WHAT'S GOING ON DOWN THERE?

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Anyone who has ever flown will recall how the panorama appears to change as the aircraft gains altitude. The individual leaves on the trees in a patch of forest can no longer be seen, then the trees themselves meld, and finally the forest is no longer discernible from the general green of the terrain below. The ability of the human eye to determine an object's character decreases as the intervening distance increases.

In ocean survey and exploration, the human eye is useful only at very short ranges, usually 30 feet or less. It must be augmented at longer ranges by additional sensors. But, miraculous as they are, these visual surrogates of ours, these sensors, have all seemed to suffer from an inborn astigmatism or myopia. Moreover, the view has been made fuzzy by the wobbly platforms on which the sensors were placed. And, added to the problems caused by platform configuration and instability, have been the headaches caused by inadequate data processing or inefficient display and recording equipment.

If, then, we are to have reliable information about the ocean floor, we must have sensors which can close the gap between the present capabilities of the standard bottom echo sounder and those pictures which are the product of close-up photography. This coverage gap extends from roughly five metres on a side — the equivalent of tree-sized objects — up to roughly 100 metres on a side — the equivalent of a grove of trees. And, of course, such sensor systems will have to be installed on a stabilized undersea platform.

In a recently published book, "The Face of the Deep", (Oxford University Press, 1971) the authors, Messrs. Heezen and Hollister describe the classical methods of sampling and examining the deep-sea floor. One of the illustrations from their book is shown in figure 1. Not shown is the use of large, self-supporting submarines as exploration systems.

