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SIDE SCAN SONAR FOR HIGH RESOLUTION SEABED SURVEY

Martin Klein
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Recent availability of commercial side scan sonar instruments has greatly enhanced the ability of the geophysicist to quickly survey a large undersea area and to make a rapid qualitative investigation of the sea floor topography. The side scan technique gives results similar to aerial photography, except acoustic beams are used instead of light beams. The acoustic beams are used in conjunction with a display technique which uses a special dual channel graphic recorder to make a graphic picture which the eye can interpret. This article is a basic introduction to the side scan technique with comments on history, equipment, applications, record interpretation and examples, as well as thoughts on future developments.

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INTRODUCTION

Over the past ten years, side scan sonar has "come of age" as an accepted tool of the geophysicist to quickly survey a large undersea area. The sonar allows a rapid qualitative investigation of the sea floor topography. The side scan sonar uses high frequency sound beams in conjunction with special dual channel recorders to create sound pictures or "sonographs" of the sea floor.

HISTORY

Although side scan sonar technology apparently goes back to the latter part of World War II, non military uses only began to appear in the literature in 1958. Early developments were generally made in government or academic research laboratories such as the U.S. Mine Defense Laboratory, the National Institue of Oceanography, Bath University, Hudson Laboratories and the Massachusetts Institute of Technology. In the early 1960's, the only commercially available systems were the very high-priced Westinghouse "Ocean Bottom Scanning Sonar: and the low-priced, single channel Kelvin-Hughes "Transit Sonar".

In late 1967, the author and his colleagues introduced the E.G.&G. Mark I Side Scan Sonar, the first medium priced dual channel side scan system which could be towed near the sea floor. The system gained wide publicity when, on its first major expedition, Klein used it to help George Bass pinpoint a 2000 year old shipwreck off the coast of Turkey. Soon after it was used to help find the Mary Rose. The first commercial clients to purchase the system were Decca Survey and Hunting Survey, two United Kingdom companies who were already familiar with the side scan technique.

A few months later, in January 1968, Klein Associates was formed, and new developments continued (and still continue) as Klein and E.G.&G. competed. Slowly the side scan systems began to receive world-wide acceptance, and eventually other United States companies including O.R.E., U-Tech and Edo introduced systems. Recently, two U.K. companies, UDI and OAL also began producing side scan systems.

THE BASIC SYSTEM

Side scan sonar systems utilize a towed device ("towfish" or "fish") which emits high frequency, high intensity pulses of sound to either side of a moving vessel. Photo 1 shows an artist's conception of the side scan technique. The sound beams are narrow in the horizontal plane and wide in the vertical plane. The pulses echo off objects and features on the sea floor and return to the towed vehicle. They are then converted to electrical signals and are sent up the tow cable to a special graphic recorder. The recorder typically has two channels which make a continuous permanent strip chart recording of the echoes. The record generally shows the bottom directly below the ship as well as the terrain on either side of the ship.

Commercial side scan sonars generally use an acoustic frequency of 35 to 200 KHz, although experimental units have been built with lower and higher frequencies. Horizontal beamwidths may be anywhere from a few degrees to fractions of a degree. Devices with very narrow beams require more sophisticated towing vehicles which are free from instability or "yaw". Pulse lengths on the order of fifty microseconds to one millisecond are used. Sound travels approximately 1500 meters per second underwater, so a 100 microsecond pulse gives a range resolution on the order of 15 centimeters. The rate of pulse transmission depends on the range scale desired and the time it takes for sound to travel out and return. For instance, on a 150 meter range, the time for each sweep is 200 milliseconds so the pulse rate is five per second.

Photo 2 shows a typical side scan system installed on a small craft. The system runs on automobile batteries (which can be obtained almost anywhere in the world) or on 110 or 220 volts A.C. from the mains. Modern systems are relatively portable and can be operated in small outboard motor boats in confined waters or on large survey vessels.

A major factor in the success of modern systems is that they are towed near the bottom rather than hull mounted. This frees the transducers from the ships motion, since the cable acts as a decoupling element. Proximity to the bottom also allows much more detailed, higher resolution records. Since towing is an important part of the side scan operation, most manufacturers now sell a variety of towing accessories including winches and depressors.

Although most side scan work is done with specialized recorders, transcievers are now available which allow side scan records to be made on standard geophysical survey recorders. A typical transceiver for this purpose is shown in Photo 3.Sophisticated digital adapters are also available to convert single channel recorders to dual channel and to reverse one of the channels to give the standard "center out" type of side scan display.

APPLICATIONS

SIDE SCAN SONAR has seen widespread application in many phases of undersea endeavor. It has been used extensively on the ocean as well as on inland lakes, rivers and canals. Some typical applications follow:

• GEOLOGIC STUDY	The Sonar is able to "see" both small and large features on the ocean bottom such as rock outcroppings, individual rocks, rough and smooth mud, sand, gravel or other bottom types.
• SAND RIPPLE STUDY	The sonar is able to take a quick look at sand waves or ripples as small as a few centimeters in height. With daily or periodic checks, a simple evaluation of the changing sand patterns can be made. This can provide valuable insight into the near-floor ocean currents.
• BATHYMETRY AND HYDROGRAPHY	The sonar can be used to give a detailed topography of the bottom not only below the Towfish, but out to both sides as well. This gives a much more rapid coverage than a standard depth sounder, and it helps prevent "holidays" or skips of important targets between sounding lines.
• MINERAL SEARCH	The sonar can be used to locate a field of a certain mineral deposit such as manganese nodules, and it can also be used to determine the extent of the deposit.
• CABLE AND PIPELINE LOCATION	The sonar can be used prior to cable and pipeline placement to determine if there are any bottom hazards in the path of implantation. After placement, the sonar can be used to check the location of the cable or pipe and to determine whether it has become uncovered.
• ENGINEERING SURVEYS	The sonar can provide a wealth of detail on bottom conditions prior to a lake, river, harbor or ocean bottom installation. Site conditions, topography and hazards can be detailed to determine the best location and method of placement for piers, oil rigs, dredging and other projects.
• GENERAL SEARCHING	Side Scan Sonar has an enviable record of success in looking for objects on the ocean floor including wellheads, downed airplanes, stolen automobiles, torpedoes and shipwrecks.
• UNDERWATER ARCHAEOLOGY	Side Scan Sonar has been used to locate ancient ships and the protruding walls of ancient harbors. When used in conjunction with subbottom profiling apparatus, it can be used to search for ancient harbors and submerged structures.
• GAS SEEPS	Side Scan Sonar can often be used to locate seepage of gas from pipelines or from the sea floor.

RECORD INTERPRETATION

Photo 4 shows a typical side scan sonar record made near the coast of Massachusetts. The record reads from the center out to the edges. The two center lines represent the outgoing pulse. The right side of the chart represents echoes received from the transducer which points to starboard, and the left side represents the echoes from the transducer which points to the port side. The first thing to be received is generally an echo from the sea bottom directly below the towfish. Since each transducer is equally distant from the bottom, this first line is generally symmetrical on each side. This first trace is basically the same as an echo sounder trace.

In shallow water, a surface trace is also generally received, which allows the operator to measure the depth of the transducer below the surface.

After the bottom trace the various surfaces which project from the bottom on each side show up on the record. Note that a perfectly smooth bottom will produce almost no signal return except directly below the transducers. This is because all of the sound transmitted at an angle will bounce away from the towfish. A rougher bottom will reflect some of the signal back to the towfish. This signal, referred to as "backscatter", is related to the surface roughness and the angle of the transmitted pulse as well as the nature of the material. The bottom directly below the transducers is at a 90^{o} angle, so it produces the most reflection even though it is somewhat out of the main beam of the transducer. The bottom out at a distance from the transducer is hit at a shallow reflection angle so that it returns the least backscatter.

Sophisticated circuits are utilized which vary the gain of the system in time to try to compensate for these factors and to attempt to create a relatively uniform signal across the record. Although this ideal is rarely achieved, the time-variable-gain does improve the record quality considerably. One of the problems encountered in the design of a side scan sonar is the limitation of the recording techniques and recording papers. These tend to have a dynamic range on the order of ten or one hundred to one, while the signals encountered in sonar may have a dynamic range of a million to one or more, from the transmitted pulse to the weakest echoes. Again, the time-variable-gain helps the situation, and various types of automatic gain control have been tried. One of the recent breakthroughs in this area has been the development of a patented signal processing technique we call Hands-Off-Tuning® with Texture Enhancement. This proprietary circuitry greatly improves the uniformity of the sonar records across the paper and also makes the sonar much easier to tune for an inexperienced operator. The process also helps bring out the fine texture details of the bottom, although in many situations "manual" tuning may produce superior results.

The longer ranges on the side scan sonar record tend to be fuzzy, mainly because the sound beam pattern spreads out at long distances. The distance of spreading is directly proportional to the angle of the transducer (measured in radians) multiplied by the distance to the target area. This is shown in Figure 1. Experimental systems have been proposed and built with variable focus and computer controlled synthetic aperture techniques, but such systems are not yet commercially available.

A closer look at Photo 1 shows the shadow effect from a narrow beam side scan sonar. A target projecting from the bottom will block off some of the backscatter and create an acoustic shadow on the record. This shadow can be measured to give a rough idea of the target height off the bottom as shown in Figure 2. Note, of course, that in areas of low backscatter, there will be no real shadow effect.

