ACOUSTIC COMMUNICATIONS WORKSHOP

WORKSHOP RECORD

2, 3, 4 AUGUST 1982

THE GEORGE WASHINGTON UNIVERSITY
MARVIN CENTER
21-st & H Streets, NW
Washington, DC

CO-SPONSORED BY

THE INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS
ACOUSTICS, SPEECH AND SIGNAL PROCESSING SOCIETY
(Washington Section)

and

THE GEORGE WASHINGTON UNIVERSITY
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

A C O U S T I C   C O M M U N I C A T I O N S   W O R K S H O P

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ORGANIZING COMMITTEE:

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Edgar Neal of EG&G
Roman Paska of EG&G
Robert Pierce of the David W. Taylor Naval Ship R&D Center

FORWARD

Undersea acoustic methods are often the only viable means for communications. Other methods, such as electromagnetic and optical based systems, experience severe attenuation; special requirements for such systems -- metallic conductors, for example, strung between sending and receiving units -- are often not acceptable.

Use of the undersea acoustic communications channel provides the design engineer and researcher with an interesting, varied, and often vexing array of obstacles. Depending upon the specifics of the system, the engineer may be faced with either very severe or little multipath distortion. The received signals may be deeply buried in noise, or they may be relatively noise free. The arrays that transmit or receive the signals may be very directional or essentially omnidirectional. Many of the characteristics of the acoustic channel are time varying; each situation that arises provides a unique set of design conditions.

While the obstacles and opportunities to improve system performance are not unique to the undersea environment, their variability and our limits to their understanding are unique. In an effort to clearly establish the limits of our understanding and to aid, foster, and encourage research in undersea acoustic communications, this workshop was organized. Based on the excellent quality of the papers submitted, the respected members of the Technology Interchange Panel, and the other planned activities, it is sincerely believed that the Acoustic Communications Workshop will achieve these objectives.

ADDITIONAL WORKSHOP ACTIVITIES

TUESDAY EVENING: TECHNOLOGY INTERCHANGE

CHAIRMAN: Carey D. Smith of NAVSEA
James Bartram of Raytheon
Philip Bello of MILCOM, Inc.
Frank Finlon of Penn State Univ.
James W. Hicks of Univ. of Florida
Harry Hollien of Univ. of Florida
Raymond L. Pickholtz of George Washingtion Univ.
Morris Schulkin of Univ. of Washington
Philip Stocklin, Private Consultant
Robert J. Urick of Catholic Univ.

WEDNESDAY MORNING: STATUS AND REQUIREMENTS FOR ACOUSTIC COMMUNICATIONS -- THE WORKSHOP'S UNDERSTANDING OF --

SESSION A: THE UNDERWATER ACOUSTIC CHANNEL

CHAIRMAN: Anthony I. Eller of Naval Research Lab.

SESSION B: MODEM DESIGNS

CHAIRMAN: James F. Bartram of Raytheon
Donald E. Jackson of Sperry

SESSION C: CURRENT AND FUTURE REQUIREMENTS

CHAIRMAN: Philip Stocklin, Private Consultant

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Paper for Presentation at an I.E.E.E. A.S.S.P. Society Workshop on
Acoustic Communication
2-4 Aug., 1982

MULTIPATH DISTORTION IN THE SEA

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INTRODUCTION

Perhaps the most important property of the sea affecting underwater communication is the distortion of signals travelling through it. By means of its own peculiarities the sea imposes its own characteristics upon a signal emitted by a source, modifying that signal and altering it so as to make it almost unrecognizable at a distant receiver. In this paper I would like to discuss the causes of this distortion, emphasizing the most important one - multipath transmission - and to illustrate distortion by a variety of field examples.

CAUSES OF DISTORTION

We are all familiar to some extent with absorption of sound in the sea, and how high frequencies are removed from a broad band signal by conversion to heat. Another cause of frequency distortion is the moving sea surface, which imposes its own motional spectrum as sidebands in the spectrum of narrow band sound reflected from it. A third cause of distortion is the acoustic non-linearity of water which causes harmonic generation-like a non-linear circuit element - when a narrow-band signal travels through it and, most importantly, generates the difference frequency when two signals of different frequencies travel together.

