CHAPTER 2

A MODULAR SONAR SYSTEM FOR SEABED MAPPING

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ABSTRACT

This paper is a summary of a talk given at the SEMINAR ON SIDE SCAN SONAR TECHNIQUES, DESIGN OF TRANSDUCERS AND PARAMETRIC ARRAYS WITH SPECIAL REFERENCE TO SEA BED SURVEY at the University of Cape Town, 3rd and 4th January, 1980.

Developments in commercial side scan sonar systems are proceeding at a fast pace. In this paper a variety of new techniques and products for improving side scan imagery are presented. One of the most important recent developments has been in the development of systems that are capable of producing direct isometric sonographs. One of these is the Klein Modular Automated Plotting Sonar (K-MAPS^{TM}) which automatically corrects on-line compression and slant-range distortions, while at the same time removes the water column. In this manner isometric sonar mosaics of the seabed can be assembled without requiring costly and time-consuming manual reduction procedures in the drawing office. Other developments include a combined side scan sonar/sub-bottom profiling system, alphanumeric record annotation, a digital processor with memory for data storage, which also allows image delay or selective image expansion, a very high resolution side scan sonar with a 0.2° beam angle, operating at a frequency of 500 kHz and a new medium range 50kHz side scan sonar.

INTRODUCTION

Side scan sonar continues to gain increasing popularity as a tool for mapping the seabed. Although each user may have the same basic goal of obtaining information about the seabed, the sonar is used by a wide variety of people who operate over many different kinds of conditions and economic constraints. Many applications seem to push the sonar technology to its limits, so that typical sonar manufacturers are constantly working on improvements and new technological developments. In recent years digital and microprocessor electronics have allowed a rapid evolution in system capabilities and sophistication. Because there is such a diversity of clients and applications, we at Klein Associates have taken the approach of making our equipment flexible and modular. We also make every effort to configure our new developments so that they may be retrofitted into existing systems. In this paper, some of the new developments are outlined and some recent results with the latest systems are presented.

NEW DEVELOPMENTS

Figure 1 illustrates an artist's concept of a side scan sonar system in operation. This picture is now quite familiar to side scan sonar users. It has been reproduced again as a reminder that the sonar is, indeed, a system, and that each of the individual parts of the system are critical to the overall operation. Some of the components are purely mechanical, others are electro-mechanical and still others involve high technology electronics. In refining our sonars, we continue to investigate improvements in every component part of the system. In the following sections a number of such refinements are being discussed and illustrated.

VERY HIGH RESOLUTION TOWFISH

One of the most exciting developments in the side scan sonar field has been our introduction of a side scan towfish which operates at a frequency of 500 kHz. This unit achieves a horizontal beam angle of only 0,2 degrees. It has a pulse length of only 20 microseconds to give a range resolution of less than 3 centimetres. The new towfish can be plugged in as a direct replacement of a standard 100 kHz unit. Of course there is a trade-off of range versus resolution. The high frequency unit has a maximum range of 100 metres on either side, with an optimum range of about 50 metres. Before the introduction of this new towfish, high resolution of this order was only possible with very expensive and complicated military systems.

The 500 kHz sonar allows for detection of small targets and small geological features which were not picked up in the past. In Figure 2 a 500 kHz image of a small wooden ladder is compared with a 100 kHz image. Whereas the ladder is clearly delineated on the former scan, it requires considerable skill to recognise the same object on the latter, lower resolution scan. Figure 3a shows a high frequency sonograph of some small automobile and truck tires, which are illustrated in Figure 3b. Figure 4a shows a sonograph of a ship wreck, the Buzzard Bay Lightship and Figure 4b shows a sonograph of a small airplane in the harbour of Gloucester, Massachusetts. Note how the high frequency sonagraph begins to truly resemble an underwater photograph.

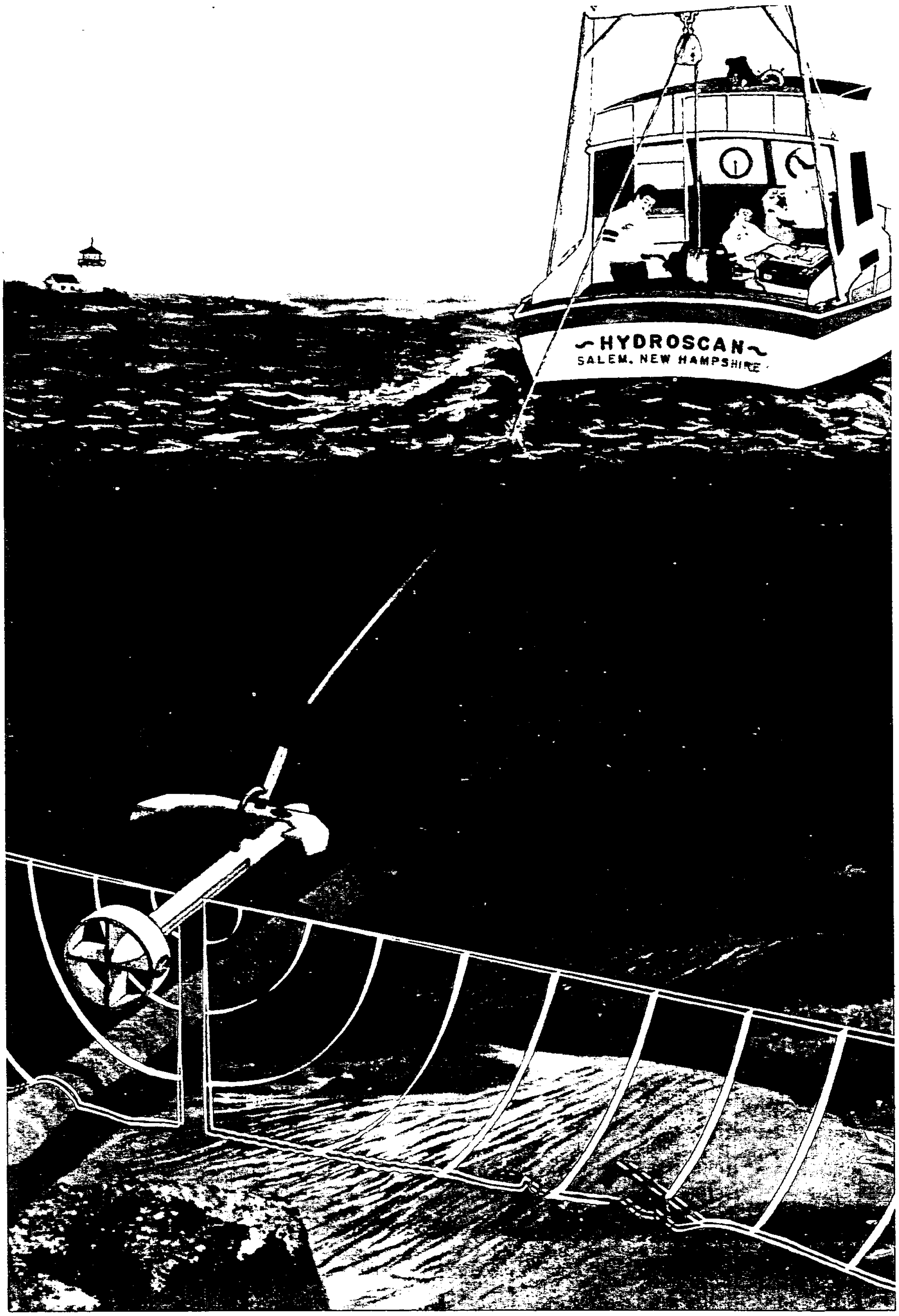

Fig. 1. Artist's concept of the side scan sonar technique. Each component of the system from the towfish to the final display is important in producing the final result.

MEDIUM RANGE TOWFISH

When commercial side scan sonar systems were introduced in the late 1960's, there was one question which was universally asked - "What is the range of the sonar?". As the marketplace and applications developed, users realized that they required relatively high resolution, a feature that could not be achieved at long range. Most of the short range systems which are in use around the world use a frequency of 100 kHz which gives a good compromise between range and resolution. Recently, there has again been an increased demand for longer range systems, particularly for mapping relatively large scale geological features. To satisfy this need we have developed a 50 kHz towfish with a horizontal beam angle of 1.5 degrees. Tests have shown it to be capable of ranges of up to 600 metres on each side. We have also built an experimental "dual pod" 50 kHz towfish which is illustrated in Figure 5. This unit has the unique feature of allowing the transducers to be independently tilted in the vertical plane in increments of 10 degrees from straight up to straight down. The towfish can be adjusted, for instance, to have one transducer aiming slightly up and the other slightly down in order to obtain more uniform results when towed parallel to a sloping sea bottom. The dual pod unit also has a vertical beam which may be varied from 40 degrees to 20 degrees. The narrower vertical beam is useful in shallow water to help eliminate sea clutter. We also make a version of our 100 kHz towfish which has this variable beam capability. The dual pod towfish was recently tested by the Canadian Hydrographic Service and the Geological Survey of Canada to look at geological features called "pingos" in Tuktoyaktuk, Northwest Territories. Ranges of over 600 metres were achieved (Fig 6). On the same expedition, iceberg scours were also recorded (Fig 7a). Figure 7b shows ice scours using the 450m range per channel.

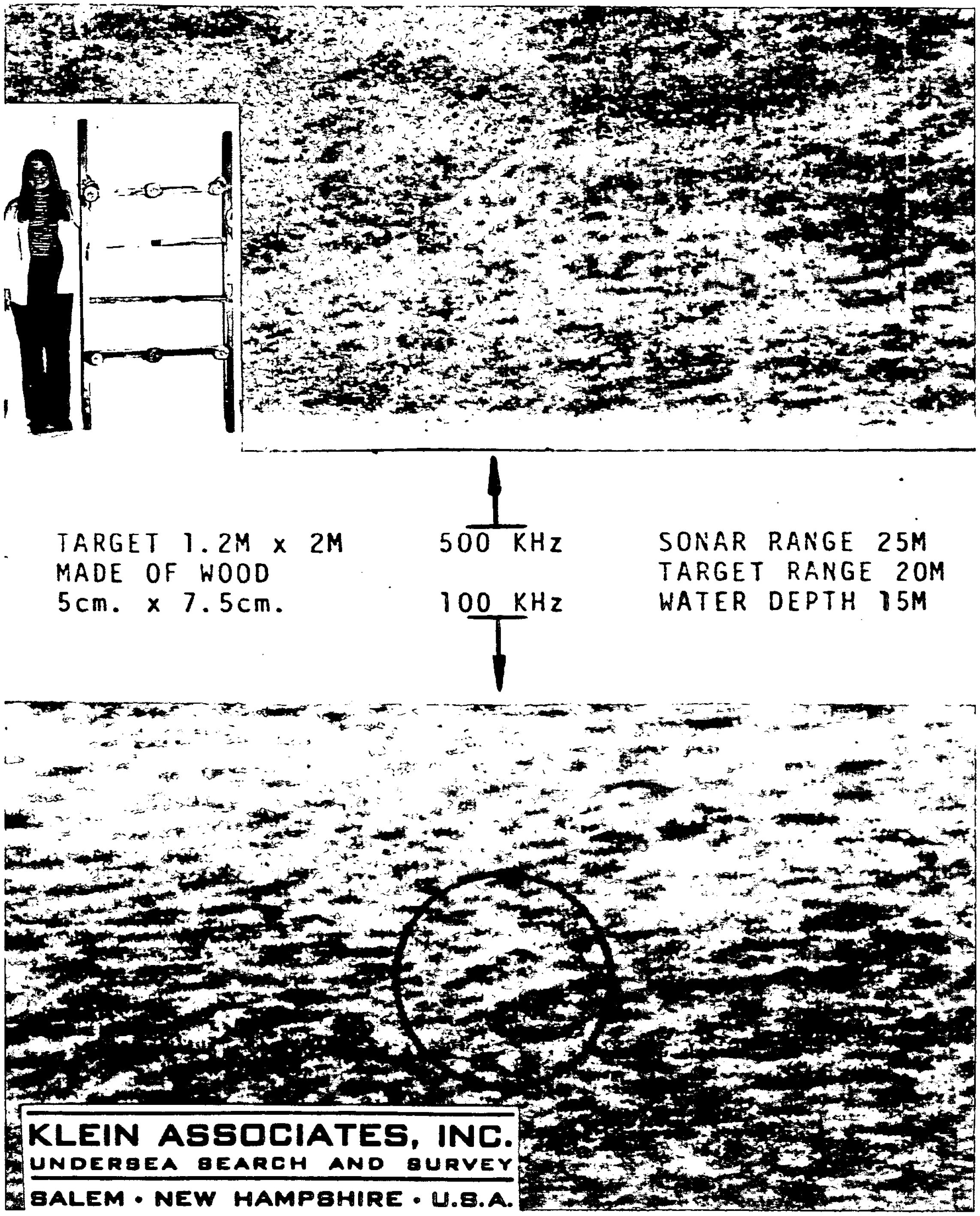

Fig. 2: Comparison sonagraphs using a small wooden ladder as a target. The upper trace was made using a 500 kHz side scan sonar while the lower trace was made using a 100 kHz sonar. Note that the high frequency sonar reveals the details of the ladder.

