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Tektite 1, Man-in-the-Sea Project: Marine Science Program

Sixty days in a sea-floor habitat provides unprecedented opportunity to study reef fauna and reef sedimentology.

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The sea becomes increasingly important as a source of man's vital resources: food and minerals. The successful exploitation of these resources requires careful preliminary research that in many instances can be done effectively only within the marine environment itself. Project Tektite 1, the nation's recently completed man-in-the-sea experiment, was designed to evaluate a sea-floor habitat as a research platform and to test the research capability of a small team of scientists over an extended period of submarine habitation under nitrogen-saturated conditions (*1*). The project was successfully terminated on 15 April 1969, after the team—two biological oceanographers, a fisheries biologist, and a marine geologist—had spent 60 days approximately 15 meters beneath the surface of the sea.

The project was sponsored jointly by the U.S. Department of the Interior, the U.S. Navy, the National Aeronautics and Space Administration, and the General Electric Company. The experiment not only provided opportunities for marine research, particularly on the behavior and ecology of reef fauna and reef sedimentology, but also yielded data on a variety of behavioral, biomedical, and engineering problems, such as habitability and psychomotor performance (*1*)

Design of Tektite 1 Habitat

The underwater habitat (Fig. 1), designed and built by the General Electric Company, consists of two vertical cylinders (3.81 meters in diameter and 5.64 meters high) mounted on a rectangular base. Each cylinder contains an upper and a lower compartment, which provide a total of four rooms within the habitat. The lower compartment of one cylinder contains bunks and a small galley. The upper compartment serves primarily as the bridge or communications center but also houses atmospheric monitoring equipment, alarm devices, and a complex array of equipment required for biomedical measurements. It also contains a modicum of space for compiling data and for microscopy. A tunnel 4.5 feet (1.37 meters) in diameter connects the bridge with the upper compartment of the second cylinder, which is largely occupied by the air-conditioning and air-purification system. The lower compartment of the second cylinder provides storage space for scuba and research equipment and provides counter space for preparing and analyzing biological and geological specimens. This compartment contains the entry trunk through which the team enters the water on daily sorties into the sea. Each compartment contains hemispheric ports that allow broad, undistorted visibility of the undersea area adjacent to the habitat. A cupola on top of one of the cylinders provides 360-degree visibility.

During the project, umbilical lines from a nearby barge supplied air, water, and electricity to the habitat. Air was added as required to maintain a constant level of oxygen and air pressures. The breathing mixture was 92 percent nitrogen and 8 percent oxygen; this mixture, at the ambient pressure of the experiment, closely approximates the partial pressure of oxygen at atmospheric pressure. Carbon dioxide was removed within the habitat by chemical absorption with barium hydroxide.

Site

The experimental site, in Greater Lameshur Bay on the south side of St. John, U.S. Virgin Islands (Fig. 2), was selected for generally moderate sea-surface swell, warm clear water, and a biologically diverse coral environment. Visibility generally extended 18 to 25 meters in the morning but decreased to 9 to 15 meters by late afternoon. Although the water was warm (78 degrees Fahrenheit) throughout the dive, exposure suits were required for divers during extended periods of underwater work. Nearly all research was conducted using standard scuba, but it was possible to work within 30 meters of the habitat by using an air hose or hookah system.

The habitat was anchored in a reentrant in the coral reef on the eastern side of the bay (Fig. 2). The massive reef structure extending south from the habitat to Cabritte Horn Point is crossed by several linear sets of grooves partly filled with carbonate sand. A wide variety of stone corals compose the reef, which has a relief of 3 to 4.5

The authors compose the scientific team of Project Tektite 1. Dr. Clifton (a geologist) is with the U.S. Geological Survey in Menlo Park, California; Conrad Mahnken (an oceanographer) and John Van Derwalker (a fisheries biologist) are with the Bureau of Commercial Fisheries Biological Research Laboratory, Seattle, Washington; Richard Waller (an oceanographer) is with the Bureau of Commercial Fisheries, Washington, D.C.