But the severest distortion is caused by multipath transmission. Sound in the sea travels to a far-distant receiver over a number - sometimes a large number - of propagation paths. These paths are associated with different amplitudes and travel times. A short pulse is received as a string of short pulses if the pulselength is short enough, or as a long drawn-out pulse with an irregular envelope if it is not. This is illustrated by Fig. 1a, showing four paths, two refracted and two reflected from the ocean boundaries, that cause a short pulse to be received as a string of four pulses. A similar multipath effect is produced by the extension in range of a sonar target in echo ranging, as illustrated in Fig. 1b. A submarine has on it clusters of scatterers, external to the pressure hull, located in the region of the bow, amid-ships in the sail area, and toward the stern in the propeller and control planes. A short pulse produces an echo under certain conditions that has a tripartile structure caused by this non-uniform distribution of scatterers. Examples of such echoes may be seen in Fig. 2, where we see a series of echoes of a 15 ms pulse taken 1 second apart from a short-range approaching submarine. An example of an explosive echo from a submarine at an aspect angle of 49^{0} is given in Fig. 3. In the examples of Figs. 2 and 3, the range was so short that any distortion produced by the medium was negligible; the distortion was entirely produced by the target.

In order to illustrate multipath distortion produced by transmission through the sea, let us examine the appearance of an explosive pulse at different ranges and depths, starting close to the source and going outward in range. Near the explosion, the wave-form produced by the detonation of a 1 lb. charge of TNT looks like Fig. 4. It consists of a shock wave followed by a series of bubble pulses, the whole signature lasting no more than a few milliseconds depending on the depth. Going outward to ranges of 1 - 2000 yds.

at a shallow depth, the surface reflection - the most obvious multipath - comes in and eats away, so to speak, at the shock wave, as illustrated in Fig. 5, until, in the surface shadow zone, only very weak scattered sound is present. At greater ranges and depths, surface and bottom reflections become a prominent part of the overall signature, as shown in Fig. 6. If examined closely, each one of the bottom-surface bounces of Fig. 6 would be found to be distorted by multipath effects caused by a mixture of reflection and scattering at the sea bed, and reflection and refraction by a sedimentary bottom.

A short pulse thereby acquires a long tail after encountering the bottom, as illustrated in Fig. 7. At short ranges these multipath arrivals are widely separated in time and are readily eliminated by directionality. At longer ranges, the bottom-surface bounces become closer together in time and weaker, in amplitude and eventually die out altogether because of the many encounters with the lossy boundaries required to reach long ranges.

Turning now to totally refracted multipaths, we see in Fig. 8 the result of the reversal in sound velocity gradient characteristic of the deep sea. A sound channel exists, and a receiver at a distance receives sound via a number, often large, of refracted paths. Fig. 8 is a now-classic ray diagram drawn by hand during World War II illustrating the many transmission paths from a source on the axis of this so-called Deep Sound Channel (it is not always "deep") and showing, curiously, the surface convergence zone at 32-1/2 miles. The distortion of an explosive pulse caused by this kind of propagation is shown in Fig. 9. At 19 km a received explosive pulse begins strongly and dies away after several seconds; at 560 km, the envelope is reversed with the slow, strong, near-axial ray arrivals coming last; at 1880 km, the envelope is greatly lengthened into a crescendo of sound having a sudden termination.

A series of shot envelopes at ranges out to 1490 miles, with source and receiver on the "axis", or depth of minimum sound velocity of the sound channel, is shown in Fig. 10. This is the most extreme case of distortion occurring in the ea; a pulse initially a few milliseconds long is stretched out to one lasting 10 seconds or more after travelling a distance of a thousand miles in the sea. This time-stretching as well as the smooth envelope is caused by the very great number of consecutive refracted multipath arrivals, each with a different travel time. The transmission path with the smallest number of loops (Fig. 8) comes in first, whereas sound travelling straight down the axis comes in last, and has the highest amplitude.

When source or receiver, or both, are off-axis, the individual ray arrivals become distinguishable. Fig. 9 is a portion of the envelope of a shallow shot as received 600 miles away on a hydrophone located on-axis at a depth of 4000 feet. In Fig. 9a, the dots show the calculated travel times and levels of ray arrivals identified by a pair of numbers giving the number of loops and troughs of the ray path. Even a single one of the of the arrivals is distorted in propagation by scattering and diffraction, as is shown by the expanded un-rectified traces of Fig. 9b.

