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SEA FLOOR INVESTIGATIONS USING HYBRID ANALOG/DIGITAL SIDE SCAN SONAR

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ABSTRACT

During the past decade, side scan sonar has become an accepted tool for ocean exploration. Early systems used basic analog signal processing. In recent years, more sophisticated analog techniques have been adopted, and these have been supplemented by digital techniques. The microprocessor has opened up new possibilities, and developments in this area are accelerating. In this paper, some of the new processing techniques are outlined, and other new equipment developments are presented. Photographs of equipment and results are shown.

INTRODUCTION

Side scan sonar systems have been commercially available since 1967 - a relatively short time compared to other remote sensing tools. Systems are now in use in many places around the world with a wide variety of applications. Until recently, basic systems primarily used straightforward analog signal processing, and digital techniques were confined to recorder functions such as stepping motor drivers. In recent years, increasing customer acceptance and new competition in the field has encouraged an acceleration of the use of more sophisticated analog and digital techniques to improve the quality of the sonar images.

Photo 1 shows an artist's concept of the basic side scan sonar technique. A towed underwater vehicle or "towfish" sends out beams of high frequency, high intensity sound bursts along the sea floor. The beams are narrow in the horizontal plane (typically 1°) and wide in the horizontal plane (typically 40°). The sound beams echo off features on the sea floor and return to the towfish. The echoes are received, converted into electrical pulses, and sent up a towing cable to a special graphic recorder on the ship. The recorder scans continuously, first printing the outgoing sound pulse and then the incoming echoes. As the towfish moves, the recorder places each scan side by side. Slowly a sonar image is built up on a permanent graphic recording. These images, or "sonagraphs", often resemble aerial photographs of the sea floor topography.

GRAPHIC RECORDERS

One of the important elements in the quality of the sonar images is the graphic recording mechanism. There are a variety of methods available including "wet" and "dry" electrosensitive paper recorders; stylus, moving band and helical scan electrodes; multi-stylus electrodes; and fiber-optic recorders. Each technique has its own advantages and disadvantages. At Klein Associates, we use a precision helical scan recorder of our own design and manufacture. We find that this recorder seems to have the best combination of wide dynamic range, simplicity, reliability, low power consumption, versatility and ease of paper loading and maintenance. It also allows immediate viewing of the records, which we find is an important consideration in many operations at sea. We typically use "wet" paper although a new patented process allows the use of "dry" paper in the same recorder (U.S. Patent 4,137,538). We also have transceivers available which allow a customer to use any graphic recorder.

The recorders can operate on 24 volts D.C.(typically two standard automobile batteries in series) or on 110 or 220 volts A.C. Photo 2 shows a typical side scan recorder.

MAGNETIC TAPE RECORDING

One of the new graphic recorder developments is the ability to record sonar data on magnetic tape and then play it back again on the graphic recorder. This presented a number of interesting and difficult technical challenges. The graphic recorder helix drum is a high inertia load for the helix motor which turns the drum. It is also a load with widely varying torque and a large spread in the speeds required for the different sonar ranges. Yet the drum must turn at a precision constant rate in order to keep the quality of the sonar images. We used a printed circuit motor, an optical tachometer and a precision crystal oscillator as a frequency source combined with a highly sophisticated phase-lock loop and a special power driver for the motor. The end result is a system which can still be battery operated but which has a maximum sweep rate of 30 scans per second. This is more than three times faster than any other mechanically scanned graphic recorder on the market. Photo 4 shows the range switches on a typical recorder and Photo 5 shows the tape-related controls. A unique feature of the system is the automatic slew. This allows the servo drive to lock on to a trigger pulse which is coded on the magnetic tape and to automatically position the start of each sonar trace at the edge of the paper. Slewing may also be manual to provide a fixed offset in the trace. Another unique feature is the ability to check a magnetic tape immediately as it is being made(read after write). This allows the operator to make sure proper tapes are recorded.

An interesting capability of the post-processing of the magnetic tapes is the ability to "speed up time". The tapes may be made on one recorder speed and then played back on a faster speed. Of course the data on magnetic tape may be further processed before playback using some of the techniques outlined in this article as well as other computer processing.

SONAR SIGNAL VARIATIONS

The side scan sonar signals vary a great deal from the strong bottom echoes to the remote echoes. Typically this variation may be on the order of a million to one (or 120 db). Unfortunately, the recording paper used to present the images typically has a much narrower dynamic range - on the order of 20-30 db. Therefore a variety of schemes are used to try to compress the range of the signals on to the range of the paper. Typical standard systems use a time-variable-gain to increase the gain as the signals become weaker. Unfortunately, the curve of signal versus time is affected by a variety of parameters including spreading acoustic losses, attenuation losses of high frequency sound, beam patterns and the backscatter variations of the sea floor. Therefore, a typical time variable gain must have a variety of controls which must be versatile enough to handle a wide change of situations. Often these controls are difficult to operate, particularly if the sonar operator is not technically oriented.

One important improvement in this area is a proprietary, patented signal processing technique which we call Hands-Off-Tuning® (U.S. Patent 3,975,704). The method is basically a judicious combination of signal compression, envelope detection and differentiation. The system allows a totally inexperienced sonar operator to turn up all of the time-variable-gain controls and to get a good quality sonar picture. The technique is not a panacea, however, and in many cases the best record is obtained by proper manual tuning of the time-variable-gain knobs by an experienced operator.

By using digital storage of the signal versus time curve, we expect to be able to use an adaptive time-variable-gain which will automatically set up the gain controls. However, in many situations we expect there will be no substitute for the judgement of the operator.

MAGNETIC TAPE STORAGE

The sonar data may be stored on analog tape recorders or a variety of digital magnetic tape recorders. Since the sonar is basically continuous video data, there is a large information flow. This means that in order to store the data in digital form, a lot of bits are required, even to record the "processed" data (which has less dynamic range than the "raw" data). Typically an analog tape recorder can store around 4 hours of data while a large reel of digital tape can only store about 20 minutes of data. So at present, analog tape is typically used mainly for convenience and economic considerations. If digital conversion is required, an analog to digital converter is used after the analog tape. Improvements in digital tape storage capability are continuing, however, so we can expect digital storage to be better in the future.

