SOME EFFECTS OF LARGE SCALE OCEANOGRAPHY ON ACOUSTIC PROPAGATION

by

A.N. Guthrie, J.D. Shaffer, and R.M. Fitzgerald
Naval Research Laboratory, Washington, DC 20375

ABSTRACT

A propagation experiment was conducted along a great circle track in the North American Basin, beginning at a point 400 km north of Antigua, W.I. and ending at the Grand Banks of Newfoundland. Shallow explosive sources were detonated at half hour intervals and shallow-13.89 and 111.1 Hz cw sources were operated continuously. The acoustic fields were detected by a deep sound channel hydrophone located near Antigua. The shot signatures were aligned in time and range forming a pattern which was dependent on and could be interpreted in terms of large-scale oceanography. Major features of the transmission loss curves for the two continuous wave sources are similarly interpretable in terms of averaged oceanographic parameters.

INTRODUCTION

Ocean acoustic modeling for prediction of propagation of sound in the ocean is a most complicated problem. Transmission from a source to a receiver is a multipath process with a relatively large number of acoustic paths. In traveling these paths the signals are modified in complex ways by interaction with the ocean surface and bottom, and with the sound speed gradients in the water. Further modifications result from loss of energy by absorption and from scattering by various agents encountered along the paths. The modifications that result depend on the signal frequency, the grazing angles at the surfaces, and a number of other parameters. A signal traversing one path may be changed in a significantly different way from one traveling by another path. The task of determining the parameters and incorporating them in a useful model is a difficult one.

In some cases a greatly simplified model, with some of the difficult-to-determine parameters eliminated, may be used to perform significant computations. For example, a very-low-frequency signal behaves as if the ocean surface were smooth, especially for small grazing angles. In the deep Atlantic and for a source depth of one to 1.5 wavelengths, the propagation paths responsible for convergence zone peaking and for major energy transmission, have grazing angles at the surface no larger than 10°. And these propagation paths do not intersect the bottom. For signals in the low-frequency range (10 Hz to 30 Hz) the ocean surface, although rough by ordinary standards, may be treated as a smooth reflector and the bottom as a perfect absorber. Absorption in the ocean medium is negligible and scattering effects may be extremely small at these frequencies. This case is one in which the propagation is determined largely by the ocean surface temperature, the ocean depth, and the depth of the SOFAR axis, three large-scale oceanographic features.

The presence of a near-surface channel, or acoustic duct, may be ignored and a ray model used for frequencies well below cutoff. But for frequencies above cutoff, a wave model is required for solution of the problem of propagation and leakage.

It is clear, however, that as the frequency is reduced to 10 Hz and below, attenuation in the bottom may decrease to such a low value that propagation through the bottom will become an essential part of the problem.

At the Naval Research Laboratory, and earlier at Hudson Laboratories,[1,2,3] experiments to study long-range propagation of low-frequency cw sound signals in the 10 to 15 Hz band were carried out. One of the later experiments[4,5] is the basis of this report and the results of that experiment will serve to show the effects of large-scale oceanographic features on acoustic propagation.

I. DESCRIPTION OF THE EXPERIMENT

The source ship towed two continuous wave (cw) sources across the North American Basin along the track shown in Fig. 1. The track lay along the arc of a great circle passing through the hydrophone. The tow began at a range of 400 km from the hydrophone and ended at 2800 km.

A source operating continuously at 13.89 Hz was towed at a depth of 104 m, or about one wavelength. The second source operated continuously at 111.1 Hz and was towed at a depth of

21 m, or about 1.5 wavelengths. Explosive charges, equivalent to 5 lbs. of TNT, were detonated every half hour along the track at a nominal depth of 110 m. The ship maintained, as nearly as possible, a speed of 7 knots, about 13 km/hr, on a steady course.

All signals were received by a hydrophone located off the island of Antigua, W.I., and at a depth near that of the deep sound channel (SOFAR) axis.

The cw signals, after narrowband filtering (Q = 20) at the signal frequencies, were recorded graphically and on magnetic tape. The shot signals were filtered in a band between 15 and 250 Hz and recorded on magnetic tape.

