*Surveying the Deep-Sea Floor with Cameras**

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INCREASED interest in underwater photography during World War II opened up a new field of scientific research. Submerged wrecks and other underwater targets had to be identified; the camera, encased in a waterproof container, proved to be an efficient method of gaining such information.

As a result of the limited use of cameras during this period, it soon became apparent that the camera lens could serve as a human eye to view sea floor sediments and other geological phenomena in place. It is unfortunate that the early oceanographic expeditions of worldwide extent such as the great Challenger Expedition of 1872 were deprived of the use of underwater cameras. In spite of this handicap, published data on thousands of sediment samples by Murray and Renard have paved the way for modern oceanographic research (2).

For this use, the first camera was developed for the U. S. Navy by M. Ewing *et al.* (1) It was a simple yet effective single-shot, 35 mm. device which utilized flash bulbs for illumination. Lowerings were, however, limited to shallow coastal waters, but basic operating techniques were developed which have proven very useful in lowering cameras or improved design to greater depths. These techniques resulted in bottom photographs which were of use in constructing bottom sediment charts for military and scientific purposes.

Following the end of World War II, a greater emphasis was placed upon camera development for deeper areas. Although diver-operated equipment was developed at a faster pace, rapid progress was made on deep-sea cameras during the period just preceding the Korean War. A U. S. Navy designed 35 mm. camera (3), equipped to take up to 24–35 frames on a single lowering to 10,000 feet with the aid of electronic flash illumination, made possible successful lowerings to the top of Sylvania Seamount in the Marshall Island area of the Pacific Ocean. Manganese-encrusted rocks were disclosed on ripple-marked calcareous ooze. The presence of oscillatory wave action of deep origin on the sea floor introduced photo interpretation to the submarine geologist. From this point on, no doubt lingered as to the usefulness of photography in underwater investigations.

Because 70 percent of the earth's surface is covered by water, and since the average depth of the Pacific and other major oceans is approximately 2150 fathoms, full photographic coverage would be a mountainous task if not impossible. As more reliable multiple-shot cameras were developed by various private and government agencies following the Korean hostilities, it became clear to many scientists that any coverage would be desirable even if only in isolated but preselected areas.

In 1950, Scripps Institution of Oceanography, located in La Jolla, California, began a program of mapping the Pacific. Full U. S. Navy cooperation with this ambitious program enabled U. S. Navy-designed cameras to reach many deep-sea environments of scientific interest (4). Thus began a new era of underwater exploration in which photography continued increasingly to aid in the procurement of new scientific data of both economic and military value.

Surveying underwater with cameras, however, poses many new problems (5). Some phenomena are advantageous while others work to the detriment of desired objectives. Being in a region of total darkness, small areas of the deep-sea floor can be illuminated rather easily by electronic flash. And too, deeper waters are usually more transparent than muddy coastal waters or surface flows. However, the scattering and absorption of artificial light by even the clearest of ocean waters means that target distances are limited to relatively short distances underwater. Only the smallest particles of matter in water suspension have a diameter of less than the wave-length of light, so that all other par-

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ticles will reflect all wave-lengths of light.

Since selective scattering cannot occur to any extent, complete filtering of a turbidity haze is impossible. Another disturbing factor in underwater photography is that light from the flash tube has to travel to the target and to return to the camera lens. This doubles the light path and leads to greater absorption unless the light source can be placed close to the target. This, however, is physically impossible in most feasible camera designs. The result is that, when using color film, the light from electronic flash tubes is attenuated rapidly, and unless the target distance is kept to a short distance, all wave lengths except in the blue-green spectrum are lost for photographic use. Filters can be used to a limited extent. Color film, therefore, is effective only at very short target distances. Electronic flash light sources are normally placed below and in front of the camera lens to increase illumination and produce the maximum detail of microrelief.

One must also keep in mind that objects underwater appear nearer and larger both to the eye and camera. This is due to the ratio of the index of refraction in air to the index of refraction in water. Normally, $\frac{3}{4}$ of the air distance is equal to the water distance. Spherical and chromatic aberrations are kept to a negligible factor in most camera lens look-through ports by keeping the plane of the window perpendicular to the axis of the camera; but each glass-air surface of the lens system causes a loss of about 10 per cent of the light transmitted. Camera lens are placed close to but not touching the look-through windows, and if possible, the latter are made of a material like clear lucite plastic which has an index of refraction close to that of sea water.

