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THE 1957 DIVING PROGRAM OF THE BATHYSCAPH TRIESTE

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THE PROBLEM

Evaluate the potentialities of a bathyscaph as an oceanographic research vehicle.

RESULTS

1. A diving program employing the bathyscaph TRIESTE and involving dives to depths of nearly 2 miles was conducted in the Mediterranean in the summer of 1957. Representing the first use of a bathyscaph by Americans, the program provided scientific investigators with new information about the deep sea, and showed the bathyscaph to be an extremely useful tool for *in situ* investigations of deep ocean waters.

2. Observations and measurements were made of the distribution of ambient noise, distribution of marine organisms, occurrence of weak water currents, gravity, and extinction of sunlight; *in situ* observations were made of sea-floor sediments and of the biological factors that tend to alter the sea-floor topography.

RECOMMENDATIONS

1. Continue deep-sea research using a bathyscaph.

2. Encourage modification and further development of the bathyscaph and/or bathyscaph-type craft.

3. Promote the development of more versatile deep-submersible research craft.

4. Evaluate the usefulness of bathyscaphs and deep-submersible craft for military purposes.

5. Develop acoustic and oceanographic instrumentation for use on the bathyscaph.

ADMINISTRATIVE INFORMATION

Contract N62558-1342, Office of Naval Research, provided financial assistance to Jacques Piccard for a series of scientific dives using the bathyscaph TRIESTE to be made during the summer of 1957 in the Tyrrhenian Sea. Scientific personnel from the U. S. Navy Electronics Laboratory, U. S. Navy Underwater Sound Laboratory, Hudson Laboratories, Columbia University, and the Office of Naval Research, Washington and London were the American participants in the diving program. NEL participation was carried on under IO 15401, NE 120221-847.13 (NEL L4-1). The report was approved for publication 28 December 1959.

The author wishes to thank Dr. E. C. LaFond, Dr. G. H. Curl, and Dr. R. S. Dietz for their critical review of this manuscript.

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INTRODUCTION

The bathyscaph, invented by Professor Auguste Piccard, has made it possible, for the first time, for man to descend to the greatest ocean depths. The formerly impenetrable pressure barrier has been surmounted and it is now possible to visually explore the contents and characteristics of the deep sea. In addition to seeing and evaluating, the observer can now sample, measure, and work with greater precision and comprehension than ever before.

The bathyscaph is a self-contained, surface-independent, navigable diving chamber, accommodating two people, instruments, and power supply, with a possible submersion time of more than 48 hours. At present, there are only two of these craft, both products of the Piccard family. The first was built by Professor Piccard with funds provided by the Belgian National Fund for Scientific Research between 1938 and 1948. Following historic dives off Dakar, Africa, the craft was turned over to the French Navy. In the light of experience with an unusual submarine craft, they rebuilt the flotation tank and produced a structurally altered vessel now known as the FNRS 3. A second and improved version of the bathyscaph, the TRIESTE, was built by Auguste Piccard in collaboration with his son Jacques in 1952 and 1953, with Italian and Swiss cooperation.

The Office of Naval Research entered into a contract with Jacques Piccard in February 1957 to assist in the further development of the bathyscaph, TRIESTE. The contract provided financial assistance to Mr. Piccard for a series of scientific dives to be made during the summer of 1957 in the Tyrrhenian Sea. The scientific program was to be primarily an American effort, but provided that Italian, Swiss, or other European scientists could participate.

The broad objectives of investigation proposed by the U. S. Navy Electronics Laboratory were:

(1) To investigate the ocean environment at great depths taking maximum advantage of being *in situ* for observations.

(2) To evaluate the potentialities of the bathyscaph as a research tool.

(3) To encourage modification and further development of the bathyscaph or bathyscaph-type craft.

(4) To examine possible naval uses for this type of craft, e. g., in submarine rescue work, or as a deep-diving submarine.

Objective (1) was to pursue a study of the ocean environment by the direct means, such as visual observations, offered by the bathyscaph. Objective (2) was to be an evaluation of the scientific results and the problems involved with a bathyscaph when used for research purposes. Objectives (3) and (4) were to some extent dependent upon a successful program of scientific research. To fulfill these objectives with a diverse scientific program would be difficult; therefore, the scope of the research program was restricted to the study of the field of sound in the ocean and associated phenomena. This decision was predicated upon the Navy's great interest in underwater acoustics in submarine warfare. The bathyscaph offers a much needed capability for research in this field. Although the program emphasized acoustical studies, it was supported by a program in oceanography and included studies of the biology, geology, and physics of the deep ocean — these investigations contributing directly to the main program through the identification of sound sources and the determination of the sound-transmission qualities of the ocean and the bottom.

