AN ACOUSTICAL SURVEYING TECHNIQUE FOR DETERMINING SEA-FLOOR SEDIMENTS

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INTRODUCTION

It is reasonable to believe that acoustic echoes received from the sea-floor are influenced by the geological nature of the bottom and therefore might be used for limited identification of reflectors. However, the overwhelming complexity of the generalised reflection process, the variability in echo characteristics from echo to echo, and the sheer tedium of making the acoustic measurement and performing the geological correlation have largely defeated previous attempts to use acoustic reflectivity for geophysical exploration. This present work circumvents the above-mentioned difficulties by accepting a simplified, but neverthless generally usable, acoustic model for the sea-floor, performing the shipboard acoustic measurements in a semi-automated fashion, measuring only easily recognisable qualities of the echo wave train, and analysing the data with highspeed digital devices. An effort was made to create a technique that eventually could be fully automated to perform its task on a ship underway at cruising speed.

Acoustic reflectivity was parameterised (determination of a parameter of a simple model which is assumed to represent a complex physical process) according to a specular-reflection model in which the sea-floor is considered to be represented by a plane interface between two fluids. This, of course, is an over-simplification of the condition that exists but is considered to be the best « a priori » representation of the sea-floor that is possible. Examination of oscillographs of wave trains of echoes received from the sea-floor has shown that the specular component is usually dominant (at normal incidence) and the assumed model justifiable. This model breaks down, and therefore this acoustical technique is not useful, where the sea-floor possesses a texture that is extremely rough compared with the wavelength of sound used or where the bottom is prominently layered.

The acoustic-reflectivity measurements were made at normal incidence and with two milli-second pulses of 12-KCPS sound. Normal incidence provides the largest echo return available in single-ship operation and, in fact, is the only practical way to achieve a usable signal-to-noise ratio under typical field conditions. A semi-automated 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 energy versus time waveform 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.

Both the peak amplitude and total energy of the acoustic echo were used as measures of acoustic reflectivity in this investigation. These quantities are easily discernable characteristics of an acoustic wave train and are amenable to machine determination. 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 and is obtained by measuring the final value of the time integral of the squared pressure (generated by an on-line analogue computer) of the wave train.

The tedium involved in analysing the acoustic and geologic data was minimised by the use of high speed digital devices. Both the acoustic and geologic data were put on punched cards for machine processing; the acoustic oscillograms were read by a manually operated analogue-to-digital converter and the geologic data was tabulated and hand punched. Once this step had been taken, all other operations including data reduction, statistical analysis, and tabulation and plotting of final results were performed by the digital computer, tabulator and plotter.

Theoretical development.

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

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

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, $1/(2D)^2$ is the transmission loss due to spherical spreading, and $e^{-\alpha 2D}$ is transmission loss due to dissipative attenuation of sound in sea-water. The fractional loss of intensity at the sea-floor, K, may be expressed on a pressure basis, thusly :

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

or on an energy basis, thusly :

$$K = \frac{\int_T^{T+\tau} P_R^2 \, dt}{P_{S\,(RMS)}^2 \times \tau} \times (2D)^2 \times \frac{1}{e^{-\alpha 2D}} \qquad \text{(Eq. 3)}$$

where P_R is the pressure of the echo, P_S is the pressure of the source at unit distance, D is the water depth, α is the dissipative transmission loss constant, T is the arrival time of the echo, and τ is the pulse length.

The fractional loss of intensity at the sea-floor, K, can be measured aboard the ship using equation 2 or equation 3. This measurement can then be related to the physical character of the sea-floor through the Rayleigh reflection coefficient (RAYLEIGHT, 1945) under the assumption that the water-sediment interface acts acoustically as a fluid-fluid boundary. The Rayleigh reflection coefficient is given as :

$$R = P_{REF} / P_{INC} = \left(\frac{\rho 2}{\rho 1} - \frac{\sqrt{C_1^2/C_2^2 - \text{SIN}^2\theta}}{\sqrt{1 - \text{SIN}^2\theta}} \right) \Bigg/ \left(\frac{\rho 2}{\rho 1} + \frac{\sqrt{C_1^2/C_2^2 - \text{SIN}^2\theta}}{\sqrt{1 - \text{SIN}^2\theta}} \right) \qquad \text{(Eq. 4)}$$

where P_{INC} and P_{REF}, respectively, represent the pressure of the acoustic waves incident on and reflected from the sea floor, ρ_1 and ρ_2, respectively, may be considered as the densities of the sea water and sea-floor sediment, C_1 and C_2, respectively, may be considered as the acoustic velocities of the water and sea-floor, and θ is the angle of incidence.