In spite of the perplexing problems that confront the underwater researcher, photographic methods are improving steadily to provide faster information which is of higher quality. Underwater camera surveys are normally undertaken to study the character of deep-sea floor sediments and outcrops and the microrelief that results from the biological, physical, and chemical processes that create, alter, and disturb the sediments (6).

Since underwater photography is merely opening up a new phase of photogrammetry, aerial photographic interpretation can be adapted to underwater methods of viewing bottom scapes. Many patterns exist on the sea floor just as in aerial landscapes. The texture of the latter is likened to the many sea bottom features too small to be individually distinct but which together give the origin of environment. Contrast determines the effectiveness with which bottom features or elements are related to one another. The sharpness of definition required in aerial views is even more important underwater where organic and inorganic suspended matter in the water tends to obliterate the sharp edges of all targets more than just a few feet from the camera lens. Sharpness of definition in this relatively new environment depends upon such factors as the transparency of water, exposure and distance settings, use of fine grain film, quality of the camera lens, look-through window and the processing of the film.

After the proper views have been exposed upon film in pre-selected areas, the greatest importance is naturally placed upon photographic interpretation to produce reliable results. Shadow effects are used extensively to bring out weak contrast on smooth, flat-lying sediments. Lack of visible churning by benthos organisms denotes a lack of organic matter, while micro roughness due to churning indicates an abundance of both organic matter and benthos bottom feeders. Turbidity clouds that result from stirring fine sediments on the sea floor are likened to atmospheric clouds. Artificially produced sediment clouds are used to study bottom current and wave motions with special cameras. Asymmetrical ripple marks contrast with symmetrically formed ripple marks to explain the types of physical forces present. Exposed bedrock and scour marks give clues to sediment cover, rates of sedimentation and bottom currents and direction. Repetition of sea floor feature patterns greatly assist in extending photo interpretation to other areas. Direct changes in sediments would imply boundaries between environments and water conditions.

The use of photo interpretation has already corrected misunderstandings about rates of sedimentation, revealed the firmness of the sea floor as well as the extensive distribution of economic minerals at the sediment-water interface. Deep sea photography although still of rather limited use is being utilized in five basic ways. It will be shown how principles of aerial photography can be adapted to underwater surveying (7).

I. Bottom Contact Cameras

Bottom contact cameras, such as the NEL Type III developed by the author are being lowered to the bottom by a drifting vessel to shoot vertical and high-angle photographs of

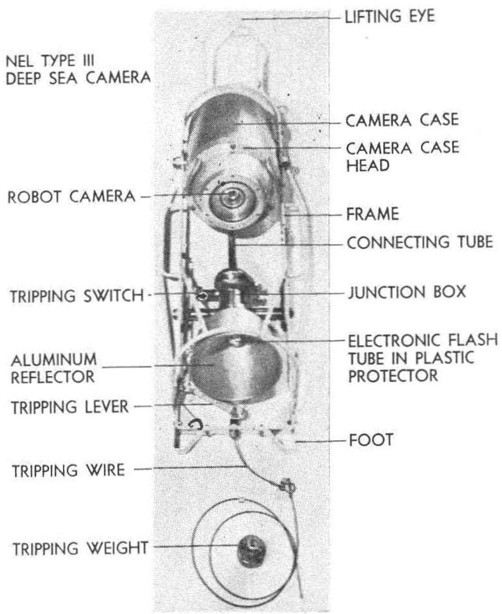


FIG. 1. NEL Type III Deep Sea Camera.

the sea floor (4, Figure 1). A mechanical tripping device automatically activates the NEL camera at a pre-set target distance. Successive photographs are taken at not less than 15-second intervals by bouncing the camera on the bottom along the track of a vessel having a known set and drift. This method of surveying has been used successfully to map the distribution of minerals such as free manganese nodules on the sea floor (Figures 5 and 7). Coordination of photographic stations with sediment sampling stations has produced data from which areas have been delineated and mineral tonnages estimated. The bottom contact method of photography is also ideally suited to boundary crossings where changes from one sediment to another must be located.

Additional tracks criss-crossing an area with good navigational control will provide sufficient data to construct sediment charts, make known the general attitude of rock outcrops, and the presence of bottom currents through the detection of ripple marks.

