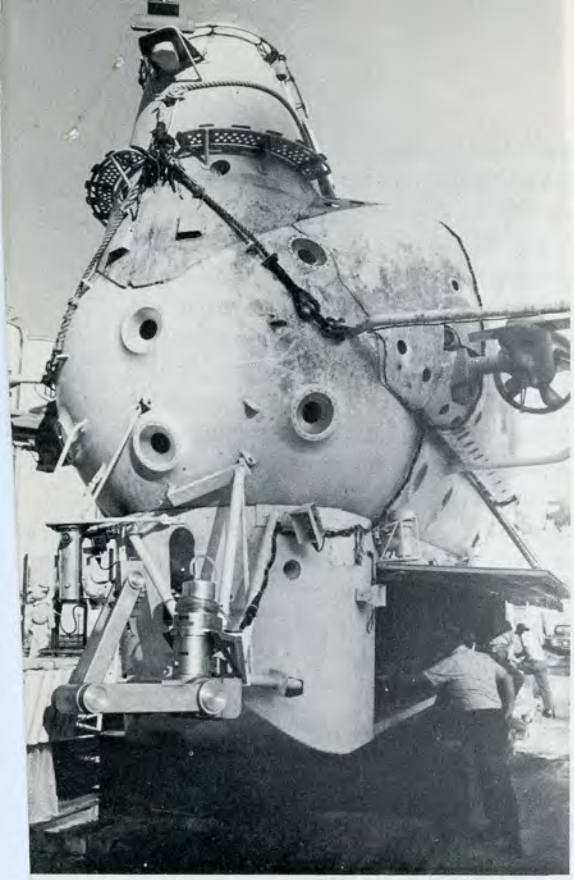

Figure 1. Grumman Aircraft Engineering Corporation's *Ben Franklin* at the home port in West Palm Beach, Florida. The manipulator arm and sample tray belonging to Woods Hole Oceanographic Institution's *Alvin* are attached in working position near the forward viewports.

A DIVE ABOARD "BEN FRANKLIN" OFF WEST PALM BEACH FLORIDA

K. O. Emery[1], *R. D. Ballard*[1], *and R. L. Wigley*[2]

ABSTRACT

A 24-hour dive was conducted aboard BEN FRANKLIN off West Palm Beach, Florida, in order to make geological and biological observations. Supplemented by surface soundings from R/V *Privateer,* the study spanned a 4.5-kilometer traverse of the sea floor in depths of 32 to 165 meters. Six bottom stations were occupied; they start with remnants of an ancient reef that forms the seaward edge of the continental shelf, and they end with a typical deep-sea environment of reworked silt having subdued microrelief and a dominant population of Jonah crabs. The submersible was found to be a particularly useful platform for investigating the larger visible features, both geological and biological, on the sea floor in these environments.

INTRODUCTION

At the invitation of Grumman Aerospace Corporation the writers participated in a 24-hour dive aboard *Ben Franklin* (Figure 1) off the submersible's home port of West Palm Beach, Florida, during 4 and 5 December 1969. The dive objectives were: (1) to observe the geological and biological characteristics of the bottom along a traverse from the seaward edge of the narrow continental shelf to a point low on the adjacent slope bordering the Straits of Florida, and (2) to relate these observations to previous information gathered aboard surface ships.

The topography of the sea floor off West Palm Beach is fairly well known through the detailed soundings of the U.S. Coast and Geodetic Survey that have been contoured

[1]Woods Hole Oceanographic Institution, Woods Hole, Mass. Contribution No. 2439.

[2]U.S. Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Mass.