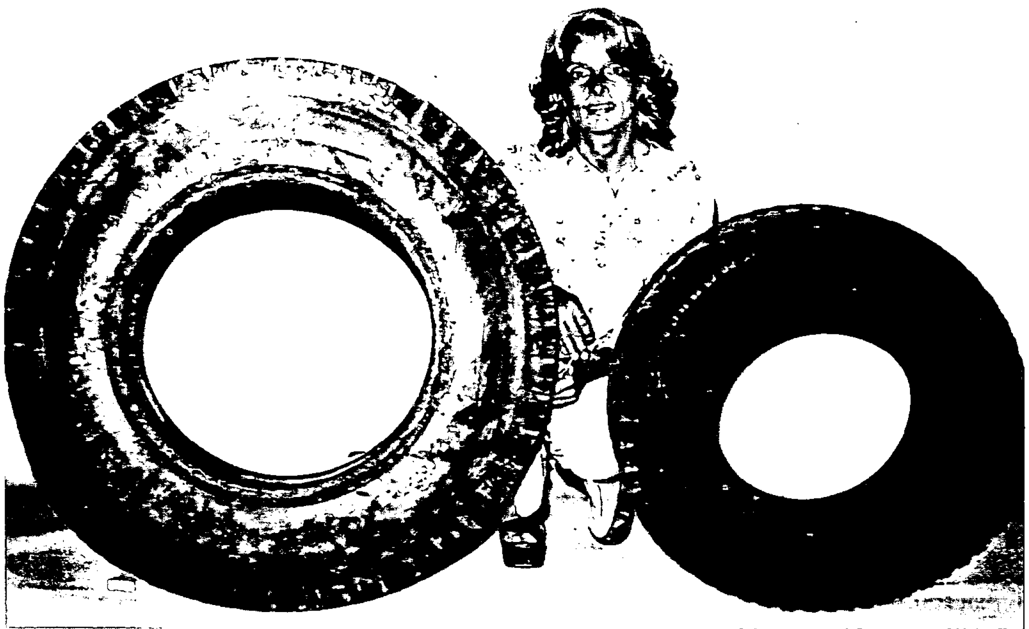

Fig. 3a: Photograph of small automobile tyre and small truck tire to show relative size.

Fig. 3b: Side scan sonar trace of the tires of Fig. 3a. Record was made using Klein 500 kHz very high resolution side scan sonar.

Fig. 4a Klein Hydroscan 500kHz Side Scan Sonar Record of the Buzzard Bay Lightship.

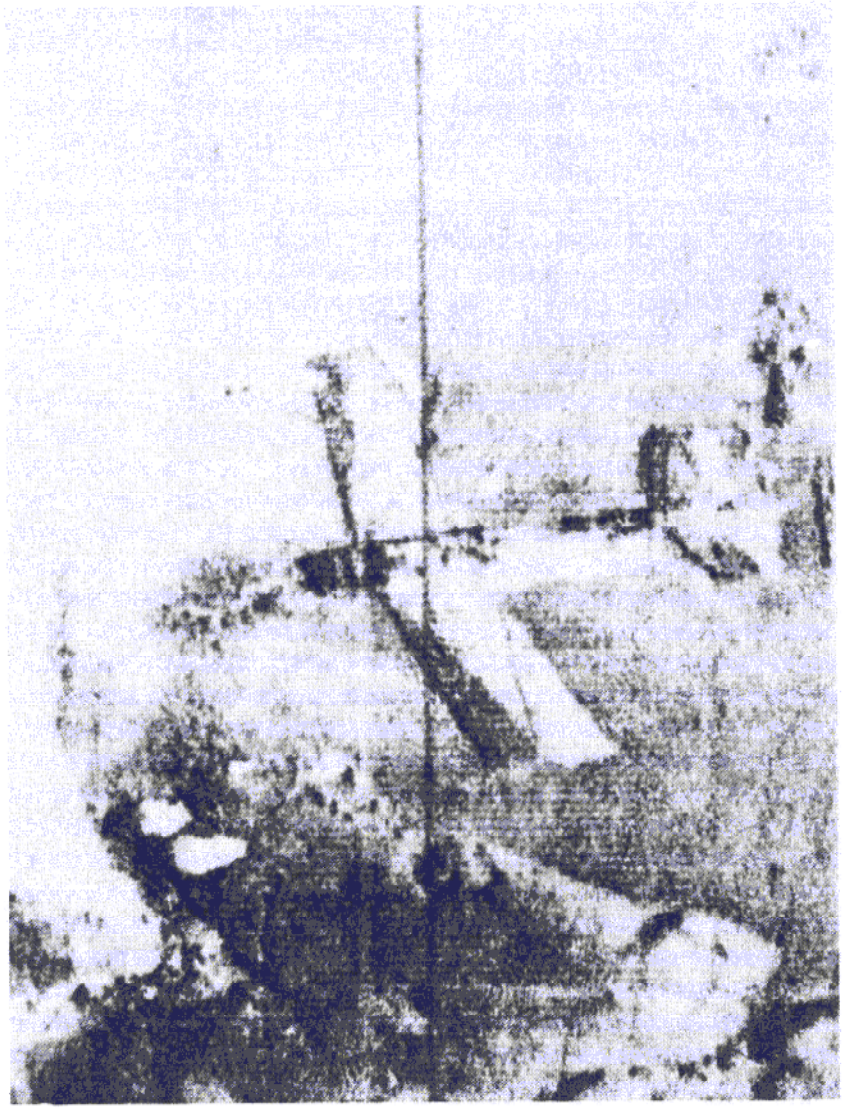

Fig. 4b: Record of a small aircraft in the harbour of Gloucester, Massachusetts using a Klein 500 kHz very high resolution side scan sonar.

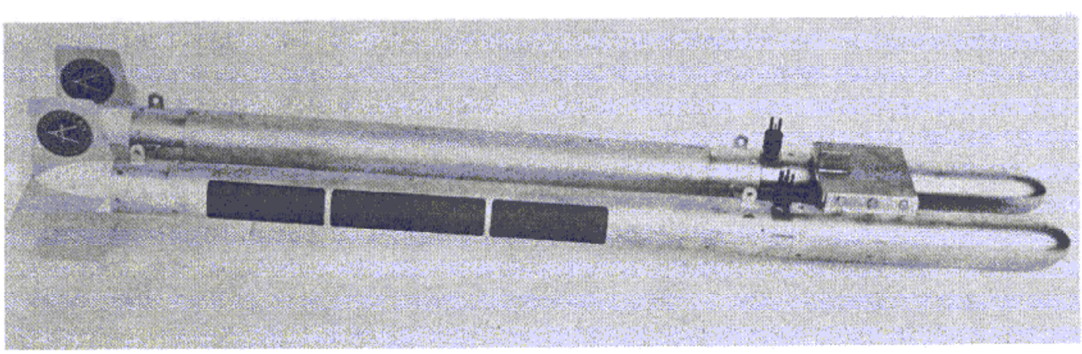

Fig. 5: New "Dual Pod" Klein 50 kHz long range side scan sonar towfish. The unit features independently adjustable tilt and variable transducer vertical beam angle.

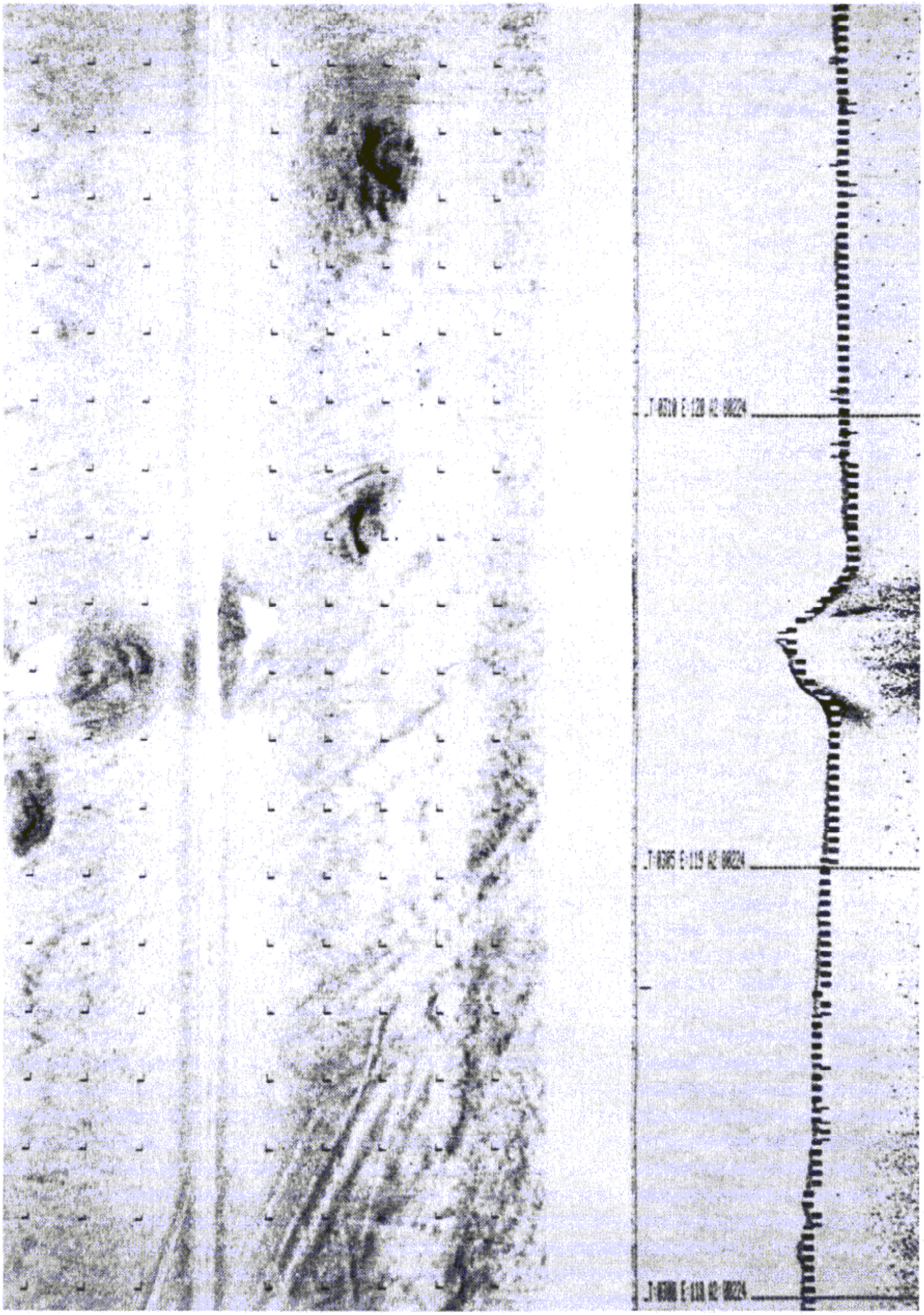

Fig. 6: Klein HYDROSCAN Side Scan Sonar record of pingo-like features.
Location: Tuktoyaktuk, Northwest Territories, Canada.
Frequency: 50 kHz
Range per Side: 600 Meters Corrected
Courtesy Geological Survey of Canada

