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THE DEVELOPMENT OF A HIGH-RESOLUTION SEISMIC PROFILING SYSTEM FOR SHALLOW WATER 1971 and 1972.

by

B.H. Dolan

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SUMMARY

The Bureau of Mineral Resources, Geology & Geophysics is carrying out a development program for obtaining high-resolution seismic profiling data in shallow water for engineering and marine geological applications. This record outlines the developments to the end of 1972. A sparker system which has given records with resolution better than 1 ms and depth of penetration to 30 m has been tested. A comparison of the acoustic waveforms of various transducers is given.

1. INTRODUCTION

Program

The program for the experimental shallow profiling was formulated in March 1971. The aims were to devise systems or techniques which would meet the following needs -

(1) For shallow geological work:
   (a) Penetration of 30 m.
   (b) Resolution of 1 millisecond or better
   (c) Operational depths, say 2 m to 30 m; 2 m is about the shallowest water into which a 10-m boat could venture.

(2) For deeper geological work the existing equipment and techniques were considered adequate.

(3) For engineering geophysics the needs were covered in (1) and (2) above with emphasis on (1).

Tasks were allocated as follows:

(1) Literature search and theoretical investigations - B.H. Dolan, Engineering Geophysics Group.

(2) Planning of experiments - B.H. Dolan.

(3) Equipment preparation - A.G. Spence and A.B. Devenish (from the Electronics Sub-section) with R. Dulski (from Marine Geology Group) and M.J. Dickson (from Engineering Geophysics Group) assisting.

Basic seismic system

Marine seismic profiling systems consist basically of (a) an acoustic energy source, and (b) a recording system.

A pressure pulse is emitted by a transducer in the water. A pressure pulse reflected from an interface is received by another or in some cases by the same transducer and converted to an electric pulse. This pulse is amplified and recorded on electrosensitive paper. The emission of the pressure pulse is synchronized with the sweep of a stylus across the recording paper. The stylus carries a current which is proportional to the signal amplitude from the receiving transducer. The speed of the stylus across the paper is constant. When a current passes through the paper a mark is made on the paper and the intensity of the mark is proportional to current intensity. Therefore marks on the paper represent a pressure pulse being received and the distance down the chart is proportional to the delay time between the transmitted and received pulse. The three acoustic energy sources investigated - sparker, boomer, and pinger - are briefly described below.

Energy sources

Sparker. The sparker uses an intense electric discharge into the sea water to produce the pressure pulse. The electric discharge vaporizes the water around it, causing a sudden increase in pressure. The sparker transducer element is an insulated electrode one end of which is bared and exposed to the water. The circuit is completed through the water via an earthed metal frame (see Fig. 1) which surrounds the element. A bank of capacitors is charged to several kilovolts, the energy of discharge being determined by the capacitance of the capacitor bank. Since relatively small energy levels are used in shallow-water profiling (up to 1 kJ) the sparker and frame can be made quite small and easy to handle.

Boomer. The boomer also uses the discharge from a bank of capacitors, but in this case it is passed through a flat coil of heavy gauge copper in an insulated block, which is in contact with an aluminium plate (see Fig. 1). The transient magnetic field produced by current in the coil induces eddy currents in the aluminium plate, and the magnetic field produced by these currents causes the plate to be violently repelled from the coil, so producing an acoustic pulse.

Pinger. The pinger is a magnetostrictive or piezo-electric transducer which is either excited into oscillation at its resonant frequency by an electric pulse or driven by an oscillating electric signal. Generally, a relatively high frequency (3-12 kHz) is used, and the peak pressure produced is much less that that from the sparker.

Approach to the problem

The energy sources and receiving systems were examined both theoretically and experimentally. A field test of various systems was carried out in Mallacoota Inlet, where the depth of water varied from 1 to 20 m.

This record reviews the work up to the end of 1972.

2. METHODS AND EQUIPMENT

Bibliography

A bibliography (see Chapter 9) of work related to the general problem of continuous seismic profiling was completed; special attention was given to information about high-resolution systems and systems for use in shallow water. Duplication of information has been avoided in the printed Bibliography.

This information served as a guide for the experimental program outlining the special problems involved.

Energy sources

The acoustic output characteristics desired are: (a) short transmission period (for high resolution) and a wide range of frequencies (for both penetration and resolution); (b) sufficiently high peak pressure.

The sources examined were the Sparker, Sonar Boomer, and Pinger. The construction of the first two is shown in Figure 1. The sparker transducers were constructed in the BMR laboratories. The Sonar Boomer transducers were made by Edgerton, Germeshausen & Grier, Inc. (E.G. & G.). One was modified by BMR (see Fig. 1) following a suggestion of Professor Sargent (1969) for bubble suppression.

Both these transducers were activated by an E.G. & G. Sonar Boomer model 232 power supply with a model 231 triggered capacitor bank. This was modified to provide energy discharge steps of 0.1 kJ, (16μF at 3.5 kV). The cable to the sparker had a calculated inductance of 13μH.

Two pinger systems were used: an EGG 5-kHz sediment probe and a Raytheon 3.5-kHz type PTR-105A.

Measurement of acoustic output. A block diagram of the equipment used in static tests to measure acoustic output is shown in Figure 2. The pressure pulses were picked up with an Aquatronics type 1210 piezo-electric hydrophone or an E.G. & G. type 262G hydrophone. Both these hydrophones have a wide frequency response. The 1210 has a sensitivity of -88 ± 5 dB ref. 1 volt per microbar from DC to 11 kHz. The 262G has an essentially flat response from 20 Hz to 10kHz at the same sensitivity.

The output from these hydrophones was recorded on a Tektronix type 564 storage oscilloscope and photographed with a Polaroid camera. A frequency spectrum was obtained by digitizing the recordings and computing the Fourier amplitude spectrum.

Modifications. Based on a theoretical study of published data, and on the results of the measurement of the acoustic output of the available acoustic sources, a number of modifications were tested. The objects of these modifications were to produce a single pulse of short duration. Figure 1 illustrates modifications to the sparker and the modification to the boomer suggested by Prof. Sargent. These are discussed in Chapter 3.

The acoustic output of the modified sources was measured and compared with the unmodified sources.

Receiving transducers for survey work

The acoustic energy from the reflections is received by a pressure-sensitive transducer. The pingers generally use the same transducer to transmit and receive, whereas a separate transducer or assembly of transducers forming a hydrophone streamer cable is used to receive the reflections from acoustic pulses.

The hydrophones used were an E.G. & G. Type 262G single-element hydrophone and multi-element hydrophone streamer constructed by BMR using Aquatronics type 1210 hydrophones. The array was designed to minimize the effect of ambient ship noise and to enhance vertically incident signals. Details of both hydrophones are discussed in Chapter 4.

The acoustic range of both hydrophones extended well above and below the spectrum of the transmitting transducers. Both were easily handled and suitable for use in shallow water.

Signal processing and recording

An E.G. & G. model 254 recorder was used for the field tests. This recorder uses an Alden wet-paper recording system.

Because the energy spreads radially from the source, the amplitude of the received signal decreases with time. It would therefore be desirable to increase amplifier gain as later signals are received. An amplifier with time-varied gain was constructed by the Electronic Maintenance and Testing group of BMR. The gain of this amplifier increases linearly with time at a predetermined interval after it is triggered (see Fig. 5).

A Krohnhite bandpass filter was used in the field test to determine the effect of frequency filtering on the record.

3. RESULTS - ACOUSTIC OUTPUT

Recordings were made of the acoustic output of sparkers, boomers, and pingers. Representative records were selected and digitized and their Fourier transforms were computed. These records and their transforms are shown in Figures 6 and 7.

Sparker

The features of the sparker which were examined were the peak pressure, pulse duration, frequency content, and bubble pulse, and the relation of these factors to the stored energy. The effect of the modified sparker on these factors was examined.

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The relation between the pressure signal and the discharge current of the initial pulse is covered by Caulfield (1962). The bubble pulse is dealt with by Cole (1948), Roth (1963), Lavergne (1970), and Cassand & Lavergne (1970).

Caulfield showed experimentally that there is a linear relation between the peak pressure and peak discharge current of a single electrode sparker, and that the decay constant and hence the pulse duration of the initial acoustic pulse is within 10-15 percent of the decay constant for the discharge current. The relations are shown in Figure 3. Considering the sparker system to be an RCL (resistance, capacitance, and inductance) circuit it is therefore possible to adjust these parameters to obtain a desired peak current and decay constant.

The equation relating the current to the circuit parameters (Caulfield, 1962) is,

$$I = Be^{+bt} \sinh kt \qquad \text{for } R^2 > 4L/C \qquad (1)$$

(overdamped case)

or

$$I = Be^{-bt} \sin kt \qquad \text{for } R^2 < 4L/C \qquad (2)$$

(underdamped case)

where
- I = instantaneous current
- $B = Vo/Lk$
- $b = R/2L$
- $k = \sqrt{R^2/4L^2 - 1/LC}$
- t = time
- Vo = initial voltage
- L = total inductance
- C = total capacitance

The effect on the peak pressure of changing parameter C only is illustrated in Table 1. Since the capacitance is changed so also is the stored energy ($\frac{1}{2} CV^2$). The inductance in the E.G. & G. triggered capacitor bank is 25μH and the inductance of the cable used was calculated to be 13μH (Grover, 1946; Harnwell, 1949). This slows the rate of increase of current and hence the time of discharge. For small C the delay to peak current and

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the current duration will be significantly less than for large C. The relation is shown in Plate 4.

The bubble period (see 'Bubble Pulse', below) is tabulated against energy level to illustrate the increase in the bubble period with stored energy. See formula (4).

TABLE 1

Unmodified Sparker

Energy level (kJ)	Capacitance (μF)	Peak current from formulas 1 & 2	Pressure pulse duration (ms) measured	Peak pressure at 1 m (kPa) Initial pulse	Bubble pulse	Bubble period (ms) at 1 m	Bubble system energy as % of stored energy
0.1	16	1.5–1.7		20	26	5.3	16.0
0.4	64	2.2–2.5	0.1	58	86	8.6	17.1
0.7	112	2.5–2.8		78	90	10.8	19.4
1.0	160	2.6–3.0	0.4	90	95	12.8	22.6
Modified Sparker							
0.4	64		0.1	60	5	3.7	
0.7	160		0.4	50	50	14.5	

__Bubble pulse__. One of the principal difficulties with the sparker when used in shallow water is the production of a secondary or 'bubble' pulse. This is caused by the violent implosion of the cavity containing the vapour produced by the initial discharge. The delay between the initial pulse and the bubble pulse (called the bubble period) was measured to be 8–9 ms for a 400-J single-electrode spark at a depth of 1 m.

