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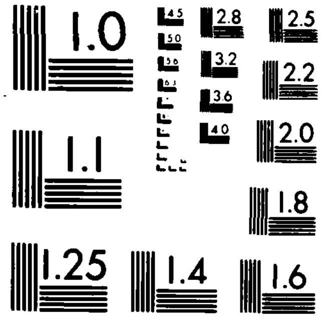

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THE PRECISION OF BOTTOM LOSS PREDICTIONS FROM A PHYSICAL SEDIMENT MODEL

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THE PRECISION OF BOTTOM LOSS PREDICTIONS FROM A PHYSICAL SEDIMENT MODEL

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PREFACE

This work was performed under U.S. Navy Contract N00014-83-C-0650. PSI employees who contributed substantially to the content of this report include Mr. Wilburt Geddes who assisted greatly in the identification of geophysical data sources, Messrs. Robert Hagg, David Delaney, and Michael Switney who performed the manual data entry, Mr. Douglas Waugh who generated the software for digital data entry and the Monte Carlo Biot/Stoll runs, and Mr. Daniel B. Asher who generated, operated or modified all the remaining software. The holdings of the National Geophysical Data Center, Boulder, Colorado were the primary source for the data used in this research. The REFLEC model was developed by the Naval Ocean Research and Development Activity under the Bottom Interaction Program and made available for this effort. The Bottom Interaction Program also sponsored the development at PSI of the PHYSED and SETUP software version of the Biot/Stoll model which provided software modules used in the present study. In addition, the Bottom Interaction Program sponsored a PSI study of depth dependence of geophysical properties that led to the selection of the procedure used in the present work.

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Name and Title of Principal Investigator

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Title of Project

Precision and Accuracy of Geoacoustic Predictions
from a Physical Sediment Model

Technical Abstract (Limit to two hundred words)

Bottom loss (BL) can be computed from profiles of the geoacoustic parameters density, compressional speed and compressional attenuation. The geoacoustic properties can be derived from physical properties of the sediments, which are more readily available, using a physical sediment model (PHYSED) based on the Biot theory of acoustic propagation in porous media. We predict BL for sediments on the continental terrace and evaluate those predictions in terms of their precision. We use readily available physical properties assembled into the data base PHYPROSE, with the PHYSED model to produce geoacoustic profiles for the calculation of BL by the computer program REFLEC. We divide continental terrace sediments into provinces based on water depth ranges and grain size classes. We find that useful separations of BL values by province do occur. Some provinces show significantly different mean BL values and some provinces show significantly reduced variances. This result has particular importance in the shallow water environment, since sediment physical properties are often the only readily obtainable information describing the seafloor. We strongly recommend the application of this physical sediment approach in shallow water to further the development of seafloor interaction models and data bases suitable for operational use.

Anticipated Benefits/Potential Commercial Applications of the Research or Development

The PHYSED model and the PHYPROSE data base have been used in research supporting sediment province determinations for mine warfare and ASW applications. Their continued use in such applications is indicated through funding by the Acoustic Bottom Interaction Program at NORDA, and the AEAS Program at ONR.

1.0 INTRODUCTION

1.1 Background

Navy acoustic ASW system performance can be affected by the properties of the seafloor. The seafloor can act as part of the acoustic waveguide that connects source and receiver, as a barrier blocking such transmissions, or as a scattering element contributing to the variance in acoustic system performance on short scales. The weapons and sonar systems affected by bottom interaction include systems designed to exploit bottom-bounce paths (SQS-26/53 surface ship sonars, BQS-13 and BQQ-5 Sphere submarine sonars, VLAD air deployed sonobuoys), all systems operating in a "close and localize" mode, emerging broadband localization systems (WAA, RAPLOC, LSI concepts, ACSAS, TARP), active adjunct, shallow water torpedo sonars, mine hunting sonars, and bottom or near-bottom mounted surveillance systems. The frequency range of interest for performance estimates of such systems spans from less than 100 Hz to greater than 10^6 Hz. For a given system and geometry, whether the seafloor acts as barrier or waveguide depends upon its acoustic properties. This report is concerned with the problem of predicting the acoustic properties of the seafloor in terms useful for assessing the performance of ASW systems.

The measure of seafloor interaction employed in the sonar equations is bottom loss (BL). BL is expressed in decibels (dB) relative to the energy of the incident acoustic wave and is a function of frequency and grazing angle. BL is controlled by compressional wave speed and attenuation, shear wave speed and attenuation, and sediment density. These we term the geoacoustic properties. Methods that can predict bottom loss or geoacoustic properties for a given location are extremely valuable.

The Navy recently developed the Bottom Loss Upgrade (BLUG)[1] model and data base to provide bottom loss for deep ocean locations. BLUG defines, for a location, smoothed vertical profiles of the geoacoustic properties that produce BL curves essentially equivalent to measurements of BL at that location. Locations devoid of BL measurements are associated with nearby geoacoustic profiles derived from BL if sediment type and thickness are similar. BLUG defines a single curve for shallow water, continental shelf and slope sediments. Given the extreme variability of shallow water sediments compared to deep ocean sediments and the strategic importance of shallow water straits, coastal boundaries, and choke points, a single shallow water geoacoustic profile is inappropriate for many applications.

Because direct measurements of the geoacoustic properties are costly and time consuming, other approaches have been developed. One approach, developed and pursued by Hamilton[2], is to establish empirical relationships between geoacoustic properties of a sediment and physical properties which are more numerous or less costly to accumulate. Another approach is to relate the geoacoustic properties to the physical properties based on physical principles and a single comprehensive theory of porous media developed by Biot[3,4,5] and applied to saturated

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[1] Spofford, C.W., R.R. Greene, and J.B. Hersey, 1983, "The Estimation of Geo-Acoustic Ocean Sediment Parameters from Measured Bottom-loss Data", SAI-83-879-WA, Science Applications International Corp., McLean, VA.

[2] Hamilton, E.L., 1980, "Geoacoustic Modeling of the Sea Floor", J. Acoust. Soc. Am., 68, pp 1313-1340.

[3] Biot, M.A., 1956 "Theory of Elastic Wave Propagation in a Fluid-Saturated Porous Solid", I. Low Frequency Range, J. Acoust. Soc. Am., 28, pp 168-178.

[4] Biot, M.A., 1956, "Theory of Elastic Wave Propagation in a Fluid-Saturated Porous Solid", II. Higher Frequency Range, J. Acoust. Soc. Am., 28, pp 179-191.

[5] Biot, M.A., 1962, "Generalized Theory of Acoustic Propagation in Porous Dissipative Media", J. Acoust. Soc. Am., 34, pp 1254-1264

marine sediments by Stoll.[6,7,8] The advantages of the Biot/Stoll approach over the Hamilton and BLUG approaches have been described elsewhere.[9,10] They include allowing a more realistic dependence of attenuation on frequency for a broader range of sediments, providing internally consistent geoacoustic descriptions, and requiring fewer empirical relationships to generate a full geoacoustic description (thereby accelerating the description process). The accuracy of the Biot/Stoll approach (as implemented and extended in the computer program PHYSED) in marine sediments has been demonstrated to be as good as the measurements to which it was being compared[9,10,11] when the inputs were properly defined.

To be useful as a predictor of BL at a shallow water location, the physical properties upon which PHYSED depends must be in sufficient supply to great enough precision that uncertainties in the resulting BL are acceptably small. Improvement over existing capability is attained if the precision is on the order of that for BL measurements, or better, and physical property availability is greater than BL and geoacoustic measurements combined. It is the purpose of the work presented here to estimate the availability and the precision of BL predictions based upon

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[6] Stoll, R.D., 1974. "Acoustic Waves in Saturated Sediments", in L. Hampton (Ed.), Physics of Sound in Marine Sediments.

[7] Stoll, R.D., 1974, "Acoustic Waves in Ocean Sediments", Geophysics, 42, pp 715-715.

[8] Stoll, R.D., 1980, "Theoretical Aspects of Sound Transmission in Sediments", J. Acoust. Soc. Am., 68, pp 1341-1350.

[9] Brunson, B.A., and E.J. Molinelli, 1982, "A Physical Sediment Model for the Prediction of Seafloor Geoacoustic Properties", PSI, TR-216227 for ONR, Planning Systems Inc., McLean, VA, 22101

[10] Holland, C.W., and B.A. Brunson, 1985, "The Biot/Stoll Model: An Experimental Assessment", PSI TR-185331 for NORDA Code 113, Planning Systems, Inc., McLean, VA., 22102

[11] Beebe, J.H., 1980, "An Experimental Investigation of Ocean Sediment Effects Upon Long-Range Transmission Loss in Shallow Water", Technical Memorandum TM 80-247, Pennsylvania State Univ.

the PHYSED model. By precision we mean the spread, or variance, or uncertainty, in BL values associated with a given prediction.

The PHYSED model is a formulation that relates the sound speed and attenuation of acoustic waves in the sediment to the physical properties of sediment constituents -- the sediment grains, the pore fluid, and the structure of the grains within the sediment (the dry "frame"). Table 1-1 lists the sediment constituent properties that are required as input to the PHYSED model. These properties, together with their units and typical values, are discussed in some detail by Brunson and Molinelli.[9]

Table 1-1. PHYSED Model Physical Inputs

SYMBOL	PHYSICAL PROPERTY	UNITS
	Grain Properties	
ρ_r	Density of sediment grains	g cm^{-3}
K_r	Bulk Modulus of sediments grains	dyne cm^{-2}
	Pore Fluid Properties	
ρ_f	Density of pore fluid	g cm^{-3}
K_f	Bulk modulus of pore fluid	dyne cm^{-2}
η	Viscosity of pore fluid	g cm^{-1} s-1
	Frame Properties	
β	Porosity	--
k	Permeability	cm^{-2}
a	Pore size parameter	cm
α	Structure factor	--
μ_b	Shear modulus of frame (real part)	dyne cm^{-2}
μ_b^*	Shear modulus of frame (imaginary part)	dyne cm^{-2}
K_b	Bulk modulus of frame (real part)	dyne cm^{-2}
K_b^*	Bulk modulus of frame (imaginary part)	dyne cm^{-2}

The output of the PHYSED model is the complete frequency-dependent description of compressional wave speeds and attenuations and shear wave speeds and attenuation valid in the frequency range from 10 to 10^6 Hertz. The output is listed in Table 1-2. The type II compressional wave is a diffusion type wave that is only noticeably excited in materials in which the interstitial fluid has a small bulk modulus compared to the frame. It is not important in most marine sediment applications.

Table 1-2. PHYSED Geoacoustic Output Parameters

Symbol	**Geoacoustic Property**	**Units**
v_p	Compressional wave speed - Type I	$m\ s^{-1}$
a_p	Compressional wave attenuation - Type I	$dB\ m^{-1}$
v_{pII}	Compressional wave speed - Type II	$m\ s^{-1}$
a_{pII}	Compressional wave attenuation - Type II	$dB\ m^{-1}$
v_s	Shear wave speed	$m\ s^{-1}$
a_s	Shear wave attenuation	dB m-1

To use the PHYSED model to derive the geoacoustic properties at a location it is necessary to provide all thirteen inputs listed in Table 1-1. However, for a given location, values for all thirteen physical properties are rarely, if ever, available. This makes it necessary to obtain several of the thirteen inputs by other means. Some of them may be derived from other available properties using relationships based on <u>physical</u> principles. Others may be derived using <u>empirical</u> relationships to available properties. Finally, some may have to be assigned values within some global or local range known to apply for them. The specific options so far assembled for obtaining the thirteen inputs have been described in reference 9. The combined use of empirical relationships as introduced by Stoll and others with the theory of Biot has led to our use of the term "hybrid model" for the suite of formulas assembled as the model PHYSED.[12,13,14] Figure 1-1 diagrams the relationship between the thirteen inputs (along the bottom of the figure) and these other properties, which we term the "genesis" parameters, along the left margin of the figure. Table 1-3 lists the genesis parameters, their symbols and units. Computer software that enables a user to run the model on either the input or genesis parameters was developed as the program PHYSED. This software had to be modified for the purposes of the present effort as described in our approach.

The central issue in assessing the operational utility of PHYSED modeling is whether the input or genesis parameters can be provided with sufficient horizontal and vertical resolution, with sufficient global coverage, with enough accuracy, with the needed precision to obtain useful geoacoustic descriptions of the seafloor. Usefulness implies that the model inputs are more easily obtained than collecting and compiling measurements of BL and geoacoustic profiles. The first part of the assessment requires assembling a data base of available physical properties and manipulating them so as to provide complete inputs for the model. If enough information is available to drive the PHYSED model then the assessment requires that the observed variability of the inputs be carried through to the variability of geoacoustic outputs and thence to the variability in predicted BL. PHYSED modeling will be considered operationally useful if

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[12] Ogushwitz, P.R., 1983, "Applicablity of the Biot Theory, I. Low Porosity Materials", J. Acoust. Soc. Am., .

[13] Molinelli, E.J., and B.A. Brunson, 1983, "PHYSED: Physical Sediment Model Software -- Technical Manual", PSI TR-185246 for NORDA Code 113, Planning Systems, Inc., McLean, VA, 22102.

[14] Watters, P.D., 1983, "PHYSED: Physical Sediment Model Software -- User's Manual", TR-185245 for NORDA Code 113, Planning Systems Inc., McLean, VA, 22102.

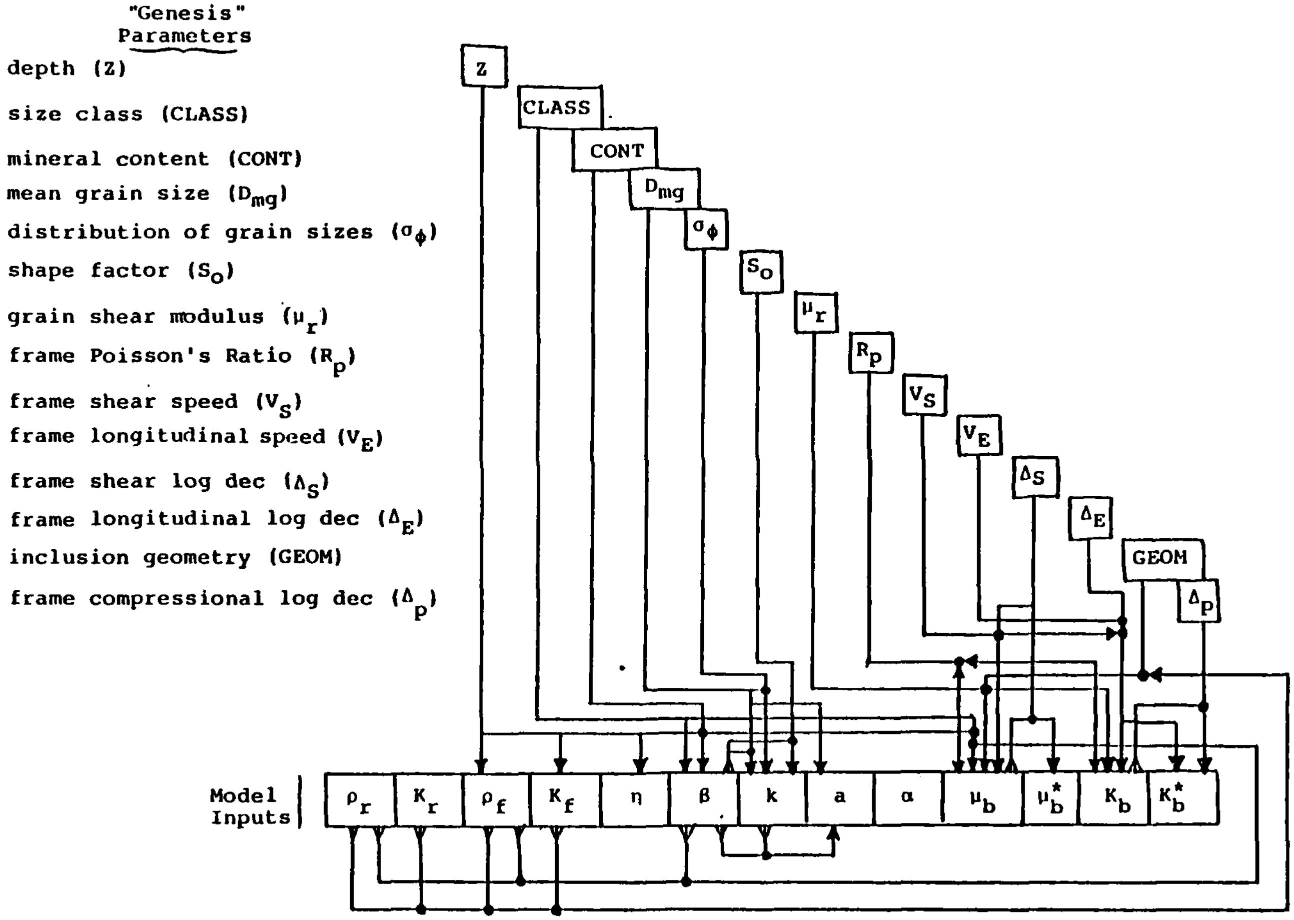

Figure 1-1. Diagram Showing Paths for Generating Inputs to Model

Table 1-3. Genesis Physical Parameters

Symbol	Physical Property	Units
Z	Depth	m
-	Size class (sand, silt, clay)	-
-	Mineral content (calcareous, etc.)	-
d_{mg}	Mean grain diameter	cm
ϕ	$-\log_2$ of grain diameter in mm	phi units
$\sigma\phi$	Standard deviation of ϕ value	phi units
S_o	Specific surface (area/volume)	cm-1
μ_r	Shear modulus of grains	dynes cm^{-2}
R_p	Poisson's ratio of sediment frame	-
V_s	Shear wave speed in frame	cm sec^{-1}
V_E	Longitudinal wave speed in frame	cm sec^{-1}
Δ_s	Frame shear wave log dec	-
Δ_E	Frame longitudinal wave log dec	-
-	Inclusion geometry	-
Δ_p	Frame compressional wave log dec	-

the variability in predicted BL is no worse than what can now be associated with a "province", whether by theory or measurements. We will define a "province" later in the report.

Table 1-4 illustrates the stages of development of the PHYSED model. The model is considered at stage IV by virtue of the results of Holland and Brunson.[10] The objective of the present study is to develop and evaluate the PHYSED model for use in the predictive mode. This report therefore records the progress of the model through stage V and and into stage VI. The physics of the formulation having been tested and the utility of the hybrid model in field applications having been shown, we now address the question of how well BL can be predicted for a given location in shallow water.

1.2 Objective

Here we state our objective again for clarity and emphasis. The objective of these efforts is to estimate how well we can predict BL at a given shallow water site. We will use four criteria to assess the quality of our predictions.

1) The precision of the BL value assigned to a class, or province, of sediments -- expressed in terms of estimates of BL variance in dB.

2) The location of the BL distribution for a class -- expressed in terms of the estimated mean BL in dB

3) The accuracy of the geoacoustic values associated with a province -- expressed, if possible, in terms of estimates of probability that a given measurement of BL or a geoacoustic property is not a member of the distribution assigned to the province

Table 1-4. Stages in the Development of a Geoacoustic Description Using the Biot/Stoll Approach

Stage	Name	Research Topics
I	Theoretical Model Development	Principles and Mechanisms
II	Theoretical Model Validation	- Measurement/model comparisons simple, laboratory sediments - Measurement/model comparisons in complex, laboratory sediments
III	Hybrid Model Development	- Published measurements and relationships and literature searches - Empirical relationship adaptation
IV	Hybrid Model Validation	- Measurement/model comparisons for in situ sediments
V	Predictive Model Development	- Assemble a data base of hybrid model inputs - Determine precision of inputs - Determine precision of outputs
VI	Predictive Model Evaluation	- Couple geoacoustic description to an acoustic model - Determine effect of geoacoustic variations on acoustic model outputs - Compare acoustic model outputs to acoustic measurements
VII	Predictive Model Validation	- Extend data base of hybrid model inputs - Design and perform EVA experiment(s) - Validation experiment/model comparisons - Operational evaluation

4) the availability of information necessary to assign a geographical location to a province -- expressed in terms of estimates of percent of available information.

We consider that for the Biot/Stoll model to represent potential for real improvement in capability the information needed to assign a location to a province should be at least twice as available as direct measurements of geoacoustic profiles and BL combined. In addition at least one of the following must occur.

1) The precision found for a province must be greater (i.e. have significantly lower variance) than that for shallow water sediments as a whole.

2) The mean BL for a province must be significantly different than the mean BL for shallow water sediments overall.

3) The probability that a measurement is not from the population ascribed to its province should be less than one percent.

1.3 Approach

Our basic approach is to use real data to characterize the variance (uncertainty) of the physical properties that drive the PHYSED model, to propagate that variance through to geoacoustic profiles using PHYSED, to propagate that variance further to BL with the REFLEC model, and to describe the resulting precision. The details of the approach require many steps, some approximations, and a few assumptions. These are described in the remainder of this section.

The first step is to assemble data into a computer data base. For this effort data sources have to be identified, a computer file structure designed, and software developed to allow data from digital tapes and reports to be loaded into the base. This effort is described further in another report[15] and summarized in Section 2.

Next, data availability has to be characterized and the observations grouped into provinces that reduce the uncertainity of the physical inputs. Our plan is to group the data a priori by sediment type following Hamilton's classification schemes.[2] Since we concentrate on shallow water and continental margin areas, however, all our data fall into one physiographic province under Hamilton's scheme -- continental terrace. From that point the only classification parameter remaining is sediment size class (sand, silt, clay, and mixtures). We further separate our observations based on an analyses of variance of one of the physical parameters in our data base -- void ratio (an expression of porosity). We choose void ratio/porosity because other work[9,10,16,17] shows the sensitivity of normal incidence reflection to this parameter. After provincing, the variability of PHYSED inputs must be quantified by province. This step is described in Section 2 and in reference 18.

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[15] Molinelli, E.J., D.A. Waugh, O.P. Council, and B.A. Brunson, 1985, "PHYPROSE -- A Data Base for Physical Properties of Ocean Sediments," PSI TR-291304 for NORDA Code 113, Planning Systems Inc., McLean, VA 22102.

[16] Molinelli, E.J., B.A. Brunson, and D.A. Waugh, 1984, "Acoustic Reflectivity and Mine Burial Properties of Sediments", PSI TR-301298 for NCSC Code 003, Planning Systems Inc., McLean, VA 22101.

[17] Brunson, B.A., E.G. McLeroy, C.W. Holland, and R.K. Hagg, 1985, "Acoustic Sea Bottom Classification: A Requirements Analysis", PSI TR-335313 for NCSC Code 401, Planning Systems Inc., McLean, VA 22101.

[18] Council, O.P., R.K. Hagg, D.A. Waugh, and E.J. Molinelli, 1985, "Statistical Analysis of the PHYPROSE Data Base", PSI TR-291315 for NORDA Code 113, Planning Systems Inc., McLean, VA 22101.

The variability of the physical properties within a province must then be propagated through the PHYSED model to produce variability in the geoacoustic profiles output. We choose not to attempt to propagate errors analytically for several reasons. Generating the analytic partial derivatives of each output with respect to each input is a tedious and error prone operation, especially because of the use of complex numbers; the resulting partials will usually be functions of the other variable inputs and sometimes will be nonlinear functions; and, there is an alternative approach. The alternative we use is to simulate the variance in the geoacoustic profiles by randomly sampling from the distribution of physical properties defined for a province, performing the PHYSED calculations on each sample, and accumulating the resulting geoacoustic profiles. This we call the Monte Carlo approach.

For the Monte Carlo approach several physical properties are allowed to vary independently while others are held fixed. We specifically fixed the three pore fluid properties so that our variations could be attributed to sediment properties and not water column variations. Also fixed were the structure factor and the bulk modulus of the grains for which no data were available and which have little impact on compressional speeds. Void ratio (porosity), grain density, and mean specific surface (which, with porosity, determines permeability and the pore size parameter) were sampled from probability distribution functions generated from the data base. Poisson's ratio (which affects frame bulk modulus), and frame log decrements (which affect frame losses) were varied uniformly over a conservative, large range based on values published by Hamilton[2, 19] because they were not

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[19] Hamilton, E.L., 1976, "Attenuation of Shear Waves in Marine Sediments", J. Acoust. Soc. Am. 60, pp 334-338.

available in the data base, yet had shown some effect on BL in previous work.[9] Frame shear modulus was derived from porosity using the "Stoll stress" procedure.[13] Where approximations had to be made they were chosen conservatively, so as to reduce the variability of shallow sediments overall or to increase the variability within a province. In this way, any advantages discovered for the provincing will be robust, i.e. not likely to dissipate under different approximations.

A further approximation is the use of "Stoll stress" constants appropriate for sands for the case of shallow sediments overall. We consider this simplification preferable to introducing an arbitrary discontinuity of frame modulus to shallow sediments that are otherwise continuous in void ratio and grain size. This step is described in Section 3.

The PHYSED model must be run at single frequencies. Because the frequencies of interest are those associated with ASW detection, we select 5 frequencies for the 4 octaves in the range 100 to 1600 Hz.

The next step is to compute bottom loss for each geoacoustic profile resulting from the PHYSED Monte Carlo runs. We use the numerical model REFLEC to perform this computation. This model has been developed by scientists at the Naval Ocean Research and Development Activity using an approach described by Brekhovskikh[20] and has been used in studies designed to test the sensitivity of the complex reflection coefficient to sediment layering.[21] The model is capable of using the compressional wave

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[20] Brekhovskikh, L.M., 1960, Waves in Layered Media, Academic Press, New York.

[21] Gilbert, K.E., 1980, "Reflection of Sound from a Randomly Layered Ocean Bottom", J. Acoust. Soc. Am., 68, pp 1454-1458.

properties provided by the PHYSED model and generating a multi-layered approximation to the vertical profiles. The number and thickness of the layers are selected automatically by a preprocessor which takes into account the sound speed gradient and the frequency at which the reflection coefficient calculation is to be performed. The layers are not allowed to exceed 0.1 wavelengths in thickness, thus ensuring a smooth approximation of the sound-speed profile. The output of REFLEC consists of either the complex reflection coefficient or a bottom loss. These are available at any grazing angle specified for any frequencies of interest. The model can produce estimates for any desired frequency bandwidth (e.g., one-third octave) by averaging the results for discrete frequencies within the desired band; however, we do not employ the bandwidth averaging option. REFLEC does not account for energy loss due to the generation of shear waves, hence REFLEC is a "fluid" sediment model not a "solid" sediment model. We find REFLEC satisfactory for our purposes as discussed in Section 4. For the problem of long-range detection, the BL at the low grazing angles are of primary interest. We decide that a grazing angle of 5^{o} is representative of BL that impacts detection. The generation of BL distributions is described in Section 4.

Finally, we assess our results in terms described in the objective -- mean and variance of BL in an individual province and for shallow sediments overall, difference between an individual province and all shallow sediments, accuracy of predictions, and availability of information to assign a geographic position to a province. This step requires careful statistical procedures and the analyses of variance as described in Section 5.0.

There are a few assumptions built into our approach. We cannot know exactly the distribution of a property in a province;

we can only estimate the distribution based on samples from that province. We therefore use statistical methods to help us distinguish those conclusions which can be drawn with a high probability of being correct. Stated another way, our values for means, variances, differences, probabilities, and percentages are estimates in which we have some statistical confidence; but these values can not be considered exact.

We also make the assumption that the marine sediment physical data we could assemble into a data base with one man-year of effort represents the sediment physical data available at large. We have made every effort to obtain a cross section of physical observations on the continental terrace (continental shelf, continental slope, and continental rise) so we further assume the data we did assemble is representative of continental terrace conditions. Though the conclusions we reach can not be applied to continental margins everywhere, we believe that to justify the large effort required to do that complete job, it is first necessary that the data set we have here assembled show some exploitable trends.

In our calculation of the distribution of properties from the data base we assume measurements from different depths in the same core are independent observations. Each depth is independently assigned to a province. This can skew our distributions because deep cores come from soft sediments and thus more weight is assigned per soft core than to a hard sediment core. When we generate a geoacoustic profile during a Monte Carlo run, the only depth dependence is that associated with the Stoll stress procedure; porosity and the other properties identified for the run remain constant with depth. We thus are modeling a vertically homogeneous sediment that is one member of the class of sediments belonging to a province.

2.0 THE PHYSICAL DATA

2.1 The PHYPROSE Data Base

As described in a separate report,[15] all the physical sediment data used in this study were obtained from the National Geophysical Data Center (NGDC) in Boulder, Colorado. NGDC supports a computerized summary of their digital and technical report holdings which was searched for us. We eliminated from our search those holdings that had only descriptive accounts of sediment color or biological stratification. The physical properties upon which we could key our searches were sediment "texture" data, "engineering" data and "acoustic" data. By far the most extensive holdings (thousands of entries) were found for texture data. The descriptions of the texture holdings were studied to identify those which included "raw" texture data and simultaneously had acoustic or engineering data. We noted whether measurements were in high-priority, shallow-water, areas. When we had thus narrowed our choices, we ordered data to cover as many areas as possible, favoring digital data sets with large numbers of stations over similarly located data published in reports. Digital data were ordered as magnetic computer tape; non-digital data were ordered as microfiche.

Using the criteria set forth above, twenty-seven (27) data reports were ordered from NGDC comprising 95 sheets of microfiche. The area represented by each data report, its NGDC identification number, the number of microfiche sheets, remarks on its contents and disposition with respect to the PHYPROSE data base, are summarized in Table 2-1.

The data entry process consisted of reading the microfiche and tabulating PHYPROSE parameters onto work sheets. Then a BASIC language program on a TEKTRONIX 4052 desktop computer was run to accept information in many different units and combinations and to output formatted records using PHYPROSE conventions.

Table 2-1. Microfiche Ordered from NGDC

Area	NGDC ID No.	No. of Sheets	No. of Stations	Entered	Remarks
U.S. West Coast	09005007	6	39		Texture, Mineralogy, & Engineering
	09005058	5	102	X	NCEL, Texture, & Engineering
	09595004	2	10	X	NOO, Texture, Engineering, & Acoustics
	09825001	2	10		NOO, Texture, Engineering, & Acoustics
	20995001	3	1,103		Texture
Mediterranean Sea	09005022	1	3		NOO, Texture, & Engineering
	09055005	6	21	X	NOO, Texture, Engineering, & Acoustics
	09535002	2	59		NOO, Texture
	03045003	3	7	X	NOAA, Texture, & Engineering
Arctic	09245001	3	64		NOO, Texture
	09325001	1	38		USSR
	09375002	6	54		NOO, Texture & Engineering
	09995032	4	20	X	NOO, Texture & Engineering
Europe	09995004	2	154	X	NOO, Texture
Persian Sea	09315004	8	108		NOO, Texture
Caribbean	03035001	4	31	X	Engineering
	09005012	3	65	X	Texture, Engineering
	09065007	3	26		NOO, Texture & Engineering
	09265005	2	12	X	NOO, Texture, Engineering, & Acoustics
	09295001	2	40		NOO, Texture
Gulf of Alaska	06255002	2	16	X	Texture, Engineering
Indonesia	09255001	1	27		NOO, Texture
Indian Ocean	09005024	1	8		NOO, Texture
	09645001	5	57	X	NOO, Texture
	09785006	5	4	X	NOO, Texture, Engineering, & Acoustics
	09785007	7	9		Too dark to read
So. Hemisphere	09995010	5	33		No data

These records were transferred to a VAX 11/780 run by the Naval Ocean Research and Development Activity (NORDA) at NSTL Station, Mississippi through a a communications bus and telephone connection. Listings of the resultant VAX files were made and compared to the original microfiche for quality control. Finally, VAX FORTRAN programs were run to load the records into PHYPROSE.

In Table 2-1, no mark in the "Entered" column indicates that data from that report have not been entered into PHYRPOSE. Only eight of twenty-seven reports have been incorporated because the data must be entered manually and the process requires extensive uses of manpower. The reports were added to the data base in an order that reflected the importance of the area, the widest geographic coverage possible, and the expectation of additions from digital sources. Consequently no U.S. east coast data were entered by hand (or even ordered) because of the vast number of stations available from the USGS tape discussed below. Substantial numbers of stations were expected from digital tapes for the Arctic, the Gulf of Mexico, the Pacific margin, and southeast Asia. Also anticipated was a digital tape of unclassified NAVOCEANO data; so, microfiche of NAVOCEANO observations were not used until the contents of that tape could be viewed to avoid duplication of effort. When the tape proved extremely limited in coverage (due to classification) late in the effort only a few NAVOCEANO stations could be entered.

During the search of NGDC holdings, several digital computer tapes were identified as having useful data in priority areas. Five of these tapes were ordered to provide as wide a global coverage as possible. The area represented by each tape, its NGDC identification number, the number of stations it contains, its disposition with respect to PHYPROSE, and remarks on its content are presented in Table 2-2. The NAVOCEANO tape was not ordered from NGDC but received directly, therefore it is not included in this table. Because it did not prove useful, it will not be discussed further.

Table 2-2. Computer Tapes Ordered from NGDC

AREA	NGDC ID #	STATIONS	ENTERED	REMARKS
U.S. East Coast	06995002	3715	yes	USGS, texture
Arctic	20995002	688	yes	U. Washington, texture
Gulf of Mexico	23055001	561	yes	Texas A&M, texture
North Pacific	15995012	688	no	NOO(Scripps)--no useful data
Southeast Asia	15995014	8168	no	NOO(Scripps)--no useful data

The process of retrieving data from the computer tapes consisted of writing and running special purpose VAX FORTRAN software to read data from the tapes and load the information into PHYPROSE-like files. These were screened for errors, edited and appended to the end of the actual PHYPROSE files. Not all stations on the tape were appended to PHYPROSE because not all stations had values for the select PHYPROSE parameters. Especially disappointing was the fact that the NAVOCEANO (NOO) data compiled onto tape by the Scripps Institution of Oceanography (the last two tapes in Table 5-2) contained no information other than qualitative grain size.

2.2 PHYPROSE Contents

The contents of the PHYPROSE data base as of 1 April 1985 are described in terms of the total number of stations, the number of stations with particular types of data (common properties, engineering properties, etc.), the total number of records of each data type and maps of station locations.[15] In summary, PHYPROSE contains:

- *4,355 stations
- * 233 stations reporting common properties (including void ratio & grain density)
  2,277 records
- * 106 stations reporting engineering properties (shear strength, etc.)
  933 records
- *1,950 stations reporting mineral properties (percent Calcium Carbonate, etc.)
  2,935 records
- *2,109 stations reporting qualitative grain sizes (sand, silty sand, etc.)
  2,898 records
- * 180 stations reporting size class information (percent sand, percent silt, etc.)
  1,353 records
- *3,900 stations reporting full grain size distributions (percent by weight in one phi size bins)
  9,214 records
- * 40 stations reporting acoustic properties (including compressional speed)
  921 records
- * 40 stations reporting fluid properties (including temperature) 168 records

These stations are distributed over 17 ocean areas as follows (ocean area code in bold numerals):

- *U.S. East Coast **11** (Nova Scotia to Key West)
  2,109 stations
- *Caribbean Sea **12** (Lesser Antilles)
  48 stations
- *Gulf of Mexico **13** (Mississippi delta)
  206 stations
- *Beaufort Sea **24**
  13 stations

*Chukchi Sea **25**
700 stations
*East Siberian Sea **26**
154 stations
*Laptev Sea **27**
114 stations
*Barents Sea **29**
2 stations
*Mediterranean Sea **30, 31**
104 stations
*Black Sea **34**
2 stations
*Indian Ocean margin **50, 51**
13 stations
*U.S. West Coast **60** (Los Angeles & Gulf of Alaska)
101 stations
*South China Sea **62**
20 stations
*Sea of Okhotsk **66**
20 stations
*Bering Sea shelf **67**
739 stations

One of the most dramatic features of the PHYPROSE holdings is the vast quantities of textural (i.e., grain size) information and the lack of geoacoustic data. It is true that a bias against acoustic data resulted from our decision to pass over NAVOCEANO reports ("lab items") in anticipation of receiving a digital tape. However, had we biased our data base in the opposite direction by incorporating all stations with acoustic data from our twenty-seven reports, we would have had only 57 stations with geoacoustic measurements -- only 1% of the stations that are in the data base already, and less than 1% of the stations had we entered all the data listed in Table 2-1. It is fair to state that there is a vast amount of textural data and a lack of geoacoustic data. However, for PHYPROSE to enable testing of

Biot/Stoll outputs some geoacoustic data had to be included in the data base.

The ratio of the number of texture observations to the number of common properties observations (including void ratio and grain density) also seems well represented by PHYPROSE. In the listing of high quality microfiche in Table 2-1, there are about 2040 stations described; 2009 of them report texture data. In the same set, about 420 stations report engineering properties (including common properties). Therefore, in the specialized subset described in Table 2-1, common properties are available about 20% of the time and texture properties are available 98% of the time. Given that Table 2-1 selectively ignored purely textural data sets, one can expect common properties to be available much less than 20% of the time. In PHYPROSE, common properties are present 5% of the time. This is not unreasonable.

We therefore conclude that PHYPROSE adequately represents the relative abundance of geoacoustic data, void ratio and grain density data, and grain size distribution data in shallow waters. The stated abundances indicate that a great advantage in predicting BL is achieved if a geographic position in shallow water can be allocated to a BL province based on grain size data rather than on acoustic data, geoacoustic data, or engineering data.

2.3 The Definition of Provinces

It is beyond the scope of this effort to discover the optimum provincing of ocean sediments based on BL. We wish first to demonstrate that there is some advantage to provincing; specifically we wish to quantify the advantage in provincing based on the Hamilton classification scheme.[2] For shallow water sediments on the continental shelf, continental slope, and continental rise, Hamilton defines a single physiographic province called the continental terrace. Within the terrace, he separates sediments into qualitative size classes -- coarse sand, fine sand, very fine sand, silty sand, sandy silt, silt, sand-silt-clay, clayey silt, and silty clay. Based on 212 samples assigned to these size classes he describes ranges for physical and geoacoustic parameters. Hamilton's scheme is shown in Figure 2-1.

For the large amount of data in PHYPROSE we need to define a qualitative sediment size class based on grain size data unambiguiously. By convention, the gravel size class includes grains with diameters greater than 2 millimeters. A convenient scale for grain diameters is the phi-scale. By definition:

$$\phi = -\log_2 \text{ (grain size in millimeters)}$$

On the phi scale, gravel corresponds to values less than -1. The sand size class includes grains with diameters from 2 down to .0625 millimeters($-1<\phi<4$); and, silt grains are in the range from .0625 to .0039 millimeters ($4<\phi<8$). The clay size class includes all grains smaller than .0039 millimeters ($\phi>8$). The relative percentages of the sediment in these size classes can be used to define an unambiguous, qualitative grain size class as illustrated in Figure 2-2. We adopt a numbering system for the qualitative size classes as shown in that figure; sand is sediment size class 1, silty sand is 2, etc. Not shown is an eleventh class, gravel, which is presumed to describe sediments with more than 50% gravel fraction. No sediments in the PHYPROSE data base were so labeled. The percentages that bound these classes are consistent with the data displayed by Hamilton.[2] Silty-clay mixtures are termed muds in our convention; and, no distinction is made among the sands (coarse, fine, very fine) in our convention.

The separation of continental terrace sediments by qualitative size class is an <u>a priori</u> provincing likely to affect BL because of the differing compressional speeds claimed for each type in Figure 2-1. Our experience with PHYSED modeling has shown the importance also of porosity/void ratio to bottom reflectivity.[16,17] We therefore tested whether continental terrace sediments could be separated based on their void ratio

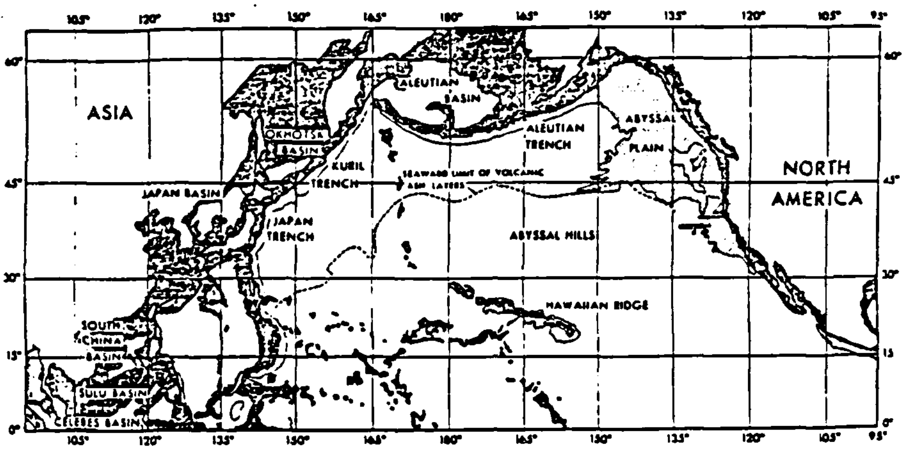


FIG. 1. Physiographic provinces and related environments, North Pacific and adjacent areas. See Hamilton[3] for references and discussion. The three general environments are continental terrace (shelf and slope): solid, horizontal lines; Abyssal plain (turbidite): horizontal, dashed lines; and abyssal hill (pelagic): white areas.

TABLE IA. Continental terrace (shelf and slope) environment; average sediment size analyses and bulk grain densities.

Sediment type	No. samples	Mean grain diam. (mm)	Mean grain diam. (φ)	Sand (%)	Silt (%)	Clay (%)	Bulk grain density (g/cm³)
Sand							
Coarse	2	0.5285	0.92	100.0	0.0	0.0	2.710
Fine	22	0.1593	2.65	90.9	4.9	4.2	2.704
Very fine	12	0.0960	3.38	81.9	10.5	7.6	2.684
Silty sand	27	0.0490	4.35	57.6	28.9	13.5	2.689
Sandy silt	26	0.0308	5.02	28.0	59.2	12.8	2.680
Silt	19	0.0237	5.40	7.8	80.1	12.1	2.661
Sand–silt–clay	23	0.0172	5.86	32.3	41.6	26.1	2.701
Clayey silt	62	0.0077	7.02	7.3	60.0	32.7	2.660
Silty clay	19	0.0027	8.52	4.8	41.2	54.0	2.701

TABLE IB. Continental terrace (shelf and slope) environment; sediment densities, porosities, sound velocities, and velocity ratios.

	Density[a] (g/cm³)		Porosity[a] (%)		Velocity[a] (m/s)		Velocity ratio[a]	
Sediment type	Av	SE	Av	SE	Av	SE	Av	SE
Sand								
Coarse	2.034	···	38.6	···	1836	···	1.201	···
Fine	1.941	0.023	45.6	1.02	1749	11	1.145	0.006
Very fine	1.856	0.022	50.0	0.97	1702	18	1.115	0.012
Silty sand	1.772	0.020	55.3	0.72	1646	10	1.078	0.006
Sandy silt	1.771	0.033	54.1	1.49	1652	12	1.080	0.007
Silt	1.740	0.047	56.3	1.30	1615	8	1.057	0.005
Sand–silt–clay	1.596	0.022	66.3	1.53	1579	8	1.033	0.005
Clayey silt	1.488	0.016	71.6	0.86	1549	4	1.014	0.003
Silty clay	1.421	0.015	75.9	0.82	1520	3	0.994	0.002

[a] Laboratory values: 23 °C, 1 atm; density: Saturated bulk density; porosity: Salt-free; velocity ratio: Velocity in sediment/velocity in sea water at 23 °C, 1 atm, and salinity of sediment pore water. SE: Standard error of the mean.

Figure 2-1. From Hamilton[2], page 1315

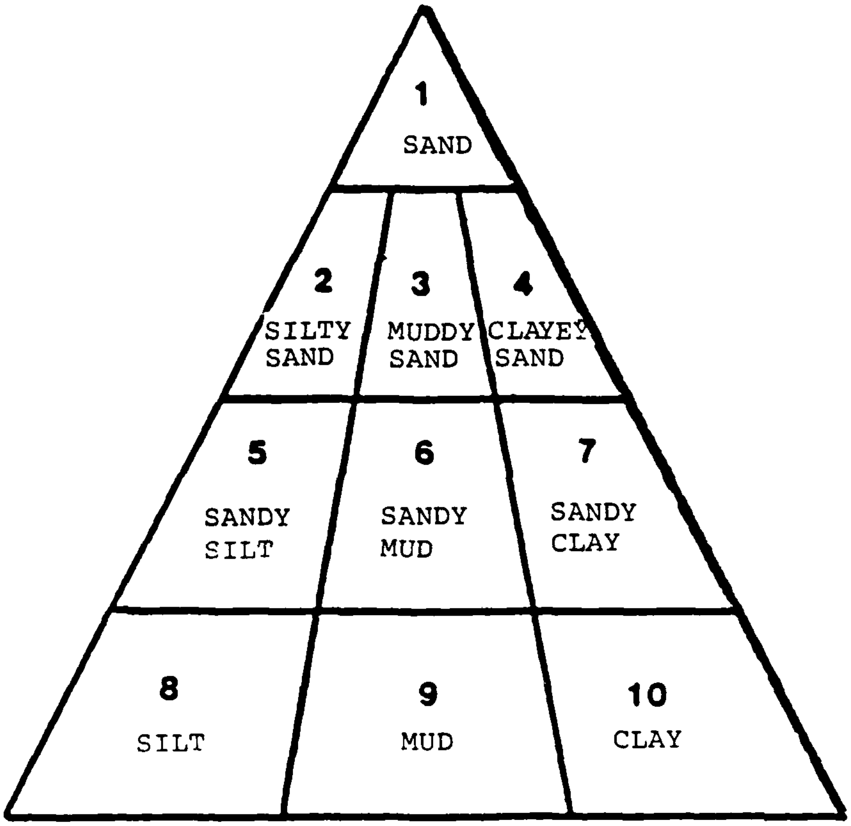


Figure 2-2. The classification of sediment by relative proportions of grain sizes. A sediment that is more than 75% sand is classed as sand; a sediment that is less than 25% sand is classed as silt, mud or clay depending upon the non-sand portion. If the non-sand portion is more than 66% silt, the sediment is termed a silt; between 66% and 33% silt, the sediment is a mud; and, less than 33% silt, the sediment is a clay. Mixtures are classified according to the diagram.

values, and found that both depth of the seafloor and ocean area were additional criteria more important than sediment size type in explaining void ratio variance.[18] We summarize the results of that study in the next paragraphs.

Figure 2-3 shows a histogram of all void ratio values in the PHYPROSE data base for which there was also grain size information. The distribution shows two major peaks and is asymmetric, strongly suggesting that there are several factors influencing void ratio. We use one-way classification analysis of variance (ANOVA) to demonstrate the relative significance of four "treatments", i.e. sediment grain size type, seafloor depth, ocean area, and depth in sediment core. For the sediment type "treatment" the ten classes already described and depicted in Figure 2-2 are used. For the seafloor depth treatment we define four classes: shelf (0 to 200 m), upper slope (200 to 1000 m), lower slope (1000 to 2000 m), and continental rise (2000 to 4000 m). For ocean area we use the regions defined for the PHYPROSE data base; the ocean areas with data were listed in Section 2.1. Finally, we define depth intervals within the core as follows: 0 to 10 cm, 10 to 60 cm, 60 to 80 cm, 80 to 100 cm, 100 to 120 cm, 120 to 140 cm, and deeper than 140 cm.

One-way ANOVA calculations for each treatment are presented in Tables 2-3 through 2-6. Here, the influence of water depth, sediment type, ocean area and depth in sediment core on void ratio are separately tested. The table shows the F-statistic for each factor. These values are compared to the distribution of the F-statistic for the appropriate degrees of freedom and all four values are found to be significant. This means that there is a significant difference in void ratio between at least one pair of treatment classes in each of the four treatments; it does not guarantee that all treatment classes are significantly different from all others.

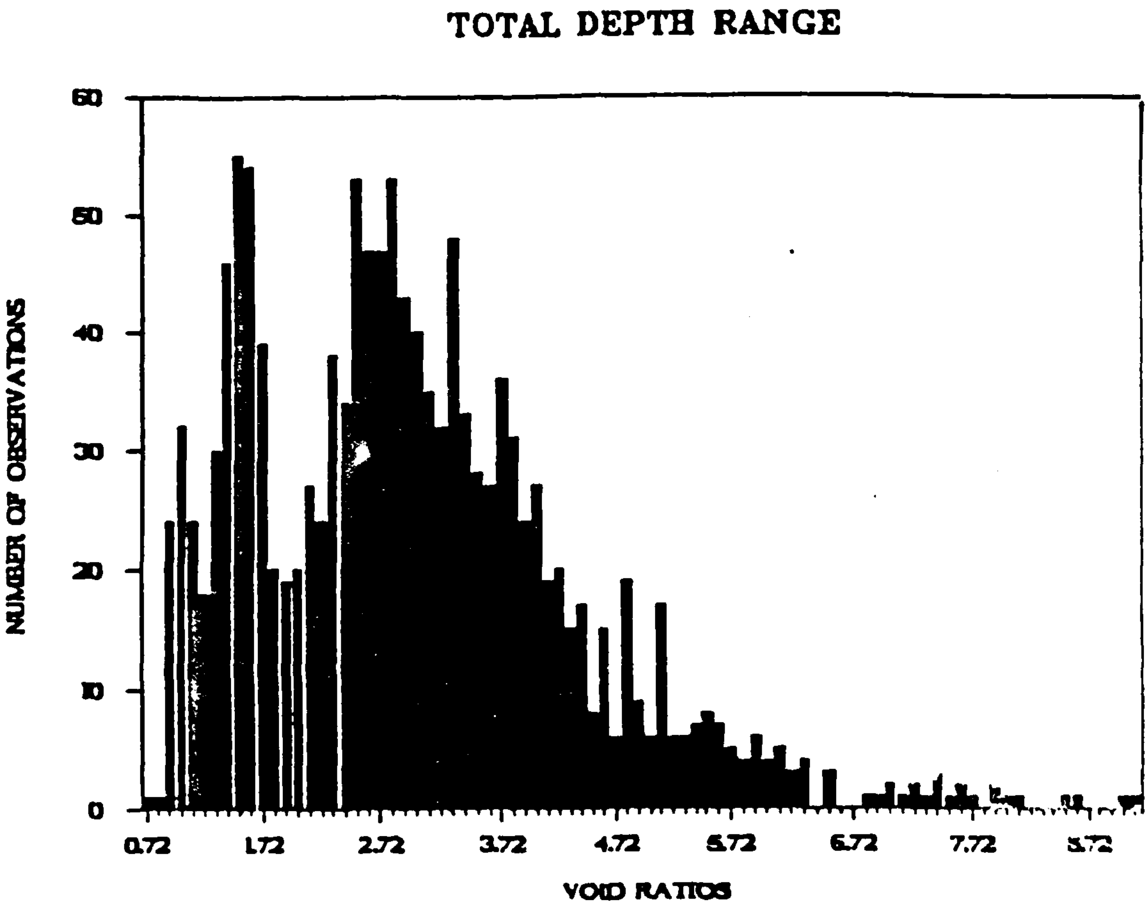


Figure 2-3. Histogram of all void ratio values

Table 2-3. One-way ANOVA on Seafloor Depth

Depth	Number of Observations (n)	Sum	Sum of Squares	Contribution to Square of Sum per Observation	Mean
0-200	237	324.021	480.1941	442.994	1.367
200-1000	227	556.130	1571.374	1362.469	2.449
1000-2000	136	429.288	1634.992	1325.060	3.156
2000	492	1870.780	7879.046	7113.451	3.802

$S_c^2 = 337.419$ $S^2 = 1.187$ $F = 284.224$

Table 2-4. One-way ANOVA on Ocean Area

Ocean Area Code	Number of Observations (n)	Sum	Sum of Squares	Contribution to Square of Sum per Observation	Mean
12	66	136.50	3110.553	282.307	2.0682
30	5	18.28	60.260	66.832	3.656
31	135	278.960	614.027	576.435	2.066
34	4	16.740	78.574	70.057	4.185
50	33	89.30	256.754	241.651	2.706
51	295	1143.8700	4964.747	4435.386	3.877
60	326	709.009	1990.045	1542.001	3.104
62	193	599.010	2109.785	1859.135	3.104
66	35	188.550	1172.133	1015.745	5.387

$S_c^2 = 103.479$ $S^2 = 1.36167$ $F = 75.99$

Table 2-5. One-way ANOVA on Depth in Sediment Core

Sediment Core Depth (m)	Number of Observations (n)	Sum	Sum of Squares	Contribution to Square of Sum per Observation	Mean
0-.10	59	115.515	296.861	226.165	1.957
0.10-0.60	215	455.493	1199.897	964.995	2.118
0.60-0.80	59	123.004	331.719	256.440	2.085
0.80-1.00	27	57.399	154.258	122.024	2.126
1.00-1.200	6	14.700	45.442	36.015	2.450
1.200-1.400	9	23.566	80.403	61.706	2.618
1.400	17	55.832	192.016	183.365	3.284

$S_c^2 = 4.5038$ $S^2 = 1.1685$ $F = 2.85$

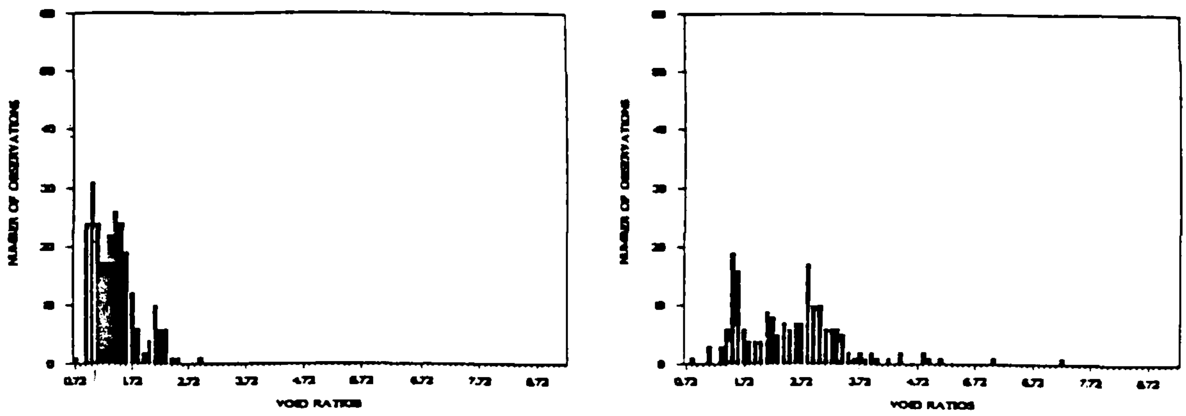
Table 2-6. One-way ANOVA on Sediment Type

Sediment Type	Number of Observations (n)	Sum	Sum of Squares	Contribution to Square of Sum per Observation	Mean
Sand	12	11.66	11.605	11.337	0.972
Silty Sand	80	223.783	855.108	625.734	2.797
Muddy Sand	51	118.007	350.074	273.052	2.3139
Sandy Silt	57	81.225	135.150	115.746	1.425
Sandy Mud	48	78.0110	140.938	126.786	1.625
Sandy Clay	4	7.11	13.153	12.638	1.777
Silt	87	172.372	396.047	341.518	1.981
Mud	314	906.089	3220.703	2614.64	2.886
Clay	439	1581.823	6442.821	5699.69	3.603

$S_c^2 = 62.7677$ $S^2 = 1.6107$ $F = 38.96$

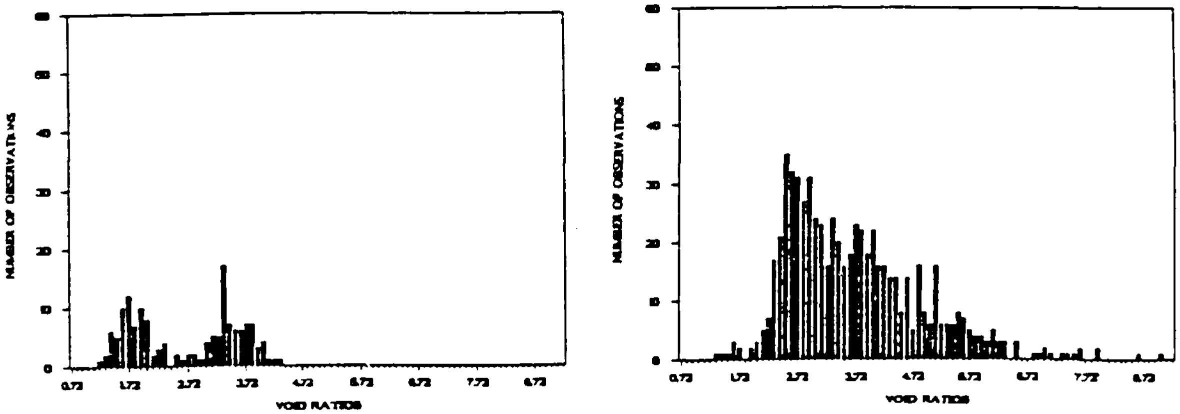
Inspection of Tables 2-3 through 2-6 indicates that the mean square between classes, S_c^2, is largest for variation due to water depth. This suggests that water column depth has a greater influence on void ratio than the other factors. The influence of water depth on void ratio was further examined by plotting histograms of void ratio for 4 different water depth intervals. These plots are presented in Figure 2-4. The distributions at 1 to 200 and greater than 2000 m seem reasonably homogeneous (although this was not explicitly tested). The distributions for the continental slope (200-1000 m and 1000-2000 m) in contrast show two separate peaks, i.e. are bimodal, suggesting that at these depths some other factor influences void ratio. These two distributions are therefore divided up according to ocean area code -- that is, according to the area in the ocean where the measurements were taken. The void ratios in the 200-1000 m interval come from the Mediterranean Sea and the Gulf of Alaska as shown in Figure 2-5a and 2-5b. The void ratios in the 1000 to 2000 m interval come from the Caribbean, the Mediterranean and the South China Seas as shown in Figures 5c, d and e. The high void ratios in the deeper interval are associated with the void ratios for the South China Sea shown in Figure 2-5e. Also, the high void ratio data in Figure 2-4b for the 200-1000 m interval seems to come primarily from void ratio taken in the Gulf of Alaska, shown in Figure 2-5b.