CONCLUSION

We may conclude by saying that multipath distortion is an unavoidable characteristic of propagaion in the sea. It is the result of its peculiar boundaries and its sound velocity structure. Except in certain circumstances multipath distortions cannot be predicted in detail. Its deleterious effects on acoustic communication are apparent. It can be partially overcome by source or receiver directionality. Another way to obviate distortion in communication is to send, ahead of the message, a short transient like the shock wave from a small explosion, and to convolve the received distorted message with the distorted received transient.

Multipath transmission is not all bad. It causes higher signal levels than would exist if only a single transmission path were present when the received stretched-out signal is integrated. Multipaths cause signal fluctuations which enable targets to be detected better during signal surges but to be lost during signal fades. Multipaths cause signals to become decorrelated between separated receivers and thereby degrade the gain of arrays. They cause frequency broadening when the sea surface is encountered in propagation. In target detection, multipath distortion prevents elegant detection schemes like replica correlation from being used.

Thus, generally speaking, multipath transmission may be said to be deleterous for long range communications and detection, even though it makes life interesting for students of sound propagation in the sea.

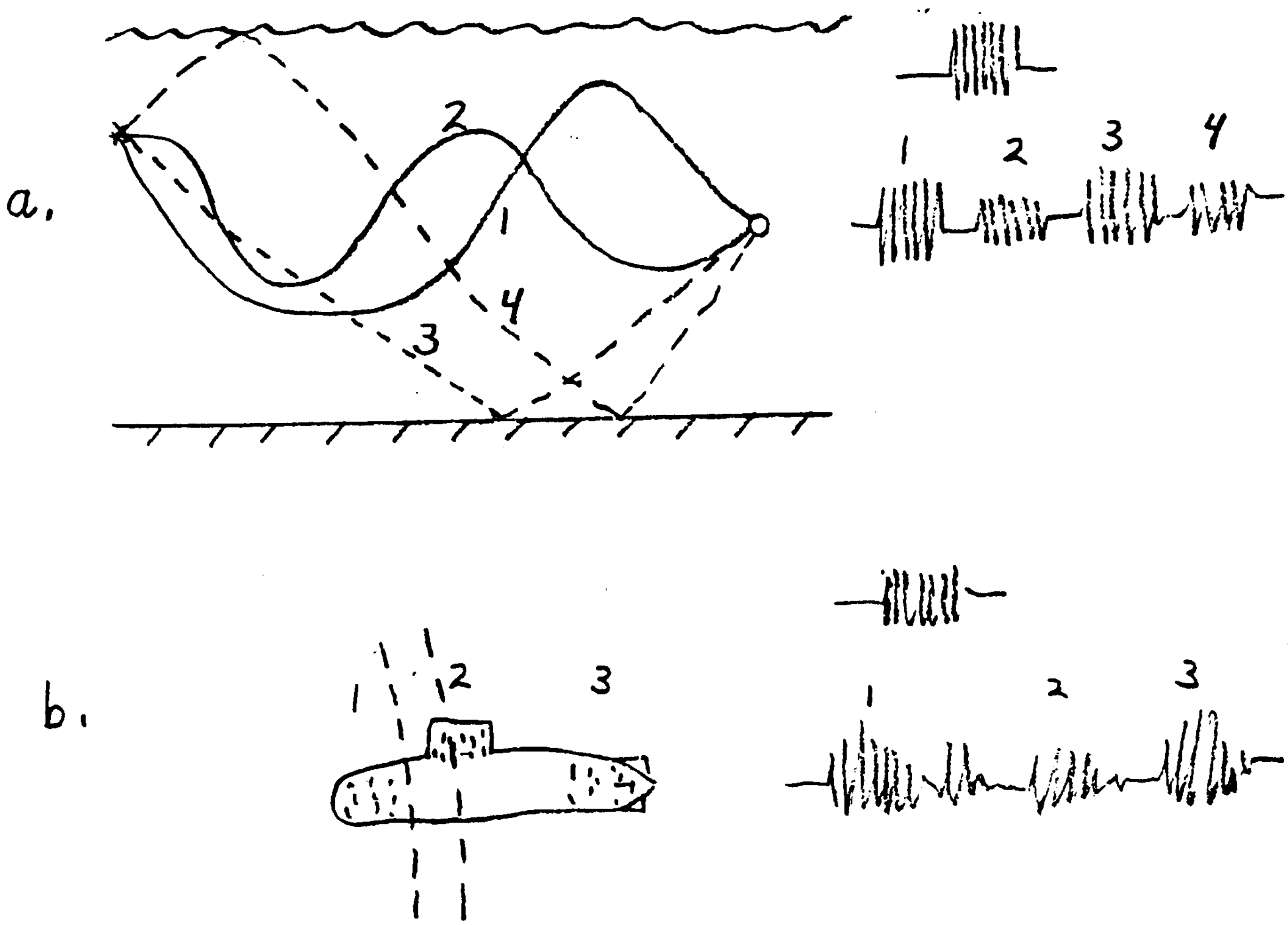

Fig. 1 Multipath distortion produced by a) propagation and b) scattering from a submarine target.

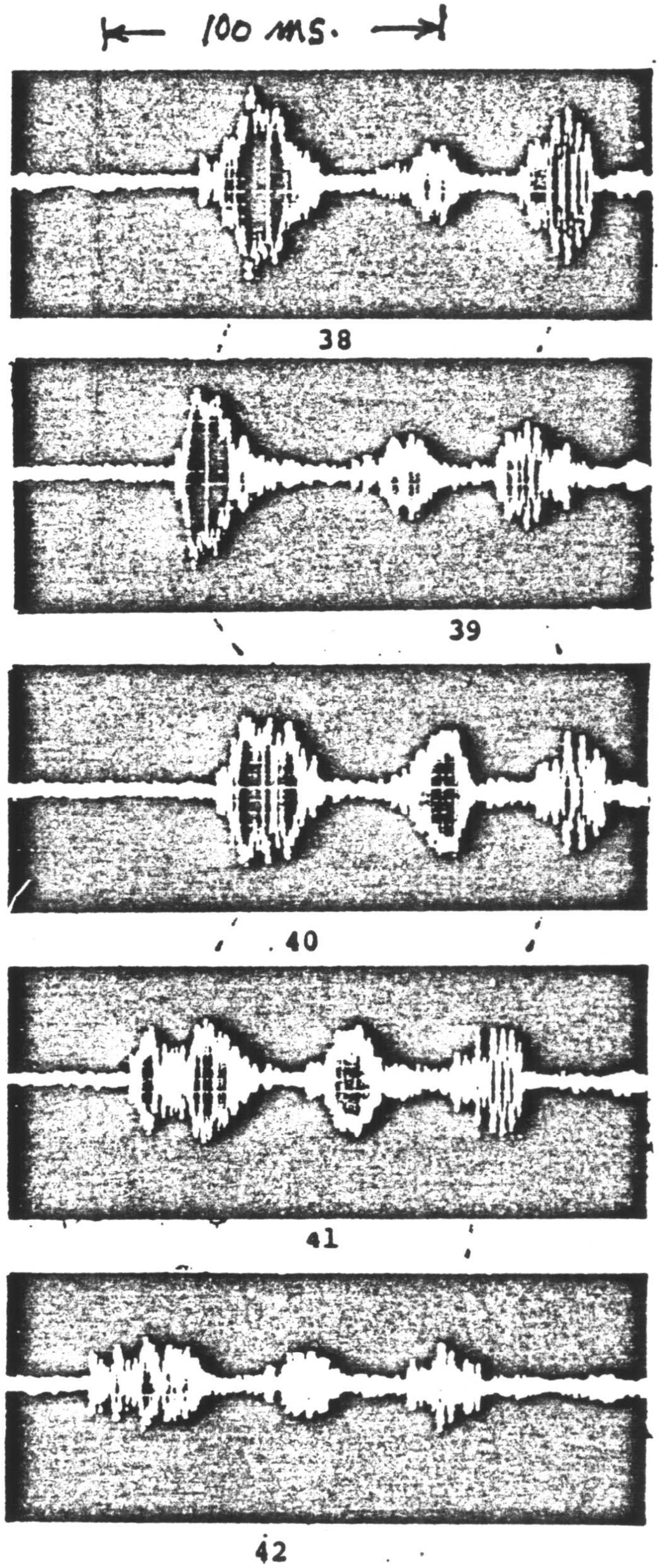

Fig. 2 Echoes received one second apart from an approaching close-range submarine. The source pulse was a conventional flat-top sinusoid 15 milliseconds long.