Unfortunately, the aerial-type controlled mosaic is unobtainable underwater with present cameras. However, a series of regularly-spaced photos along a series of spaced lines can produce an excellent representative view of the sea floor for any particular area. Even though the bottom photographs do not overlap, time-controlled touchdowns with the bottom contact camera can expand or contract the area to be surveyed (Figure 9). Normally, the winch operator touches the camera down at not less than one-minute intervals.

The accuracy of this survey method depends to a great extent upon ship positioning along lines of drift. On the high seas, celestial navigation is still depended upon for location. Needless to say, errors of position up to many miles are not uncommon. The deep-sea floor, unlike the landscapes photographed by the aerial cameraman, cannot be used for positioning. Thus, it is necessary for a vessel conducting an oceanographic survey to be positioned by indirect methods such as *Loran* and other radio techniques.

Once a bottom photograph is taken, the problem of oblique photographs is somewhat the same for both aerial and underwater surveys, but on different scales. Figures 2 and 3 show the nature of the angular coverage and optics for the NEL Type III camera. The area covered is trapezoidal in shape (Figure 4). The scale of an oblique photo is constant along any one line parallel to the horizon but is decreased in geometric progression from foreground to background. Distortions on the bottom photographs are, however, systematic and since only a small area of the bottom is photographed by oblique methods, the microrelief does not introduce large errors; but the shadows created even by microrelief re-

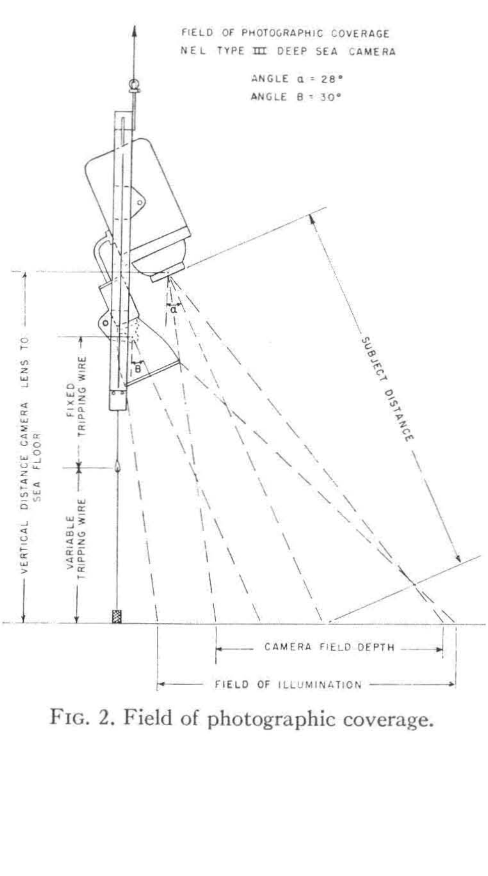


FIG. 2. Field of photographic coverage.

sulting from benthic animal churning and currents, are examined to provide useful measurements.

The oblique bottom photograph is essentially the same as a tilted aerial photograph (Figure 4). The vertical reference lines converge towards vertical line *AA* and the horizontal lines remain parallel to each other; but the spacing between them is decreased from foreground to background. Plastic overlay grids constructed from photographic test patterns are utilized on underwater photographs to obtain concentration counts on nodules, measure ripple marks, and the length, shape and width of various targets exposed to view at the sediment-water interface.

II. Presetting at Intervals

The second basic way in which cameras are being used in underwater environments requires a unit which can be pre-set to take photos at various intervals. A shutterless camera devised by the author utilizes a one RPM motor to transport 35 mm film at two frames-per-minute. A cam arrangement triggers an electronic flash for each frame. This camera has been placed in a watertight case, which in turn, is mounted in a sled-like frame that permits the taking of low-angle photographs along the sea floor.

