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25 October 1994
NPC/ra
Ser TL-AS-94-07

From: Advanced Sonar Division

To: Office of Naval Research
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Attn: Dr. Mohsen Badiey, Code 324OA

Subj: Semi-annual Performance Report on "Multiple Scatter Theory of Ocean Sediments," under on Grant No. N00014-94-1-0438, for the period 1 February 1994 through 31 July 1994

Ref: (a) Office of Naval Research Grant No. N00014-94-1-0438, "Multiple Scatter Theory of Ocean Sediments"

Encl: (1) Semi-annual performance report
(2) Material Inspection and Receiving Report (DD Form 250) ASG0263

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Nicholas P. Chotiros

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OMB No. 0704-0188

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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED Technical Letter, 1 Feb 94 - 31 Jul 94
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4. TITLE AND SUBTITLE Semi-annual Performance Report on Multiple Scatter Theory of Ocean Sediments	5. FUNDING NUMBERS
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6. AUTHOR(S) Nicholas P. Chotiros	Accession For DTIC CRA&I <input checked="" type="checkbox"/> DTIC TAB <input type="checkbox"/> Unannounced <input type="checkbox"/> Justification <input type="checkbox"/>
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7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES) Applied Research Laboratories The University of Texas at Austin P.O. Box 8029 Austin, Texas 78713-8029	8. PERFORMING ORGANIZATION REPORT NUMBER TL-AS-94-07
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research Dr. Mohsen Badiey, Code 3240A 800 North Quincy Street Arlington, VA 22217-5660	Availability Codes Dist: <input type="checkbox"/> Avail and/or Special: <input type="checkbox"/> A-1
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11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE
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13. ABSTRACT (Maximum 200 words)
To develop a new model of acoustic bottom backscatter from sandy sediments, based on a multiple scattering theory approach, and hence, properly explain observed phenomena, including Lambert's rule and frequency dependence of backscattering strength, particularly at shallow grazing angles, for which current theories are at a loss.

14. SUBJECT TERMS	15. NUMBER OF PAGES 5
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT
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Semi-Annual Performance Report
Grant No. N00014-94-1-0438
1 February 1994 - 31 July 1994

Principal Investigator: Nicholas P. Chotiros

Title of grant: Multiple scatter theory of ocean sediments

Grant: N00014-94-1-0438

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Long-term goals:

To develop a new model of acoustic bottom backscatter from sandy sediments, based on a multiple scattering theory approach, and hence, properly explain observed phenomena, including Lambert's rule and frequency dependence of backscattering strength, particularly at shallow grazing angles, for which current theories are at a loss.

Scientific Objectives:

The idea underlying our current approach to this problem is that real sediments are granular. The hypothesis we are trying to prove is that physical mechanisms for both attenuation and scattering may be found in the interaction of acoustic waves with the granular structure.

Background:

The process of scattering of sound by the interior of the ocean sediment has two components: the conduction of acoustic energy into the sediment and the scattering mechanism. Results of recent sandy bottom penetration experiments by Chotiros[1,2] have shown that Biot's theory[3] is the most plausible model of the conduction process, particularly at shallow grazing angles. The scattering mechanism itself is not well understood. Current theories, such as the composite roughness scattering model by Jackson[4] and the volume scattering models by Ivakin[5], require a degree of sediment surface roughness to conduct energy into the sediment interior at subcritical grazing

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angles, and are unable to explain experimentally observed backscattering from a smooth sand surf

Approach:

Our starting point is Biot's parallel tube model of a porous medium in which plane acoustic waves propagate in the direction of the tubes, as shown in Fig. 1. No scattering is possible in this model, because the wave and particle velocity vectors are parallel to the pore boundaries. To model the scattering, Biot's model is extended by introducing step changes in the pore diameter, as shown in Fig. 2. On a macroscopic scale, a sediment with pore diameter variations is modeled as a finely layered porous medium in which each layer has a different porosity.

