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ACOUSTICAL CHARACTERISTICS OF THE SEA FLOOR:
EXPERIMENTAL TECHNIQUES AND SOME EXAMPLES FROM THE MEDITERRANEAN SEA

by

TUNCAY AKAL

1 NOVEMBER 1974

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Reprinted from: **PHYSICS OF SOUND IN MARINE SEDIMENTS**
Edited by Loyd Hampton
Book available from: Plenum Publishing Corporation
227 West 17th Street, New York, New York 10011

ACOUSTICAL CHARACTERISTICS OF THE SEA FLOOR: EXPERIMENTAL TECHNIQUES AND SOME EXAMPLES FROM THE MEDITERRANEAN SEA

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ABSTRACT

The acoustical properties of the sea floor are primarily determined by the physical properties of the sediments, layering in the sediments, and the roughness of the bottom and sub-bottom. Over the last decade many cores and bottom photographs have been taken and acoustical measurements made to improve our understanding of the mechanism governing the physics of sound in marine sediments. The results of such studies made by NATO SACLANT ASW Research Centre in different regions of the Mediterranean Sea are presented. Methods of observation and data analysis are briefly discussed. The relationships among those properties of the sediments that affect the acoustical characteristics of the bottom are given and results are compared with the acoustical measurements.

INTRODUCTION

As the physical properties of the sea floor affect the propagation of acoustic energy in this medium, knowledge of these properties and their relation to acoustical parameters is essential for the understanding of the physics of sound in marine sediments.

Research on the physical and acoustical properties of the Mediterranean sea floor has received considerable attention in the SACLANT ASW Research Centre and a number of theoretical and experimental studies have been made since the early 1960's. In the studies conducted the main emphasis has been:

i) To determine the magnitude of bottom reflection losses with respect to frequency and the angle of incidence, the distortion of the reflected waves, and scattering.

ii) To relate these acoustic parameters to the environmental characteristics of the sea floor, such as physical properties of the sediments, layering in the sediments, and the roughness of the bottom.

The Mediterranean Sea is one of the major closed basins of the world and is composed of a western and an eastern basin separated by a shallow sill across the Strait of Sicily (Fig. 1)[Akal 1972a]. These basins have many physiographic and sedimentary features that are characteristic of oceanic basins, such as well-developed continental shelves (comparatively narrow in the Mediterranean), continental slopes (steep and generally cut by submarine canyons), continental rises and abyssal plains (extensive areas where the depths are about 3000 meters in the western basin, the greatest depth of 5081 meters being in the eastern basin) where sediment deposition mostly occurred by turbidity currents. These two basins can be subdivided further into a complex of small basins with quite arbitrary boundaries. The western basin contains the Alboran-Balearic zone, which includes an extensive abyssal plain, and the Tyrrhenian basin, with a central abyssal plain and its characteristic volcanic seamounts. The eastern basin, which is remarkably different from the western basin, mainly comprises (i) a small abyssal plain in the Ionian basin, (ii) the Mediterranean ridge extending from the Ionian basin and covering the central part of the Levantine basin, (iii) small plains located around the Mediterranean ridge, and (iv) the Nile cone.

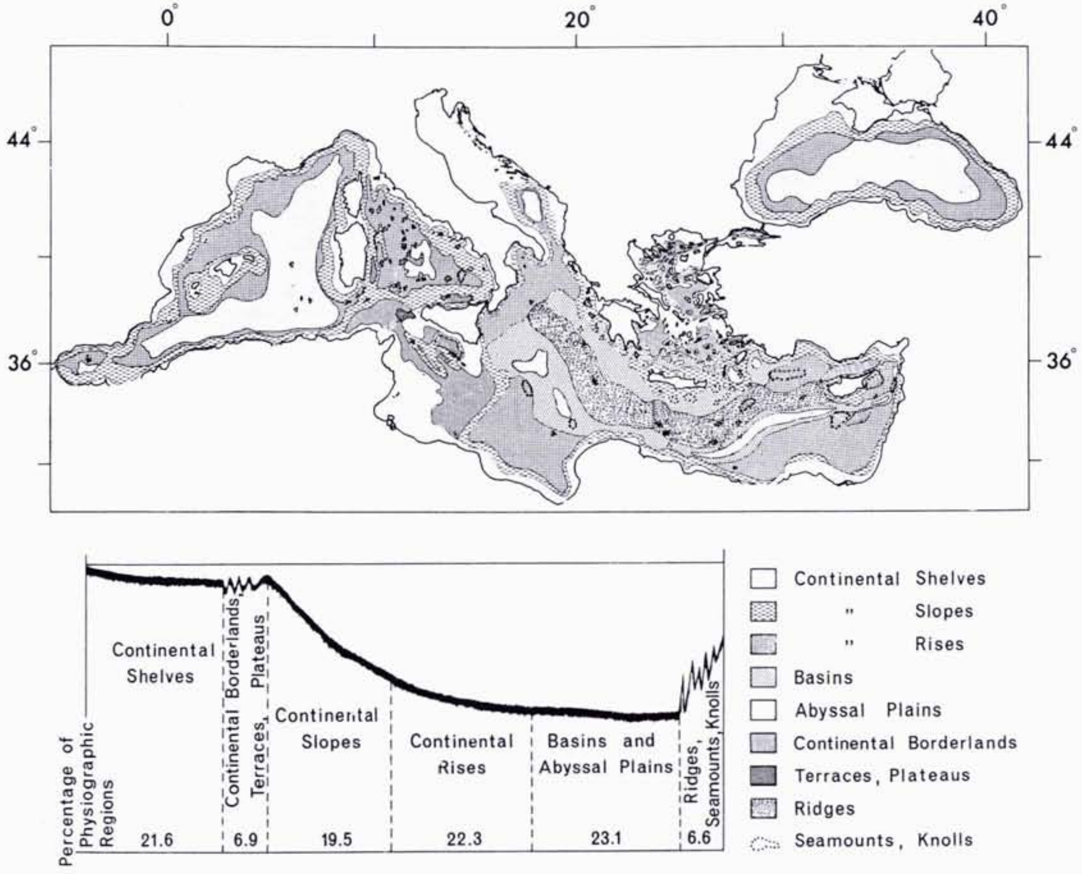


FIGURE 1

MAJOR PHYSIOGRAPHIC REGIONS OF THE MEDITERRANEAN AND BLACK SEAS. [AFTER AKAL (1972a)].

METHODS OF DATA ACQUISITION AND ANALYSIS

Acoustical Parameters

Most of our present knowledge of the sea floor has been obtained through geophysical methods using acoustics as a tool. Seismic continuous profiling, reflection, and refraction measurements are three important and "direct" uses of acoustics in sea floor studies. Generally, continuous profiling methods give the gross features of the configuration of bottom and sub-bottom, and reflection/refraction measurements give detailed information of the velocities in the layers, losses, signal distortion and impulse responses.

Reflection methods have been used at SACLANTCEN to investigate the acoustical properties of the bottom, with emphasis on the intensity of reflection, the distortion of the reflected wave, and scattering. Since all these parameters are frequency and angle dependent, explosive sound sources with firing-ship and receiving-ship combinations have been used to cover a large frequency band and different angles of incidence.

There are mainly two techniques used during reflectivity measurements, as seen in Fig. 2. Although the technique of operating

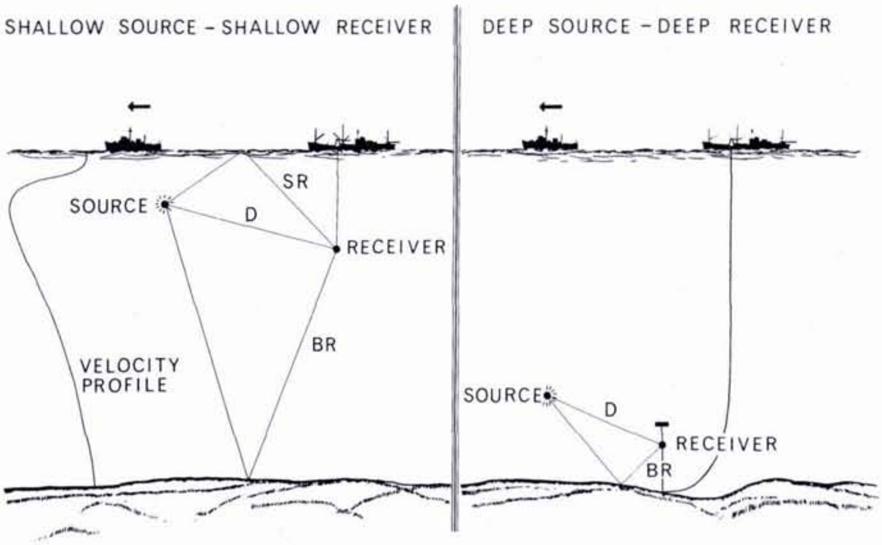


FIGURE 2

BOTTOM REFLECTIVITY MEASURING TECHNIQUES.

with shallow source and receiver is very rapid, the deep source and receiver technique has the advantages that it is self-calibrating, no surface reflections are involved, rays pass through a rather constant environment, and small areas are insonified.

The signals are generally recorded on both ships in digital form. Figure 3 shows the block diagram of the equipment most often used. A typical example of a recorded signal is shown in Fig. 4, where direct and bottom reflected signals are apparent.