DIGITAL PROCESSOR

One of our new developments is a Digital Processor which is a module which can connect to a graphic recorder. Units are available which can accept one, two or three channels of side scan sonar and/or sub-bottom profiler data. The processed sonar signals are converted to digital form using an 8 bit analog to digital converter which runs at a rate of 30 kHz (per channel). The 8 bit parallel binary data is brought out to a port on the instrument for possible further processing by computer or for possible storage on a digital tape recorder. The signals are stored in memory, and then the stored signals may be played out at a controlled rate. This allows signal delay and expansion, or "A delayed by B" similar to an oscilloscope delay. In this way a portion of the record may be blown up to a larger size. This is a kind of electronic "zoom lens".

Two memories are used. One is used to store data, while the other is reading out data. Then the memories are switched so the first reads out and the second stores. Four bits are used for storage since this is typically adequate for the dynamic range of the recorder. A unique feature of the unit is that a full 1000 points of data are used regardless of the amount of expansion. This preserves the point density of the record, and allows the full resolution of the side scan to be brought out.

The unit may also be used to remove the "water column" which is the space on the sonar record created before the first sounds from the towfish bounce off the closest bottom and return.

Photo 8 shows the delay and expansion range on the unit. Note that each channel may be individually adjusted for delay and range. For instance, this allows a sub-bottom profiler portion of a record to have a different range than the side scan portion. Photo 9 shows a side scan record of a shipwreck before and after digital processing and expansion.

SIDE SCAN DISTORTION FACTORS

Side scan sonar records are subject to a variety of distortions. These are primarily due to altitude error, aspect ratio error and slant range error. Altitude error is basically the blank area or "water column" at the beginning of the record. This space will vary as the towfish height varies. Aspect ratio error is due to the fact that the distance measured along one axis of the recorder is typically not the same as the distance along the other axis. Therefore, the picture will be streched or squeezed. This situation will be aggravated as the ship speed is changed. Slant range distortion is created by the fact that the sonar actually reads the distance from the towfish to the bottom target, not the true distance along the bottom.

In the past, some clever schemes were devised to correct for some of these distortions. For instance, Westinghouse used a helical scan recorder with a non-linear sweep to try to eliminate the water column and correct for slant range distortion. Unfortunately the system required the towfish to fly an exact height off the bottom.

K-MAPS™

Klein Associates has recently introduced the K-MAPS™ (Klein Modular Automated Plotting System) a microprocessor based system for correcting the side scan distortions. The system is modular so that it may plug into a standard Klein HYDROSCAN system.

In order to correct for the water column, the system first uses a built-in echo sounder to sense the height off the bottom. The sonar signal is stored in memory, and the output of memory is delayed by a time equivalent of the time for the first echo to go out to the bottom directly below the fish and return. A thumbwheel also allows the height off the bottom to be manually entered.

Aspect ratio is corrected by sensing the boat speed or by using a navigation system to give the parameter of speed to the system. A microprocessor programmed controller then calculates the required paper speed and feeds out the correct pulse rate to the digitally controlled stepping motor paper advance on the graphic recorder. Since recorders may have different paper widths, this variable must be considered. Ship speed may also be manually set by a thumbwheel panel on the unit.

In order to correct for slant range, the towfish altitude must again be measured (or entered manually by thumbwheel). Then the sonar data is stored and read out in non-linear fashion. The microprocessor must basically solve the equation of a right triangle in which the actual measured range is the hypotenuse, the altitude is one leg of the triangle and the true range along the bottom is the other leg. The system assumes a reasonably flat bottom.

The resultant sonagraph after all of the corrections is typically a great improvement. The operator can now often lay traces side by side and create a sonar mosaic of the sea bottom, similar to a photographic mosaic. Unfortunately the record is still subject to a variety of distortions, but we can expect that future computer processing of the data will continually improve the record quality.

ALPHANUMERIC RECORD ANNOTATOR

Another new development to assist the sonar operator is a new Alphanumeric Record Annotator. This unit allows a variety of data parameters including Time, Date, Event, Position information and other information to be entered either manually or automatically on the sonar chart. Photo 8 shows the controls on the unit. The instrument is also a modular plug-in to a standard recorder. A microprocessor controller is used which allows the character size, spacing and position to be changed easily. Also the unit may be programmed so characters can print right to left, left to right, and also upside down. The unit has an external port so information from an outside source such as a positioning system may be entered. A keyboard is also availble which permits up to 200 characters per line to be printed instead of the internally set digits.

AUTO-RANGING

An important feature of the Digital Processor, the Alphanumeric Record Annotator and the K-MAPS™ is the ability to auto-range. This means that the units will automatically determine what range scale the recorder is set on and will adjust itself accordingly. This allows the unit to be used with most oceanographic graphic recorders. It also allows the instrument to keep a constant character size even though the recorder range scale may be changed.

VERY HIGH RESOLUTION SONAR

Another important new development is a new Very High Resolution Side Scan Sonar Towfish. This unit uses a frequency of 500 kHz and a horizontal beam angle of 0.2°. The unit has a pulse length of approximately 20 microseconds for a range resolution of 3 centimeters. This angular and range resolution is five times better than any previously available commercial system. Photo 3 shows a standard 100 kHz side scan sonar towfish. The 500 kHz unit looks identical, except that it uses a circular tail shroud for additional towing stability.

Photo 16 shows a side scan sonar record of a tree with branches made with the Very High Resolution unit. Photo 17 shows a comparison of a sonar record of a small wooden ladder made with a standard 100 kHz unit and the 500 kHz unit. Note that the new unit can detect the ladder details. We find in field operations that the new unit can resolve subtle bottom features which we had never seen before on the standard units. Of course there is a tradeoff - the higher frequency unit has less range than the lower frequency unit. Therefore, many customers are now using both units - one for a broad look and one for close-up target inspection.

FULL OCEAN DEPTH OPERATION

Another interesting development is a new side scan sonar towfish which can go to the full known depth of the ocean (12,000 meters). The sonar towfish has specially constructed transducers as well as a special electronics pressure housing with high strength stainless steel. The unit has been tested to ultimate depth in a small pressure vessel. It has also been tested to a lesser depth (around 6500 meters) in the large pressure vessel at the U.S. Naval Ship Research and Development Center in Annapolis, Maryland. This tank was large enough so we had enough clear time to look at the actual acoustic output of the towfish as the pressure increased. No substantial difference in output was observed through the pressure cycle.