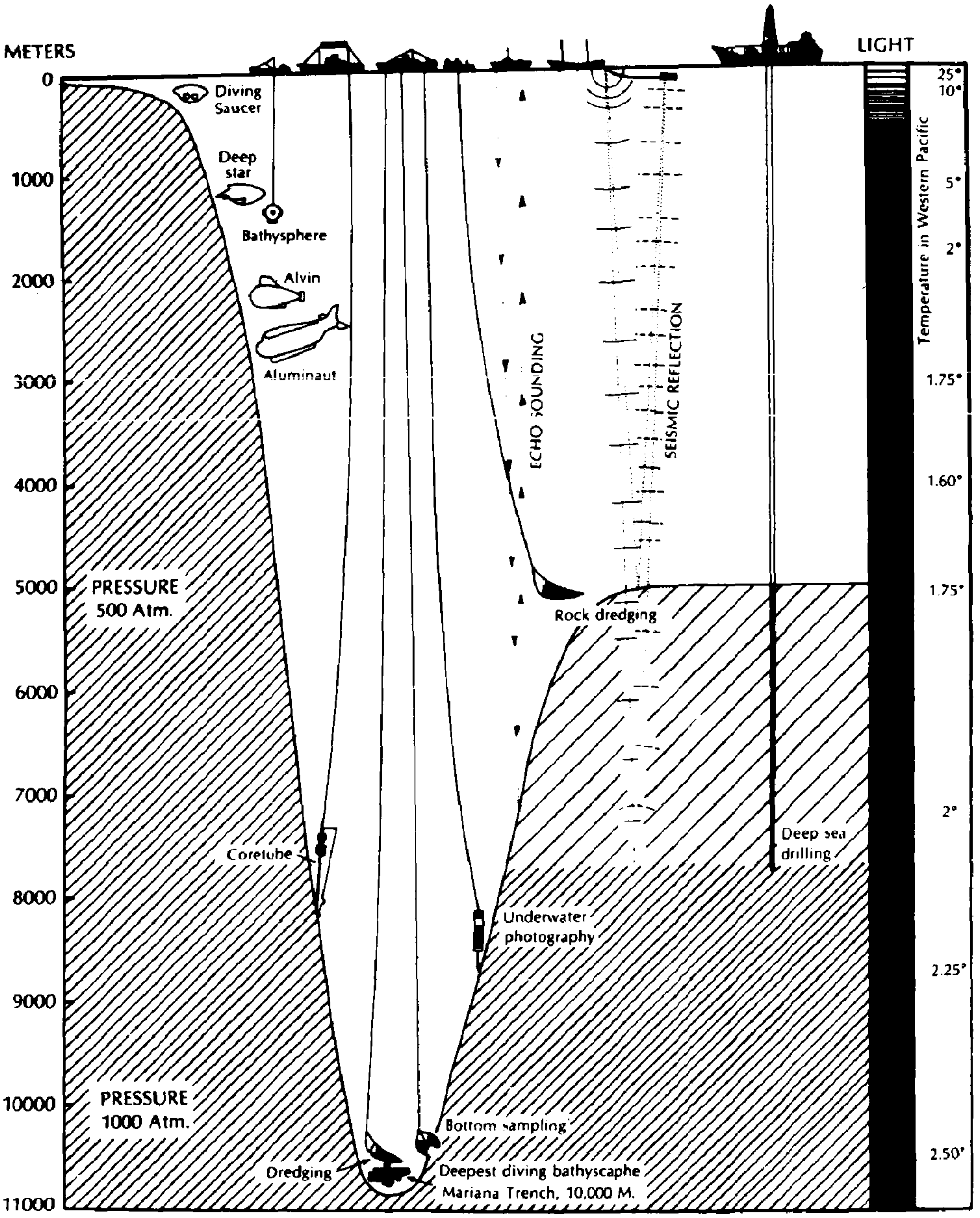


FIG. 1. — Methods of sampling and examining the deep-sea floor. (Reprinted from " The Face of the Deep ").

Figure 2, also reproduced from this excellent book, shows us, among other things, how few are the kinds of objects that can be visually observed under normal procedures. Conversely, even though most bottom-dwelling organisms are too tiny to be seen in photographs, the camera lens can and does capture the elusive images of such large organisms as starfish and sea urchins, and incredibly, can trace their tracks and trails. Figure 2 shows us, too, that mysterious region extending from five metres to 100 metres

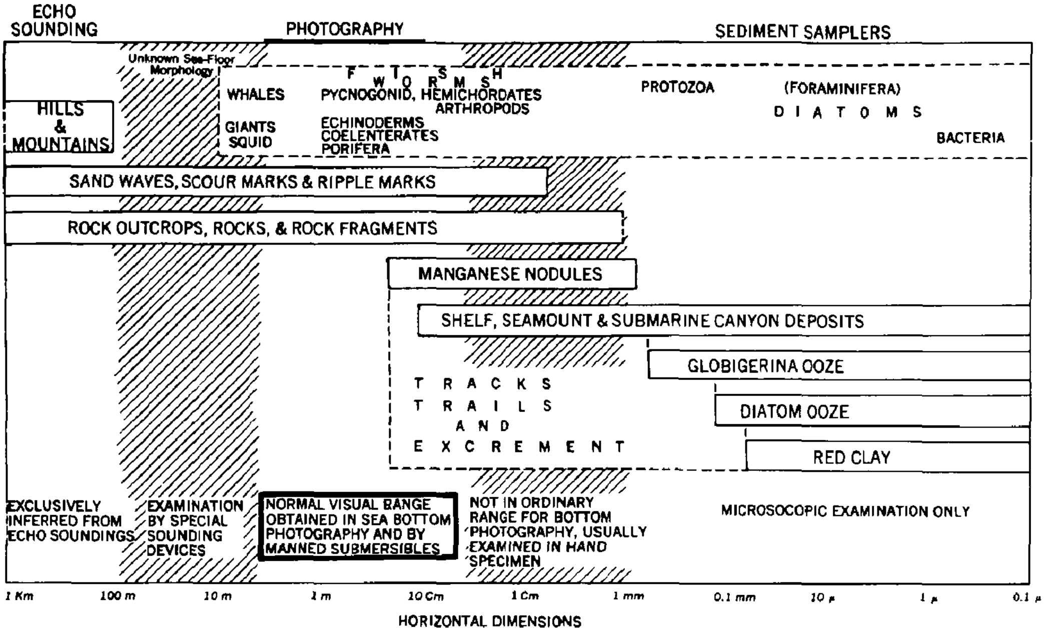


Fig. 2.

(Reprinted from "The Face of the Deep").

which will yield its secrets only under "examination by special sounding devices". This is the coverage gap referred to earlier.

"Special" is the appropriate adjective since such equipment is not readily at hand in the normal oceanographic ship's sensory equipment suite today. Still, many of the relevant techniques have been developed in other fields close to ocean engineering, or — as was true of the low-light TV sensors — in the space program.