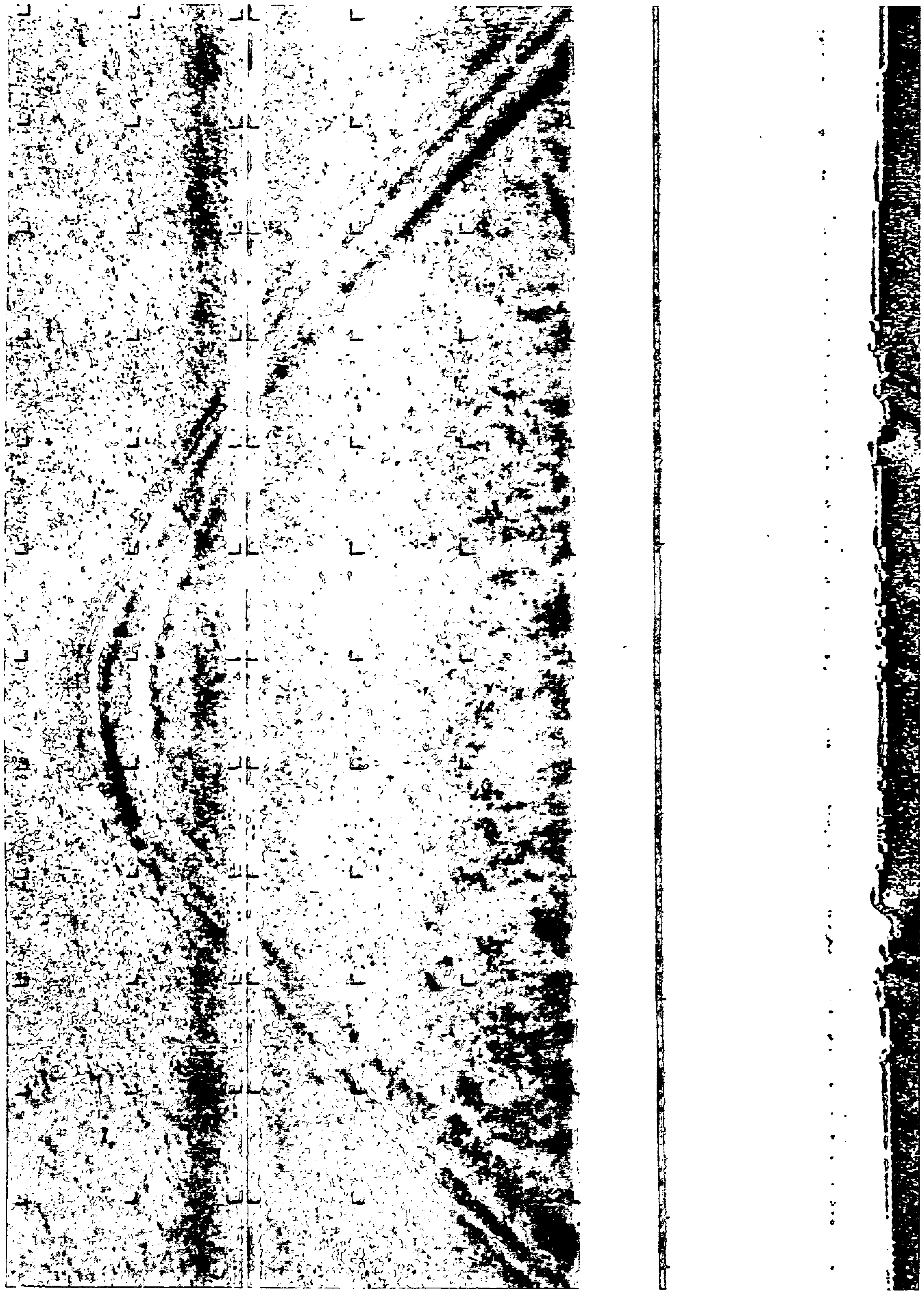

Fig. 7a: Klein HYDROSCAN Side Scan Sonar record of an iceberg scour in the Beaufort Sea. The record was made with a Klein 50 kHz towfish on a range of 300 meters per side. The record is water column and speed corrected. The third trace shows the altimeter record.

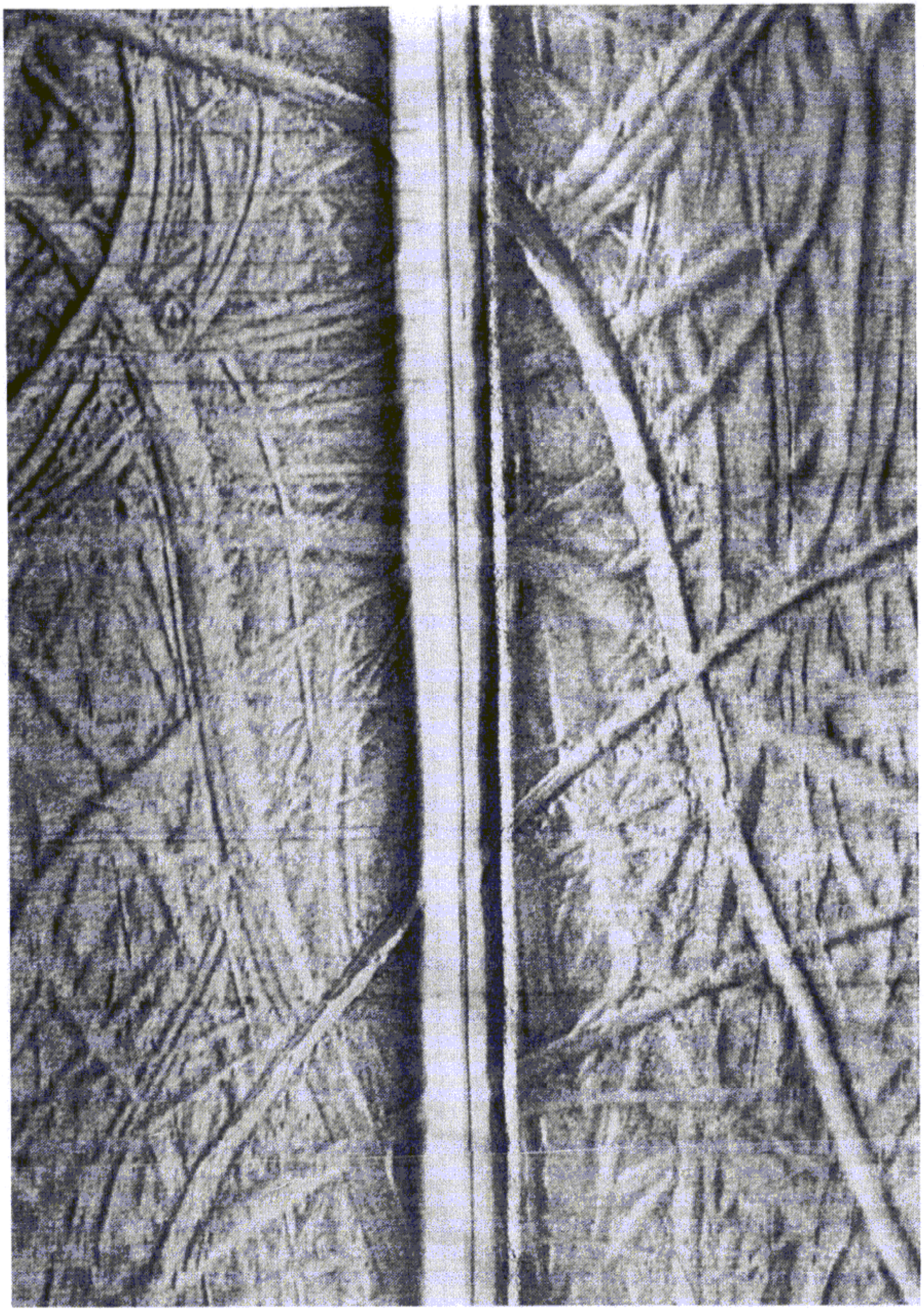

Fig. 7b. Klein HYDROSCAN Side Scan Sonar Record of iceberg scours in the Beaufort Sea using the 50 kHz K-Maps™ II System with the 450 meter range per channel.

COMBINED SIDE SCAN SONAR/SUB-BOTTOM PROFILING

Another important development of the last few years is the combination of a sub-bottom profiler transducer with the side scan sonar transducers in a single towfish. Such a unit, which we call a Trifish^{TM}, is illustrated in Figure 8. The unit is designed in modular form so that the profiler section can be connected or disconnected rapidly in the course of a survey. The sub-bottom profiler in this case consists of a 3.5 kHz transducer with a short pulse for high resolution profiles of up to 30 m penetration. Figure 9 shows an example of the three channel graphic recorder. The sub-bottom profile and the side scan sonar record are displayed on a single three-channel recorder (Fig 10). By having both types of information side by side on the same piece of chart paper, record interpretation is often greatly facilitated. In fact, the "whole" or combined record is usually of greater value than the combined parts or the individual records as it allows a three-dimensional reconstruction without further complicated data manipulation. Figure 11 shows the combined side scan/sub-bottom towfish rigged to hang from a boom off the bow of a small boat.

BUILT-IN ALTIMETER

Another new development involving the towfish, is the installation of a built-in altimeter. In this configuration the centre section of the towfish contains a downward looking transducer which measures the depth of the seabed below the towfish (Fig 12). The actual altitude transducer is illustrated in Figure 13. The electronics for the altimeter are built into the nose of the towfish along with the side scan electronics.

CABLES AND TOWING ACCESSORIES

As mentioned earlier, we continue to look at all aspects of the sonar system, including the towing accessories and the tow cables. For example, we supply two types of tow cables with our systems. One of these is a lightweight, flexible cable for small boat and shallow-water operations. The other is a cable with a heavy duty armouring of counter-wound steel strands. The lightweight cable in particular required solutions to a number of relatively difficult parameters such as small diameter, high strength, flexibility, suitable electrical properties, low twist and sea water integrity. To achieve this combination we worked closely with cable manufacturers. Our modern lightweight cables use a strength member of counter-wound layers of Kevlar[R] which is a high strength Dupont aramid fibre. We also now use a double-wall outer jacket with abrasion resistant polyurethane. Using this type of cable made it possible to successfully tow our system from a helicopter as shown in Figure 14.

Another example of a towing accessory developed by us is a slip ring assembly used in combination with cable winches. This obviates the problem of disconnecting the cable each time the winch is being operated. Since we were unable to find a slipring assembly suitable for oceanographic service of this kind, we developed a special heavy duty unit (Fig 15).

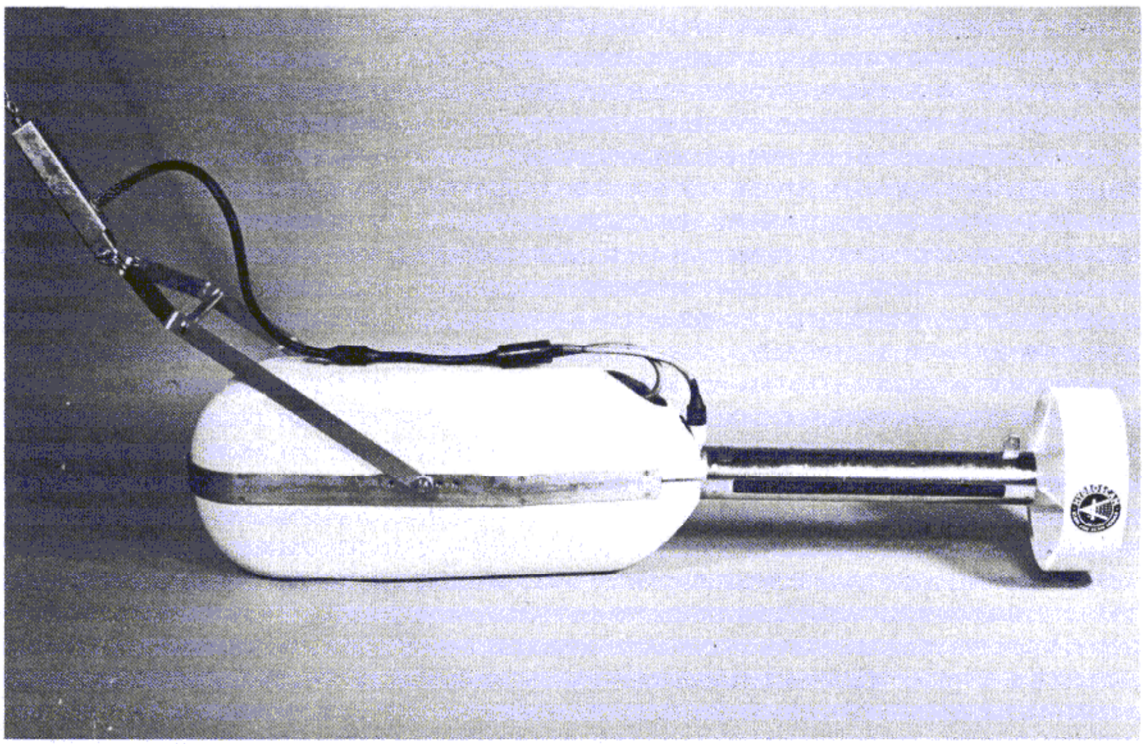

Fig. 8: Trifish[TM] combined side scan sonar / sub-bottom profiler towfish. The profiler section is a module which may be removed.