The direct arrival of this second pulse causes amplifier saturation and obliterates any reflected signal received at that time; the bubble pulse also results in each reflector being represented on the record by two lines, one from the first pulse and one from the bubble pulse. This means that following reflectors may be obscured by the bubble reflections. In shallow water, multiple reflections between the water surface and strong reflectors add to the confusion of the data, and discriminating multiple from 'real' events is made even more difficult by the existence of the bubble pulse.

The motion of the vapour bubble is oscillatory. After radiation of the initial shock, which takes less than ½ msec, half of the energy of the discharge remains in the form of internal energy of the vapours in the

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bubble and kinetic energy of the outward flowing water (Cole, 1948). The initial energy of the bubble is transferred to the kinetic energy of the water as the bubble expands. The pressure in the bubble decreases rapidly on expansion and owing to the inertia of the outward moving water actually falls below the external hydrostatic pressure. The bubble thus reaches a point of maximum radius, whereafter it starts to contract. This rapid contraction causes reheating and an increase in pressure of the vapour to such an extent that at the point of minimum radius the pressure is so great that a second pressure pulse is emitted. This oscillatory expansion and contraction of the bubble can continue for many cycles if the bubble does not break the water surface.

Cole derives two formulas relating the bubble period (T), liquid density (p), hydrostatic pressure (P), total energy of the bubble system (Y), and the maximum radius of the bubble (a)

$$T = 1.83\, a \left(\frac{p}{P}\right)^{\frac{1}{2}} \qquad (3)$$

$$Y = \frac{4\pi}{3} P.a^3 \qquad (4)$$

combining (3) and (4) we get

$$T = 1.14\, p^{\frac{1}{2}}\ P^{-5/6}\ Y^{1/3} \qquad (5)$$

P is equal to the total pressure due to the atmospheric pressure (10^5 Pa) plus the pressure due to the head of water (10^4 Pa per metre). Using this formula it is possible to calculate the total energy of the bubble system from measurements of the bubble period. These are tabulated as a percentage of the stored energy in Table 1.

In order to suppress the bubble pulse the energy of oscillation of the bubble must be dissipated before it collapses. This would mean that on collapse of the bubble less energy would be available to produce a larger pressure pulse.

The use of perforated cages around underwater explosions in order to eliminate the bubble pulse has been tested previously (Knudsen, 1961; Lavergne, 1970). This gave significant reduction in the bubble pulse, its amplitude being reduced to as little as 1/50.

Modifications. The sparker system was modified in order to reduce the pulse length of the initial pulse and to minimize the secondary or bubble pulse. The pulse length has been discussed above.

The bubble period and the peak pressure of the bubble pulse increase with increasing total energy of the expanding bubble of vapour and displaced water. The method used in trying to reduce this bubble effect was to dissipate the energy of the expanding bubble.

The use of screens pierced with holes (Knudsen, 1961; Lavergne, 1970), by analogy with the cages of the Flexotir system, has been tried without success (Cassand & Lavergne, 1970). Attempts to use this system were also made in the present investigation but without success. Cages with an internal diameter of 25 mm to 75 mm were used. These cages were made of polythene 30 percent perforated with 10-mm holes or of fly-screen wire. There was no significant reduction in the bubble pulse.

The most successful means of reducing the bubble effect was by using a fabric-reinforced rubber tube around the sparker. Rubber tubes with internal diameters ranging from 25 mm to 75 mm and lengths from 0.3 to 1.0 m were used.

Best results were obtained using a rubber hose of internal diameter 50 mm and of such a length that the spark is at least 0.2 m from the openings at each end. A reduction of the peak pressure of the bubble pulse to 1 percent of its original value is possible at an energy level up to 0.4 kJ (see Fig. 7). There was no significant effect on the peak pressure of the initial pulse.

Satisfactory reduction of the bubble pulse with the available rubber hoses was not obtained at higher energy levels. The best results were again with the 50 mm diameter hose but were not satisfactory (see Fig. 7).

It is considered that the reduction in the bubble pulse was due to loss of energy of the expanding bubble by inelastic deformation and heating of the rubber tube, and by the formation of vortices in the water being forced out of the tube.

Boomer

The following features of the acoustic output of the boomer were examined: peak pressure, pulse duration, frequency, and any additional undesirable transmissions (see Fig. 6).

The acoustic output of the boomer consists of an initial pulse lasting for approximately 1 ms and a train of high-frequency vibrations lasting for 5 to 8 ms.

The frequency spectrum of the initial pulse is shown in Figure 6. The train of vibrations that follows consists of predominantly two frequencies, around 12 kHz and 100 kHz. These frequencies were estimated from measurements of period taken from the original photographs. The Fourier analysis included frequencies up to only 7 kHz. The amplitude of these vibrations is generally 0.2 times the peak pressure of the initial pulse. Between 0.7 and 7 ms after the initial pulse, depending on the energy level, there is a sudden increase in the amplitude of the train of pulses. The amplitude of this pulse is approximately equal to the initial pulse (see 5, Fig. 6).

Modifications. The train of high-frequency vibrations produced by the boomer is due to vapour bubble cavitations on the surface of the aluminium disc.

The acoustic output of a modified boomer was also recorded. This boomer has a rubber sheet retaining the aluminium plate in place of the spring. This means that the aluminium is no longer in contact with the water. This modification reduced the train of vibrations (Fig. 6).

The Fourier spectrum of the acoustic output of the modified boomer is also shown in Figure 6.

Pingers

Two types of pingers were tested. One was constructed by E.G. & G. and the other by Raytheon.

Acoustic outputs. Recordings of the acoustic output of the pingers were made and two examples are shown in Figure 6. The Fourier analysis of the pressure signature is also shown. The duration of the wave train produced by the E.G. & G. pinger is from about 1 ms to 2 ms depending on the energy level used. The predominant frequency of the vibrations is 4.5 kHz.

The Raytheon pinger transmits an envelope of predominantly one frequency: 3.7 kHz (see Fig. 6). The minimum duration of this envelope is 1.5 ms or approximately 5 wave periods.

4. RESULTS - RECEIVING TRANSDUCERS

Two hydrophone arrangements were tested; one was a single-element E.G. & G 262G'eel'-type hydrophone, the other was a 7-element 'eel'-type hydrophone made by BMR. In both cases the element has a sensitivity of -88 dB ref. 1 volt per microbar. The response of the separate elements is essentially omnidirectional for wavelengths much greater than the size of the crystal, i.e. for frequencies much less than 100 kHz.

The BMR hydrophone array consisted of seven Aquatronics Type 1210 hydrophones equally spaced in a piece of clear PVC tubing of approximately 5.3 metres long. The tubing was filled with a mixture of Isopar and paraffin oil to render it neutrally buoyant. It was towed by a screened two-core electrical cable, and a 5-metre length of nylon rope served as a tail. The 65-cm spacing between hydrophones corresponded to a half-wavelength at approximately 1000 Hz, which was the frequency of the bulk of the output of the BMR modified sparker energy source. The purpose of this was to cancel any horizontally propagated signal at this frequency and to give some vertical directivity to the array. The hydrophones were electrically connected in parallel to lower output impedance and cancel incoherent noise.

Surface reflections

The incident signal is reflected off the water/air interface, resulting in a phase shift of π radians; i.e. a positive pressure will become negative and vice versa. This signal now interferes with the signal that travels direct to the hydrophone.

The nature of this interference will depend on the phase delay between the direct and surface reflected waves, which in turn depends on the depth of the hydrophone, the angle of the incoming waves, and the frequency (see Fig. 8).

The amplitude of the resultant signal is given (Jenkins & White, 1957, Ch. 13) by the formula

$$a(\theta) = A\left[1 - R\cos\left(4\frac{\pi d}{v} f \sin\theta\right)\right]$$

where A is the amplitude of the incoming signal
d is the depth of the hydrophone
f is the frequency of the signal
v is the velocity of the signal
θ is the angle (radians) of the signal ray path to the horizontal
R is the reflectivity of the water/air interface.

R is very nearly 1.0 and can be left out of the formula.

For maximum constructive interference of vertically incident ($\theta = \pi/2$) signals, the depth of the hydrophone should be equal to a quarter wavelength. This will also result in destructive interference of the signal for θ less than $\pi/2$. At $\theta = \pi/6$ the resultant is half the value at $\theta = \pi/2$, and when $\theta = 0$ the resultant is zero.

Therefore by adjusting the depth of the hydrophones to one-quarter the wavelength of the dominant frequency of the reflected signal one can both enhance the bottom and sub-bottom reflections and reduce noise that is incident at an angle to the vertical.

Hydrophone arrays

Further improvement of the signal can be achieved by using a receiving array. The use of a number of spaced elements will reduce the resultant output from random noise. The effectiveness of the noise cancelling increases as the square root of the number of elements used (Lombardi, 1955; Jenkins & White, 1957).

The signal incident on the hydrophone array can be considered to consist of the summation of a spectrum of sinusoidal waves. The relative amplitudes of the components of the spectrum will be different and the spectrum itself may vary with different bottom and sub-bottom conditions but the components are still sinusoidal. Therefore the theoretical response of the hydrophone array to different components of the spectrum can be calculated using the formula

$$A = a \frac{\sin (N \delta/2)}{\sin (\delta/2)} \qquad \text{(Jenkins \& White, 1957)}$$

where A is the resultant amplitude of the signal

a is the amplitude at each element (assumed equal)

N is the number of elements

and δ is the phase change from one element to the next (also equal). The response of the BMR seven-element hydrophone to various frequencies is shown in Figure 9. Effects of the surface reflected signal are ignored in these diagrams.

5. RESULTS - SIGNAL PROCESSING

Time-Varied Gain (TVG) amplifier

A time-varied gain amplifier was constructed by the Electronic Maintenance and Testing group of BMR. This amplifier has three important features. The gain varies linearly with time from 1.5 to 100, the rate at which the gain varies can be changed, and the time of mimimum gain after triggering can be predetermined. A graph illustrating the operation of the amplifier is shown in Figure 5.

This amplifier provides suppression of the direct pressure pulses from the transducer to the hydrophone. The gain can then be increased linearly to lift the level of the later, weaker signals. In this way saturation of the amplifiers by strong early signals can be avoided and adequate amplification of the late signals can be achieved. Diagram 4 in Plate 1 shows results from the BMR modified sparker with TVG; a common position on all the cross-sections in Plate 1 is marked with an arrow.

For recordings made in very shallow water the TVG amplifier enables reflections from near the bottom to be seen clearly.

Frequency filtering

The best results were obtained by using a filter with a passband to include most of the spectrum of the transmitted energy. The optimum limits of the passband depend on the ambient recording conditions. For example if there is excessive tow noise from the sea, mechanical vibrations of hydrophone, vibrations from the ship, and flow noise, it may be necessary to narrow the passband, particularly at the low-frequency end. With quiet seas and generally low noise this may not be necessary.

No signal processing methods were employed other than those available in the standard recorders used.