$$R = (\rho_2 C_2 - \rho_1 C_1) / (\rho_2 C_2 + \rho_1 C_1) \qquad \text{(Eq. 5)}$$

The expression $\rho \times C$ is called the specific acoustic impedance of the medium and is designated as Z. Using this convention, Eq. 5 can be put down in the following form :

$$R = (Z_2 - Z_1) / (Z_2 + Z_1) \qquad \text{(Eq. 6)}$$

where Z_1 and Z_2 refer to the specific acoustic impedance of sea-water and sediment respectively.

The fractional loss of intensity, K, is proportional to the square of the Rayleigh reflection coefficient since acoustic intensity is proportioned to pressure squared. K can be measured by the relationship expressed in Eq. 2, or by the relationship expressed in Eq. 3, the former is considered to be a measurement on a pressure basis and the latter on an energy basis. Since it is convenient and conventional to express hydroacoustic measurements in decibel form, the fractional loss of intensity at the sea-floor is usually reported as « bottom loss » where bottom loss is defined as — 10 log K. Therefore bottom loss (BL) can be expressed as follows :

$$BL = -20 \log R \qquad \text{(Eq. 7)}$$

The relationship between bottom loss and the Rayleigh reflection coefficient, given in Eq. 7, and the relationship between the Rayleigh reflection coefficient and the acoustic impedance contrast at the water-sediment interface, given in Eq. 6, 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 occuring oceanic sediments, it is possible to establish a relationship between bottom loss and porosity. This relationship will be developped 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 occuring 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 ot 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 :

$$\rho_{SED} = \rho_{WAT} \times \Phi + \rho_{SOL}\left[1 - \Phi\right] \qquad \text{(Eq. 8)}$$

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 occuring 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 were plotted versus porosity without regard to sediment type. 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 :

$$C = \left[\frac{K + (4/3)\mu}{\rho}\right]^{1/2} \qquad \text{(Eq. 9)}$$

where ρ is the density, K is the bulk modulus, and K is the modulus of rigidity.

Where rigidity is negligible Eq. 9 reduces to : $C + (B \times \rho)^{-1/2}$ ((Eq. 10

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. 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 :

$$B_{SED} = B_{WAT} \times \Phi + B_{SOL} \left[1 - \Phi \right] \qquad \text{(Eq. 11)}$$

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. 10. The density and bulk compressibility may be approximated by Eq. 8 and Eq. 11 respectively. The compressional-wave velocity may therefore be expressed in the following form (Wood's Equation) :

$$C = \left(\left[\rho_{WAT} \times \Phi + \rho_{SOL} (1 - \Phi) \right] \times \left[B_{WAT} \times \Phi + B_{SOL} (1 - \Phi) \right] \right)^{-1/2} \qquad \text{(Eq. 12)}$$

using Eq. 8, Eq. 10, and Eq. 11. 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 have been plotted versus porosity.

The specific acoustic impedance of the sediment may be obtained by taking the product of the density (Eq. 8) and compressional-wave velocity (Eq. 12). This impedance, in conjunction with the specific acoustic impedance of sea-water, may be used to determine the Rayleigh reflection coefficient (Eq. 6). The bottom loss, in decibel form may then be obtained through Eq. 7. A plot of density, velocity, impedance, reflection coefficient, and bottom loss versus porosity is presented in figure 1 to portray the relationships that exist between these variables according to Eq. 6, Eq. 7, Eq. 8, Eq. 10, Eq. 11, and Eq. 12. Densities of 1.03 g/cm^3 and 2.75 g/cm^3 and compressibilities of 43×10^{-12} cm^2/ dynes and 2.0×10^{-12} cm^2/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 physical properties of sediments has been discussed above. 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 of textural 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 occuring in natural sediments are not spheres and considering them as much is oversimplifying the situation to the point that is misleading. The porosity of a natural sediment is a function of the grain size (median grain size), distribution of grain sizes (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 comcomitantly related in natural sediments, and it is difficult to isolate individual effects. Neverthless, 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

