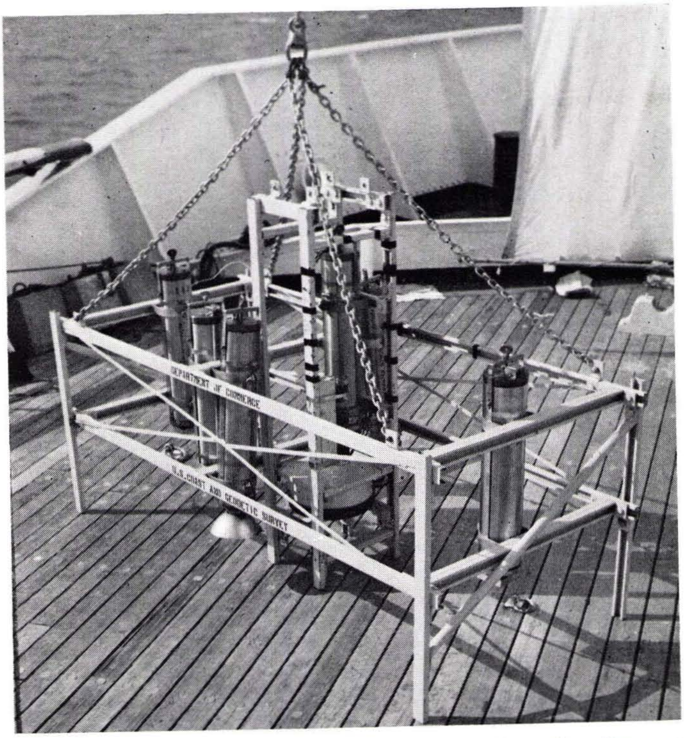

FRONTISPIECE. Original Model B deep-sea camera configuration. See page 918.

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A Deep-Sea Camera System

Microcontour maps with an interval of one-fourth inch at a depth of 215 fathoms.

(*Abstract on next page*)

ONE OF THE MAJOR responsibilities of the Coast and Geodetic Survey is the mapping of the ocean floor from the high-water line to the edge of the continental slope. Methods of obtaining more comprehensive data on the configuration and the topography of the ocean's floor, for water current studies, for deep-sea biological studies and recording the actual water depths, are mandatory for oceanographic and other related studies within this region. The assimilation and evaluation of these factors will ultimately provide improved safety in navigation. The metric stereo deep-sea camera systems were developed to obtain ocean bottom studies, where microcontoured "mini" charts could be constructed not to be used as a chart per se, but rather to represent an inaccessible area correctly.

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1967, under the title of "Photogrammetric Deep-Sea Camera System" as one of several papers on underwater photography, all contained in this issue.

IN ORDER THAT underwater photography be successful numerous major problems, which were alien to aerial photography as we photogrammetrists had known it, had to be overcome. The problems of: (1) protecting the camera and the lenses from the ocean water; (2) protecting the camera from the enormous pressures related to the depths of the ocean; (3) actual operation of the camera, opening and closing the shutter, furnishing light in the area to be photographed, and winding the film after each exposure; and (4) developing a technique of positioning the photographs to the degree of accuracy required in mapping. Of the four problems mentioned only the last, positioning of the photographs, has not been, as yet, satisfactorily solved.

The camera was encased in a container with a quartz window strong enough to withstand the pressures at depths of more than 30,000 feet. The camera lens, designed by Professor Robert Hopkins for use with the Edgerton, Germeshausen and Grier underwater camera, has corrected the distortion caused by the quartz and the ambient water. Due to absence of light at the usual depths where the photographs are taken, shutters are neither required nor used on the camera. The light is supplied by a strobe light and the film is automatically wound after the lights have flashed.