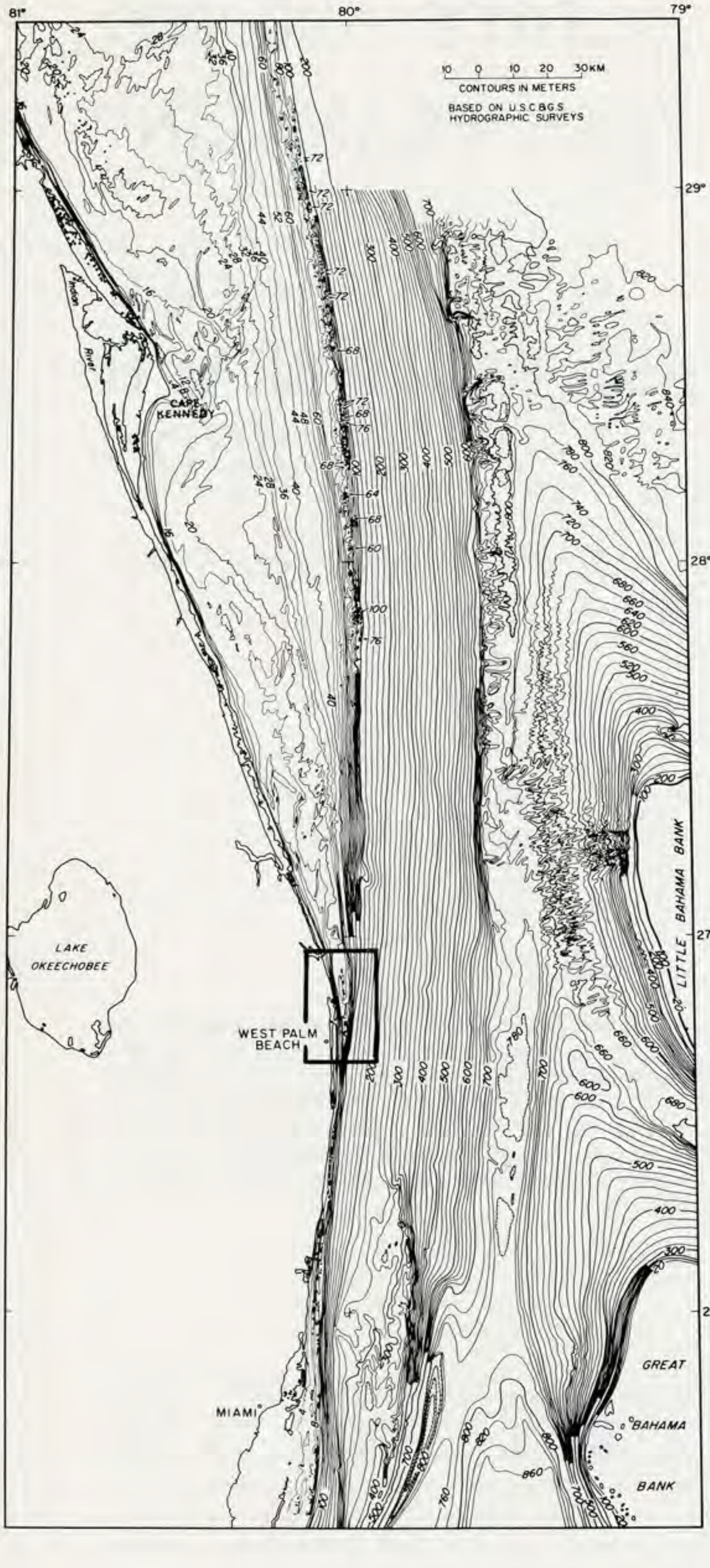

Figure 2. General ocean-floor topography off West Palm Beach. From Uchupi (1970). The rectangle shows the area of Figure 3.

(Figure 2) by Uchupi (1970). Irregular topography near the edge of the shelf is known from dredgings and continuous seismic reflection profiles to be an algal reef that flourished about 10,000 years ago. Portions of the former reef extend along the shelf edge from West Palm Beach northward to Cape Hatteras and were studied in detail by Menzies and others (1966) off North Carolina, and more generally elsewhere by Kofoed and Malloy (1965) and Zarudzki and Uchupi (1968). Off West Palm Beach this reef occurs in 34 m depth. At least one older reef lies farther offshore in depths of about 1,000 m at the seaward edge of the Blake Plateau. Mounds of deep-water corals occur on the Blake Plateau (Stetson, Squires, and Pratt, 1962), but they are not to be confused with massive reef-building organisms. Several reefs shallower than 34 m have also been revealed by soundings and seismic reflection profiles particularly from the somewhat wider shelf that lies nearer Miami (Duane and Meisburger, 1969).

Additional details of local ocean-floor topography were obtained during a one-day cruise aboard R/V *Privateer,* a vessel chartered by Grumman to support the *Ben Franklin* operations. During this short cruise seven sounding traverses were completed with the ship's precision Gifft depth recorder supplemented by a Furuno sounder in the wheelhouse. Navigation was by optical bearings with a gyro-pelorus. The profiles were at approximate right angles to the coast and from 9 km south of West Palm Beach to 17 km north of it (Figure 3). Accent was placed upon the major topographic irregularity, the reef at the edge of the continental shelf (Figure 3). The topographic features start nearest shore with a shallow (20 m) inner reef surface (profiles 6 and 7). The shelf seaward of this inner reef appears to be smooth sand that grades into a deeper reef surface having irregularities of a few meters height and a few tens to hundreds of meters length. The seaward edge of the outer reef establishes the margin of the narrow continental shelf at 34 m depth, except in profile 7 where the 34-m reef has apparently been buried under the 20-m one. Immediately south of profile 7 the 20-m reef marks the edge of the shelf. Wide variations in the depth of the shelf edge support the findings of other studies in this region (Uchupi and Tagg, 1966). The steepest portion of the profiles is the face of the dominant reef, a slope of about 7 degrees. Beyond the reef the bottom slopes seaward with some undulations, but at an average steepness of 3 degrees in profiles 1 to 6, and 5 degrees in profile 7. Steepness gradually diminishes until at depths between 140 and 170 m the angle is only about 0.7 degree. Further flattening in greater depths is shown by Figure 2.

