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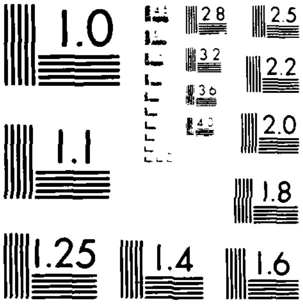

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A SYNOPSIS OF RECENT RESULTS OF RESEARCH ON ACOUSTIC BOTTOM INTERACTION

Annual Report under Contract N00014-78-C-0113

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Robert A. Koch
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This report summarizes research on the acoustic interaction with the seafloor, carried out during 1982 at Applied Research Laboratories, The University of Texas at Austin (ARL:UT). Major topics considered are the role of scattering from a rough substrate in areas having thin sediment cover and the development of geoacoustic measurement techniques for use in shallow water. Other topics include bottom interaction processes in shallow water, bottom interaction at higher frequencies, and propagation in range variable environments.

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laterally varying sediment type.

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I. INTRODUCTION

For a wide variety of source-receiver geometries, acoustic frequencies, sound speed profiles, and water depths, sound propagation in the ocean can be heavily influenced by the ocean bottom. Although seafloor structure and composition has been a subject for study by geophysicists and seismologists for many years, only comparatively recently has it been appreciated that seafloor makeup can impact sound propagation over ranges, frequencies, and geometries of concern to ASW applications. Applications which must be concerned with bottom interaction effects include system performance prediction, resource allocation, system design, the improvement of existing systems, the interpretation of acoustical data, the integration of geophysical data into acoustic modeling, and the design of experiments intended to gather acoustic data in the ocean.

The broad range of concerns in which acoustic bottom interaction can play a significant role requires various levels of description of bottom interaction effects. Traditionally, the nature of bottom interaction has been characterized by a single quantity, bottom loss. For many applications knowledge of this quantity is indeed sufficient, for example, in ray trace estimates of propagation loss used in some system performance prediction models. However, more complex problems involving phase interference between multipaths, questions concerning the functioning of arrays, the nature of Doppler line broadening, and a range changing bathymetry, all require more detailed characterization of the seafloor to quantitatively understand these phenomena. Many of these problems require fairly comprehensive descriptions of the ocean sub-bottom including detailed sound speed and attenuation profiles, the location of major interfaces (reflectors), shear wave parameters, and possibly surface and basement roughness parameters. Treatment of such problems must go beyond a simple regional characterization of bottom loss estimated in 1/3 octave bands, however useful such information may be for certain applications.

With NAVELEX, Code 612, sponsorship through a program administered by NORDA, ARL:UT has been conducting a study of the influence of the ocean bottom on sound propagation. In view of the various levels of description of the ocean bottom required by the intended applications, this research program has encompassed four primary areas: (1) the influence of sub-bottom parameters on bottom loss, (2) the role of the bottom in range changing environments, particularly problems involving slopes, range variable sub-bottom structures, and bottom roughness, (3) the effect of the sub-bottom on the coherence of the sound field, and (4) bottom interaction effects such as those involved in array studies, cw line structure, and the interpretation of experimental acoustic data.

Since its inception in 1975, the emphasis of the ARL:UT program has been on investigating bottom interaction at the low frequencies and for the deep ocean environments important to surveillance applications. Considerable progress has been made in identifying the major loss processes occurring in relatively simple sub-bottom structures and influencing long range, low frequency propagation. For these problems the top few hundred meters to 1 km of the sub-bottom influence propagation.

Recent work at ARL:UT has also been aimed at problems at mid-frequencies (below 1500 Hz) and in shallow water. The higher frequencies are influenced by the more detailed aspects of the sediment structure in the top tens of meters (layering). In shallow water the rapid attenuation of energy penetrating deeply into the sub-bottom also makes the top tens of meters very important in determining propagation characteristics. These two new regimes of bottom interaction research have placed an emphasis on processes occurring in the near-surface sedimentary structure that was lacking in the deep water, low frequency bottom interaction problem. New physical mechanisms, not important in deep water, may be important, or a reordering of major loss processes identified by past work in deep water environments may be required to understand bottom interaction in these new regimes. A simple extrapolation of past work is not possible.

A number of 6.3 programs routinely benefit from the results of the ARL:UT bottom interaction program. These include NAVOCEANO and the Surveillance Environmental Acoustic Support (SEAS) and Tactical ASW Environmental Acoustic Support (TAEAS) programs. Three recent applications of ARL:UT 6.2 bottom interaction research results and expertise leading to an increase in Navy capabilities are: (1) Bottom Loss Upgrade Project (BLUG), (2) ARL:UT analyses for SUBPAC of errors in bottom-bounce hyperbolic cross-fix (HCF) localization, and (3) the recent implementation by NAVOCEANO of onboard processing of bottom loss data.