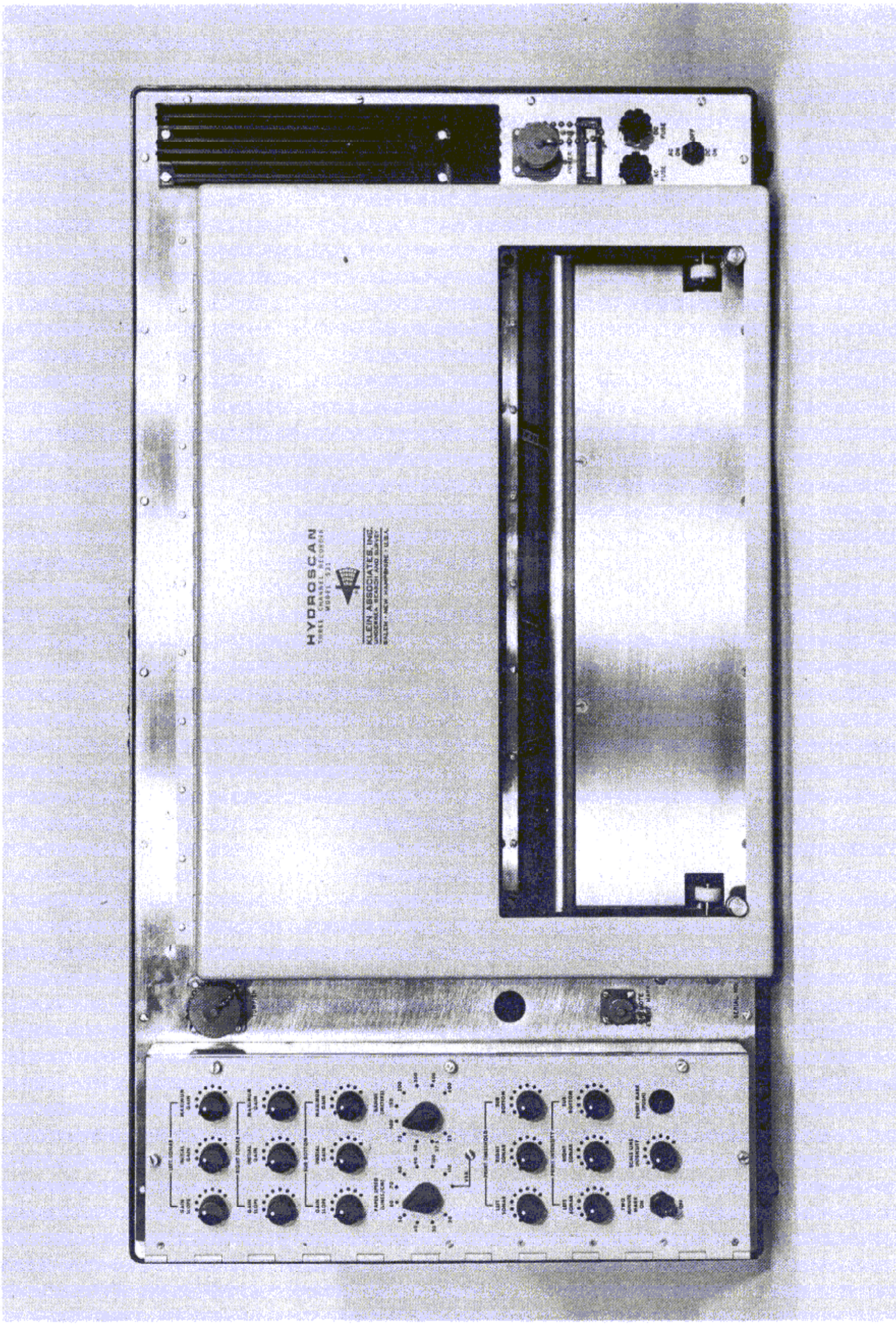

Fig. 9: Klein HYDROSCAN three channel graphic recorder.

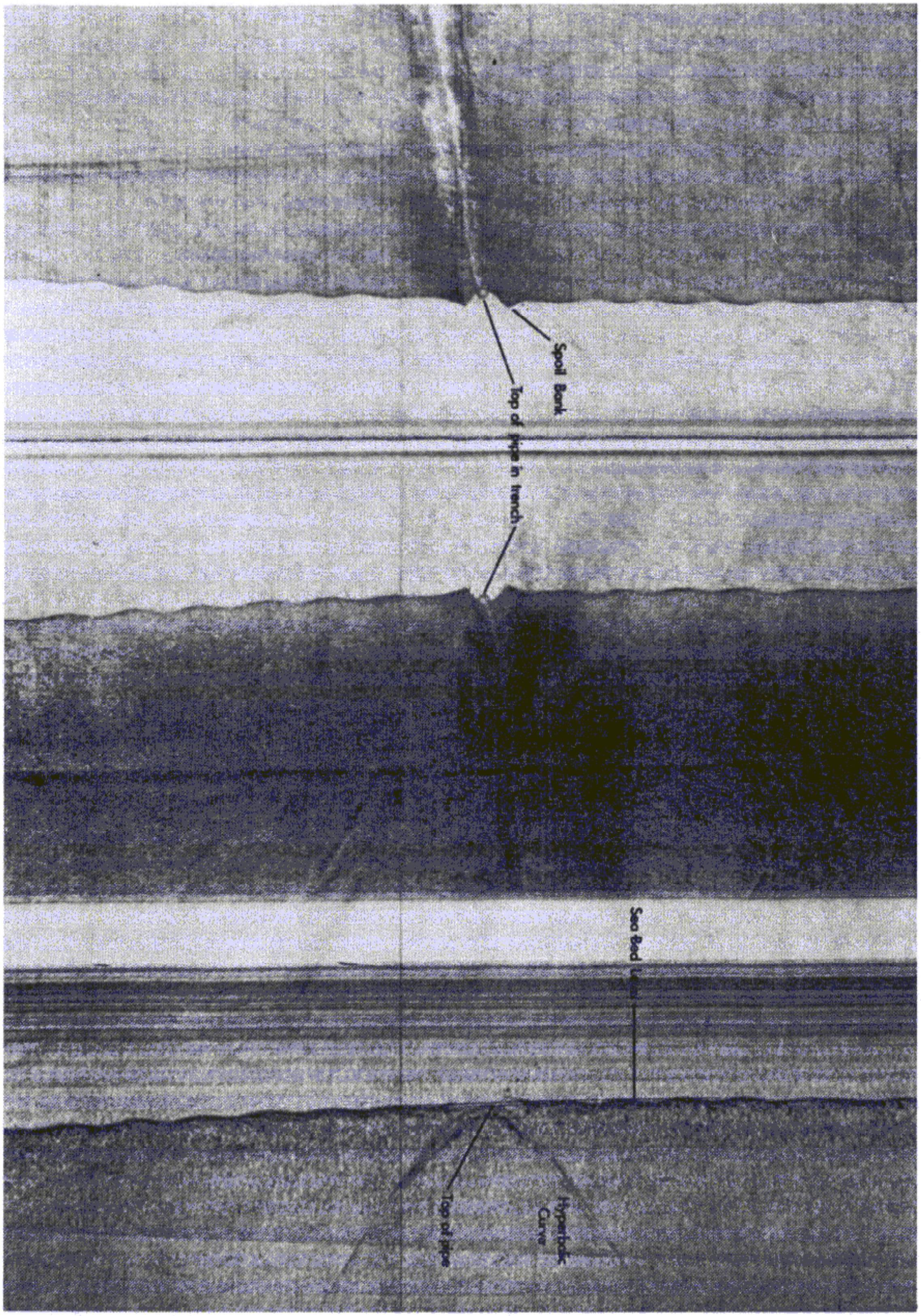

Fig. 10: Three channel side scan sonar/sub-bottom profile recording. The record shows a North Sea pipeline. Because the profiler has a relatively wide beam, the pipe shows up as a hyperbola on the bottom trace. Record courtesy of Offshore Transportation and Services, Ltd.

Fig. 11: Combined side scan sonar/sub-bottom profiler mounted off the bow of a small survey vessel. Photo courtesy Nortrek.

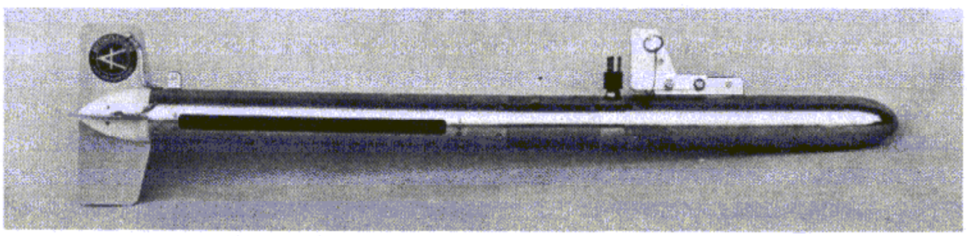

Fig. 12: Side scan sonar towfish. The altimeter electronics are in the nose of the towfish along with the side scan electronics.

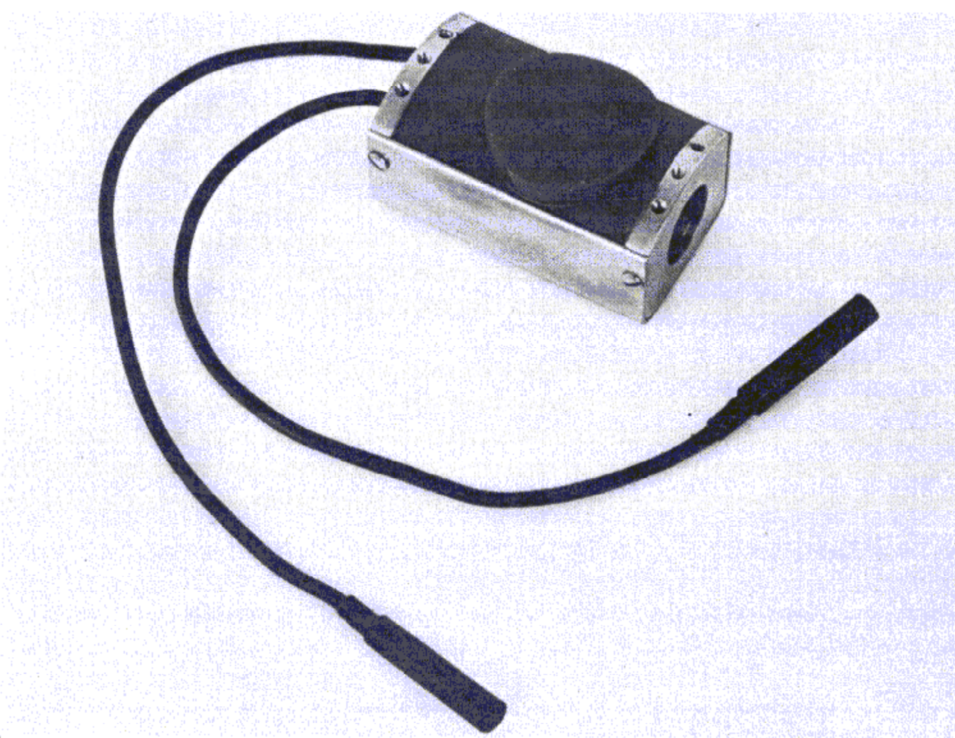

Fig. 13: Detail of the altimeter transducer. The unit has a conical beam which is aimed straight down.