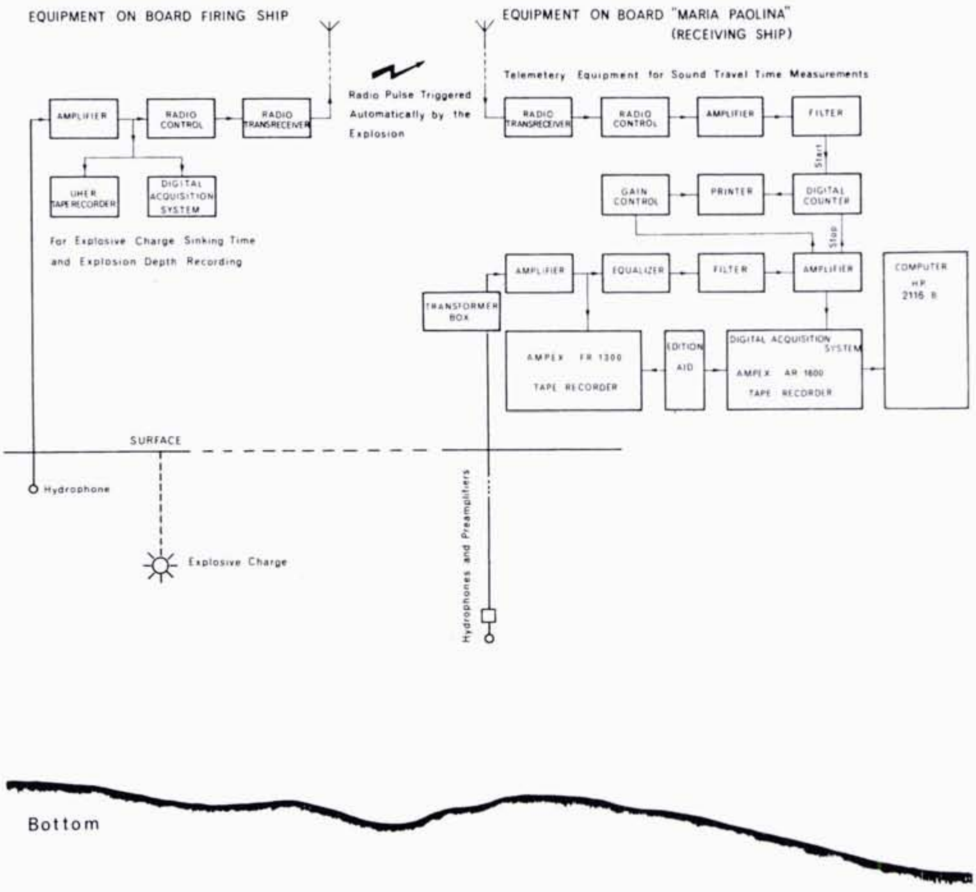


FIGURE 3

BLOCK DIAGRAM OF THE EQUIPMENT.

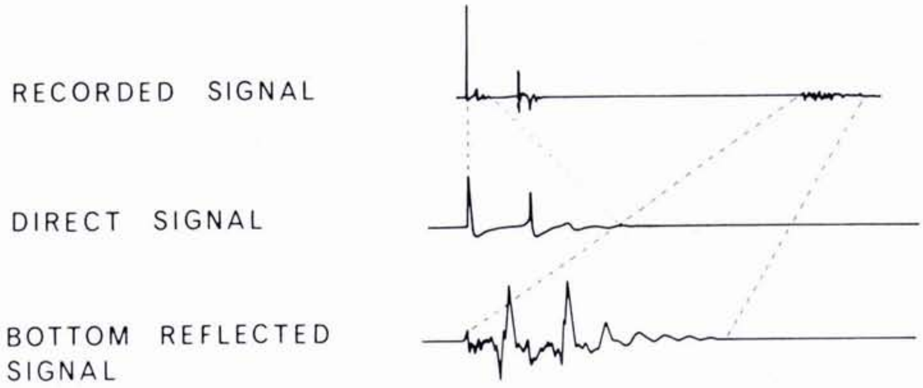


FIGURE 4

AN EXAMPLE OF A RECORDED SIGNAL AND ITS COMPOSITION.

Many different techniques exist to compute reflection losses from experimental results. The methods used at SACLANTCEN were developed by O. Hastrup, and references [Hastrup 1966a,b,c.,1967a,b., 1968,1969a,b.] give details of these techniques. These methods are briefly discussed below.

1. For water/sediment interface. When the first bottom layer is sufficiently thick, the reflected explosive source signals from the water-sediment interface can be resolved in time from the deeper reflections. Thus it is possible in a simple way to calculate the frequency-independent reflection loss as the ratio between the amplitude of the shock pulse and the peak of the first reflection (after correction for phase shift, absorption, and differences in spreading loss). Recorded signals and reflection losses as a function of grazing angle are shown together with the physical properties of the cores in Fig. 5 [Michelozzi 1973, Akal et al. 1972].

2. For layered bottom. Since sea floors are usually layered, the reflection losses for the whole bottom cannot be obtained by the peak amplitudes method because of the frequency dependence. In this case the analysis (Fig. 6) is based on considering the bottom to be a linear system and computing its transfer function (or the reflection coefficient) from the deconvolution of the direct signal with the reflected signal, using Fourier transforms. Examples of the phase shift and reflection loss as a function of frequency are also shown in Fig. 6.

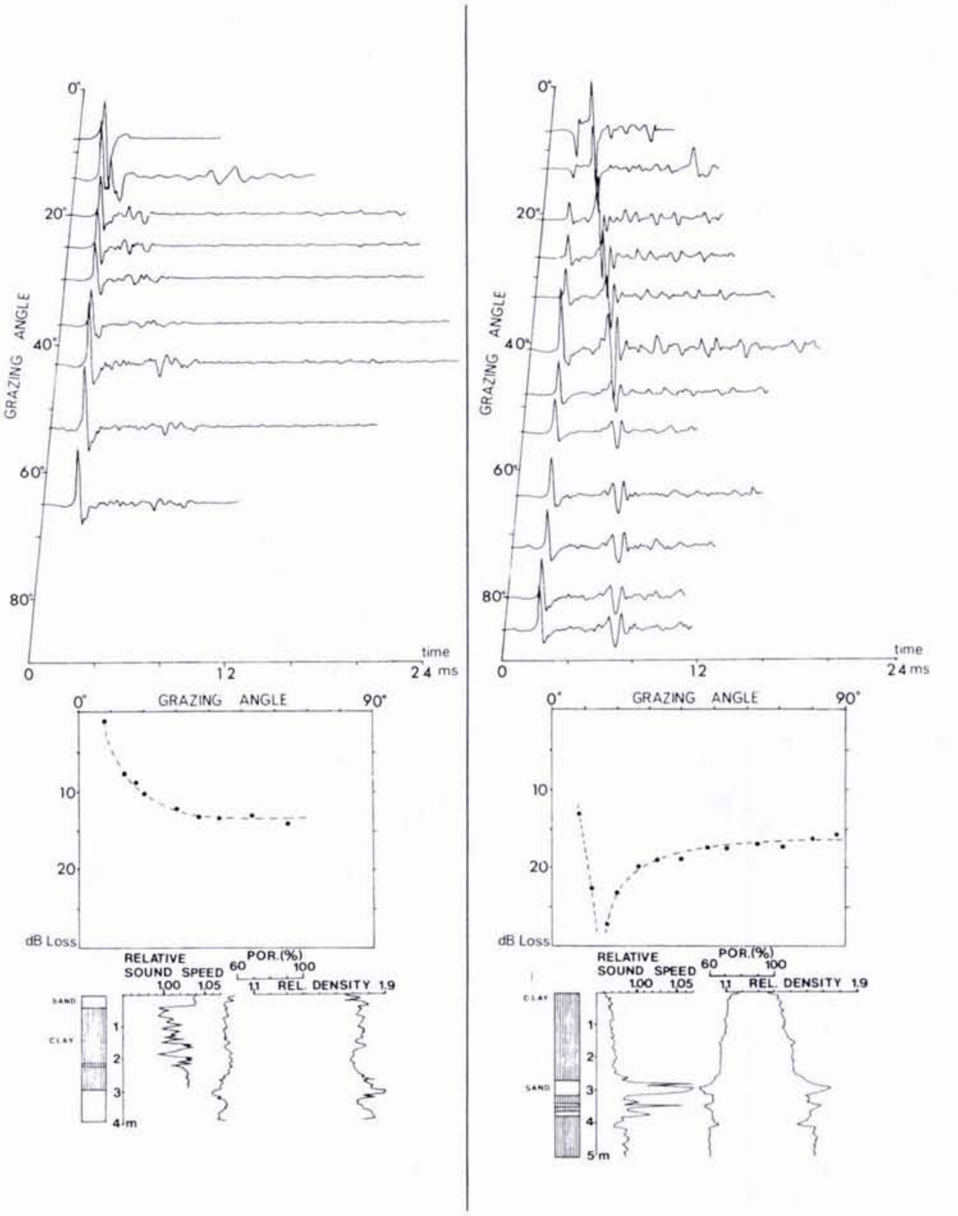


FIGURE 5

RECORDED SIGNALS AND REFLECTION LOSS AS A FUNCTION OF GRAZING ANGLE AND CORE PROPERTIES. [AFTER AKAL (1972a) AND MICHELOZZI (1973)].

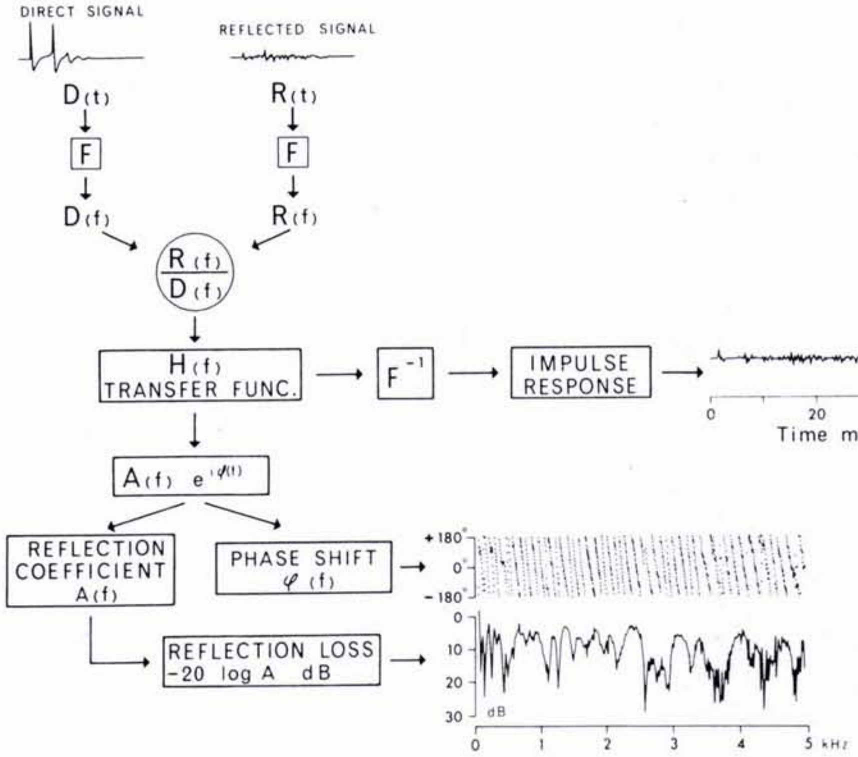


FIGURE 6

DATA ANALYZING TECHNIQUE FOR LAYERED BOTTOM.

