A LONG RANGE SIDE-SCAN SONAR FOR USE IN THE DEEP SEA

(G.L.O.R.I.A. PROJECT)

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FOREWORD

This brief description of a long range side-scan sonar, developed by the National Institute of Oceanography, has been written at the request of the International Hydrographic Bureau. A more detailed paper is being written at the moment by the team responsible for its development, which will describe the system more adequately.

INTRODUCTION

In 1960 the National Institute of Oceanography developed the first side-scan sonar [1] based on earlier work first reported by Chesterman, Clynick and Stride [2]. With this type of sonar a pulsed beam of sound is radiated at right angles to the path of the survey ship. The beam is narrow in the horizontal plane (typically 2° wide) and fairly broad in the vertical plane (10-20° wide). The axis of the beam is depressed slightly from the horizontal so that the sound strikes the sea floor at a small angle. The backscattered energy from successive sweeps is displayed contiguously on a recorder, and in this way an acoustic picture or map of the floor is built up. They operate typically at about 35 kHz with a range of 1 000 metres in a maximum water depth of 300 metres.

The success of this device, and its descendants, in providing geologists with useful information about features and materials on the Shelf prompted the Institute in 1964 to undertake the design study for a similar sonar for use in the deep sea. Since the depths now envisaged would be as great as 8 000 metres it was decided to try and "scale-up" the geometry and performance of the original system by a factor of 25, giving a maximum required range of 12 nautical miles or 22 kilometres.

It was clear that if there was to be any chance of achieving this range the operating frequency would have to be radically lowered, since sound energy is absorbed as the square of the frequency. However it was also essential for good angular resolution that the narrow horizontal beam should be maintained at a width of about 2°. Since the latter is dependent on the baseline length of the array in terms of the wavelength used, any severe reduction in frequency would lead to a physically long array. A compromise was reached at about 6.5 kHz where the required array length was 5 metres, and the estimated power needed was about 50 kW. The design study also showed that due to refraction the maximum range would only be achieved in water depths greater than 2 000 metres.

One of the problems was yaw stability. Sound takes approximately 30 seconds to travel a 44 kilometre round trip, and during that period the array would have to be held steady in yaw to better than the horizontal beam width, say ½°. This precluded, amongst a number of other good reasons, having the array attached to the ship. It seemed likely that this sort of yaw stability could only be achieved by mechanically decoupling the array as far as possible from the moving ship, through placing it in a vehicle and towing it at a considerable depth. This would have other advantages. It would then be possible to radiate 50 kW of acoustic power successfully without waveform distortion or cavitation, it would reduce the initial refraction of the sound by the near surface temperature structure, and it would remove the array from the immediate vicinity of the noise at this frequency — which is predominantly caused by the ship's propeller.

DEVELOPMENT OF THE SONAR SYSTEM

Two major investigations were undertaken as a result of the design study: the development of a transducer capable of radiating the required power level efficiently at this frequency, and a study of the hydrodynamic stability of a suitably shaped vehicle to carry the array.

The first investigation resulted in the development of a piezoelectric lead zirconate titanate tranducer with an electro-acoustic efficiency of over 90%, and a power handling capability of 600 watts at a duty cycle of 1/6. This element is shown in figure 1. It has no nodal mounting and is simply held by a clamping ring around the compliant edge of the aluminium alloy radiating head. This eliminates the accurate machining tolerances required

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FIG. 1. – The lead zirconate titanate transducer element designed for the G.L.O.R.I.A. array. An accelerometer is shown attached to the diaphragm for monitoring its performance.

FIG. 2. — The 1/3rd scale model of the proposed sonar vehicle, seen at night on board R.R.S. *Discovery* during trials.

FIG. 3. — The sonar vehicle seen in its davits on R.R.S. *Discovery*. The nose and tail sections have been withdrawn for ease of servicing.

FIG. 4. — An 'exploded' view of the sonar vehicle.