From the outset the primary goals of the ARL:UT bottom interaction research program have been fourfold: (1) determine and provide guidance on the level of detail of sub-bottom parameters required for acoustic applications, (2) determine which aspects of mode (or multipath) conversion caused by slope coupling, lateral variability, and roughness are predictable and exploitable, (3) develop analysis tools appropriate to the study of a wide range of complex bottom interaction problems, and (4) interact with experimental measurement programs and operational problems via exercise planning, data analysis, and interpretation.

The overall goal of our bottom interaction program is to provide the capability for understanding and exploiting bottom interaction in surveillance and tactical applications. With this in mind, our focus is on problems associated with systems applications. The effect of nearfield bottom interaction on fixed and mobile array performance provides the focus for our work in range variable environments. Work on bottom interaction in shallow water is necessary to understand and develop systems for use in this bottom interaction dominated environment. Loss processes in complex sub-bottom environments must be understood to effectively use near-bottom sensors, particularly vertical arrays. Problems in modeling bottom loss in various parts of the world such as the vast thin sediment areas in the Pacific, the low loss areas in the Atlantic, the extensive bottom limited areas of the South Atlantic, and unique environmental areas such as the Arctic provide the challenge and goal of our work in understanding loss processes in increasingly complex sub-bottom structures.

During 1982, ARL:UT conducted research to study the acoustic bottom interaction in five work areas: (1) loss processes in layered deep sea sediments, (2) shallow water, (3) range changing environments, (4) bottom interaction at higher frequencies, and (5) data analysis techniques for geoacoustic measurements in shallow water. In the first work area, scattering from the rough basement in thin sediment areas and the major loss processes in layered sediments is being studied. The investigation of scattering is aimed at improving BLUG predictions in thin sediment areas of the Pacific. The work on layered sediments pursues our long-term goal of identifying major loss processes. In the second area the physical mechanisms responsible for the optimum frequency effect and the role of gradient driven coupling in sand sediments is being studied. This work will lead to an understanding of some of the major physical processes influencing propagation in shallow water. It will also provide the basis for a shallow water geoacoustic parameter set for BLUG and allow the prediction of optimal frequency effects in areas where exercise data is not available. The work on range variable environments is reaching maturity. Studies of the effects of lateral sub-bottom variability and propagation over slopes is being concluded. The understanding of propagation over range variable environments is being tested by comparing model predictions to available data for cw propagation and ambient noise. The work in the fourth area has two goals: (1) to determine whether the enhanced high frequency reflectivity from near-surface layering can be statistically described for possible use in BLUG and (2) to determine potential bottom interaction problem areas at higher frequencies (below 1500 Hz) and the extent to which current understanding can be extrapolated to higher frequencies. Higher frequencies are particularly useful in shorter range tactical applications. In the final work area a prototype data analysis technique is being developed for use in shallow water. The heart of this method is the use of a modal analysis of propagation over a wide frequency band to infer the geoacoustic structure of the sub-bottom. This technique is being developed with the eventual goal of implementation, for example by NAVOCEANO, to complement the currently existing capability for measurements in deep water environments.

This report contains a summary of the progress made in each of the research areas. This work will be documented in detail through journal articles and other reports as the projects reach maturity. Appendix A is a listing of documentation appearing in 1982. Appendix B lists documentation for the complete project to date.

II. LOSS PROCESSES IN LAYERED DEEP SEA SEDIMENTS

A continuing aspect of bottom interaction studies at ARL:UT is the use of bottom reflection loss as a "measure" of bottom interaction. Computational models of bottom reflection loss are used as vehicles for determining the major loss processes and the importance of sub-bottom parameters and their uncertainties. Past studies at ARL:UT have explored the acoustical importance of seafloor parameters such as density, sound speed, shear speed, absorption, and their gradients. More recent work has examined the role of near-surface [illegible]ing and hydrate formation in marine sediments. During 1982 work concentrated on the role of large scale layering and scattering from the rough basement in areas having thin sediment cover.

A. Review of Previous Work

The study at ARL:UT of the sensitivity of bottom reflection loss to sub-bottom parameter variations began in 1976. Initially the work concentrated on the properties of a fluid sediment and used a computation model[1] developed at ARL:UT. The importance of seafloor parameters such as density gradient,[2] sound speed,[3] absorption gradients,[4] and substrate rigidity[5,6] was established.

In 1978, the direction of these studies turned toward the inclusion of shear wave propagation within the sediment. A new computational model[7] of bottom reflection loss from a single solid sediment layer was developed and used to gauge the importance of sediment shear wave excitation. Initial studies[8] using this model showed that sediment cover is an important factor in determining the role of sediment shear waves. Sediment shear wave excitation is not important for areas having thick sediment cover, but could be dominant in areas of thin cover. A ray path analysis[9] of processes in a thin sediment layer over a substrate established compressional wave conversion at the substrate interface as the physical mechanism generating shear waves in the sediment. This analysis resulted in a detailed understanding of the physical processes by which sediment shear waves influence bottom reflection loss. Further sensitivity studies[10] have identified important sub-bottom parameters affecting bottom reflection loss from a thin sediment layer.