As a related development, we have a new electronics multiplex system which allows all of the side scan sonar data including power to be transmitted over a single coaxial cable. This is very useful for deep operations. The time-variable-gain controls are coded and sent down the cable so that the operator can use the system in the normal fashion.

COMBINED SIDE SCAN SONAR/SUB-BOTTOM PROFILING

Side scan sonar has also been combined with sub-bottom profiling in one tow vehicle and the data is presented on one recorder. Customers find that using the two instruments together with a single chart presentation greatly facilitates record interpretation. Photo 6 shows a combined side scan sonar/ sub-bottom profiler towfish.

CRT DISPLAY

For submersible applications, there is often not enough room for a graphic recorder. For this application we have developed a Transceiver/CRT Display shown in Photo 7. This unit has similar power supplies and gain controls as a graphic recorder. The data is observed on the CRT screeen instead of the recorder. The unit also has a read-after-write capability so it can be used to make sonar tapes and check their quality at the same time. The tapes may then be played on a graphic recorder for a hard copy.

EXAMPLE RECORDS

Side scan sonar has been involved in a lot of interesting searches for a wide variety of undersea targets. Some of the sonar results are presented here in Photos 9, 10, 11, 12, 13, 14, 15, 16 and 17 which are explained in their respective captions.

CONCLUSIONS

Although great improvements have been made, the side scan sonar field remains in its infancy. To a large extent the medium itself imposes many limits on the ultimate quality of the results. The speed of sound is very slow compared to light or radar so that the data rate is correspondingly low. Sound rays are bent and distorted in other ways underwater. Still, with increased use of computer processing, we can expect to see great strides in the relatively near future. A great deal of work has been done on optical image processing, and already a number of researchers are looking at similar techniques for side scan image enhancement. Side scan radar techniques such as synthetic aperture are already in the development stage with sonar. Perhaps the day is not far off where the sonar images will truly look like photographs, where we will be able to recognize targets and where we will be able to make quantitative remote evaluation and recognition of bottom composition.

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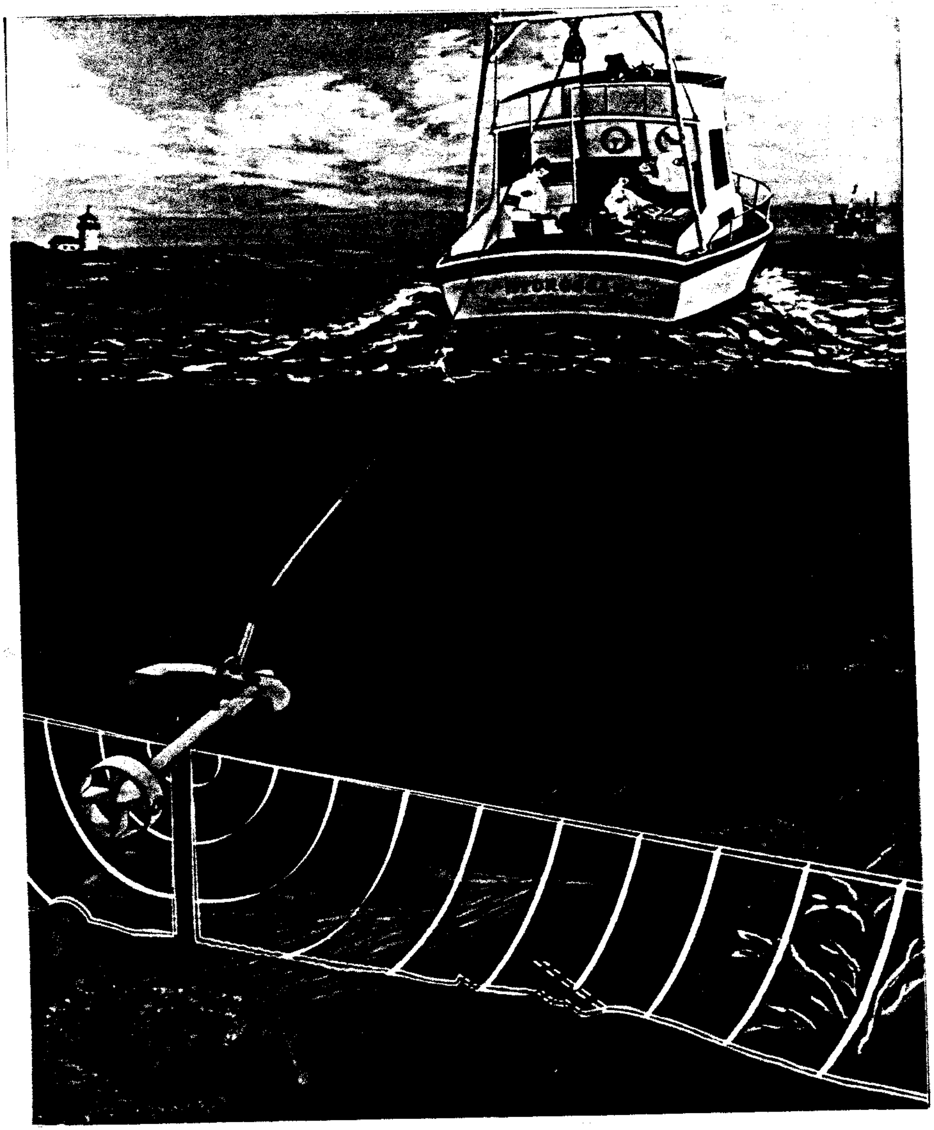


PHOTO 1 - Artist's concept of the Side Scan Sonar Technique.