DESCRIPTION OF THE BATHYSCAPH

Before proceeding into the program and results, it is desirable to familiarize the reader with the construction and capabilities of a bathyscaph. The two Greek root words *bathy* and *scaph* mean deep and boat, respectively. The bathyscaph is a self-contained, untethered, deep-diving vehicle. It may be likened to an underwater version of a nonrigid, lighter-than-air ship. Basically, it consists of a heavier-than-water manned sphere capable of withstanding the great hydrostatic pressures encountered in the ocean depths (fig. 1 and 2). The sphere is the only component of the craft that is strong enough to resist destruction by the great pressures. This sphere is suspended below a nonrigid buoyant hull which is filled with gasoline and is capable of withstanding the buffeting of surface waves and towing but not the hydrostatic pressure of the deep sea. Equilibrium between external and internal pressures about the float is maintained by allowing the sea water, which is immiscible with and heavier than gasoline, to enter the hull through special "breathing" valves. Vertical movement of the bathyscaph is controlled by changes in buoyancy. Diving is initiated by flooding air-filled tanks at each end of the hull and the entrance tube leading to the sphere with sea water.The bathyscaph then commences to sink. As it settles into the ocean, the gasoline is compressed by hydrostatic pressure causing an additional loss in buoyancy. The temperature of the gasoline is also lowered by the decrease in ambient sea-water temperatures with depth. Such contraction of the gasoline adds further to the decrease in buoyancy. With only minor control in the buoyancy, the bathyscaph will continue to sink at about 6000 feet per hour until it reaches the bottom. Return to the surface is accomplished by jettisoning enough of the iron shot used as ballast to regain positive buoyancy. Further control of buoyancy can be attained by liberating gasoline from a special compartment. The bathyscaph can be made to hover momentarily at mid-depths or to rest on density discontinuities within the ocean by these control mechanisms. At the sea floor, the descent is dampened by a loss in negative buoyancy as the steel cable guide rope hanging below the bathyscaph gains support from the sea floor.

Although the primary movement of the bathyscaph is in the vertical direction, some horizontal maneuverability is provided by propellers driven by electric motors mounted on the upper deck of the hull (fig. 2). A horizontal speed of about 1 knot can purportedly be maintained for 4 hours.

The sphere of the TRIESTE has an inside diameter of 2 meters with a minimum wall thickness of 9 centimeters which increases to 15 centimeters in the vicinity of the port and hatch. It can accommodate two people and approximately 3 cubic feet of instrumentation without difficulty. The sphere, forged out of "fatigueless" steel, is designed to withstand the pressure at a depth of 15 kilometers (22,500 psi) before collapsing and is considered safe to dive to 6 kilometers. The cabin has two portholes — one looking forward and slightly down, the other aft and upward. The ports consist of truncated right-angle cones of plastic 15 centimeters thick, and are 40 centimeters and 10 centimeters across on the outside and inside, respectively. This provides a 90-degree field of view. Surrounding the forward port, there are twelve separate lead-throughs into the cabin. Two of these are used for snorkels; in times of emergency, it is possible to take in air while at the surface. The remaining lead-throughs provide electrical cables and manometer tubing for the operation of the bathyscaph and its scientific equipment. The entire power supply (30 kwh dc, provided by silver-zinc batteries) for the TRIESTE is contained wholly within the sphere.

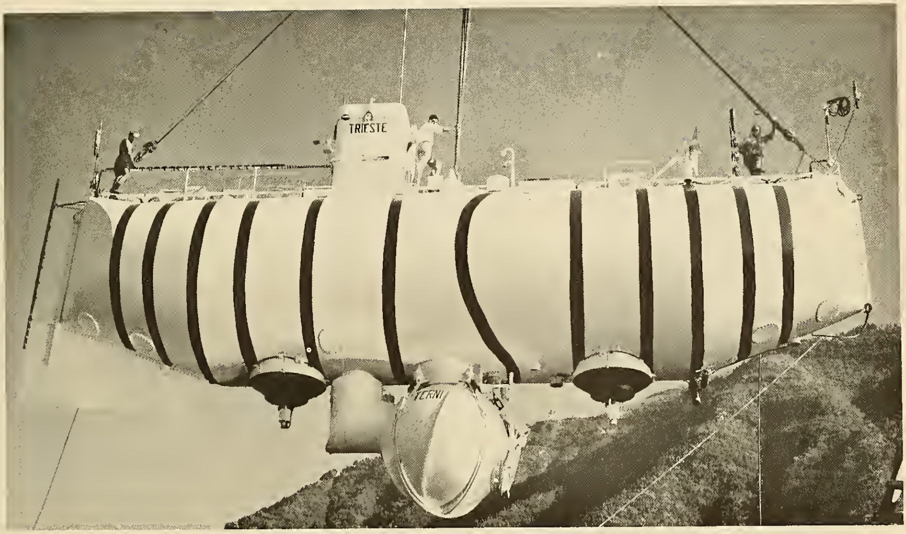

Figure 1. The bathyscaph TRIESTE. The pressure-resistant gondola and ballast tanks hang beneath a compartmented gasoline-filled float.

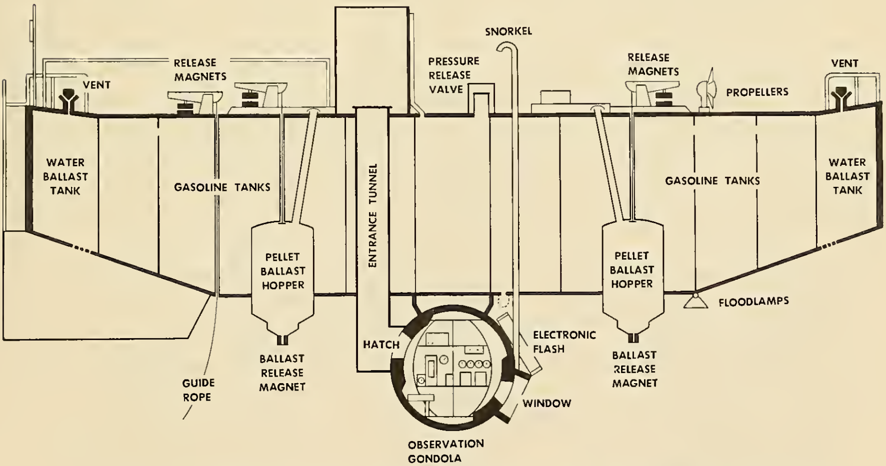

Figure 2. A schematic cross-section of the bathyscaph TRIESTE. Note: The diagonal filling tubes for the ballast tanks were not present at this time on the TRIESTE.