6. RESULTS - FIELD TESTS

Field tests were carried out in Mallacoota Inlet, Victoria, and some of the systems were used on a field survey in Port Phillip Bay. Each of the transducers discussed was tested using the energy settings which gave a pulse with the least amount of spurious secondary pulses. Both hydrophones were used. The same line was run with each system. Five of these cross-sections are shown in Plate 1, in which a common position is marked with an arrow. Variations in the sub-bottom information are due to inability to precisely retrace the line.

Configurations

Diagrams of the final configurations of transmitting transducers and hydrophones are shown in Figure 10. These configurations proved to be best for reducing noise, reducing the direct arrival, for ease of handling, and for easy control of depth and distance. Reduction of noise and direct arrival, both coming from the direction of the boat, are reduced by the radial response of the linear array. The hydrophone was towed by a section of Bungee cord, which acted as an acoustic isolator reducing mechanical vibrations travelling from ship to cable.

Energy sources comparison

The same traverse was surveyed using (a) 0.4 kJ modified sparker, (b) 0.4 kJ unmodified boomer (c) 0.4 kJ modified boomer, and (d) Raytheon 3.5 kHz pinger. These sources were chosen for the field tests because they produced short single-burst pulses within the frequency range of the recorder. An E.G. & G. model 254 recorder and BMR 7-element hydrophone were used. Sample records are shown in Plate 1.

For these tests the same traverse, hydrophone, transducer depths, and recorder were used. The frequency passband was 20 to 20 000 Hz.

Test of TVG amplifier

A prototype model of the TVG amplifier was also tested over the same area, and a sample record is shown in Plate 1. The prototype used for the test introduced some low-frequency noise, which results in a broad horizontal dark band followed by a light one. A different design of TVG amplifier was produced after the Mallacoota field tests. A sample boomer record using the new TVG amplifier is shown in Plate 2.

Both records show the early reflections clearly and also enhance the later arrivals.

Other observations

Monitoring. It is necessary to monitor the signal level on a Cathode-ray oscilloscope (CRO) at all stages of amplification to ensure that minimum distortion is taking place with the particular amplifier setting in use. This is also advisable when setting the TVG amplifier, in order to see that the marginal level is adequate all the way down the record and yet not saturated at the top.

Sea state and boat speed. The sea state and boat speed have a critical effect on the quality of the records. Both these factors have a direct influence on the acoustic noise level of the system and cause changes in the depth of the transducers. The choppiness of the water can cause rapid deterioration of the record quality. If the hydrophone is lowered below the chop the resolution suffers because the time between the surface-reflected and direct signals is increased, and if it is too close to the surface the hydrophone picks up increased noise and may even break the surface, causing loss of signal.

The maximum boat speed at which sparker or boomer records of good quality were obtained in smooth water was 6 knots. Generally 4-5 knots proved to be the best speed for the systems tested.

Transducer depths. The depth of transducers is a particularly critical parameter for the reasons discussed earlier under 'Surface reflections'.

In most situations it is impossible to measure accurately the depth of the transducers since they generally trail behind the boat. There are two practical ways of depth adjustment: (a) Observe the reflections on the record and adjust alternately the transmitter depth and the hydrophone depth until the clearest record is obtained, i.e. the one in which a single reflector is represented by the fewest lines; (b) Observe the hydrophone signal on a CRO and slowly raise the sparker until the leading edge of a negative-going pulse from a reflector is seen to join the trailing edge of a positive pulse. The hydrophone should now be raised until two negative pulses are seen to merge. If both transmitter and hydrophone are too deep a single reflector will appear as a number of separate lines.

Earthing. Since the sparker and boomer systems depend on a high-voltage discharge, a good earthing system is essential for safety and minimum electrical interference to recorders. The transmitter power supply, trigger unit, capacitor banks, and generator should have their frames connected by an earth strap and to the earth of the sparker.

7. FUTURE DEVELOPMENT

(a) One of the major deficiencies with systems used for the tests was that there was no means of recording the data on magnetic tape and then playing back on a recorder at some later stage. The advantages of such a system would be that a wider dynamic range of signal levels and a wider frequency band could be recorded undistorted, a number of chart records could be made using different amplifier and filter setting, and further analyses of the data could be carried out.

(b) By examining relative signal strengths and Fourier analyses of the reflections an indication of the nature of bottom and sub-bottom materials could be obtained.

(c) Methods of minimizing the effect of the multiples could be examined.

(d) Means of improving the resolution of higher-energy sparkers or boomers for deeper penetration have to be examined. The present methods of reducing the bubble effect are effective up to energy levels of 0.5 kJ.

(e) Some sediment (mud with air bubbles) in the test area completely obscured any reflectors underlying it (see Plate 1). This problem is likely to arise in other areas and has not been overcome at present.

(f) A tow body should be designed to enable the transducers to be towed at a predetermined depth.

(g) A directional array of transmitting transducers would be advantageous in shallow water work where side reflections often interfere with sub-bottom reflectors.

8. CONCLUSIONS

The basic aims have been achieved, viz. penetration of 30 m, resolution of 1 ms, and operational depths from 30 m to 2m. An improved sparker system has been developed. The bubble effect has been made negligible by using a fabric-reinforced rubber tube over the sparker for energy levels

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up to 0.5 kJ. Techniques and equipment for achieving high-resolution seismic profiling records in shallow water have been developed. Directions for further development have been proposed.

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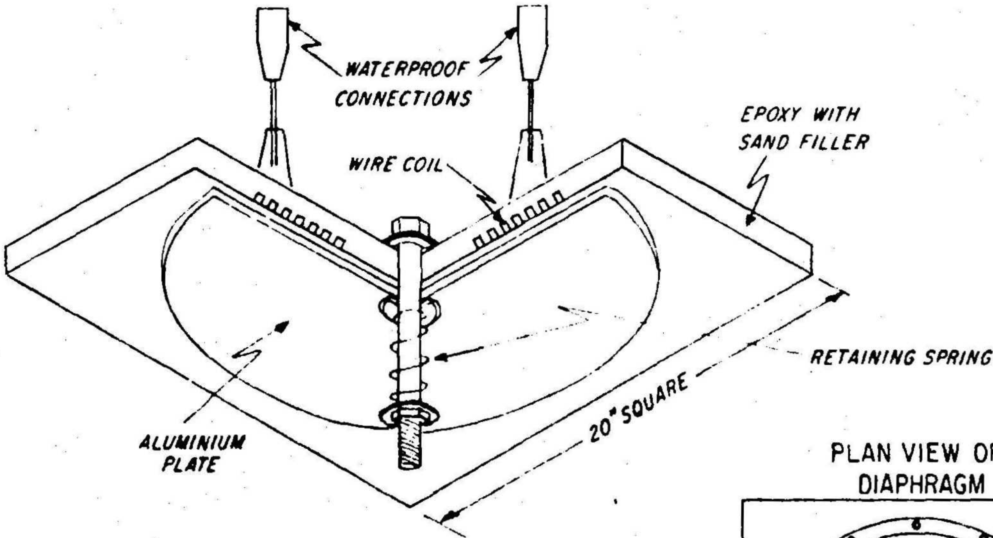
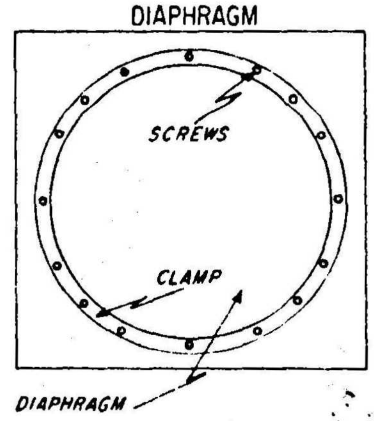
Fig. 1

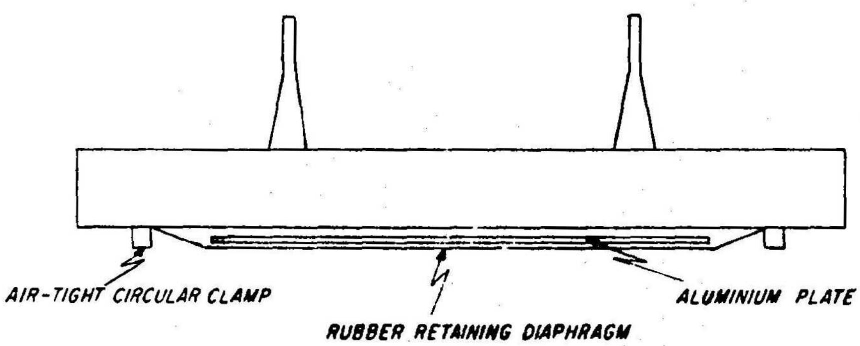
UNMODIFIED E.G. and G.1000J BOOMER TRANSDUCER MODEL 236