These results, however, still support the general interpretation that depth has a greater influence on void ratio than ocean area. The separation in the void ratio data created by grouping according to seafloor depth is greater than that created by grouping according to ocean area in Figure 2-5. More generally, the histograms in Figure 2-4 indicate that no other factor is likely to have as great an influence on the void ratio data as water depth. A two-way classification ANOVA calculated for the effects of sediment type and seafloor depth simultaneously gives a similar result. Seafloor depth has a greater influence on void ratio than sediment grain size class.



a - water column depth 1-200m

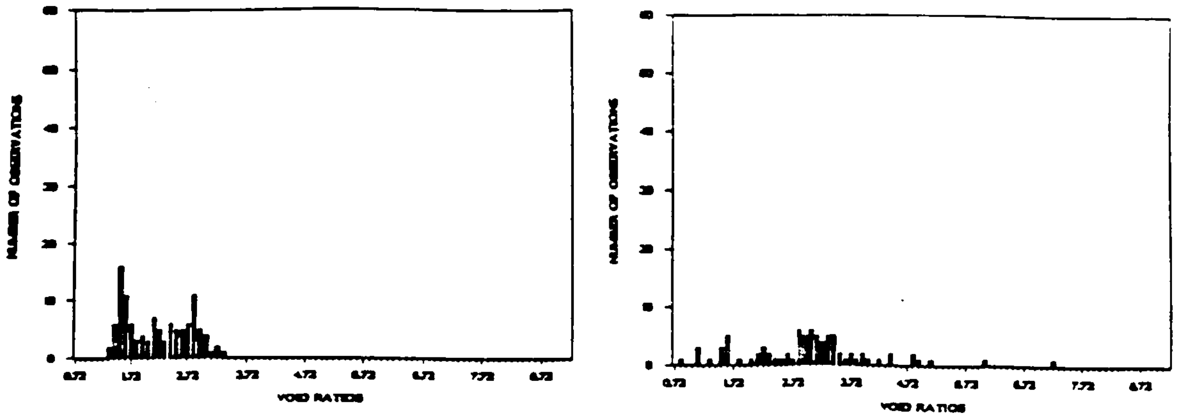
b - water column depth 200-1000m



c - water column depth 1000-2000m

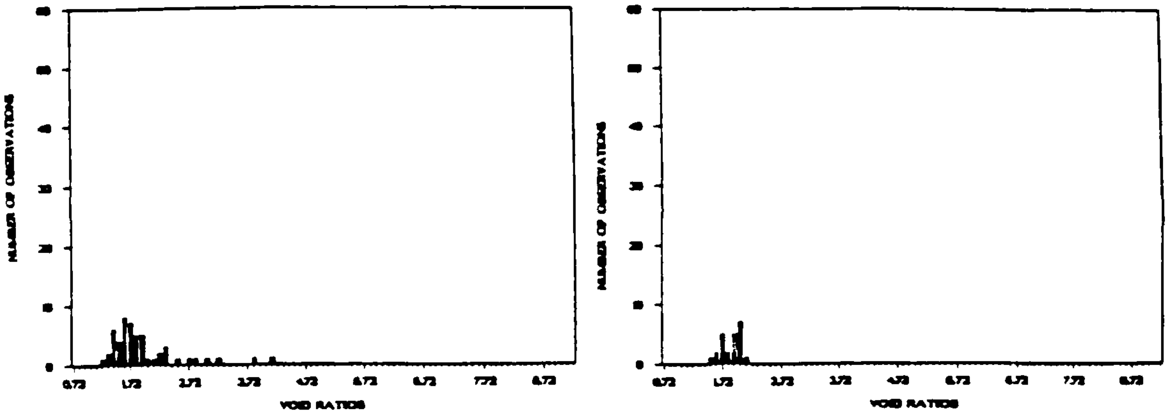
d - water column depth 2000m

Figure 2-4. Histogram of void ratio values separated by water column depth



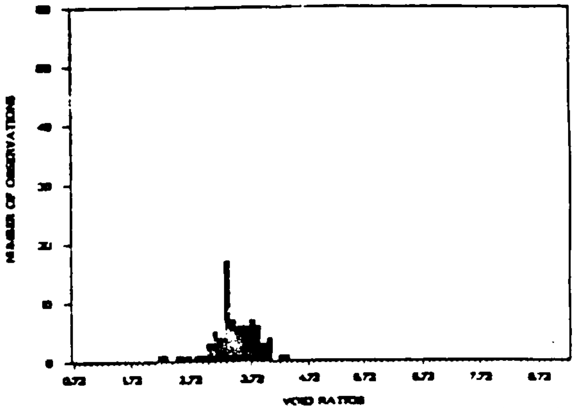
a - water depth 200-1000m, ocean area = western Mediterranean Sea

b - water depth 200-1000m, ocean area = Gulf of Alaska



c - water depth 1000-2000m ocean area = Caribbean Sea

d - water depth 1000-2000m, ocean area = western Mediterranean Sea



e - water depth 1000-2000m, ocean area = South China Sea

Figure 2-5. Histograms of void ratios for the two depth intervals 200-1000m and 1000-2000m separated according to ocean area

Because of the importance of seafloor depth for void ratio, and the importance of void ratio/porosity for seafloor reflectivity, we have provinced continental terrace sediments by seafloor depth in addition to sediment grain size type. To keep the number of provinces manageably small, and the number of samples per province meaningfully large, we have combined some classes using for guidance the mean values listed in the one-way ANOVA tables (2-3 and 2-6) and the histogram. Thus we combine the upper and lower slope depths into one class (slope -- 200 to 2000 m); and we group silty sand with muddy sand (and call the group dirty sand), we group sandy silt with sandy mud and with sandy clay (sandy muds), and we group mud and clay (muds).

We do not separate continental terrace sediments by ocean area at first in order to keep sample sizes large; but, we reserve these ocean area criterion for use during refinemen stages if we do not obtain sufficient separation of BL with the original provincing scheme. As will be shown in Section 5, there is adequate separation of BL for the purpose of this report using the original provincing scheme.

We adopt a two-letter naming convention to facilitate references to the provinces. The first letter refers to the seafloor depth and the second letter refers to the grain size type using the codes in Table 2-7.

2.4 Province Physical Properties

There were sufficient data in the PHYPROSE data base to describe, for each shelf and slope province, the distribution of three of the PHYSED input parameters -- void ratio/porosity, grain density, and mean specific surface (which drives permeability and pore size paramter). Table 2-8 lists the number of observations available from PHYPROSE for each of the three parameters in each of eleven provinces. Province ZZ is taken to represent continental terrace sediments as a whole. Measurements at different depths within the same core were included as separate observations.

Table 2-7. Province Name Code

First Letter (seafloor depth)		**Second Letter (grain size type)**		
Letter	Depth Interval (m)	Letter	Name(s)	Class Number (s)
A	0-200	A	Sand	1
B	201-2000	B	Silty sand Muddy sand Clayey sand	2 3 4
C	2001-4000	C	Sandy silt Sandy mud Sandy clay	5 6 7
Z	All depths			
		D	Silt	8
		E	Mud Clay	9 10
		Z	All size types	1 thru 10

Table 2-8. Number of Observations that Define Distributions for the Provinces

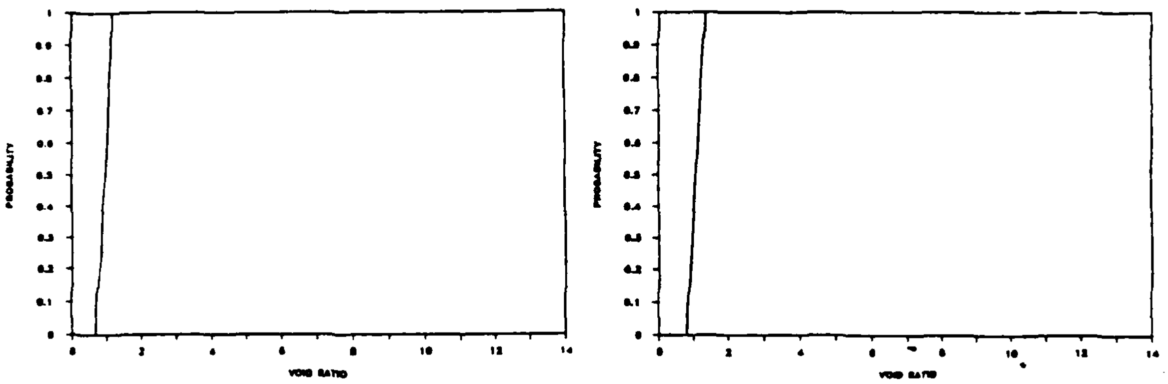
Province Code	**Void Ratio: Number of Observations**	**Grain Density: Number of Observations**	**Mean Specific Surface: Number of Observations**
AA	8	16	1,870
AB	24	48	822
AC	36	37	1,061
AD	22	22	2,359
AE	41	43	1,140
BA	2	18	169
BB	10	17	111
BC	44	49	164
BD	4	5	42
BE	294	310	451
ZZ	1,457	1,542	9,214

The distributions are represented as cumulative distribution functions which are more easily computed from real data than histograms because no bins have to be defined, and which are directly used by the Monte Carlo sampling routines. The cumulative distribution functions are plotted for void ratio in Figure 2-6, for grain density in Figure 2-7, and for mean specific surface in Figure 2-8.

These distributions were computed by sorting according to value the observations of each parameter in each province, assigning each sorted observation a sequence number (from 1 to the total number of observations), defining the "probability" by dividing each sequence number by the total number of observations, dropping all duplicate points but the one with the highest sequence number, and defining a zero probability point by extrapolating the mean slope back to the parameter axis (providing it did not intersect below the smallest possible value of the parameter -- zero for void ratio and mean specific surface, one for grain density). The resulting probability associated with each value on the parameter axis represents an estimate of the fractional chance that the given parameter value or a lesser one will occur in that province.

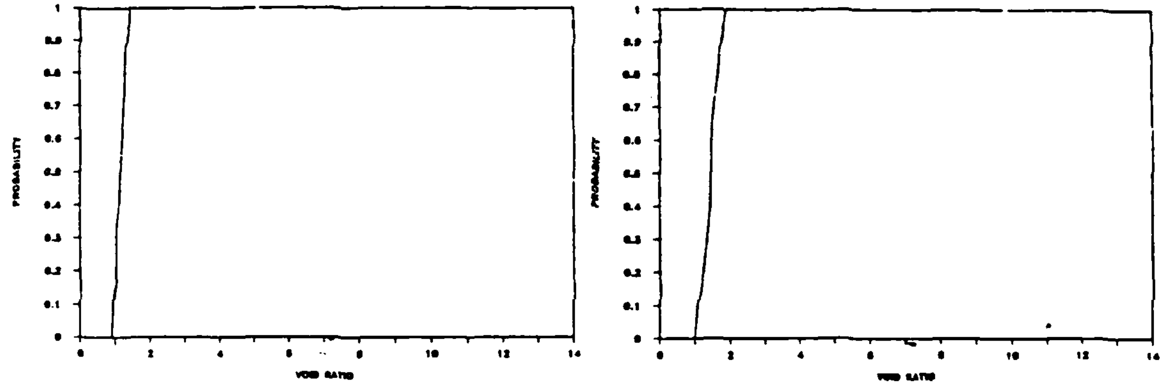
The void ratios in Figure 2-6 have about a value of 1.0 in the coarse sediments and vary, predominately between 1.0 and 2.0 in the finer sediments, except for muds (Provinces AE and BE) which usually have values above 2.0. Terrace sediments overall (Province ZZ) show a smooth, relatively broad distribution of void ratios.

The shelf grain densities usually lie quite close to a value of 2.6 gm cm^{-3} while slope grain densities are much closer to 2.7 gm cm^{-3}. Province BA shows a large percentage of grain densities above 2.8 gm cm^{-3} -- an unusually high value.



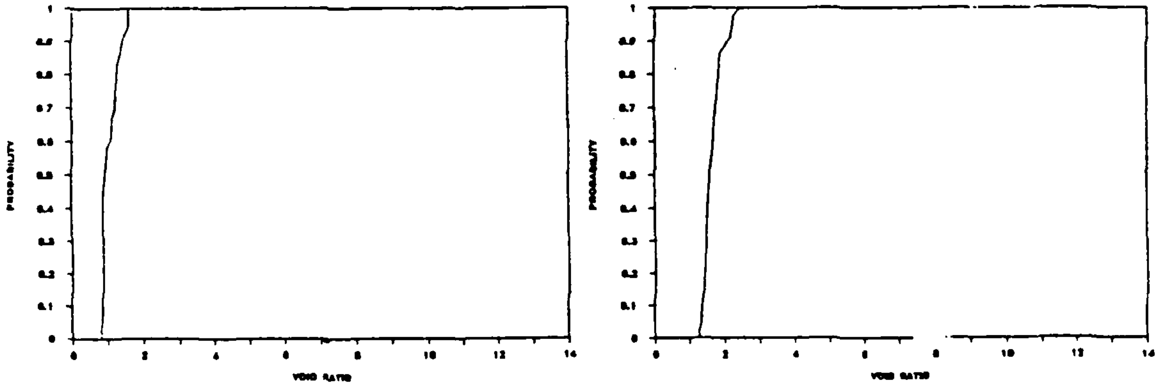
a. Province AA

b. Province BA



c. Province AB

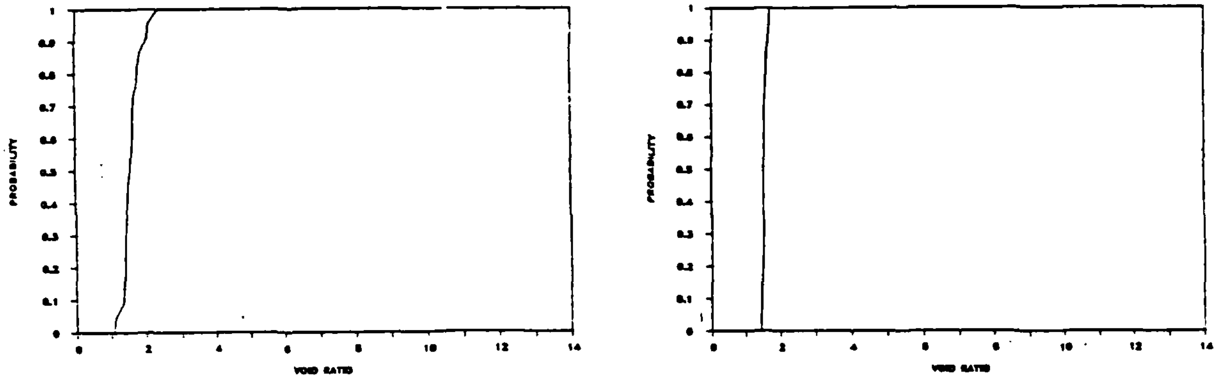
d. Province BB



e. Province AC

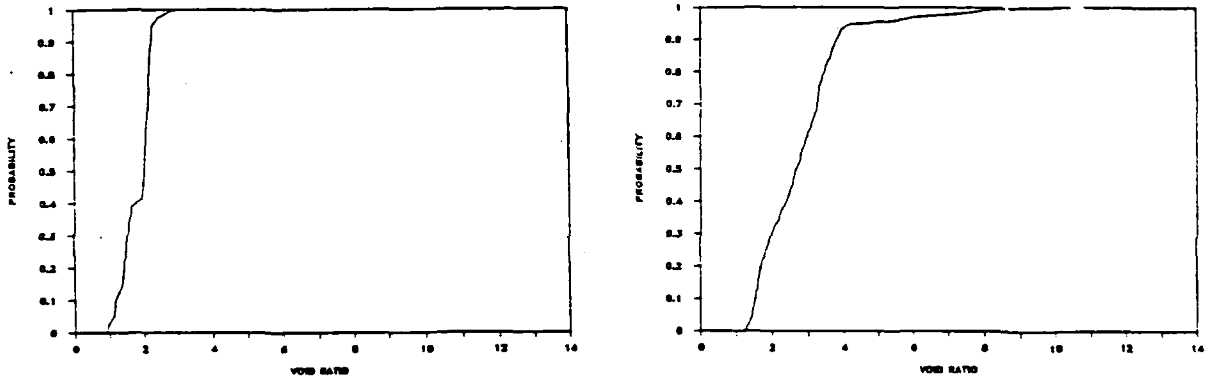
f. Province BC

Figure 2-6. Void Ratio Empirical Cumulative Distribution Functions. The left curves are for shelf, the right curve is for slope sediments of the same grain size type.



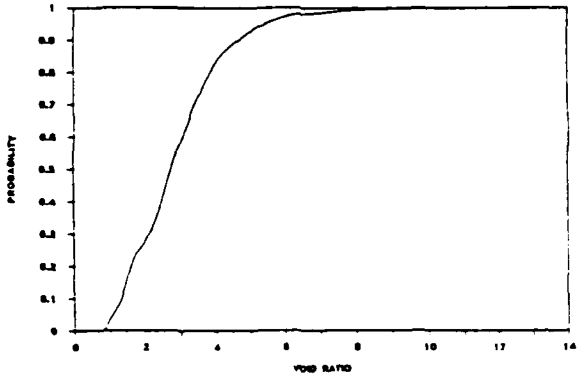
g. Province AD

h. Province BD



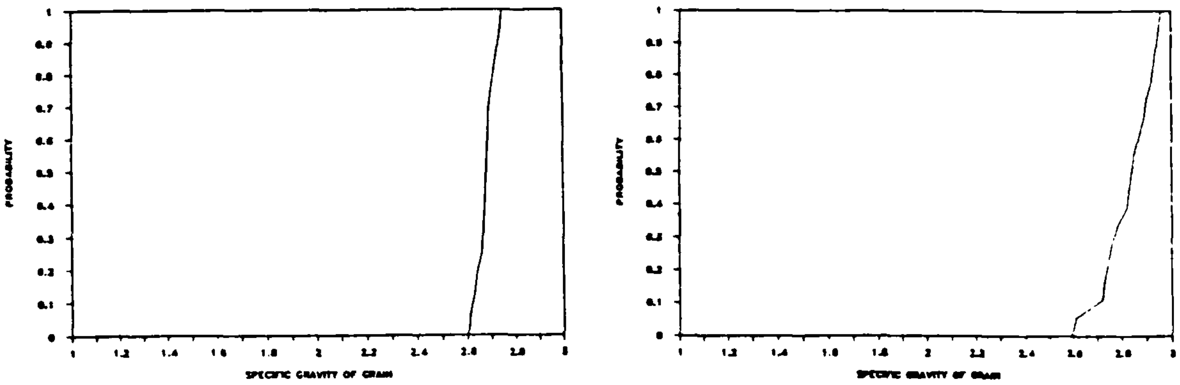
i. Province AE

j. Province BE



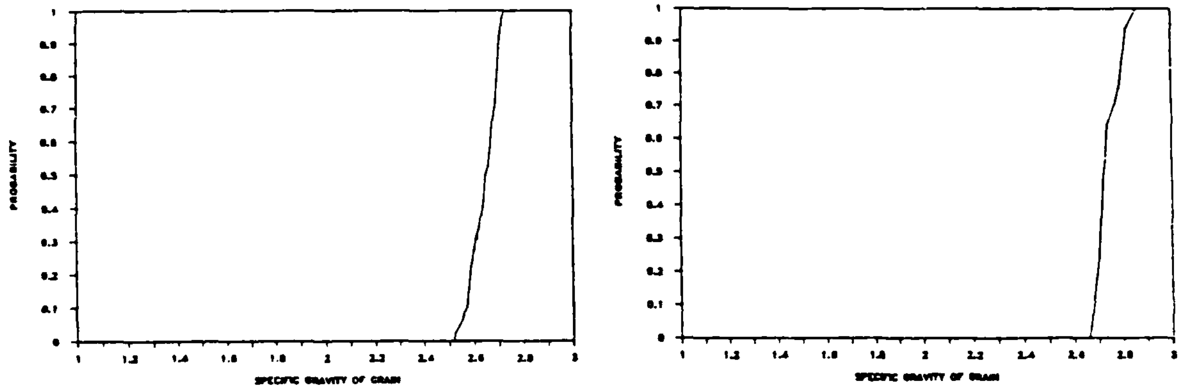
K. Province ZZ

Figure 2-6 (cont'd)
Province ZZ represents continental terrace (shelf, slope, rise) sediments as a whole.



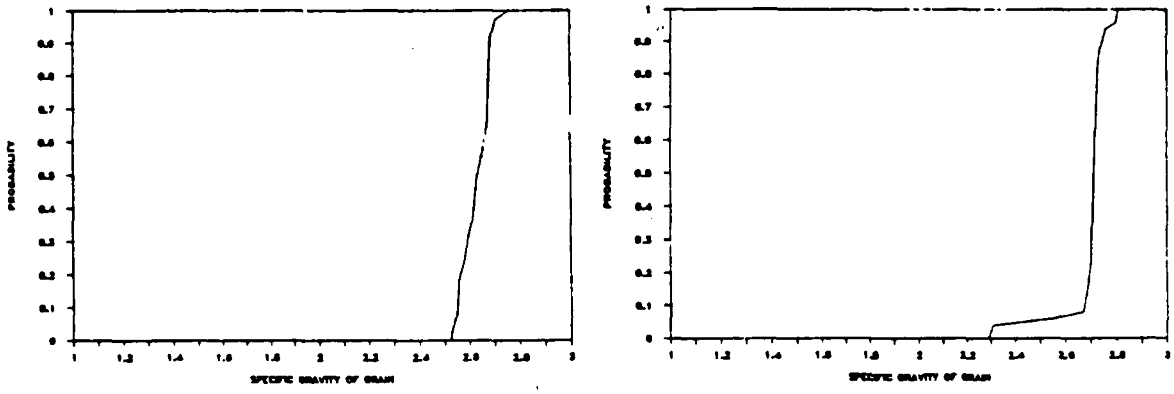
a. Province AA

b. Province BA



c. Province AB

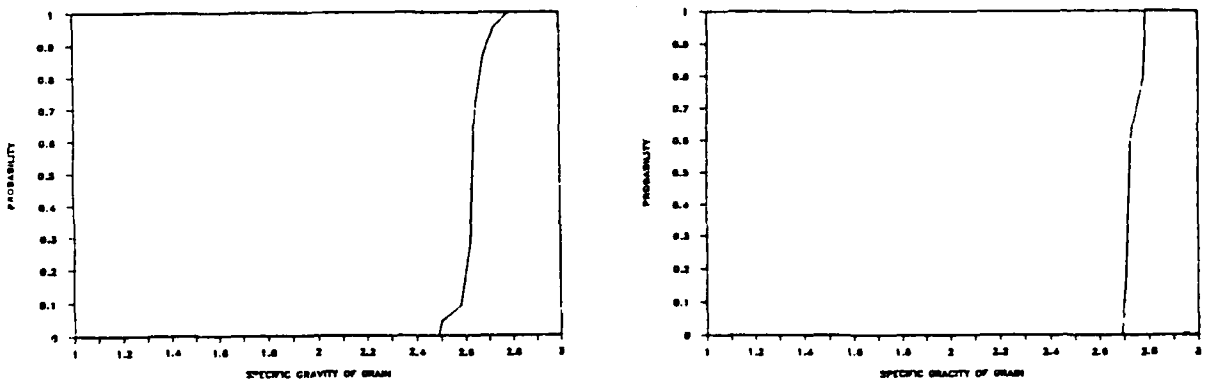
d. Province BB



e. Province AC

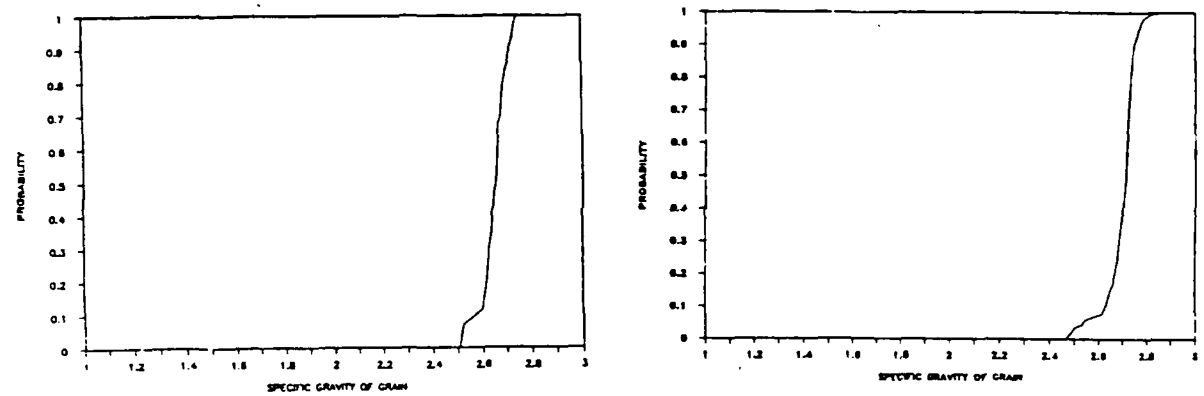
f. Province BC

Figure 2-7. Grain Density Empirical Cumulative Distributions. The left-hand curves are for shelf sediments, the right-hand curve is for slope sediments of same size type.



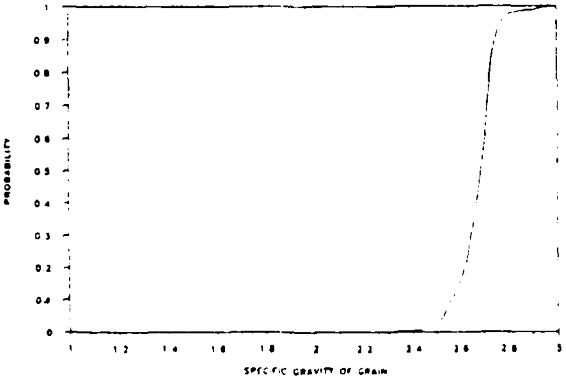
g. Province AD

h. Province BD



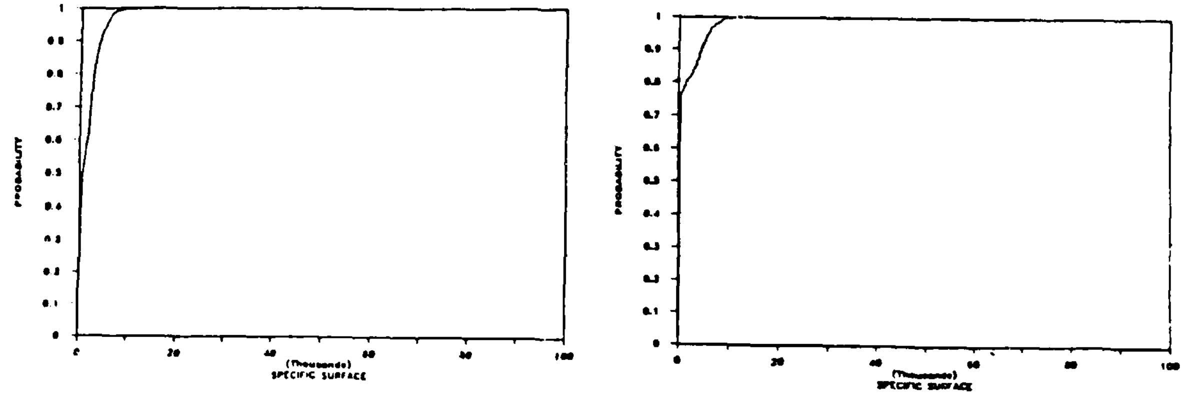
i. Province AE

j. Province BE



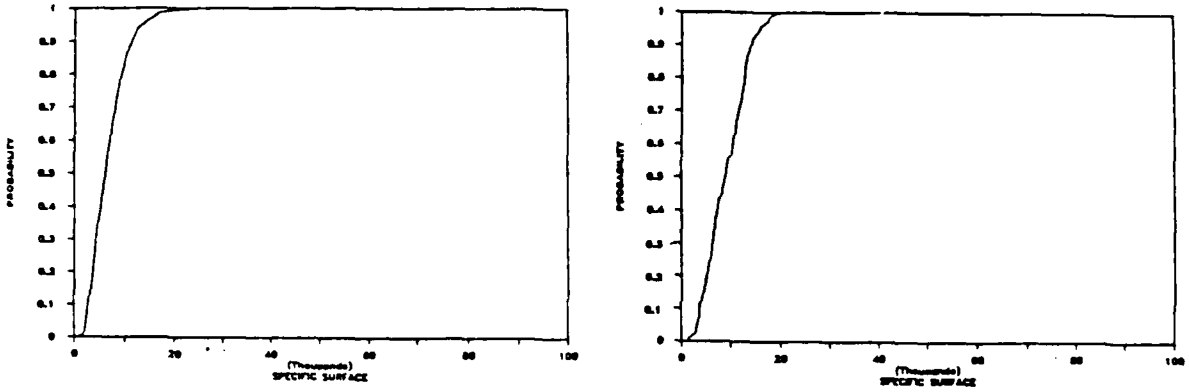
k. Province ZZ

Figure 2-7 (cont'd)
Province ZZ represents continental terrace (shelf, slope, rise) sediments as a whole.



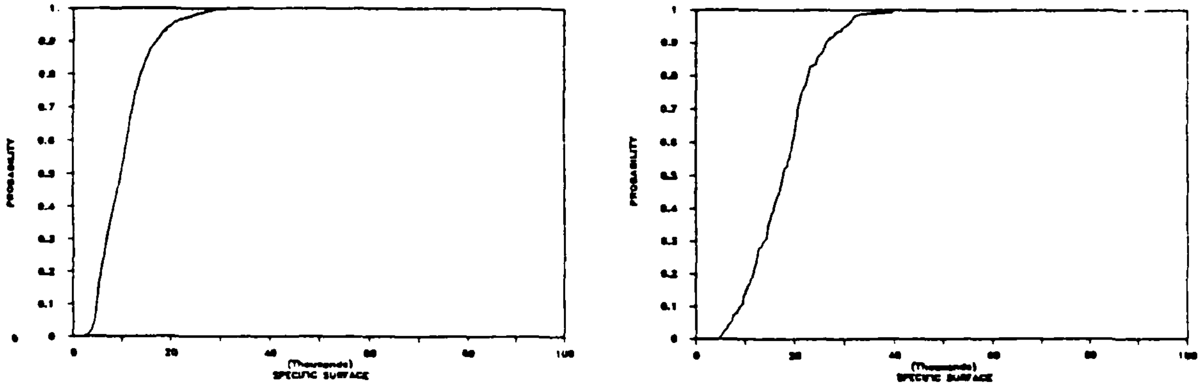
a. Province AA

b. Province BA



c. Province AB

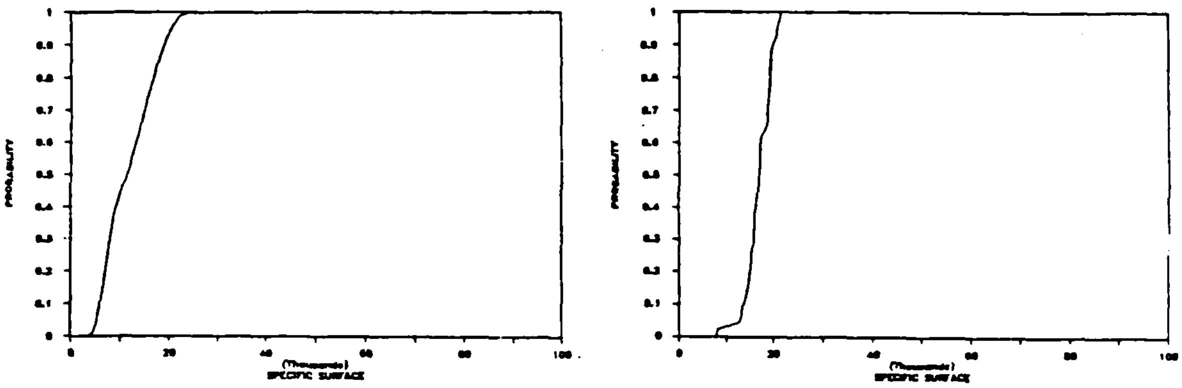
d. Province BB



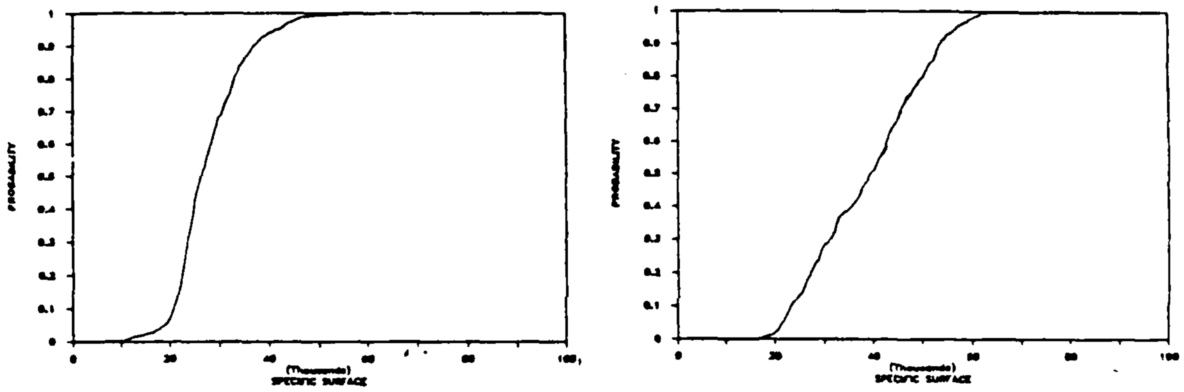
e. Province AC

f. Province BC

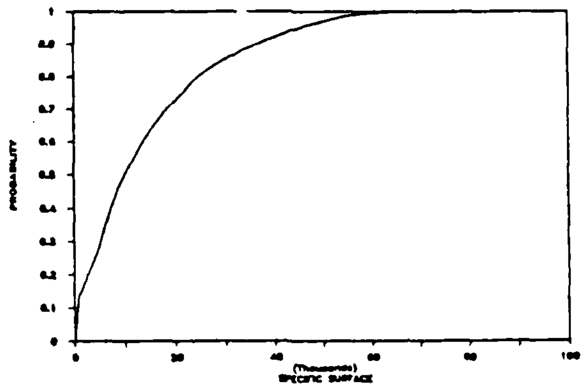
Figure 2-8. Mean Specific Surface Empirical Cumulative Distribution Functions. The left-hand curves are for shelf sediments, the right-hand curve is for slope sediments of the same grain size type.



g. Province AD h. Province BD



i. Province AE j. Province BE



k. Province ZZ

Figure 2-8 (cont'd)
Province ZZ represents continental terrace (shelf, slope, rise) sediments as a whole.

The mean specific surface shows a stronger dependence on sediment grain size type than it does on shelf/slope differences. Sands (AA and AB) lie in the range 0 to 10,000 cm^{-1}; dirty sands (AB and BB) lie approximately between 5,000 to 15,000 cm^{-1}; sandy muds (AC and BC) in the range 5,000 to 30,000 cm^{-1}; silts (AD and BD) in the range 10,000 to 20,000 cm^{-1}; and muds (AE and BE) in the range 20,000 to 60,000 cm^{-1}. Continental terrace sediments overall (ZZ) vary smoothly from 0 to 60,000 cm^{-1}.

Other physical property characteristics of these provinces are not available from the PHYPROSE data base, yet are needed as input to the PHYSED model. Three parameters considered important to the results[9] are frame Poisson's ratio, frame log dec of compressional waves, and frame log dec of shear waves.

We define ranges for these three properties in Table 2-9. The values tabulated there are based upon guidelines published by Hamilton[19]. Poisson's ratio for marine sediments should fall in the range from 0.1 to a theoretical upper limit of 0.5. In sands, values between 0.1 and 0.3 are typical, while in muds, higher values are expected. Thus, we use 0.2 to 0.4. The frame log dec for compressional waves is expected to lie in the range 0.00 (for negligible loss at grain to grain contacts) to 0.3 in lossy frames. Silts and clays are expected always to show loss, so their range is assigned as 0.1 to 0.2; sands are allowed negligible loss and assigned a range of 0.0 to 0.15. Shear log decs for the frame are expected to be higher than compressional log decs; therefore, ranges are assigned as in Table 2-9. It is assumed that values of these three parameters are evenly distributed across the ranges given.

Table 2-9. Ranges for Poisson's Ratio, Frame Compressional Log Dec and Frame Shear Log Dec.

Province	**Poisson's Ratio**		**Frame Compressional Log Dec**		**Frame Shear Log Dec**	
	min	**max**	**min**	**max**	**min**	**max**
AA	0.1	0.3	0.00	0.15	0.10	0.30
AB						
BA						
BB						
AC	0.2	0.4	0.10	0.20	0.10	0.40
AD						
AE						
BC						
BD						
BE						
ZZ	0.1	0.5	0.00	0.30	0.00	0.40

2.5 Physical Properties Summary

Based on our survey of available sediment physical property data, we find texture (grain size) information ten times more readily available than void ratio/porosity information and one hundred times more readily available than geoacoustic information. Based on the data from 233 sites in the PHYPROSE data base, we find that void ratio/porosity varies not just with sediment texture but also with depth of the seafloor and ocean area. We therefore define provinces based on grain size type and seafloor depth. We retain the option of introducing ocean area as a provincing criterion if we cannot achieve sufficiently reduced variance in the BL predicted for a province. We use the entire PHYPROSE data base, with its data at 4,355 different sites, to define the distributions of grain density, void ratio/porosity, and mean specific surface in the provinces on the shelf and slope. We cite the literature to establish the ranges of three other parameters -- Poisson's Ratio, frame compressional log dec, and frame shear log dec. The remaining Biot/Stoll physical inputs are presumed fixed and therefore independent of province.

3.0 THE GEOACOUSTIC PROFILES

The results of the Biot/Stoll calculations are the geoacoustic profiles of speeds and attenuations for compressional and shear waves in the sediment. From these profiles, BL will be calculated as described in Section 4. In the present section, however, we describe how the Biot/Stoll computations use the distributions generated for each province, and we show the distribution of the resulting speed and attenuation profiles. We also compare the results of the computations to the few compressional speed measurements available in the PHYPROSE data base.

3.1 Monte Carlo PHYSED Calculations

The many options available for defining the thirteen PHYSED inputs, as illustrated by Figure 1-1 and the list of "genesis parameters" in Table 1-3, were reduced to those few which could be characterized for each province. PHYSED software[13] was modified to hardwire the input generation as follows.

The fluid properties were kept fixed for all provinces at a density of 1.025 gm cm^{-3}, a bulk modulus of 2.384 x 10^{10} dynes cm^{-2}, and a viscosity of .018 poise. (These values correspond to a fluid compressional speed of 1525.1 m s^{-1}.) The grain bulk modulus was fixed at 4.2 x 10^{11} dynes cm^{-2}, a value appropriate for quartz grains, and the grain densities were sampled from the PHYPROSE distributions as described later.

The structure factor was fixed at 1.25 for all provinces. Though this is a good value for sands,[6,22] a value of 3.0 has produced good comparions with silts and clays.[6,10] However, to

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[22] Brunson, B.A., 1983, "Shear Wave Attenuation in Unconsolidated Laboratory Sediments," Ph.D. Dissertation, Oregon State University.

avoid introducing an artificial break among sediments in the same province (i.e., province ZZ), a constant fixed value of structure factor is used.

Porosity of the frame is calculated from void ratio, sampled from the empirical distribution, using equation 3-1.

$$\beta = \frac{\varepsilon}{1+\varepsilon} \qquad (3\text{-}1)$$

where β is porosity (decimal)
and ε is void ratio.

The procedure is described later for sampling void ratio from the distribution based on PHYPROSE data.

Permeability (k, in cm^2) and pore size parameter (a, in cm) are both derived from the porosity value obtained as above and the mean specific surface (S_o) sampled from the empirical distributions. According to the Kozeny Carman relationship[23] for permeability,

$$k = \frac{1}{5.0 \cdot S_o^2} \cdot \frac{\beta^3}{(1-\beta)^2} \qquad (3\text{-}2)$$

The pore size, following Hovem and Ingram,[24] can be set equal to twice the hydraulic radius (ratio of volume filled with fluid to the wetted surface). Hence,

$$a = \frac{2\beta}{(1-\beta) S_o} \qquad (3\text{-}3)$$

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[23] Carman, P.C., 1956, Flow of Gases Through Porous Media, Academic Press, New York.

[24] Hovem, J.M. and G.D. Ingram, 1979, "Viscous Attenuation of Sound in Saturated Sand," J. Acoust. Soc. Amer., 66, pp 1807-1812.

The frame shear modulus (μ_b) can be derived as a function of depth from the porosity and grain density using a procedure described by Stoll[25] based on empirical relationships between stress and shear modulus determined by Richart, et al.[26] The vertical stress, τ_1 (in dynes per cm^2), at a depth, Z (in cm), in the sediment is computed by integrating the buoyancy-reduced weight of the overlying material, i.e.,

$$\tau_1 = \int_0^Z (1-\beta)\ (\rho_r - \rho_f) g \quad dz \tag{3-4}$$

where g is gravitational acceleration (set to 980 cm s^{-2}), β is porosity (kept constant with depth), ρ_r is density of grain (constant with depth), and z is the integration variable representing depth. Given τ_1, the average stress, τ_o (used in the Richart equations), is

$$\tau_o = \frac{1}{3}(\tau_1 + \tau_2 + \tau_3) \tag{3-5}$$

where τ_2 and τ_3 are the horizontal components of stress. A value for τ_o is obtained by assuming τ_2 and τ_3 each is equal to τ_1 in clays, and that each is half of τ_1 in sands. The Richart equation for sand is

$$\mu_b = \frac{1230\ (2.97-\varepsilon)^2}{(1+\varepsilon)} \cdot \tau_o^{\frac{1}{2}} \tag{3-6}$$

The equation for clay is

$$\mu_b = \frac{1630\ (2.97-\varepsilon)^2}{(1+\varepsilon)} \cdot \tau_o^{\frac{1}{2}} \tag{3-7}$$

---

[25] Stoll, R.D., 1977, "Acoustic Waves in Ocean Sediments," Geophysics, 42, pp 715-725.

[26] Richart, Hall, and Woods, 1970, Vibrations in Solids.

The result of the calculation is a frame shear modulus that increases with depth even though porosity (hence ϵ) is held constant.

The imaginary part (μ_b*, dynes cm^{-2}) of the frame shear modulus is a function of the real part and the logarithmic decrement (Δ_μ, dimensionless)

$$\mu^* = \frac{\mu_b \cdot \Delta_\mu}{\pi} \qquad (3\text{-}8)$$

Neither frame log decs nor imaginary parts are well known for any of the provinces; so, a range is defined for log decs according to Table 2-9, log decs are chosen randomly from that range, and μ_b* is calculated using Equation 3-8.

The frame bulk modulus (K_b, dynes cm^{-2}) is derived from the frame shear modulus already described and a Poisson's ratio (Rp, dimensionless) sampled from a range defined for each province (see Table 2-9). The equation is

$$K_b = \frac{2\ (1+R_p)}{3\ (1-2)R_p}\ \mu_b \qquad (3\text{-}9)$$

The derivation of the imaginary part (K_b*) of the frame bulk modulus is based on the real part and the logarithmic decrement (Δ_K) sampled from a range for each province (Table 2-9). The equation in effect is analogous to (3-8).

$$K_b^* = \frac{K_b \cdot \Delta_K}{\pi} \qquad (3\text{-}10)$$

As mentioned above, six properties were sampled from distributions defined for each province; the six are: void ratio, grain density, mean specific surface, Poisson's ratio, frame compressional log dec, and frame shear log dec. Here we describe how this sampling was accomplished.

The empirical cumulative distribution functions for each property for each province were stored as computer files of property value/probability pairs. Six independent sequences of random numbers, distributed evenly between 0.0 and 1.0, were produced using a FORTRAN subroutine with six different seeds. Each random number can be converted to a value of one of the properties using that property's empirical cumulative distribution curve, and associating that random number with its position on the probability axis. For example, if the random number is 0.2, then, for the curve depicted in Figure 2-6k, a probability of 0.2 is associated with a void ratio of about 1.6. The six sequences of random numbers were thus used to generate sequences of the six properties for each province, using a computer subroutine to interpolate between the probability/property pairs in the computer files. The resulting sequences of property values are thus distributed as if sampled from populations with the same statistics as depicted in Figures 2-6, 2-7, 2-8 and Table 2-9. The same six sequences of random numbers were used to generate property values in each of the eleven provinces.

The computer software MCPHYS, a FORTRAN program listed in Appendix A, samples the six properties named above for a given province and computes the Biot/Stoll solutions; then, repeats the process using the next elements of the six sequences, until a specified number of Biot/Stoll solutions (or runs) are obtained. Using MCPHYS, we made fifty runs per province in order to have sufficient samples to simulate a reasonable distribution of PHYSED results associated with that province.

At this point it is worth noting two features of this procedure. First, the six properties are treated as if they are independent of each other because they are derived from random number sequences with different seed values. Thus, for example, a high value of void ratio (resulting from a random number near 1.0) can occur with a high, low, or medium value of any of the others -- say grain density -- because a different random number sequence is used with that other property. We considered the possibility that this independence might not be realistic in some cases, especially with respect to the two properties void ratio and mean specific surface. As a general rule sands (larger grains with smaller specific surfaces) tend to be more tightly packed (hence have smaller void ratios). So one might suspect that void ratio and specific surface are correlated in the sediments. Using the data in PHYPROSE, however, we were unable to demonstrate a strong enough correlation (see Figure 3-1 for Province ZZ) between void ratio and mean specific surface; so we considered it reasonable to treat them as independent.

The second feature of our procedure is that the samples of a given property from different provinces, but the same position in sequence, are correlated. This is because the same random number sequence is used for a given property for all provinces. For example, if the fourth random element of the Poisson's Ratio sequence were high (say .85) for province AA, than it would be high (=.85) for province AB, and AC, etc. The Poisson's Ratio that results from this high random number may be different from one province to the next, but it will be true for all provinces that the fourth Poisson's Ratio will be high (in the limit of many samples, higher than 85% of the Poisson's Ratios in that province). This is an important point because it will allow us, when comparing provinces, to detect small differences in BL between two province. We can do this by accumulating differences between individual members of the two provinces that occur at the same position in sequence (e.g., the fourth BL of province AA subtracted from the fourth BL of province AB).

3.2 Distribution of Geoacoustic Profiles

The results of the PHYSED calculations are compressional and shear speeds and attenuations as functions of frequency. In addition, because we use a shear modulus that increases with pressure, our Biot/Stoll results vary with depth, especially in the upper 10 meters. We performed our calculations at several

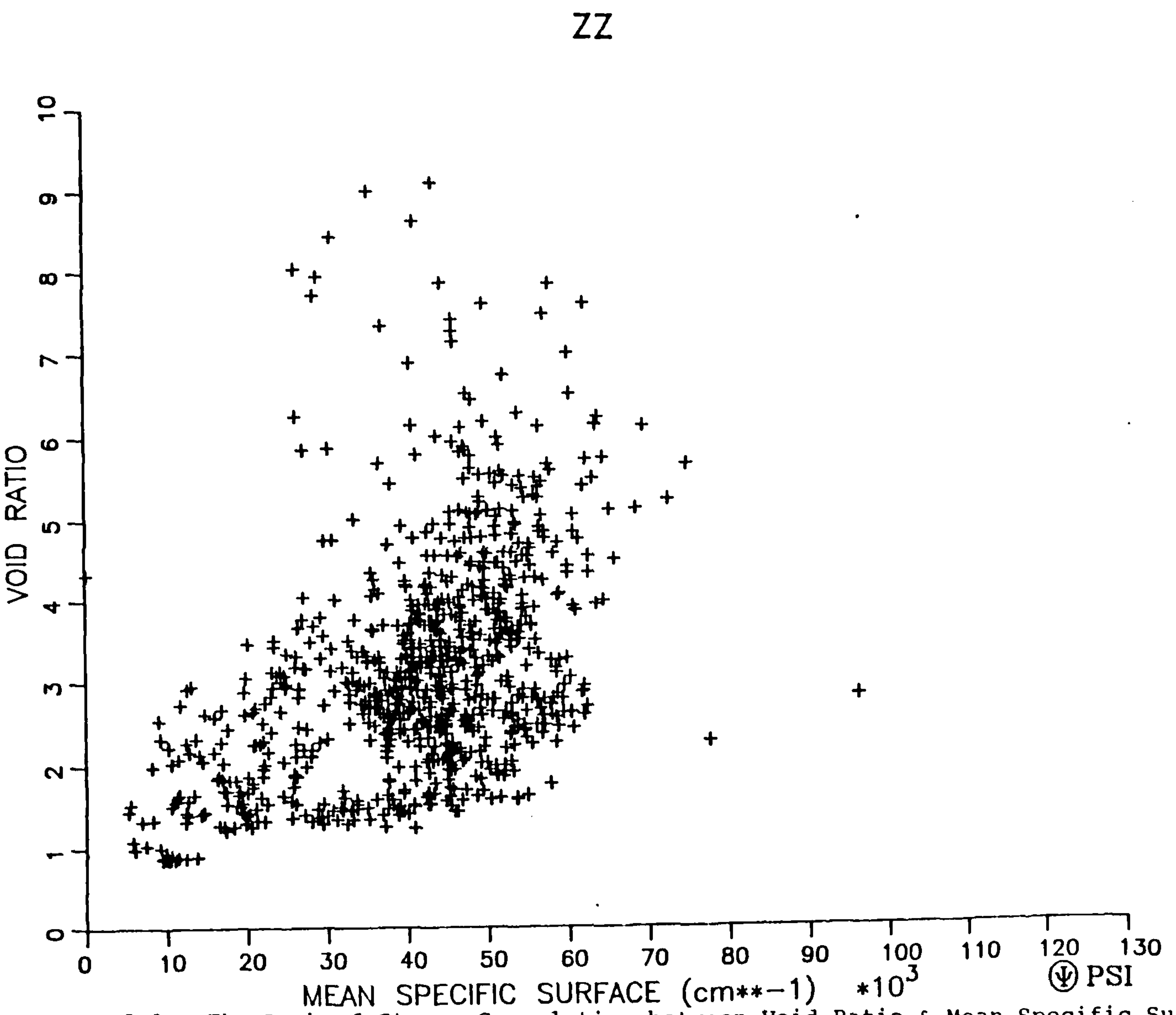


Figure 3-1. The Lack of Strong Correlation between Void Ratio & Mean Specific Surface

frequencies and depths appropriate to ASW applications, and list them in Table 3-1.

Table 3-1. Seven Frequencies and Six Depths at which Compressional Wave and Shear Wave Speed and Attenuation are Calculated.

Frequencies (Hz)	Depths (m)
100	0
200	1
400	5
800	10
1600	50
3500	100
10000	

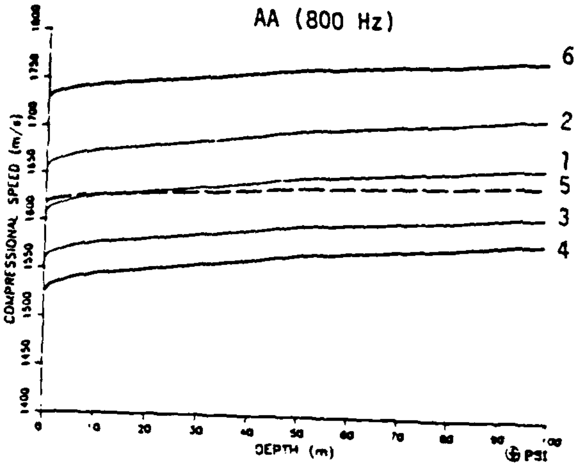
The values of a geoacoustic parameter as a function of depth or frequency we term a geoacoustic profile. As a result of the Monte Carlo runs, we have produced profiles with 6 depths for each of six geoacoustic parameters (Table 1-2), at each of seven frequencies, for each of 50 runs, for each of eleven provinces. Thus we have generated 138,600 values to describe the distribution of the geoacoustic properties in these provinces -- too many to list in this report.

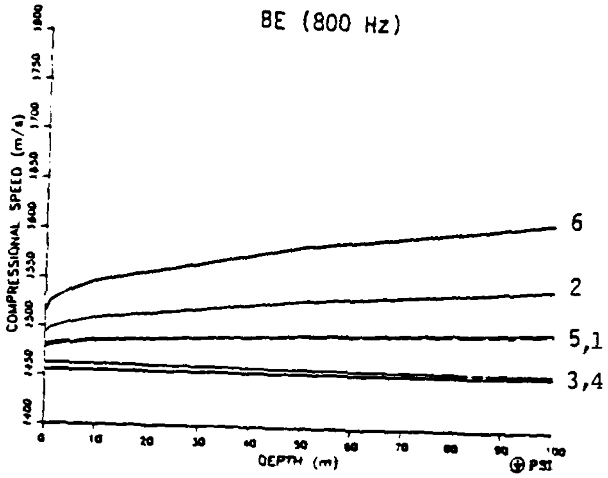
We have devised a presentation that depicts the general character of our results more simply. We display (depth) profiles of compressional speed and shear speed for an intermediate frequency (since these are only weakly frequency dependent), and we display compressional attenuation and shear attenuation as functions of frequency for an intermediate depth (since these are strongly frequency dependent). Instead of showing all fifty depth profiles for speeds we define a depth profile of mean speeds, and a square root of variance in speeds at a given depth. In addition we can define a "typical" profile, and two "extreme" profiles. These six profiles then describe the essentials of the distribution of compressional or shear speeds in the province. In a similar way, six frequency profiles can describe the essentials of the distribution of attenuation in the province for either compressional or shear waves. The FORTRAN program PROFIL, listed in appendix A, computes the mean and variance of any profile through the data and selects the typical and extreme profiles.