ABSTRACT: *The metric, deep-sea, stereoscopic camera systems of the Coast and Geodetic Survey developed from a modest beginning to a configuration which is designed to operate 25 to 30 feet off the ocean floor with a base of 5 feet, using two strobe lights mounted off-axis, and using a "pinger" system to aid in controlling the height off the bottom. All the components of the system were manufactured by Edgerton, Germershausen and Grier of Cambridge, Mass. Microcontour maps have been compiled at intervals of 5, 10, and 15 mm using standard Kelsh and Multiplex plotters. The area of coverage of one model is about 400 square feet.*

THE C&GS EXPERIMENTATION and testing of available commercial equipment began in the spring of 1961. Working with the assistance of the personnel at the David Taylor Model Basin, two types of camera lenses were tested, the f3.5 Elmar and the f/11 Hopkins. The lenses were tested on underwater grids. Upon completion and evaluation of these tests, the slower Hopkins lens was selected because it gave much less metric distortion.

The basic camera system and component parts were purchased from the Edgerton, Germeshausen and Grier Company of Cambridge, Mass. After trial exposures with the cameras set side by side (in the manufacturer's configuration) to determine the range of the electronic flash unit-lens-film combination, the main frame of the system was rebuilt to separate the cameras 0.2 of the range, which was found to be 10 feet. The base height ratio of 0.2 was set arbitrarily, within limits dependent on the mechanical clearances of the stereoscopic plotters and on the ratio of the heights of the bottom features to the height of the camera above the actual bottom. Photogrammetric experience in aerial survey operations, available plotting instruments, and the belief that the ocean floor is relatively flat, were the prime factors in the estimate of a base-height ratio of 0.2 for good high yield of microtopographic data.

C&GS'S FIRST CAMERA system was equipped with two cameras containing the Hopkins f/11 lenses and a 12-volt battery system with a single 100 watt-second strobe lamp. Each camera contained a 100-foot spool of film providing 500 exposures at the standard 24 ×36 mm. frame size. The film used was 35 mm. Kodak Plus X for black and white and Super Anscochrome for color. On each exposure a data strip was used to record the exposure number, time, date, and depth.

A battery-powered pinger unit (consisting of a driver, transformer, and transducer, attached to the camera unit frame) is the reference between the camera and the shipboard personnel. The sound impulse emanating from the pinger is transmitted upward toward the ship and down to the ocean floor, simultaneously, every second.

The cameras were placed 24 inches apart. This spacing has worked rather well at from 4 to 10 feet above the ocean floor, depending on the clarity of the water. This camera system became known as the Model-A. (Figure 1)

DEVELOPMENT OF AN underwater metric stereo deep-sea camera is not really com-

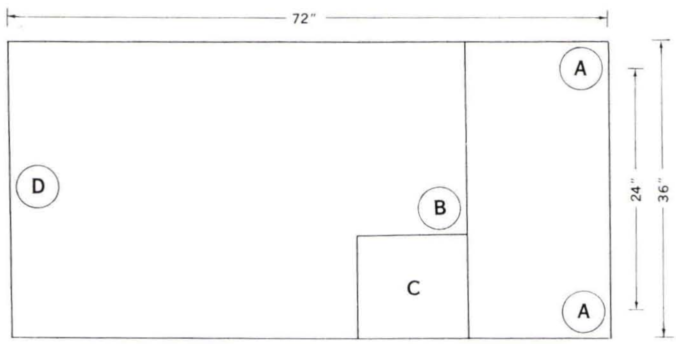

FIG. 1. Top view of the original Model A camera configuration. *A*, camera unit; *B*, battery unit; *C*, sonar pinger unit; *D*, strobe lamp.

plete with the establishment of the unit itself. Following a flight line to obtain aerial photography for a given area is rather mundane when compared to the complicated procedure required to operate the underwater camera efficiently. In most lowerings, constant vigil for a period of from two to four hours is required by the winch operator and the man with the fathometer/oscilloscope unit. This attentiveness is required because the camera must be constantly corrected to the proper height as the bottom rises and falls. A simple operational procedure was created as a guide to follow during actual lowering operations. The following is an abbreviated and simplified description of this procedure.