Standard commercial side scan systems generally produce a record which is a "negative" in the sense that signal areas show up dark and shadows show up light. Klein has recently patented an electronic reversal technique which allows "positive" as well as"negative" images to be used. These "positive" records are often easier to interpret simply because we are used to looking at the real world in this way. Photo 5 shows an example of an electronically reversed side scan record.

APPLICATION EXAMPLES

One of the biggest applications of side scan sonar has been to assist in underwater pipeline placement and checking. Pipeline routes are surveyed in detail to make sure there are no serious obstacles in the proposed pipeline path. The author participated in a survey in the Caribbean where the bottom had mile after mile of flat sand. In fact the bottom appeared featureless on the echo sounder. However, on occasion, a very large rock outcropping would appear on the side scan trace...an important bit of information on where not to run the pipeline. After the pipeline is put in, side scan is often used to check its location and to see if it is buried. Photo 6 shows a typical pipeline record in the North Sea. Note that on this record a computer was tied in to the navigation system and also to the event marker on the sonar to correlate the traces.

Photo 7 shows a section of a pipeline crossing on the Merrimac River in Massachusetts. This record was made in very shallow water - five to fifteen feet. The river is tidal and has a very swift current. Periodic checks with the side scan reveal that the pipeline is sometimes covered with sand or gravel in sections.

Side scan sonar is often used in harbor engineering work. Photo 8 shows an interesting record made along the North Mole of the enormous Europort in Rotterdam. Note that the sonar clearly delineates the various sizes of stones used in building the wall.

The side scan has also proved very useful in locating undersea cables, as in Photo 9 and lost anchor chains as in Photo 10.

One of the most interesting uses for side scan sonar has been the search for shipwrecks. Photo 11 shows a typical sonar record of a broken shipwreck off the coast of Florida. Sometimes wreck hunting is important for environmental considerations. For instance, one of our sonars was recently used off the coast of Italy to help locate a ship which went down with many barrels of poisonous tetra-ethyl lead compound.

Photo 12 is a sonar record of one of the most amazing finds made to date with side scan sonar. The Royal Ontario Museum and the Canada Centre for Inland Waters found two ships from the War of 1812 lying in 300 feet in Lake Ontario. The records reveal that both wrecks are nearly intact with their masts standing. On some of the records the cannons on deck are clearly delineated. Finds such as this are continuing. One of our clients recently sent us a sonar trace very similar to Photo 11 showing an old schooner with masts standing in another part of the Great Lakes. And recently, Decca Survey assisted the Atlantic Charter Maritime Archaeological Foundation in the probable location of the *Bonhomme Richard*, flagship of Commodore John Paul Jones.

Side scan sonar has also assisted in the location of aircraft which have fallen into the sea. Recently a unit was used to locate a United States F-14 Tomcat which fell off the deck of an aircraft carrier. Photo 13 shows a sonar trace of a PBY aircraft which sank in Loch Ness during World War II.

NEW DEVELOPMENTS AND CONCLUSIONS

Recently, many geophysicists have recognized the usefulness of simultaneous recordings of side scan sonar with echo sounding and/or high resolution sub-bottom profiling. Interpretation of records is greatly enhanced by displaying the output of the side scan and the profilier on a single recorder. Several manufacturers have recently introduced multi channel systems of this type.

In the coming years we can expect side scan sonar technology to at least catch up with side looking radar techniques, at least up to the limitations imposed by the medium. Problems of low speed transmission (and hence low data rate), high attenuation, ray bending and other variables will remain, however, unless there are real breakthroughs in the state of the art.

We can expect to see increased use of computer processing for scale corrections, mapping, signal enhancement and target recognition and evaluation. Continued development in the small computer field should allow for a certain amount of on-line shipboard processing. For precision mapping, we can expect computer tie-in with navigation schemes. Digital schemes are already in use to convert single channel recorders to multi-channel units and to allow for various scale factors on a single recording.

There are still problems involved with the graphic recorders used in side scan recording. As the facsimile field progresses, we can expect a fallout of improved recorders and data transmission techniques.

There are still many places in the world where side scan sonar is essentially unheard of, while other areas are using it as a routine tool. In general, however, its use is accelerating. More manufacturers are entering the market place, and this competition will benefit the technology and the user.

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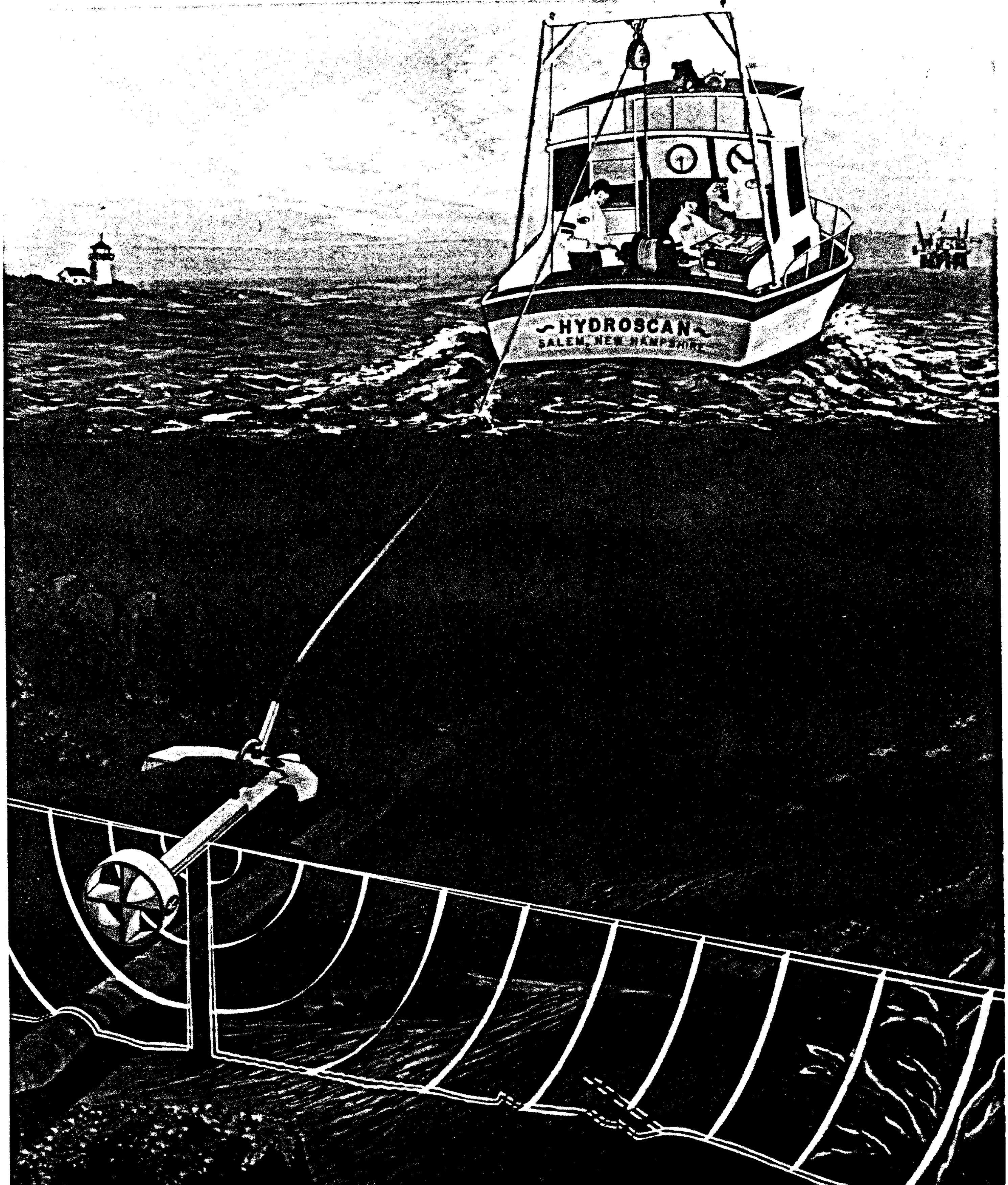
LIST OF CAPTIONS