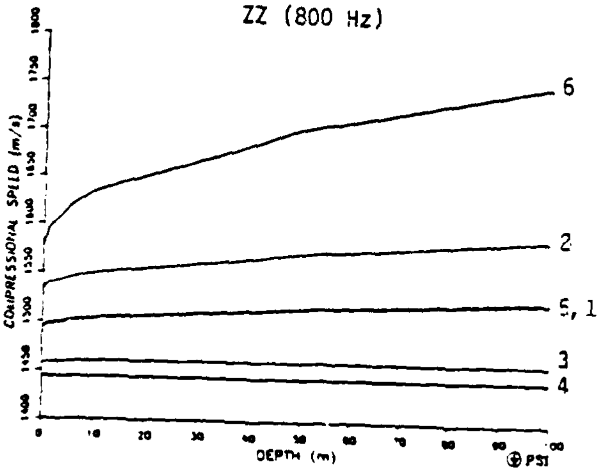
In Figures 3-2 through 3-5 we present some of our results in the form just described. Figure 3-2 shows the distribution of compressional speed depth profiles in three provinces: ZZ (all continental terrace sediments combined), AA (continental shelf sands), and BE (continental slope muds). These profiles are well behaved in the sense that the typical profile and the mean are nearly identical in location and shape, and even the extreme profiles are roughly parallel to the mean profile. Note the differences among the provinces in location (compressional speed of the mean) and spread (compressional speed difference between the mean-plus-the-root-variance and the mean-minus-the-root-variance) of the profiles. Shelf sands (AA) have the highest speeds at about 1620 ms^{-1} while slope muds have the lowest at about 1480 ms^{-1}. The provinces are well separated with almost no overlap of their distribution envelopes. Province ZZ shows an intermediate speed with a distribution that overlaps both of the other provinces. It is precisely these kind of differences that we anticipate will lead to reduced uncertainity in BL predictions when sediments are divided into provinces.

In Figure 3-4 we illustrate the distribution of compressional attenuations in the same three provinces: ZZ, AA, and BE. These profiles again are well behaved; but, there is a decided asymmetry. Deviations below the typical profile are small compared to deviations above the it. Again note the differences among the provinces in location and spread of the profiles. Slope muds have lower attenuations and smaller variance than shelf

Figure 3-2. Compressional speed versus depth for three provinces. For each province we plot the mean speed at a given depth (curve 1), the mean speed plus the square root of the variance (curve 2), the mean speed minus the square root of the variance (curve 3), an actual profile with typical values (curve 5), and two actual profiles with extreme values (curves 4 and 6).


AA (800 Hz)


BE (800 Hz)


ZZ (800 Hz)

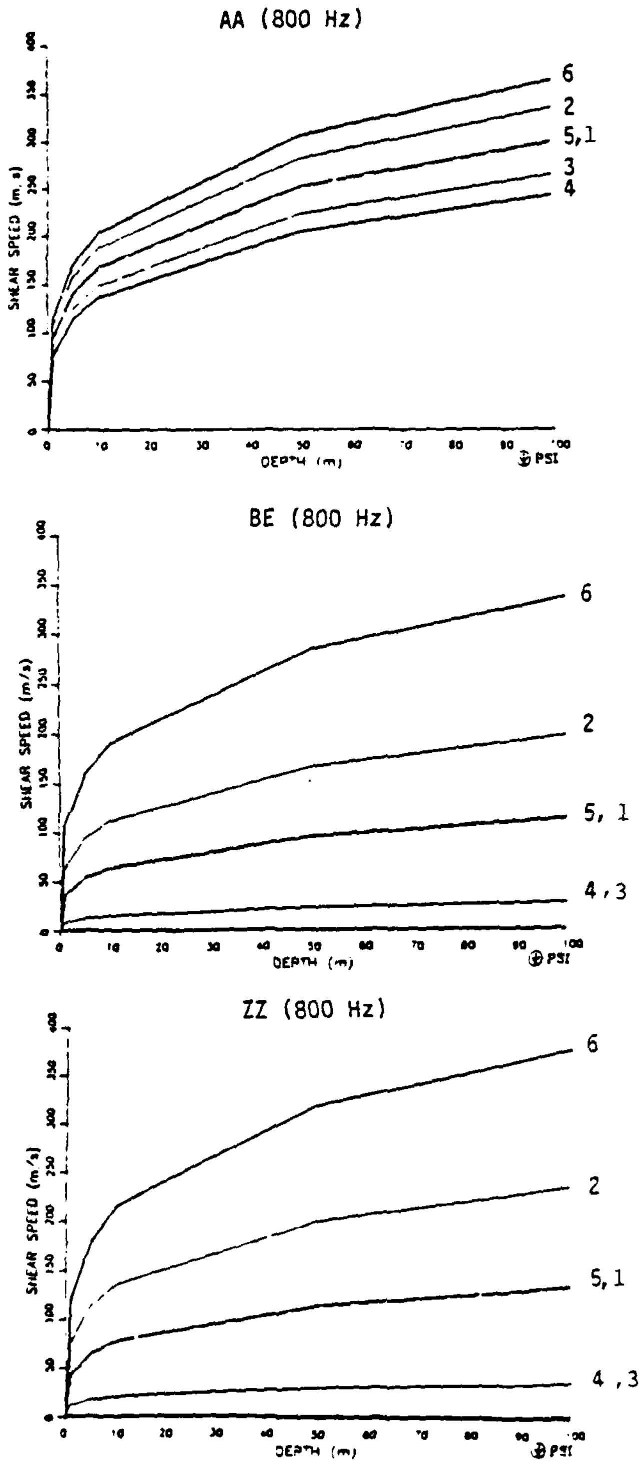


Figure 3-3. Same as Figure 3-2 but for Shear Speed versus Depth, for Three Provinces.

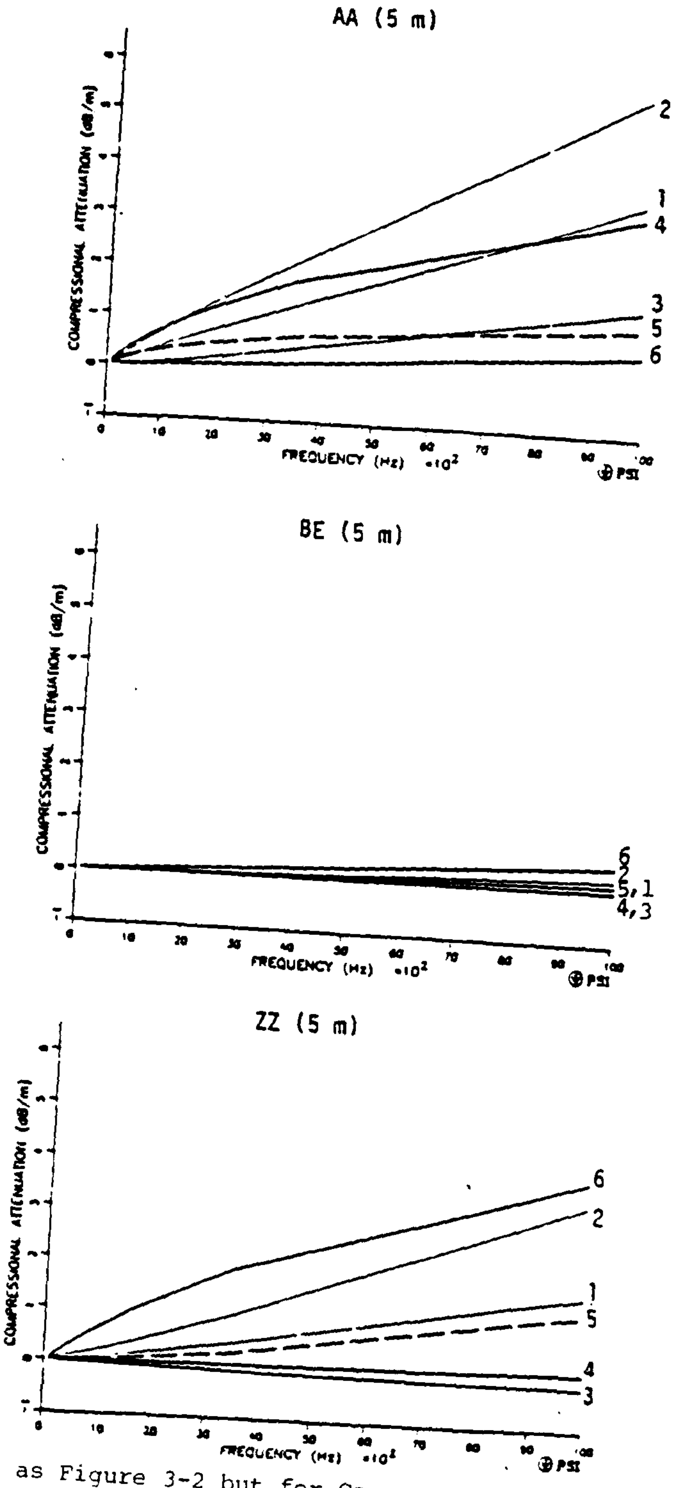


Figure 3-4. Same as Figure 3-2 but for Compressional Attenuation versus Frequency, for Three Provinces. Because these distributions are highly asyymetric, subtacting a large variance from a small mean (curve 3) gives negative values. These are, of course, impossible. The smallest extreme profile (curve 4) provides a realistic lower limit that is non-negative.

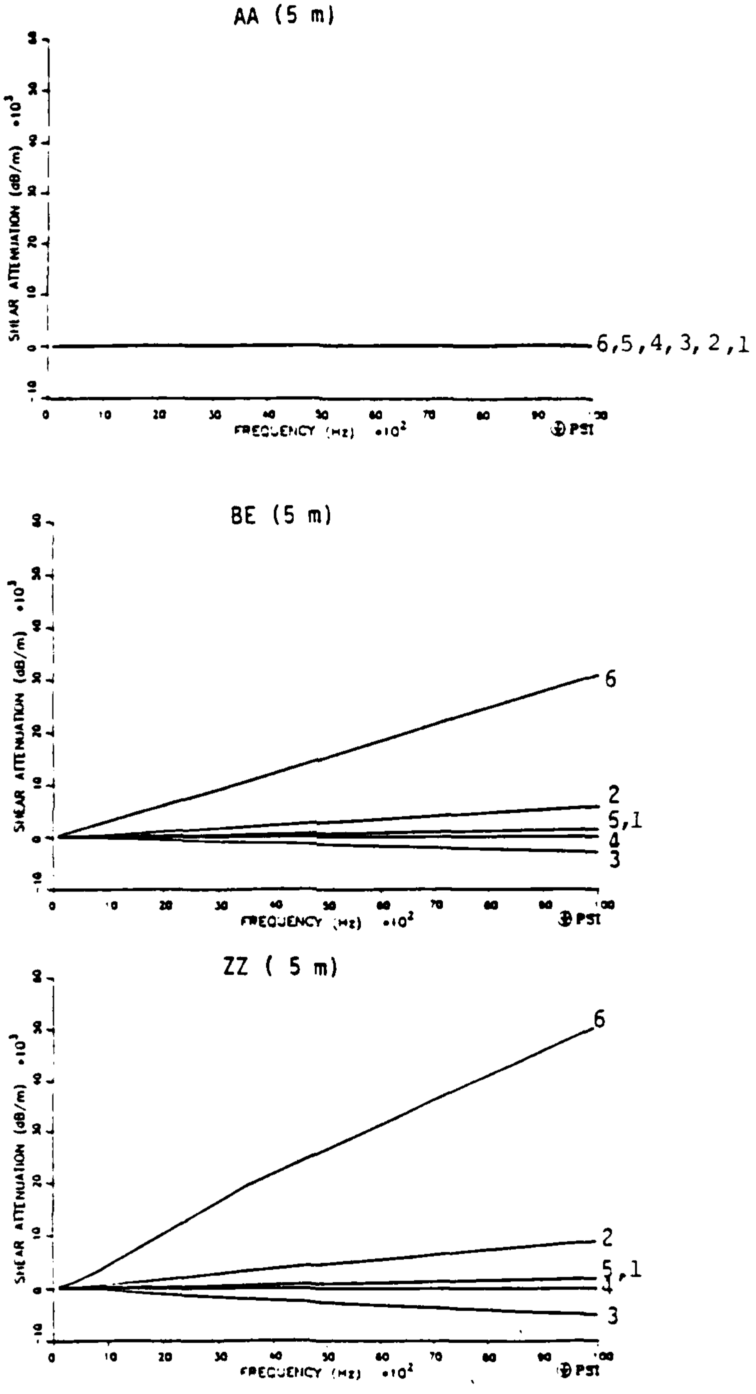


Figure 3-5. Same as Figure 3-4 but for Shear Attenuation versus Frequency for Three Provinces.

sands; continental terrace sediments overall are intermediate in mean attenuation and attenuation variance.

In Figures 3-3 and 3-5 we present similar results for shear speeds and attenuations, respectively, for the same three provinces. We will not launch into a thorough and formal evaluation of the differences among the provinces in this section for one reason. The geoacoustic profiles are not the operationally relevant parameters -- bottom loss (BL) is. Thus we will reserve our comparisons until after we have described the derivation of BL in Section 4 and presented those distributions.

3.3 Accuracy of Geoacoustic Distributions

We assess the accuracy of the distributions calculated for our provinces by comparing them to available observations of geoacoustic parameters.

The PHYPROSE data base contains geoacoustic measurements only of compressional speed at various depths in the upper two or three meters. Because these are the only measurements of either geoacoustic parameters or BL available to us, they represent our only opportunity to assess the accuracy of the distributions we have attributed to our provinces.

We are comparing measurements made under shipboard conditions (room temperature and atmospheric pressure) with predictions of in situ conditions, under fixed seawater properties, produced by our calculations. To eliminate these differences in conditions we calculate the ratio of speed in the sediment to speed in seawater at the temperature and pressure of the measurement or calculation. This speed ratio is then insensitive to the variations of water properties and reflects only the properties of the sediment. Our calculations are based on seawater with a density and bulk modulus that correspond to a seawater sound speed of 1525.1 ms^{-1}; so all our compressional speed results are divided by this value. The PHYPROSE data base archives not only speeds measured in the sediment core but also the temperature of the measurement. This temperature is used with a salinity of 35 parts per thousand (ppt) and a pressure of 1 atmosphere in the Wilson sound speed equation[27] to compute the seawater compressional speed to divide into that measurement.

Compressional speed measurements are available for four provinces. In Figure 3-6 through 3-9 we plot the sound speed ratio profiles calculated for each province together with the speed measurements in that province. Except for one suspicious measurement in province AC, all observations fall within two standard deviations of the mean profile, indicating that our definition of provinces is consistent with the observations. We do not attempt to compute the probability that the mean of the observations is the same as the mean of the predictions because in no case do we have a sufficient number of independent observations. Most observations of compressional speed ratio for a province are collected at a few locations in close proximity from a single cruise. They do not span the range of sediments that belong to a province. We are unable therefore, with the present data, to quantify the accuracy of our distributions. We can say that a comparison with data does not show any problems with the distributions. This is a negative, but necessary, result.

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[27] Wilson, W.D., 1960 J. Acoust. Soc. Am., 33.

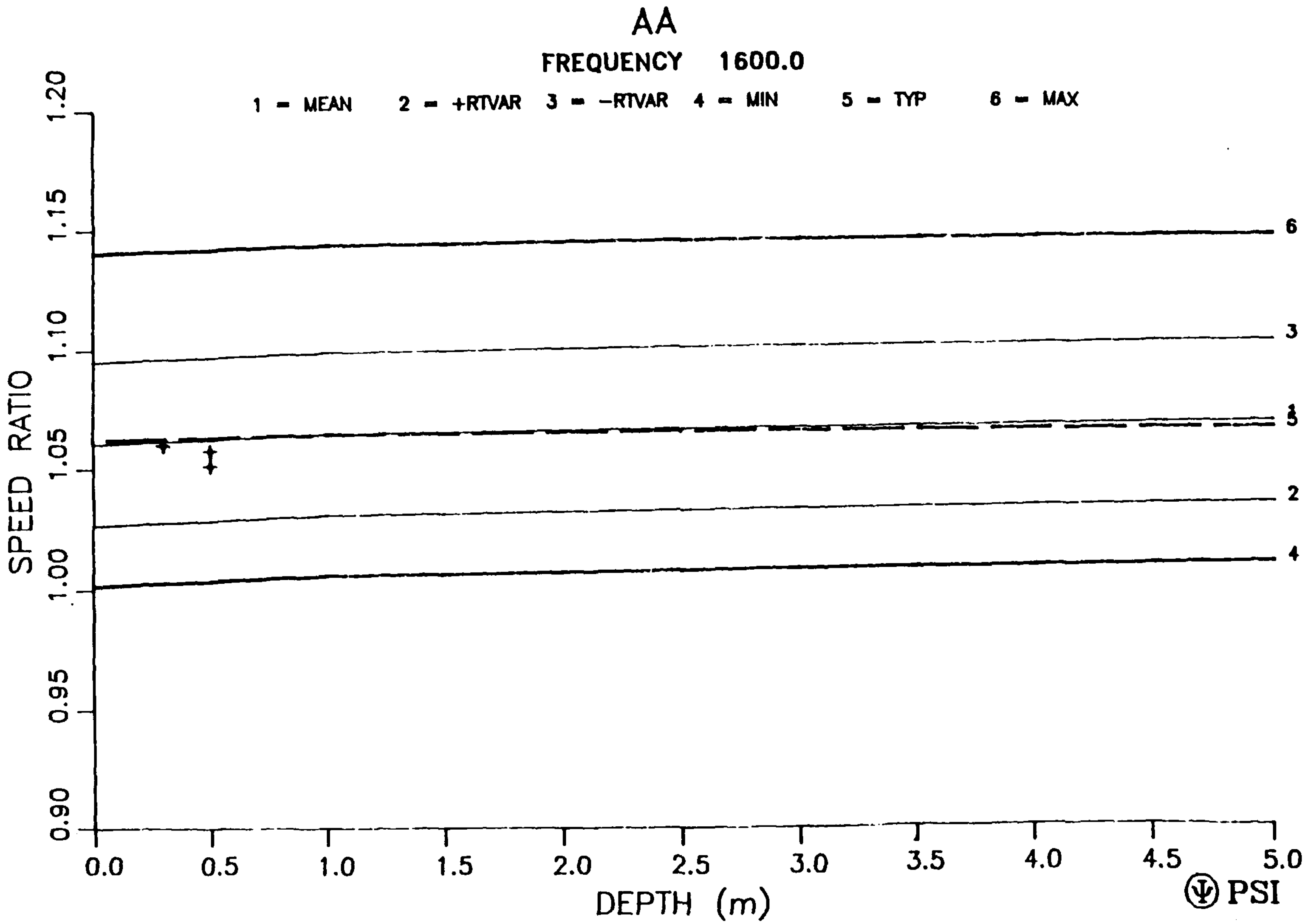


Figure 3-6. Agreement between Observations (+)and Province Distributions. (See Figure 3.2 for description of curves 1 thru 6).

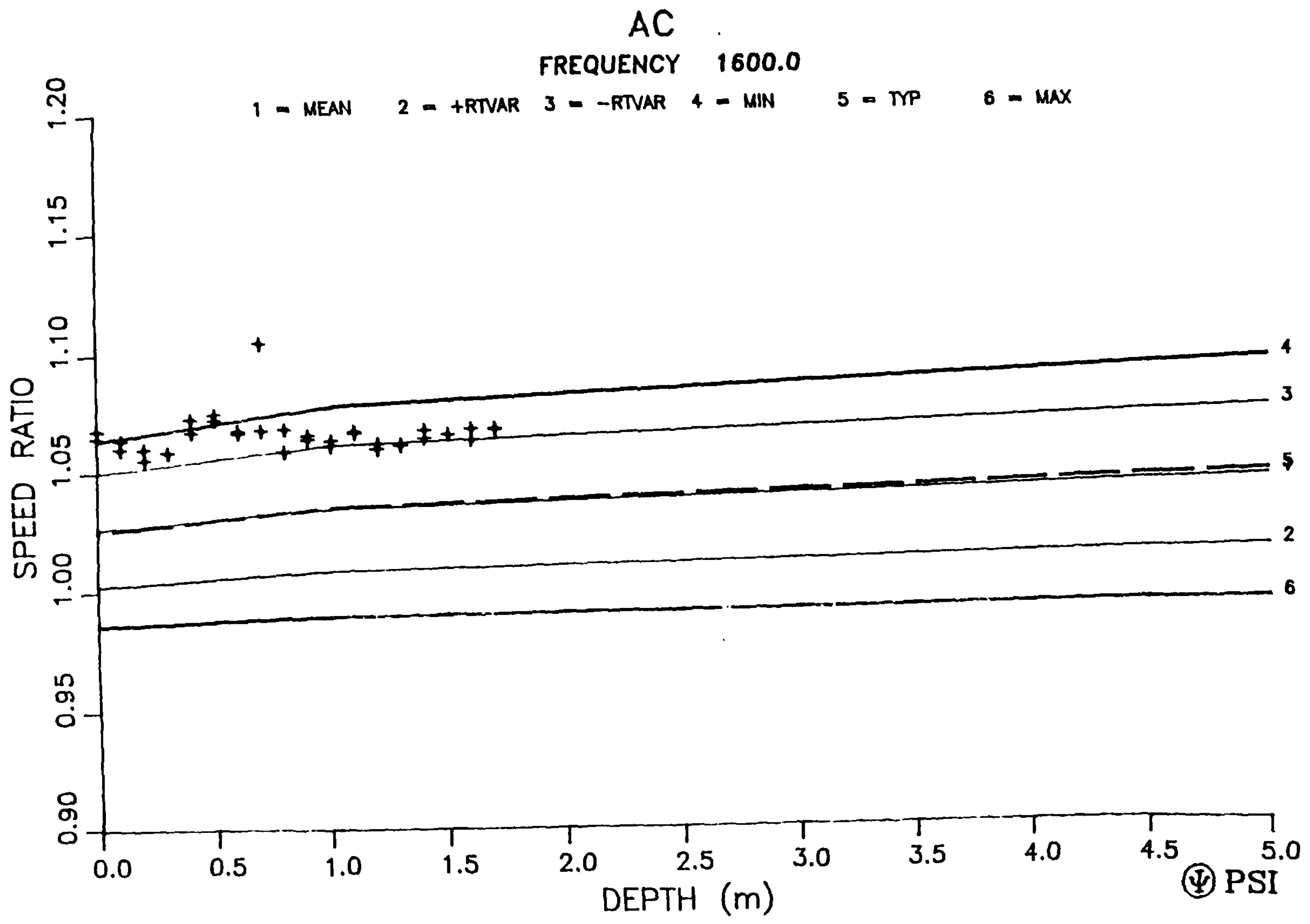


Figure 3-7. Agreement between Observations (+) and Province Distributions. (See Figure 3.2 for description of curves 1 thru 6).

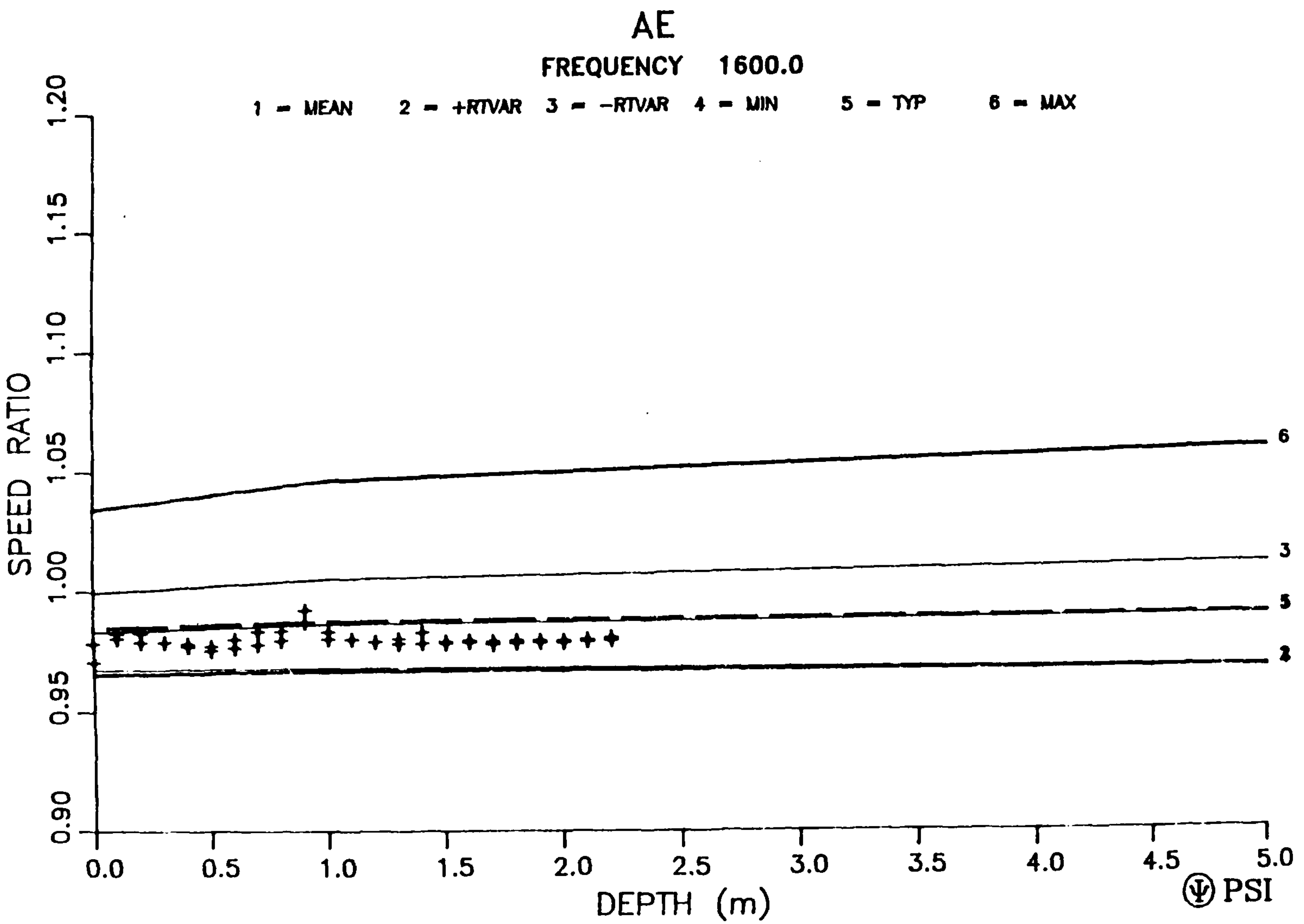


Figure 3-8. Agreement between Observations (+) and Province Distributions. (See Figure 3.2 for description of curves 1 thru 6).

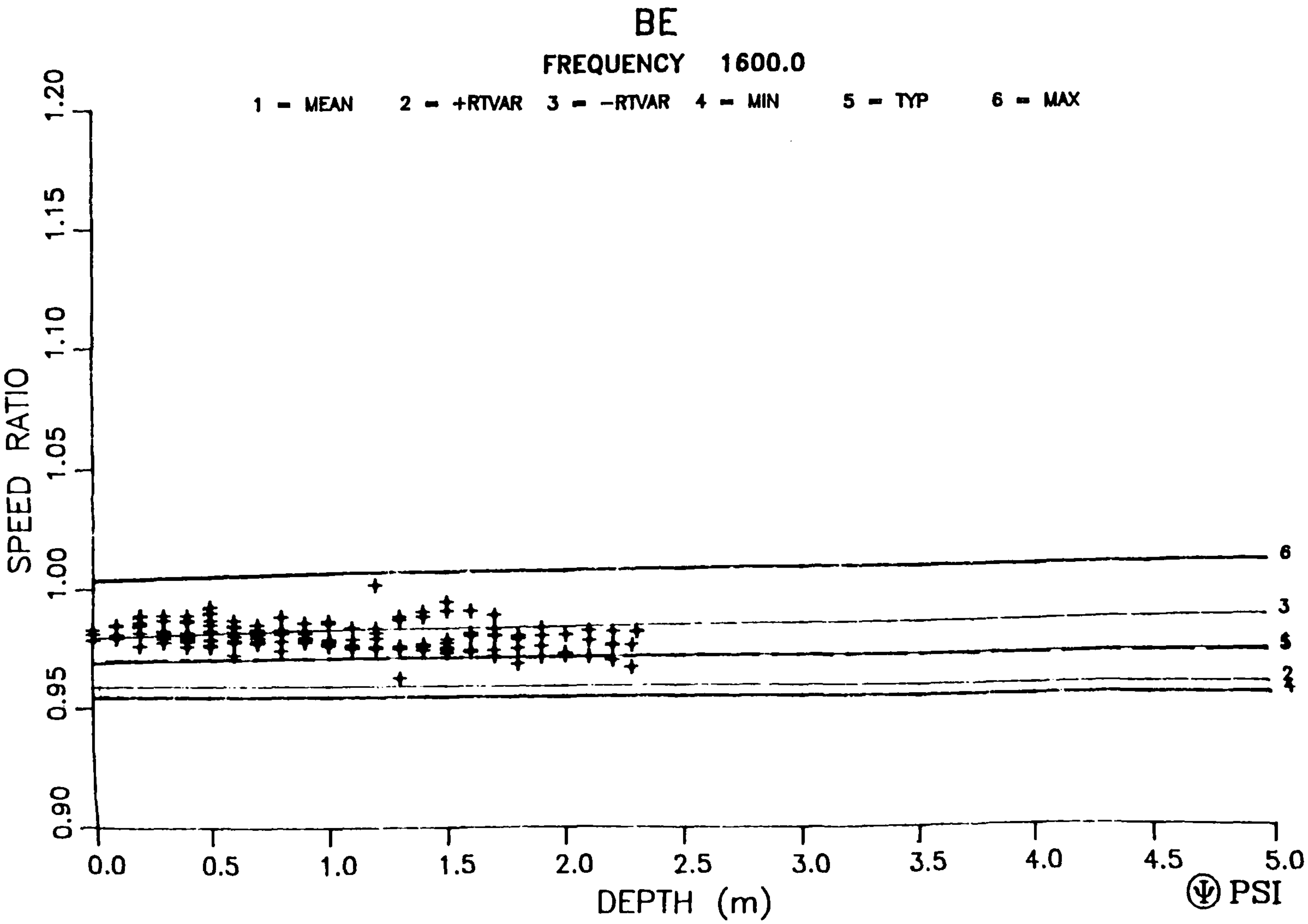


Figure 3-9. Agreement between Observations (+) and Province Distributions. (See Figure 3.2 for description of curves 1 thru 6).

4.0 BOTTOM LOSS DISTRIBUTIONS

The geoacoustic profiles of Section 3 are here used to calculate the Bottom Loss (BL). The resulting distributions of BL in each province are presented and the statistics that will serve as criteria for evaluating improvement are tabulated.

4.1 Calculation of Bottom Loss

In the bottom loss calculation we treat the sediment as a fluid using the NORDA computer program REFLEC[21]. While most sediments possess some rigidity the shear wave velocities are small enough so that bottom loss, for our purposes, will not be appreciably influenced. This is not necessarily true for environments more complex than a sediment halfspace; however, the sediment halfspace (homogenous sediment) is the only environment type that we consider in this study.

Figure 4-1 shows the magnitude of the reflection coefficient $|R|$ at 100 Hz for a clay where the clay is modeled as a fluid and, again, as a porous viscoelastic solid. The results are essentially identical. Table 4-1 lists the geoacoustic inputs to the model for the clay case. These inputs were smoothed before running the reflection coefficient program.

Table 4-2 lists the geoacoustic inputs to the models for a sand case. Figure 4-2 shows $|R|$ at 100 Hz plotted for sand where the sand is modeled as a fluid and, again, as a solid. At angles below critical (including 5^o where we choose to look at BL) the solid model shows higher loss due to excitation and subsequent attenuation of the shear waves. The geoacoustic inputs to the model, for Table 4-2 which were smoothed, show high shear velocities to provide a "worst-case" input set.

When we model sands as a fluid, then, we slightly underestimate the true BL value. This, however, will not appreciably influence our analysis of BL variance because the

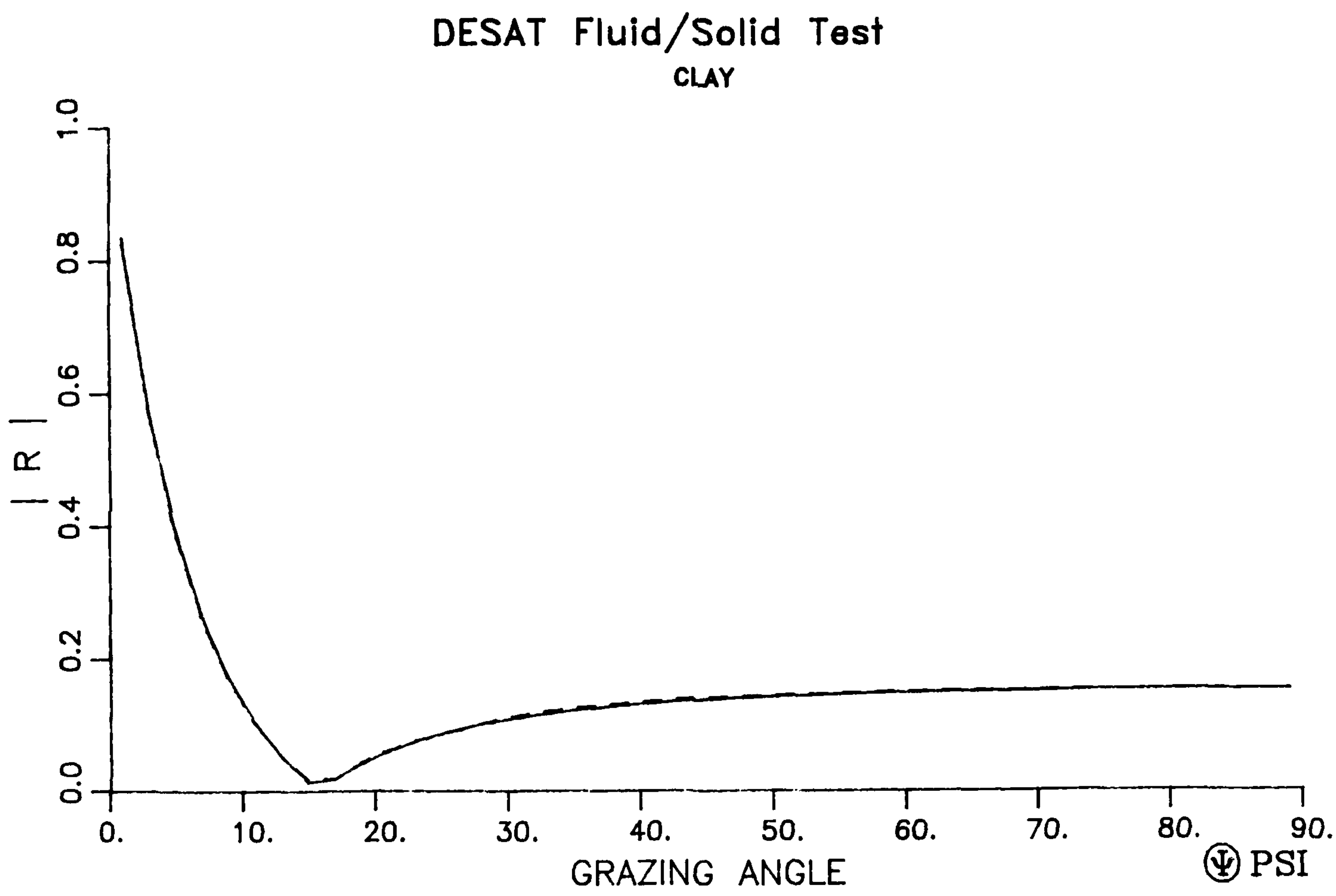


Figure 4-1. Similarity of Bottom Loss (-20 log |R|) calculated for clay using solid and fluid models.

Table 4-1. Geoacoustic Model for Clay

V_p (m/s)	k_p (dB/m/kHz)	V_s (m/s)	k_s (dB/m/kHz)	ρ (g/cm^3)	Depth (m)
1470.69	.0001	5.00	20.00	1.42	0
1470.91	.0002	11.13	15.60	1.42	5
1471.08	.0002	13.23	13.10	1.42	10
1471.38	.0003	15.74	11.03	1.42	20
1472.21	.0005	19.79	8.77	1.42	50
1473.54	.0007	23.53	7.37	1.42	100

Table 4-2. Geoacoustic Model for Sand

V_p (m/s)	k_p (dB/m/kHz)	V_s (m/s)	k_s (dB/m/kHz)	ρ (g/cm^3)	Depth (m)
1636.69	.3983	87.76	18.0	2.02	0
1656.31	.3764	167.76	14.48	2.02	5
1664.45	.3683	199.51	12.17	2.02	10
1675.98	.3577	237.25	10.24	2.02	20
1698.88	.3394	298.33	8.14	2.02	50
1724.74	.3226	354.78	6.85	2.02	100

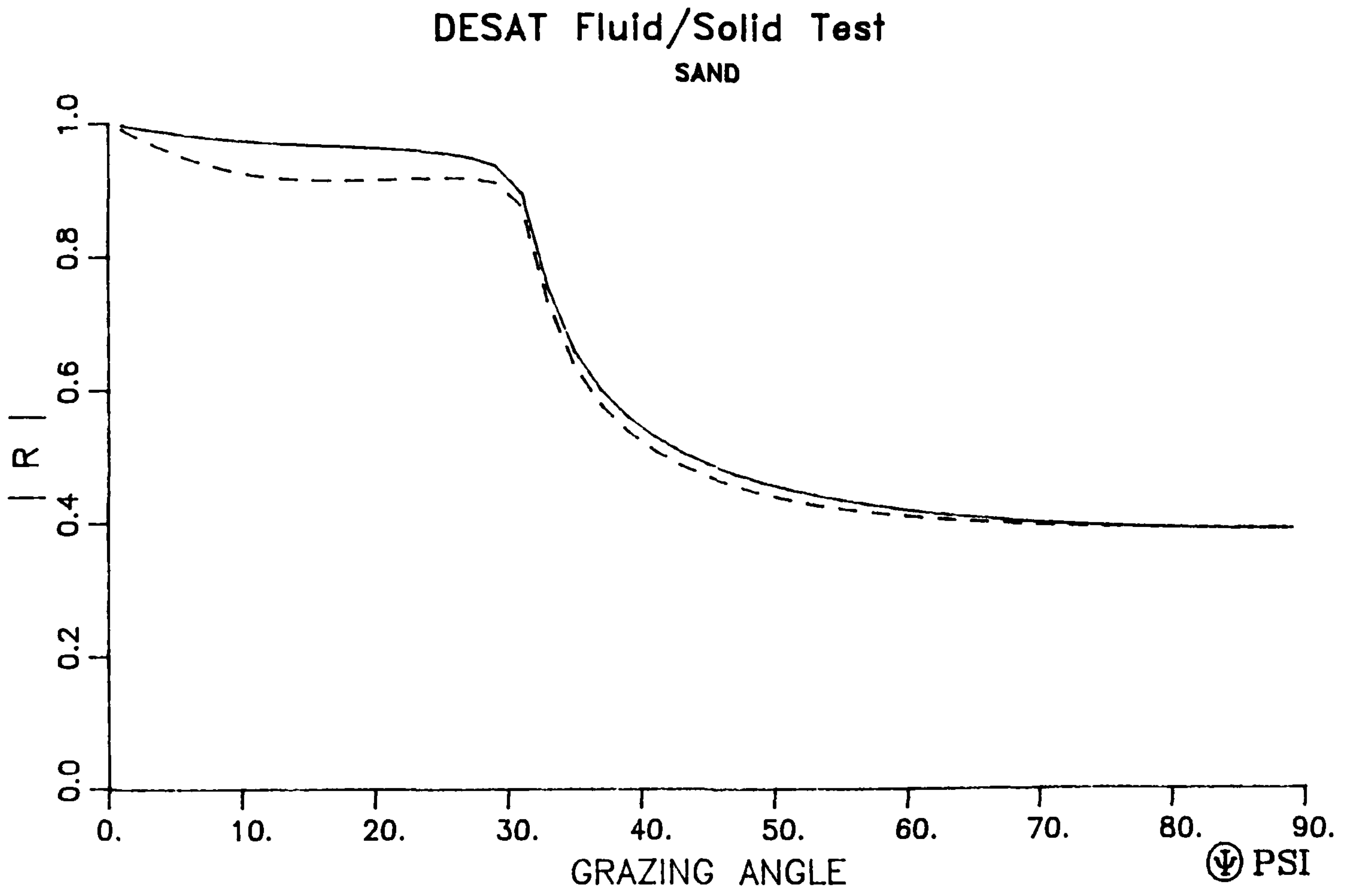


Figure 4-2. Similarity of Bottom Loss (-20 log |R|) calculated for sand using a solid (dashed line) and a fluid (continuous line) model.

variance is principally dependent on the existence of the critical angle, which is in turn dependent on other features of the sediment than conversion to shear waves.

4.2 Bottom Loss Distributions

Figures 4-1 and 4-2 display the two types of BL curves expected when acoustic waves impinge on fluid sediments with densities greater than seawater. Figure 4-1 shows the characteristic curve for reflection from sediments with compressional speeds lower than seawater. There is an angle of intromission (about 15° in Figure 4-1) at which all of the incident energy is transmitted (hence there is infinite bottom loss at the angle). For fixed water properties, as in our study, the angle of intromission will vary with the density of the sediment and the compressional speed in the sediment. At grazing angles from the angle of intromission to zero, the reflection coefficient rises steeply to one, (and BL drops steeply to zero) at a near-uniform rate.

Figure 4-2 shows the characteristic curve for reflection from sediments with compressional speeds higher than seawater. There is a critical angle (about 32° in Figure 4-2) below which there is nearly complete internal reflection (and near-zero BL). Because of attenuation in the sediment actual BL at these angles can vary from 0 dB to 3 dB. At the critical angle, reflection drops drastically (and BL rises rapidly); and, at grazing angles a few degrees greater than the critical angle, BL levels out. The critical angle is a function of the compressional speed in the sediment.

The above characteristics of BL curves for sediments will be important in interpreting our results. The BL at a grazing angle of 5° is considered indicative of the lower angles important to longer range propagation in ASW applications. Thus we calculate and present distributions of BL at 5° to characterize our provinces. Note that 5° is typically in the near-zero BL range for fast sediments (i.e., sediments in which compressional sound speed is greater than in seawater); and that 5° is typically in the steep BL ramp between 0° and the angle of intromission for slow sediments (in which compressional speed is less than in seawater).

4.3 BL in Provinces AA and BE and ZZ

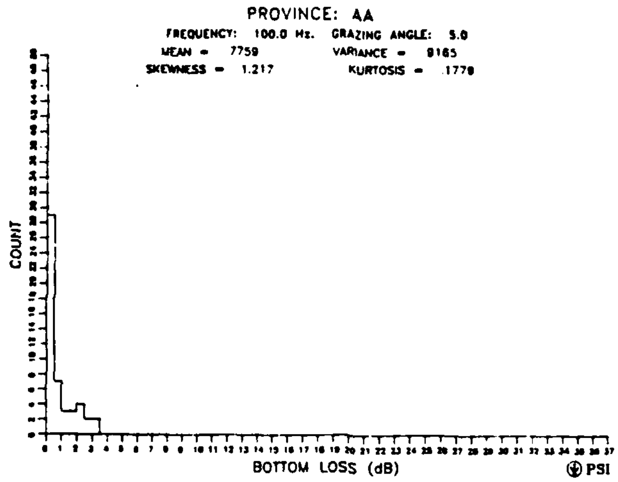
Figure 4-3 shows histograms of BL at 100 Hz for three provinces: AA (shelf sands), BE (slope muds), and ZZ (all continental terrace sediments combined). Figure 4-4 shows histograms of BL for the same three provinces but at 1600 Hz.

Appendix B contains twenty-two BL histograms that show the same two frequencies in each of the eleven provinces of this study. All these histograms have a BL resolution of 0.5 dB.

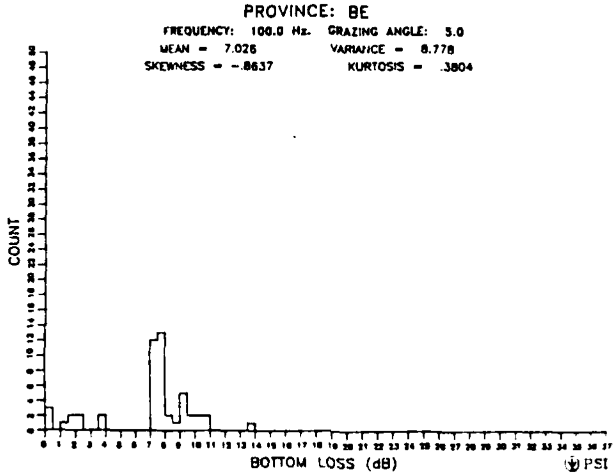
Figure 4-3a, for province AA, shows a BL distribution expected for fast sediments. All values lie between 0 and about 3 dB. This is consistent with the compressional speeds presented for the province in Figure 3-2 because they are everywhere greater than the seawater speed of 1525 m s^{-1}. In spite of the wide range of speeds associated with the province, the BL values are distributed tightly near 0 dB. There is a BL mode in the 0 to 0.5 dB interval, the mean BL is .8 dB, and the root variance is less than 1 dB.

Figure 4-3b, for province BE, shows a very different distribution. The BL values are higher and are distributed more widely with a mode in the 7.5 to 8.0 dB interval, a mean of 8.8 dB, and a root variance of almost 3 dB. This is consistent with

4-3a



4-3b



4-3c

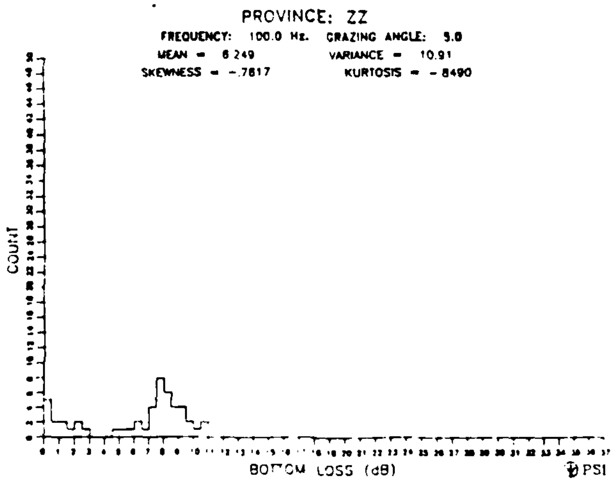


Figure 4-3. Histograms (with 0.5 dB resolution) representing the distribution of Bottom Loss at 100 Hz in three provinces: shelf sands (AA), slope muds (BE), and all continental terrace sediments combined (ZZ). Total number of BL values in each province is 50.

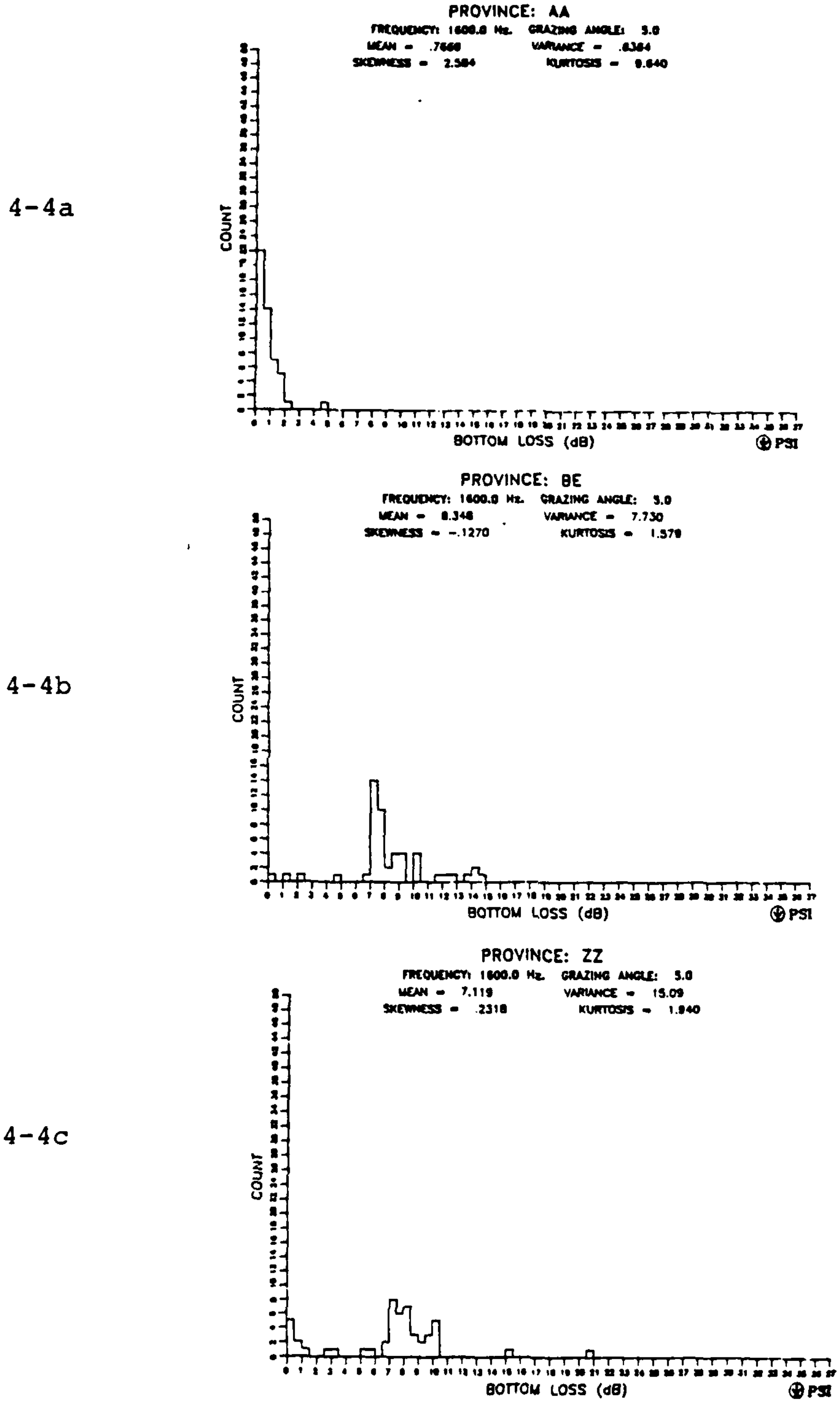


Figure 4-4. Histograms (with 0.5 dB resolution) representing the distribution of Bottom Loss at 1600 Hz in three provinces: shelf sands (AA), slope muds (BE), and all continental terrace sediments combined (ZZ). Total number of BL values in each province is 50.

slow sediments and a angle of intromission varying about a value like that shown in Figure 4-1. Province BE is definitely a slow sediment because, as shown for Figure 3-2, its compressional wave speeds are always less than the seawater value of 1525 m s^{-1}.

Province ZZ, whose BL histogram is Figure 4-3c, shows two modes; one near 0 dB associated with the fast sediments on the terrace and one near 8 dB, apparently associated with the slow sediments. The mean BL for province ZZ (6.2 dB) falls between the means for province AA and BE. The root variance is greater, at 3.3 dB, than in either province.

The story is essentially the same at 1600 Hz, as told in Figure 4-4. These three provinces clearly demonstrate an advantage to provincing. By the criteria set up in Section 1.2 (page 11), we have shown that:

- Provinces defined on the basis of water depth and grain size are based on information about a hundred times more plentiful than geoacoustic and BL measurements (as shown in Section 2.1).

...and...

- The variances found for province AA and BE are lower than those for ZZ.

- The means found for provinces AA and BE are different those for ZZ.

This is our definition of improved capability; the provinces AA and BE satisfy this definition qualitatively. In Section 5.0 we present statistical tests to determine whether these differences in means and variances are significant.

4.4 BL in other Provinces

The distributions of BL in the other provinces (appendix B) are not always as simple as those already presented. There is some overlapping of results, and some high variances. Problems arise that can be associated with deficiencies in the contents of the PHYPROSE data base. However, we believe the data base problems can be alleviated by the addition of more representative data, and that the overlapping of results can be reduced by redefining provinces -- both of which are beyond the scope of this study. As we show in the next section, significant improvement is attained by the provincing presented here; consequently, there is sufficient justification within this study to pursue this approach in future efforts.

Provinces AB and AC (shelf mixtures with sands -- dirty sands and sandy muds) both show results analogous to Province AA at 100 Hz. They have strong modes at 0 dB BL and root variances less than 1 dB, indicative of fast sediments. However, at 1600 Hz both provinces show a few cases (about 10%) with exceedingly large BL values (above 20 dB). These deviates displace the distribution mean away from the mode, and introduce two of the largest root variances encountered in our study (8.3 dB and 6.3 dB). These root variances are double the root variance of continental terrace sediments as a whole (Province ZZ with 3.9 dB).

In each of these provinces at 1600 Hz, the compressional speed distribution has a mean value about one standard deviation above the seawater speed (see Figure 3-7). Thus, in about 15% of the cases, AB and AC should behave as slow sediments and give BL values in excess of 3 dB. These slow speeds are found only in the upper 10 meters of provinces AB and AC; consequently waves at 100 Hz, responding to average conditions in the upper fifty to one hundred meters, do not behave as if interacting with a slow sediment.

There still remains the question of why BL associated with the slow sediment in the provinces is so high. The maximum BL encountered in the slow sediments of province BE is 15 dB; yet provinces AB and AC show BL values over 20 dB. This difference is reasonable given the greater density of the sandy sediments of AB and AC over the clay sediments of province BE. The higher density sediments have angles of intromission at lower grazing angles than the lower density sediments; hence, a grazing angle of 5^o is closer to total loss in sandy sediments than in clayey sediments.

The following argument makes this case more rigorously. The definition of the angle of intromission (θ_I, relative to normal incidence) is given by Kinsler, et al.[28] in their equation 6.34 as

$$\sin \theta_I = \sqrt{\frac{1-(r_1/r_2)^2}{1-(\rho_1/\rho_2)^2}} \tag{4.1}$$

where: the subscript 1 refers to seawater and the subscript 2 refers to the sediment

ρ is density

r is impedance, equal to the product of compressional speed and density

and θ_I is measured in degrees from the perpendicular to the sediment surface

In our notation, this becomes

$$\cos \phi_I = \sqrt{\frac{1-(\rho_f V_f/\rho V_p)^2}{1-(\rho_f/\rho)^2}} \tag{4.2}$$

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[28] Kinsler, L.E., A.R. Frey, A.B. Coppens, and J.V. Sanders, 1980, Fundamentals of Acoustics, 3rd Ed., John Wiley & Sons Inc., New York, New York.

where ρ_f = density of fluid = 1.025 gm cm $^{-3}$
V_f = compressional speed in fluid = 1525 m s^{-1}
ρ = sediment density -- a function of grain density and porosity
V_p = compressional speed in sediment
$\emptyset_I$ = grazing angle of intromission (degrees from the sediment surface)

We use equation 4.2 to show that the angle of intromission $\emptyset_I$ is much smaller for province AB than for BE. Typical values in AB under slow conditions for speed and density are 1510 m s^{-1} and 1.86 gm cm^{-3} (based on a void ratio of 1.0 and a grain density of 2.70). In province BE all conditions are slow and a typical speed is 1480 m s^{-1}, and a typical density is 1.43 gm cm^{-3} (based on a void ratio of 3.0 and a grain density of 2.65). These values lead to a grazing angle of intromission of 5.4° for AB and 14.8° for BE. It is clear that our angle of 5° is near total loss in the sandy provinces. Thus in those few cases of slow sediments in provinces AB and AC, the higher densities lead to smaller angles of intromission and therefore higher BL values than are found in province BE.

The pattern introduced by the distribution of BL at 1600 Hz in provinces AB and AC is repeated and reinforced through most of the remaining provinces. Two processes control the bottom loss within a province, one at sediment compressional speeds greater than those of seawater (characterized by low bottom loss) and one at speeds lower than those of seawater (characterized by high bottom loss). The competition of these two processes leads to distributions that are bimodal for many of the provinces. We can define a low BL mode as that BL bin below 4 dB with more counts than any other bin. We can define a high BL mode as that BL bin above 4 dB with more counts than any other bin. We select no mode unless there are at least two counts in a bin; and we name a bin by the BL value at the lower end of its interval. With these guidelines we are able to construct Table 4-3, which shows the modes in the BL distributions for 100 Hz, and Table 4-4 for 1600 Hz.