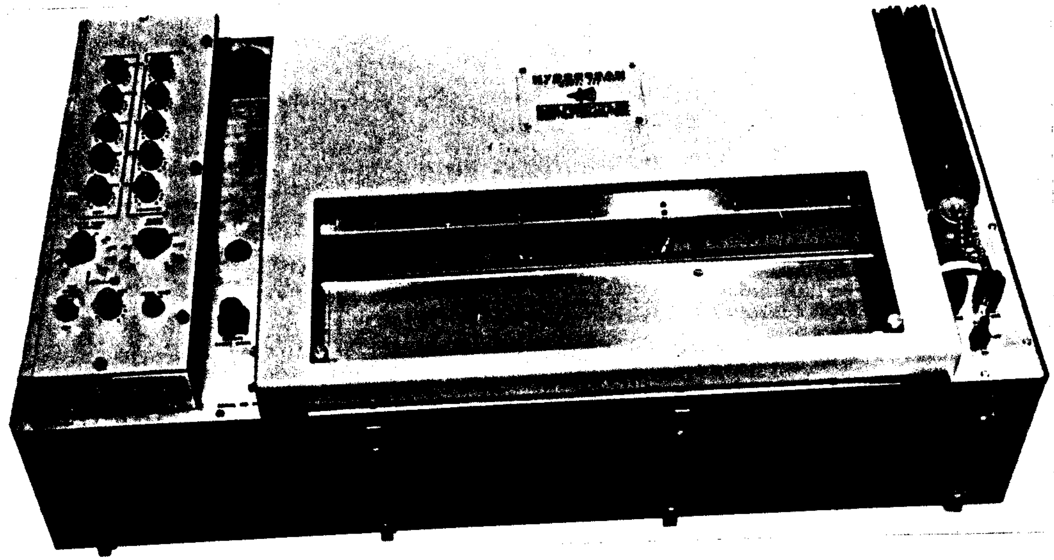


PHOTO 2 - Dual Channel Side Scan Sonar Recorder (Klein Associates, Inc.)

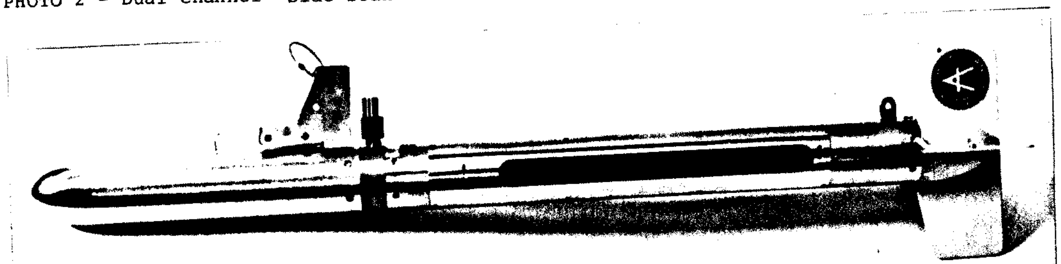


PHOTO 3 - Dual Channel HYDROSCAN Side Scan Sonar Towfish (100 kHz)
(Klein Associates, Inc.

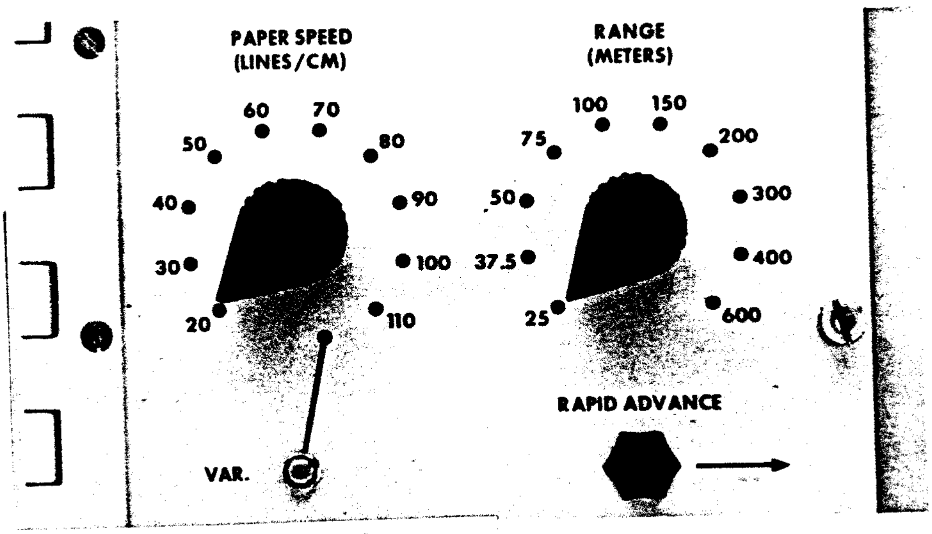


PHOTO 4 - Recorder range and paper controls. Note the helical scan recorder has real time capability of 25 meters (30 scans per second)

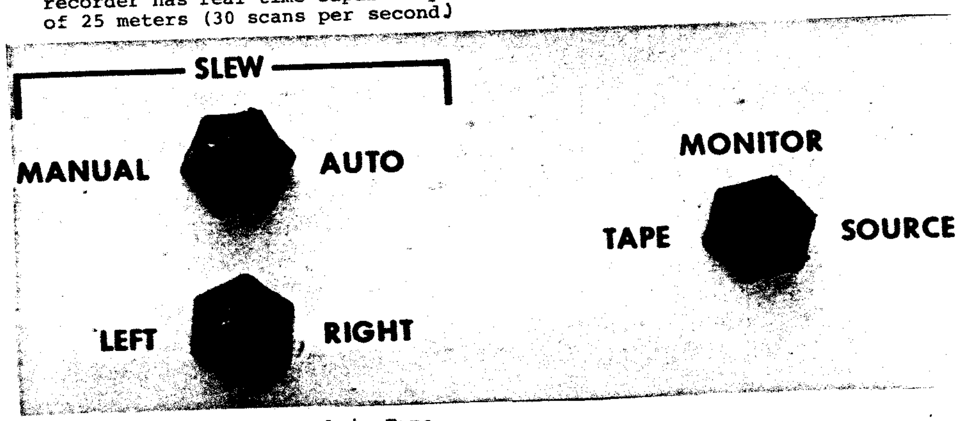


PHOTO 5 - Controls on Klein Tape Compatible Graphic Recorder. Recorder may display taped data immediately after it is taped (read after write).

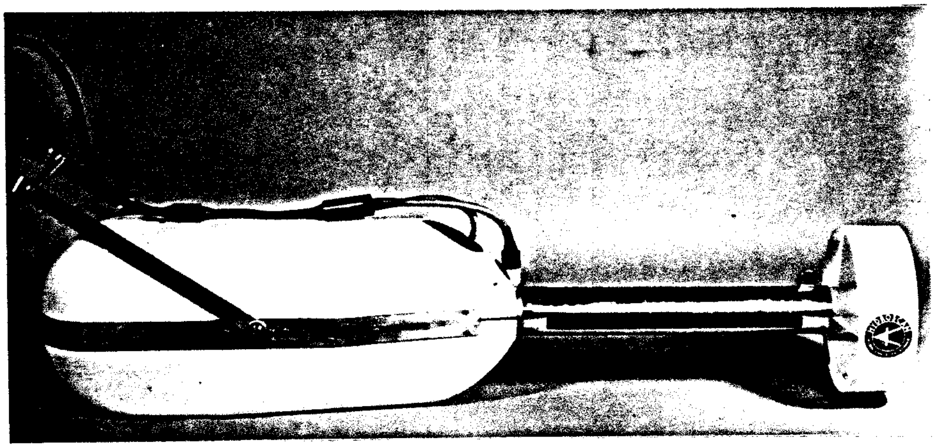


PHOTO 6 --TRIFISH™ -Combined Side Scan Sonar/Sub-Bottom Profiler Towfish (Klein Associates, Inc.)