The understanding of bottom reflection loss resulting from these studies of a single deep sea sediment layer has been synthesized in a coherent structure[11] for use in modeling applications. The major loss processes were identified, and a small set of linked geoacoustic profiles and computation models keyed to these processes was developed. The loss processes included were reflection, refraction, absorption, and shear wave excitation. Scattering from rough interfaces may be an additional major loss process for a thin layer, but was not well enough understood to be included in the synthesis.

Four generic geoacoustic profiles were developed for use in modeling a single sediment layer overlying a substrate. The first profile includes only the fluid parameters of the water-sediment interface. The second profile adds the depth dependent compressional wave velocity and absorption as parameters. The third profile adds the substrate parameters and the sediment shear velocity at the substrate. The fourth, and most detailed, profile adds the depth dependent shear velocity and attenuation.

These four geoacoustic profiles are associated with a set of dominant physical processes and hence computational requirements. For the first profile, the dominant process is reflection from the water-sediment interface. It is appropriate for use at high frequencies for which any energy entering the sediment is totally absorbed. The second profile adds compressional wave refraction and absorption within the sediment. It is appropriate for cases in which the compressional wave does not interact with the substrate, i.e., low grazing angles. The third profile adds the effects due to interaction with the substrate and the energy lost to sediment shear waves at the substrate. It can be used for frequencies high enough for the sediment shear wave to be totally absorbed in the sediment. The fourth profile adds effects due to sediment shear wave propagation through the sediment layer and the reconversion of energy back to compressional waves.

In 1981 work at ARL:UT shifted toward an analysis of more complex sub-bottom structures. The major emphasis was on layered sub-bottom structures, scattering from rough interfaces, and effects occurring at higher frequencies. The particular topics addressed were stimulated largely by problems associated with BLUG, sponsored by the TAEAS and SEAS programs and carried out in part at ARL:UT. Two specific bottom interaction problems were identified by BLUG. The first is the existence of anomalously low bottom loss areas in nominally thick sediment areas in the Atlantic. Naval Air Development Center (NADC) bottom loss data from these areas shows octave averaged bottom loss at 1600 Hz as low as 5 dB at high grazing angles, whereas the expected bottom loss for sediment types typical of these deep ocean areas would be about 15 dB. To cope with this large discrepancy, the BLUG geoacoustic profiles for these areas contain a nonphysical, thin, high density surface layer to enhance the reflected energy at high frequencies. Since the actual mechanism leading to the anomalous reflectivity is not known, there is concern about the usefulness of these BLUG profiles and the correct means for extrapolating them geographically. ARL:UT identified and investigated two potential mechanisms: hydrate formation in marine sediments[12] and small scale, near-surface layering.[13]

The second BLUG problem area is associated with defining the geoacoustic parameter set for the areas of the Pacific having thin sediment cover. The current BLUG parameter set does not include sediment shear wave parameters, nor does it treat scattering from the rough basaltic basement. The basement interaction is included through an angle and frequency independent reflectivity parameter. In FY81, ARL:UT began an analysis to include the role of shear wave generation in the investigation of the role of scattering from a rough substrate. This must be treated since acoustic interaction with the substrate is the process by which shear waves are generated within the sediment. Theoretical work was begun in FY81 to determine the effect of scattering from a single sediment layer over a rough substrate when correlation effects are negligible. Initial parameter studies indicated that for 1 m rms height the scattering of shear waves is so strong that the shear wave energy is effectively lost. This is physically equivalent to a very large shear wave attenuation.

B. Summary of Major Results

1. Scattering from a Rough Substrate

During 1982, the description of scattering in the Kirchoff limit was used to examine the role of scattering. A parameter study was performed to determine frequency ranges for which scattering from the water-sediment and sediment-substrate interfaces are important for a typical thin layer of sediment over a basaltic crust. This study suggested a simple method for treating the generation and scattering of shear waves. This method was implemented[14] as a scattering correction to the ARL:UT bottom loss measurement simulator.[15] The modified simulator was used[14] to investigate the role of basement scattering in determining bottom loss measured by NADC in thin sediment areas of the Pacific. Work was also initiated to determine potential values for the mean slope of the rough basaltic substrate from an analysis of time series data from several NAVOCEANO sites in the Pacific, which show an anomalous elongation of received shot waveform for basement interacting energy.

The parameter studies to establish the role of scattering for a typical deep sea, thin sediment layer had four major results. First, the roughness of the water-sediment interface does not couple significant energy into sediment shear waves. A rough water-sediment interface for typical deep-sea sediment types can still be treated as a fluid-fluid interface. Second, for typical rms heights (1-10 cm), scattering from the water-sediment interface is unimportant at low frequencies. This extends previous work[16] to include shear wave generation at the sediment surface. Third, for typical rms heights suggested for the substrate (1-10 m), the sediment shear waves, generated by compressional wave conversion at the substrate, are so strongly scattered that they have no acoustical impact. Fourth, the scattering of the compressional wave at the substrate is the major source of the frequency and angle dependence introduced by the roughness.