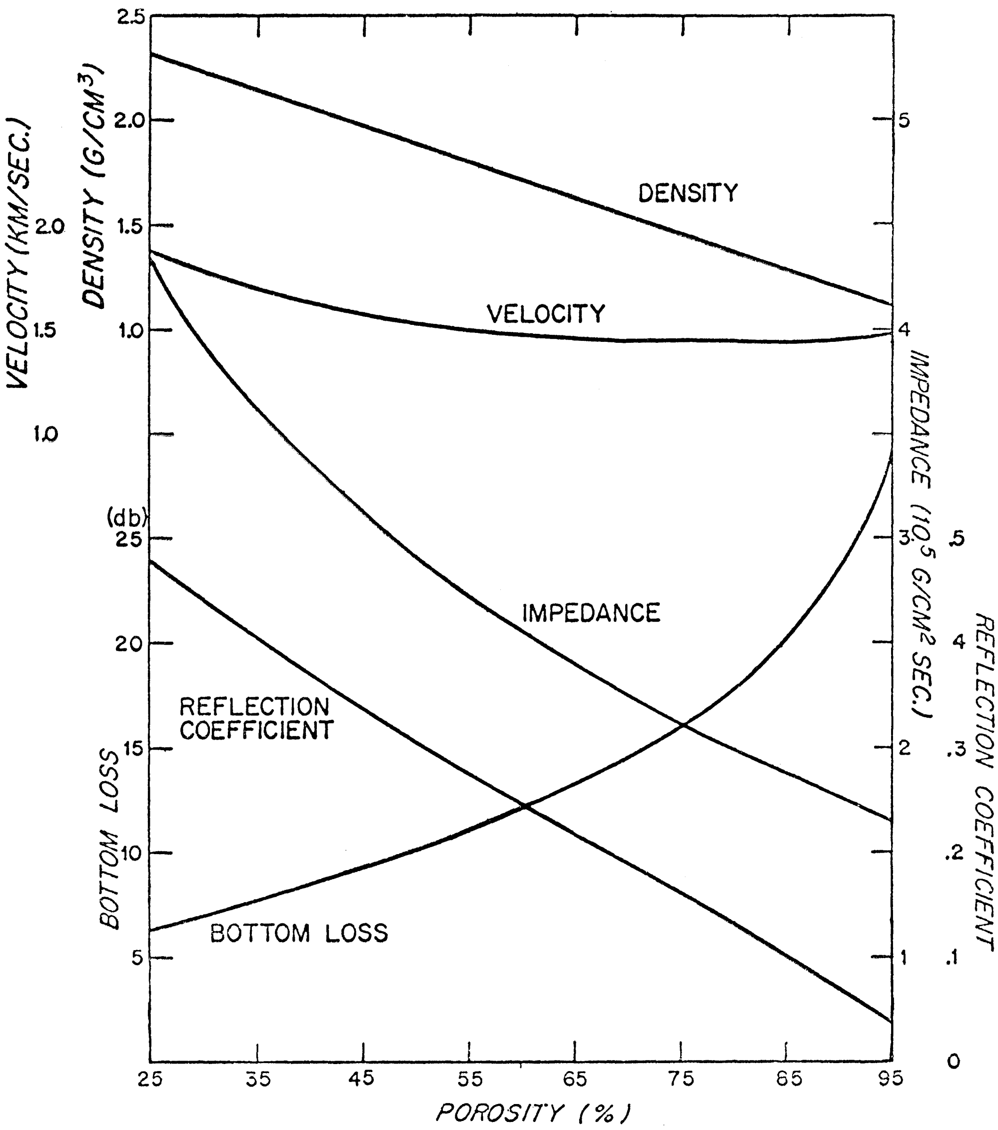

FIG. 1. — *Theoritical curves of density, velocity, impedance, and reflection coefficient versus porosity.*