The reflectivity can also be described in the time domain by the impulse response, which is the inverse Fourier transform of the transfer function, also shown in Fig. 6. Here the effect of the bubble pulse has disappeared due to the use of a deconvolution process (Fig. 7) developed by J. Hovem [1969]. Figure 8 shows some of the results obtained with these analysis techniques during a reflectivity measurement.

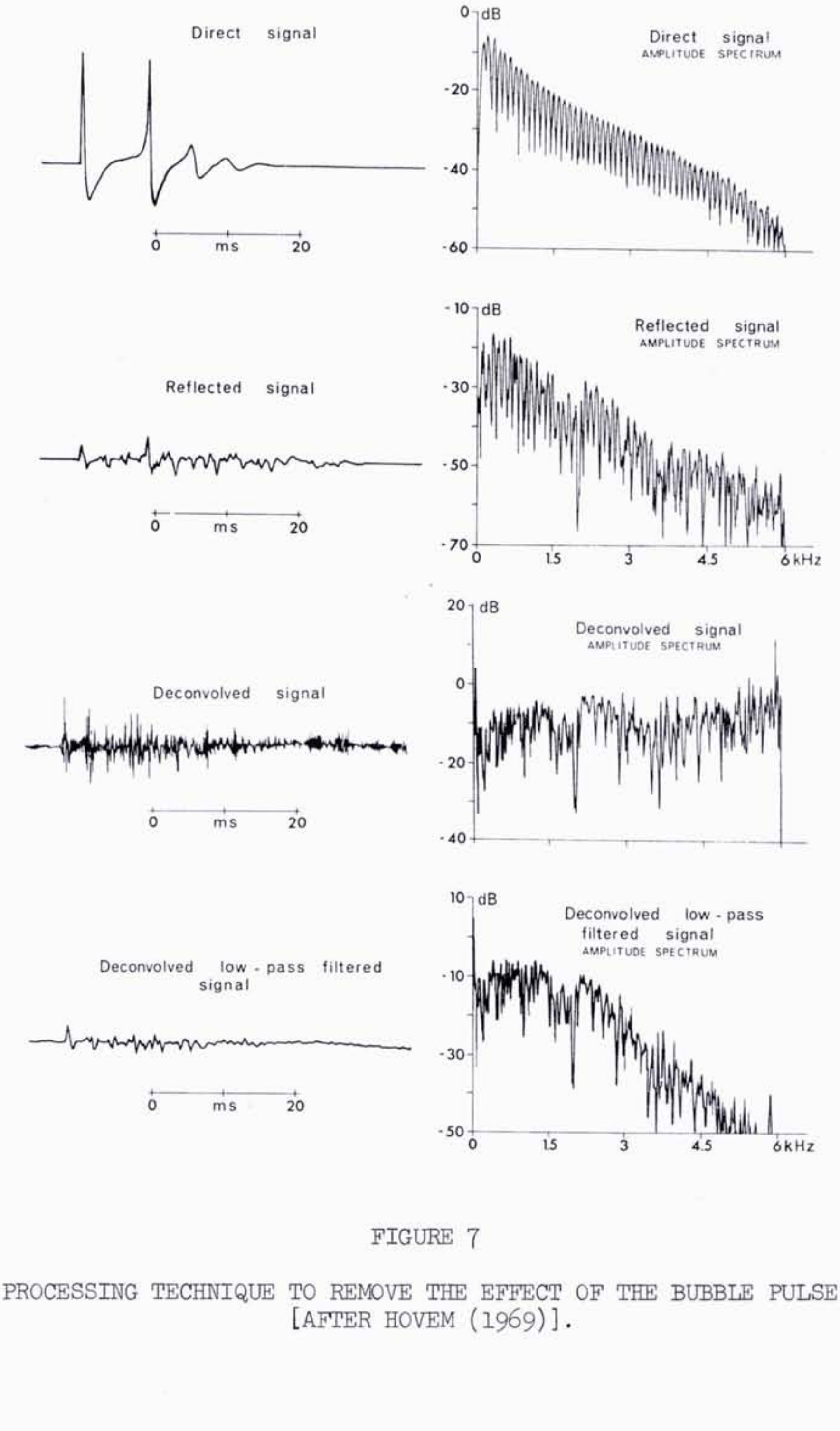


FIGURE 7

PROCESSING TECHNIQUE TO REMOVE THE EFFECT OF THE BUBBLE PULSE. [AFTER HOVEM (1969)].

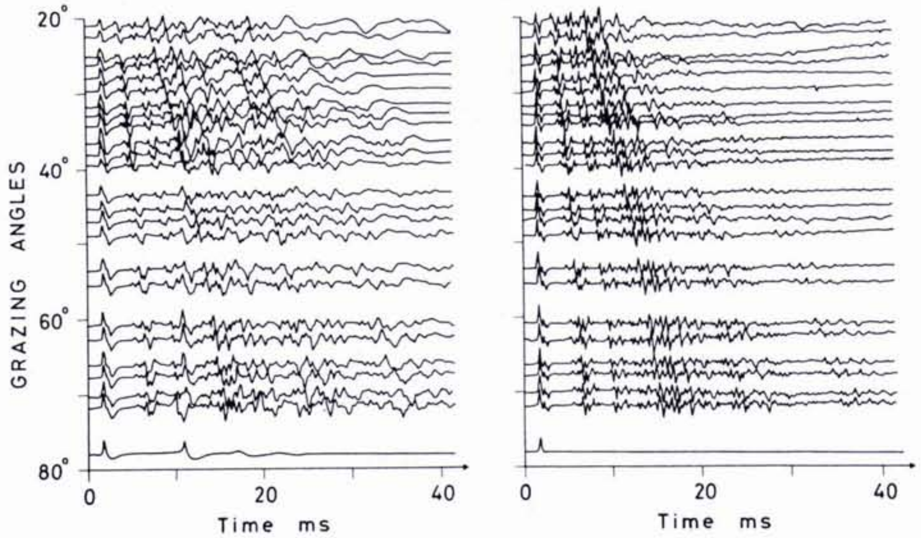


FIGURE 8

REFLECTED SIGNALS AS A FUNCTION OF GRAZING ANGLE BEFORE AND AFTER DECONVOLUTION PROCESSING. [AFTER HOVEM (1969)].

ENVIRONMENTAL PARAMETERS

Physical Properties of Sediments

One of the important objectives in acoustic studies of the sea floor is to know to what extent bottom reflectivity can be predicted from a knowledge of the physical properties of the sediments. Most of our knowledge of the physical properties of sediments is acquired through core sampling. Cores are obtained with the 12 m long and 12 cm diameter SACLANTCEN sphincter corer [Kermabon et al. 1966] and analyzed at 2 or 5 cm intervals along the core to obtain the parameters shown in Fig. 9. Sound speeds are measured by a pulse technique, where the accuracy is approximately ±0.1% in clay and ±0.4% in sand layers. Samples on which physical measurements are made are removed from the same levels at which sound speed measurements were taken. Physical measurements are made of porosity, wet and dry density, water content, void ratio, resistivity, and grain size, with estimated accuracies of about ±1% for porosity, ±0.2% for water content, ±1% for wet density, ±6% for dry density, ±0.2% for void ratio [Kermabon 1967]. After being cut in half the cores are photographed and lithological descriptions are annotated.

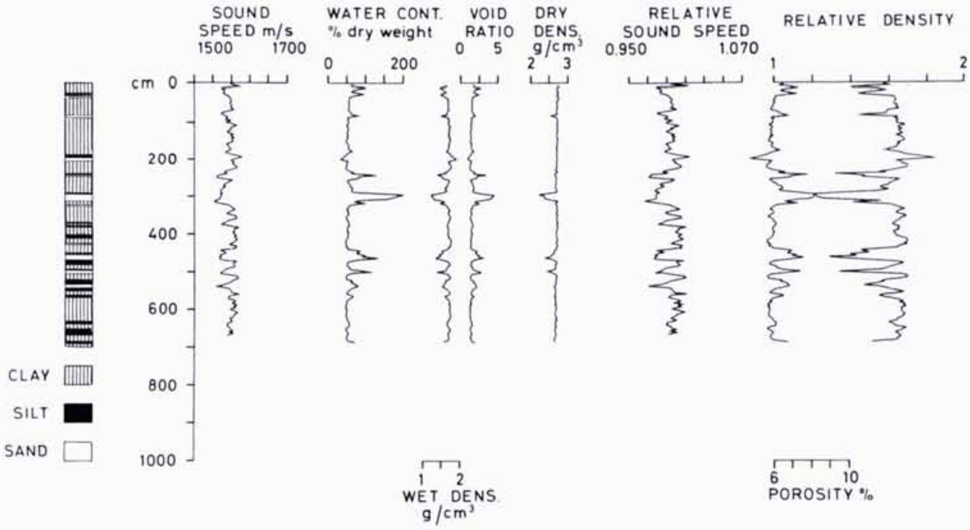


FIGURE 9

PARAMETERS MEASURED AND COMPUTED ALONG A CORE.

To establish a range of normal incidence reflection loss for any particular zone [Akal 1972a], curves can be constructed giving relative porosity from the measured data on all cores taken in the zone. From these the normal incidence reflection coefficient can be computed to give the reflection loss versus porosity relationship (Fig. 10).