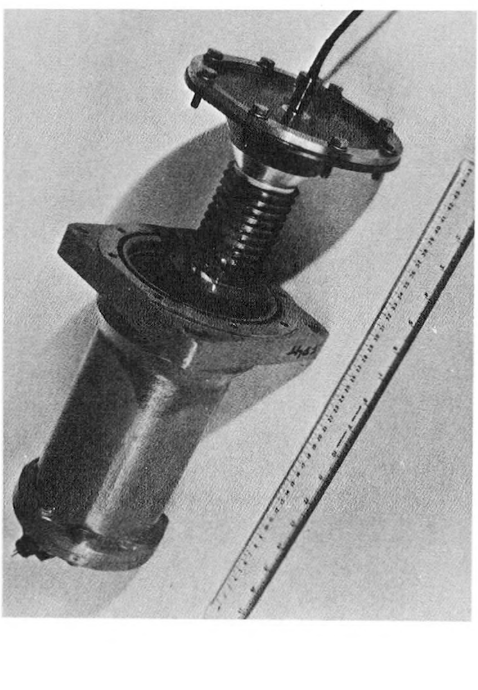

FIG. 1

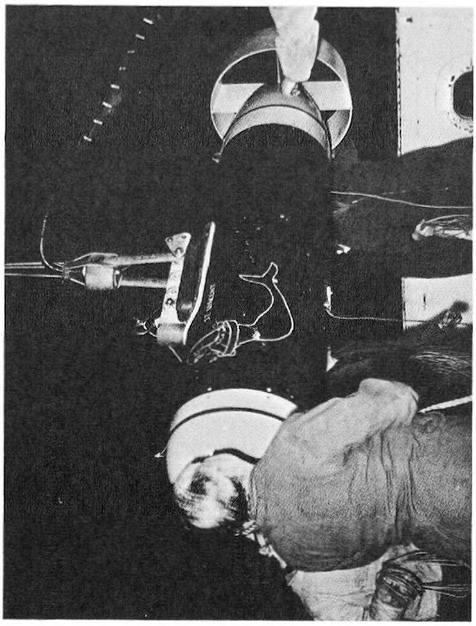

FIG. 2

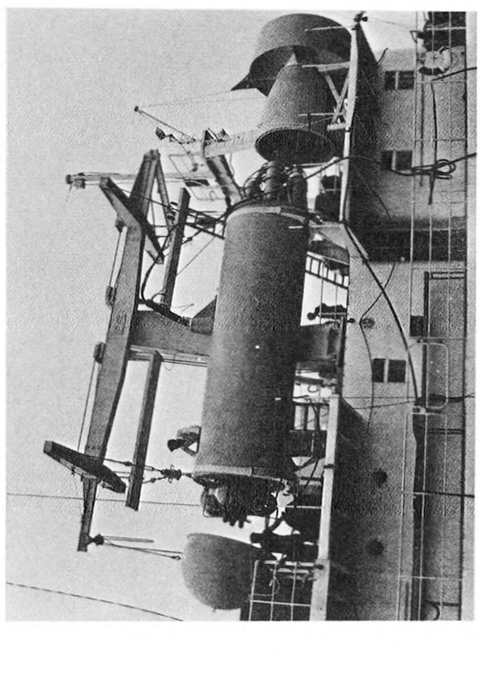

FIG. 3

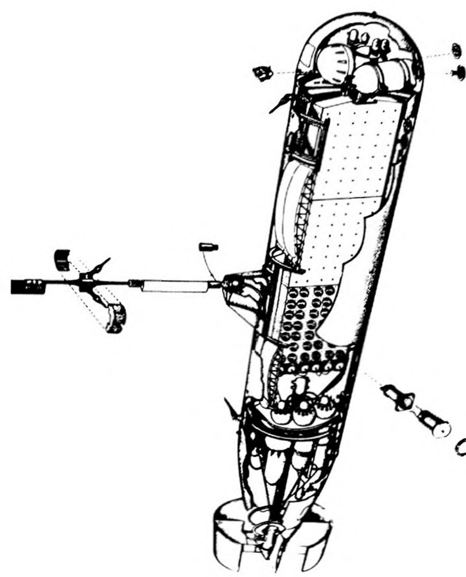

FIG. 4

between the nodal plate and the radiating head, as well as the considerable mechanical loss which the usual rolling O-ring diaphragm seal incurs. The radiating face is protected from stress corrosion in sea water by the application of a resin layer sprayed on electrostatically. The rear of the radiating head is backed by the air in the pressure case, which forms a near perfect pressure release medium. This is not spoiled by the need for liquids or other heat conducting media, since the internal dielectric and mechanical losses of the transducer are so small. This type of element is capable of operating down to a depth of 300 metres.

For the second investigation mentioned, concerned with the hydrodynamic stability of a towed vehicle, a 1/3 scale model of the proposed design was constructed and towed. The 3 metre long model is shown in figure 2 on board R.R.S. *Discovery* during trials. It had a torpedo-like shape with a fineness ratio of 5/1 and was fitted with a drogue tail assembly with aerofoil fins for good directional stability. The model was made in three glass fibre sections. The nose and tail were of glass-polyester mat construction, and the centre section was a filament wound glass-epoxy cylinder. In order to ease the recovery problem, and to duplicate the full size vehicle, the body was fitted with a flooding and deballasting system. Both yaw and roll/pitch gyros were fitted and an accelerometer monitored heave. The towing head hinge position could be altered to change its distance from the centre of pressure. The model was towed in a tank and later at sea from *Discovery* under various sea conditions and usually at 6 knots, the scale Froude speed equivalent to 10 knots. It was found to be naturally very stable in yaw. Typical results showed that if the model was running at 120 metres depth or more it yawed by $\pm \frac{1}{2}°$ for $\pm 2°$ of ship yaw. Later it was fitted with a gyro controlled rudder which improved on this figure by a factor of 3. The heave measurements showed that there was a surprising degree of coupling between the towing point and the vehicle with long lengths of cable out. Even with a rubber accumulator in circuit the model usually still experienced 50% of the heave acceleration of the towing point, when running at a depth of 150 metres.

Advantage was taken during the model trials to fit the vehicle with a transducer element of the type developed for the sonar, so that cavitation thresholds and background noise measurements could be made as a function of depth and speed. Both these additional measurements proved to be very valuable [3].