Table 4-3. Modes in the BL Distributions for 100 Hz

water depth grain size class	Shelf			Slope		
	province name	low BL mode	high BL mode	low BL mode	high BL mode	province name
sand	AA	0.0	-	0.0	15.5	BA
dirty sands	AB	0.0	-	0.0	11.0	BB
sandy muds	AC	0.0	-	0.5	9.0	BC
silt	AD	0.0	11.5	2.0	12.0	BD
mud	AE	0.0	9.5	0.0	7.5	BE

Table 4-4. Modes in the BL Distributions for 1600 Hz

water depth grain size class	Shelf			Slope		
	province name	low BL mode	high BL mode	low BL mode	high BL mode	province name
sand	AA	0.0	-	0.5	-	BA
dirty sands	AB	0.0	-	0.0	11.5	BB
sandy mud	AC	0.0	15.0	0.5	9.0	BC
silt	AD	0.0	10.5	-	13.5	BD
mud	AE	0.0	9.5	-	7.0	BE

These tables show a tendency for the high mode to occur at BL values that decrease from shelf to slope and, especially, from sand to mud. This trend is driven by the effects of void ratio on the angle of intromission via sediment density.

Of course, not all modes are equal, and in several provinces one mode dominates. Where two modes compete the variance is high; where one mode dominates the variance is low. Only province AB, at 1600 Hz, shows high variance without being able to define a high BL mode. Using a root variance of 4 dB to separate 2-mode provinces with a dominant mode from 2-mode provinces with competing modes, we can make Table 4-5. The provinces with competing modes do not show improvement over a province that groups all continental terrace sediments together.

Table 4-5.

Province	**100 Hz**	**1600 Hz**
AA		
AB		
AC		competing modes
AD	competing modes	competing modes
AE	competing modes	competing modes
BA	competing modes	
BB	competing modes	competing modes
BC	competing modes	competing modes
BD		
BE		

The sand sediments on the slope, province BA, do not give a BL distribution as similar to province AA as we expected. There are many observations of high BL (about 50% of the observations have BL greater than 3 dB) indicating a significant fraction of slow sediments in the province. This is not considered reasonable. Upon close inspection we found that the mean grain specific gravity distribution for this province was skewed by a number of measurements on an unusual sediment, where the specific gravity was unusually high (between 2.8 and 3.0). These unusual data points constitute more than half of the available data points in the province (totaling 14 in all). The high grain specific gravity in the Biot model drives the compressional speed low so that half of the runs ended up with speeds below seawater compressional speeds. Thus the anomalous grain densities created a spurious high BL mode. Province BA is unreliable because the data in PHYPROSE for this province violated our assumption that they were representative. This kind of error can only be alleviated by increasing the amount of data in PHYPROSE before pursuing further evaluations of provincing.

5.0 RESULTS

5.1 Statistical Comparison of BL Among Provinces

The trends and distinctions discussed in Section 4 are informative but are not associated with a level of significance or a degree of confidence. For these measures of reliability we turn to analysis of variance (ANOVA) procedures.[29]

Table 5-1 lists the quantities used in an analysis of variance for BL in all eleven provinces at 100 Hz, and Table 5-2 does the same at 1600 Hz.

At 100 Hz the F statistic is 23.1 and at 1600 Hz the F statistic is 31.1, which indicate highly significant differences in the means associated with the provinces at both frequences. An F statistic of greater than 2.7 is significant at the 0.5% level. Even though the means have no particular physical meaning in the provinces where the distributions are bimodal, and the analysis of variance depends on near normal distributions, the extremely high F statistics do indicate significant differences in the distributions as reflected by the means.

We employ the Q statistic[29] to isolate those provinces whose means are different from each other at the 95% confidence level. For 11 means and 539 degrees of freedom, $Q_{0.05}$ (given by Snedecor and Cochran's Table A 15[29]) is less than 4.70. This value is multiplied by the standard error of the mean, $s_{\bar{x}}$ (the square root of the mean square within the province, s^2, divided by the number of samples in the province, n) to given the significant difference, D, between means. That is

$$D = Q_{0.05} \cdot s_{\bar{x}} = Q_{0.05} \cdot \sqrt{\frac{s^2}{n}} \qquad (5.1)$$

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[29] Snedecor, G.W., and W.G. Cochran, 1973, Statistical Methods, Sixth Edition, Iowa State University Press, Ames, Iowa.

Table 5-1. Analysis of Variance Among Provinces for BL at 5° Grazing Angle at 100 Hz

Province:	AA	AB	AC	AD	AE	BA	BB	BC	BD	BE	ZZ
Number of Values:	50	50	50	50	50	50	50	50	50	50	50
BL Mean:	.7759	.2010	.2728	4.4104	6.7001	6.0276	7.3284	5.4927	4.8102	7.0259	6.2491
Sum of Deviations Squared:	45.82	4.99	11.90	1337.34	1112.66	2226.29	1401.23	1010.68	700.23	438.92	545.63

	Within Province	Between Provinces	All values combined
Sum of Squares	8835.68	3791.99	12627.7
Degrees of Freedom	539	10	549
Mean Square	16.3927	379.199	23.0012

F Statistic: 23.1321

Table 5-2. Analysis of Variance Among Provinces for BL at 5° Grazing Angle at 1600 Hz

Province:	AA	AB	AC	AD	AE	BA	BB	BC	BD	BE	ZZ
Number of Values:	50	50	50	50	50	50	50	50	50	50	50
BL Mean:	.7669	3.9064	2.5614	10.6117	9.6887	3.6047	12.9308	11.5722	13.7256	8.3475	7.1193
Sum of Deviations Squared:	31.82	3455.86	1956.91	2566.97	1730.56	1318.66	3092.21	1365.23	480.28	386.51	754.58

	Within Province	Between Provinces	All values combined
Sum of Squares	17139.6	9874.34	27013.9
Degrees of Freedom	539	10	549
Mean Square	31.7989	987.434	49.2057

F statistic: 31.0525

At 100 Hz $s^2 = 16.3927$ (Table 5.1) so D = 2.69 dB. This indicates that the means of provinces AA, AB, and AC are each significantly different from (i.e. less than) all the other provinces (but not from each other). The only other significant difference by this test is that the mean of province AD is less than the mean of province BB. At 1600 Hz, s^2 is 31.80 so D is 3.75. This leads to more complicated pairings of significant differences; but because we are most concerned with differences from province ZZ (all continental terrace sediments), we can reduce the complication. Only provinces AA and AC have means significantly less than the mean of ZZ. Only provinces BB, BC, and BD have means significantly greater than the mean of AA.

5.2 Separate Analysis of High and Low BL Regimes

Even the blind analysis of variance applied in Section 5.1 is able to ascertain the difference between provinces with a single low BL mode (AA, AB, and AC at 100 Hz) and provinces with a second mode at high BL (most of the remaining provinces). In this section we wish to exploit our understanding of the two regimes (our "model" of the process) to make more subtle statistical distinctions -- such as the difference between the high BL values of different provinces. The low BL regime occurs whenever the effective compressional speed of the sediment is greater than the compressional speed of seawater. BL values are almost always less than 3 dB in this regime. The high BL regime occurs whenever the effective sediment compressional speed is less than that of seawater. In this regime BL values are almost always greater than 4. We will now generate two new distributions from each histogram in Appendix B; one low BL distribution from 0 to 3.5 dB, and one high BL distribution from 3.5 to 40 dB. We will do comparisons between provinces only in similar regimes; e.g., compare the high BL distribution of province AA with the high BL distribution of province AB.

Table 5-3 give quantities of ANOVA for low BL conditions at 100 Hz, while Table 5-4 gives those quantities for high BL conditions at 100 Hz. The low BL (Table 5-3) means vary from .21 dB in province AB to 2.23 dB in province BD, with an F statistic of 17.17. For 324 observations spread over eleven classes, an F statistic over 2.71 is significant at better than the 0.5% level; therefore there are highly significant differences in the means. Again employing the Q statistic, we define a significant difference, D. The equation is modified from Equation 5.1 because the number of samples in a province, n, is now a function of province; according to reference 29, page 278 the standard error of the mean is now such that

$$D = Q_{0.05} \cdot \sqrt{\frac{s^2}{2}\left(\frac{1}{n_i} + \frac{1}{n_k}\right)} \tag{5.2}$$

where n_i is the number of samples in province i and

n_k is the number of samples in province k

For provinces with 50 samples D = .53 dB. For provinces with at least 18 observations to be different from ZZ (with 12 observations), D must be greater than .78 dB. There are many different pairings that can be tested, and these will be summarized and plotted later. Here suffice it to say that at 100 Hz the low BL means in provinces AB and AC are significantly less than in province ZZ, and BD is significantly greater than ZZ, with 95% confidence.

One can also test whether there are significant differences among the variances for the provinces, using the M/C statistic (reference 29, page 296). This value was computed for the low BL data at 100 Hz and is 202.9 with 10 degrees of freedom. Such a result indicates real differences in variance at better than the 0.5% level of significance. Several provinces have significantly lower variance than ZZ, as will be shown later, and no province has a significantly higher variance.

Table 5-3. Analysis of Variance Among Provinces for Low BL at 5^o Grazing Angle at 100 Hz

Province:	AA	AB	AC	AD	AE	BA	BB	BC	BD	BE	ZZ
Number of Values:	50	50	50	32	19	27	19	26	30	8	13
BL Mean:	.7759	.2102	.2728	.8867	.9951	1.1415	1.1661	1.6299	2.2318	1.2357	1.0956
Sum of Deviations Squared:	45.82	4.99	11.90	19.02	17.82	24.96	29.62	25.58	15.84	4.57	10.78

	Within Province	Between Provinces	All values combined
Sum of squares	210.906	115.709	326.616
Degrees of Freedom	313	10	323
Mean Square	.673823	11.5709	1.01119

F Statistic: 17.1721

Table 5-4. Analysis of Variance Among Provinces for Low BL at 5^{o} Grazing Angle at 1600 Hz

Province:	AA	AB	AC	AD	AE	BA	BB	BC	BD	BE	ZZ
Number of Values:	49	40	44	13	9	39	8	0	0	0	10
BL Mean:	.6864	.4949	.3230	1.2863	.4824	1.6296	.4199	.0000	.0000	.0000	.8855
Sum of Deviations Squared:	15.96	23.38	25.95	18.49	3.60	32.13	2.50	.00	.00	.00	10.43

	Within Province	Between Provinces	All values combined
Sum of squares	132.447	46.2953	178.743
Degrees of Freedom	204	7	211
Mean Square	.649250	6.61361	.847121

F Statistic: 10.1865

Table 5-4 shows similar results for 1600 Hz low BL conditions, except that three provinces (BC, BD, BE) had insufficient data (less than 5 observations) at low BL to be included in our analysis. Among the eight remaining provinces there exists an F statistic of 10.19 which is significant at better than the 0.5% level (greater than 3.09 when there are 204 observations over 8 provinces). The M/C statistic is 47.74 with 7 degrees of freedom indicating real differences in the variances among the provinces at the 0.5% level of significance.

Tables 5-5 and 5-6 show the results of ANOVA calculations for the high BL cases at 100 Hz and 1600 Hz, respectively. Under high BL conditions at 100 Hz the three provinces AA, AB and AC have insufficient data for analysis (less than 5 observations). The remaining eight give an F statistic of 6.77 which is significant at the 0.5% level also. (The 0.5% level is defined to be under 3.09 for 218 observations over 8 provinces). The M/C statistic is 468.6 with 7 degrees of freedom -- significant at well beyond the 0.5% level of chi squared, 20.28. Highly significant differences in means and variances therefore occur among the provinces at 100 Hz in the high BL class.

Finally, at 1600 Hz under high BL conditions, ANOVA results are summarized in Table 5-6. Province AA has too few observation to be included. The F statistic, at 11.53, is well beyond the 0.5% level of significance value of 2.60 based on 320 observations over 10 provinces. The M/C statistic, at 410.8, is well beyond the 0.5% level of significance for chi squared with 9 degrees of freedom, 23.59. Again, highly significant differences in means and variance occur among the provinces.

Under all conditions, 100 Hz and 1600 Hz, low BL and high BL, the provinces defined in this study lead to significant differences in means and variances. We now wish to indicate which provinces produce those differences. The results of our study are summarized in Table 5-7 for 100 Hz and Table 5-8 for

Table 5-5. Analysis of Variance Among Provinces for High BL at 5° Grazing Angle at 100 Hz

Province:	AA	AB	AC	AD	AE	BA	BB	BC	BD	BE	ZZ
Number of Values:	0	0	0	18	31	23	31	24	20	42	37
BL Mean:	.0000	.0000	.0000	10.6747	10.1967	11.7633	11.1053	9.6773	8.6779	8.1288	8.0599
Sum of Deviations Squared:	.00	.00	.00	214.65	97.44	800.08	207.90	176.88	185.76	115.05	68.26

	Within Province	Between Provinces	All values combined
Sum of Squares	1866.01	405.522	2271.53
Degrees of Freedom	218	7	225
Mean Square	8.55970	57.9318	10.0957

F Statistic: 6.76797

AD-A173 821 THE PRECISION OF BOTTOM LOSS PREDICTIONS FROM A PHYSICAL SEDIMENT MODEL(U) PLANNING SYSTEMS INC MCLEAN VA E J MOLINELLI ET AL. 31 AUG 86 TR-291343 2/3

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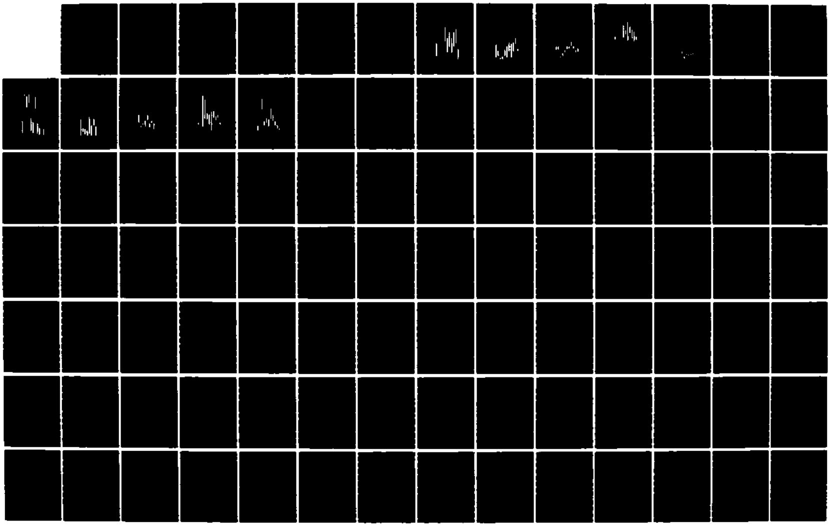
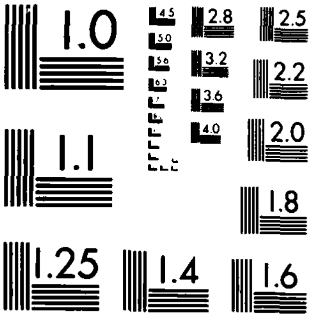




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 5-6. Analysis of Variance Among Provinces for High BL at 5^{o} Grazing Angle at 1600 Hz

Province:	AA	AB	AC	AD	AE	BA		BC	BD	BE	ZZ
Number of Values:	0	10	6	37	41	11	42	46	50	47	40
BL Mean:	.0000	17.5526	18.9764	13.8881	11.7096	10.6073	15.3138	12.5420	13.7256	8.7951	8.6778
Sum of Devia-tions Squared:	.00	1104.76	93.77	1020.77	796.71	594.99	1599.03	823.72	480.28	227.28	258.40

	Within Province	Between Provinces	All values combined
Sum of Squares	6999.70	2270.25	9269.95
Degrees of Freedom	320	9	329
Mean Square	21.8741	252.251	28.1762

F Statistic: 11.5320

Table 5-7. Summary of Results BL Variations Among Provinces at 100 Hz

PROVINCE	FREQUENCY	PROBABILITY OF LOW BL	LOW BL MEAN	LOW BL ROOT VARIANCE	PROBABILITY OF HIGH BL	HIGH BL MEAN	HIGH BL ROOT VARIANCE
ZZ	100 Hz	.26±.16	1.10±.80	.95±.14	.74±.16	8.06±.62	1.32±.22
AA	100 Hz	1.00	.78±37	.97±.11	.00	---	---
AB	100 Hz	1.00	.21±.12	.32±.07	.00	---	---
AC	100 Hz	1.00	.27±.19	.49±.12	.00	---	---
AD	100 Hz	.64±.17	.89±.38	.78±.13	.36±.17	10.67±2.41	3.55±.60
AE	100 Hz	.38±.18	1.00±.66	1.00±.12	.62±.18	10.20±.89	1.80±.50
BA	100 Hz	.52±.18	1.63±.55	1.01±.09	.48±.18	9.68±1.59	2.77±.36
BB	100 Hz	.38±.18	1.17±.85	1.28±.17	.62+.18	11.11±1.30	2.63±.37
BC	100 Hz	.52±.18	1.63±.55	1.01±.09	.48±.18	9.68±1.59	2.77±.36
BD	100 Hz	.60±.18	2.32±.37	.74±.08	.40±.18	8.68±2.00	3.13±39
BE	100 Hz	.16±.13	1.24±.13	.81±.13	.84±.13	8.13_.70	1.68±.32

Table 5-8. Summary of Results BL Variations Among Provinces at 1600 Hz

PROVINCE	FREQUENCY	PROBABILITY OF LOW BL	LOW BL MEAN	LOW BL ROOT VARIANCE	PROBABILITY OF HIGH BL	HIGH BL MEAN	HIGH BL ROOT VARIANCE
ZZ	1600	.20±.15	0.89±1.11	1.16±.30	.80±.15	8.68±.82	2.57±.88
AA	1600	.98+.05	0.69±0.22	0.58±.07	.02±.05	---	---
AB	1600	.80±.15	0.49±0.33	0.77±.06	.20±.15	17.55+11.39	11.08±1.90
AC	1600	.88±.12	0.32±0.32	0.78±.22	.12±.12	18.98±7.13	4.33±.84
AD	1600	.26±.16	1.29±1.05	1.24±.17	.74±.16	13.89±2.38	5.33±.97
AE	1600	.18±.14	0.48±0.75	.67±.16	.82±.14	11.71±3.88	4.46±1.36
BA	1600	.78±.15	1.63±.40	.92±.08	.22±.15	10.61±7.22	7.73±2.04
BB	1600	.16±.13	0.42±.74	.60±.25	.84±.13	15.31±2.62	6.24±1.17
BC	1600	.08±.10	---	---	.92±.10	12.54±1.70	4.28±.79
BD	1600	.00	---	---	1.00	13.73±1.18	3.13±.65
BE	1600	.06±.09	---	---	.94±.09	8.80±.87	2.22±.29

1600 Hz. For each province we list the probability that BL will be less than 3.5 dB. If sufficient data are available (5 observations or more), we then provide the mean BL and variance for the low BL conditions, and the mean BL and variance for the high BL conditions. We also provide error estimates for each of the values in Tables 5-7 and 5-8 to aid in selecting differences that are likely to be significant.

The error estimates are made as follows. For the proportion of observations less than 3.5 dB, the binomial distribution gives the error. The 99% confidence interval is encompassed by an error in sample properties, $\varepsilon_{\hat{p}}$ given by:

$$\varepsilon_{\hat{p}} = 2.576 \sqrt{\frac{\hat{p}\ (1-\hat{p})}{n}} \qquad 5.3$$

where $\hat{p}$ is the proportion of the sample less than 3.5 dB and n is the number of observations in the sample -- in our case, always 50.

For the mean we use the 99% confidence interval based on Student's t distribution to define an error ε_x in the sample mean.

$$\varepsilon_{\bar{x}} = t_{.01} \frac{s}{\sqrt{n}} \qquad 5.4$$

where $\bar{x}$ is the sample mean

s is the sample root variance

and n is the number of samples.

For the variance, the error is sensitive to the kurtosis of the parent distribution which we estimate from the sample distribution. We then use the expected error, ε_{s^2} of the sample variance, s^2, from a distribution with kurtosis γ.[29]

$$\varepsilon_s 2 = \sigma^2 \left[\frac{2}{f} \left\{ 1 + \frac{f}{f+1} \quad \frac{\Upsilon}{2} \right\} \right]^{\frac{1}{2}} \qquad (5.5)$$

where σ^2= population variance, approximated by s^2
Υ = population kurtosis, approximated by the sample kurtosis
f = degrees of freedom = n-1

We define a province root variance upper bound, s_U, and lower bound, s_L as follows.

$$s_U = \sqrt{s^2 + \varepsilon_s 2}$$

$$s_L = \sqrt{s^2 - \varepsilon_s 2} \qquad (5.6)$$

Finally, we define the error estimate of the root variance ε_s as the larger of the differences between s and s_U, and s and s_L.

$$\varepsilon_s = \text{maximum } (s_U - s, \ s - s_L) \qquad 5.7$$

The results of Table 5-7, for 100 Hz, are displayed in Figures 5-1 through 5-5. Figure 5-1 shows the proportion of low BL conditions. Only provinces AA, AB, AC and AD have significantly greater proportions (hence probabilities) of low BL conditions than occur in ZZ. Additionally, in provinces BA and BD it is likely that proportions of low BL conditions are greater than in ZZ, but the confidence level of this distinction is not as great as it is for the first four provinces.

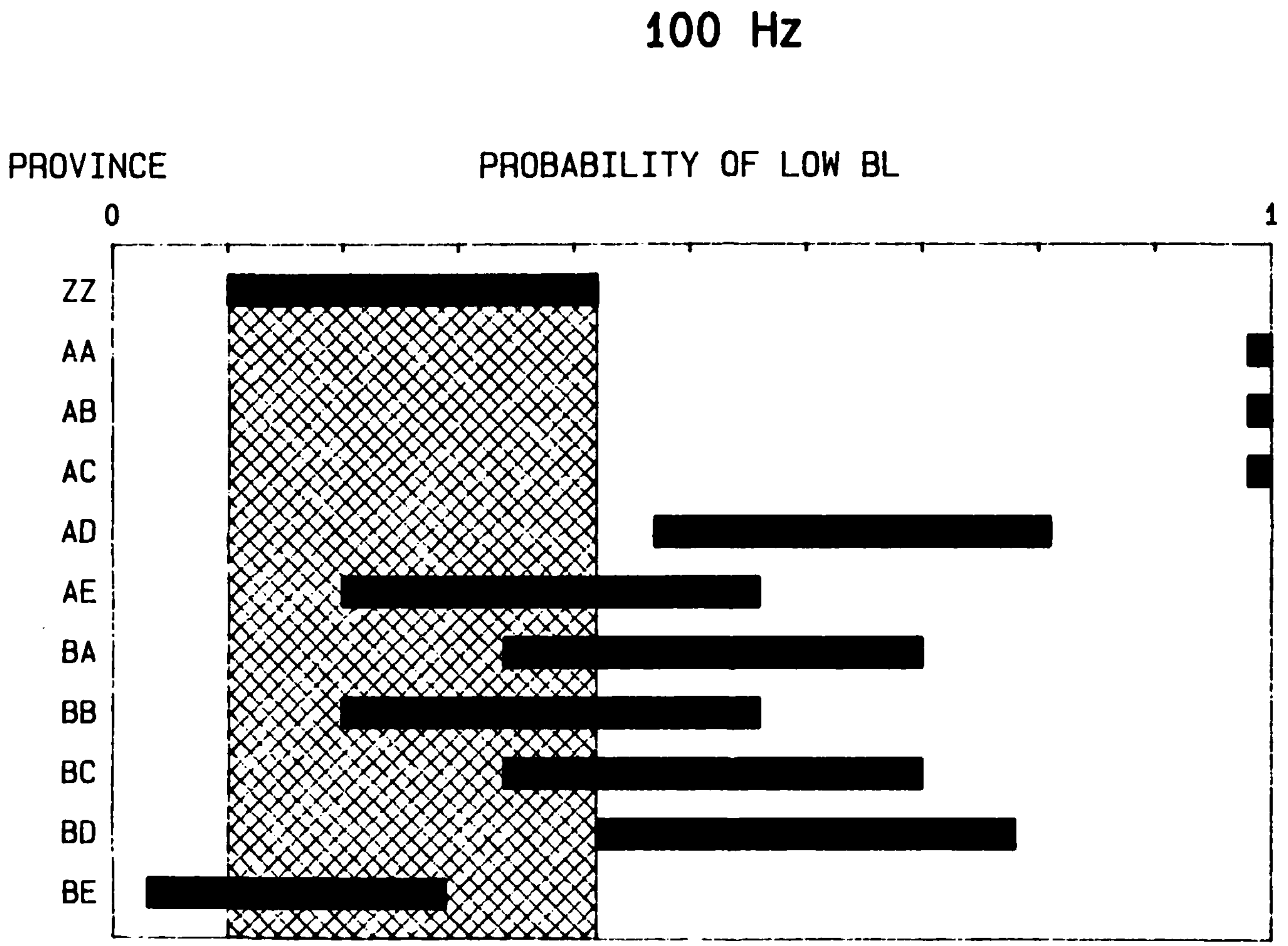


Figure 5-1. Significant differences between ZZ and the other provinces wrt proportion of low BL cases, 100 Hz. Bars represent 99% confidence limits.

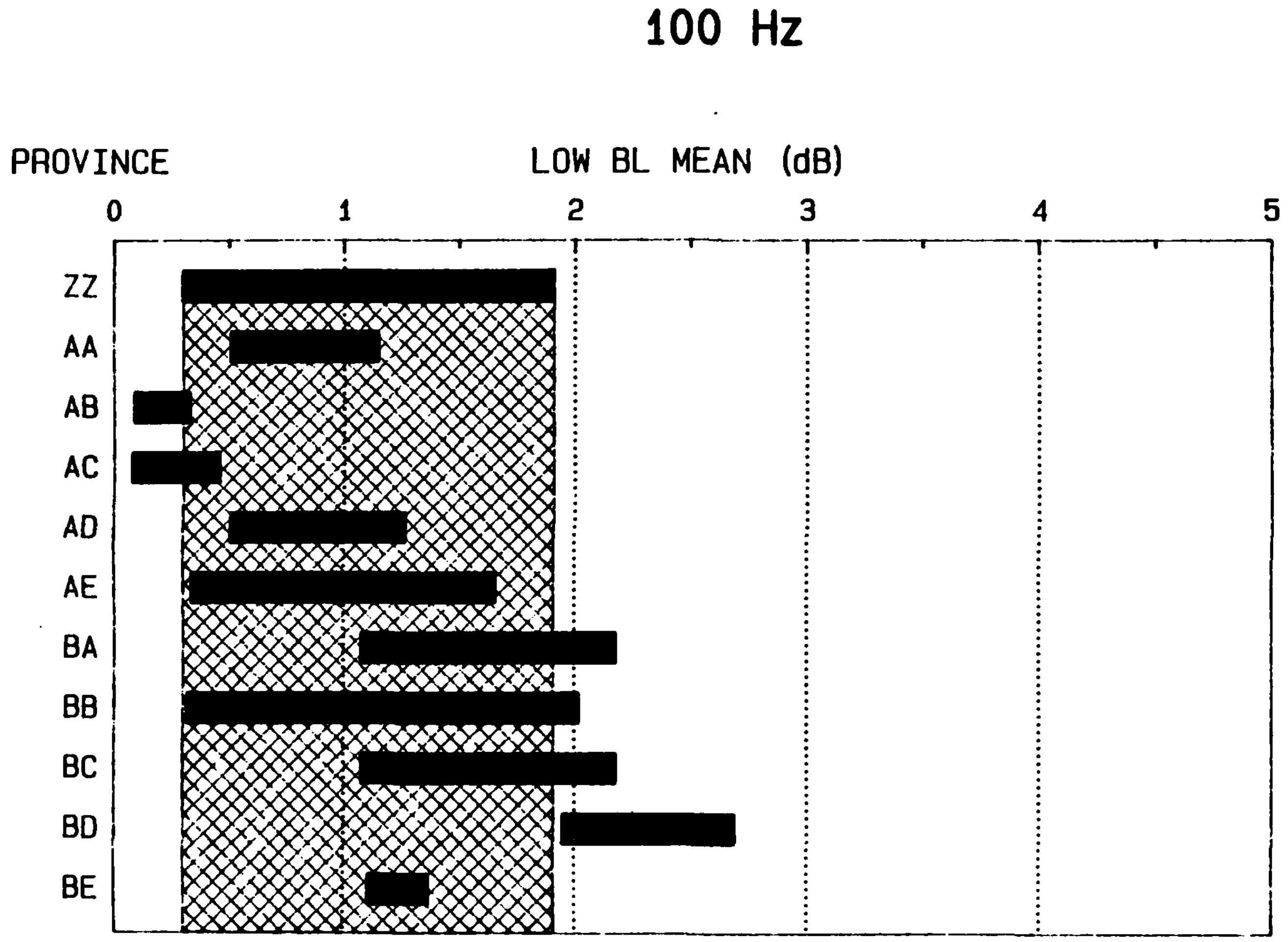


Figure 5-2. Significant differences between ZZ and the other provinces wrt low BL mean, 100 Hz. Bars represent 99% confidence limits.

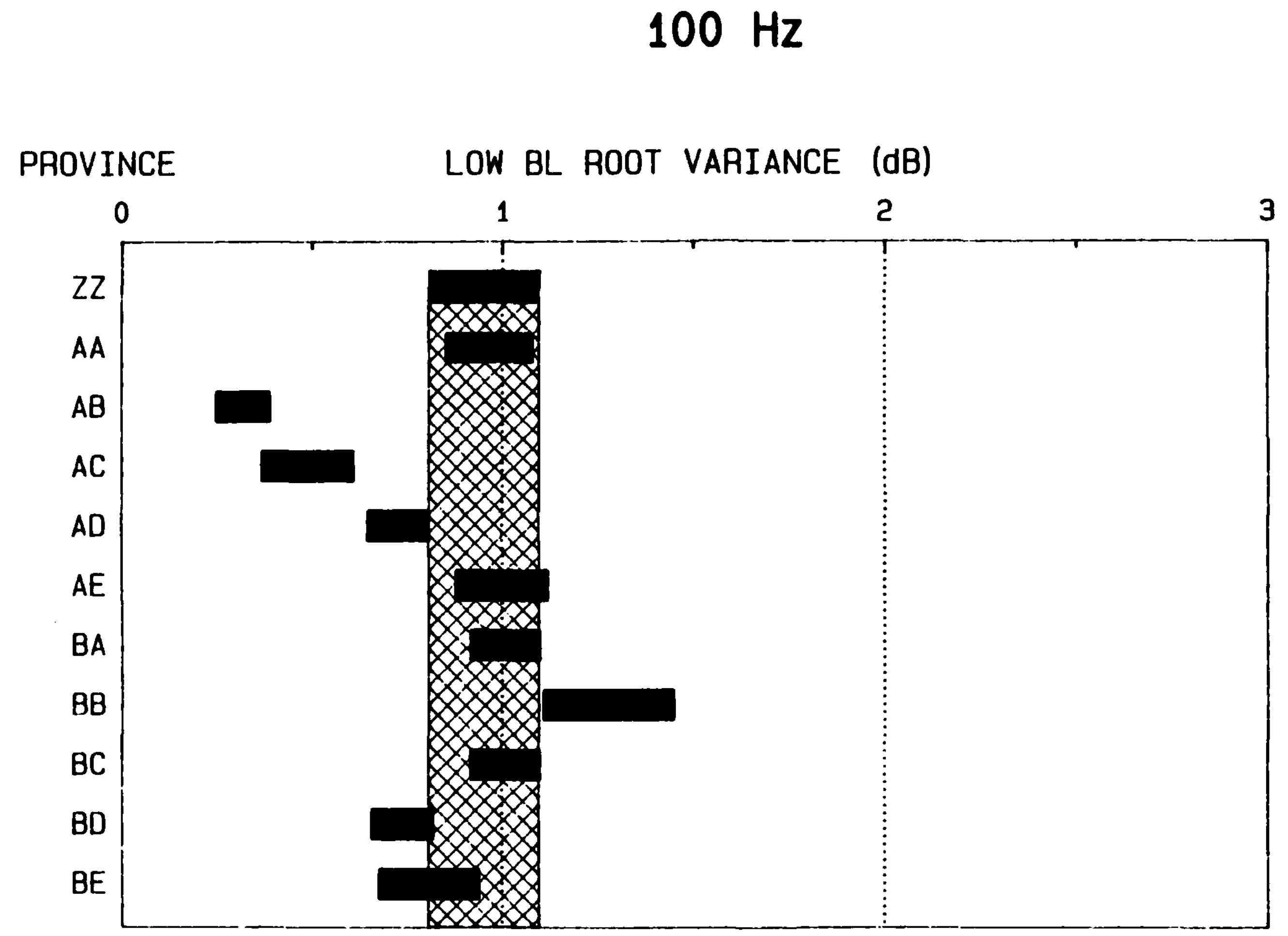


Figure 5-3. Significant differences between ZZ and the other provinces wrt low BL variance, 100 Hz. Bars represent standard error around sample variance.

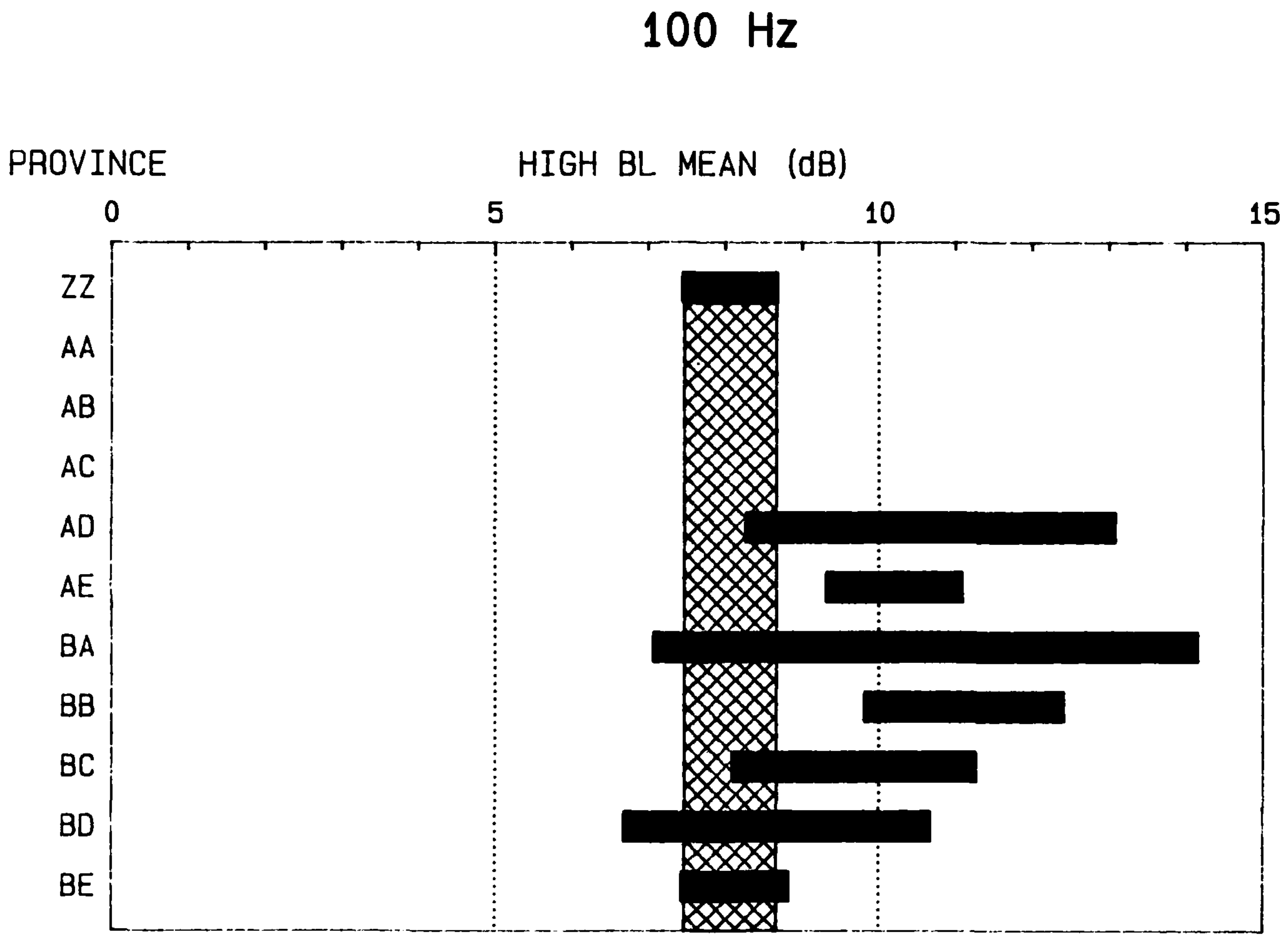


Figure 5-4. Significant differences between ZZ and the other provinces wrt high BL mean, 100 Hz. Bars represent 99% confidence limits.

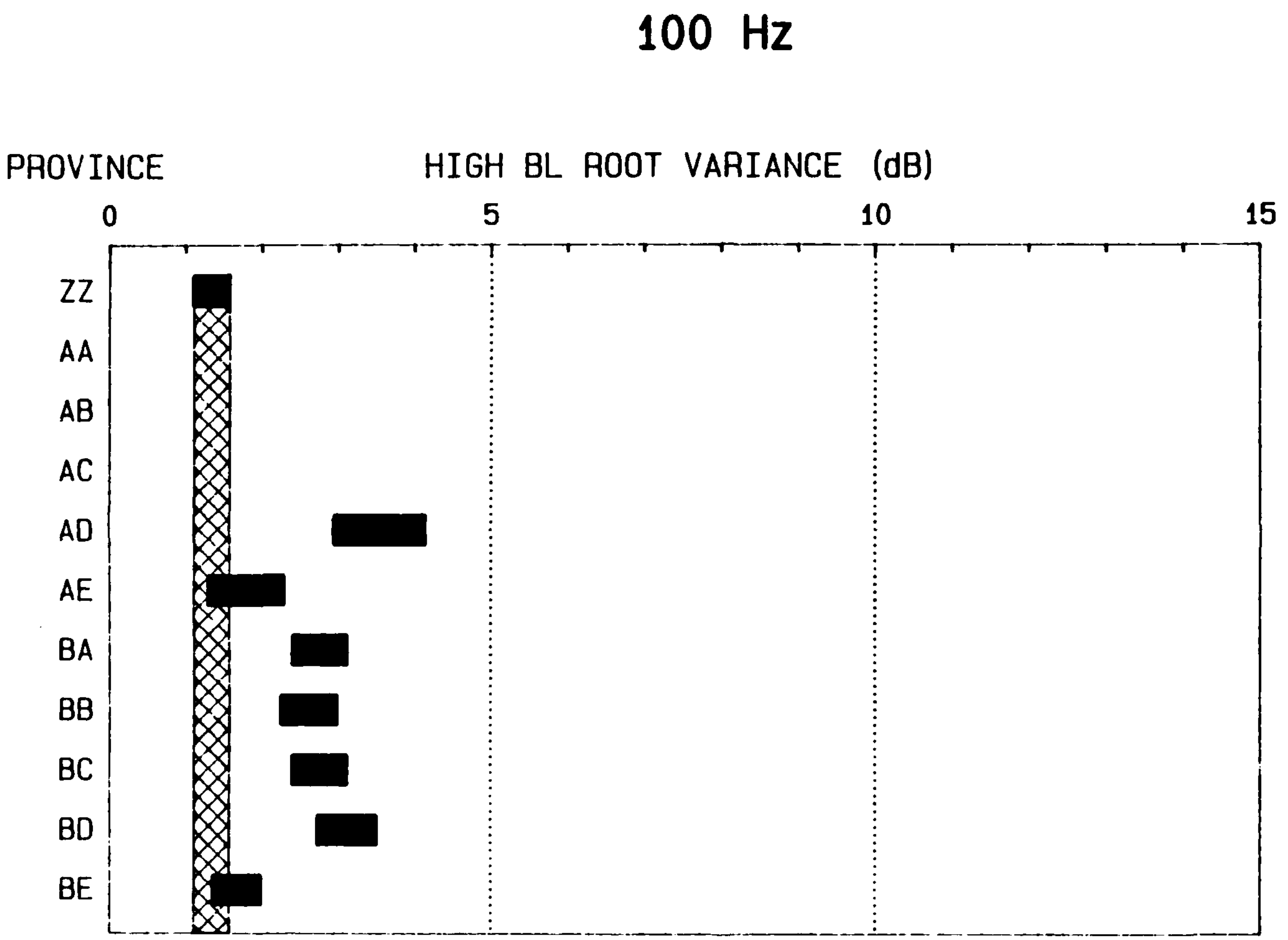


Figure 5-5. Significant differences between ZZ and the other provinces wrt high BL variance, 100 Hz. Bars represent standard error around sample variance.

Figure 5-2 shows the mean BL under low BL conditions at 100 Hz. While several significant distinctions can be made between pairs of provinces, only province AB has a significantly lower mean BL than ZZ, and only province BD has a significantly higher mean BL than province ZZ. A good part of the reason for having only two provinces distinct from ZZ is the large uncertainty in the ZZ mean because of the small sample size below 3.5 dB in that province.

Figure 5-3 shows the variance in BL under low BL conditions. Provinces AB, AC and BD have significantly lower variances than ZZ; and, province BB has a significantly higher variance. The occurrence of significantly lower variances in some provinces is a critical factor in our conclusion that there is an advantage to provincing on grain size and water depth.

Figure 5-4 shows the mean BL at 100 Hz, under high BL conditions. Note that provinces AA, AB and AC had too few observations to calculate a mean. In a real sense, as reflected in Table 5-1, these three provinces are significantly different from AA. Among the remaining provinces, AE and BB have significantly higher means than does ZZ. No province has a significantly lower mean. In terms of the mean of high BL conditions at 100 Hz, province BE is nearly identical in location and spread to province ZZ. This property was first mentioned in Section 4.2.1 when discussing Figure 4-3. The significantly different mean values in some provinces is another of the critical factors leading to our conclusion that there is an advantage to this provincing.

Figure 5-5 shows the variance of BL at 100 Hz under high BL conditions. Provinces AA, AB and AC again are different by virtue of having no high BL conditions. Among the remaining provinces, all but AE and BE have significantly greater variances than ZZ. By this measure, provincing offers no advantage. Once again province BE is most like ZZ.

The results at 1600 Hz are qualitatively similar to the findings at 100 Hz. The 1600 Hz results are listed in Table 5-8 and plotted in Figures 5-6 to 5-10. Provinces AA, AB, AC and BA have significantly greater proportions of low BL conditions than does ZZ (Figure 5-6). There are significant differences in low BL means among the provinces; but, because of a wide uncertainty in province ZZ, no province is significantly different from ZZ (Figure 5-7). Provinces AA, AB, AE and BB have significantly lower variances, under low BL conditions, than does ZZ, and no province has higher variance (Figure 5-8). Under high BL conditions, provinces AC, AD, BB, BC and BD have significantly higher mean BL than does ZZ; and province BE is nearly identical to province ZZ in location and spread (Figure 5-9). Finally, several provinces have significantly larger variances, under high BL conditions, than does ZZ (Figure 5-10).

5.3 Evaluation of PHYSED Provincing

We restate our objective (Section 1.2) using terminology introduced in this report. Use of the PHYSED model can be considered an improvement in capability to predict BL on the continental terrace if it could province by utilizing information more readily available than geoacoustic and BL measurements combined, and if at least one of the following occurs.

1) The variance in a province is significantly less than the variance of continental terrace sediments combined (province ZZ).

2) The mean BL in a province is significantly different than the mean of province ZZ.

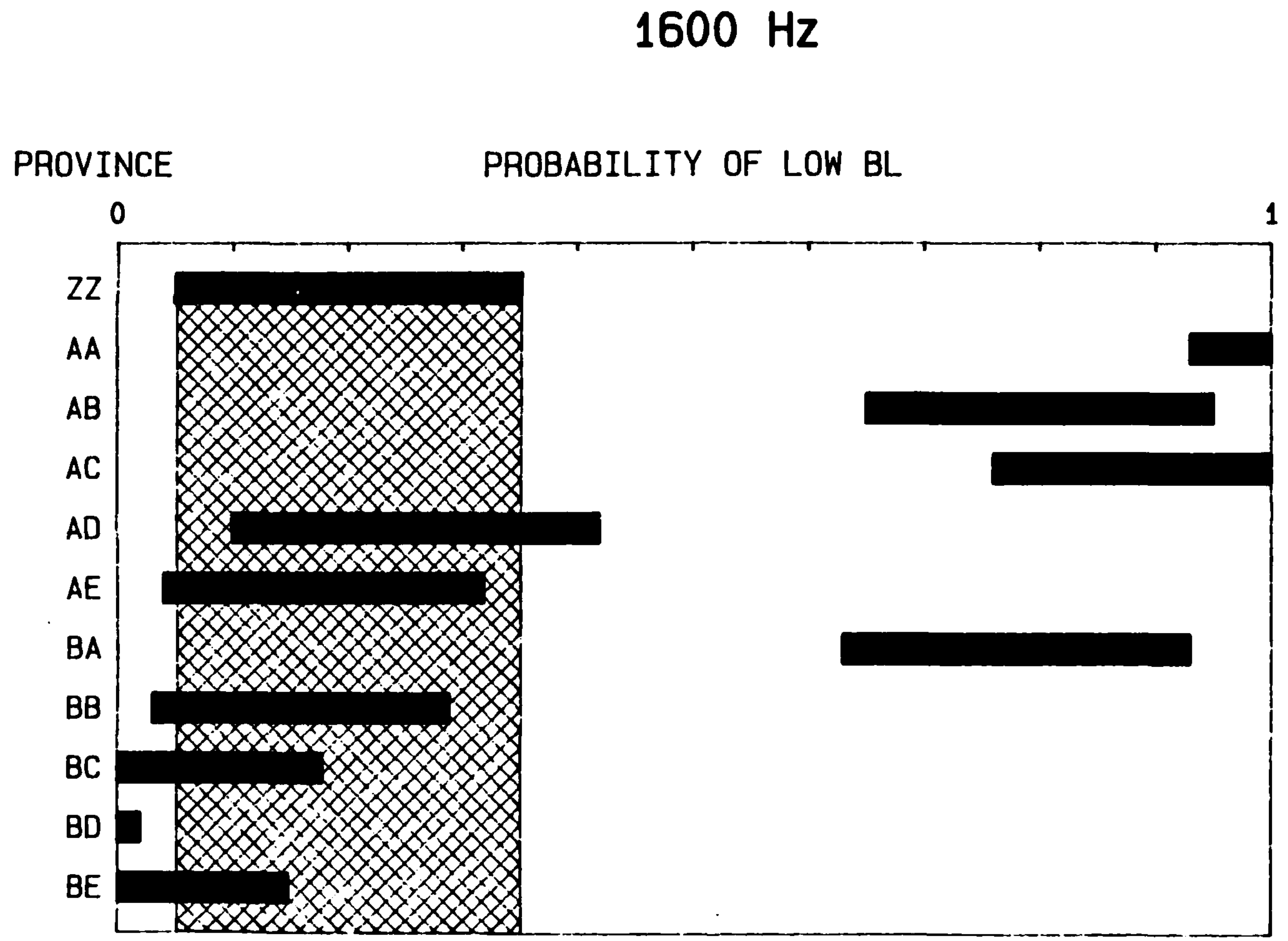


Figure 5-6. Significant differences between ZZ and the other provinces wrt proportion of low BL cases, 1600 Hz. Bars represent 99% confidence limits.

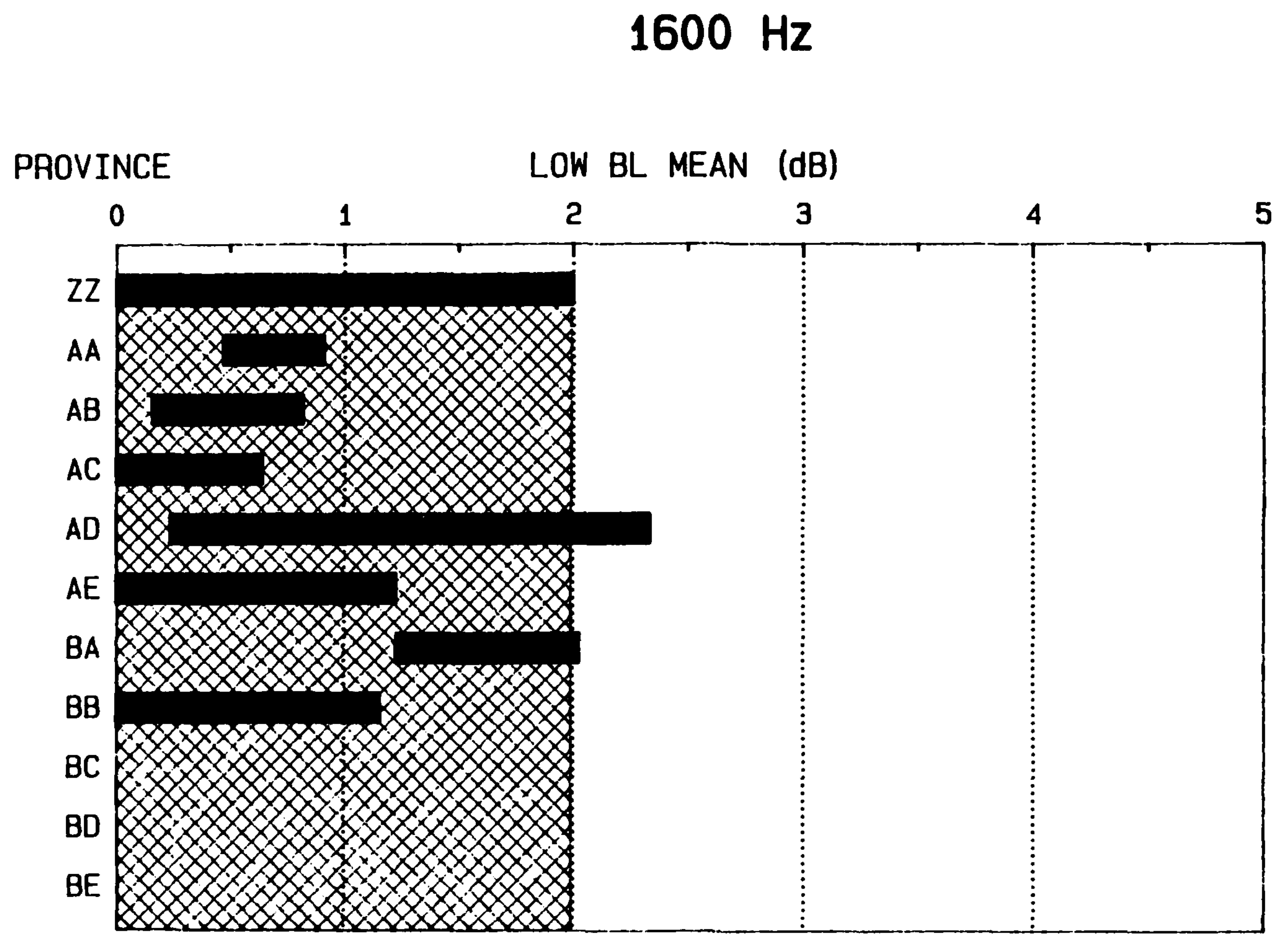


Figure 5-7. Significant differences between ZZ and the other provinces wrt low BL mean, 1600 Hz. Bars represent 99% confidence limits.

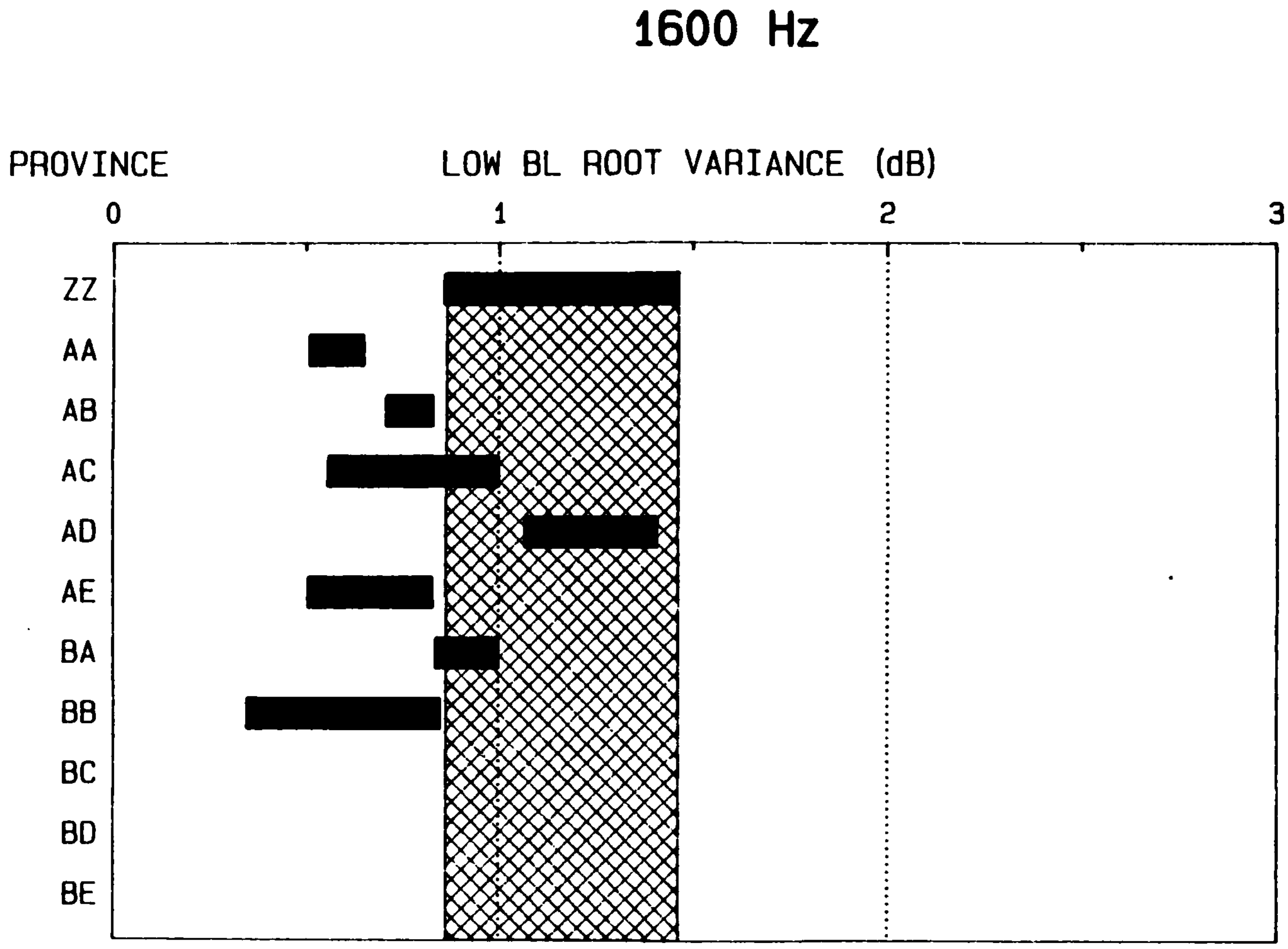


Figure 5-8. Significant differences between ZZ and the other provinces wrt low BL variance, 1600 Hz. Bars represent 99% confidence limits.