These four results combine to suggest a rather simple model of the effect of scattering (in the Kirchoff limit) in thin sediment areas. First, the sediment can be treated as a fluid. Even with rough interfaces, the major process coupling energy into shear waves in the sediment is still compressional wave conversion at the substrate. The strong scattering of shear waves at the substrate further increases the already large attenuation of shear waves within the sediment and guarantees that the energy coupled into the shear waves will not be returned to the water column. Since the propagation of shear waves does not need to be treated, the shear wave velocity and attenuation within the sediment are not necessary geoacoustic parameters, i.e., the sediment can be treated as a fluid. Second, the loss of energy to shear waves can easily be taken into account by correctly evaluating the compressional wave reflection coefficient at the substrate. The sediment shear velocity at the sediment-substrate interface is needed to correctly describe the solid-solid boundary at the substrate. Third, the effect of scattering on the compressional wave reflected from the substrate is easily included by multiplying the reflection coefficient by the exponential factor characteristic of the Kirchoff limit,

$$\exp\left[-a^2(k_1-k_2)^2/2\right]$$

Here, a is the rms height of the substrate interface, and k_1 and k_2 are the normal components of the wave numbers of the compressional waves in the sediment and substrate, respectively. These three steps can easily be implemented in ray theory approaches to propagation that treat bottom interaction in terms of separate rays reflecting from the water-sediment interface and penetrating into the sediment.

The ARL:UT one-bounce bottom loss measurement simulator was modified[15] to include scattering from the substrate as described above. The simulator was then used[15] to examine the role of scattering in determining bottom loss as measured by NADC in areas having thin sediment cover in the Eastern Pacific. The results of this study showed that an rms height of about 0.1 m was typically required to obtain the best fit to the data. The description in terms of the simple approach in the simulator produced fits to the data that were as good as those produced using the constant basement reflectivity factor in the BLUG database. This agreement with the data was important since it showed that the empirical basement reflectivity in BLUG, whose properties are not understood, could be replaced by an acoustically meaningful description, in terms of known processes such as shear wave generation and scattering.

This analysis of the role of scattering in thin sediment areas is expected to continue in 1983 with efforts to determine the role of the mean slope and to develop more complete theoretical descriptions of the scattering process. This work will be guided by available data from areas having thin sediment cover.

2. Major Processes in Layered Sediments

In 1982, a comprehensive literature search[17] was performed to determine the status of currently available information on layering in deep water environments in the Northern Hemisphere. This search will be the basis for choosing typical structures for analysis in 1983.

III. SHALLOW WATER

The nature of bottom interaction in shallow water differs from that in deep water in two principal ways. First, the reduced water depth to wavelength ratio, usually combined with the absence of a significant sound channel, implies that propagation is frequently bottom limited, especially at low frequencies. Second, the geophysical processes responsible for sedimentation in shallow water often produce sand sediments, which are unknown in the deep basins. These same processes are of a smaller spatial scale than those responsible for the structure of deep water sediments, and therefore a higher degree of lateral variability in bottom composition results. These two features make the shallow water bottom interaction problem more severe; the first, by producing bottom limited conditions, and the second, by introducing more lateral variability, as well as increasing the importance of bottom scattering. The situation is slightly eased by the shorter ranges dealt with in shallow water as compared to deep water.

One of the features of long range, low frequency propagation in shallow water is the existence of an optimum frequency of propagation.[18] The optimum frequency tends to be between about 150 Hz and 500 Hz. This may be expected on the general grounds that cutoff and consequent attenuation in the bottom occurs in the low frequency limit, while scattering or water column attenuation restricts propagation in the high frequency limit. Indeed, these loss mechanisms appear to be adequate for propagation loss predictions in areas with clay or silt sediments. On the other hand, for sand sediments, the acoustical mechanisms which determine the value of the optimum frequency and the corresponding loss have not been identified satisfactorily.[18] As a result, the phenomenon cannot be accurately predicted for an area in the absence of measured propagation loss. Given the acoustical data, accurate predictions have been made using a normal mode description of propagation.[18] However, this "predictive" capability is unsatisfactory because unrealistically large values of sediment shear wave velocity (600 m/sec versus the measured 150 m/sec) are required to increase loss at frequencies below the optimum. As a further complication, completely different alternatives have been proposed for predicting the optimum frequency, e.g., using appropriate specifications of the depth dependence of the sediment compressional wave attenuation.[19]

One potential mechanism for increasing the loss at low frequencies is the gradient driven coupling between shear and compressional waves. This coupling is not significant for high frequencies. For typical deep ocean sediments, it is negligible[7] above about 3 Hz. However, the large near-surface gradients in sand sediments may make it a significant mechanism for exciting shear waves within the sediment at significantly higher frequencies.[20] The relatively high attenuation of shear waves in the sediment[21] makes this a potentially important loss process at low frequencies.