It is well known that the reflectivity of the bottom can be expressed as a function of the compressional and shear velocities, the attenuation of compressional and shear waves, and the density. Since our analysis does not include a determination of attenuation, nor of shear velocity, these quantities are deduced from our physical measurements using the results obtained by Hamilton [1971a,b and 1972]. These data are then used as inputs to a computer model to predict bottom losses and impulse responses. The measured and computed results are shown in Fig. 11, where it can be seen that the agreement is remarkably good [Hastrup 1969a].

Layering in the Sediments

The layering of the upper 10 m has a significant effect on the reflection process. An inspection of deep water cores taken in the Mediterranean shows that generally they are of two distinct types. As seen in Fig. 12, core No. 137 consists of many layers (turbidity sediments), whereas core No. 138 is very homogeneous (pelagic sediments). They were both taken from the Ionian basin about 220 km apart. The changes of sound speed, density, and porosity as a function of depth are shown in the same figure. The changes in the properties are also evident from plots of sound speed and density versus porosity. Changes in these parameters naturally cause the reflection characteristics of the bottom to change. The signals

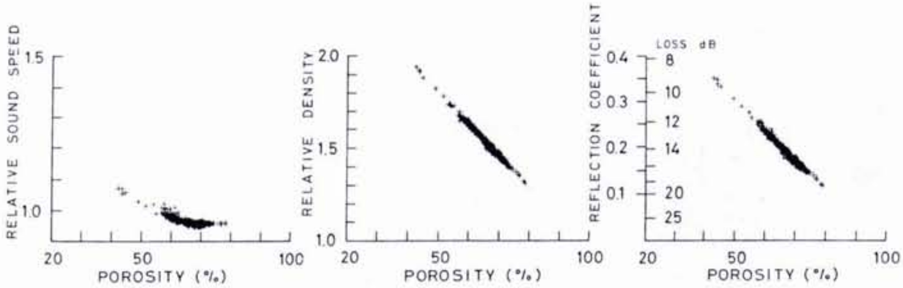


FIGURE 10

RELATIONSHIP BETWEEN SOME OF THE MEASURED PARAMETERS AND COMPUTED NORMAL INCIDENCE BOTTOM LOSS FOR ONE AREA.

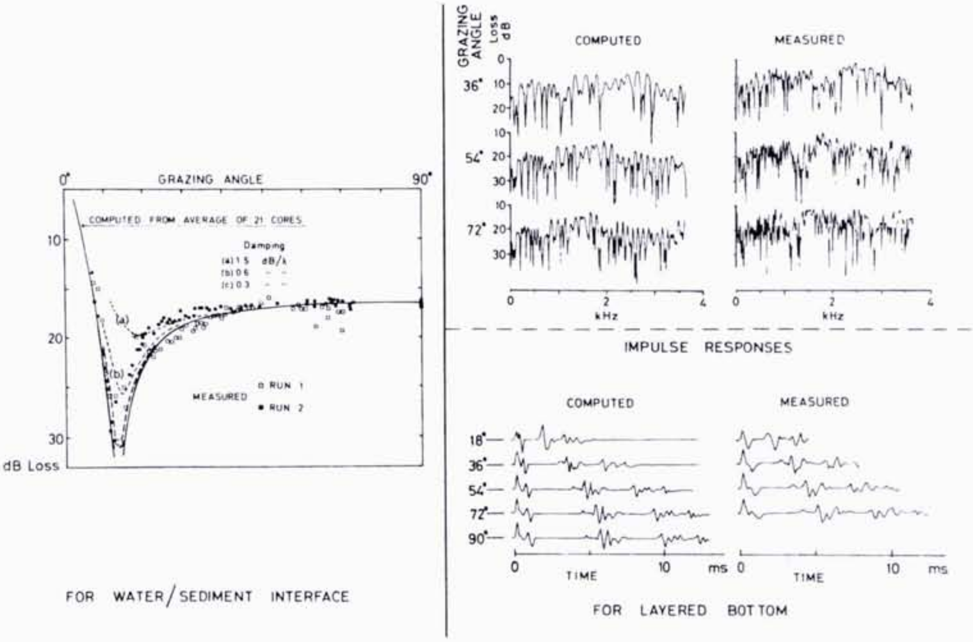


FIGURE 11

MEASURED AND COMPUTED RESULTS FOR WATER/SEDIMENT INTERFACE AND LAYERED BOTTOM. [AFTER HASTRUP (1969a)].

received from a layered bottom are characterized by multiple arrivals corresponding to reflections from the sub-bottom layers (core No. 137), whereas the homogeneous bottom, by contrast, shows a strong pulse from the water/sediment interface followed by a decaying part (core No. 138) (Fig. 12).

Hastrup [1969b] established that very low losses result from a system of regular layering when the thickness of double layers equals half the acoustic wavelength. Such periodicity exists in the areas where turbidity currents play an important role in the sedimentation process. To summarize the information concerning layering in the sediment, we may examine the spectra of the various physical parameters measured in the cores. Figure 13 gives the spectrum of the density versus depth plots obtained from three cores taken from the same area.

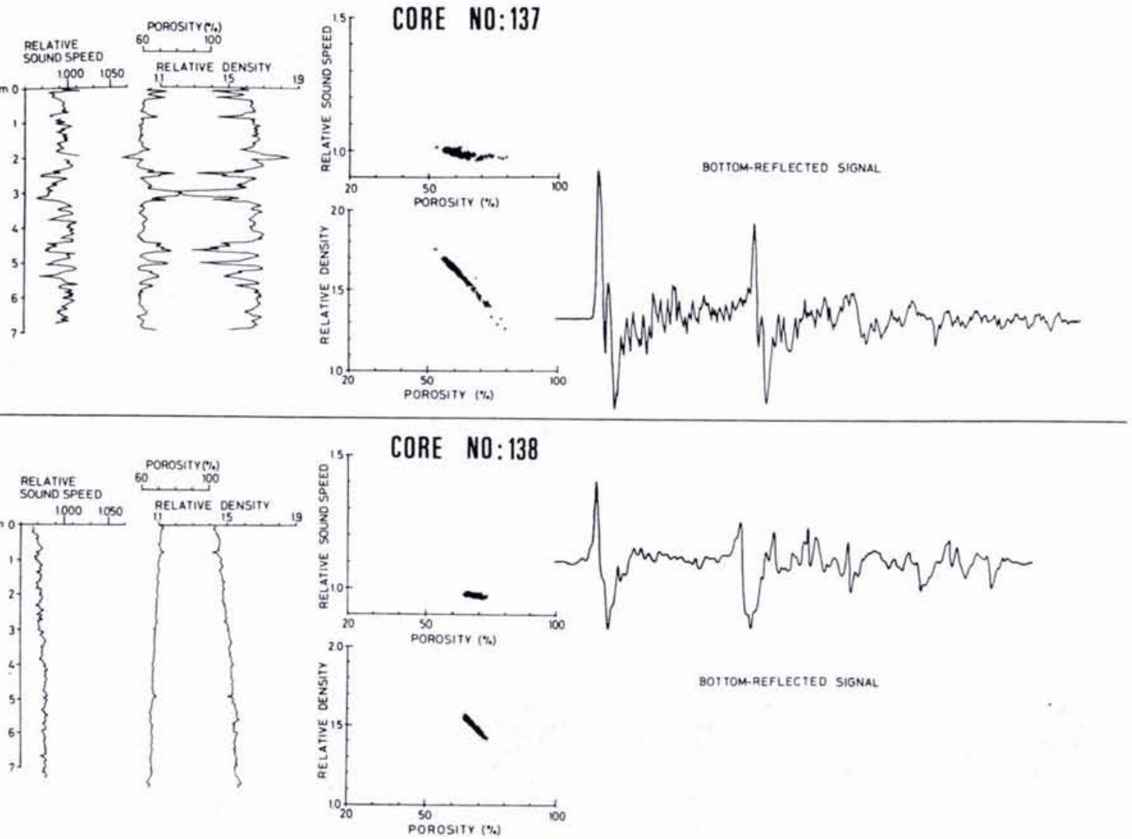


FIGURE 12

MEASURED PARAMETERS FROM CORES NO. 137 AND 138 AND SAMPLES OF BOTTOM REFLECTED SIGNALS FROM THE SAME ZONE.

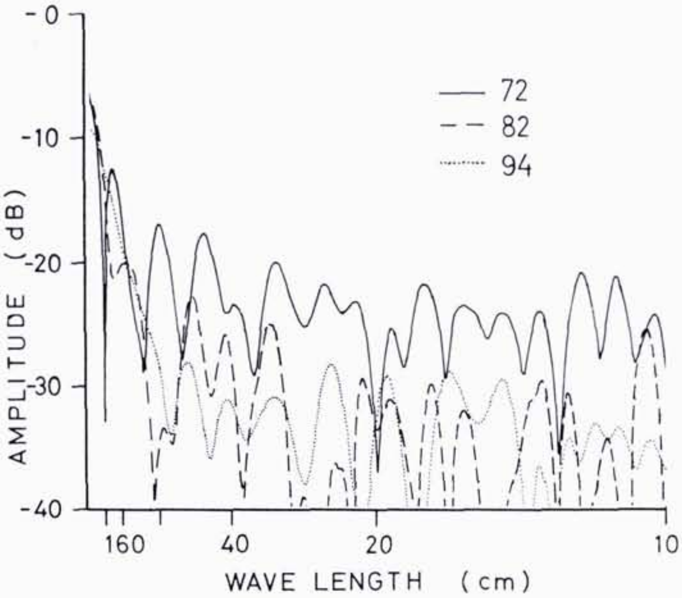


FIGURE 13

DENSITY SPECTRA OF THREE CORES TAKEN FROM THE SAME AREA. THE ORDINATE IS NORMALIZED SPECTRAL AMPLITUDE IN dB. WAVELENGTH IS DISTANCE UNITS ALONG THE CORE.

