FEB. 1973
CANADIAN HYDROGRAPHIC CONFERENCE

NEW DEVELOPMENTS IN SIDE SCAN SONAR FOR HYDROGRAPHY

MARTIN KLEIN, KLEIN ASSOCIATES, INC.

ABSTRACT: *Side Scan Sonar has gained increasing attention and acceptance by hydrographers as an operational tool. Some of the recent developments in side scan sonar are reviewed including towing systems, mosaic techniques, recording techniques, signal processing, record reversal, stereo side scan and isometric correction. Factors which have limited side scan developments are reviewed and prospects for the future are discussed.*

****

INTRODUCTION

In recent years, ocean ships and their cargo have grown to enormous proportions. The public has become keenly aware of the financial and environmental problems associated with damage to these ships due to uncharted undersea obstacles. As the margin for error has narrowed, hydrographic surveyors around the world have begun to take a closer look at side scan sonar as an operational tool to aid in the survey of ocean bottom topography.

Early side scan systems were basically single channel echo sounders turned horizontally. The results were impressive, and the powerful nature of the technique was recognized by enthusiasts. Towed systems were later introduced with specially shaped acoustic beams. Then, most important, dual channel systems appeared which allowed coverage on both sides of a moving vessel. Over the years a relatively small group of individuals from universities, government agencies and industry have worked to improve the side scan technique. Some of the developments are reviewed briefly, and further information is available from references listed in the bibliography.

PORTABILITY

Most near shore hydrographic work is done from relatively small boats which have a minimum of cabin space, deck space and handling equipment. In recent years we have seen the development of relatively lightweight, portable side scan sonar equipment which is suitable for operation from small vessels and which can be operated on the battery power available on these vessels. Photo 1 shows a typical system installed aboard a 15 foot outboard motor boat.

In order to produce lightweight systems, we have been fortunately able to borrow some technology from space applications with high strength materials, small dc-dc converters, special plastics and integrated circuits.

One of our projects in recent years has been the development of special tow cables for these portable applications. We have confronted manufacturers with an almost impossible problem - to produce cable which is lightweight, small in diameter, very strong, very tough, very flexible, low in noise and crosstalk,in small quantities at a reasonable price. Several manufacturers, most notably South Bay Cable Division of Consolidated Products, have worked with us to produce these exotic cables. We are hopeful that new synthetic materials which are under development will further enhance the strength and durability of these cables.

The new cables have also required the development of special termination techniques in order to develop the full strength of the strain member fibers used in the cables.

New lightweight depressors have also been developed to aid in keeping the side scan towed vehicle down at a selected depth. AZA Scientific of Saline, Michigan has introduced the Michelsen depressor which provides an extraordinary downward force from a lightweight package. Another lightweight depressor is shown mounted directly to the towfish in Photo 1. This unit was developed by MAT Reinforced Plastics of Amesbury, Massachusetts for Klein Associates.

RECORDING TECHNIQUES

A key element in side scan systems is the graphic record and the mechanism which makes this "hard copy" output. The mechanical recorders which are in use in most commercial side scan systems still suffer from a variety of problems, but they have seen enough subtle improvements in the past few years to make them reasonably operational and reliable.

An important improvement in this regard has been the development of new "wireless helices" for helical scan recorders, which allow for reasonably long periods of adjustment-free operation. This development has come from the Alden Electronic and Impulse Recording Equipment Company of Westboro, Massachusetts who have pioneered many of the improvements in graphic recorders. The author is grateful to J.B. Henry of the Canada Centre for Inland Waters for introducing a simple run-in technique for these wireless helices which greatly imporves their uniformity and reliablity.

A few manufacturers have recently introduced multi-stylus recorders which use a number of finely spaced electrode wires to replace the standard helices or moving belt recorder electrodes. The wires are scanned electronically which allows for faster sweeps than can be achieved on mechanical recorders.

Recently we have also seen the development of fiber optic recorders by Honeywell, Edo and others. These recorders use photographic film in front of the face of a cathode ray tube which has a special faceplate which is made of fiber optic bundles. The sweeps of the oscilloscope may be programmed for a wide variety of parameters while the intensity of the beam (the "Z-axis") is modulated by the sonar signals. Obviously these recorders have a tremendous amount of versatility for more sophisticated side scan recording. They also have the capability of accepting alpha-numeric data for simultaneous recording of navigation or other data.

Another fascinating output technique was introduced by Westinghouse at the 1972 Washington, D.C. meeting of the Marine Technology Society. Side scan records were put on tape and processed and then played onto a television screen in such a way that the viewer could see the moving record as if he were flying over the bottom terrain.

