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Sub-Bottom Sounding - A Survey for Naval Applications

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UNITED STATES NAVAL POSTGRADUATE SCHOOL

THESIS

SUB-BOTTOM SOUNDING --

A SURVEY FOR NAVAL APPLICATIONS

by

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[redacted]

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A SURVEY FOR NAVAL APPLICATIONS

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ABSTRACT

The sub-bottom profiling techniques have vastly improved over the last several years. Many commercial companies are presently engaged in the manufacture of either individual components or the entire system largely as a result of its applicability to petroleum exploration. New systems and innovations are developing at a rate whereby it is difficult to remain current.

Interest in the technique has likewise increased within the Navy, and more than several research projects built around its use are currently receiving Navy funding. It was therefore deemed advisable that a survey of existing equipment characteristics and manufacturers be made to serve as a guide to potential Navy users as to the possible applications of this technique.

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1. INTRODUCTION

Continuous relection profiling is basically a seismic reflection technique used to determine the attitude of subsurface strata. Marine seismic profilers are essentially low-frequency echo sounders that indicate not only the depth and shape of the sea floor, but also the sediment layering.

For many years relatively thin upper layers of the ocean bottom have been sampled by coring techniques and dated by paleontological studies. Until recently, the conditions that existed beyond the reach of the coring tube were largely speculative. The seismic profiler effectively extends the reach of the corer. In instances, layers have been traced from deeply buried positions to locations where the same rock is directly exposed on the sea floor as an outcrop. Seismic profiler surveys may also give indications as to source areas, modes of deposition, and sediment type from the examination of lateral variations in layer thicknesses, interface characteristics, and certain acoustic properties of the sea floor.(9)

Seismic profiling has performed a most important role in petroleum prospecting, and here it receives its greatest attention and investment. The combination of seismic surveys and core drilling are proving equally beneficial to the study of the sea floor for scientific purposes.

It is natural that the varied oceanic interests of the Navy requires the extension of this interest beyond the surface of the sea floor. Possible applications of seismic profiling within the

Navy are many. The advent of long range, bottom-bounce sonars means that the configuration of the bottom and sub-bottom is of ever increasing importance. Some of the guess work can now be removed in determining the type and characteristics of foundations required for both harbor and offshore structures. Other applications of seismic profiling of interest to the Navy could be listed.

In recent years many varied projects which have dealt directly or indirectly with seismic profiling have been conducted by Naval activities or by organizations and firms supported by the Navy. A few such activities are the Naval Oceanographic Office, the Marine Environmental Division of the Naval Underseas Warfare Center (formerly the Navy Electronics Laboratory), University of California at San Diego and others. This work has served as a stimulus to the Navy's interest in the sub-bottom field. At present however, very little collected information is available within the Navy as to the types and characteristics of the profiling equipment, the suitability of the various techniques, and the economic factors involved.

In recognition of the need for establishing a comprehensive source of information on sub-bottom sounding for potential Navy users, a study is presently being conducted by the Naval Civil Engineering Laboratory (NCEL) to evaluate seismic profiling equipment available from commercial sources, and the specific suitability of each of the techniques. This particular study is divided into four parts:

(a) The accumulation of literature sources together with a survey of currently available sounding equipment;

(b) Conducting of both shallow and deep water field tests of such equipment in conjunction with the manufacturers;

(c) Comparison of results obtained and an evaluation of the particular applicability of each type of equipment; and

(d) Preparation of a guide as to the capabilities of this equipment for potential government users.

This paper under the sponsorship of NCEL, partially fulfills part (a) of the above program.

An attempt will be made herein to present, in some detail a survey of the types and characteristics of commercial equipments for sub-bottom sounding together with means for record interpretation. During the course of such a summary investigation certain conclusions are reached as to how best to continue the other facets of the NCEL investigation. The final section of this report will therefore include both conclusions and recommendations to assist in the planning and preparation of the subsequent portions of the overall study.

2. HISTORICAL BACKGROUND AND GENERAL THEORY

At the present time there is little descriptive information available in the literature on the details of sub-bottom sounding. An introduction to this technique is therefore warranted. More detailed information concerning the various components is covered in a subsequent section. Some minimal background information is required before one can examine the various commercial products available and comprehend their characteristics.

(a) HISTORY OF DEVELOPMENT. A seismologist named Robert Mallet first suggested some four generations ago that artificial seismic waves could be used for determining the geological nature of the subsurface rocks. More than 70 years passed however, before the first commercial use of his suggestion was applied to the exploration for salt domes.

The seismic reflection technique was first used in 1927, and has since become the single most extensive and successful petroleum exploration tool. Seismic studies of the crust in deep sea areas began soon after World War II in the pioneering work of Maurice Ewing and his associates at the Lamont Geological Observatory. During the 1950's continuous seismic profiling emerged as an outgrowth of standard depth sounding and ranging techniques and since then these have been rapidly developed and diversified. During the year 1966 over $500 million was expended in the free world on petroleum exploration using seismic reflection techniques of which marine seismic exploration accounted for over $180 million.(25)

(b) GENERAL DESCRIPTION OF TECHNIQUE. All continuous seismic reflection profiling systems consist of essentially the same basic components of sound source, receiving hydrophone, amplifier, variable filters, graphic recorder, and trigger as shown in Figure 1. The source and hydrophone are towed through the water, operating much as a conventional echo-sounding instrument. The source emits sound pulses at regular intervals, and the hydrophone receives the subsequent echoes reflected from the bottom of the ocean and from reflecting interfaces beneath the bottom. These echoes are then converted to electrical signals, and after suitable filtering and amplification are fed ultimately to a graphic recorder.

The cycle of events described is essentially equivalent to earlier methods of seismic reflection shooting on land. The advantage of continuous-reflection profiling is that the cycle of events is repeated at intervals of a few seconds or a few tenths of seconds so as to produce a continuous recording of the returning signals. With the survey vessel moving, a horizontal reflecting surface therefore appears as a straight horizontal line on the record, and a reflecting surface of changing elevation will result in a curved or sloping line. These lines may then be interpreted as topographic and structural profiles of the materials over which the survey vessel has passed.

Soon after the first precision graphic recorders were applied to echo-sounding equipment, it became apparent that echoes were being received from reflecting layers beneath the bottom. Penetration in these early instances was in the order of 20 to 30 feet as a result of the high frequencies being used. Experiments were carried out

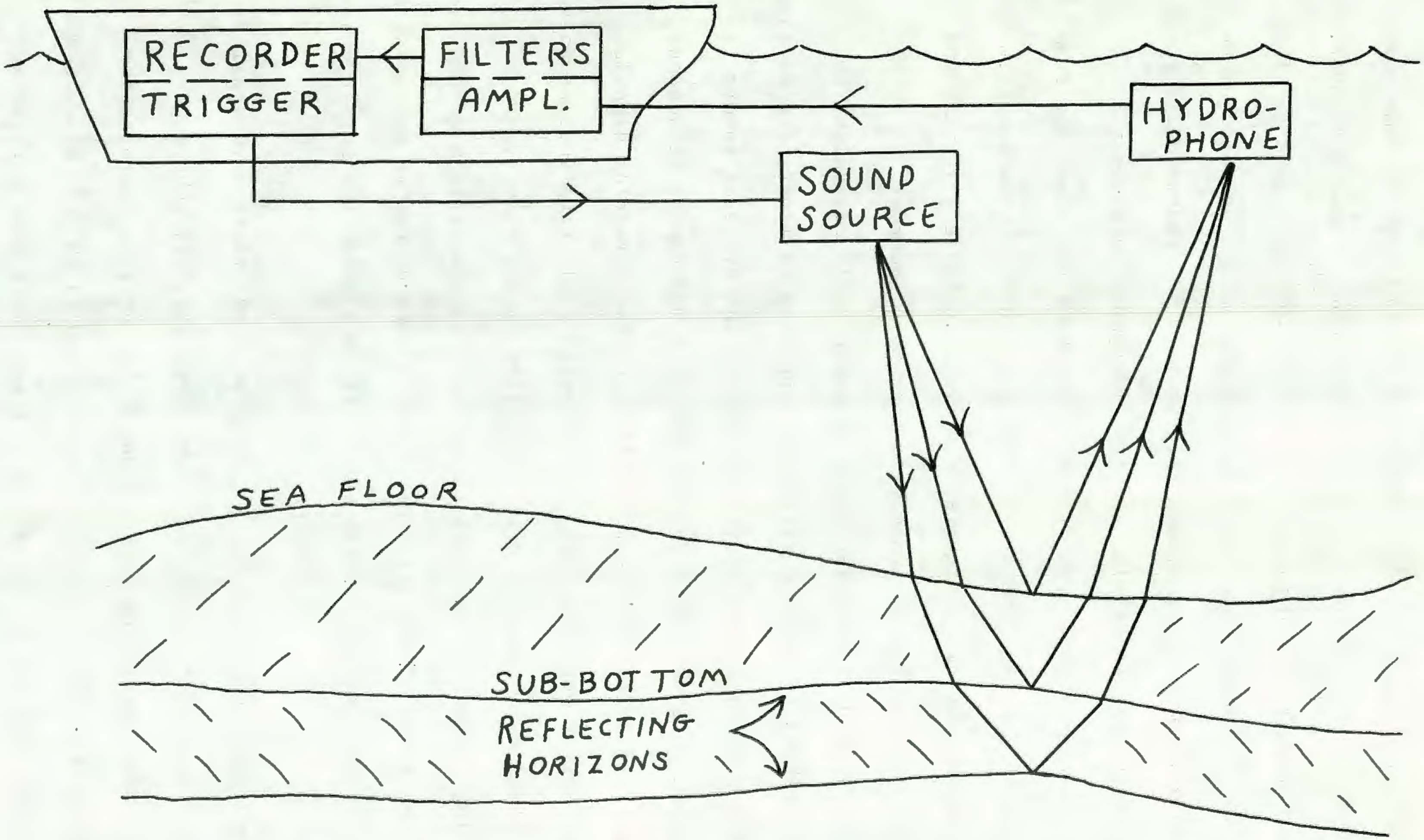


FIGURE 1. Schematic diagram of continuous profiling system

with the object of obtaining deeper penetration and better resolution. These experiments established the theory of and the requirements for effective sub-bottom sounding systems.

The prime requirement of sub-bottom profiling systems is a sound source which can be actuated repeatedly on a rapid and regular schedule in order to correlate echoes from sub-bottom reflectors over a considerable distance. For good resolution the sound pulse that is generated should be short, in that long pulses tend to obscure echoes from layers only a few tens of feet below the bottom. Equally important is the utilization of a source operating within the proper range of frequencies and at the correct levels of energy for the desired scale of profiling. The frequency of the source is a most important consideration. Sound absorption per unit distance increases rapidly with frequency in both water and sediment.(11) Further the absorption in sediment is much higher than in water at all the frequencies of interest. Low frequencies are therefore required to penetrate sediment or rock layers. The question as to how low a frequency has been answered empirically. Although successful penetrations to 100 feet or more have been obtained in soft mud bottoms with 6-14 kc/s sound sources, experience has indicated that the band from 20 to 150 c/s is the most practical for very deep penetration. A wide choice within the range of frequencies quoted above is thus provided, the one selected being dependent on the requirements of the intended survey. In instances when fine detail is required, as in studying thin bedded sediments, a lower limit exists as to the frequency band that will serve the purpose. For deep penetration the low frequencies are required, but at the expense of fine detail. As a consequence both low and high frequencies may be needed and a good design will provide for either a wide choice of frequency bands, or several discrete frequencies.

Most graphic recorders designed to operate with conventional echo-sounding equipment give a presentation of bottom depth in feet (or some other linear measurement) based on a velocity of sound through sea water of approximately 4800 feet per second. In adapting recorders to sub-bottom sounding work no such arbitrary correlation can be made since the sound velocity in the different types of sediments varies, often by a significant amount from its value in sea water.

(c) DETERMINATION OF SOUND VELOCITY IN SEDIMENTS. Several techniques can be used in determining the velocity of sound through the sediments ranging from simple to the extremely complicated. If the type of sediment is known then from tables that have been published (23,24) a reasonably good estimate of sound velocity may be obtained. The quality of sound transmission depends markedly on the porosity of the sediment so that without positive evidence (for example from a core sample) estimates of this type may be much in error. Nevertheless, in the absence of other techniques or under the pressure of a limited time schedule, an estimation by this method may have to be used.

The two techniques that have been used for many years to determine velocities of sound in unconsolidated sediments and rocks are the wide-angle reflection technique and the seismic refraction technique.(15) In the wide-angle reflection technique, the separation of the sound source and the hydrophone is steadily increased while recording so that the angle between the incident and reflected wave-paths progressively increases. Calculation of the velocities from such data is by comparison with examples of assumed velocity structure. Several successive approximations are generally required.

The refraction method makes use of the fact that at sufficiently wide separations of the sound source and the hydrophone a part of the sound energy travels directly through the water to the hydrophone, while other portions are refracted at the sea floor and underlying interfaces. These refracted waves travel at greater speeds through the rock and are eventually again refracted through the water to the hydrophone. In practice the hydrophone cable is extended to its full length, while the sound source is located near the survey vessel. The hydrophone cable is hauled in while a record is being made. The refracted waves initially arrive before the direct waves, the difference in transit times becoming smaller as the cable length is decreased. Eventually the two waves arrive together, and thereafter the refracted wave record is obscured by the stronger direct wave. The slope of the refracted-arrival record, measured in time vertically and distance horizontally, is the reciprocal of the velocity. Usually a second record is made in the reverse direction and the average velocity is computed from the two sets of data.

Another procedure for determining sound velocities through sediments incorporates the common depth point method and becomes practical with assistance of a computer.(11,21). This technique is widely used by companies engaged in petroleum exploration and is particularly applicable when concerned with layers at great depths. It depends on the principle of recording reflections at different surface detectors from different surface shot positions, chosen so as to maintain the same reflecting points on subsurface reflectors. Investigation of the results can yield a time varying measure of primary and multiple velocity. The primary is the initial reflection, while the significance of multiples will be considered shortly.

(d) SOME FEATURES OF SEISMIC RECORDS. Two distinct problems arise in the interpretation of reflection-profiler records: (1) differentiating between unwanted signals and noise on the graphic record which degrade the data, and (2) interpreting the data itself in terms of geologic structure. Unwanted marks may result from correlated signal sequences resulting from power line cross-feed and repetitive noise generated by the survey ship. Marks such as these should be eliminated during the survey, if possible, since they only tend to complicate, mask, or confuse the record.

Other unwanted correlated signal sequences develop which although associated with the reflection of acoustic energy are nevertheless detrimental to geological interpretation. These occur in the form of "side echoes",(19)that are produced by reflections from topographic highs or other points not directly below the source and receiver, and also in the form of multiples. Multiples are frequently observed on records and result from compound reflections between the sea floor, or from other strong reflectors, and the air-water interface. If sufficient energy is involved, two or even three multiples may be completed and recorded thus confusing the record. It is possible to recognize the first multiple in reflector plots as occurring at twice the depth and at twice the slope of the actual first echo. As long as these multiples do not overlap, data interpretation is usually simple, but may become complex when multiples are intermixed with sub-bottom reflections on the record.

Unwanted traces may also frequently appear in the form of several close traces recorded from a single reflecting surface. These may occur when bottom-reflected sound is received at the detectors, and also passes to the sea surface, and is then reflected to the detectors. Moore (19) and others feel that this effect has been overemphasized in the past and that the traces are more commonly a result of amplitude excursions caused by restriction of the band width in electrical filtering. With proper selection of wider band width filters an optimum can be attained in balancing between noise elimination, utilization of the acoustical energy spectrum and generation of multiplicity of traces.

(e) DATA PROCESSING TECHNIQUES. The enhancement of signals over undesirable noise may be accomplished through the use of highly sophisticated systems of data processing. These are usually included between the receiving array and the final printing of the processed data on the graphic recorder. Signal enhancement methods may be divided into analog and digital processing systems. Analog processing is done with electronic and electromechanical circuits by storing sequences of signals for comparison to a later single one, by correlation of bottom signal characteristics to those of sub-bottom reflectors, and by several other means. Digital processing has evolved with the computer. In this the seismic signals are recorded on magnetic tape while at sea, and later at the computer center they are processed through application of statistical methods of analysis of time series.

These data processing techniques are of fundamental importance in reflection profiling interpretation, particularly in areas of complex geologic structure and when dealing with highly reflective bottoms. While the digital method undoubtedly provides the best results, it has an inherent disadvantage of a time lag and the results are consequently not immediately available. In some instances a return to the survey area is necessary if the computer processed results indicate that the data collected is inadequate. Analog processing, though less precise, provides an on-the-spot record for immediate review. The major geophysical companies engaged in seismic profiling presently all utilize the digital methods because of their greater accuracy and versatility.

3. COMPONENTS OF A PROFILING SYSTEM

(a) ENERGY SOURCES. Seismic reflection methods for exploring buried structures have previously depended principally on explosive sound sources. The explosive source used is a specially developed nitro-carbo-nitrate compound (1) and the charges (ranging from 16 to 100 pounds) are suspended in the water at a controlled depth of two to ten feet so that the radius of the gas bubble generated is equal to the charge depth. The venting of the first bubble results in an elimination of the bubble pulse. Charges may be exploded at intervals ranging from three minutes down to forty seconds.

The difficulties associated with explosives have severely limited its use in exploration. Application has been restricted in areas where marine life may be jeopardized, and is generally limited to daylight hours. Consumption of explosives has increased as the need for larger charges and deeper data has arisen. The explosions result in a water plume large enough to be visible at some distance and when operating near land these sometimes may have a disturbing effect on the local residents. The biggest draw-back, however, is the impracticality of shooting many shots in close sequence, and these limitations have led to the development of other marine acoustic sources.

Certain requirements were considered in the development of other possible sources to put them on a competitive basis with explosives. The energy level was deemed of primary importance in that the total acoustic energy from a 100 pound explosive shot is very large. The explosive source has a broad frequency, although only its low-frequency content is useful in seismic recording. It was necessary therefore, that the pulse of the weaker non-explosive source be shaped to match the reflection pulse returned from the subsurface. The acoustic source must have a rapid duty cycle and the pulses must be highly reproducible. This allows a large number of individual pulses to be summed or integrated, thus achieving an energy equivalence. Reliability was an important factor, as was reduced amortization and operating costs. On the basis of these requirements, many different types of energy sources were eventually developed.

(1) TRANSDUCERS. The earliest reflection profiling records were made with conventional echo sounders employing ceramic crystal transducers having a relatively high frequency. Records were made on early-model graphic recorders. As the potential of the technique became apparent, the echo sounders were modified for better performance, and then complete systems were devised for recording sub-bottom reflections. The Marine Sonoprobe (16) represents one such system utilizing a magnetostrictive transducer for transmission and a matched crystal transducer as a receiving hydrophone. Other systems making use of crystal transducers were also developed. All are characterized by relatively high frequency ranges, approximately 2-12 kc/s, and therefore useful for only shallow penetration, although resolution is usually very good.

(2) SPARKER. The use of an electrical-spark discharge in water for echo sounding was introduced a number of years ago for shallow subsurface mapping. In this the electrical energy (10,000 to 120,000 joules) is stored in a condenser bank and

discharged through an electrode system towed behind the survey vessel. As the energy is released, the water immediately surrounding the anode is vaporized and an expanding plasma envelope is developed. A bubble pulse then forms which is equivalent to that generated by the expanding gases of conventional chemical explosives. The pulse shape produced is a function of depth below the surface, electrode configuration, and power input. The bubble-pulse frequency generated by a single spark discharge, like that of explosives, is proportional to the 5/6th power of water depth and inversely proportional to the 1/3rd power of the stored energy.(19) By regulating the electrical energy of the discharge and the towing depth of the electrode, the acoustical waveform may be varied from a short pulse of several hundred c/s to a relatively long pulse with a frequency well under 100 c/s. The sparker may be fired in arrays to give better directionality to the signal. Depth of penetration equivalent to an explosive shot is often achieved by the summation of a large number of individual discharges. With the long pulse length some loss in definition may result from the cross-section becoming reverberatory in appearance. If the data is recorded for digital processing, compression techniques can be applied to enhance the resolution.