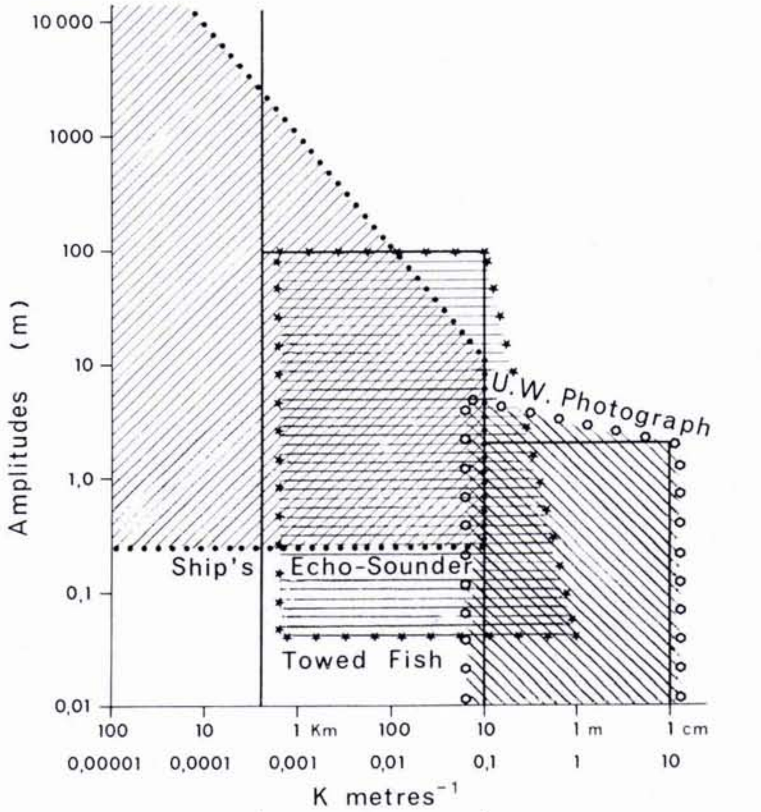
Sea Floor Roughness

Another important environmental parameter to be considered in reflectivity studies is the roughness of the bottom. The sea floor contains a wide spectrum of topographic roughness, from features of the order of tens to hundreds of kilometers, to those of the order of centimeters. This very broad spectrum can be divided into three parts, as shown in Fig. 14:

a. Gross features, of the order of tens to hundreds of kilometers, are mainly physiographic features such as ridges, abyssal plains, trenches, etc.

b. Intermediate features, of the order of hundreds or thousands of meters, are usually part of the gross features (banks, valleys, hills, etc.).

c. Small features, of the order of centimeters to tens of meters, are the most important ones in reflection processes because they are of the same order as the acoustic wavelengths (ripples, boulders, mounds, rock outcrops, etc.).



GROSS FEATURES	INTERMEDIATE FEATURES	SMALL FEATURES
RIDGES ABYSSAL PLAINS TRENCHES ETC.	BANKS VALLEYS HILLS ETC.	RIPPLES BOULDERS MOUNDS ROCK OUTCROPS ETC.

FIGURE 14

SPECTRUM RANGE OF THE SEA FLOOR ROUGHNESS AND RESOLUTION CAPABILITIES OF THE MEASUREMENT TECHNIQUES.

The gross scale features of the sea floor are reasonably well known due to the convenience of such measuring techniques as the use of echo sounders. On the other hand there is little known about small scale roughness due to the difficulties of measurement. Figure 14 also compares the resolution capabilities of the equipment used to study the roughness of the sea floor.

Small scale roughness is measured at SACLANTCEN by means of a stereo underwater camera and a 50 kHz narrowbeam echo-sounder towed close to the bottom (5-10 m). It is a very recent development at SACLANTCEN and we have not yet collected many records for analysis, but the technique works well in water depths less than 200 m. Figure 15 shows examples of the recordings obtained with different sampling techniques and the spectra obtained from these recordings.

Whereas the narrowbeam echo-sounder provides information along individual tracks, the stereo cameras can provide a mosaic over small areas and photogrammetric techniques can be subsequently employed to provide very fine-scale contour charts (of the order of 5 mm resolution) of the sea floor. We have developed a very simple method of digitizing these contours to obtain, through the computer, two-dimensional power spectra and autocorrelation functions of the surfaces, as shown in Fig. 16. The technique has the advantage of revealing any fine roughness directionality of the sea floor.

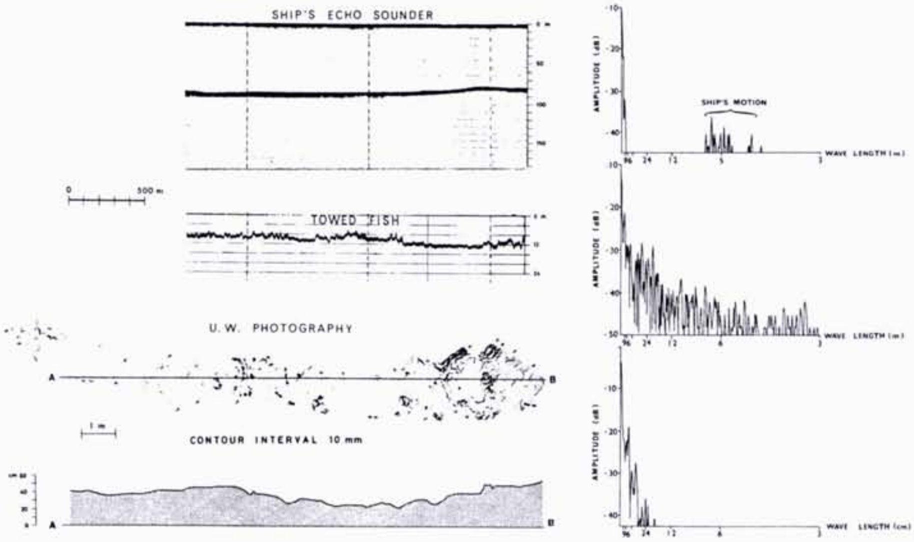


FIGURE 15

EXAMPLES OF RECORDINGS OBTAINED WITH DIFFERENT TECHNIQUES AND THE SPECTRA OBTAINED FROM THESE RECORDINGS.

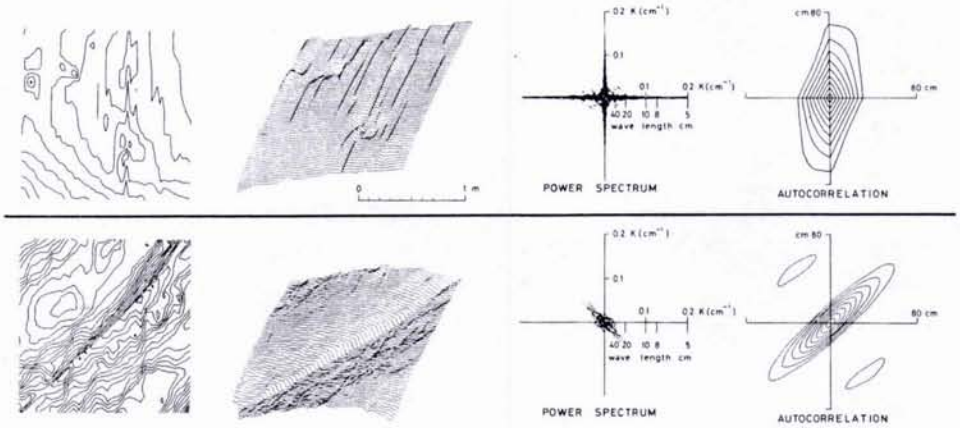


FIGURE 16

CONTOUR PLOTS OBTAINED FROM STEREO PHOTOGRAPHS, PERSPECTIVE VIEWS OF THE SURFACES, TWO-DIMENSIONAL POWER SPECTRA, AND AUTOCORRELATION FUNCTIONS OF THE SURFACES.

THE PHYSICAL PROPERTIES OF THE SEDIMENTS IN SOME OF THE MEDITERRANEAN PHYSIOGRAPHIC REGIONS

Figure 17 shows the areas from which information concerning the physical properties of the sediments was obtained. Figure 18 shows the positions of recent cores taken from different regions of the Mediterranean together with bathymetric profiles recorded in their vicinity. For each area a figure (Figs. 19-27) has been prepared to summarize the data. These show:

a. In the upper part, porosity versus relative sound speed, relative density, and computed normal incidence reflection coefficient.

b. At the lower left, relative sound speed, porosity, and relative density measured along a typical core.

c At the lower right, the spectrum of the relative density measured along some of the cores taken in the area.