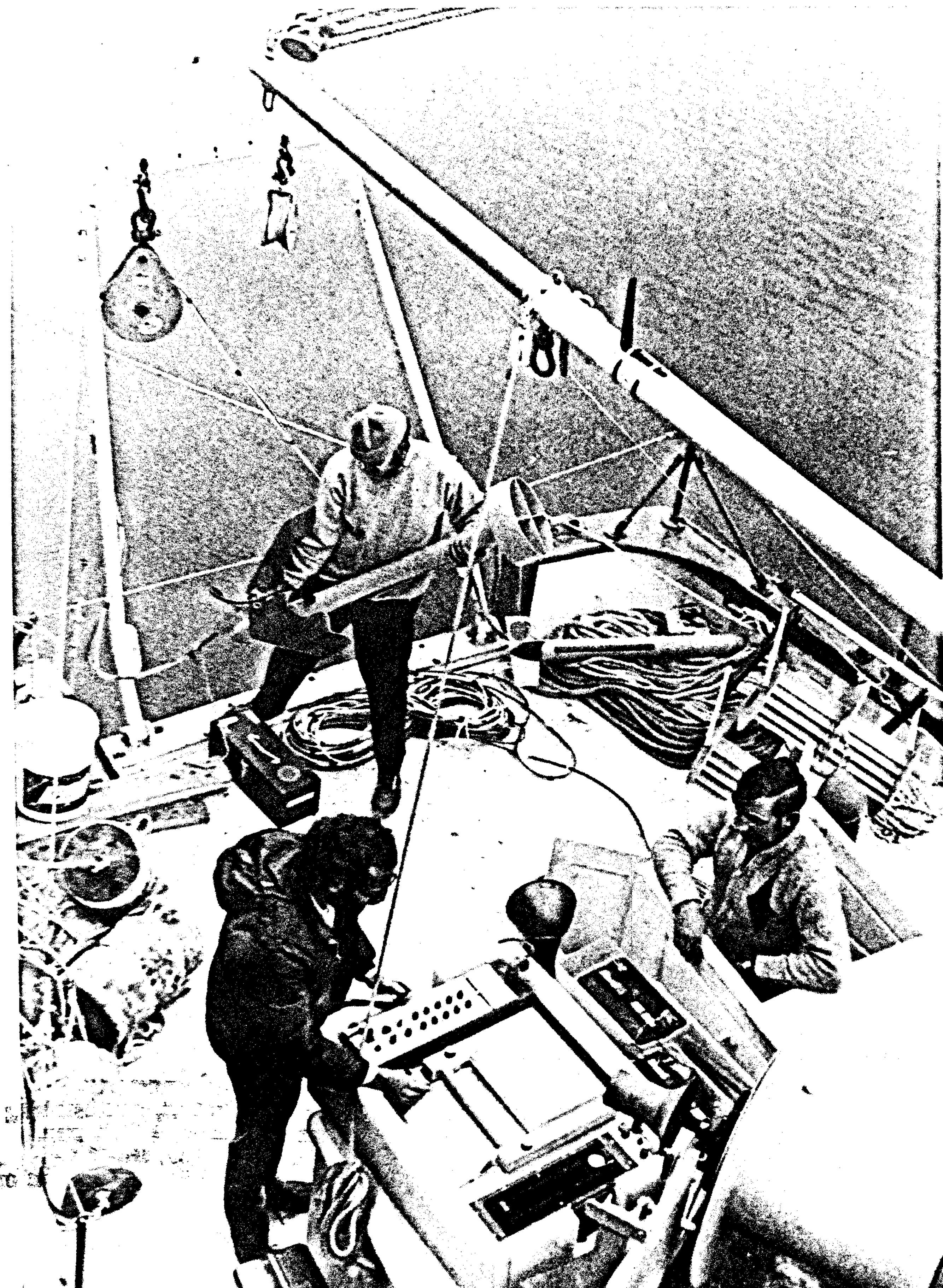
PHOTO

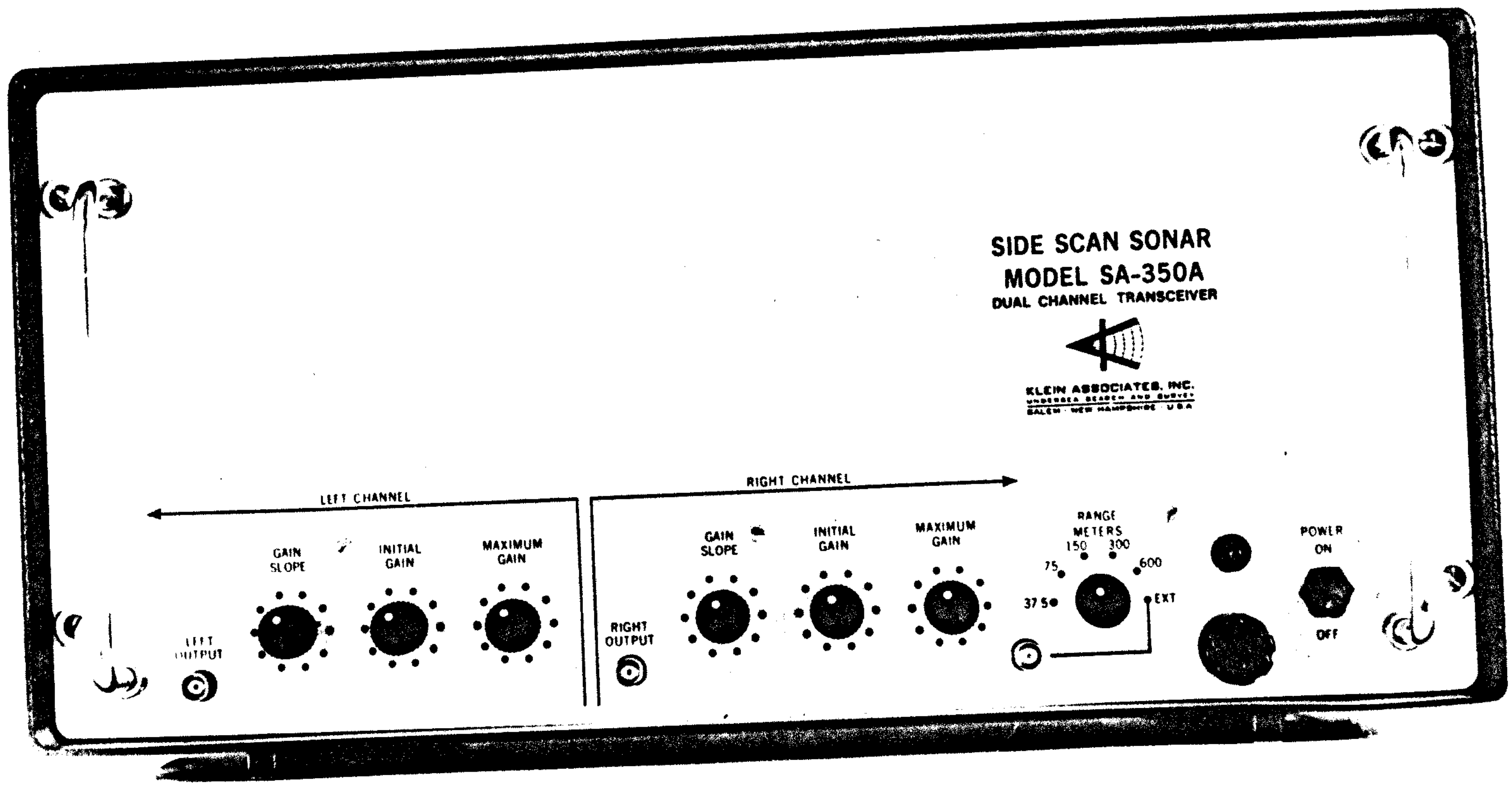
1. Artist's Conception of the Side Scan Sonar Technique. Copyright: Klein Associates, Inc.
2. A typical Side Scan Sonar installed on a small survey boat.
3. A Side Scan Sonar transceiver which adapts a side scan towfish to a standard graphic recorder.
4. A typical dual channel Side Scan Sonar recording made off the coast of Massachusetts.
5. A Side Scan Sonar recording showing electronic reversal.
6. A Side Scan Sonar recording of a pipeline in the North Sea. Record courtesy of Viking Offshore Pipeline Services.
7. A Side Scan Sonar record showing gas pipelines in a shallow river.
8. Side Scan Sonar record taken along the North Mole of Europort in Rotterdam.
9. Side Scan Sonar recording of 1/2" diameter steel cable on a sand bottom. Courtesy U.S. Navy.
10. Side Scan Sonar record of an anchor chain off the coast of Florida. Courtesy of Harbor Branch Foundation.
11. Side Scan Sonar record of a broken shipwreck off the coast of Florida. Note the school of fish above the shipwreck. Courtesy of Harbor Branch Foundation.
12. Side Scan Sonar recording of the ship HAMILTON in 300 feet of water in Lake Ontario. Courtesy of Canada Centre for Inland Waters and the Royal Ontario Museum.
13. Side Scan Sonar of a PBY Airplane lying in 100 feet of water in Loch Ness.

FIGURE

1. Beam coverage of the Side Scan Sonar in the Horizontal plane.
2. The geometry of the Side Scan Showing calculation of estimated target height of the bottom.


HYDROSCAN
SALEM, NEW HAMPSHIRE





SIDE SCAN SONAR
MODEL SA-350A
DUAL CHANNEL TRANSCEIVER
KLEIN ASSOCIATES, INC.
LEFT CHANNEL
RIGHT CHANNEL
GAIN SLOPE
INITIAL GAIN
MAXIMUM GAIN
LEFT OUTPUT
RIGHT OUTPUT
RANGE METERS
37.5
75
150
300
600
EXT
POWER
ON
OFF