The weight of the sphere, 11 tons, dictates the over-all size of the craft. The compartmented flotation hull is 16 meters in length and 4 meters in diameter and holds approximately 28,000 U. S. gallons of gasoline. When filled with gasoline having a specific gravity of 0.70, it provides a positive buoyancy of 34.5 tons. Fore and aft of the cabin, within the flotation hull, are two bins, each containing 4.5 tons of ballast. The net positive buoyancy of the hull when fully loaded is more than one ton. The ballast of iron shot, averaging 2.6 millimeters in diameter, may be jettisoned through magnetic (solenoid) valves at a rate of 1200 pounds per minute. Approximately one ton of ballast is expended for every 1000 meters descended. The solenoid valves are controlled by 4 watts of power. When the current is interrupted, the ballast is released. The system is, therefore, designed to be "fail safe" in the event of a power failure. If for any reason the valves become plugged or the guide chain fouled on the bottom, it is possible to jettison the bins and guide chain.

SCIENTIFIC PROGRAMS

To provide maximum utilization of the bathyscaph for scientific research, several Navy and Navy-contract-supported laboratories were invited to participate in the summer's program. In April 1957, representatives of the Office of Naval Research, U. S. Navy Underwater Sound Laboratory, U. S. Navy Electronics Laboratory, Hudson Laboratories of Columbia University, and Woods Hole Oceanographic Institution drafted a preliminary research program for the TRIESTE.

The U. S. Navy Underwater Sound Laboratory's portion of the program consisted of three parts: providing the bathyscaph with underwater telephone communications, studying the directional characteristics of background noise versus depth, and determining the correlation pattern of the noise field occurring during any one diving period. Initial planning indicated five dives for the above purposes, out of a total of 19 dives for the entire program. Actually, four dives out of a total of 18 made for scientific purposes were made by USNUSL (table 1).

The acoustic program of the Hudson Laboratories was similar to that of the Underwater Sound Laboratory but with its emphasis on the lower frequencies. The program consisted essentially of two parts, ambient-level and directionality measurements.

The observations proposed by the Navy Electronics Laboratory, which are the main subject of this report, were: determination of the distribution, type, size, population, habits, and abundance of marine organisms throughout the vertical water column; observation of the response of deep-sea organisms to various levels of sound energy, light, and tactile stimulation; qualitative determination of bottom current; and viewing of the sea floor.

The bathyscaph's primary attribute is that it permits visual observation of the deep sea. Observation of the poorly understood deep-sea realm permits identification of organisms and physical phenomena. Future investigations of a quantitative nature can be effectively planned once the phenomena present are better identified.

To supplement the data gathered by the bathyscaph, a surface ship was outfitted with a hydrographic winch capable of reaching the bottom anywhere in the Mediterranean. Nansen bottles, reversing thermometers, and two types of bottom samplers were available for use with the winch. In addition, a 900-foot bathythermogram was on hand. NEL also provided self-contained underwater breathing equipment. This was used for underwater filming of the diving TRIESTE, changing film in the Edgerton camera, and inspection and cleaning of the bathyscaph ports, as needed. All of the dives were made in the Tyrrhenian Sea (fig. 3).

An underwater telephone transducer was used as a sound source to study the response of animals to a particular frequency band. Visual observations at great depths were supplemented by photographs taken with a special camera and flash designed and built by Dr. H. E. Edgerton. The camera and flash were located 5 meters from the sphere near the bow where it could photograph objects illuminated by the far mercury lamp. Features near the sphere could be effectively photographed using other cameras inside the sphere. The Edgerton camera was capable of taking 800 35-millimeter exposures at a rate of one every 5 seconds. As an adjunct to these observations, a remotely controlled plankton sampler was installed on the bathyscaph's deck. This was capable of collecting and retaining twenty separate samples and was controlled from within the sphere. An electronic temperature-sensitive unit was installed for the diving program.

TABLE 1. Summary of dives made by the bathyscaph during 1957.

TRIESTE Dive No.	Location	Latitude	Longitude	Depth (meters)	Depth (ft)	Observer	Date	Purpose
23	Costellammare			34	112	Kielhorn	5-	Technical
24	Capri	40°24'50N	14°16'05E	260	853	Jerlov	7-1	Light penetration
25	Capri	40°26'00	14°15'15	310	1017	Jerlov	7-1	Light penetration
26	Capri	40°30'00	14°15'00	600	1968	Jerlov	7-3	Light penetration
27	Capri	40°30'00	14°15'00	1080	3543	Dietz	7-3	Oceanography
28	Capri	40°30'00	14°15'00	1100	3510	Lewis	7-18	Acoustics
29	Capri	40°30'00	14°15'00	1125	3691	Rechnitzer	7-20	Oceanog. & biol.
30	Capri	40°30'00	14°15'00	1080	3543	Lomask	7-25	Acoustics
31	Capri	40°31'56	14°13'55	178	584	Madison	7-26	Demonstration
32	Capri	40°31'56	14°13'48	300	984	Kobr	7-26	Biol.
33	Capri	40°31'43	14°14'12	470	1542	Rechnitzer	7-26	Oceanog. & biol.
34	Castellammore	40°42'00	14°27'50	53	174	Maxwell	8-30	Technical
35	Capri	40°30'55	14°27'45	1090	3576	Lewis	9-2	Acoustics
36	Ponza	40°35'00	13°00'00	2800	9189	Lewis	9-9	Acoustics
37	Ponza	40°35'00	13°00'00	310	1017	Lewis	9-11	Acoustics
38	Ponza	40°35'00	12°55'00	3200	10,500	Lomask	9-20	Acoustics
39	Ponza	40°30'00	13°00'00	3000	9843	Frossetto	9-21	Acoustics
40	Capri	40°31'00	14°15'00	1090	3576	Rechnitzer	10-12	Oceanog. & biol.
41	Capri	40°30'36	14°14'21	1035	3396	Batteron	10-14	Geol.
42	Capri	40°30'18	14°13'54	1080	3543	Frossetto	10-14	Acoustics
43	Sorrento Pen.	40°33'35	14°21'24	820	2690	Diceglie	10-16	Gravity
44	Capri	40°33'30	14°14'20	24	79	None	10-17	Photography
45	Capri	40°33'50	13°59'30	220	722	Salvi	10-18	Demonstration
46	Capri	40°33'50	13°59'30	270	885	Stearns	10-18	Demonstration
47	Capri	40°33'50	13°59'30	245	804	Baume	10-18	Photography
48	Castellammare	40°41'50	14°24'15	92	302	Ventura	10-25	Demonstration