In contrast to aerial photography, low-

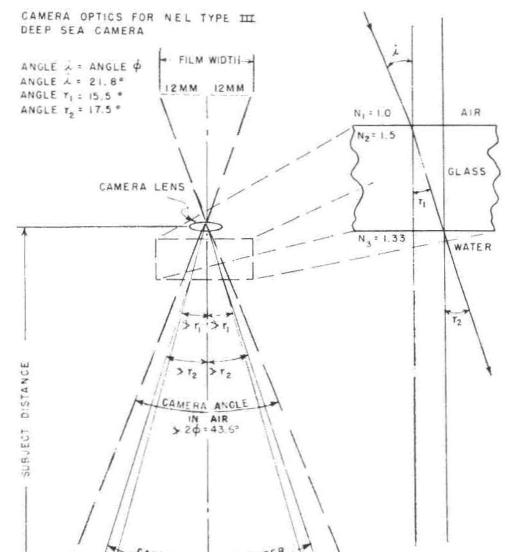


FIG. 3. Camera optics.

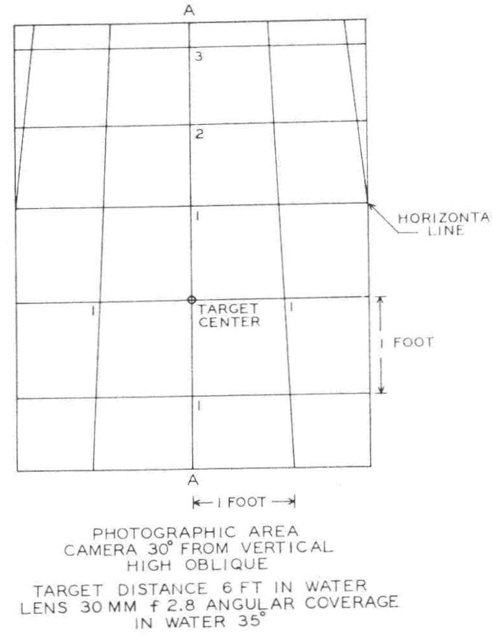


FIG. 4. Photographic area—high oblique.

angle photographs taken with this new camera look past the immediate fore ground to the horizon beyond. The distinction to be remembered is that low-angle underwater cameras look at a larger area than high-angle cameras which cover a relatively small area.

Since the camera and light source are effective to distances of about 14 feet and because water absorption knocks out any return of light to the camera from much greater distances, the background will be black and constitute the horizon when it meets the recognizable sea floor background.

The high angle photographs taken by the bottom-contact camera in method number I. are normally taken at an angle of 30° from the vertical; this limits bottom coverage to about 20 square feet for a normal target distance of six feet water distance. The low-angle underwater cameras look at an area of about 50 square feet which is an area greatly distorted in scale.

The low-angle camera is known as a time-sequence camera and has a built-in time device for turning the camera and flash unit on and off at pre-set intervals. Shadows resulting from the low-angle illumination are utilized to detect the very small relief resulting from benthic fauna as well as from physical currents and waves of deep origin. A bottom detecting device can be used with this second type of camera to allow it to hover over the

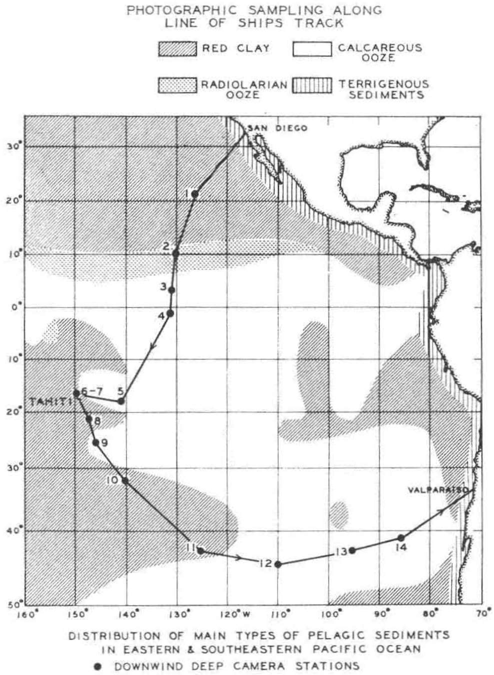


FIG. 5. Photographic sampling along line of ship's track.

bottom as the towing vessel drifts along a track determined by the wind and sea current. The second type of camera is also being used to study the concentration of biological life in the vertical water column and their relationships to the bottom sediments.

Future studies call for time-sequence photos on the sea floor to determine indirectly the velocities of bottom currents. Successive photos of blobs of dye emitted in front of the camera will be used to determine the character of water motion near the interface.