The geological interpretation of the topography from both old and new soundings is that when sea level rose from its lowest level of about 130 m below the present position

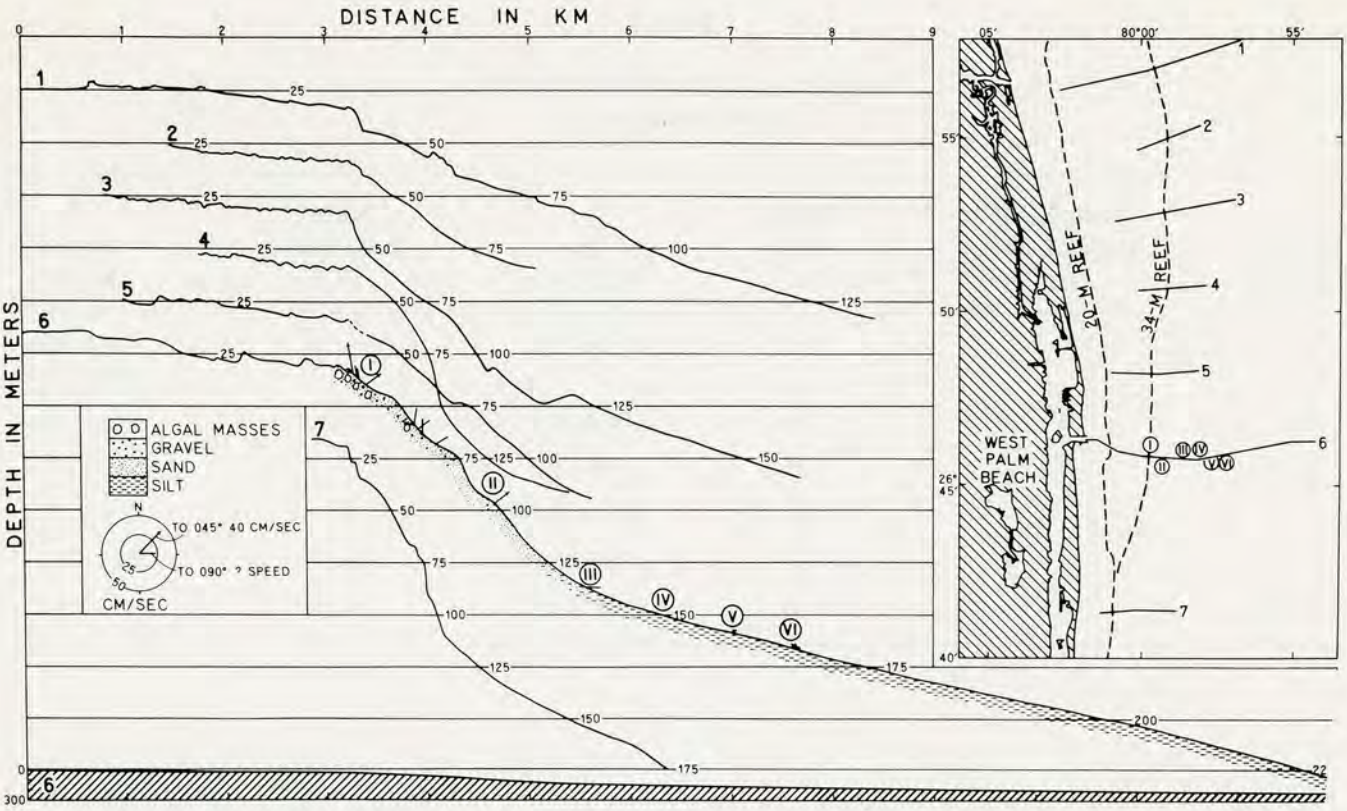

Figure 3. Sounding profiles made aboard R/V *Privateer* on 3 December 1969. The trends of the 20-m and the 34-m submerged ancient reefs are indicated by dashed lines on the insert map. The profiles have a vertical exaggeration of 1 to 20, but profile 6 is repeated with no exaggeration at the bottom. Dive stations of *Ben Franklin,* current directions and speeds, and notations of bottom materials are superimposed upon profile 6.

about 15,000 years ago, it paused at 34 m for perhaps a thousand years 10,000 years ago. During this time the 34-m reef was built. A period of more rapid melting of glaciers caused them to return their water to the ocean so rapidly that the rise of sea level outpaced the growth of the reef. A possible decrease in water temperature and increase in amount of suspended sediment may also have contributed to the demise of the reef. The renewed rise of sea level was followed by another pause at 20 m about 7,000 years ago when the 20-m reef was built about 1.5 km beyond the present shoreline (Figure 3). Where the 34-m reef lay nearest the present shoreline (profile 7 and southward), the 20-m reef covered it. After perhaps 500 years of stationary or only slow rise, sea level again rose intermittently to its present position, leaving several shallow reefs to mark brief stillstands. The reef topography, particularly on the inner half of the shelf, has been smoothed by subsequent deposition of sediments from both inorganic and organic sources. Beach and nearshore sediments are known to move southward toward the West Palm Beach area and have done so for probably thousands of years (Gorsline, 1963; Duane and Meisburger, 1969). Some of these sediments were and still are being deposited on the inner half of the continental shelf and probably even farther seaward. Calcareous sediments from the reefs and from organisms living in the water and on the bottom have built the gently sloping embankment that laps against the 34-m reef. These deposits are hundreds of meters thick, as shown by seismic reflection profiling (Uchupi, 1966; Uchupi and Emery, 1967). The surface of the embankment is made irregular by mass movements down the slope, and subsequently smoothed by movements of the Gulf Stream and associated deep-water currents (Hurley and Fink, 1963; Barrett, 1965; Heezen, Hollister, and Ruddiman, 1966; Rowe and Menzies, 1968; and Neumann and Ball, in preparation).