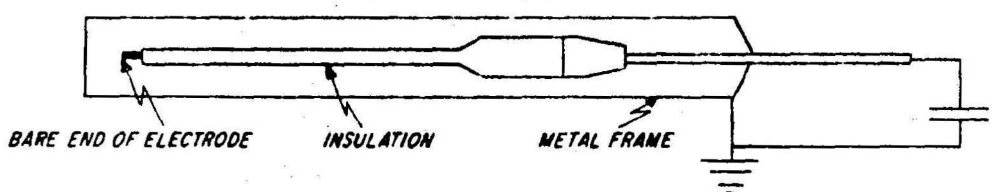
PLAN VIEW OF DIAPHRAGM



MODIFIED BOOMER



SPARKER WITHOUT BUBBLE PULSE SUPPRESSOR



SPARKER WITH BUBBLE PULSE SUPPRESSOR

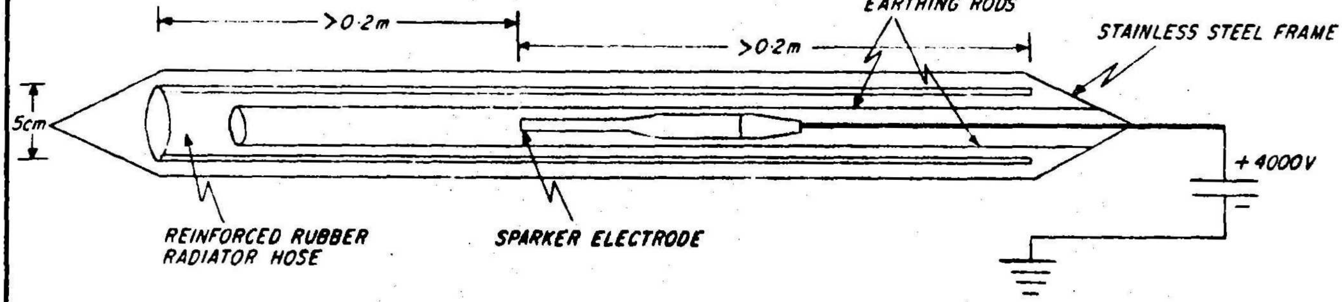
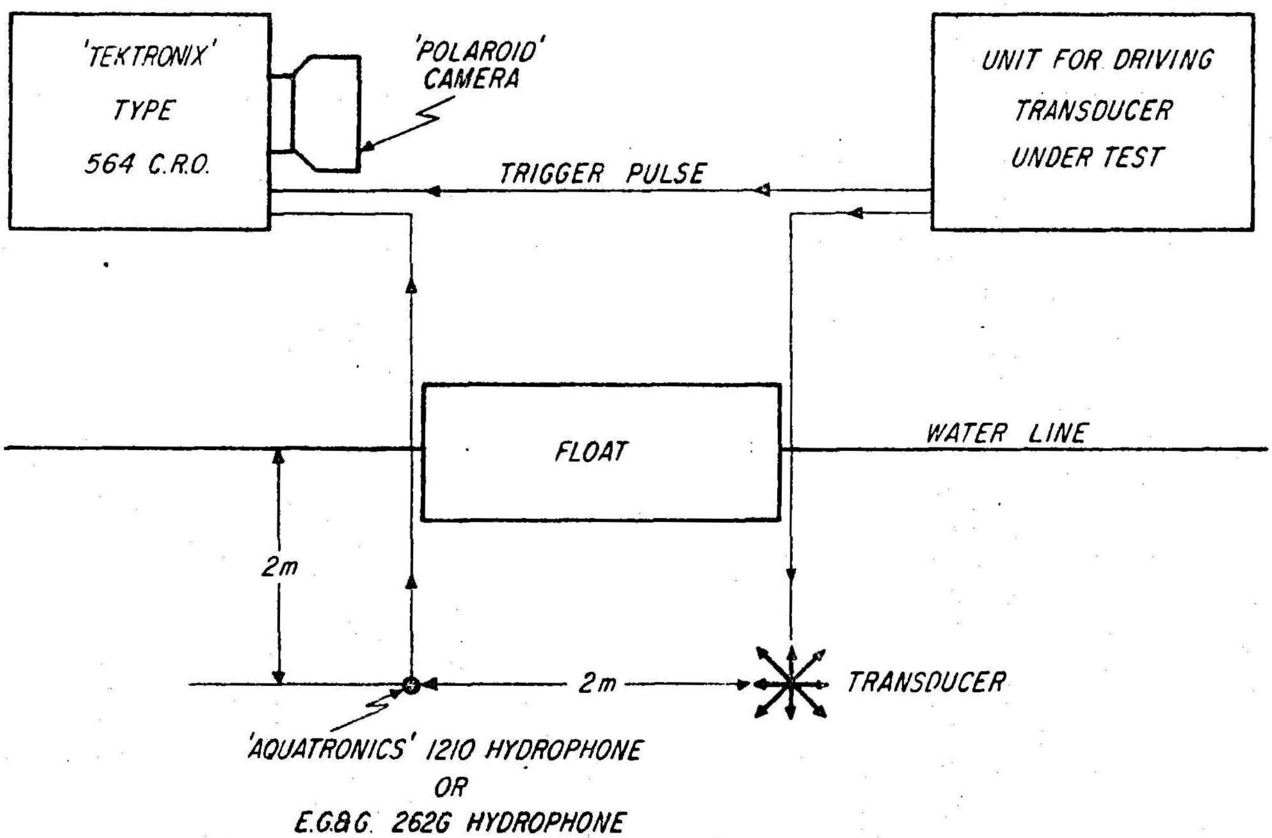
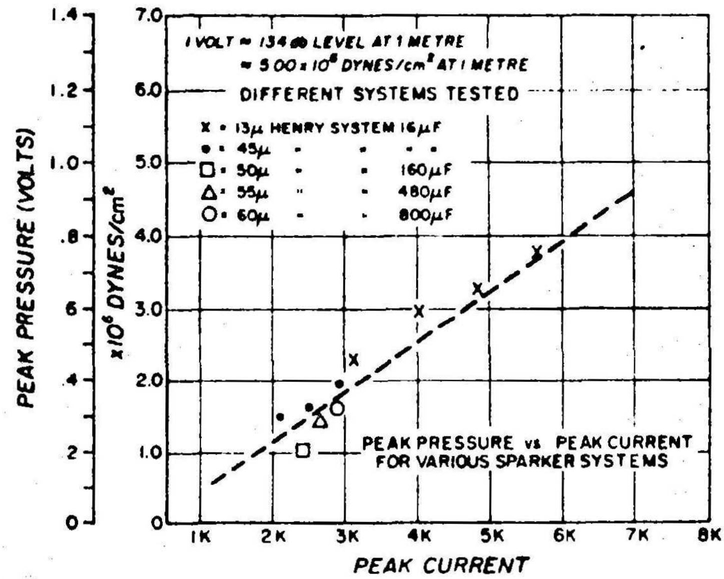


Fig.2

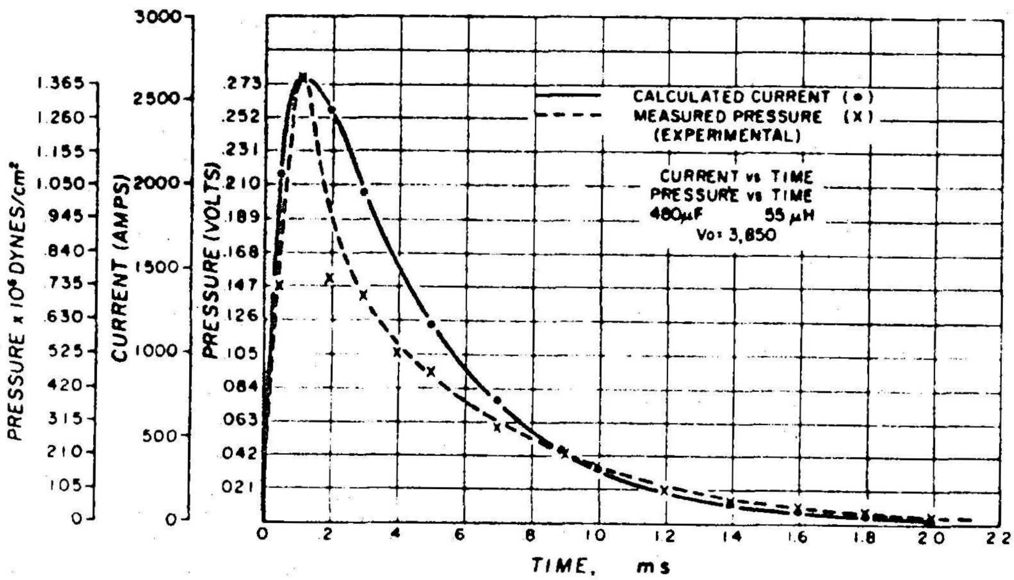


. MEASUREMENT OF ACOUSTIC OUTPUT - EXPERIMENTAL LAYOUT

Fig.3



Peak pressure versus peak current for various sparker systems.

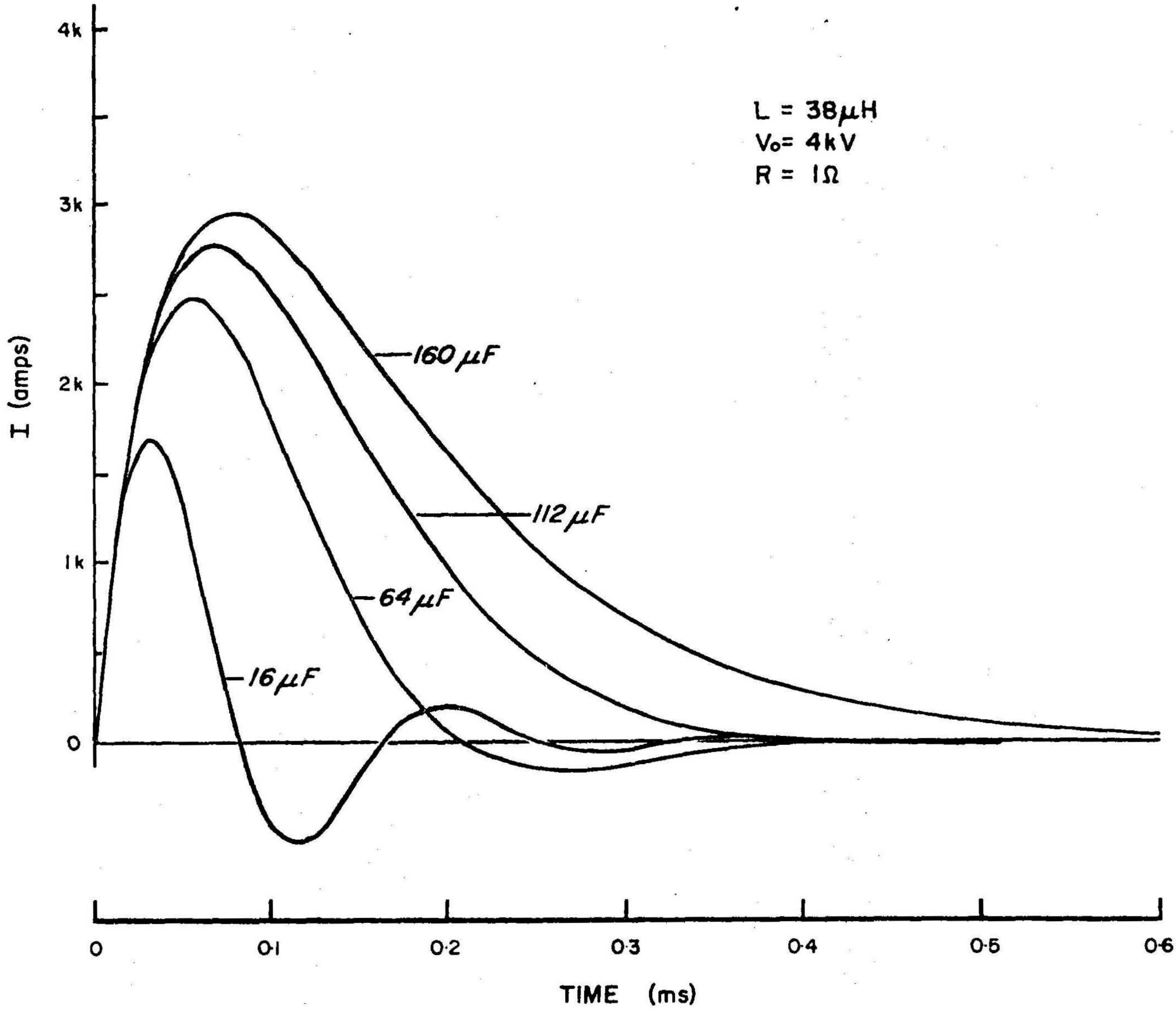


Current and pressure versus time.