OPTICAL SENSORS

As mentioned in the flying analogy, the resolution capability of the sensor is reduced as the distance to the object is increased. In figure 3, this inverse relationship is expressed for three typical sensors : photographic cameras; high-quality, real time closed-circuit television (RTTV); slow-scan narrow bandwidth television (SSTV); and both forward-scanning and side-scanning sonars.

The scale of the resolution is given from 0.1 millimetre up to 100 metres, and the range at which the sensors are capable of resolving objects is shown from 1 to 1 000 metres.

The forward-scanning sonar technique uses a fan-shaped beam of acoustic energy to scan the underwater space ahead of an undersea vehicle. The sidelooking sonar, on the other hand, builds up a line-by-line picture of the bottom beneath the moving undersea vehicle, much as a TV system

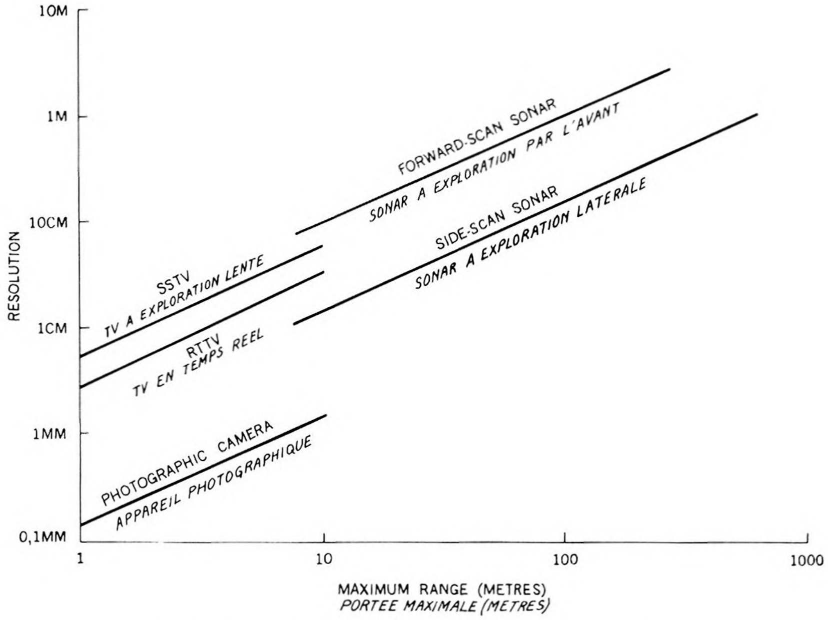


FIG. 3. — The ranges of cameras and sonars.

FIG. 4 — An oyster bar in Chesapeake Bay.

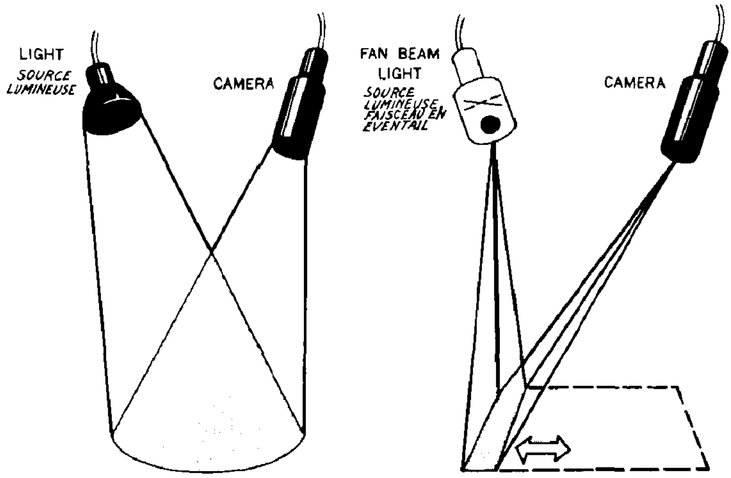
constructs a picture of a scene line-by-parallel-line to make up each rectangular frame of the TV picture.

Photographic camera techniques, whether used on the ocean floor by unmanned systems or operated by men in small vehicles, can customarily resolve very small objects with high quality pictures, as shown in the lower left hand portion of figure 3. Photographic cameras, however, tend to be range-limited to about 10 metres except under optimum lighting and minimum back-scatter underwater conditions. Back-scatter is the condition wherein much of the light energy used in illuminating the scene is reflected by the suspended microscopic particles in the water. This is analagous to the difficulty experienced when trying to see in a fog, where the moisture particles in the air scatter the light, thus making object recognition difficult if not impossible.