OBSERVATIONS DURING THE DIVE

General

The 24-hour dive of *Ben Franklin* included 20 hours of submerged time, most of which was spent on the bottom or travelling a few meters above the bottom. The more important sets of observations are grouped as six stations

Table I

Station Data for BEN FRANKLIN Dive
off West Palm Beach

Station Number	Distance East of Harbor Entrance (km)	Water Depth (m)	Time (4, 5 Dec.)	Water Temperature (°C)	Bottom Material
I	3.1 - 3.4	32 - 38	1510-1536	27 - 26	Algal masses, gravel, sand
II	4.6	94	1310-1418	20	Gravel, sand
III	5.5	135	1740-1815	15	Sandy silt
IV	6.3	148	1830-1900	15	Silt
V	6.9	157	1950-0010	14.2	Silt
VI	7.6	165	0100-0725	13.5	Silt

having bottom depths between 32 and 165 m. These six stations, their depths, distances from the harbor entrance, and times of occupation are listed in Table I, with geological and biological descriptions in the following paragraphs. Positions of the stations also are noted on both profile 6 and the map (Figure 3).

Water Characteristics

Observations from the surface ship showed a gradual transition from light green of the shelf water to dark blue of the Gulf Stream in the region near the shelf edge. Water temperatures measured during the dive were nearly constant at 27° to 26° C in a mixed layer between the surface and about 90 m. At greater depths the temperature decreased to about 13.5° C at 165 m. Visibility within the harbor was poor, less than 0.5 m. In the vicinity of the shelf edge (about 3.2 km beyond the harbor entrance) visibility was about 10 m, and farther seaward the water near the bottom permitted viewing to between 15 and 25 m from the submersible.

Bottom currents along the entire traverse flowed generally from south to north with minor variations in direction but substantial reduction in speed with depth. At the edge of the shelf, near the 34-m reef, the bottom currents were estimated to be 20 to 40 cm/sec. Erosion on the southward sides of boulders and other large objects, and leeward accumulations of sand on the north sides indicated that the northward flow of bottom current is typical. The lee accumulations varied from a few centimeters to several meters in length, depending upon the size of the obstacle. At several places between 32- and 71-m depths the lee accumulations were so prominent as to form clear lineations directed northward. In contrast, inshore currents reported by ship operators and indicated by drift bottles (Bumpus, 1969) are directed southward. The zone of lee accumulations disappeared at about 70-m depth, probably because the current was too slow to develop either lineations or ripple marks. No evidence of current erosion and related deposition on the bottom was detected below a depth of about 100 m. Currents were so slow below 100 m that they could be measured only by estimating the direction and speed of silt brought into suspension by fish or by the manipulator arm. At the deepest station, VI, the current was 3 to 5 cm/ sec, and three measurements made during a 6-hour period suggested a counterclockwise shift in direction.

Station I

The area of the shelf edge was characterized by a thick algal cover and a strong northerly-flowing bottom current. The algal growth appeared as dark patches and constituted most of the bottom. Large (50 to 150 cm) brown boulder-like masses of dead calcareous algae were spaced about 50 m apart and blocks of reef rock (25 to 50 cm) were considerably more common. Intermixed were lighter-colored patches of sand or coral fragments. In spite of the bottom current, the sand patches contained no ripple marks nor did they have any apparent lineation. This observation and the lack of surface scarring caused by a chain which was dragged behind the submersible indicate that sand was coarse-grained and probably formed only a thin veneer over the algal bottom.

Animal life in the vicinity of the shelf edge was abundant as well as diverse in species. The epibenthic fauna was characterized by attached filter-feeding forms of coral, sponges, hydroids, bryozoans, and numerous related forms. Immense vase sponges, graceful alcyonarions, and gorgonians of various kinds were the most obvious forms. Live corals were common at depths of 32 to 35 m, but even where they were most abundant they were in isolated knolls and formed only a small percentage of the total bottom area.

The nektonic fauna, as seen from the submersible, consisted entirely of fish. Particularly striking were the large angelfishes (*Holacanthus* and *Pomacanthus*) 30 to 60 cm long. They consistently veered obliquely downward and to one side when the ship passed nearby. Other common species were the amberjack (*Seriola*), butterflyfishes (Chaetodontidae), and triggerfishes (Balistidae). The larger fish typically swam several meters above the sea bottom, and a large proportion were frightened by *Ben Franklin* as she cruised slowly 5 to 7 m above bottom. In contrast, the small butterflyfishes and unidentified small fishes that hovered in the lee of large rocks, sponges, and other obstructions on bottom were undeterred by the submersible's presence.