After Caulfield, 1962

23

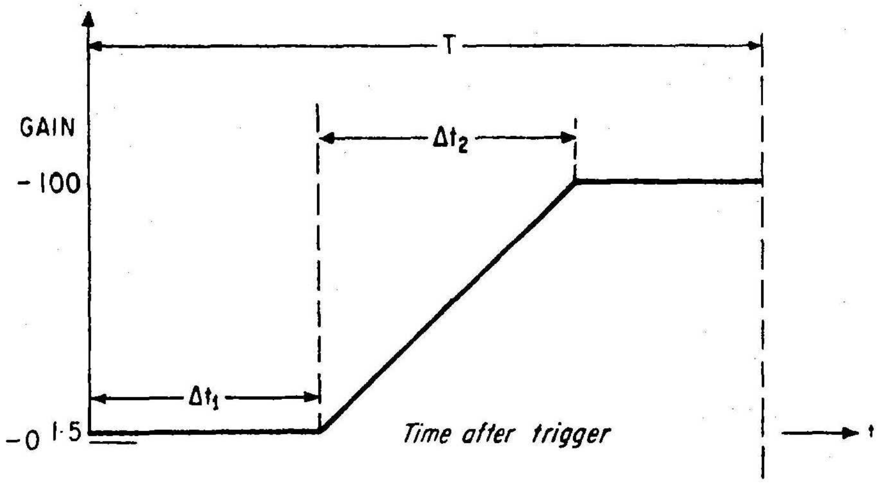
Fig. 4



CALCULATED CURRENT(I) VERSUS TIME

24

Fig.5



Δt_1 dead time 1 to 100 ms

Δt_2 slope time 1, 10, 100 ms or 1 sec.