Techniques using real time television and slow-scan television allow the same range scale to be examined. However, because of the line structure of the television type of display and video band-width limitations of deep-tow cables, the resolution is poorer than that obtainable from photography. Video enhancement techniques can, nevertheless, be applied to improve a variety of aspects of underwater viewing, including the range capability, over that obtainable by normal photographic techniques.

A typical underwater photograph of a marine resource — an oyster bar in the muddy waters of the Chesapeake Bay — is shown as figure 4. The camera was within two metres of the bottom and the individual oyster shells can be seen. Thus, with an overlapping photographic montage of the area encompassed by an oyster bar, a population count could be made of its living resources.

Numerous techniques exist for improving the TV-aided optical type of underwater imaging system. To date, these have been directed primarily toward improving the sensitivity of the optical system so that it can operate under low-light-level conditions. A good quality silicon target, secondary electron conduction (SEC) image, intensified low-light-level TV camera



CONVENTIONAL SYSTEM
SYSTEME CLASSIQUE

VOLUME SCANNING SYSTEM
SYSTEME A FAISCEAU LUMINEUX EN EVENTAIL

FIG. 5. — Underwater optical techniques.

system, for example, can be 10 000 times more light-sensitive than a standard vidicon TV camera tube.

A second feature that a TV-scan type of system can provide is the enhancement of some of the colors that are normally lost from an underwater photographic system. For example, a multicolor underwater television system can compensate for the attenuation of the red end of the optical spectrum, as compared with the green portion at a given range. This color-corrected view of the underwater scene could also be corrected manually or adjusted at will.

A third technique available to the designer of an electronically aided underwater optical system is the possibility of reducing the back-scatter interference problem common to underwater optical techniques because of the suspended matter in the underwater medium. Figure 5 shows a conventional optical system on the left, illuminating a conical volume of the back-scattering medium. This can be compared with that of the wedge of illuminated volume on the right, which will occur with the scanned system shown. The difference can be taken as a representation of the improvement that is theoretically possible with a fan-beam light source. As a practical matter, the volume scanning technique offers modest improvements of range under medium scattering conditions. Under severely turbid conditions, however, no optical technique will produce adequate results, and one must revert to sonic imaging techniques.

IMAGING SONARS

Turning our attention to the imaging sonar techniques, figure 6 shows an oyster bar in the Chesapeake Bay, as seen by a simple side-looking imaging sonar. For the purpose of resource assessment, the coverage capability of such a sonar is orders of magnitude greater than that of the optical techniques. A detail photomontage of the oyster bar is not necessary when the boundaries of the oyster bar can be differentiated from the surrounding mud. Occasional spot check verification of the characteristics of the oyster bar and the surrounding regime should be taken.

Figure 7 shows the resolution and range capabilities of a variety of existing imaging sonars. These are in the three categories of : (1) the side-scanning sonars; (2) the forward-scanning sonars, both pulse type and continuous transmission type, frequency modulation (CTFM); and (3) the Mills cross bottom mapping sonar. On the extreme right-hand end of the curve is a data point representing a very large British three-kilohertz, side looking sonar system. The remaining data points are represented by a variety of currently available U. S. towed-body-mounted and hull-mounted imaging sonars. The Mills cross bottom mapping sonar is a multibeam system with multiple orthogonal transducer elements for transmit and receive. This system has been fitted to a small number of U. S. Navy oceanographic and survey ships. It is capable of producing a medium resolution map using the large number of one-degree beamwidth elements. A total