(3) BOOMER. The Sonar Boomer transducer produces acoustic energy by a unique electromechanical design using the eddy current effect.(26) The transducer consists of a flat-wound coil mounted in an epoxy body and an aluminum plate spring-loaded against the face of the coil (Figure 2). A high-voltage, high current pulse is discharged from a condenser bank through the coil.

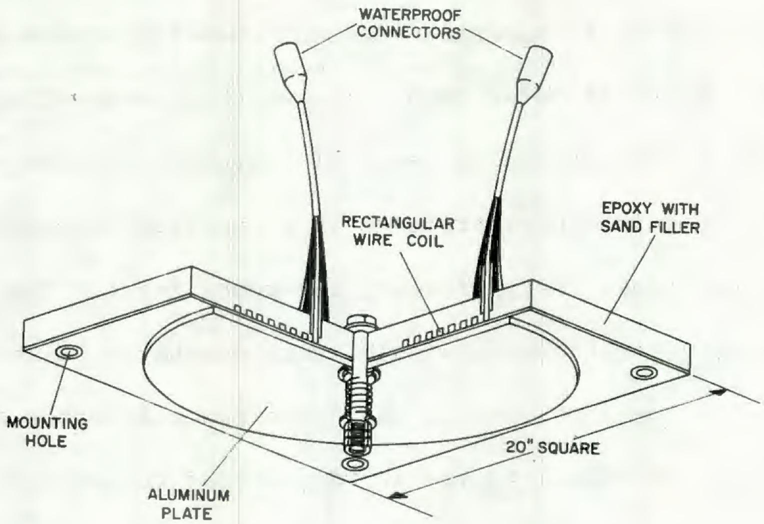


FIGURE 2. Boomer transducer

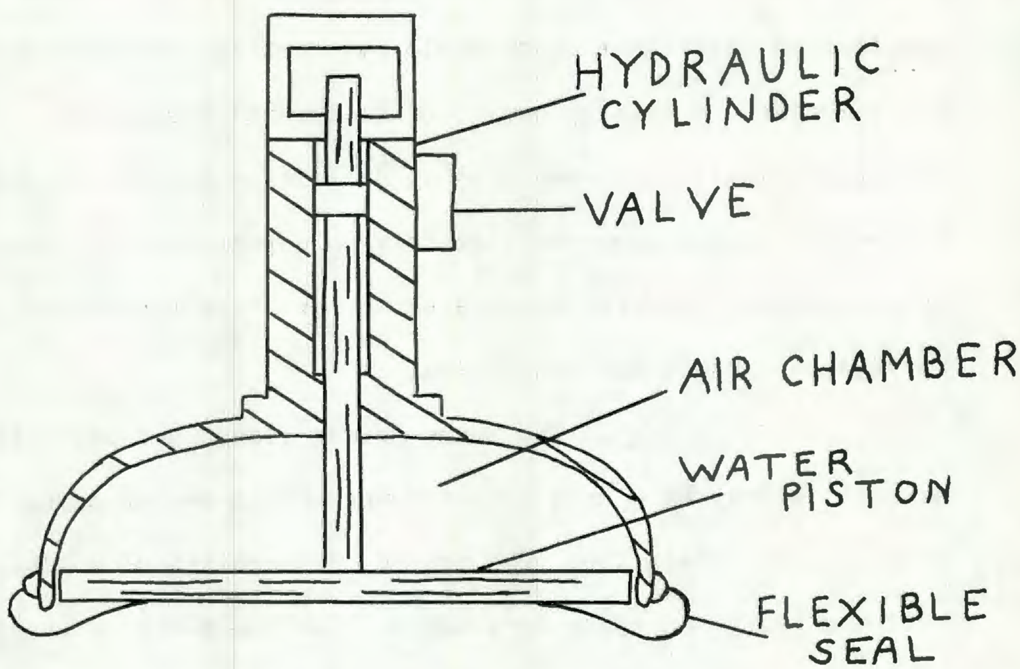
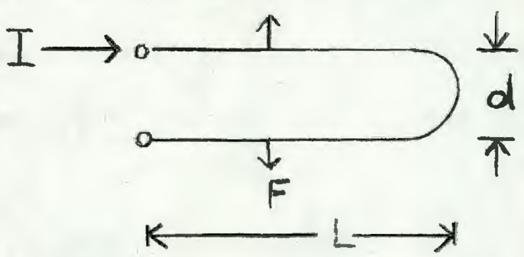


FIGURE 3. Vibroseis transducer

The resulting eddy currents repel the plates violently, creating a relatively low-frequency sound signal (approximately 500 to 800 c/s). Power supplies are essentially the same as those for a spark source and are frequently used interchangeably. The Boomer does not produce an oscillating bubble, but the plates themselves oscillate enough to produce several cycles of signal.(22) There is a finite limit to the amount of energy that can be put through a single Boomer, so higher power systems are ordinarily obtained by using several transducers in parallel.

(4) LINE SOURCE. The Line Source has been developed to achieve directionality by actuating several single long elements or a number of shorter elements placed end to end. Each element consists of a flat ribbon wound longitudinally into a coil encased in a neoprene jacket. From a condenser bank current discharges into a hairpin loop consisting of parallel conductors, thus generating a repelling force between the wires given by:

$$F = \frac{KN^2I^2L}{d}$$



Where N is the number of turns, I is the current, L is the length, and d is the separation between coil sides. K is a proportionality constant. The acoustic impulse is free of bubbles or cavitation and has a flat frequency spectrum from 5 to 1000 c/s. Because of its flat frequency and freedom from secondary pulses, the Line Source is used whenever good resolution is desired.(1)

(5) MARINE VIBROSEIS.* (5) The energy source for the Vibroseis system is a hydraulically driven transducer. As contrasted to impulse-type systems, the pressure wave propagating from this source has its energy distributed over a very long period of time. The operating frequency is controlled by a selected input or driving signal, and the signal returns are generally processed digitally.

Four units are used for normal operations synchronized by a common control signal. Each transducer consists of a piston-cylinder assembly actuated by high-pressure hydraulic fluid (Figure 3). A hydraulic power unit consisting of a diesel engine driving a 3,000-psi hydraulic pump furnishes oil to each of the transducers. Once in the water, the air pressure inside the chamber is adjusted to equal the static pressure of the water. The piston, which is in contact with the water, is then driven sinusoidally by the servo-hydraulic actuator. The resulting vibratory input is a ramp or chirp with a frequency sweep of 10-70 c/s. An important feature of the Vibroseis is the ability to control the spectrum of the input energy and to integrate energy input over a long period of time.

(6) PNEUMATIC SOUND SOURCE. (Figure 4) The pneumatic sound source, or "Air Gun", receives a supply of air at 2000 psi from an air compressor located on the survey ship and generates an acoustic impulse by suddenly discharging this volume of air to form a bubble. The air bubble resonates to generate several additional impulses. The energy content is controllable from about 7-500 c/s;

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*Registered trademark of Continental Oil Co.

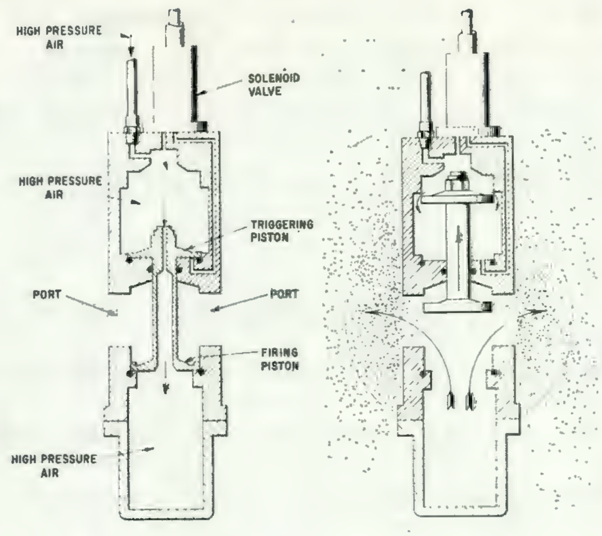

FIGURE 4. Pneumatic sound source - cutaway

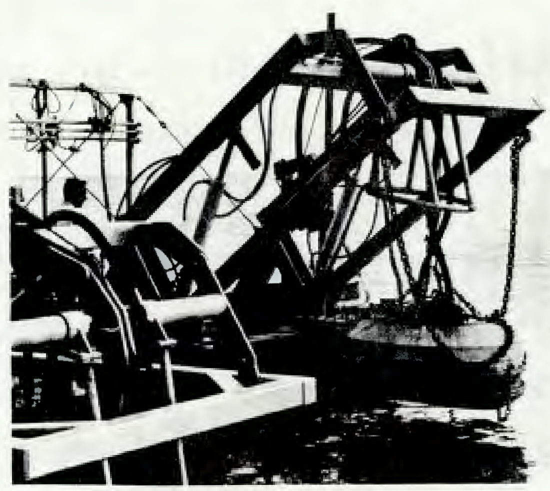

FIGURE 5. Large gas gun with deck handling frames

the dominent frequency of the bubble can be varied by changing the air pressure or the size of the air chamber, or by changing the working depth. These controllable features can be used to vary the power spectrum by using an array of different sizes of guns.

(7) THERMO-DYNAMIC SOURCES. A number of these sources, commonly referred to as "gas guns" or "gas exploders", have been developed. The gas exploder is used to study deep formations (to 6000 feet) where lower frequencies and greater energy are required.(17) These sources involve the ignition of a mixture of combustible or explosive gases (usually propane and oxygen) in a chamber to generate an impulse and/or bubble pulses. In some varieties the gases are contained in enclosed chambers, whereas in other types the gases are entrapped in an inverted chamber. (Figure 5)

In a typical source the acoustic impulse generated is a combination of an impulse caused by detonation or ignition followed by bubble pulses and reflections from the water surface. It is possible to control the pulse shape within narrow limits. The power spectrum of the pulse peaks at 10 c/s with considerable power in the 5-45 c/s range.

(b) DETECTOR (HYDROPHONE) SYSTEMS. The hydrophone streamer is a result of an evolution -- starting with individual velocity sensitive geophones, pulled along the bottom in relatively shallow water; to pressure sensitive hydrophones, suspended from a surface floating cable; to a neutrally buoyant streamer containing as many as 960 hydrophones.(1) Piezoelectric and magnetostrictive hydrophone elements have been used more or less indiscriminately according to habits developed by various investigators depending on preference, convenience, and estimates of performance in towing. Hydrophones are usually chosen for broad-band flat response and for the best towing characteristics.

The hydrophone streamer, a multi-hydrophone linear array, generally gives significantly better results than a single phone for several reasons.(19) First, the flow noise generated by movement through the water is much greater with single phones than with multiple-element systems. Secondly, the proper spacing of hydrophones making up the streamer allows cancellation of unwanted ship noise and minimizes direct source-to-phone signals. Hydrophone spacing at intervals of one-half wave length of the central frequency within the range used for the survey accomplishes this cancellation effect. Acoustic energy at, or near, this wavelength, traveling along the length of the streamer will produce positive and negative pressure maxima on alternate phones. Since the phones are wired together in parallel the result is cancellation of the signal. The cancellation produces another advantageous effect of linear arrays by providing some directivity in a fore and aft direction. Under certain conditions reflections from topographic highs resulting from the omnidirectional signal will be effectively cancelled from the recorder spectrum.

The trend in streamer design for present-day high-speed profiling is toward the use of many small, closely spaced phones in small diameter housings. The objectives of this arrangement are cancellation by half-wavelength spacing and the reduction of flow noise. Many investigators find it to be more economical to design and construct their own streamers after procurring the components separately. As a result streamers of many sizes (lengths and diameters) are in use today. One very narrow streamer is a type with a diameter the size of a garden hose which is being tried by Scripps Institute and the Naval Underwater Warfare Center at San Diego (personal communication with G. G. Shor of Scripps and D. G. Moore of NUWC).

An inherent problem associated with long streamers is that of depth control. It is normally desirable for long streamers to maintain a tow depth of about 40 feet with a tolerance of $\pm$ 10 feet, as this is the best depth for re-enforcement of acoustical signals with reflections from the air-water interface in the low frequency ranges. Surface noise and poor signal response occurs if the streamer gets too shallow, and a similar loss in signal response results if the streamer is too deep. In shallow water, streamer damage from dragging the bottom is also possible.

Three possible factors can cause a loss of depth control with a neutrally buoyant streamer -- environmental changes, fluid leakage from the streamer jacket causing a mass and volume change, and up-welling or down-welling currents. The environmental changes are generally the most predominent, particularly in areas near the coast where fresh water streams can create relatively large and sudden density variations.

Consideration of some of the parameters can lead to improvement of streamer tow depth control. That faster tow velocities improve depth control of long streamers can be concluded intuitively and proven mathematically.(7) Too high a velocity, however, may produce unacceptable flow noise. Less obvious is the fact that small diameter streamers are desirable for optimum depth control. Streamer diameter becomes particularly critical at lower tow velocities. The effect of environmental change cannot be altered through design. To minimize its effect it is clear that a small diameter streamer constructed in such a way as to allow greater tow velocities without depreciating signal-to-noise ratio is necessary. Present streamers are designed to reduce as much as possible the magnitude of the depth control problem.

(c) AMPLIFIERS AND FILTERS. Conventional broad-band amplifier designs are usually used, being altered and improved almost continually. In that these are standard items, no particular effort will be devoted to their consideration.

Commercially available passive and electronic filters are usually used in the profiling systems. Care must be taken to match the filters to surrounding circuitry. Dual filtering systems are usually employed to split the pre-amplifier output to one high-frequency channel and one low-frequency channel. The high-frequency band is selected to discriminate between side echoes and the sub-bottom reflections and for better resolution of shallow echoes, whereas the low-frequency band is chosen for maximum penetration. The two bands are recorded on a dual-channel graphic recorder.

Moore (19) advocates the combination of wide-band acoustic sources with a one-octave filter as most effective. One octave is equivalent to a doubling of a given frequency, e.g., 200 to 400 c/s. He reasons that this is more practical because an octave filter allows removal of a major part of the random noise while retaining reasonable resolution of reflection from adjacent layers.

(d) RECORDERS. All systems utilize graphic recorders which record intensity changes as a relative darkening of an electro-sensitive recording paper. Automatic correlation provided by the graphic recorder together with the ease of measuring travel time make it most suitable for seismic profiling.

Graphic recorders may be divided into dry paper and wet paper, and into stylus- and helix- types. The several commercial varieties are familiar to those experienced with conventional echo sounding equipment. Recorders also differ in the amount of sophisticated options that they include. One significant difference from the conventional echo sounding depth recorder is the ability of the profiler graphic recorder to eliminate most of its trace associated with travel time through the water to the sea floor, thus reserving the major portion of its display for the sub-bottom profile. This becomes a consideration in water of great depth. Additional detail on recorders is presented in a subsequent section.

4. INTERPRETATION OF TYPICAL RECORDS

Criteria for interpreting sub-bottom data provided by profiler records cannot be rigidly defined, and a certain amount of intuitive geological reasoning and experience in the area is involved in arriving at a valid analysis. Features such as angular unconformities, erosion surfaces, faults, folds, crossbedding, original dip structure, are frequently evident. On some records these may be prominent and easily recognizable, while in others they may be quite inconspicuous.

Figures 6 through 13 are examples of profiling records which are available from various commercial sources. They are typical of the better records obtained using the different types of energy sources. Figure 6 indicates a section of approximately 700 feet of unfolded horizontal sediments resting on an irregular surface of folded bedrock. The record was made using a large air gun operating at reduced power with a center frequency of 240 c/s and shows moderately deep penetration with good resolution. Figure 7 was made with the same type of air gun, this time at full power with a center frequency of 30 c/s. The record shows a typical salt dome; penetration is very deep (greater than 10,000 feet) with no resolution. Another representation of a salt dome using a gas gun sound source is provided by Figure 8. Once again very deep penetration has been achieved with the characteristic loss of resolution. A low power spark array operating at half energy level was utilized to provide the record in Figure 9. This was made as part of a survey for the proposed English Channel tunnel and shows an average water depth

