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Woods Hole Oceanographic Institution

ASSESSMENT OF SEABED SEISMIC SYSTEMS

by

Elizabeth T. Bunce

April 1980

TECHNICAL REPORT

*Prepared for the Sandia Laboratories under
Contract 13-9944.*

WOODS HOLE, MASSACHUSETTS 02543

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ASSESSMENT OF SEABED SEISMIC SYSTEMS

E. T. Bunce

Introduction

This project was initiated to accomplish the necessary research and documentation of existing seismic techniques and systems for the study of sediments and sedimentary structures in the oceans. In this respect, it is an 'inventory' of methods and techniques for looking at small-scale features or changes in structures lying from 10 to 1000 m beneath the sea floor. It attempts to assess the vertical and lateral resolution capabilities of existing and technically feasible seismic systems. Some of the questions posed are: how closely can we determine vertical variation such as sediment layer thickness and vertical variation with depth; also lateral coherence or its disruption by such agents as facies changes, thinning or thickening, slumping, faulting; the nature of the basement structure, its areal coherence, velocity structure and associated anomalies?

The rationale lies in the growing need to dispose effectively of high level radioactive waste, that such disposal will be beneath the sea floor, and of course in conformity with present guidelines (Hollister et al, 1979). In the event that such a decision is made, the necessity exists for establishing criteria for site selection (ibid) and then for intensive study of such site or sites using suitable seismic-acoustic techniques either presently available or capable of development.

One would have assumed this study to be a straightforward exercise in review of current scientific and technical literature on methods and techniques of reflection seismology. This is true to a point, but the variable nature of the geologic and acoustic-physical parameters involved complicates the picture.

In its simplest form the normal incidence seismic reflection process is one in which an acoustic pulse transmitted from the sea surface reflects from the sea floor back to the surface. Since the signal transits the water column its travel time is a function of the velocity of sound in water; depth is thus measured in time, taking into account the double path, and converted to meters (or fathoms) on the basis of the precision time base that controls the system. In certain cases, some of the incident energy penetrates the sea floor to reflect from deeper layers; the travel time through each layer is then a function of the velocity in that layer.

Acoustic or seismic reflection occurs when there is such a change in the geotechnical properties (density ρ , velocity C) of the seabed material that there is a difference in acoustic impedance (the ρc) of the materials. The most obvious example of this is the water-seabed interface, another is the sediment-basement contact of oceanic areas. Table 1 shows values of the acoustic impedance for some representative seabed velocity materials, with the calculated reflection coefficient, $\frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1}$, for normally incident sound on the interface. Tabulated values range from 0.10 to 0.56, though they can be lower or higher. There are no references in the pertinent literature,

TABLE 1

Acoustic Impedance and Reflectivity Index (Rayleigh coefficient)
for Representative Seabed Material Velocities

VELOCITY (c) km/sec		DENSITY (ρ) g/m cm ³	ACOUSTIC IMPEDANCE (ρc)	REFLECTIVITY INDEX RAYLEIGH COEFFICIENT (R)
c ₁	1.64	1.74	2.85	
c ₂	1.80	1.96	3.5	0.10
c ₂	2.25	2.20	5.5	0.32
c ₂	3.0	2.35	7.0	0.42
c ₂	4.0	2.55	10.2	0.56
c ₁	1.80	1.96	3.5	
c ₂	2.25	----	----	0.22
c ₂	3.0	----	----	0.33
c ₂	4.0	----	----	0.49
c ₁	3.0	2.35	7.0	
c ₂	4.0	----	----	0.19
c ₂	4.5	2.60	11.7	0.25
c ₂	5.0	2.68	13.4	0.31
c ₂	5.5	2.75	15.1	0.37

to the best of my knowledge, to such valuable information as the minimum impedance change that will support a reflection. Reflections have been recorded from hot, high salinity layers in the water column where the velocity difference is minimal and the density difference small (Ross et al, 1969).

The ability to detect small vertical or lateral changes in the sediment layers or structures depends on the resolving power of the acoustic system. Resolution, or resolving power, can be defined as 'the ability to distinguish between the properties of two or more elements'. In the context of this study, it is the ability to detect thin layers, or small offsets in the layers (faults), or lateral inhomogeneities such as thickening or thinning, or changes in the nature (lithology) of the layers.

The relatively high, narrow band, frequency systems (3.5, 12kHz for instance) generally used to define sea floor topography are also capable of shallow penetration in sediments. Penetration is limited due to the rapid attenuation of the signal by the sediments for a variety of reasons (Stoll & Bryan, 1970) but can be effective for looking at seabed structures as deep as 200 m. The resolution of these structures is a function of the acoustic character of the incident signal, to wit, the pulse length. Theoretically, the shorter the pulse length, the smaller the resolvable dimension. Since the travel time resolution of a pulse signal is proportional to its band width, a broad band source capable of pulsed operation should yield the best results. The so-called narrow band high frequency transducers mentioned above are effectively broad

band, due to their configurations and the driver characteristics, allowing pulse lengths of 0.1 sec. to be used in flat terrain.

Another critical dimension is the effective wave length of the signal, a function of frequency and propagation velocity. Again theoretically, it should not be possible to resolve dimensions less than those of the signal wave length, at the selected frequency or band width center of a broad band signal. Yet there are seismic reflection records in existence that show layer sequences with layers thinner than supposedly resolvable at the band pass frequency used. This is one apparent paradox of reflection seismics: that it is possible to resolve differences smaller than theoretically feasible in light of the acoustic-geologic parameters. The principles of physics of sound in the sea are sometimes strained by exceptions.