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 absorbed water to particle volume with attendant increase in porosity; for small particles the surface absorbed 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

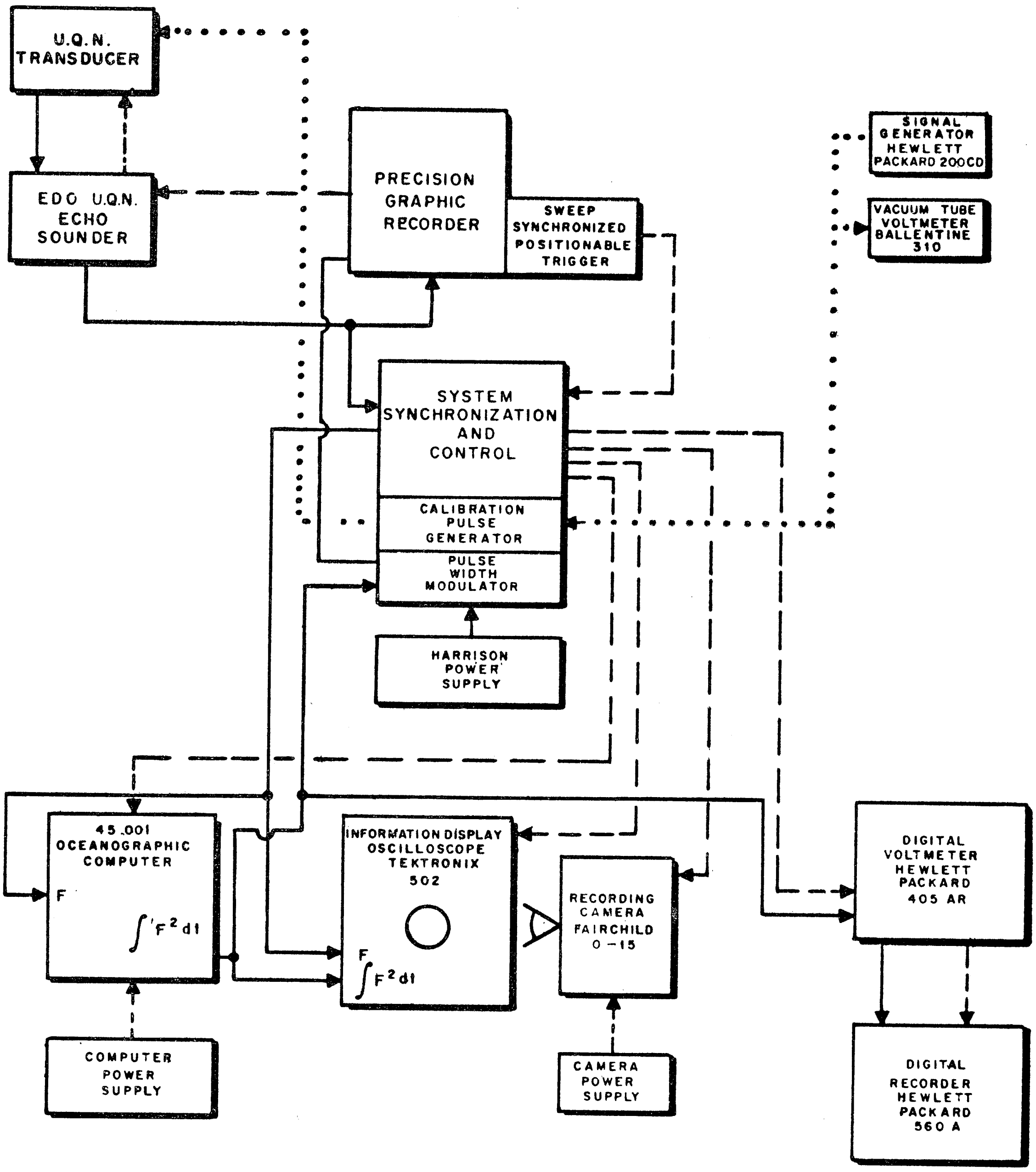

FIG. 2. — *Block diagram of the acoustic reflectivity system.* ——— Information signal flow path, · · · · Calibration signal flow path, — — — Synchronization control and power flow path.