The camera frame is attached to the oceanographic winch wire (stainless steel cable with 4,000-pound breaking strength) by a balanced chain bridle secured by a seized shackle with a swivel between the wire and chain bridle. The rate at which the camera can be lowered and recovered critically depends on the weather conditions, the speed of local currents, and the amount of water friction on the camera. The amount of water friction differs greatly in different regions of the seas. A pinger mounted in the camera frame provides the signal source. As the camera is lowered below the water surface, two traces appear on the Precision Depth Recorder (PDR). The first and direct ping signal is always stronger than the bottom reflected signal.

THE DIRECT SIGNAL is used to synchronize internally the oscilloscope trace. As the camera is descending through the water, the two traces on the scope approach each other. The PDR records without regard to the true depth, and subsequently the paths of the traces will cross one another to form a large *X*. The number of crossings is directly related to the depth of the water. (For example, if a ship is in 1800 fathoms, a 400-fathom scale PDR would record four crossings. The first crossing would take place at 400 fathoms, and repeated crossings would occur every 400 fathoms. The fifth time the traces approach each other, the point of impact would be indicated.) (Figure 2) Some degree of success has been obtained by estimating depths off the bottom on the PDR. In order to provide better control in the last few critical feet, it has been necessary to tie an oscilloscope (Tektronix) into the EDO/UQN receiver output. This method has proven to be the most accurate.

The calibration of a Time/Division scale as a Depth/Division scale permits a more reliable control of depth verification. The Time /Division calibration can be made for a wide range of distances, such as 500 feet/cm. to 2½ feet/cm. Approaching the bottom using the PDR as a reference, identification of the reflected signal on the oscilloscope is simplified. The velocity of sound, 4800 feet/second, may be used to establish a Time/Division to Distance/Division conversion. (See Table 1).

ON JULY 23, 1961, 90 miles southeast of Nantucket Island, Massachusetts, (40°00′N,

TABLE 1

CONVERSION TABLE FOR TIME/DIVISION TO DISTANCE/DIVISION

Time/Division	*to*	*Distance/Division*
1 second	–	4800 feet
1/10 second	–	480 feet
1/100 second	–	48 feet
1/1000 second	–	5 feet
1/5000 second	–	2½ feet

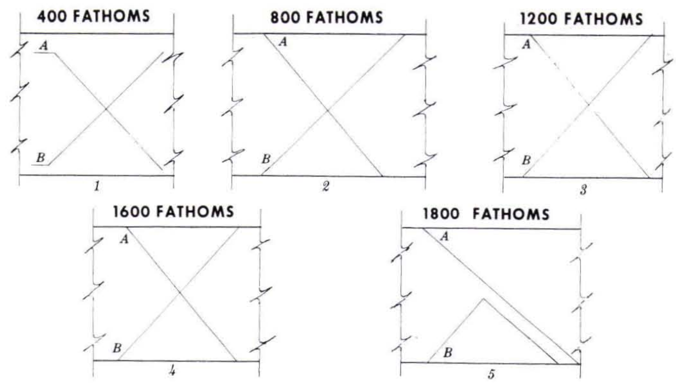

FIG. 2. Recording of camera lowering as shown by the Precision Depth Recorder. *A*, direct ping signal; *B*, bottom reflected signal.

69°09′W), the crew of the USC&GS Ship *EXPLORER* lowered the camera for the first time. The quantity and quality from this lowering (215 to 320 fathoms) was more sucesful than had been anticipated. A number of photographs were sent to the staff at the Smithsonian Institution in order that marine life specimens might be positively identified.

In October 1961, after a few minor problems had been rectified, the camera was returned to the *EXPLORER*. Along the continental slope, east of Ocean City, Maryland, the camera again performed very satisfactorily at 215 fathoms. A stereopair of photographs from this operation was used to compile our first microcontour map of the ocean floor. In the illustration the contours have been superimposed on the deep-sea photographs. (Figure 3)

THE SHIPBOARD METHOD of determining the distance the camera is suspended above the ocean floor is satisfactory within the limited operating range of the camera (Model-A, 10 feet).