A. Review of Previous Work

During 1981, ARL:UT began an examination of bottom interaction in shallow water. The theoretical work to develop an exact generalized potential description of shear and compressional wave propagation was completed.[20] Initial analyses of the results showed that the gradient driven coupling can occur over a fairly narrow depth interval near the sediment surface and that the coupling may be important for frequencies up to about 60 Hz.

B. Summary of Major Results

The examination of the importance of gradient driven coupling between shear and compressional waves continued in 1982. A method for using the exact generalized potential description to calculate the plane wave reflection coefficient was developed and implementation was started.

Other work was performed to examine some additional processes that could affect the optimum frequency. Parameter studies were conducted to examine the role of source and receiver depths and the attenuation profile of the sediment.

IV. HIGHER FREQUENCIES

Recent work[22] aimed at developing geoacoustic profiles for use in computation of bottom loss (the Bottom Loss Upgrade project) has revealed several areas in which higher frequencies measured bottom loss substantially lower than expected from estimates based on sediment type and physiographic province. At high grazing angles (above 60°) at relatively high frequencies (1600 Hz), measured bottom loss can be about 4 dB compared to expected values ranging from 12 dB to 18 dB. The anomalous bottom loss is known to occur in a variety of locations in the North Atlantic, including areas of thick sediment cover for which bottom loss at low frequencies (below 400 Hz) is fairly well understood.

One possible explanation for this behavior is the existence of small scale layering in the near-surface sediment.[13] Such layering would have little effect on low frequency, long wavelength bottom loss; but the high impedance contrasts at the interfaces could result in significant reflected energy at higher frequencies. This layering can, in fact, produce decreases in 1/3 octave averaged bottom loss, consistent with the data.

During 1982, ARL:UT initiated research to determine the level of detail required in geoacoustic profiles to adequately predict bottom loss at higher frequencies (150-1600 Hz). In particular, the goal is to determine the statistical parameters (rms spacing, thickness, etc.) of the layering that produces the loss at higher frequencies. Preliminary work has identified the need to develop techniques for efficient computation of bottom loss, modal propagation, and accurate reflection of rays when the ocean floor has a sequence of layers rather than a single layer with continuous parameters. Hybrid WKB and numerical integration approaches and the use of beam displacement were identified as promising approaches for further examination and use in 1983.

V. GEOACOUSTIC MEASUREMENT TECHNIQUES FOR USE IN SHALLOW WATER

The work discussed in this section is focused on the development of data reduction and analysis techniques that would permit geoacoustic parameters to be extracted from measurements made in shallow water areas. The goal is to use field data as currently acquired and routinely generate sub-bottom geoacoustic models as part of the data reduction.

During the 1970's, understanding of 50-2000 Hz acoustic propagation in shallow water advanced to the point that propagation measurements in reasonably well behaved environments are readily analyzed by propagation models if adequate measurements of the geoacoustic properties of the bottom are available. State-of-the-art acoustic measurement techniques are currently limited to measurements of total propagation loss from explosive (SUS) sources or cw projectors and are ill-suited for detailed analysis of the acoustic channel and, in particular, the acoustic properties of the bottom. Analysis at ARL:UT of exercise data obtained from SUS demonstrated that a geoacoustic model for the bottom can be determined by doing more than simple propagation loss measurements. The additional effort involved several manual and "trial and error" steps, but employed present signal processing and propagation modeling programs.

In 1982, ARL:UT concentrated on developing procedures to determine the compressional attenuation and sound speed profiles in shallow water. At this time, these are thought to be the major geoacoustic parameters influencing propagation in shallow water. The compressional attenuation is a primary loss mechanism and the compressional sound speed profile is important in determining the effect of dispersion.

The basic principle of the measurement techniques developed in 1982 has been discussed[19] in part. The idea is to use the frequency and mode number dependence of normal mode penetration into the bottom to probe successively deeper into the bottom attenuation and sound speed structure. Figure 1 illustrates the frequency dependence of the penetration of mode 1 into the sediment. Typically, for a given mode number, the depth of penetration decreases with frequency, as seen in Fig. 1. Thus, higher frequencies can be used to probe the near-surface geoacoustic structure. Then, the deeper structure is obtained from propagation data at lower frequencies. Similarly, at a given frequency use can be made of the fact that the depth of penetration into the sediment increases with mode number. This permits data from the lowest order mode arrivals in a given frequency window to be used to probe near-surface sediment geoacoustic properties. Then, the deeper geoacoustic structure can be extracted from higher order mode arrivals in the same frequency window.