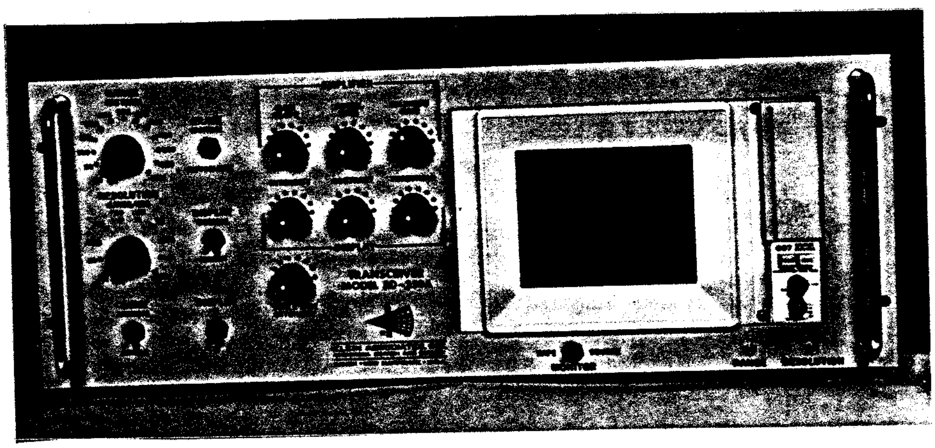


PHOTO 7 - Transceiver/CRT Display for Side Scan Sonar and/or Sub-Bottom Profiling. Unit may be used on manned submersibles to make magnetic tapes and check the tapes. Tapes may then be replayed on a Graphic Recorder.

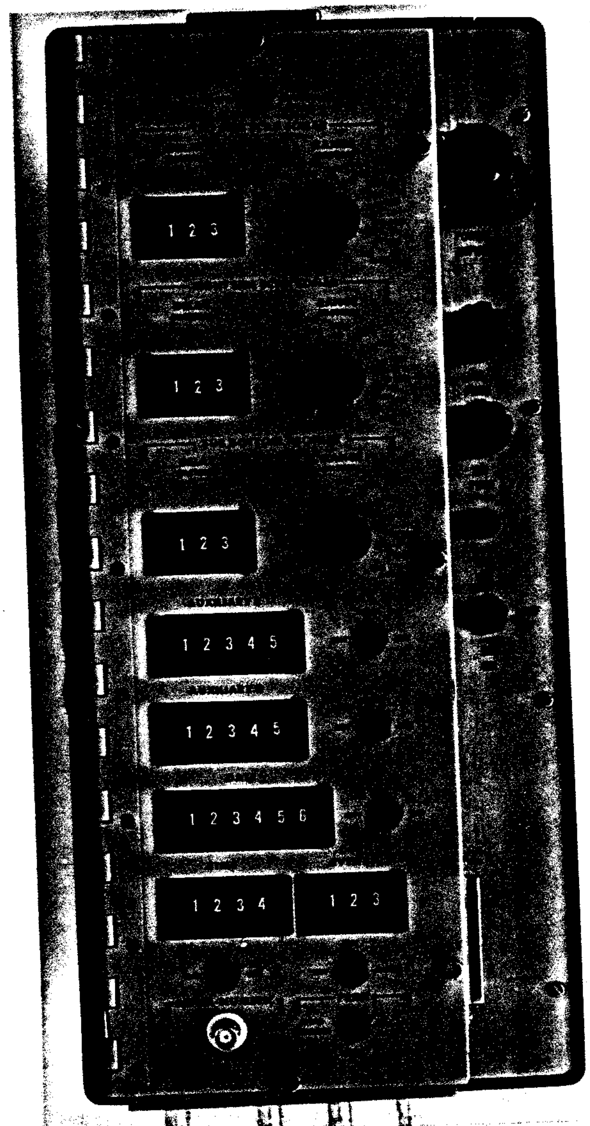
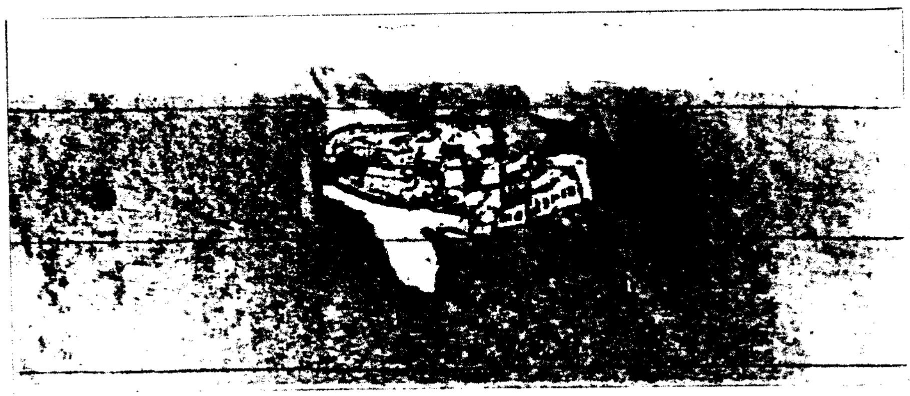


PHOTO 8 -Combined Alphanumeric Record Annotator with Three Channel Digital Processor. The Annotator enters Time, Date, Event and other parameters on the graphic record. The Digital Processor acts as an electronic "zoom lens" to blow up a portion of the sonar record. (Klein Associates, Inc.)



