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THE NORMALLY-INCIDENT REFLECTIVITY OF THE SEA FLOOR
AT 12 KC AND ITS CORRELATION WITH PHYSICAL AND
GEOLOGICAL PROPERTIES OF NATURALLY-OCCURRING
SEDIMENTS

L. R. Breslau

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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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WITH PHYSICAL AND GEOLOGICAL PROPERTIES OF NATURALLY-OCCURRING SEDIMENTS

by

Lloyd R. Breslau

April 1967

TECHNICAL REPORT

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ABSTRACT

THE NORMALLY-INCIDENT REFLECTIVITY OF THE SEA FLOOR AT 12KC AND ITS
CORRELATION WITH PHYSICAL AND GEOLOGICAL PROPERTIES OF NATURALLY-
OCCURRING SEDIMENTS

by

Lloyd Robert Breslau

The objective of this investigation was to measure bottom loss in normal incident reflection of pulses of twelve kcps sound and to study its geological significance. To this end a semi-automatic instrument system was developed which is capable of making continuous measurements of the peak pressure and the time integral of the square of the pressure of the sea floor echo, from a vessel underway.

Observations were taken in both deep and shallow water areas in the Western North Atlantic. The early cruises were conducted in deep water to investigate the range and variability of bottom loss values. Geological control consisted mainly of a precise bathymetric record. The later cruises were conducted in shallow water, in areas where the geology has been well studied previously by investigators using techniques of classical geology. In these latter cruises the acoustic measurements were correlated with a schedule of sediment dredging and underwater photography.

Thirty-one thousand acoustic measurements were made. Median bottom loss values and standard deviations were computed and the results summarized in eleven hundred sets, each set corresponding to a location at sea.

Seventy-seven sediment stations were occupied. A complete particle size analysis and a water content analysis were performed on these sediments to determine their size and mass characteristics. The size characteristics included the median grain size, the sorting coefficient, and the percentages of gravel, sand, silt, and clay. A sediment class name was determined from the gravel, sand, silt, and clay percentages according to the Shepard system of classification. The mass characteristics included porosity, bulk density, sound velocity, acoustic impedance, Rayleigh reflection coefficient, and theoretical bottom loss.

The combined results show a good correlation between measurements of bottom loss and both mass and size characteristics of the sediment. The measured bottom loss increases as the porosity increases. The measured bottom loss also increases as the silt-clay percentage increases since the porosity of sediments generally increases as this fraction increases.

It seems that the Rayleigh reflection coefficient can be used to predict acoustic bottom loss at normal incidence. Conversely, normally-incident bottom loss can be used under the assumption of a Rayleigh reflection process to determine the nature of the bottom sediment.

The acoustical and geological results have been made available in tabulations, scatter diagrams, and as geographical plots. Except for the initial measurements, all operations, including the final displays, were accomplished through automatic digital processing machines.

FORWARD

This report is a condensation of the author's doctoral dissertation entitled "Sound Reflection from the Sea-Floor and its Geological Significance", which was submitted to the Department of Geology and Geophysics at the Massachusetts Institute of Technology in June, 1964. This condensation has been achieved mainly at the expenses of the following material: (1) description of electronic circuitry, (2) list of computer program instructions, (3) tabulations of acoustic and geological data, (4) cumulative size distribution curves of the sediment samples, and (5) photographs of the sea-floor at the sediment stations. The complete dissertation may be consulted at the Science Library in MIT.

This work represents a joint effort between the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology. The author's personal support has come from Contract Nonr 1841(74), NR 083-157 with the Office of Naval Research and MIT. The IBM Computation Center and MIT donated time on the 7090 computer located there. Support for equipment, ship time, and computer time on the G.E. 225 computer at WHOI has come from Contracts NObsr-72521 and NObsr-89464 with the Bureau of Ships and WHOI.

This work was performed while the author was located at WHOI and working under the supervision of Prof. J. B. Hersey. At present the author is located at the SACLANT ASW Research Center in La Spezia, Italy.

CHAPTER I

INTRODUCTION

General Objectives

The primary objective of this investigation was to measure the acoustic reflectivity of the sea floor and to study its geological significance. A secondary objective was to develop a practical technique that could be used for routine acoustical surveying of sea floor sediments from a vessel underway.

In principle, acoustic echoes received from the sea floor are influenced by the geological nature of the bottom and might be used for limited identification of reflectors. However, the overwhelming complexity of the generalized reflection process, the variability in echo characteristics from echo to echo, and the sheer tedium of making the measurement and performing the geological correlation have largely defeated attempts to use acoustic reflectivity for geophysical exploration.

The general plan of this investigation was to reduce the measurement of acoustic reflectivity to its simplest form, perform the shipboard data acquisition in a semi-automated fashion, measure only easily recognizable qualities of the echo wave-train, and analyze the data by high-speed digital computer. An effort was made to create a technique that eventually could be fully automated and could perform its task on a ship underway at cruising speed without restricting any of the ship's activities. Conventional Navy sonar equipment, instruments commonly used in hydroacoustical oceanography, and standard laboratory apparatus were employed wherever feasible, primarily because of initial convenience and, additionally, so that this surveying technique, if proven fruitful, could be readily adopted by others.

Historical Background

Because of its military application much work was done in the field of underwater acoustics by numerous investigators during World War II and was later reported in summary form. The section pertaining to sound transmission studies (Physics of Sound in the Sea, Part I Transmission, Summary Technical Report of the National Defense Research Committee; 1946) contains information relevant to the reflecting properties of the sea floor which was a by-product of horizontal sound-transmission studies. These measurements, taken at various frequencies and angles of incidence with only cursory investigation of the geological environment, nevertheless established that different geological bottom types react differently acoustically, and that rock, stone, and sand bottoms are better reflectors than sand and mud, or mud bottoms. The general relationship between acoustical and geological properties was utilized to predict the acoustical behavior of a region from available geological information,

as evidenced by sediment charts prepared for pro-submarine operations (The Application of Oceanography to Sub-surface Warfare, Summary Technical Report of the National Defense Research Committee; 1946). The converse prediction is attempted in this investigation.

The work done after the war that contributed toward an understanding of the acoustic reflectivity of the sea-floor progressed along two separate lines of investigation. One line of investigation, exemplified by Liebermann (1948), Urick (1954), Urick and Saling (1962), Mackenzie (1960), McKinney and Anderson (1964), and Jones et al. (1964), was concerned mainly with sound transmission and studied sound reflected from the sea floor. The other line of investigation represented by Hamilton et al. (1956), Shumway (1960), Sarmiento and Kirby (1962), Richards (1962), and Nafe and Drake (1963) was concerned mainly with sea-floor sediments per se and studied their physical and sedimentological properties.

There have been very few attempts to use the results of the acousticians and sedimentologists in a quantitative approach toward acoustical surveying of sea-floor sediments. Semi-quantitative surveys, using tonal shading of echo-sounding records as an indicator of acoustic reflectivity, have been made by Erath (1959), Loring (1962), and Hoffman and Wilkes (1962). A crude quantitative recording of average echo strength was used for a time prior to 1950 by the geophysics group at Woods Hole (Hersey, private communication). The output signal from an echo sounder was rectified and fed to an integrating condenser with a decay constant equal to about ten or twelve ping intervals. A recording was made of the potential across the condenser. Reproducible profiles of echo strength were made in shallow water near Woods Hole, but this work was dropped then because of other pressures. Quantitative surveying, using the amplitude of the peak pressure in the bottom echo, has been performed in the Caspian Sea and Continental Shelf by Sergeev (1958).

The work described in the present paper represents an extensive field investigation of acoustic reflectivity and detailed comparison with characteristics of the sea-floor sediment, using a highly automated system of data collection and analysis. This work adds a new dimension to echo sounding by utilizing the magnitudes as well as travel times of the echoes.

CHAPTER II

THEORETICAL DEVELOPMENT

The Acoustic Measurement; Rayleigh Reflection Coefficient

The approach used in this investigation was to parameterize (determine a parameter of a simple model which is assumed to represent a complex physical process) acoustic bottom loss according to a specular-reflection model in which the sea-floor is considered to be a plane interface between two fluids. Bottom loss, according to this model, is determined by the Rayleigh Reflection Coefficient at the water-sediment interface when the sound source is sufficiently far from the interface that the impinging waves are essentially plane.

The intensity of an echo which is specularly-reflected from the sea-floor is given by

$$I_R = I_S \times K \times \frac{1}{(2D)^2} \times e^{-\alpha 2D} \quad (\text{Eq. 1})$$

where I_R is the intensity of the echo, I_S is the intensity of the source, K is the fractional loss of intensity at the sea-floor $\frac{1}{(2D)^2}$ is transmission loss due to spherical spreading and $e^{-\alpha 2D}$ is transmission loss due to dissipative attenuation of sound in sea-water. Since

$$I_R = \frac{P_R^2}{\rho_1 c_1} \quad (\text{Eq. 2}) \quad \text{and} \quad I_S = \frac{P_S^2}{\rho_1 c_1} \quad (\text{Eq. 3})$$

where P_R is the pressure of the echo, P_S is the pressure of the source,

ρ_1 is the density of the water and c_1 is the sound velocity in the water, Eq. 1 becomes (P_S is the pressure estimated at

$$D=1) \quad \frac{P_R^2}{\rho_1 c_1} = \frac{P_S^2}{\rho_1 c_1} \times K \times \frac{1}{(2D)^2} \times e^{-\alpha 2D} \quad (\text{Eq. 4})$$

Taking the integral with respect to time of both sides of Eq. 4 gives

$$\frac{1}{\rho_1 c_1} \times \int_T^{T+T} P_R^2 dt = \frac{1}{\rho_1 c_1} \times K \times \frac{1}{(2D)^2} \times e^{-\alpha 2D} \times \int_0^T P_S^2 dt \quad (\text{Eq. 5})$$

Since the source is a sine wave of duration T

$$\int_0^T P_S^2 dt = P_{S(RMS)}^2 \times T \quad (\text{Eq. 6})$$

where the root mean square of the pressure is equal to the peak pressure divided by the square root of two, Eq. 5 becomes

$$\frac{1}{\rho_1 c_1} \times \int_T^{T+T} P_R^2 dt = \frac{1}{\rho_1 c_1} \times K \times \frac{1}{(2D)^2} \times e^{-\alpha 2D} \times P_{S(RMS)}^2 \times T \quad (\text{Eq. 7})$$

It is seen that K may be defined on a peak pressure basis through Eq. 4 thusly

$$K = \frac{P_R^2}{P_S^2} \times (2D)^2 \times \frac{1}{e^{-\alpha 2D}} \quad (\text{Eq. 8})$$

or on an energy basis through Eq. 7 thusly

$$K = \frac{\int_T^{T+T} P_R^2 dt}{P_{S(RMS)}^2 \times T} \times (2D)^2 \times \frac{1}{e^{-\alpha 2D}} \quad (\text{Eq. 9})$$

If P_{INC} represents the pressure of the wave incident on the sea-floor and P_{REF} represents the pressure of the wave reflected from the sea-floor, the K , the fractional loss of intensity at the sea-floor is given by

$$K = \frac{P_{REF}^2}{\rho_1 c_1} / \frac{P_{INC}^2}{\rho_1 c_1} = \left(\frac{P_{REF}}{P_{INC}} \right)^2 \quad (\text{Eq. 10})$$

For the above mentioned model and incident plane waves, the ratio of the pressure of the wave incident on the sea-floor to the pressure of the wave reflected from the sea-floor is given by the Rayleigh Reflection Coefficient (Rayleigh, 1945) (Officer, 1958) thusly

$$R = \frac{P_{REF}}{P_{INC}} = \frac{\frac{\rho_2}{\rho_1} - \frac{\sqrt{c_1^2/c_2^2 - \sin^2 \theta}}{\sqrt{1 - \sin^2 \theta}}}{\frac{\rho_2}{\rho_1} + \frac{\sqrt{c_1^2/c_2^2 - \sin^2 \theta}}{\sqrt{1 - \sin^2 \theta}}} \quad (\text{Eq. 11})$$

where θ is the angle of incidence. For normal incidence ($\theta = 0$), which was the case for the measurements made in this investigation, the expression for the Rayleigh Reflection Coefficient is simplified since Eq. 11 reduces to

$$R = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1} \quad (\text{Eq. 12})$$

The expression $\rho \times c$ is called the specific acoustic impedance of the medium and is designated as Z . Using this convention, Eq. 12 can be put in the following form

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (\text{Eq. 13})$$

where Z_1 and Z_2 refer to the specific acoustic impedances of seawater and sediment respectively. The Rayleigh Reflection Coefficient was derived for incident plane waves by assuming a velocity potential and requiring continuity of pressure and normal component of particle velocity at the interface. However, it has been shown (Officer, 1958) that it is a valid approximation for the reflection of an incident spherical wave under the conditions that

$$\frac{c_1}{\omega D [c_1^2/c_2^2 - \sin^2 \theta]^{3/2}} \ll 1 \quad (\text{Eq. 14})$$

For normal incidence ($\theta = 0$) this reduces to

$$\frac{h_1}{D \times 2\pi \times c_1^3/c_2^3} \ll 1 \quad (\text{Eq. 15})$$

which means that the approximation is valid when the sound source is a moderate number of wavelengths away from the sea floor. This condition was always satisfied in this investigation.

The relationship between the fractional loss of intensity at the sea-floor, K , and the Rayleigh Reflection Coefficient, R , is shown by Eq. 10 and Eq. 11 to be

$$K = R^2 \quad (\text{Eq. 16})$$

The fractional loss of intensity, K , can be measured either by the relationship expressed in Eq. 8 or by the relationship expressed in Eq. 9; both are used in this investigation. The former is considered to be a measurement on a pressure basis and the latter on an energy basis.

It is convenient and conventional to express hydroacoustic measurements in decibel form. Taking ten times the logarithm of both sides of Eq. 8 gives

$$10 \log K = -20 \log P_S + 20 \log P_R + 20 \log 2D + 10 \times 20 \log e \quad (\text{Eq. 17})$$

which may be expressed as

$$BL = S_{PL} - E_{PL} - TL_S - TL_A \quad (\text{Eq. 18})$$

where BL is bottom loss in db and is equal to $-10 \log K$, S_{PL} is the pressure level of the source in db//1 dyne/cm² and is equal to $20 \log P_S$,

E_{PL} is the pressure level of the echo in db//1 dyne/cm² and is equal to

$20 \log P_R$, TL_S is the spreading loss in db and is equal to $20 \log 2D$, TL_A

is the attenuation loss in db and is equal to $10 \times 20 \log e$ or to $a \times 20$

where a equals $10 \times \log e$

Taking ten times the logarithm of both sides of Eq. 9 gives

$$10 \log K = -10 \log (P_{S(RMS)}^2)^T + 10 \log \int_T^{T+T} P_R^2 dt + 20 \log 2D + 10 \times 20 \log e \quad (\text{Eq. 19})$$

which may be expressed as

$$BL = S_{EL} - E_{EL} - TL_S - TL_A \quad (\text{Eq. 20})$$

where S_{EL} is the energy level of the source in db//1 erg/cm² and is equal to $10 \log (P_s^2 (RMS) \times T)$ or to $10 \log (P_s^2 \times T/2)$

E_{EL} is the energy level of the echo in db//1 erg/cm² and is equal to $10 \log \int_T^{T+T} P_R^2 dt$, and BL , TL_S , and TL_A are the same as described in Eq. 18.

Taking ten times the logarithm of both sides of Eq. 14 gives

$$10 \log K = 20 \log R \quad (\text{Eq. 21})$$

which may be expressed as

$$BL = 20 \log R \quad (\text{Eq. 22})$$

where BL is bottom loss in db and R is the Rayleigh Reflection Coefficient.

The Relationship Between Bottom Loss and Physical Properties of Sediments

The relationship between bottom loss and the Rayleigh Reflection Coefficient, given in Eq. 22, and the relationship between the Rayleigh Reflection Coefficient and the acoustic impedance contrast at the water-sediment interface, given in Eq. 13, serve to establish the relationship between bottom loss and mass characteristic of the sediment. Since the acoustic impedance of the sediment is the product of the density and compressional velocity, and since these properties can be related to the porosity of naturally occurring oceanic sediments, it is possible to establish a relationship between bottom loss and porosity. This relationship will be developed below.

A marine sediment is an aggregate of rock and mineral particles whose interstices are filled with sea-water. As such it can be thought of as a multi-component system whose bulk properties are some combination of the properties of the individual components. Fortunately, since the range of specific gravities of minerals commonly occurring in natural marine sediments

is slight, and since the compressibility of water is between one and two orders of magnitude larger than the compressibilities of mineral grains, it is possible to consider the marine sediment as a two component system with regard to these properties. For the purpose of arriving at acoustic impedance the sediment may be thought of as composed of a fraction which is sea-water and a remainder which is solid material. Porosity, which is a measure of the volume fraction of the sediment occupied by sea-water, is therefore seen to be an important parameter of marine sediments in describing the way they react acoustically.