Because the ship is permitted to drift during the filming operation, the bottom topography is constantly changing. The camera must be raised or lowered between exposures to accommodate these changes, causing a scale change between successive stereopairs. The true scale of any selected stereopair of photographs must be determined by a precise method if compilation is the ultimate goal. Mr. Carper Tewinkel, C&GS office of Research and Development, using measurements made on the film (35 mm.) and a prescribed formula, solved the scale problem. He showed that by using a 10 power magnifying glass, the film, and a metric scale, an accuracy in camera height of two inches is obtainable. The following is from Mr: Tewinkel's instructions dated August 1961.

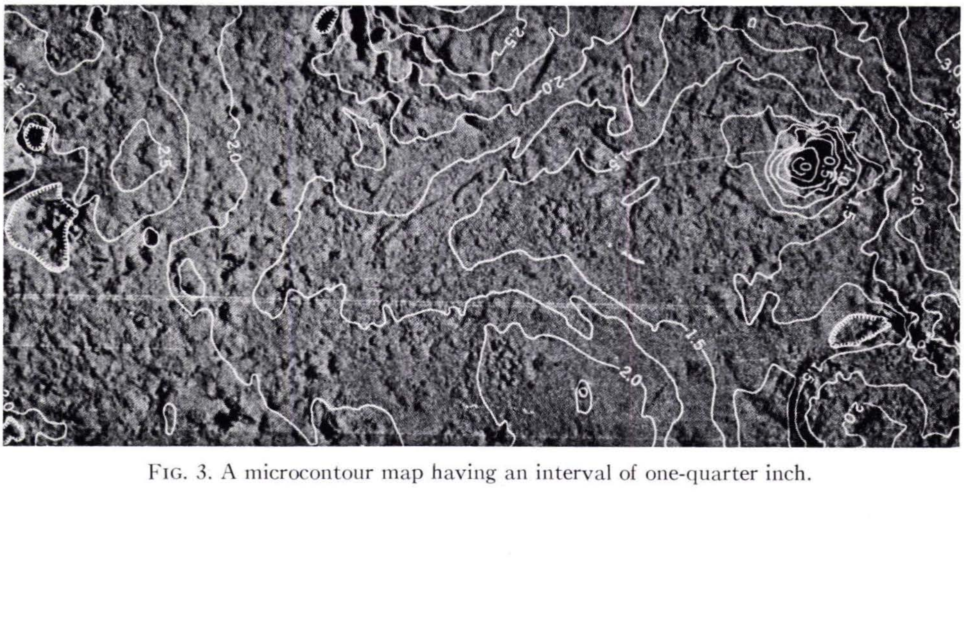

FIG. 3. A microcontour map having an interval of one-quarter inch.

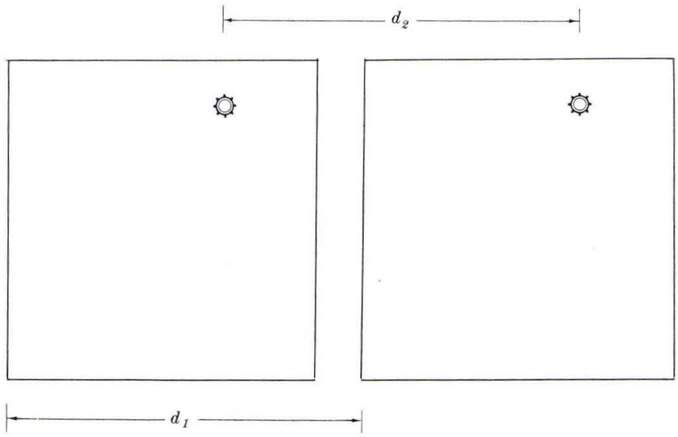

FIG. 4. Orientation of stereopairs to determine scale data.

1. Fasten the two pieces of strip film on a flat surface (preferably on a light table) alongside each other in the same relative position as used in stereoviewing, oriented according to the self edge of the films, and at any convenient separation (perhaps touching one another, or at one's viewing separation, but the distance is immaterial.)
2. With a metric scale and magnifier, . . . measure to the nearest tenth of a millimeter and record the distance, d_1, (Figure 4) from the picture frame of one photo to the corresponding part of the frame of the second, and also the distance, d_2, from an image on one photo to the corresponding image on the other.
3. Substitute these two distances into the formula,
   $h = 70/(12 + d_1 - d_2)$
   $B = 2$ feet, $f = 35$mm, $b = 12$mm
   and compute the distance, h feet, from the camera to the object, which may be on the ocean floor or suspended in the water above the floor. For example, if $d_1 = 43.3$ mm and $d_2 = 41.5$ mm, $h = 70/(12 + 43.3 - 41.5) = 70/13.8 = 5.07$ feet.