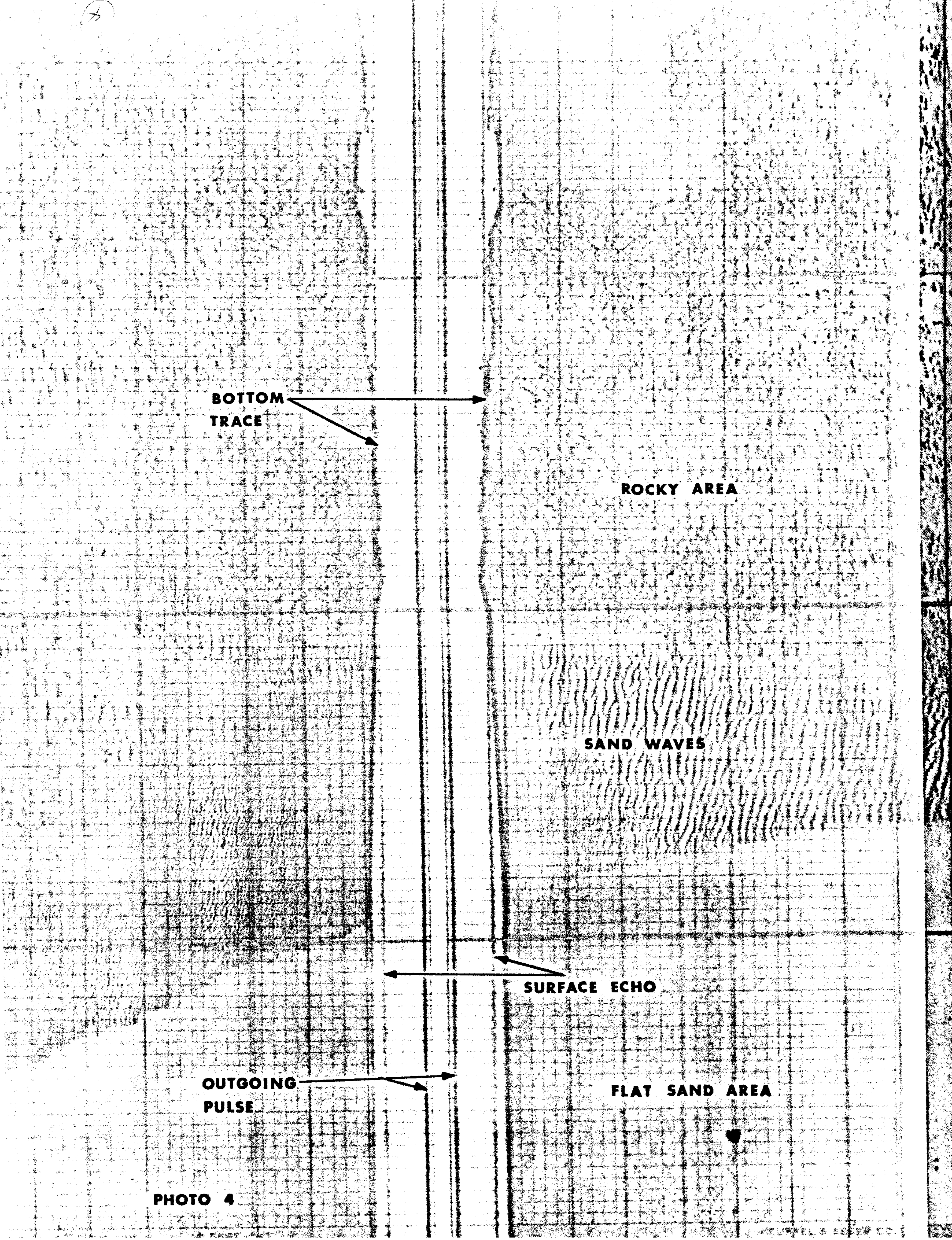
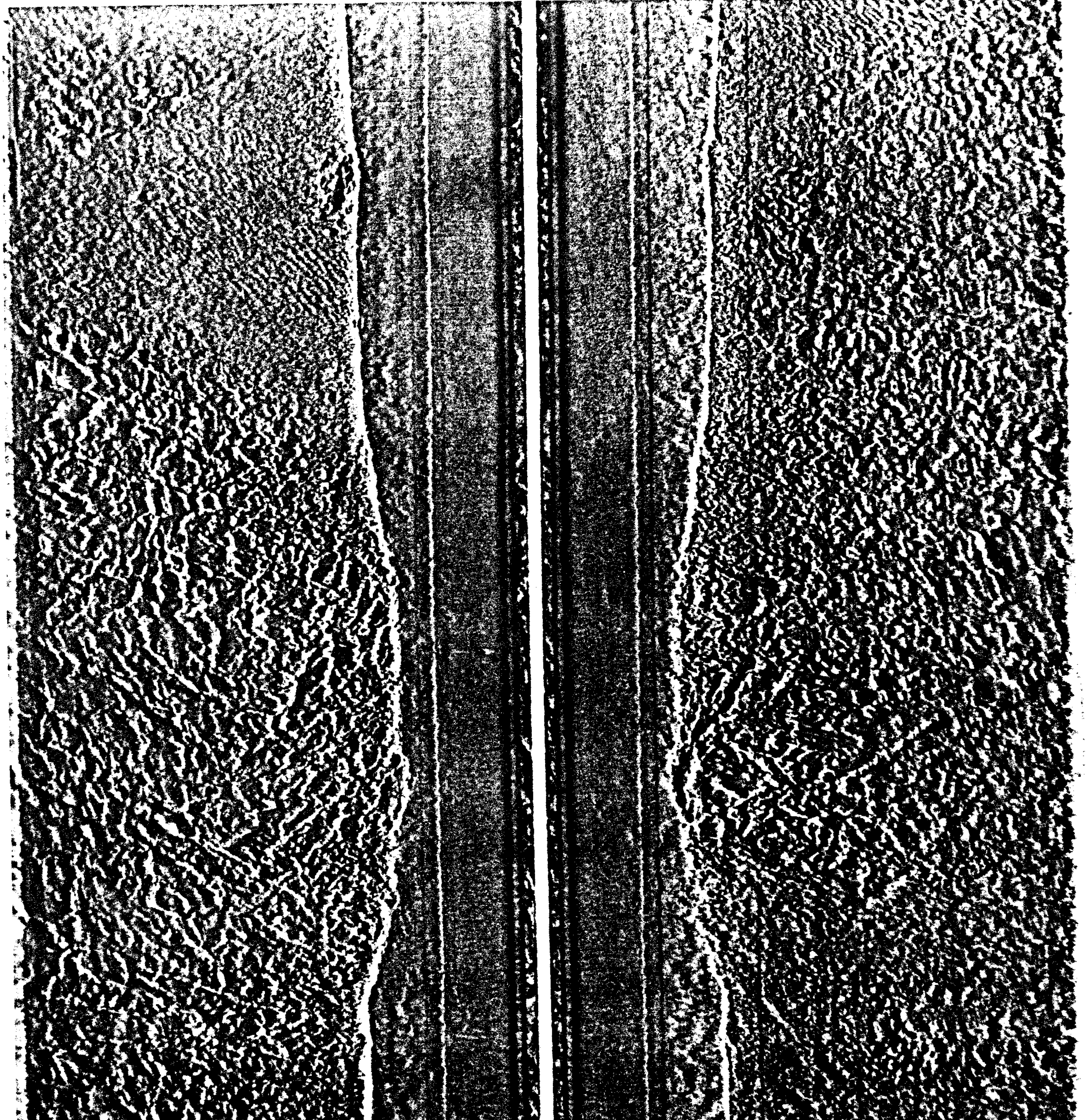