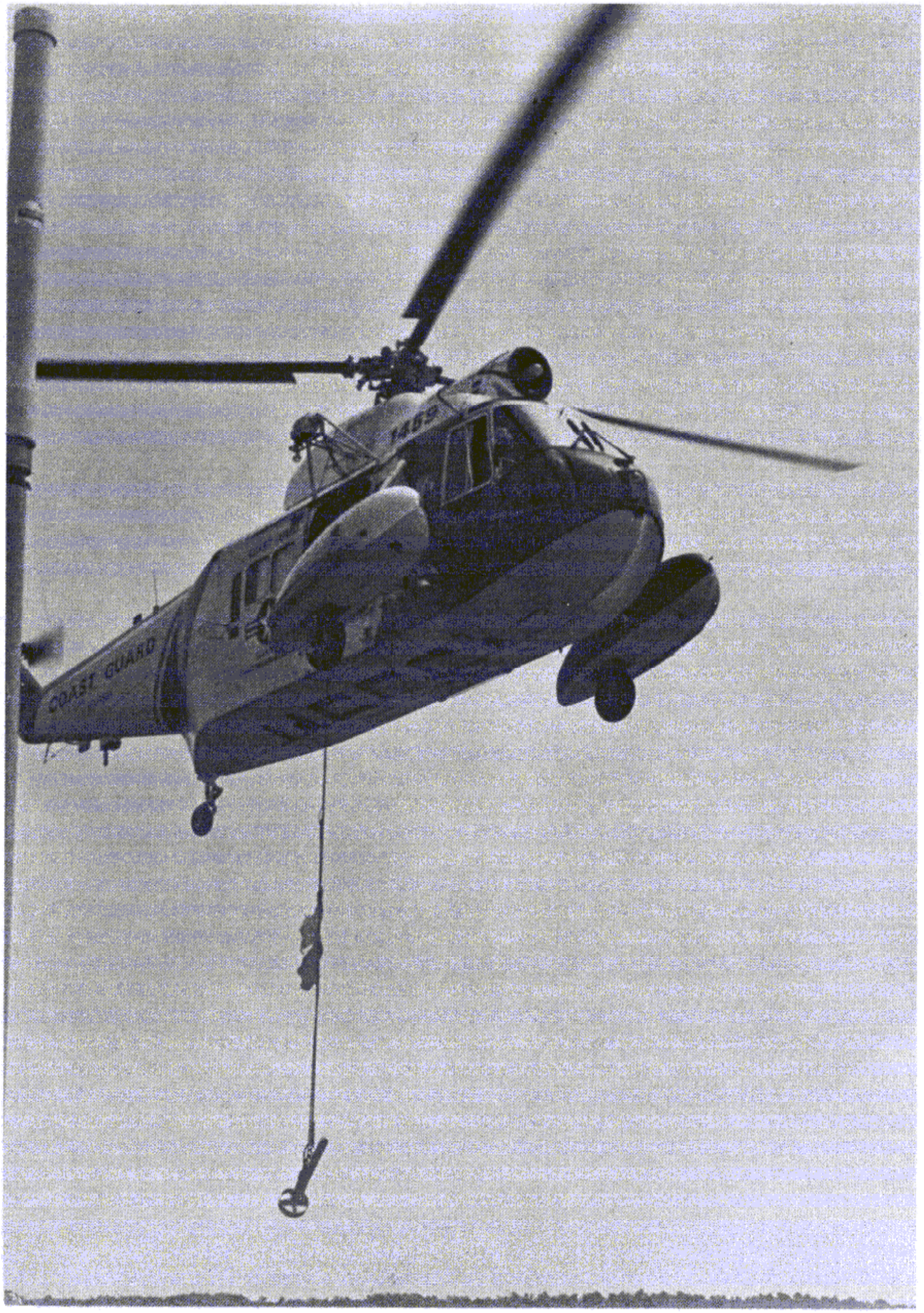

Fig. 14: Klein side scan sonar towfish shown in a successful sea trial with a helicopter. The towfish was towed with a special high strength lightweight cable.

DIGITAL PROCESSING

Although we have made many advances in the design of the towfish, transducers, tow cables and other towing accessories, the most significant recent developments have been in the area of signal processing for display enhancement. The new capabilities have primarily been made possible through the use of digital and microprocessor technology.

Since we have many systems out working in the field, we have chosen to take a modular approach so that new capabilities could be plugged into existing hardware.

In order to lead into the use of some of the new techniques, we first developed a version of our graphic recorder which is magnetic tape compatible. In the case of Klein graphic recorders, this required the development of a very sophisticated phase lock servo to drive the helix drum in the graphic recorder over a wide range of speeds. The graphic recorder can interface with a magnetic tape recorder at recording speeds of up to 30 sweeps/sec (a sonar range of 25 meters real time). The graphic recorder can be used to trigger the sonar, and magnetic tapes of the data can be made. The system has a "Tape Monitor" facility so that the graphic recorder displays the data which is going onto the tape (using a "read after write" head). This ensures that good tapes are being made.

One of the modules which plugs into the graphic recorder is a Digital Processor illustrated in Figure 16. This unit has an independent 8 bit analogue to digital converter for each of the three (right side scan, left side scan and sub-bottom profiler) sonar channels. The digitized data is brought out to a connector in the rear of the unit. The data may be formatted for use with a digital tape recorder or it may be fed into a computer for further processing. Four bits of the digitized signal are stored in a memory, and then the data may be taken out of memory at a controlled rate. This allows the graphic image to be delayed and expanded. Figure 17 shows an example of a sonograph of a shipwreck which has been expanded using the digitizer. The delay on the digitizer may also be used to take away the "water column" which often takes up a large portion of the sonar or profiler records. Another application of the digitizer is to put the profiler on a different scale than the sonar. For example, the sonar could be set up for 200 metres per channel while the profiler might be set for 50 metres full scale, thereby achieving higher sub-bottom resolution. The digitizer is set up so that it can accept and process data in real time (while the sonar is operating). Alternatively, it can be used for post-processing. In this latter mode, it can accept data, in analogue or digital form, from a magnetic tape recorder.

Another module which can be added to the system is an Alphanumeric Record Annotater (ANRA^{TM}). For example, in Figure 16 the ANRA^{TM} is included with the digitizer in one package. The controls are seen in the lower half of the illustration. Separate modules are also available with the digitizer and ANRA^{TM} functions. The Alphanumeric Record Annotator adds to the sonar record the parameters Time, Event Mark, Date as well as two auxiliary five digit inputs. The auxiliary inputs can, for example, be two co-ordinates of navigation data. One of the auxiliary channels may also be used with a keyboard so that manual entries may be made. The auxiliary channels may be set by thumbwheels or they can be controlled by external signals. Data from the ANRA^{TM} is brought out on a jack so it also can be tape recorded.

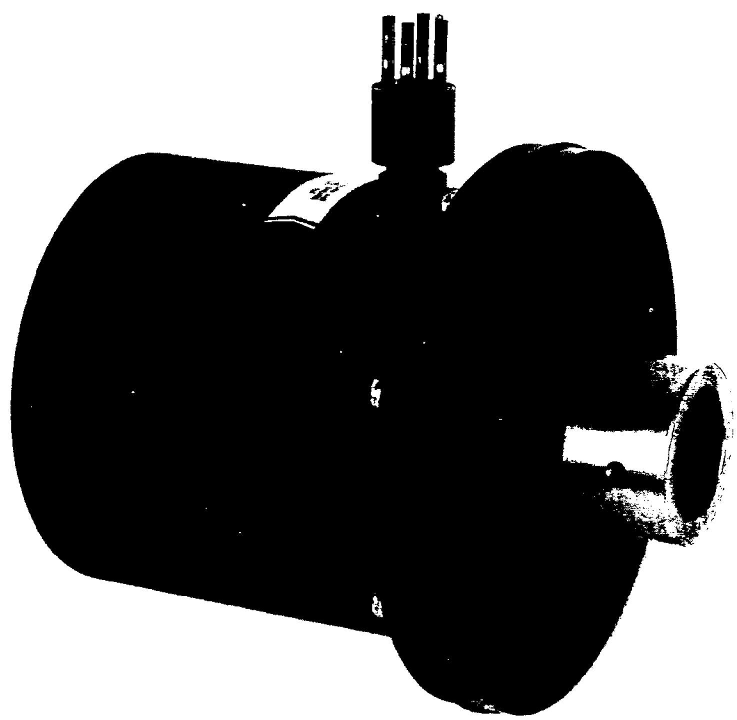

Fig. 15 Klein sealed slip ring assembly for mounting on sonar winches.

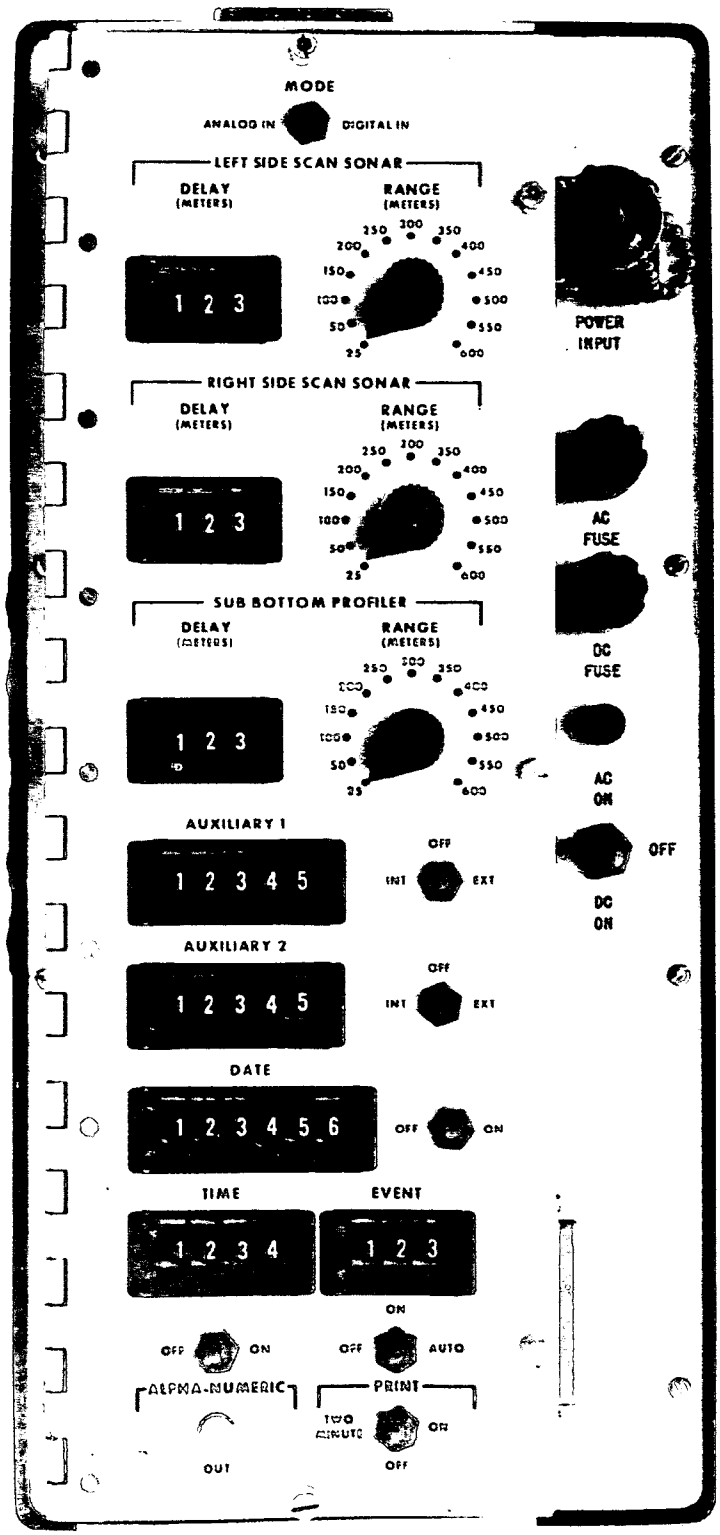

Fig. 16: Combined Digitizer and Alphanumeric Record Annotator (ANRATM)