Total dives, 26:

Scientific	18	
Technical	2	(Kielhorn & Maxwell)
Demonstration	4	
For movies	2	
	26	

Personnel Participating:

American	17
Italian	4
Swedish	3
Swiss	2

Details of Operations:

Total time under water: 70 hours
Total distance traversed: 43.6 kilometers (27.2 miles)

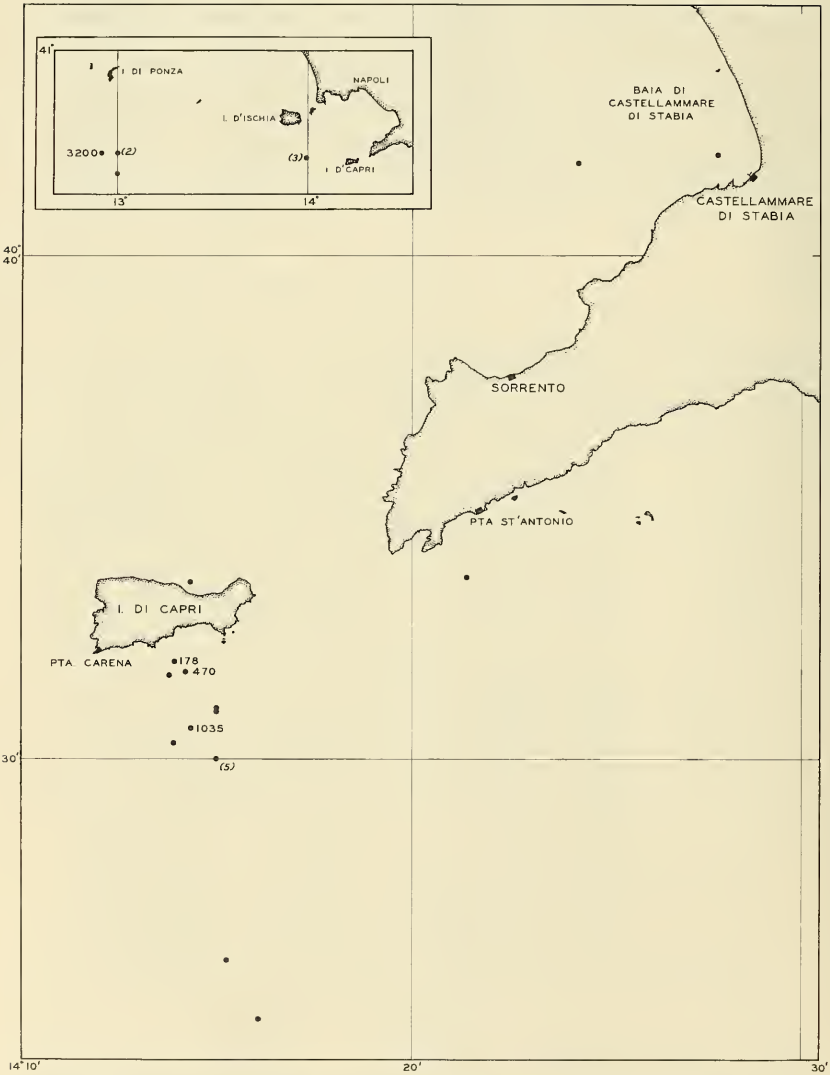

Figure 3. Location of diving descents off Italy. Dots indicate geographic location of descents. Numbers indicate depth in meters at that location.

marine biology

The Mediterranean area is recognized as being biologically unproductive relative to the great oceans and should, therefore, be only sparsely populated with deep-sea organisms. With such knowledge at hand, it was a pleasant surprise to find during the dives that the deep waters of the Mediterranean are not devoid of animals and the population and variety of deep-sea organisms appear to be fairly large.

Time on the bottom was restricted on many dives by the nature of the research being conducted. Despite this shortcoming, marine life such as fishes, was noted on nearly every dive (fig. 4 and 5). Alterations of the sea-floor surface remained as evidence of recent animal presence (fig. 6). The bathyscaph provided an opportunity to observe directly the animals and their motions and the materials that exist in the deep sea.

The need for a better understanding about the sound-scattering characteristics of biological populations and how they interfere with acoustic detection devices prompted the expenditure of considerable effort toward determining the distribution and quantities of biological material in the water column.