OCEANOGRAPHERS AND other marine scientists reaped the early benefits of color underwater photography. The photos greatly aided their research by offering a permanent visual record of the most remote regions of the seas. The stereoscopic instruments available for compiling underwater topography were not readily adapted for work with color photography. As these plotters (Kelsh and Multiplex) were designed for use with black and white photography, only the addition of stroboscopic lights and synchronized shutters would make them compatible to color transparencies. To avoid this expense, the color film was processed, and lantern slides (black-and-white glass contact diapositives) were printed. Though this printing process reverses the light and dark tones, an experienced instrument operator encountered no difficulty during compilation.

THE PRECEDING efforts concluded the initial five phases of the development of the C&GS deep-sea camera system: (1) testing of available lenses; (2) development of a functional camera frame configuration; (3) lowering procedure; (4) method of scale determination required to furnish a quantitative analysis; and (5) compilation of microtopographic study. The present systems are the direct outgrowth of the conclusions obtained from our early ventures. Experiments conducted in December 1961 in 14,000 feet of water, beyond the continental slope, reaffirmed our opinion that a number of improvements were needed. Trenchant efforts were made toward: (1) a more powerful light source; (2) a greater separation between the cameras in order to increase areal coverage; and (3) a more efficient lens.

The availability of the new Hopkins wide-angle f/4.5 lens in early 1962 precipitated two decisions:

(1) The initial camera system (Model-A) would not be altered. As new and better components became available they would be added to the unit. The camera was to be used in the regions of the continental slope where the turbid water does not permit the camera to operate efficiently more than 10 feet above the ocean floor.

(2) A new camera system (Model-B) was to be designed. The camera separation was increased to five feet to maintain a base height ratio of 0.2 to 0.3 at a greater range. Edgerton, Germeshausen and Grier, Inc., manufactured all components included in this system: (Frontispiece) 2 cameras, Model 204 with Hopkins f/4.5 lens; 2 lights, Model 214 (200 watt-second); 2 battery packs, Models

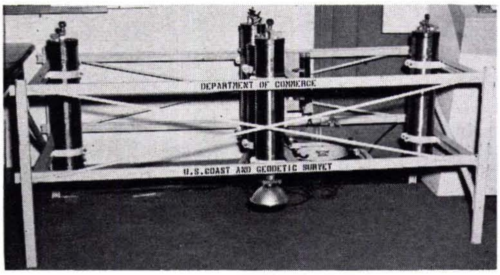

FIG. 5. Narrow frame Model B deep-sea camera configuration.

280 and 281; 2 Yardney "Silvercell" 24-volt batteries; 1 Sonar Pinger (driver, transformer and transducer). (These components are presently used in both camera systems.)

The new camera system with the more powerful light source, operating 25–30 feet above the ocean floor, was expected to increase the area coverage six fold. The 1961 camera (Model-A) captured 65 square feet, the new system's goal was 400 plus square feet.

The experimental tests of the Model-B configuration were conducted off the coast of Puerto Rico in July 1962. The new camera system was not an instant success; the problems were diverse—camera malfunctions, signal interference, and excessive time consumed in lowering the camera.

The relatively poor showing of the deep-sea camera (Model-B) cast a shadow of doubt on the feasibility of successful operations at extreme depths. The continuation of a stereo system, as opposed to a single camera unit, was scientifically justified. The scientific purpose of a stereo system is to obtain dimensional information in the pictures and facilitate accurate measurements of "life forms" photographed. A single photo is attractive and interesting but has relatively little scientific value.

Extensive tests were conducted. Scale models were devised to evaluate different camera frame conformations. Various combinations of instrument alignments were advanced. Consideration was given to a system that was lowered on end. A dropped messenger would release the unit in the proximity of the bottom where minor adjustments would position the unit at proper height.