A continuous bathymetric record was made along the track and expendable bathythermograph casts were made to a depth of 760 m at two hour intervals. Three types of navigational data were used to determine the ship's position in time. Position fixes were obtained using the Navy Navigation Satellite System; shot travel times were measured; the ship's speed away from the hydrophone was determined by measurement of the Doppler shift in the cw signals. A combination of all three sets of data was used to determine the final range versus time relation.

II. OCEANOGRAPHIC DATA

Figure 2 shows the oceanographic data pertinent to an interpretation of the acoustic data. The depths of sound speed minima and maxima are plotted as function of range. Between 1150 and 2450 km there is a secondary sound channel. The depths of minimum and maximum sound speeds in this secondary channel are marked by lines (A) and (B) respectively. From 1150 to 2040 km the channel is a subsurface channel with an average axis depth of 108 m and an average bottom depth of 358 m. From 2040 to 2440 km the channel becomes a surface channel with an average depth of 371 m but with a gap between 2230 and 2290 km where three successive sound speed profiles show no channel exists. Line (C) shows the depth of the SOFAR axis. Where this axis is below 760 m, the depth was taken from National Oceanographic Data Center files. Off Antigua the SOFAR axis is relatively shallow but its depth increases slowly with increasing range to a maximum of 1200 m at about 1820 km. Beyond 1820 km the axis rises slowly until about 2640 km after which it rises rapidly toward the surface. Line (D) marks the limiting depth: the depth at which the sound speed equals that at the ocean surface.

The marked differences between sound speed profiles of the different oceanographic regions along the ship's track are produced by the differing temperature and salinity characteristics of distinct water masses encountered in those regions. The characteristics and origins of these water masses are well known[6] and need not be discussed here.

The bathymetry from zero range to 400 km was taken from bathymetric charts. Beyond 400 km the depths were obtained from the bathymetric record made during the tow.

III. ACOUSTIC DATA

A. Shot arrivals and propagation paths

The term "shot signature" denotes the total sequence of time dispersed pressure pulses, or shot arrivals, recorded on the hydrophone from an explosive source detonated in the ocean. Each of the arrivals of the signature travels by a different path from source to hydrophone and each arrival has a different travel time. A series of signatures from shots spaced at small range intervals can be aligned in a systematic manner to aid in identifying the propagation paths of the various arrivals.

Figure 3 is an alignment of all the shot signatures recorded during the tow. The vertical placement is on a range scale and the horizontal placement is on a reduced travel time scale; i.e., measured travel time minus range (km)/1.520 (km/sec). This system of alignment is seen to place the strong arrivals of 9 or 10 successive shots in approximately vertical columns, and to place these columns along a positive-slope diagonal. This diagonal is a prominent feature of Fig. 3 and its pattern continues essentially unchanged through Region 1, 2, 3, and 4.

These strong arrivals have traveled by RSR (refracted -- surface reflected) paths or deep SOFAR (refracted --refracted) paths that cycle deep into the ocean. Near the source the RSR arrivals turn under below the limiting depth, and the SOFAR arrivals turn under at or slightly above the limiting depth, and turn over between the surface and the source depth. Toward the south the temperature of the near-surface water increases, the turn over depth of the paths increases and some RSR's become SOFAR's. But the depth of the turn under changes little. So much of the travel paths (and travel times) of these deep-cycling arrivals is in the stable layers of the deep ocean that they are scarcely affected by the small-scale changes that occur in the shallow upper layers.

To the right and below the diagonal of Fig. 3 are SOFAR arrivals that have traveled by paths cycling nearer the SOFAR axis, and traveling more slowly, than the strong SOFAR arrivals lying along the diagonal. There is no evidence of BRSR (bottom reflected - surface reflected) arrivals from even the shortest range of 400 km.

Those arrivals above and to the left of the diagonal have traveled by leakage paths, i.e., they were trapped in the near-surface channel of Region 2 for some distance, leaked out and then traveled by SOFAR paths to the hydrophone. The effect of this channel, a small-scale oceanographic feature, on signals of different frequencies is shown in Fig. 4. This shot was detonated at a range of 1452 km in Region 2. The recorded signature was played back through three half-octave bandpass filters centered at 22.5, 90, and 250 Hz respectively. The sound channel of Region 2 is seen to have a cutoff frequency between 22.5 and 90 Hz. Trapping occurs for frequencies above the cutoff but propagation of frequencies below cutoff is unaffected by the presence of the channel.

