DIRECTIONAL MEASUREMENTS OF LOW-FREQUENCY ACOUSTIC BACKSCATTERING FROM THE SEAFLOOR

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ABSTRACT

Long-range, low-frequency directional measurements of acoustic backscattering from the seafloor were made in the Tyrrhenian Sea using explosive sound sources. The signals were received by a horizontal towed array of hydrophones and were processed by a beamforming procedure to obtain the directional distribution of the scattered field as a function of time. These data are used to form images of scatterers and to estimate the backscattering strength of specific physiographic features. From the data obtained the scattering strengths were estimated to range from -25 dB to -35 dB and did not exhibit strong dependence on frequency.

INTRODUCTION

Low-frequency acoustic backscattering from the seafloor has often been studied using omnidirectional measurement techniques [1-4]. Generally, omnidirectional sources and receivers are used. The calculation of scattering strength assumes uniform scattering in a ring-shaped area on the seafloor for a given element of travel time. Such measurements can be contaminated by non-bottom returns having the same travel time as the scattering ring [5] or by non-uniform roughness within the scattering ring [6]. Although careful measurements using omnidirectional geometries will yield proper estimates of scattering strength, these techniques are more limited than directional methods in application. Directional methods make it possible to obtain images of the scattering features and to estimate the scattering strength of specific physiographic features such as seamounts and continental slopes. Images of seafloor topography from long-range directional measurements of acoustic backscattering have been obtained by various methods: broad-side beam, side-scan mode with towed array [7], full beamforming with a towed array [8,9], and full beamforming with two-dimensional arctic arrays [10]. Backscattering values have been reported for some of these measurements [9,10].

Previously the authors have reported beamforming methods applied to sensors of a towed array receiving backscattered sound [11] and aspects of resolution of seafloor images that were obtained [12]. In this paper we further describe the technique used for processing broadband data received from an explosive source and report additional measurements of bottom backscattering strength for the Tyrrhenian Sea.

EXPERIMENTAL METHODS

An omnidirectional explosive source (broadband) is deployed near a hydrophone array. The sounds reflected and scattered back to elements of the array are processed to form beams, as in Fig. 1. For processing, the hydrophone signals are split into time increments. For each time increment, a beamforming procedure is used to obtain the angular distribution of energy over a given frequency band of the source.