T time between triggers

CHARACTERISTICS OF BMR-TVG AMPLIFIER

25

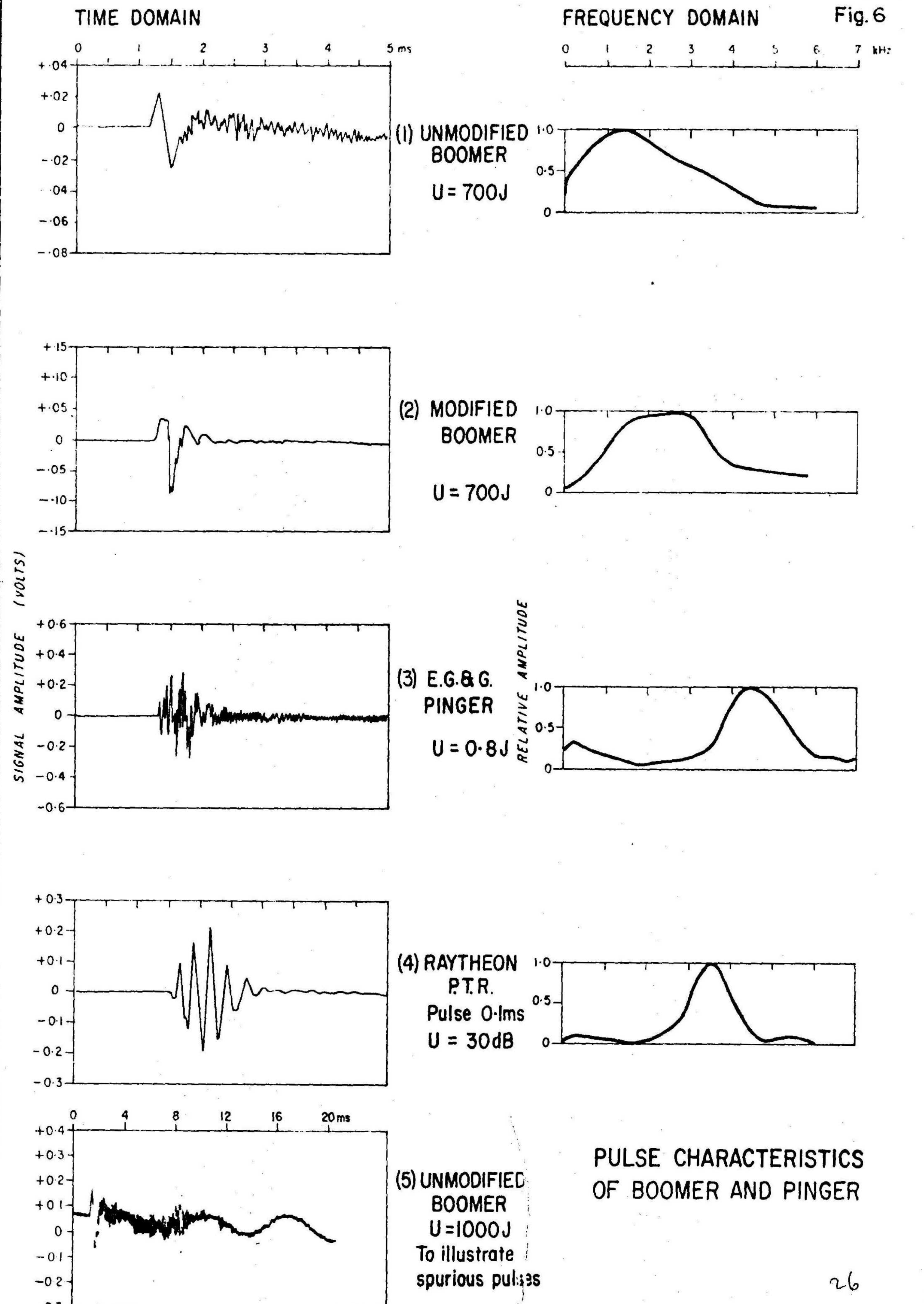


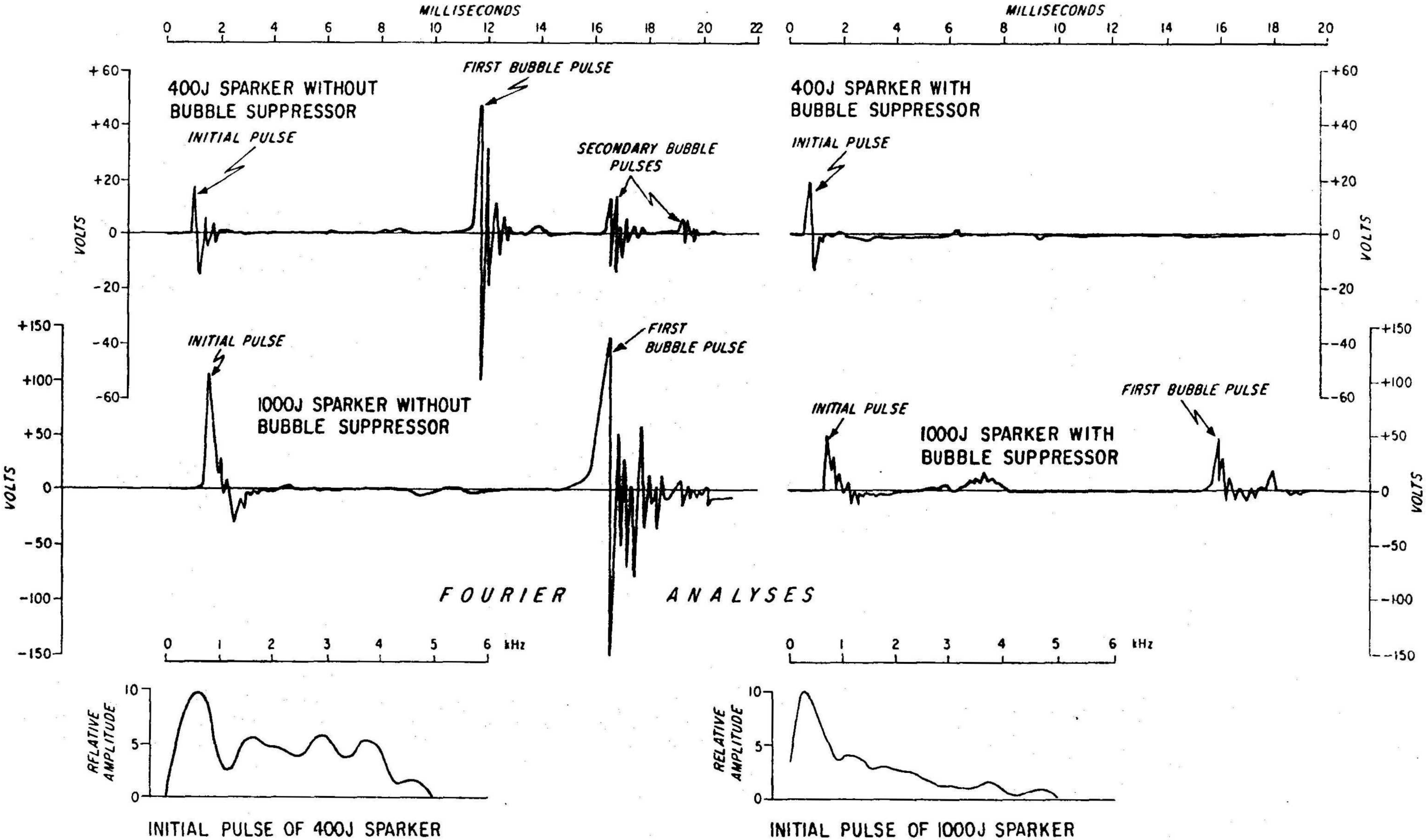
Fig. 6

PULSE CHARACTERISTICS OF BOOMER AND PINGER

Record No. 1975/150

G16-109A

To accompany Record No. 1973/195 and 1975/150

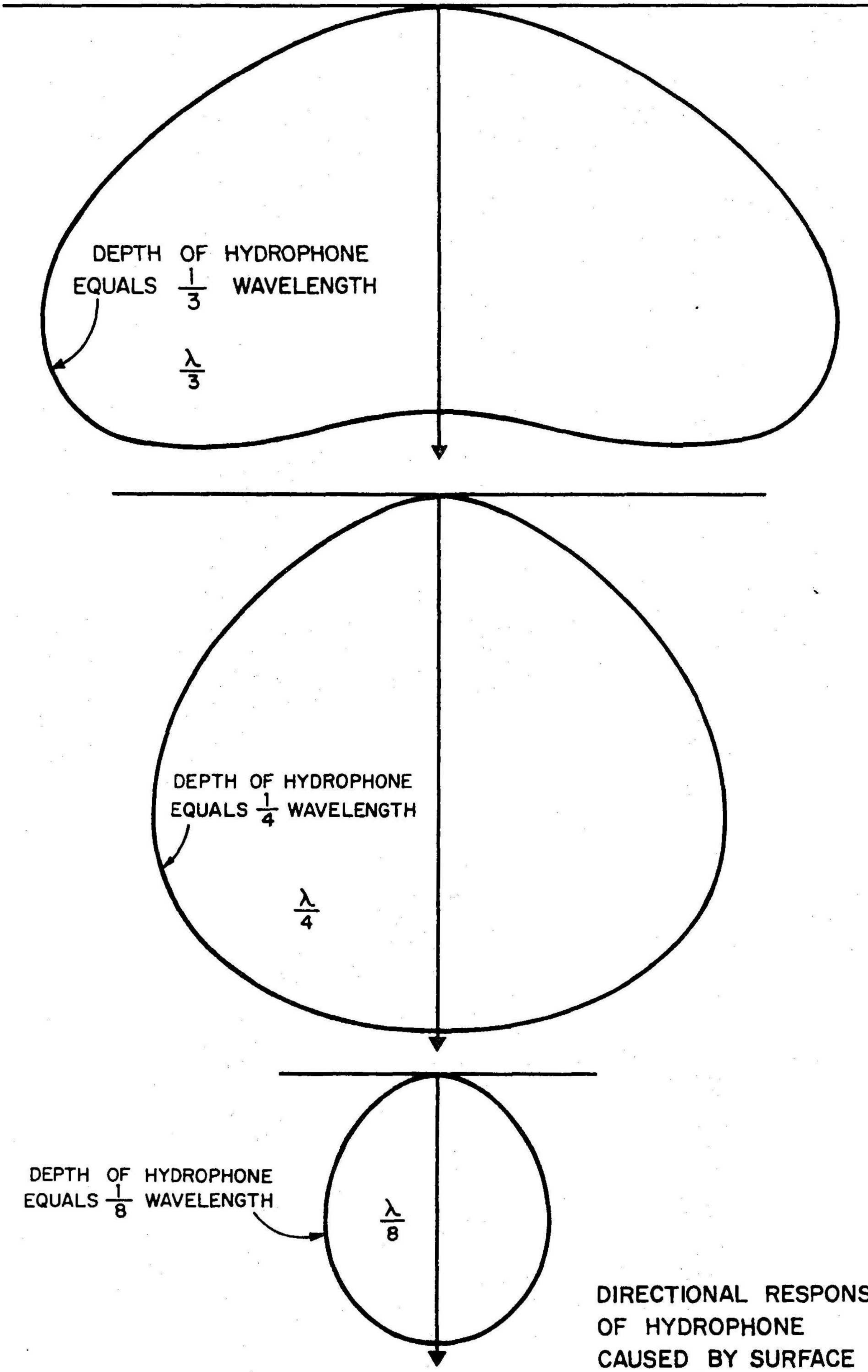


PULSE CHARACTERISTICS OF SPARKERS

Fig. 7

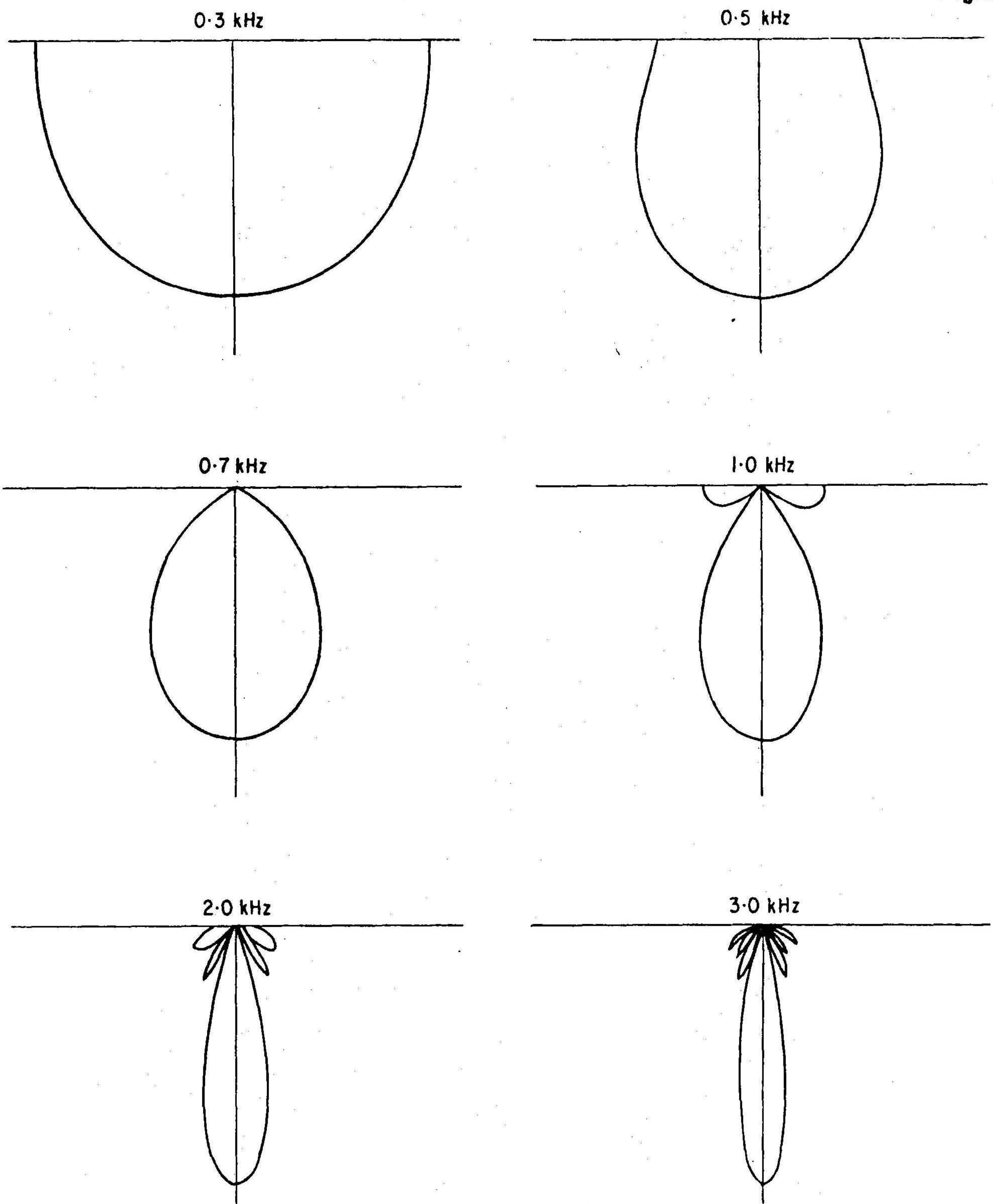
G16-113A

Fig. 8



DIRECTIONAL RESPONSE OF HYDROPHONE CAUSED BY SURFACE REFLECTIONS

Fig. 9