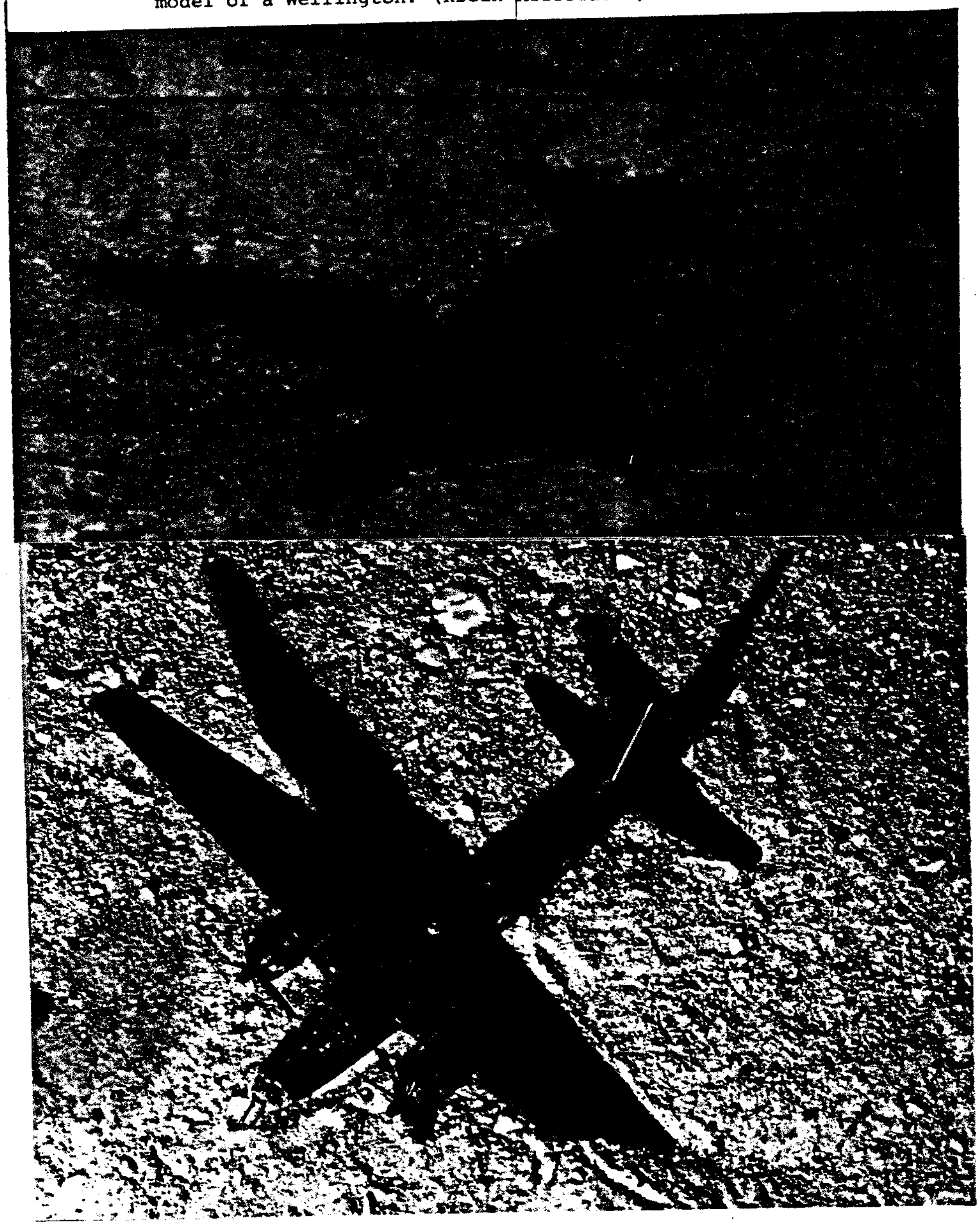
SHIPWRECK (ORIGINAL RECORD)
SONAR RANGE - 50 METERS
PAPER SPEED - 60 L./cm.
WATER DEPTH - 18 METERS

KLEIN ASSOCIATES, INC.
UNDERSEA SEARCH AND SURVEY

SHIPWRECK (TAPE RECORDED DATA)
13 METER DELAY - 25 METER RANGE SCALE
USING A KLEIN MODEL 600 DIGITAL PROCESSOR
PAPER SPEED - 30 L./cm.

PHOTO 9 - HYDROSCAN Side Scan Sonar record of a car ferry in Buzzards Bay, Massachusetts. Record was expanded during post-processing from magnetic tape recording using the Klein Model 600 Digital Processor. Expansion is 2 times normal. The photos show one channel of the Klein 531T HYDROSCAN Graphic Recorder which displayed the record.

PHOTO 10 - HYDROSCAN Side Scan Sonar record of a Wellington aircraft which went down in 1942 in Loch Ness. Bottom photo shows a plastic model of a Wellington. (Klein Associates, Inc.)