The third type of camera is not in general use but has only recently been developed by J. Costeau of France. It is mentioned here very briefly. It consists essentially of a specially-cased camera and light source mounted on a sled which is bodily towed over the bottom by connection to a surface craft (8). Slow-motion movies or normal 16 frame/sec. are utilized to obtain interesting action of bottom life and the roughness of the sea floor. Needless to say, the general nature of the sea floor relief is revealed in a spectacular manner.

The fourth type of camera deals with stereo photography. By adding a third dimension to bottom photographs, the investigation of relief and other sea floor animal occurrences is aided in the determination of size, shape, and concentration. Stereo cameras are being constructed by the U. S. Navy Electronics Laboratory at the present time.

The fifth type of camera is any camera or flash unit designed to be attached to diving submersibles such as the bathyscaph or underwater detached vehicles.

In the past few years, the deep-sea camera has taken its place as a regular oceanographic tool on most research cruises of both short and long duration. Although still a primitive tool due to the factors which limit its use underwater, the camera has been developed sufficiently well to meet the present needs of reconnaisance surveys into unknown areas. In some areas, it has proven capable of providing almost complete coverage of a bottom environment by properly executed successive photos.

One difficulty not yet fully overcome is the inability of nearly all deep-sea cameras to obtain lapping photographs or oriented and matched photographs. In other words, the aerial-type mosaic as earlier mentioned is not yet possible but the next best goal is satisfactorily accomplished. Successive photographs are taken along a line of drift with the spacing between frames known accurately enough to plot the views for a composite look at the bottom. Also, as was pointed out earlier, it is next to impossible to photograph a large area by piecing individual photos together. In any appreciable depth of water, the lowering vessel cannot hold the camera over an exact spot; nor can it control the exact spacing between photos. Good bottom coverage has resulted in shallow waters where the vessel lowering the camera is anchored fore-and-aft and has the ability to maneuver in short increments.

In deeper water, however, this is not possible and the camera can only be touched down in the approximate vicinity of a preselected area. Consequently, a series of photos at each selected station are normally utilized with core and dredge samples to determine the general character of the bottom for that area. Since no two ships' tracks are exactly along the same line, it is thereby possible to obtain a variety of bottom photographs over great areas of the Pacific Ocean. A group of bottom photographs taken by the author are shown to illustrate their usefulness in underwater surveying. Figure 5 shows the locations of a number of stations along a ship's track in the Eastern Pacific. At Station #4 (Figure 6) in the east Equatorial Pacific, the bottom sediment is a calcareous ooze with abundant biological evidence revealed by numerous vis-

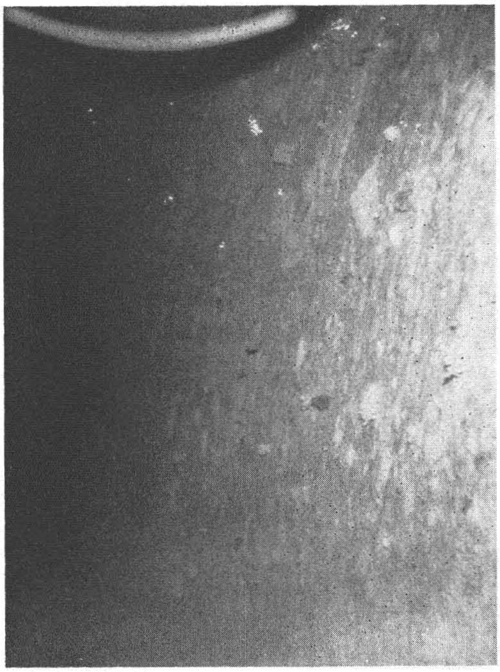


FIG. 6. Bottom photograph, station #4, East equatorial Pacific.

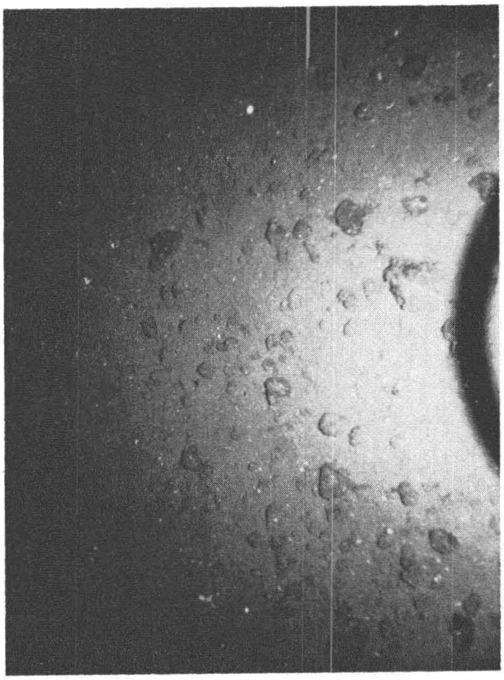


FIG. 7. Bottom photograph, station #10, Southwestern Pacific Basin.