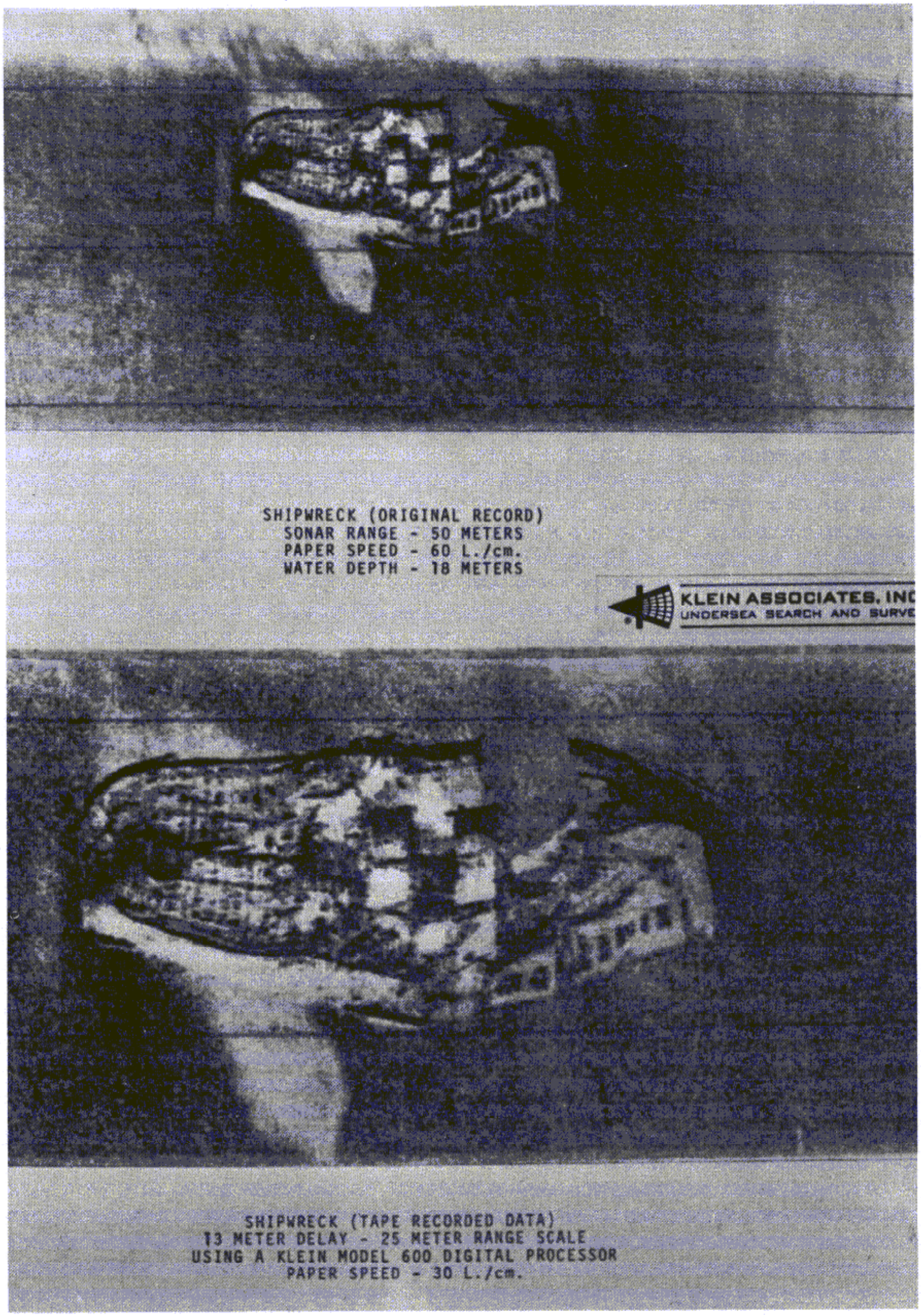

Fig 17: Example of a shipwreck record which was digitized and then expanded to show additional details. Data was stored on magnetic tape for further processing.

KLEIN MODULAR AUTOMATED PLOTTING SONAR (K-MAPS^{TM})

Conventional side scan sonar records, although satisfactory for many applications, have three major scale distortions. The first of these is scale distortion. The typical sonar record has a different scale in one axis than in the other axis. This means that bottom features appear on the sonar record as too thin or too thick. For instance, a square object on the bottom would appear as a rectangle. A lot of good material on this subject can be found in Flemming (1976) and Flemming (this volume). A second distortion comes from the blank space or "water column" in the centre of the side scan record. This space is created by the fact that it takes a certain amount of time for the sonar signal to project out from the towfish, hit the bottom and return to the towfish. The third major distortion is the so called slant range factor. The standard sonar measures the distance from the towfish to a point on the bottom rather than the true distance along the sea bottom. Water column and slant range distortion increase as the towfish height off the bottom increases.

In order to correct for the side scan distortions, Klein Associates has developed the K-MAPS^{TM}, Klein Modular Automated Plotting Sonar. The complete system includes the towfish with built-in altimeter, the tow cable and the graphic recorder. One version of these modules is shown in Figure 18.

The first, and generally most important, correction adjusts the sonar record so that the distance along both axes are the same. In order to do this, we control the speed of the digital stepping motor drive in the graphic recorder. In order to be able to make the speed correction, we must input the speed of the vessel into the system. This can be done in three different ways. The simplest (but generally least reliable) way is to estimate the speed and dial it in on a thumbwheel which is situated on the control panel of the module. Another way is to use a towed speed sensor. The bottom of this unit is shown in Figure 20. The sensor uses a small paddle wheel and a built-in magnetic pickup to generate a pulse train which has a rate proportional speed. Of course, the unit measures only relative speed, not the true speed of the vessel through the water. The best way to input speed is to use a ship's navigation system which has an output in digital format which indicates the true ground speed of the vessel. If the navigation system is working properly, this third method gives the most accurate sonar records.

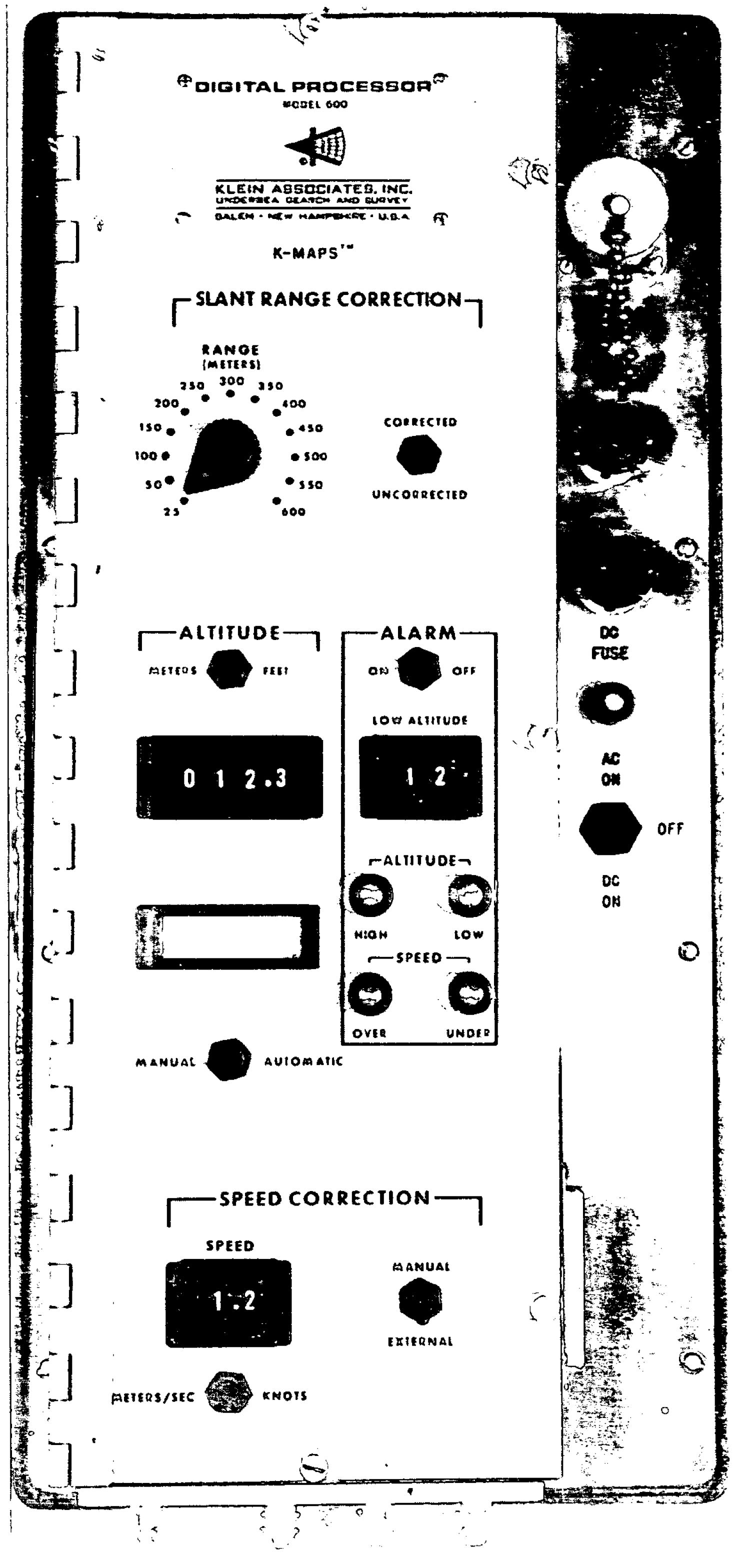

Fig. 18: K-MAPS™ signal processing box for speed correction, water column removal and slant range correction.

In order to do the corrections for water column removal and slant range correction, the altitude or height off the bottom of the towfish must be entered. This can be done in several ways. The altitude may simply be estimated and then dialed in on the thumbwheel. The K-MAPS^{TM} systems are also supplied with a built-in altimeter in the towfish which measures the required altitude parameter and reads it out on a front panel liquid crystal display. The system can also acquire altitude from the side scan sonar data, although in some cases this may be less accurate than the built-in altimeter. If a sub-bottom profiler is in use, the system can also obtain the parameter altitude from the profiler.

Once the parameter altitude is obtained, the system can remove the water column by delaying the data by an amount equal to the altitude. This function is similar to the delay function which is performed by the digitizer, except the function of delay is now automatically represented by the altitude of the towfish. The system has a built-in alarm which sounds (and lights) if the towfish is too near the bottom for safety or if it is too high off the bottom to make proper corrections. The low altitude alarm setting can be adjusted by a thumbwheel switch. The system also has an alarm to indicate if the ship is going too fast or too slow to do proper speed corrections.

In order to do slant correction, the system is basically solving the equation for a right triangle. The hypotenuse (slant range) and one leg (altitude) of the triangle are known, and the system solves for the other leg of the triangle which is the true range. In practice this is accomplished by loading the sonar data linearly in a memory and then reading it out of memory in a non-linear fashion. Of course, the slant range correction assumes the sea bottom to be flat, which in most situations is, in fact, a reasonable approximation.

Typically on a K-MAPS^{TM} record we use a three-channel, 19 inch graphic recorder. Two of the channels are used for the side scan data. The third channel typically displays the altimeter data as well as the alphanumeric data. Alternatively, a sub-bottom profiler may be displayed on the third channel. The altitude data must be digitized for the K-MAPS^{TM} processing. This digitized version of the altitude data appears as a dotted line on or above the altitude trace to allow the operator to see if the altimeter is properly locking to the bottom. An example of such a dotted line is illustrated in Figure 6.

For the convenience of our customers, the K-MAPS^{TM} system has been broken up into modular form. The customer may choose a system with speed correction only, a system with speed correction and water column removal or a full-blown system with speed correction, water column removal and slant range correction. This allows a lot of versatility from an operational as well as an economic point of view.

Figure 19 shows a complete K-MAPS^{TM} system installed on a small boat. The system is designed to run either on two small automobile batteries (24 volts d.c.) or on 110/220 volts a.c. The digitizing and correcting modules can be removed for applications where they are not needed.

With the K-MAPS^{TM} system, the survey vessel can run parallel track lines to obtain complete coverage of an area. Each strip of the sonar record is automatically corrected and reproduced in isometric form. The strips of record can then be put together side-by-side to produce a true scale sonar mosaic of the area. The mosaic will resemble an aerial photograph of a large area of the seabed. Scale lines on the sonar records facilitate their assembly into mosaics. The scale lines have a special shape to indicate whether the sonar channels were scanning to the right or the left of a survey track. The record correction can be done either in real time on the ship or, alternatively, the uncorrected data can be recorded on magnetic tape to be processed further in the laboratory later. This post-processsing mode generally gives more versatility. If navigation data is input in alphanumeric form on the altimeter portion of the trace, it also helps to align the sonar mosaics.