The relationship between the density and porosity of marine sediments would be perfectly linear if the specific gravity of the solid material of all marine sediments was the same. For this case the density of the sediment would be equal to that of the solid material at zero porosity, equal to that of sea-water at one hundred percent porosity, and equal to an intermediate value determined by linear interpolation at any other value of porosity. This relationship is expressed as

$$\rho_{SED} = \rho_{WAT} \times \Phi + \rho_{SOL} [1 - \Phi] \quad (\text{Eq. 23})$$

where ρ_{SED} is the density of the sediment, ρ_{WAT} is the density of sea water, ρ_{SOL} is the density of the solid material, and Φ is the porosity of the sediment. While the densities of the solid material of naturally occurring marine sediments do differ somewhat, their range is sufficiently restricted that a good straight-line fit for sediment density versus porosity can be made. The degree to which a linear relationship exists has been demonstrated by Nafe and Drake (1963) in which density measurements taken from Birch (1942), Hamilton, et al. (1956), Shumway (1960), Sutton, et al. (1957) and Kershaw (unpublished) were plotted

versus porosity without regard to sediment type (Figure 1, after Nafe and Drake). Richards (1962) has demonstrated a similar relationship with his data, which comprise nearly 500 oceanic samples.

The equation for compressional-wave velocity in elastic media (Ewing, Jardetsky, Press, 1957) is given by

$$C = \left[\frac{K + (4/3)\mu}{\rho} \right]^{1/2} \quad (\text{Eq. 24})$$

where ρ is the density, K is the bulk modulus, and μ is the modulus of rigidity. Where rigidity is negligible Eq. 24 reduces to

$$C = (B + \rho)^{-1/2} \quad (\text{Eq. 25})$$

where B is the compressibility. Wood (1945) noted that in a suspension of solid particles in water, the bulk compressibility is equal to the sum of the individual compressibilities of the particles, weighted according to their fractional volumes in the suspension. Urick (1947) tested this experimentally and found it valid. Since the compressibility of sea water is so very much larger than the compressibilities of mineral grains that occur in natural sediments, the volume fraction of sea-water in a natural sediment (the porosity) exerts a dominant effect on the bulk compressibility of the sediment, regardless of its mineralogical composition. This relationship is expressed as

$$B_{SED} = B_{WAT} \times \Phi + B_{SOL} [1 - \Phi] \quad (\text{Eq. 26})$$

where B_{SED} is the bulk compressibility of the sediment, B_{WAT} is the compressibility of sea-water, B_{SOL} is the compressibility of solid material, and Φ is the porosity of the sediment.

A natural unconsolidated sediment may be considered to resemble a suspension of solid particles in sea-water and possess a compressional-wave velocity approximating that defined by Eq. 25. The density and bulk compressibility may be approximated by Eq. 23 and Eq. 26 respectively. The com-

Figure 1 Experimental Values of Density Versus Porosity for Typical Oceanic Sediments (After Nafe & Drake, 1963)

pressional-wave velocity may therefore be expressed in the following form

(Wood's Equation)

$$C = \left([\rho_{WAT} \times \bar{\Phi} + \rho_{SOL} (1 - \bar{\Phi})] \times [\beta_{WAT} \times \bar{\Phi} + \beta_{SOL} (1 - \bar{\Phi})] \right)^{-\frac{1}{2}} \quad (\text{Eq. 27})$$

using Eq. 23, Eq. 25 and Eq. 26. The degree to which this expression adequately describes the compressional-wave velocities of unconsolidated sediments has been demonstrated by Nafe and Drake (1963) in which measurements of compressional-wave velocity taken from Sutton (1957), Hamilton (1956), Shumway (1960), Laughton (1957) and Kershaw (unpublished) have been plotted versus porosity (Figure 2, after Nafe and Drake).

The specific acoustic impedance of the sediment may be obtained by taking the product of the density (Eq. 23) and compressional-wave velocity (Eq. 27). This impedance, in conjunction with the specific acoustic impedance of sea-water, may be used to determine the Rayleigh Reflection Coefficient (Eq. 13). The bottom loss, in decibel form, may then be obtained through Eq. 22. A plot of density, velocity, impedance, reflection coefficient, and bottom loss versus porosity is presented in Figure 3 to portray the relationships that exist between these variables according to Eq. 13, Eq. 22, Eq. 23, Eq. 25, Eq. 26, and Eq. 27. Densities of 1.03 g/cm³ and 2.75 g/cm³ and compressibilities of 43 x 10⁻¹² cm²/dynes and 2.0 x 10⁻¹² cm²/dynes were assumed for sea-water and solid material, respectively. It is seen that bottom loss increases as the porosity of the sediment increases.

The Relationship Between Bottom Loss and Geological Properties of Sediments

The relationship between bottom loss and physical properties of sediments has been discussed in the previous section. In particular, bottom loss was shown to be related to the porosity of the sediment. Since the porosities of natural sediments are related, though not rigorously, to the grain-size or textural

Figure 2 Experimental Values of Velocity Versus Porosity for Typical Oceanic Sediments (After Nafe & Drake, 1963)

Figure 3 Theoretical Curves of Density, Velocity, Impedance, and Reflection Coefficient Versus Porosity

characteristics of natural sediments, it is also possible to establish a general relationship between bottom loss and geological properties of sediments.

Theoretically, sediments composed of spheres and possessing equal degrees of sorting would have the same porosity regardless of grain size, and a decrease in the degree of sorting would allow interstices to fill in and result in reduced porosity (Graton and Fraser, 1935). Actually, grains occurring in natural sediments are not spheres and considering them as such is oversimplifying the situation to the point that it is misleading. The porosity of a natural sediment is a function of the grain size (median grain size), distribution of grain size (sorting), shapes of the grains (roundness and sphericity), and packing or orientation (fabric). The exact form of this function is not known; the variables are usually concomitantly related in natural sediments, and it is difficult to isolate individual effects. Nevertheless, a consideration of some physical factors involved will serve to establish general relationships.

Particles in the sand and coarse silt size ranges are sufficiently large that gravity plays the major role in determining their structures in sediments. These sediments exhibit single-grained and mixed-grained structures, which are tight fabrics with attendant low porosities. Particles in the fine silt and clay size ranges are small enough to be appreciably affected by intermolecular forces. These particles tend to stick to the first grain encountered during the sedimentation process and are prone to form honeycomb and honeycomb-flocculent structures, which are loose fabrics with attendant high porosities (Hamilton and Menard, 1956).

As the particles become smaller, the ratio of their surface area to volume increases. This results in an increase in the ratio of surface adsorbed water to particle volume with attendant increase in porosity; for small particles the surface adsorbed water may be more than that contained in the geometrical

interstices of the sediment (Emery, 1960). This applies particularly to particles in the clay size range.

An increase in the angularity of the particles will generally be associated with an increase in the porosity of the sediment because the attendant increase in friction between the particles will retard the development of a tight fabric and any decrease in the sphericity or roundness will increase the surface area and therefore the volume of surface-adsorbed water. There is a general inverse relationship between angularity and particle size for natural sediments because of the platy habit of clays and the fact that smaller particles usually have experienced less rounding by natural forces (Hamilton et al., 1956).

An increase in the clay content of a sediment will increase its porosity because of the associated structural, size, and shape effects that have been previously discussed. In addition, clay particles increase the porosity of a sediment by a phenomenon known as bridging. The clay particles with their flat sides horizontally oriented in the sediment cause a bridging effect between other grains which increases the sizes of the interstices (Terzaghi and Peck, 1948).

The degree of sorting does not seem to have a pronounced relationship to the porosity of natural sediments in contradistinction to what might be expected at first thought. It would seem that the extent to which finer grains would fill interstices between coarser grains and thus lower the porosity would be inversely related to the degree of sorting. This process is most effective for coarser sediments in which most of the water is contained in geometrical voids rather than adsorbed on grain surfaces (Fraser, 1935); it is not an important factor in finer sediments in which surface effects play a major role. Indeed, since finer sediments usually exhibit a direct relationship between degree of

sorting and grain size, a decrease in sorting will be associated with an increase in porosity due to the dominant effect of grain size.

The net result of the above mentioned physical factors that influence the porosity of natural sediments is that the porosity generally increases as the grain size decreases or the percentage of silt plus clay (fine fraction of the sediment) increases; clay exerts a stronger influence on the porosity than silt. These relationships for natural sediments have been empirically established (Fraser, 1935), (Trask, 1932), (Krynine, 1947), (Birch et al., 1942), (Hamilton et al., 1956), (Shumway, 1960), (Sutton et al., 1957), (Sarmiento and Kirby, 1962), (Ryan, Workum, and Hersey, 1962), and (Richards, 1962). The relationship between grain size and porosity is shown in Figure 4 (after Shumway). The relationship between the coarse fraction (the complement of the fine fraction) and porosity is shown in Figure 5 (after Shumway).

Sedimentary nomenclature is commonly based on sand-silt-clay ratios. Since clays are more porous than silts and both silts and clays are much more porous than sands, a general relationship exists between class names and porosities of natural sediments. Since each class name encompasses a range of sand-silt-clay ratios, the relationship between class name and porosity is necessarily broad and poorly defined. Nevertheless, it is useful because many sedimentological observations are reported by class name only.

A method exists by which the median grain size of a sediment can be estimated from its sand-silt-clay percentages (Plumley and Davis, 1956) based on the assumption that sediment sizes are normally distributed. This method has been applied to the commonly used classification system of Shepard (1954) in order to establish approximately the rank and range of sizes represented by the various class names of that system. The size ranks and ranges are shown in Figure 6; because of the inverse relationship between porosity and grain

Figure 4 Experimental Values of Mean Diameter Versus Porosity for Typical Oceanic Sediments (After Shumway, 1960)

Figure 5 Experimental Values of Coarse Fraction Versus Porosity for Typical Oceanic Sediments (After Shumway, 1960)

Figure 6 General Range of Median Grain Sizes for Sediments Classified According to a Sand-Silt-Clay System

size, this figure also indicates the porosity ranks and ranges.

In resumé, bottom loss is inversely related to the grain size and directly related to the fine fraction for natural sediments. Where the Shepard classification system is used, bottom loss increases according to the following sequence: sand, silty sand, sandy silt, silt, sand-silt-clay, clayey silt, silty clay, and clay. The ranges of the class names overlap and silty sand, sand-silt-clay, and silty clay are the worst offenders in this respect.

CHAPTER III

METHODS

Acoustic Measurements

The acoustic-reflectivity measurements of this investigation were made only at normal incidence and only with pulses of 12-kcps sound. Normal incidence provides the largest echo return available in single-ship operation and, in fact, is the practical way to achieve a usable signal-to-noise ratio under typical field conditions. The frequency 12-kcps was used because it is a common frequency in echo sounding, and equipment employing it was available. The ping length used was 5 milliseconds in deep water and 1 or 2 milliseconds in shallow water.

The peak amplitude and total energy of an acoustic wave-train are two easily measurable qualities which characterize the observed reflection. These two qualities were used as measures of reflectivity in this research. The peak-amplitude measurement is obtained by measuring the maximum peak-to-peak excursion of the pressure wave-train. The total-energy measurement is a representation of the sum total of the energy in the echo. It is obtained by measuring the final value of the time integral of the squared pressure of the wave-train, which function is generated by an on-line analogue computer. A time of 100 milliseconds after the first arrival of the echo was arbitrarily selected as the time at which the energy content of the echo would be considered to have reached its final value. This procedure makes the measurement not only purely objective but also amenable to machine determination, and is a compromise necessary for analyzing the large sample of data taken in this investigation.

The shipborne instrumentation system used to make the acoustic-reflectivity measurements is described in detail in this chapter. The acoustic-source level and echo strength were determined by electrical measurements made inside the transducer. This is inferior to an acoustic calibration, since it makes the measurement dependent on the transmitting and receiving characteristics of the transducer, but it was the only method practical during this investigation.

The transducer used as the source and receiver was the UQN-1b (Edo Corp., undated), mounted on the hull of the ship or in a towed fish (Knott and Witzell, 1961). This is a standard sonar transducer employing ammonium dihydrogen phosphate (ADP) crystals (these crystals possess piezoelectric properties; their effect in an electrical circuit is predominantly capacitative.) as the active element inside a cylindrical housing 16 inches in diameter. Included inside the transducer housing are a multi-tapped inductor and a 10-ohm resistor in series with the active element. The multi-tapped inductor is adjusted to tune the series circuit to resonance at 12-kcps, where the transducer impedance appears real and equal to a nominal value of 200-ohms. A voltage measurement across the 10-ohm resistor, henceforth called the calibration resistor, was used as a measure of the acoustic input and output of the transducer.

Since voltages appearing anywhere in a series loop are additive, an externally generated voltage impressed upon the calibration resistor has the same effect on the circuit as a signal voltage generated by the transducer in response to an acoustic signal. The acoustic signal required to generate this signal voltage was determined by reference to the receiving sensitivity of the transducer, which is directly stipulated by the manufacturer as -73 db//1 volt for a sound field of 1 dyne/cm².

The voltage developed across the calibration resistor by the outgoing ping is a measure of the current passed and power dissipated by the active element of the transducer. The acoustic output was determined by reference to the relationship between the peak-to-peak source level and peak-to-peak voltage on the calibration resistor where the source level equals 79 db + 20 log (voltage). This relationship was established by measurements made on three UQN-1b transducers using a calibrated receiver (Atlantic Research Corp., 1963) and projector (Underwater Sound Reference Laboratory, 1954), (David Bogen Co., 1946). The transducers were selected at random and were considered representative of the typical UQN-1b since their measured receiving sensitivity agreed with that specified by the manufacturer.

A semi-automated measurement system, henceforth called the Acoustic Reflectivity Measurement System, was designed and constructed to facilitate the acquisition of acoustic data on shipboard. This system is capable of automatically performing acoustic measurements repeatedly at two-second intervals after the controls involving time synchronization and dynamic range have been set manually. Data is recorded in both stored form and in real time. The pressure and the energy versus time waveforms of the echo are recorded in stored form as oscilloscope photographs. Real-time measurements of the energy in the echo are presented as digital print-out, and as a length-modulated trace on the record of the Precision Graphic Recorder.

The system, in final form, incorporates the AN/UQN-1b Sonar Sounding Set, a familiar Navy echo sounder (Edo Corp., 1954); the Precision Graphic Recorder (PGR), a correlation recorder adapted to high resolution echo-sounding (Knott and Hersey, 1956; Knott and Witzell, 1961; Knott, 1962); the Oceanographic Computer, Model 45.001, a squaring and integrating on-line analogue computer (Baxter, 1960); the System Synchronization and Control Unit, a device made especially for this investigation which governs the operation of the entire system; the Sweep-Synchronized Positionable Trigger, an appendage to the Precision Graphic Recorder which provides synchronization with the anticipated arrival of the echo (Witzell, in preparation); and two systems for recording the measurement; a dual-beam oscilloscope (Tektronix Inc., 1959) and camera (Fairchild Camera and Instrument Corp., 1952) and a digital voltmeter and recorder (Hewlett-Packard Co., 1961). A functional block diagram of the equipment is shown in Figure 7 and a photograph of the shipborne measurement system in Figure 8. The annotated titles in the photograph correspond to those in the block diagram.

A description of the operation of the system follows: The PGR keys the echo sounder which causes a 12-kcps sonic pulse of rectangular envelope to be emitted into the water by the UQN-1b transducer. The echo from the sea floor is received back at the transducer and is amplified by the echo sounder. The amplified signal is applied to the PGR for making the usual bathymetric trace,

THE MODEL II ACOUSTIC REFLECTIVITY INDICATOR

————— INFORMATION SIGNAL FLOW PATH
 CALIBRATION SIGNAL FLOW PATH
 - - - - - SYNCHRONIZATION CONTROL & POWER FLOW PATH

Figure 7 Block Diagram of the Acoustic Reflectivity System

Figure 8 Photograph of the Components of the Acoustic Reflectivity System

to one channel of the dual-beam oscilloscope for display of the pressure wave train, and to the Oceanographic Computer which squares and integrates the signal and thus provides a measure of its energy content. The output of the computer is applied to the other channel of the dual-beam oscilloscope for a display of the energy contained in the wave train and also to the digital voltmeter and recorder combination which digitizes and prints the value of the complete integral. The face of the oscilloscope is photographed by means of an automatically recording camera capable of obtaining 1600 exposures on a single hundred-foot reel of 35-mm film. In addition, a pulse-width modulator inspects the value of the complete integral and generates a pulse whose duration is equal to the analogue of the energy in the received echo. This pulse is fed to the PGR, where it appears as a mark on the record (next to the bathymetric trace) whose length is proportional to the energy contained in the reflected echo.

The system also generates a 12-kcps electrical pulse of rectangular envelope and of known voltage and duration. The pulse is automatically applied to the transducer at a time slightly earlier than that of the bottom-reflected signal. This is used in obtaining a measurement of the strength of each acoustic return as discussed in the previous chapter.