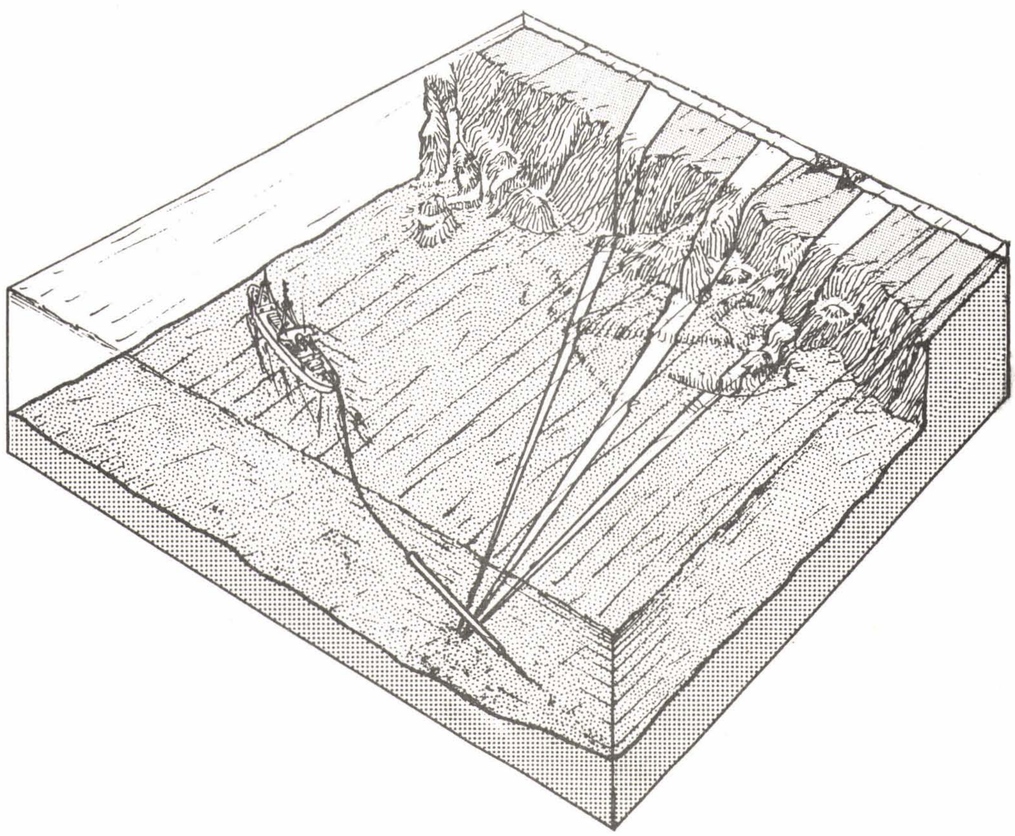

Fig. 1
Experimental geometry for backscattering measurement (not to scale): returns from an omnidirectional sound source (not shown) are received on directional receiving beams. The beams, which actually scan a vertical section of the volume, are indicated by their wedge-shaped areas on the seafloor. For simplicity only three beams on the right-hand side of the array are shown in their far field and the complementary (ambiguity) beams on the left-hand side of the array are omitted.

The beamforming procedure has been described in Refs. [11] and [12] and is based on the assumption of plane-wave sound signals of uniform velocity and is an application of frequency-domain beamforming based on the Fast Fourier Transform [13]. The procedure applied to sensors of a line array results in the estimation of beam power values equally spaced in spatial wavenumber, k_x, for the different acoustic frequencies, f, of the analysis band. With the assumption of uniform sound velocity, we can discriminate plane waves with different beam-pointing angles, α, where

$$k_x = (\omega/c) \sin \alpha. \tag{1}$$

in which c is the speed of sound and ω is the angular acoustic frequency, $\omega = 2\pi f$. The method of processing broadband data is shown graphically in Fig. 2. For each k_x value at the central frequency of the band, a set of interpolated beam powers is determined for the other frequencies. This is

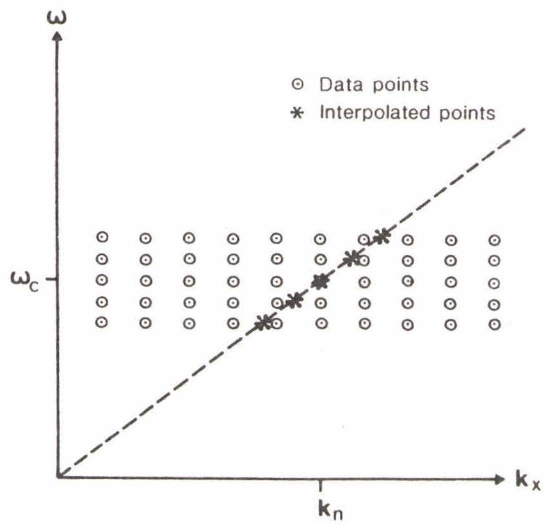

Fig. 2
Beam-power interpolation for wavenumber k_n: beam-power levels are interpolated for the points indicated by stars from the data at the points indicated by circles. The interpolated points fall along the azimuth line (dotted) of the central frequency of the band ω_c.

done by linearly interpolating between the appropriate beam-power values in such a way that the beam azimuth equals the beam azimuth that corresponds to the central frequency of the band. An average beam-power value over a given frequency band is obtained at each k_x value by averaging the interpolated powers. This procedure corresponds in $k_x - \omega$ space to averaging data points along a line.