Figure 7, for example, shows a single strip of corrected side scan sonar data on a scale of 300 metre per channel using a Klein 50 kHz towfish. The record shows an iceberg scour in the Beaufort Sea. The third channel of the record shows the altimeter trace. Figure 21 shows a sonar mosaic of an area known as the Gunboat Shoals off the coast of New Hampshire. This mosaic, made with a 100 kHz towfish, covers an area of 1.05 km by 0.7 km, with water depths ranging from 13 meters to

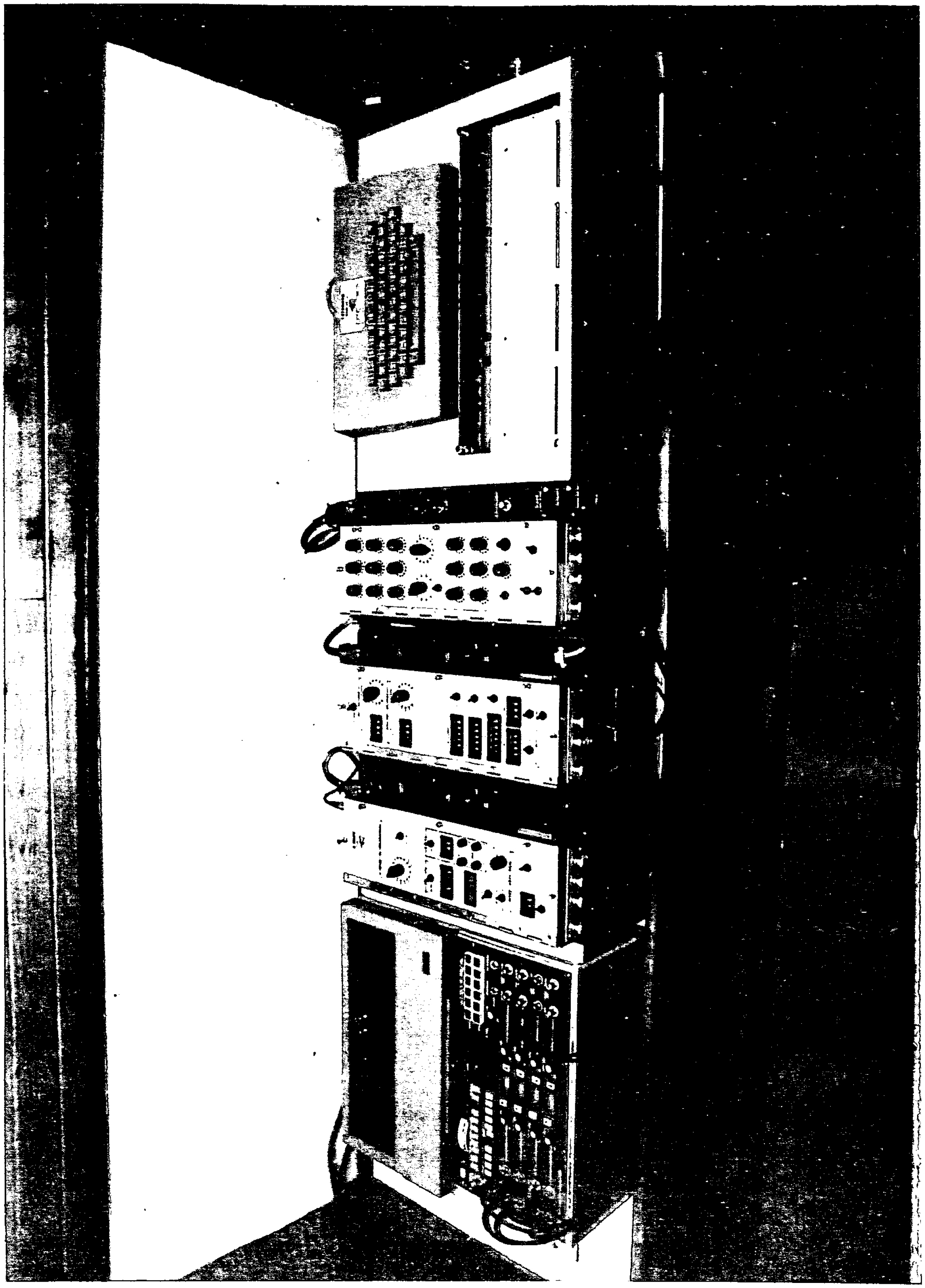

Fig. 19: A typical complete K-MAPS™ shipboard installation including the Three Channel Graphic Recorder, Digitizer/Alphanumeric Record Annotator with Keyboard, K-MAPS™ module and Magnetic Tape Recorder.

27 meters. The side scan survey was done with the 100 meters scanning range at towfish altitudes of 10 to 25 meters while scanning at speeds of 2,5 to 3,5 knots. The sea state at the time of survey was SS3. The clarity of the bottom composition is remarkable. Rock outcrops, coarse sand, fine sand and mud are well defined. The sand ripples can be clearly seen and are an example of the exceedingly good resolution that can be achieved. Figure 22 shows a mozaic of a nearby area and Figure 23 was made using a Klein 50 kHz towfish, covering an area of 5,6 km by 4,0 km. Figure 24 is a mozaic showing rock outcrops with sand and silt in an area north-east of the Isle of Shoals, New Hampshire in water depths of 30 m to 60 m, made with a 50 kHz and 3,5 kHz Trifish, a 531T Recorder, the 606 Digital Processor, the 612 Digital Processor and a 100 meter light-weight cable. The survey was done using Loran C for positioning and the lines were run at 3,5 to 4,1 knots with scanning ranges of 500 meters per channel. The sonar signals were recorded on an HP 8 track tape recorder. Figure 25 is a mozaic of an area off Newburyport, Massachusetts, done using the 100 kHz and 3,5 kHz Trifish, the 531T Recorder, 606 Digital Processor, 612 Digital Processor, HP 8 track tape recorder and 100 meter light weight cable. The sonographs show a bottom composition of sand and clay with a few rock outcrops. The survey was carried out using Loran C for positioning, with lines run at 3,1 to 3,7 knots. The scanning range was 150 meters per channel and the water depths of the area scanned ranged from 25 meters to 45 meters.

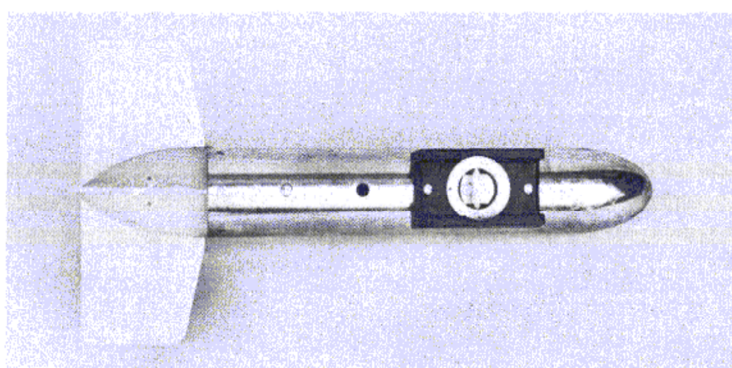

Fig. 20 : Bottom view of towed speed sensor.

CONCLUSION

Side scan sonar systems have come a long way from a standpoint of technology and customer acceptance. In order to improve the sonar results we have had to look in detail at every aspect of the sonar system, from the towfish to the final readout. Because of many types of customer applications and budgets and working conditions, we have tried to keep our systems modular and flexible. The biggest advances, however, have come in the area of digital and microprocessor electronics. Now that these new technologies are built into the sonar systems we can expect to see continual improvements in the sonar data. As the sonar pictures improve, they will come closer and closer to the quality of aerial photographs. We are finally within reach of the possibility of making the ocean transparent.

ACKNOWLEDGEMENTS

After nearly twenty years of working in the design and field operation of side scan sonar systems, I sometimes think of myself as a maker of fine "musical instruments" or "violins". One of the great joys of this profession comes when someone produces really fine results.

It was an honour for me to share the platform at this seminar with Dr Burg Flemming. As a user, record interpreter and author in the side scan field, Dr Flemming is one of the world's great "violinists". I also wish to thank Bill Russell-Cargill for inviting me and Specialist Offshore Surveys Ltd for sponsoring my visit.

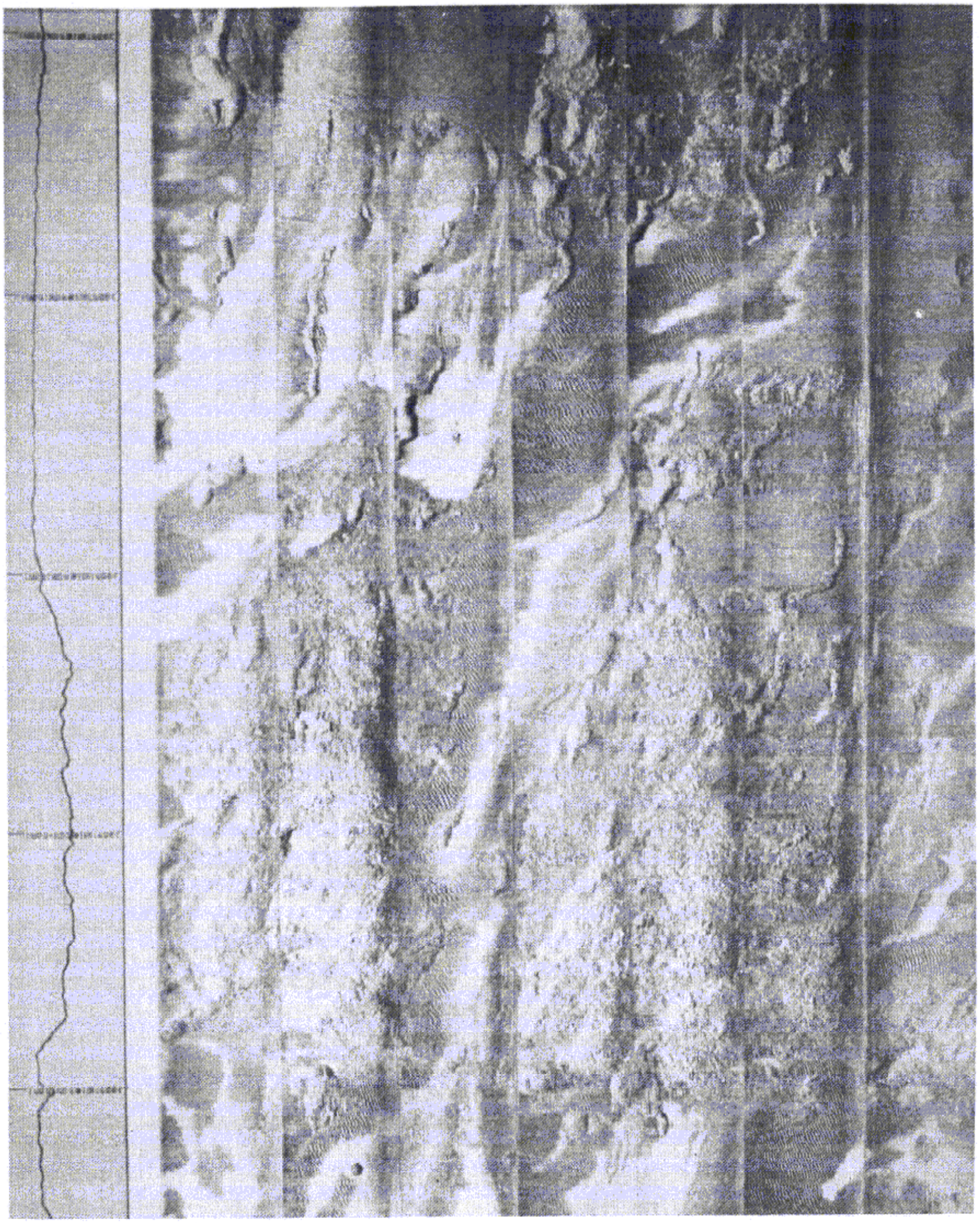

Fig 21.: K-MAPS™ sonar mosaic made off the coast of New Hampshire. The mosaic was made with a 100 kHz sonar using a corrected range of 100 meters per side. The mosaic covers an area of 1.05 km by 0.7 km. Note the altimeter trace from the section of the record. Each original strip of record has its own altimeter trace.