ible mounds, trails, and unidentifiable benthos organisms. The depth is 14,000 feet and the field coverage is approximately 20 square feet. To show how the environment changes, Station #10 (Figure 7) in Southwestern Pacific Basin disclosed a red-clay bottom covered with manganese nodules. At camera Station #11 (Figure 8), which is close to a boundary between red clay and calcareous ooze, a bottom photograph revealed a calcareous ooze covered with both large and small manganese nodules. The freshness of the black surfaces and the tracks and marks on the calcareous ooze indicate this area to be one of slow sediment accumulation.

Photographic sampling at a number of preselected stations in a surveyed area in the central Pacific revealed an abundance of ripple marks in coarse sediments of recent origin (Figure 9). Figure 10 shows a typical 20 square foot area of symmetrical ripples with a high degree of sorting at 1100 fathoms depth. At a scale of 2″ = 1 ft., in the center of the photograph, the distance between ripple crests is approximately six inches. The oscillatory wave motion indicated has washed the finer materials off into deeper water.

At a camera station between San Diego, California and Hawaii, a series of deep photographs across a mineral boundary in red clay revealed a rapid change from small nodules to slab-like chunks of manganese-impregnated ash of probable terrigenous origin. Figures 12 and 13 show the extreme variation in concentration at this station; whereas the small nodules cover about 25 per cent of the

FIG. 8. Bottom photograph, station #11, Southwestern Pacific Basin.

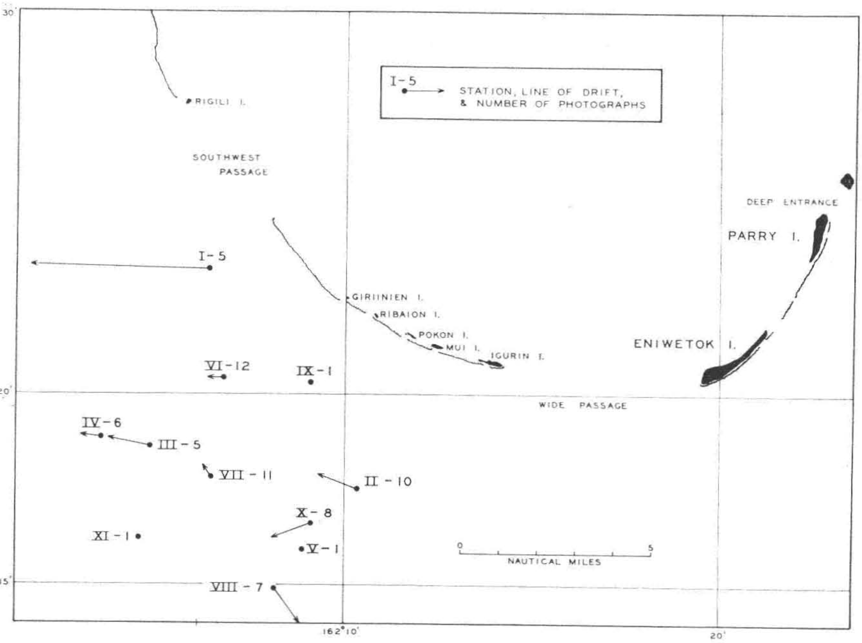


FIG. 9. Photographic sampling at preselected stations of surveyed area.

bottom, the larger slab-like chunks cover at least 75 percent of the bottom. The location map for this area is shown in Figure 11.

CONCLUSIONS

As navigational control of oceanographic vessels is improved, so will underwater sur-

FIG. 10. Bottom photograph, Station #4, Eniwetok Survey Area.