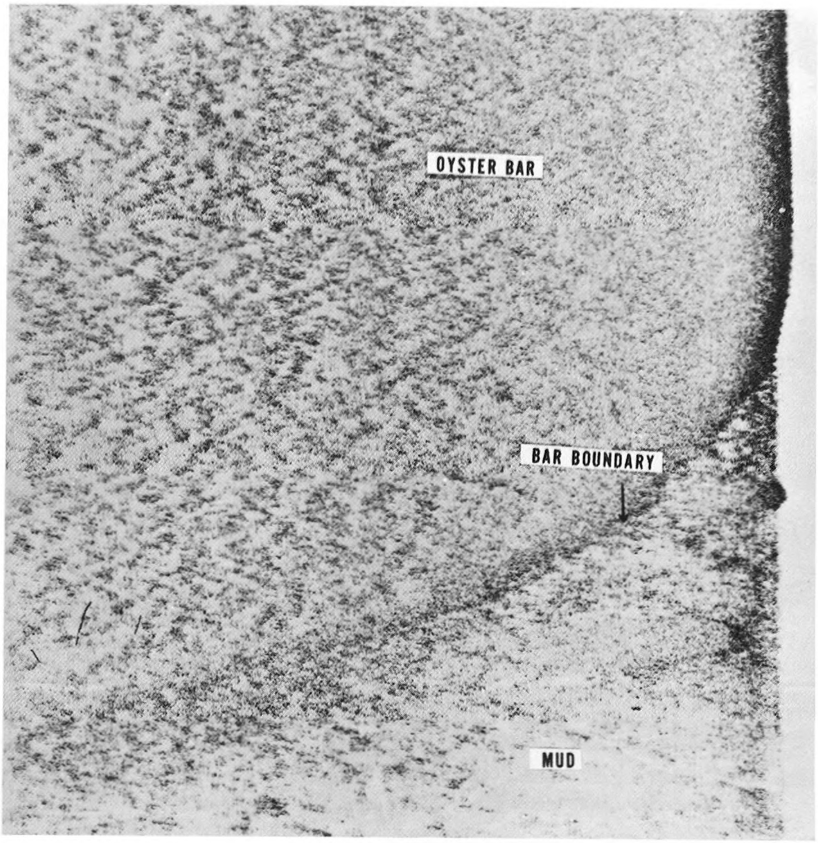


Fig. 6. — As viewed by a side-looking imaging sonar.

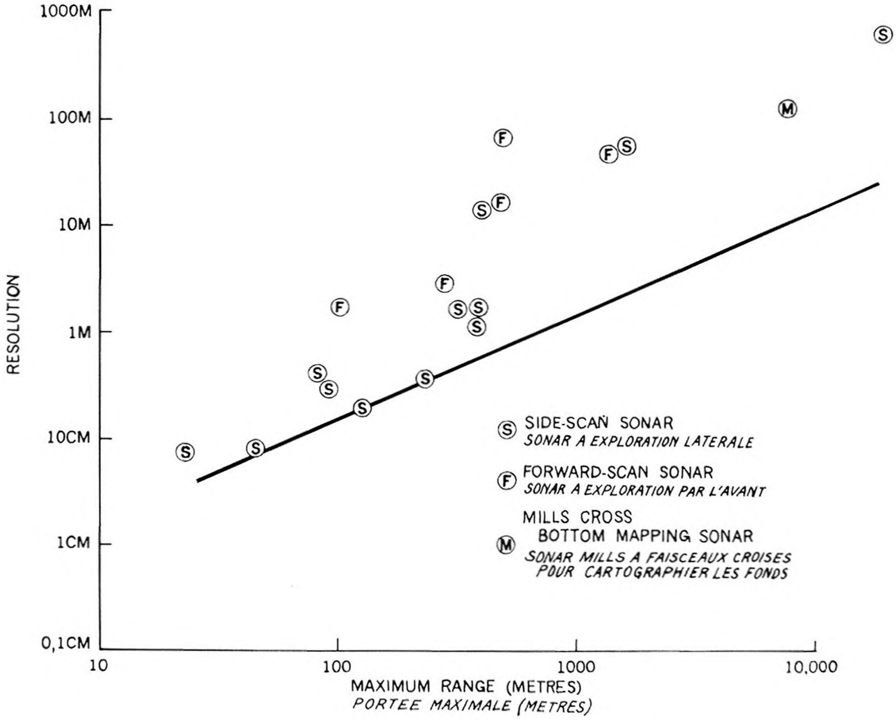


Fig. 7. — Resolution and range capabilities.