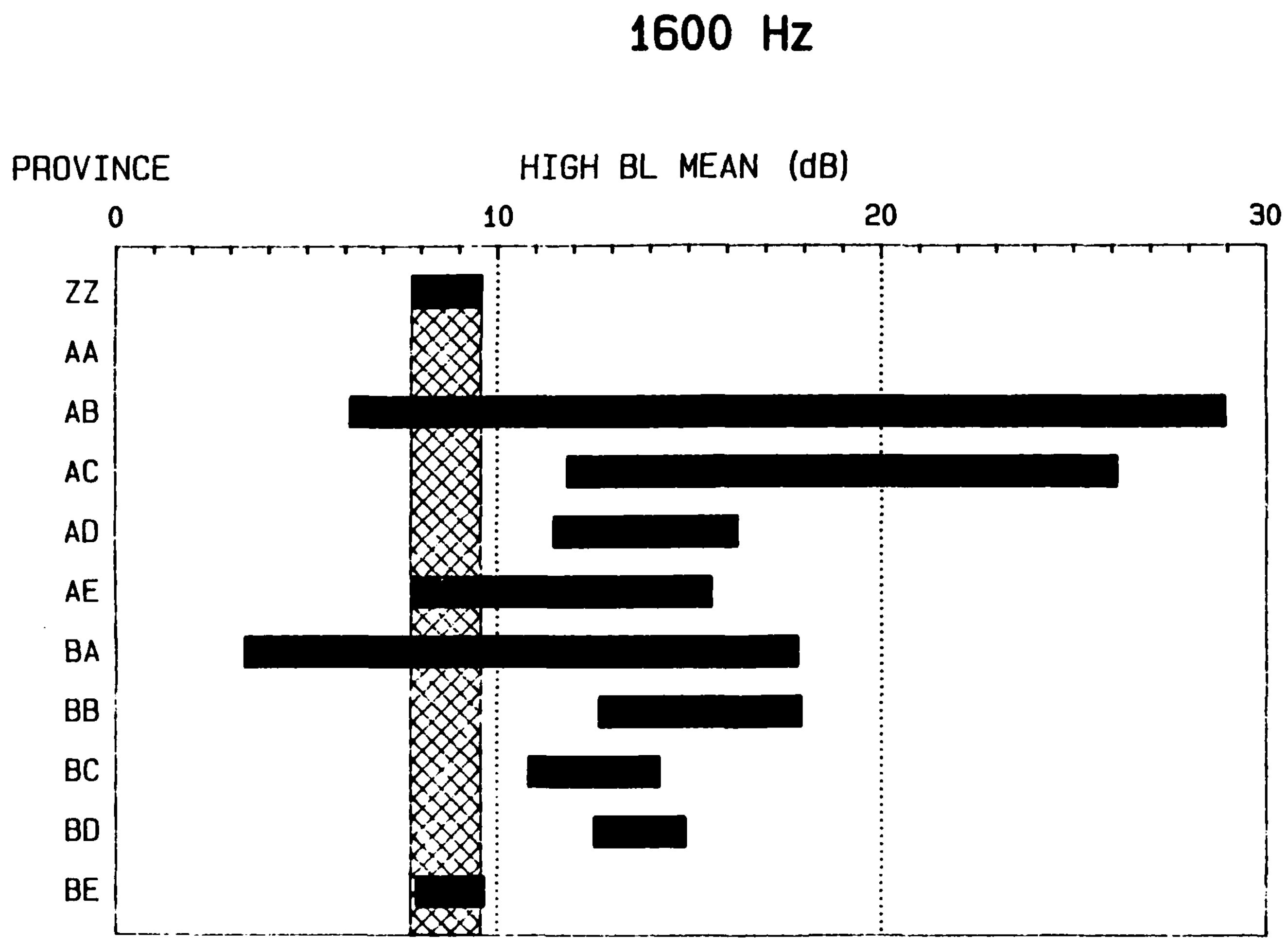


Figure 5-9. Significant differences between ZZ and the other provinces wrt high BL mean, 1600 Hz. Bars represent 99% confidence limits.

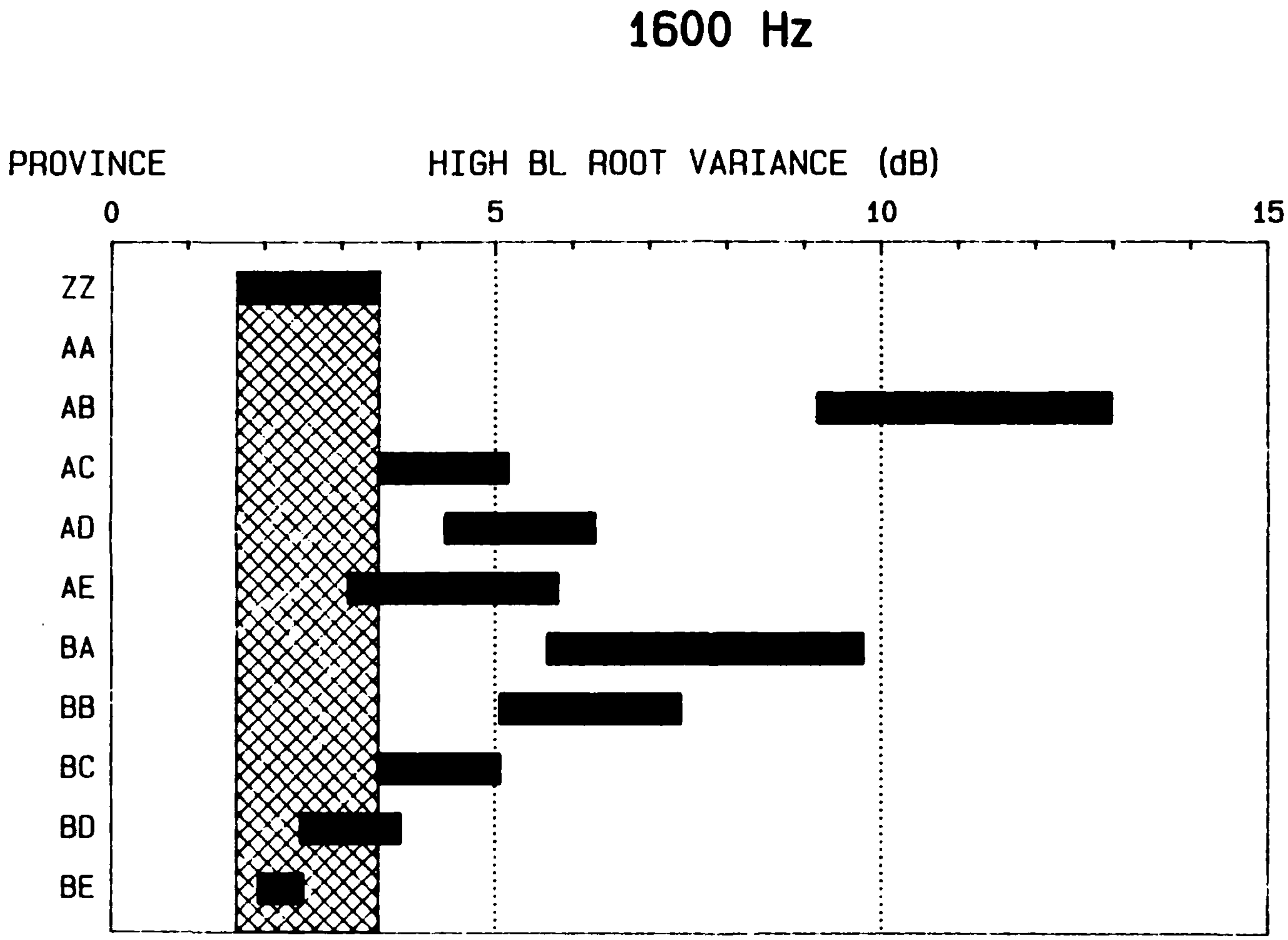


Figure 5-10. Significant differences between ZZ and the other provinces wrt high BL variance, 1600 Hz. Bars represent standard error around sample variance.

3) The probability that a measurement of compressional speed is not from the province associated with it should be less than one percent.

The provinces considered in this study, useful for the PHYSED model, are based on readily available information for a given site -- water depth and qualitative size class. Water depth is well enough known worldwide to assign a location to the shelf (0-200 m), slope (200 - 2000 m), or rise (2000 - 4000 m) provinces. As shown in Section 2, qualitative size class (texture) information is on the order of one hundred times more readily available than geoacoustic measurements and BL measurements. Thus, the first prerequisite for Biot/Stoll modeling to improve capability in BL prediction has been met.

Examples can be cited for significantly reduced variances in some provinces compared to ZZ. Especially dramatic are the cases of provinces AA, AB and AC. All show significantly greater preponderance of low BL conditions *and significantly* lower variance of BL values than does ZZ. Not only are variances reduced in some provinces, but means are significantly different in others as shown in Figures 5-2, 5-4, and 5-9. Thus, the second prerequisite for Biot/Stoll modeling to improve capability in BL prediction has also been met.

An insufficient amount of compressional speed data has precluded our formally estimating the probability that a sediment was incorrectly assigned to a province. In light of our other findings, however, we do not need such an estimate to show substantial improvement due to provincing.

5.4 Conclusions and Recommendations

We conclude that PHYSED modeling, when combined with provincing based on water depth and qualitative size class, represents a real improvement in our capability to predict Bottom

Loss (BL) on the continental terrace. This conclusion is based both on reduced variances in some provinces and on relocated means in some provinces.

We also conclude that the provincing done here provides a better separation from combined sediments (province ZZ) for AA, AB and AC (shelf sands, shelf dirty sands, and shelf sandy muds) than it does for the other provinces. This is based upon the significant differences found in the proportion of low BL, low BL means, and low BL variances.

We recommend that the sediments in the other provinces should be divided in different ways than done here in an attempt to discover a provincing scheme that reduces the variance under high BL conditions. Separation by ocean area is suggested by our void ratio analysis in Section 2.2. Separation by void ratio ranges directly is also reasonable but this procedure depends on engineering data which is less readily available than ocean area.

Before pursuing further provincing schemes, we recommend increasing the amount of data in PHYPROSE. Province BA seems to have been affected by unrepresentative high grain densities. Also, the near agreement of the BL distribution belonging to province ZZ with province BE, under high BL conditions, points to a high percentage of silts in the PHYPROSE data base. Continental terrace sediments as a whole were expected to be closer to sands. The high silt content in ZZ may be an artifact of using data from all depths of a core, which results in more observations per silty site than observations per sandy site. Another reason for this possible error is that the data selected may not be a random sample of real terrace sediments but are, for some reason, biased.

Given these provincing results and the current interest in developing geoacoustic or bottom loss models for operational use in shallow water areas, we strongly recommend the continued development of the physical sediment approach. In Section 1.1 we discussed the stages of development of this hybrid model. We have shown significant progress through six stages of the seven stage development plan displayed as Table 1-4. Progress on Stage VI, Predictive Model Evaluation had been shown in this effort. However, the scarcity of acoustic measurements precluded a credible model-to-data evaluation. Effort should be directed toward such an evaluation. Once we are confident of the model, then validation efforts (Stage VII) will be warranted. We expect to continue such efforts under Navy research and development.

APPENDIX A

FORTRAN CODE for major programs used in this effort:

PROGRAM SAUCE

```
$LARGE
        PROGRAM SAUCE
C       Program, based on program Tomato, to select data from
C       provinces defined by:
C                           1.)  Water Depth
C                           2.)  Sediment Size Type
C                           3.)  Ocean Area
C       Provinces will be indicated using four characters as follows:
C       1st character indicates Water Depth.
C           A = 0 to 200 meters
C           B = 201 to 2000 meters
C           C = 2001 meters and greater
C           Z = All depths combined
C
C       2nd character indicates sediment size type.
C           A = Sand (Qual. Size code 1)
C           B = Sand with finer fractions (codes 2, 3, and 4)
C           C = Sandy finer fractions (codes 5, 6, and 7)
C           D = Silt (code 8)
C           E = Clays (codes 9 and 10)
C           Z = All sizes combined
C
C       3rd & 4th characters indicate Ocean Area codes (see Phyprose
C       Report).
C           ZZ = All Ocean Areas Combined
C       Output files willbe named with Province Name and Parameter
C       codes as follows:
C                         ****VOID = Void ratios in province
C                         ****SGGR = Grain densities in province
C                         ****SZRO = So, mean specific surfaces in
C                                    province
C
C       Where **** indicates the province name
C
C       This naming convention can easily be expanded to include
C       other provincing criteria, as needed.
      LOGICAL*2 WORK
        character*14 FNAM1, FNAM2, FNAM3
      character*13 FNAM4
        character*1 IALPH(6,2),ICHAR(2)
        character*10 STRING,NCRUIS,NSAMP
      common/A1/ARR1,OUT1
      common/A2/ARR2,OUT2
      common/A3/ARR3,OUT3
      dimension ARR1(5000,2),OUT1(100,2),ARR2(5000,2),OUT2(100,2),
     +          ARR3(9500,2),OUT3(100,2),GSPD(16),TEMPV(100,2),
     +          TEMPZ(100,2),NACV(100),NACZ(100)
        data IALPH/'A','B','C','D','E','Z','a','b','c','d','e','z'/
 7001   format (' ENTER WATER DEPTH:'/
     +          ' A = 0 to 200 meters'/
     +          ' B = 201 to 2000 meters'/
     +          ' C = 2001 to and greater'/
     +          ' Z = All depths')
```

```
7002   format (' ENTER SEDIMENT SIZE TYPE:'/
   +           ' A = Sand (Code 1)'/
   +           ' B = Sand & Finers (Codes 2,3,& 4)'/
   +           ' C = Sandy Finers (Codes 5,6,& 7)'/
   +           ' D = Silt (Code 8)'/
   +           ' E = Clays (Codes 9 & 10)'/
   +           ' Z = All Sizes (Codes 1 thru 10)')
7003   format (' ENTER OCEAN AREA:'/
   +           ' Two digit Ocean Area code or'/
   +           ' enter ZZ for all ocean areas'/
   +           ' (Codes 00 thru 99)')
6000   format (' WATER DEPTH:')
6001   format (' SED. SIZE TYPE:')
6002   format (' OCEAN AREA:')
6010   format (13x,' 0 to 200 meters ')
6011   format (13x,' 201 to 2000 meters ')
6012   format (13x,' 2001 meters & greater ')
6013   format (13x,' All Depths ')
6030   format (15x,' Sand (Code 1) ')
6031   format (15x,' Sand & Finers (Codes 2,3,&4) ')
6032   format (15x,' Sandy Finers (Codes 5,6,&7) ')
6033   format (15x,' Silt (Code 8) ')
6034   format (15x,' Clays (Codes 9&10) ')
6035   format (15x,' All Sizes (Codes 1 thru 10) ')
6050   format (13x,' All areas (Codes 00 thru 99) ')
6051   format (13x,i3)
6099   format (//)

      WORK = .FALSE.

       write (*,6099)
  30   write (*,7001)
       read (*,6101) ICHAR(1)
6101   format (a1)

       do 50 I = 1, 6
          do 50 J = 1, 2
             if (ICHAR(1) .eq. IALPH(I,J)) goto 60
  50   continue
  55   write (*,6102)
6102   format (/' *?* NOT ACCEPTABLE RESPONSE.  TRY AGAIN.'/)
       goto 30
  60   if (I .eq. 4 .or. I .eq. 5) goto 55
       LOOPD = I

       write (*,6099)
  80   write (*,7002)
       read (*,6101) ICHAR(1)

       do 100 I = 1, 6
          do 100 J = 1, 2
             if (ICHAR(1) .eq. IALPH(I,J)) goto 110
 100   continue
 105   write (*,6102)
       goto 80
 110   LOOPS = I

       write (*,6099)
 130   write (*,7003)
       read (*,6104) ICHAR(1),ICHAR(2)
```

```
 6104   format (2a1)
        if ((ICHAR(1) .eq. IALPH(6,1) .or. ICHAR(1) .eq. IALPH(6,2))
     +     .and.
     +     (ICHAR(2) .eq. IALPH(6,1) .or. ICHAR(2) .eq. IALPH(6,2)))
     +     then
           LOOPA = 0
        else
           if (ICHAR(2) .eq. ' ') then
              ICHAR(2) = ICHAR(1)
              if (ICHAR(2) .eq. ' ') then
                 ICHAR(1) = 'Z'
                 ICHAR(2) = 'Z'
              else
                 ICHAR(1) = ' '
              end if
           end if
           write (string,6104) ICHAR(1),ICHAR(2)
           read (STRING,6105,ERR=135) IOAREA
 6105      format (i2)
           LOOPA = 1
        end if
        goto 140

  135   write (*,6102)
        goto 130

  140   continue

C       Generate output file names in FNAM1, FNAM2, FNAM3

        if (LOOPA .eq. 0) then
           ICHAR(1) = 'Z'
           ICHAR(2) = 'Z'
        end if

        write (FNAM1,6106)IALPH(LOOPD,1),IALPH(LOOPS,1),
     +                    ICHAR(1),ICHAR(2)
 6106   format ('E:',4a1,'VOID.DAT')
        write (FNAM2,6107)IALPH(LOOPD,1),IALPH(LOOPS,1),
     +                    ICHAR(1),ICHAR(2)
 6107   format ('E:',4a1,'SGGR.DAT')
        write (FNAM3,6108)IALPH(LOOPD,1),IALPH(LOOPS,1),
     +                    ICHAR(1),ICHAR(2)
 6108   format ('E:',4a1,'SZRO.DAT')
      WRITE (FNAM4,6111) IALPH(LOOPD,1),IALPH(LOOPS,1),
     +                   ICHAR(1),ICHAR(2)
 6111 FORMAT ('E:',4A1,'COV.DAT')

C       List results for operator.

        write (*,6109)
 6109   format (///' YOU CHOSE A PROVINCE WITH ')
        write (*,6000)
        if (LOOPD .eq. 1) then
           write (*,6010)
        else if (LOOPD .eq. 2) then
           write (*,6011)
        else if (LOOPD .eq. 3) then
           write (*,6012)
        else
```

```
            write (*,6013)
         end if

         write (*,6001)
         if (LOOPS .eq. 1) then
            write (*,6030)
         else if (LOOPS .eq. 2) then
            write (*,6031)
         else if (LOOPS .eq. 3) then
            write (*,6032)
         else if (LOOPS .eq. 4) then
            write (*,6033)
         else if (LOOPS .eq. 5) then
            write (*,6034)
         else
            write (*,6035)
         end if
         write (*,6002)
         if (LOOPA .eq. 0) then
            write (*,6050)
         else
            write (*,6051) IOAREA
         end if
         write (*,6110) FNAM1, FNAM2, FNAM3
 6110    format (/' FOR THIS PROVINCE'/
     +             ' VOID RATIOS ARE IN FILE ',A12/
     +             ' GRAIN DENSITIES ARE IN FILE ',A12/
     +             ' & SPECIFIC SURFACE MEANS ARE IN FILE ',A12)

C        Open output files

         open (60, file=FNAM1, status='new',
     +         access='sequential', form='formatted')
         open (70, file=FNAM2, status='new',
     +         access='sequential', form='formatted')
         open (80, file=FNAM3, status='new',
     +         access='sequential', form='formatted')
        OPEN (90,FILE=FNAM4, STATUS='NEW',
     +        ACCESS = 'SEQUENTIAL', FORM = 'FORMATTED')

C        Open input files

         open (10, file = 'HEADER.DAT', status = 'OLD',
     +         access = 'SEQUENTIAL', form = 'UNFORMATTED')

         open (20, file = 'COMMONP.DAT', status = 'OLD',
     +         access='DIRECT',form='UNFORMATTED',recl=44)

        open (30, file = 'SIZEDIS.DAT', status = 'OLD',
     +        access = 'DIRECT', form = 'UNFORMATTED', recl = 80)

         open (40, file = 'SIZECLS.DAT', status = 'OLD',
     +        access = 'DIRECT', form = 'UNFORMATTED', recl = 36)

         open (50, file = 'C:QUALSIZ.DAT', status = 'OLD',
     +        access = 'DIRECT', form = 'UNFORMATTED', recl = 20)

         NVOID = 0
         NSGGR = 0
         NSZRO = 0
```

```
      KOUNTV = 0
      KOUNTZ = 0

  200 read (10, end = 500) NAC,
     +      INSTS,IPLAT,NCRUIS,NSAMP,LAT,DLAT,LON,DLON,
     +      IOCEAN,IDAY,MONTH,IYEAR,MEAST,COREL,WDEPTH,
     +      IWDM,IPHYSG,ISURST,ICOMP,IENGP,IMINP,IQGS,
     +      IGSC,IGSD,IACOP,IFLUD

  201 format (i6,i4,1x,i4,1x,a10,a10,i3,f5.4,i4,f5.4,
     +        1x,4i2,i3,f7.2,f6.1,2x,3i2,5x,8i6)

C     Reject if out of area, unless all areas are accepted.

      if (LOOPA .eq. 0) goto 220
      if (IOCEAN .ne. IOAREA) goto 200

C     Reject if out of water depth, unless all depths are accepted.

  220 if (LOOPD .eq. 6) goto 230
      if (WDEPTH .lt. 0.0) goto 200
      if (LOOPD .eq. 1) then
         if (WDEPTH .gt. 200.0) goto 200
      else if (LOOPD .eq. 2) then
         if (WDEPTH .le. 200.0 .or. WDEPTH .gt. 2000.0) goto 200
      else if (LOOPD .eq. 3) then
         if (WDEPTH .le. 2000.0) goto 200
      end if

C     Reject if no Sed. Size info, unless all types are accepted.
C     NOTE: Must do final reject on size type at each depth in core.

  230 if (LOOPS .eq. 6) goto 240
      if (IQGS .eq. 0 .and. IGSC .eq. 0 .and. IGSD .eq. 0) goto 200

C     Load VOID RATIO and SGGR values into ARR1 and ARR2.

  240 if (ICOMP .eq. 0) goto 400

  300 read (20, rec = ICOMP, err=500) NACCES,DTOP,DBOT,
     +      WETWT,SGGR,WATCON,VOID,SVOID,POROS,DMG,PERM

  301 format (i6,2f7.2,2f4.2,f7.1,f6.3,f7.3,f4.3,f7.4,e10.3)

      if (NAC .ne. NACCES) goto 400
      if (LOOPS .eq. 6) goto 340
      IGSD1 = IGSD
      IGSC1 = IGSC
      IQGS1 = IQGS
      call TYPES(NAC,IGSD1,IGSC1,IQGS1,ICLASS,DTOP,DBOT)
      if (ICLASS .eq. 12) goto 310
      if (LOOPS .eq. 1) then
         if (ICLASS .ne. 1) goto 310
      else if (LOOPS .eq. 2) then
         if (ICLASS .ne. 2 .and. ICLASS .ne. 3 .and.
     +       ICLASS .ne. 4) goto 310
      else if (LOOPS .eq. 3) then
         if (ICLASS .ne. 5 .and. ICLASS .ne. 6 .and.
     +       ICLASS .ne. 7) goto 310
      else if (LOOPS .eq. 4) then
```

```
            if (ICLASS .ne. 8) goto 310
         else if (LOOPS .eq. 5) then
            if (ICLASS .ne. 9 .and. ICLASS .ne. 10) goto 310
         end if
         goto 330
  310    ICOMP = ICOMP + 1
         goto 300
  330    continue

C        Present class is correct, load VOID RATIO & SGGR if present.

C        1st, VOID RATIO

  340 if (VOID .ne. -9.0) then
            NVOID =  NVOID + 1
            ARR1(NVOID,1) = 0.0
            ARR1(NVOID,2) = VOID
            KOUNTV = KOUNTV + 1
            TEMPV(KOUNTV,1) = DTOP
            TEMPV(KOUNTV,2) = VOID
            NACV(KOUNTV) = NACCES
         else if (SVOID .ne. -9.0) then
            NVOID = NVOID + 1
            ARR1(NVOID,1) = 0.0
            ARR1(NVOID,2) = SVOID
            KOUNTV = KOUNTV + 1
            TEMPV(KOUNTV,1) = DTOP
            TEMPV(KOUNTV,2) = SVOID
            NACV(KOUNTV) = NACCES
         else if (POROS .gt. 0.0) then
            NVOID = NVOID + 1
            ARR1(NVOID,1) = 0.0
            ARR1(NVOID,2) = POROS / (1.0 - POROS)
            KOUNTV = KOUNTV + 1
            TEMPV(KOUNTV,1) = DTOP
            TEMPV(KOUNTV,2) = POROS / (1.0 -  POROS)
            NACV(KOUNTV) = NACCES
         end if

C        Now, SGGR

  350    if (SGGR .gt. 0.0) then
          write (*,*) 'Nacces = ',nacces
          write (*,*) 'Dtop = ',dtop
          write (*,*) 'Dbot = ',dbot
            NSGGR = NSGGR + 1
            ARR2(NSGGR,1) = 0.0
            ARR2(NSGGR,2) = SGGR
         end if
         ICOMP = ICOMP + 1
         goto 300

C        Now read FULL GRAIN SIZE DISTRIBUTION records to compute SZRO

  400    if (IGSD .eq. 0) then
            KOUNTV = 0
            GOTO 200
         end if
  401    read (30, rec = IGSD, err = 200) NA,
     +         DTOP,DBOT,GSPD(1),GSPD(2),GSPD(3),GSPD(4),
```

```
     +        GSPD(5),GSPD(6),GSPD(7),GSPD(8),GSPD(9),GSPD(10),
     +        GSPD(11),GSPD(12),GSPD(13),GSPD(14),GSPD(15),
     +        GSPD(16),DM
  402  format (I6,2F7.2,16F7.3,F7.4)

       if (NA .ne. NAC) THEN
        IF (KOUNTV .GT. 0 .AND. KOUNTZ .GT. 0) THEN
           I = 1
           J = 1
  405      IF (TEMPV(I,1) .EQ. TEMPZ(J,1)) THEN
              WRITE (90,6112) NACV(I),TEMPV(I,2),NACZ(I),TEMPZ(J,2)
 6112         FORMAT (I5,1X,F7.3,1X,I5,G13.5)
              IF (I .EQ. KOUNTV .AND. J .EQ. KOUNTZ) GOTO 408
              IF (I .NE. KOUNTV) I = I + 1
              IF (J .NE. KCUNTZ) J = J + 1
           ELSE IF (TEMPV(I,1) .LT. TEMPZ(J,1)) THEN
              IF (I .EQ. KOUNTV) GOTO 408
              I = I + 1
           ELSE IF (TEMPV(I,1) .GT. TEMPZ(J,1)) THEN
              IF (J .EQ. KOUNTZ) GOTO 408
              J = J + 1
           END IF
           GOTO 405
  408   CONTINUE
        END IF
        KOUNTV = 0
        KOUNTZ = 0
        GOTO 200
       END IF
       if (LOOPS .eq. 6) goto 440
       IGSD1 = IGSD
       IGSC1 = IGSC
       IQGS1 = IQGS
       call TYPES(NAC,IGSD1,IGSC1,IQGS1,ICLASS,DTOP,DBOT)
       if (ICLASS .eq. 12) goto 410
       if (LOOPS .eq. 1) then
          if (ICLASS .ne. 1) goto 410
       else if (LOOPS .eq. 2) then
          if (ICLASS .ne. 2 .and. ICLASS .ne. 3 .and.
     +        ICLASS .ne. 4) goto 410
       else if (LOOPS .eq. 3) then
          if (ICLASS .ne. 5 .and. ICLASS .ne. 6 .and.
     +        ICLASS .ne. 7) goto 410
       else if (LOOPS .eq. 4) then
          if (ICLASS .ne. 8) goto 410
       else if (LOOPS .eq. 5) then
          if (ICLASS .ne. 9 .and. ICLASS .ne. 10) goto 410
       end if
       goto 430
  410  IGSD = IGSD + 1
       goto 401
  430  continue

C      Present class is correct, compute SZRO

  440  SZRO = 0.0
       do 450 I = 1, 16
          PHI = (float(I) + 0.5) - 6.0
       if (nac .eq. 34) write (*,*) i,phi
```

```
            DIAM = (2.0 ** (- PHI)) / 10.0
         if (nac .eq. 34) write (*,*) diam
            S0 = 6.0 / DIAM
         if (nac .eq. 34) write (*,*) s0,gspd(i)
            if (GSPD(I) .gt. 0.0) then
               SZRO = SZRO + S0 * GSPD(I) / 100.0
            if (nac .eq. 34) write (*,*) szro
            end if
  450    continue

       if (nac .eq. 34) write (*,*) szro
         NSZRO = NSZRO + 1
         ARR3(NSZRO,1) = 0.0
         ARR3(NSZRO,2) = SZRO
       KOUNTZ = KOUNTZ + 1
       TEMPZ(KOUNTZ,1) = DTOP
       TEMPZ(KOUNTZ,2) = SZRO
       NACZ(KOUNTZ) = NA
         IGSD = IGSD + 1
         goto 401

C        Arrays are full of data, now compute cumulative
C        distribution functions and write files.

  500 CONTINUE

       CLOSE (90)

C        Void Ratio

       WRITE (*,*) 'NVOID = ',NVOID
         call CDF(ARR1,5000,NVOID,OUT1,N1)
         write (60,601) N1,(OUT1(J,1),OUT1(J,2),J=1,N1)
  601    format (1x,i3,100(f7.4,f7.3))

       CLOSE (60)

C        Grain Density

       WRITE (*,*) 'NSGGR = ',NSGGR
         call CDF(ARR2,5000,NSGGR,OUT2,N2)
         write (70,601) N2,(OUT2(J,1),OUT2(J,2),J=1,N2)

       CLOSE (70)

C        Mean Specific Surface

       WRITE (*,*) 'NSZRO = ', NSZRO
         call CDF(ARR3,9500,NSZRO,OUT3,N3)
         write (80,801) N3,(OUT3(J,1),OUT3(J,2),J=1,N3)
  801    format (1x,i3,100(f7.4,e11.4))

       CLOSE (80)

C        Close all files

         close (10)
         close (20)
         close (30)
         close (40)
```

```
          close (50)

          stop
          end

      C*************************************************************

          SUBROUTINE CDF(ARR,ISIZE,N,OUT,NOUT)

      C   Takes data in the array ARR, computes a cumulative
      C   distribution function (CDF) and returns the CDF in
      C   the array OUT.  ARR has N values (up to 9500), but
      C   OUT will contain NOUT values (no more than 100).

          dimension ARR(ISIZE,2), OUT(100,2)

      C   "Bubble" sort routine to rank order the measurements
      C   from I = 1 (being the largest) to I = N (being the smallest).

         if (N .eq. 1) then
            NOUT = 1
            OUT(1,1) = 0.0
            OUT(1,2) = ARR(1,2)
            GOTO 150
         end if

          if (ARR(2,2) .gt. ARR(1,2)) then
             A = ARR(2,2)
             ARR(2,2) = ARR(1,2)
             ARR(1,2) = A
          end if

         if (N .eq. 2) then
            NOUT = 2
            OUT(1,1) = 0.0
            OUT(2,1) = 1.0
            OUT(1,2) = ARR(2,2)
            OUT(2,2) = ARR(1,2)
            GOTO 150
         end if

      C  WRITE (*,*) ' ENTER 110 LOOP'
          do 110 I = 3, N
             if (ARR(I,2) .gt. ARR(I-1,2)) then
                A = ARR(I-1,2)
                ARR(I-1,2) = ARR(I,2)
                ARR(I,2) = A
                K = 1
   70           if (ARR(I-K,2) .gt. ARR(I-(K+1),2)) then
                   A = ARR(I-(K+1),2)
                   ARR(I-(K+1),2) = ARR(I-K,2)
                   ARR(I-K,2) = A
                   K = K + 1
                   if (I-K .eq. 1) goto 110
                   goto 70
                end if
             end if
  110     continue
      C  WRITE (*,*) ' EXIT 110 LOOP'
```

```
C      Now compute the probabilities for each observed value.
C      The array ARR(I,J=1,2) is now ordered from I=1 (Largest)
C      to I=N (Smallest).  Duplicate values presumably are
C      located adjacent to one another.

C    WRITE (*,*) ' ENTER 120 LOOP'
      ARR(1,1) = 1.0000
      do 120 I = 2, N
         ARR(I,1) = FLOAT(N - (I - 1)) / FLOAT(N)
 120  continue
C    WRITE (*,*) ' EXIT 120 LOOP'

C      Set to zero the probability value for all but the first
C      observation in a string of duplicates.

C    WRITE (*,*) ' ENTER 130 LOOP'
      KICK = 0
      do 130 I = 1, N - 1
         if (ARR(I,2) .eq. ARR(I+1,2)) then
            ARR(I+1,1) = 0.0
            KICK = KICK + 1
         end if
 130  continue
C    WRITE (*,*) ' EXIT 130 LOOP'

C      If more than 99 points still exist, then set the probabilities
C      of the values, which are cloest together, to zero.
C      (Don't drop the first or last points.)

C    WRITE (*,*) ' ENTER 132 to 139 LOOP'
 132 DMIN = ARR(1,2) - ARR(N,2)
C    WRITE (*,*) 'DMIN=',DMIN,'  ARR(1,2)=',ARR(1,2),
C   +          '  ARR(N,2)=',ARR(N,2)
C    WRITE (*,*) ' N=',N,'  KICK=',KICK
     if ((N - KICK) .le. 99) goto 139
     I = 1
 133 J = 1
 134 CONTINUE
C    WRITE  (*,*)' I=',I,'  J=',J
     if (I+J .ge. N) goto 136
C   WRITE (*,*) ' ARR(I+J,1)=',ARR(I+J,1)
     if (ARR(I+J,1) .ne. 0) goto 135
     J = J + 1
C    WRITE (*,*) 'J=',J
     goto 134
 135 DIF = ARR(I,2) - ARR(I+J,2)
C    WRITE (*,*) ' DIF=',DIF,'  ARR(I,2)=',ARR(I,2),
C                '  ARR(I+J,2)=',ARR(I+J,2)
C    WRITE (*,*) ' DIF=',DIF,'  DMIN=',DMIN
     if (DIF .lt. DMIN) then
        IMIN = I + J
        DMIN = DIF
     end if
     I = I + J
     goto 133

 136 ARR(IMIN,1) = 0.0
      KICK = KICK + 1
C    write (*,*) kick
      goto 132
```

```
  139   continue
C     WRITE (*,*) ' EXIT 132 to 139 LOOP'

C       Next condense the array to "plot" only those points with
C       non-zero frequency.  Condense from smallest value to
C       largest value.

C     WRITE (*,*) ' ENTER 140 LOOP'
        J = 1
        do 140 K = 1, N
           I = N + 1 - K
           if (ARR(I,1) .ne. 0.0) then
              J = J + 1
              OUT(J,1) = ARR(I,1)
              OUT(J,2) = ARR(I,2)
           end if
  140   continue
        NOUT = J
C     WRITE (*,*) ' EXIT 140 LOOP'

C       Fill OUT(1,2) with a value extrapolated from overall
C       distribution slope to "zero" probability.

        SLOPE = (OUT(NOUT,2) - OUT(2,2)) / (1.0 - OUT(2,1))
        OUT(1,2) = OUT(NOUT,2) - SLOPE
        OUT(1,1) = 0.0

  150 return
      end

C***************************************************************

        subroutinetypes(nac,igsd,igsc,iqgs,iclass,dtop,dbot)

        dimension gspd(16)

   10 format (' ',i6,' ',i6,' ',i6,' ',i6,' ',i2,' ',f7.2,' ',f7.2)

 1000      PCOURSE = 0.0
           PSAND   = 0.0
           PSILT   = 0.0
           PCLAY   = 0.0
           PFINE   = 0.0

           if (IGSD  .gt. 0) then

 1400         read (30, rec = IGSD, err = 1406) NA,
     +              DTOP1,DBOT1,GSPD(1),GSPD(2),GSPD(3),GSPD(4),
     +              GSPD(5),GSPD(6),GSPD(7),GSPD(8),GSPD(9),GSPD(10),
     +              GSPD(11),GSPD(12),GSPD(13),GSPD(14),GSPD(15),
     +              GSPD(16),DM

 1401         format (I6,2F7.2,16F7.3,F7.4)

              if (NA .ne. NAC) goto 1406

              if (DTOP .ne. DTOP1) then
               if (DBOT1 .le. DTOP .or. DTOP1 .ge. DBOT) then
                  IGSD = IGSD+1
```

```
                 GOTO 1400
              end if
             end if

             do 1402 K = 1, 4
                if (GSPD(K) .ge. 0) PCOURSE = PCOURSE + GSPD(K)
1402         continue

             do 1403 K = 5, 9
                if (GSPD(K) .ge. 0) PSAND = PSAND + GSPD(K)
1403         continue

             do 1404 K = 10, 13
                if (GSPD(K) .ge. 0) PSILT = PSILT + GSPD(K)
1404         continue

             do 1405 K = 14, 16
                if (GSPD(K) .ge. 0) PCLAY = PCLAY + GSPD(K)
1405         continue

             goto 1800

          end if

1406      if (IGSC .gt. 0) then

1500         read (40, rec = IGSC, err = 1502) NA,
    +          DTOP2,DBOT2,PCOURSE,PSAND,PSILT,PCLAY,PMUD,DD

1501         format (I6, 2F7.2, 5F7.3, F7.4)

             if (NA .ne. NAC) goto 1502

             if (DTOP .ne. DTO2) then
              if (DBOT2 .le. DTOP .or. DTOP2 .ge. DBOT) then
                 IGSC = IGSC + 1
                 goto 1500
              end if
             end if

             goto 1800

          end if

1502      if (IQGS .gt. 0) then

1600         read (50, rec = IQGS, err = 1700) NA,
    +              DTOP3, DBOT3, DMG, IQSC

1601         format (i6, f7.2, f7.2, f7.4, i2)

             if (NA .ne. NAC) goto 1700

          if (DTOP .ne. DTOP3) then
              if (DBOT3 .le. DTOP .or. DTOP3 .ge. DBOT) then
                 IQGS = IQGS + 1
                 goto 1600
              end if
          end if
```

```
             ICLASS = IQSC
             goto 1900

          end if

1700      ICLASS = 12
          goto 1900

1800      PFINE = PSAND + PSILT + PCLAY

          if (PCOURSE .gt. 50.0) then
             ICLASS = 11
             goto 1900
          end if

          if (PFINE .lt. 0.001) then
             ICLASS = 12
             goto 1900
          end if

          P1 = PSAND / PFINE

          if (P1 .ge. 0.75) then
             ICLASS = 1
             goto 1900
          end if

          if (P1 .lt. .75 .and. P1 .ge. .5) then
             ICLASS = 3
             P2 = PSILT / (PSILT + PCLAY)

             if (P2 .lt. 0.33) ICLASS = 4
             if (P2 .gt. 0.66) ICLASS = 2

             goto 1900
          end if

          if (P1 .lt. 0.5 .and. P1 .ge. 0.25) then
             ICLASS = 6
            P2 = PSILT / (PSILT + PCLAY)

             if (P2 .lt. 0.33) ICLASS = 7
             if (P2 .gt. 0.66) ICLASS = 5

             goto 1900
          end if

          if (P1 .lt. 0.25) then
             ICLASS = 9
             P2 = PSILT / (PSILT + PCLAY)

             if (P2 .lt. 0.33) ICLASS = 10
             if (P2 .gt. 0.66) ICLASS = 8
          end if

1900      continue
       return
       end
```