On completion of this work it was possible to go ahead at the Institute on the design of the full-sized vehicle and the auxiliary apparatus needed. The vehicle which emerged from this work is shown in its davits on board *Discovery* in figure 3, and an 'exploded' view is given in figure 4. Almost identical in form to the model, it carries the sonar array in the filament wound centre section on bearings fitted at either end in aluminium bulkheads. The aluminium array frame and transducers are shown in figure 5. The frame is 5 metres long and 1.25 metres high, giving a 2° horizontal beam and 10° vertical beam, and carries 144 transducer elements whose performance can be monitored by *in situ* accelerometers. The frame can be remotely rotated through 240° from the ship, to look either to port or starboard, and to adjust the sound launching angle for the particular propagation conditions which apply. The vehicle contains its own compressed air supply capable of fully deballasting the 13 cubic metres of entrained water at a maximum depth of 200 metres. Various services are provided in the vehicle including monitors of depth, water temperature, roll, pitch, yaw and heave. The yaw gyro also provides information to the rudder control servo system, as well as to a receiver beam steering loop which is fitted in the vehicle. The latter effectively locks the receiving beam on to the direction in which the last pulse was transmitted, compensating for any residual yaw during the listening period.

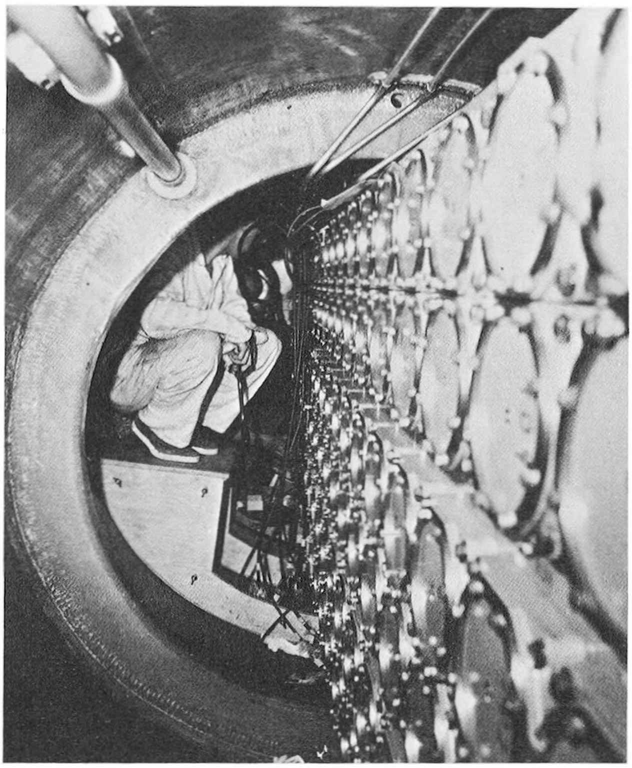

FIG. 5. — A view taken inside the vehicle of the transducer array. During a sonar run the vehicle is flooded and there is a loss of about ½ dB through the vehicle skin on transmission and reception.

The load of the vehicle, which weighs 6.7 tons in air and 3.5 tons in water, is passed through the structure to a towing head assembly with a ball and socket joint which can be seen in figure 4. The ball is part of the cable termination and allows it to take up the correct angle for any particular towing speed.

Apart from the vehicle many other parts of the system had to be thought about and made. These included an electric strain cable for towing it, constant tension davits for handling it in a seaway, and a power amplifier capable of providing 60 kW for the array. The towing cable was manufactured by Standard Telephones and Cables Special Cables Division in

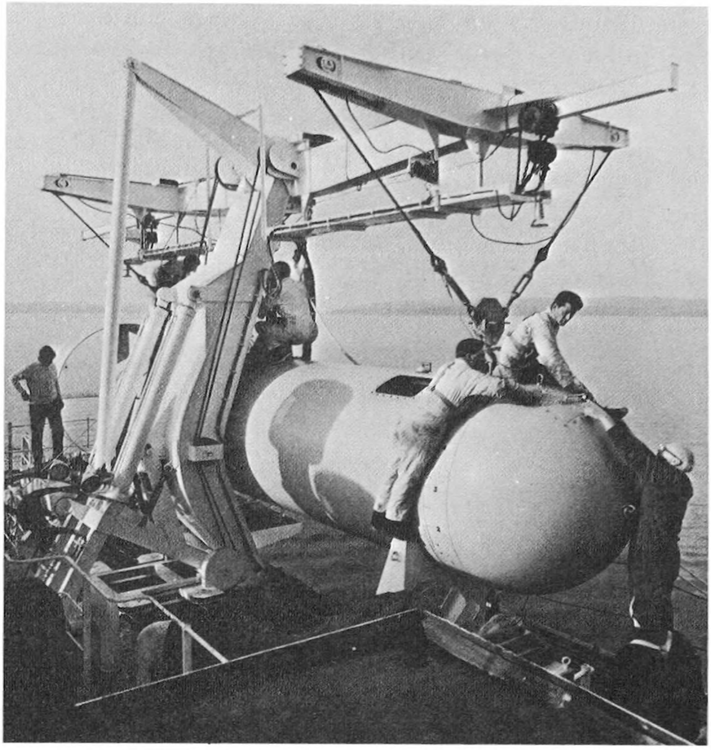

FIG. 6. — The sonar being prepared for a calibration run in Loch Fyne.