DIRECTIONAL SENSITIVITY OF THE BMR HYDROPHONE ARRAY

Record No. 1975/150

G16-112A

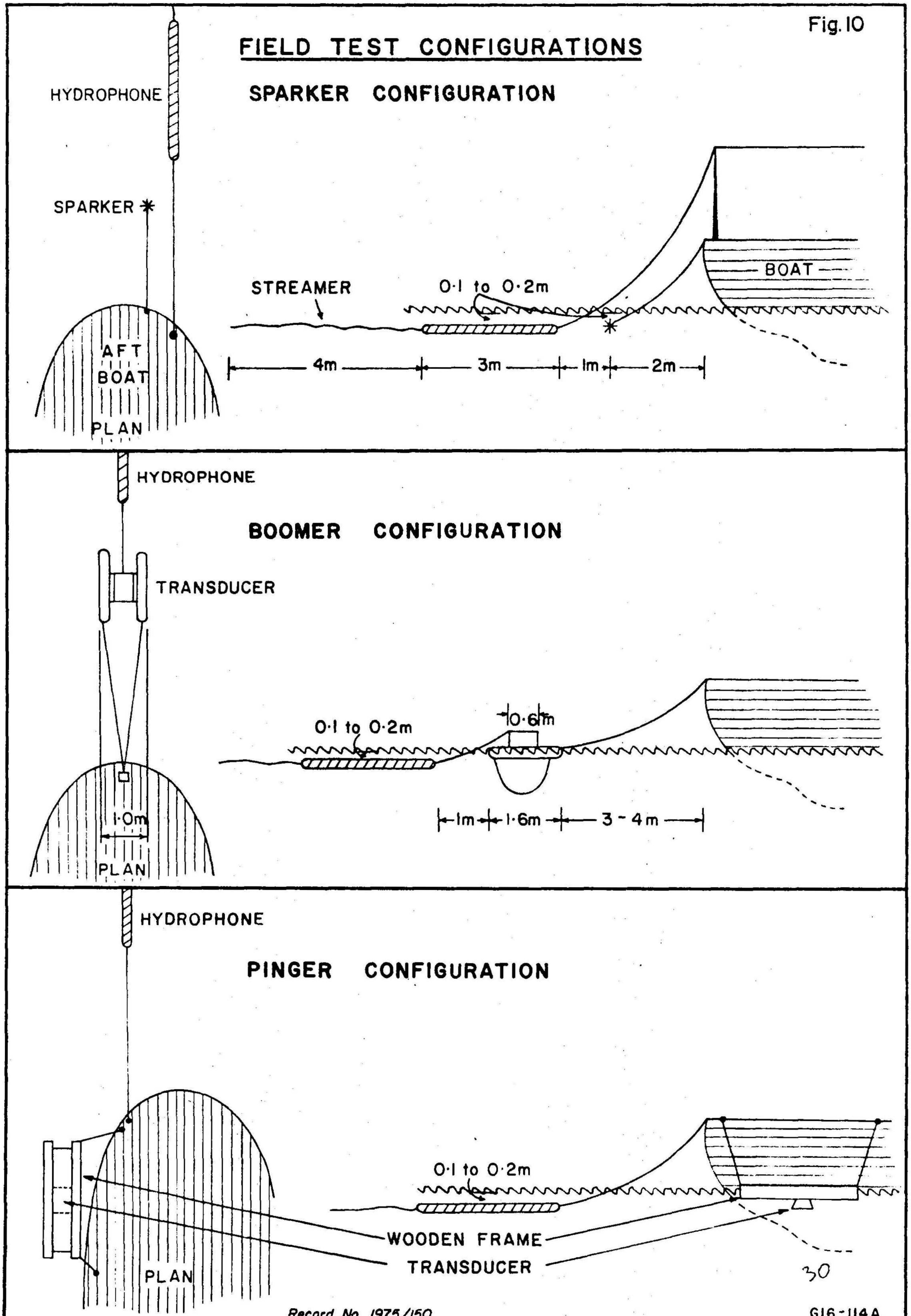
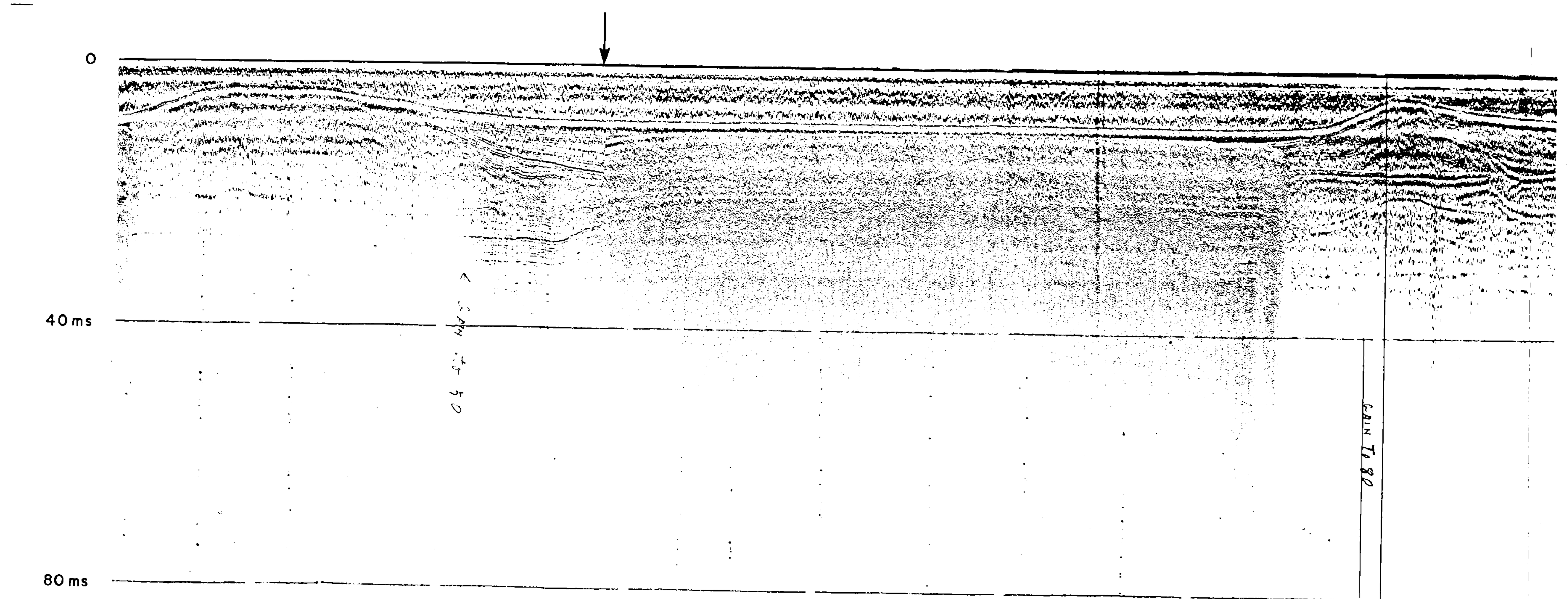
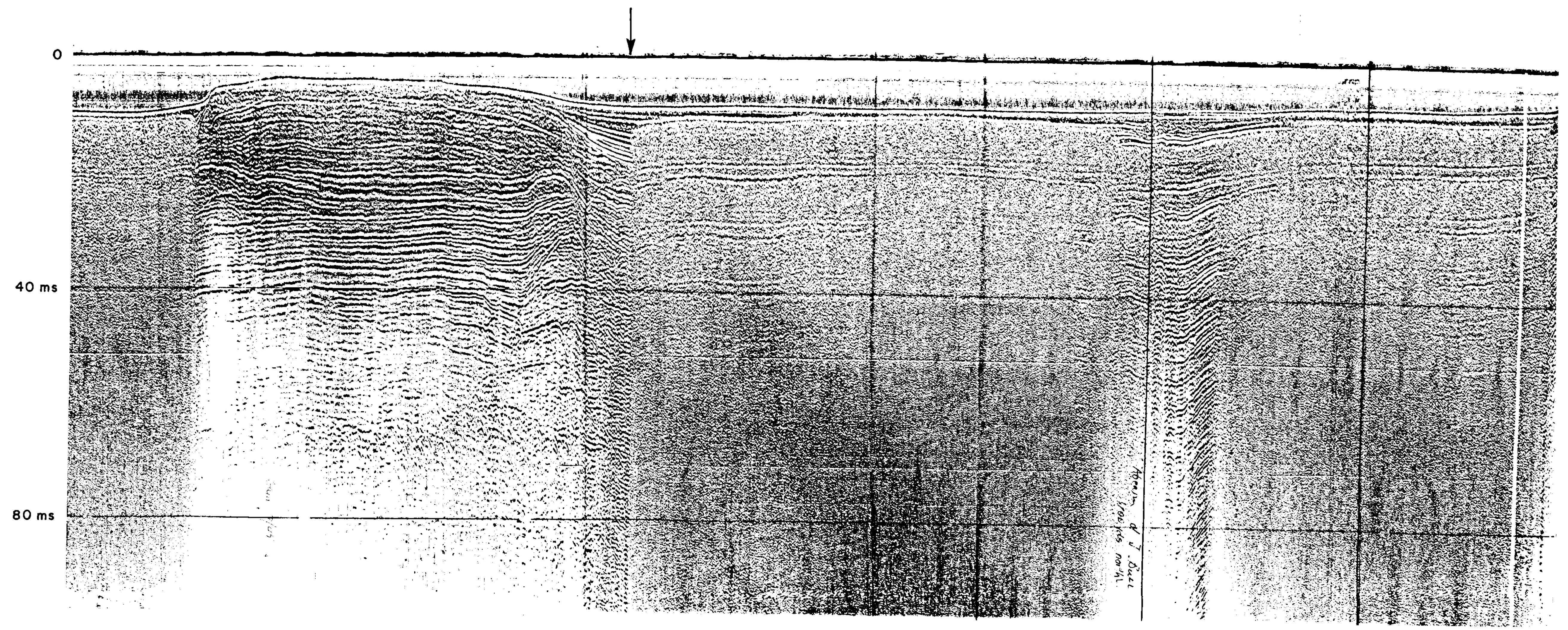


Fig. 10
FIELD TEST CONFIGURATIONS
SPARKER CONFIGURATION
HYDROPHONE
SPARKER
AFT BOAT
PLAN
STREAMER
0·1 to 0·2m
BOAT
4m
3m
1m
2m
HYDROPHONE
BOOMER CONFIGURATION
TRANSDUCER
0·1 to 0·2m
0·6m
1·0m
PLAN
1m
1·6m
3 - 4m
HYDROPHONE
PINGER CONFIGURATION
0·1 to 0·2m
WOODEN FRAME
TRANSDUCER
PLAN