The distribution of organisms in the water column was determined only qualitatively. Below the depth where the ambient light from the sun and sky was sufficient, the observations were assisted by three mercury vapor lamps and one small tungsten lamp. Two of the mercury lights were located in front of the sphere and one behind. These lamps provided excellent illumination for the detection of animals and particulate matter in midwater or on the sea floor. Intermittent use of the lamps in midwater probably did little to frighten marine life away from the bathyscaph. Phototropic response of the organisms was studied very carefully while the TRIESTE was stationary on the sea floor.

It became obvious on the first dive that a volume of water follows closely behind the ascending bathyscaph, thereby disrupting the continuity of the water mass and its constituents. From within the sphere, therefore, the most reliable quantitative estimate of suspended materials can be made only on the descent. Another disturbing factor encountered in attempting to determine the quantity of planktonic material is the presence

Figure 4. Shadow of a 6-foot eel at 1090 meters depth, south of the Isle of Capri.

Figure 5. Shadow of a 6-foot eel at 1090 meters depth, south of the Isle of Capri (same individual as in figure 4). Debris, probably a piece of wood, is seen just beneath the tail. Open wire bait-can at upper center was filled with cheese-bait to attract creatures such as this eel.

Figure 6. The sea floor south of Capri at 1000 meters is pock-marked with small holes, mounds, and sculpturings indicating the presence or recent presence of animals.

of ambient sunlight to depths of 350 meters. The twilight or "dusk" light condition between 50 and 350 meters interferes with the visual observations by reducing the effectiveness of the mercury vapor light beam, yet the ambient light inadequately illuminates the suspended materials.

The water column was found to contain suspended matter from the surface to the sea floor. Within the area of greatest illumination, the water above the thermocline, it was difficult to discern any animals except some large siphonophores, salps, and medusae. Below the thermocline, which usually occurred at 25 to 40 meters during the diving season, the amount of suspended material appeared to increase. At the maximum level of sunlight as determined by the human eye, 500 meters, there is a marked increase in the abundance of suspended material and bioluminescence.

Below 350 meters, the artificial light becomes quite effective and it is possible to appreciate the voluminous amount of existing "snow." The descending bathyscaph produces the illusion of snow falling upwards. The "snow" appeared to lack individual particle movement, suggesting that much of the material might be inanimate. However, when the TRIESTE was stationary on the sea floor, it was noted that many organisms allow themselves to be carried by the prevailing currents and that they only occasionally resort to active swimming.

The only recognizable living elements in mid-water are the macroplankton. The "snow" is probably composed of radiolarians, diatoms, and coccoliths. Clusters of diatoms observed and collected at shallow pelagic depths of water off California resemble the snow and mist observed from the bathyscaph window. Often, elongate flocs hang vertically in the water. Some long threads of mucus-like material, probably of animal origin, appear like broken medusa tentacles. Aggregates of many small organisms, such as radiolarians and diatoms, might well serve as effective sound absorbers and scatterers and will be investigated further.

Using the lamps intermittently at about every 100 meters, it was found that there was an increase in the amount of "snow" between 450 and 600 meters. Suspended materials throughout the water column varied in size from diffuse clusters to minute flecks the size of a pea. Below this layer there was a reduced concentration. Scattering quantities appeared to remain virtually unchanged between 600 meters and the sea floor. No clear area free of suspended matter was noted near the sea floor as has been reported by observers using the French bathyscaph.[1]

The great concentration of material at the boundary between darkness and twilight coincides quite closely with the depth usually occupied by the deep-scattering layer. Here it was anticipated that the large macroplankton organisms that are considered responsible for the deep-scattering layer might be found. Although an effort was made to view macroplankton at this level, no animals active enough to make the great vertical migrations, characteristic of scattering layers, were noted. Isolated individuals of medusae, salps, and phosphorescing animals of undetermined species could hardly be construed as being active or abundant enough to produce a migrating deep-scattering layer. Unfortunately, no echo-sounding equipment was available aboard the Italian surface vessels to provide a record indicating the presence of such a layer prior to our dive.

When the artificial lights were not in use it was possible to detect bioluminescence produced by planktonic animals. This phenomenon was found to be slight and only great enough to reveal that some organisms possessing this capacity were in the water column. Momentary flashes of bluish-white or greenish-white were noted from 350 meters to the bottom, with the greatest activity between 450 and 600 meters. The movement of the bathyscaph through the water did not, by tactile stimulation, incite an abundance of bioluminescence. However, the mass of water carried behind the moving bathyscaph on the ascent possessed more phosphorescence than the undisturbed water beyond its influences. Occasionally, a chain of salps or a large medusa would become entangled in the rigging of the bathyscaph. The animal would then glow brightly for a long period. It is concluded that only a few organisms capable of illuminating themselves were present, as Piccard indicated that during the 1956 dives made in the same area at comparable times a spectacular display of phosphorescence was noted. The principal sources of illumination at that time were salps. A vertical distribution of bioluminescence was comparable to the distribution of "snow," as regards uniformity, below 600 meters, with the highest concentration in the water column between 450 and 600 meters. Bioluminescence could be observed on the ascent up to the 350-meter level. As on the descent, the ambient light above this level tends to nullify the effectiveness of the artificial lights.

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[1] Pérès, J. M. and Picard, J., "Observations Biologiques Effectuées au Large de Toulon avec le Bathyscaphe F. N. R. S. — 3 de la Marine Nationale," *Institut Oceanographique, Monaco. Bulletin*, no. 1061, p. 1-8, 1955.

Fishes up to 1 foot in length were noted to make up the deep-sea fauna. It is suspected, therefore, that relatively large organisms are available for them to feed upon. Since there must be a rather complete food chain in the vicinity of the sea floor, it is further assumed that living organisms represent a considerable quantity of the materials observed suspended in the water. Conspicuous organisms were noted on most descents.