Figure 5 shows shot signatures from Region 1 on an expanded scale. The arrivals are sufficiently spread in time to separate the upgoing, A & B, and the downgoing, C & D, arrivals at the hydrophone. The further split into A and B, and into C and D, may be the downgoing and upgoing pulses at the source but the spread, about 0.05 sec, is very nearly the bubble pulse period for 5 lbs. of TNT detonated at 110 m depth.

The group of shot signatures in Fig. 6 is from Regions 3 and 4. The diagonal pattern of strong RSR and deep SOFAR arrivals is seen to continue into these regions. On passing from Region 2 to Region 3 the Gulf Stream is crossed and cold arctic water is encountered. The effect on propagation of the much colder near-surface water is shown by the immediate proliferation of the more slowly traveling SOFAR arrivals.

In these regions the SOFAR axis is rising toward the surface and at the range of the final shot drop it has reached shot depth. This shot signature at farthest range shows a typical SOFAR axis arrival, the slow rise to a high signal level and the sharp cut-off abruptly ending the signature. The solid line drawn through the terminations of the shot signatures of Fig. 6, if extended to the origin, will pass through zero range and zero travel time. This leads to the conclusion that this asymptote marks the SOFAR axis arrival cutoffs for all these shots.

B. CW signals and frequency effects

In Fig. 7 transmission loss (TL) versus range curves are shown for the two cw frequencies used in the experiment. The bottom pair of curves, (a) and (b), are for the 13.89-Hz signal, the top pair, (c) and (d), for the 111.1-Hz signal. The bottom curve of each pair, (a) and (c), is the digitized data for the respective frequencies with samples of sound pressure amplitude taken at 2 minute (0,430 km) intervals for the 13.89-Hz signal, and at one minute (0.215 km) intervals for the 111.1-Hz signal.

Curves (b) and (d) are smoothed versions of (a) and (c) respectively. The smoothing was accomplished by taking a 7-km running average of sound pressure amplitude squared. Smoothing serves to remove short range fluctuations and to reveal the convergence zone peaks more clearly.

The convergence zone peaks are a prominent feature of the TL curves for both frequencies from the beginning of the tow at 400 km to the range where Region 2 begins. Beyond that range the convergence zone peaks are poorly defined, if not missing, in the 111.1-Hz curve but remain sharp and well defined in the 13.89-Hz curve. Both sources couple strongly to the subsurface channel of Region 2 but the cutoff of the channel suppresses leakage paths for the 13.89-Hz signal. Thus, the leakage increases the number of propagation paths for the higher frequency while the number for the lower frequency remains essentially unchanged. It is reasonable to assume that the increased arrivals by the leakage paths tend to obscure the convergence zone peaks by filling in the nulls between them. Leakage from the channel is a continuous process and the leakage arrivals do not form a pattern that will contribute to formation of convergence zones.

For ranges at and beyond the Gulf Stream the convergence zone peaks disappear from the TL curve for 13.89 Hz. This is not unexpected. The Gulf Stream is a sufficiently large oceanographic feature to have a large effect on the propagation paths for both the 13.89-Hz and the 111.1-Hz signals.

IV. SUMMARY AND CONCLUSIONS

A series of shallow shots were detonated at small range increments along a great circle track to a range of 2800 km. An alignment of their signatures has lead to the identification and classification of the propagation paths of the individual arrivals. The aligned shot signatures exhibit a symmetry which is independent of changes in small scale features of the oceanography. This symmetry exists because certain dominant propagation paths are determined largely by relatively stable large-scale oceanographic features.

Over that part of the track where the shots were detonated within a surface sound channel the filtered shot signatures show an increased number of propagation paths for the higher frequencies: the leakage paths. The leakage arrivals obscure convergence zone peaking in the cw data for frequencies above the cutoff frequency of the channel. A comparison of the 13.89 and 111.1 Hz cw transmission loss curves shows well defined convergence zones at 13.89 Hz but ill defined zones at 111.1 Hz in the presence of the surface channel.

The conclusion drawn from these studies is that meaningful computations may be made for low-frequency sound signals propagating in the deep ocean using simplified ocean models including only the large-scale oceanographic features of the real ocean.