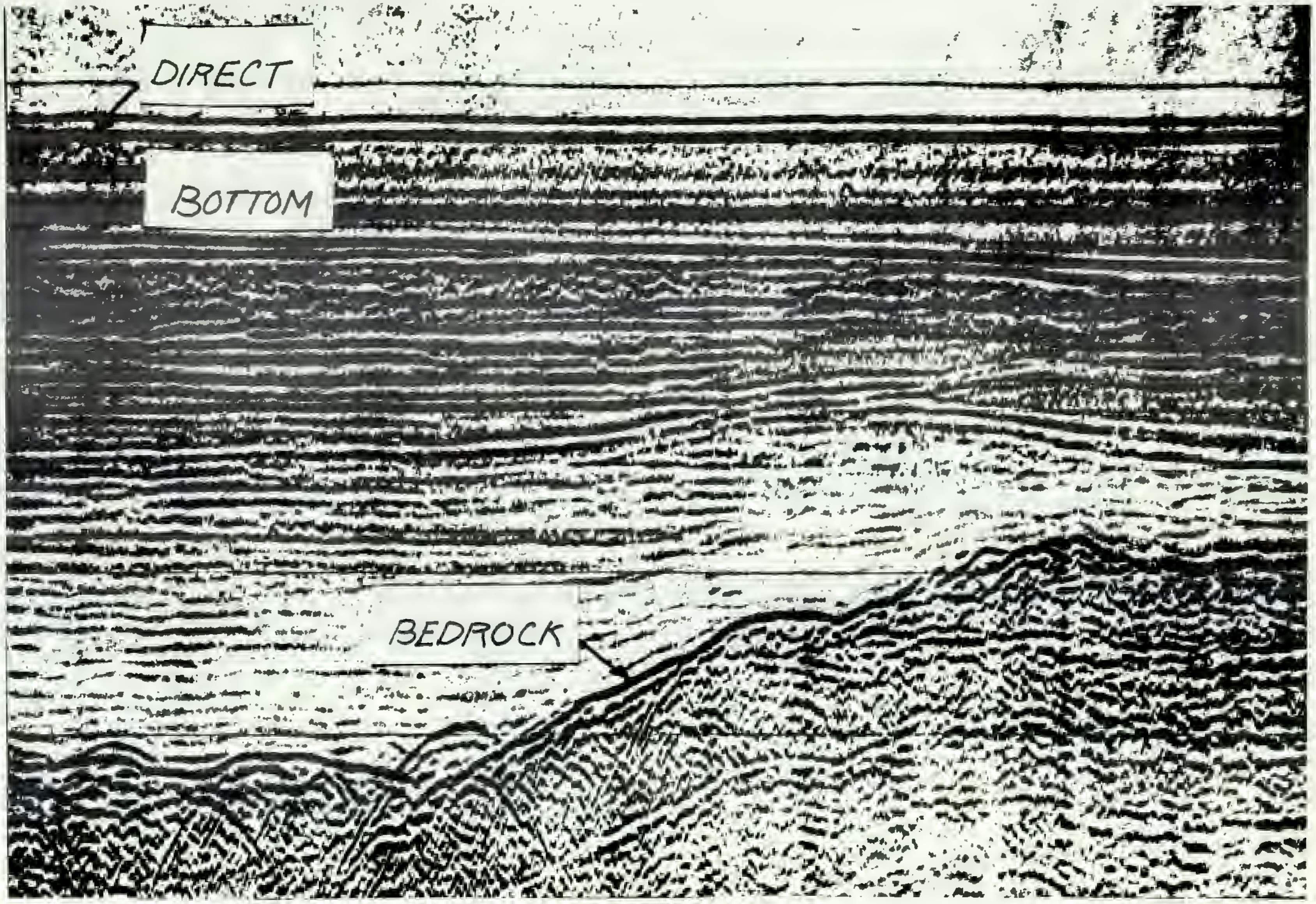

FIGURE 6. Seismic reflection profile, Long Island Sound, pneumatic sound source

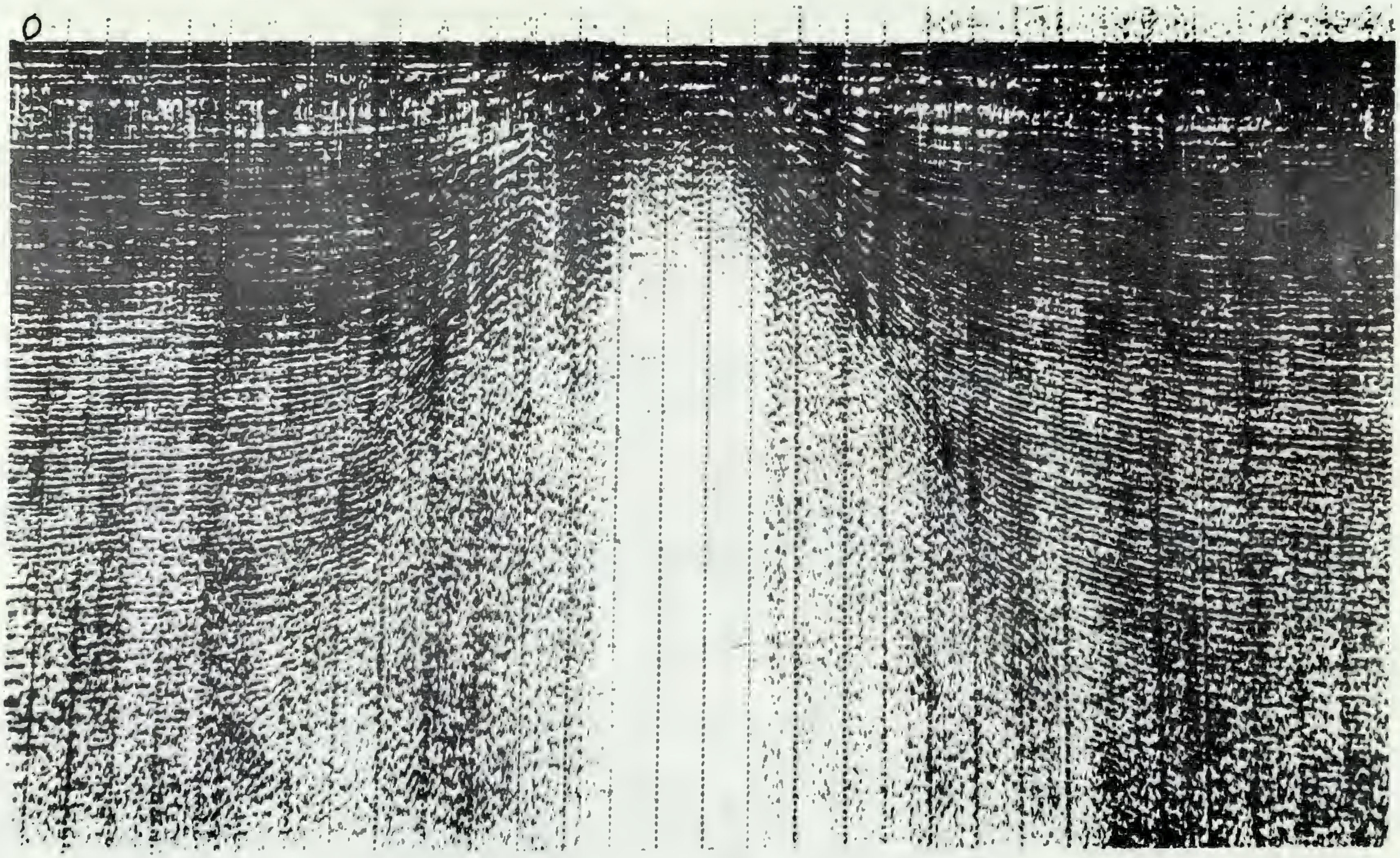

FIGURE 7. Salt dome representation in Gulf of Mexico, pneumatic sound source

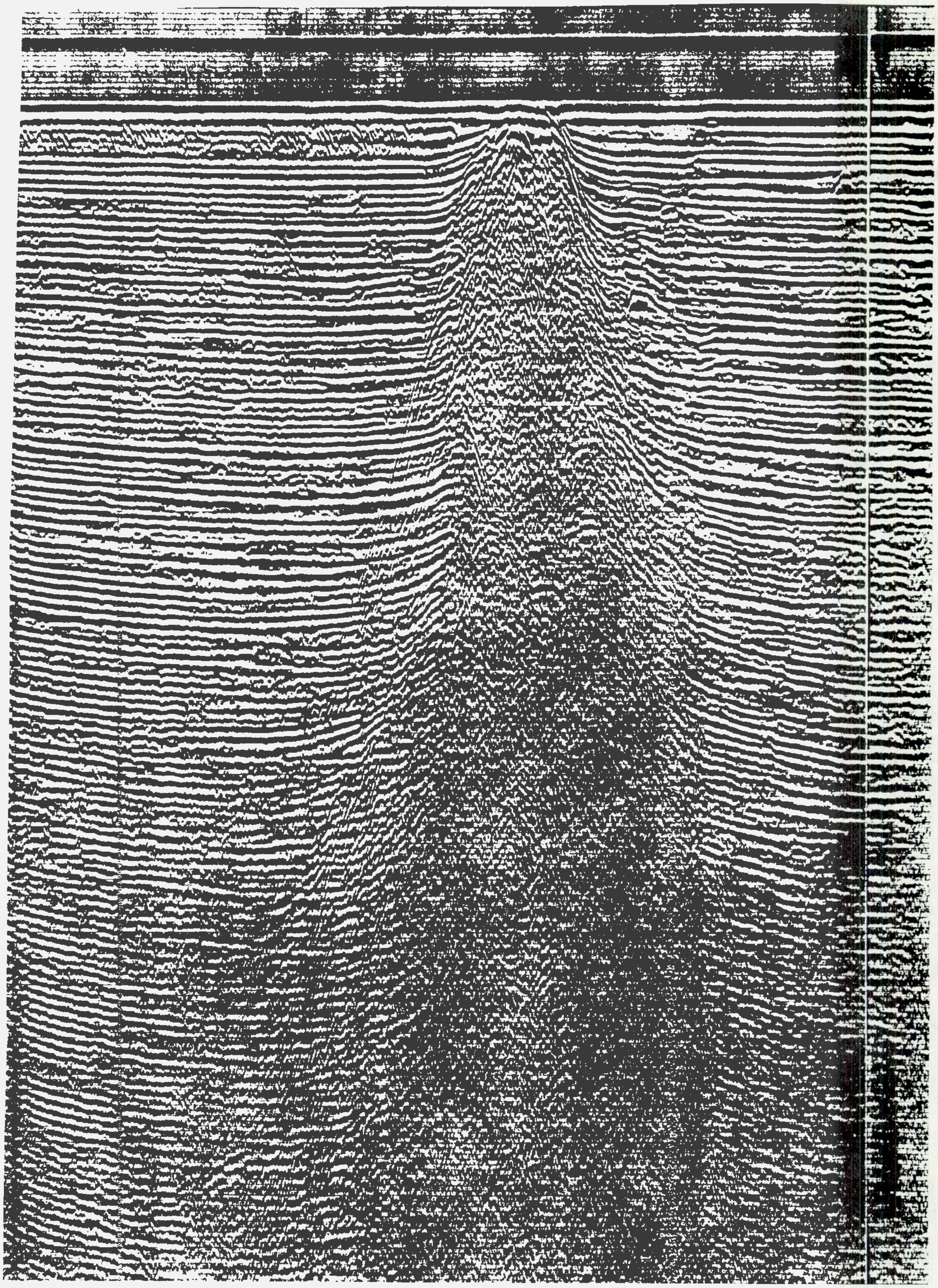

FIGURE 8. Seismic reflection profile, Gulf of Mexico, gas gun sound source

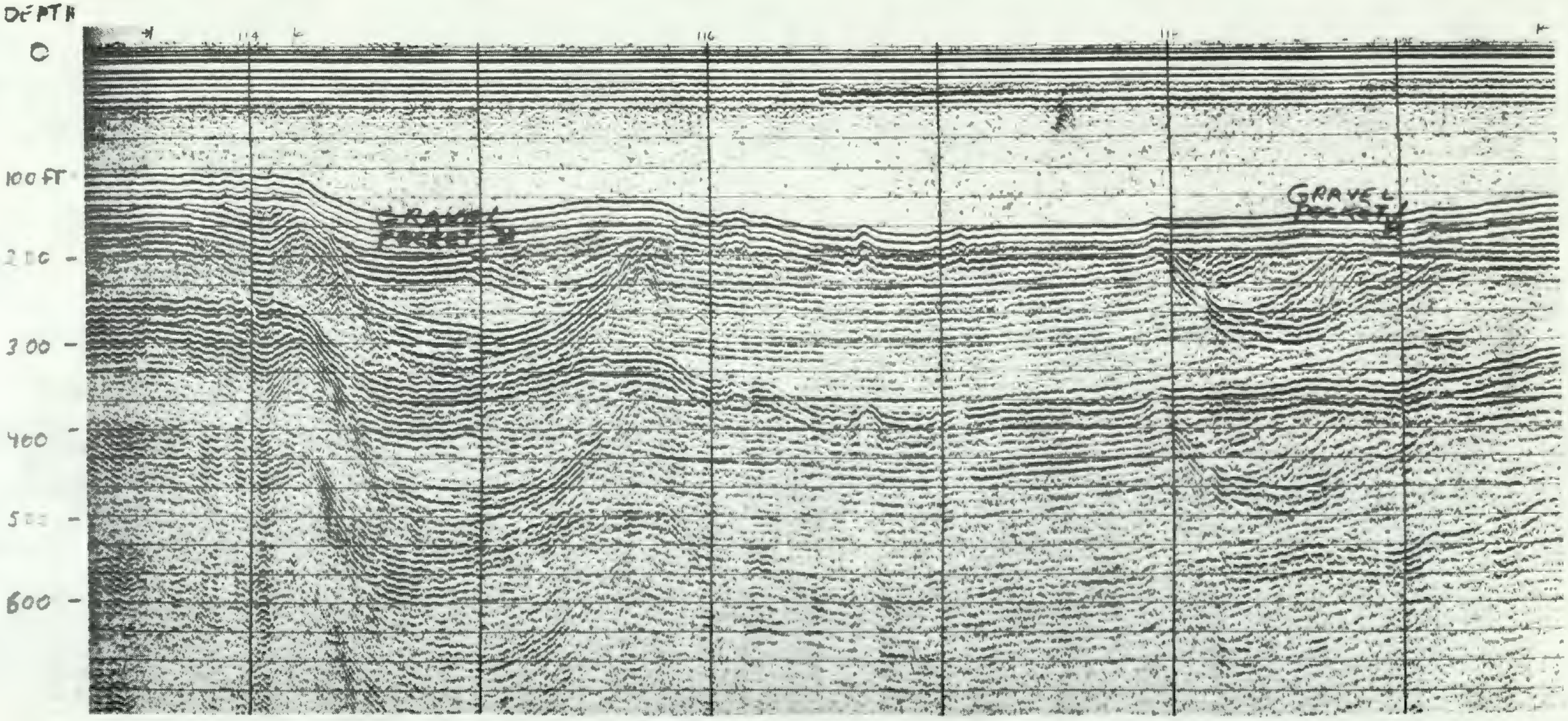

FIGURE 9. Gravel pockets in English Channel, spark array sound source

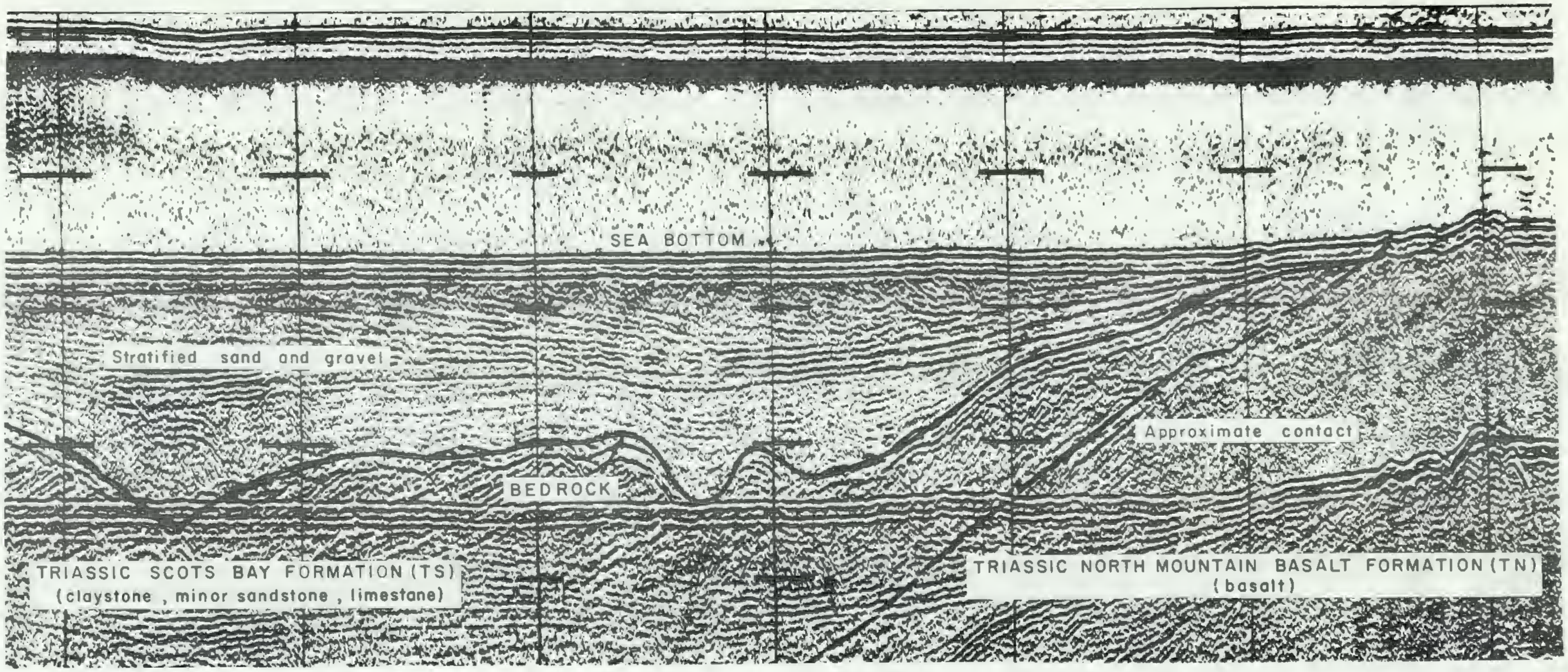

FIGURE 10. Seismic reflection profile, Bay of Fundy, sparker sound source

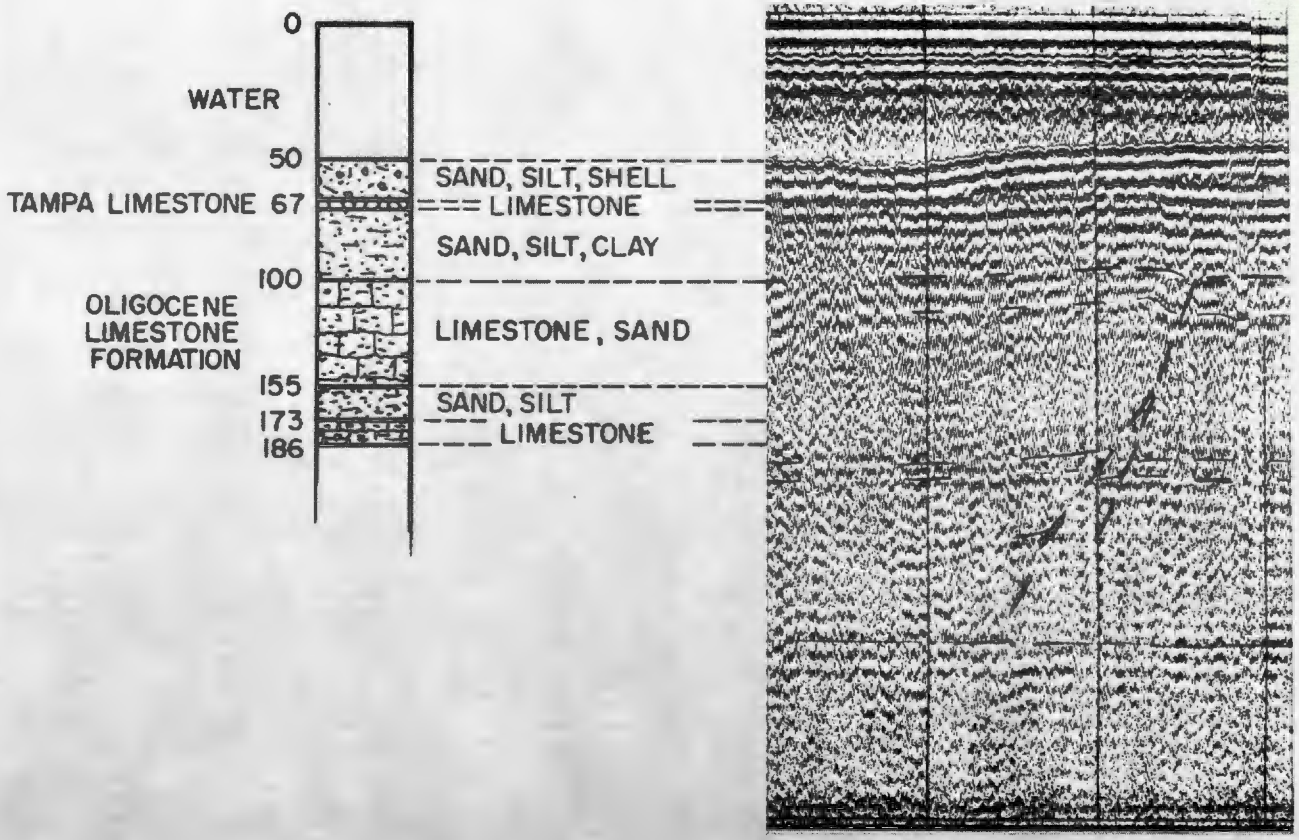

FIGURE 11. Boomer record with core correlation, offshore Georgia

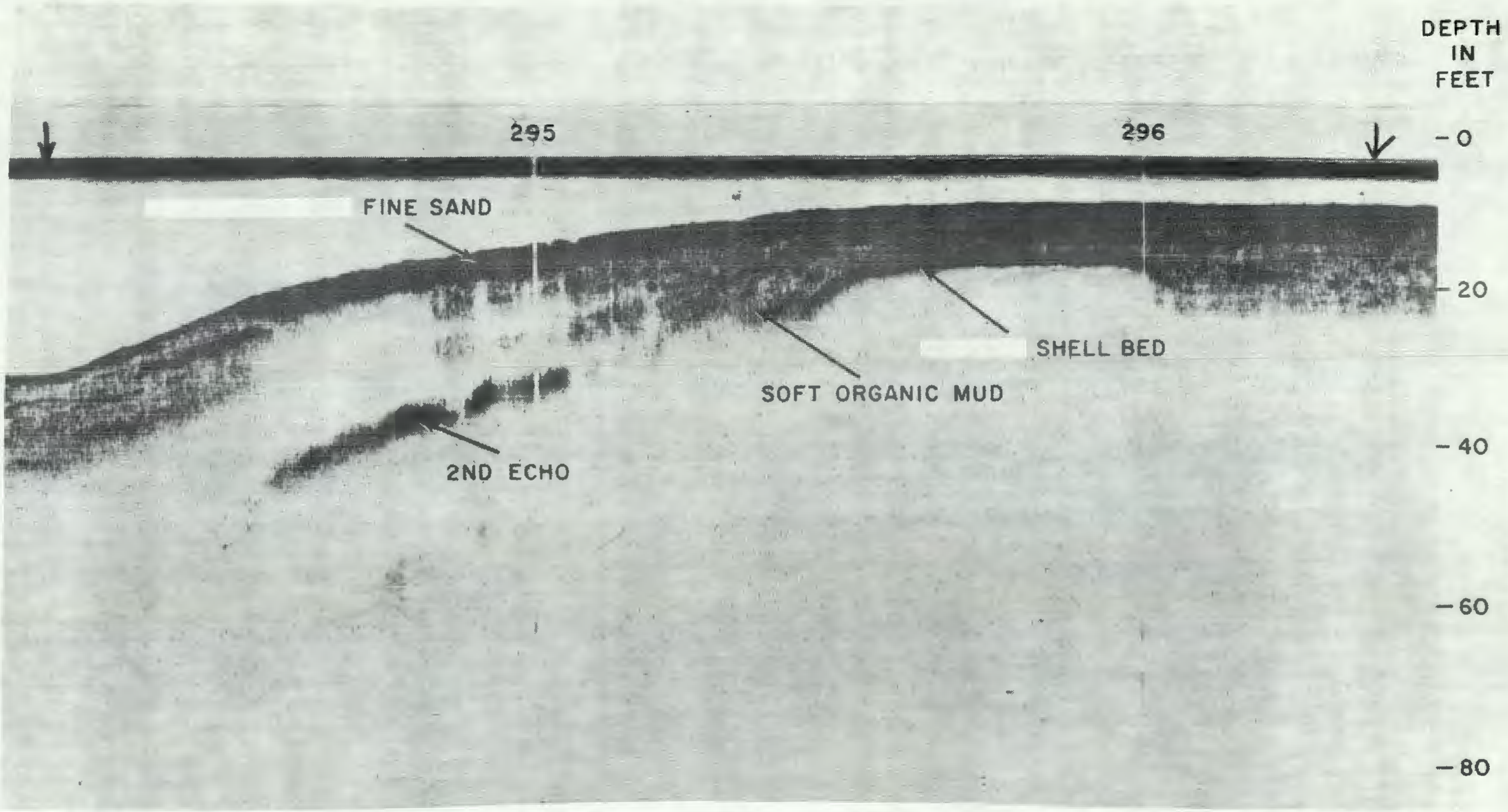

FIGURE 12. 12KC transducer record in Hudson River

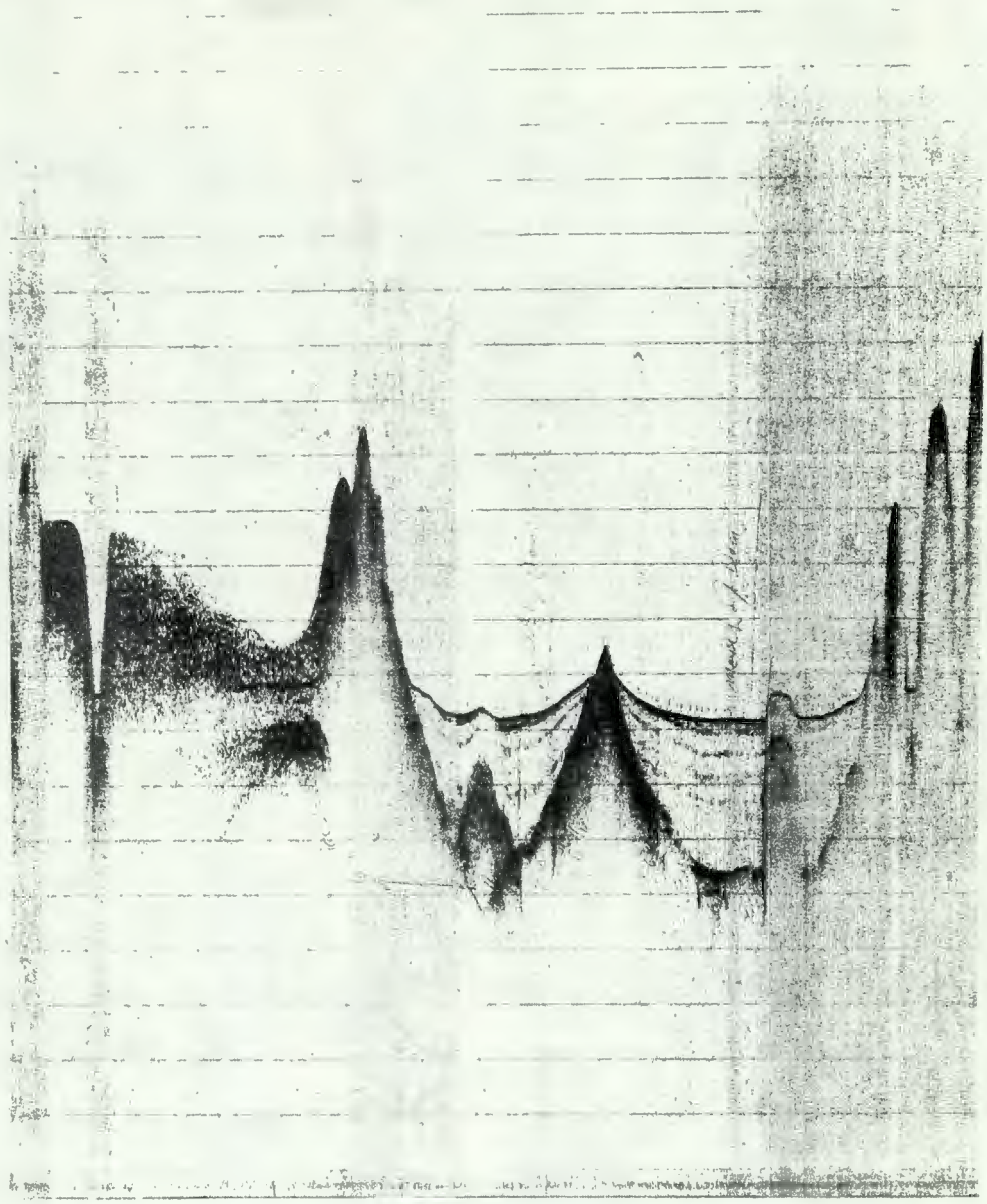

FIGURE 13. 7KC transducer record in Lake Mead, Nevada

of 100 feet and penetration of about 600 feet. Multiples of the sea bottom and underlying layers are evident. Figure 10 is another example of horizontal sediments overlying an irregular bedrock formation. A multiple of the sea bottom is clearly evident in this record which was obtained using a sparker sound source with penetration of approximately 300 feet. Correlation of a boomer record with a previous boring is presented in Figure 11. Sediment identification and aging as well as the depths at which the sediments occur are indicated in the figure. An example of fine resolution is shown in Figure 12 which was obtained using a 12KC transducer. In this case the very high frequency resulted in very shallow penetration, just over 20 feet. Figure 13 also shows good resolution as obtained with a transducer sound source operating at a frequency of 7 kc/s.

Figures 14 through 21 are all concerned with one specific survey conducted in 1963 off the coast of southern California. Detailed analysis of the record of this survey had not previously been attempted. The interpretation is based on information obtained from various geologic maps including the Santa Maria Sheet, Geologic Map of California, and from Emery (8) and Hironaka and Smith.(13)

A gas gun energy source was used to conduct this survey in an area southwest of San Miguel Island of the Santa Barbara Channel Island group located approximately 23 miles due south of Point Conception (Figure 14). Two traverses were made, the first on a heading of 65 degrees west of south (line A-B), and the second and shorter traverse intersecting the first on a heading of 45 degrees east of south (line C-D). The depths of water encountered during the survey ranged from

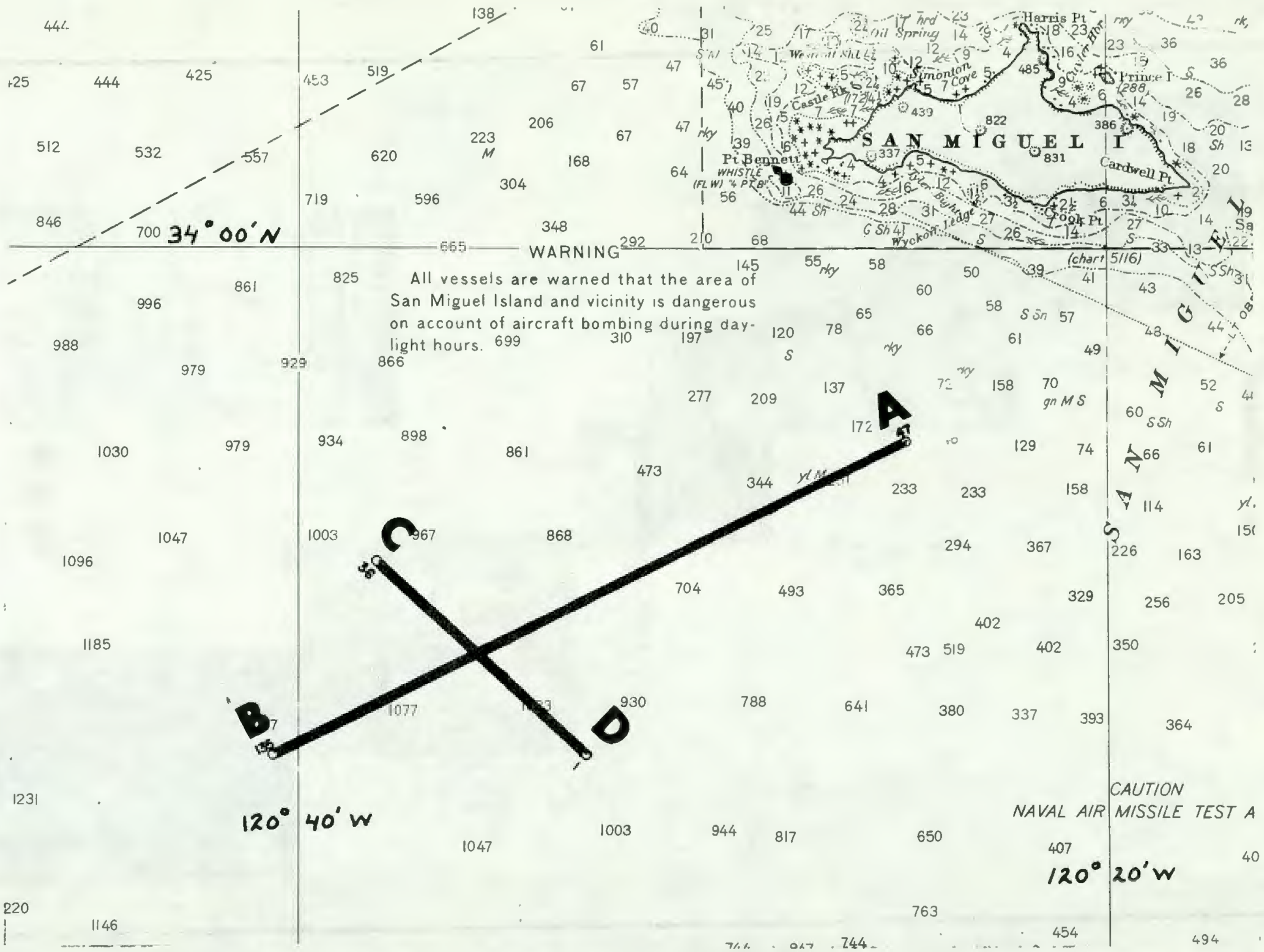

FIGURE 14. San Miquel Island offshore survey area