Accomplishments and results:

We constructed a model of a sediment layer bounded above by a semi-infinite fluid layer (water) and below by a semi-infinite Biot layer. The sediment layer is modeled as a finely layered porous medium. In modeling the acoustic field in a multi-layered system, we discovered that the proper choice of a reference point for the reflection and transmission parameters within each layer dramatically simplifies the mathematics of the problem. Prior to this discovery, solving an n-layer problem required solving a $(6n+4) \times (6n+4)$ banded matrix equation. Problems with a few hundred layers would require several hours to run. With our new simplifications, a 500-layer calculation can now be performed in minutes. This leap in computational efficiency was made possible by reducing the problem to a 4x4 matrix calculation:

$$(A|Q)x = b,$$

where the 4x4 matrix $(A|Q)$ consists of a 4x1 matrix A which depends solely on the properties of the semi-infinite fluid overlayer, augmented with a 4x3 matrix Q, where Q is the product of three matrices: a 4x6 prefix matrix P that is independent of fluid, sediment, or semi-infinite Biot layer properties, a 6x6 matrix S that depends solely on the layered sediment properties, and a 6x3 matrix C that depends solely on the semi-infinite Biot layer properties. The 4-vector x contains the solution for the reflection coefficient and the transmission coefficients through the multi-layered sediment for the Biot fast, slow, and shear

waves. The 4-vector b depends solely on the properties of the fluid overlayer. Since S contains all the layered sediment information, the problem reduces largely to studying the properties of this matrix. Furthermore, S has the following simple form:

$$S = L(1)L(2)L(3) \dots L(n),$$

where the 6x6 matrix $L(i)$ depends solely on the properties of the i th sediment layer. And $L(i)$, in turn, can be written as:

$$L(i) = B(i) D(i)/B(i),$$

where the 6x6 matrix $B(i)$ depends solely on the material properties of the i th Biot sediment layer and $D(i)$ is a diagonal 6x6 matrix depending on both the material properties and the thickness of the i th layer. All the layer thickness information is contained in the $D(i)$ matrices.

Our initial attempt was simply to consider the case of a uniformly layered Biot medium, where each layer has a thickness on the order of one grain diameter. The layers within the sediment alternate between two values of porosity centered on a mean value of 0.36. We are in the process of quantifying the scattering loss incurred by the poresize variation.

Transition/integration expected:

The result will lead to a unified theory of propagation and scattering in porous media, applicable to ocean sediments over a broad range of frequencies, which will replace much of the disjointed collection of submodels currently in use, and which will properly explain the observed frequency, grain size and grazing angle dependencies. After follow-on laboratory experimental verification, the results of this project will transition into sonar performance prediction models, such as the sonar performance models under development in the Mine Counter Measure Tactical Environmental Data System (MTEDS) project.

Relationship to other projects:

There is a parallel effort funded by Naval Research Laboratory (NRL) that uses a different approach. The two approaches are complementary.

References:

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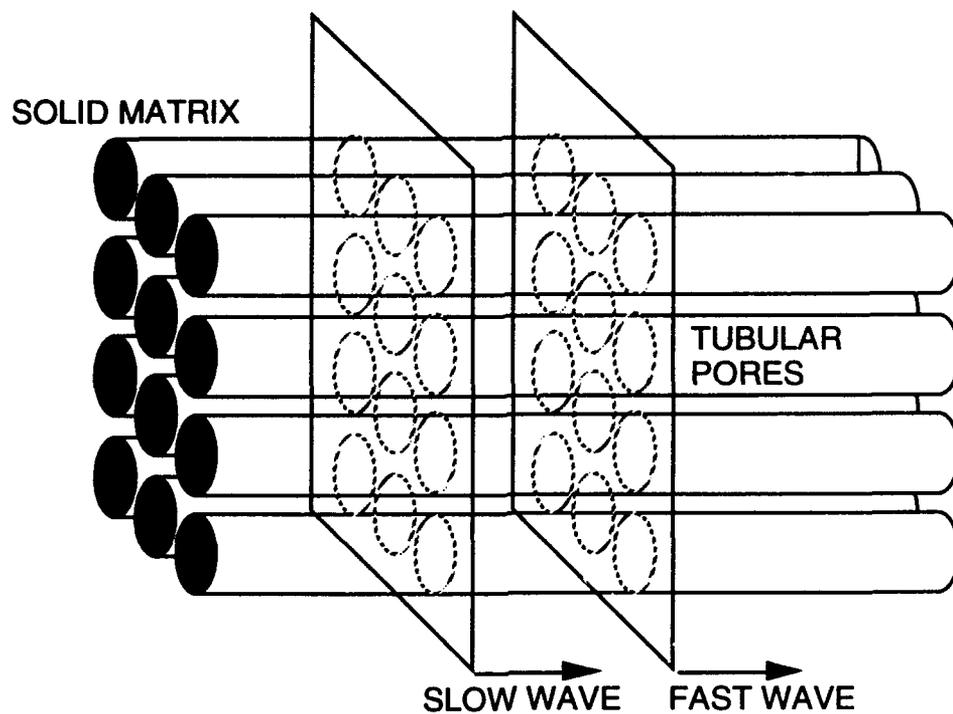


Fig. 1: Original Biot's model

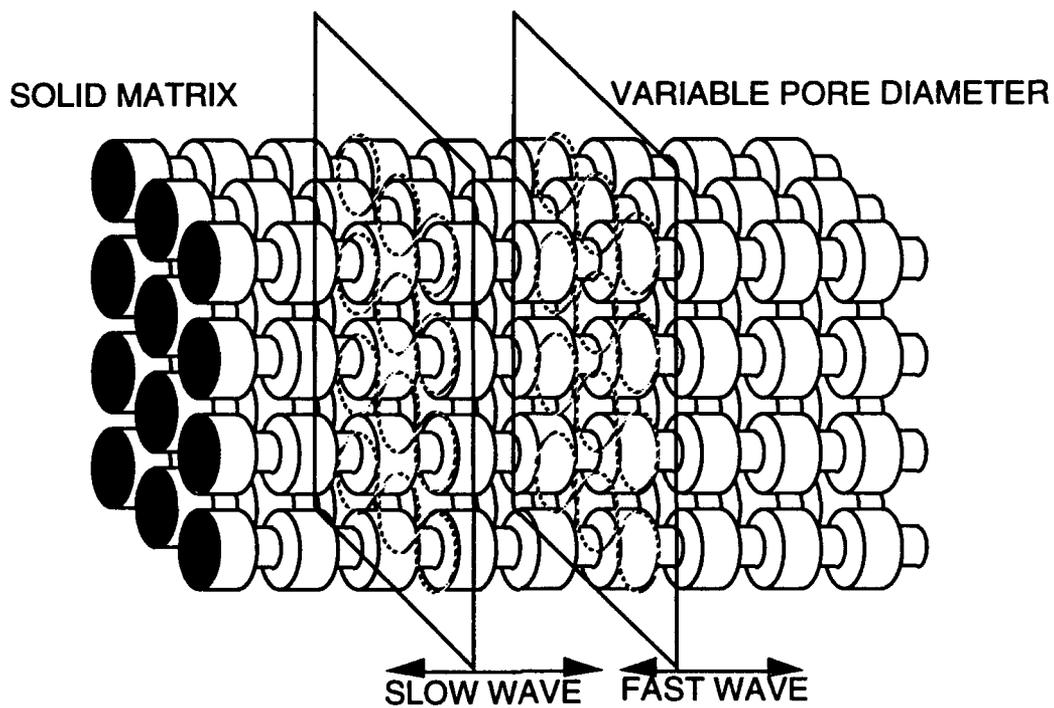


Fig. 2: Extended model