meters above the adjacent sand flats. The deeper parts of the seaward reef wall are typical of deep Caribbean coral reefs as described by Goreau (*2*), and *Montastrea annularis* is the primary hermatypic species. Landward from the deep reef is an extensive patch reef area of isolated coral heads on sandy bottom corresponding to the "cervicornis" zone of Goreau. The seaward reef zones differ from Goreau's description, however, by lacking an intermediate "buttress" zone or shallow "palmata" zone, presumably because of the low-energy condition that prevails in the bay. The patch reef area is bordered instead on the landward side by an area of slightly coral-encrusted bedrock cobbles and boulders that locally adjoins submerged outcrops of bedrock, largely volcanic rock of the Water Island Formation of possible Early Cretaceous age (*3*). *Acropora palmata*, an indicator of high-energy zones, occurs along this rock outcrop near Cabritte Horn Point. On the seaward side of the reef lie extensive sand flats that are either barren or vegetated by *Thalassia* or by *Udotea* and are sprinkled with sporadic patches of *Penicillus* and *Halimeda*. An unvegetated sand strip 9 to 15 meters wide along the reef separates it from the *Thalassia* and algae flats.

Marine Research

The marine science program included a wide variety of biological and geological studies. Although most studies of Tektite 1 were programmed before the dive began, several were generated during the dive as a result of the continuous contact with the submarine environment. The intercommunication between team members of diverse disciplines promoted considerable insight into the overall ecologic and geologic environment as the dive progressed. The habitat proved an excellent base from which to monitor the reef fauna and the factors influencing sedimentation.

Supporting the marine science program was a second team of scientists at the surface (*4*), who acted as diving alternates for the crew in the habitat. This team complemented the underwater studies conducted from the habitat by extending the research diving into areas beyond swimming range of the primary team or into water shallower than 6 meters, from which the undersea team was excluded because of the hazard of decompression sickness.