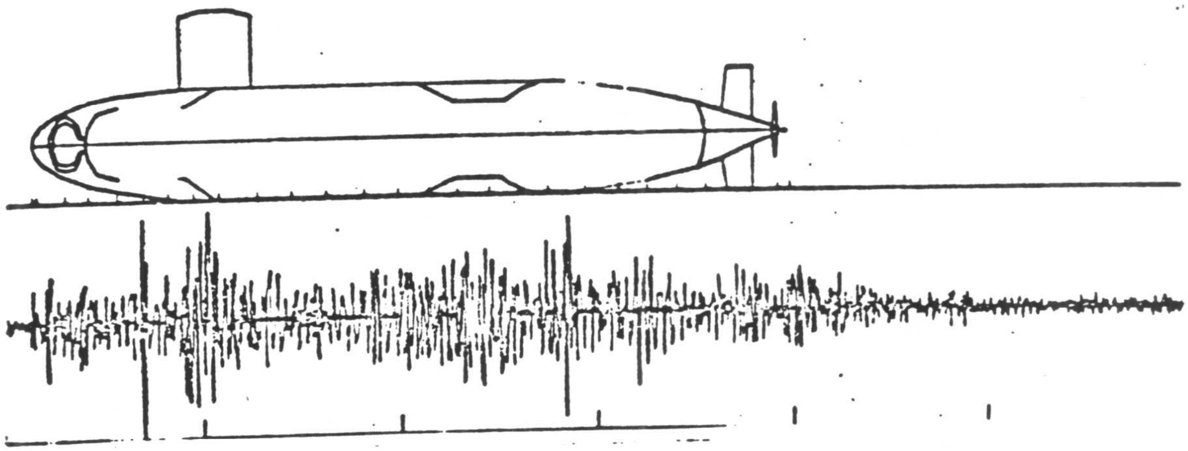

Fig. 3 The echo from a short-range submarine at an aspect angle of 49°. The source was an explosion of a small charge of TNT.

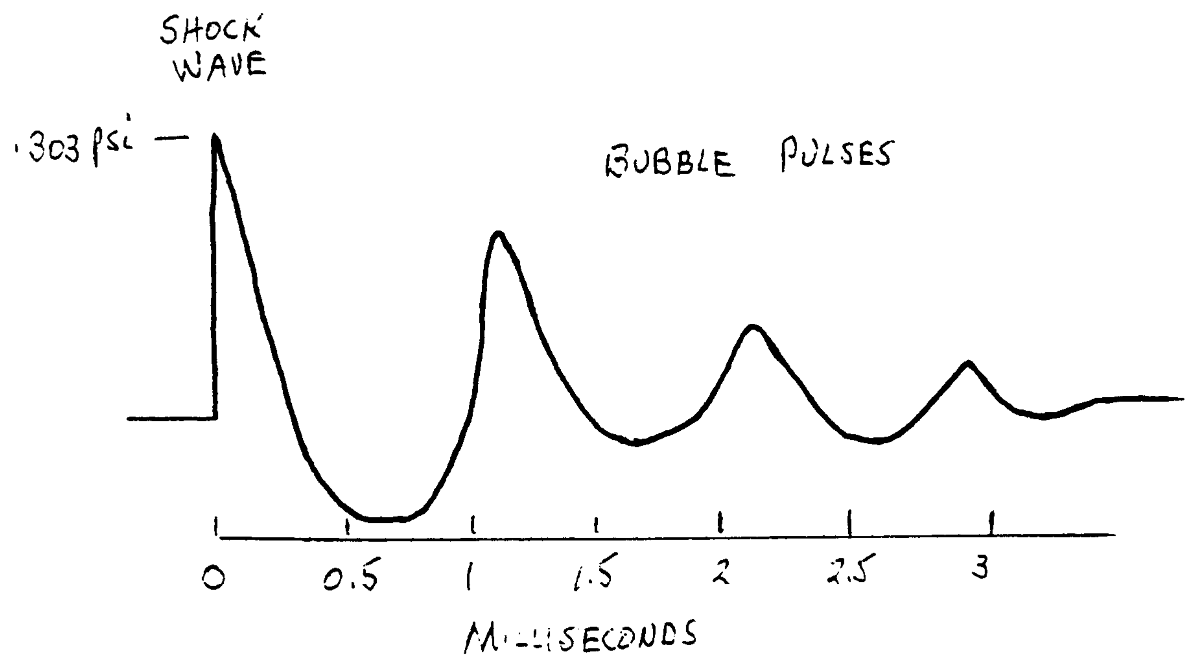

Fig. 4 Explosion signature from one lb. of TNT detonated at 22,000 feet and received at a shallow depth overhead.