REFERENCES

[1] A. N. Guthrie, I. Tolstoy, and J. Shaffer, "Propagation of Low Frequency cw Sound Signals in the Deep Ocean," J. Acoust. Soc. Am. 32, 645-647 (1960).

[2] J. Shaffer, D. Nutile, and A. N. Guthrie, Propagation of Very Low Frequency cw Sound Signals in the Deep Ocean," Hudson Laboratories Tech. Rep. No. 172 (April 1969) (AD-689 744).

[3] A. N. Guthrie and J. D. Shaffer, "Propagation of Low-Frequency cw Sound Signals in the Deep Ocean," J. Acoust. Soc. Am. 38, 1060-1061 (1965).

[4] R. M. Fitzgerald, A. N. Guthrie, D. A. Nutile, and J. D. Shaffer, "Influence of the Subsurface Sound Channel on Long-Range Propagation Paths and Travel Times," J. Acoust. Soc. Am. 55, 47-53 (1974).

[5] A. N. Guthrie, R. M. Fitzgerald, D. A. Nutile, and J. D. Shaffer, "Long-Range Low-Frequency cw Propagation in the Deep Ocean: Antigua-Newfoundland," J. Acoust. Soc. Am. 56, 58-69 (1974).

[6] Don F. Fenner and Paul J. Bucca, "The Sound Velocity Structure of the North Atlantic Ocean," U. S. Naval Oceanographic Office Informal Report No. 71-13 (Nov. 1971) (Unpublished).