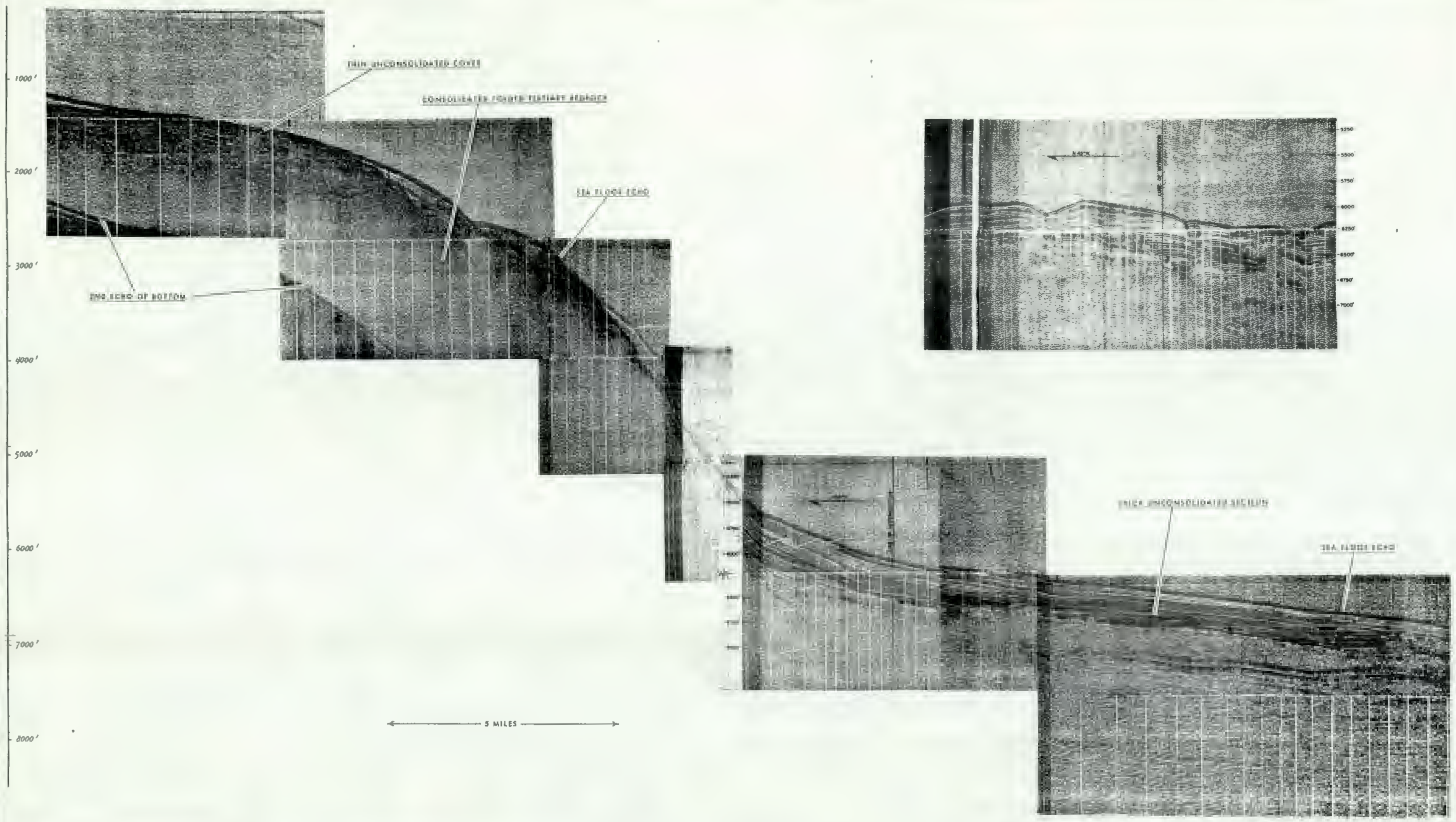

FIGURE 15. Composite record of survey

approximately 1000 feet to close to 7000 feet. An overall view of the record of the survey is presented as Figure 15.

The shallower portion of the record (Figures 16,17 and 18) indicates almost all the sub-bottom material as bedrock with only a thin overlying cover of unconsolidated sediments. The bedrock consists of a series of folded un-named Eocene sandstones; Oligocene nonmarine sands, conglomerates, and shales; all intruded by Miocene pyroclastic volcanic rocks. The folding exhibited on the profile took place during early Pliocene time and it can be concluded that the region was all above water at this time as no sediments of this age are found on the adjacent islands. The overlying cover is most likely Upper Miocene sands and shales of the Santa Margarita formation. It is generally very thin, to approximately 50 feet, in this portion of the record except where it has filled in irregularities in the bedrock layer along the slope. In this case thicknesses of up to 200 feet are observed. This portion of the record also reveals the evidence of a multiple of the sea bottom echo. Coverage in depth is not sufficiently broad throughout the rest of the record to display the continuation of this multiple.

Within the basin area, which includes the second traverse (Figures 19, 20, and 21), the bedrock is overlain by a cover of approximately 400 to 500 feet of sediments. The folded rocks beneath are probably of the same age and type as those described in the upper portion of the record with no evidence of Miocene intrusions. The loosely overlying sediments are most likely Late Pliocene, Pleistocene, and Recent deposits, with the greater accumulation here attributed to a continual movement of sediment from the upper slope areas by turbidity current flow. These sediments have filled up the somewhat irregular topography of the underlying bedrock. There is an indication of a possible fault located along the second traverse to the right in Figure 21.

This record confirms in part the findings of Emery (8) that folded Miocene and older age rocks are at or very close to the surface in the higher areas. Locally the Miocene may be exposed to the sea, but this record shows, in general, a small amount of cover overlying it.

The age of the unconsolidated cover is undeterminable. Nearby samples off of San Miguel Island have been dated (13) with inconclusive results. Foraminifera were noted as all of the living types with some appearances like Pliocene assemblages. This may have resulted from a water depth factor yielding a fauna of characteristics similar to shallow water foraminifera as found in the onshore Pliocene section.