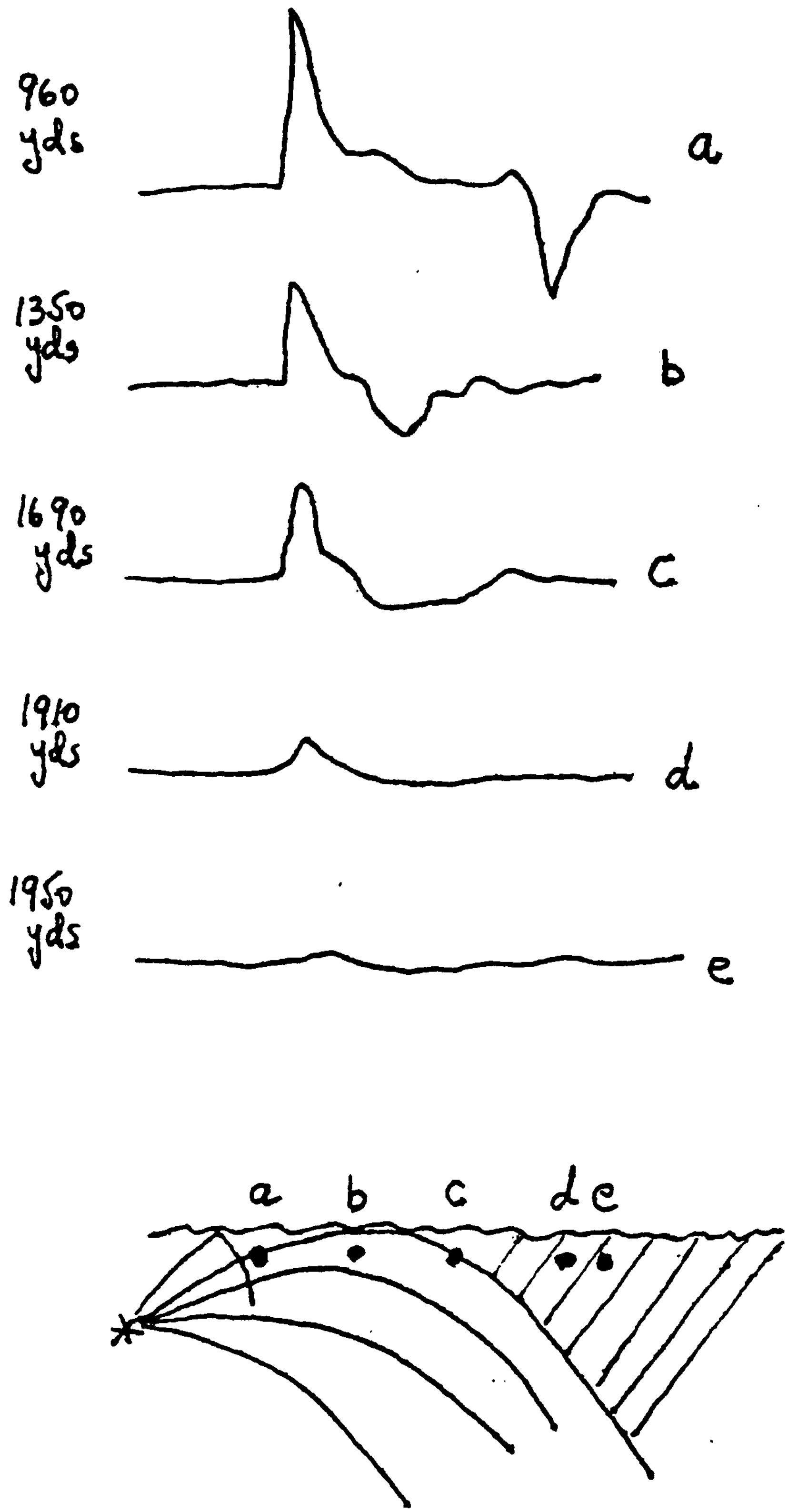

Fig. 5 Explosive signatures at a shallow depth inside and outside a shadow zone. From "Physics of Sound in the Sea," NDRC Sum. Tech. Rept 8, p. 202.