PROGRAM MCPHYS

```
      PROGRAM MCPHYS
C
C           A NEW VERSION OF PHYSED ALTERED FOR THE
C           ALLOWANCE OF MONTE CARLO TESTING OF THE VARIABILITY
C           OF THE BIOT-STOLL THEORY IN PHYSED.  STATISTICS
C           FOR THE TESTING ARE DERIVED FROM THE PHYPROSE
C           DATA BASE AND APPLY TO THE FOLLOWING VARIABLES:
C
C           RHOR ( GRAIN DENSITY )
C           VOID ( VOID RATIO )
C           S0 ( MEAN SPECIFIC SURFACE )
C           DECBS ( SHEAR LOG DECREMENT )
C           DECBE ( COMPRESSIONAL LOG DECREMENT )
C           PRATIO ( POISSON'S RATIO )
C
C
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/VDEPTH/EVERY(20)
      COMMON/VFREQ/FREQ(16)
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
      COMMON/BCOEF/CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CFAC1,CH,CC,CM
      COMMON/FVARS/OMEGA,EKAPPA,EM
      COMMON/COMKLV/CFAC,CFAC2,CFAC3,CFAC4,CF
      COMMON/FINALS/A1(20,16),V1(20,16),A2(20,16),V2(20,16),
     +              A3(20,16),V3(20,16)
C
      COMMON/IO/ IN,IOUT,IDEBUG
      CHARACTER*12  FNAME
      CHARACTER*4 NAMEP
      CHARACTER*1 YESNO
      REAL*8 RNUM
      COMPLEX CFAC,CFAC1,CFAC2,CFAC3,CFAC4,CF
      COMPLEX CBLKF,CDEN,CH,CC,CM
      COMPLEX CBLKR,CBLKB,CSHRB
C
      DOUBLE PRECISION TCQ1R,TCQ1C,TCQ2R,TCQ2C,TCQ3R,TCQ3C,TDSCRR
      DOUBLE PRECISION TDSCRC,TROOTR,TROOTC,TDEN,TNUMR,TNUMC,TLSQR
      DOUBLE PRECISION TLSQC,TLR,TLC,THOLD,DIV
C
      DIMENSION RARR(100,2),VARR(100,2),SARR(100,2)
      DIMENSION DSARR(100,2),DEARR(100,2),PARR(100,2)
C
C          A RANDOM NUMBER GENERATOR SEED FOR EACH
C          OF THE SIX VARIABLES TO BE SAMPLED
C
      X1 = .1
      X2 = .2
      X3 = .3
      X4 = .4
      X5 = .5
      X6 = .6
C
C           PLUG-INS FOR THE PRESENT
C
C
C     INDICATE PROVINCE TO BE RUN
```

```
C
  100   WRITE (*,6000)
 6000   FORMAT (///' ENTER THE FOUR CHARACTER NAME'/
     &             ' OF THE PROVINCE TO BE RUN.')
        READ (*,6001) NAMEP
 6001   FORMAT (A4)
        WRITE (*,6002) NAMEP
 6002   FORMAT (/' IS ',A4,' CORRECT ? (Y/N)')
        READ (*,6003) YESNO
 6003   FORMAT (A1)
        IF (YESNO .NE. 'Y' .AND. YESNO .NE. 'y') GOTO 100
C
C       READ DATA FROM FILES
C
        WRITE (FNAME,6004) NAMEP
 6004   FORMAT (A4,'VOID.DAT')
        OPEN (20, FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6020) NV,(VARR(J,1),VARR(J,2),J=1,NV)
 6020   FORMAT(1X,I3,100(F7.4,F7.3))
        CLOSE (20,STATUS='KEEP')

        WRITE (FNAME,6005) NAMEP
 6005   FORMAT (A4,'SGGR.DAT')
        OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6020) NR,(RARR(J,1),RARR(J,2),J=1,NR)
        CLOSE (20,STATUS='KEEP')

        WRITE (FNAME,6006) NAMEP
 6006   FORMAT (A4,'SZRO.DAT')
        OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6021) NS,(SARR(J,1),SARR(J,2),J=1,NS)
 6021   FORMAT (1X,I3,100(F7.4,E11.4))
        CLOSE (20,STATUS='KEEP')

        WRITE (FNAME,6007) NAMEP
 6007   FORMAT (A4,'POIS.DAT')
        OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6022) NP,(PARR(J,1),PARR(J,2),J=1,NP)
 6022   FORMAT (1X,I3,100(F7.4,F5.3))
        CLOSE (20,STATUS='KEEP')

        WRITE (FNAME,6008) NAMEP
 6008   FORMAT (A4,'DECS.DAT')
        OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6022) NDS,(DSARR(J,1),DSARR(J,2),J=1,NDS)
        CLOSE (20,STATUS='KEEP')

        WRITE (FNAME,6009) NAMEP
 6009   FORMAT (A4, 'DECE.DAT')
        OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     &        FORM='FORMATTED',STATUS='OLD')
        READ (20,6022) NDE,(DEARR(J,1),DEARR(J,2),J=1,NDE)
        CLOSE (20,STATUS='KEEP')
C
C       OPEN OUTPUT FILES
```

```
C
        WRITE (FNAME,6010) NAMEP
 6010   FORMAT (A4,'BIOT.DAT')
        OPEN (10,FILE=FNAME,ACCESS='SEQUENTIAL',
     &       FORM='UNFORMATTED',STATUS='NEW')
        WRITE (FNAME,6011) NAMEP
 6011   FORMAT (A4,'BIOT.MTX')
        OPEN (11,FILE=FNAME,ACCESS='SEQUENTIAL',
     &       FORM='FORMATTED',STATUS='NEW')
C
C       INPUT THE NUMBER OF TIMES TO STEP
C       THROUGH THE MONTE CARLO LOOP.
C
  150   WRITE (*,6030)
 6030   FORMAT (///' ENTER THE NUMBER OF MONTE CARLO STEPS.')
        CALL ISREAL (10,RNUM,IER)
        IF (IER .NE. 0) GOTO 150
        MCLOOP = RNUM
C
C ------------------ MAIN PROGRAM --------------------------------
C
C            REQUESTING THE MODEL CONSTANTS
C
      CALL MODCONSTS (ISED)
C
C           REQUESTING TESTING DEPTHS (UP TO 20 ALLOWED)
C
      CALL QDEPTH (.FALSE.)
      DO 1 I = 2,20
         IF (EVERY(I).LE.0.0) GOTO 2
    1 CONTINUE
      I = I + 1
    2 NDEPTH = I - 1
C
C           REQUESTING TESTING FREQUENCIES (UP TO 16 ALLOWED)
C
      CALL QFREQ (.FALSE.)
      DO 3 I = 2,16
         IF (FREQ(I).LE.0.0) GOTO 4
    3 CONTINUE
      I = I + 1
    4 NFREQ = I - 1
C
C           BEGINNING OF THE MONTE CARLO LOOPING
C
      MIDDEP = NDEPTH / 2 + 1
      MIDFRE = NFREQ / 2 + 1
      INT = FLOAT(MCLOOP + 79) / FLOAT(80)
      MCEND = MCLOOP / INT

      DO 99 M = 1,MCLOOP
C
C
C           INITIALIZATION
C
      CFAC = CMPLX(0.0,1.0)
      EPRESS = 0.0
C
C         RANDOM SAMPLING OF VALUES FOR RHOR,
C         VOID, SO, DECBS, DECBE, AND PRATIO
```

```
C
C      WRITE (*,7001)
C 7001 FORMAT (' CALLS RNDSMP (FIRST)')
      CALL RNDSMP (RARR,NR,X1,RHOR)
C      WRITE (*,7000)
C 7000 FORMAT (' RETURN')
C      WRITE (*,7002)
C 7002 FORMAT (' CALLS RNDSMP (SECOND)')
      CALL RNDSMP (VARR,NV,X2,VOID)
C      WRITE (*,7000)
C      WRITE (*,7003)
C 7003 FORMAT (' CALLS RNDSMP (THIRD)')
      CALL RNDSMP (SARR,NS,X3,S0)
C      WRITE (*,7000)
C      WRITE (*,7004)
C 7004 FORMAT (' CALLS RNDSMP (FOURTH)')
      CALL RNDSMP (DSARR,NDS,X4,DECBS)
C      WRITE (*,7000)
C      WRITE (*,7005)
C 7005 FORMAT (' CALLS RNDSMP (FIFTH)')
      CALL RNDSMP (DEARR,NDE,X5,DECBE)
C      WRITE (*,7000)
C      WRITE (*,7006)
C 7006 FORMAT (' CALLS RNDSMP (SIXTH)')
      CALL RNDSMP (PARR,NP,X6,PRATIO)
C      WRITE (*,7000)

C
      BETA = POROS (VOID)
      PERM = PMBTY (BETA,HOVEMK,S0)
      PSIZE = PORSIZ (BETA,S0)
C
      DO 10 I = 1,NDEPTH
C      WRITE (*,7017) I,NDEPTH
C 7017 FORMAT (' I = ',I2,' NDEPTH = ',J2)
C
C         WRITE (*,7007)
C 7007    FORMAT (' CALLS OVERPRES')
         CALL OVERPRES (I)
C         WRITE (*,7000)
C         WRITE (*,7008)
C 7008    FORMAT (' CALLS FSHEAR')
         CALL FSHEAR
C         WRITE (*,7000)
C         WRITE (*,7009)
C 7009    FORMAT (' CALLS FSHRIAM')
         CALL FSHRIAM
C         WRITE (*,7000)
C         WRITE (*,7010)
C 7010    FORMAT (' CALLS FBULK')
         CALL FBULK
C         WRITE (*,7000)
C         WRITE (*,7011)
C 7011    FORMAT (' CALLS FBLKIAM')
         CALL FBLKIAM
C         WRITE (*,7000)
C         WRITE (*,7012)
C 7012    FORMAT (' CALLS BIOTCOF')
         CALL BIOTCOF
C         WRITE (*,7000)
```

```
C
         DO 20 J = 1,NFREQ
C         WRITE (*,7018) J,NFREQ
C 7018    FORMAT (' J = ',I2,' NFREQ = ',I2)
C
C            WRITE (*,7013)
C 7013       FORMAT (' CALLS FRQVARS')
            CALL FRQVARS (J)
C            WRITE (*,7000)
C            WRITE (*,7014)
C 7014       FORMAT (' CALLS SKLVN')
            CALL SKLVN
C            WRITE (*,7000)
C            WRITE (*,7015)
C 7015       FORMAT (' CALLS BDISREL')
            CALL BDISREL (I,J)
C            WRITE (*,7000)
C
   20    CONTINUE
   10 CONTINUE

      CALL GRFDAT(11,INT,MCEND,M,MIDDEP,MIDFRE)

      CALL WRIT (10,M,NDEPTH,NFREQ)

   99 CONTINUE
C
      CLOSE (10)
      CLOSE (11)
C
      STOP
      END
C
C ----------- END OF MAIN PROGRAM ------------------------------
C
C         SUBROUTINES USED BY THE PROGRAM
C
C
      SUBROUTINE MODCONSTS (ISED)
C
C
C          THIS SUBROUTINE PROCEEDS TO FILL THE VARIOUS CONSTANTS
C          USED IN THIS VERSION OF BIOT-STOLL.
C
C
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      CHARACTER*1 ANS
C
C
      BLKRR=4.2E11
      RHOF=1.025
      BLKFR=0.2384E11
      ETA=0.018
      ALPHA=1.25
      HOVEMK=5.0
      GC2=2.97
      GC3=0.5
      ISED = 10
C
```

```
   98 WRITE (*,100) BLKRR
  100 FORMAT(' Grain Bulk Modulus = ',E10.3,' DYNES/CM^2')
      WRITE (*,101) RHOF
  101 FORMAT(' Fluid Density = ',F5.3,' GRAMS/CM^3')
      WRITE (*,102) BLKFR
  102 FORMAT(' Fluid Bulk Modulus = ',E10.4,' DYNES/CM^2')
      WRITE (*,103) ETA
  103 FORMAT(' Pore Fluid Viscosity = ',E10.3,' POISE')
      WRITE (*,104) ALPHA
  104 FORMAT(' Structure Factor = ',F5.2)
      WRITE (*,105) HOVEMK
  105 FORMAT(' Kozeny-Carmen Constant = ',F5.1)
      IF (ISED .EQ. 10) THEN
         WRITE (*,108)
  108    FORMAT (' Stoll Stress Formula is for Silts/Clays.')
      ELSE IF (ISED .EQ. 1) THEN
         WRITE (*,109)
  109    FORMAT (' Stoll Stress Formula is for Sand.')
      END IF
   99 WRITE (*,106)
  106 FORMAT(' Do you wish to change any or all of these ? (Y/N):'/)
      READ (*,107) ANS
  107 FORMAT (A1)
      IF (ANS.EQ.'Y') GOTO 1000
      IF (ANS.EQ.'N') GOTO 3000
      GOTO 99
C
 1000 WRITE (*,2001)
      WRITE (*,1001)
      WRITE (*,1002) BLKRR
 1001 FORMAT(' Give a Grain Bulk Modulus, Real Part',
     +        ' or ''RETURN'' to continue.')
 1002 FORMAT(' (DEFAULT = ',E10.3,' DYNES/CM^2): '/)
      READ (*,2001,ERR=1000) TEST1
 2001 FORMAT(E10.3)
      IF (TEST1.NE.0.0) BLKRR=TEST1
C
      WRITE (*,2002)
 1003 WRITE (*,1004)
      WRITE (*,1005) RHOF
 1004 FORMAT(' Give a Pore Fluid Density',
     +        ' or ''RETURN'' to continue.')
 1005 FORMAT(' (DEFAULT = 'F5.3,' GRAMS/CM^3): '/)
      READ (*,2002,ERR=1003) TEST2
 2002 FORMAT(F5.3)
      IF (TEST2.NE.0.0) RHOF=TEST2
C
      WRITE (*,2003)
 1006 WRITE (*,1007)
      WRITE (*,1008) BLKFR
 1007 FORMAT(' Give a Fluid Bulk Modulus',
     +        ' or ''RETURN'' to continue.')
 1008 FORMAT(' (DEFAULT = ',E10.4,' DYNES/CM^2): '/)
      READ (*,2003,ERR=1006) TEST3
 2003 FORMAT(E10.4)
      IF (TEST3.NE.0.0) BLKFR=TEST3
C
      WRITE (*,2004)
 1009 WRITE (*,1010)
      WRITE (*,1011) ETA
```

```
 1010 FORMAT(' Give a Pore Fluid Viscosity',
     +        ' or ''RETURN'' to continue.')
 1011 FORMAT(' (DEFAULT = ',E10.3,' POISE): '/)
      READ (*,2004,ERR=1009) TEST4
 2004 FORMAT(E10.3)
      IF (TEST4.NE.0.0) ETA=TEST4
C
      WRITE (*,2005)
 1012 WRITE (*,1013)
      WRITE (*,1014) ALPHA
 1013 FORMAT(' Give a Structure Factor',
     +        ' or ''RETURN'' to continue.')
 1014 FORMAT(' (DEFAULT = ',F5.2,' ): '/)
      READ (*,2005,ERR=1012) TEST5
 2005 FORMAT(F5.2)
      IF (TEST5.NE.0.0) ALPHA=TEST5
C
      WRITE (*,2006)
 1015 WRITE (*,1016)
      WRITE (*,1017) HOVEMK
 1016 FORMAT(' Give a Kozeny-Carmen Constant',
     +        ' or ''RETURN'' to continue.')
 1017 FORMAT(' (DEFAULT = ',F5.1,' ): '/)
      READ (*,2006,ERR=1015) TEST6
 2006 FORMAT(F5.1)
      IF (TEST6.NE.0.0) HOVEMK=TEST6
      WRITE (*,111)
  111 FORMAT (' Indicate Stoll Stress Formula.'/
     &        ' Default is Silts/Clays.'/
     &        ' Do you want to change it to Sand Formula ? (Y/N):')
      READ (*,107) ANS
      IF (ANS .EQ. 'Y' .OR. ANS .EQ. 'y') ISED = 1
C
      GOTO 98
C
 3000 IF (ISED.GE.1.AND.ISED.LE.4) THEN
          GC1=1230.0
          VDH=0.5
      END IF
C
      IF (ISED.GE.5.AND.ISED.LE.10) THEN
          GC1=1630.0
          VDH=1.0
      END IF
C
C
      WRITE (*,2006)
      WRITE (*,2006)
      WRITE (*,2006)
C
      RETURN
      END
C
C
C
      SUBROUTINE QDEPTH(LOOK)
C
C *** UPDATES 'EVERY' FOR DEPTHS
C
      LOGICAL LOOK
```

```
      INTEGER CASE,MAX
      CHARACTER D*5,M*6
C
      COMMON /VDEPTH/EVERY(20)
C
      D='DEPTH'
      M='METERS'
C
      EVERY(1)=0.0
      EVERY(2)=0.5
      EVERY(3)=1.0
      EVERY(4)=2.0
      EVERY(5)=5.0
      EVERY(6)=10.0
      EVERY(7)=20.0
      DO 1 I=8,20
         EVERY(I)=0.0
   1  CONTINUE
C
    5 IF (.NOT.LOOK) THEN
         CASE=MENU1(D,5)
      ELSE
         CASE=1
      END IF
      MAX=20
      IF (CASE.EQ.1) THEN
           CALL RLIST(D,5,M,6,MAX,EVERY)
      ELSE IF (CASE.EQ.2) THEN
           CALL RADD(D,5,M,6,MAX,EVERY)
      ELSE IF (CASE.EQ.3) THEN
           CALL RCHNGE(D,5,M,6,MAX,EVERY)
      ELSE IF (CASE.EQ.4) THEN
           CALL RINSRT(D,5,M,6,MAX,EVERY)
      ELSE IF (CASE.EQ.5) THEN
           CALL RDELET(D,5,M,6,MAX,EVERY)
      END IF
      IF ((CASE.GT.1 .AND. CASE.LT.6) .OR.
     +    (CASE.EQ.1 .AND. .NOT.LOOK)) GO TO 5
      RETURN
      END
C
C =======================================================
C
      SUBROUTINE QFREQ (LOOK)
C
C *** UPDATES 'FREQ' FOR FREQUENCIES
C
      LOGICAL LOOK
      INTEGER CASE,MAX
      CHARACTER F*9,H*5
C
      COMMON /VFREQ/FREQ(16)
C
      F='FREQUENCY'
      H='HERTZ'
C
      FREQ(1)=100.0
      FREQ(2)=200.0
      FREQ(3)=400.0
      FREQ(4)=800.0
```

```
      FREQ(5)=1600.0
      DO 1 I=6,16
         FREQ(I)=0
   1  CONTINUE
C
    5 IF (.NOT.LOOK) THEN
         CASE=MENU1(F,9)
      ELSE
         CASE=1
      END IF
      MAX=16
      IF (CASE.EQ.1) THEN
           CALL RLIST(F,9,H,5,MAX,FREQ)
      ELSE IF (CASE.EQ.2) THEN
           CALL RADD(F,9,H,5,MAX,FREQ)
      ELSE IF (CASE.EQ.3) THEN
           CALL RCHNGE(F,9,H,5,MAX,FREQ)
      ELSE IF (CASE.EQ.4) THEN
           CALL RINSRT(F,9,H,5,MAX,FREQ)
      ELSE IF (CASE.EQ.5) THEN
           CALL RDELET(F,9,H,5,MAX,FREQ)
      END IF
      IF ((CASE.GT.1 .AND. CASE.LT.6) .OR.
     +    (CASE.EQ.1 .AND. .NOT.LOOK)) GO TO 5
      RETURN
      END
C
C ========================================================
C
      FUNCTION QUERY(TOTAL)
C
C *** QUERY PROMPTS FOR TOTAL SELECTION
C
      INTEGER TOTAL
C
   5  WRITE (*,10) TOTAL
      WRITE (*,20)
  10  FORMAT (' ENTER A NUMBER (1 -',I2,') CORRESPONDING TO THE')
 0  FORMAT (' OPTION DESIRED.  (ENTER 0 FOR MENU): '/)
      READ (*,30,ERR=5) NUMBER
  30  FORMAT(I2)
      IF (NUMBER.LT.0.OR.NUMBER.GT.TOTAL) GOTO 5
      QUERY=NUMBER
      RETURN
      END
C
C ========================================================
C
      FUNCTION MENU1(OPTION,LENGTH)
C
C *** MENU1 PRINTS THE DEPTHS AND FREQUENCY MENUS
C
      CHARACTER OPTION*9
C
      IF (LENGTH.EQ.5) THEN
          WRITE(*,3) OPTION
    3     FORMAT ('0',A5)
      ELSE
          WRITE(*,4) OPTION
    4     FORMAT('0',A9)
```

```
      END IF
    5 CHOICE=QUERY(6)
      IF (CHOICE.EQ.0) THEN
           WRITE(*,10)
   10      FORMAT ('0OPTIONS:        '/
     +             '     1 -- LIST'/
     +             '     2 -- ADD'/
     +             '     3 -- CHANGE'/
     +             '     4 -- INSERT'/
     +             '     5 -- DELETE'/
     +             '     6 -- EXIT    ')
           GO TO 5
      ELSE
           MENU1=CHOICE
      END IF
      RETURN
      END
C
C ========================================================
C
      SUBROUTINE RLIST(PARAM,LP,UNITS,LU,MAX,ARRAY)
C
C *** LISTS REAL 'ARRAY'.
C
      CHARACTER PARAM*9,UNITS*6
      DIMENSION ARRAY(MAX)
      COMMON /VDEPTH/EVERY(20)
      COMMON /VFREQ /FREQ(16)
C
      DO 5 I=1,MAX
          IF (MAX.EQ.20) THEN
              ARRAY(I)=EVERY(I)
          ELSE
              ARRAY(I)=FREQ(I)
          END IF
    5 CONTINUE
      IF (MAX.EQ.20) THEN
           WRITE(*,30) 1,ARRA(1)
      ELSE
           WRITE(*,35) 1,ARRAY(1)
      END IF
   30 FORMAT (' ',I2,': ',F6.2)
   35 FORMAT (' ',I2,': ',G10.5)
      DO 40 I=2,MAX
           IF (ARRAY(I).NE.0.) THEN
               IF (MAX.EQ.20) THEN
                    WRITE(*,30) I,ARRAY(I)
               ELSE
                    WRITE(*,35) I,ARRAY(I)
               END IF
           ELSE
               GO TO 41
           END IF
   40 CONTINUE
   41 CONTINUE
      RETURN
      END
C
C =======================================================
C
```

```
      SUBROUTINE RADD(PARAM,LP,UNITS,LU,MAX,ARRAY)
C
C *** ADD APPENDS DATA AFTER THE LAST VALID ELEMENT OF 'ARRAY'
C
      COMMON /VDEPTH/EVERY(20)
      COMMON /VFREQ /FREQ(16)
      CHARACTER PARAM*9,UNITS*6
      DIMENSION ARRAY(MAX)
C
      IF (ARRAY(1).EQ.0. .AND. ARRAY(2).EQ.0.) THEN
           NDX=1
      ELSE
           DO 10 I=2,MAX
                IF (ARRAY(I).EQ.0.) THEN
                     NDX=I-1
                     GO TO 11
                END IF
   10      CONTINUE
   11      CONTINUE
      END IF
   12 IF (MAX.EQ.20) THEN
          WRITE(*,20) ARRAY(NDX)
      ELSE
          WRITE(*,25) ARRAY(NDX)
      END IF
   15 WRITE (*,30)
   20 FORMAT ('0LAST IS: ',F6.2)
   25 FORMAT ('0LAST IS: ',G8.3)
   30 FORMAT ('$ENTER ADDITION(S); (0 TO EXIT) ')
   40 WRITE(*,42)
   42 FORMAT (' : '/)
      IF (MAX.EQ.20) THEN
           READ(*,45,ERR=12) VALUE
      ELSE
           READ(*,47,ERR=12) VALUE
      ENDIF
   45 FORMAT (F6.2)
   47 FORMAT (G8.0)
      IF (VALUE.LT.0.) THEN
           WRITE(*,50)
   50      FORMAT (' ENTER A POSITIVE NUMBER: '/)
           GO TO 40
      ELSE IF (VALUE.NE.0.) THEN
           NDX=NDX+1
           ARRAY(NDX)=VALUE
           GO TO 40
      END IF
      DO 60 I=1,MAX
          IF (MAX.EQ.20) THEN
              EVERY(I)=ARRAY(I)
          ELSE
              FREQ(I)=ARRAY(I)
          END IF
   60 CONTINUE
      RETURN
      END
C
C =========================================================
C
      SUBROUTINE RCHNGE(PARAM,LP,UNITS,LU,MAX,ARRAY)
```

```
C
C *** CHANGES VALUE IN SPECIFIED INDEX OF REAL 'ARRAY'
C
      CHARACTER PARAM*9,UNITS*6,ANS1*1,ANS2*1
      DIMENSION ARRAY(MAX)
      COMMON /VDEPTH/EVERY(20)
      COMMON /VFREQ /FREQ(16)
C
      WRITE(*,5)
    5 FORMAT('0')
   10 WRITE(*,20)
   20 FORMAT (' INDEX OF ONE TO CHANGE; (0 TO EXIT): '/)
      READ(*,35,ERR=10) NDX
   35 FORMAT (I2)
      IF (NDX.EQ.0) GO TO 1000
      IF (NDX.GT.MAX .OR. NDX.LT.0) THEN
           WRITE(*,40) MAX
   40      FORMAT (' INDEX MUST BE A NUMBER, 1-',I2,': '/)
           GO TO 10
      END IF
      IF (MAX.EQ.20) THEN
           WRITE(*,50) PARAM,NDX,ARRAY(NDX),UNITS
      ELSE
           WRITE(*,52) PARAM,NDX,ARRAY(NDX),UNITS
      END IF
   50 FORMAT (' ',A6,' # ',I2,' IS ',F6.2,' ',A6,'.')
   52 FORMAT (' ',A9,' # ',I2,' IS ',G8.3,' ',A6,'.')
   55 WRITE(*,60)
   60 FORMAT (' DO YOU WANT TO CHANGE IT? (Y/N): '/)
      READ(*,998) ANS1
      IF (ANS1.EQ.'Y') THEN
   70     WRITE(*,80)
   80      FORMAT (' ENTER NEW VALUE: '/)
           IF (MAX.EQ.20) THEN
                READ(*,90,ERR=70) VALUE
           ELSE
                READ(*,95,ERR=70) VALUE
           END IF
   90      FORMAT (F6.2)
   95      FORMAT (G8.0)
           IF (VALUE.LT.0.) THEN
                WRITE(*,100)
  100           FORMAT ('$ENTER A NON-NEGATIVE NUMBER: '/)
                GO TO 70
           END IF
           ARRAY(NDX)=VALUE
      ELSE IF (ANS1.NE.'N') THEN
           GO TO 55
      END IF
  110 WRITE(*,120)
  120 FORMAT (' CHANGE ANOTHER ? (Y/N): '/)
      READ(*,998) ANS2
      IF (ANS2.EQ.'Y') THEN
           GO TO 10
      ELSE IF (ANS2.NE.'N') THEN
           GO TO 110
      END IF
      DO 130 I=1,MAX
          IF (MAX.EQ.20) THEN
              EVERY(I)=ARRAY(I)
```

```
          ELSE
              FREQ(I)=ARRAY(I)
          END IF
  130 CONTINUE
  998 FORMAT (1A1)
 1000 CONTINUE
      RETURN
      END
C
C ========================================================
C
      SUBROUTINE RINSRT(PARAM,LP,UNITS,LU,MAX,ARRAY)
C
C *** INSERTS VALUES BEFORE THE SPECIFIED INDEX IN REAL 'ARRAY'
C
      CHARACTER PARAM*9,UNITS*6,ANS1*1
      DIMENSION ARRAY(MAX)
      LOGICAL L
      COMMON /VDEPTH/EVERY(20)
      COMMON /VFREQ /FREQ(16)
C
      WRITE(*,5)
    5 FORMAT ('0')
   10 WRITE(*,20)
   20 FORMAT (' INDEX OF VALUE TO INSERT BEFORE; (0 TO EXIT): '/)
      READ(*,25,ERR=10) NDX
   25 FORMAT (I2)
      L=(NDX.EQ.0 .OR. (NDX.EQ.1 .AND. ARRAY(1).EQ.0.0))
      IF (L) GO TO 1000
      IF (NDX.GE.MAX .OR. NDX.LT.0) THEN
          WRITE(*,30) MAX-1
   30     FORMAT (' INDEX MUST BE A NUMBER, 1-',I2,': '/)
          GO TO 10
      END IF
   40 IF (MAX.EQ.20) THEN
          WRITE (*,50) NDX,ARRAYNDX),UNITS
      ELSE
          WRITE (*,55) NDX,ARRAY(NDX),UNITS
      END IF
   50 FORMAT (' DO YOU WANT TO ENTER VALUES BEFORE #',I2,
     +               ', ',F6.2,' ',A6,'? (Y/N): '/)
   55 FORMAT (' DO YOU WANT TO ENTER VALUES BEFORE #',I2,
     +               ', ',G8.3,' ',A6,'? (Y/N): '/)
      READ(*,998) ANS1
      IF (ANS1.EQ.'Y') THEN
   60     WRITE(*,70)
   70     FORMAT(' ENTER VALUE(S) TO INSERT, (0 TO EXIT) ')
   80     WRITE(*,84)
   84     FORMAT (' : '/)
          IF (NDX.GE.MAX) THEN
              WRITE(*,90) MAX
   90         FORMAT (' ONLY ',I2,' VALUES ALLOWED.')
          ELSE
              IF (MAX.EQ.20) THEN
                  READ(*,95,ERR=60) VALUE
              ELSE
                  READ(*,97,ERR=60) VALUE
              END IF
   95         FORMAT (F6.2)
   97         FORMAT (G8.0)
```

```
                IF (NDX.GT.1 .AND. VALUE.EQ.0.0) GO TO 1000
C              *
C              * FIND INDEX OF LAST ARRAY VALUE
C              *
                DO 100 I=2,MAX
                    IF (ARRAY(I).EQ.0.) THEN
                         LAST=I
                         GO TO 101
                    END IF
  100           CONTINUE
  101           CONTINUE
C              *
C              * SHIFT RIGHT & INSERT VALUE
C              *
                DO 110 I=LAST,NDX,-1
                    ARRAY(I+1)=ARRAY(I)
  110           CONTINUE
                ARRAY(NDX)=VALUE
                NDX=NDX+1
                GO TO 80
           END IF
      ELSE IF (ANS1.NE.'N') THEN
           GO TO 40
      END IF
      DO 120 I=1,MAX
          IF (MAX.EQ.20) THEN
              EVERY(I)=ARRAY(I)
          ELSE
              FREQ(I)=ARRAY(I)
          END IF
  120 CONTINUE
  998 FORMAT (1A1)
 1000 CONTINUE
      RETURN
      END
C
C =======================================================
C
      SUBROUTINE RDELET(PARAM,LP,UNITS,LU,MAX,ARRAY)
C
C *** DELETES RANGE OF VALUES BETWEEN SPECIFIED INDECES
C
      CHARACTER PARAM*9,UNITS*6,ANS1*1,ANS2*1
      DIMENSION ARRAY(MAX)
      COMMON /VDEPTH/EVERY(20)
      COMMON /VFREQ /FREQ(16)
C
      WRITE(*,5)
    5 FORMAT ('0')
   10 WRITE(*,20)
   20 FORMAT (' FIRST INDEX OF RANGE TO DELETE; (0 TO EXIT): '/)
      READ(*,25,ERR=10) NDX1
   25 FORMAT (I2)
      IF (NDX1.EQ.0) GO TO 1000
      IF (NDX1.GT.MAX) GO TO 10
   30 WRITE(*,40)
   40 FORMAT ('$LAST INDEX OF RANGE TO DELETE, (0 TO EXIT): '/)
      READ(*,25,ERR=30) NDX2
      IF (NDX2.EQ.0) GO TO 1000
      IF (NDX2.LT.NDX1 .OR. NDX2.GT.MAX) GO TO 30
```

```
      DO 50 I=NDX1,NDX2
          IF (MAX.EQ.20) THEN
               WRITE(*,60) I,ARRAY(I)
          ELSE
               WRITE(*,62) I,ARRAY(I)
          END IF
   50 CONTINUE
   60 FORMAT (' ',I2,': ',F6.2)
   62 FORMAT (' ',I2,': ',G8.3)
   65 WRITE(*,70)
   70 FORMAT (' DELETE? (Y/N): '/)
      READ(*,998) ANS1
      N=MAX-NDX2
      IF (ANS1.EQ.'Y') THEN
           IF (NDX1.LT.MAX) THEN
                DO 80 I=1,N
                    ARRAY(-1+NDX1+I)=ARRAY(NDX2+I)
   80           CONTINUE
                IF (NDX1.EQ.NDX2) N=N-1
                DO 85 I=NDX1+N,MAX
                    ARRAY(I)=0.0
   85           CONTINUE
           END IF
           ARRAY(MAX)=0.0
      ELSE IF (ANS1.NE.'N') THEN
            GO TO 65
      END IF
      DO 87 I=1,MAX
          IF (MAX.EQ.20) THEN
              EVERY(I)=ARRAY(I)
          ELSE
              FREQ(I)=ARRAY(I)
          END IF
  87  CONTINUE
   90 WRITE(*,100)
  100 ORMAT (' DELETE ANOTHER VALUE ? (Y/N): '/)
      READ(*,998) ANS2
      IF (ANS2.EQ.'Y') THEN
           GO TO 10
      ELSE IF (ANS2.NE.'N') THEN
           GO TO 90
      END IF
  998 FORMAT (1A1)
 1000 CONTINUE
      RETURN
      END
C
C
C
      FUNCTION POROS (VOID)
C
C        FUNCTION TO CALCULATE POROSITY
C
      POROS = VOID/(1+VOID)
C
      RETURN
      END
C
C
C
```

```
      FUNCTION PMBTY (BETA,HOVEMK,S0)
C
C        FUNCTION TO CALCULATE PERMEABILITY
C        USING KOZENY-CARMEN
C
      PMBTY = BETA**3/(HOVEMK*S0**2*(1-BETA)**2)
C
      RETURN
      END
C
C
C
      FUNCTION PORSIZ (BETA,S0)
C
C        FUNCTION TO CALCULATE PORE SIZE
C        USING HOVEM AND INGRAM FOR PORE
C        SIZE BEING EQUAL TO TWICE THE
C        HYDRAULIC RADIUS WHICH IN TURN
C        DEPENDS UPON MEAN SPECIFIC SURFACE (S0)
C
      PORSIZ = 2*BETA/((1-BETA)*S0)
C
      RETURN
      END
C
C
C
      SUBROUTINE OVERPRES (ICOUNT)
C
C        SUBROUTINE TO CALCULATE OVER BURDEN PRESSURE
C
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/VDEPTH/EVERY(20)
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/DEPLOOP/EPRESS,G,C[illegible]I,E,EPRI
C
C        G = GRAVITATIONAL CONSTANT (CM/SEC)
C
      G = 980.665
C     IF (ICOUNT.EQ.1) THEN
         DDEPTH = EVERY(1)
      ELSE
         DDEPTH = EVERY(ICOUNT) - EVERY(ICOUNT-1)
      END IF
      DPRESS = DDEPTH*(RHOR - RHOF)*(1 - BETA)*G*100
      EPRESS = EPRESS + DPRESS
C
      RETURN
      END
C
C
C
      SUBROUTINE FSHEAR
C
C        SUBROUTINE TO CALCULATE FRAME SHEAR MODULUS
C        USING THE STOLL STRESS PROCEDURE WHICH INCLUDES
C        A DEPTH DEPENDANCE
C
```

```
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
C
C
      SGMVRT = EPRESS*(1.45E-05)
      SGMBAR = ((1.0 + (2.0*VDH))*SGMVRT)/3.0
      TLC = GC2 - VOID
      G = (GC1*(TLC*TLC)*(SGMBAR**GC3))/(1.0 + VOID)
      G = G/(1.45E-05)
C
C
      RETURN
      END
C
C
C
      SUBROUTINE FSHRIAM
C
C        SUBROUTINE TO CALCULATE THE IMAGINARY PART OF
C        THE FRAME SHEAR MODULUS
C
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
C
C
      PI = 3.1415926535898
      GPRI = (G/PI)*DECBS
C
C
      RETURN
      END
C
C
C
      SUBROUTINE FBULK
C
C        SUBROUTINE TO CALCULATE THE FRAME BULK MODULUS
C        AS IT IS DERIVED FROM THE FRAME SHEAR MODULUS
C
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/DEPLOOP/EPRES,G,GPRI,E,EPRI
C
      E = ((2.0*G)*(1.0 + PRATIO))/(3.0*(1.0 - (2.0*PRATIO)))
C
      RETURN
      END
C
C
C
      SUBROUTINE FBLKIAM
C
C        SUBROUTINE TO CALCULATE THE IMAGINARY PART OF
C        THE FRAME BULK MODULUS
C
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
C
      PI = 3.1415926535898
```

```
      EPRI = (E/PI)*DECBE
C
      RETURN
      END
C
C
C
      SUBROUTINE BIOTCOF
C
C         SUBROUTINE TO CALCULATE THE BIOT COEFFICIENTS
C
      COMPLEX CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CFAC1,CH,CC,CM
C
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
      COMMON/BCOEF/CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CFAC1,CH,CC,CM
C
      CBLKR = CMPLX(BLKRR,0.0)
      CBLKF = CMPLX(BLKFR,0.0)
      CBLKB = CMPLX(E,EPRI)
      CSHRB = CMPLX(G,GPRI)
C
      CDEN = (CBLKR*(1.0 + (BETA*((CBLKR/CBLKF) - 1.0)))) - CBLKB
      CFAC1 = CBLKR - CBLKB
      CH = ((CFAC1*CFAC1)/CDEN) + CBLKB + ((4.0/3.0)*CSHRB)
      CC = (CBLKR*CFAC1)/CDEN
      CM = (CBLKR*CBLKR)/CDEN
C
C
      RETURN
      END
C
C
C
      SUBROUTINE FRQVARS (ICOUNT)
C
C         SUBROUTINE TO CALCULATE OMEGA, EKAPPA, AND EM
C
      COMMON/CONSTS/BLKRR,RHO,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/VFREQ/FREQ(16)
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/FVARS/OMEGA,EKAPPA,EM
C
      PI = 3.1415926535898
C
      OMEGA = (2.0*PI)*FREQ(ICOUNT)
      EKAPPA = PSIZE*SQRT((OMEGA*RHOF)/ETA)
      EM = (ALPHA*RHOF)/BETA
C
      RETURN
      END
C
C
C
      SUBROUTINE SKLVN
CC    COMPUTES CORRECTION FACTOR FOR DYNAMIC VISCOSITY
CC    SEE ABRAMOWITZ AND STEGUN, HANDBOOK OF MATHEMATICAL FUNCTIONS, P.
```

```
      COMMON/BCOEF/CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CFAC1,CH,CC,CM
      COMMON/FVARS/OMEGA,EKAPPA,EM
      COMMON/COMKLV/CFAC,CFAC2,CFAC3,CFAC4,CF
      COMPLEX CFAC1,CFAC2,CFAC3,CFAC4,CFAC,CF,CPHIM,CPHIP,CTHTM,CTHTP
      COMPLEX CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CH,CC,CM,CTEMPA,CTEMPB
C
      PI = 3.1415926535898
C
      IF(EKAPPA.GE.119) GO TO 2003
 2000 IF(EKAPPA.GE.8.0) GO TO 2005
      X=EKAPPA/8.0
      XSQ=X*X
      XFO=XSQ*XSQ
      CFAC1=1.0 + XFO*(-64.0 + XFO*(113.77777774 + XFO*(-32.36345652 +
     1    XFO*(2.64191397 + XFO*(-8.349609E-02 + XFO*(1.22552E-03 +
     2    XFO*(-9.01E-06)))))))
      CFAC2=XSQ*(16.0 + XFO*(-113.77777774 + XFO*(72.81777742 +
     1    XFO*(-10.56765779 + XFO*(0.52185615 + XFO*(-1.103667E-02 +
     2    XFO*(1.1346E-04)))))))
      CFAC3=(EKAPPA*XSQ)*(-4.00 + XFO*(14.22222222 + XFO*(-6.06814810 +
     1    XFO*(0.66047849 + XFO*(-2.609253E-02 + XFO*(4.5957E-04 +
     2    XFO*(-3.94E-06)))))))
     CFAC4=EKAPPA*(0.5 + XFO*(-10.66666666 + XFO*(11.37777772 +
     1    XFO*(-2.31167514 + XFO*(0.14677204 + XFO*(-3.79386E-03 +
     2    XFO*(4.609E-05)))))))
      CF=(CFAC3 + (CFAC*CFAC4))/(CFAC1 + (CFAC*CFAC2))
      GO TO 2010
C
C     USE ASYMPTOTIC APPROXIMATION FOR LARGE KAPPA
C     KELVIN(KAPPA)=KAPPA/(4*SQRT(2))
C                  =.176777*KAPPA
C     MARCH,1984   DAW
C
 2003 CF=.176777*EKAPPA
      GO TO 2099
C
C
 2005 X=8.0/EKAPPA
      XSQ=X*X
      CFAC1=(0.0,-0.3926991) + XSQ*((0.0,-9.765E-04) +
     1    XSQ*((-2.52E-05,0.0) + XSQ*((6.0E-07,1.9E-06))))
      CFAC2=X*((1.10486E-02,-1.10485E-02) + XSQ*((-9.06E-05,-9.01E-05) +
     1    XSQ*((-3.4E-06,5.1E-06))))
      CTHTP=CFAC1 + CFAC2
      CTHTM=CFAC1 - CFAC2
      CFAC3=(0.7071068,0.7071068) + XSQ*((-1.3813E-03,1.3811E-03) +
     1    XSQ*((3.46E-05,3.38E-05) + XSQ*((1.6E-06,-3.2E-06))))
      CFAC4=X*((-6.25001E-02,-1.0E-07) + XSQ*((5.0E-07,2.452E-04) +
     1    XSQ*((1.17E-05,-2.4E-06))))
      CPHIP=CFAC3 + CFAC4
      CPHIM=CFAC3 - CFAC4
      CFAC1=1.0/(SQRT(2.0*PI*EKAPPA))
      CFAC2=(1.0 + CFAC)/(SQRT(2.0))
      CFAC3=(-CFAC2*EKAPPA) + CTHTM
      CFAC4=(CFAC2*EKAPPA) + CTHTP
      X=4.0
C     write (*,*) cexp(cfac3/x),cfac3,x
      CF=CEXP(CFAC3/X)
C     write (*,*) cf
      CF=CF*CF
```

```
C     write (*,*) cf
      CF=CF*CF
C     write (*,*) pi,cfac1,cf
      CFAC3=(PI*CFAC1)*CF
C     write (*,*) cexp(cfac4/x),cfac4,x
      CF=CEXP(CFAC4/X)
C     write (*,*) cf
      CF=CF*CF
C     write (*,*) cf
      CF=CF*CF
C     write (*,*) cfac1,cf
      CFAC4=CFAC1*CF
C     write (*,*) cfac,pi
      CFAC1=CFAC/PI
C     write (*,*) ' ONE',cfac4,cphip,cfac1,cfac3,cphim
      CTEMPA = (CFAC4 * CPHIP) - (CFAC1 * CFAC3 * CPHIM)
C     write (*,*) ' A',ctempa,cfac4,cfac1,cfac3
      CTEMPB = CFAC4 + (CFAC1 * CFAC3)
C     write (*,*) ' B',ctempb
      TEMPRA = REAL(CTEMPA)
      TEMPRB = REAL(CTEMPB)
      TEMPIB = AIMAG(CTEMPB)
C     write (*,*) ' C',tempra
      TEMPIA = AIMAG(CTEMPA)
      TEMPRB = TEMPRB / TEMPRA
      TEMPIB = TEMPIB / TEMPRA
      TEMPIA = TEMPIA / TEMPRA
      TEMPRA = TEMPRA / TEMPRA
      CTEMPA = CMPLX(TEMPRA,TEMPIA)
C     CTEMPA = CTEMPA / TEMPRA
C     write (*,*) ' D',ctempa
      CTEMPB = CMPLX(TEMPRB,TEMPIB)
C     CTEMPB = CTEMPB / TEMPRA
C     write (*,*) ' E',ctempb
      CF = CTEMPA / CTEMPB
C     CF=((CFAC4*CPHIP)-(CFAC1*CFAC3*CPHIM))/(CFAC4+(CFAC1*CFAC3))
C2010 write (*,*) ' TWO',ekappa,cf,cfac
 2010 CF=(0.25 *(EKAPPA*CF))/(1.0 - ((2.0 *CF)/(CFAC*EKAPPA)))
 2099 RETURN
      END
C
C
C
      SUBROUTINE BDISREL (I,J)
CC
CC    SOLVE BIOT DISPERSION RELATIONS
CC
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +                 GC1,GC2,GC3,VDH
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/BCOEF/CBLKR,CBLKF,CBLKB,CSHRB,CDEN,CFAC1,CH,CC,CM
      COMMON/FVARS/OMEGA,EKAPPA,EM
      COMMON/COMKLV/CFAC,CFAC2,CFAC3,CFAC4,CF
      COMMON/FINALS/A1(20,16),V1(20,16),A2(20,16),V2(20,16),
     +                 A3(20,16),V3(20,16)
CC
      COMPLEX CFAC1,CFAC2,CFAC3,CFAC4,CFAC,CF
      COMPLEX CBLKF,CDEN,CH,CC,CM,CQ1,CQ2,CQ3
      COMPLEX CBLKR,CBLKB,CSHRB,CTEMPA,CTEMPB
```

```
CC
      DOUBLE PRECISION TCQ1R,TCQ1C,TCQ2R,TCQ2C,TCQ3R,TCQ3C,TDSCRR
      DOUBLE PRECISION TDSCRC,TROOTR,TROOTC,TDEN,TNUMR,TNUMC,TLSQR
      DOUBLE PRECISION TLSQC,TLR,TLC,THOLD,DIV
CC
      DIMENSION THOLD(6)
CC
      RHO = (RHOF*BETA) + (RHOR*(1.0 - BETA))
      NOFRAM = 1
      D = 10.0
      EX = CABS(CBLKB)
      GX = CABS(CSHRB)
      IF (EX.LT.D.AND.GX.LT.D) NOFRAM = 2
CC
CC*** CALCULATE VELOCITY AND ATTENUATION
      OSQ=OMEGA*OMEGA
      GO TO (330,320), NOFRAM
  320 CFAC1=(CFAC*ETA*CF)/(OMEGA*PERM)
      CFAC2=(((ALPHA/BETA) - (RHOF/RHO))*RHOF) - CFAC1
      CFAC3=RHO + (((ALPHA/BETA) - 2.0)*RHOF) - CFAC1
      CFAC4=1.0/((BETA/CBLKF) + ((1.0 - BETA)/CBLKR))
      CF=((RHO/CFAC4)*(CFAC2/CFAC3))*OSQ
      TLSQR=REAL(CF)
      TLSQC=AIMAG(CF)
      CALL SCROOT (TLSQR,TLSQC,TLR,TLC)
      A1(I,J)=-434.294481*TLC*2.0
      V1(I,J)=(OMEGA/TLR)/100.0
      A2(I,J)=0.0
      V2(I,J)=0.0
      A3(I,J)=0.0
      3(I,J)=0.0
      GO TO 350
  330 CFAC1=RHOF*OSQ
      CFAC2=(CFAC*OMEGA*CF*ETA)/PERM
      CFAC3=EM*OSQ
      CFAC4=RHO*OSQ
      CQ1=(CC*CC) - (CH*CM)
      CQ2=((CH*CFAC3) + (CM*CFAC4)) - (2.0*CC*CFAC1) - (CH*CFAC2)
      CQ3=(CFAC1*CFAC1) - (CFAC3*CFAC4) + (CFAC4*CFAC2)
      TCQ1R=REAL(CQ1)
      TCQ2R=REAL(CQ2)
      TCQ3R=REAL(CQ3)
      TCQ1C=AIMAG(CQ1)
      TCQ2C=AIMAG(CQ2)
      TCQ3C=AIMAG(CQ3)
      THOLD(1)=DABS(TCQ1R)
      THOLD(2)=DABS(TCQ1C)
      THOLD(3)=DABS(TCQ2R)
      THOLD(4)=DABS(TCQ2C)
      THOLD(5)=DABS(TCQ3R)
      THOLD(6)=DABS(TCQ3C)
CC---PSI MOD---REDUCE COEFFICIENTS TO PREVENT OVERFLOW
      LOGT=0
      DIV=1.0
      KOUNT=0
      DO 335 II=1,6
           IF (THOLD(II).NE.0.0D0) THEN
                LOGN=DLOG10(THOLD(II))
                KOUNT=KOUNT+1
                LOGT=LOGT+LOGN
```

```
         END IF
  335 CONTINUE
      IF (KOUNT.NE.0) THEN
         LOGAV=LOGT/KOUNT
         IF (LOGAV.NE.0) THEN
            DIV=10.0**LOGAV
         END IF
      END IF
      TCQ1R=TCQ1R/DIV
      TCQ1C=TCQ1C/DIV
      TCQ2R=TCQ2R/DIV
      TCQ2C=TCQ2C/DIV
      TCQ3R=TCQ3R/DIV
      TCQ3C=TCQ3C/DIV
CC---END OF PSI MOD---
      TDSCRR=(TCQ2R*TCQ2R) - (TCQ2C*TCQ2C)
      TDSCRR=TDSCRR - (4.0*((TCQ1R*TCQ3R) - (TCQ1C*TCQ3C)))
      TDSCRC=2.0*(TCQ2R*TCQ2C)
      TDSCRC=TDSCRC - (4.0*((TCQ1R*TCQ3C) + (TCQ1C*TCQ3R)))
      CALL SCROOT (TDSCRR,TDSCRC,TROOTR,TROOTC)
      TCQ1R=2.0*TCQ1R
      TCQ1C=2.0*TCQ1C
      TDEN=(TCQ1R*TCQ1R) + (TCQ1C*TCQ1C)
      TNUMR=(-TCQ2R) + TROOTR
      TNUMC=(-TCQ2C) + TROOTC
      TLSQR=((TNUMR*TCQ1R) + (TNUMC*TCQ1C))/TDEN
      TLSQC=((TNUMC*TCQ1R) - (TNUMR*TCQ1C))/TDEN
      CALL SCROOT (TLSQR,TLSQC,TLR,TLC)
      A1(I,J)=-434.294481*TLC*2.0
      V1(I,J)=(OMEGA/TLR)/100.0
      TNUM=(-TCQ2R) - TROOTR
      TNUMC=(-TCQ2C) - TROOTC
      TLSQR=((TNUMR*TCQ1R) + (TNUMC*TCQ1C))/TDEN
      TLSQC=((TNUMC*TCQ1R) - (TNUMR*TCQ1C))/TDEN
      CALL SCROOT (TLSQR,TLSQC,TLR,TLC)
      A2(I,J)=-434.294481*TLC*2.0
      V2(I,J)=(OMEGA/TLR)/100.0
      CDEN=CFAC3 - CFAC2
C      WRITE (*,7010) CDEN
C 7010 FORMAT (1X,2E11.4)
C      WRITE (*,7011) DIV
C 7011 FORMAT (1X,E11.4)
      CTEMPC = DSQRT(DIV)
      CTEMPA = CDEN/CTEMPC
      CTEMPA = CTEMPA/CTEMPC
      CTEMPB = CFAC1/CTEMPC
      CTEMPB = CTEMPB/CTEMPC
      CQ1 = ((CFAC4*CTEMPA) - (CTEMPB*CFAC1))/(CSHRB*CTEMPA)
      TCQ1R=REAL(CQ1)
      TCQ1C=AIMAG(CQ1)
      CALL SCROOT (TCQ1R,TCQ1C,TLR,TLC)
      A3(I,J)=-434.294481*TLC*2.0
      V3(I,J)=(OMEGA/TLR)/100.0
CC*** IDENTIFY TYPE I, TYPE II DILATATIONAL WAVES
      IF(V1(I,J).GE.V2(I,J)) GO TO 350
      EM=V1(I,J)
      V1(I,J)=V2(I,J)
      V2(I,J)=EM
      EM=A1(I,J)
      A1(I,J)=A2(I,J)
```

```
      A2(I,J)=EM
CC
CC
  350 RETURN
      END
CC
CC
CC
      SUBROUTINE SCROOT (TINR,TINC,TOUTR,TOUTC)
CC    COMPUTES DOUBLE PRECISION COMPLEX SQUARE ROOT
      DOUBLE PRECISION TINR,TINC,TRSQ,TCSQ,TSUM,TT,TW,
     +                 TOUTR,TOUTC,DIV
CC    TO PREVENT EXPONENT OVERFLOW TAKE OUT A CONSTANT FACTOR
      DIV=1.0
      COR=1.0
      LOGC=0
      IF (DABS(TINR).LE.1.0D0.OR.DABS(TINC).LE.1.0D0) GOTO 1200
      LOG1=DLOG10(DABS(TINR))
      LOG2=DLOG10(DABS(TINC))
      LOGM=LOG1
      IF (LOG2.LT.LOG1) LOGM=LOG2
      LOGC=LOGM/2
      DIV=10.**(LOGC*2)
      COR=10.**LOGC
      TINR=TINR/DIV
      TINC=TINC/DIV
 1200 TRSQ=TINR*TINR
      TCSQ=TINC*TINC
      TSUM=TRSQ+TCSQ
      TW=DSQRT(TRSQ)
      TT=DSQRT(((DSQRT(TSUM))+TW)/2.0)
      TW=(DSQRT(TCSQ))/(2.0*TT)
      SIGNS=-1.0
      IF(TINC.GE.0.0) SIGNS=1.0
      TOUTR=TT
      TOUTC=TW*SIGNS
      IF(TINR.GE.0.0) GOTO 1299
      TOUTR=TW
      TOUTCTT*SIGNS
 1299 TINR=TINR*DIV
      TINC=TINC*DIV
      TOUTR=TOUTR*COR
      TOUTC=TOUTC*COR
      RETURN
      END
C
C
C
      SUBROUTINE RNDSMP (ARR,NSIZE,XRND,SMP)
C
C        SUBROUTINE TO DETERMINE VALUES FOR THE
C        VARIABLES RHOR, VOID, S0, DECBS, DECBE,
C        AND PRATIO BY RANDOM SAMPLING OF THEIR
C        RESPECTIVE CUMULATIVE DISTRIBUTION CURVES
C
      DIMENSION ARR(100,2)
C
      CALL RAND (XRND)
C
      RND = XRND
```

```
C
      DO 1 I = 2,NSIZE
         IF (ARR(I,1).GE.RND) GOTO 2
    1 CONTINUE
      SMP = ARR(NSIZE,2)
      RETURN
C
    2 IF (ARR(I,1).EQ.RND.AND.I.LT.NSIZE) THEN
          DO 3 J = I+1,NSIZE
             IF (ARR(J,1).GT.RND) GOTO 4
    3     CONTINUE
          J = J+1
    4     SMP = (ARR(I,2)+ARR(J-1,2))/2.0
      ELSE IF (ARR(I,1).EQ.RND.AND.I.EQ.NSIZE) THEN
          SMP = ARR(NSIZE,2)
      ELSE
          FRACT = (RND-ARR(I-1,1))/(ARR(I,1)-ARR(I-1,1))
          AMOUNT = FRACT*(ARR(I,2)-ARR(I-1,2))
          SMP = ARR(I-1,2)+AMOUNT
      END IF
C
      RETURN
      END
C
C
C
      SUBROUTINE RAND (X)
C
C        A SUBROUTINE TO GENERATE RANDOM NUMBERS
C        WITH A UNIFORM DISTRIBUTION OVER THE RANGE
C        OF 0.0 TO 1.0
C
C
      DATA K,J,M,RM/5701,3612,566927,566927.0/
C
      IX = INT(X*RM)
      IRAND = MOD(J*IX+K,M)
      X = (REAL(IRAND)+0.5)/RM
C
      RETURN
      END
C
C
C
      SUBROTINE WRIT (IFILE,MCRUN,NDEPTH,NFREQ)
C
C        SUBROUTINE TO WRITE VARIOUS PARAMETERS OF
C        INTEREST FROM EACH MONTE CARLO GROUP OF RUNS
C        AS WELL AS FROM EACH INDIVIDUAL RUN
C
      COMMON/CONSTS/BLKRR,RHOF,BLKFR,ETA,ALPHA,HOVEMK,
     +              GC1,GC2,GC3,VDH
      COMMON/VDEPTH/EVERY(20)
      COMMON/VFREQ/FREQ(16)
      COMMON/DISTVALS/RHOR,VOID,S0,DECBS,DECBE,PRATIO
      COMMON/FCTVLS/BETA,PERM,PSIZE
      COMMON/DEPLOOP/EPRESS,G,GPRI,E,EPRI
      COMMON/FINALS/A1(20,16),V1(20,16),A2(20,16),V2(20,16),
     +              A3(20,16),V3(20,16)
C
```

```
      IF (MCRUN.EQ.1) THEN
         WRITE (IFILE) ( EVERY(I), I = 1,20 )
         WRITE (IFILE) ( FREQ(I), I = 1,16 )
         WRITE (IFILE) BLKRR,RHOF,BLKFR,ETA,ALPHA
C         WRITE (IFILE,101) ( EVERY(I), I = 1,20 )
C         WRITE (IFILE,102) ( FREQ(I), I = 1,16 )
C         WRITE (IFILE,103) BLKRR,RHOF,BLKFR,ETA,ALPHA
C  101    FORMAT (20(F7.2,2X))
C  102    FORMAT (16(F7.1,1X))
C  103    FORMAT (E11.5,1X,F5.3,1X,E11.5,1X,E10.4,1X,F4.2)
      END IF
C
      WRITE (IFILE) MCRUN,RHOR,VOID,S0,DECBS,DECBE,PRATIO
      WRITE (IFILE) BETA,PERM,PSIZE,G,GPRI,E,EPRI
C      WRITE (IFILE,200) MCRUN,RHOR,VOID,S0,DECBS,DECBE,PRATIO
C      WRITE (IFILE,201) BETA,PERM,PSIZE,G,GPRI,E,EPRI
      DO 10 I = 1,NDEPTH
         WRITE (IFILE) ( V1(I,J), J = 1,NFREQ )
         WRITE (IFILE) ( A1(I,J), J = 1,NFREQ )
         WRITE (IFILE) ( V2(I,J), J = 1,NFREQ )
         WRITE (IFILE) ( A2(I,J), J = 1,NFREQ )
         WRITE (IFILE) ( V3(I,J), J = 1,FREQ )
         WRITE (IFILE) ( A3(I,J), J = 1,NFREQ )
C         WRITE (IFILE,202) ( V1(I,J), J = 1,NFREQ )
C         WRITE (IFILE,203) ( A1(I,J), J = 1,NFREQ )
C         WRITE (IFILE,202) ( V2(I,J), J = 1,NFREQ )
C         WRITE (IFILE,203) ( A2(I,J), J = 1,NFREQ )
C         WRITE (IFILE,202) ( V3(I,J), J = 1,NFREQ )
C         WRITE (IFILE,203) ( A3(I,J), J = 1,NFREQ )
C  200    FORMAT(I5,1X,2(F5.3,1X),F10.3,1X,3(F4.3,1X))
C  201    FORMAT(F6.4,6(E11.5,1X))
C  202    FORMAT(16(E11.5,1X))
C  203    FORMAT(16(E11.5,1X))
   10 CONTINUE
C
C
      RETURN
      END
        SUBROUTINE ISREAL(IEND,RNUMB,IERR)

C       **  ERROR                          ERROR
C       **  CODES                        EXPLAINED
C       **  -----      ---------------------------------------------
C       **    1        Contains at least 1 non-real character.
C       **    2        Negative sign error.
C       **    3        Imbedded blank.
C       **    4        Decimal point error.
C       **    5        All blanks entered.
C       **    6        Argument "IEND" is too large.
C
C       ** IMPORTANT: Subroutine argument RNUMB is defined as REAL*8.
C
        character*1 CH(10)
        logical NUMBER,DECI
        real*4 CHLEFT(10),CHRITE(10)
        real*8 RNUMB

        if (IEND .gt. 10) then
           IERR = 6
           RNUMB = 0.0
```

```
            goto 301
         end if

   4     NUMBER = .false.
         DECI = .false.
         J = 0
         K = 0
         SIGN = 1.
         RNUMB = 0.
         IERR = 0
C        write (*,5)
C  5     format (' Enter Real number:')
         read (*,10) CH(1),CH(2),CH(3),CH(4),CH(5),CH(6),CH(7),CH(8),
     &               CH(9),CH(10)
  10     format (10a1)

         do 100 I = 1,IEND
            if ((CH(I) .ne. '1') .and. (CH(I) .ne. '2') .and.
     &          (CH(I) .ne. '3') .and. (CH(I) .ne. '4') .and.
     &          (CH(I) .ne. '5') .and. (CH(I) .ne. '6') .and.
     &          (CH(I) .ne. '7') .and. (CH(I) .ne. '8') .and.
     &          (CH(I) .ne. '9') .and. (CH(I) .ne. '0') .and.
     &          (CH(I) .ne. '-') .and. (CH(I) .ne. ' ') .and.
     &          (CH(I) .ne. '.')) then
               IERR = 1
               RNUMB = 0.0
               goto 301
            end if

            if ((CH(I) .eq. '1') .or. (CH(I) .eq. '2') .or.
     &          (CH(I) .eq. '3') .or. (CH(I) .eq. '4') .or.
     &          (CH(I) .eq. '5') .or. (CH(I) .eq. '6') .or.
     &          (CH(I) .eq. '7') .or. (CH(I) .eq. '8') .or.
     &          (CH(I) .eq. '9') .or. (CH(I) .eq. '0')) then
               NUMBER = .true.
               if (.not. DECI) then
                  J = J + 1
                  call RVALUE(CH(I), CHLEFT(J))
               else
                  K = K + 1
                  call RVALUE(CH(I), CHRITE(K))
               end if
               goto 100
            else if (CH(I) .eq. '-') then
               if (I .eq. IEND) then
                  IERR = 2
                  RNUMB = 0.0
                  goto 301
               end if
               if (NUMBER) then
                  IERR = 2
                  RNUMB = 0.0
                  goto 301
               else
                  SIGN = -1.
                  NUMBER = .true.
                  goto 100
               end if
            else if (CH(I) .eq. ' ') then
               if (NUMBER) then
```

```
                  do 80 L = I, IEND
                     if (CH(l) .ne. ' ') then
                        IERR = 3
                        RNUMB = 0.0
                        goto 301
                     end if
 80               continue
               else
                  goto 100
               end if
            else if (CH(I) .eq. '.') then
               if (DECI) then
                  IERR = 4
                  RNUMB = 0.0
                  goto 301
               else
                  DECI = .true.
                  NUMBER = .true.
                  goto 100
               end if
            end if
100      continue

         if ((J .eq. 0) .and. (K .eq. 0)) then
            IERR = 5
            if (DECI) IERR = 4
            if (SIGN .eq. -1.) IERR = 2
            RNUMB = 0.0
            goto 301
         end if

         PLIER = 1.
         do 200 I = J,1,-1
            RNUMB = RNUMB + (CHLEFT(I) * PLIER)
            PLIER = PLIER* 10.
200      continue

         VIDER = 1.
         do 300 I = 1,K
            VIDER = VIDER * 10.
            RNUMB = RNUMB + (CHRITE(I) / VIDER)
300      continue

         RNUMB = RNUMB * SIGN

301      continue

         return
         end

C*************************************************************

         SUBROUTINE RVALUE(CH,R)

         character*1 CH
         real*4 R

         if (CH .eq. '1') R = 1.
         if (CH .eq. '2') R = 2.
         if (CH .eq. '3') R = 3.
```

```
         if (CH .eq. '4') R = 4.
         if (CH .eq. '5') R = 5.
         if (CH .eq. '6') R = 6.
         if (CH .eq. '7') R = 7.
         if (CH .eq. '8') R = 8.
         if (CH .eq. '9') R = 9.
         if (CH .eq. '0') R = 0.

         return
         end

C*************************************************************

       SUBROUTINE GRFDAT(IFILE,INT,MCEND,MCRUN,MIDDEP,MIDFRE)
       CHARACTER*1 CHAR(24,80)
       COMMON/FINALS/A1(20,16),V1(20,16),A2(20,16),V2(20,16),
      +              A3(20,16),V3(20,16)
       COMMON/VDEPTH/EVERY(20)
       COMMON/VFREQ/FREQ(16)

       DOUBLE PRECISION SQSV1,SQSA1,SDV1,SDA1,SQSV3,SQSA3,
      +                 SDV3,SDA3

       IF (MCRUN .EQ. 1) THEN

          ICOMP = 1
          ICOL  = 0

          DO 10 I = 1,24
             DO 10 J = 1,80
                CHAR(I,J) = '.'
   10     CONTINUE

          SUMV1 = V1(MIDDEP,MIDFRE)
         SUMA1 = A1(MIDDEP,MIDFRE)
          SQSV1 = V1(MIDDEP,MIDFRE)**2
          SQSA1 = A1(MIDDEP,MIDFRE)**2
          RAVGV1 = SUMV1
          RAVGA1 = SUMA1
          SDV1 = 0.
          SDA1 = 0.
          A = 0.
          B = 0.
          SUMV3 = V3(MIDDEP,MIDFRE)
          SUMA3 = A3(MIDDEP,MIDFRE)
          SQSV3 = V3(MIDDEP,MIDFRE)**2
          SQSA3 = A3(MIDDEP,MIDFRE)**2
          RAVGV3 = SUMV3
          RAVGA3 = SUMA3
          SDV3 = 0.
          SDA3 = 0.
          C = 0.
          D = 0.
          IF (INT .EQ. 1) THEN
             ICOMP = 0
             ICOL = 1
             IROWA = A/.25 + 13
             IROWB = B/.25 + 13
             IROWC = C/.25 + 13
             IROWD = D/.25 + 13
```

```
           IF (IROWA.LT.25.AND.IROWA.GT.0) CHAR(IROWA,ICOL) = 'A'
           IF (IROWB.LT.25.AND.IROWB.GT.0) CHAR(IROWB,ICOL) = 'B'
           IF (IROWC.LT.25.AND.IROWC.GT.0) CHAR(IROWC,ICOL) = 'C'
           IF (IROWD.LT.25.AND.IROWD.GT.0) CHAR(IROWD,ICOL) = 'D'
        END IF
     ELSE
        ICOMP = ICOMP + 1
        SUMV1 = SUMV1 + V1(MIDDEP,MIDFRE)
        SUMA1 = SUMA1 + A1(MIDDEP,MIDFRE)
        SQSV1 = SQSV1 + V1(MIDDEP,MIDFRE)**2
        SQSA1 = SQSA1 + A1(MIDDEP,MIDFRE)**2
        RAVGV1 = SUMV1 / MCRUN
        RAVGA1 = SUMA1 / MCRUN
        SDV1 = DSQRT(SQSV1 / MCRUN - RAVGV1**2)
        SDA1 = DSQRT(SQSA1 / MCRUN - RAVGA1**2)
        A = DLOG10(SDV1)
        B = DLOG10(SDA1)
        SUMV3 = SUMV3 + V3(MIDDEP,MIDFRE)
        SUMA3 = SUMA3 + A3(MIDDEP,MIDFRE)
        SQSV3 = SQSV3 + V3(MIDDEP,MIDFRE)**2
        SQSA3 = SQSA3 + A3(MIDDEP,MIDFRE)**2
        RAVGV3 = SUMV3 / MCRUN
        RAVGA3 = SUMA3  MCRUN
        SDV3 = DSQRT(SQSV3 / MCRUN - RAVGV3**2)
        SDA3 = DSQRT(SQSA3 / MCRUN - RAVGA3**2)
        C = DLOG10(SDV3)
        D = DLOG10(SDA3)
        IF (INT .EQ. ICOMP) THEN
           ICOMP = 0
           ICOL = ICOL + 1
           IROWA = A/.25 + 13
           IROWB = B/.25 + 13
           IROWC = C/.25 + 13
           IROWD = D/.25 + 13

           IF (IROWA.LT.25.AND.IROWA.GT.0) CHAR(IROWA,ICOL) = 'A'
           IF (IROWB.LT.25.AND.IROWB.GT.0) CHAR(IROWB,ICOL) = 'B'
           IF (IROWC.LT.25.AND.IROWC.GT.0) CHAR(IROWC,ICOL) = 'C'
           IF (IROWD.LT.25.AND.IROWD.GT.0) CHAR(IROWD,ICOL) = 'D'

           WRITE (*,1000)
1000       FORMAT ('123456789|123456789|123456789|123456789|',
    +              '123456789|123456789|123456789|123456789|')
           DO 50 I = 24,1,-1
              WRITE (*,1001) (CHAR(I,J),J = 1,MCEND)
1001          FORMAT (80A1)
  50       CONTINUE

           IF (ICOL .EQ. MCEND) THEN
              SCALE = 3.25
              WRITE (IFILE,1010)
1010          FORMAT ('       123456789|123456789|123456789|'
    +   '123456789|123456789|123456789|123456789|123456789|')
              DO 90 I = 24,1,-1
                 SCALE = SCALE - .25
                 WRITE (IFILE,1011) SCALE
1011             FORMAT (F5.2)
                 WRITE (IFILE,1012)(CHAR(I,J),J = 1,MCEND)
1012             FORMAT ('      ',80A1)
  90          CONTINUE
```

```
               SCALE = SCALE - .25
               WRITE (IFILE,1011) SCALE
               WRITE (IFILE,1014) EVERY(MIDDEP),FREQ(MIDFRE)
 1014          FORMAT (//23X,'DEPTH = ',F7.2,
     +                 '   FREQUENCY = ',F9.2)
               WRITE (IFILE,1013) RAVGV1,SDV1,RAVGA1,SDA1,
     +                            RAVGV3,SDV3,RAVGA3,SDA3
 1013          FORMAT (/25X,'V1  =  ',E9.4,'  + or -  ',E9.4/
     +                   25X,'A1  =  ',E9.4,'  + or -  ',E9.4/
     +                   25X,'V3  =  ',E9.4,'  + or -  ',E9.4/
     +                   25X,'A3  =  ',E9.4,'  + or -  ',E9.4)

            END IF

         END IF


      END IF

C      WRITE (*,200) MCRUN
C      WRITE (*,201) SUMV1,SUMA1
C      WRITE (*,201) SQSV1,SQSA1
C      WRITE (*,201) RAVGV1,RAVGA1
C      WRITE (*,201) SDV1,SDA1
C      WRITE (*,202) A,B
C      WRITE (*,201) SUMV3,SUMA3
C      WRITE (*,201) SQSV3,SQSA3
C      WRITE (*,201) RAVGV3,RAVGA3
C      WRITE (*,201) SDV3,SDA3
C      WRITE (*,202) C,D
C  200 FORMAT (' MCRUN = ',I3)
C  201 FORMAT (1X,E11.5,1X,E11.5)
C  202 FORMAT (1X,F9.6,1X,F9.6)

      RETURN
      END
```