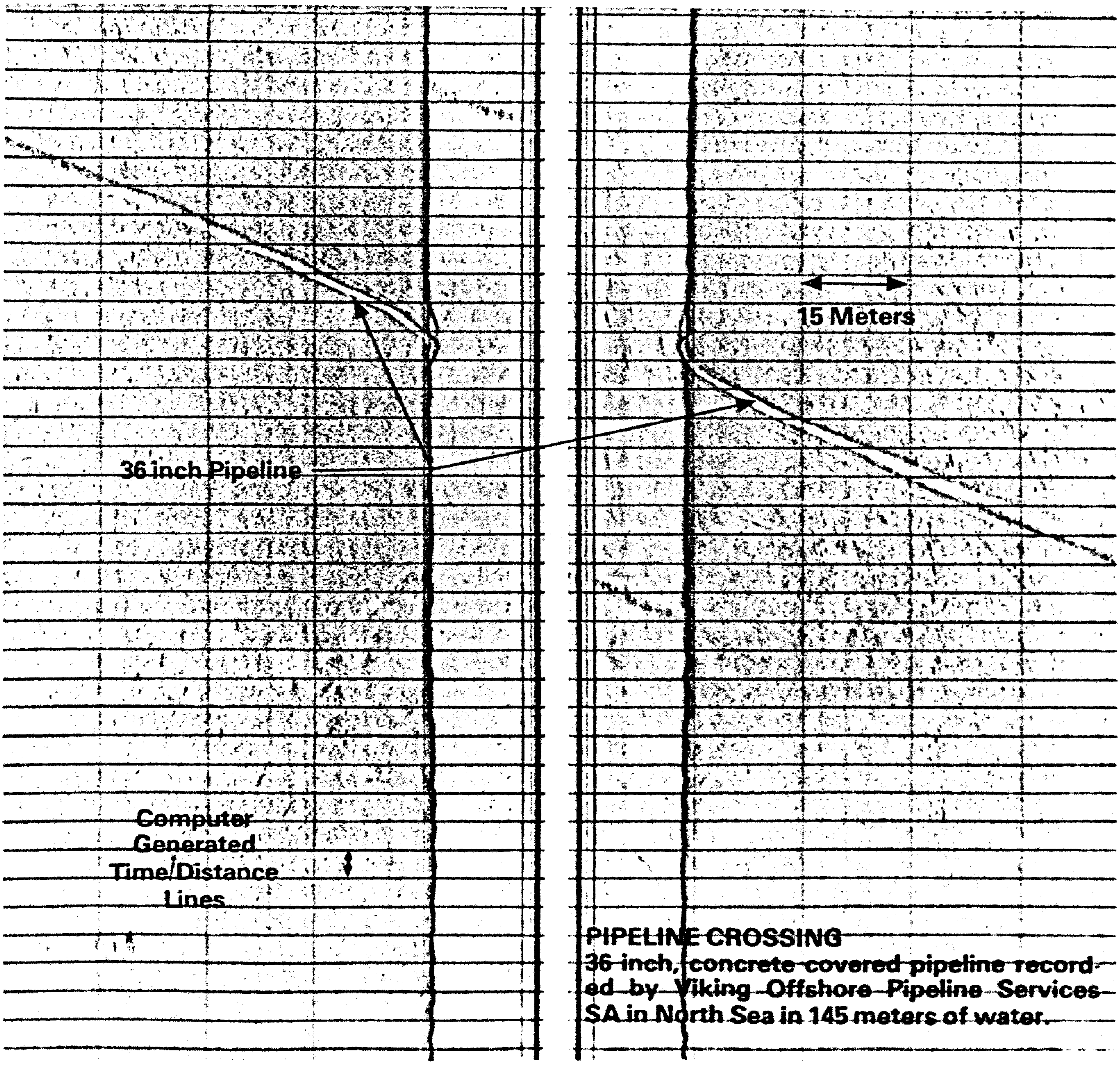
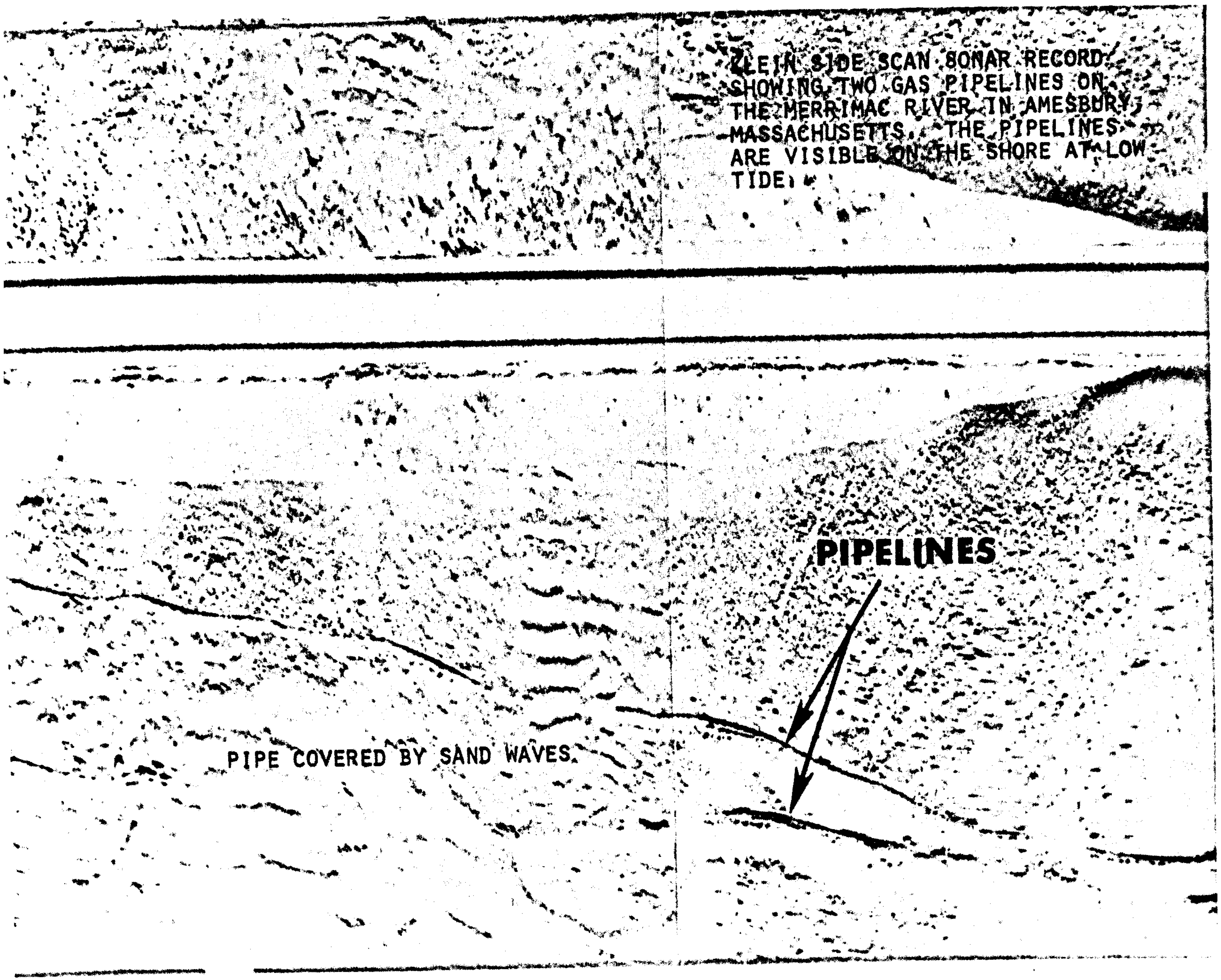