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 and MENARD, 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; these relationships for natural sediments have been empirically established (FRASER, 1935; TRASK, 1932; KRYNINE, 1947; BIRCH *et al.*, 1942; HAMILTON *et al.*, 1956; SUTTON *et al.*, 1957; SHUMWAY, 1960; SARMIENTO and KIRBY, 1962).

In resume, bottom loss is directly related to the porosity, inversely related to the grain size, and directly related to the fine component fraction (silt plus clay), for natural marine sediments.

Instrumentation.

The shipborne instrumentation system used to make the acoustic-reflectivity measurements incorporated the AN/UQN-1b Sonar Sounding Set, a familiar Navy echo sounder (Edo Corp.); the Precision Graphic Recorder (PGR), a correlation recorder adapted to high-resolution echo-souding (KNOTT and HERSEY, 1956); 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 governed the operation of the entire system; the Sweep-Synchronized Positionable Trigger, an appendange to the Precision Graphic Recorder which provided synchronization with the anticipated arrival of the echo; and two systems for recording the measurement : a dual-beam oscilloscope (Tektronic Inc.) and camera (Fairchild Camera and Instrument Corp.), and a digital voltmeter and recorder (Hewlett-Packard Co.). The transducer used as the source and receiver was the UQN-1b mounted in a towed fish, which is a standard sonar transducer utilizing the piezoelectric properties of ammonium dihydrogen phosphate (ADP) crystals.

A functional block diagram of the system is shown in figure 2. 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, 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.

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. Measurements of the total energy contained in the are also provided by both the pulse-width modulator, a sub-system 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.

Field work.

An extensive (31,000 measurements at 1,100 locations) field investigation of acoustic reflectivity was made 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 and geological control consisted mainly of a precise bathymetric record. The latter cruises were conducted in shallow water, in areas where the geology had been well studied previously by investigators using techniques of classicial geology. In these latter cruises some acoustic measurements were taken in conjunction with dredged sediment samples and it is this data which is presented in this report.

Seventy-six combined acoustic and sediment stations were occupied on the Continental Shelf south of New England and in Narragansett Bay. The ship was stopped at the site of each station and an acoustic and sediment sample were taken in parallel. The acoustic samples were taken by the shipborn acoustic reflectivity system described in the instrumentation section of this report. The geologic samples were taken with a Van Veen dredge (Thamdrup, 1938) which is a member of the « Clamshell » group of bottom samplers and takes a grab sample. The original acoustic and sediment samples dried out during storage and therefore were good for a grain-size analysis only. Therefore, the sites of the combined acoustic and sediment stations were later revisited and samples were taken in a manner that permitted them to be used for a water-content analysis.

Data analysis.

The original acoustic data are predominantly in the form of cathode-ray oscilloscope photographs of the echo wave-train, displayed on 100-feet strips of 35 mm negative film. The negative film was processed to form a continuous-strip positive print which was directly read with a manual analogue to digital oscillogram scanner; the displacements representing the peak pressure and final value of the time integral of the squared pressure, of the bottom echo and associated calibration pulse were measured and automatically recorded on punched cards, which were manually re-punched to include the water depth and geographical position of the measurement. This data was then processed by a digital computer which selected the median echo on both a peak-pressure and total-energy basis (over fifty individual acoustic echoes were measured at each station) and computed the median value of bottom loss on both of these basis. The computation was made by recourse to the formulas presented earlier in this report ($\alpha = 1.2$ dB per kiloyard; Horton, 1959) and the response characteristic of the transducer; the receiving sensitivity was taken as — 73 dB// 1 volt for a sound field of 1 dyne/cm^2 and the « source » level was taken as equal to 79 dB + 20 log V where V is equal to the voltage developped across a 10 ohm resistor located inside the transducer and in series with the ADP crystal.