A prototype of a solid-state sonar transceiver (T. H. Giff & Associates, undated) was designed and built by T. H. Giff and used in place of the driver and amplifier sections of the EDO UQN-1b echo sounder, during cruises of the R/V BEAR and R/V ASTERIAS.

The transmitting and receiving directivity pattern of the transducer is circularly symmetrical and has a thirty-degree beam-width as defined by the limits where the response is 3 db down. The peak of the back lobe is more than 25 db down even when mounted in a towed fish.

The System Synchronization and Control Unit (Figure 9) performs the entire task of synchronization between the various other units of the reflectivity measurement system. A calibration-pulse generator and the pulse-width modulator mentioned above are incorporated into this unit. The system functions that are performed by this unit are the following: 1) the zeroing of the Oceanographic Computer, 2) the injection of a calibration pulse at the transducer, 3) the opening of the shutter of the oscilloscope camera, and 4) the triggering of the information display oscilloscope, all just before the anticipated arrival on the echo, 5) the closing of the shutter of the oscilloscope camera, 6) the freezing of the output of the Oceanographic Computer, and 7) the commanding of the digital voltmeter to digitize the output of the Oceanographic Computer, all at a proper time after the arrival of the echo, 8) the generation of a calibration pulse to be injected at the transducer, and 9) the generation of a width-modulated pulse for display on the PGR. A description of the electronic circuitry of this unit is presented in the Appendix.

The Sweep-Synchronized Positionable trigger is employed to provide synchronization of the System Synchronization and Control Unit with the anticipated arrival of the echo. This instrument uses a small, permanent magnet, which is rigidly fixed to the shaft of the recording drum of the PGR, and a magnetic reed switch which may be positioned throughout 360° in a plane perpendicular to this shaft. The Sweep-Synchronized Positionable Trigger provides a trigger pulse at a manually-selectable time within a single sweep of the PGR. When used in conjunction with the recording program gate in a dual-channel PGR, it can be adjusted

Figure 9 Photograph of the System Synchronization and Control Unit of the Acoustic Reflectivity System

to feed a trigger output to the System Synchronization and Control Unit, which is synchronized to the arrival time of the echo from the sea floor. The System Synchronization and Control Unit then synchronizes and controls the remainder of the units of the reflectivity system so as to effect the automatic measurement of an echo.

Measurements are recorded as oscilloscope photographs which subsequently are treated by digital processing equipment located ashore. The oscilloscope photographs contain both the pressure versus time and energy versus time waveforms of the echo in addition to an electrical pulse injected as a calibration. A typical oscilloscope photograph is shown in Figure 10. The calibration pulse leads the echo on both traces and the trace of the pressure function is above the trace of the energy ($\int p^2 dx$) function. These photographs represent the data in its most useful though cumbersome form. This form of presentation permits culling of the data in the analysis stage to remove gross errors due to spurious electrical signals, quenching (air getting under the transducer because of violent ship motion), water slap on the transducer, and excessive ship or animal noise.

Measurements of the total energy contained in the echo are also provided by both the pulse-width modulator, a subsystem of the System Synchronization and Control Unit, and the digital voltmeter and recorder combination. The output of the pulse-width modulator is presented on the PGR record as a bar graph so that the energy content of successive echoes can be correlated conveniently with the travel-time plot. The digital voltmeter and recorder combination presents the same information in the form of numbers printed on roll paper. These real-time measurements do not represent bottom loss, but rather only echo strength, since no consideration has been made of the propagation loss associated with the water depth. A real-time computer could be put on-line to correct this, but has not yet been done.

A pulse-width modulated section taken over a relatively flat sea floor is shown in Figure 11. The range of variability of the energy of the received echoes is immediately apparent as is the correspondence between the tone of the echoes in the standard bathymetric recording and the quantitative representation of their strength by the pulse-width modulator.

The instrument system was developed and refined throughout this investigation. The description of the Acoustic Reflectivity Measurement System as presented above represents the final form achieved.

The discussion above pertains to the measurement of acoustic reflectivity, which comprises the major acoustic investigation. In addition, a subsidiary experiment, using a lowered pinger was made to study the nature of the reflection process at the sea-floor. A pinger was lowered on a wire from an oceanographic winch. At various intervals the winch was stopped and the bottom echo from the pinger was measured at the ship using the shipborne instrument system, previously mentioned. The relationship between echo strength received at the pinger and the distance of the pinger above the sea floor is indicative of the degree to which the sea floor acts as a specular reflector.

Figure 10 An Oscilloscope Photograph of a Typical Echo Received from the Sea Floor

ECHO RECEIVED FROM THE SEA FLOOR
DEPTH = 47 FATHOMS

OUTPUT OF THE PULSE LENGTH MODULATOR
SECTION OF THE ACOUSTIC REFLECTIVITY
INDICATOR

THE LENGTH OF EACH LINE IS PROPORTIONAL TO THE
ENERGY CONTAINED IN THE ECHO SHOWN DIRECTLY
BELOW

Figure 11 Section of Acoustic Reflectivity Record Obtained as an Output
of the Pulse Width Modulator

A pinger with precision timing was needed to permit synchronization to be maintained between the shipboard Acoustic Reflectivity System with its associated PGR and the pinger suspended over the side. A Precisely Timed Submersible Pinger (Breslau, Hersey, Edgerton and Birch, 1962) was made by including a Miniaturized Precision Time Source (Breslau, 1961) in a standard Edgerton Submersible Pinger (Edgerton and Cousteau, 1959; E.G. & G., Inc., 1961). The resulting precisely-timed pinger emits a 12-kcps pulse at precise one-second intervals.

The Miniaturized Precision Time-Source employs a 100-kcps crystal oscillator as its frequency standard. This frequency is counted down by five transistor decade-dividers to provide a synchronizing signal occurring at one-second intervals and at a voltage level adequate for direct application to a cold-cathode trigger-tube. The frequency stability is better than two parts per million per degree centigrade as determined by the temperature coefficient of the quartz crystal currently employed, which is operating at ambient temperature.

Geologic Measurements

A suite of samples of the surficial sediment was obtained in parallel with some of the measurements of acoustic reflectivity. These samples dried out during storage and therefore were suitable for a grain-size analysis only. The sites of these original sediment stations were later revisited and samples were taken in a manner that permitted them to be used for a water-content analysis.

A Van Veen dredge (Figure 12) (Thamdrup, 1938) was used to obtain all the sediment samples. This is a member of the "clamshell" group of bottom samplers and takes a grab sample. The two heavy jaws of the "clamshell" are held open during the descent by a trigger-bar which is itself kept in position by the weight of the dredge on the taut cable. When the dredge strikes the bottom, the slackened cable releases the trigger-bar. When a strain is taken by the winch aboard ship, preparatory to the ascent, the jaws are drawn shut by their own weight, enclosing an undisturbed sediment sample covering one and one-half square feet of the water-sediment interface with a maximum vertical section of one-half foot.

The samples for the grain-size analysis were allowed to soak overnight in distilled water, with sodiumhexametaphosphate added as a dispersing agent, before being analyzed. The size analysis was then performed using sieve, settling tube (Ziegler, Whitney, and Hayes, 1960), and pipette (Krumbein, and Pettijohn, 1938) techniques, for sizes in the gravel, sand, and both silt and clay fractions, respectively. Cumulative size distribution curves (Krumbein and Sloss, 1956) were constructed to obtain the median grain size and the sizes at the twenty-five and seventy-five percent quartiles. Gravel, sand, silt, and clay percentages, using the Wentworth Particle Size Scale (Wentworth, 1922) were picked off the cumulative size distribution curves.

The samples for the water-content analysis were taken by pressing a tin can into an undisturbed surface section of the dredge haul and slicing the excess sediment off the top with a trowel. Water was added to fill the can when the sample was coarse grained in order to simulate the in situ conditions. The

Figure 12 Photograph of a Van Veen Dredge

contents of the can were then placed in pre-weighed bottles in order to minimize transfer error. The bottles and contents were subsequently weighed ashore on a triple-beam balance both before and after drying in an oven at 105°C for 24 hours to obtain the wet (natural state) and dry weights. The water content of a sediment is defined in soil mechanics as the ratio of its weight of water to weight of solid matter (Taylor, 1948) and is determined by direct measurement of these wet and dried weights.

Photographs of the sea-floor were taken at the sites of some sediment stations. The resulting photographs were inspected to determine small-scale roughness of the areas investigated.

An underwater stereoscopic camera designed by Dr. Harold Edgerton of M.I.T. (E.G. & G. Inc., 1960) and one designed by Mr. David Owen of WHOI (Owen, 1961) were used at various times depending on the preference of the photographer present. Mr. David Owen accompanied some cruises and used his camera and the author used the Edgerton Camera.

The Edgerton apparatus employs specially designed 35-mm cameras, an electronic flash light source, and a hydrosonic positioning pinger. In operation, the apparatus is suspended above the bottom, where it automatically takes a picture every twelve seconds; its height above the bottom is monitored aboard ship with the aid of the positioning pinger. The cameras are focused at six feet and the photographs obtained at this distance cover a field about four by six feet. The Owen apparatus employs commercial, spring-driven still cameras, an electronic-flash light-source, and a bottom-sensing trigger-weight. In operation, the apparatus is raised and lowered at the bottom and takes a picture each time the suspended trigger weight contacts the bottom. The cameras are focused at two and one-half feet and the photographs obtained cover a field about one by one and one-half feet.

Visual observations of the sea-floor in shallow water were occasionally performed by SCUBA divers in connection with sediment sampling and determinations of bottom roughness and homogeneity. A self-contained, portable tape-recording system was devised for use by a SCUBA diver (Breslau, Zeigler, and Owen, 1962), which enables him to continuously record his observations during a dive by speaking into his full-face breathing mask. It consists of a miniature ceramic hydrophone fastened inside a full-face breathing mask and a battery-operated tape recorder enclosed in a submersible housing.

CHAPTER IV

DESCRIPTION OF OPERATIONS AT SEA

The specific approach utilized in this investigation made it possible to obtain the large number of measurements of acoustic reflectivity at sea needed in a study of the relationship of acoustic reflectivity to the sediment forming the actual sea floor. Observations were taken both in deep and in shallow water in the Western North Atlantic. A section of a physiographic diagram of the Atlantic Ocean (Heezen, Tharp, and Ewing, 1959) showing the location of the areas investigated is presented in Figure 13. The deep-water investigations are considered to be the ones taken over the "Bermuda" or "Puerto Rico" Profiles (these names were taken from cruise designations and are misleading), and the shallow-water ones are considered to be those taken over the Martha's Vineyard and Block Island Profiles and in Narragansett Bay.

The early cruises took place in deep water as a preliminary investigation to establish the range and variability of the acoustic reflectivity present in the natural environment. Long profiles of echo strength versus geographical location were sought. Geological control consisted mainly of continuous precise bathymetric recordings. The instrumentation system was field-tested and refined on these cruises. The better laboratory facilities and more stable platform found on the large ships used for deep-water work permitted on-the-spot modifications.

The later cruises took place in shallow water where extensive efforts were made to maintain good geological control. The areas chosen for study were ones where the bottom had been thoroughly studied previously by other investigators using the techniques of classical geology. In particular, the Narragansett Bay area, studied by Dr. Robert McMaster of the Narragansett Marine Laboratory (McMaster, 1960), and profiles along the Continental Shelf south of Cape Cod, studied by the late Mr. Henry Stetson of the Woods Hole Oceanographic Institution (Stetson, 1938), were selected because of their proximity to the Woods Hole Oceanographic Institution. A moderate schedule of sediment dredging and underwater photography was undertaken by methods described previously to obtain additional geological control.

The field work can best be described in a cruise-by-cruise review. A list of the cruises performed in chronological order and a brief resumé of what each attempted and accomplished with respect to this particular investigation follow:

CHAIN 19: This deep-water cruise took place from June 13 to July 7, 1961 aboard the Research Vessel CHAIN, a former T-ARS Class U.S. Navy Deep-Sea Salvage vessel 215 feet long and displacing 2000 tons. The ship made a passage from Woods Hole to the Puerto Rico Trench and back to perform various geophysical tasks. Advantage was taken of this cruise to check out the

Figure 13 Physiographic Map of the Western North Atlantic (After Heezen, et al., 1959). Showing the Location of the Areas Investigated

original instrumentation system, and to make echo strength profiles where opportune. The bulk of the effort expended on this cruise was directed toward working the "bugs" out of the electronics; nevertheless, approximately six hundred echo-strength measurements were obtained at 49 locations (Figures 47 and 48) along the so-called "Puerto Rico" Profile (Figure 15), which extended from 26°05'N Lat, 67°27'W Long. to 35°54'N Lat., 67°55' W Long. The measurements were taken with a hull mounted transducer while the ship was underway at about 10 knots. Navigation consisted of Loran-A fixes on an hourly basis. Positions were obtained by interpolation between fixes and are considered good within a three-mile radius. A continuous, precise, bathymetric recording was also obtained along the profile.

CHAIN 21: This deep-water cruise took place from November 27 to December 18, 1961 aboard the Research Vessel CHAIN. The ship made a passage from Monaco to Woods Hole via Bermuda to perform various geophysical tasks. Echo strength measurements were taken over the Madeira Abyssal Plain but proved unusable due to improper mounting of the transducer. This situation was corrected at Bermuda by switching to a transducer mounted on a towed fish. Approximately one thousand echo-strength measurements were obtained at 78 locations (Figures 47 and 48) along the so-called "Bermuda Profile" (Figure 24), which extended from 34°18'N Lat., 66°05'W Long. to 39°46'N Lat., 69°57'W Long. The measurements were taken while the ship was underway at about 10 knots. Navigation consisted of Loran-A fixes on an hourly basis. Positions were obtained by interpolation between fixes and are considered good within a two-mile radius. A continuous, precise, bathymetric recording was also obtained along the profile.

CRAWFORD 73:- This deep water cruise took place on February 23 and 24 1962 aboard the Research Vessel CRAWFORD, a former Coast Guard Cutter, 125 feet long and displacing 320 tons. The ship sailed due south of Cape Cod to a 1500-fathom depth on the Continental Rise to field test the Precisely Timed Precision Fingerprint.

CHAIN 27: This deep-water cruise took place from June 9 to June 19, 1962 aboard the Research Vessel CHAIN. The ship made a passage from Woods Hole to the Bermuda area and back to service current metering buoys. This cruise provided an opportunity to obtain repeat measurements along the Bermuda Profile and to field test the newly developed Synchronization and Control Unit of the Acoustic Reflectivity System. This single unit replaced numerous separate units in the old system. It was developed in anticipation of the more stringent space limitations on the smaller ships used for shallow water work, as well as to increase overall system reliability. Approximately five thousand echo-strength measurements were obtained at 213 locations (Figures 47 and 48). The ship pursued various courses in the immediate region north of Bermuda as it hunted drifting buoys, so that only 151 of these points actually make up the Bermuda Profile (Figure 17), which extended from 33°15'N Lat., 65°25'W Long. to 40°35'N Lat., 70°30'W Long. The measurements were taken with a hull-mounted transducer while the ship was underway at about 10 knots. Navigation consisted of Loran-A fixes on an hourly basis. Positions were obtained by interpolation between fixes and are considered good within a two-mile radius. A continuous, precise, bathymetric recording was also obtained along the profile.

ASTERIAS 1: This shallow-water cruise took place from July 11 to July 27, 1962 aboard the Motor Vessel ASTERIAS, a western dragger type of fishing boat, 40 feet long and displacing 20 tons. The cruise was made specifically to obtain echo-strength measurements under conditions of good geological control. Operations took place in Narragansett Bay and were guided by sediment charts and much advice provided by Dr. Robert McMaster of the Narragansett Marine Laboratory. The cruise demonstrated that this acoustic technique could be successfully performed from a small ship. Approximately six thousand echo-strength measurements were obtained at 195 locations (Figures 41 and 42). Measurements were made from a transducer mounted on a towed fish while the ship was underway at 6 knots. 13 sediment stations were occupied at which acoustic measurements were performed and sediment samples obtained by means of a Van Veen dredge. Underwater photographs were taken with the Owen Camera at the sites of 4 sediment stations where the water was not too turbid. Some direct observations of the bottom by SCUBA divers were made. A continuous, precise, bathymetric recording was taken whenever acoustic measurements were made. Position keeping was done by visual bearings on navigation marks and shore objects shown on the charts of the area, using a bearing circle mounted on a magnetic compass, and are considered good within a radius of one-twentieth of a mile.