RECORD REVERSAL

An interesting techniqe which can be used to enhance interpretation of side scan sonar records is a process of reversal in which black becomes white and vice-versa. This makes acoustic shadows show up as black and highlights as white which is more normal to the eye. Photo 2 shows an example of a reversed record. Other excellent examples of this technique are shown in Sonagraphs of the Sea Floor[14].

RANGE VS. RESOLUTION

One interesting development in the recent history of side scan sonar is psychological rather than technical. In earlier days, the first question (and often the only question) asked about a sonar of any type was "What is its range?" as discussed in an article by the author in 1967 (Reference 3). So early sonar designers concentrated on maximizing system range. Now, fortunately, professional users have become aware of the tradeoff between range and resolution, and more concentration is made on record quality and target discrimination and other operational matters.

A similar parallel situation happened in the seismic profiling field. The author participated in some of the early developments in high resolution subbottom profiling. At that time it was possible to actually have people laugh at systems which could not achieve thousands of feet of penetration. Now, high resolution shallow subbottom profilers are in use throughout the world, and customers are seeking systems which can provide detail on the first few meters and even the first few centimeters of the sea floor.

An interesting system has been proposed by the Marine Physical Laboratory (Reference 6) which would correct the range-resolution problem to some extent by using a side scan transducer with electronically variable focus. Systems have been built with fixed focus which greatly enhance resolution over a short range span.

RANGE RESOLUTION

A subtle, but important development has been the introduction of side scan sytems which utilize capacitor discharge techniques in order to produce very short, very high intensity sound bursts. This method, pioneered by Professor Harold E. Edgerton of M.I.T., allows very tiny transmitting circuits to generate enormous power levels for a short time. These short pulses allow the sonar to have excellent range resolution (on the order of 15 centimeters).

Another advantage of the short pulse technique is that it tends to eliminate "zeros" in the lobes of the acoustic beam of the sonar transducer. This is because there are not enough cycles to cause the usual phase cancellations. The transmitted vertical beam is, therefore, fairly uniform so that the records are more uniform. When conventional long tone bursts are used, the zeros in the beam cause streaks on the record which lose data and which confuse interpretation. The smooth vertical beam in the short pulse technique also allows the side scan sonar to make a clean trace of the bottom directly below the towfish.

A disadvantage of the short pulse is that it requires a wide bandwidth for accurate recording which presents difficulties in taping data. The wider bandwidth can also increase noise problems, although at the frequencies used in high resolution side scan sonar this is not usually a problem.

SIMULTANEOUS SIDE SCAN AND PROFILING

Recently, many surveyors have recognized the usefulness of simultaneous recordings of side scan sonar with echo sounding and/or sub bottom profiling. Interpretation of records is enhanced by displaying the output of the side scan sonar and the profiler on a single recorder. Wimpey Laboratories in England have accomplished this by splitting the trace on a Hydro Products Gifft Recorder. Hydro Products has now made the split trace a standard option. Others including Decca, ORE, E.G. & G. and U-Tech have produced similar systems. Klein Associates has recently developed a three channel recorder which allows two side scan channels plus a channel for profiling. This recorder overcomes the problem of lost data which occurs on the split trace recording technique.

ISOMETRIC SONAR

One of the problems in side scan record interpretation is scale distortion. Generally distance measured across a sonar chart is not the same as distance along the chart. This problem can be corrected to some extent by the use of a continuously variable paper drive which is available as an option on Klein side scan recorders.

Professor W.D. Chesterman of the Bath University of Technology has pioneered a technique of "isometric side scan sonar". Side scan data as well as navigation data is recorded on magnetic tape and then fed into an oscilloscope. The scope's intensity is modulated by the acoustic signal while a camera records the display frame-by-frame. The oscilloscope sweeps are adjusted so that the record scale is corrected, as in Photo 3.

In a further refinement of the technique the average bearing angle of the ship is taken into account and automatically corrected on the oscilloscope. The present system does not correct for slant range distortion, although this parameter could be programmed into the sweep.

Another method for correcting, to an extent, scale distortion is by non-linear photography of the sonar records. This interesting optical technique is accomplished by an anamorphic lens which has a different magnification in one direction than another. Such lenses were developed for cinema photography so that wide angle photos could be reproduced on normal film sizes. A special variable anamorphic lens was developed by Institut Francais du Petrole called an"Anamorphoser".

SIDE SCAN MOSAICS

As in aerial photography, it is desirable to put side scan records together to form a mosaic of the area of interest.

Side scan sonar mosaics using photographic scale correction, Decca navigation and a towfish with controlled height off the bottom were reported in 1964 by Clay, Ess and Weisman of Hudson Laboratories (Reference 1).