PROGRAM PROFIL

```
$LARGE
      PROGRAM PROFIL
      CHARACTER*1 YESNO,SCHEME
      CHARACTER*2 PARNAM
      CHARACTER*4 PROV,PROF
      CHARACTER*7 TITLE
      CHARACTER*12 SNAME,BNAME1,BNAME2,BNAME3,
     +             FNAME,BNAME4,BNAME5,BNAME6
      LOGICAL FIRST,SOLID,FLUID
      REAL*8 TMEAN,TSUMSQ,TRTVAR,VALUE,SCORE,SCRLO,SCRHI
      DIMENSION TMEAN(20,16,4),TSUMSQ(20,16,4),TRTVAR(20,16,4),
     +          WEIGHT(20,16,4),VALUE(20,16,4),SCORE(2000),
     +          DEPTH(20),FREQ(16),V1(20,16),A1(20,16),
     +          V2(20,16),A2(20,16),V3(20,16),A3(20,16),
     +          TNSRMN(20,16,4),TNSRTP(20,16,4),TNSRMX(20,16,4),
     +          TEMP1(20,16,4),TEMP2(20,16,4),AW(20),BW(16),
     +          CW(4),PARNAM(4),IFPTR(16),IDPTR(20),THICK(19)
      DIMENSION WSADEP(20),WSAFRQ(16),WSAPAR(4),
     +          WSBDEP(20),WSBFRQ(16),WSBPAR(4),WSGPAR(4),
     +          WSCDEP(20),WSCFRQ(16),WSCPAR(4),WSFDEP(20),
     +          WSDDEP(20),WSDFRQ(16),WSDPAR(4),WSEPAR(4)
      DATA WSADEP/6*1.0,14*0.0/
      DATA WSAFRQ/7*1.0,9*0.0/
      DATA WSAPAR/4*1.0/
      DATA WSBDEP/6*1.0,14*0.0/
      DATA WSBFRQ/3*0.0,1.0,12*0.0/
      DATA WSBPAR/1.0,3*0.0/
      DATA WSCDEP/3*0.0,1.0,16*0.0/
      DATA WSCFRQ/7*1.0,9*0.0/
      DATA WSCPAR/0.0,1.0,2*0.0/
      DATA WSDDEP/6*1.0,14*0.0/
      DATA WSDFRQ/7*1.0,9*0.0/
      DATA WSDPAR/2*1.0,2*0.0/
      DATA WSEPAR/0.0,0.0,1.0,0.0/
      DATA WSFDEP/2*0.0,1.0,3*0.0,14*0.0/
      DATA WSGPAR/3*0.0,1.0/
      DATA PARNAM/'V1','A1','V3','A3'/

      FIRST = .TRUE.

      WRITE (*,6000)
 6000 FORMAT (/' Enter 4 character province code'/
     +         ' of file with Monte Carlo results: ',$)
      READ (*,6001) PROV
 6001 FORMAT (A4)

      WRITE (FNAME,6002) PROV
 6002 FORMAT (A4,'BIOT.DAT')

      OPEN (20,FILE=FNAME,ACCESS='SEQUENTIAL',
     +      FORM ='UNFORMATTED',STATUS='OLD')

    3 WRITE (*,6005)
 6005 FORMAT (/' Enter Weighting Scheme below'/
     +         '  A = All parameters weighted equally (1.0)'/
     +         '  B = Compressional Speed & All Depths'/
     +         '      weighted (1.0). Mid-Frequency weighted (1.0)'/
     +         '  C = Compressional Attenuation & All Frequencies'/
     +         '      weighted (1.0). Mid-Depth weighted (1.0)'/
     +         '  D = Compressional Speed/Attenuation and All'/
```

```
     +          '       Depths and Frequencies weighted (1.0)'/
     +          '   E = Shear Speed and All Depths weighted (1.0).'/
     +          '       Mid-Frequency weighted (1.0).'/
     +          '   F = Compressional Attenuation & All Frequencies'/
     +          '       weighted (1.0). 5m. Depth weighted (1.0).'/
     +          '   G = Shear Attenuation and All Frequencies'/
     +          '       weighted (1.0). 5m. Depth weighted (1.0).'/
     +          ' Enter Scheme: ',$)
      READ (*,6105) SCHEME
 6105 FORMAT (A1)
      IF (SCHEME .EQ. 'A' .OR. SCHEME .EQ. 'a') THEN
         SCHEME = 'A'
      ELSE IF (SCHEME .EQ. 'B' .OR. SCHEME .EQ. 'b') THEN
         SCHEME = 'B'
      ELSE IF (SCHEME .EQ. 'C' .OR. SCHEME .EQ. 'c') THEN
         SCHEME = 'C'
      ELSE IF (SCHEME .EQ. 'D' .OR. SCHEME .EQ. 'd') THEN
         SCHEME = 'D'
      ELSE IF (SCHEME .EQ. 'E' .OR. SCHEME .EQ. 'e') THEN
         SCHEME = 'E'
      ELSE IF (SCHEME .EQ. 'F' .OR. SCHEME .EQ. 'f') THEN
         SCHEME = 'F'
      ELSE IF (SCHEME .EQ. 'G' .OR. SCHEME .EQ. 'g') THEN
         SCHEME = 'G'
      ELSE
         GOTO 3
      END IF

      WRITE (SNAME,6006) PROV,SCHEME
 6006 FORMAT (A4,'WS',A1,'.PRO')

      OPEN (10,FILE=SNAME,ACCESS='SEQUENTIAL',
     +      FORM='FORMATTED',STATUS='NEW')

      WRITE (TITLE,6007) PROV,SCHEME
 6007 FORMAT (A4,'WS',A1)

    5 WRITE (*,6010)
 6010 FORMAT (/' Enter the number of Monte Carlo steps'/
     +          ' performed to produce the above'/
     +          ' mentioned results: ',$)
      READ (*,6015,err=5) MCLOOP
 6015 FORMAT (I4)

      DO 10 I = 1,20
         DO 10 J = 1,16
            DO 10 K = 1,4
               TMEAN(I,J,K) = 0.0
               TSUMSQ(I,J,K) = 0.0
               TRTVAR(I,J,K) = 0.0
               VALUE(I,J,K) = 0.0
   10 CONTINUE

      READ (20) (DEPTH(I), I = 1,20)
      READ (20) (FREQ(I), I = 1,16)
      READ (20) BLKRR,RHOF,BLKFR,ETA,ALPHA

      DO 19 I = 2,20
         IF (DEPTH(I) .LE. 0.0) GOTO 20
   19 CONTINUE
```

```
      I = I + 1
   20 NDEPTH = I - 1

      DO 29 I = 2,16
         IF (FREQ(I) .LE. 0.0) GOTO 30
   29 CONTINUE
      I = I + 1
   30 NFREQ = I - 1

      SOLID = .FALSE.
      FLUID = .FALSE.

 1000 WRITE (*,6110)
 6110 FORMAT (/' Choose from below:'/
     +          '  A = Create Multilayer (Solid) Model'/
     +          '      input files (Min, Max, Typ)'/
     +          '  B = Create Reflec (Fluid) Model'/
     +          '      input files (Min, Max, Typ)'/
     +          '  C = Create Both (Solid & Fluid) Model'/
     +          '      input files (Min, Max, Typ)'/
     +          '  D = None of the above.'/
     +          ' Enter choice: ',$)
      READ (*,6105) YESNO
      IF (YESNO .EQ. 'A' .OR. YESNO .EQ. 'a') THEN
         SOLID = .TRUE.
      ELSE IF (YESNO .EQ. 'B' .OR. YESNO .EQ. 'b') THEN
         FLUID = .TRUE.
      ELSE IF (YESNO .EQ. 'C' .OR. YESNO .EQ. 'c') THEN
         SOLID = .TRUE.
         FLUID = .TRUE.
      ELSE IF (YESNO .EQ. 'D' .OR. YESNO .EQ. 'd') THEN
         GOTO 31
      ELSE
         GOTO 1000
      END IF

      WRITE (*,6115)
 6115 FORMAT (/' Choose Frequencies for Bottom Loss'/
     +          ' profiles from the following list:')
      LBFREQ = 0
      DO 1010 I = 1,NFREQ
         WRITE (*,6120) FREQ(I)
 6120    FORMAT (1X,G9.3,' Hz. [Y/N]? ',$)
         READ (*,6105) YESNO
         IF (YESNO .EQ. 'N' .OR. YESNO .EQ. 'n') GOTO 1010
         LBFREQ = LBFREQ + 1
         IFPTR(LBFREQ) = I
 1010 CONTINUE

 1014 WRITE (*,6121)
 6121 FORMAT (/' Choose Depths (All or One) for Bottom'/
     +          ' Loss profiles from the following list:'/
     +          '  0 = All Depths')
      DO 1015 I = 1,NDEPTH
         WRITE (*,6122) I, DEPTH(I)
 6122    FORMAT (1X,I2,' = ',G9.3)
         IDPTR(I) = I
 1015 CONTINUE
      WRITE (*,6123)
 6123 FORMAT (' Enter choice: ',$)
```

```
      READ (*,6124) IVAL
 6124 FORMAT (I2)
      IF (IVAL .LT. 0 .OR. IVAL .GT. NDEPTH) GOTO 1014
      IF (IVAL .NE. 0) THEN
         NUMLAY = 1
         THICK(NUMLAY) = DEPTH(NDEPTH)
         IDPTR(NUMLAY) = IVAL
      ELSE
         NUMLAY = NDEPTH - 1
         PRETHK = 0.0
         DO 1016 I = 1,NUMLAY
            TEMP = (DEPTH(I+1) - DEPTH(I)) / 2.0
            THICK(I) = TEMP + PRETHK
            PRETHK = TEMP
 1016    CONTINUE
      END IF

      ANGMIN = 1.0
      ANGMAX = 90.0
      ANGINC = 1.0

      IF (SOLID) THEN
         WRITE (BNAME1,6160) PROV,SCHEME
 6160    FORMAT ('S',A4,'WS',A1,'.MIN')
         OPEN (30,FILE=BNAME1,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')

         WRITE (BNAME2,6165) PROV,SCHEME
 6165    FORMAT ('S',A4,'WS',A1,'.TYP')
         OPEN (40,FILE=BNAME2,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')

         WRITE (BNAME3,6170) PROV,SCHEME
 6170    FORMAT ('S',A4,'WS',A1,'.MAX')
         OPEN (50,FILE=BNAME3,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')
      END IF
      IF (FLUID) THEN
         WRITE (BNAME4,6175) PROV,SCHEME
 6175    FORMAT ('F',A4,'WS',A1,'.MIN')
         OPEN (60,FILE=BNAME4,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')

         WRITE (BNAME5,6180) PROV,SCHEME
 6180    FORMAT ('F',A4,'WS',A1,'.TYP')
         OPEN (70,FILE=BNAME5,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')

         WRITE (BNAME6,6185) PROV,SCHEME
 6185    FORMAT ('F',A4,'WS',A1,'.MAX')
         OPEN (80,FILE=BNAME6,ACCESS='SEQUENTIAL',
     +           FORM='FORMATTED',STATUS='NEW')
      END IF

   31 DO 32 I = 1,NDEPTH
         IF (SCHEME .EQ. 'A') AW(I) = WSADEP(I)
         IF (SCHEME .EQ. 'B') AW(I) = WSBDEP(I)
         IF (SCHEME .EQ. 'C') AW(I) = WSCDEP(I)
         IF (SCHEME .EQ. 'D') AW(I) = WSDDEP(I)
         IF (SCHEME .EQ. 'E') AW(I) = WSADEP(I)
```

```
        IF (SCHEME .EQ. 'F') AW(I) = WSFDEP(I)
        IF (SCHEMEM.EQ. 'G') AW(I) = WSFDEP(I)
   32 CONTINUE

      DO 34 I = 1,NFREQ
        IF (SCHEME .EQ. 'A') BW(I) = WSAFRQ(I)
        IF (SCHEME .EQ. 'B') BW(I) = WSBFRQ(I)
        IF (SCHEME .EQ. 'C') BW(I) = WSCFRQ(I)
        IF (SCHEME .EQ. 'D') BW(I) = WSDFRQ(I)
        IF (SCHEME .EQ. 'E') BW(I) = WSBFRQ(I)
        IF (SCHEME .EQ. 'F') BW(I) = WSAFRQ(I)
        IF (SCHEME .EQ. 'G') BW(I) = WSAFRQ(I)
   34 CONTINUE

      DO 36 I = 1,4
        IF (SCHEME .EQ. 'A') CW(I) = WSAPAR(I)
        IF (SCHEME .EQ. 'B') CW(I) = WSBPAR(I)
        IF (SCHEME .EQ. 'C') CW(I) = WSCPAR(I)
        IF (SCHEME .EQ. 'D') CW(I) = WSDPAR(I)
        IF (SCHEME .EQ. 'E') CW(I) = WSEPAR(I)
        IF (SCHEME .EQ. 'F') CW(I) = WSCPAR(I)
        IF (SCHEME .EQ. 'G') CW(I) = WSGPAR(I)
   36 CONTINUE

      DO 38 I = 1,NDEPTH
        DO 38 J = 1,NFREQ
          DO 38 K = 1,4
            WEIGHT(I,J,K) = AW(I) * BW(J) * CW(K)
   38 CONTINUE

      DO 100 M = 1,MCLOOP

        SCORE(M) = 0.0

        READ (20) MCRUN,RHOR,VOID,SO,DECBS,DECBE,PRATIO
        READ (20) BETA,PERM,PSIZE,G,GPRI,E,EPRI
        DO 40 I = 1,NDEPTH
          READ (20) (V1(I,J), J = 1,NFREQ)
          READ (20) (A1(I,J), J = 1,NFREQ)
          READ (20) (V2(I,J), J = 1,NFREQ)
          READ (20) (A2(I,J), J = 1,NFREQ)
          READ (20) (V3(I,J), J = 1,NFREQ)
          READ (20) (A3(I,J), J = 1,NFREQ)
          DO 40 K = 1,NFREQ
            TMEAN(I,K,1) = TMEAN(I,K,1) + V1(I,K)
            TMEAN(I,K,2) = TMEAN(I,K,2) + A1(I,K)
            TMEAN(I,K,3) = TMEAN(I,K,3) + V3(I,K)
            TMEAN(I,K,4) = TMEAN(I,K,4) + A3(I,K)
            TSUMSQ(I,K,1) = TSUMSQ(I,K,1) + V1(I,K)**2
            TSUMSQ(I,K,2) = TSUMSQ(I,K,2) + A1(I,K)**2
            TSUMSQ(I,K,3) = TSUMSQ(I,K,3) + V3(I,K)**2
            TSUMSQ(I,K,4) = TSUMSQ(I,K,4) + A3(I,K)**2
   40   CONTINUE

  100 CONTINUE

      DO 110 I = 1,NDEPTH
        DO 110 J = 1,NFREQ
          DO 110 K = 1,4
            TMEAN(I,J,K) = TMEAN(I,J,K) / MCLOOP
```

```
                    VALUE(I,J,K) = TMEAN(I,J,K)
                    TRTVAR(I,J,K) = DSQRT((TSUMSQ(I,J,K) - MCLOOP *
     +                                (TMEAN(I,J,K) ** 2))/ (MCLOOP - 1))
  110 CONTINUE

 6023 FORMAT (' ')

  115 CONTINUE

      SCRLO = 1.0E35
      SCRHI = -1.0E35

      REWIND (20)

      READ (20) (DEPTH(I), I = 1,20)
      READ (20) (FREQ(I), I = 1,16)
      READ (20) BLKRR,RHOF,BLKFR,ETA,ALPHA

      DO 200 M = 1,MCLOOP
         READ (20) MCRUN,RHOR,VOID,SO,DECBS,DECBE,PRATIO
         READ (20) BETA,PERM,PSIZE,G,GPRI,E,EPRI
         DO 140 I = 1,NDEPTH
            READ (20) (V1(I,K), K = 1,NFREQ)
            READ (20) (A1(I,K), K = 1,NFREQ)
            READ (20) (V2(I,K), K = 1,NFREQ)
            READ (20) (A2(I,K), K = 1,NFREQ)
            READ (20) (V3(I,K), K = 1,NFREQ)
            READ (20) (A3(I,K), K = 1,NFREQ)
            DO 140 J = 1,NFREQ
               IF (TRTVAR(I,J,1) .NE. 0.0)
     +         SCORE(M) = (DABS(V1(I,J) - VALUE(I,J,1)) /
     +                     TRTVAR(I,J,1)) * WEIGHT(I,J,1) +
     +                     SCORE(M)
               IF (TRTVAR(I,J,2) .NE. 0.0)
     +         SCORE(M) = (DABS(A1(I,J) - VALUE(I,J,2)) /
     +                     TRTVAR(I,J,2)) * WEIGHT(I,J,2) +
     +                     SCORE(M)
               IF (TRTVAR(I,J,3) .NE. 0.0)
     +         SCORE(M) = (DABS(V3(I,J) - VALUE(I,J,3)) /
     +                     TRTVAR(I,J,3)) * WEIGHT(I,J,3) +
     +                     SCORE(M)
               IF (TRTVAR(I,J,4) .NE. 0.0)
     +         SCORE(M) = (DABS(A3(I,J) - VALUE(I,J,4)) /
     +                     TRTVAR(I,J,4)) * WEIGHT(I,J,4) +
     +                     SCORE(M)
  140    CONTINUE

         IF (SCORE(M) .LT. SCRLO) THEN
            SCRLO = SCORE(M)
            MVALLO = M
            DO 150 I = 1,NDEPTH
               DO 150 J = 1,NFREQ
                  RHOR1 = RHOR
                  BETA1 = BETA
                  TEMP1(I,J,1) = V1(I,J)
                  TEMP1(I,J,2) = A1(I,J)
                  TEMP1(I,J,3) = V3(I,J)
                  TEMP1(I,J,4) = A3(I,J)
  150       CONTINUE
         END IF
```

```
         IF (SCORE(M) .GT. SCRHI) THEN
            SCRHI = SCORE(M)
            MVALHI = M
            DO 160 I = 1,NDEPTH
               DO 160 J = 1,NFREQ
                  RHOR2 = RHOR
                  BETA2 = BETA
                  TEMP2(I,J,1) = V1(I,J)
                  TEMP2(I,J,2) = A1(I,J)
                  TEMP2(I,J,3) = V3(I,J)
                  TEMP2(I,J,4) = A3(I,J)
160         CONTINUE
         END IF

         SCORE(M) = 0.0

200   CONTINUE

      DO 240 I = 1,NDEPTH
         DO 240 J = 1,NFREQ
            DO 240 K = 1,4
               IF (FIRST) THEN
                  TNSRTP(I,J,K) = TEMP1(I,J,K)
                  TNSRMX(I,J,K) = TEMP2(I,J,K)
                  VALUE(I,J,K) = DBLE(TNSRMX(I,J,K))
                  RHORTP = RHOR1
                  BETATP = BETA1
                  RHORMX = RHOR2
                  BETAMX = BETA2
                  SCRTYP = SNGL(SCRLO)
                  MTPVAL = MVALLO
                  SCRMAX = SNGL(SCRHI)
                  MAXVAL = MVALHI
               ELSE
                  TNSRMN(I,J,K) = TEMP2(I,J,K)
                  RHORMN = RHOR2
                  BETAMN = BETA2
                  SCRMIN = SNGL(SCRHI)
                  MINVAL = MVALHI
                  MSAME = MVALLO
                  SCRNEW = SNGL(SCRLO)
               END IF
240   CONTINUE

      IF (FIRST) THEN
         FIRST = .FALSE.
         GOTO 115
      END IF

      WSPEED = SQRT(BLKFR/RHOF) / 100.0
      DENSMN = RHOF * BETAMN + RHORMN * (1 - BETAMN)
      DENSTP = RHOF * BETATP + RHORTP * (1 - BETATP)
      DENSMX = RHOF * BETAMX + RHORMX * (1 - BETAMX)

      IF (SOLID) THEN
         WRITE (30,6500) ANGMIN,ANGMAX,ANGINC
         WRITE (40,6500) ANGMIN,ANGMAX,ANGINC
         WRITE (50,6500) ANGMIN,ANGMAX,ANGINC
6500     FORMAT (3F10.1)
```

```
         WRITE (30,6505) WSPEED,RHOF,LBFREQ
         WRITE (40,6505) WSPEED,RHOF,LBFREQ
         WRITE (50,6505) WSPEED,RHOF,LBFREQ
 6505    FORMAT (F10.1,F10.3,I4)

      DO 245 I = 1,LBFREQ
         TF = FREQ(IFPTR(I))/1000.0
         WRITE (30,6510) TF,NUMLAY
         WRITE (40,6510) TF,NUMLAY
         WRITE (50,6510) TF,NUMLAY
 6510    FORMAT (F10.4,I4)

         WRITE (30,6515) TNSRMN(NDEPTH,IFPTR(I),1),
     +                   TNSRMN(NDEPTH,IFPTR(I),3),DENSMN
         WRITE (40,6515) TNSRTP(NDEPTH,IFPTR(I),1),
     +                   TNSRTP(NDEPTH,IFPTR(I),3),DENSTP
         WRITE (50,6515) TNSRMX(NDEPTH,IFPTR(I),1),
     +                   TNSRMX(NDEPTH,IFPTR(I),3),DENSMX
 6515    FORMAT (2F10.1,F10.3)

         CAVMN = TNSRMN(NDEPTH,IFPTR(I),2) / (FREQ(IFPTR(I))/1000.)
         SAVMN = TNSRMN(NDEPTH,IFPTR(I),4) / (FREQ(IFPTR(I))/1000.)
         CAVTP = TNSRTP(NDEPTH,IFPTR(I),2) / (FREQ(IFPTR(I))/1000.)
         SAVTP = TNSRTP(NDEPTH,IFPTR(I),4) / (FREQ(IFPTR(I))/1000.)
         CAVMX = TNSRMX(NDEPTH,IFPTR(I),2) / (FREQ(IFPTR(I))/1000.)
         SAVMX = TNSRMX(NDEPTH,IFPTR(I),4) / (FREQ(IFPTR(I))/1000.)
         WRITE (30,6520) CAVMN,SAVMN
         WRITE (40,6520) CAVTP,SAVTP
         WRITE (50,6520) CAVMX,SAVMX
 6520    FORMAT (2F10.4)

         DO 245 J = 1,NUMLAY
            WRITE (30,6525) TNSRMN(IDPTR(J),IFPTR(I),1),
     +                      TNSRMN(IDPTR(J),IFPTR(I),3),DENSMN
            WRITE (40,6525) TNSRTP(IDPTR(J),IFPTR(I),1),
     +                      TNSRTP(IDPTR(J),IFPTR(I),3),DENSTP
            WRITE (50,6525) TNSRMX(IDPTR(J),IFPTR(I),1),
     +                      TNSRMX(IDPTR(J),IFPTR(I),3),DENSMX
 6525       FORMAT (F10.1,F10.2,F10.3)

            CAVMN=TNSRMN(IDPTR(J),IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
            SAVMN=TNSRMN(IDPTR(J),IFPTR(I),4)/(FREQ(IFPTR(I))/1000.)
            CAVTP=TNSRTP(IDPTR(J),IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
            SAVTP=TNSRTP(IDPTR(J),IFPTR(I),4)/(FREQ(IFPTR(I))/1000.)
            CAVMX=TNSRMX(IDPTR(J),IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
            SAVMX=TNSRMX(IDPTR(J),IFPTR(I),4)/(FREQ(IFPTR(I))/1000.)
            TTH = THICK(J) * 100.0
            WRITE (30,6530) CAVMN,SAVMN,TTH
            WRITE (40,6530) CAVTP,SAVTP,TTH
            WRITE (50,6530) CAVMX,SAVMX,TTH
 6530       FORMAT (2F10.4,F10.1)

  245 CONTINUE

         CLOSE (30)
         CLOSE (40)
         CLOSE (50)
      END IF

      IF (FLUID) THEN
```

```
        WRITE (60,6124) LBFREQ
        WRITE (70,6124) LBFREQ
        WRITE (80,6124) LBFREQ
        IFILE = 1
        WRITE (60,6600) IFILE,BNAME4
        WRITE (70,6600) IFILE,BNAME5
        WRITE (80,6600) IFILE,BNAME6
 6600   FORMAT (I5,A50)

        DO 2900 I = 1,LBFREQ
           KEY1 = 1
           KEY2 = 0
           KEY3 = 0
           KEYPAR = 3
           WRITE (60,6605) KEY1,KEY2,KEY3,KEYPAR
           WRITE (70,6605) KEY1,KEY2,KEY3,KEYPAR
           WRITE (80,6605) KEY1,KEY2,KEY3,KEYPAR
 6605      FORMAT (4I5)

           NCASE = 1
           NANG = 90
           BANG = 1.0
           DINC = 1.0
           FLO = FREQ(I)
           FHI = FREQ(I)
           NPTF = 1
           WRITE (60,6610) NCASE,NANG,BANG,DINC,FLO,FHI,NPTF
           WRITE (70,6610) NCASE,NANG,BANG,DINC,FLO,FHI,NPTF
           WRITE (80,6610) NCASE,NANG,BANG,DINC,FLO,FHI,NPTF
 6610      FORMAT (2I5,2F10.2,2F10.2,I5)

           HC3 = -1.0
           HALF1 = 0.0
           HALF3 = 0.0
           CAMN = TNSRMN(NDEPTH,IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
           CATP = TNSRTP(NDEPTH,IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
           CAMX = TNSRMX(NDEPTH,IFPTR(I),2)/(FREQ(IFPTR(I))/1000.)
           WRITE (60,6615) WSPEED,TNSRMN(NDEPTH,IFPTR(I),1),
     +                     HC3,RHOF,DENSMN,HALF1,CAMN,HALF3
           WRITE (70,6615) WSPEED,TNSRTP(NDEPTH,IFPTR(I),1),
     +                     HC3,RHOF,DENSTP,HALF1,CATP,HALF3
           WRITE (80,6615) WSPEED,TNSRMX(NDEPTH,IFPTR(I),1),
     +                     HC3,RHOF,DENSMX,HALF1,CAMX,HALF3
 6615      FORMAT (3F10.2,2F10.3,2F10.8,F10.7)

           WRITE (60,6620) NUMLAY
           WRITE (70,6620) NUMLAY
           WRITE (80,6620) NUMLAY
 6620      FORMAT (I5)

           DO 2899 J = 1,NUMLAY
              WRITE (60,6625) TNSRMN(IDPTR(J),IFPTR(I),1),DENSMN
              WRITE (70,6625) TNSRTP(IDPTR(J),IFPTR(I),1),DENSTP
              WRITE (80,6625) TNSRMX(IDPTR(J),IFPTR(I),1),DENSMX
              CAMN = TNSRMN(IDPTR(J),IFPTR(I),2) /
     +               (FREQ(IFPTR(I))/1000.)
              CATP = TNSRTP(IDPTR(J),IFPTR(I),2) /
     +               (FREQ(IFPTR(I))/1000.)
              CAMX = TNSRMX(IDPTR(J),IFPTR(I),2) /
     +               (FREQ(IFPTR(I))/1000.)
```

```
                 WRITE (60,6625) CAMN,THICK(J)
                 WRITE (70,6625) CATP,THICK(J)
                 WRITE (80,6625) CAMX,THICK(J)
 6625            FORMAT (2F10.4)
 2899          CONTINUE

 2900        CONTINUE
         END IF

         WRITE (10,6029) TITLE
 6029    FORMAT (A7,'  PROFILE')
         WRITE (10,6023)

         WRITE (10,6030) MTPVAL,SCRTYP,MAXVAL,SCRMAX
 6030    FORMAT ('SCORE ',I4,' TYPICAL = ',G12.4,
     +        '    SCORE ',I4,' MAXIMUM = ',G12.4)
         WRITE (10,6031) MSAME,SCRNEW,MINVAL,SCRMIN
 6031    FORMAT ('SCORE ',I4,' NEW     = ',G12.4,
     +        '    SCORE ',I4,' MINIMUM = ',G12.4)
         WRITE (10,6095) NDEPTH
 6095    FORMAT (I2)
         DO 250 I = 1,NDEPTH
            WRITE (10,6075) DEPTH(I), AW(I)
 6075       FORMAT ('DEPTH ',F9.3,' WEIGHT FACTOR = ',F4.2)
  250    CONTINUE
         WRITE (10,6095) NFREQ
         DO 260 I = 1,NFREQ
            WRITE (10,6080) FREQ(I), BW(I)
 6080       FORMAT ('FREQUENCY ',F9.3,' WEIGHT FACTOR = ',F4.2)
  260    CONTINUE
         WRITE (10,6023)
         DO 270 I = 1,4
            WRITE (10,6085) PARNAM(I), CW(I)
 6085       FORMAT ('PARAMETER ',A2,' WEIGHT FACTOR = ',F4.2)
  270    CONTINUE

         WRITE (10,6023)
         WRITE (10,6090)
 6090    FORMAT (6X,'DEPTH(I)',4X,'FREQUENCY(J)',4X,'PARAMETER(K)',
     +          7X,'TMEAN',11X,'TRTVAR',10X,'TNSRMN',10X,'TNSRTP',
     +          10X,'TNSRMX')
         WRITE (10,6023)
         DO 300 I = 1,NDEPTH
            DO 300 J = 1,NFREQ
               DO 300 K = 1,4
                  WRITE (10,6035) I,J,K,TMEAN(I,J,K),TRTVAR(I,J,K),
     +                            TNSRMN(I,J,K),TNSRTP(I,J,K),
     +                            TNSRMX(I,J,K)
 6035             FORMAT (9X,I2,12X,I2,14X,I1,10X,5(E13.7,3X))
  300    CONTINUE

         CLOSE (20)
         CLOSE (10)

         STOP
         END
```

APPENDIX B

Table B-1. Province Name Code

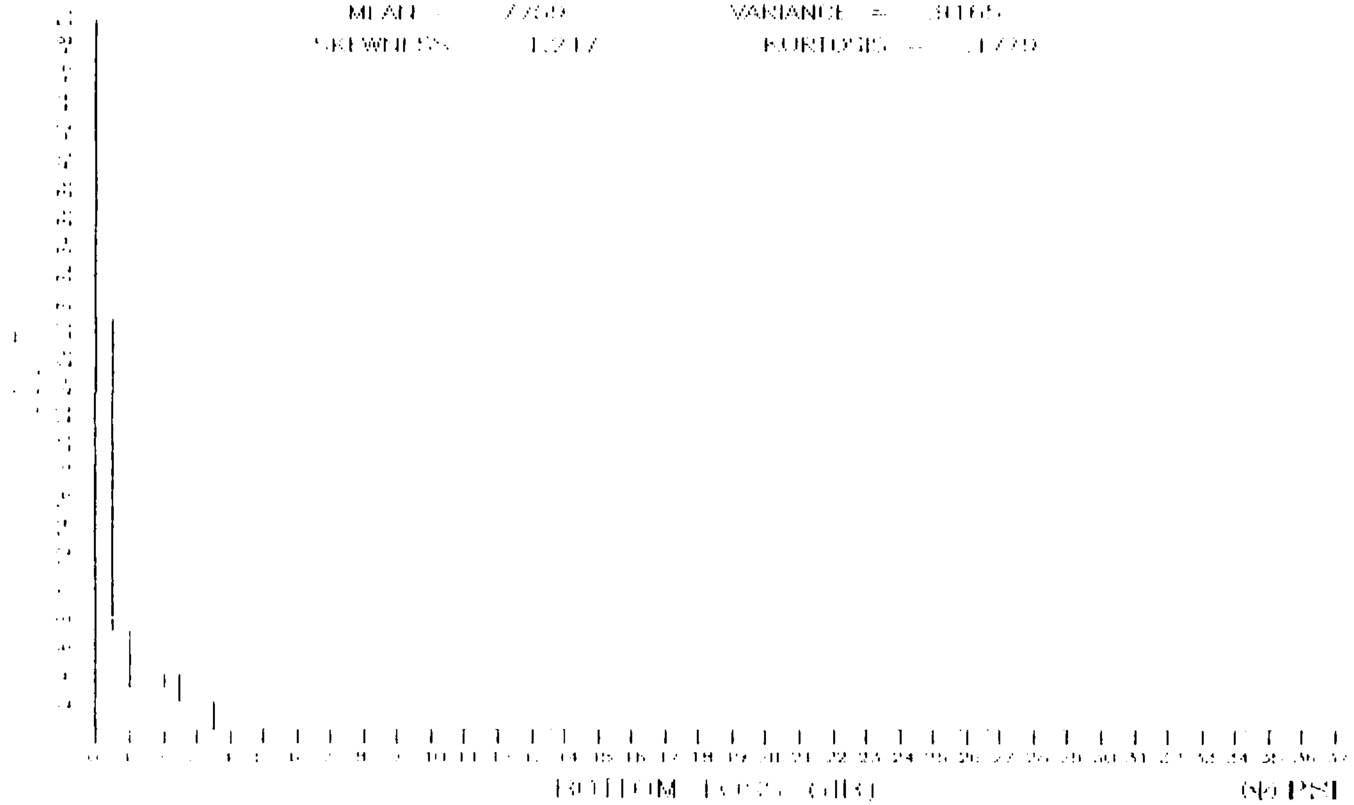
First Letter (seafloor depth)		**Second Letter (grain size type)**		
Letter	Depth Interval (m)	Letter	Name(s)	Class Number (s)
A	0-200	A	Sand	1
		B	Silty sand	2
B	201-2000		Muddy sand	3
			Clayey sand	4
C	2001-4000	C	Sandy silt	5
			Sandy mud	6
			Sandy clay	7
Z	All depths			
		D	Silt	8
		E	Mud	9
			Clay	10
		Z	All size types	1 thru 10

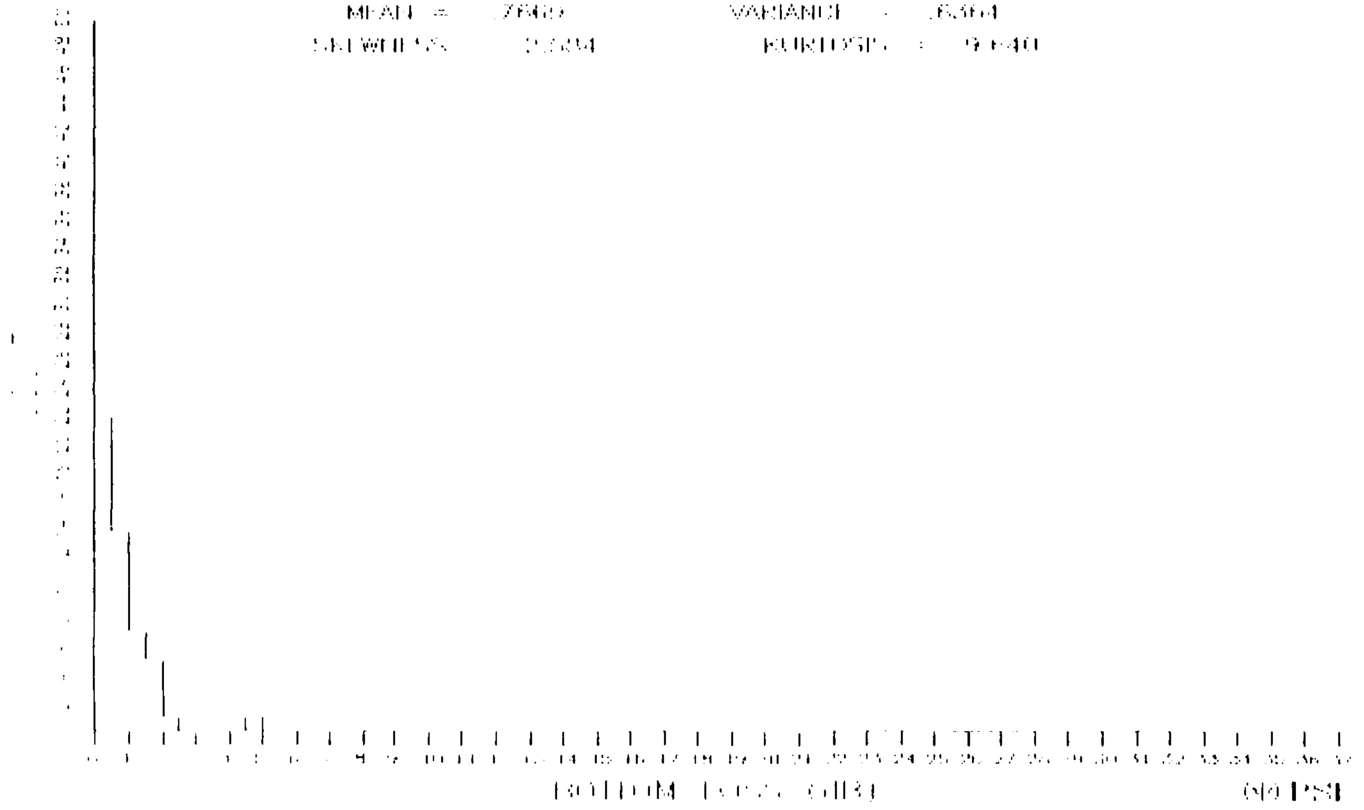
PROVINCE: AAZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = .7759 VARIANCE = .3165

SKEWNESS = 1.217 KURTOSIS = .1779





PROVINCE: AAZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = .7869 VARIANCE = .6364

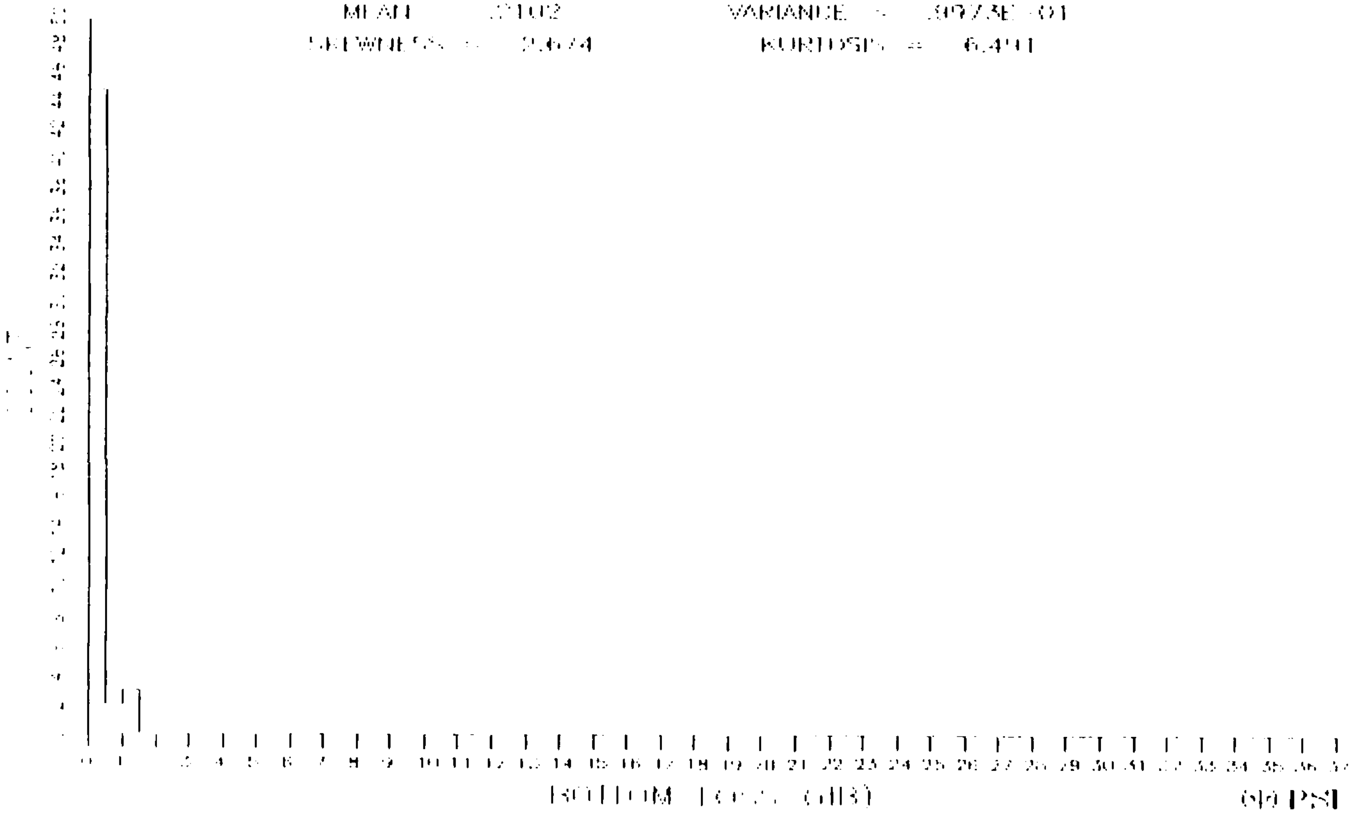
SKEWNESS = 2.284 KURTOSIS = 9.640

PROVINCE: ABZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = .0102 VARIANCE = .3973E-01

SKEWNESS = 2.674 KURTOSIS = 6.491

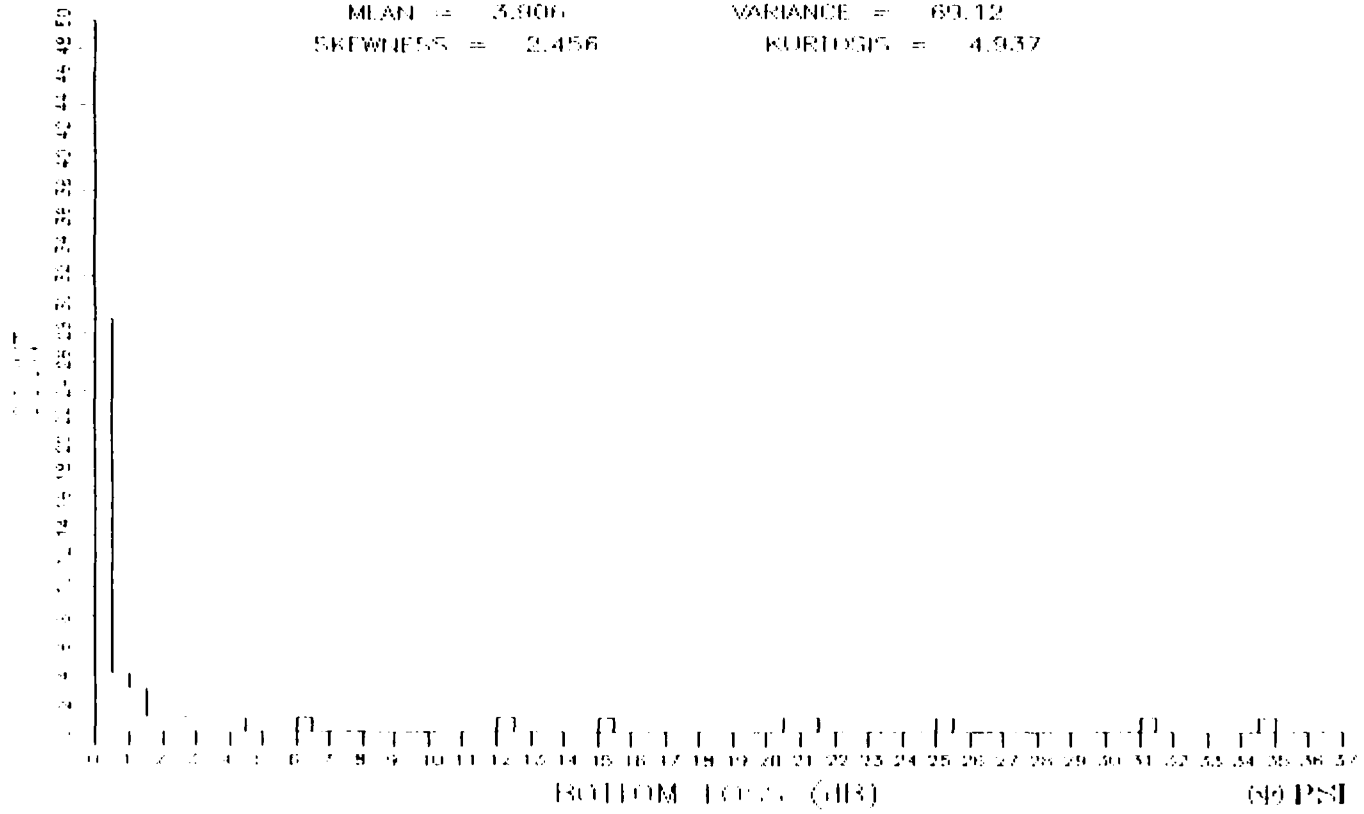


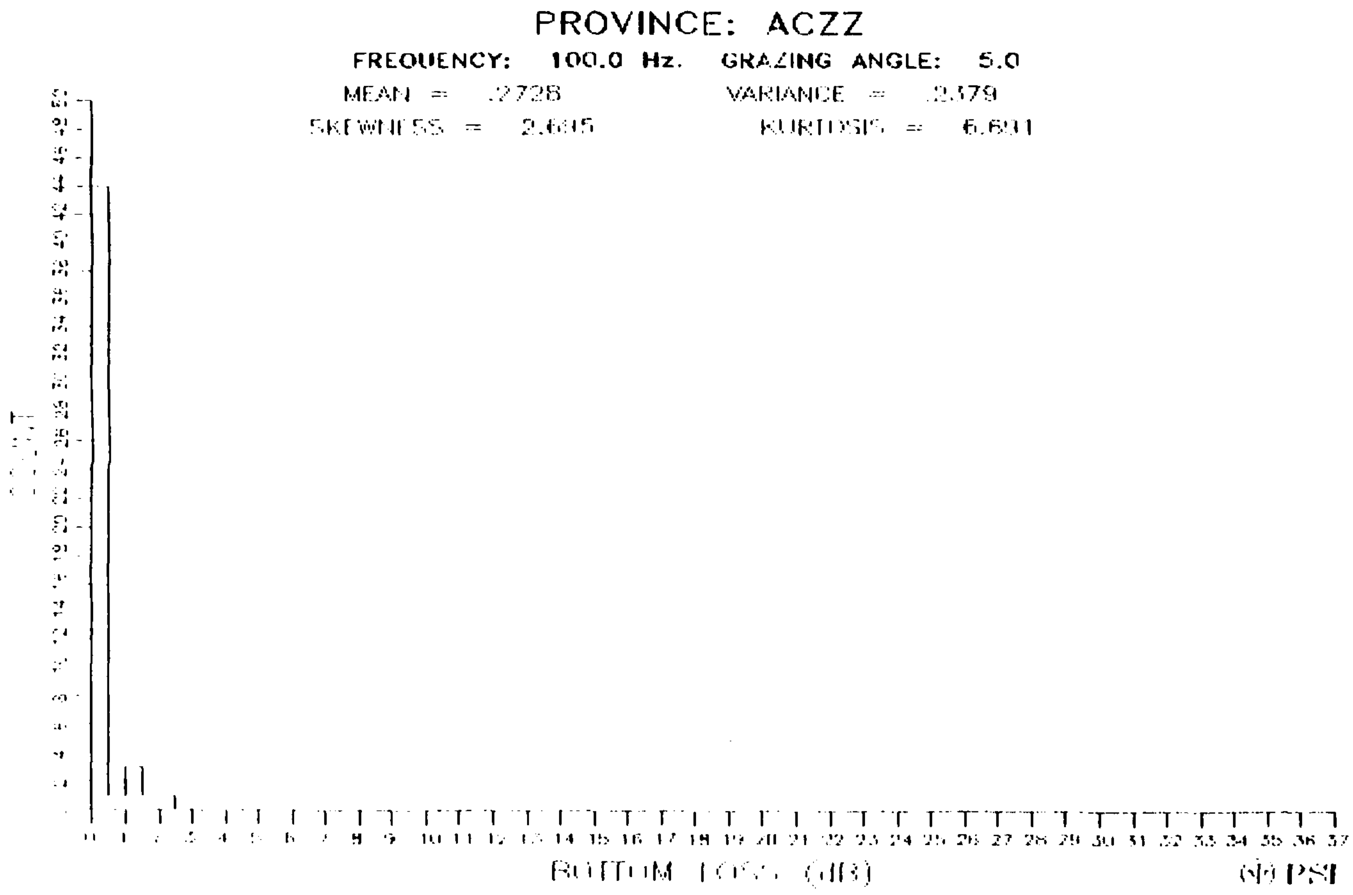
PROVINCE: ABZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 3.906 VARIANCE = 69.12

SKEWNESS = 2.456 KURTOSIS = 4.937



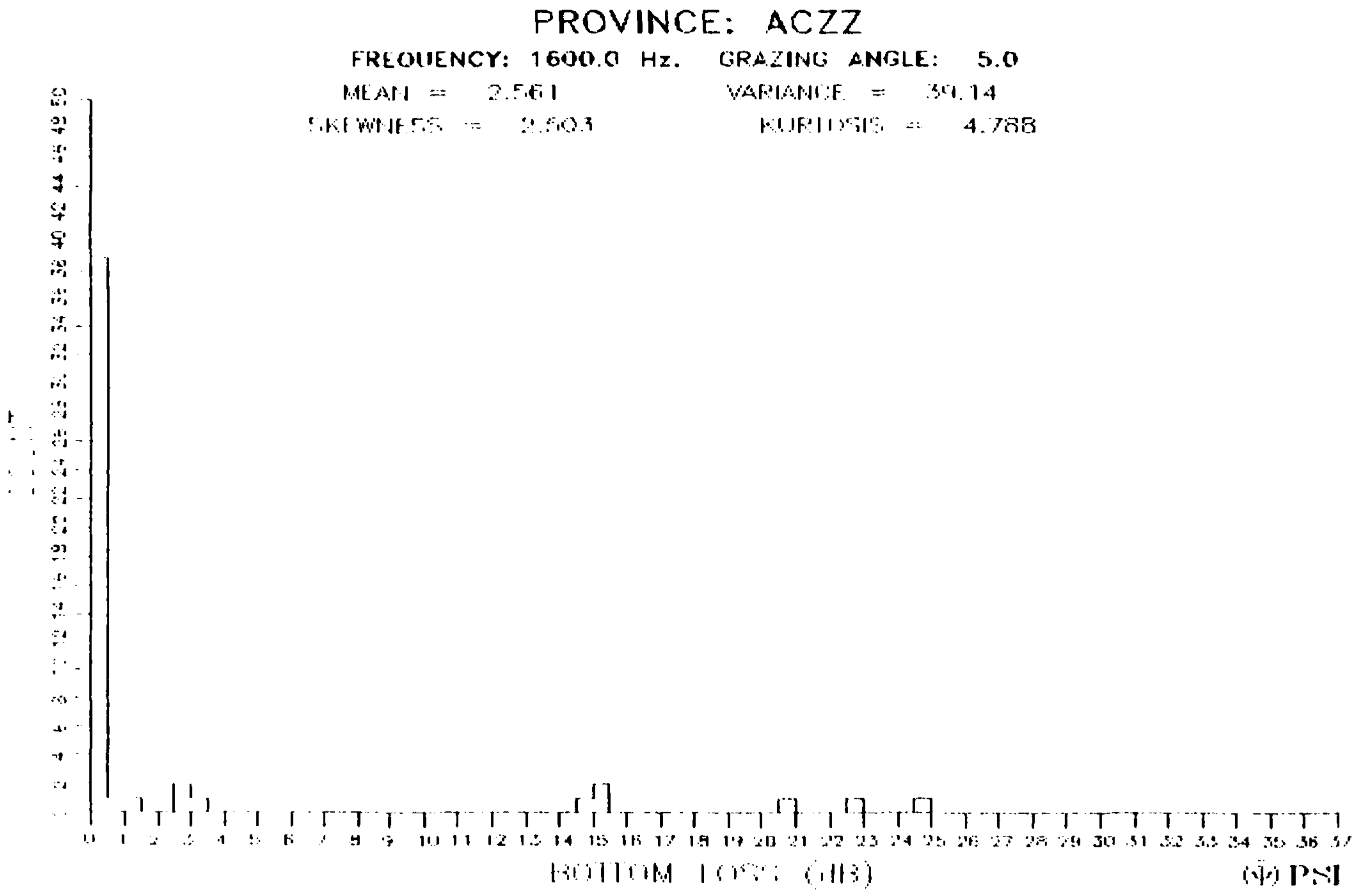


PROVINCE: ACZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = .2728 VARIANCE = .2379

SKEWNESS = 2.605 KURTOSIS = 6.691



PROVINCE: ACZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 2.561 VARIANCE = 39.14

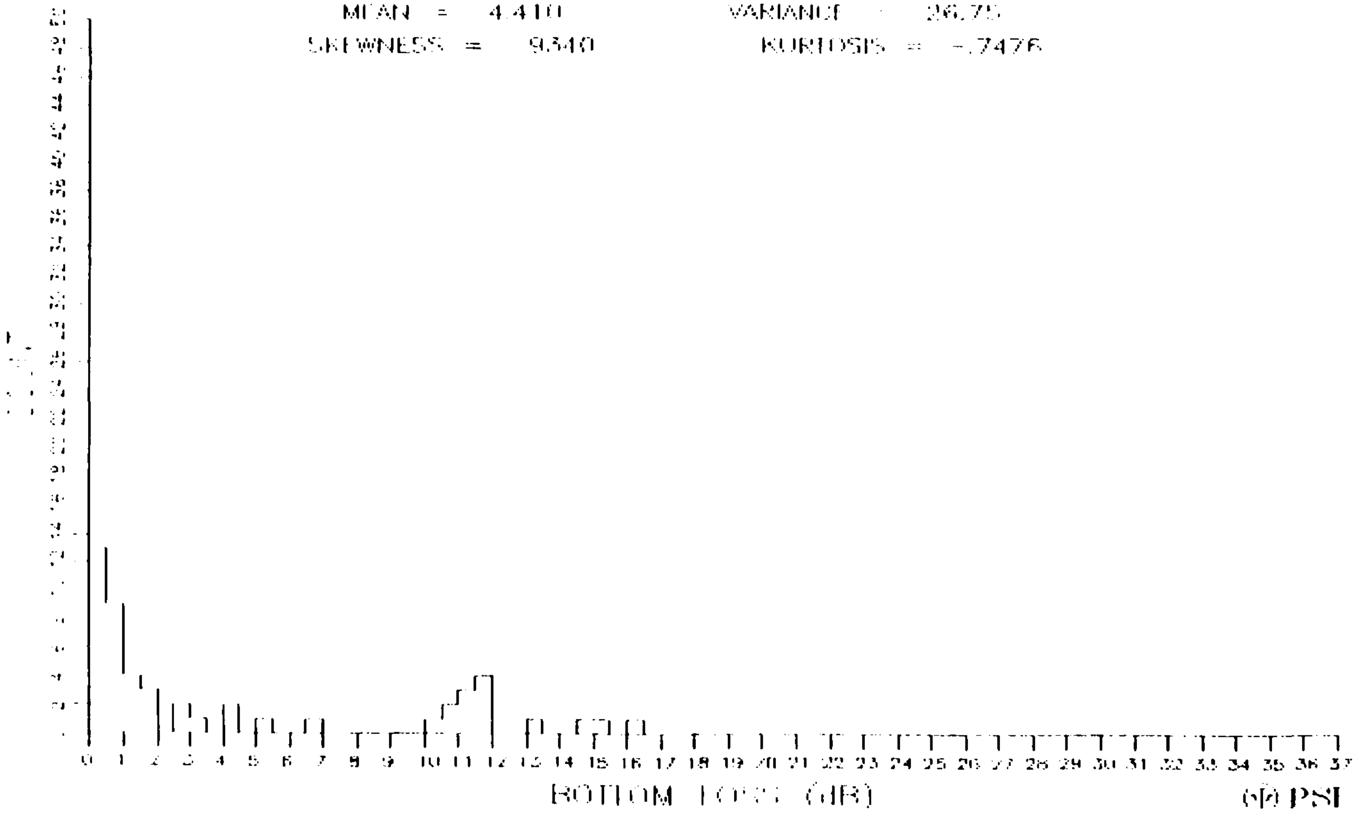
SKEWNESS = 2.503 KURTOSIS = 4.788

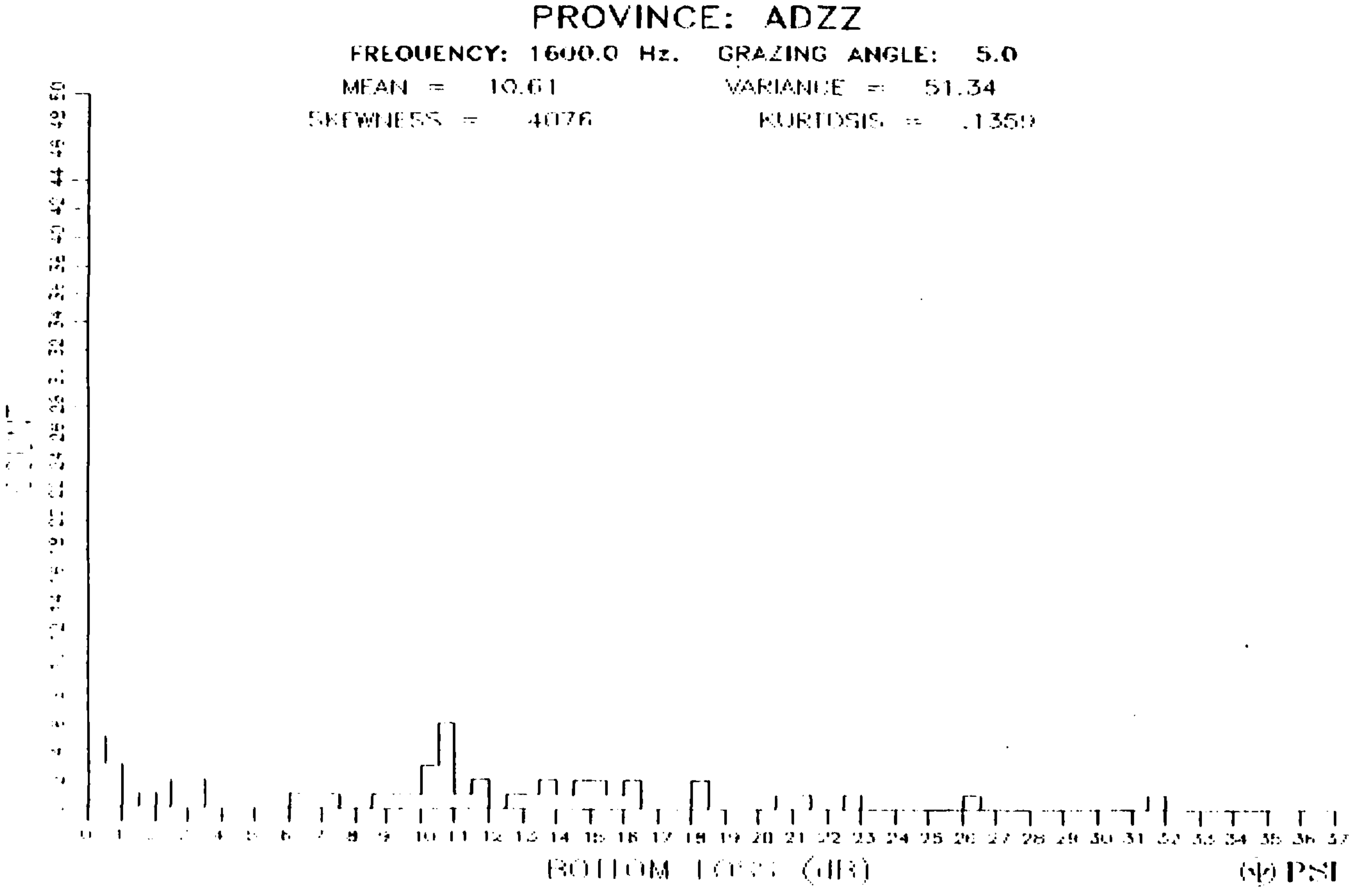
PROVINCE: ADZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 4.410 VARIANCE = 26.75