BEAR 281: This shallow-water cruise took place from August 6 to August 15, 1962 aboard the Research Vessel BEAR, a former coastal freighter, 100 feet long and displacing 300 tons. The cruise was made specifically to obtain echo-strength measurements under conditions of good geological control on the Continental Shelf south of Cape Cod. A severe storm developed during the early part of the cruise causing conditions on the open sea to be too hazardous to allow any work over-the-side. Therefore, the ship sought refuge in Narragansett Bay where it was able to carry on a program similar to that performed during the ASTERIAS 1 Cruise. Approximately seven thousand echo-strength measurements were obtained at 209 locations (Figures 41 and 42). 19 sediment stations were occupied. 12 underwater photographs were taken with the Owen Camera at sites of sediment stations where water conditions permitted. When the storm abated the ship resumed its original plan and carried out investigations along the Block Island and Martha's Vineyard Profiles. Underwater photographs were obtained and pinger lowerings were performed using an Edgerton Camera and Precisely timed Submersible Pinger Combination. Approximately ten thousand echo-strength measurements were made at 330 locations (Figures 43 and 44) and 24 sediment stations were occupied on the Continental Shelf. Of these, approximately three and one-half thousand echo-strength measurements were made at 113 locations and 10 sediment stations were occupied along the Block Island Profile (Figure 18), which extended from 40°11'N Lat., 71°22'W Long. to 41°08'N Lat., 71°39'W Long. Approximately three and one-half thousand echo-strength measurements were made at 117 locations and 9 sediment stations were occupied along the Martha's Vineyard Profile (Figure 19), which extended from 40°15'N Lat., 70°43'W Long. to 41°20'N Lat., 70°39'W Long. Measurements were made from a transducer mounted on a towed fish while the ship was underway at 6 knots. Navigation consisted of Loran-A fixes on an hourly basis. Positions were obtained by interpolation between fixes and are considered good within a one-mile radius. A continuous, precise, bathymetric recording was also obtained along the profile.

BEAR 285: This shallow-water cruise took place from September 7 to September 9, 1962 aboard the Research Vessel BEAR. The cruise was made specifically to field-test the newly designed pulse-width modulator, a sub-system of the System Synchronization and Control Unit of the Acoustic Reflectivity System, and to obtain measurements along the Martha's Vineyard Profile. Difficulty was experienced with the new device. This proved too severe to be corrected at sea and no data were obtained.

BEAR 290: This shallow-water cruise took place from October 1 to October 3, 1962 aboard the Research Vessel BEAR. This cruise was another attempt to achieve the objectives of BEAR 285. The cruise was successful and approximately one thousand echo-strength measurements were obtained at 21 locations (Figures 43 and 44) along the Martha's Vineyard Profile (Figure 20). Measurements were made from a transducer mounted on a towed fish while the ship was hove-to. Sediment stations were occupied at all of the locations and bottom photographs were obtained using the Owen Camera. A long record of the output of the pulse-width modulator was obtained and presented alongside the continuous bathymetric track on the record of the Precision Graphic Recorder. Navigation consisted of Loran-A fixes on an hourly basis. Positions were obtained by interpolation between fixes and are considered good within a one-mile radius.

ATLANTIS 293: This shallow-water cruise took place from July 1 to July 3, 1963 aboard the Research Vessel ATLANTIS, a steel ketch 140 feet long and displacing 550 tons, designed for oceanography. The purpose of this cruise was to revisit the sites of the previous sediment stations on the Continental Shelf to obtain wet-sediments. Loran-A was used to direct the ship to the recorded positions of the previous sediment stations.

ASTERIAS 2: This shallow-water cruise took place from July 10 to July 13, 1963 aboard the Motor Vessel ASTERIAS. The purpose of this cruise was the same as that of ATLANTIS 293 except that the area sampled was Narragansett Bay. Visual bearings on navigation marks and shore objects with a bearing circle mounted on a magnetic compass were used to direct the ship to the recorded positions of the previous sediment stations.

CHAPTER V

DATA PROCESSING AND ANALYSIS

General Description of Techniques

The inherent variability among acoustic echoes reflected from the sea floor and measured at the ship necessitated taking a large number of measurements at each location (data point) to obtain a significant sample. The general objective and scope of this investigation required samples to be obtained at a large number of locations. A consideration of these two factors indicated that a highly automated system of data processing and analysis was imperative. This was accomplished through recourse to the Data Analysis Laboratory (Geophysics Department) and the Information Processing Center at WHOI, and the IBM Computation Center at M.I.T.

The Data Analysis Laboratory contains a Gerber Data Recording System (Gerber Scientific Instrument Co., undated), a manual analogue-to-digital converter which measures displacements on oscillograms and makes punched cards; a Printing Card Punch (International Business Machines Corp., 1959), a manual card punch which accepts information entered into a keyboard and makes punched cards; and a Dataplotter (Electronic Associates Inc., 1961), an automatic digital X-Y recorder which reads punched cards and makes point and line plots. The first two machines were used to put raw data into machine-language form for acceptance by a digital computer and the last was used to display the computed results.

The Information Processing Center and IBM Computation Center both contain high-speed digital computers; these are the GE 225 (General Electric Co., Inc., 1963) and the IBM 7090 (International Business Machines Corp., 1961). Both computers were used, though either could have done the entire job; the IBM 7090 was available at M.I.T. before the GE 225 became available at WHOI and consequently, the earlier work was performed at M.I.T. and the later work at WHOI. The computer programs used in the analysis were written in FORTRAN (McCracken, 1961) which is a widely used computer compiling language that most present-day computers, including the above mentioned ones, can accept and translate into their specific instructional code. Brief descriptions of what these programs do are contained in the remaining sections of this chapter.

Analysis of Acoustic Data

The original data are predominantly in the form of cathode-ray oscilloscope photographs of the echo wave-train (Figure 10), displayed on 100-foot strips of 35-mm negative film. The negative film was processed to form a continuous-strip positive print which was directly read with the Gerber Data Recording System (Figure 14). The displacements representing the peak pressure, of the bottom echo and associated calibration pulse were measured and automatically recorded on punched cards. These punched cards were manually repunched to include the water depth and geographical position of the measurement, and comprise the acoustic raw-data deck. This deck was listed by an IBM Accounting Machine, Model 407 (International Business Machines Corp., 1959), which had been especially arranged to emit titles and transpose columns, and bound in a 683 page volume which is on file at the Geophysics Department of the Woods Hole Oceanographic Institution.

Figure 14 Photograph of the Analogue to Digital Data Reduction System being used to Digitize the Acoustic Echoes

This deck was processed by the ECHO-STRENGTH PROGRAM which accepts the acoustic raw-data deck as input and produces an echo-strength deck as output. The program converts the peak-pressure and total-energy displacements of the echo and calibration pulse into values of echo strength using the method described in Chapter III. The program selects the median and maximum echo and calculates the median value of echo strength, the maximum value of echo strength, the sample size, and the standard deviation for each datum point on both a peak-amplitude and total-energy basis. Each card of the echo-strength deck represents a summarized measurement corresponding to a geographical position and contains the selected information from all of the acoustic-echo samples taken at the datum point.

The echo-strength deck was processed by the Bottom-Loss Program which accepts the echo-strength deck as input and produces a bottom-loss deck as output. The program computes the median and minimum value of bottom loss on both a peak-pressure and total-energy basis by subtracting the appropriate echo strength and propagation loss from the appropriate source level, assuming spherical spreading and an attenuation loss of 1.2 db per kiloyard (Horton, 1959). A parameter card stipulating the source level, pulse width, and units of depth must precede the deck.

Various programs have been written to shape the results into a form acceptable for plotting on the Dataplotter. In particular, one program computes running averages of three values for profiled data and another converts latitudes into Mercator displacements for directly plotting locations on Mercator charts.

The locations of all the acoustic measurements have been automatically plotted on Mercator charts of the appropriate regions (Figures 41, 42, 43, 44, 47, and 48), and the values of bottom loss obtained at these locations have been indicated by a color code. Curves of acoustical quantities versus distance along profiles (Figures 15-20, 49, 50, and 51) have been automatically plotted by passing the punched cards through the Dataplotter twice, once to plot the points and once to draw the lines.

Analysis of Geologic Data

Gravel, sand, silt and clay percentages and quartile values of the cumulative size distribution curves of the sediment samples were manually punched onto cards to generate the particle-size raw-data deck. This deck was processed by the Sediment Classification Program which accepts the particle-size raw-data deck as input and produces a grain-size-characteristic deck as output. The program gives each sediment sample a class name in accordance with the commonly used three-component sand-silt-clay system (Shepard, 1954). This name is punched on the cards in Hollerith text along with a related code number for future machine analysis. The program also computes the Trask sorting-coefficient, defined as the square root of the ratio of the larger quartile to the smaller quartile (Krumbein and Sloss, 1956), and the phi median grain-size, defined as minus the log to the base two of the median grain-size in millimeters (Inman, 1952).

ACOUSTIC MEASUREMENTS
PUERTO RICO PROFILE
CHAIN 19 CRUISE

Figure 15 Bottom Loss Measurements Obtained on CHAIN 19 Cruise
Along the Puerto Rico Profile

Figure 16 Bottom Loss Measurements Obtained on CHAIN 21 Cruise
Plotted Versus Distance Along the Bermuda Profile

Figure 17 Bottom Loss Measurements Obtained on CHAIN 27 Cruise
Plotted Versus Distance Along the Bermuda Profile

ACOUSTIC MEASUREMENTS
BLOCK ISLAND PROFILE
BEAR 281 CRUISE

Figure 18 Bottom Loss Measurements Obtained on BEAR 281 Cruise
Plotted Versus Distance Along the Block Island Profile

ACOUSTIC MEASUREMENTS
MARTHAS VINEYARD PROFILE
BEAR 281 CRUISE

Figure 19 Bottom Loss Measurements Obtained on BEAR 281 Cruise Plotted Versus Distance Along the Martha's Vineyard Profile

ACOUSTIC MEASUREMENTS
MARTHAS VINEYARD PROFILE
BEAR 290 CRUISE

Figure 20 Bottom Loss Measurements Obtained on BEAR 290 Cruise Plotted Versus Distance Along the Martha's Vineyard Profile

The wet and dry weights of the sediment samples were manually punched onto cards to generate the water-loss raw-data deck. This deck was processed by the Mass Properties Program which accepts the water-loss raw-data deck as input and produces a mass-characteristic deck as output. The program computes the water content, porosity, density, velocity, acoustic impedance, Rayleigh reflection coefficient, and theoretical bottom loss in db, according to the relationships developed in Chapter II.

The bottom-loss measurements taken at the sites of sediment stations were correlated with geological characteristics of the sampled sediments by use of the Correlation and Regression Program. This is a general purpose statistical program to perform a correlation and regression analysis on any two input variables and lists, as output, the correlation coefficient, the slope of the regression line, the Y intercept, the standard error of estimate, the "Z" value, and the standard deviation of "Z" (Hoel, 1962). The geological characteristics tested were the percentage of silt, clay, and fine material (silt plus clay), the median grain size, the sorting coefficient, and the porosity.

Curves of geological quantities versus distance along profiles (Figures 22-25) and scatter diagrams of acoustical versus geological quantities (Figures 29-38) have been automatically plotted. In some cases, the name of the sediment is indicated by a particular symbol automatically selected by the Dataplotter from information on the punched cards.

CHAPTER VI

ACOUSTIC RESULTS

A tabulation of all the bottom-loss measurements obtained during the course of this investigation is available for inspection at the Woods Hole Oceanographic Institution. Table I is a sample from this tabulation. An explanation of the column headings follows: TAG represents the datum identification number; PEAK PRESS. MED. and PEAK PRESS. DEV. represent the median and standard deviation of bottom loss measured on a peak-pressure basis respectively; TOTAL ENG. MED. and TOTAL ENG. DEV. represent the median and standard deviation of bottom loss measured on a total energy basis respectively; AMT. is the number of echoes that were sampled to produce the datum; DEPTH is the transducer depth; and LATITUDE DG., LATITUDE MN., LONGITUDE DG., and LONGITUDE MN., are the values of latitude and longitude in degrees and minutes at the location of the acoustic measurement. The acoustic quantities are in decibels; the depth is in fathoms for measurements obtained on the CHAIN 19, CHAIN 21, and CHAIN 27 cruises and is in feet for measurements obtained on the ASTERIAS, BEAR 281 and BEAR 290 cruises.

The median value, minimum value, and standard deviation of bottom loss on both a peak pressure and total energy basis, along with the depth, have been plotted versus distance in miles along the profiles depicted in Figure 13 of Chapter IV. These acoustic measurement profiles are presented in Figures 15 to 20.

These profiles are shown here in order to present an overall picture of the range and variability of the acoustic measurements and to establish some of their general relationships; a discussion of their geological significance, which will shed additional light on them, is postponed until Chapter VIII.

Certain features of the acoustic quantities are immediately apparent. The similarity of the bottom-loss values for both the BEAR 281 and BEAR 290 cruises over the Martha's Vineyard Profile and for the CHAIN 21 and CHAIN 27 cruises over the Bermuda Profile attest to the repeatability of this type of measurement. This result is particularly significant since it indicates that bottom loss at normal incidence can be used to sense some characteristic of the sea floor.

The general trend of both the median bottom-loss values measured on a peak-pressure basis and those measured on a total-energy basis are observed to be similar on all of the profiles. This outcome indicates that both types of measurement sense the same characteristic of the sea floor. The median bottom-loss values measured on a total-energy basis do tend to be somewhat lower than those measured on a peak-pressure basis. This is ascribed to the reverberation component in the echo which is integrated along with the specular component when bottom loss is measured on a total-energy basis.

TABLE I

MEASUREMENTS OF ACOUSTIC BOTTOM LOSS AT NORMAL INCIDENCE

TAG	PEAK PRESS. MED. DEV.	TOTAL ENG. MED. DEV.	AMT.	DEPTH	LATITUDE DG. MN.	LONGITUDE DG. MN.
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MEASUREMENTS OBTAINED ON R/V CHAIN CRUISE 21

1	17.7 2.7	14.9 2.9	5	2730	34 17.5	66 5.0
2	14.7 2.5	11.1 1.9	20	2730	34 18.5	66 6.5
3	15.8 1.9	12.1 2.1	20	2780	34 35.5	66 17.5
4	15.9 1.4	12.0 1.9	14	2700	34 50.0	66 27.0
5	14.4 2.7	10.4 2.5	12	2700	35 1.5	66 34.5
6	14.5 1.7	11.6 2.0	8	2700	35 6.0	66 37.5
7	15.9 2.6	12.8 2.1	16	2690	35 10.5	66 41.0
8	15.0 2.6	11.7 2.9	13	2660	35 12.5	66 42.5
9	14.9 2.4	12.4 3.4	15	2660	35 15.0	66 44.5
10	15.5 3.3	12.5 2.4	13	2630	35 17.5	66 46.5
11	16.8 2.2	15.2 2.7	11	2640	35 20.0	66 48.0
12	17.6 1.8	14.9 2.0	16	2630	35 22.0	66 50.0
13	11.6 3.9	9.8 3.3	20	2650	35 25.0	66 51.5
14	15.8 2.8	12.9 2.9	14	2650	35 28.0	66 54.0
15	17.3 1.6	13.3 2.1	5	2630	35 30.5	66 56.0
16	18.2 4.0	12.9 3.7	9	2630	35 39.0	67 1.5
17	15.0 2.6	10.5 1.3	12	2680	35 43.5	67 5.0
18	14.4 2.5	11.9 2.6	7	2680	35 49.5	67 9.5
19	11.8 2.1	8.4 1.3	12	2680	35 52.5	67 12.0
20	15.1 1.6	10.7 1.2	14	2650	35 55.0	67 13.5
21	8.2 1.8	5.2 1.2	9	2630	35 56.0	67 14.5
22	9.2 2.2	7.7 2.7	14	2620	35 58.5	67 16.0

The standard deviations of the median bottom loss measured on a total-energy basis tend to be slightly smaller than those measured on a peak-pressure basis as expected. This means that fewer echoes need be sampled to obtain a given significance level for median bottom loss when measured on a total-energy basis as opposed to a peak-pressure basis.

The general trend of both the minimum bottom-loss values measured on a peak-pressure basis and those measured on a total-energy basis are observed to parallel their respective medians. Nevertheless, minimum values are not good sensors of a characteristic of the sea floor since their value has a dependence on the number of echoes measured. This is clearly shown by observing that the spread between the medians and minimums on both a peak-pressure and total-energy basis for the CHAIN 21 cruise is less than that for the CHAIN 27 cruise, which covered the same profile but sampled more echoes per measurement.

A tabulation of echo-strength measurements received at the ship during the lowered-pinger experiments is presented in Table II. The column headings are self-explanatory, and the geographical location of the lowerings are given by the sites of sediment stations shown in Figures 43 and 44 of Chapter VIII. The values of echo strength are relative to the value measured along the shortest total path (total path is equal to the depth of water plus the pinger height off the bottom) used in each individual lowering; absolute values are not useful since the battery charge and attendant source-level of the pinger varied from lowering to lowering.

These echo-strength measurements have been plotted versus total path in Figure 21 and a best-fitting line, determined by a least-squares analysis, has been drawn through the experimental points of each pinger lowering. The Y axis of this graph is quite expanded and the scatter of experimental points about the best-fitting line can be ascribed to experimental error. Also plotted are lines representing the theoretical relationship expected for scatterer and specular models of the reflection process and a line representing the average measured relationship for all the pinger lowerings. It seems that the experimental relationships of echo strength versus total path of the individual pinger lowerings are not significantly different from each other and that the specular reflection process is dominant.