Transition Zone between Stations I and II

The nature of the bottom between the shelf edge at 34 m and Station II in 94 m of water was controlled by three environmental factors: water depth, distance from shore, and bottom current velocity. The increase in water depth resulted in a decrease in ambient light and water temperature and the disappearance of actively growing calcareous algae and coral. These reef forms gave way to a deeper-growing cover, probably of soft algae, interspersed with large sponges in various stages of reduced growth. The algal cover ranged from a general distribution to isolated pockets in a matrix of sand. Reef-rock rubble was scattered over the bottom, reaching a maximum concentration at depths less than 34 m and again at 67 m where several blocks 2 to 3 m in diameter were observed. Below 70 m the reef-rock fragments decreased in number and size.

The increased distance from shore was reflected in the bottom sediments. Fewer coarse fragments of shallow-water origin were intermixed with finer grained sand particles as the depth increased. At 85 m the sand content had reached about 95 percent. Subtle transitions between sand and algal patches gave way to sharp boundaries separating large sand areas from isolated groups of reef-rock fragments.

Decreased bottom currents influenced the nature of the bottom in several respects. Deposits in the lee of large objects became smaller, and lineations in the light and dark patches were more evident at 69 m depth than near the shelf edge. This apparent contradiction to the idea of a general decrease in current velocity may be explained by the fact that the current near the shelf edge was sufficiently fast to completely remove the finer grained particles which form the lineations seen in deeper water. The decrease in current velocity at depth also was shown by the presence of mounds of freshly reworked sediments in 69 m depths, whereas the faster currents in shallower depths were able to remove this reworked material.

Station II

The submersible came to rest on the bottom in 94 m at Station II. Water clarity, estimated at 13 m, with a sparse plankton population, was sufficient to permit viewing under ambient light conditions. Geological and biological observations showed the area to be a transition between the algal province of the upper slope and the silt province of the middle slope. Some observations, however, were unique to this depth zone.

Reef-rock fragments were seen scattered in random fashion over the floor, with lower concentrations than noted upslope. The sharp boundaries characteristic of reduced current speeds were observed, but some lineations in the general distribution pattern were present. A surface sample taken by the *Alvin* manipulator showed the bottom to be a mixture of organic calcareous sand and shells with a small amount of detrital sand. Fragments of kitten's paw (*Plicatula*), a rather heavy-shelled bivalve mollusk, were found in this sample along with foraminiferans, worm tubes, and fragments of reef rock. The surface of the sediments, however, was biologically scarred and typical of a deep-sea environment.

The faunal assemblages at this locality were sparse, particularly when compared with the abundant life at the shelf edge. Fish, which were the dominant animals present, were few in number. A 1-m long king mackerel (*Scomberomorus cavalla*) was seen at the beginning of the station, and a 10-cm sculpin-like fish was observed hiding on the bottom. During the latter portion of this station, a school of four amberjack (*Seriola*) each about 0.5 m long investigated the submersible from one end to the other, showing particular interest in the motions or noise of the mechanical arm as it retrieved a bottom sediment sample. The amberjacks occasionally dove to the sea floor, turned sideways, and rubbed their bodies on the sediment, apparently an attempt to remove ectoparasites. Several small hippolytid shrimp moved about quickly, appearing unafraid of the submersible. Live scallops (*Pecten*) and fragments of their shells along with shells of other dead mollusks such as the angel wing (Pholadidae) were noted on the bottom.

Station III

Station III was somewhat typical of a deep-sea environment, and observations made during this station set the stage for the remainder of the dive. The shallow-water features noted at 94 m had disappeared completely at 135 m. Neither fragments of reef rock, nor live scallops were seen, but some small mollusks were present. The coral sands had given way to a silty bottom having no algal growth. The silty bottom had a well-developed microrelief formed by burrowing organisms and modified by the movements of fish, crustaceans, and mollusks. Although the organisms left numerous tracks, trails, and hollows, the role played by their modifying action was less than in deeper water, where the mounds were less well defined and the pits had less relief. Common microforms were 2-cm diameter holes at the bottom of cavities that were 10 cm across and 1 to 2 cm deep.

The animal life at this station was dominated by the Jonah crab (*Cancer borealis*). Its density was estimated to be approximately one crab per several hundred square meters. They were rather uniform in size, ranging from 10 to 20 cm in carapace width, and no small specimens were observed here or at any other locality visited during the entire cruise. Numerous gastropod mollusks were present, and one specimen (*Calliostoma*) was found in a surface sample collected with the mechanical arm. All were similar in size, 2 to 3 cm in shell height, and they averaged one gastropod per square meter. None was seen moving, but tracks in the sediment (1 cm wide and 0.5 cm deep) revealed random movement over the bottom. Two hermit crabs were noted travelling only 1 or 2 cm per minute and occasionally making quick movements partly out of their shells.