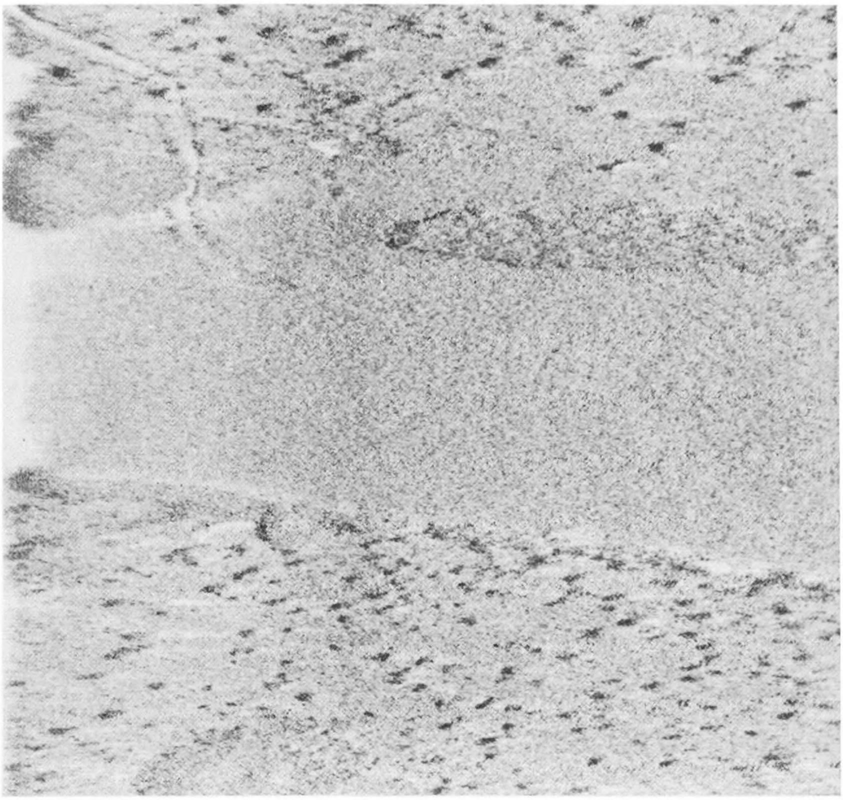


FIG. 8. — The boundaries of the Annapolis channel in the Chesapeake Bay.

of 90 beams are fitted in an athwartship direction to allow 60° of coverage below the ship. The remaining 30 beams, 15 to port and 15 to starboard are required to allow beam-steering to compensate for ship roll. In the fore-and-aft direction, 12 degrees worth (plus or minus 6 degrees) of pitch compensation is also provided by multiple fore-and-aft beams.

The value of the imaging type of sonar is illustrated in figures 8 and 9. In figure 8, the side-looking sonar clearly delineates the boundaries of the Annapolis channel in the Chesapeake Bay. An oceanic resource assessment system on the ocean floor could easily find such a man-made channel in an area where mining had been carried out. As another example, figure 9 shows large-scale ripples on the bottom of the Pacific Ocean, as seen by a side-looking sonar system. In this case, two beams are shown, one beam facing to port, and the other to starboard, from the towed body. The closing of the "coverage gap" that now exists between echo sounding and photography is going to be achieved by these types of imaging sonars. But what of the future ?

PLATFORM CONSIDERATIONS

The capability of the single beam imaging sonar is no longer a basic limitation. In the case of sophisticated, high resolution, high coverage rate,

FIG. 9. — Large-scale ripple marks in the bottom of the Pacific.

imaging sonar systems, the system constraints come down to platform limitations and accuracy of platform navigation.

The first consideration is to achieve a suitable platform where adequate size will be available for mounting a large number of beams. The second is to provide adequate interior space which can be allocated to the associated precision platform navigation, multibeam signal processing and the data production so that these functions can be carried out on board in real time. The large arrays of elements required to achieve the high resolution, and the number of channels to improve the coverage rate of data processing equipment require a platform of generous dimensions, in terms of both interior volume and hull length.

The third consideration relates to the need to minimize the motion of the platform during the round trip time of the sonar signal, from the hull to the bottom and return, so as to maximize the coverage from the beams on the platform, and minimize the effect of random platform motions that "smear" the signals from the bottom. The present 1° beamwidth, downward-looking, Mills cross-system concept could easily be extended to a 0.1° or 0.05° beam system if platform motion were to be reduced significantly. Similarly, the side-looking sonar technique, which is suitable for looking out to the sides of the moving vehicle, benefits from the same type of platform motion minimization.

The fourth consideration is depth or, if you will, altitude above the bottom. Imaging sonar systems tend to be focused and are therefore optimized for "altitude following" rather than being independent of the depth below the keel of the sensor platform.

The fifth reason for using a submerged platform is that the sonar can be made to work entirely through homogeneous deep water. The first few hundred feet of water depth is subject to significant temperature changes and other factors which can randomly bend the narrow sonar beam of energy. This also "smears" the signals received from the bottom. Surface ships are unable to enjoy this important submarine advantage.