Figure 21 Measurements of Echo Strength Versus Total Path Distance Between Discharge and Clin-

TABLE II

RELATIVE MEASUREMENTS OF ECHO STRENGTH RECEIVED FROM SUBMERSIBLE PINGER
LOWERING

PINGER LOWERING	SEDIMENT STATION SITE	HEIGHT ABOVE BOTTOM (FEET)	SAMPLE SIZE	TOTAL PATH (FEET)	ECHO STRENGTH (db/1 erg/cm ²)
1	39	30	27	163	0.0
		50	24	183	-2.2
		70	14	203	-2.2
2	41	30	13	230	0.0
		60	8	260	-0.7
		90	13	290	-2.1
		120	23	320	-0.7
		150	15	350	-2.4
3	43	30	11	245	0.0
		60	15	275	0.0
		90	16	305	-1.7
		120	9	335	-1.9
		150	22	365	-1.6
4	45	30	18	280	0.0
		60	20	310	+0.1
		90	20	340	-2.2
		120	43	370	-0.9
		150	33	400	-0.6
		180	19	430	-4.0
5	47	30	39	320	0.0
		60	25	350	+1.5
		90	23	380	-1.5
		120	16	410	+0.7
		150	19	440	-1.8
6	74	30	20	315	0.0
		60	15	345	-1.3
		90	23	375	-1.3
		120	22	405	-2.7
		150	17	435	-1.3
		180	28	465	-4.6
7	67	30	23	232	0.0
		60	16	262	-2.7
		90	20	292	-0.3
		120	19	322	-1.1
		150	15	352	-3.7

TABLE II (Cont'd)

RELATIVE MEASUREMENTS OF ECHO STRENGTH RECEIVED FROM SUBMERSIBLE PINGER
LOWERINGS

PINGER LOWERINGS	SEDIMENT STATION SITE	HEIGHT ABOVE BOTTOM (FEET)	SAMPLE SIZE	TOTAL PATH (FEET)	ECHO STRENGTH (db//1 erg/cm ²)
8	60	30	28	200	0.0
		60	23	230	+0.3
		80	18	250	-0.7
		100	26	270	-0.5
		120	26	290	-1.9
9	54	30	9	169	0.0
		50	19	189	+1.1
		70	9	209	-2.5
		90	24	229	-0.5
10	49	30	23	114	0.0
		50	21	134	-1.5
		70	23	154	-1.8

CHAPTER VII

GEOLOGIC RESULTS

The object of the geological phase of this investigation was to determine the character of the sea-floor where the acoustic measurements were made. The geologic measurements were used directly for correlation with the acoustic-reflectivity measurements and to spot-check the geologic results of other investigations which were correlated with the acoustic-reflectivity measurements. No attempt was made to study the regional geology since more extensive geological investigations have already been made in the areas involved. The correlation of acoustic and geologic results are discussed in Chapter VIII; the geologic results are presented in this chapter.

A tabulation of the grain-size characteristics of all the sediment samples obtained during the course of this investigation is presented in Table III. An explanation of the column headings follows: TAG represents the identification number of the sediment station; CLASS represents the sedimentological name (Shepard, 1954); SIZE represents the phi median grain-size (Inman, 1952); SORT represents the Trask sorting-coefficient (Krumbein and Sloss, 1956); and FINE, GRAV., SAND, SILT, and CLAY, represent the percentages of material in the fine (silt + clay), gravel, sand, silt, and clay size-categories. The locations of the sites of all the sediment stations are shown in Figures 41, 42, 43 and 44 of Chapter VIII. The numerals represent the identification numbers of the sediment stations and the arrows pin-point their geographical positions.

Grain-size characteristics obtained from the sediment samples, and those published by Stetson (1938) have been plotted versus distance in miles along both the Martha's Vineyard profile (Figure 22) and the Block Island Profile (Figure 23); the values obtained by this investigation are indicated by circles and Stetson's are indicated by squares. The median grain size expressed both in millimeters and phi units, Trask sorting coefficient, and percentages of material in the clay, silt, and sand + gravel categories, as well as the bathymetry, are presented. In addition, the class names of the sediments are indicated by symbols that are coded in accordance with the associated legend. The grain-size characteristics obtained in this investigation in general agree well with those published by Stetson as evidenced by the above mentioned figures. The disagreement that does exist is probably in part caused by a positional error between the two investigations; modern navigational equipment was not available to Stetson.

The grain-size characteristics obtained from the sediment samples and those published by McMaster (1960) for Narragansett Bay are not amenable to a profiled display since there is no regular positional relationship between the sample sites of both investigations. They may be compared, however, by reference to the table of grain-size characteristics (Table III) and the charts of Narragansett Bay with their sedimentological overlays (Figures 41 and 42); the sedimentological overlays are taken from McMaster and indicate the

Figure 22 Size Characteristics of Sediment Samples Plotted Versus Distance Along the Martha's Vineyard Profile

Figure 23 Size Characteristics of Sediment Samples Plotted Versus Distance Along the Block Island Profile

TABLE III

GRAIN SIZE CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	CLASS	SIZE	SORT.	FINE	GRAV.	SAND.	SILT	CLAY
1	Sandy Silt	5.1	5.7	62.0	0.	38.0	46.0	16.0
2	San Sil Cly	5.6	4.5	69.0	0.	30.0	44.0	25.0
3	San Sil Grv	3.3	3.3	36.0	17.0	47.0	28.0	8.0
4	Sand	1.2	1.6	13.0	0.	87.0	13.0	0.
5	Grav Sand	-0.3	3.8	3.0	42.0	55.0	3.0	0.
6	Sandy Grav	-2.2	5.5	4.0	60.0	36.0	4.0	0.
7	Sand	3.3	1.2	10.0	0.	90.0	10.0	0.
8	Sand	2.8	1.3	12.0	0.	88.0	12.0	0.
9	Silty Sand	3.4	3.6	43.0	0.	57.0	43.0	0.
10	Sand	3.2	1.4	20.0	0.	80.0	20.0	0.
11	Silty Sand	3.3	1.7	30.0	0.	70.0	30.0	0.
12	Sand	2.4	1.6	17.0	0.	83.0	17.0	0.
13	Silty Sand	2.3	2.5	35.0	0.	65.0	30.0	5.0
14	Sand	3.4	1.2	8.0	0.	92.0	8.0	0.
15	Sand	3.2	1.1	10.0	0.	90.0	10.0	0.
16	Silty Sand	3.4	1.5	28.0	0.	72.0	24.0	4.0
17	Sand	3.2	1.2	10.0	0.	90.0	10.0	0.
18	Sand	2.8	1.2	1.0	0.	99.9	1.0	0.
19	Sand	1.8	1.6	5.0	0.	95.0	5.0	0.
20	Sand	3.3	1.1	4.0	0.	96.0	4.0	0.
21	Sandy Silt	6.0	2.8	79.0	0.	21.0	60.0	19.0
22	Clayey Silt	6.0	2.2	91.0	0.	9.0	73.0	18.0
23	Sandy Silt	5.5	2.8	76.0	0.	24.0	60.0	16.0
24	Grav Sand	-0.5	2.3	0.	38.0	62.0	0.	0.

TABLE III (Cont'd)

GRAIN SIZE CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	CLASS	SIZE	SORT.	FINE	GRAV.	SAND	SILT	CLAY
25	Sand	2.3	1.1	0.1	0.	99.9	0.1	0.
26	Sand	2.5	1.3	4.0	0.	96.0	4.0	0.
27	Sandy Silt	5.2	3.1	71.0	0.	29.0	57.0	14.0
28	Sand	2.3	1.2	2.0	0.	98.0	2.0	0.
29	Sand	2.3	1.1	2.0	0.	98.0	2.0	0.
30	Sand	2.3	1.5	2.0	0.	98.0	2.0	0.
31	Sand	3.0	1.4	2.0	0.	98.0	2.0	0.
32	Sand	2.5	1.4	2.0	0.	98.0	2.0	0.
33	Sand	2.4	1.9	10.0	0.	90.0	10.0	0.
34	Silty Sand	3.2	2.2	34.0	0.	66.0	26.0	8.0
35	Gravel	-3.4	2.8	0.	82.0	18.0	0.	0.
36	Sand	2.3	1.1	0.1	0.	99.9	0.1	0.
37	Sand	3.1	1.2	10.0	0.	90.0	7.0	3.0
38	Sand	0.1	1.3	0.	8.0	92.0	0.	0.
39	Sand	0.3	1.2	0.1	0.	99.9	0.1	0.
40	Sand	2.2	1.2	2.0	0.	98.0	2.0	0.
41	Sand	2.6	1.3	6.0	0.	94.0	6.0	0.
42	Sand	2.1	1.5	15.0	0.	85.0	15.0	0.
43	Sand	2.6	2.2	24.0	0.	76.0	17.0	7.0
44	Sand	2.2	1.5	12.0	0.	88.0	12.0	0.
45	Silty Sand	2.1	2.6	26.0	0.	74.0	22.0	4.0
46	Silty Sand	3.1	3.1	45.0	0.	55.0	37.0	8.0
47	Sand	1.2	1.1	2.0	0.	98.0	2.0	0.
48	Sand	2.2	1.2	4.0	0.	96.0	4.0	0.

TABLE III (Cont'd)

GRAIN SIZE CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	CLASS	SIZE	SORT.	FINE	GRAV.	SAND	SILT	CLAY
49	Sand	0.9	1.7	0.	6.0	94.0	0.	0.
50	Sand	0.1	1.5	0.1	0.	99.9	0.1	0.
51	Sand	1.2	1.2	1.0	0.	99.0	1.0	0.
52	Sand	1.7	2.2	1.0	14.0	85.0	1.0	0.
53	Sand	0.7	1.1	1.0	0.	99.0	1.0	0.
54	Sand	2.2	1.1	1.0	0.	99.0	1.0	0.
55	Sand	1.9	1.5	6.0	0.	94.0	6.0	0.
56	Sand	2.2	1.3	4.0	0.	96.0	4.0	0.
57	Sand	2.6	1.4	9.0	0.	91.0	9.0	0.
58	Sand	2.4	1.5	17.0	0.	83.0	17.0	0.
59	Sand	2.2	1.9	12.0	0.	88.0	12.0	0.
60	Sand	1.3	1.2	0.1	0.	99.9	0.1	0.
61	Sand	0.8	1.3	2.0	0.	98.0	2.0	0.
62	Silty Sand	2.9	2.8	30.0	0.	70.0	22.0	8.0
63	Silty Sand	3.8	2.7	46.0	0.	54.0	33.0	13.0
64	Sand	2.7	1.9	22.0	0.	78.0	18.0	4.0
65	Silty Sand	4.0	3.4	52.0	0.	48.0	38.0	14.0
66	Silty Sand	3.7	1.5	30.0	0.	70.0	26.0	4.0
67	Silty Sand	3.3	2.3	36.0	0.	64.0	28.0	8.0
68	Sandy Silt	4.4	2.1	68.0	0.	32.0	54.0	14.0
69	Sandy Silt	4.8	2.4	77.0	0.	23.0	59.0	18.0
70	Sandy Silt	4.7	2.4	70.8	0.	30.0	58.8	12.0
71	Sandy Silt	4.8	2.6	78.0	0.	22.0	60.0	18.0
72	Clayey Silt	5.2	2.9	82.0	0.	18.0	59.0	23.0

TABLE III (Cont'd)

GRAIN SIZE CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	CLASS	SIZE	SORT.	FINE	GRAV.	SAND	SILT	CLAY
73	Clayey Silt	5.0	2.4	83.0	0.	17.0	63.0	20.0
74	Sandy Silt	5.0	2.6	72.0	0.	28.0	58.0	14.0
75	Sandy Silt	4.6	2.4	70.0	0.	30.0	54.0	16.0
76	Clayey Silt	5.0	2.4	85.0	0.	15.0	65.0	20.0
77	Clayey Silt	5.1	2.5	83.0	0.	17.0	63.0	20.0

class name and percentage of the sand fraction of the sediment flooring Narragansett Bay. The results of both investigations in general agree moderately well; about two-thirds of the class names of the samples of this investigation are located in regions of corresponding class name (gravel is taken as sand for classification on a three-component basis) as published by McMaster, whereas about one-third differ by one class unit and one-tenth are in complete disagreement. The disagreement between the results of both investigations is larger in Narragansett Bay than on the Continental Shelf. This is ascribed to a combination of two factors: the comparison made on sedimentological regions defined by interpolated boundaries and the extreme variability or patchiness of the sediment distribution in Narragansett Bay.

A tabulation of the mass characteristics of all the sediment samples obtained during the course of this investigation is presented in Table IV. An explanation of the column headings follows: TAG represents the identification number of the sediment station; WATER represents the water content of the sediment (Taylor, 1948); and POROUS, DENSITY, VELCTY, IMPED, REF COEF, and BTMLOSS represent respectively the density, compressional velocity, acoustic impedance, Rayleigh reflection coefficient, and bottom loss calculated from the measured water content according to the relationships developed in Chapter II.

Mass characteristics obtained from the sediment samples have been plotted versus distance in miles along both the Martha's Vineyard Profile (Figure 24) and the Block Island Profile (Figure 25). The water content, porosity, impedance, reflection coefficient, bottom loss, velocity, and density, as well as the bathymetry, are presented. These quantities may be observed for the Narragansett Bay region by reference to the table of mass characteristics (Table IV) and the charts of Narragansett Bay (Figures 41 and 42). No comparisons are made with the results of other investigations because there have been none.

The photographs which were obtained at the sites of the sediment stations were examined by eye to ascertain the surficial nature of the sea-floor. Samples of these photographs are presented as figures 26A and 26B, which were taken at the sites of sediment stations 41 and 25 respectively. The photograph of figure 26A was taken with the Edgerton Camera which was aimed perpendicular to the sea-floor; the cropped photographs that are presented cover a distance of about three feet in both their horizontal and vertical directions. The photograph of figure 26B was taken with the Owen Camera (by Owen) which was aimed at an angle to the sea-floor; the photographs cover a distance of 17 inches in the horizontal direction and 16 to 17.5 inches in the vertical direction (about one and one-half feet in both horizontal and vertical directions). Therefore, the photographs taken with the Edgerton Camera are presented at approximately half the magnification of those taken with the Owen Camera.

SEDIMENT SAMPLES

MASS CHARACTERISTICS
MARTHAS VINEYARD PROFILE

Figure 24 Mass Characteristics of Sediment Samples Plotted Versus Distance Along the Martha's Vineyard Profile

Figure 25 Mass Characteristics of Sediment Samples Plotted Versus Distance Along the Block Island Profile

Figure 26
A

Figure 26
B Photographs of the Sea-floor Taken at Sediment Station Sites
41 and 25 Respectively

TABLE IV

MASS CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	WATER	POROUS	DENSTY	VELCTY	IMPED	REF COEF	BTMLOSS
1	0.74	66.5	1.61	1.46	2.34	0.21	13.7
2	1.03	73.3	1.49	1.45	2.16	0.17	15.6
3	1.02	73.2	1.49	1.45	2.16	0.17	15.5
4	0.48	56.4	1.78	1.50	2.66	0.27	11.5
5	0.72	65.7	1.62	1.46	2.37	0.21	13.5
6	0.42	52.7	1.84	1.52	2.79	0.29	10.8
7	0.49	56.6	1.78	1.49	2.66	0.27	11.5
8	0.58	60.9	1.70	1.48	2.51	0.24	12.4
9	0.32	46.2	1.96	1.56	3.06	0.33	9.6
10	0.49	56.5	1.78	1.49	2.66	0.27	11.5
11	0.73	66.2	1.61	1.46	2.35	0.21	13.6
12	0.74	66.3	1.61	1.46	2.35	0.21	13.6
13	0.60	61.7	1.69	1.47	2.49	0.24	12.6
14	0.51	57.7	1.76	1.49	2.62	0.26	11.7
15	0.49	56.6	1.78	1.49	2.66	0.27	11.5
16	0.48	56.1	1.79	1.50	2.67	0.27	11.4
17	0.34	47.7	1.93	1.55	2.99	0.32	9.9
18	0.29	43.6	2.00	1.59	3.17	0.35	9.2
19	0.27	41.5	2.04	1.61	3.27	0.36	8.9
20	0.46	55.3	1.80	1.50	2.70	0.27	11.3
21	0.46	55.0	1.80	1.50	2.71	0.28	11.2
22	0.96	72.0	1.51	1.45	2.19	0.17	15.2
23	1.78	82.6	1.33	1.45	1.92	0.11	19.1

TABLE IV (Cont'd)