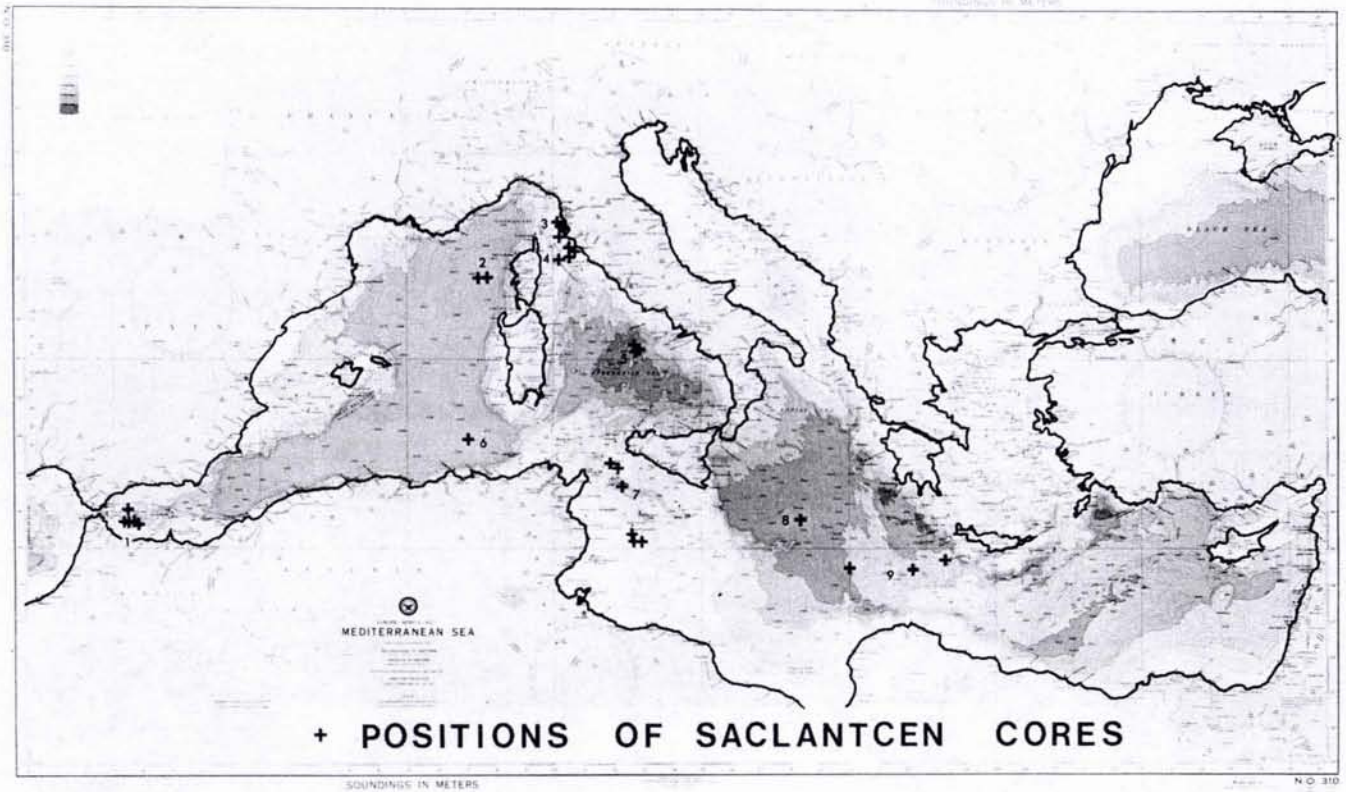


FIGURE 17

POSITIONS OF THE SACLANTCEN CORES.

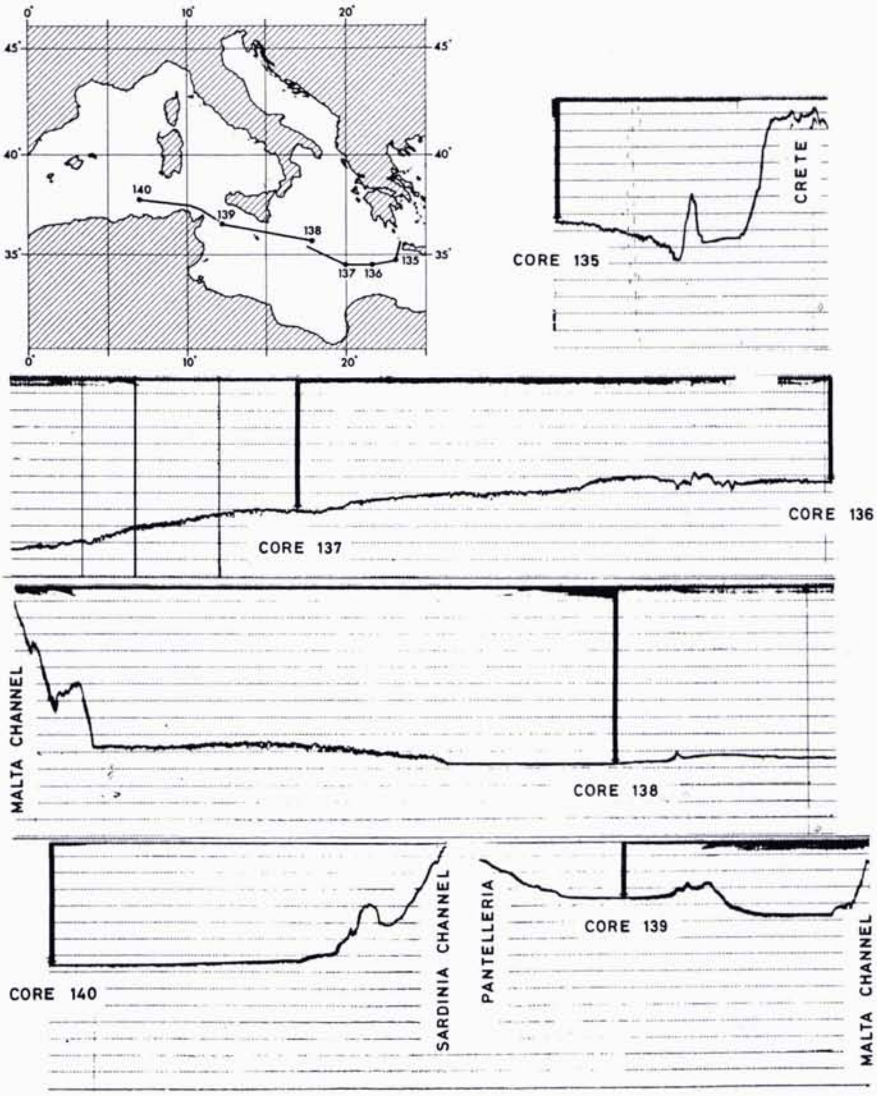


FIGURE 18

ECHO-SOUNDING RECORDS AND POSITIONS OF RECENT SACLANTCEN CORES.

1. (Fig. 19) Western Alboran Basin: Sedimentological investigation of the western basin has been made by extensive coring [Gehin et al. 1971]. The cores taken in this area show homogeneous material with some strips of sand layers believed to be caused by turbidity currents. As can be seen from the figure homogeneous material has more than 60% porosity, with most of the data falling between 60% to 80%, giving sound speeds of less than that in water. The spectra of relative density indicate marked layers approximately 12, 30, 50, 160, and 300 cm thick.

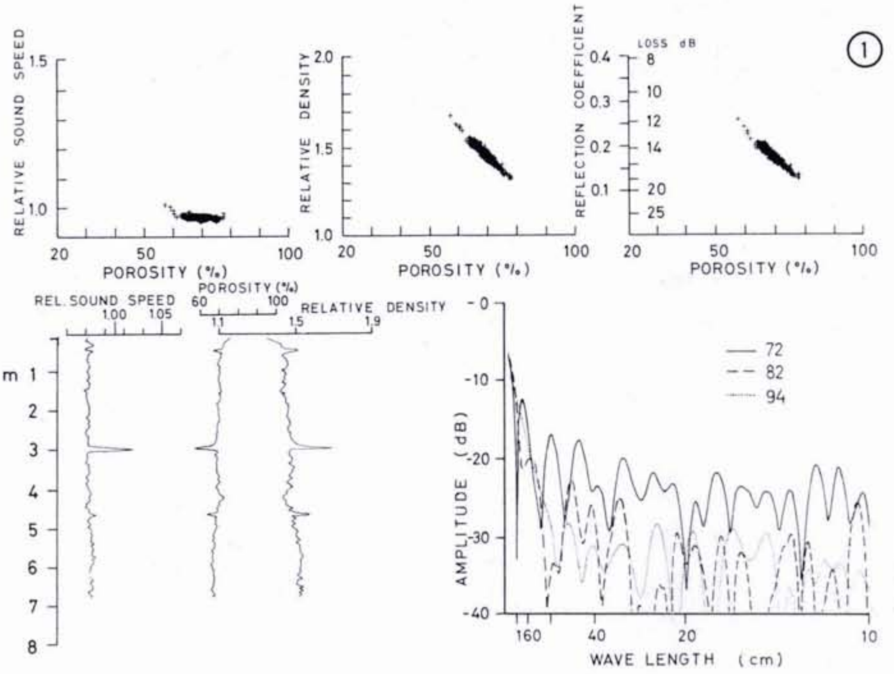


FIGURE 19

WESTERN ALBORAN BASIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

2. <u>(Fig. 20) Northern Balearic Basin</u>: The cores taken in this area contain alternating layers of sand, silt, and clay that appear as equally distributed data points of 45% to 75% porosity. There are also marked layers whose thicknesses vary from 10 to 250 cm.

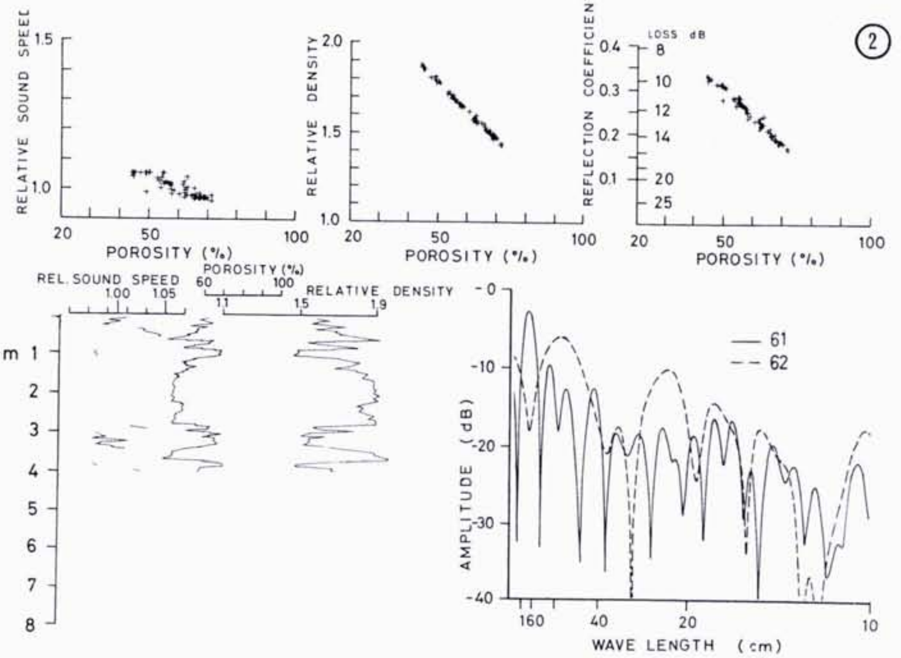


FIGURE 20

NORTHERN BALEARIC BASIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

3. <u>(Fig. 21) Northern Elba Shelf</u>: The cores taken in this zone also show mixed layers of clay, silt, and sand, and the porosities measured vary between 40% and 80%.