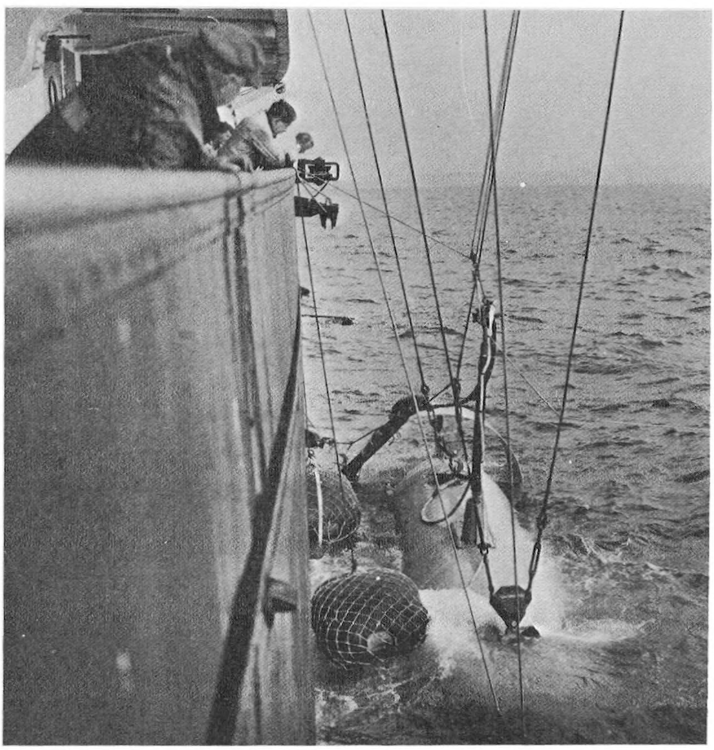

FIG. 7. — The vehicle being deballasted alongside *Discovery* before being hoisted aboard.

Wales, and includes about 80 signal and power cores in addition to the main sonar cores. Two high tensile steel armour wire layers give a breaking load of 30 tons, which results in a safety factor of about 4 when the vehicle is towed at 6-8 knots from a heaving towing point. The davits were designed and made by Schat Davits of London, and incorporate electro-hydraulic constant tension winches for each fall. They can be seen in figure 6, and in action in figure 7, where they are rendering and tensioning in response to the wave motion while the vehicle is being deballasted alongside before being lifted on board *Discovery*. The acoustic power amplifier was built by Derritron and is capable of producing 80 kW at a maximum duty cycle of 1/6, corresponding to the longest pulse used.

The model trials showed that although yaw was usefully attenuated with towing cable length, heave was rather poorly reduced. It had been hoped that the cable catenary would provide a useful decoupling compliance. In order to try and combat the expected heave the full size system incorporated twin nylon ropes 250 feet long to act as accumulators. These were mounted on each side of the ship around low inertia aluminium sheaves. They were terminated by wire bridles led round dynanometers and attached to the towing cable. This scheme was reasonably successful, although it was important to keep the ropes well oiled, with castor oil, where they were worked around the sheaves. When surveying, as a precaution, they were replaced every five days.

FIG. 8. — Scientists examining a sonar record from the display recorder mounted on the central console.

The sonar is designed to radiate either short CW or long FM broadband pulses. The latter are correlated against a replica stored in a Deltic correlator. In fact the correlator has been very little used so far: quite adequate signal to noise values have been obtained with a 30 millisecond CW pulse at 6.5 kHz.

All the signal generation and processing circuits, the vehicle controls and monitors, as well as the display recorder, are mounted in a control console, part of which can be seen in figure 8. The recorder is a normal wet paper device with twin helices. The helix and paper drive is geared in such a way that a true scale display appears on the right hand record, for a variety of ship speeds and sonar ranges.

RESULTS OBTAINED

On completion the sonar was taken to Loch Fyne in June 1969 to carry out handling, towing and calibration trials. After successfully completing these *Discovery* moved into the Western Mediterranean to try out the sonar against a variety of geological targets. Later in the summer a brief visit was made to an Atlantic site to test the performance of the system in true oceanic depths. Some examples of these first results [4] will be shown and briefly described.

Figure 9 gives the positions of the areas covered by the Mediterranean records shown in this paper. In these records dark markings indicate high signal returns, i.e., from coarse sediment or rock, while light toned areas indicate fine sediments or acoustic shadows. The direction of 'illumination', or sound radiation, is always shown by a broad arrow, and the down slope direction of the Continental Slope in each example is given by a long thin arrow. The provisional geological interpretation of the Mediterranean records is based on that given by BELDERSON, KENYON and STRIDE (see reference [5]), who were the geologists present during the Mediterranean trials.

Figure 10 shows a true scale record of a canyon running down the Continental Slope off Barcelona. It is about 3 km wide with walls which are reasonably smooth and nearly parallel for a distance of at least 10 km. The floor of the canyon appears nearly white because it lies in the shadow of the 'near' wall. The effects of the deep shadow zone, due to insufficient water depth, can be seen to the right of the record where details beyond the right hand wall are lost in a light toned area. Further records in this region showed a number of similar canyons, some of which contained stepped lenticular features which have been provisionally interpreted as slumps.