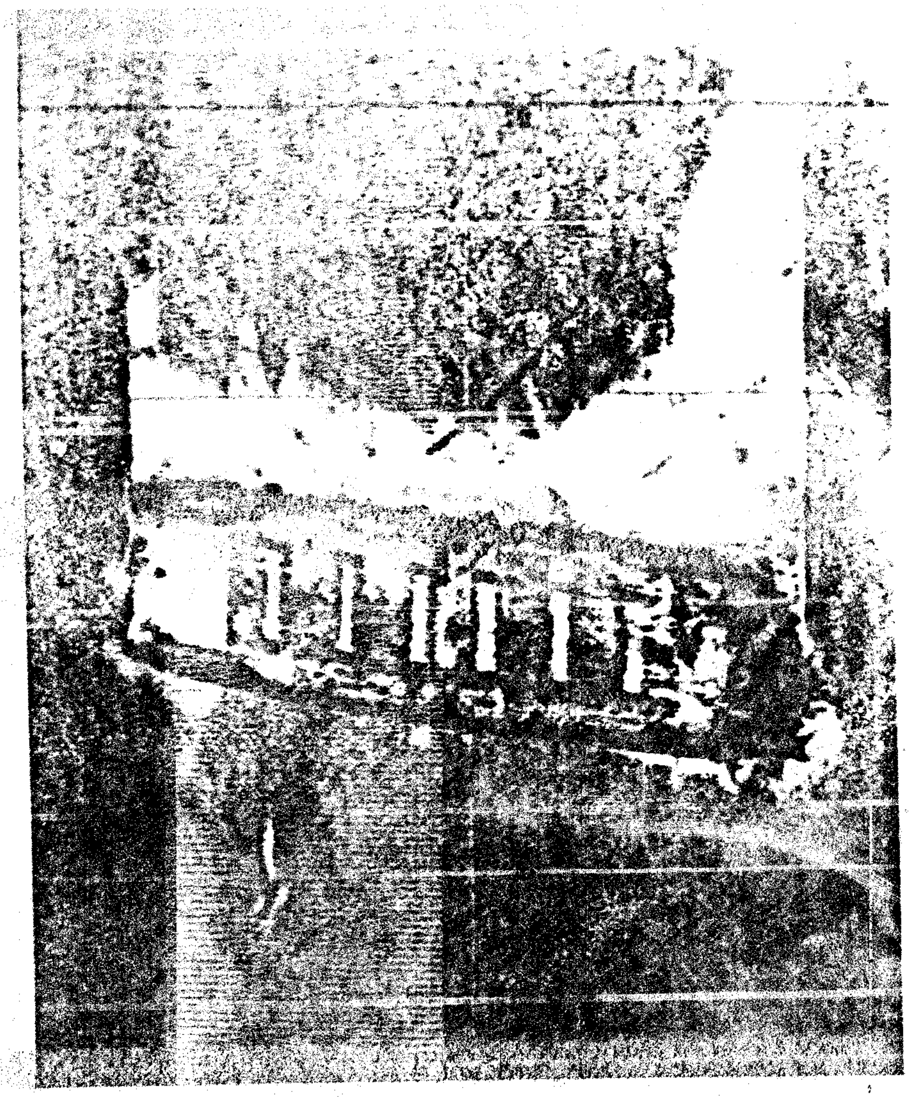


PHOTO 11 - HYDRO-SCAN Side Scan Sonar record of an old wooden sailing barge in the Great Lakes. (G. Kozak, Klein Associates, Inc.)

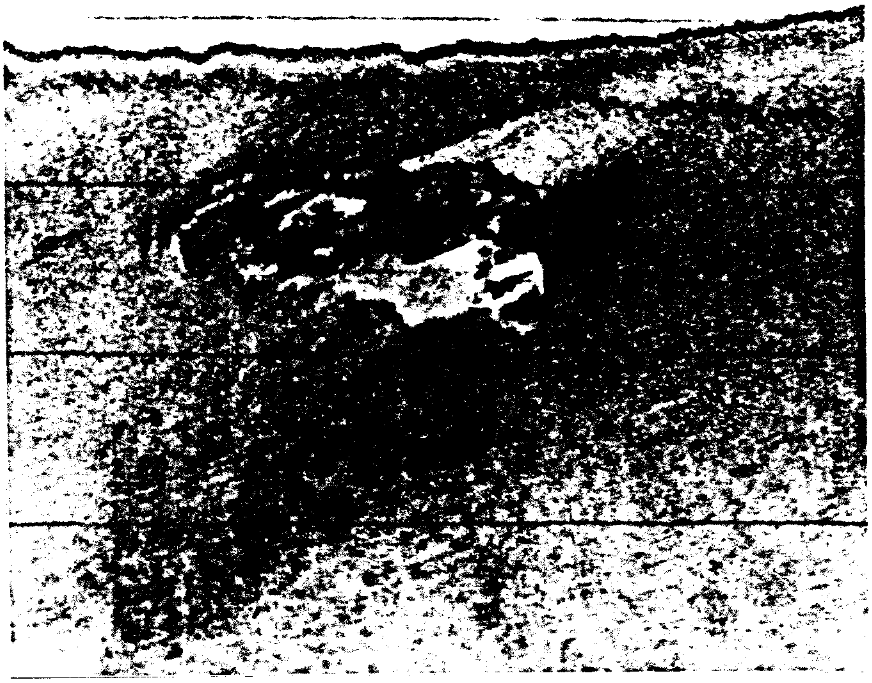


PHOTO 12 - HYDROSCAN Side Scan Sonar record of the U.S.S. Monitor (Courtesy of the Harbor Branch Foundation).