On the sea floor, the planktonic animals could be better discerned because of the bathyscaph's stationary condition. Here, fish, isopods, copepods, shrimp, medusae, and other marine life could be viewed for longer periods. Frequently "clouds" of suspended sediment, illuminated by the mercury vapor lamps, passed through the viewing area (fig. 7). These were assumed to be generated by fishes outside the field of view.

Animal response to light was found to be both positive and negative. Most of the bottom fishes that live well below the penetration of sunlight showed little or no concern for the strong artificial illumination. One fish, at 450 meters, which is still within the influence of sunlight, displayed a strong negative reaction by darting into the sea floor in complete panic. *Cyclothone*, the most abundant in numbers of any deep-sea fish genus, were positively phototropic, but never appeared in concentrated numbers as might be expected considering their frequent occurrence in net hauls.

An undetermined species of isopod accumulated in the light zone, at times by the hundreds. They appeared at nearly every location reached on the sea floor. As these isopods appear only as diffuse white areas in our photographs, it is highly probable that they represent the type of animal noted in many photographs of the deep-sea floor (fig. 8 and 9). Identification of animal forms such as were made possible here represent a valuable contribution of the bathyscaph to our knowledge about small deep-sea fauna.

At the greater depths, the sea floor is quite firm. Materials apparently remain on the surface of the sea floor for extended periods. At the 1000-meter level, south of Capri, broken pieces of the eelgrass *Posidonia* were found on the sea floor (fig. 10). Although these fragments represent a rich source of organic matter, no animals were seen to be feeding on them. Dives to 170 and 2800 meters revealed the presence of wood fragments, boxes, and bottles (fig. 11 and 12).

sea floor

A knowledge of the nature of the sea floor is useful in evaluating its probable effect on sound reflection and absorption. Careful scrutiny of the sea floor was included in the NEL program. The sea floor was the ultimate destination of nearly all the dives.

On all descents in the vicinity of the Isle of Capri, the sea floor at 1000 meters was found to be covered with a fine sediment. Two dives to 175 and to 300 meters, made immediately adjacent to the island, revealed cobbles but no discernible bedrock. Several attempts were made to locate rock outcrops at the base of the slope (900 meters) leading up to the island (dives 27, 29, 33, 40, 41). The lack of a surface-ship fathometer and other navigational aids precluded precise depth location and dives that exceeded 900 meters resulted.

On dive 33, a narrow bench 5 to 10 meters wide was found at 450-meter depth south of Marina Piccola, Capri. Figure 13 is an artist's conception of the dive. At the seaward edge of this bench, the sea floor abruptly dipped to form a slope of 50 to 60 degrees, covered with a mantle of clay and silt. Although the bathyscaph was in a state of only slight negative buoyancy, it would not rest motionless on the steep, soft, sediment cover of the slope. Not wishing to halt the sliding descent of the craft, we skidded down the incline. For ease of observation and safety of the craft, it was fortunate that the bathy-

Figure 7. "Clouds" of suspended sediment generated by organisms outside of the viewing area frequently passed by the observation window. Depth 1000 meters, south of Capri.

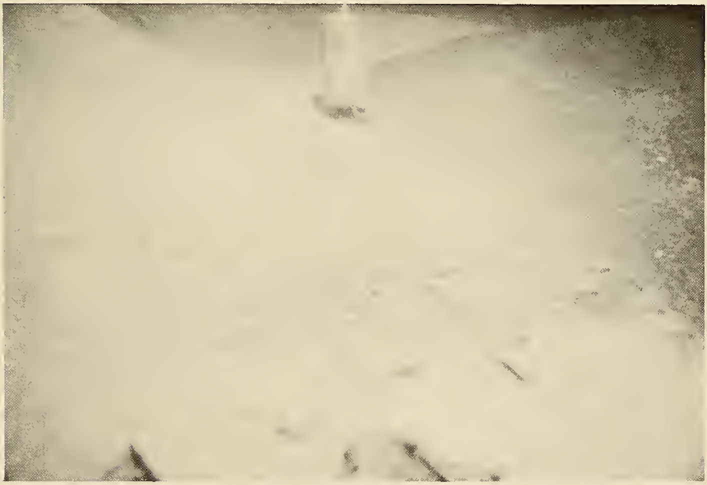

Figure 8. The sea floor at 1000 meters depth south of Capri. Diffuse, whitish spots, primarily on left side of figure are isopod crustacea. A pile of iron ballast remains on the sea floor at the upper right. The open metal bait canister appears at upper center. Clumps of sediment displaced by the impact of the falling ballast appear in the center of the figure. Plastic sediment extruded past irregularities on the under surface of the bathyscaph sphere remains intact in the lower right-hand corner of the figure.

Figure 9. The sea floor at 1000 meters depth south of Capri. Figure shows appearance of bottom immediately to the right of the ballast pile shown in figure 8. The undisturbed sea floor sediment appears "gravelly." This feature is possibly due to the delicate sculpturing activity of the numerous isopod crustacea.