Records obtained near south eastern Majorca, again on a Slope, show a succession of linear and almost horizontal features which extend for many kilometres. An example of this type of picture is shown in figure 11 which is a true scale record that extends from near the top of the Slope down to a depth of about 1 400 metres near the bottom of the record. One

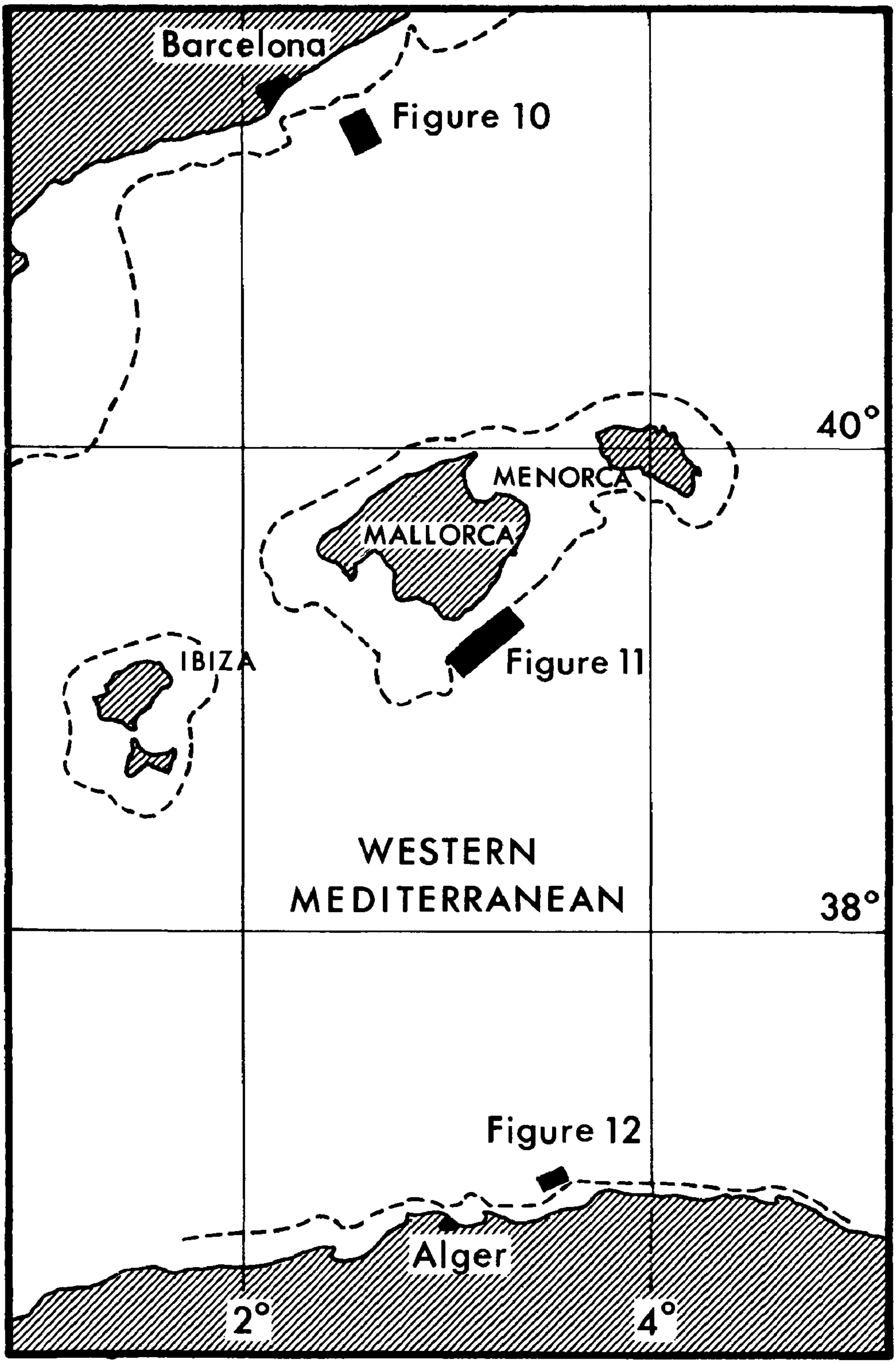

FIG. 9. — A chart showing the approximate geographical positions of the records shown in figures 10, 11 and 12. Pecked lines give the approximate limit of the Continental Shelf.