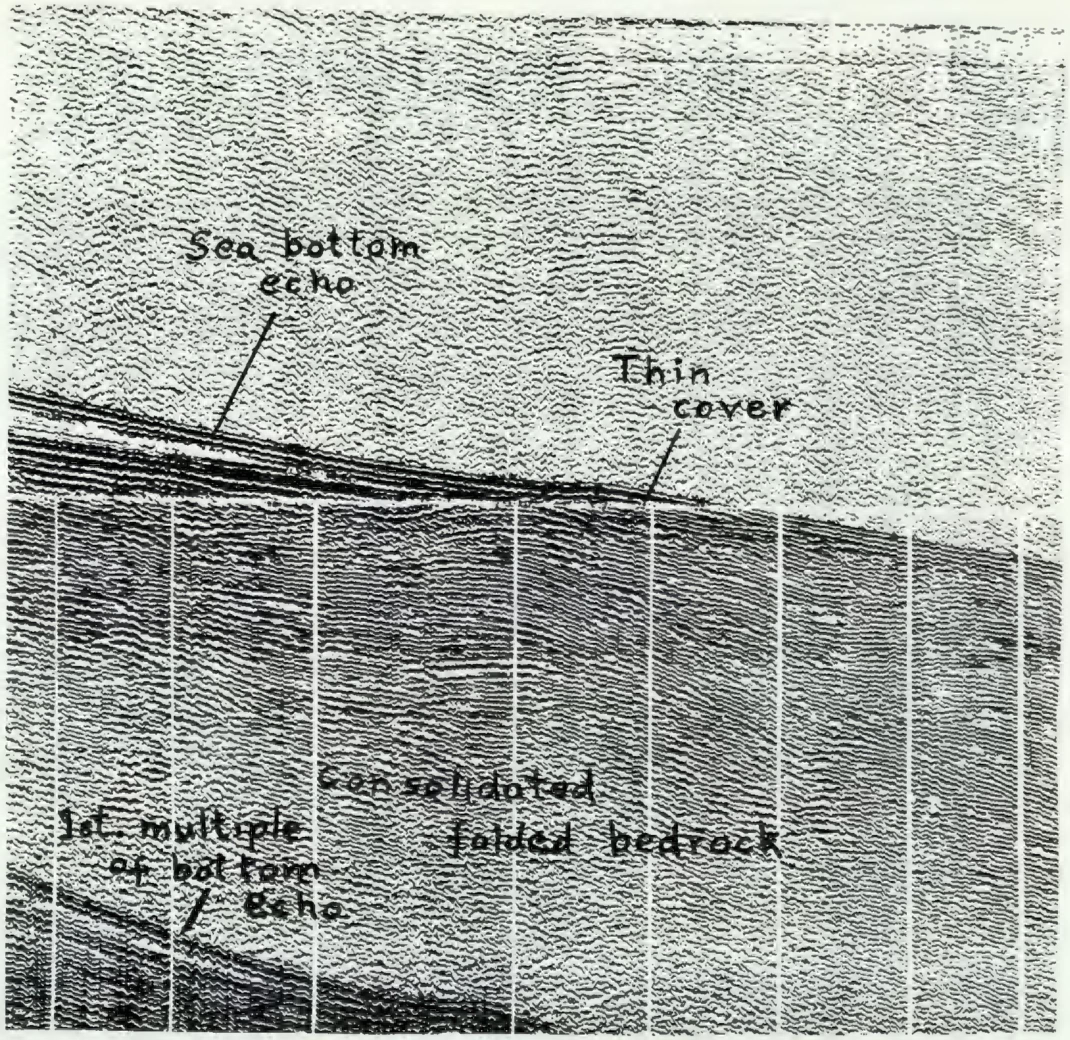

FIGURE 16. Traverse #1 - upper portion

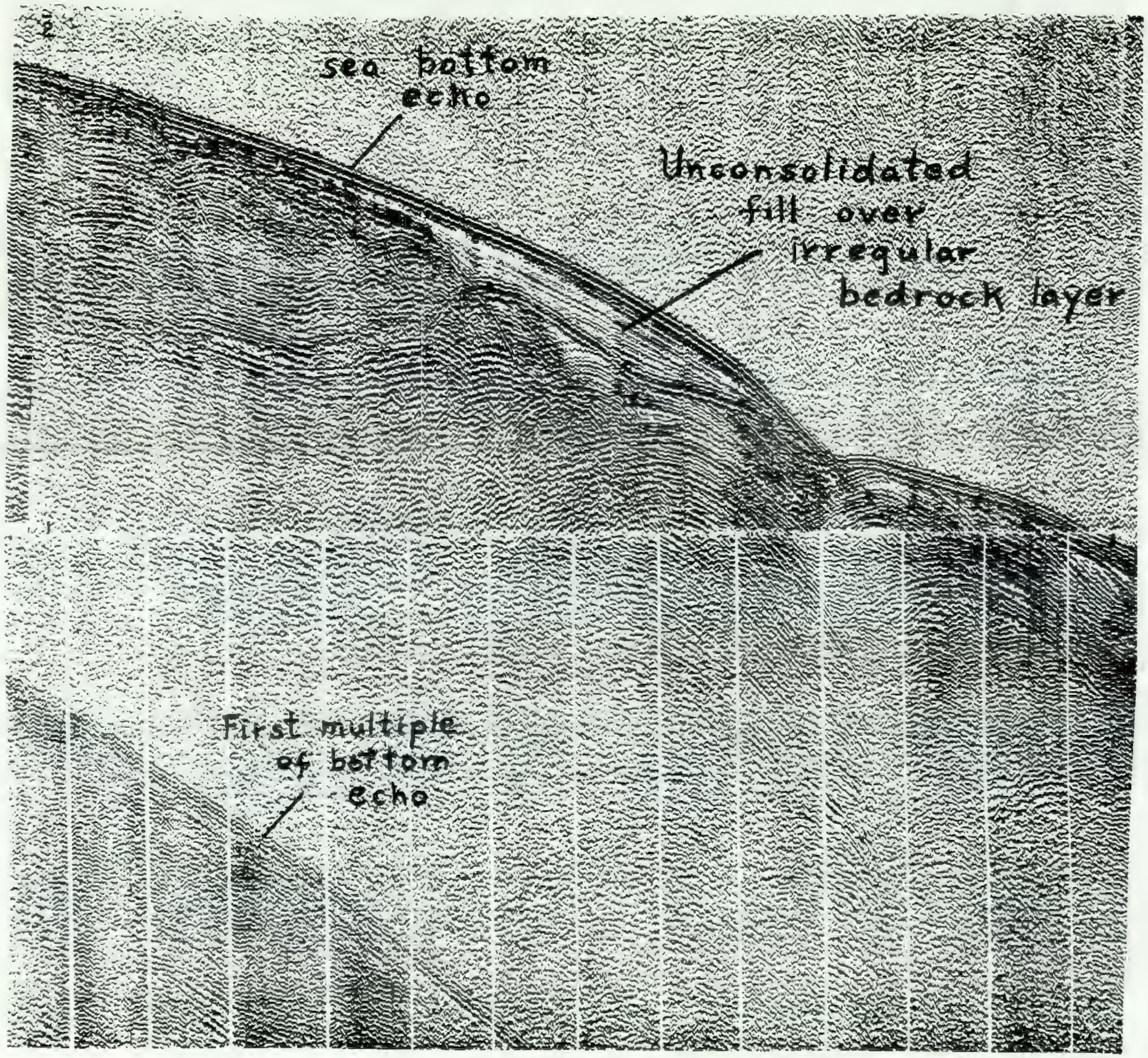

FIGURE 17. Traverse #1 - upper slope

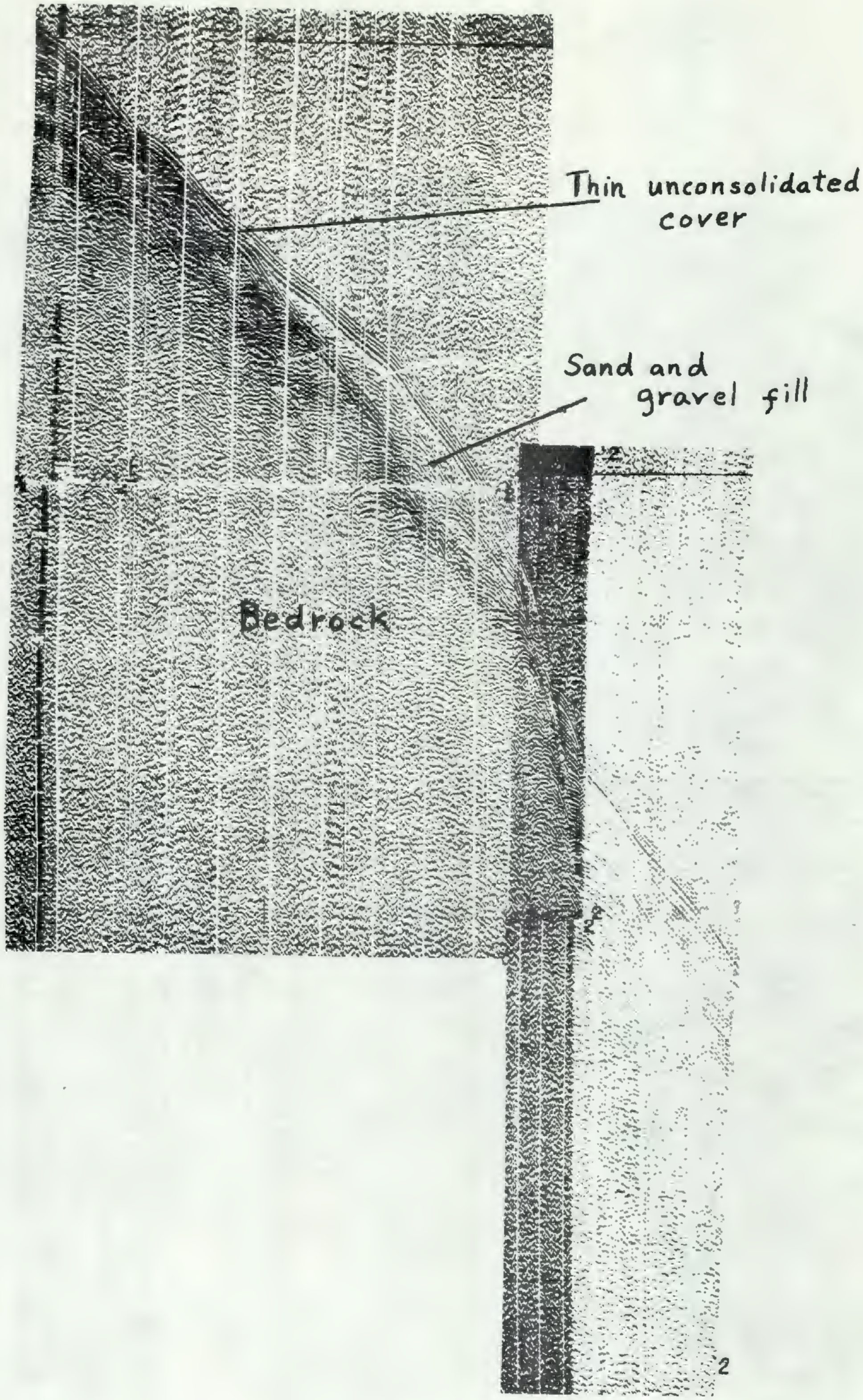

FIGURE 18. Traverse #1 - middle of slope

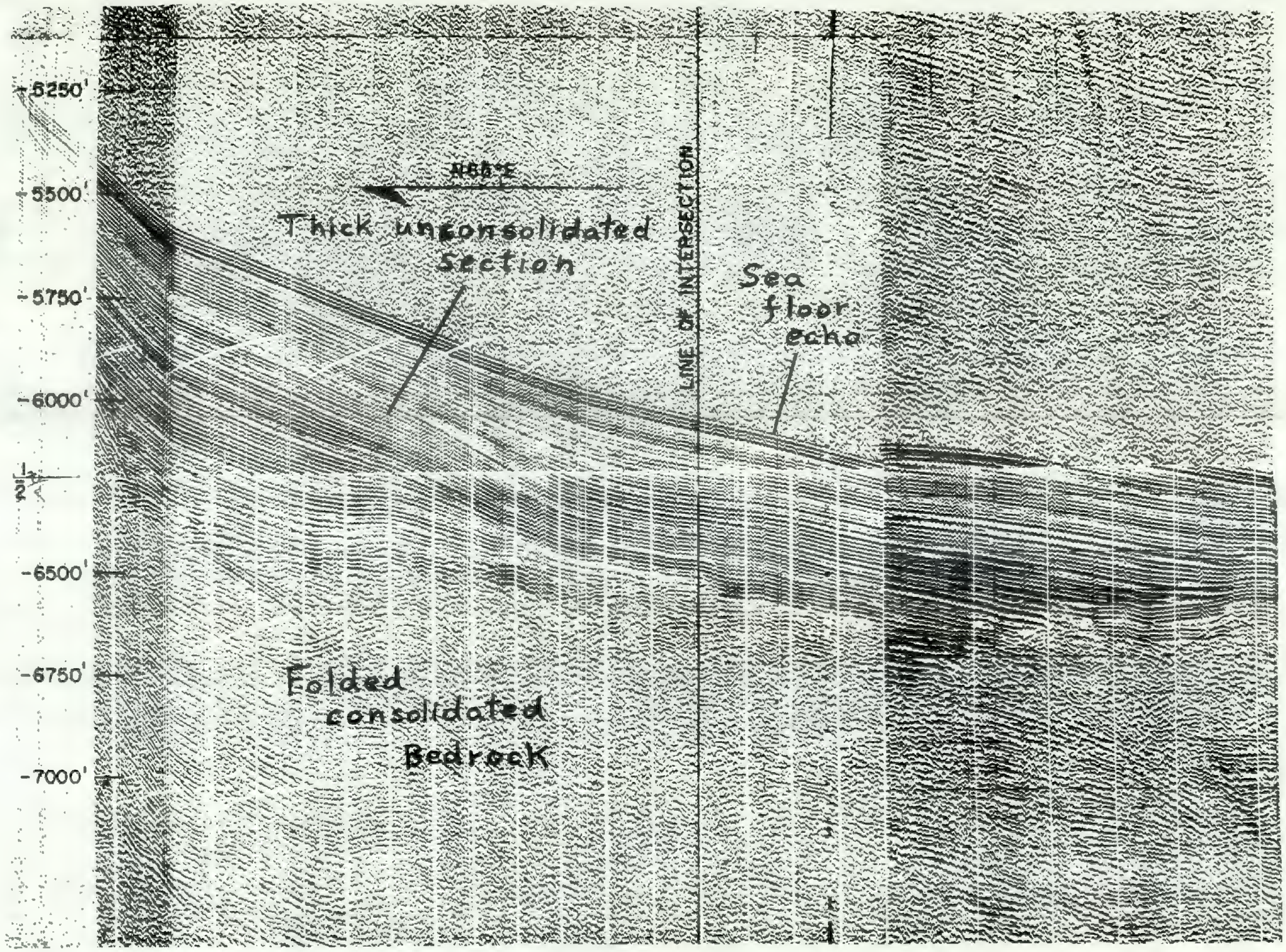

FIGURE 19. Traverse #1 - bottom of slope

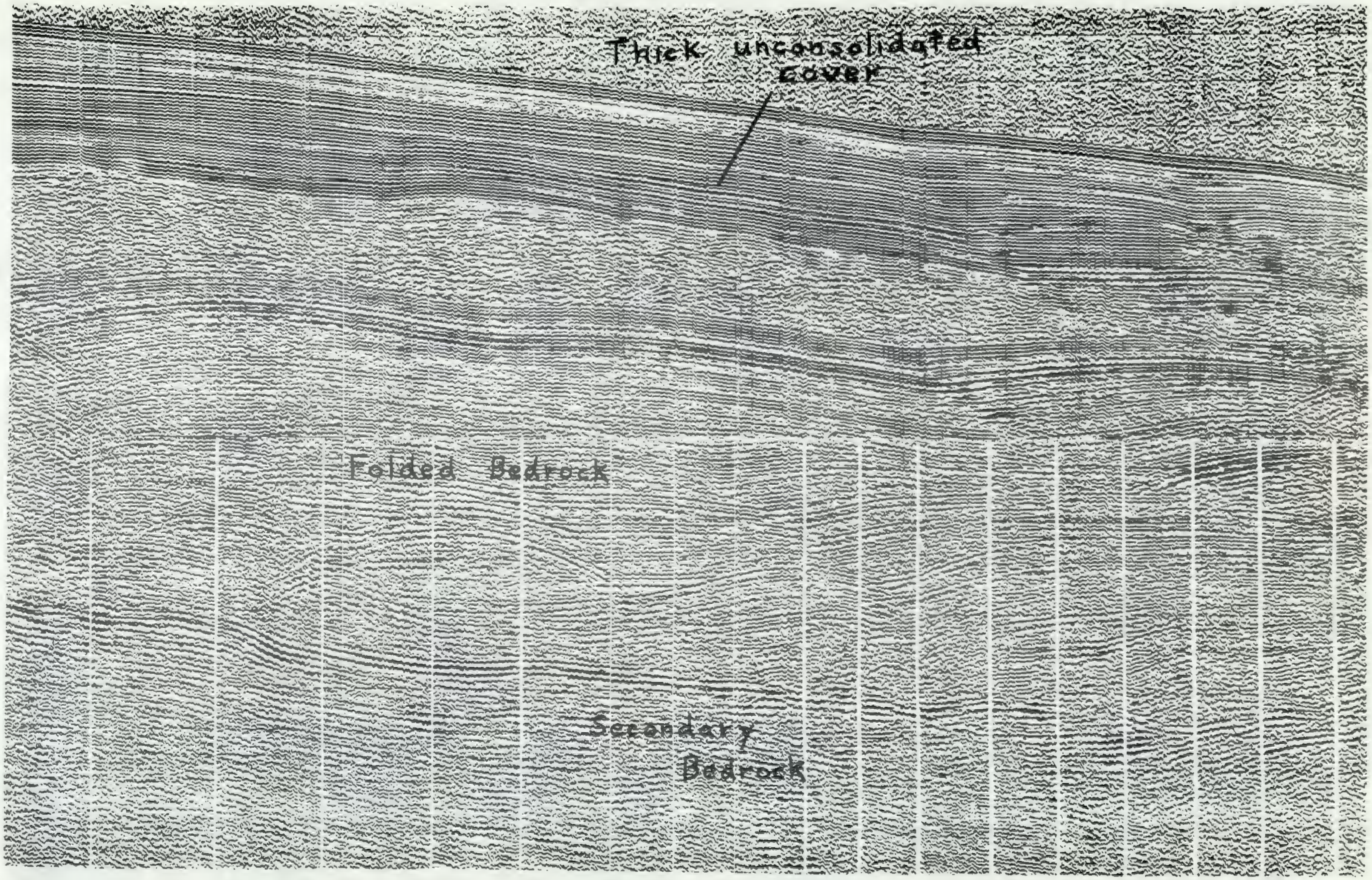

FIGURE 20. Traverse #1 - abyssal plain

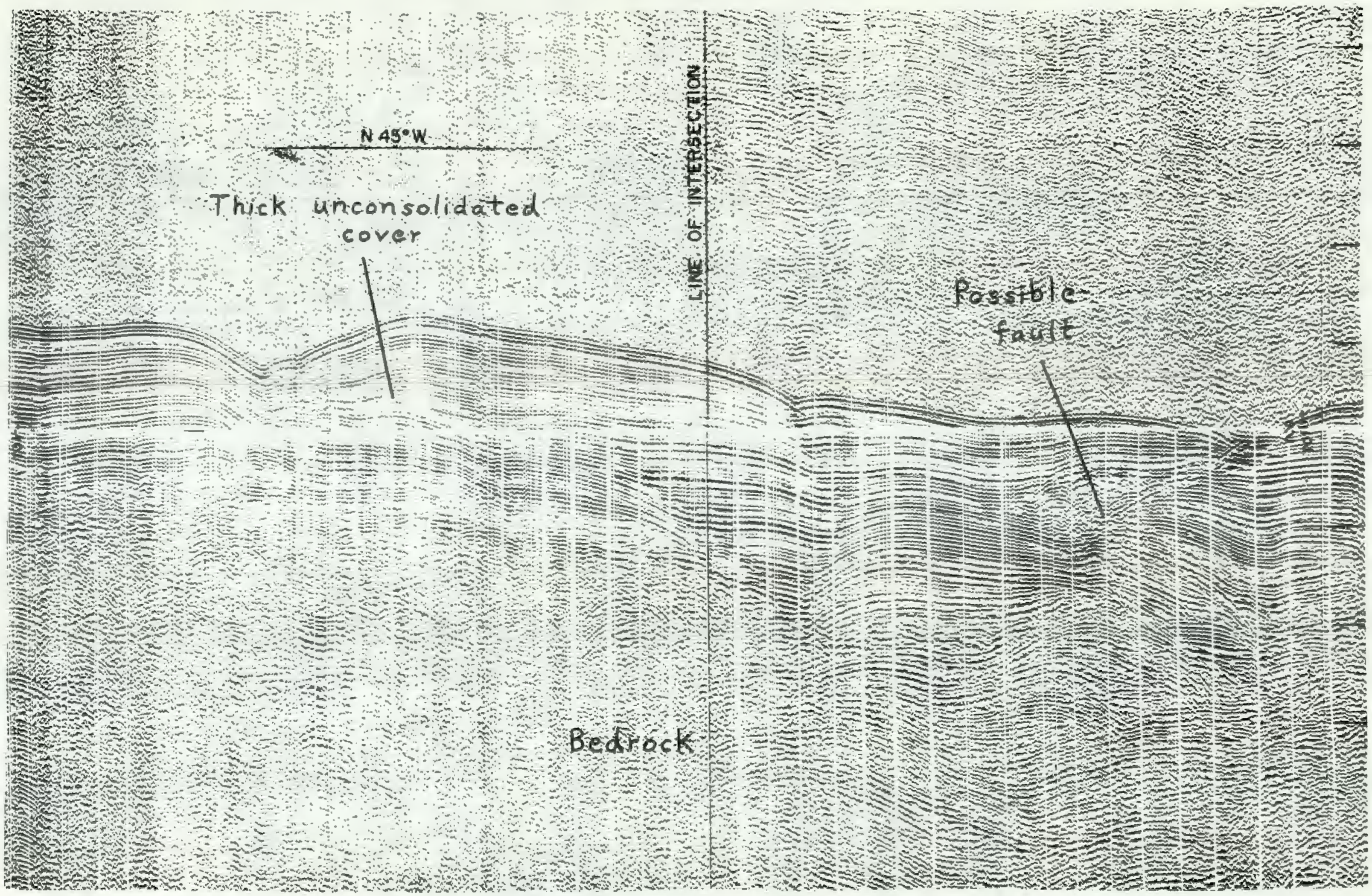

FIGURE 21. Traverse # 2

5. COMMERCIAL PRODUCTS AND SERVICES

A listing of products currently used in continuous marine reflection profiling from commercial sources is included in the appendix. This information has been compiled from varied sources including discussions with the manufacturers' representatives. To some extent the listing represents the performance characteristics of equipment as indicated by the manufacturer and should not be considered as constituting an endorsement or an opinion by the Navy.