MASS CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	WATER	POROUS	DENSTY	VELCTY	IMPED	REF COEF	BTMLOSS
24	0.23	37.8	2.10	1.65	3.47	0.38	8.3
25	0.20	35.4	2.14	1.68	3.60	0.40	7.9
26	0.29	43.6	2.00	1.59	3.17	0.35	9.2
27	0.66	63.9	1.65	1.47	2.42	0.22	13.1
28	0.29	43.7	2.00	1.58	3.17	0.35	9.2
29	0.27	42.3	2.02	1.60	3.23	0.35	9.0
30	0.25	40.4	2.05	1.62	3.33	0.37	8.7
31	0.24	39.0	2.08	1.64	3.40	0.38	8.5
32	0.29	44.0	1.99	1.58	3.15	0.34	9.3
33	0.17	31.6	2.21	1.74	3.84	0.43	7.4
34	0.43	53.5	1.83	1.51	2.77	0.28	10.9
35	0.24	39.0	2.08	1.64	3.40	0.38	8.5
36	0.24	39.3	2.07	1.63	3.38	0.37	8.5
37	0.42	53.2	1.84	1.51	2.78	0.29	10.9
38	0.21	36.1	2.13	1.67	3.56	0.40	8.0
39	0.26	41.1	2.04	1.61	3.29	0.36	8.8
40	0.27	42.2	2.02	1.60	3.24	0.36	9.0
41	0.34	47.9	1.93	1.55	2.98	0.32	9.9
42	0.49	56.5	1.78	1.49	2.66	0.27	11.5
43	0.42	53.1	1.84	1.51	2.78	0.29	10.9
44	0.51	57.6	1.76	1.49	2.62	0.26	11.7
45	0.37	50.0	1.89	1.53	2.90	0.31	10.3
46	0.37	49.5	1.90	1.54	2.92	0.31	10.2

TABLE IV (Cont'd)

MASS CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	WATER	POROUS	DENSTY	VELCTY	IMPED	REF COEF	BTMLOSS
47	0.51	57.5	1.76	1.49	2.62	0.26	11.7
48	0.30	44.3	1.99	1.58	3.14	0.34	9.3
49	0.25	40.1	2.06	1.62	3.34	0.37	8.7
50	0.27	41.9	2.03	1.60	3.25	0.36	8.9
51	0.25	39.9	2.06	1.62	3.35	0.37	8.6
52	0.33	47.2	1.94	1.55	3.01	0.32	9.8
53	0.30	44.4	1.99	1.58	3.14	0.34	9.3
54	0.24	39.3	2.07	1.63	3.38	0.37	8.5
55	0.31	45.3	1.97	1.57	3.10	0.34	9.5
56	0.38	50.2	1.89	1.53	2.89	0.30	10.3
57	0.39	50.8	1.88	1.53	2.87	0.30	10.4
58	0.41	52.0	1.85	1.52	2.82	0.29	10.7
59	0.36	49.1	1.91	1.54	2.94	0.31	10.1
60	0.35	48.7	1.91	1.54	2.95	0.31	10.1
61	0.22	36.6	2.12	1.67	3.53	0.39	8.1
62	0.67	64.3	1.64	1.46	2.41	0.22	13.2
63	0.86	69.6	1.55	1.45	2.26	0.19	14.5
64	0.94	71.6	1.52	1.45	2.20	0.18	15.1
65	0.96	71.9	1.51	1.45	2.19	0.17	15.2
66	0.70	65.2	1.63	1.46	2.38	0.21	13.4
67	0.76	67.0	1.60	1.46	2.33	0.20	13.8
68	1.12	74.9	1.46	1.45	2.11	0.16	16.1

TABLE IV (Cont'd)

MASS CHARACTERISTICS OF SEDIMENT SAMPLES

TAG	WATER	POROUS	DENSTY	VELCTY	IMPED	REF COEF	BTMLOSS
69	0.87	69.8	1.55	1.45	2.25	0.19	14.6
70	0.58	60.9	1.70	1.48	2.51	0.24	12.4
71	1.05	73.8	1.48	1.45	2.14	0.16	15.7
72	1.05	73.8	1.48	1.45	2.14	0.16	15.7
73	0.92	71.1	1.53	1.45	2.21	0.18	14.9
74	0.95	71.8	1.51	1.45	2.19	0.18	15.1
75	0.84	69.1	1.56	1.45	2.27	0.19	14.4
76	0.81	68.3	1.58	1.45	2.29	0.20	14.2
77	1.00	72.7	1.50	1.45	2.17	0.17	15.4

The results of all of the photographic observations are tabulated in Table V. The relief of the sea-floor is considered to be flat, moderate, or rough, respectively, depending upon whether the magnitudes of the vertical excursions of protuberances and depressions are generally smaller than one inch, between one and three inches, or larger than three inches. The bottom material is noted as coarse when a considerable amount of gravel is observed; otherwise it is noted as fine. This is a classification based on the resolution obtained in these photographs and of course is not the same as the classification used in grain size analysis (coarse is equal to gravel + sand; fine, equal to silt + clay).

TABLE V

PHOTOGRAPHIC OBSERVATIONS AT SITES OF SEDIMENT STATIONS

SEDIMENT STATION SITE	SURFICIAL CHARACTER OF THE SEA FLOOR
4	Small relief, coarse material, many mussels, few starfish
5	Moderate relief, coarse material, some rockweed, few starfish
9	Small relief, coarse material, many mussels, few starfish
10	Small relief, coarse material, many mussel shells
14	Small relief, fine material
16	Small relief, fine material
17	Small relief, some ripples < 1" high and 2"-4" λ , fine material
18	Moderate relief, some ripples 1"-2" high and 4"-5" λ , fine material
19	Small relief, fine material
20	Small relief, fine material, a starfish
24	Small relief, coarse material, rockweed
25	Small relief, coarse material
26	Small relief, fine material
28	Small relief, coarse material
29	Small relief, fine material, worm tubes
31	Small relief, coarse material
39	Small relief, fine material, sand dollar
41	Small relief, fine material, fish
43	Small relief, fine material, small dimples < 1/2" deep, starfish
45	Small relief, fine material, crab
47	Small relief, fine material, few starfish, few sea pens
48	Small relief, small dimples < 1/2" deep, fine material
50	Small relief, gentle ripple mark < 1/2" high and 10" λ , fine material
51	Small relief, fine material, starfish
53	Small relief, small dimple < 1/2" deep, fine material
54	Small relief, fine material
55	Small relief, small dimples < 1/2" deep, fine material
56	Small relief, small dimples < 1/2" deep, fine material
58	Small relief, small dimples < 1/2" deep, fine material
59	Small relief, small dimples < 1/2" deep, fine material
60	Small relief, fine material, starfish
61	Small relief, fine material
62	Small relief, fine material

TABLE V (Cont'd)

PHOTOGRAPHIC OBSERVATIONS AT SITES OF SEDIMENT STATIONS

SEDIMENT STATION SITE	SURFICIAL CHARACTER OF THE SEA FLOOR
63	Small relief, few tracks $\angle$ 1/2" deep and $\angle$ 1" wide, fine material
65	Small relief, few tracks $\angle$ 1/2" deep and $\angle$ 1" wide, fine material
66	Small relief, few tracks $\angle$ 1/2" deep and $\angle$ 1" wide, fine material, starfish
67	Small relief, fine material, starfish
68	Small relief, fine material, starfish
69	Small relief, fine material
71	Small relief, fine material
72	Small relief, few tracks $\angle$ 1/2" deep and $\angle$ 1" wide, fine material, sea pens, starfish
73	Small relief, fine material
74	Small relief, fine material, sea pens
75	Small relief, fine material, some worm tubes
76	Small relief, fine material, some worm tubes
77	Small relief, fine material, some worm tubes

CHAPTER VIII

CORRELATION OF ACOUSTIC AND GEOLOGIC RESULTS

Sediment Stations

Several times, during the shallow-water cruises, the ship was hove-to and measurements of acoustic bottom loss (Table VI) and sediment samples from the sea-floor were obtained. These sediments were subjected to a grain-size analysis (Table III). At a later date, the same sites of the sediment stations were revisited and a second set of sediment samples was obtained. This second set was subjected to a water-content analysis (Table IV). The location of these measurements are shown by the numerals and associated arrows on figures 41, 42, 43, and 44.

A correlation and regression analysis (Table VII) was performed between the acoustic measurements and the characteristics of the sediment samples. The statistical quantities obtained were the regression equation, the correlation coefficient, and the Z statistic (Hoel, 1962). Bottom loss measured on both a peak-pressure and on a total-energy basis, was tested against porosity (Figures 27 and 28), median grain-size (Figures 29 and 30), sorting coefficient (Figures 31 and 32), percentage of fine material (silt + clay) (Figures 33 and 34), percentage of silt (Figures 35 and 36), and percentage of clay (Figures 37 and 38). The experimental points have been plotted in the form of scatter diagrams in these figures along with the regression line for all the geological quantities except porosity. For this particular case the experimental points are plotted along with the theoretical curves of mass characteristics versus porosity, which were developed in Chapter II.

The regression line is the best-fitting line, chosen on a least squares basis, through the experimental data. The correlation coefficient is a measure of the degree to which the experimental data indicates that a linear relationship exists between the variables tested. The Z statistic is a normally distributed function of the correlation coefficient and is used to test its statistical significance. A correlation coefficient is considered significant (at the 95% level) when its absolute value is larger than two standard deviations of the Z statistic. The standard deviation of the Z statistic depends solely on the number of experimental points and is equal to .117 for this investigation (76 points were used; the measurements at Station 23 seemed to be grossly in error and were not considered in the statistical analysis).

The magnitudes of the correlation coefficients presented in Table VII demonstrate that a significant correlation exists between bottom loss and all of the geological quantities that were tested. In particular, bottom loss is directly related to porosity and amount of fine material, silt, and clay, and inversely related to median grain size (the phi unit is an inverse measure of the logarithm of grain size) and degree of size sorting (the Trask sorting coefficient is an inverse measure of sorting). The strength of the relationship appears greatest for amount of fine material, silt, and clay,

Figure 27 Bottom Loss Measurements (Peak Pressure Basis) at Sediment Stations Versus Measured Porosity of the Sediment

Figure 28 Bottom Loss Measurements (Total Energy Basis) at Sediment Stations Versus Measured Porosity of the Sediment

Figure 29 Scatter Diagram of Bottom Loss (Peak Pressure Basis) Versus Median Grain Size

Figure 30 Scatter Diagram of Bottom Loss (Total Energy Basis) Versus Median Grain Size

Figure 31 Scatter Diagram of Bottom Loss (Peak Pressure Basis) Versus Sorting Coefficient

Figure 32 Scatter Diagram of Bottom Loss (Total Energy Basis) Ver-

BOTTOM LOSS
(PEAK PRESSURE BASIS)
VS
FINE (SILT & CLAY) %

21

18

15

12

9

6

3

BOTTOM LOSS (db)

Figure 34 Scatter Diagram of Bottom Loss (Total Energy Basis) Versus Fine (Silt Plus Clay) Percentage

Figure 35 Scatter Diagram of Bottom Loss (Peak Pressure Basis) Versus Silt Percentage

Figure 36 Scatter Diagram of Bottom Loss (Total Energy Basis) Versus Silt Percentage

Figure 37 Scatter Diagram of Bottom Loss (Peak Pressure Basis) Versus Clay Percentage

Figure 38 Scatter Diagram of Bottom Loss (Total Energy Basis) Versus Clay Percentage

TABLE VI
ACOUSTIC MEASUREMENTS AT SITES OF SEDIMENT STATIONS

TAG	DEPTH (Feet)	LATITUDE	LONGITUDE	BOTTOM LOSS (db) (PRESSURE BASIS)	BOTTOM LOSS (db) (ENERGY BASIS)
1	20	41°37.5'	71°22.3'	16.5	17.2
2	27	41°38.8'	71°22.4'	14.2	14.7
3	51	41°33.3'	71°19.5'	14.9	14.9
4	83	41°30.5'	71°21.2'	9.4	9.0
5	84	41°28.9'	71°20.5'	11.0	12.8
6	50	41°28.4'	71°20.8'	7.7	8.9
7	30	41°28.6'	71°22.9'	10.1	11.9
8	98	41°28.0'	71°22.6'	12.4	10.3
9	100	41°28.4'	71°21.4'	12.1	9.9
10	32	41°33.3'	71°23.7'	9.2	8.4
11	31	41°33.2'	71°24.6'	13.2	12.6
12	38	41°32.7'	71°24.0'	11.6	10.5
13	43	41°29.6'	71°24.5'	14.4	12.5
14	26	41°28.6'	71°22.8'	10.3	9.2
15	25	41°28.6'	71°22.9'	9.5	11.1
16	60	41°25.7'	71°26.1'	11.6	9.8
17	41	41°25.7'	71°26.6'	10.1	9.3
18	30	41°25.8'	71°27.0'	8.6	7.0
19	74	41°25.9'	71°23.1'	12.4	10.1
20	76	41°26.9'	71°22.2'	13.1	11.9
21	23	41°28.7'	71°22.9'	11.4	11.3
22	28	41°30.6'	71°24.0'	15.2	14.6
23	50	41°37.5'	71°17.2'	9.7	7.9
24	65	41°25.2'	71°21.4'	8.1	6.2
25	68	41°25.3'	71°13.8'	8.8	6.4
26	33	41°29.7'	71°13.2'	10.4	8.1
27	25	41°31.8'	71°12.9'	11.0	10.7
28	46	41°28.3'	71°12.5'	9.2	6.6
29	77	41°26.0'	71°17.2'	12.4	11.6
30	50	41°28.1'	71°16.3'	10.5	10.3
31	30	41°28.7'	71°15.6'	10.8	7.2
32	40	41°28.4'	71°16.6'	8.6	5.1
33	120	41°15.4'	71°25.2'	10.1	8.8
34	131	41°10.8'	71°25.5'	12.5	11.6
35	101	41°7.0'	71°25.6'	9.5	7.2
36	82	41°7.1'	71°27.9'	10.1	9.6
37	74	41°11.6'	71°36.5'	13.1	13.3
38	44	41°7.8'	71°38.6'	6.1	5.4
39	133	40°59.6'	71°35.7'	8.8	7.5
40	180	40°53.8'	71°33.0'	11.4	10.1

TABLE VI (Cont'd)

ACOUSTIC MEASUREMENTS AT SITES OF SEDIMENT STATIONS

TAG	DEPTH (Feet)	LATITUDE	LONGITUDE	BOTTOM LOSS (db) (PRESSURE BASIS)	BOTTOM LOSS (db) (ENERGY BASIS)
41	200	40°47.3'	71°31.8'	11.1	10.5
42	204	40°40.8'	71°29.9'	12.2	11.6
43	215	40°34.4'	71°27.3'	14.9	13.2
44	230	40°29.4'	71°26.5'	15.5	13.2
45	250	40°23.5'	71°24.6'	14.2	12.4
46	272	40°16.8'	71°22.8'	16.3	12.8
47	289	40°11.6'	71°21.7'	13.4	11.2
48	62	41°16.5'	70°39.4'	10.6	9.4
49	82	41°14.9'	70°41.5'	12.1	10.6
50	72	41°13.4'	70°39.6'	9.5	9.0
51	90	41°10.2'	70°39.5'	10.6	10.7
52	122	41°80.0'	70°40.8'	12.8	11.5
53	114	41°7.5'	70°39.0'	10.4	10.2
54	139	41°4.6'	70°40.5'	12.7	10.8
55	122	41°4.0'	70°39.0'	10.6	10.7
56	132	41°0.0'	70°40.0'	10.1	10.2
57	162	40°58.9'	70°40.3'	14.3	11.6
58	136	40°57.1'	70°41.4'	12.3	12.4
59	147	40°54.5'	70°42.4'	10.8	10.0
60	170	40°53.4'	70°41.1'	10.8	8.7
61	150	40°51.5'	70°42.5'	10.4	9.7
62	164	40°48.8'	70°42.5'	14.3	13.0
63	174	40°45.5'	70°42.5'	13.5	12.0
64	191	40°44.7'	70°42.4'	14.9	11.4
65	180	40°42.0'	70°40.8'	12.8	11.5
66	182	40°40.0'	70°42.8'	14.3	13.0
67	202	40°39.2'	70°45.2'	14.9	12.2
68	192	40°37.2'	70°41.5'	13.9	11.8
69	204	40°33.5'	70°42.0'	16.5	14.2
70	234	40°30.9'	70°44.6'	18.7	16.0
71	216	40°30.5'	70°42.2'	17.1	15.0
72	236	40°26.5'	70°42.5'	18.0	16.0
	255	40°24.4'	70°43.5'	16.8	14.4
	285	40°23.8'	70°44.5'	17.6	13.8
	285	40°22.1'	70°43.5'	16.3	14.0
	336	40°18.7'	70°42.8'	19.2	17.6
	366	40°15.4'	70°43.0'	20.8	16.6

TABLE VII

STATISTICAL RELATIONSHIPS BETWEEN ACOUSTIC MEASUREMENTS
AND SEDIMENT PROPERTIES

	<u>Regression Line Slope</u>	<u>Correlation Coefficient</u>	<u>Z Statistic</u>
	* Bottom Loss (db)	* Bottom Loss (db)	* Bottom Loss (db)
Porosity	.171 ± .039 db/% (.166 ± .034 db/%)	.706 (.745)	.878 ± .234 (.962 ± .234)
Grain Size	1.074 ± .292 db/phi unit (.961 ± .274 db/phi unit)	.646 (.627)	.768 ± .234 (.737 ± .234)
Sorting	1.054 ± .660 db/trask unit 1.258 ± .580 db/trask unit	.343 (.445)	.358 ± .234 (.478 ± .234)
Fine Material	.083 ± .015 db/% (.073 ± .014 db/%)	.786 (.752)	1.060 ± .234 (.977 ± .234)
Silt	.108 ± .020 db/% (.095 ± .020 db/%)	.782 (.742)	1.052 ± .234 (.954 ± .234)
Clay	.293 ± .060 db/% (.266 ± .056 db/%)	.727 (.716)	.922 ± .234 (.898 ± .234)

* Measurements made on a total-energy basis are bracketed and those on a peak-pressure basis are not.