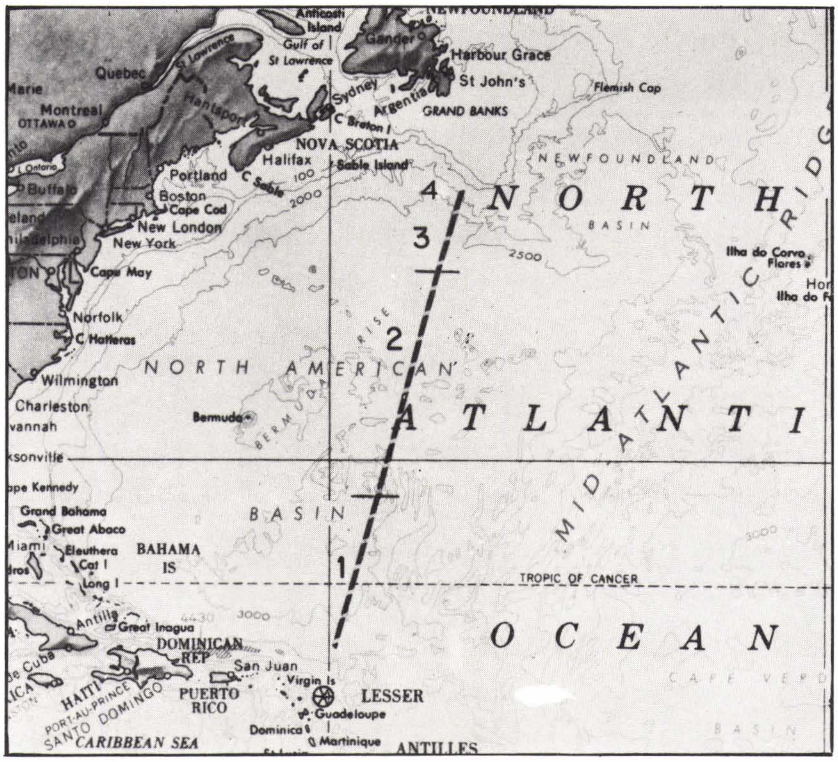

FIG. 1 SHIP'S TRACK. THE NUMBERS ALONG THE TRACK REFER TO THE OCEANOGRAPHIC REGIONS OF FIG. 2

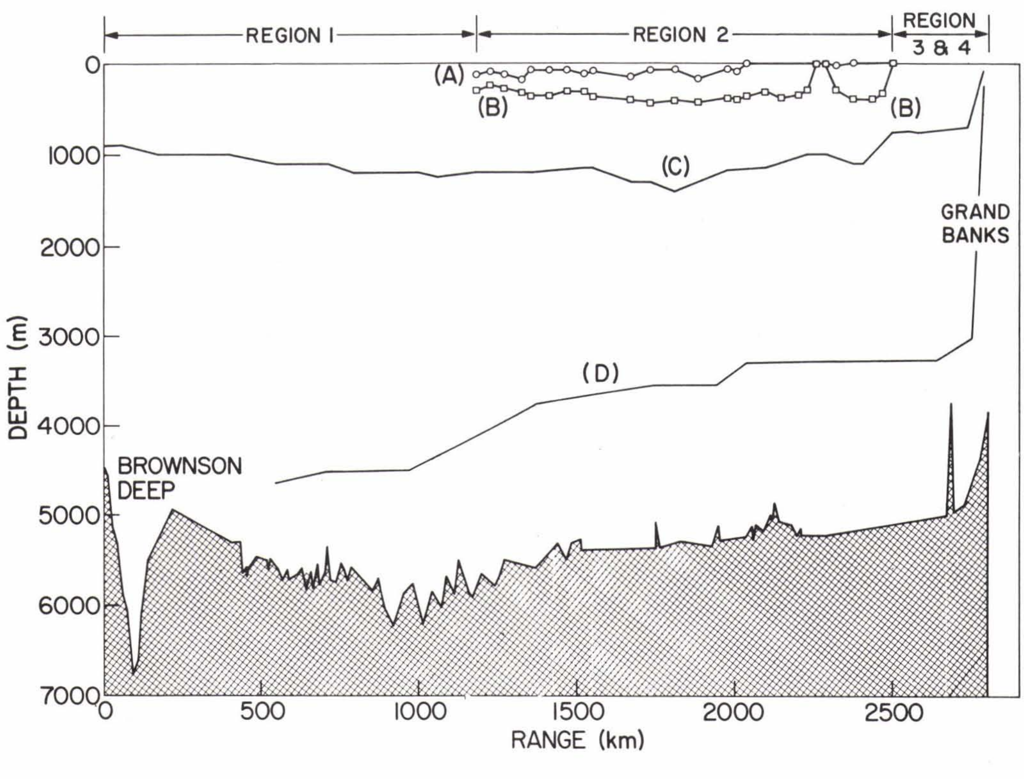

FIG. 2 BATHYMETRY AND SOUND CHANNELS WHERE (A) IS THE SUBSURFACE CHANNEL AXIS, (B) IS THE BOTTOM OF THE SUBSURFACE CHANNEL, (C) IS THE SOFAR CHANNEL AXIS, AND (D) IS THE LIMITING DEPTH