Determination of companies engaged in the manufacture of reflection profiling products proved difficult, and it is likely that some omissions occur. The responsibility for such omissions rests solely with the author. Current price information, when available, has been included as an approximation rather than a precise figure. A summary of the commercial suppliers as contained in the Appendix is presented as Table 1.

TABLE I

SUMMARY OF THE COMMERCIAL SUPPLIERS

Manufacturer	Sub-bottom System	Energy Source	Detector	Recorder
Alden Electronic & Impulse Recording Equipment Co.				OSR-19, 19T OSR-11, 11T
Alpine Geophysical Associates, Inc.	Seismic Reflection Profiler System; Continuous Stratification Profiler System.	Series 501 Sparkers; Gas Exploder	Eel Array	PESR Mod 460, 465; CSPR Mod 464; Dual Channel Mod. 462.
Bolt Associates, Inc.		PAR Mod 600A, 1900, 1500B, 800A (air gun).		
Edgerton, Germeshausen, & Grier, International, Inc.	1,000 watt-second, 8,000 watt-second, 24,000 watt-second, Seismic Profiling Systems.	Boomer Mod. 236; Sparkarray Mod. 267A; Pinger Probe Mod 228A; Pinger Probe Mod 229.	Mod 262G; Mod 263B; Mod 264A (arrays).	Alden
Edo Western Corp.	Mod 415 Acoustic Bottom Penetration System; Mod 400 Acoustic Bottom Penetration System.	Mod 404 Transducer; Mod 240 HC Transducer	Mod 404 Transducer Mod 240 HC Transducer	PBR Mod 333 (modif.) PBR Mod 333
Geo Space Corp.		24" Land/Marine Dinoseis; Marine Dinoseis	MP-1 MP-3 MP-4 MP-7 MP-9 MP-8 (single geophones & hydrophones)	

TABLE I (continued)

Manufacturer	Sub-bottom System	Energy Source	Detector	Recorder
Geotech	SUBot	"Hydrode" arcer Mod 25441	SUBot Hydro-streamer	Ratheon & Magnetic Tape.
	SSP	"Lectro-Pulse" sparker Mod 24218	Hydrostreamer Mod 24257	(same)
	WASSP	wire-arc Mod 24218	(same)	(same)
	GASSP	gas gun	(same)	(same)
			CDP Streamer Cable.	
T.H.Gifft, Co.				GDR-1C-19,-19T GDR-1C-11,-11T
Huntec, Ltd.	Hydrosonde Mark 2A	MK2A Sparker (& Bolt PAR)	MP37 Single detector	Alden
Mystic Oceano-graphic Co.	Precision Acoustic Pulse System;	Sparker (100,000 joule)	array	Alden
	Low Power Sparker Profiling System	Sparker (3000-25,000 joule)	array	Alden
Ocean Science & Engineering Co. (services only)	Lizard Acoustic Profiler; Pulser Acoustic Profiler.	Towed fish transducer	(magnetostructure)	Gifft
		Towed fish transducer	(eddy current-repulsive)	Gifft, Alpine
Raytheon Co.		Mod BF-1146-1,-2 Hydroacoustic.		PSR-1910B; PFR-193B

Some groups utilizing seismic reflection results prefer to employ the services of a specialty firm to prepare the records for them, and this is the role of the geophysical services companies. The many commercial groups engaged exclusively in this service field therefore provide an important market for profiling equipment. They are able to provide ships, equipment, and personnel for marine profiling work at sea and, can further conduct the digital data processing and even the geophysical interpretation of the data if required. The final geologic interpretations are usually accomplished however by the contracting group.

Some geophysical services companies are included in the summary of equipment suppliers because of some unique form or variation of equipment that they employ. Many of the manufacturing firms listed also provide a service function. In general, however, the geophysical services companies have not been included in the listing.

Little or no mention has been made of towed bodies or mechanical handling systems within this report. Many of the firms that manufacture seismic equipment, and especially those supplying complete systems, also furnish winches, cabling, booms, etc. Many other firms also exist capable of providing this type of mechanical equipment.

6. SUMMARY COMMENTS.

The usefulness of sub-bottom sounding equipment can be measured chiefly by the experience and ability of the group utilizing it. Capabilities and characteristics alone do not describe the total suitability of a piece of equipment or a particular system. Other factors enter the picture that must be given consideration.

One important factor facing a potential user is that of the needs of the intended project. Establishing the basic requirements will therefore take priority over other factors, and in most cases will determine the path of the investigation. As noted earlier the various types of energy sources are centered about different frequencies,which influence the degree of penetration and resolution possible. The objectives of a project, therefore, will automatically determine the class of energy sources to be considered. Further more specific requirements are usually necessary. For example, shallow penetration with good resolution is not adequate to define the type of survey necessary. Is 20 to 50 feet penetration and one foot resolution or up to 200 feet penetration and 3 to 4 feet resolution required? Each case necessitates a different type of energy source, or at least a different version of the same general type.

Once the field of energy sources to be considered has been narrowed the other components must be selected. The type of survey itself may dictate whether a graphic format type of presentation is sufficient or whether a more sophisticated system should be adopted. The merits and shortcomings of digital versus analog systems should be weighed.

Tye type survey ship is also a factor. Hersey (12) indicates that for almost any type of vessel a system is available that can be effectively operated from it. The opposite problem is usually encountered, however, a specific survey ship is necessary to suit the needs of the system. Ten to twelve knots is the usual maximum towing speed for most systems. Some require a speed considerably less than ten knots, so such survey ships should exhibit good sea keeping ability at low speeds and in moderate seas. The ship must have adequate space for installation of the system. Various forms of electrical power, hydraulic power, and air pressure will also be required. Either these should be already on board or the vessel must be capable of accepting the source components of these systems.

The quality of the operating and maintenance personnel is another important consideration, for it has been estimated that for every energy source unit in operation there will be one undergoing repair. Qualified electricians should be on board capable of understanding and repairing a high voltage sparker system, plus, if needed, mechanics who can dismantle and repair a pneumatic gun or air compressor.

Underlying all of the previous factors is the matter of cost, which in the long run may very well exert the greatest influence on the type of system utilized. The higher cost, more sophisticated systems should yield the most accurate data and information, but usually funds are too limited to allow purchase of such systems. It has been estimated that the cost of a complete survey operation is about doubled by inclusion of digital processing requirements. In many instances it is possible to accept lesser accurate records than those produced by computer processing.

Cost may initially be reduced by selecting individual components from different sources rather than purchasing an entire system, for some items may be included that are not necessary for the intended survey. Most suppliers are not sufficiently versatile to completely produce each of the components themselves. This is indicated by the fact that many manufacturers of complete systems include components produced by other companies. By securing individual components considerable saving may be made say in energy sources with similar capabilities. Hydrophones are relatively inexpensive items, as are tubing and tow cables, and these can be combined into a streamer having characteristics equivalent to a commercial model. In considering graphic recorders, controlling factors should be economy, versatility, and mechanical efficiency. The degree of sophistication and the number of options usually increase the price of a recorder and if these are not necessary, two cheaper models might be secured allowing one as a replacement. Many areas exist wherein an initial reduction can be realized.

In the instance of a group anticipating working in the sub-bottom area, it is clear that personnel conducting evaluation of various devices must be completely familiar with the processes and aware of what to expect. The sub-bottom sounding field is still relatively new, and a particular type of unit may prove satisfactory unless the investigator knows where to look for shortcomings.

In evaluating equipment the selection of the test site is critical. Certain areas tend to give very good sub-bottom records using almost any type of equipment. While testing can be done in such areas these results should be compared with those obtained from other areas where it has proved more difficult to secure reflections. Furthermore, testing should be done over many areas having different water depths and varying sediment composition. Such locations should be known to the investigator in advance so that he may anticipate what to expect in the profiling results. This usually implies the services of both a competant geologist and a geophysist on an investigating team.

An important and sometimes overlooked factor in planning a sub-bottom survey is that of orientation of the traverse lines to the regional topographic and structural trends. If possible, traverses should be oriented to pass up or down regional dip rather than along strike. Structures causing topographic irregularities can normally be better depicted if crossed at high angles.

Any combination of profiling system and survey ship will have its particular acoustic characteristics, which normally reach peaks and nulls of noise at different propeller speeds and actual speeds through the water. Accordingly, preliminary testing at varying combinations of speed and acoustic band-pass filters generally produces a better quality record. Whenever possible, the adaptability of various units should be established by testing them in a number of systems made up of components from various sources.

The conducting of tests, making of evaluations and comparisons, and preparing general guidelines on sub-bottom equipment requires investigating personnel already completely knowledgeable in the various techniques and the different kinds of equipment. Potential followers of these guidelines will additionally need more than just a fundamental knowledge of sub-bottom sounding. Within the Navy persons with this background and experience are very few in number. Personnel must be trained before proceeding deeply into the field of sub-bottom profiling. Under existing circumstances it would seem that this training should be obtained from actual experience.

A proposed approach to satisfy this requirement would be:

(1) Selection of a team to be trained in sub-bottom profiling having varied backgrounds including all pertinent areas such as electronics and mechanics, which are inherent in a profiling system.

(2) Securing of a profiling system comprised of inexpensive components. Such a system will have very limited applications, but it should be more than sufficient for training purposes.

(3) Providing ship time and the opportunity to practice obtaining records with the equipment. Before long the team will be modifying the equipment or even redesigning various components. All this time they will be gaining much needed experience.

Those having gone through this process would provide the nucleus of persons trained in sub-bottom profiling. These would serve to test and evaluate equipment for future requirements. The initial phase will likely take at least a year if adequate experience is to be obtained.

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APPENDIX

Alden Electronic and Impulse Recording Equipment Company, Incorporated, Westboro, Massachusetts 01581.

Alden Electronics has recently formed Ocean Sonics,Incorporated, in El Sequndo, California, a subsidiary primarily oriented toward the development and manufacture of oceanographic instrumentation with emphasis on design of standard sonar recorders and associated sonar instruments. The OSR Series recorders produced by Alden Electronics are applicable to sub-bottom profiling, and can be supplied with or without acoustic transceivers built into the instrumentation.

Two models of 19 inch recorders are available. The OSR-19 is a basic recorder which can be combined with a sparker or similar source for broadband profile studies, or with a standard sonar transceiver to form a general purpose survey recorder for echo sounding. The OSR-19T includes an integral sonar transceiver and can be operated either as a recorder alone or as a complete echo sounder. The standard OSR-19T operates at 12 kc/s, although it can be equipped to furnish output frequencies from 3.5 kc/s to 34 kc/s.

The OSR-11 model has the same operating characteristics as the OSR-19 series, but with scan rates from 10 to 1000 fathoms across 11 inches of chart paper. This model is applicable where space requirements are at a premium. When combined with a programmer/transceiver it becomes an OSR-11T with features similar to the OSR-19T. Where power requirements are limited, the OSR-11 series recorders can be modified to operate from a battery power supply thus mobilizing this unit for more complete survey applications.

All Alden recorders use Alfax electrosensitive recording papers capable of being stored for an unlimited time without adverse affect. Recordings can be marked and erased without smudging, and the records have a wide range of tone shade to match the fidelity of signals received. A variable cycle length programming capability is standard with all units. This permits separation and collation of desired data from strong interfering signals such as surface reflection or multiples. This capability is necessary when attempting to observe the fine structure of echoes at a great distance when the recorder scanning rate greatly exceeds the echo transit time. The units include a range of seven sweep rates from 20 to 2000 fathoms across the width of the record. Variable paper feed ratios are also incorporated, and simultaneous magnetic taping with subsequent playback into the recorder is possible.

The characteristics of the OSR-19 and OSR-19T instruments are summarized below:

Printing width:	19 inches
Sweep scales:	20,40,100,200,400,1000,2000, fathoms (scales in meters or time also available)
Chart advance rates:	50 to 250 lines/inch
Printing electrode:	continuous loop
Recording paper:	Alfax Electrosensitive, Type A
Transceiver Output Power*:	800 watts peak
Transceiver Output Impedance*:	variable from 100 to 250 ohms
Transceiver Bandwidth*:	matched to key pulse lengths
Transceiver Operating Frequency*:	12 kc/s standard; 3.5-34 kc/s available

*OSR-19T only.

Input power:	90-140 volts AC, 45 to 70 c/s
Power consumption:	100 watts
Weight:	85 pounds
Size:	9 x 28 x 21 inches

Alpine Geophysical Associates, Incorporated

Norwood, New Jersey 07648

Alpine Geophysical designs, develops, and manufactures a wide variety of oceanographic and geophysical instruments and equipment. In the geophysical category their sub-bottom sounding equipment has been designed as complete systems though the individual components are available separately.

SOUND SOURCES

Alpine produces a group of sparkers (Series 501) as sound sources. Dependent on the model of sparker, acoustic energy can be developed to penetrate the sub-bottom from fractions of a second to several seconds. Each model incorporates a 250 foot cable and spark discharge electode. The sparkers are keyed by the recorder (PESR) or other keying device. Output is continuously variable from zero to the maximum rating for controlling the acoustic intensity. The triggers incorporate a hydrogen thyratron circuit, ignition coil, and adjustable high voltage trigger switch.

Series Number	Rating (Joules)	Approximate Penetration (Seconds)	Maximum Repetition Rate	Required Power
501-50	50	1/4	4/sec	5 KW
501-100	100	1/2	4/sec	5 KW
501-200	200	3/4	2/sec	8 KW
ESP*	5,000-20,000	1/2 - 4	1,2,4/sec	20 KW

*Electro-Seismic Profiler, a new source utilizing a high intensity arc.

DETECTORS

Alpine produces three different sets of hydrophone arrays (eels). Each include 10 pressure sensitive hydrophones arranged in two parallel sets of five phones connected in series, with an output impedance of 560 ohms. The hydrophones and leadwire are enveloped in clear, acoustically compliant, polyvinyl chloride tubing filled with antifreeze and water, or in some instances plain water. The active array length is 14 feet. Usable frequency range is 240 c/s to 6 kc/s.

Number	Cable length	Weight	Cable type
446	300 ft.	105 lbs.	2 conductor
446B	300 ft.	160 lbs.	Buoyant, 2 conductor
446C	1000 ft.	350 lbs.	Neoprene jacket, 3 conductor

The towing cables of the 446B and C are reinforced with a polypropylene stress member having a minimum breaking strength of 750 pounds. The outer diameter of the acoustic tubing is 2 1/4 inches.

RECORDERS

Precision Echo Sounder Recorder (PESR). The PESR recorders are of the wet paper, helix type using 18-3/4 inch paper. Depth and sub-bottom geologic information is presented in a nominal frequency range (of echoes) from 100 c/s to 15 kc/s, at a minimum level of 1.2 volts.

There are two models in this series, 460 and 465, and each can be equipped with a variety of optional components. The characteristics of these recorders are as follows:

Dimensions:	29 x 23 x 16 inches
Weight:	125 pounds
Recording Rate:	96 lines (sweeps) per inch
Number of sweep speeds:	3 for Model 460 6 for Model 465
Input impedance:	500 ohms

<u>CONTINUOUS STRATIFICATION PROFILE RECORDER</u>. This recorder (Model 464) is primarily designed for stratification profiling, but can also be used to make bathymetric records. Sound pulses and reflected returns in a frequency range of 5 c/s to 15 kc/s are recorded. A shot detecting hydrophone is necessary to trigger this recorder for seismic profiling.

<u>DUAL CHANNEL STRATIFICATION PROFILE RECORDER</u>. This recorder (Model 462) divides the chart to record two channels simultaneously. Two pulsed sound sources of different acoustic frequencies and intensities are employed to record topography and some subsurface structure on one channel, and the corresponding sub-bottom strata on the other channel. Two sound sources are alternately keyed by the recorder. A system utilizing the Model 462 recorder would include two sparker sources, two variable band-pass filters, a preamplifier and a hydrophone array.

Additional sub-bottom profiling equipment components manufactured by Alpine are as follows:

<u>Variable band-pass filter</u>. This filter (Model 542) has a frequency range of 0.2 c/s to 20 kc/s with the controls continually variable for both high and low cut-off.

Preamplifier. The 505 Series preamplifiers are designed to boost the hydrophone signal to an appropriate level for recording. They tolerate a 200 percent input overload with no evidence of interference from a strong outgoing pulse. Input impedance can be matched to the input source in steps from 50 to 1000 ohms. There are nine different preamplifiers available in the 505 series, with varying specifications as to gain, frequency range, noise level, impedance and output.

Bolt Associates, Incorporated

Norwalk, Connecticut

PAR Pneumatic Sound Sources

The PAR Sound Sources, models 600A, 1900, 1500B, 800A, provide a high energy yield concentrated in the usable seismic-frequency band of from 5 to 80 c/s by the explosive release of high-pressure air directly into the water. The charge of air at 200-2000 PSIG (absolute pounds per square inch) is provided by a shipboard compressor using either diesel or electric drive. The high pressure air is admitted directly to the unit through a hose from the air compressor and stored in the fixed volume chamber of the device. Release of energy is accomplished by energizing a solenoid valve mounted on the underwater unit. The solenoid actuates a piston (shuttle) which releases the air.

When the source is released near the surface less than two to five feet depending on the size of the unit, the output wave is characterized by a single sharp pulse. At depths greater than this an oscillatory pulse of a few cycles duration develops, with almost all of the output energy concentrated at a single fundamental frequency.

Arrays of PAR Sound Sources including up to 30 units have been used to synthesize special output characteristics. Space diversity, frequency diversity, and time diversity have been achieved by variations in towing arrangements, the "mixing" of firing-chamber volumes, and by varying the delay times. These techniques are used singly or in combination.

The characteristics of the PAR Sound Sources are as follows:

PAR Sound Source Model	600A	1900	1500B	800A
Chamber volume (cu.in.)	1-10	10-40	40-300	200-2000
Operating pressure (PSIG)	200-2000	300-2000	300-2000	300-2000
Minimum firing interval (sec)	0.25	1.0	4.0	6.0
Max sound-pressure level (db re 1 microbar at 1 yd.)	+117	+123	+128	+138
Fundamental frequency (c/s) (at 33 ft. depth, max output)	34	21.5	11	7
Housing material	Aluminum-Bronz, Type 303 Stainless Steel			
Overall length (inches)	14.5	25	34	45
Outside diameter (inches)	5.25	6.5	8	15
Weight (pounds)	26	75	138	875

Edgerton, Germeshausen, and Grier, Incorporated (EG & G)

Boston, Massachusetts 02215

EG & G provides geophysical services and also manufactures seismic profiling equipment. The latter role falls under a subsidiary, EG & G International, Incorporated. Several different sound sources have been developed by this firm to satisfy a wide range of seismic profiling requirements.

Boomer Transducer

The Boomer Transducer (Model 236) consists of a plastic encapsulated copper coil and an aluminum plate spring-loaded to hold it against the insulated coil. When stored electrical energy is released to the coil, eddy currents repel the aluminum plate, generating a precise, repeatable, positive pressure sound pulse. Although the Boomer sound pulse has frequency components over a wide range, the largest percentage of the energy is in the 500 to 800 c/s region. The Boomer therefore provides a device for moderate penetration with better resolution than is offered by sparkers.