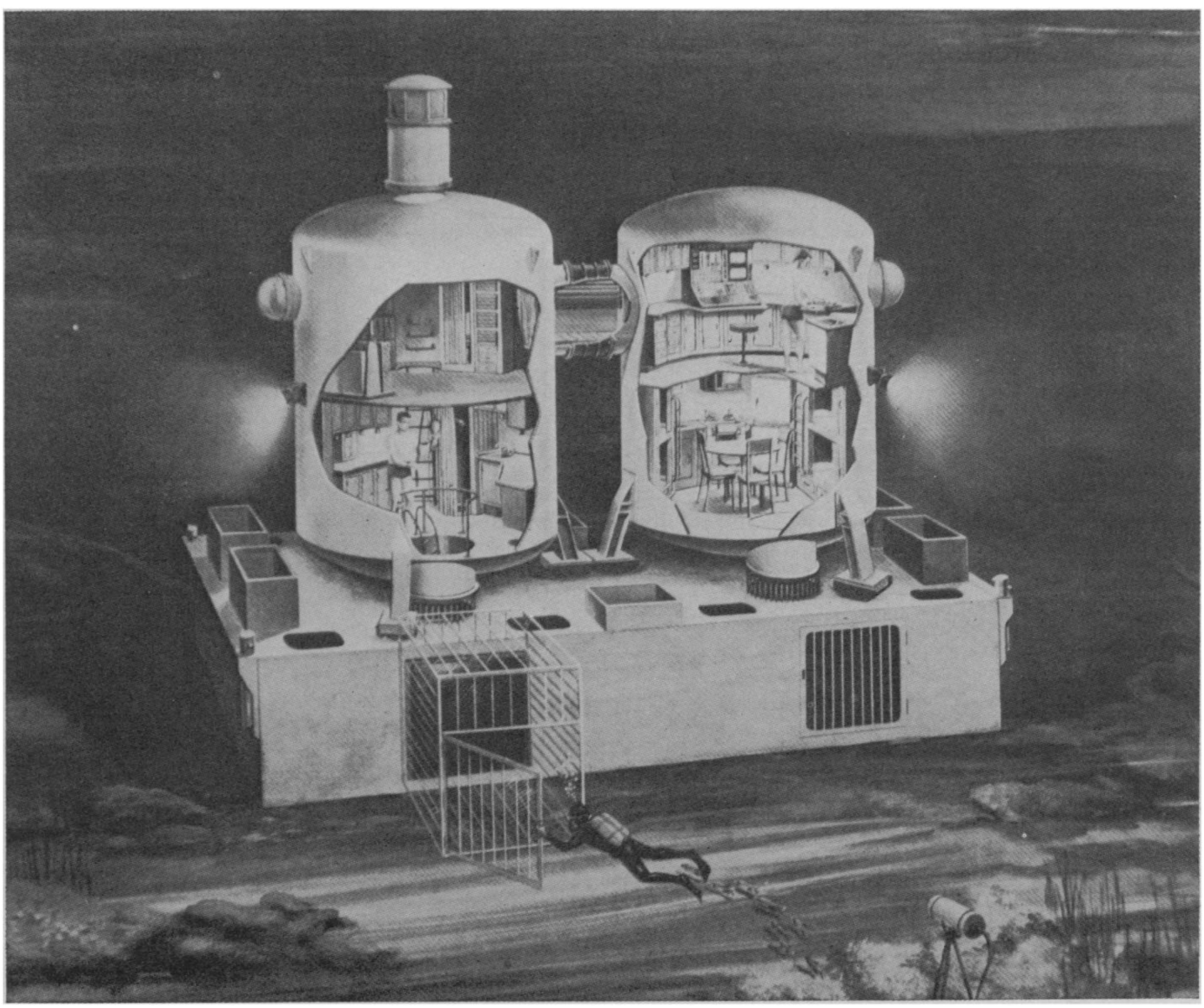

Fig. 1. Cutaway showing the design of the Tektite habitat.

Reef Fauna

A major effort during Tektite was devoted to study of the diurnal pattern of behavior and the population density of the spiny lobster *Panulirus argus*. Two different tagging techniques were employed for this study. Small sphyrion tags, each with a unique color code, were attached to 137 lobsters in the study area; the tags were large enough to permit identification without handling the lobster. In the second technique, small sonic pingers were glued to the dorsal surface of the lobster's carapace (Fig. 3). A small underwater sonic receiver, developed by the Bureau of Commercial Fisheries Biological Laboratory in Seattle, Washington, could, under ideal conditions, detect tagged lobsters as far away as 600 meters; this range greatly diminished when the lobster hid beneath coral rock. Neither type of tag seemed to interfere significantly with the lobster's normal behavior.

Mature spiny lobsters normally spent the daylight hours on the reef in dens under coral growth or rocks, with only their antennae projecting. Most of the lobsters showed definite preferences for inhabiting particular areas of the reef and particular dens. Usually several (as many as 20) lobsters occupy a single den, and solitary lobsters, mostly large males or egg-bearing females, generally stay in dens within a few meters of sites occupied by other lobsters. Dens occupied by lobsters rarely contain other large marine animals such as fish, moray eels, or sea urchins. Observations of the lobsters lashing their antenna toward intruding fish suggest that the lobsters either evict or prevent entry of other large organisms. Larger lobsters react similarly to the diver who places his hand into a den. Commonly the lobster would attempt to catch the hand between his antennae; if the hand were caught, the lobster would drive forward and impale the hand with the spines that ring the antennae. Further threatened, the lobster would lodge itself with legs and spines in the furthest recess of the den. As was noted by Lindberg (*5*), antagonized lobsters would occasionally change their residence shortly after the antagonist had left. The low ceiling at the entrance to most of the dens precludes entry by large predators. In one area, a group of large lobsters living relatively unprotected under ledges disappeared within 3 days after the arrival of a school of seven 2.5- to 4-meter nurse sharks. Lobster remains scattered on the sea floor near the ledges suggest their fate.