THESE EXPERIMENTS led to the instruments being rearranged on a narrower frame. (Figure 5) The estimated lowering time was expected to be reduced by twenty percent.

The USC&GS Ship *PIONEER* was scheduled to conduct oceanographic studies in a corridor extending from the Hawaiian Islands to the Aleutian Islands. The modified unit was test lowered in 250 to 350 fathoms off the coast of Hawaii (23°30′N, 160°00′W) in the spring of 1963. Information gathered from these lowerings supported the laboratory evaluation that a more rapid descent would be possible. Satisfied with the results of these lowerings, all subsequent photographic operations were to be scheduled in conjunction with two or more of the following oceanographic observations: underwater surface current observations, bottom sample corer PVC, Roberts' current meter observations, parachute drogue current observations, or shallow pinger current observations.

Twenty-eight camera stations were "occupied" during the Hawaii to the Aleutian voyage. The maximum range of the camera was 22 feet. Approximately 5,000 good stereo-pairs were obtained from 2,800 feet of film exposed. Two of the more significant events were photographs of a sea mount and of the Aleutian Trench. The Aleutian Trench (52°05′N, 166°15′W) furnished the first transparencies of the ocean bottom more than four miles (3700 fathoms) below the surface of the water.

The following excerpt from the camera log illustrates one of the many and varied prob-

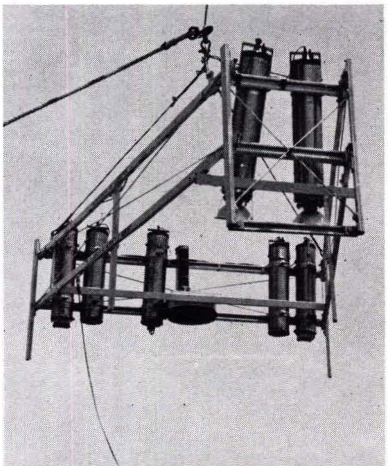

FIG. 6. *A*-frame configuration Model B of a deep-sea camera being lowered over the side.

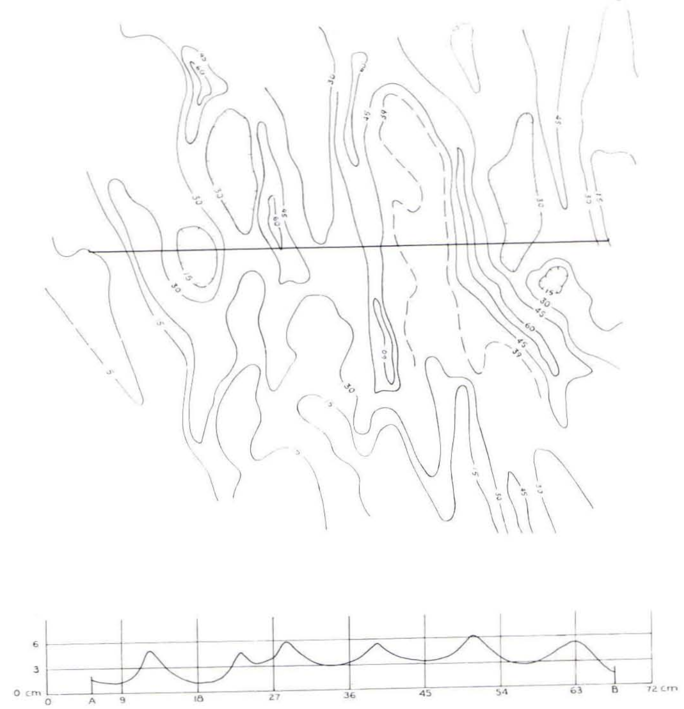

FIG. 7. Microcontour map of sand ripples. (Interval, 15 mm)

lems that the camera operators have encountered, " . . . 1200 fathoms . . . 28°09′N, 162°20′W . . . camera up then down a very steep sea mount, then snagged on a nearly vertical obstruction, where it held firm for 35 minutes. Maneuvered ship and freed camera. All damage repaired. . . . " Difficulties of this nature have arisen occasionally, but the frequency of unusual happenings, camera malfunctions and failures, has diminished. As in any new undertaking, a certain amount of profit can be derived from mistakes.