These considerations suggest strongly that the only suitable long-term platform for mounting the imaging sonar sensors is a submarine. Such a submarine could be of a shallow-depth type which could tow a deep traveling sonar body for deep ocean exploration or survey. Alternately, she could be provided with the hull-mounted sonars for use in a terrain-following mode down to and including the comfortable design depth of the submarine.

What would constitute an adequate survey and exploration submarine system ? First and foremost, a true long-endurance submarine would necessarily have to be nuclear powered. We would want her to be equipped to make maps of the bottom with high-resolution imaging sonars, and then, as necessary, she ought to be able to stop and allow examination of the bottom in micro detail with subsidiary vehicles, such as small, manned submersibles and unmanned craft.

The Manned Undersea Science and Technology (MUS&T) program office in NOAA is projecting the need for such mobile undersea support laboratories in the future. Although the submarine system is here described as a mobile support laboratory with subordinate elements, the Navy's oceanographic community might see her as a submerged Auxiliary (ship) General Oceanographic Research (AGOR).

Figure 10 is an artist's rendition of a submarine that is equipped with multibeam sonar surveying the bottom. A significant fraction of the length of a submarine is required for mounting a high-resolution multibeam sonar system. One of the methods by which a multibeam sonar system could be implemented is a series of electronically delayed transducer assemblies to electrically form and steer multiple beams directed perpendicular to the submarine hull.

The improvement in the ocean bottom survey coverage achieved with multiple beam systems is in direct proportion to the number of beams employed, up to a point. For example, a single beam system which could achieve a coverage rate of one square nautical mile per hour could become a 10-beam system with a coverage rate of 10 square nautical miles per hour at the same speed over the bottom.

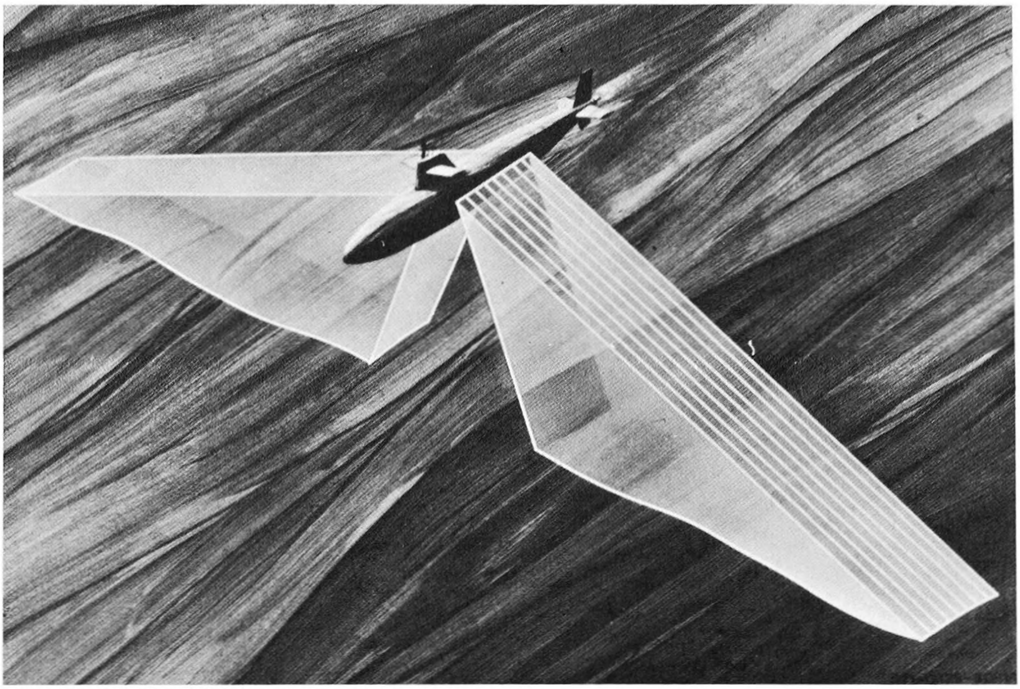


FIG. 10. — A submarine equipped with multibeam imaging sonar.