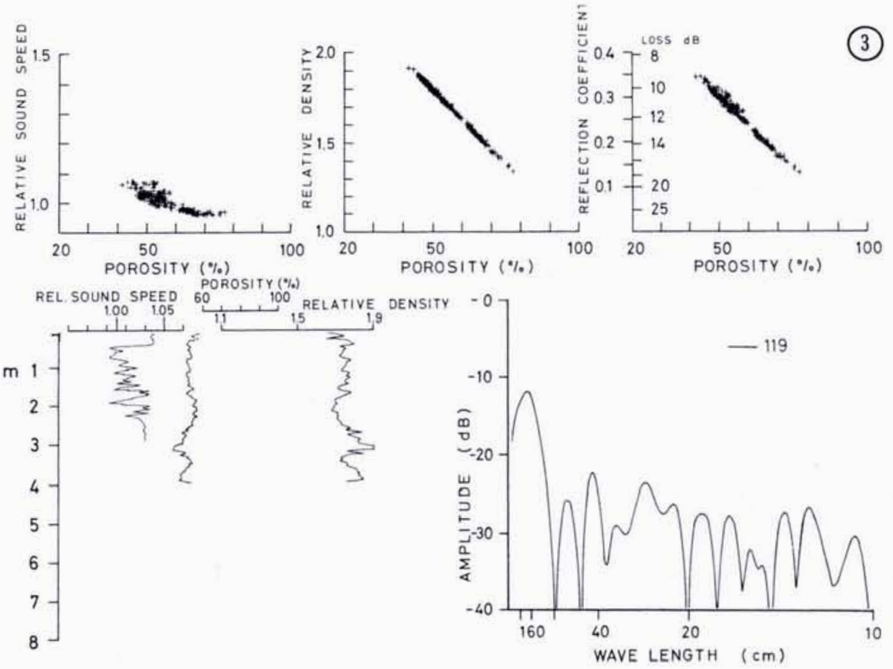


FIGURE 21

NORTHERN ELBA SHELF:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

4. (Fig. 22) Southeastern Elba Shelf: This area shows completely different characteristics from those in the northern zone. The cores contain homogeneous clay material with some layers of sand. Data points on the plots are mostly in the 55% to 80% porosity range except for a few points with lower porosity that correspond to the sand layers. A layer approximately 3 m thick is a common feature of most cores taken in this area.

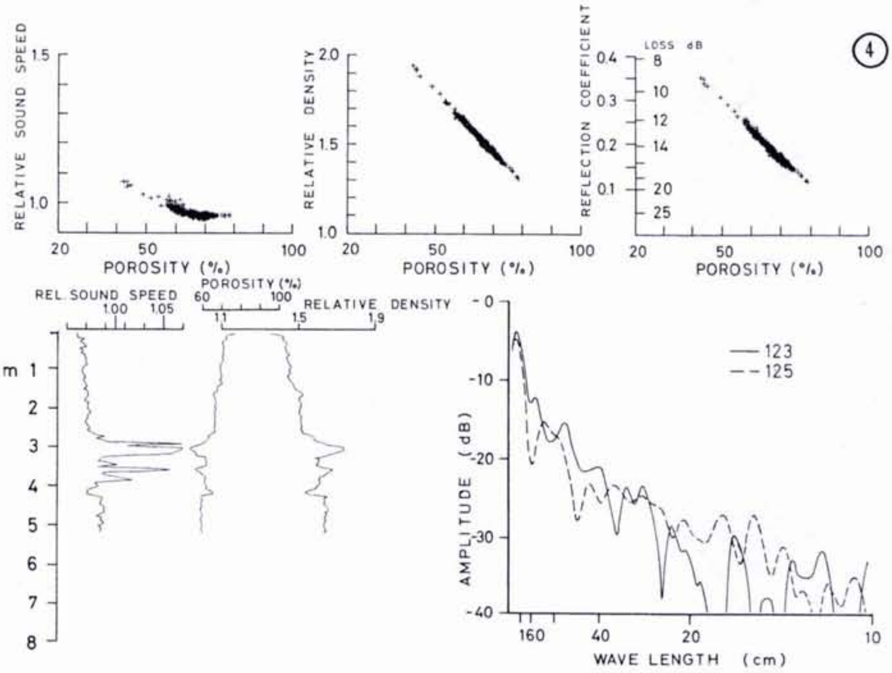


FIGURE 22

SOUTHEASTERN ELBA SHELF:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

5. <u>(Fig. 23) Tyrrhenian Abyssal Plain</u>: Analyses of the cores taken in this plain [Kermabon et al. 1968] indicate clay, silt, and sand layers. The thicknesses of the clay layers vary from a few millimeters to 3 m, the silt and sand layers from 1 cm to 1 m. Coarse material, which makes a sharp contrast with the clay layers, was most probably caused by turbidities or volcanic ash depositions. The spectrum of the relative densities measured along the cores shows good correlation from one core to another.

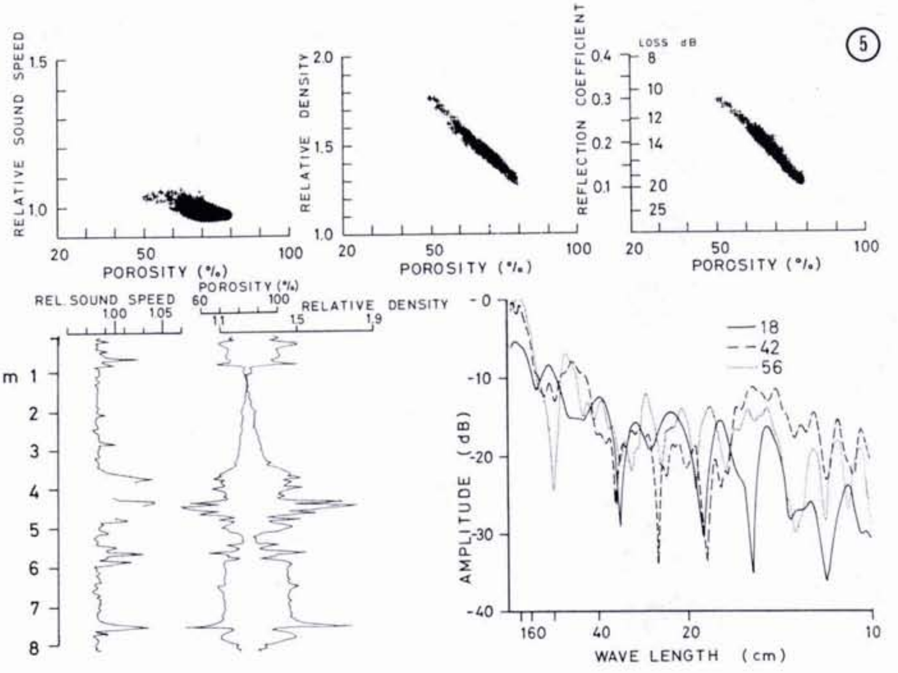


FIGURE 23

TYRRHENIAN ABYSSAL PLAIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

6. <u>(Fig. 24) Southeastern Balearic Basin</u>: This core (140) contains alternating layers of clay and sand. The data points fall in two clusters, with the clay material having porosities of more than 60%. There is a high density material at a depth of about 3 m.

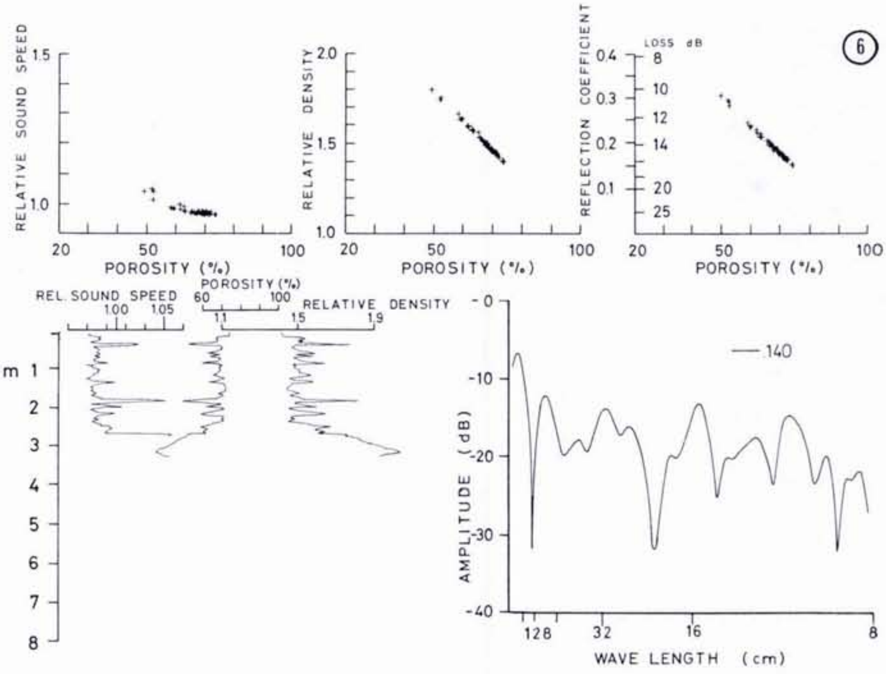


FIGURE 24

SOUTHEASTERN BALEARIC BASIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

7. (Fig. 25) Pantelleria Basin: The core (139) taken from this small basin (southeast of the island of Pantelleria) is very homogeneous. As shown by the plots of porosity relationships, the relative sound speeds are less than one and the porosities vary between 65% and 80% [Akal 1972b].