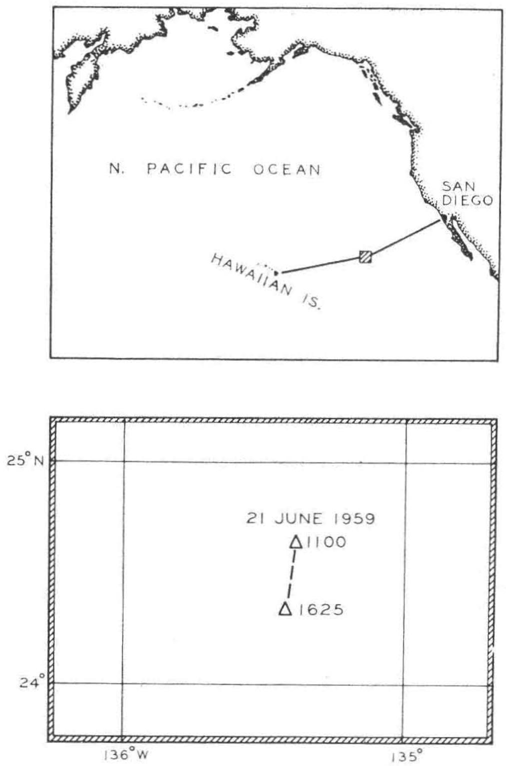
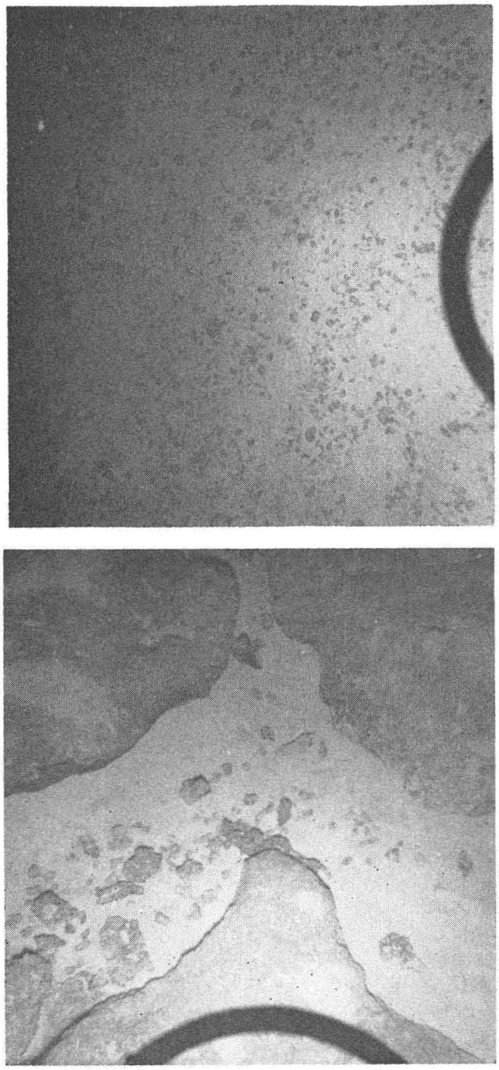


FIG. 11. Photographic sampling across sediment mineral boundary.



FIGS. 12–13. Bottom photographs showing change in mineral concentration.

veying methods be improved. Especially in the field of underwater photographic mapping, the demand for better station positioning is paramount. Only when station keeping reaches a high degree of accuracy will aerial-type mosaics be possible of underwater features, even if only on a small scale. It is equally important that improved methods of photography be developed to contend with absorption and scattering of light through water. Wide-angle lens, correcting lenses, filters, new light sources and as yet unknown new devices are rapidly being incorporated into underwater equipment to meet present and future needs.

Underwater mapping with cameras is a new field and a strong challenge to our young scientists. When a camera is developed to view much larger areas of the sea floor on a single exposure than is now possible, underwater photography will have reached a goal comparable to some of the great achievements of aerial photography.

At the present time deep-sea cameras are being operated by only six institutions in the world; three of these are in Russia, France, and England. The other three are in the United States: Woods Hole Oceanographic Institution, The Lamont Geological Observatory of Columbia University, and that operated by the author in cooperation between the U. S. Navy Electronics Laboratory and Scripps Institution of Oceanography.

If planned underwater photography surveys in the deep trenches and other unmapped abyssal areas of the Pacific Ocean during the next two years prove successful, the deep sea camera will have opened up the last of the earth's unknown surface to photogrammetry.

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