SEDIMENT SAMPLES

PLOTTED ON A THREE COMPONENT TEXTURAL DIAGRAM USING SAND, SILT, AND CLAY AS VERTICES
 (GRAVEL CONSIDERED AS SAND; CIRCLES BORDER SAMPLES CONTAINING SIGNIFICANT GRAVEL)

COLOR CODED ACCORDING TO ACOUSTIC MEASUREMENTS TAKEN CONCURRENTLY WITH THE SAMPLED SEDIMENTS

MEASURED BOTTOM LOSS (PEAK PRESSURE BASIS)

● 19(db)	● 15	● 11	● 7
● 18	● 14	● 10	
● 17	● 13	● 9	
○ 16	○ 12	○ 8	

Figure 39 Bottom Loss Measurements (Peak Pressure Basis) at Sediment Stations Color Coded and Plotted on a Sand-Silt-Clay Diagram.

SEDIMENT SAMPLES

PLOTTED ON A THREE COMPONENT TEXTURAL DIAGRAM USING SAND, SILT, AND CLAY AS VERTICES
 (GRAVEL CONSIDERED AS SAND; CIRCLES BORDER SAMPLES CONTAINING SIGNIFICANT GRAVEL)

COLOR CODED ACCORDING TO ACOUSTIC MEASUREMENTS TAKEN CONCURRENTLY WITH THE SAMPLED SEDIMENTS

MEASURED BOTTOM LOSS (TOTAL ENERGY BASIS)

● 18 (db)	● 14	● 10	● 6
● 17	● 13	● 9	
● 16	● 12	● 8	
○ 15	○ 11	○ 7	

Figure 40 Bottom Loss Measurements (Total Energy Basis) at Sediment Stations Color Coded and Plotted on a Sand-Silt-Clay Diagram.

this traverse demonstrates the general tendency of bottom loss to increase as the percentage of fine material in the sediment increases. The cluster of cold intermediate, and warm colors in the sand, silty sand, and both sandy silt and clayey silt zones, respectively, indicate that sand is a good reflector, silty sand is a moderate reflector and both sandy silt and clayey silt are poor reflectors. In particular, the average values of bottom loss for sand, silty sand, sandy silt and clayey silt are 10.9 db, 13.8 db, 15.4 db, and 16.0 db, respectively, when measured on a peak-pressure basis and 9.8 db, 12.2 db, 13.8 db, and 15.8 db, respectively, when measured on a total-energy basis.

Narragansett Bay Area

An investigation of the relationship between acoustic bottom loss and bottom sediment was made in the Narragansett Bay area. This area was selected because its geology had previously been studied and published (McMaster, 1960), and because of its proximity to the Woods Hole Oceanographic Institution. Approximately thirteen-thousand acoustic measurements were taken at different locations. Samples of sediment were taken at 32 different locations to check and supplement the published geological control.

The values of acoustic bottom loss, measured on both a peak-pressure and total-energy basis, have been color coded according to the system previously mentioned and plotted on charts of the area (Figures 41 and 42). The sites of the sediment stations are indicated by numerals and arrows, and the characteristics of the samples are listed in Tables III and IV. Transparent overlays showing the distribution of sediment types and showing the zonal distribution of sand content (after McMaster) are hinged to the edges of the figures, and may be flipped onto the chart to compare the quantities they represent with the measurements of acoustic bottom loss. The exactness of the boundaries of these distribution patterns must be viewed in the light of the sample spacing used by McMaster; this was a grid of one-half minute spacing within the Bay proper and one minute spacing off-shore.

Inspection of Figures 41 and 42 with both overlays flipped off of the chart shows that while the measurements of bottom loss made on an energy basis tend to be about 1 db lower than those made on a pressure basis, the general spatial distribution of the acoustic reflectivity of the region is the same for measurements made on either basis. The slight discrepancy in absolute value between the two types of acoustic measurements is ascribed to the reverberation component in the echo which is integrated along with the specular component when bottom loss is measured on a total-energy basis. Nevertheless, the equivalence of the patterns of relative reflectivities of this region, when measured on either basis, and the knowledge that the region encompasses a large variety of sediment types, leads to the conclusion that bottom loss measured on either basis is indicative of the same characteristic of the bottom sediment.

Figure 41 Bottom Loss Measurements (Peak Pressure Basis) Color Coded and Plotted on a Chart of Narragansett Bay.

Figure 41 Bottom Loss Measurements (Peak Pressure Basis) Color Coded and Plotted on a Chart of Narragansett Bay.

Figure 42 Bottom Loss Measurements (Total Energy Basis) Color Coded and Plotted on a Chart of Narragansett Bay.

Figure 42 Bottom Loss Measurements (Total Energy Basis) Color Coded and Plotted on a Chart of Narragansett Bay.

A comparison of the measurements of bottom loss and the sand content of the sediment is achieved by inspection of Figures 41 and 42 with the appropriate overlays flipped onto the charts. When this is done, it becomes apparent that generally the areas in which the sand content of the sediment is high (greater than 75 percent), moderate (between 50 and 75 percent) and low (less than 50 percent) respectively, exhibit high (cold colors), intermediate (intermediate colors) and low (warm colors) degrees of acoustic reflectivity.

In particular, good agreement is found for the extensive region of high-sand-content sediment south of Aquidneck Island extending into the mouths of East and Sakonnet Passages, the strip of high-sand-content sediment along the western border of the mouth of West Passage, the tongue of high-sand-content sediment extending almost across West Passage at its mid-point, the region of moderate-sand-content sediment in the middle and lower section of East Passage, the region of moderate-sand-content sediment south of Conanicut Island, the extensive region of low-sand-content in the upper bay extending down into the upper sections of both East and West Passages, and the region of low-sand-content sediment in the lower-middle section of West Passage. A lack of agreement is found for the small region of high and moderate-sand-content sediment in the topmost section of the upper bay, the region of low-sand-content sediment east of Prudence Island. This is believed to result from a disharmony between the sediments that exist in specific parts of these regions and those generally indicated on the overlay; the samples at Station 2 (sand-silt-clay) and 16 (silty sand) are low and high-sand-content sediments, respectively, and the area south of Prudence Island has been and still is a dumping ground for dredged material (McMaster, 1960), (Captain Harold Payson, personal communication).

A comparison of the measurements of bottom loss and the type (class-name) of the sediment is achieved by inspection of figures 41 and 42 with the appropriate overlays flipped onto the charts. When this is done it becomes apparent that, in general, regions of sand or gravel exhibit a high degree of acoustic reflectivity (cold colors), regions of silty sand exhibit an intermediate degree of acoustic reflectivity (intermediate colors), and regions of sandy silt, clayey silt, or sand-silt-clay, exhibit a low degree of acoustic reflectivity (warm colors). This is to be expected in view of the relationship previously observed between bottom loss and sand content, since the class-name of a sediment is related to its sand content; sands contain more than 75% sand, silty sands usually contain between 50 and 75% sand, and sandy silts, clayey silts, and sand-silt-clays usually contain less than 50% sand.

The extent to which the measurements of bottom loss are related to the geological control has been discussed in the above paragraphs. The data indicate a definite correlation between the measurements of bottom loss and class-name of the sediment.

Shallow Water Profiles

An investigation of the relationship between acoustic bottom loss and bottom sediment was made along two separate profiles on the continental shelf; one extending due south from Martha's Vineyard for a distance of 65 miles and the other extending south by east from Block Island for a distance of 58 miles. These particular profiles were selected because their geology had previously been studied and published (Stetson, 1938) and because of their proximity to the Woods Hole Oceanographic Institution. Approximately seven-thousand acoustic measurements were taken at 230 different locations. Samples of sediment were taken at 40 different locations to check and supplement the published geological control.

The values of acoustic bottom loss, measured on both a peak-pressure and total-energy basis, have been color coded according to the system previously described and plotted on charts of the area (Figures 43 and 44). The sites of the sediment stations are indicated by numerals and arrows and the characteristics of the samples are listed in Tables III and IV. Pictorial representations of the amounts of sand, silt, and clay in the sediment, based on the samples obtained during this investigation and those published by Stetson, are presented in conjunction with the acoustic measurements to facilitate comparison between them.

Inspection of Figures 43 and 44 shows a decrease in acoustic reflectivity (increase in the warmth of color plotted) progressing seaward along both profiles, which is associated with a decrease in sediment sand content (increase in silt + clay). In particular, the Martha's Vineyard Profile is characterized by a long section of cold colors (good reflectors) abruptly followed by a short section of intermediate colors (moderate reflectors) abruptly followed by a long section of warm colors (poor reflectors), and the Block Island Profile is characterized by a short section of cold colors (good reflectors) gradually followed by a long section of predominately intermediate colors (moderate reflectors). These acoustic trends are representative of the geological control. Well sorted sands gravels are present at the inshore ends of the profiles and grade outward toward poorly sorted silts and clays; the zoning is abrupt and the content of fine material increases to about 80% along the Martha's Vineyard Profile, whereas the zoning is blurred and the content of fine material increases to only about 60% along the Block Island Profile (Stetson, 1938).

In addition, acoustic, mass, and grain-size characteristics are jointly displayed versus distance in miles along both the Martha's Vineyard (Figure 45) and Block Island (Figure 46) profiles. The top two curves represent acoustic measurements of bottom loss on a peak-pressure and total-energy basis, respectively (each point represents the running average of three measurements); the next two curves down represent bottom loss and porosity calculated from the measured water content of the samples; the next curve down represents the median grain size measured from the sediment samples; below this is a pictorial representation of the sand, silt, and clay fraction of the sediment; below this is a plot of the bathymetry based on water depths obtained in this investigation

Figure 43 Bottom Loss Measurements (Peak Pressure Basis) Color Coded and Plotted on a Chart of the Continental Shelf South of Cape Cod.

Figure 44 Bottom Loss Measurements (Total Energy Basis) Color Coded and Plotted on a Chart of the Continental Shelf South of Cape Cod.

RELATIONSHIP BETWEEN ACOUSTICAL MEASUREMENTS
AND SEDIMENT SAMPLES

ACOUSTIC, MASS, AND SIZE CHARACTERISTICS
SMOOTHED CURVES
MARTHAS VINEYARD PROFILE

RELATIONSHIP BETWEEN ACOUSTICAL MEASUREMENTS
AND SEDIMENT SAMPLES

ACOUSTIC, MASS, AND SIZE CHARACTERISTICS
SMOOTHED CURVES
BLOCK ISLAND PROFILE

Figure 46 Acoustic, Mass, and Size Characteristics Plotted Versus Distance Along the Block Island Profile

type of measurement. Two profiles (the "Bermuda" Profiles) were made along a track from Bermuda to Woods Hole and one profile (the "Puerto Rican" Profile) was made along a north-south track centered approximately west of Bermuda. The geological control over these profiles is not so good as that attained in the shallow-water investigations since the geology of the deep-water is not so well known and it was not convenient to obtain sediment samples during the investigation. Nevertheless, since the profiles extend over various physiographic provinces of the ocean, it is at least possible to compare broadly the measurements of bottom loss on this basis.

Approximately six and a half-thousand acoustic measurements were taken at 340 different locations. The values of acoustic bottom loss, measured on both a peak-pressure and total-energy basis, have been color coded according to the system previously described and plotted (Figures 47 and 48) on physiographic charts (Heezen et al., 1959).

Inspection of Figures 47 and 48 shows that the outer continental shelf, the continental slope, and the Bermuda rise are poor reflectors and the continental rise and abyssal plain are good reflectors; the poorest reflectors are found on the Bermuda rise at a great distance from the continent and the best reflectors are found on the abyssal plain at the base of the continental rise. This pattern of acoustic reflectivity may broadly be explained by the type of sediment that is characteristic of these physiographic provinces in this region. The outer continental shelf is characterized by fine sediments with a narrow band of coarse sediment along the crest of the shelf break (Stetson, 1938). The continental slope receives fine material winnowed off the shelf (Stetson, 1949) (Uchupi, 1963). The sediments of the continental rise and abyssal plain are likely to be composed of turbidites (generally coarse material) that have originated on the continent and flowed down the various submarine canyons on the continental slope; Block Canyon, Atlantis Canyon, and Veatch Canyon are present in this area. The Hudson Canyon cuts across the continental slope and rise and empties into the abyssal plain near Caryn Seamount to form a large alluvial delta (Heezen et al., 1959). A large majority of the sediment cores taken on the continental rise and abyssal plain in this region (Ericson et al., 1961) contain sand and silt; those on the Bermuda rise do not. This is because the deposition of turbidites is terminated by the topographic irregularities that skirt the edge of the Bermuda rise and only pelagic sedimentation containing generally fine material occurs on the Bermuda rise.

Measurements of bottom loss on both a peak-pressure and total-energy basis, their standard deviations, and the bathymetry based on echo-soundings obtained during this investigation, are jointly displayed in Figures 49, 50, and 51 for measurements made on the "Puerto Rican" and "Bermuda" Profiles, respectively. The values of the acoustic measurements have been smoothed by taking the running average of three measurements. The measurements made on the "Bermuda" profiles have been plotted versus distance in miles along their common track, with Bermuda taken as its origin.

Inspection of Figures 49, 50, and 51 shows that the curves representing bottom loss, measured on either a peak-pressure or total-energy basis, versus

RELATIONSHIP BETWEEN ACOUSTICAL MEASUREMENTS
AND SEDIMENT SAMPLES

ACOUSTIC, MASS, AND SIZE CHARACTERISTICS
SMOOTHED CURVES
BLOCK ISLAND PROFILE

Figure 46 Acoustic, Mass, and Size Characteristics Plotted Versus Distance Along the Block Island Profile

and published by Stetson; and lastly, the class-names of the sediments that were sampled along these profiles either during this investigation or by Stetson are indicated by symbols coded according to the accompanying legend. This type of presentation facilitates comparison between all of the qualities mentioned.

As noted previously the curves representing bottom loss, measured on either a peak-pressure or total-energy basis, versus distance in miles along profile, have a similar shape which indicates that both types of measurement sense the same characteristic of the bottom sediment. The measurements of bottom loss made on an energy basis tend to be about 1.5 db lower than those made on a pressure basis which is attributed to reverberation in the echo. The curves of bottom loss, calculated from the measured water content of the second set of sediment samples, versus distance along profile, have a shape that is similar to the curves of directly measured bottom loss versus distance along profile. This is considered significant evidence of a correlation between measured bottom loss and mass characteristic of the sediment. The absolute values of the computed bottom losses are slightly lower than the measured bottom losses but this is considered not significant in view of the experimental uncertainty in the absolute measurement of bottom loss. Finally, the similarity between the curves of computed bottom loss and measured porosity is noted. This is due to the approximately linear relationship between these qualities (Figure 3) over the range of porosities experienced in this investigation.

The curves of measured bottom loss versus distance in miles along profile are representative of the zoning of sediments parallel to the shore that was reported by Stetson; the zoning of sediments along the Block Island Profile is less distinct than along the Martha's Vineyard Profile. The bottom loss measurements best represent the percentage of fine material (silt + clay) in the sediment. This is explained by the association between porosity and percentage of fine material in the sediment that was hypothesized in Chapter II and is demonstrated here. While the bottom loss measurements are generally related to grain size, they are affected very little by the wide variations in the median grain size that occur in the northern sections of the profiles. The reason for this is that the porosity of well-sorted pure sands, which are present there, is not strongly dependent on grain size.

The results of this experiment indicate a definite correlation between the acoustic measurements of bottom loss and the mass and grain-size characteristics of the sediment. Bottom loss increases as the porosity of the sediment increases. Bottom loss also increases as the percentage of silt + clay in the sediment increases (or as the sand-content of the sediment decreases) and as the sediment type progresses from sand to silty sand to sandy silt, sand-silt-clay, or clayey silt.

Deep Water Profiles

Long profiles of acoustic bottom loss were made during the early phase of this investigation to observe the range and variability of acoustic reflectivity present in the natural environment and to establish the repeatability of this

type of measurement. Two profiles (the "Bermuda" Profiles) were made along a track from Bermuda to Woods Hole and one profile (the "Puerto Rican" Profile) was made along a north-south track centered approximately west of Bermuda. The geological control over these profiles is not so good as that attained in the shallow-water investigations since the geology of the deep-water is not so well known and it was not convenient to obtain sediment samples during the investigation. Nevertheless, since the profiles extend over various physiographic provinces of the ocean, it is at least possible to compare broadly the measurements of bottom loss on this basis.