The sediment samples for the grain-size analysis were allowed to soak overnight in distilled water, with sodium-hexamtaphosphate added as a dispersing agent, before being analysed. A classical grain-size analysis was then performed using sieve, settling tube (Ziegler, Whitney and Hayes, 1960), and pipette (Krumbein and Pettijohn, 1938) techniques to obtain the median grain size, the sizes at the twenty-five and seventy-five percent quartiles, and the gravel, sand, silt, and clay percentages. This data was then processed by a digital computer to give each sediment sample a class name in accordance with the commonly used three-component sand-silt-clay system (SHEPARD, 1954), and compute the TRASK sorting-coefficient, defined as the square root of the ratio of the larger quartile to the smaller quartile (KRUMBEIN and PETTIJOHN, 1938).

The sediment samples for the water-content analysis were 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. This data was then processed by a digital computer to calculate porosity, density, velocity, acoustic impedance, Rayleigh reflection coefficient, and theoretical bottom loss in dB, according to the relationships presented earlier in the section on theoretical development.

	Regression Line Slope	Correlation Coefficient	Z Statistic
	*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 ± .580db/trask unit)	.343 (.445)	.358 ± .234 (.478 ± .234)
Fine Material	0.83 ± .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.

TABL. 1. — *Statistical relationships between acoustic measurements and sediment properties.*

A correlation and regression analysis was performed between the acoustic measurements (Median values) and the characteristics of the sediment samples. The statistical quantities obtained were the regression equation (the best-fitting line, chosen on a least squares basis, through the experimental data), the correlation coefficient (a measure of the degree to which the experimental data indicates that a linear relationship exists between the variables tested), and the Z statistic (HOEL, 1962) (a normally distributed function of the correlation coefficient used to test its statistical significance). Bottom loss, measured on both peak-pressure and on a total-energy basis, was tested against porosity, median grain-size, sorting coefficient, percentage of fine material (silt + clay), percentage of silt and percentage of clay.

Results and conclusions.

Acoustic-reflectivity measurements made over areas where the geology had been studied previously by other investigators were found to agree well with the results of the previous geological work. In particular, acoustic reflectivity, on both a peak-pressure basis and total energy basis, was found to carrelate with the grain-size and silt + clay content of the sediment and be indicative of sediment type (class name).

The magnitudes of the correlation coefficients presented in table 1 demonstrate that a significant correlation exists between bottom loss and all of the geological quantities that were tested; a correlation coefficient is considered significant (at the 95 % level) when the value of its corresponding Z statistic is larger than two standard deviations of the Z statistic. 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

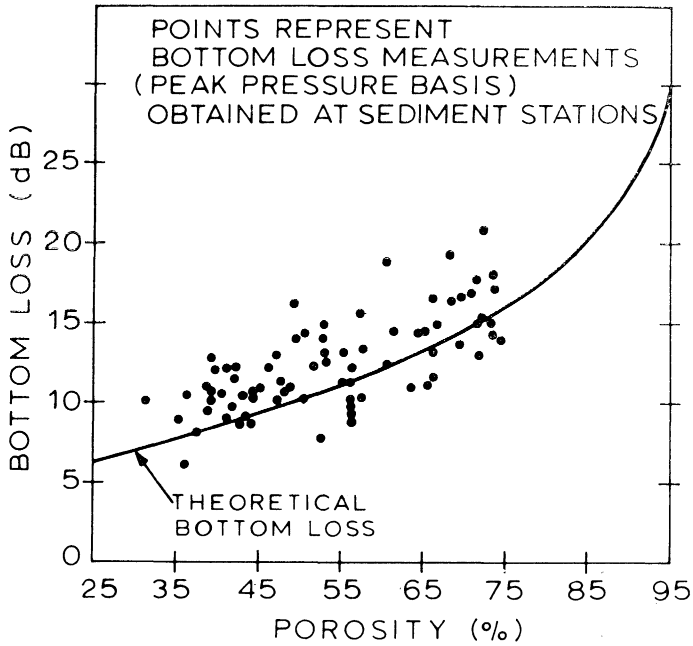

FIG. 3. — *Bottom loss measurements* (Peak Pressure Basis) *at sediment stations versus measured porosity of the sediment.*

of sorting). The strength of the relationship appears greatest for amount of fine material, silt, and clay, slightly less for porosity, slightly less again for median grain size, and weakest for degree of size sorting. No significant difference was found between the acoustic measurement made on a peak-pressure basis and that made on a total-energy basis, with regard to correlation observed between bottom loss and the various geological quantities tested.