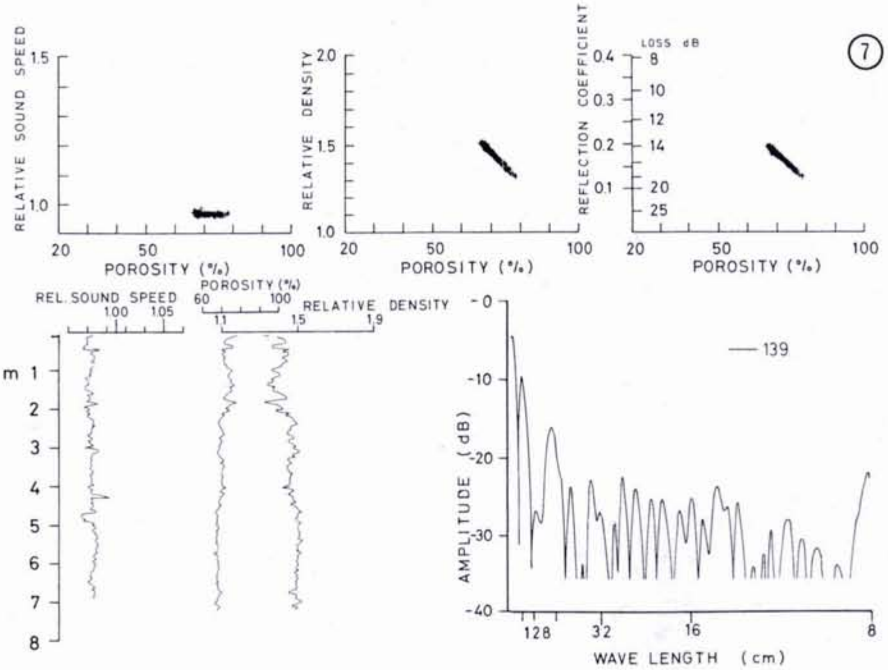


FIGURE 25

PANTELLERIA BASIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

8. <u>(Fig. 26) Messina Abyssal Plain</u>: This core (138) is also very homogeneous and the porosity of the clay material varies between 65% and 75%.

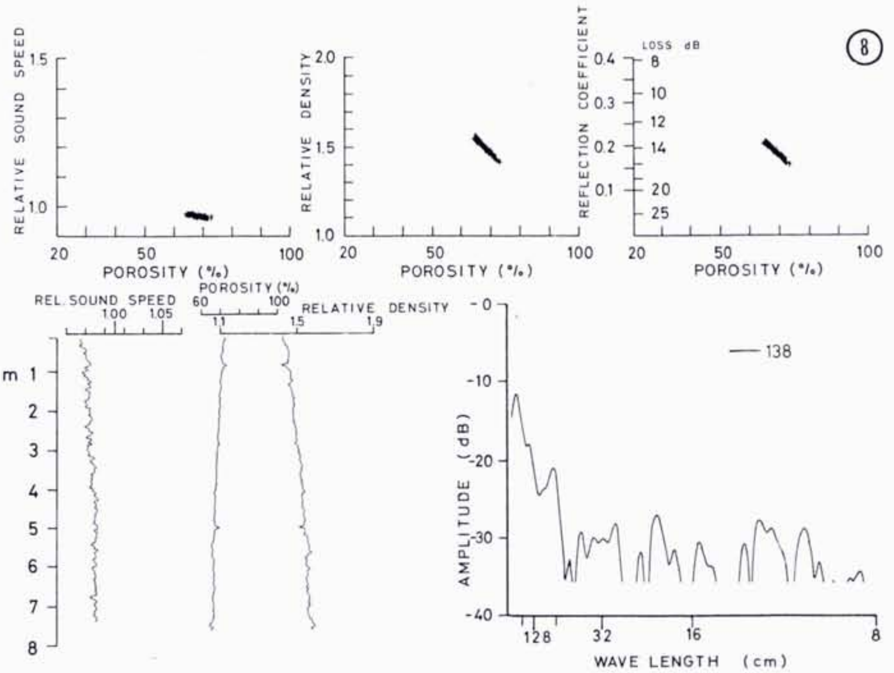


FIGURE 26

MESSINA ABYSSAL PLAIN:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

9. (Fig. 27) Mediterranean Ridge: The cores taken in this area show completely different structure from those taken from the Messina Abyssal Plain. They contain layers of clay, silt, and sand with different thicknesses and colors. The porosities of the material vary between 50% and 80%, with most of the data points falling between 50% and 70%. There are many layers whose thicknesses correlate very well from one core to another.

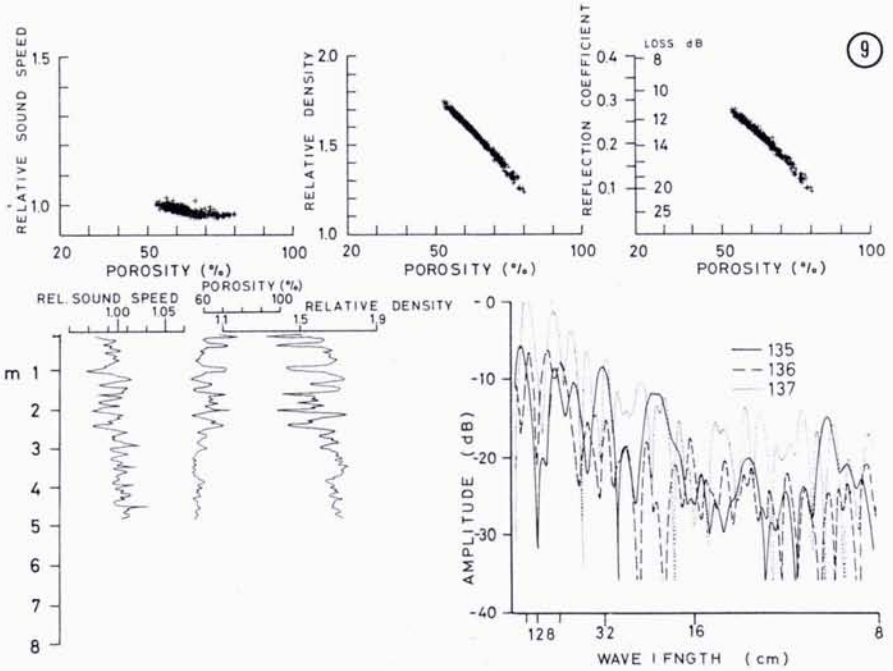


FIGURE 27

MEDITERRANEAN RIDGE:
SUMMARY OF SOME OF THE PHYSICAL PROPERTIES OF THE SEDIMENTS.

CONCLUSIONS

1. Acoustical characteristics of the sea floor can be predicted from a knowledge of the physical properties of the sediments.

2. Displays of relative sound speed, relative density, and computed normal incidence reflection coefficient versus porosity give a general idea of the acoustical characteristics of an area.

3. The porosity of the marine sediments stands out as the most important parameter causing variations in compressional sound speed and density.

4. The relationships between relative sound speed, relative density, and computed normal incidence reflection coefficient versus porosity for different Mediterranean regions agree well with the statistical relationships previously calculated [Akal 1972a] from an analysis of world data (Fig. 28).

5. Layering information can be summarized by obtaining the spectra of the various physical parameters along the core.

6. The sea floor contains a wide spectrum of topographic roughness that can be divided into three parts and can be resolved by different sampling techniques. Univariate and/or bivariate spectra of the bottom roughness give statistical information for the roughness of the sea floor.

7. The cores taken from different regions of the Mediterranean are, in general, of two distinct types.

   a. Homogeneous cores [Pelagic sediments], generally consisting of clay whose porosity varies between 65% and 80%.

   b. Layered cores (turbidity sediments), consisting of clay, silt, and sand layers where porosities vary between 40% and 80%.

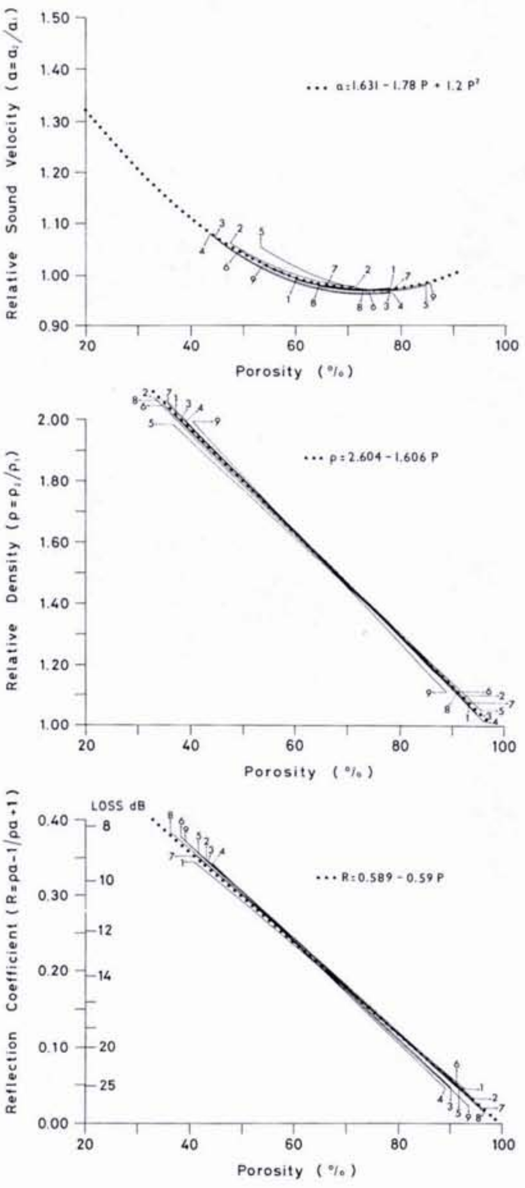


FIGURE 28

COMPARISON OF POROSITY RELATIONSHIPS FROM DIFFERENT MEDITERRANEAN REGIONS (NUMBERED) WITH THOSE CALCULATED (AKAL 1972a) FROM WORLD DATA (DOTTED). 1. WESTERN ALBORAN BASIN, 2. NORTHERN BALEARIC BASIN, 3. NORTHERN ELBA SHELF, 4. SOUTHEASTERN ELBA SHELF, 5. TYRRHENIAN ABYSSAL PLAIN, 6. SOUTHEASTERN BALEARIC BASIN, 7. PANTELLERIA BASIN, 8. MESSINA ABYSSAL PLAIN, 9. MEDITERRANEAN RIDGE.

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