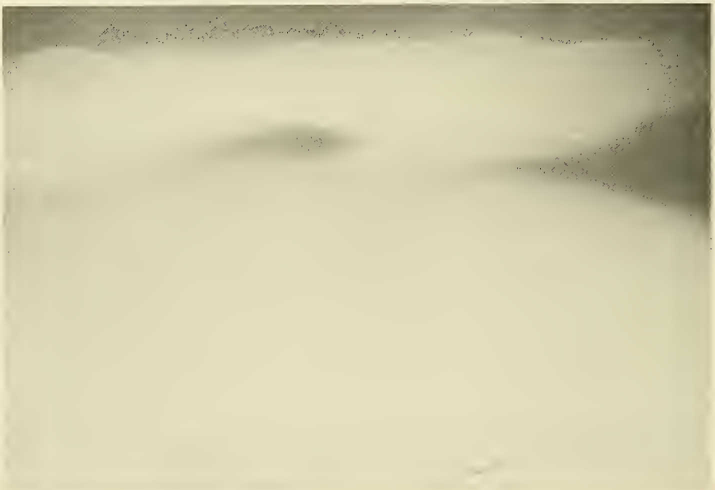

Figure 10. The sea floor at 1000 meters south of Capri. Bits of detritus, mostly from the littoral growing eelgrass, *Posidonia,* was often seen. Low mounds, presumably of biological origin, are silhouetted in the background.

Figure 11. The sloping sea floor at 170 meters on the south slope of the Isle of Capri. Large quantities of detrital material, primarily the eelgrass *Posidonia*, migrate down this slope toward deeper water. Note broken bottle at upper center.

Figure 12. An unidentified "chest" rests on the sea floor at 1000 meters. Microrelief formed by animal activity is evident throughout the figure.

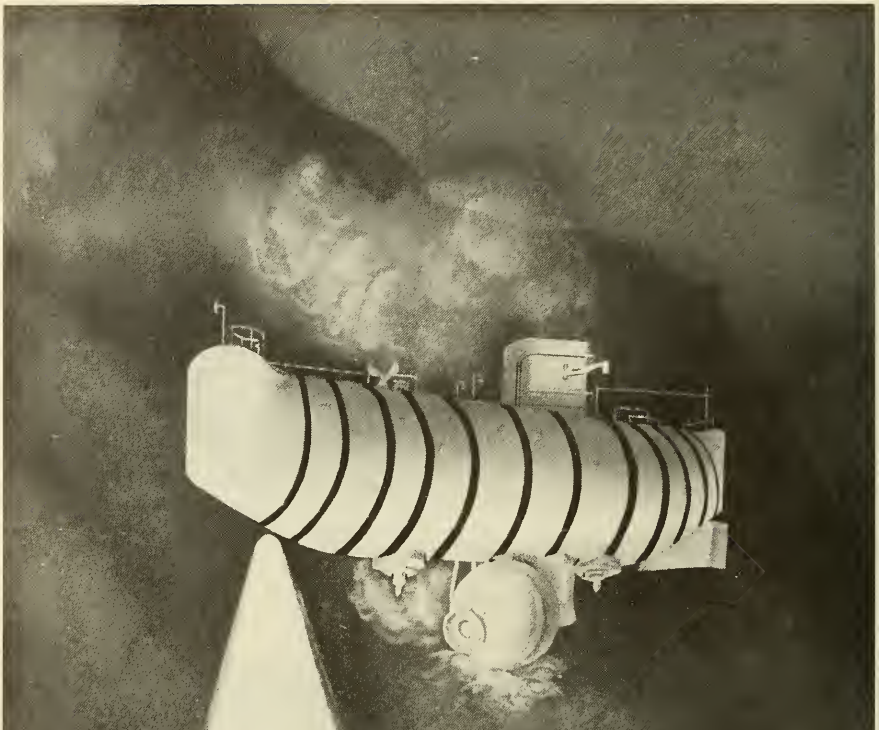

Figure 13. Artist's conception of the bathyscaph's journey down a steep submerged slope, Isle of Capri, Dive No. 33.

scaph was oriented with the flotation tank parallel to the incline. This position also permitted a view across the slope. A series of channels running downslope were seen to have a crest-to-crest distance of about 4 meters. The height of the crests was about ½ meter above the trough axis. These channels suggested that sloughing down these paths had occurred.

Evidence that the sediment was at its maximum angle of repose was clearly indicated by the cohesive blocks that had begun to slip from the mantle, but were temporarily halted in their downslope movement by the resistance and structural strength of the sediment. A well-defined leading edge on the blocks extended 2 to 3 inches above the sea floor.

The bathyscaph landed on the crest of an undulation that scored the face of the incline. Sliding down the slope, the bathyscaph remained slightly ahead of a turbidity cloud that was generated. Small chunks of sediment gouged out of the sea floor by the bathyscaph sphere tumbled and slid ahead of the cloud, producing a series of additional trails. Stationary "sediment blocks" were noticed only in the channels. Although small depressions appeared immediately above these blocks, no well-defined grooves or erosion channels were seen. A more complete survey of this slope by a more mobile craft might well reveal such features, particularly since the initiation of such grooves was suggested by the slipping sediment.

During this dive the TRIESTE's descent was abruptly interrupted by a sudden impact with a solid object. It is assumed that the mantle of sediment became very thin over a bedrock pinnacle or a ridge and that this was responsible for the pronounced scar found on later examination of the sphere. The craft tilted, at least 1½ meters, into the sediment on the slope. The forward ballast-tank orifice was so firmly filled with sediment that it blocked any possible discharge of ballast. The orifice was washed free of the occlusion during our ascent which was brought to an early completion following this harrowing incident.

The microrelief of the sea floor a few miles south of Capri and the Sorrento Peninsula, where most of the diving was accomplished, was always found to be irregular (fig. 8, 10, 14). It was pocked by holes, depressions, and diggings of various types, and trails and a pebbly appearance to the mud bottom attested to the variety of biological activities that prevail (fig. 15, 16).