Professor Chesterman's isometric sonar apparatus has been used by the Unit of Coastal Sedimentation to produce excellent side scan mosaics, as shown in Photo 4, and in Reference 12. N.C. Kelland has produced further interesting results by making scans from one side of an area and then from the opposite side of the area. Transparencies of the two mosaics may be laid on top of one another to get a more complete sonar picture of each area.

SLANT RANGE DISTORTION

Another of the problems in side scan record interpretation is the slant range distortion caused by the fact that the sonar measures the distance from the towfish to the side rather than the actual distance along the bottom. The geometry of the situation and pertinent equations are shown in Figure 1. Of course these sketches and equations only apply in the special case of a relatively smooth, non-sloping bottom.

In order to obtain a reasonably linear range scale to correct for slant range distortion, it is necessary to generate a non-linear sweep on the sonar recorder. Various schemes have been used to create this correction.

Westinghouse made a system using non-linear helix wires on an Alden recorder. Such a fixed correction requires a fixed towfish height off the bottom and, therefore, a highly sophisticated towing arrangement.

EPC Labs of Beverly, Massachusetts has a recorder which may be programmed, on long sweeps, for a non-linear sweep.

Of course the simplest way to achieve a non-linear sweep is with an oscillographic recorder. The height of the sonar off the bottom may be monitored by the side scan transducer itself or by a supplementary device. Then the oscilloscope sweep can be programmed according to the formula for a correct distance along the bottom. Of course simply correcting the slant range does not compensate for the fact that echo characteristics obtained along the record vary due to the varying acoustic grazing angle.

One drawback of correcting slant range is that some of the subtle character of the side scan record at the beginning of the bottom trace will be lost. This first portion of the bottom trace is often very important in creating a "feel" for the bottom characteristics.

STEREO SIDE SCAN SONAR

Initial attempts have been made by the Naval Civil Engineering Laboratory in Port Hueneme, California (Reference 13) to produce side scan sonar images in stereo. This has been accomplished by the use of two high resolution towfish towed simultaneosly at slightly different height and distance. Early results are very encouraging, and this work is continuing.

TOWING PARAMETERS

Although some side scan systems are hull mounted or outrigger mounted, these systems are subject to ship motion, surface noise and are relatively useless in deep water. Therefore, most side scan systems use a towed transducer assembly. Unfortunately this creates for the hydrographer a navigation problem since the distance from the fish to the ship is not known unless additional acoustic sensors are put into the system.

In order to help improve this situation, we have made computer calculated curves and tables of towing parameters including fish depth, distance behind the ship and line tension for a variety of speeds, tow cables and depressors.

SIGNAL PROCESSING

Signal processing is one important area where improvements may be made to enhance the quality and interpretability of side scan sonar results.

Various types of time-variable-gain (TVG) and automatic gain control (AGC) systems have been devised and are installed in commercial and experimental systems. The signal situation is complicated by the number of variables (spreading losses, absorbtion losses, grazing angle variations, widely varying bottom characteristics) and by operational factors such as the nature of the survey mission and the preferences (and skills) of the operator.

The author has experimented a great deal with TVG and AGC schemes including combinations of TVG with fast and slow AGC together. It turns out that, except for special situations, AGC of any type tends to falsify proper interpretation, whereas TVG can be very beneficial in almost all situations. In order to experiment, it is useful to tape the "raw" signal data so that lab experiments can be performed. This is not always possible since some processing is often necessary to put signals within the bandwidth or dynamic range of the tape recorder.

One of the problems with signal processing schemes, particularly for a manufacturer, is to obtain quality results without overwhelming the operator with too many adjustment variables. Unfortunately, some compromise must be made in this situation. The author introduced a commercial system some years ago in which it was hoped that all adjustments could be factory set so that the operator would have only a single gain control. It was embarrasing to discover that every operator promptly had to open up the recorder to tweak all the little internal controls!

With the assistance of Donald Krotser (now with GSO Associates of Cambridge, Massachusetts) we now have a TVG which is versatile, relatively simple to adjust and which, in many cases, can provide reasonably uniform signal levels across the side scan record.

Still, there is a great deal more which can be done in this area, particularly with computer processing. Hopefully, it will be possible to extract far more information from the incoming echoes in order to improve image quality and to determine the actual composition of target reflectors along with their true spatial relationships. Work on recognizing materials by their acoustic signals is going on for subbottom signals by the University of New Hampshire and in the oil industry.

FUTURE PROSPECTS

In the coming years we can expect side scan 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 of 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 to see new navigation schemes which can be tied in directly to the sonar by computer.