Shortly after sunset the lobsters be-

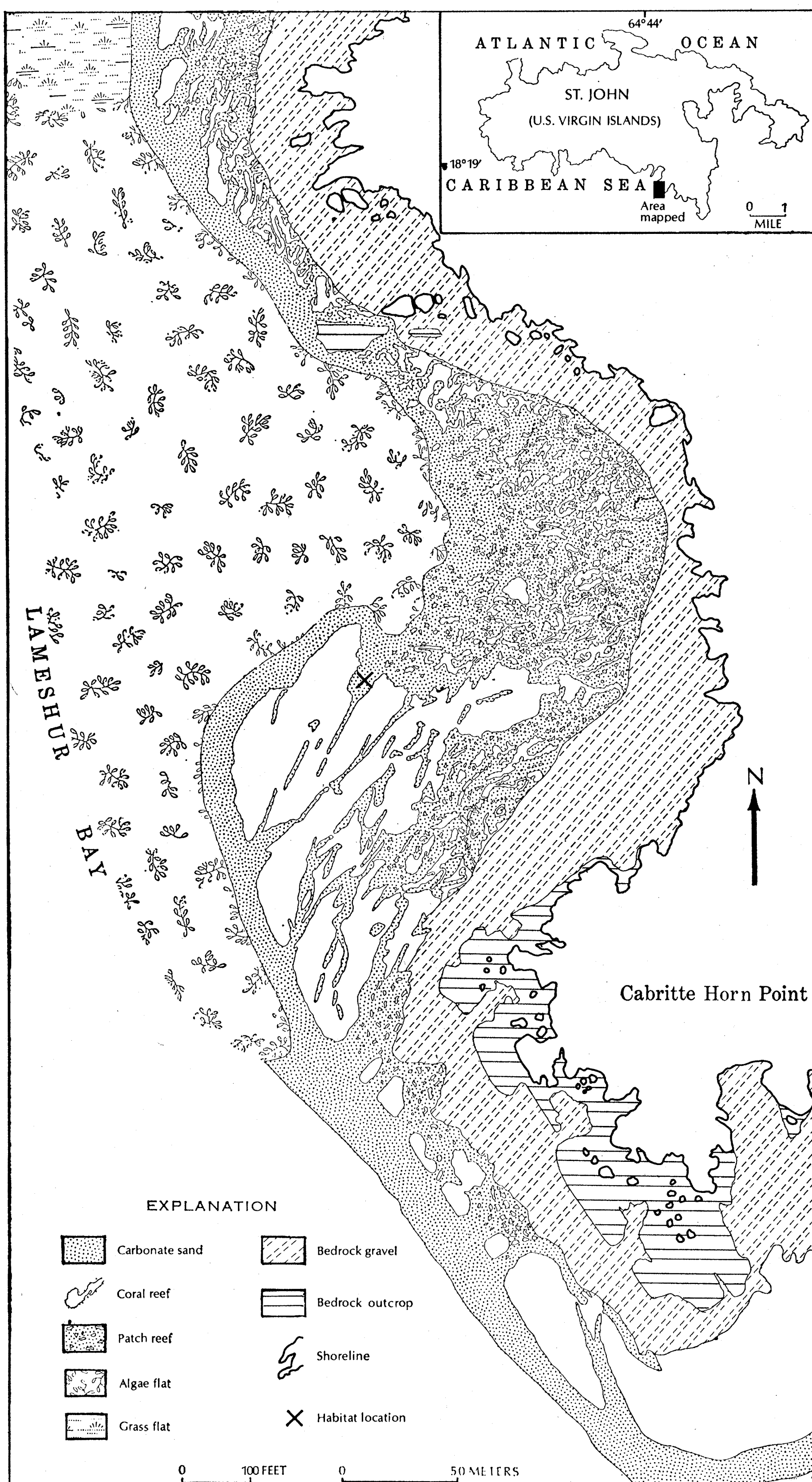

Fig. 2. Sedimentary facies in the vicinity of the Tektite habitat.

gin to move out of their dens, and within 2 or 3 hours they ordinarily migrate as far as 100 meters onto the algae-covered sand flats adjacent to the reef. The purpose of this migration presumably is feeding, although actual feeding activity was not observed. The lobsters moved surprisingly rapidly; one traveled more than 240 meters in less than 4 hours. When approached in the dark by unlighted divers, they either attempted to escape or became immobile, with their antennae held back over their body. Such behavior suggests that the lobsters, while on the flats, are particularly vulnerable to predators. The remains of a sonically tagged lobster were found on the flats; the carapace had been crushed and most of the tissue had been removed from the abdomen and cephalothorax.

The lobsters' diurnal movement to and from the reef seems to be well directed. One egg-bearing female followed the same route at the same time over several consecutive nights. Such observations indicate that the lobster has a well-developed navigational ability. Egg-bearing females showed a tendency to move to well-concealed dens in shallow water.

The range of lobster movement may be relatively restricted. Of the 137 lobsters carrying sphyrion tags, 42 were resighted after tagging; all were found within 460 meters of the initial tagging site. Sonically tagged lobsters generally remained within 100 meters of their tagging site. However, the inability of the team to locate the 95 remaining lobsters that carried sphyrion tags and the disappearance of two sonically tagged lobsters leaves the range of movement open to question.

The behavior of immature lobsters differs distinctly from the behavior of the mature population. On the reef itself, immature lobsters were present only in very shallow water. They were also seen on the sand flats, living within dense colonies of the spiny sea urchin *Diadema antillarum*, which slowly migrates across the bottom. This association apparently shields the young lobsters from predators and continuously provides them with new feeding grounds. Small lobsters removed from an urchin colony would immediately return to the colony. These colonies may be selected by the young lobsters as their first home on the sea floor.