Several squid having the shape, size (20 cm mantle length), and coloration of the genus *Loligo* exhibited an interesting behavior. They swam slowly back and forth over the bottom a few centimeters above it. Without any apparent change in speed they dove into the sediment tail first at an angle of 10 to 20 degrees. The caudal end was completely covered with sediment 1 to 2 cm thick. The dorsal portion of the anterior half of the mantle, plus the head and bases of the arms remained above the bottom. The arm tips were pressed into the sediment out of view. Except for breathing activity the squid remained motionless in the sediment. Lights of the submersible were on during this burrowing process, but subsequent switching off and on of the lights elicited no reaction from the squid. Hake that appeared to be the southern hake (*Urophycis floridanus*) were observed as they burrowed tail first into the bottom in what seemed to be a resting position. When they emerged and moved over the bottom they used their long pelvic fins to locate organisms on or in the bottom.

Plankton was judged to be moderately abundant. This apparent abundance, however, probably resulted from the attraction of animals to the vicinity of *Ben Franklin* by external lights and light emitted through the numerous viewports. Some of the larger plankton forms that were distinguishable were: pelagic annelids (*Tomopteris*), hyperiid amphipods, crab larvae, euphausiids, copepods, siphonophores, and salps.

Station IV

The submersible left Station III and proceeded downslope in search of a bait barrel dropped from the surface the day before by R/V *Privateer*. The depths covered during the search ranged from 135 to 157 m. The general biological and geological setting remained similar to that of Station III, but minor variations were recorded. Jonah crabs were slightly more numerous than at the preceeding station. Density was judged to be about one crab per several hundred square meters and increased as the submersible continued downslope. Crab sizes and activities were the same as previously observed. Most individuals were stationary and sifting sediment for food with their chelipeds; only about 5 percent of the population was walking at any one time. A few specimens were partly buried in the sediment with only their eyes and part of the carapace visible. The presence of the submersible had no effect upon these resting crabs. Crabs not covered by sediment, however, faced the passing submersible but turned away when approached by another crab. A beer can on the bottom provided a convenient scale for measuring the crabs' size; both were of the same size, approximately 12 to 15 cm.

A grayish-white sea anemone, 10 cm in diameter and about 5 cm in height, was attached to an unidentified smaller object. It may have been the same combination of animals (a sea anemone and a gastropod mollusk, *Conus*) as was collected at Station VI, since both produced the same tracks in the sea floor.

The scarcity of fish was very obvious. Among the few fishes present were two zoaroid-types that were resting motionless in small depressions. Both individuals were the same size; 30 cm long and 2 cm in body diameter. They remained motionless with their bodies curved in an *S* pattern and their heads resting on the rim of the depression. Two other sculpin-like fish, one 15 cm and the other 10 cm long, remained motionless on the exposed sediment surface, undisturbed by the passing submersible.

One spider crab (*Rochinia*) was sighted at this station. It was 10 m from *Ben Franklin,* but its light color and large size made it easily detectable. This crab had a carapace estimated to be about 10 cm long. If this animal had been spread out, the total span across the longer walking legs would have been 70 cm or more. The crab walked with only its dactyls in contact with the sediment and the legs folded inward below the body. Additional observations of spider crabs were made at Station VI.

Associated with the increase in tracks was a subtle reduction in the microrelief below that seen previously. There was less variation in the heights of mounds and the depths of pits. The ratio between mounds and pits increased, with mounds still being the dominant form. The pits that were present, however, were larger in their horizontal dimension, averaging 30 cm in diameter and 5 cm in depth.

Figure 4. Bait barrel surrounded by Jonah crabs on a silt bottom in 157 m depth at Station V.

Station V

A bait barrel dropped from the surface the previous day had been filled with fish remains and pushed overboard 6.9 km from shore at a depth of 157 m. A float containing a sonic pinger was attached to the barrel with a 6-m length of line. *Ben Franklin* used an internal receiver and internal hydrophone placed against port and starboard forward viewports to come within visual range of the bait barrel. Near the barrel, the population of Jonah crabs increased markedly, and crabs were heavily concentrated around the barrel (Figure 4). At times a few climbed atop the barrel. Crab sizes were the same as previously noted, ranging from 10 to 20 cm in carapace width. Even among this large aggregation there were no small crabs. Within an area of 100 square meters around the barrel were approximately 150 crabs. A substantial number of them were actively walking about. During its stay, the submersible had a slightly negative buoyancy, and it slowly drifted away from the barrel. The skid marks were followed back to the barrel. Despite the short time that had elapsed, the crabs had quickly moved into the marks and were seen feeding on the exposed benthic organisms. This feeding behavior quickly rounded the skid marks, significantly reducing their relief in a short time.

Fish were noticeably sparse in the vicinity of the barrel. Four hake (*Urophycis floridanus*?) 20 to 30 cm long were recorded actively searching for food. The hake swam slowly over the bottom with their pelvic fins extended forward and in contact with the sea floor, and they occasionally swam vertically up the barrel with their fins still positioned anteriorly. They frequently passed within a few cm of a crab without being attacked. Periodically, they rested on the bottom with the caudal end curled forward opposite the opercular region. After a minute or two they resumed their search for food.