Synthetic aperture[15], stereo[13] and other exotic schemes will hopefully move out of the theoretical and laboratory stage into operational systems.

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 still essentially unheard of, while other countries are using it as a routine tool. As the side scan concept gains operational status, we can expect more manufacturers to enter the marketplace. This competition will benefit the technology and the user.

FINAL COMMENTS

Several major factors have unfortunately held back technical progress in the side scan sonar field, for non-military and commercial and academic use. The first of these is military secrecy. Much to our dismay, we are often forced to reinvent the wheel. Many of the techniques discussed in the article have long been in operation in side looking radar. A limitation from a manufacturer's standpoint is that customers demand, legitimately, standard off-the-shelf equipment. Such equipment must, of necessity, be a compromise to please a variety of clients.

The most important factor is the medium itself. The sea does not reveal her secrets easily. But we have learned a great deal,and we are enthusiastic about the possibilities for the future.

****

BIBLIOGRAPHY

1. Clay,C.S., Ess, J. and Weisman, I. "Lateral Echo Sounding of the Ocean Bottom on the Continental Rise," Journal of Geophysical Research, Vol. 69, Sept. 15, 1964.

2. Edgerton, H.E.,"Exploring the Sea With Sonar," Discovery, Sept. 1966.

3. Klein, M., "Side Scan Sonar", Undersea Technology, April 1, 1967.

4. Tucker, M.H., "Sideways Looking Sonar for Marine Geology", Geo-Marine Technology, October 1966.

5. Yules, J.A. and Edgerton, H.E., "Bottom Sonar Search Techniques", Undersea Technology, November 1964.

6. Anderson, V.C. and Lowenstein, C.D., Improvements in Side-Looking Sonar for Deep Vehicles, Marine Physical Laboratory Report MPL-U-5/68.

7. Klein, M. and Edgerton, H.E., "Sonar-A Modern Technique for Ocean Exploitation", IEEE Spectrum, June 1968.

8. Sargent, G.E.G., "Applications of Acoustics and Ultrasonics to Marine Geology", Ultrasonics, January 1968.

9. Klein, M. and Jolly, J., "The Use of Side Scan Sonar to Identify Sea Floor Characteristics", Procedings of the International Symposium on the Engineering Properties of Sea-Floor Soils and Their Geophysical Identification, Seattle, Washington, July 25, 1971.

10. Klein, M., "Sonar Search at Loch Ness", Preprints of the Seventh Annual Conference, Marine Technology Society, Washington, D.C., August 16-18, 1971.

11. Klein, M., Van Koevering, B.D., and Michelsen, F.C., "A New Depressor and Recovery Method for Undersea Towed Vehicles", Preprints of the 8th Annual Conference, Marine Technology Society, Washington, D.C. September 11-13, 1972.

12. Kelland, N.C. and Hopkins, J.C.,"Mosaics From High Resolution Side Scan Sonar", Offshore Services, October 1972.

13. Mittleman, J.R. and Malloy, R.J., "Stereo Side Scan Imagery", Preprints of the Seventh Annual Conference, Marine Technology Society, Washington, D.C., August 16-18, 1971.

14. Belderson, R.H., Kenyon, N.H., Stride, A.H. and Stubbs, A.R., Sonagraphs of the Sea Floor, Elsevier Publishing Company, 1972.

15. Walsh, G.M. and Moss, G.J., "A New Approach to Preliminary Site Surveillance", Navigation, Volume 17, No. 2, Summer 1970.

BIOGRAPHY - MARTIN KLEIN

Martin Klein is President and founder of Klein Associates, Inc. of Salem, New Hampshire. He received his degree in Electrical Engineering from the Massachusetts Institute of Technology in 1962. Prior to forming Klein Associates, he was Program Manager for Sonar Systems at E.G.&G., Inc. where he was responsible for design and development of the E.G.& G. Side Scan Sonar Systems. He was responsible for the design and installation of the first side scan sonar on the bathyscaph Trieste. He has participated in dives of the Alvin, the Trieste and other research submarines.

He participated in the subbottom seismic profiling survey of the English Channel for the proposed tunnel between France and England. He has also participated in numerous surveys including oil exploration in Australia and the Gulf of Mexico, cable and pipeline surveys and various marine searches. He has worked with marine archaeologists to locate ancient shipwrecks and harbors, and he has contributed to the search for the famous Loch Ness Monster.

Mr. Klein is a member of the Marine Technology Society, the Acoustical Society of America, the Academy of Applied Science, the Institute of Navigation, the Institute of Electrical and Electronic Engineers and the United States Naval Institute.