The bathyscaph provides an opportunity to view some of the biological and physical forces operating to alter the face of the sea floor and its upper layers of sediments in deep water. Redistribution of sediment is assisted by the activities of animals stirring and digging up the mud, much of which is subsequently transported by the current. A current, about 1 centimeter per second at about 270° true, was found to be present south of Capri at 1000-meter depth. There were no ripple marks.

Fishes were observed to mark or alter the sea floor by grubbing for food, squirming into the mud to rest or feed, and swimming close enough to the bottom so that they left a trail. Materials lifted into suspension by these actions were noted to be carried many meters while we remained in a fixed position. Other clouds of mud were seen to pass through the area of illumination. The source of these clouds was assumed to be due to fish activities outside of our view (fig. 7).

Any interpretation of the source of sediments now located southwest of Capri has to include, after considering these observations, the possibility of contributions from material coming from the bays of both Salerno and Naples as well as from the volcanic ash disbursed via an aerial route. Any inferences about a chronological history of the earth attributed to uniform sediment deposition in deep water must include the possible effects of the deep-sea animal populations disrupting the continuity of sedimentation processes.

Figure 14. This photograph, taken at 2800 meters, reveals objects of terrestrial origin, such as the piece of material at the right. The bathyscaph came to rest atop a ridge. The external lights illuminated two additional ridges and their intervening troughs. A mound can be seen, center, on the first ridge.

Figure 15. Numerous trails appear among the granular clumps of sediment at 3000 meters. Very low mounds are discernible in the background.

Figure 16. Microrelief in the form of penetrations, biological sculpturing, and depressions, at 820 meters on the south side of the Sorrento Peninsula. Whitish objects in the figure appeared as broken pigeon eggs.

The structural characteristics of the sea-floor sediments found south of Capri were indicated in several ways. Landing the bathyscaph on the sea-floor sediments never caused the sphere to penetrate the sediment more than a few inches. Settling of the craft due to a decrease in buoyancy displaced the sediment laterally. Grooves and ridges were formed as the clay-silt squeezed past irregularities on the hull (fig. 8). Observations revealed that these grooves and the main depression remained unchanged, even after several hours of exposure to the current. The sediment on the slope of Capri and on the more level sea floor was firm. Cohesive blocks of sediment were seen in the slump channels on the steep-south incline. Discharged ballast (iron pellets) remained on the sea-floor surface in volcano-shaped piles (fig. 8, 9). The heavy guide rope (2.3 pounds per yard) coiled on the surface and remained in view at all times. Dragging the rope produced a shallow groove that seldom exceeded a depth of 1 inch.

A thin mantle or "crust" of buff sediment overlaying a black layer of equal thickness at 1000 meters depth suggests bacterial activity reducing organic matter. The guide rope effectively uncovers this dark stratum a few millimeters below the surface. Prevailing current across the bottom apparently inhibits any thick accumulation of light organic matter and hence prevents surface blackening. Disturbance of the sea floor by the bathyscaph, the guide rope, and feeding fishes generated clouds of mud with no indication of freshly chemically reduced organic matter occurring on the surface. Eroding processes reveal the presence of this delicate "crust" (fig. 17). Nemertean worms feed across the surface of the sea floor while a portion of their bodies remains embedded in the sediments (fig. 18).

The abundance of holes in the area visited suggests that there is probably a considerable overturn in the sea-floor sediments, primarily by animals. Very low mounds, 1 to 2 inches high, with diameters of about 2 feet appeared to be spread-out cones, originally erected by burrowing animals but subsequently modified and smoothed out (fig. 10, 12). Although no animals were seen to occupy these holes in the deeper waters, it is a reasonable inference that they are formed by worms. Sediment discharged to the surface by biological activity to form small volcano-shaped mounds was greyer than the surface layer. Clay-silt samples taken with a gravity corer from a surface vessel revealed that such grey sediments normally occur several inches below the surface.

On a dive to 2800 meters, dune-like formations of great magnitude were seen (fig. 14). These elongated ridges had a crest-to-crest distance of approximately 5 meters and were oriented in a north-south direction. Their clarity and uniform shape suggest that they produced by some physical force acting upon the sea-floor sediments. As this dive was made primarily for acoustic measurements, little time was devoted to determining whether or not the current was present.

Figure 17. Holes, sculpturing, trails, and living nemertean worms suggest a significant amount of biological activity at 270 meters depth west of Capri. The nemertean worm extends itself, left of center, to feed along the surface of the sea floor. Numerous other holes penetrate the sediment.

Figure 18. Two nemertean worms, in the process of contraction, are viewed in the same vicinity as that in figure 16.

CONCLUSIONS

Oceanographic, biological, and sea-floor studies in the Mediterranean by an American scientific team using a bathyscaph indicate that such a craft is very useful as a deep-sea research vehicle. Observations in the mid-waters and on the sea floor clearly show that the bathyscaph can provide information not readily obtainable in any other way. The combination of visual observations, supplemented by the utilization of human judgment and the control of quantitative sampling and measuring devices, provides a unique and revolutionary technique for the study of the deep sea.

It is not intended to imply that the deep sea cannot be effectively investigated by other means such as self-contained instrumentation, underwater television, or remotely controlled equipment, but rather to point out the existence of the further potentialities of the bathyscaph. The very fact that it now exists and does not require an expensive or long period of development is indeed sufficient justification for its continued use.

RECOMMENDATIONS

1. Continue deep-sea research using a bathyscaph.
2. Encourage modification and further development of the bathyscaph and/or bathyscaph-type craft.
3. Promote the development of more versatile deep-submersible research craft.
4. Evaluate the usefulness of bathyscaphs and deep-submersible craft for military purposes.
5. Develop acoustic and oceanographic instrumentation for use on the bathyscaph.

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