Summarizing this section: in order to look at features of small dimension(s) (1 m to one to two hundred m) we need high frequency source-receiver systems, but these are limited in penetration capability by attenuation so we must go to broadband or low-frequency rich sources and compatible receivers, and add as well some form of signal processing to attain maximum resolution at depth. The processing can be as simple a technique as filtering the received signal in different bandwidths depending on the information needed (but the signal is preferentially attenuated by the sediments, so enhancement of deep features is not a consideration) to sophisticated signal processing techniques operating on multi-channel array data obtained using pulsed sources programmed for the depth interval and resolution factor.

Other considerations include those of increasing the signal to noise level and decreasing the "tail" of the outgoing pulse, such as bubble pulse oscillations. The former can be partially achieved by use of larger sources and longer arrays, and thus more effective signal processing; the latter can be reduced by use of such multiple sources simultaneously fired as spark or air gun/gas gun/etc. arrays and some pulsed sources all of which are effective in breaking up the bubble pulse, as are cage and sleeve shooting of explosives.

The spark in general has a shorter transient higher peak pressure pulse, but the air gun is richer in low frequencies so the former gives better resolution but the latter deeper penetration. (WHOI scientists for some years towed both a large (100 kjoule rating) spark source and a 20 or 40 cu in. air gun, fired simultaneously (Knott and Bunce, 1968) in one effort to resolve some of these problems).

Lateral continuity of reflections requires continuity of physical properties; with changes in elastic properties or with thickening and/or thinning the "nature" of the reflection appears to change. Such changes are more apparent with closely spaced reflections, obtainable by fast repetition rate at low speeds of advance, for instance. Changes in physical properties may occur as a result of faulting, intrusions, facies changes, slumping, or other natural features. While these may be detectable as differences in reflectivity, it is not always possible to determine the causative agent uniquely, particularly if depth of burial is such that direct sampling (core, drill) techniques are not feasible.

The preceding discussions have been largely confined to the surface source - surface receiver mode of operation, including near-surface towed vehicles. There are, however, conspicuous advantages to be gained from the use of near sea floor or bottom mounted equipments.

Placing the sounder near the sea floor not only minimizes two-way transmission losses at the higher frequencies by shortening the water path, but also greatly reduces the bottom and sub-bottom area reflecting acoustic energy back to the receiver. Decreasing the area insonified by each pulse permits measurement of sediment thickness and sub-bottom features and underlying basement relief over a lateral extent of a few hundred meters. Use of very narrow beam sources, with deep receivers, further increases lateral resolution. These should be of particular value where lateral variation of sediments (layer) thickness is comparable to the thickness itself, say a few to a few hundred meters, which are small scale changes in oceanic depths of 1000 m or more. Drilling results that show changes in the lithology over distances ranging from a few centimeters to several meters, indicate the necessity for near or bottom mounted instruments.

In general this use is applicable to narrow band (high frequency) sources, since pressure at oceanic depths poses major operative problems for most broadband sources, (except explosives, implosive sources, and such) although broadband receivers are routinely deployed on or near bottom.

Several large systems, at least one near bottom (Deep Tow) and one near surface (Gloria, 15 to 25 meters deep) have been constructed and used for geophysical measurements; these are the subject of a separate study.

A deep package should incorporate instrument versatility; a broadband receiver would allow reception of the range of frequencies of most interest, say 20 Hz to 12 kHz or higher, which could be used with a deep source for the higher end, and near-surface or deep towed source for the lower. The possible value of deep detonated explosives in such a mode should not be dismissed. They are a "white noise" source of great energy.

Conclusions:

There exists at this time no one system capable of defining small vertical features or lateral inhomogeneities in the shallow and deep seabed.

In the area of shallow seabed penetration (100 to 200 m) existing techniques-systems can resolve relatively small (a few meters) vertical displacements; both these and lateral discontinuities are amenable to resolution by deep towed systems. In the deeper sediments and at the basement surface, the optimum surface systems today appear to be multiple-source, multi-channel receivers configured for signal processing dedicated to the question in hand (for example, Hunttec's Deep Towed Seismic System). Deep source-deep receiver techniques should be developed for these particular applications.

The study of the buried structures is usefully enhanced by imagery of the surface of the seabed. Buried structures occurring in a given vertical section and having lateral extent may have surficial expression to the left or right of the reflection profile. Digitally acquired side-scan sonar data, together with the micro-processor based slant-range and spreading correction equipment, provide direct mapping imagery of the smaller scale seabed morphology.

Such advances as the use of fibre optics now under development for ASW systems should be most useful.

Present day technology would indicate a combination of existing systems and methods, utilizing the best components for each application, and operating the variety of sources necessary by computer, programming the complexity of output pulses and receiving windows to their most advantageous extent.

Finally, the real question is what do we need to resolve? What do we really wish to look at, in dimension and resolution, that would allow a real dimensional analysis of equipment?

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H. Hoskins of W.H.O.I. helped obtain information on commercially available systems; Dave Porta of Datadyne introduced us to the Geophysical Directory, an invaluable source. The sometimes scathing criticism of various colleagues has also been helpful.

Useful compendia of information include: Sea Technology Buyer's Guide/Directory, Compass Publications, Inc., 1117N 19th st., Arlington, VA 22209 and the Geophysical Directory, P. O. Box 13508, Houston, Texas 77109. Obviously we have drawn heavily on manufacturer's literature and Offshore Technology Conference material in the course of this survey. Since all the names are available in one or the other of the above annual publications they are not included here.

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Appendix 1

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