****

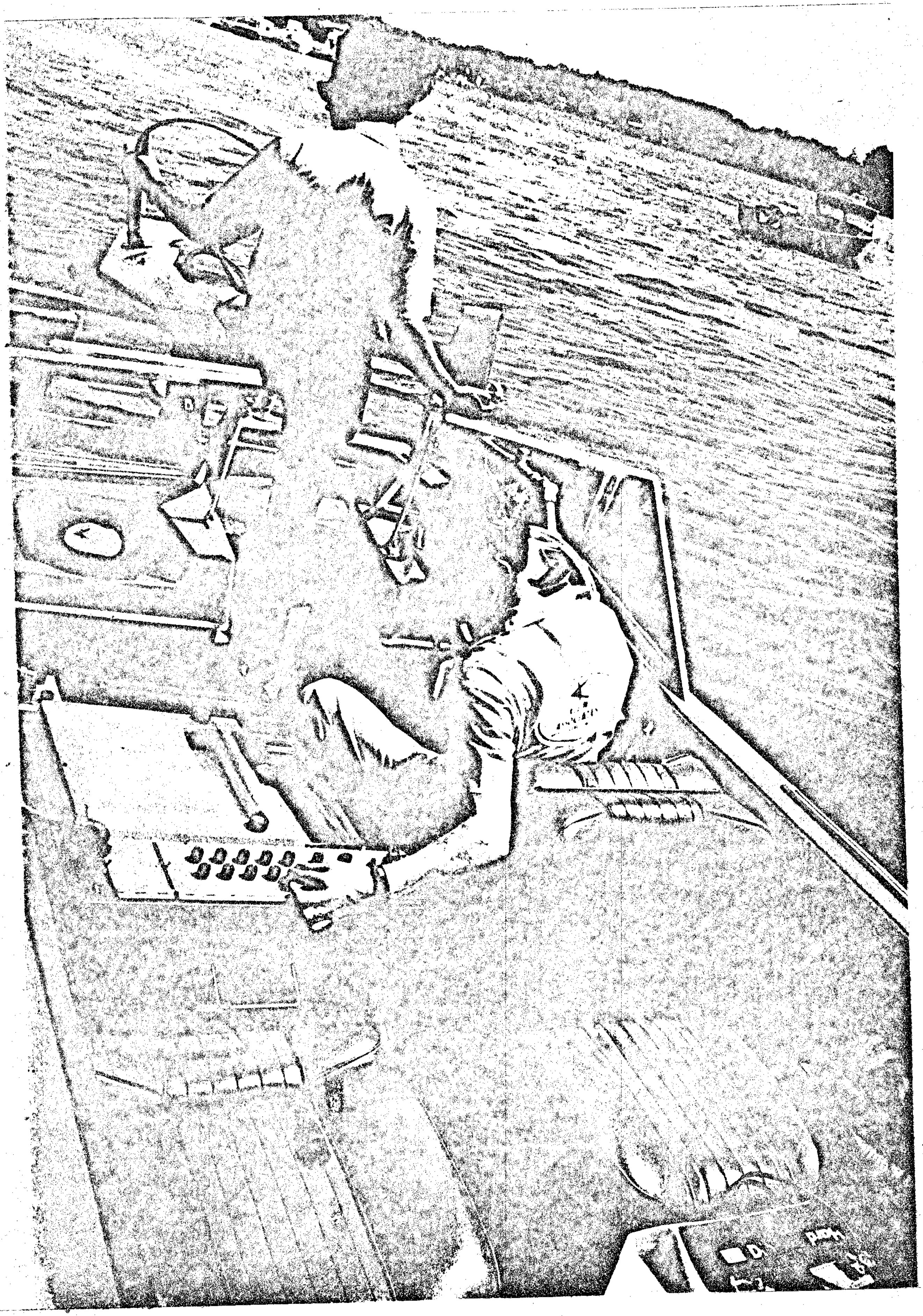


PHOTO 1 - KLEIN MODEL 400 SIDE SCAN