The dependence of penetration depth on frequency and mode number lead to two possible routes to the construction of a geoacoustic profile of the sediment, as illustrated in Fig. 2. The dichotomy in the structure of SUS recordings observed in data from clayey versus sandy sediments suggests that one of these routes applies to sands and the other to clays. The compressional speed profile may be extracted more readily using an analysis of the frequency dependence of the single mode arrival structure typical of sand sediments. The dependence on mode number is appropriate for clay sediments where the arrival of a number of individual modes is usually observed. The frequency dependence can be used to extract the compressional attenuation profile from propagation loss for both sediment types.

During 1982, the procedures for producing attenuation estimates were essentially completed and automated. Work was begun on the procedures for analyzing the dispersion in shot data as a means for obtaining the sound speed structure of the sediment.

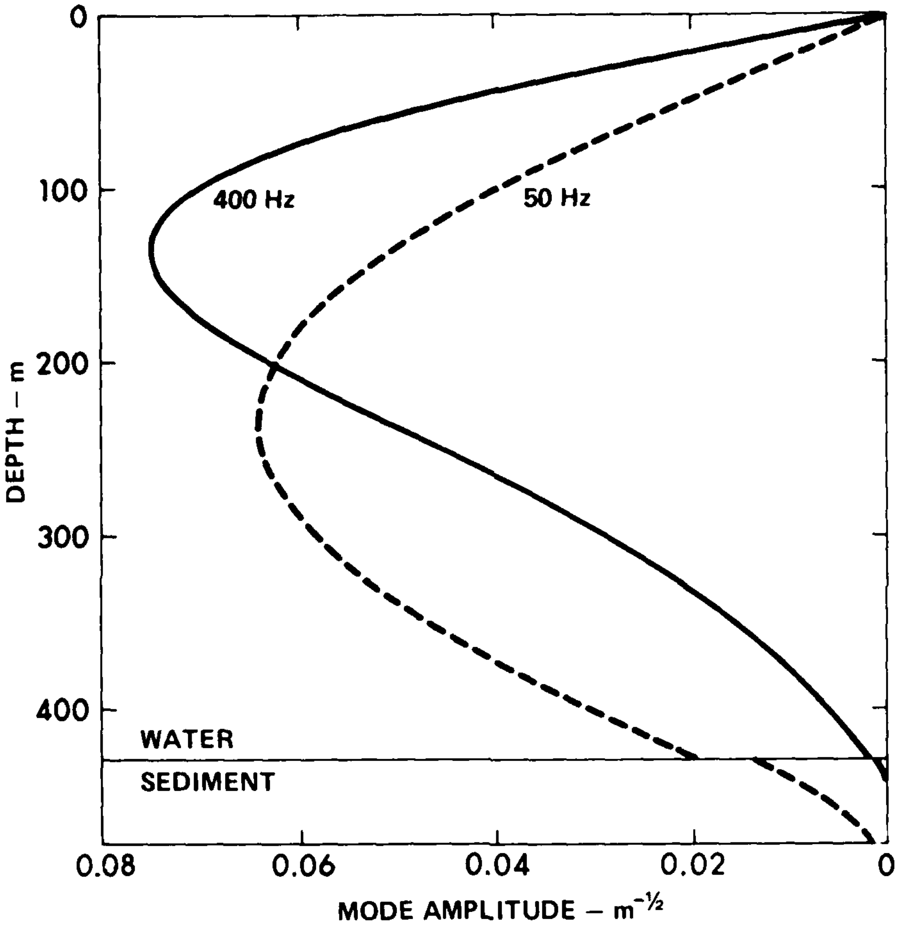

FIGURE 1
AMPLITUDE OF MODE 1 AT 50 Hz AND 400 Hz

Fig. 2
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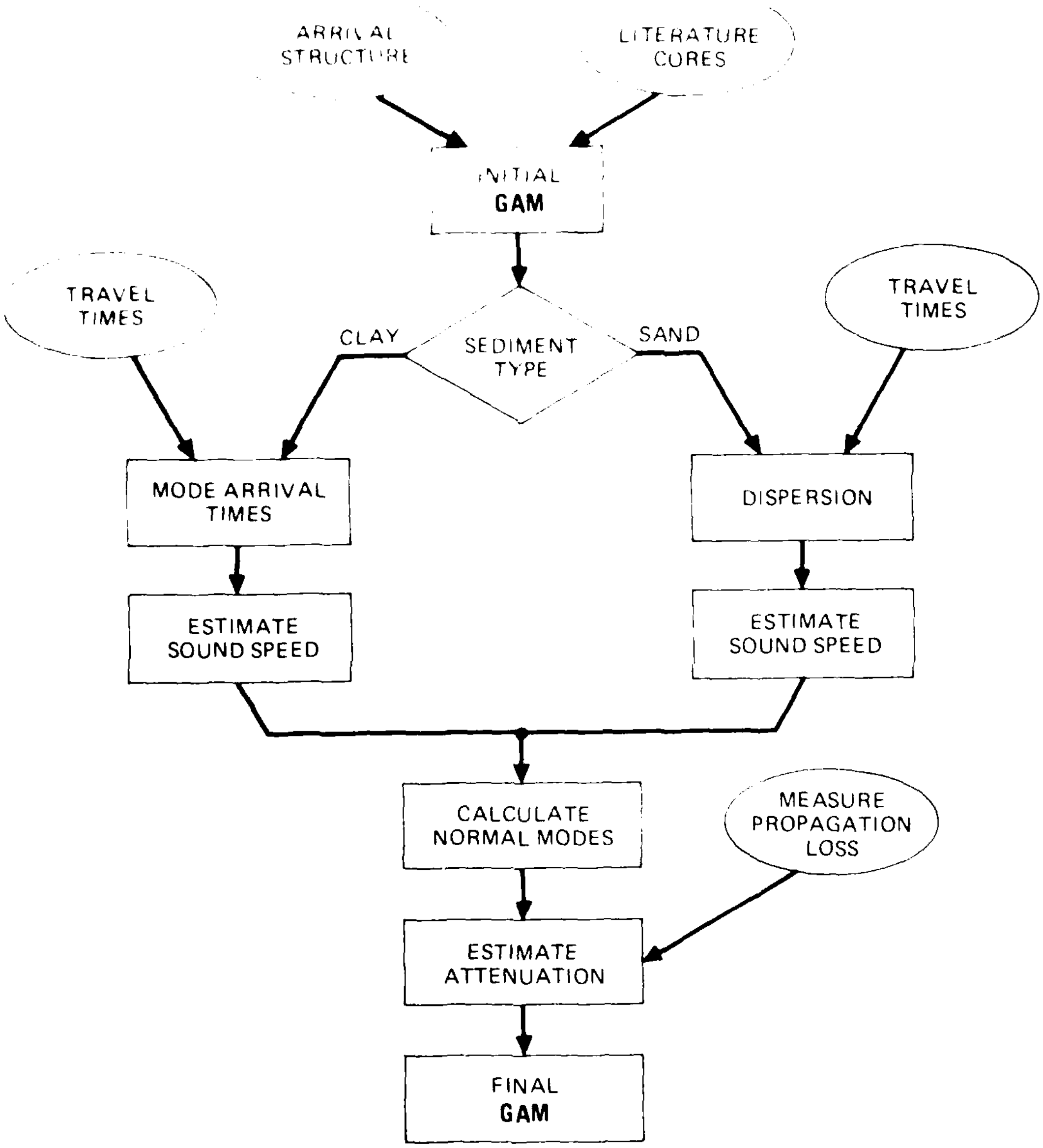

FIGURE 2
GEOACOUSTIC MEASUREMENTS PROCEDURE FOR SHALLOW WATER

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VI. RANGE CHANGING ENVIRONMENTS

The work encompassing acoustic propagation in a range variable environment is summarized in this section. The effect of changes in both bathymetry and lateral sub-bottom composition have been investigated. The goal of this work has been to determine the importance of the geometrical and geoacoustic factors (such as slope angle, the depth and range dependence of the compressional sound speed and attenuation profiles, and sediment thickness) and the level of detail in the geoacoustic and bathymetric descriptions necessary to characterize propagation.

A. Review of Previous Work