The Boomer requires a special mount for towing which is provided as the Model 261 Towing Fish. It is usually rigged from a boom to be towed alongside the survey vessel at speeds of 3 to 4 knots. Some characteristics of the Boomer system are:

Dimensions (mounted in 261 Fish):	12 x 26 x 108 inches
Weight:	164 pounds
Energy input:	1000 watt-sec, maximum
Frequency range:	500-800 c/s
Towing speed:	3-4 knots (nominal)

Transducer cable length:	50 feet
Pricing range - Boomer:	$520
Model 261 Tow Fish:	$230
Cable:	$110

Sparkarray

The Sparkarray (Model 267A) is a low frequency sound source for deeper penetration in profiling. As electrical energy is discharged between three electrodes and a grounded stainless steel frame, the conducting sea water between the electrodes and the frame is heated, vaporized, and plasma bubbles are formed. The explosively formed bubbles generate high intensity acoustic pulses.

The electrical energy is transmitted to the Sparkarray by means of a 100 foot neoprene-covered cable, which is also used to tow the Sparkarray. At slower towing speeds no tow fish is needed. At higher speeds, weight is usually added to keep the unit at an adequate distance beneath the surface.

Dimensions:	10 x 10 x 106 inches
Weight:	30 pounds
Energy input:	500-8000 watt-sec.
Frequency range:	80-120 c/s
Max towing speed:	10 knots (weighted)
Pricing range - Sparkarray:	$490
Cable:	$280

12 KC Pinger Probe Assembly

The Pinger Probe (Model 228A) is a discrete-frequency, high resolution sound source assembly consisting of a 12 kc crystal transducer and a pulse transformer mounted on a steel fish towed with a 50 foot length of transducer cable.

This device is designed for fine resolution, differentiating between sediment layers with but small variations in acoustic impedance. In that it is of high frequency it is not intended to be used for deep penetration.

The power is supplied either by an energy source module in the recorder or by a Driver/Receiver (Model 402-4). A separate hydrophone is not needed in that the transducer receives its own reflected signals.

Characteristics of the 12 KC Pinger Probe assemblies are as follows:

Components of Assembly:	Transducer (Model 221), Pulse Transformer (Model TR-27), Tow Fish, Cable
Frequency:	12 kc/s
Pulse duration:	0.3 msec
Pulse rate:	to 20 per sec.
Weight (less cable):	80 pounds
Dimensions (less cable):	14 x 13 x 90 inches
Pricing range - Assembly:	$2,410
Driver/Receiver:	$1,250

5 KC Pinger Probe Set

The Model 229 Pinger Probe Set is a discrete-frequency, high-resolution sound source and receiver assembly used to obtain shallow penetration, high-resolution profiles of sub-bottom layers in continental-shelf or shallower depth water. It consists of four 5 kc transducer sound sources, operating in either series or parallel mounted on a fish with 50 feet of tow cable. The receiving hydrophone is towed with 70 feet of cable. The Model 402-4 Driver/Receiver provides power as it does with the 12 kc model.

The depth of penetration of the 5 KC Pinger Probe ranges from about 30 meters in soft sediments to a few meters in sand and gravel. This is considered suitable for archaeological exploration, salvage work, engineering studies, dredging and mining operations.

The characteristics of the 5 KC Pinger Probe set are as follows:

Peak output:	98 db re 1 microbar at 1 meter
Pulse duration:	0.4 millisec.
Weight:	110 pounds
Dimensions:	7 x 1 x 1 feet
Pricing range:	$2,700

Hydrophones

EG & G International has three standard models of hydrophone designs for various uses. All employ acceleration-cancelling hydrophone elements ("jugs") mounted in a 2-inch diameter oil-filled rubber tubing. The cost of hydrophone arrays includes all components, such as electronics section, battery supply section, and tail section, in addition to the cable and active sections.

Model 262G is a single-element hydrophone designed to be used with the Boomer, Sparkarray or 5 KC Pinger Probe Set for shallow penetration work. It is towed either astern or alongside the survey ship.

Model 263B is an array hydrophone equipped with battery powered solid state low-noise preamplifiers and a summing circuit located in the electronics section immediately forward of the active section. It is designed for use with low energy sources such as the Boomer or Sparkarray when operating at less than 5000 watt-seconds.

Model 264A is an array hydrophone specifically designed for deep sub-bottom penetration reception. It employs a greater active hydrophone length, a much longer tow cable, and a mechanical isolator located ahead of the active sections, all designed to reduce interference from ship's noise.

Characteristics of the hydrophones are as follows:

Model	262G	263B	264A
Number of hydrophone elements	1	10	18
Nominal element sensitivity (db re 1 v/microbar)	-85	-85	-85
Frequency response	25c/s-7kc/s	20c/s-7kc/s	20c/s-7kc/s
Active hydrophone length	-	15 Ft.	150 Ft.
Cable length (feet)	75	250	1000
Pricing range	$570	$2,200	$9,000

Supporting Units

Various supporting units to accompany the energy sources and detectors listed above are also available. These include:

Model 232A Power Supply to provide high-voltage direct current for charging the capacitor banks in the standard Boomer and Spark-array Systems.

Model 231 Triggered Capacitor Bank for all systems.

Model 233 Capacitor Bank for the Sparkarray systems.

Model 254 Seismic Recorder (an Alden Alfax recorder).

Entire seismic profiling systems depending on type will range in price from $19,915 to $47,765.

Edo Western Corporation

Salt Lake City, Utah 84115

Edo Western Corporation produces a wide variety of equipment associated with underwater acoustics. Among these are included two systems designed for sub-bottom profiling.

Acoustic Bottom Penetration System. The Model 415 Acoustic Bottom Profiling System is designed to provide high resolution sub-bottom data of the first 30 to 150 feet of strata in water depths of the Continental Shelf or shallow water. It utilizes a piezoelectric transducer to provide an extremely short, high powered pulse. Operating at 3.5 or 7 kc, the transducer generates 1-2 cycles of signal with no noticeable ringing or delay time. The short pulse permits sub-bottom resolution to within one foot. Presentation of the received data is provided by an adjustable wide dynamic range TVG (time varied gain) receiver system. The TVG control permits a low receiver gain prior to receipt of the first bottom echo, with rapid increase in gain following the bottom signal to accentuate the sub-bottom data. The data is displayed on a precision bathymetric recorder providing a 19-inch record.

Packaging of the 415 system permits either portable operation or perminent installation in a 19-inch equipment rack. Components of the system are as follows:

Model 404 Survey Transducer. This transducer is designed specifically for high resolution survey work having the characteristics of a short energy pulse, fast rise time and short ring time. Two standard models of the 404 are available, one for operation at 7 kc and one for 3.5 kc, although other frequencies are also available.

Characteristics of this transducer are:

Operating frequency:	7 kc/s	3.5 kc/s
Active material:	Lead titanate zirconate-----	
Efficiency:	30% minimum-----------------	
Max power input at 10% duty cycle:	2000 Watts	7000 Watts
Source level at max input power:	107 db	110 db
	(re 1 microbar at 1 yard)	
Impedance:	50-2000 ohms selectable-----	
Beam pattern:	30 degrees conical at -3db--	
Max depth:	100 feet -------------------	
Weight:	35 lbs.	60 lbs.

Model 240 Precision Acoustic Transmitter/Receiver System.

The signal generators, power amplifier, transmit-receive network, and the receiving amplifier of the Model 415 System are combined in the Model 240 Transceiver.

Power requirement:	115 $\pm$ 10 V-AC, 50-400 cycles
Line current:	Max. 5 amps, Avg. 2.5 amps.

Transmitter section.

Output power:	variable to max. of 5 KW
Operating frequency:	3.5 kc/s nominal
Output impedance:	50 ohms nominal
Output pulse lengths:	10, 20, and 30 ms.
Pulse repetition rate:	2 PPM internal or externally keyed

Receiver section.

Dynamic operating range:	50 db.
Output frequency:	3.5 kc/s nominal
Band width:	500 cycles
Gain:	0-100 db. variable
Output impedance:	100 ohms
Transceiver weight:	65 pounds

Model 333 Precision Bathymetric Recorder (PBR). Designed for either rack mount or portable operation, the Model 333 recorder provides four ranges of 0-300, 0-1200, 0-3000, or 0-12000 feet (these are modified range selections for use with the 415 system). The PBR is also equipped for manual programming which allows the operator to transmit, gate, or receive on any multiple interval of the base range, up to 10 cycles. With this feature it is possible to follow a given echo on an expanded scale while rejecting intermediate ranges that are not of interest. The PBR contains all solid state electronics, uses dry recording paper, and contains no gear changes or clutches. It can synchronized for simultaneous operation with one or more other recorders.

Recorder ranges:	0-300, 0-1200, 0-3000, 0-12000 feet
Chart paper width:	18.85 inches
Marking density:	50 or 100 lines per inch
Power requirement:	115 V, 60 c/s, 115 W
Dimensions:	19 x 24.5 x 10 inches
Weight:	95 pounds, rack mount.

The pricing for the 7 KC system is $19,500 and for the 3.5 KC system, $14,500.

Model 400 Acoustic Bottom Penetration System. The Model 400 System is a deep water acoustic bottom penetration system in which the operating frequency and power represent a compromise between directivity, depth of penetration, and maximum bottom depth. The 400 System uses three standard Edo Western components:

Model 240 HC Transducer. This is a 3.5 kc transducer consisting of an array of 12 interchangeable barium titanate ceramic elements. The 12 self-contained elements are mounted on a cadmium plated, cold rolled steel frame in a manner so as to produce a 30-degree beam.

The efficiency of the 240 HC is reported as over 65%, thereby producing a maximum source level of 124 db, referred to one dyne per square centimeter at a distance of one yard. The output is 2000 watts, resulting in a maximum source level of 118 db re 1 dyne per square centimeter at one yard. Some features of this transducer are:

Acoustic power:	8000 watts maximum
Beam width:	Conical 30 degrees
Size:	35 inch diameter by 26 inch length
Weight:	800 pounds

Model 248 A Sonar Transceiver. This transceiver performs functions similar to those of the Model 240 in the 415 System.

Primary voltage:	115V ± 10%
Primary line frequency:	50-400 c/s
Power:	180 watts peak, 68 watts average at maximum duty cycle, 45 watts quiescent.
Size:	19 x 8.75 x 15 inches
Weight:	59 pounds.

Transmitter.

Power output:	1400 watts
Output impedance:	50, 100, 140, 175, 240 ohms
Frequency:	12 kc/s
Fixed pulse length:	0.2 ms, 5 ms, and 30 ms.
Max. pulse rate:	240 ppm

Receiver.

Input impedance:	1800 ohms
Frequency:	12 kc/s
Bandwidth	± 900 c/s
Output impedance:	less than 50 ohms
Gain:	106 db
Gain control:	manual

<u>Model 333 PBR</u>. The 400 system utilizes the same recorder as the 415 system. While in the 415 system modifications were made in order to obtain the recorder ranges desired, the standard range selections of 0-600, 0-2400, 0-5000, and 0-24000 feet are maintained in the 400 system. Range scales can also be in fathoms or meters.

Geophysical Service, Incorporated

Dallas, Texas

Geophysical Service, Incorporated of Texas Instruments offers services in the field of seismic profiling, in addition to supplying equipment.

Pneumatic Acoustic Energy Source. The primary energy source is an air gun comprised essentially of two moving parts, the shuttle and the solenoid. Compressed air is supplied at a maximum of 2000 psi, and through positioning of the shuttle (a piston like valve), this air eventually fills two separate chambers in the gun. An electric signal opens the solenoid causing a venting of the air pressure in one chamber followed by movement of the shuttle and subsequent release of air from the other chamber into the water.

As noted previously one of the factors controlling the frequency of the generated pulse is the size of the air chamber of the gun. Guns with chamber sizes ranging between 10 and 160 cubic inches are made. The use of several guns with different chamber sizes seems the best and simplest means of broadening the frequency spectrum. A flat frequency spectrum between 8 and 40 c/s can be obtained which provides for deep penetration.

Geo Space Corporation

Houston, Texas 77036

The Geo Space Corporation produces a complete line of instruments for seismic prospecting, most of which are designed for use on land or in marsh areas. Equipment for marine use falls within the catagories of energy sources and hydrophones.

Energy Sources

24" Land/Marine Dinoseis*. The 24" Dinoseis Gas Gun is primarily a land energy source, but through use of a conversion kit can be adapted to marine use. A 30 foot boat can accommodate two of these guns for shallow water work in bays or rivers.

An automatic firing unit is available. This automatically fills the guns with gas and fires them every six seconds if necessary.

Gas Gun:

Size:	27 inches diameter overall by 26 inches high
Weight:	1700 pounds
Fuel:	Propane and oxygen

Firing Unit:

Capacity:	1 to 4 guns
Cycle time:	Manual-operator controlled
	Automatic - 6-10 seconds

Marine Dinoseis. This version of the gas gun has been designed specifically for marine use. For bay work this unit has been used in water depths as shallow as three feet satisfactorily.

*Dinoseis is a Sinclair Trademark.

Synchronization of multiple units presents no difficulties. Two to four guns are usually fired simultaneously in order to reduce stacking requirements and to increase the speed of the survey.

Hydraulic deck handling frames are used to lift the guns over the side and position them at the underwater depth desired. A gun may be placed on deck or lowered into the water in less than 15 seconds.

For deep water work all equipment can be mounted on a single boat. Uninterrupted operation is possible with continuous towing speeds up to six knots. A six second repetitive firing rate is possible when using the automatic firing system.

This gun makes use of an equal pressure gas mixing system, and a self-contained ignition coil. The Marine Dinoseis is supplied as a complete system consisting of guns, fuel system, electronic firing controls and deck handling frames with associated hydraulic power supply.

Gas Gun:

Size:	60 inches diameter by 36 inches high
Weight:	6700 pounds
Finish:	Carbo-zinc
Fuel:	Propane and oxygen

Firing Control System:

Units:	2 - electronic firing unit and gun monitor unit.
Capacity:	1 to 4 guns
Cycle time:	6 second minimum
Power requirement:	12 V-DC

Detectors

Pressure Sensitive Geophone (Model MP-1). This economical geophone is designed to replace fragile diaphrams and bulky cases. The tiny case is completely sheathed in rubber for trouble free operation. MP-1 geophones are also made molded within a marine cable.

Weight:	3 ounces
Length:	4 inches
Diameter:	1.250 inches
Impedances available:	250, 1500, 3250, 5000 ohms

The output of the MP-1 is generated by varying the reluctance of a magnetic circuit. Two iron armatures are positioned near each end of a magnet and are coupled directly to two pressure sensitive diaphrams. Movement of the armatures with pressure variations changes the air gaps, thus producing changes in flux linkage. A coil is wrapped around the magnet and the voltage generated in the coil is proportional to the rate of change of the flux linkage.

Pressure Sensitive Geophone (Model MP-3). As in the previous model this utilizes the variable reluctance principle and combines greater sensitivity with the other characteristics. It is more suitable for applications where only a small number (one to ten) geophones are required per trace, and it is designed to provide a high sensitivity together with ruddedness and reliability.

Size:	5½ inches by 2½ inches diameter
Weight:	1 pound
Standard impedances:	250, 500, 1000 ohms.

Pressure Sensitive Geophone (Model MP-4). The MP-4 is both a marsh and marine geophone and for off-shore or bay operations it can be attached directly to the main spread cable. For multiple array applications, leader cable can exit from both ends.

This geophone has extremely low motional sensitivity which eliminates high amplitude surface motion response. It additionally relieves AGC overloading and minimizes third harmonic problems.

Size:	8 inches by 1.5 inches diameter
Weight:	9.5 ounces
Resistances:	56 to 600 ohms, standard is 560 ohms
Standard frequency:	125 c/s
Case material:	polycarbonate plastic.

Crystal Pressure Sensitive Hydrophones (Models MP-7 and MP-9). These are low cost hydrophones for marine streamer applications. The MP-7 is a single piezoelectric crystal phone, whereas the MP-9 has two crystals mounted back to back connected in series (MP-9S) or in parallel (MP-9P).

Their extremely small in size makes these hydrophones well suited for minimum diameter streamer cable applications. They offer a broad frequency response, high sensitivity, excellent damping characteristics, and freedom from spurious resonances over a wide range of operating conditions and are easily adapted to linear array configurations.

Size:	3.125 inches by 0.65 inches diameter
Weight:	0.75 ounces
Case material:	Polycarbonate, Hycar diaphram

Crystal Pressure Sensitive Hydrophone (Model MP-8). This is a high performance, universal application pressure sensitive unit, offering the broadest frequency response of all the phones produced by this company. The MP-8 is a piezoelectric crystal, combining low impedance with a plastic case to reduce problems of extraneous electrical pick up, often very troublesome in marine work.

Size:	8 inches by 1.5 inches diameter
Weight:	12 ounces
Material:	Polycarbonate plastic
Impedances:	125 to 600 ohms, standard 560 ohms.

Geotech

Garland, Texas 75040

The Geotech Company makes four different systems, each a completely integrated controlled source system designed to provide data for particular applications and requirements. These four systems are as follows:

SUBOT (Sub-Bottom Profiling System). This system is designed for high resolution profiling to depths of up to 3000 feet. The components are:

Acoustic source: From 100 to 3000 joules of electrical energy are available by connecting individual capacitors in parallel. The unit is operated at 9.5 kV, producing a high current discharge with resulting high peak pressure in the water. The "bubble time" of the gas bubble can be controlled, providing a frequency spectrum tailored to specific application. Multiple "Hydrode" (trade mark) arcer configurations produce acoustic power in the desired frequency band.

Acoustic detectors: The Hydrostreamer (trade mark) has good signal-to-noise ratio at towing speeds up to 10 knots. The standard Hydrostreamer contains 100 MP-7 crystal detectors spaced 8 inches apart. A self-powered preamplifier is located in the forward end of the active section. The streamer is fitted with a 600 foot towing leader, which includes all conductors, depth monitoring tube, and depth control features.

Magnetic Tape Recorder: The data are recorded simultaneously on a seven-channel magnetic tape recorder. This unit, with dual-channel recording, has a dynamic range of 60 db and a frequency band sufficient for both low-and high-resolution seismic data.

Hydrophone Amplifier System: The Model 25475 Amplifier System is designed for high-resolution marine seismic profiling. The seismic amplifier, model 25950 has been designed for filtering between 100 and 1000 c/s. Maximum AGC rate exceeds 500 db/second.

Graphic Recorder Unit: A Geotech Signal Programmer, model 26140 provides precision frequency outputs and identification marks to a modified Raytheon PFR recorder.

SSP (Seismic Section Profiler). This system also uses an electrical arcer as the source of the seismic signal, but it is compatible for use with other source types. It has an acoustical source of up to 120,000 joules of electrical energy available in multiples of independently controlled and operated "Lectro-Pulse" units of 30,000 joules each.

The other components are similar to those in the SUBOT System, such as the Hydrostreamer, magnetic tape recorder and graphic recorder unit. The system normally employs four Model 111 transistorized seismic amplifiers programmed in units of two each to the graphic recorder and to the magnetic recorder. Data may thus be tape recorded "broad band" while optimum filtering is applied to the variable density recording. SSP data can be further processed through digital computer.

WASSP (Wire Arc Seismic Section Profiler). The main difference between this system and the SSP is the implimentation of the exploding wire phenomenon. A small wire, placed across a conventional pair of SSP electrodes, vaporizes during high voltage discharge, generating a significantly greater amount of acoustical energy. Being more efficient, the WASSP develops energy at lower frequencies. It is designed to produce energy in the 15-30 c/s region without a bubble problem or long wave train.

GASSP (Gas Source Seismic Profiler). This system uses a gas detonator designed by Shell Development Company in which the energy is obtained from a detonation of acetylene gas and oxygen. The other components are conventional profiling units as described above.

In operation a mixture of oxygen and acetylene gas is metered into one or more 20-foot long by eight inch wide neoprene tubes and detonated by a triggering device. Pressures created are 300 psi at frequencies with maximum amplitudes in the 40 c/s range. Reflected energy above the background persists for three to four seconds, or longer. Operating at low frequencies this system can produce medium-resolution data at depths to 20,000 feet.