SONAR INSTALLED ON A 15 FOOT OUTBOARD BOAT

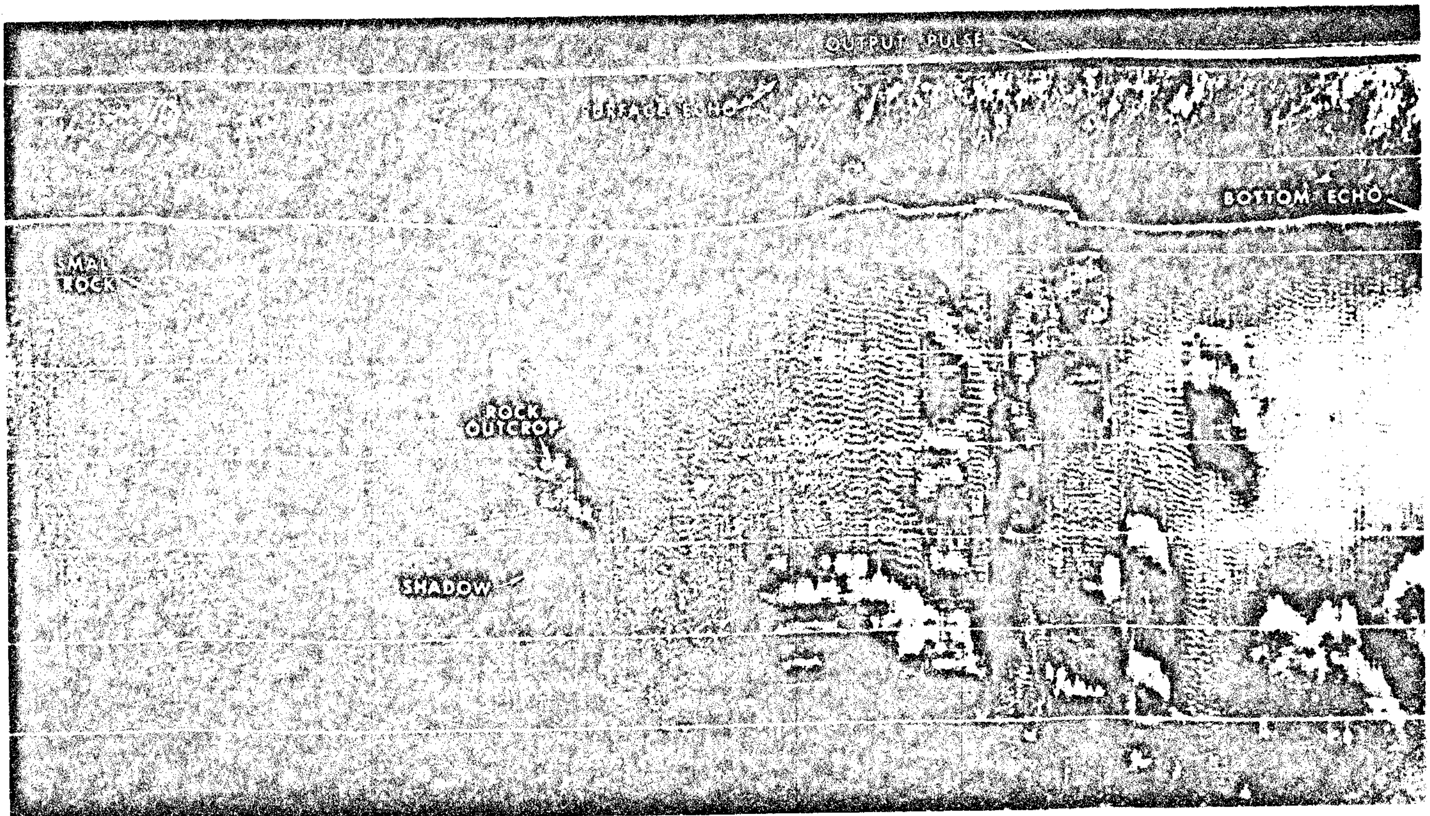