An eel approximately 1 m long swam past the submersible only a few cm off the bottom. It obviously was not interested in the bait and probably was not frightened by the vehicle.

Loligo squid were observed at a distance of less than 2 m from *Ben Franklin's* viewports. They slowly swam back and forth within a few centimeters of the bottom. Once in a while they would stop and lie on bottom with the caudal region and anterior half of the arms touching bottom. The anterior part of the mantle, the head, and arm bases appeared to be raised slightly above the sediment. The arm tips were pressed into the sediment out of sight, but the tentacles lay extended on the sediment surface. One specimen, estimated to be 50 cm long, rested in one place for five minutes. Others remained for one to ten minutes. This pose is similar to that described for the squid that burrowed in the sediment at Station III. Another behavioral action of squid that was observed several times was what appeared to be a search for food in the sediment surface. Individual squid swam forward at a moderately slow speed with the arms spread to a width of 5 to 10 cm. The arm tips dragged along the bottom and created a small sediment cloud. No feeding or other special action was noted during these traverses.

Plankton was moderately abundant, but probably due to attraction by *Ben Franklin's* lights. Some of the common components were aggregate salps, tomopterid annelids, larval crabs, copepods, fish larvae, sihponophores, and numerous small unidentified animals.

While the submersible rested on bottom clouds of detritus obscured our view from time to time. We later found that fish were stirring up the sediments. A group of at least four jacks (*Caranx*) chased a school of 30 or more bumpers (*Chloroscombrus chrysurus*). Several of the bumpers struck bottom, either deliberately or unintentionally as they evaded the jacks, causing a substantial cloud of detritus to swirl up in the affected area. Whether or not the jacks also struck bottom was not determined, but the turbulence of the water created by the fast-moving fish aided in dispersing the detritus and sediment.

A rock located close to the barrel was collected, but subsequent inspection showed it to be orthorhombic sulfur at least 95 percent pure, and evidently dropped from a passing ship. One might wonder whether it may have been released from SS *Marine Sulfur Queen* which disappeared without trace between 4 and 7 February 1963 probably off Florida with her cargo of molten sulfur.

Station VI

Six and one-half hours were spent at the deepest and last station, number VI. The trends noted in the microrelief at the last previous stations continued, and the concentration of benthic tracks reached its maximum. Few mounds and pits were seen and those present were of reduced relief and occurred in equal proportions. The sediment was fine silt which was easily placed in suspension by benthic activity.

The majority of the time at this station dealt with the behavior of the benthic or near-benthic organisms. No hake were seen during the bottom stay, but numerous schools of blue runners (*Caranx*) swam into the lighted area. The schools ranged from 100 individuals to two or three, with an average of about ten. The fish swimming near the bottom placed more sediment into suspension than did the feeding Jonah crabs. Two sharks, one 125 cm and the other 100 cm long, were seen from the submersible, but they stayed for only two to five seconds. One of the more interesting tracks on the bottom was a 2-cm wide ribbon-like depression having small ridges on either side. The track followed a random circular pattern having no apparent design. The organism responsible was sighted and described as a sea anemone. It was later captured by means of the mechanical arm. Subsequent inspection after the submersible surfaced showed that it was a sea anemone, but the organism responsible for the tracks was a cone shell (*Conus*), a gastropod mollusk on which the anemone had attached itself.

Of special interest was the opportunity to study the habits of two spider crabs (*Rochinia crassa*). While *Ben Franklin* rested on bottom, the two crabs were seen approaching from a distance. They passed below the bow and proceeded beyond and out of sight, heading directly into the slow current. The carapace of each specimen was partly covered with a brownish growth of colonial animals, probably hydroids or similar forms. The carapace size was estimated to be 10 cm broad and 12 cm long, the estimated length of the chelipeds was 40 cm on the left-hand side and slightly shorter on the right-hand side. The left cheliped, especially the merus of one specimen was clearly observed to be literally covered with several dozen goose barnacles (Lepadidae). Each barnacle was 0.5 to 2 cm long. Goose barnacles also were common on the walking legs, but were fewer in number than on the chelipeds. These crabs walked with just their dactyles in contact with the bottom. The extremities of the legs were bent inward beneath the body. Because the anterior legs were longer than the posterior ones, the forward part of the body rode higher than the back end. The smaller Jonah crabs moved aside for the passing spider crabs as though to avoid a confrontation. By means of a calibrated viewport, the speed of the spider crabs over the bottom was calculated to be 2 m per minute. The same calibrated viewing system permitted the behavior of the Jonah crab population to be studied. This viewing system consists of an eyepiece that places the observer's eye at a known distance from the porthole, and a series of grids made for various heights of the submersible off the bottom (Ballard, in preparation). Since the optics of the plexiglas portholes are known, as are the viewing distances and heights, grids were constructed prior to the dive. Use of a stop watch permitted study of many crabs simultaneously to determine their rates of movement, periods of feeding, and feeding behavior.