The scattering area is defined by the intersection of the beam and the scattering ring boundaries for the particular travel time and processing-time window, as in Fig. 3. Assuming a process of totally incoherent scattering, the scattering strength S, for a given frequency band may be

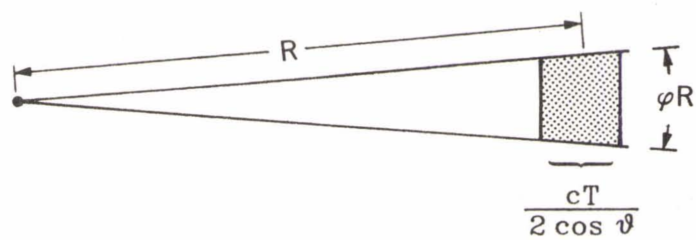

Fig. 3 Plan view of scattering area at seafloor: approximate dimensions of scattering area for small grazing angles;
c is the sound speed in seawater;
T the processing time;
ϕ the 3-dB beamwidth (rad);
θ the grazing angle at the bottom; and
R the range.

expressed in terms of the sonar equation as

$$S = RL - SL + TL1 + TL2 - 10 \log A , \qquad (2)$$

where S is the scattering strength in dB/m^2; RL and SL are respectively the equivalent reverberation level and source level in dB re 1 μPa; TL1 and TL2 are the one-way transmission losses in dB; and A is the effective scattering area of the bottom in m^2. If the process involves a combination of scattering, reflection, and diffraction, then the estimated scattering strength may have errors or may be inappropriate. However, if the process is entirely that of specular reflection for an area of the seafloor greater than a Fresnel zone, a reflection loss parameter would be more appropriate.

MEASUREMENTS

Measurements were made in the Tyrrhenian Sea at the locations shown in Fig. 4; the same figure also indicates the major scattering features. Explosive SUS sources (0.8 kg TNT) were set at a depth of 245 m near a receiving array towed at a depth of 100 m. The hydrophone signals were split into increments that were processed by the beamforming technique described above and implemented in the processing system presented schematically in Fig. 5. Repetition of the beamforming procedure for adjacent

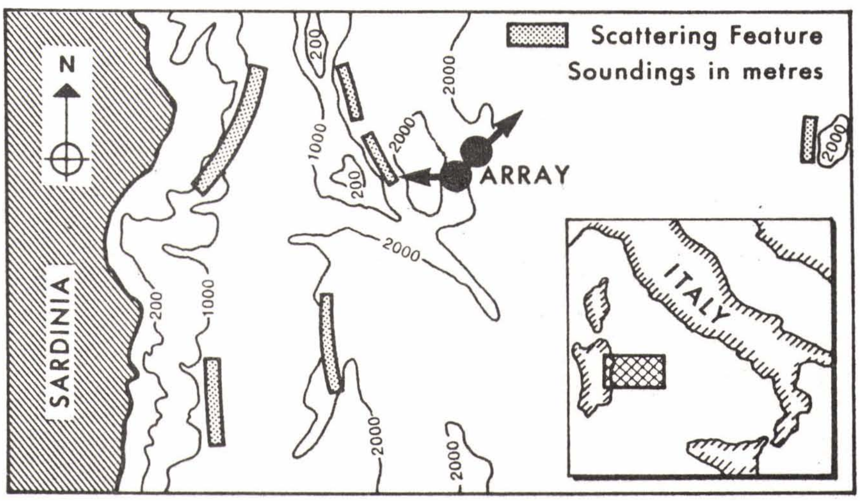

Fig. 4 Location of experiment: estimated positions of major scattering features are shown in shading.

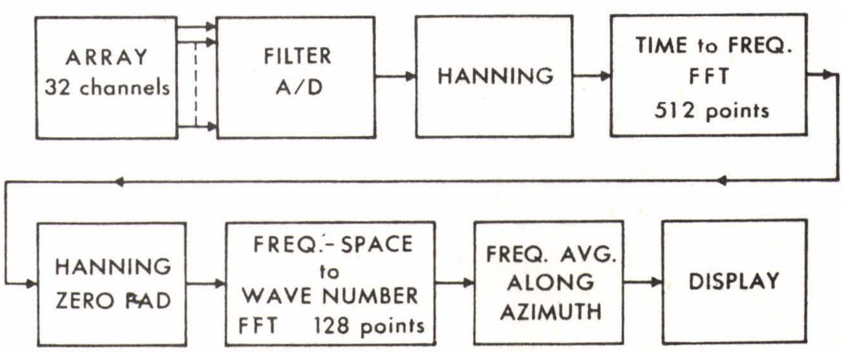

Fig. 5 Acquisition and processing system.