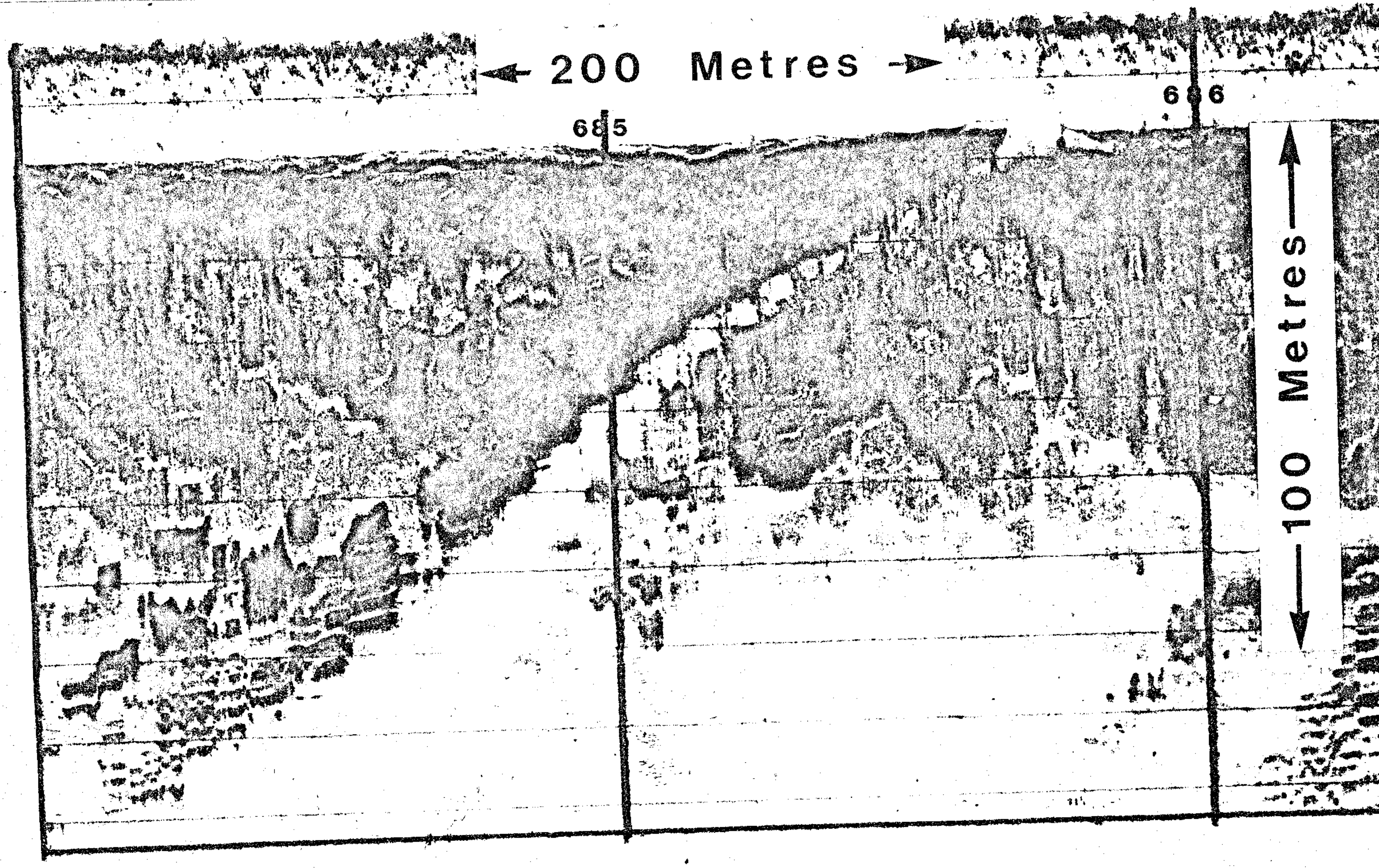
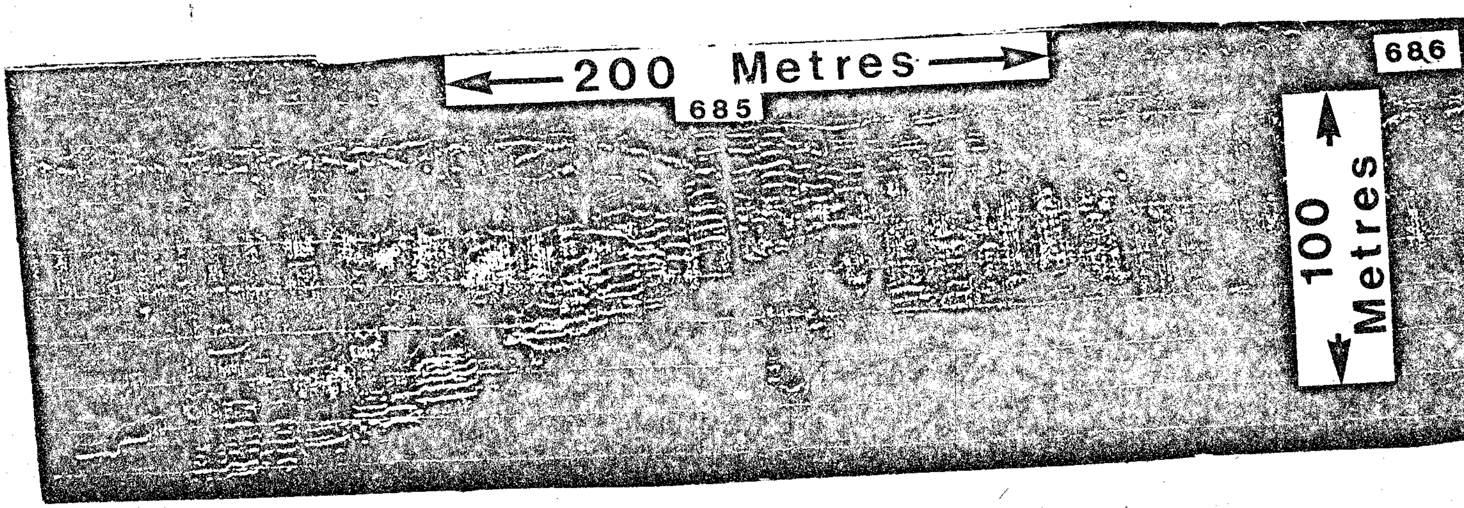