BOTTOM
TRACE
ROCKY AREA
SAND WAVES
SURFACE ECHO
OUTGOING
PULSE
FLAT SAND AREA

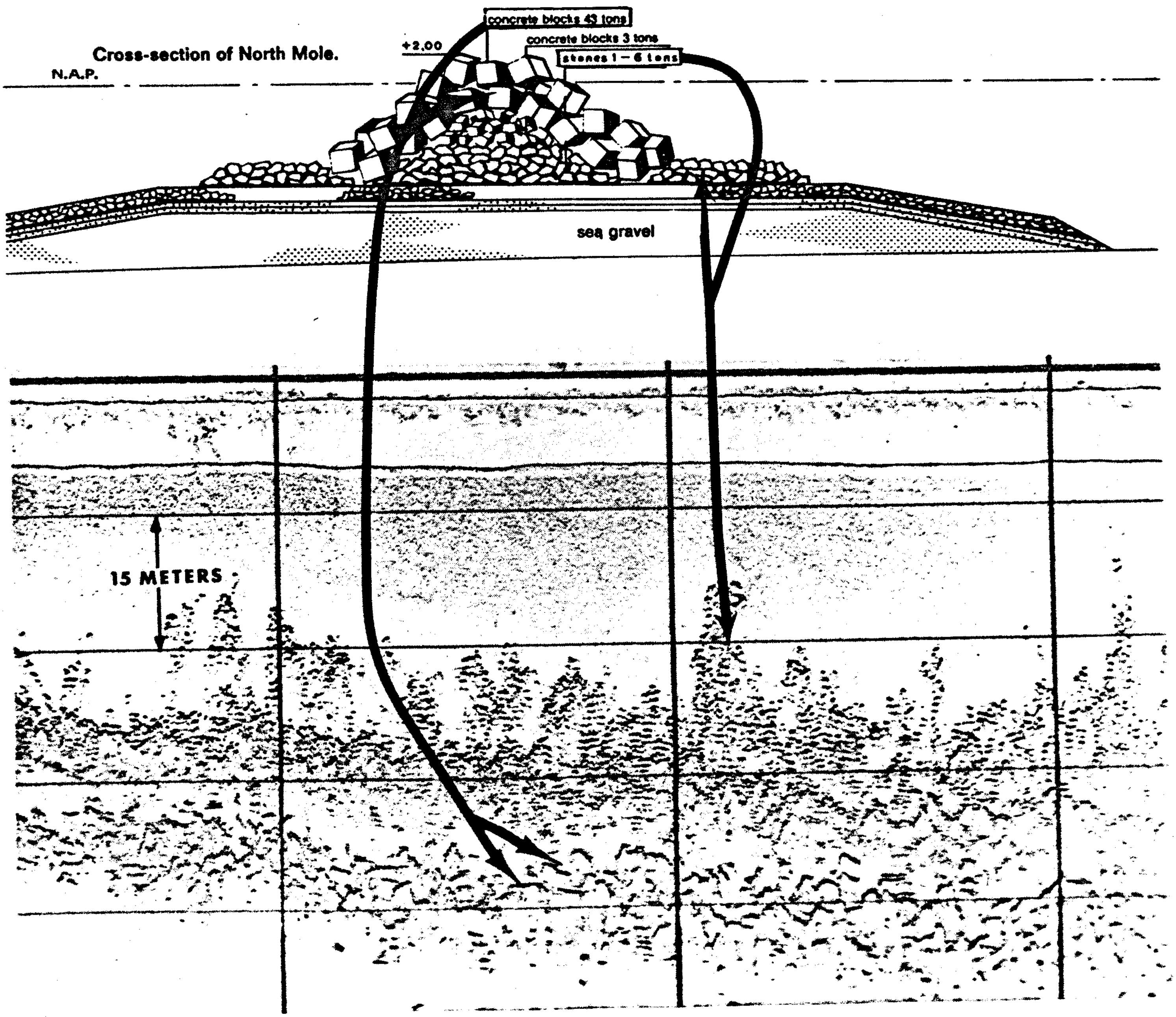
PHOTO 4



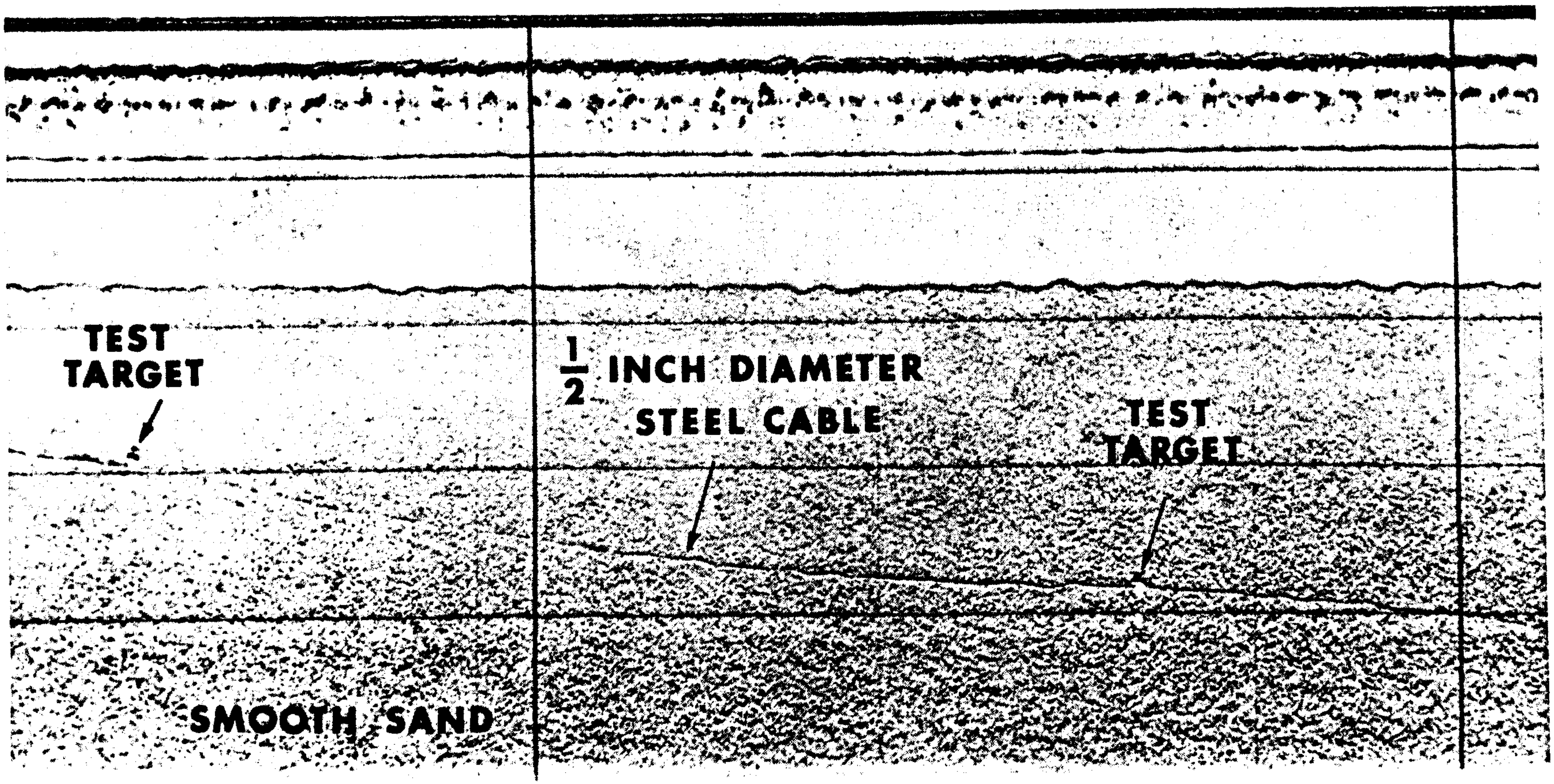


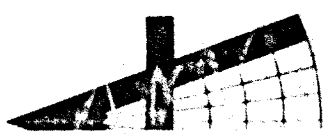
PIPELINE CROSSING
36 inch, concrete covered pipeline recorded by Viking Offshore Pipeline Services SA in North Sea in 145 meters of water.

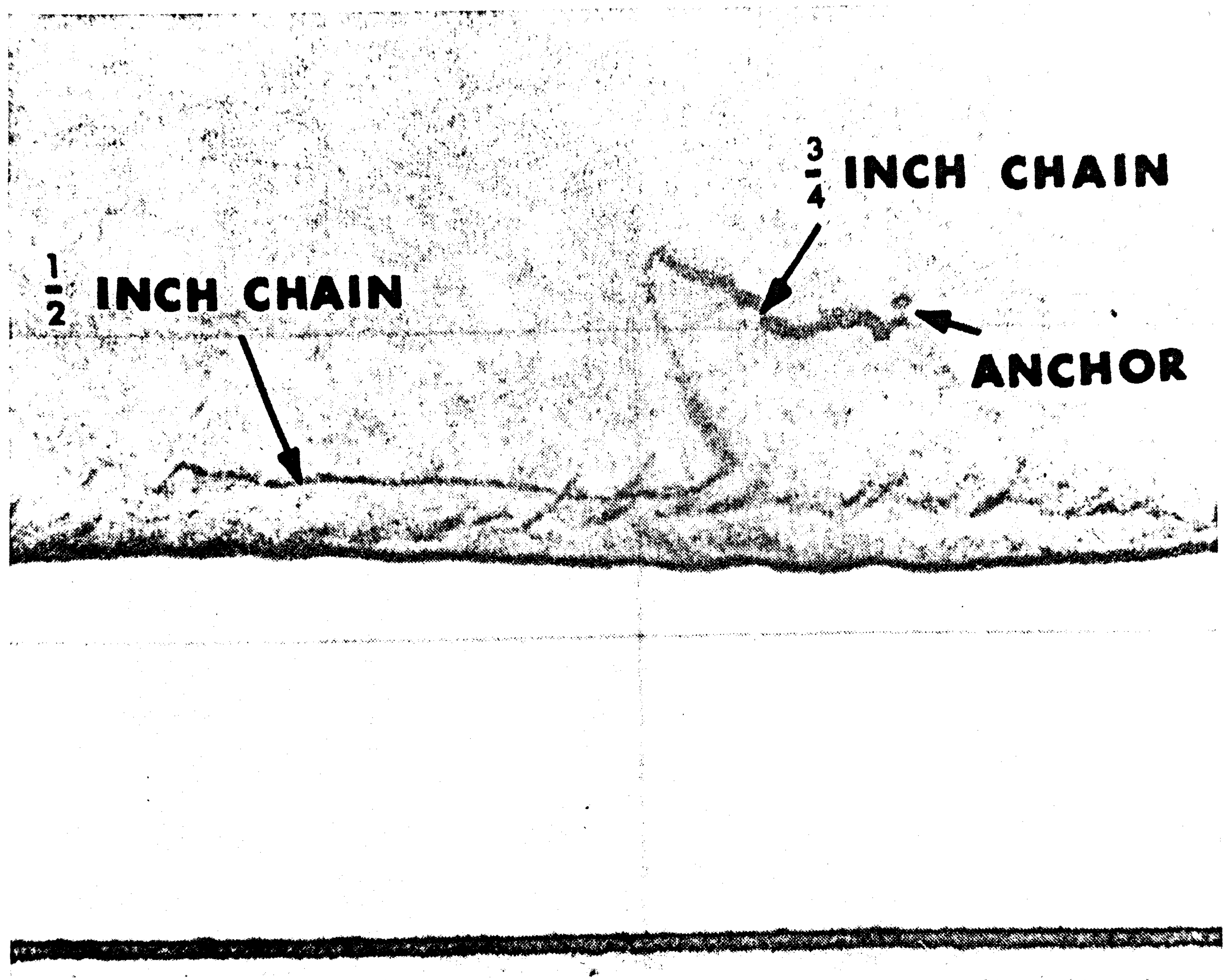

KLEIN SIDE SCAN SONAR RECORD SHOWING TWO GAS PIPELINES ON THE MERRIMAC RIVER IN AMESBURY, MASSACHUSETTS. THE PIPELINES ARE VISIBLE ON THE SHORE AT LOW TIDE.
PIPELINES
PIPE COVERED BY SAND WAVES


Cross-section of North Mole.
N.A.P.
+2.00
concrete blocks 43 tons
concrete blocks 3 tons
stones 1 – 6 tons
sea gravel
15 METERS