Now underway at NOAA is a plan to resurvey the continental shelf and waters adjacent to Alaska. Such surveying and charting is highly subject to the weather and ice cover in the region north of the Aleutian chain. A charting and mapping function could readily be performed by submerged systems for much of these waters, where a comfortable submarine operating depth is available, say, 100 feet depth or greater. For an Arctic under-ice survey, the submarine would be equipped with sonar transducers to provide the coverages shown in figure 11. Downward-facing sonars, both forward and side-looking, would be provided as well as upward-facing sonars to chart the underside of the ice cover, and provide for obstacle avoidance.

Under-ice exploration is not new. U. S. Navy submarines transited beneath the polar ice-cap in the late 1950s and made sonar track records across the bottom using single-beam Fathometers. Unfortunately, such Arctic missions did not include ocean resource assessments and ecological studies. They were simply charting possible transit lanes for military submarines and looking for dangerous obstacles such as seamounts.

The kind of capability that would enable the Arctic ocean floor to be systematically explored and surveyed in detail is still not with us. But, given the development and deployment of suitably equipped exploration submarine systems, such activities are entirely feasible by the end of the 1970s.

This paper has not considered the various forms of classical oceanographic sensors ranging from seismometers to gravity meters, or from sediment shear-strength sensors to salinometers. Nor has it considered the

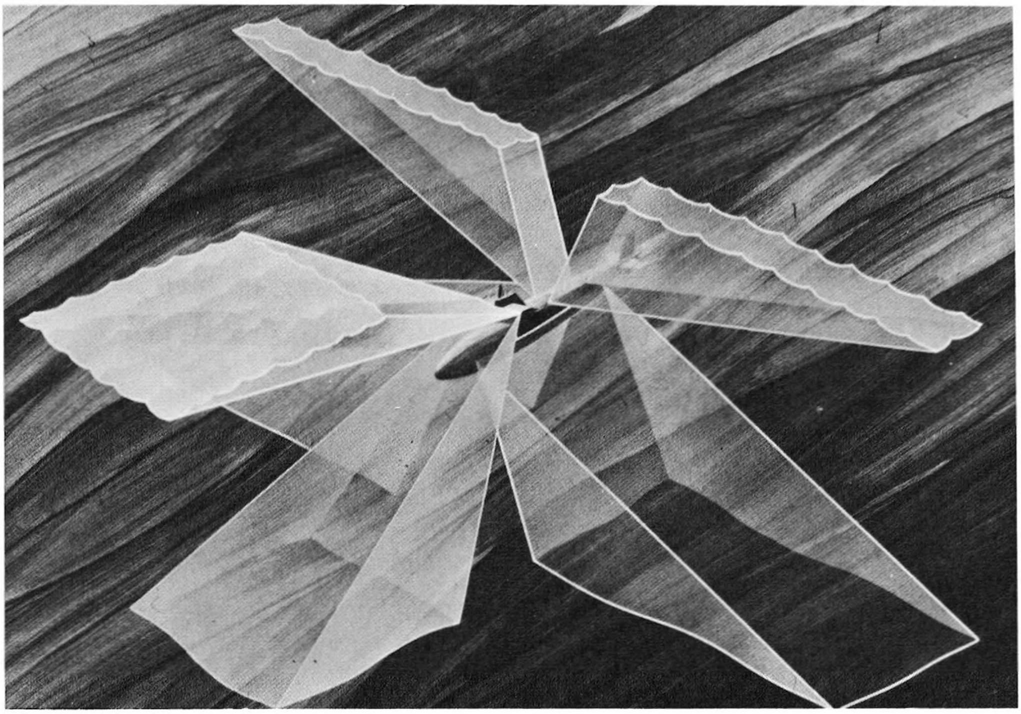


FIG. 11. — Sonar coverages for under-ice surveys.

microscopic examination end of the resolution spectrum, or the degree to which buoys and other synoptic sensor platforms should be used. What it has addressed is the closing of one of the gaps in coverage between the sensors whose resolution allows us to find the mountain peaks and valleys, and the optical "window" which has been a mainstay of most detailed bottom exploration to date.

The need of multiple-beam imaging sonars for platforms of significant size, and the need for platform motion stability, provide some of the arguments for the use of submarines in the macrosurvey role. In the microsurvey mode, the submarine support of subsidiary close and microscopic examination vehicles, both manned and unmanned, would provide a quantum jump in the sophistication of this support. It is time to move ocean survey and exploration to the next level of sophistication and close the coverage gap.

(Submitted in English).