time segments gave a display of the beam-time history of features of the seafloor that scattered sound back to the array. Examples of beam-time histories are shown in Figs. 6 and 7. It can be seen that the direct arrival is followed by arrivals due to multiple reflection from the seafloor at high grazing angles. These appear strong on all beams because of sidelobe reception of the overloaded signals. Later arrivals are primarily due to backscattering from the seafloor at low grazing angles. The records also

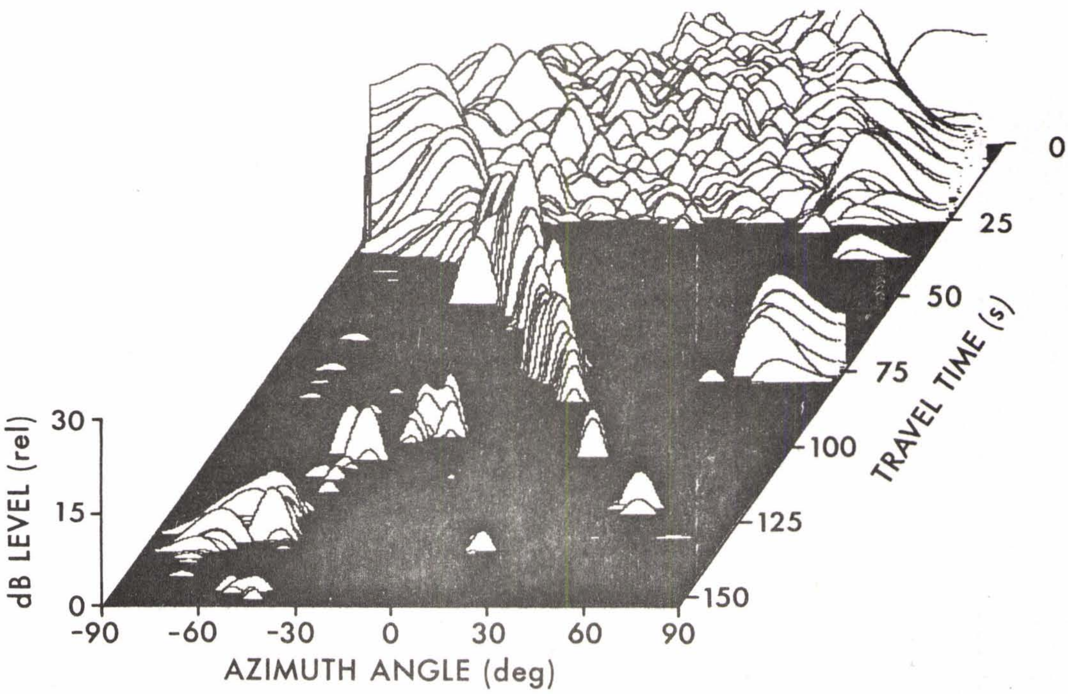

Fig. 6
Beam-time history at 600 Hz: 50-Hz bandwidth and array orientation 45°; positive azimuth toward ship; explosive source occurs at t = 6 s.