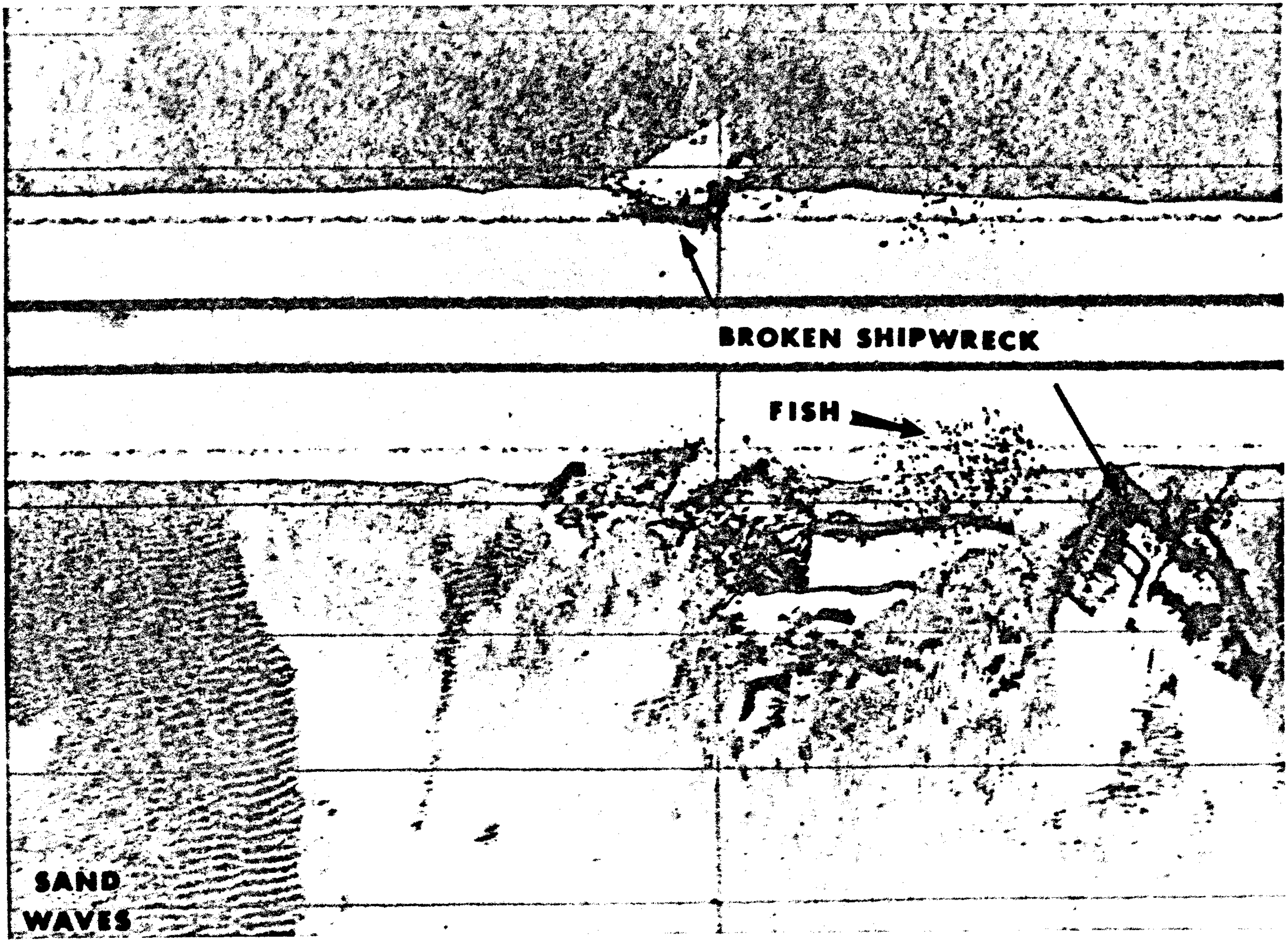
REPRINTED WITH PERMISSION
U.S. NAVY OFFICIAL PHOTOGRAPH

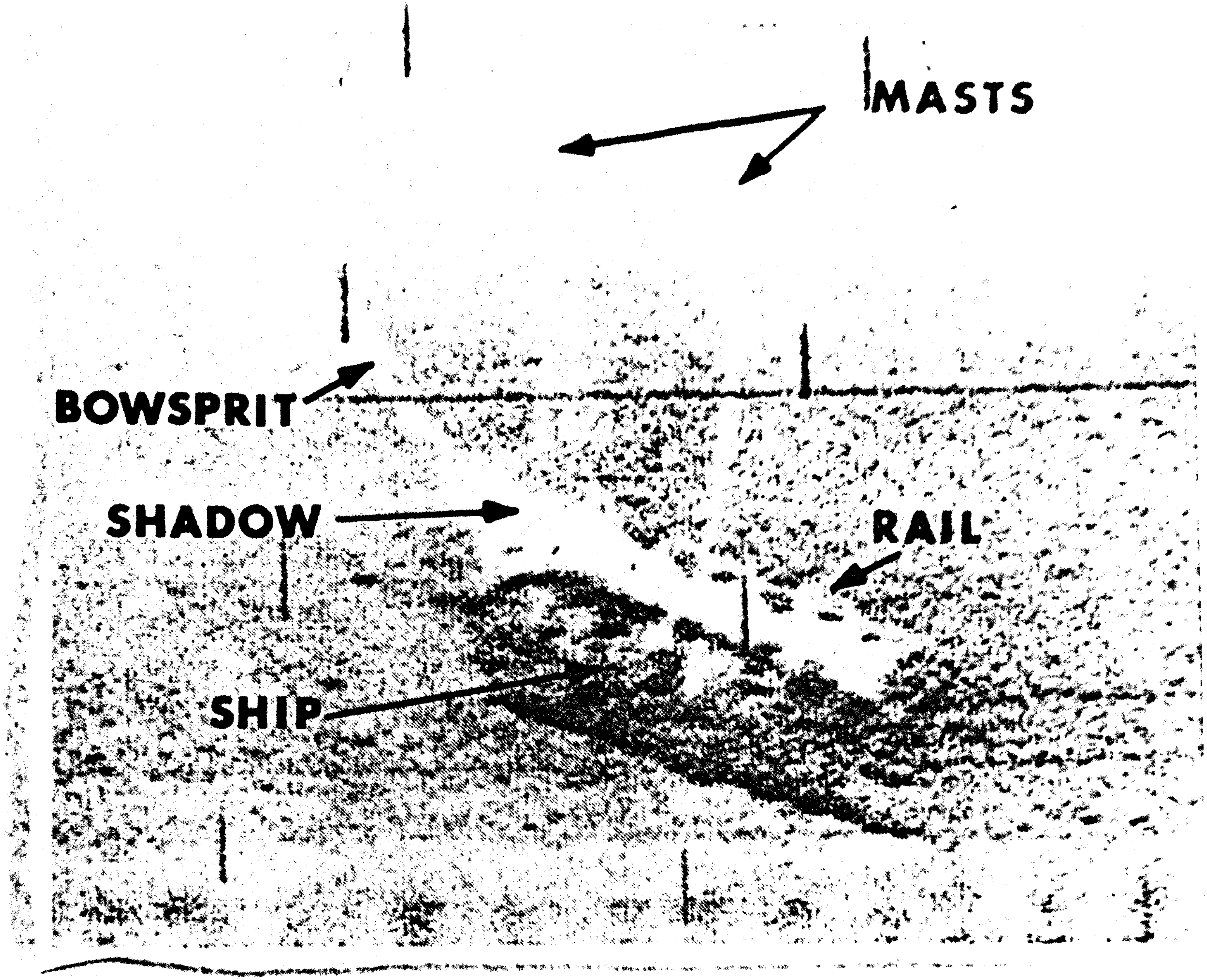






1/2 INCH CHAIN
3/4 INCH CHAIN
ANCHOR


BROKEN SHIPWRECK
FISH
SAND
WAVES


MASTS
BOWSPRIT
SHADOW
RAIL
SHIP

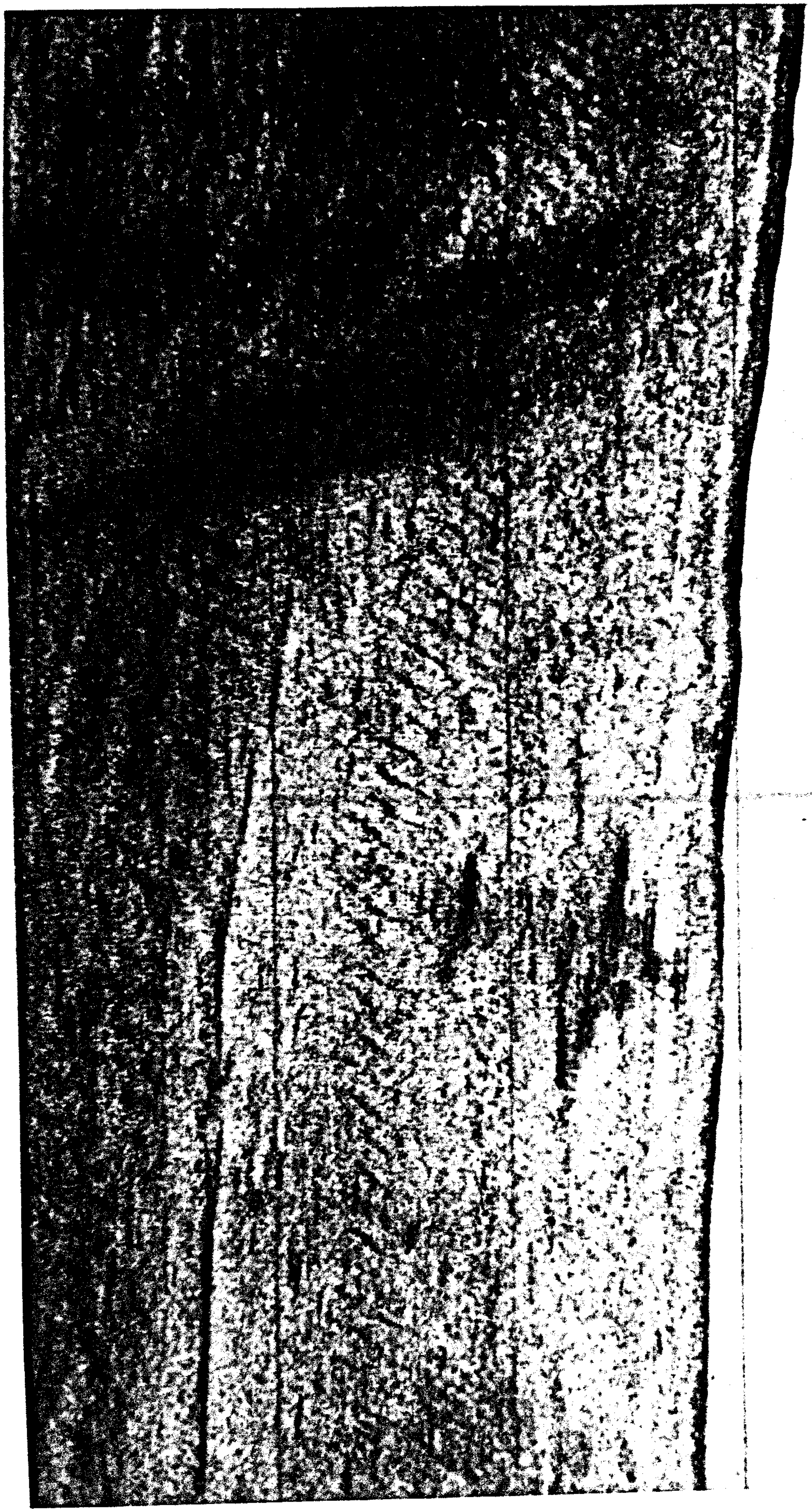


FIGURE 1

SIDE SCAN SONAR—BEAM COVERAGE HORIZONTAL PLANE

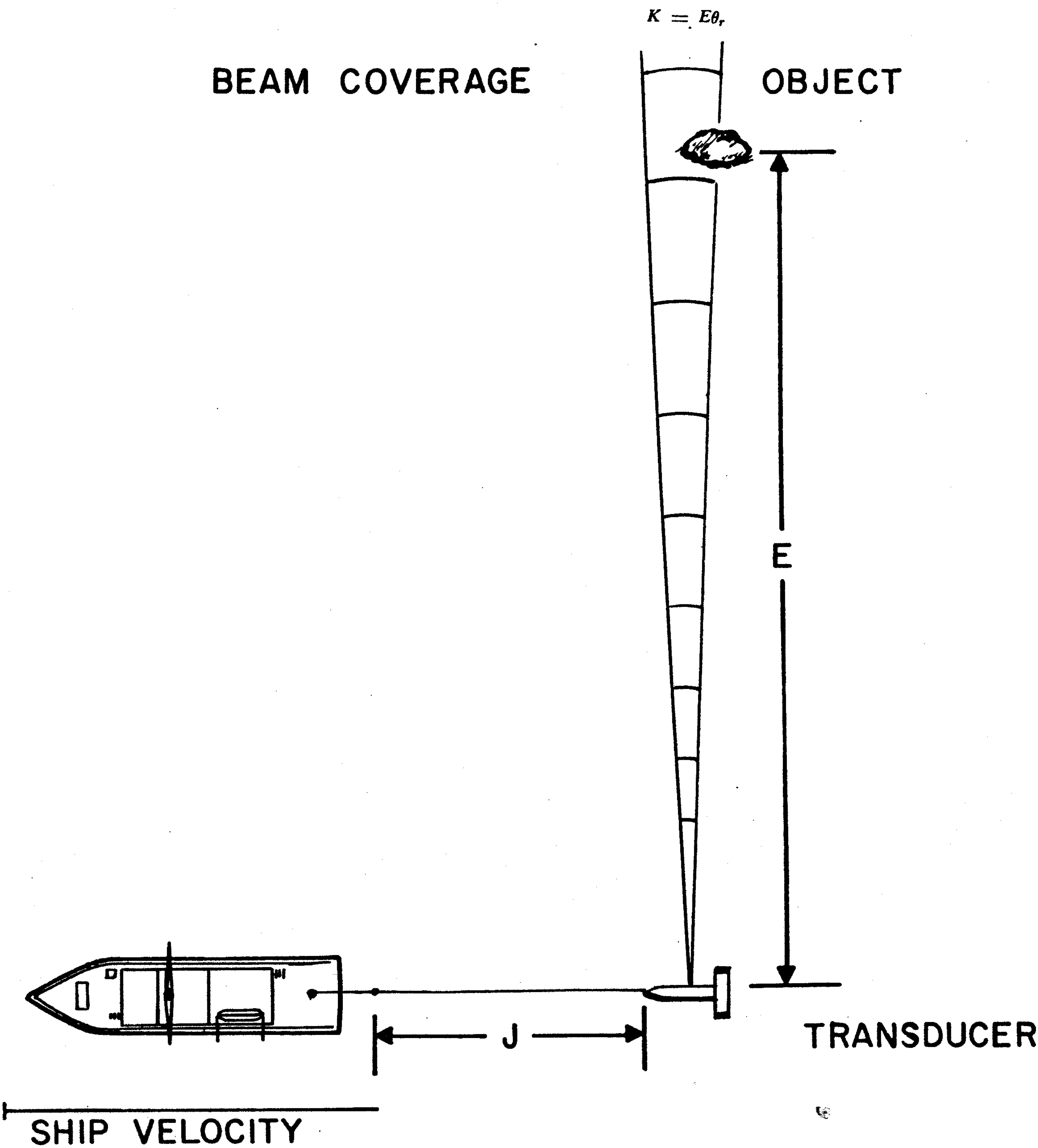


Fig 1