SKEWNESS = .9340 KURTOSIS = -.7476





PROVINCE: ADZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 10.61 VARIANCE = 51.34

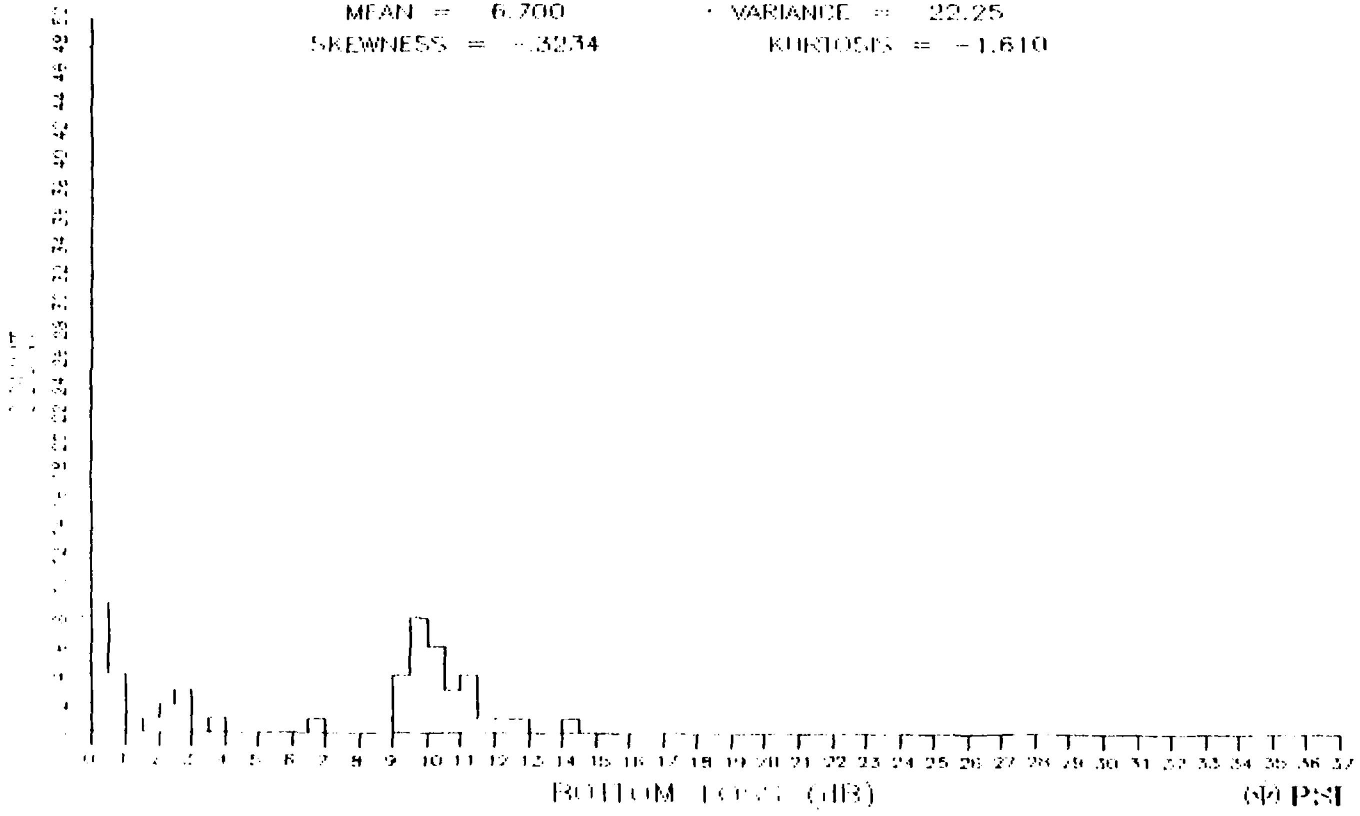
SKEWNESS = 4076 KURTOSIS = .1359

PROVINCE: AEZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 6.700 VARIANCE = 22.25

SKEWNESS = -.3234 KURTOSIS = -1.610

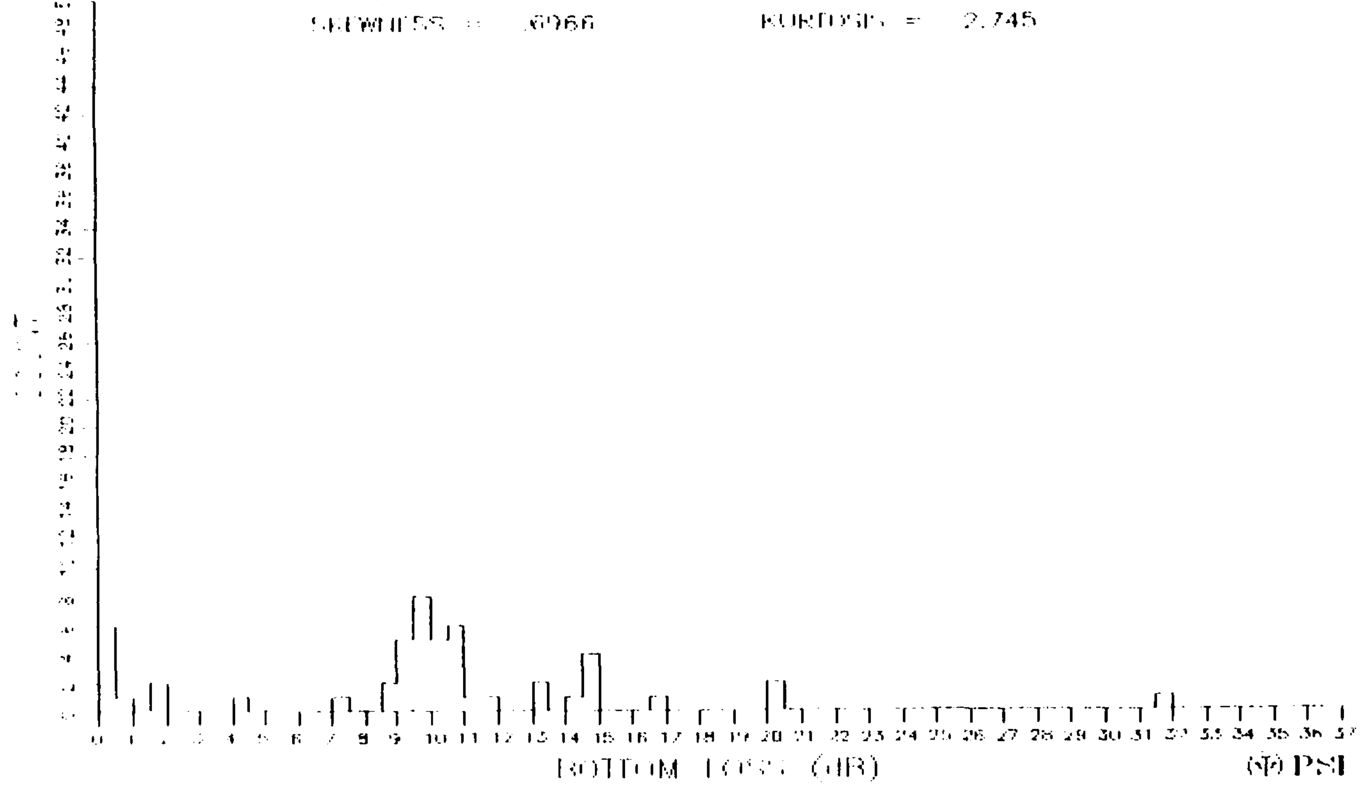


PROVINCE: AEZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 9.689 VARIANCE = 34.61

SKEWNESS = .6066 KURTOSIS = 2.745

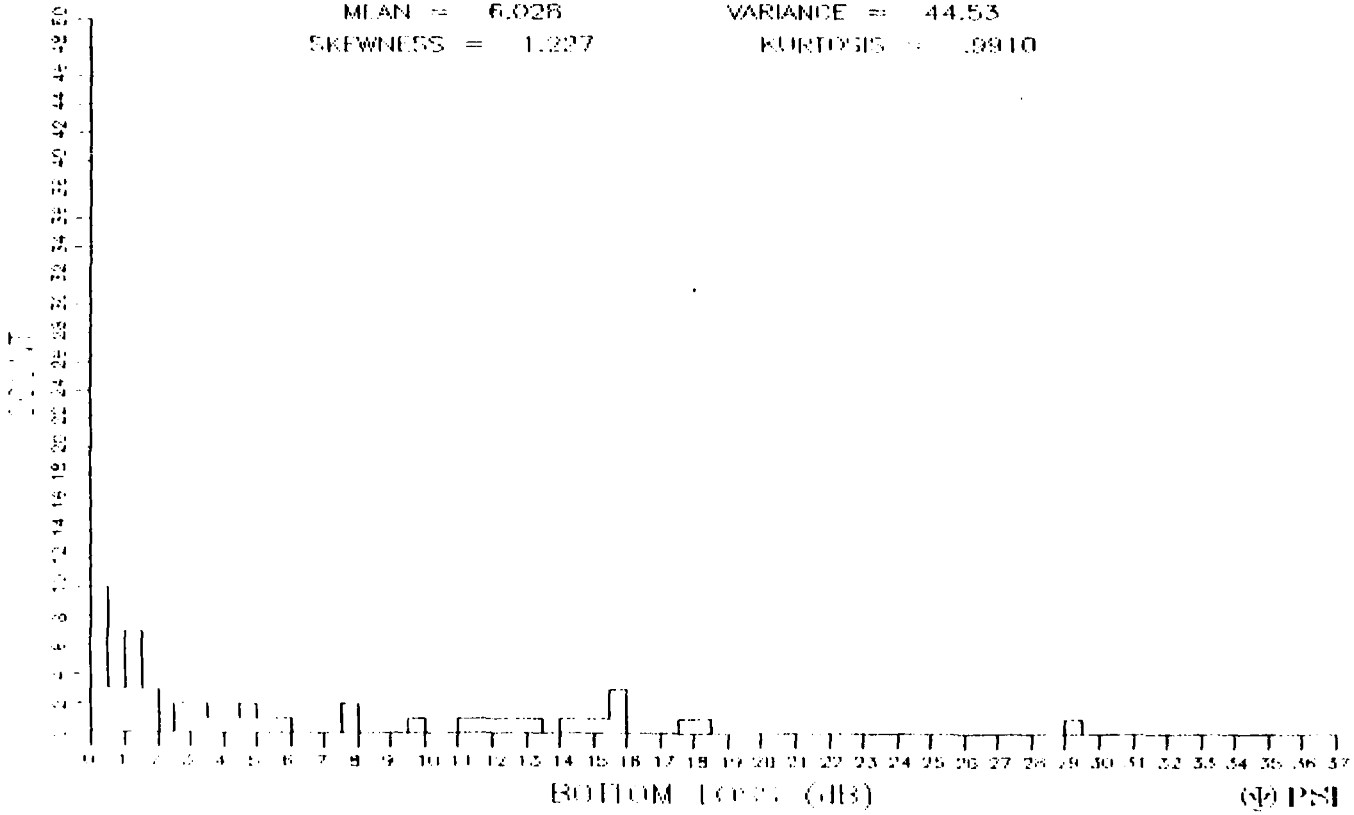


PROVINCE: BAZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 6.028 VARIANCE = 44.53

SKEWNESS = 1.227 KURTOSIS = .9910

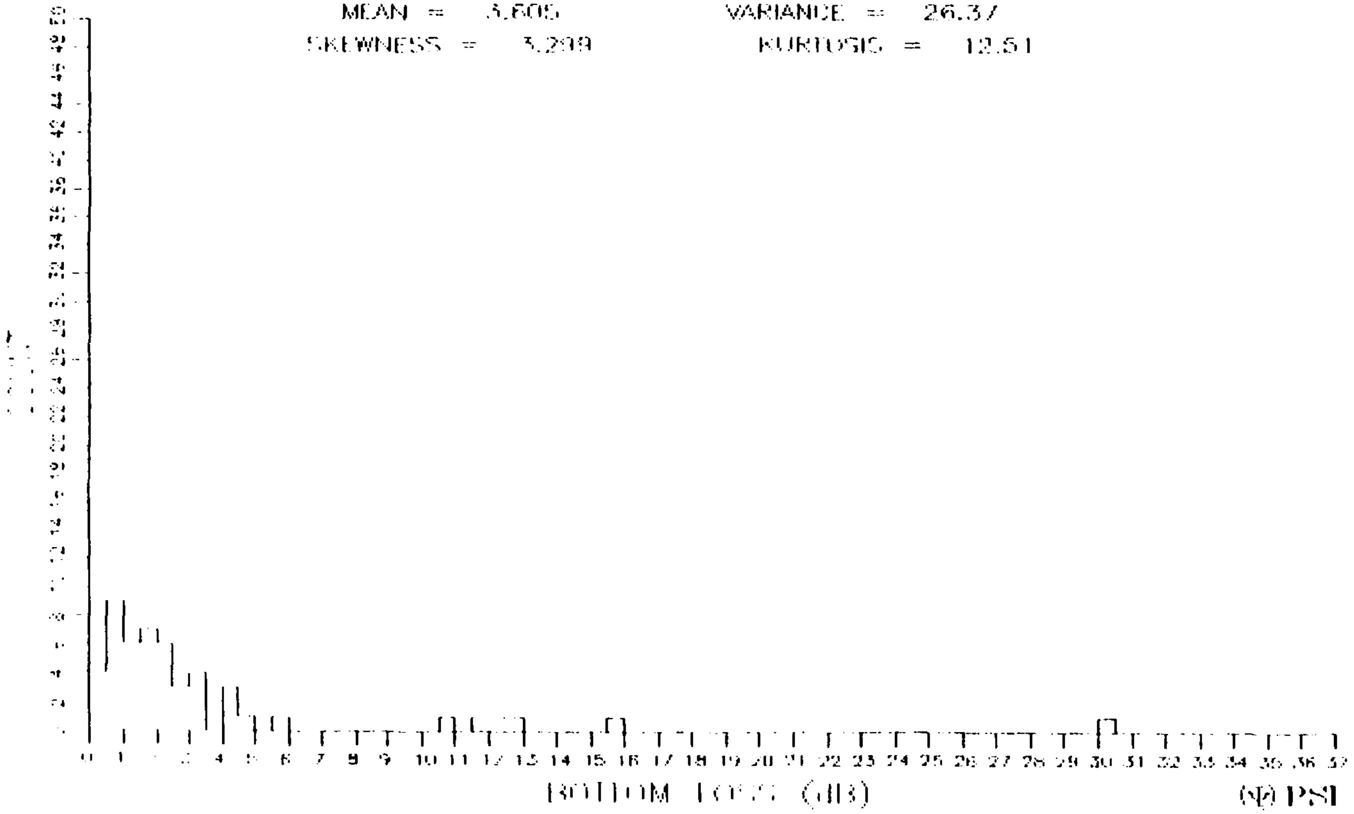


PROVINCE: BAZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 5.605 VARIANCE = 26.37

SKEWNESS = 3.299 KURTOSIS = 12.51

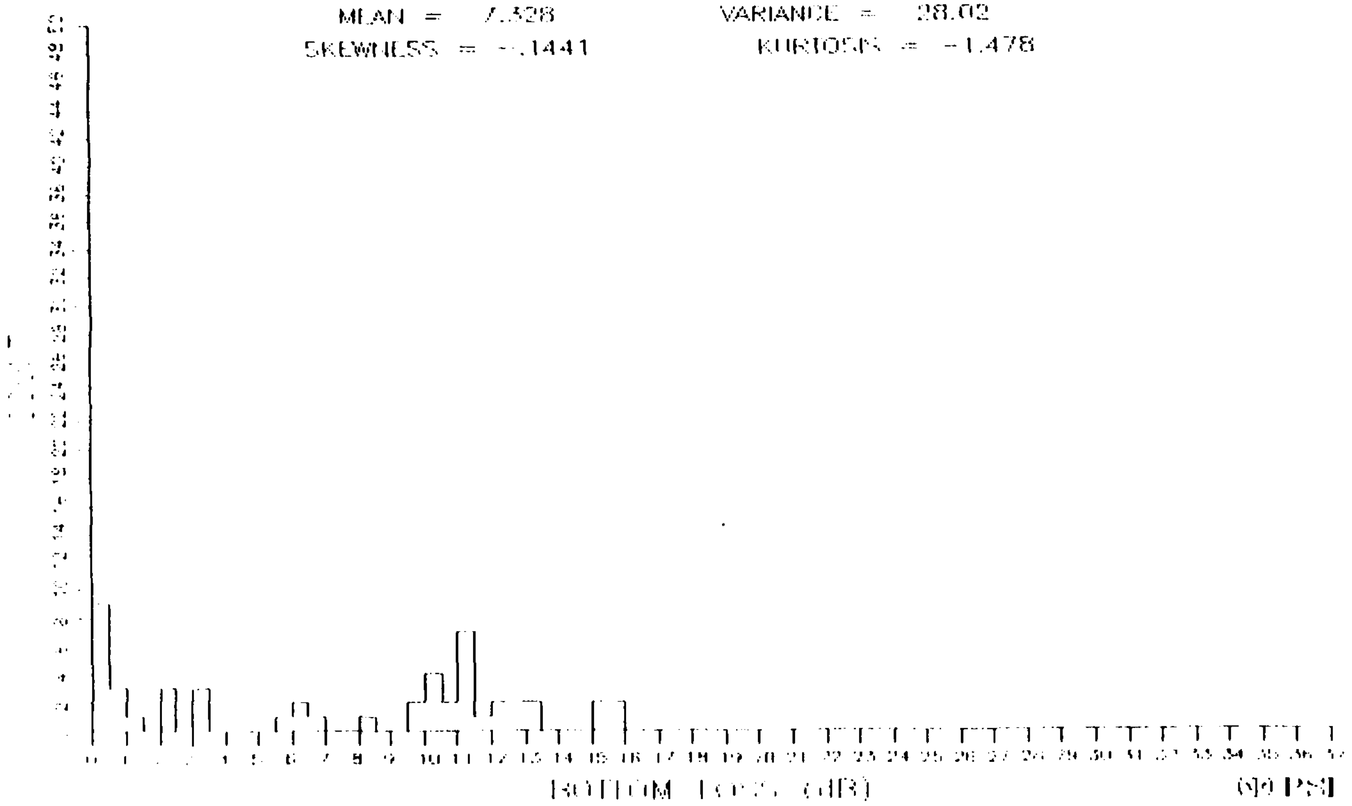


PROVINCE: BBZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 7.328 VARIANCE = 28.02

SKEWNESS = -.1441 KURTOSIS = -1.478

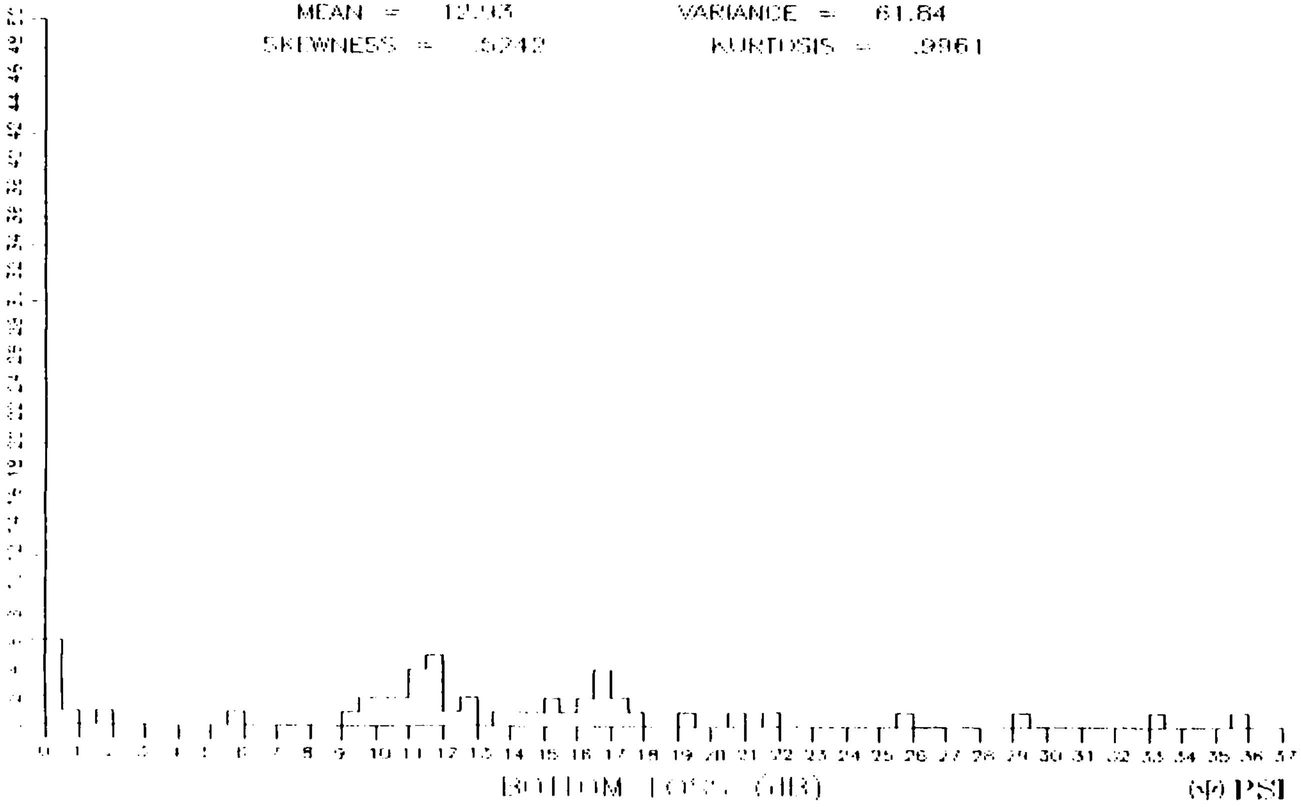


PROVINCE: BBZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 12.93 VARIANCE = 61.84

SKEWNESS = .5242 KURTOSIS = .9961

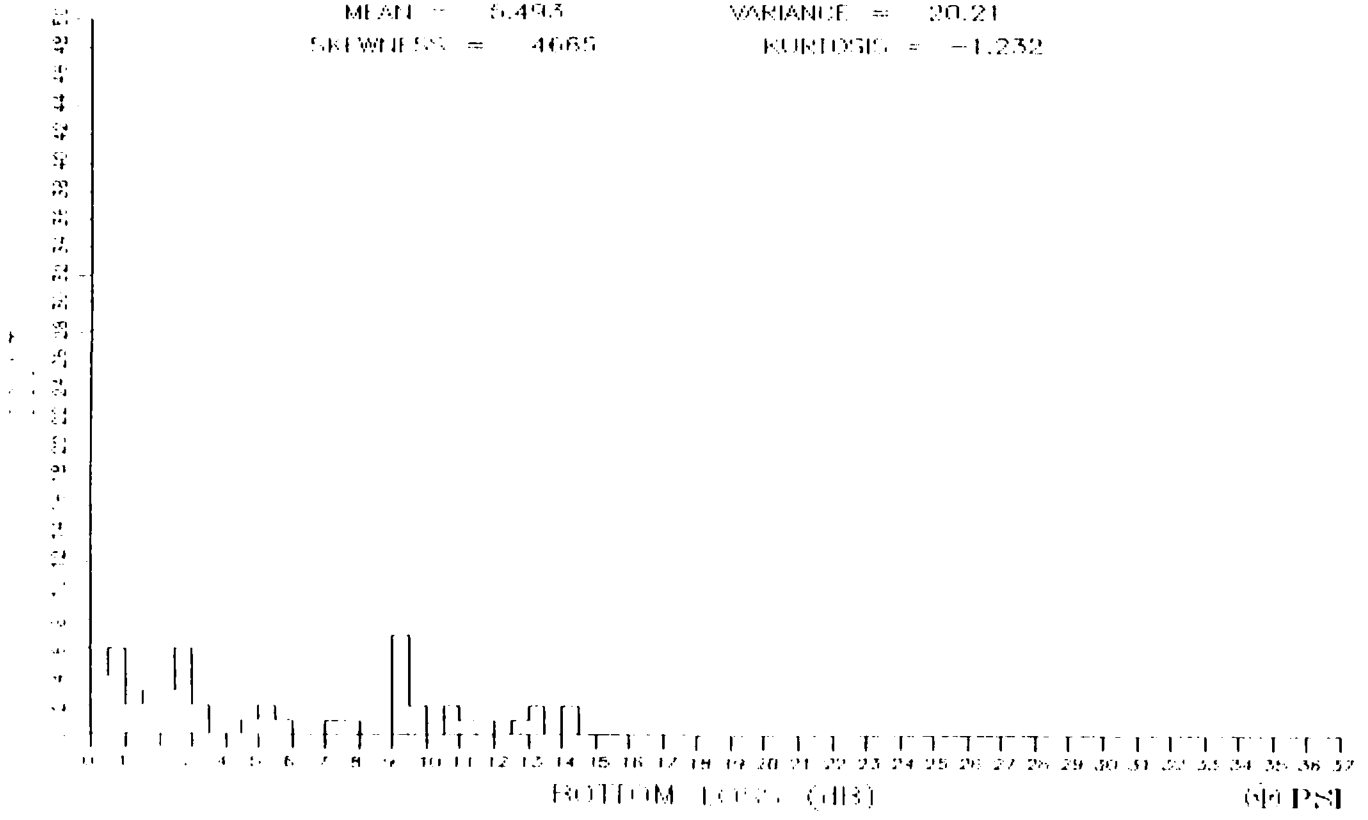


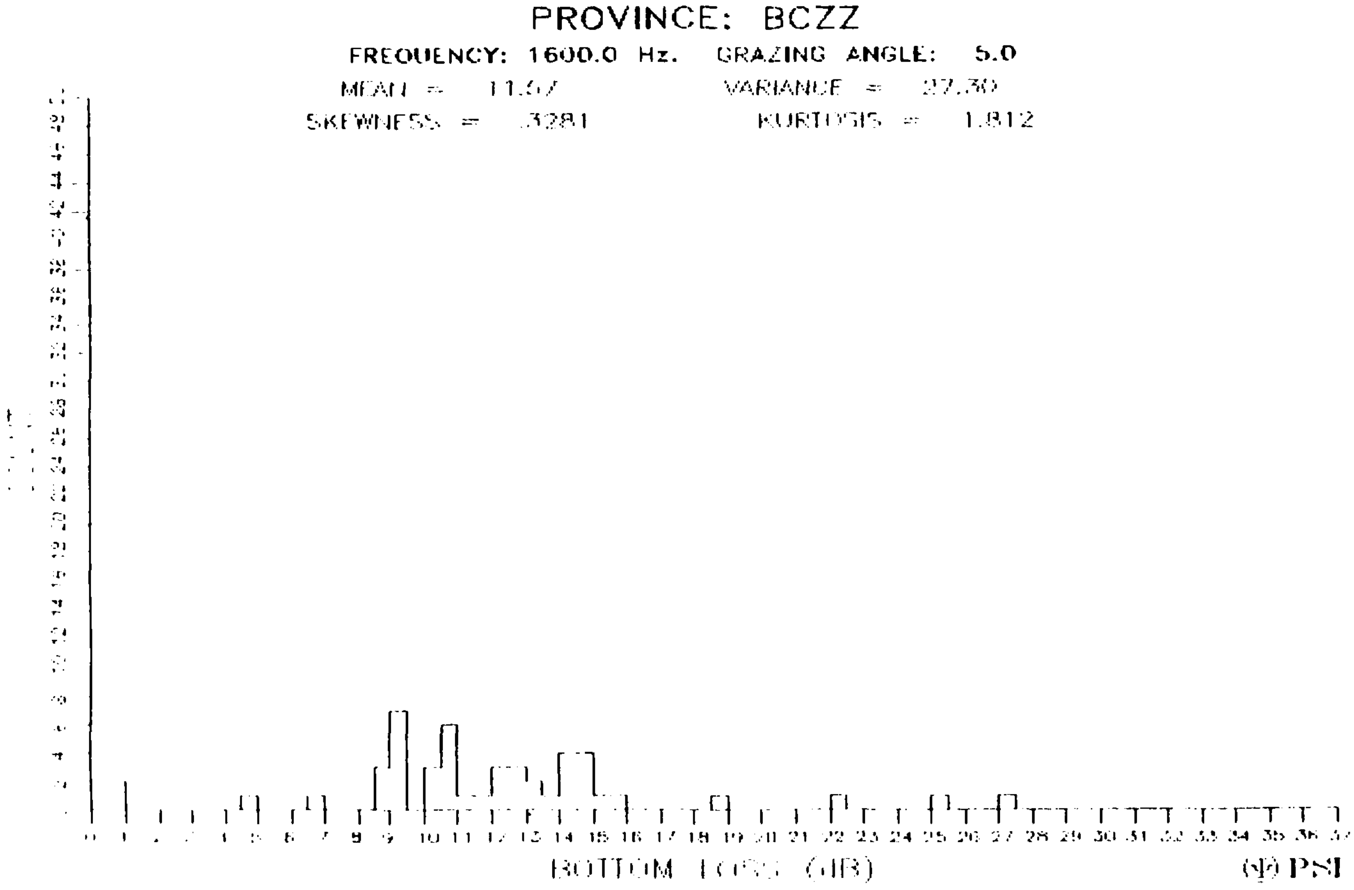
PROVINCE: BCZZ

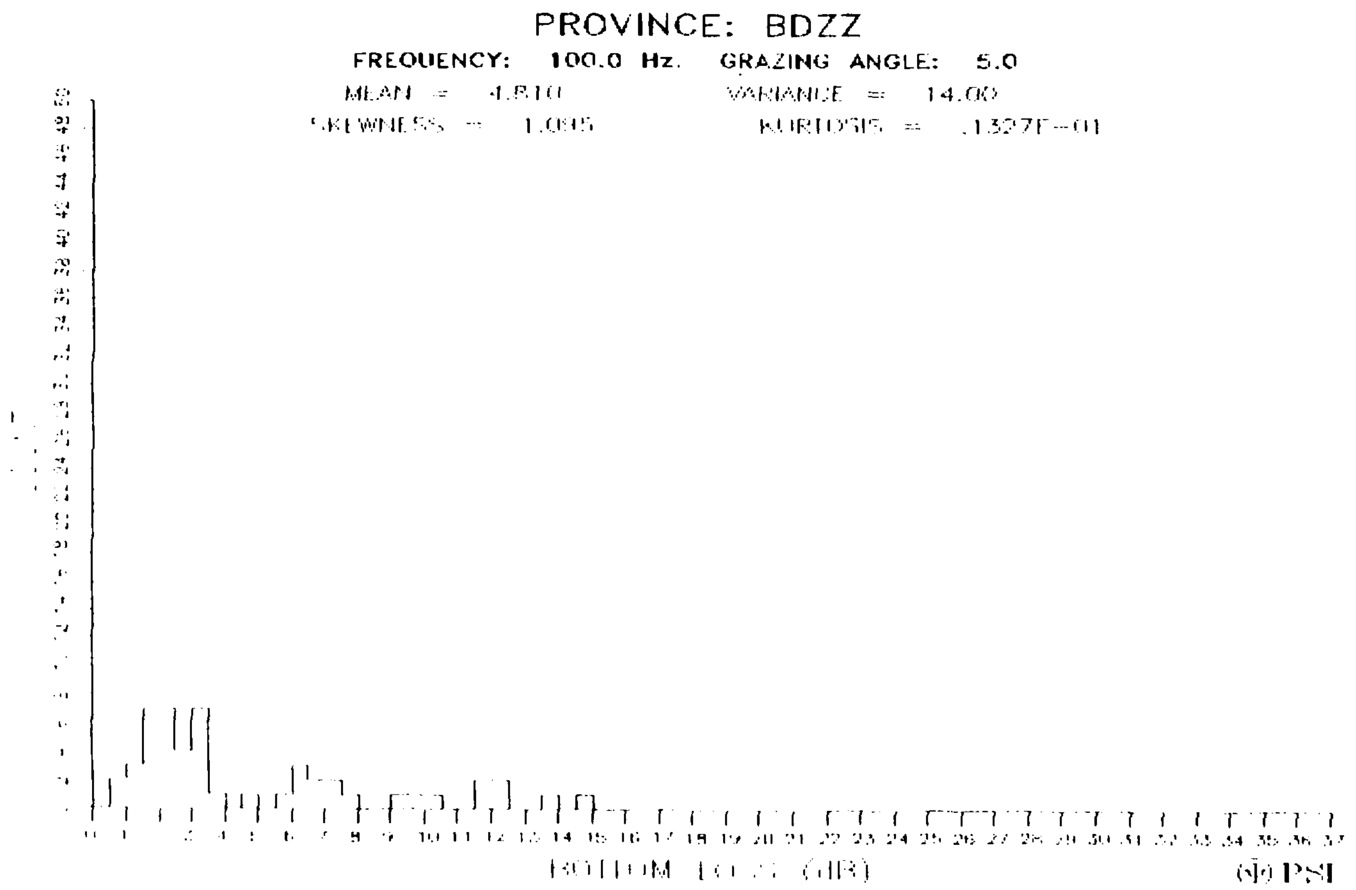
FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 5.493 VARIANCE = 20.21

SKEWNESS = 4665 KURTOSIS = −1.232




PROVINCE: BCZZ
FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0
MEAN = 11.67
VARIANCE = 27.30
SKEWNESS = .3281
KURTOSIS = 1.812
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
BOTTOM LOSS (dB)
PSI



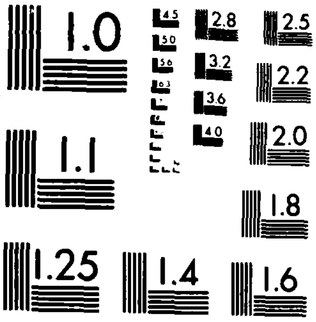
PROVINCE: BDZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 4.810 VARIANCE = 14.00

SKEWNESS = 1.085 KURTOSIS = .1327E-01

AD-A173 821 THE PRECISION OF BOTTOM LOSS PREDICTIONS FROM A 3/3
PHYSICAL SEDIMENT MODEL(U) PLANNING SYSTEMS INC MCLEAN
VA E J MOLINELLI ET AL. 31 AUG 86 TR-291343
UNCLASSIFIED N00014-83-C-0650 F/G 20/1 NL



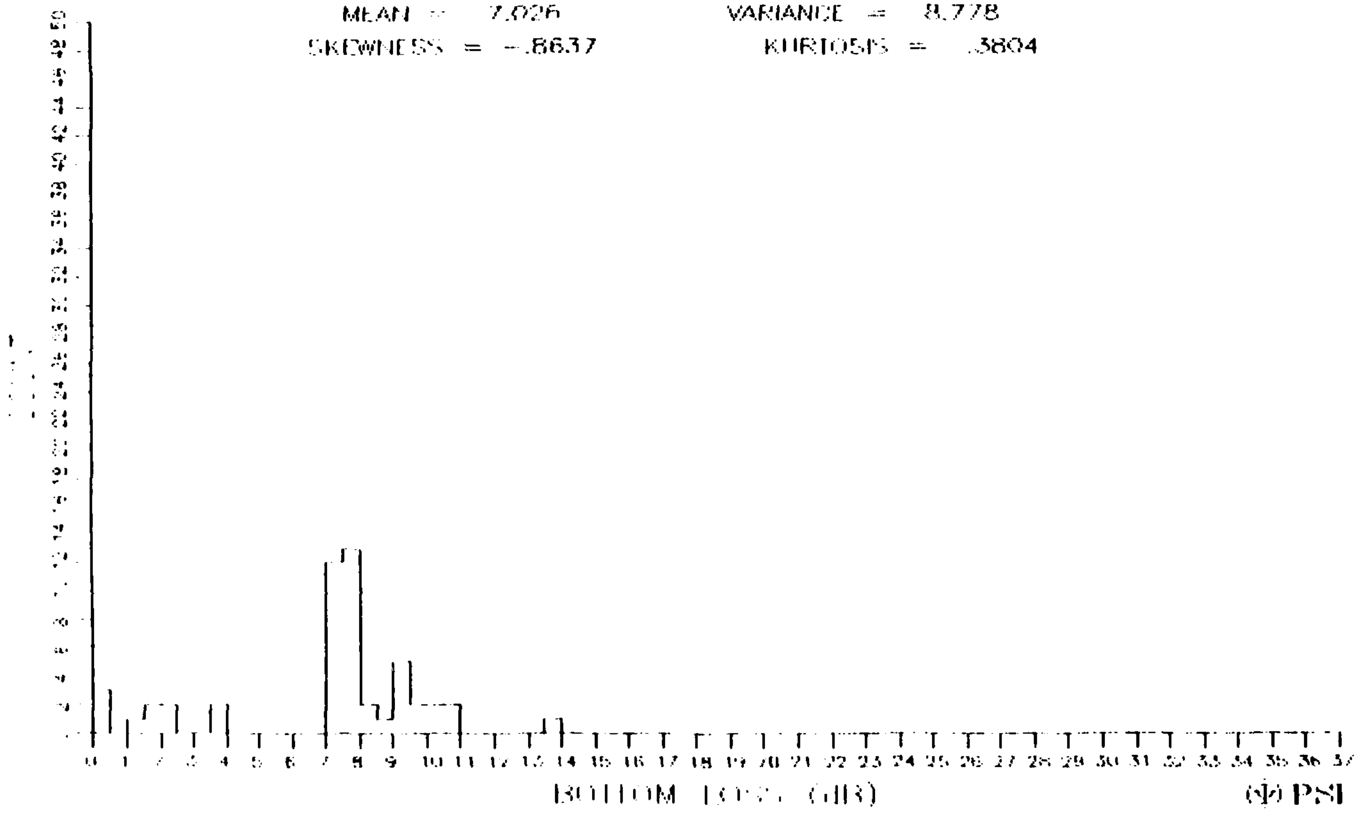
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

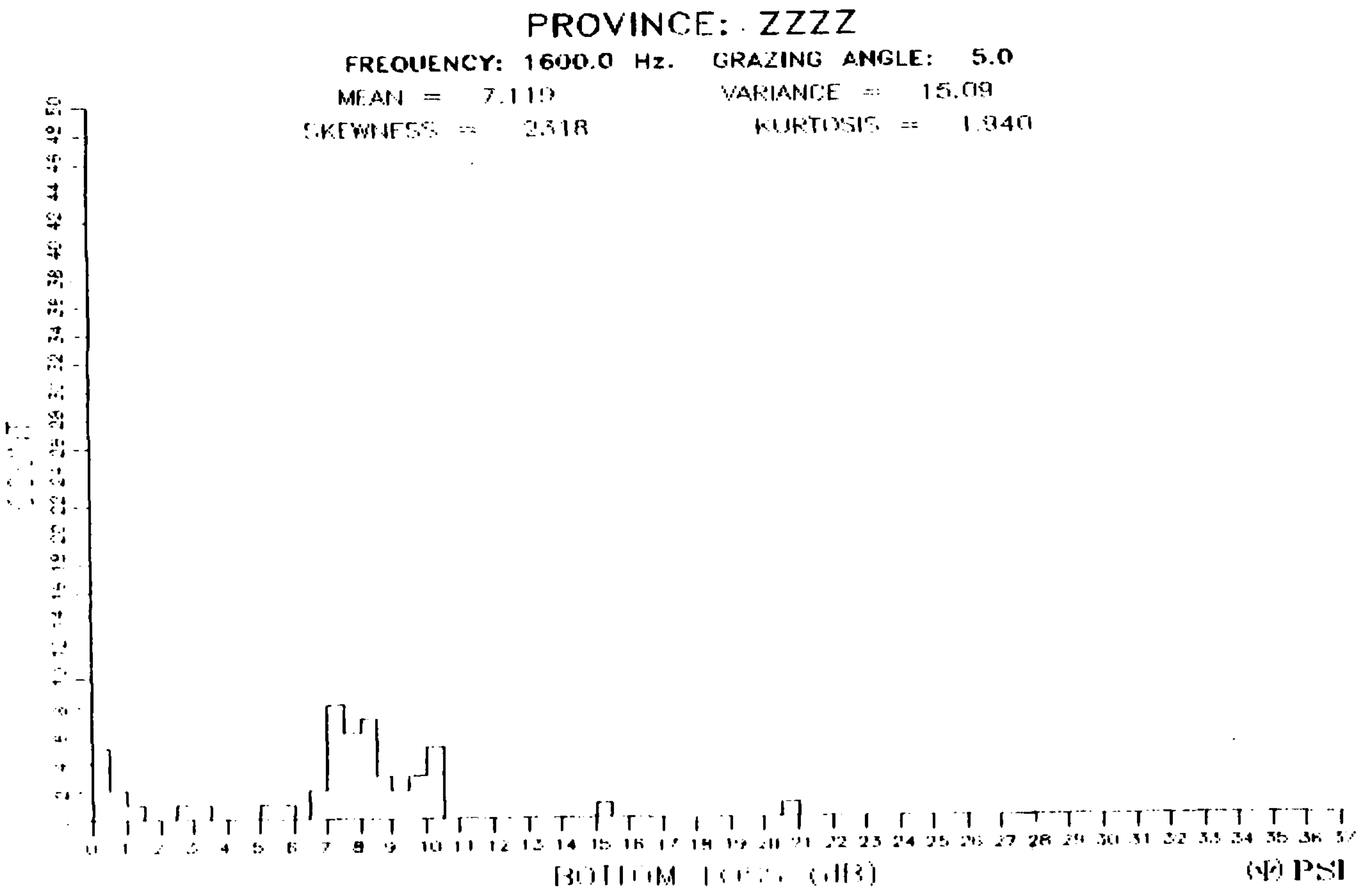
PROVINCE: BEZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 7.026 VARIANCE = 8.778

SKEWNESS = -.8637 KURTOSIS = .3804





PROVINCE: ZZZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 7.119 VARIANCE = 15.09

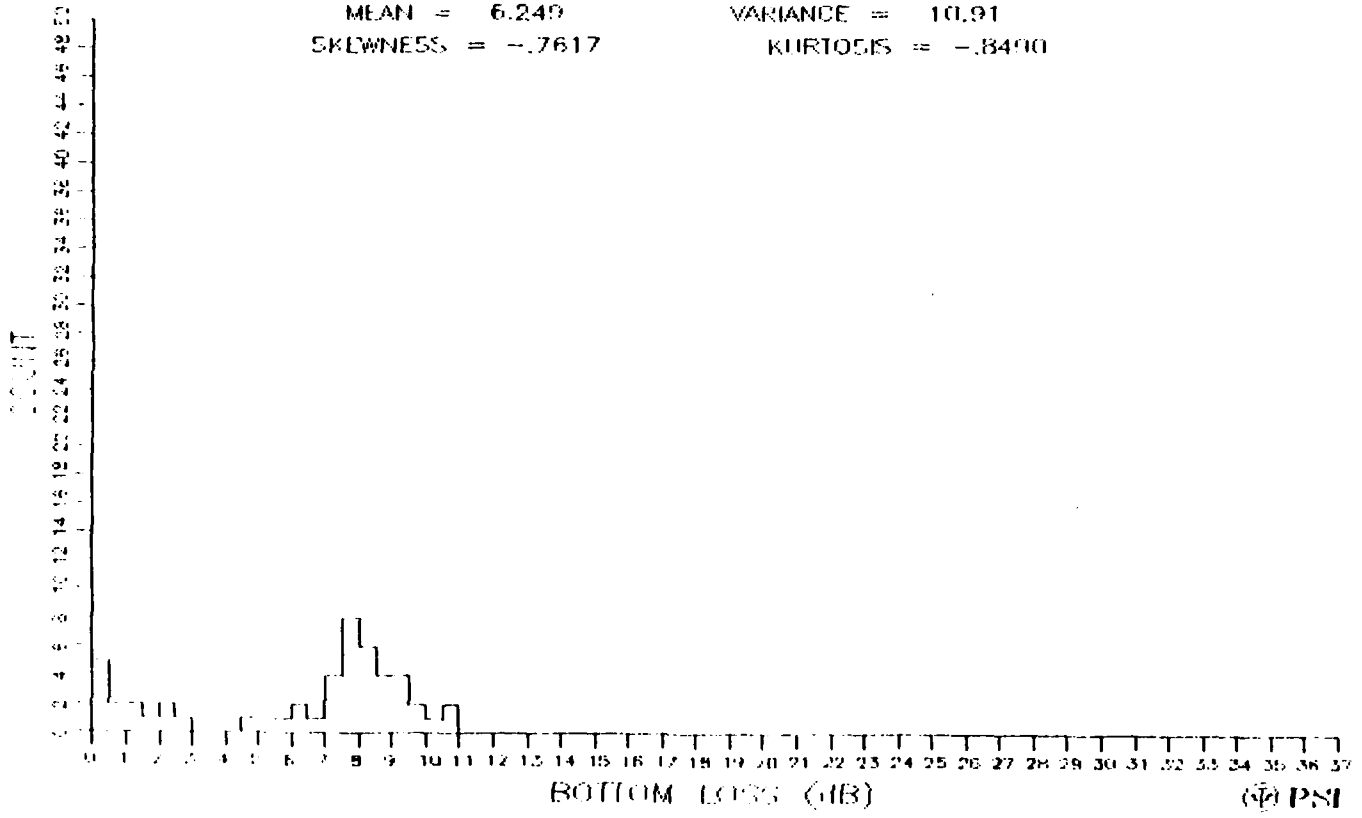
SKEWNESS = 2.318 KURTOSIS = 1.940

PROVINCE: ZZZZ

FREQUENCY: 100.0 Hz. GRAZING ANGLE: 5.0

MEAN = 6.249 VARIANCE = 10.91

SKEWNESS = -.7617 KURTOSIS = -.8490

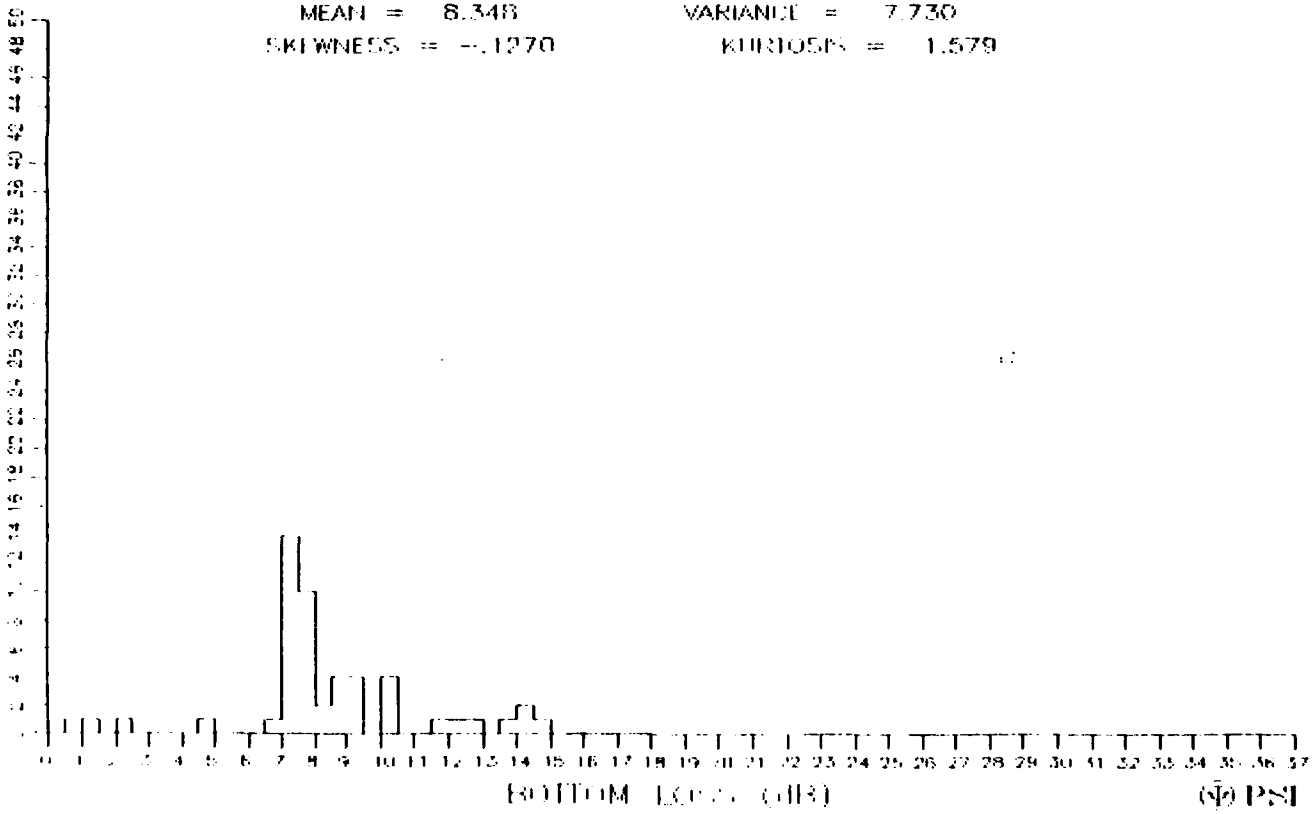


PROVINCE: BEZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 8.348 VARIANCE = 7.730

SKEWNESS = -.1270 KURTOSIS = 1.579

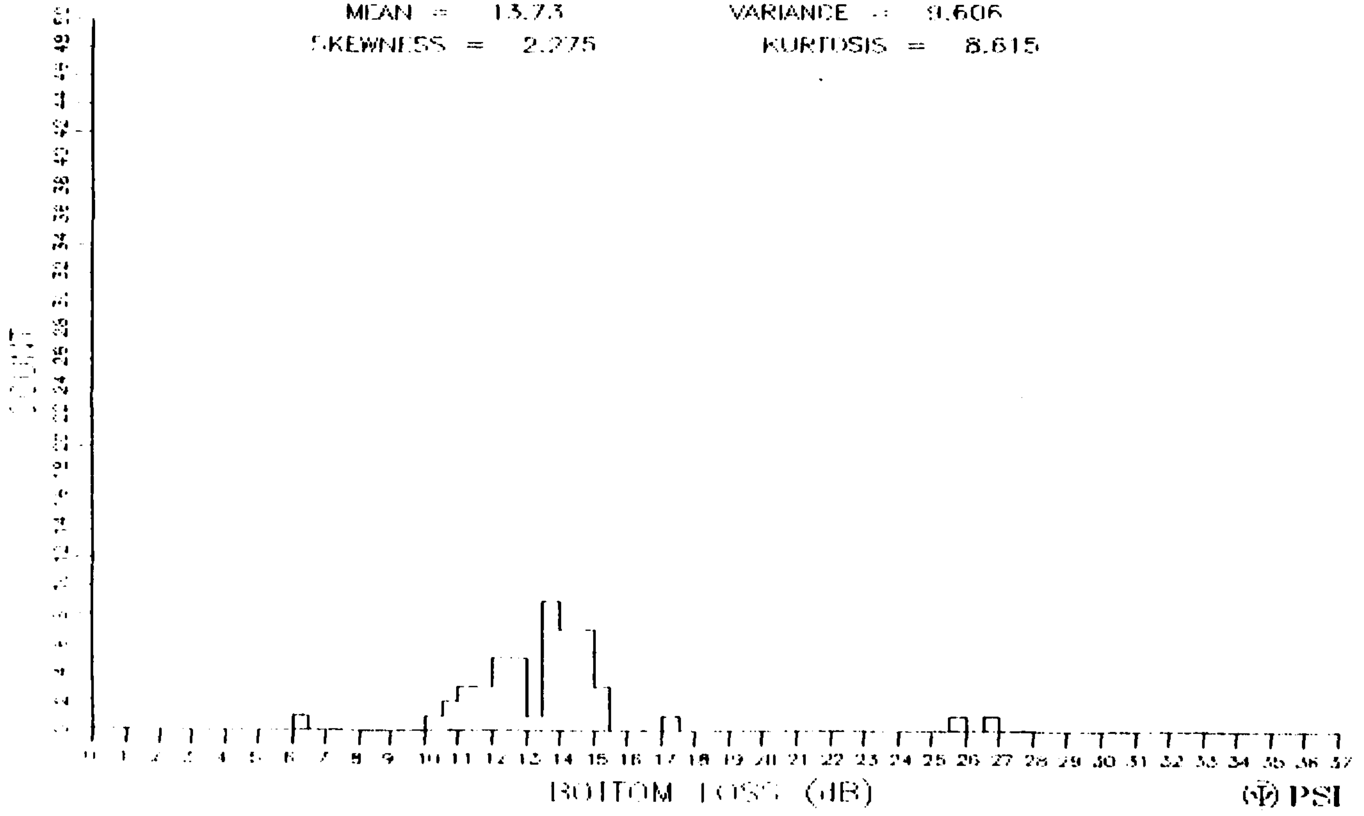


PROVINCE: BDZZ

FREQUENCY: 1600.0 Hz. GRAZING ANGLE: 5.0

MEAN = 13.73 VARIANCE = 9.606

SKEWNESS = 2.275 KURTOSIS = 8.615



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Ocean, Bottom loss, continental terrace, modeling, ASW, seafloor, geoacoustic properties, sediment properties

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

Ocean acoustic signals and noise characteristics can be significantly affected by interaction with the seafloor. One common means of quantifying those effects in terms of the sonar equations is bottom loss (BL). BL can be measured directly or computed from profiles of the geoacoustic parameters density, compressional speed and compressional attenuation. The geoacoustic properties can be derived from physical properties of the

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sediments, which are more readily available, using a physical sediment model (Biot/Stoll or PHYSED) based on the Biot theory of acoustic propagation in porous media.

Here we predict BL for sediments on the continental terrace and evaluate those predictions in terms of their precision. We use readily available physical properties assembled into the data base PHYPROSE, with the PHYSED model to produce geoacoustic profiles for the calculation of BL by the computer program REFLEC. We divide continental terrace sediments into provinces based on water depth ranges (shelf = 0 to 200 m, slope = 200 to 2000 m and rise = 2000 to 4000 m) and grain size classes (sands, muddy sands, sandy muds, silts, etc.). We find that the BL values at a 5° grazing angle for both 100 Hz and 1600 Hz waves, calculated for each province, overlap to some extent, but that useful separations of BL values by province do occur. Some provinces show significantly different mean BL values (at the 0.5% level of significance) and some provinces show significantly reduced variances (also at the 0.5% level of significance).

These results indicate a real improvement in our capability to predict BL if we base those predictions on readily available physical property data and the PHYSED model. This result has particular importance in the shallow water environment, since sediment physical properties are often the only readily obtainable information describing the seafloor. Seldom are acoustic bottom loss or transmission loss data available. We strongly recommend the application of this physical sediment approach in shallow water to further the development of seafloor interaction models and data bases suitable for operational use.

END

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