Some characteristics of these systems are summarized as follows:

	SUBOT	SSP	WASSP	GASSP
Input electrical power	3000 joules	120,000 joules	120,000 joules	-
Bubble duration-max power	8msec	20msec	33msec	25msec
Power spectrum peak	125-1000 c/s	50 c/s	30 c/s	40 c/s
Frequency range (useful)	50-1000 c/s	25-125 c/s	14-60 c/s	20-80 c/s
Maximum firing rate (shots/min)	240	15	15	7
Data depth expected (ft)	300-2000	5,000-15,000	10,000-20,000	10,000-20,000

Components:

Energy source	3000 joule Model 25441	30,000 joule Model 24218	30,000 joule Model 24218	Gas Tubes
Hydrostreamer	SUBOT Hydro-streamer	Model 24257	Model 24257	Model 24257
Hydrophone amplifier system	Model 25475	Model 24220	Model 24220	Model 242220

All systems utilize a magnetic tape recorder Model 24256 and facsimile recorder Model 24255.

Energy Sources

Model 25441. This energy source system is comprised of a capacitor storage and an arc discharge source. It consists of two units, the high voltage DC power supply, and the energy source and control unit.

Peak power output:	3000 joules at 9,500 V-DC
Arc discharge firing rate:	100-500 joules at 1/8 second intervals
	1500 joules at 1/2 second intervals
	3000 joules at 1 second intervals
	6000 joules at 2 second intervals (optional)
Trigger circuit:	solid-state trigger circuit.
Max power requirement:	220-240 V-AC, 50/60 c/s, single phase
Dimensions:	energy storage unit,51 x 30 x 20 inches
	DC power supply, 37 inches x 24 inches diameter
Weight:	energy storage unit, 375 pounds
	DC power supply, 370 pounds

Model 24218. This energy storage system is composed of an energy storage unit, Model 24216, and primary power control unit, Model 24217. As many as four of these systems can be combined for a total output of 120,000 joules. Condenser discharge is through a variable arrangement of up to 16 electrode tips.

	Power control unit	Energy storage unit
Power inputs:	240/480 V-AC, 60 c/s single or 3-phase.	14.1 kV-DC
Power output:	14.1 kV 1 Anominal	30,000 joules, 3 sec. intervals
		20,000 joules, 2 sec. intervals
		10,000 joules, 1 sec. intervals
Dimensions:	50.5 x 20 x 20 inches	50.5 x 52 x 20 inches
Weight:	475 pounds (single phase)	1400 pounds
	800 pounds (3-phase)	

GASSP. This is a gas detonation system in which metered volumes of oxygen and acetylene gas are combined at approximately a 3 to 1 ratio by volume. The mixed gas is ignited in a metal tube and expansion of the detonated gas takes place in one or more eight-inch wide by 20-foot long expandable neoprene chambers. These expansion chambers can be connected to give a live energy source up to 200 feet long. By products of the detonation are exhausted to the surface to prevent creation of bubble noise sources.

Hydrostreamers

SUBOT Hydrostreamer. This streamer cable contains MP-7 crystal detectors throughout the active length of the cable. The towing depth of the Hydrostreamer, from 0 to 35 feet, can be monitored and controlled from the ship. A self-powered preamplifier is located in the forward end of the active section.

Active section length:	100 feet, 1 inch outer diameter
Number of detectors:	100 at 8 inch intervals
Towing leader:	600 feet, 1 inch outer diameter
Towing speeds:	3-10 knots
Controllable depth:	0-35 feet
Frequency response:	35-2500 c/s

Model 24257. This hydrostreamer cable contains MP-7 crystal hydrophones interlaced in groups throughout the active length of the cable. Signals from these groups can be combined in various configurations in the amplifier unit. Two preamplifiers are located at the front of the active section. Many configurations are made. Typical Hydrostreamer characteristics are:

Active section:	200 feet, 1½ inch outer diameter
Number detectors:	100 at 16 inch intervals
Leader cable:	600 feet 1 inch outer diameter
Buoyant fluid:	Bayol
Towing speeds:	3-10 knots
Controllable depths:	0-35 feet
Frequency response:	1-2500 c/s

CDP-Common Depth Point-Streamer Cable. This is a recently developed streamer cable for use specifically with a multi-channel digital recording system. The CDP cable is 4600 feet long, and consists of three distinct sections: the leader, depth-control, and active sections.

The leader is an 800 foot, 1½ inch diameter air filled section that floats on the surface. The depth control section is 200 feet long, with a diameter of 1½ inches, that is approximately neutrally buoyant. The active section consists of six 100 foot units containing the sound sensors and five 600-foot spacer units. Total active length is 3600 feet. Each sound sensing unit is composed of a 1½ inch flexible oil-filled tube. Sensing elements are spaced at one-foot intervals for a total of 100 sensing elements per sensing unit.

Other Components

The following amplifier units are also made:

(a) Model 25950 High Resolution (HR) Amplifier developed for applications in the high end of the reflection band.

(b) Model 25475 Hydrophone Amplifier System for high-resolution marine seismic profiling.

(c) Model 24200 Hydrophone Amplifier System which can be used for seismic input of up to 20 hydrophones or hydrophone arrays.

The Seismic Profile Facsimile Recorder Model 24255 consists of a Raytheon PFR Recorder modified with a Model 26140 Signal Programmer. By gear drive changes, scan speeds on the PFR have been adjusted to make it better able to accept seismic data. Besides providing frequency outputs and identification marks to the PFR (or to magnetic tape recorder), the Signal Programmer also controls the firing rate of the energy source.

The Model 24256 Magnetic Tape Recorder continuously records up to seven channels of seismic signals on one-half inch tape. Four tape speeds from 1-7/8 to 15 ips are possible. The unit is the Ampex SP-300.

Geotech has also developed a binary gain digital seismic system which records multichannel data on one-half inch, computer-compatible, nine-track magnetic tape. The system can be used with non-explosive sources as well as with dynamite.

T. H. Gifft Company

Anaheim, California

Gifft facsimile depth recorders are produced in four different models. The GDR-IC-19 is a self contained bench-mounted recorder using 19 inch chart paper which can be combined with a sparker, airgun, or other source for broadband continuous profiling studies. The GDR-1C-19-T version includes an integrated sonar transceiver and can be operated either as a recorder alone or as a complete echo sounder. The GDR-1C-11 and GDR-1C-11-T are equivalent units using 11 inch chart paper, and are designed to be rack mounted.

Some of the characteristics of the Gifft recorders are:

Input power:	90-140 V-AC, 45-70 c/s
Power consumption:	70 watts
Weight:	75 pounds
Dimensions:	GDR-1C-19-T 7½ x 28 x 15.5 inches
	GDR-1C-11-T two units
	electronic module 5-¼ x 17 x 12 inches recorder module 7-½ x 15-½ x 10 inches
Sweep scales:	GDR-1C-19-T 1/16, 1/8, 1/4, 1/2, 1, 2, 4 seconds
	GDR-1C-11-T 1/16, 1/8, 1/4, 1/2, 1, 2 seconds
Writing blade:	Oscillating blade type. Blade of different widths can be used for different applications.
Scanner drive:	DC motor with maximum power dissipation of 3 watts.
Recording paper:	Moist electrolytic type, system compatible with Muirfax paper or Alfax paper.

Semi conductors:	Electronics solid state silicon.
Pricing:	GDR-1C-11 or 19 $4400
	GDR-1C-11-T or 19-T $5200.

Huntec, Limited

Toronto, 16, Ontario, Canada

Huntec produces a basic sub-bottom system, the Hydrosonde Mark 2A, which is designed as a light weight, portable sub-bottom profiling system. It has been operated successfully from motor launches of only sixteen feet in length.

Hydrosonde Mark 2A System. This represents the basic system consisting of the following components:

Energy source: The Mark 2A spark transmitting sub-system is provided for high resolution shallow investigations (up to 500 feet penetration). This comprises a 165-joule spark transducer, 300 feet of cable, and the Mark 2A spark transmitter. Firing rate is normally 4 shots per second or a maximum rate of 16 per second at reduced energy. The trigger is by hydrogen thyratron.

When deeper penetrations are desired a Bolt PAR Model 600 air-gun is usually applied to the Huntec system, although the system can utilize any of the common energy sources.

Hydrophone: A velocity sensitive, single detector MP37 magnetostrictive hydrophone having a frequency range of 100 c/s to 10 kc/s is used. Output impedance is 34 ohms, sensitivity 100 db re to 1 volt/microbar at 1000 c/s. It is provided with 250 feet of cable.

Receiver: The Mark 2A receiver comprises a gated signal amplifier and adjustable band pass filters, an 8 inch Alden facsimile recorder (11 inch optional), and a master timing control program panel. Push button control is utilized for variable filter selection with 14 high frequency cut-off points available and 12 low frequency cut-off points. Open filter frequency response is from 20 c/s to 10 kc/s.

Other characteristics:

a) Receiver:

Power required:	115/230 volts, 50 or 60 cycles, 150 watts
Size:	15 x 30 x 21 inches
Weight:	165 pounds
Ambient temperature:	+32 to +122 degrees F.

b) Transmitter:

Power required:	115/230 volt, 50 or 60 cycles, 1500 watts peak, 750 watts average.
Size:	20 x 28 x 18 inches
Weight:	200 pounds
Ambient temperature:	-4 to +122 degrees F.

c) Hydrophone: A pressure sensitive low noise array of 20 detectors at 12 inch spacing is also made.

d) A suitable generator is required which will provide 2.5 kw 115 volts, 60 cycle single phase.

e) Price of the complete system (less generator) is approximately $40,000.

Huntec also has available a variety of other equipment including a modular receiver system, a hydro-acoustic sound source, additional types of sparkers, variable lengths of hydrophone arrays, and similar items.

Mystic Oceanographic Company

Mystic, Connecticut 06355

The Mystic Oceanographic Company in cooperation with Alden Electronics and Impulse Recording Equipment Company, Del Electronics Corporation, and Precision Surveys Corporation has developed a basic profiling system in various types differing mainly in the size of the sparker sound source employed. Presentation is by Alden graphic recorder with tape presentation if desired. The system is adaptable to digital or analog processing. Overall price for the system ranges from $5,000 to $150,000 depending on the size of the specific system.

1. Precision Acoustic Pulse System. This system consists of four major components, all of which may be designed to specific requirements.

Sparker: Manufactured by Del Electronics, this is a 100,000 joule sparker with output characteristics - amplitude, phase, and frequency - capable of being controlled and predicted to within 5% to 10% accuracy, with its total energy and wave form shape adjustable to needs.

Hydrophone: The system utilizes a standard type hydrophone array consisting of 9 inch length, 2.25 inch diameter hydrophone produced by Precision Surveys Corporation.

Correlogical Processor: This is an exclusive feature of the Precision Acoustic Pulse System, designed and built by the Mystic Company. It provides a matched filtering and cross-correlating function which improves signal-to-noise and signal processing characteristics. Additional details on this are given in a subsequent section.

Precision Graphic Recorder: An Alden recorder is provided with this system.

2. Low Power Sparker Profiling Systems. Mystic also produces a variety of sparker systems which are of lower power than the Precision Acoustic Pulse System mentioned above. They range from a 3000 joule sparker to a 25,000 joules version. The systems are basically the same as that mentioned above with the exception that not all include the correlogical processor.

The Correlogical Processor.

Improved signal-to-noise and resolution can be obtained by employing correlation techniques. Three major approaches to group correlation have been undertaken by research and industrial groups, analog, special purpose digital, and general purpose digital systems. After investigating the three techniques, concentration has been placed on the development of an analog system, the correlogical processor, to take advantage of these signal processing techniques on an optimum cost-effectiveness basis.

The processor is designed to provide signal-to-noise improvement and pulse compression by the employment of matched filter technology. The matched filter operation determines the similarity of a signal that has undergone some operation such as reflection, with the replica of the original signal. The ideal signal-to-noise gain resulting from using matched filter processing is proportional to the bandwidth-time length product. The standard system is designed for a bandwidth of 600 c/s and time-length of 40 milliseconds thus producing an ideal signal-to-noise gain of 24.

In the actual process a delay line stores the signal for a given period, while potentiometers located at taps along the delay line provide multiplication for the cross-correlation products. These products are then summed for the resultant output. In any analog device, compromises are made in the design to tailor the device to a specific set of problems. These compromises limit the operation of the matched filter concept, thus limiting practical signal-to-noise gain to approximately 10.

Correlogical processing is designed to produce a single, easily identifiable printed line for each major reflector. This includes transforming multiples into one pulse for recorder presentation.

Some characteristics of the correlogical processor are:

Input impedance:	10 k
Output impedance:	600
Delay line length:	10-200 milliseconds
Number of correlation taps:	40
Frequency response:	4 c/s - 1 kc/s, depending on delay line employed (modified for requirements.)
Bandwidth-time product (processing gain):	Maximum 24, average 12.
Power requirements:	110 volt AC-50 watts maximum.
Dimensions:	19 x 10.5 x 10.5 inches
Pricing:	Standard unit - $9900.

Ocean Science and Engineering, Incorporated

Washington, D. C. 20014

Ocean Science and Engineering, Incorporated, is a geophysical services company, although two systems of the low power, high resolution type have been designed and constructed by them. These systems are leased by users, in that the firm prefers to have them operated and maintained by company personnel. Ocean Science and Engineering, Incorporated, is primarily oriented toward mineral exploration, and they include an interpretative report as part of their services.

Lizard Acoustic Profiler is designed for penetration of approximately 50 feet with a resolution of one foot. The elements of the system are:

Towed Fish: This is a streamlined, fiberglass housing containing a magnetostrictive transducer and hydrophone. The transducer operates on a frequency of 3.3 kc with peak power input of 10^4 volt amps and a pulsing rate of 4 per second. The detector is a low capacitance, high sensitivity hydrophone and preamplifier, molded together and mounted to the rear of the transducer. The towed fish is 8 feet 10 inches long and weighs 350 pounds.

Receiver-Transmitter Driver: This unit weighs 50 pounds and measures 12 x 12 x 12 inches. Power requirements are 110 volts AC, 50-60 cycles at 500 watts. The receiver has a gain of 0 to 100 db with a variable attenuator.

Recorder: The Lizard System uses a Gifft Model GDR-1C-19-T recorder.

The Pulser Acoustic Profiler is capable of penetrations of 200 or more feet with resolutions of 3 to 6 feet. The elements of this system are:

Towed Fish: This is composed of an Eddy Current-Dual Plate Repulsive type transducer and an eight element linear hydrophone array. The transducer operates at a center frequency of one kc with a driving power of 200 joules. Weight of the fish is approximately 100 pounds.

Receiver-Transmitter Driver: This unit contains an 80 db amplifier, a transmitter power supply, and power switching circuitry. Power requirements are 110 volt AC, 50-60 cycles at 1500 watts. The unit measures 24 x 18 x 8 inches and weighs 50 pounds.

Capacitor Banks: These units contain the energy storage capacitors. One unit is used for power levels of 100 joules or less with the addition of the second unit for full power. Each unit is 18 x 18 x 8 inches and weighs 30 pounds.

Recorder: Various recorders have been used with this system, such as the Gifft, Alpine, and others.

Raytheon Company

Submarine Signal Division

Postsmouth, Rhode Island

Hydroacoustic Transducer

This transducer (Model BF-1146-1,-2) is a low frequency, broad band, high powered, controlled sound source. It provides independent frequency-and-amplitude-control of acoustic outputs. Transmissions of selected single frequency pings, multi-frequency coded pulses, broadband chirps, or broad-limited noise may range in time from a few milliseconds to continuous duty. Individual modules can be arrayed to increase the acoustic power output.

Dimensions:	5 feet outside diameter X 3 feet long
Weight:	5000 lbs.
Hydraulic ram area:	16 sq. in. for Model 1146-1
	10.5 sq. in. for Model 1146-2
Acoustical power spectrum:	over 1 KW @ 50 c/s
Sound pressure level:	approximately 104 db re 1 microbar @ 1 yd.
Shipboard:	towed @40 feet depth at speeds up to 6 knots.

Various other equipments are required to support the sound source including hydraulic power supply (diesel engine, hydraulic pump, accumulators, filters, heat exchanger, piping manifold, valves, and gauges), servo electronics equipment, hydraulic hosing, electrical cabling, and spare parts.

Precision Seismic Recorder

The self-contained electromechanical Model PSR-1910B recording unit was designed to record in a periodic (continuous) or aperiodic (start/stop) mode. Either mode of scanning utilizes three equally spaced styli mounted on a fiberglass reinforced neoprene timing belt. Dry electrosensitive paper in roll form 19-1/8 inches wide by 350 feet long is used through the active scan is 18.85 inches. The recording ranges from near white to black with a full intermediate grey scale. Electrical dynamic range is 26 db from white to black.

Dimensions:	35¼ x 15 x 29¼ inches
Weight:	190 pounds
Scan speeds:	ten choices from ¼ second to 10 seconds per scan.
Writing density:	81 lines per inch.

Some additional characteristics that can be built into these recorders are:

1) Matched gear sets for eight individual writing density selections.

2) Print Density Selector - allows selection of any two print densities.

3) Elapsed time meter to show operating time up to 9999.9 hours.

Pricing: $13,636.

Precision Fathometer Recorder

The Model PFR-193B is used for precision bathymetric surveys including sub-bottom work. It is very similar to the PSR with the following significant differences:

Dimensions:	34-1/2 x 11-3/4 x 28 inches
Weight:	180 pounds
Scan Speeds:	1/4 second per scan
	1 second per scan
	10 seconds per scan
Writing density:	150 lines per inch

Seven available options.

Pricing: $10,155

The Raytheon Company has expressed interest in a continued study of correlation signal processing procedures for depth sounding equipment, that would incorporate a replica correlator processor into the sounding system. Instead of the conventional short pulse that is used for better resolution, an increased pulse duration would be employed with the attendant increase in signal energy. Suitable coding or modulation would be applied to the signal to maintain the bandwidth required for good resolution. The receiver (replica correlator) would provide the signal processing necessary to decode the signal and to restore the desired resolution. The resulting extra energy would be available for bottom penetration to layers tens of feet below the bottom.

Western Geophysical Company of America

Los Angeles, California

Western Geophysical has for many years provided services in the field of seismic profiling. Until recently reliance has been placed on a system using the Marine Dinoseis transducer as a sound source. Another system featuring a variation to the gas gun sound source has been recently added to their techniques. This is described below.

The Aquapulse System

The Aquapulse sound source is a development of the Esso Production Research Company with Western Geophysical having the exclusive license for its use. The sound source is basically a gas gun, improved to eliminate the follow-on bubbles and bubble pulses. This is accomplished by confining the detonation of the propane and oxygen mixture within an elastic-walled container, preventing that container from collapsing completely, and venting the combustion products through an exhaust line to the surface. Four Aquapulse units in a rectangular array around the survey vessel is the normal configuration used, with all four being controlled and fired simultaneously. The frequency range for the Aquapulse gun is about 7.5-20 c/s giving it penetration down to 1000 feet plus of sub-bottom. It is therefore not designed for shallow definition.

Other components of the Aquapulse System include binary-gain amplifiers, nine-track digital tape recording, and digital processing using amplitude and deconvolution programs.

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13. ABSTRACT

The sub-bottom profiling techniques have vastly improved over the last several years. Many commercial companies are presently engaged in the manufacture of either individual components or the entire system largely as a result of its applicability to petroleum exploration. New systems and innovations are developing at a rate whereby it is difficult to remain current.

Interest in the technique has likewise increased within the Navy, and more than several research projects built around its use are currently receiving Navy funding. It was therefore deemed advisable that a survey of existing equipment characteristics and manufacturers be made to serve as a guide to potential Navy users as to the possible applications of this technique.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sub-bottom						
reflection profiling						
seismic						
sparker						
boomer						
air gun						
gas gun						
Vibroseis						
Dinoseis						
transducer						
detector						

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