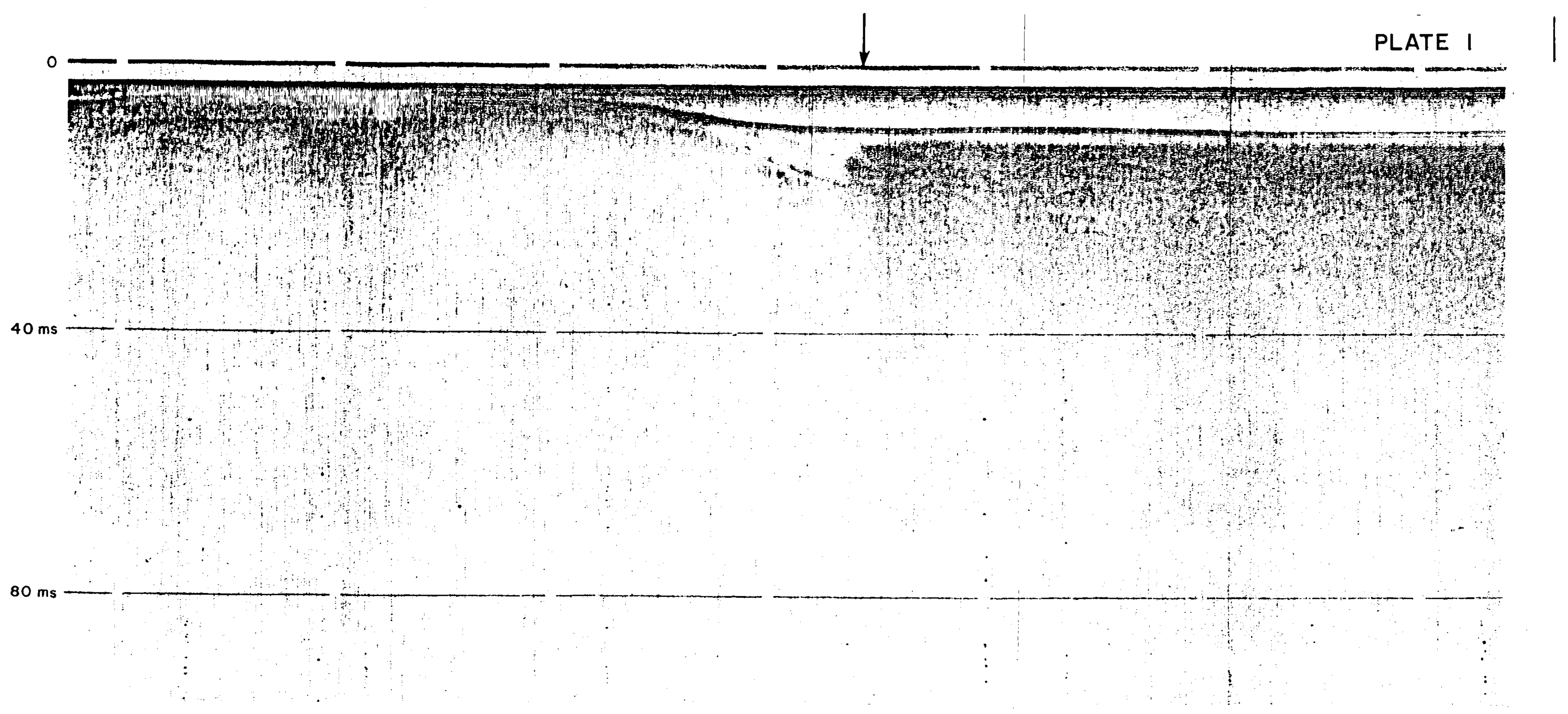
PLATE I



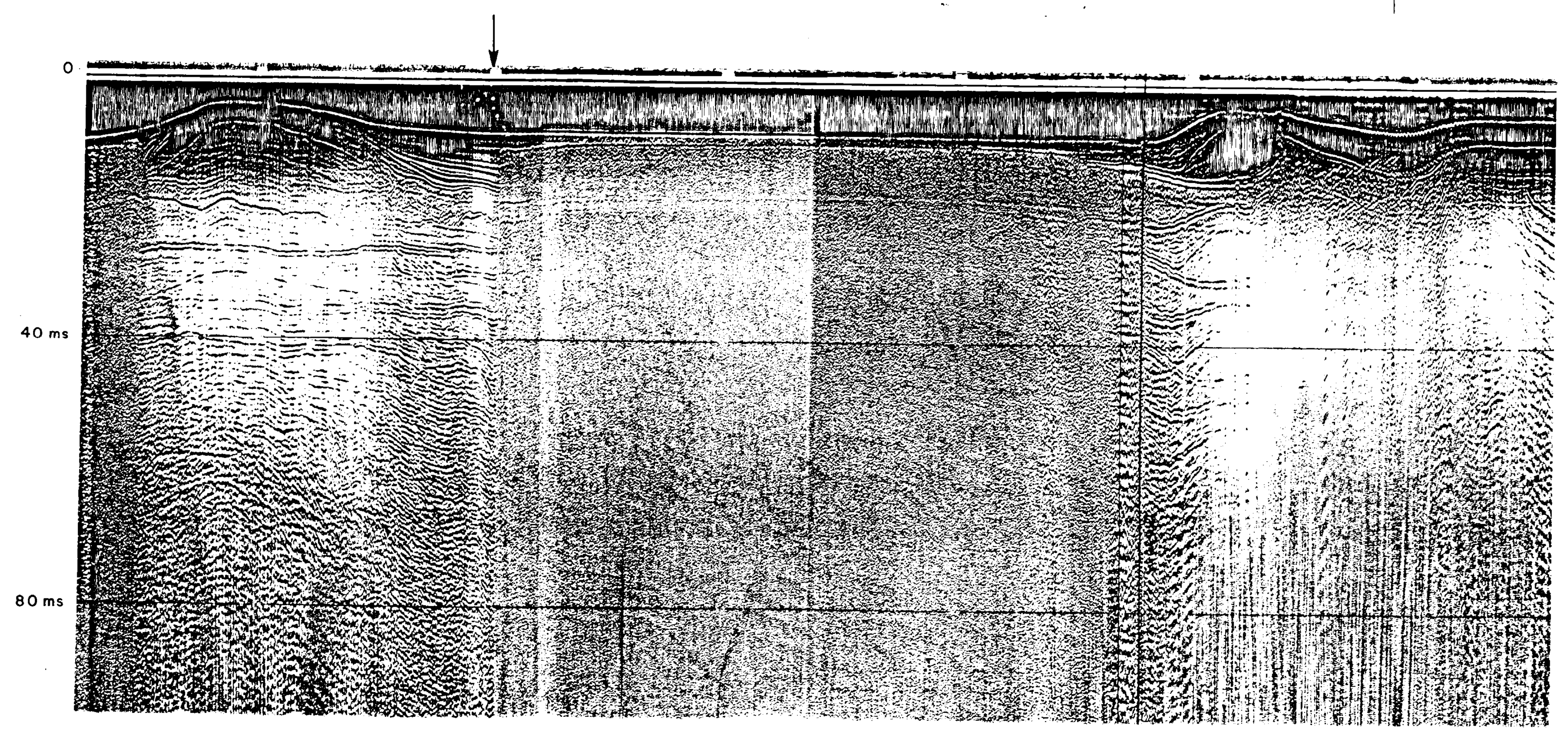
(1) MODIFIED SONAR BOOMER 0·4 kJ



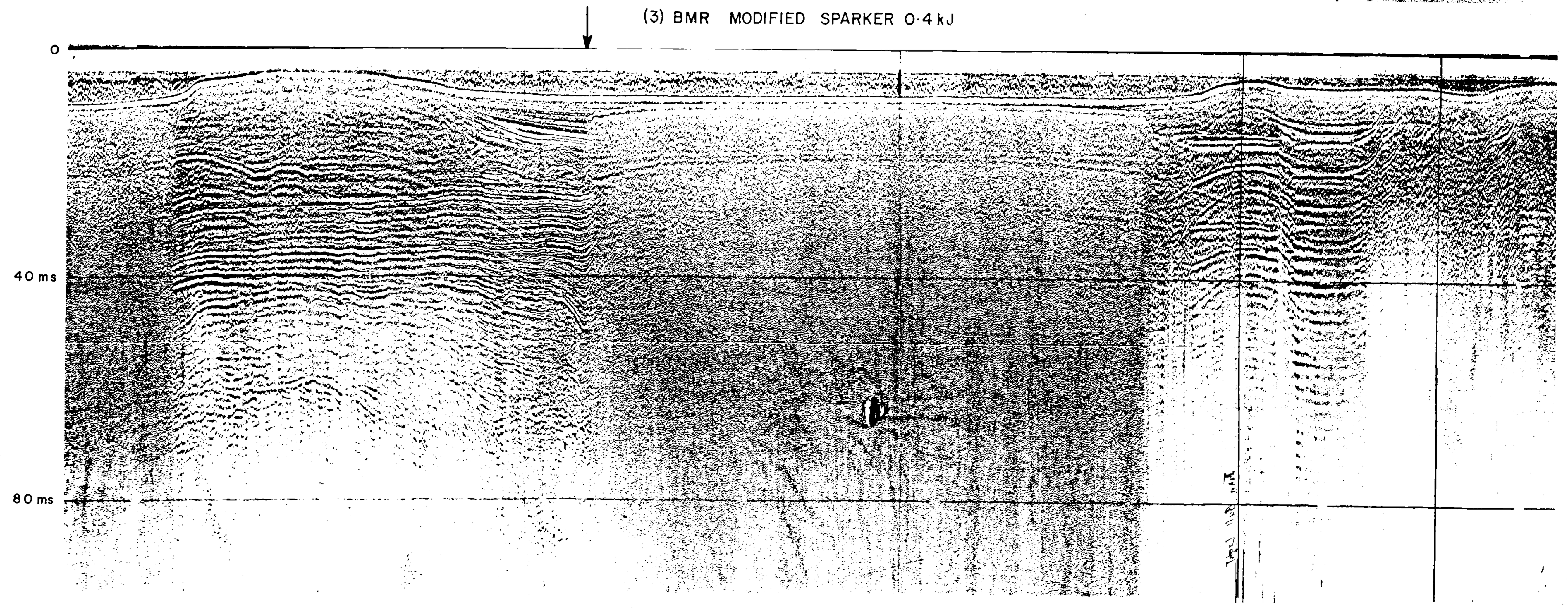
(3) BMR MODIFIED SPARKER 0·4 kJ



RAYTHEON PINGER (-30dB) FILTER AT 2–8kHz



(4) BMR MODIFIED SPARKER WITH TVG AMPLIFIER 0·4kJ



(2) UNMODIFIED SONAR BOOMER 0·4kJ

PARAMETERS COMMON TO ALL SYSTEMS

TRANSDUCER DEPTH	0·3m
HYDROPHONE	0·3m
FILTER SETTING	200Hz–11kHz
SWEEP TIME	0·1s
FIRING RATE	0·6s

THE POSITION MARKED WITH AN ARROW IS A COMMON POINT.

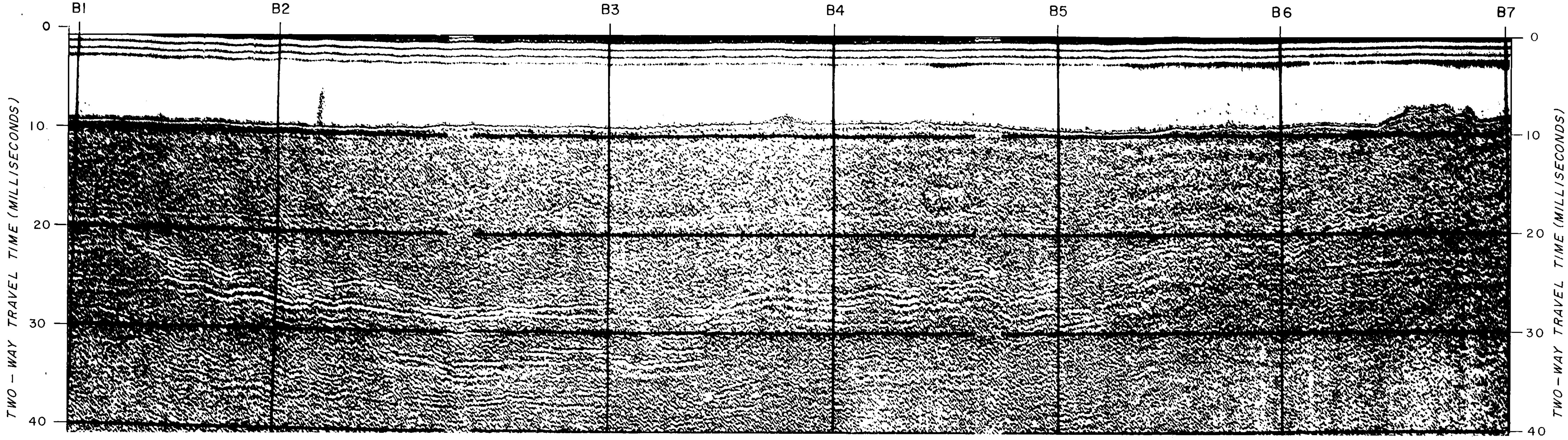
SAMPLE RECORDS FROM MALLACOOTA FIELD TESTS

J55/B5-96

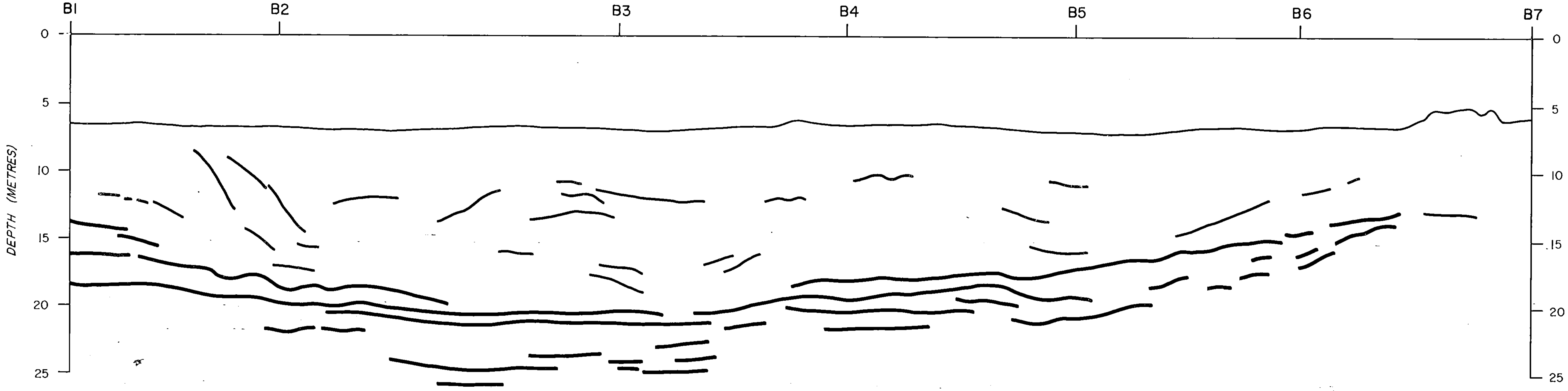
Record No. 1975/150

PLATE 2

RECORD



INTERPRETATION



BOOMER RECORD B

(With TVG amplifier)

100 50 0 100 200 300 METRES

(APPROXIMATE ONLY)

B 5 *Traverse fix number*

Strong Sub-bottom reflections

Bottom reflections

Weak Sub-bottom reflections