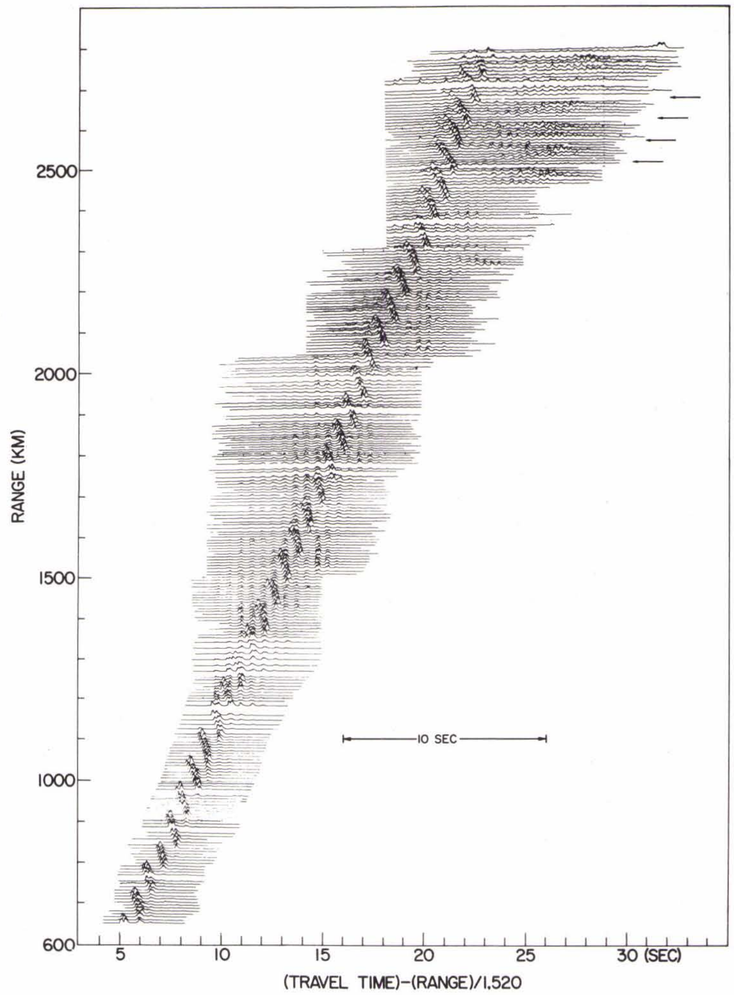

FIG. 3 ALIGNED SHOT SIGNATURES

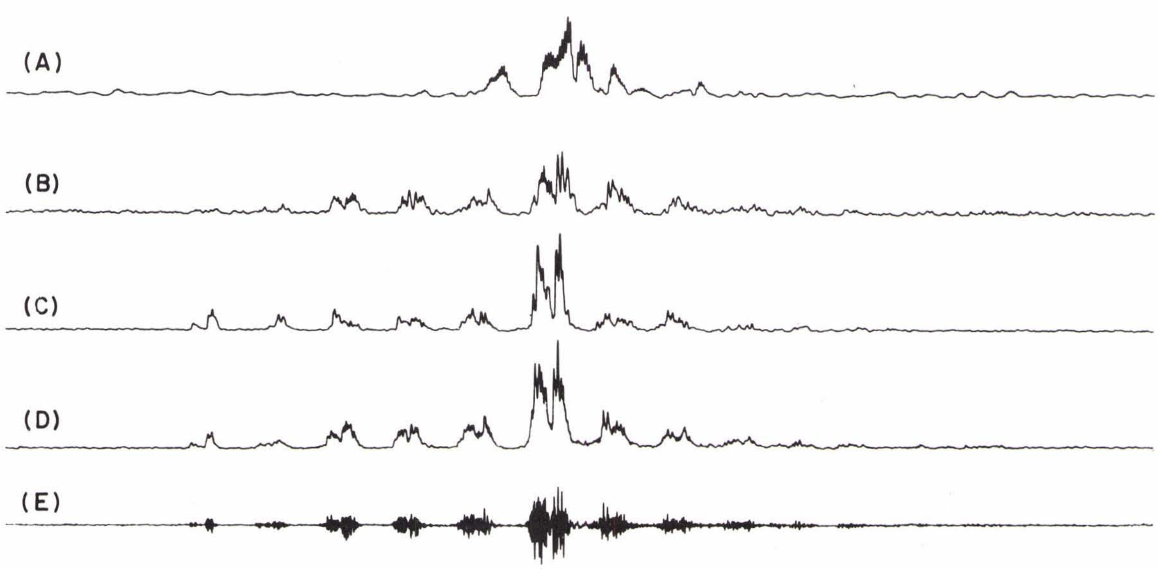

FIG. 4 FILTERED PRESSURE SIGNATURE FOR A SHOT DETONATED AT 1452 km.

(A) 22.5-Hz FILTERED SIGNAL
(B) 90-Hz FILTERED SIGNAL
(C) 250-Hz FILTERED SIGNAL
(D) BROADBAND RECTIFIED SIGNAL
(E) BROADBAND SIGNAL