Approximately six and a half-thousand acoustic measurements were taken at 340 different locations. The values of acoustic bottom loss, measured on both a peak-pressure and total-energy basis, have been color coded according to the system previously described and plotted (Figures 47 and 48) on physiographic charts (Heezen et al., 1959).

Inspection of Figures 47 and 48 shows that the outer continental shelf, the continental slope, and the Bermuda rise are poor reflectors and the continental rise and abyssal plain are good reflectors; the poorest reflectors are found on the Bermuda rise at a great distance from the continent and the best reflectors are found on the abyssal plain at the base of the continental rise. This pattern of acoustic reflectivity may broadly be explained by the type of sediment that is characteristic of these physiographic provinces in this region. The outer continental shelf is characterized by fine sediments with a narrow band of coarse sediment along the crest of the shelf break (Stetson, 1938). The continental slope receives fine material winnowed off the shelf (Stetson, 1949) (Uchupi, 1963). The sediments of the continental rise and abyssal plain are likely to be composed of turbidites (generally coarse material) that have originated on the continent and flowed down the various submarine canyons on the continental slope; Block Canyon, Atlantis Canyon, and Veatch Canyon are present in this area. The Hudson Canyon cuts across the continental slope and rise and empties into the abyssal plain near Caryn Seamount to form a large alluvial delta (Heezen et al., 1959). A large majority of the sediment cores taken on the continental rise and abyssal plain in this region (Ericson et al., 1961) contain sand and silt; those on the Bermuda rise do not. This is because the deposition of turbidites is terminated by the topographic irregularities that skirt the edge of the Bermuda rise and only pelagic sedimentation containing generally fine material occurs on the Bermuda rise.

Measurements of bottom loss on both a peak-pressure and total-energy basis, their standard deviations, and the bathymetry based on echo-soundings obtained during this investigation, are jointly displayed in Figures 49, 50, and 51 for measurements made on the "Puerto Rican" and "Bermuda" Profiles, respectively. The values of the acoustic measurements have been smoothed by taking the running average of three measurements. The measurements made on the "Bermuda" profiles have been plotted versus distance in miles along their common track, with Bermuda taken as its origin.

Inspection of Figures 49, 50, and 51 shows that the curves representing bottom loss, measured on either a peak-pressure or total-energy basis, versus

Figure 47 Bottom Loss Measurements (Peak Pressure Basis) Color Coded and Plotted on a Physiographic Map (After Heezen et al., 1959) of the Western North Atlantic.

Figure 48 Bottom Loss Measurements (Total Energy Basis) Color Coded and Plotted on a Physiographic Map (After Heezen et al., 1959) of the Western North Atlantic.

Figure 50 Bottom Loss Measurement CHAIN 21 Cruise Plotted v Profile

Figure 49 Bottom Loss Measurements (Running Average) Made During the CHAIN 19 Cruise Plotted Versus Distance Along the Puerto Rico Profile

ACOUSTIC MEASUREMENTS (RUNNING AVERAGE)
PUERTO RICO PROFILE
CHAIN 19 CRUISE

Figure 49 Bottom Loss Measurements (Running Average) Made During the CHAIN 19 Cruise Plotted Versus Distance Along the Puerto Rico Profile

ACOUSTIC MEASUREMENTS (RUNNING AVERAGE)
BERMUDA PROFILE
CHAIN 21 CRUISE

Figure 50 Bottom Loss Measurements (Running Average) Made During the CHAIN 21 Cruise Plotted Versus Distance Along the Bermuda Profile

ACOUSTIC MEASUREMENTS (RUNNING AVERAGE)
BERMUDA PROFILE
CHAIN 27 CRUISE

distance along profile, have a similar shape which indicates that both types of measurement sense the same characteristic of the bottom sediment. The measurements of bottom loss made on an energy basis tend to be about 2 db lower than those made on a pressure basis which is attributed to reverberation in the echo. Inspection of Figures 50 and 51 shows that the curves of bottom loss versus distance along profile are similar for measurements made over the same section of the common track. This attests to the repeatability of the bottom loss measurements since each of the Bermuda Profiles was obtained during a different cruise.

The results of this investigation are mainly contained in the presentation of measurements of bottom loss per se. along long profiles in the deep sea. It has been shown that these measurements are repeatable and that their values may broadly be explained in terms of the sediments characteristic of the physiographic provinces in this region.

CHAPTER IX

CONCLUSION

Summary and Conclusions

1) Acoustic reflectivity of the sea floor is indicative of certain properties of the sediment, such as porosity, silt-clay percentage, and grain size, and also indicative of sediment type as defined by the Shepard (1954) system of nomenclature. While this sort of result is known from other work the present demonstration is valuable because of its detail and extent.

2) A practical technique was developed that could be used for routine acoustical surveying of sediments on the sea floor from a vessel underway. A highly automated system of data collection and analysis was developed, tested, and brought to a usable form. A present shortcoming is that oscilloscope photographs produced by the shipborne measurement system must be digitized by hand before being processed by the land-based digital computer.

3) An extensive investigation of acoustic reflectivity was made in shallow water and compared with the geological studies of other investigators. Acoustic reflectivity correlates well with the silt-clay percentage, grain size, and sediment type reported by Stetson (1938) along profiles on the continental shelf south of Cape Cod, and with silt-clay percentage, and sediment type (grain size was not available) reported by McMaster (1960) in Narragansett Bay. Acoustic reflectivity correlates even better with the same properties of sediment samples taken during the present investigation of these areas.

4) The range and variability of acoustic reflectivity in deep water along long profiles was established. Two profiles were made along a track from Bermuda to Woods Hole and one profile was made along a north-south track centered approximately west of Bermuda. The results show that along these tracks the outer continental shelf, the continental slope, and the Bermuda rise are poor reflectors and that the continental rise and abyssal plain are good reflectors.

5) A shipborne instrument system to measure the peak pressure and integral of the squared pressure of a hydroacoustic transient was developed. This is of general utility in sound propagation studies.

Recommendations for Further Work

1) Investigations should be made over all water-covered areas and especially the deep sea, to obtain more data on the relationship between acoustic reflectivity and properties of the sediment as well as to map the sediment of the region per se. Data on the relationship between acoustic reflectivity and the very fine-grained sediments of the deep sea are particularly lacking. In addition, the advantage of acoustic surveying over sediment dredging is maximized in deep water due to the considerable time required to obtain a sample by the latter method.

2) Measurements of acoustic reflectivity should be taken in parallel with samples of sediment and in situ measurements of sound velocity and density of the sediment. Sound velocity and density, respectively, can be obtained by measurements of travel time and gamma ray absorption between probes inserted in the sediment.

3) The shipborne instrumentation system should be further refined to facilitate its use in routine surveying. The measurements should be recorded either directly in a machine-language form that is acceptable to a shore-based digital computer, or fed directly to a shipborne computer (digital computers are currently being used by oceanographers aboard ships).

4) The present system incorporated many pieces of standard laboratory equipment that were immediately available. Subsequent development could consolidate the system in a single console and drastically reduce its size.

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The author extends the appreciation to Prof. J. B. Hersey for supervising this research and for making the experimental work possible through the facilities of the Geophysics Department at the Woods Hole Oceanographic Institution. Prof. Hersey first suggested, on the basis of his observations of the tonal characteristics of echo-sounding records, that an examination of the magnitudes of echoes from the sea-floor would provide useful information about the nature of the sea-floor. He has provided numerous valuable and stimulating discussions throughout the course of this work.

Many people contributed toward the design and construction of the electronic instrumentation. The author wishes to thank Mr. S. T. Knott, Mr. W. E. Witzell, Mr. W. Dow, Mr. L. Wilharm, and Mr. F. R. Hess for their aid with the acoustic reflectivity system; Dr. H. E. Edgerton and Mr. V. M. McRoberts for their aid with the precisely-timed submersible pinger, and Mr. D. M. Owen for his aid with the self-contained submersible tape recorder.

The success of the sea-going operations was made possible by the officers and crew of the research vessels CHAIN, BEAR, ASTERIAS, ATLANTIS, and CRAWFORD, and the scientific complement on the individual cruises. In particular, Captain H. Payson, Jr. performed the navigation, Mr. D. M. Owen took photographs of the sea-floor with his camera, Mr. A. J. Nalwalk, and Mr. W. P. Horner dredged sediment, and Mr. J. E. Stiglitz operated the PGR, on many cruises. The author thanks all of them.

The acoustic data was reduced by Mrs. Fernande Breslau, my wife, who labored in my cause in numerous ways during the completion of this report. Needless to say, I am deeply grateful to her for her assistance.

The sediment samples were analyzed with the facilities of the Coastal Studies Group at WHOI. Valuable advice and assistance were proffered by Dr. J. M. Zeigler, Mr. W. D. Athearn, Mr. C. R. Hayes, Mrs. A. Biggs, and Dr. J. S. Schlee. The author appreciates their aid.

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The success of the sea-going operations was made possible by the officers and crew of the research vessels CHAIN, BEAR, ASTERIAS, ATLANTIS, and CRAWFORD, and the scientific complement on the individual cruises. In particular, Captain H. Payson, Jr. performed the navigation, Mr. D. M. Owen took photographs of the sea-floor with his camera, Mr. A. J. Nalwalk, and Mr. W. P. Horner dredged sediment, and Mr. J. E. Stiglitz operated the PGR, on many cruises. The author thanks all of them.

The acoustic data was reduced by Mrs. Fernande Breslau, my wife, who labored in my cause in numerous ways during the completion of this report. Needless to say, I am deeply grateful to her for her assistance.

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APPENDIX

THE SYSTEM SYNCHRONIZATION AND CONTROL UNIT.

The System Synchronization and Control Unit synchronizes and controls all the various components of the Acoustic Reflectivity System. It is contained in a single, completely transistorized chassis and is composed of four sections, a Main Synchronization Section, a Calibration Pulse Section, a Computer Freeze Section, and a Pulse Length Modulator Section.

The function of the Main Synchronization Section is to trigger the sweep of the information display oscilloscope, open and close the shutter of the oscilloscope camera, reset the Oceanographic Computer and initiate the operation of the Calibration Pulse and Computer Freeze Sections. In order to do all this it is necessary to convert the transient closure delivered by the Sweep Synchronized Positionable Trigger (mentioned in Chapter III) into a relay closure of precise duration. The circuitry employed (Figure 52) consists of a conventional monostable multivibrator (Lowry, 1960), and a transistorized relay. The pair of 2N525 transistors (T2 and T3) are arranged in a flip-flop configuration through the use of the collector to base cross-coupling networks and the 2N1671B unijunction transistor (T1) provides the timing for monostable operation. T3 is conducting in the quiescent state. When a transient closure from the Sweep Synchronized Positionable Trigger is received, a positive pulse is developed across the base of T3 which turns it off and consequently drives T2 into conduction. This causes a positive voltage to be applied to the base of the 2N1481 transistor (T4) which in turn energizes the relays. When T2 conducts, the timing capacitor (8 ufd) starts to discharge through the timing resistor (220 k) and after a definite interval the 2N1671B unijunction transistor fires and drives the base of T3 negative. This drives T3 into conduction which turns off T2 and deenergizes the relays to complete the cycle. The output is a relay closure which occurs when the transient closure is received from the Sweep Synchronized Positionable trigger and lasts about 1.8 seconds.

The function of the Calibration Pulse Section is to inject a 12 kcps pulse of precise duration into the transducer at the proper time for calibration purposes. In order to do this it is necessary to generate a relay closure of precise duration that is delayed a precise interval with respect to the synchronization from the Sweep Synchronized Positionable Trigger. The circuitry (Figure 53) consists of a time delay generator, a monostable multivibrator, and a transistorized relay. After this section is turned on through the output relay of the Main Synchronization Section, the 2N1671B unijunction transistor (T1) acting as a relaxation oscillator with a 50 millisecond time constant, delivers a series of positive pulses to the emitter of the 2N1671B unijunction transistor (T2) in the following stage. Since T2 is biased to bistable operation, it acts as a single-pass gate and permits the first positive pulse to pass through it and trigger the following monostable multivibrator and associated transistorized relay. The monostable multivibrator and transistorized relay then goes through their cycle as previously described except that the time constant is 10 milliseconds. The output is a relay closure of 10 millisecond duration which occurs 50 milliseconds after the transient closure is received from the Sweep Synchronized Positionable Trigger.

SYSTEM SYNCHRONIZATION AND CONTROL UNIT MAIN SYNCHRONIZATION SECTION

Figure 52 Schematic of the Main Synchronization Section of the System Synchronization and Control Unit

SYSTEM SYNCHRONIZATION AND CONTROL UNIT CALIBRATION PULSE SECTION

Figure 53 Schematic of the Calibration Pulse Section of the System Synchronization and Control Unit

The function of the Computer Freeze Section is to freeze the output of the Oceanographic Computer at the proper time and then trigger the digital voltmeter and Pulse Length Modulator Section, so that the computer output is recorded. In order to do this it is necessary to generate a relay closure of precise duration that is delayed a precise interval with respect to the synchronization from the Sweep Synchronized Positionable Trigger. The circuitry (Figure 54) is similar to that used in the Calibration Pulse Section except that the time constants are different and a single-pass gate is no longer necessary. The output is a relay closure of 1.2 second duration which occurs 400 milliseconds after the transient closure is received from the Sweep Synchronized Positionable Trigger.

The function of the Pulse Length Modulator is to generate a mark on the PGR of length proportional to the output of the Oceanographic Computer at a particular time. In order to do this it is necessary to generate a relay closure of duration proportional to the output voltage of the computer. The circuitry (Figure 55) consists of a flip-flop, a bootstrap sweep generator (Payne III, 1960), and a transistorized relay. The two left most 2N1672 transistors (T1 and T2) are arranged in a flip-flop configuration through the use of collector to base cross-coupling network and T2 is initially conducting. When a trigger is received from the Computer Freeze Section to initiate the pulse-length modulation process a negative pulse is applied to the base of T2 which turns the stage off. The accompanying rise in the collector voltage of this stage causes the diode D1 connected between it and the base of the following 2N1672 transistor (T3) to become back biased and thereby turns on the sweep circuit. This causes the voltage across the emitter resistor of T3, the sweep generator, to increase linearly with time until it reaches the value of modulating voltage that is developed at the output of the Oceanographic Computer; at this point the diode D2 between this emitter and the base of T2 becomes forward biased causing T2 to conduct, which completes the cycle. Therefore, the interval that T2 is non-conducting is proportional to the value of modulating voltage. Since the base of the 2N1310 transistor T4 in the transistorized relay is connected to the collector of T2, the interval that the relay is energized is the same as the interval of non-conduction of T2, and a closure interval proportional to the modulating voltage is developed.

SYSTEM SYNCHRONIZATION AND CONTROL UNIT COMPUTER FREEZE SECTION

Figure 54 Schematic of the Computer Freeze Section of the System Synchronization and Control Unit

SYSTEM SYNCHRONIZATION AND CONTROL UNIT PULSE LENGTH MODULATOR SECTION

Figure 55 Schematic of the Pulse Width Modulator Section of the System Synchronization and Control Unit

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THE NORMALLY-INCIDENT REFLECTIVITY OF THE SEA FLOOR AT 12 KC AND ITS CORRELATION WITH PHYSICAL AND GEOLOGICAL PROPERTIES OF NATURALLY-OCCURRING SEDIMENTS by L. R. Breslau. 129 pages. April 1967. Contract No. Nonr-4029(00) NR 260-101, Nonr-1841(74) NR 083-157, NObsr-72521 NObsr-89464.

The objective of this investigation was to measure bottom loss in normal incident reflection of pulses of 12 kcps sound and to study its geological significance. A semi-automatic instrument system was developed capable of making continuous measurements of the peak pressure and the time integral of the square of the pressure of the sea-floor echo from a vessel underway.

Observations were taken in both deep and shallow water in the Western North Atlantic. The early cruises were conducted in deep water to investigate the range and variability of bottom loss. Geological control consisted mainly of a precise bathymetric record. Later cruises were conducted in shallow water where the geology had been well studied previously. In these latter cruises the acoustic measurements were correlated with sediment dredging and underwater photography.

Thirty-one thousand acoustic measurements were made. Median bottom loss values and standard deviations were computed and the results summarized in eleven hundred sets, each set corresponding with a location at sea.

Seventy-seven sediment stations were occupied. A complete particle size analysis and a water content analysis were performed on these sediments to determine their size and mass characteristics.

The combined results show a good correlation between measurements of bottom loss and both mass and size characteristics of the sediment.

It seems that the Rayleigh reflection coefficient can be used to predict acoustic bottom loss at normal incidence. Conversely, normally-incident bottom loss can be used under the assumption of a Rayleigh reflection process to determine the bottom sediment.

1. Reflectivity of the Sea Floor
2. Bottom Loss

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