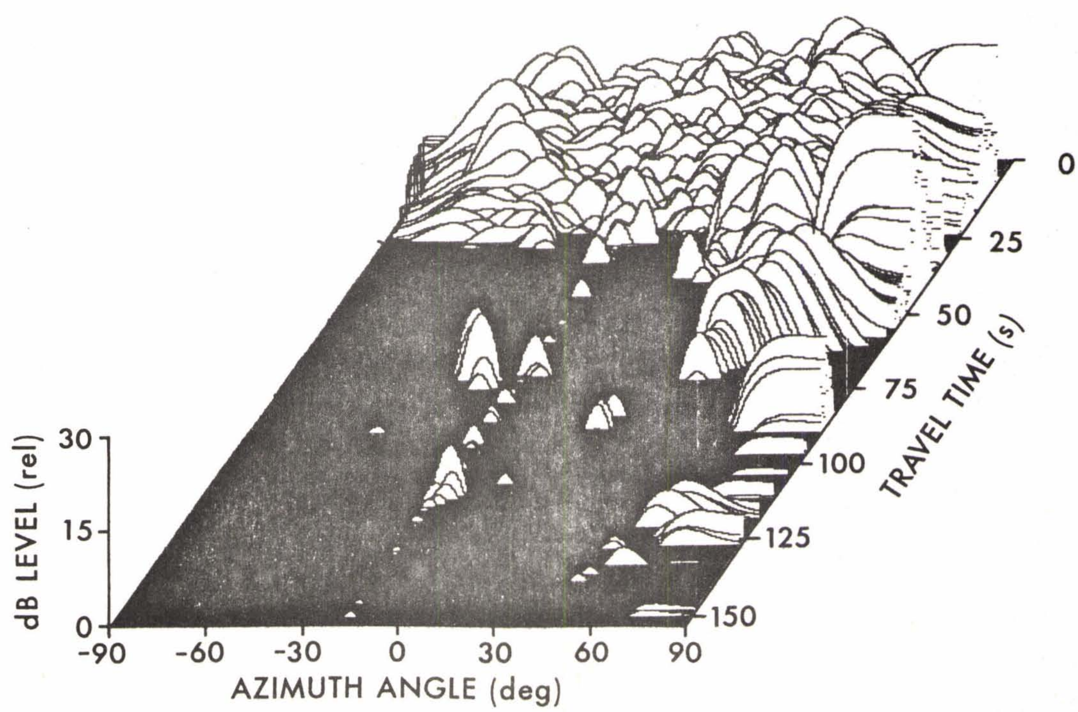

Fig. 7
Beam-time history at 700 Hz: 50-Hz bandwidth and array orientation 270°; positive azimuth toward ship; explosive source occurs at t = 6 s.

show continuous arrivals (artifacts) that are unrelated to returns from the explosive source and are comprised of towship and shipping noise. The major features are caused by backscattering from major physiographic features, e.g. island slope of Sardina and the Baconi Seamounts.

Scattering strengths were calculated using Eq. (1) and are shown in Fig. 8 as a function of frequency. Also shown are other scattering strength values calculated from directional measurements at low frequency [9,10]. The frequency dependence of the scattering strengths of these data is apparently weak. This is in agreement with most measurements of scattering from the seafloor at frequencies of 2 kHz to 100 kHz [14]. More data are required before the relationship at low frequencies can be established. However, at this point these limited data certainly do not suggest the very strong frequency dependence (about 1.6 power dependence, or 4.8 dB per octave) found in some of the high-frequency (13 to 290 kHz) data of McKinney and Anderson [15].

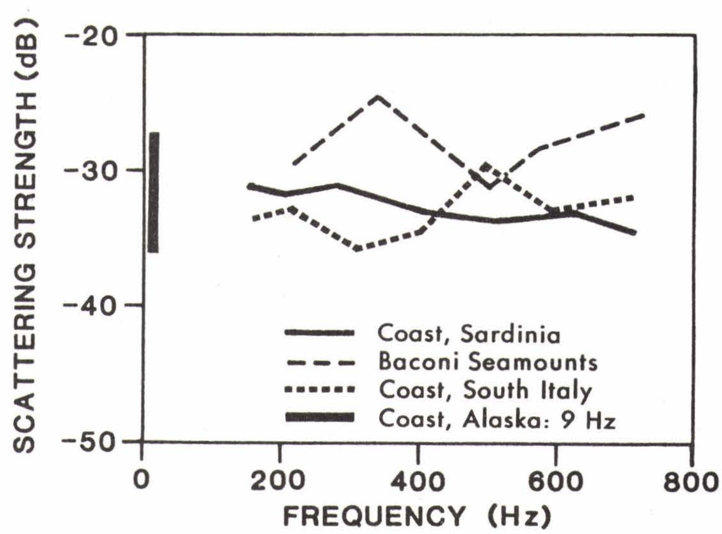

Fig. 8
Scattering strength versus frequency: data for coasts of South Italy and Alaska taken from Refs. 9 and 10 respectively.

CONCLUSION

Directional measurements of backscattering were made with an omnidirectional explosive source and a linear towed receiving array. The hydrophone signals were processed to form receiving beams and the data are displayed as images of the scattering features of the seafloor. The scattering strengths obtained exhibit weak frequency dependence, but more data are required before the frequency dependence of the seafloor features can be established.

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