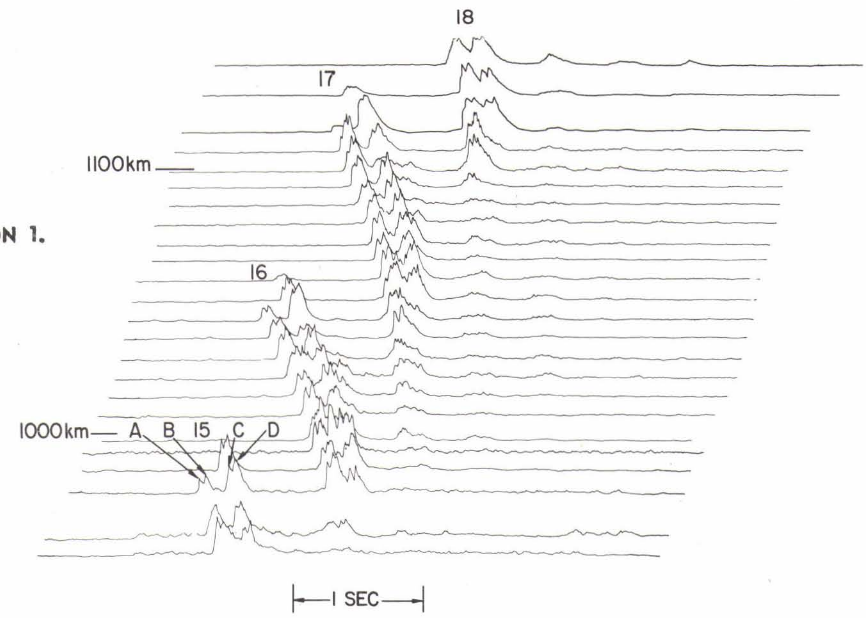

FIG. 5

DETAIL OF SHOT SIGNATURES IN REGION 1. ARRIVAL CLASSES ARE NUMBERED.

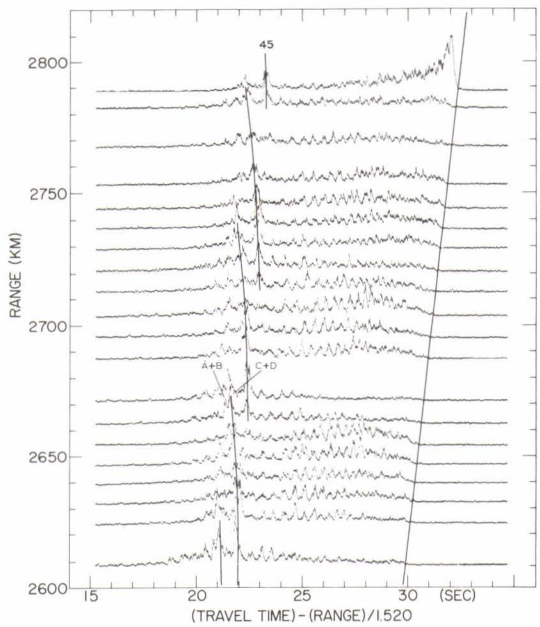

FIG. 6

DETAIL OF SHOT SIGNATURES IN REGIONS 3 AND 4

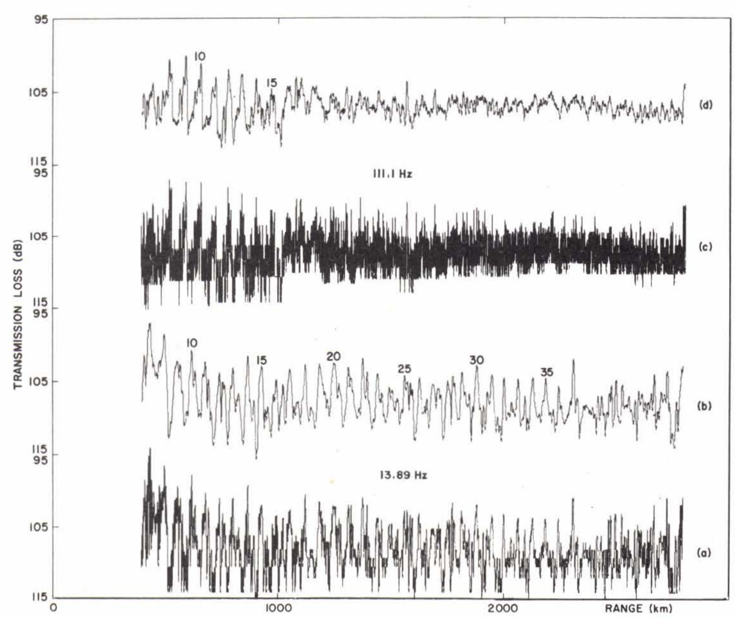

FIG. 7 ACOUSTIC TRANSMISSION LOSS (TL) VERSUS RANGE: (a) 13.89-Hz TL, (b) 13.89-Hz TL FOR THE RECEIVED INTENSITY AVERAGED OVER 7 km, (c) 111.1-Hz TL, (d) 111.1-Hz TL FOR THE RECEIVED INTENSITY AVERAGED OVER 7 km