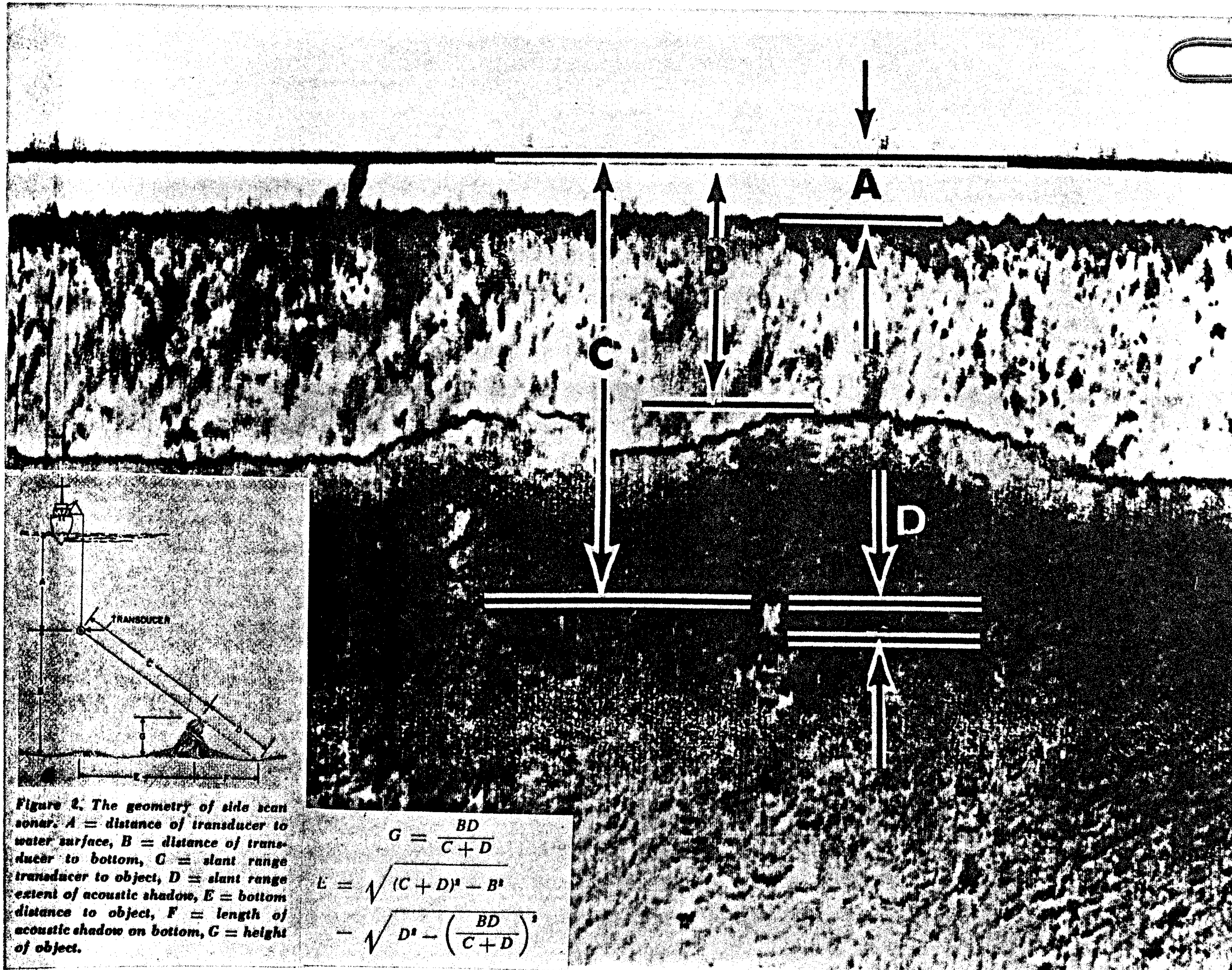


Figure 2. *The geometry of side scan sonar. A = distance of transducer to water surface, B = distance of transducer to bottom, C = slant range transducer to object, D = slant range extent of acoustic shadow, E = bottom distance to object, F = length of acoustic shadow on bottom, G = height of object.*

$$G = \frac{BD}{C+D}$$

$$L = \sqrt{(C+D)^2 - B^2} - \sqrt{D^2 - \left(\frac{BD}{C+D}\right)^2}$$