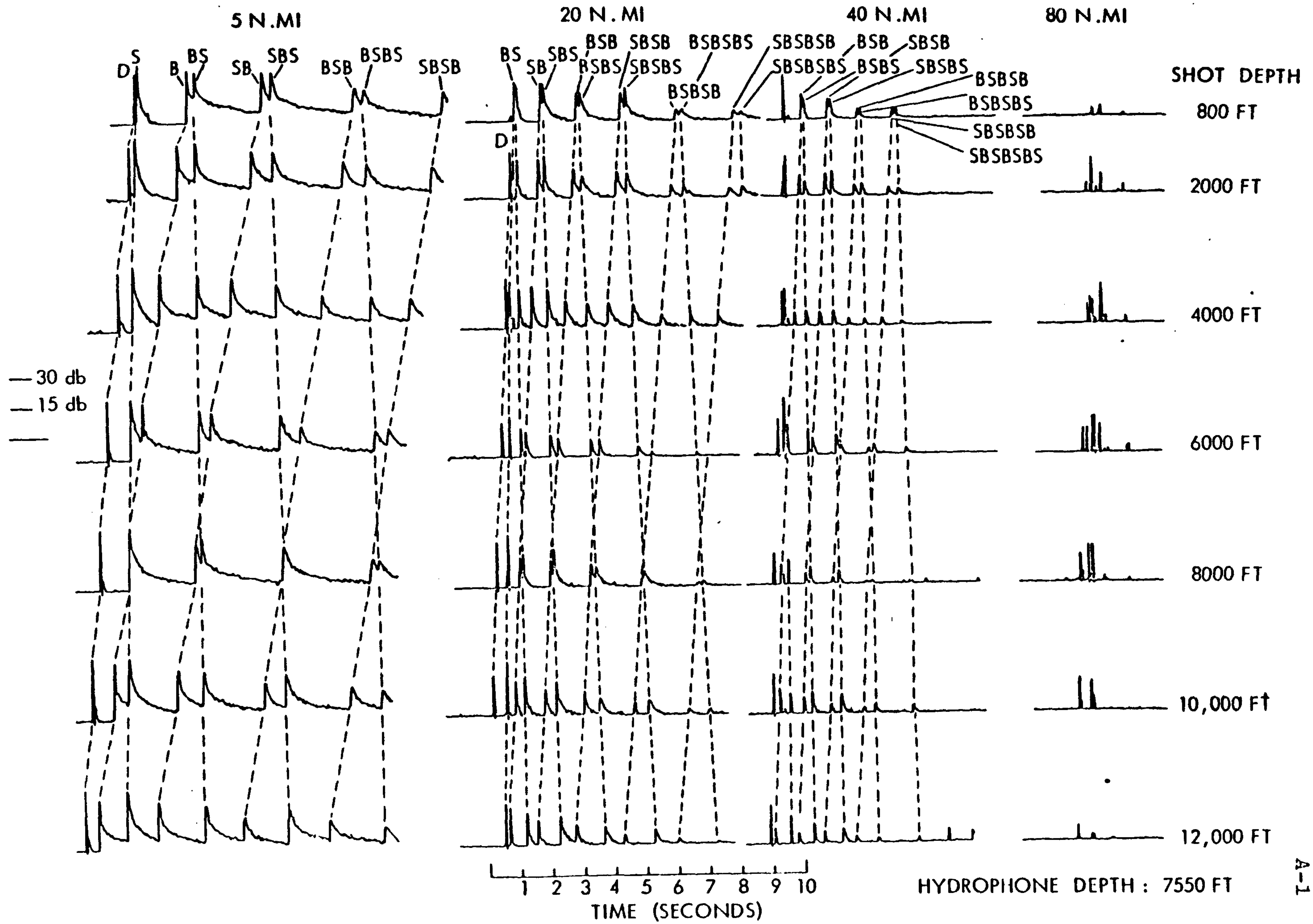

Fig. 6 Shot envelopes received at a depth of 7550 feet from shots at different ranges and depths. The letters SBS etc. at the top identify