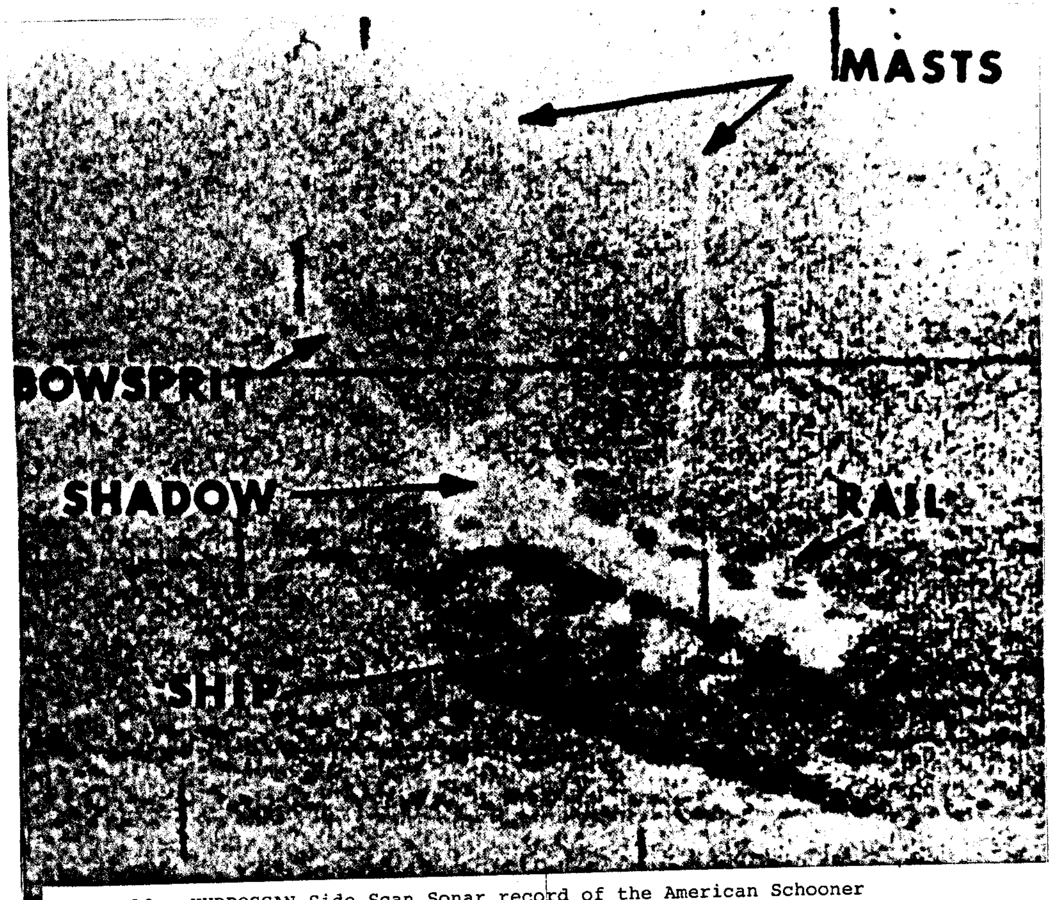


PHOTO 13 - HYDROSCAN Side Scan Sonar record of the American Schooner Hamilton which sank in Lake Ontario in the War of 1812. (Courtesy Royal Ontario Museum and Canada Centre for Inland Waters.)

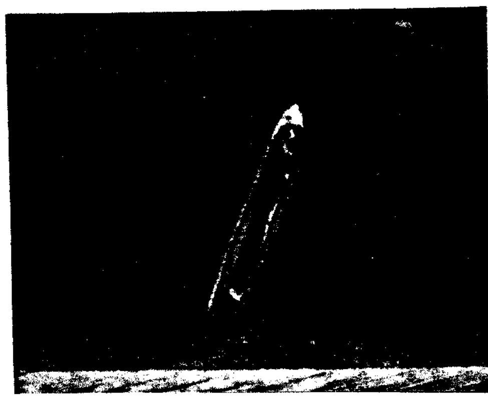


PHOTO 14 - HYDROSCAN Side Scan Record of an old schooner turned into a barge. (G. Kozak, Klein Associates, Inc.)

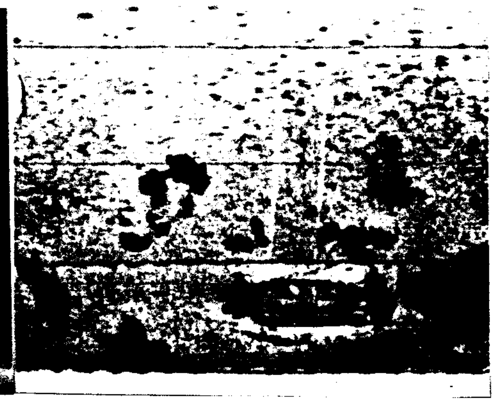


PHOTO 15 - HYDROSCAN Side Scan Record of an old two-masted schooner in the Great Lakes (G. Kozak, Klein Associates, Inc.)

PHOTO 16 - HYDROSCAN Side Scan record of a tree with branches on a river bottom. Record made with new 500 kHz Very High Resolution Side Scan. (Klein Associates, Inc.)

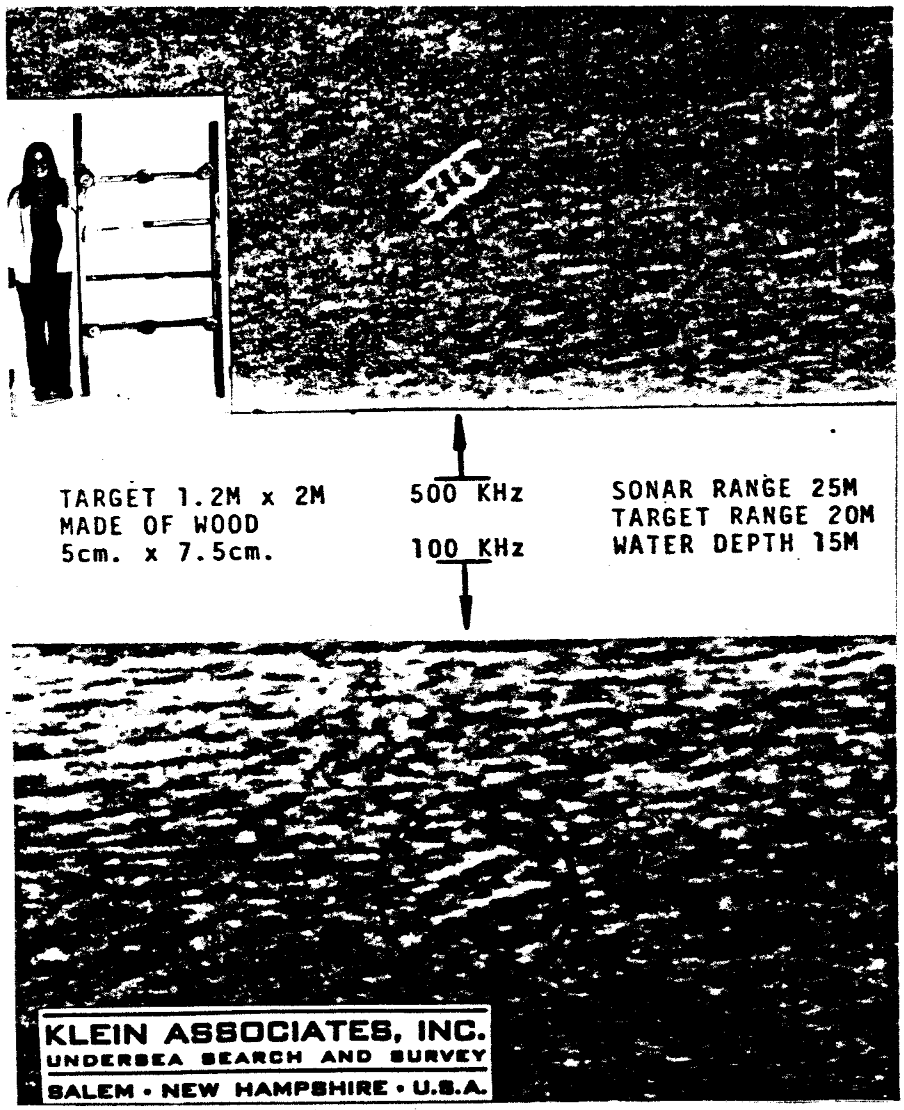


PHOTO 17 - HYDROSCAN record showing a wooden ladder on a river bottom. The upper photo shows a record made with the new Klein 500kHz Very High Resolution Side Scan. The lower photo shows a record made with a standard Klein 100 kHz side scan.