The work at ARL:UT in this area began in 1978 with an examination of the validity and sensitivity of the adiabatic approximation as a function of the range dependence of sediment geoacoustic parameters.[23-25] This work contained elements of both the sloping bottom problem and lateral inhomogeneity problems. After developing a consistent treatment and separation of the adiabatic and mode coupling effects,[23,25] the magnitude of bathymetric slopes and lateral sediment sound speed gradients, for which mode coupling corrections would be important, were computed as a function of sediment type and mode number.[24,25] The results showed that mode conversion effects associated with bathymetric changes tend to be more important for the acoustically harder sand sediments. On the other hand, mode conversion effects associated with lateral sound speed gradients in sediments tend to be more important at low bottom interacting mode numbers for clays and silts because their penetrability permits the acoustic field to sample such gradients. Finally, multipath conversion on slopes was shown to be contained in the adiabatic approximation.[25,26]

Beginning in 1980, the work at ARL:UT on range dependent environments focused on the study of the sensitivity of propagation in such environments to bottom properties[27-29] using the adiabatic description. The first of these analyses was concerned with propagation over changing bathymetry and identified the important mechanisms as being cylindrical spreading, renormalization, bottom attenuation, differential mode excitation and reception, and mode cutoff.[28-29] The phase independent structure of the acoustic field for propagation along the bathymetric gradient was shown to be sensitive to the shallow water sediment attenuation but not to the slope angle. The work elucidated the dependence on source and receiver depths of the sensitivity of propagation to sediment attenuation. Slope enhancement for both upslope and downslope propagation was discussed. These results were extended[27,29] to include an examination of the dependence on sediment type of propagation sensitivity to sediment attenuation and the importance of the combination of source and receiver depths. Also examined,[27] concerning propagation over slopes, were the partition of power between waterborne and bottom interacting modes, the effect of sediment attenuation gradients, and the effect of varying the deep water sediment type. Finally, the possible difficulties associated with range-averaged descriptions of laterally varying sediments was considered.