PHOTO 2 - REVERSED SIDE SCAN SONAR RECORD BY THE AUTHOR (KLEIN 400 SYSTEM)



High Resolution Side Scanning Sonar Record



Isometric Sonar Record

PHOTO 3 - EXAMPLE OF ISOMETRIC SONAR CORRECTION (PREPARED BY UNIT OF COASTAL SEDIMENTATION USING BATH UNIVERSITY PLAYBACK SYSTEM)

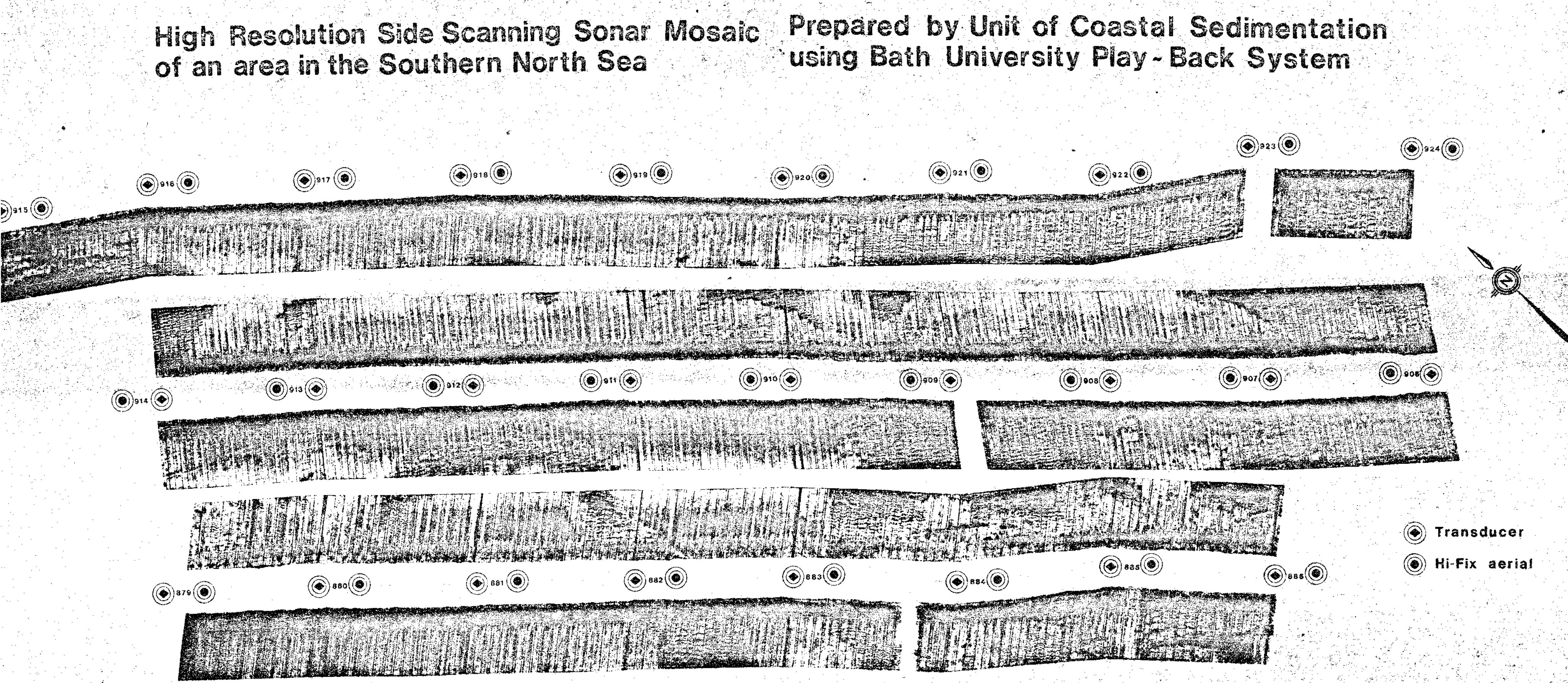


PHOTO 4 - EXAMPLE SIDE SCAN SONAR MOSAICS (PREPARED BY UNIT OF COASTAL SEDIMENTATION USING BATH UNIVERSITY PLAYBACK SYSTEM)