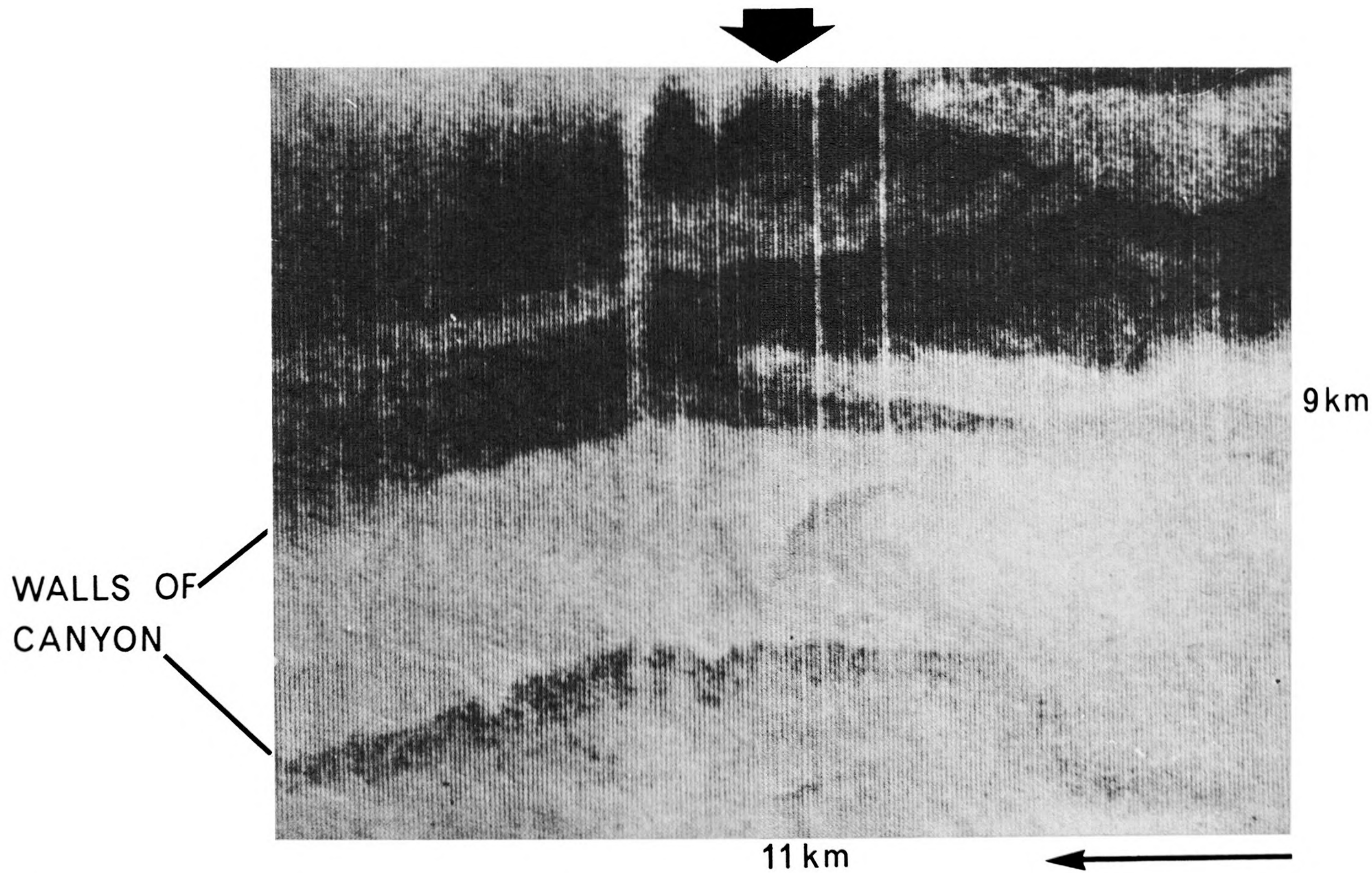

Fig. 10. — A nearly true plan view of a 3 km wide submarine canyon running down the Continental Slope off Barcelona. The broad arrow gives the direction of 'illumination', and the thin long arrow the downslope direction.

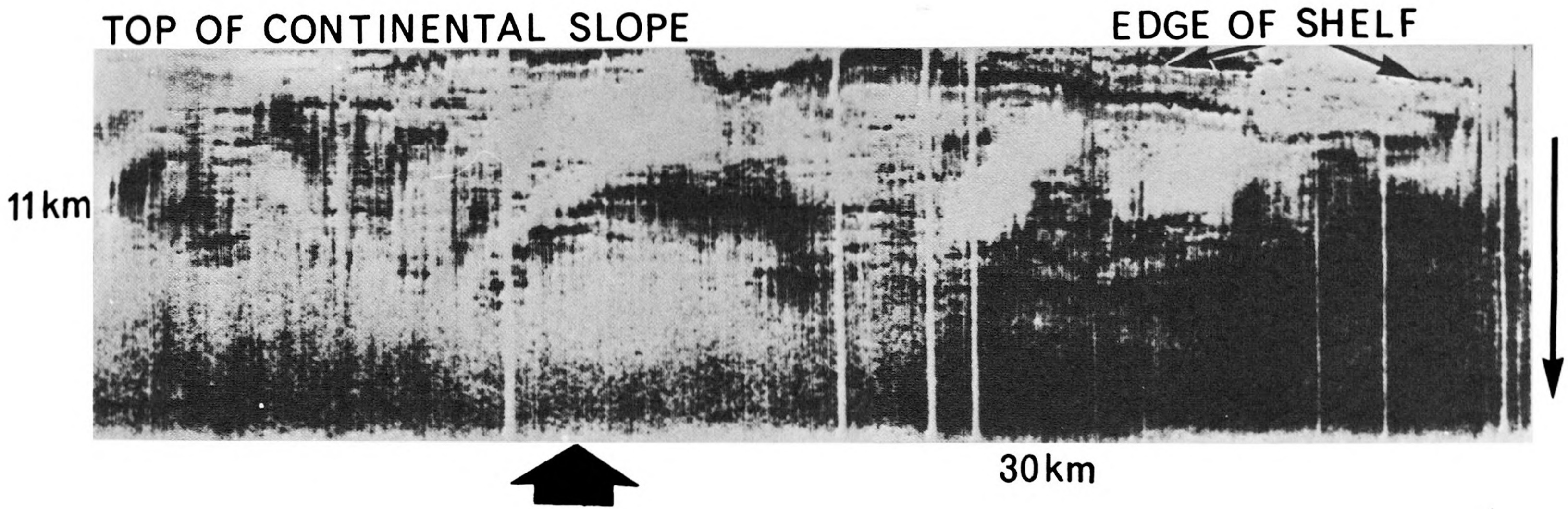

Fig. 11. — A nearly true plan view of over 300 km^2 of Continental Slope off south eastern Majorca. It is possible that the beam width causes some enhancement of the linear pattern. The broad arrow gives the direction of 'illumination', and the thin long arrow the downslope direction.