These correlation coefficients only indicate the existence of a relationship between the acoustic and geologic quantities, they do not imply any cause and effect. The relationships that do exist, however, may be explained by the causes and effects hypothesized in the theoretical development section of this report. A plot of measured bottom loss (peak-pressure basis) versus sediment porosity is presented in figure 3. The relationship between bottom loss and porosity agrees quantitatively with that predicted on theoretical grounds. The slope of the line of best fit for the experimental points is .171 dB per percent porosity; in this porosity range the theoretical curve of bottom loss versus porosity is approximately linear, and possesses a slope of .20 dB per percent porosity. It is believed that much of the scatter of the experimental points about the theoretical curve is due to positional error in sampling, and that the bottom loss versus porosity relationship would have shown the strongest correlation if the water-content measurements had been made on the original suite of sediment samples.

The relationships found between bottom loss and all the sedimentological characteristics tested agree qualitatively with those qualitatively postulated on heuristic ground. A scatter graph plot of measured bottom loss (peak-pressure basis) versus the percentage of fine material (silt and clay) in the sediment, and the regression line between them is presented in figure 4, to show the degree to which these quantities were found to be related. It is evident that there is a general tendency for bottom loss to increase as the percentage of fine material in the sediment increases.

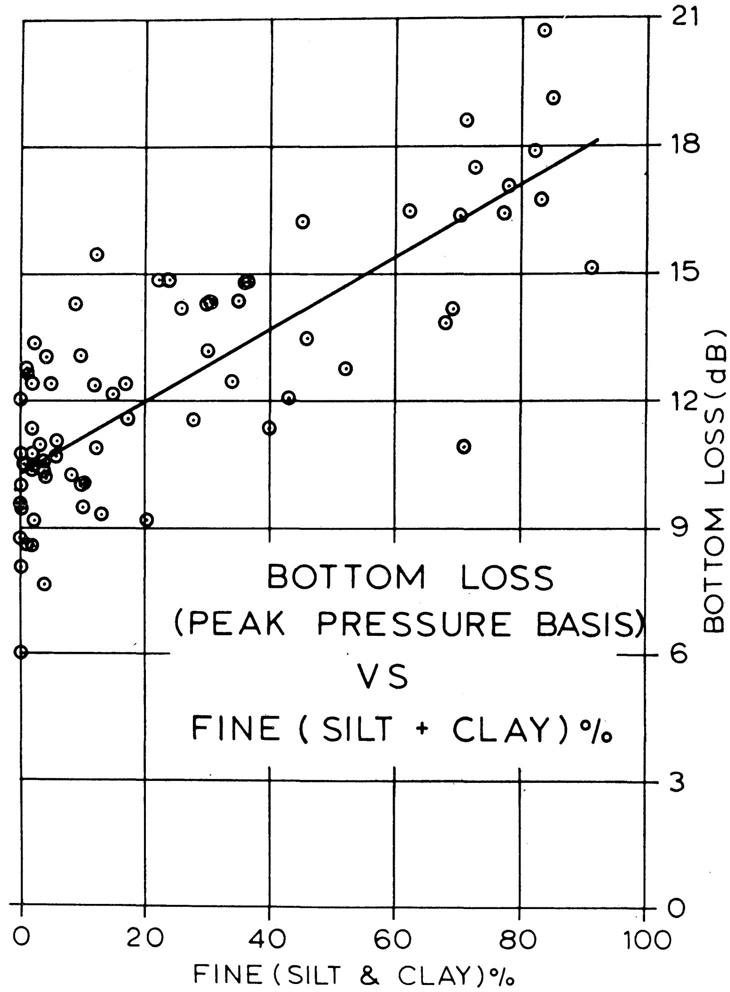

FIG. 4. — *Scatter diagram of bottom loss measurements* (Peak Pressure Basis) *at sediment stations versus percentage of fine material* (Silt + Clay) *in the sediment.*

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