Population densities at this station ranged from one crab per square meter to 15 per square meter. The crabs spent nearly 90 percent of their time in a stationary feeding position. When they did move, it was only for a short distance, usually 15 to 20 cm. Crabs frequently stayed within a 1-m square for 5 minutes before moving out of it. They were territorial about the area in which they were feeding, never allowing another crab to get nearer than about 10 cm before being challenged. Generally, the intruding crab retreated when challenged. The feeding behavior itself took the form of working the sediment with its large claws and feeding with its smaller ones. This feeding behavior left small imprints in the sediment surface. The Jonah crabs were concentrated on the down-current side of the resting submersible and moved inward to feed upon the sediment being disturbed by the submersible. The crabs seemed to be coming from this downcurrent side. Only one crab was seen on the upcurrent side, in contrast with a maximum population of 18 on the downcurrent side.

A traverse was made over the bottom to obtain a measure of the density of Jonah crabs in an area undisturbed by the submersible. Three observers made simultaneous counts from three bow viewports during a 2-minute traverse at slow speed. The density was found to be 1 crab per 50 sq. m.

CONCLUSIONS

The dive aboard *Ben Franklin* fully supported previous experiences gained on *Alvin* and other research submersibles. For efficient operations, a submersible dive must be preceded by a faster and more economical surface-ship reconnaissance. In the area of West Palm Beach, much information had been accumulated by ships of Woods Hole Oceanographic Institution, U.S. Coast and Geodetic Survey, and U.S. Bureau of Commercial Fisheries. Additional information about areas farther north and south had been gathered by ships of Duke University and University of Miami, respectively. However, the profiles made aboard R/V *Privateer* immediately before the dive provided critical data for navigation and for understanding the relationships of the various sites to each other and to their environment.

Observations of benthic animals from deep submersibles show that some animals respond visually, acoustically, or by some other sense, whereas other animals appear to ignore or to be unaware of the submersible's presence. As expected, the bait barrel proved to be a great attraction, but more for crabs than for the fish that were anticipated. We concluded that the best method for making an unbiased population census of a few large benthic animals was to station observers where one of them could view to starboard, one ahead, and one to port, while the submersible proceeded just above the bottom. In this way an area about 30 m wide and of a length that is controlled by the distance or duration of the traverse could be swept. Only Jonah crabs were seen during our census traverse, but we could have counted several different kinds of large animals simultaneously had they been present, and using only simple counting devices. Obviously, this method of determining populations requires the use of a submersible having viewports suitably oriented and available solely to the observers during the census. The length of the traverse can be adjusted to the frequency and patchiness of the animals so as to yield statistically significant counts.

During the dive a calibrated viewing system was used for the first time and proved useful in determining the scale of observed features, their density, distribution, and orientation. The system also was used to determine the density of benthic organisms and with the aid of a stop watch, the movements of these organisms on the bottom could be measured accurately.

Results of the dive aboard *Ben Franklin* supported those obtained aboard other submersibles in showing that at least 90 percent of the total information is obtained visually. Photographs serve mainly to illustrate the findings, though under some circumstances they may provide the basis for subsequent counts of clustered animals or features. Bottom samples are highly desirable for laboratory measurements of the size and composition of bottom materials and particularly for determining the species of animals whose behavior has been observed. The use of the *Alvin* manipulator during this dive proved invaluable. Had it not been available, the rock located at the bait barrel would not have been identified as introduced by man, nor would the cone shell with its attached sea anemone have been identified properly. The need for fast-acting strong manipulator arms is great enough that considerable technical advance can be anticipated in the near future.

Depth determination aboard submersibles by pressure gauge is much less reliable than by echo sounder. Since depth is a critical part of accurate positioning, we recommend that depth below the water surface, as well as height above the bottom be determined acoustically, even though this method is more expensive than by pressure techniques. The cost of submersible operations is so great that every effort also should be made to provide accurate sensors for temperature and current direction and speed. These measurements are needed for relating with the various details of the environment, a task that is especially suitable for submersibles. Even though depth, temperature, and current vectors can be measured more accurately from a surface ship than from a submersible, the surface ship has negligible ability to relate the measurements to the local environment.

KENNETH O. EMERY is Marine Geologist and Senior Scientist at the Woods Hole Oceanographic Institution. He has a BS (1935) and a PhD (1941) from the University of Illinois, and is the author or co-author of about 200 scientific publications in marine geology and related fields, including four books.

ROBERT D. BALLARD is a research associate at the Woods Hole Oceanographic Institution working in the Deep Submergence Group. As a marine geologist, he coordinates the research programs for the Institution's two submersibles *Alvin* and *Sea Cliff*. While serving a three year tour in the U.S. Navy he monitored the Office of Naval Research ocean science and engineering contracts in the New England area.

ROLAND L. WIGLEY is a biologist with the U.S. Bureau of Commercial Fisheries, and is presently Chief, Benthic Invertebrates Project at the Woods Hole Laboratory. He did his undergraduate work at the University of Maine, and has a PhD in vertebrate zoology from Cornell University.

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