Sonic tags were also used to trace the movement of other invertebrates, particularly the queen conch (*Strombus gigas*). The conchs seem to occur in groups composed of individuals of similar age. The movement pattern of a group could be traced by tying a sonic tag to one of the members. The first group traced consisted of mature individuals with well-developed spines that traveled 45 to 55 meters per day southward, beyond swimming range of the habitat. A second group traced consisted of older individuals with thick-lipped shells that were extensively eroded by boring organisms. This group remained in the same area during the period of observation. After 4 days, the tagged individual was 6 meters from the place where it had been released.

The Tektite experiment provided an excellent opportunity to study the symbiotic cleaning behavior of certain brightly colored shrimp and cooperating reef fishes. The shrimp, which are almost invariably associated with an anemone, pick and eat parasites, injured tissue, and other undesirable particles from a large variety of reef fishes, and they are probably the primary agent in the control of gill, oral, and external parasites (*6*). This activity may play a major role in maintaining local concentrations of many species of reef and pelagic fishes. Indeed, the abundance of such fishes may be directly related to the abundance of the anemone *Bartholomea annulata*, to which cling the two most abundant cleaners, the Pederson cleaning shrimp *Periclimenes pedersoni* and the spotted cleaning shrimp *P. yucatanicus*.

Ecological studies were made during Tektite 1 to determine the distribution of cleaner shrimps and anemones in various reef environments. Five different topographic features on the reef and sand flats south of the habitat were chosen as representing the major ecological zones. Anemones and shrimp were completely enumerated within each zone at least once during the study. In addition, shrimp populations on 26 anemones situated in a tract of sand strip at the reef base were monitored each week. The shrimp were found to be rather fearless and could easily be enticed to browse along the diver's hand, where they assiduously picked at hairs. It therefore became a matter of routine to measure the length of living shrimp either on the anemone or on the back of a diver's hand.

Although the anemones were equally abundant in all five of the ecologic zones, the abundance of shrimp varied. *Periclimenes pedersoni* was most abundant along the sand strip, an area at the reef base grazed clean of algae by fishes to about 10 meters from the base of the reef. The sand strip is the major corridor for fish movement along the reef and therefore supports more cleaning stations. One of the most frequented stations contained 26 individuals of *Periclimenes pedersoni*. *Periclimenes yucatanicus*, on the other hand, was most abundant on the sand flat beyond the limit of grazing, an area of scattered coral rubble and heavy algae growth.

Additional observations were made on precleaning behavior, intraspecific size dominance, interspecific competition, shrimp repopulation, and the relationship between anemones and other caridean associates. One, and possibly two, species of *Periclimenes* collected from anemones during Tektite 1 may be new species.

The habitat also proved to be an excellent base from which to study diurnal variations in the vertical distribution of zooplankton. A nonmetallic pump with a capacity of 190 liters per minute was used to pump water from a vertical standpipe composed of polyvinyl chloride located about 10 meters from the habitat. The base of the standpipe was anchored to a 1150-kilogram cement clump, and the upper end was attached to a surface buoy. Valves operated by hydraulic pressure were arranged along the pipe at 3-meter depths and could be operated one at a time from the habitat. The pipe entered the habitat through the 25.4-centimeter floor trunk in the wet room, and water was pumped into a filtration barrel containing a set of nested nitex nets. Preliminary data indicate that an undersea laboratory provides an excellent base from which to monitor zooplankton distribution.

Collaboration between biologist and geologist led to observations of the growth rate of two green algae, *Udotea* and *Penicillus*. These algae are significant not only as they relate to biologic productivity but also as contributors of aragonite needles to the lime mud of the bay. Two techniques were used to estimate growth rate: (i) repopulation and growth rate over an area of 2 square meters that had been picked clean; (ii) labeling of immature plants with carbon-14. The data have not yet been analyzed, but in situ observations indicated that *Udotea* in particular has a very rapid growth rate, with a life span from budding to senility of 3 to 4 weeks.

Geologic Studies

Geologic studies included the delineation of sedimentary facies in the vicinity of the habitat (Fig. 2) and a study of the processes that influence sedimentation. From the geologic standpoint, one of the greatest rewards of the dive was the opportunity to study on a nearly continuous basis the effect of bottom-dwelling organisms on the sediment. Throughout the experiment neither waves nor ocean currents moved the bottom sand; in contrast, organisms living on or within the sand continually worked and reworked the bottom. Mixing, particularly within the uppermost portion of the sand, was far more rapid than anticipated. One experiment demonstrated a complete reworking of the upper 5 millimeters of sediment in 4 days. Sedimentary structures produced by waves or currents tend to be rapidly destroyed by such turnover. Simulated sand ripples with a wavelength of 15 centimeters and an amplitude of 15 millimeters were completely obliterated within a week.