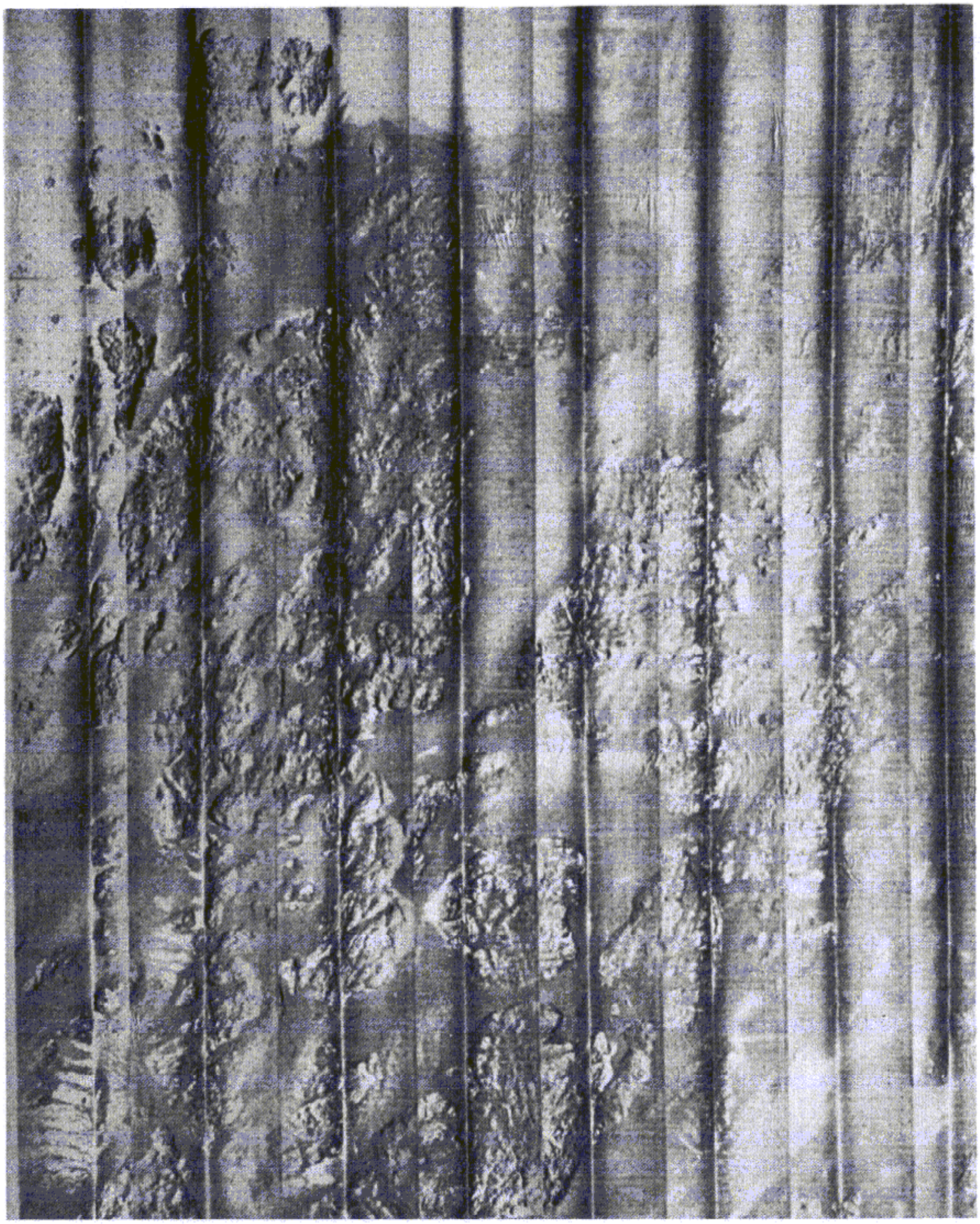

Fig. 22: K-MAPS^{TM} sonar mosaic made off the coast of New Hampshire. The mosaic was made with a 100 kHz sonar using a corrected range of 150 meters per side. The mosaic covers an area of 3.0 km x 1.85 km.

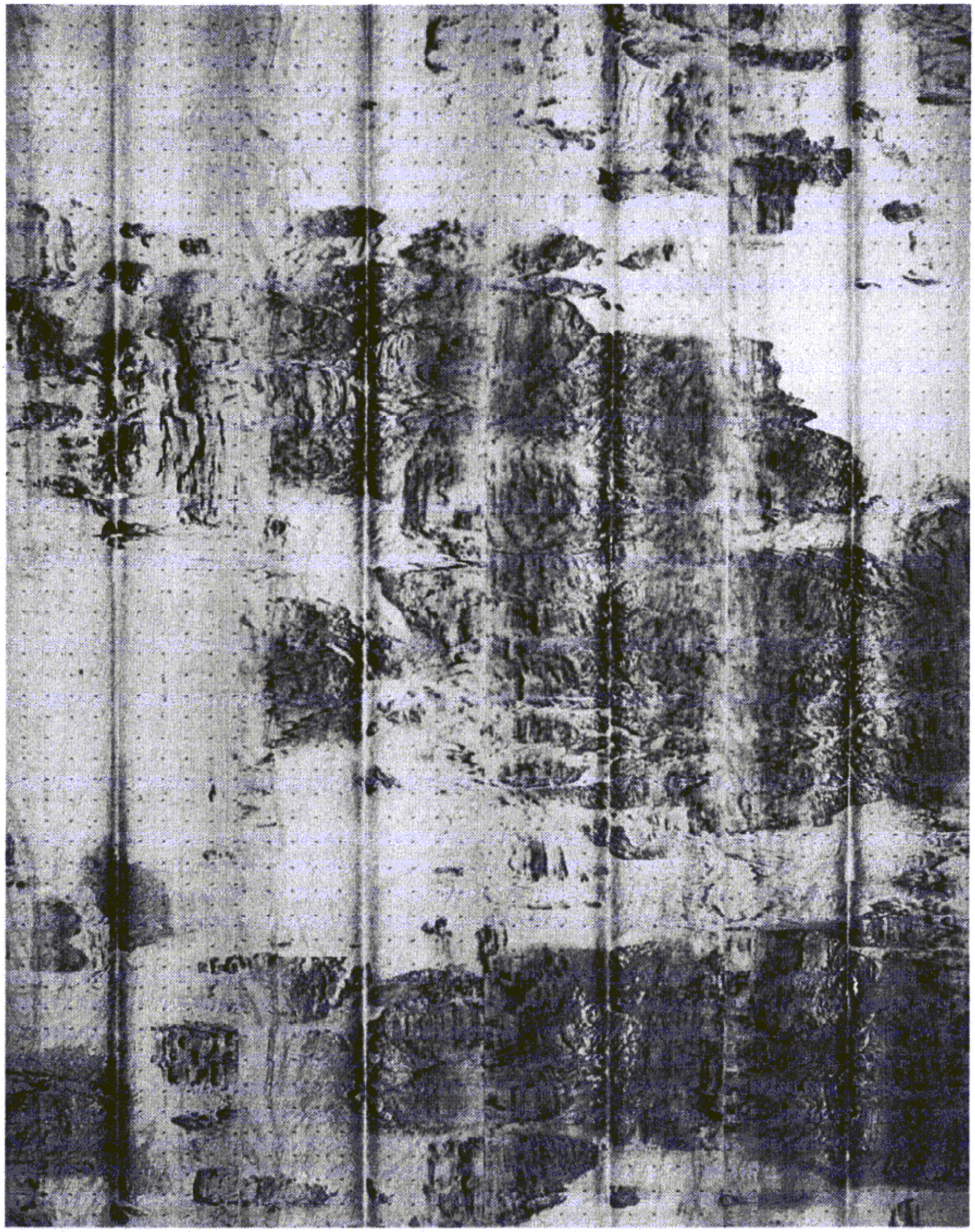

Fig. 23: Wide Area K-MAPS™ made off the coast of New Hampshire. The mosaic was made with a 50 kHz sonar using a corrected range of 550 meters per side. The mosaic covers an area of 5.6 km x 4.0 km.

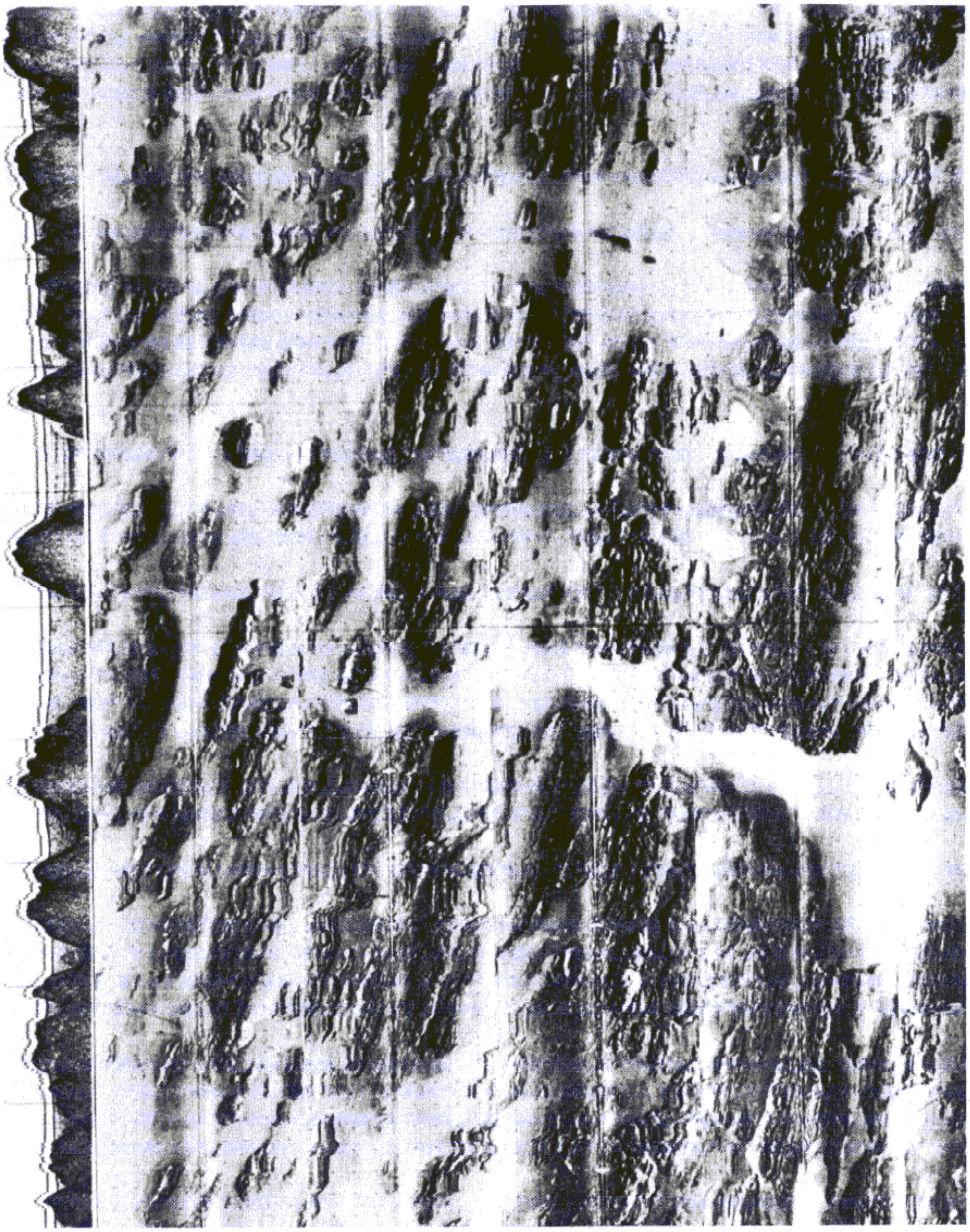

Fig. 24. K-Maps™ Sonar Mozaic of an area N.E. of Isle of Shoals, New Hampshire made using a 50 kHz and 3,5 kHz trifish. The sonographs were done on the 531-T Recorder with a range setting per channel of 500 meters. The bottom composition consists of rock outcrops with sand and silt.

Fig. 25. K-Maps™ mozaic made off Newburyport, Massachusetts with the 100kHz, 3,5kHz Trifish. A scanning range of 150 meters per channel was used and shows a bottom composition of sand and clay with a few rock outcrops.