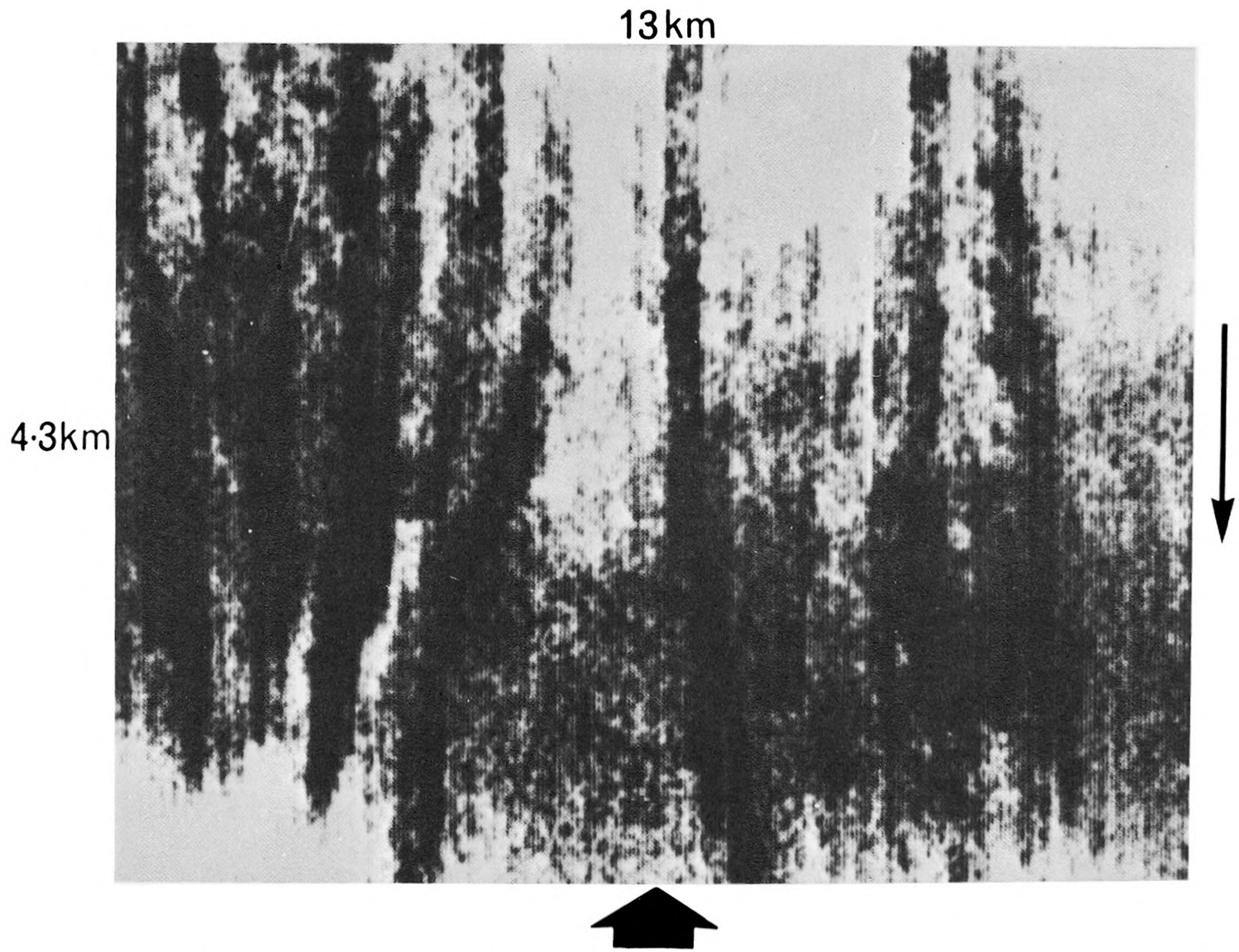

FIG. 12. — A record obtained from part of a survey carried out off the North African coast near Cape Bengut east of Algiers. The range scale is exaggerated by a factor of about 3. The broad arrow gives the direction of 'illumination', and the long thin arrow the downslope direction.