The dive also permitted study of the processes in still water that orient empty pelecypod valves with their concave surfaces up or down on the sea floor. Examination of more than 2300 shells lying on diverse substrata demonstrated that, as in deeper water on the continental shelf (*7*), shells lie predominantly with their concave surfaces up, in contrast to the predominant configuration of downward concave surfaces produced by waves and currents. Moreover, the tendency toward concave-up configuration in still water increases with increasing shell size; under the influence of waves, this tendency is reversed: the larger shells show the greater degree of concave-down configuration. Predators of the pelecypods, attendant scavengers, and bioturbation probably produce this predominantly concave-up configuration (*7*). To determine the effect of bioturbation on shell configuration, 400 matched, cleaned valves of different sizes were emplaced on the sea floor, half with the concave surface up and half with the concave surface down. Bottom-dwelling organisms overturned shells of all sizes in both sets, but, during the 2-week period of the experiment, a greater number of larger shells were rotated to the concave-up position.

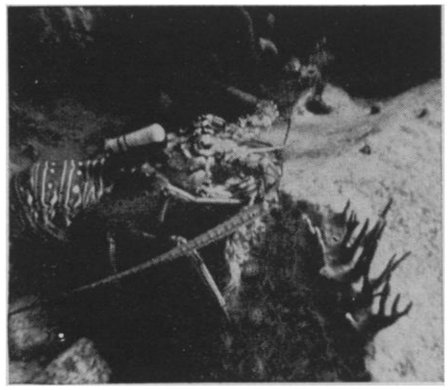

Fig. 3. Spiny lobster (*Panulirus argus*) bearing a sonic pinger.

Other geologic studies related to the history of sea-level change in the Virgin Islands area. The present sea floor contains abundant evidence of lower stands of the sea; for example, well-rounded pebbles normally restricted to the shoreline are locally common at water depths of about 14 meters. R. L. Phillips, while mapping the sea floor adjacent to the habitat area, recognized an extensive beachrock about 6 meters beneath the present sea surface.

The orientation of gorgonians and platy milleporids on the reef near the habitat consistently deviates 10 to 15 degrees from the orientation of the dominant, linear, reef groove system shown in Fig. 2. If it is assumed that these animals preferentially grow normal to the average direction of wave approach, the divergence suggests either that the groove systems are relict features formed at a lower stand of the sea when wave approach differed slightly from its present course or that the grooves result from unusual present-day events.

Summary

The Tektite experiment was designed to provide data for a number of behavioral, biomedical, and engineering studies in addition to the marine sciences program. Conditions for some of these studies were not altogether compatible with the program for the marine sciences. For example, isolation imposed by human behavioral studies precluded physical contact with the surface team, even though such contact was physically possible and desirable for the conduct of the marine sciences program. Isolation also imposed on the scientific team the duty of all in-habitat maintenance, both scheduled and unscheduled, thereby taking substantial time from scientific research. In addition, between 10 and 20 percent of the waking time was devoted to performance of psychological tests required for the biomedical studies. Most of the experiments were directed toward detecting potentially adverse changes and thus were accepted as necessary and desirable. The only health problem to affect the scientific program during the dive was a minor external ear infection contracted by all the divers. Nonetheless, the experiment demonstrated, at least to our satisfaction, the advantages of underwater habitation and saturation diving for biological and geological research. A major advantage is the opportunity for continuous monitoring of organisms or processes. In addition, underwater habitation provides for considerably more research time in the water than surface diving or intermittent bottom dwelling, and this advantage increases greatly as the depth of habitation increases. Even in the relatively shallow depths at which Tektite 1 was conducted, the undersea team could spend appreciably more time at work in the water than their colleagues on the surface.

Finally, Tektite 1 demonstrated that the scientist who lives in the sea need not have the extensive qualifications of a professional diver. Of the four scientists of the in-habitat team, only Crew Chief Waller was so qualified; the other three had used scuba as a research tool, but on a relatively limited basis. Any healthy, well-conditioned marine scientist with a basic diving background is capable of extending his research into the shallow sea on a full-time basis. It is hoped that many such scientists will in the future be able to utilize the undersea laboratory.

References and Notes

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