THE FINAL STEP to date in the evolution of the Model-B camera system materialized in 1964 prior to the Indian Ocean Expedition. Numerous scheduled lowerings in the extreme depths of the western Pacific Ocean (i.e., Mindanao Trench, 3860 fathoms) necessitated the design and fabrication of an improved frame to increase the speed of the lowering operations. The "A" form construction has proven to be the most practical and efficient to date. (Figure 6)

Two major barriers must be overcome if a practical and successful mapping program of the ocean floor is to be pursued: (1) the problem of absorption and scattering of light underwater must be solved; and (2) the establishment of scientific methods to position the photographs accurately within some specific frame of reference. Microcontouring at present can be best regarded as a laboratory study, because of the relatively small area involved in the actual compilation. The photogrammetric analysis obtained from one of the "mini" charts is highly refined. (Figures 7 and 8)

THE FOLLOWING EXCERPTS from an oceanographer's report on the stereophotographic phase of an oceanographic expedition illustrates vividly the unique and vastly interesting photographs that are obtainable. " . . . photos at all depths show evidence of marine life. . . . By chance, a marine organism . . . epifauna variety was snagged off the bottom . . . 1760 fathoms. . . . It was preserved and together with some fine transparencies of it turned over to Dr. Wallen at the Smithsonian Institution for identification. . . . "

"The bottom material appears to be fine sand or mud. However, photographs taken at biological dredge site 9A at a depth of 125 fathoms show the bottom to be composed of relatively coarse material including many shells. . . . "

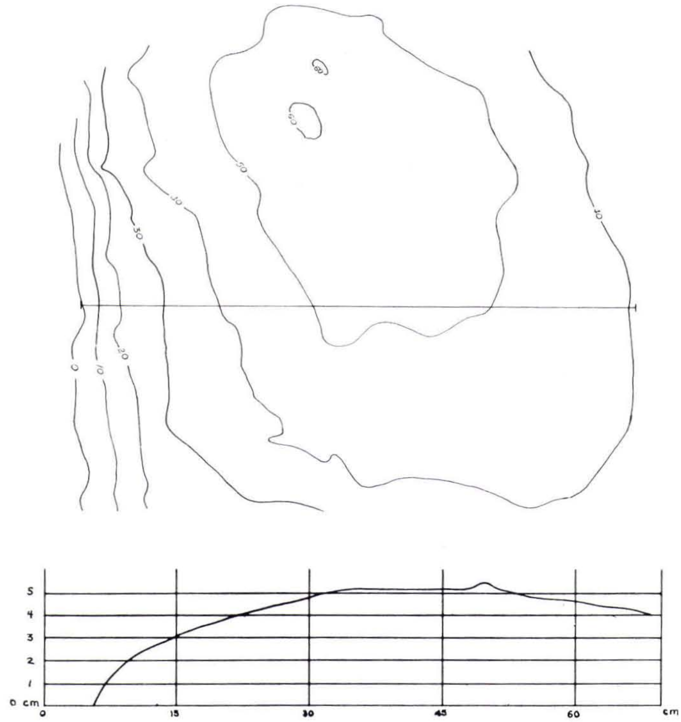

FIG. 8. Microcontour map of a boulder. (Interval, 10 mm)

"Curious mounds of unknown origin appear in many of the deep water exposures. Others show a circular pattern of holes.with the interior of the circle at a slightly different elevation than the exterior. . . . "

" . . . a systematic examination of the photos are correlation with other collected data remains to be completed."

THE DEEP-SEA CAMERA SYSTEM, although highly unsophisticated when compared to the present aerial camera systems, has grown and developed rapidly in less than a decade. Photogrammetric techniques, principles and knowledge have provided the means that permitted this challenging undertaking to begin on a note of optimism.

See announcement of 1968 Congress in Switzerland on page 940.