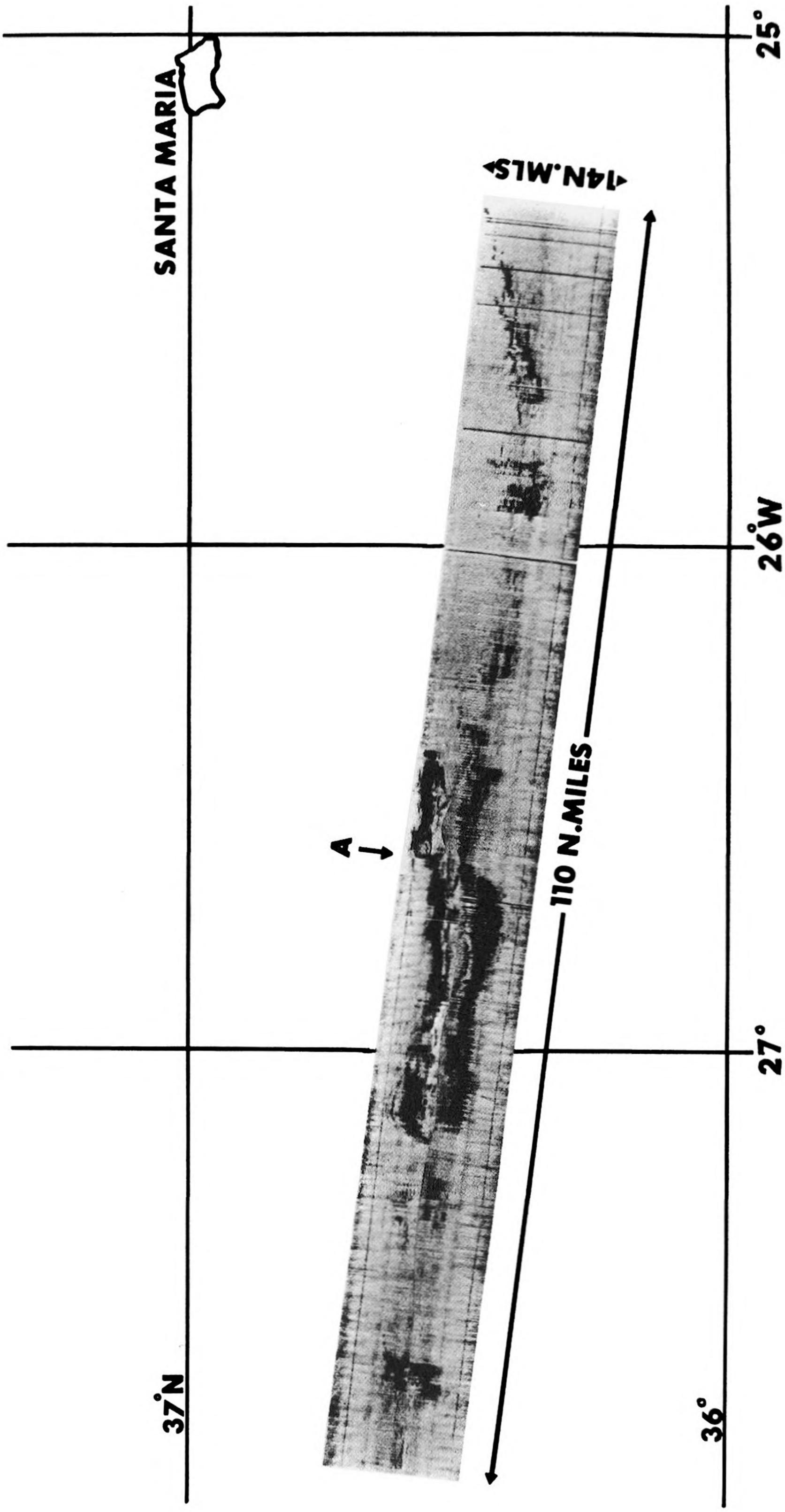

FIG. 13. — A true scale composite record of a ridge about 1 kilometre high lying at a depth of about 4 kilometres south of the Azores Islands in the Atlantic. The record covers an area 200 by 25 kilometres.

of these features, near the top, runs for about 11 km, others tend to be interrupted by light toned areas running at an angle down the Slope which may be troughs. Certain transmission scans have been lost due to failure in the transmit/receive interlocks, this has produced the straight white bands which can be seen at intervals along the records. BELDERSON, KENYON and STRIDE [5] have discussed the origin of these linear features on these records in the light of other information obtained at the same time and from other sources. They suggest that they may be sea-cut benches and cliffs, cut during pauses in the general sinking of the land from the latest Tertiary to Pleistocene periods.

Again a different type of record is shown in figure 12 obtained from a short survey of the Continental Slope off the North African coast near Cape Bengut. This shows sharply defined, nearly parallel, dark toned, ribbons running down the Slope, about ½ to 1 km wide. They were found over the full lateral extent of the sonar run made, about 30 km. Again these have been discussed in reference [5]; they may be rough surfaces which have been scoured by the passage of slumps and turbidity currents. Nearby is an area where five submarine cables were broken sequentially through the downslope movement of sediment following the Orleansville earthquake in 1954.

As a contrast to these Mediterranean records the final example shown, in figure 13, is of an east-west ridge lying at a depth of 4 500 metres south of the Azores Islands. The figure shows a true scale composite record, which was obtained using the longest range scale of 22 kilometres. Due to the greatly increased depth the effects of the deep shadow zone are not evident within this range. The record was obtained by first steaming along the southern edge of the ridge looking to starboard, and then returning along the northern edge, still looking to starboard, to illuminate the northern flank which had been in shadow on the first part of the run. From echo sounding traverses the main part of the ridge is about 900 metres high. It is possibly faulted at the point marked A, and may have a number of terraces. The survey was carried out in about 24 hours.

CONCLUSION

It appears from these results that the static and dynamic propagation characteristics of the medium do not produce a significant deterioration in the resolution of a narrow sound beam extending over many kilometres. In the vertical plane refraction does produce a deep shadow zone, but even in the Mediterranean useful ranges can be achieved. As a result the sonar was able to provide useful geological records with reasonable resolution and to survey large areas quite quickly at a speed of 6-8 knots. At this stage the interpretation of the features noticed on the records is rather tentative, but will no doubt improve when more experience is gained in the geological use of the device, particularly in combination with other instruments, and when a larger number of records have been obtained for comparison.

Work is continuing on further development of the system, particularly to try and reduce the coupling between the vehicle and the ship. It may also be found possible to improve the angular resolution of the sound beam on reception.

ACKNOWLEDGEMENTS

The development of the project and the success of the initial trials is due to the efforts of many people at the National Institute of Oceanography, and to the able assistance of the Captain and crew of R.R.S. *Discovery*.

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