B. Summary of Major Results

The 1982 work on propagation in laterally varying environments involved two topic areas. The first area concerned the influence of bottom interaction processes on observed ambient noise depth dependence. In question was the influence in deep water of shipping noise generated over continental slopes. The second area concerned the effect of laterally varying sediment types on propagation over slopes.

The previous work discussed in Section IV.A suggests that the noise field produced in deeper water should have depth dependence characterized by the water depth and sound speed profile at the source and receiver positions. The combined effect of slope enhancement and bottom attenuation should also produce, for some water depth at the source, a minimum propagation loss to deep water. Some ambient noise data from two abyssal plains sites southwest of Bermuda was examined to test these ideas. The shallower of these was bottom limited and the noise levels at 300 m and 4800 m (bottom) depths were approximately equal. At the deeper (5800 m) site, the 300 m noise levels exceeded those at the bottom by some 8 dB. Using the ARL:UT adiabatic propagation model shows that surface noise sources propagating downslope from 400 m of water dominate the noise field in deep water for depths between 500 m and 3000 m. To produce a substantial noise field at depths between 4800 and 5800 m required sources in 3000 m or more of water. Based on these results, the Bermuda noise data indicates that the noise depth dependence at the shallower site, which was also closer to Bermuda, was dominated by the nearby shipping in deep (5800 m) water. On the other hand, the noise depth gradient at the deeper site could be associated with a combination of sources in deep water and on the continental slope. A similar examination of noise depth dependence in the northeastern Pacific predicted some features of the depth dependence, such as a quiet notch deep in the water column for some locations, but was unable to explain more generally occurring features of the depth dependence. This may indicate that shear wave processes in thin sediments need to be taken into account, whereas the generally thick sediment cover eliminates these processes[8] in the Atlantic.

The work on slope propagation for laterally varying sediment type continued the initial efforts presented in Ref. 27 and are discussed in Ref. 29. The results show some sensitivity of propagation to variations in sediment type between deep and shallow water and that sediment type variations are most important on the shallow end of the slope. However, for upslope propagation, there is greater sensitivity to source depth variations than there is to variations of sediment type and attenuation over their entire range.

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APPENDIX A

DOCUMENTATION FOR 1982

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1. H. H. Holthusen and P. J. Vidmar, "The Effect of Near-Surface Layering on the Reflectivity of the Ocean Bottom," J. Acoust. Soc. Am. 72, 226-234 (1982).

2. J. M. Daniels and P. J. Vidmar, "Occurrence and Acoustical Significance of Natural Gas Hydrates in Marine Sediments," J. Acoust. Soc. Am. 72, 1564-1573 (1982).

3. P. J. Vidmar and R. A. Koch, "A Summary of Recent Research on Acoustic Bottom Interaction," Applied Research Laboratories Technical Report No. 82-14 (ARL-TR-82-14), Applied Research Laboratories, The University of Texas at Austin, 10 March 1982.

4. R. A. Koch, "A Summary of the Results of a Study of Acoustic Bottom Interaction in a Range Dependent Environment," Applied Research Laboratories Technical Report No. 82-30 (ARL-TR-82-30), Applied Research Laboratories, The University of Texas at Austin, 1 June 1982.

5. R. A. Koch, S. R. Rutherford, and S. G. Payne, "Slope Propagation: Mechanisms and Parameter Studies," J. Acoust. Soc. Am. 74, 210-218 (1983).

6. R. A. Koch, C. Penland, P. J. Vidmar, and K. E. Hawker, "On the Calculation of Normal Mode Group Velocity and Attenuation," J. Acoust. Soc. Am. 73, 820-825 (1983).

7. K. C. Focke, "Acoustic Attenuation in Ocean Sediments Found in Shallow Water Regions," Master's Thesis, Electrical Engineering, The University of Texas at Austin, 1982. Also, Applied Research Laboratories Technical Report No. 82-63 (ARL-TR-82-63), Applied Research Laboratories, The University of Texas at Austin, 6 October 1982.

8. R. A. Koch, "A Deterministic Approach to Modeling the Effect of Environmental Fluctuations," Proceedings of the Ocean Environmental Acoustics Stochastic Modeling Working Group, conducted by Naval Sea Systems Command at Naval Research Laboratory, Washington, DC, 26-29 October 1982.

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4. P. J. Vidmar, "Linked Sets of Acoustical Processes and Geoacoustic Profiles Describing the Interaction of Sound with a Class of Seafloor Structures," presented at the International Conference on Acoustics and the Sea-Bed, held at The University of Bath, Bath, England, April 1983.

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APPENDIX B

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