THE FIRST YEAR PROGRESS REPORT TO
THE NATIONAL SEA-GRANT PROGRAM
OF
THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
FOR THE PROJECT:

THE SCIENCE AND TECHNOLOGY OF UTILIZING
THE BOTTOM RESOURCES OF THE CONTINENTAL SHELF

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This Project covers activities up to June, 1971.

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ABSTRACT

This report presents a collective summary of the first year activities of the University of New Hampshire and the Raytheon Company on "The Science and Technology of Utilizing the Bottom Resources of the Continental Shelf." The primary initial objectives of this project involves the development of an effective technology to allow remote classification and assessment of the sea floor and sub-bottom sediments for both physical and engineering properties. Development of these capabilities, when teamed with the ecological, legal, and economic technologies will form a broadly based system model for a national program directed toward the exploration and utilization of our country's continental shelf resources.

The information presented in this document reviews and discusses the achievements of the project's first year efforts. More specific discussions of several specialized aspects of this program have been previously presented in the series of detailed Technical Memoranda which supplement this report. The goals attained during this initial period, however, can be conveniently segregated into three categories; management, educational, and technical.

In the management area, the diverse individual goals and capabilities of an educational and commercial institution have been successfully integrated to yield a coherent research and development program. The resulting organization offers the promise of jointly attaining significant technical achievements which would be extremely difficult, if not impossible, to attain by the respective individual institutions working separately.

Substantial educational benefits have also accrued to the University of New Hampshire which are manifest through a significantly expanded curriculum and the establishment of an applied research and development program of confirmed student interest affording the opportunity to substantive individual participation and contribution. Additional educational institution achievements have been realized as this project has further served as a keystone in advancing the inter-disciplinary aspects of university conducted oceanographic research through the integration of the multi-departmental project activities.

The third area, technical progress, has also yielded significant accomplishments. Specifically, the initial field theoretical model has been expanded to account for energy absorption through damping and to include treatment of shear wave propagation in the visco-elastic representation of the marine sediments. Model development has further proceeded to the point of also including integration of critical soil mechanics parameters.

Technical accomplishments in the experimental phase of this project have involved the development and at-sea use of a vibratory corer together with the development of a specialized acoustic data acquisition system. Both systems were employed in the collection of physical and acoustical data to establish the project data bank. The final area discussed concerns the data reduction and analysis activities. Significant progress has been achieved under the addendum funding with the implimentation of computer aided analysis. The attendant computer programming required for A/D conversion and subsequent analysis of the acoustic data is also discussed.

I. OVERVIEW

The UNH/Raytheon Sea Grant Project was conceived as a longterm, inter-institutional research project involving faculty, graduate and undergraduate students at the University of New Hampshire, and personnel from the Submarine Signal Division of the Raytheon Company. As stated in the original proposal (August, 1969), the specific project objectives are:

1) To develop means of remotely measuring sea-floor parameters of predictive or assessive value that relate directly to the extraction of resources and to the implantation of structures on the Continental Shelf. By providing a deeper understanding of the nature of the sub-bottom aggregate, a more responsible policy for protection, preservation, and rational use of the Continental Shelf can be developed.

2) To develop a model of a system for exploitation of the Continental Shelf that will integrate remote sensing, rapid analysis, ecological and related technology with the legal and economic implications. This model will be designed to permit rational, technical and business judgments to be made involving the uses of the Continental Shelf.

3) To develop a total management system which may successfully support and coordinate applied research, conducted jointly by university, industry, and public agencies.

4) To stimulate and direct cooperative experiments with interested parties to employ the system models in extraction or implantation programs.

5) To establish a process to help educate students to be scientists and engineers with career interests in the applied aspects of ocean technology.

In this context, the initial technical goals of the project are to develop the supporting science and technologies required for:

1) locating, identifying, and extracting off-shore mineral deposits, with sand and gravel serving as an initial model for the study. This includes the identification of the geomorphological structure of the sub-bottom for other purposes as well (e.g. petroleum).

2) identifying and measuring the civil engineering properties of the coastal ocean bottom by a combination of acoustical and physical testing methods.

This project integrates the resources of the two participating institutions and hence involves the talents of people in the engineering sciences, marine biology, geosciences, resource economics, and other related fields. Because institutions with disparate objectives and a broad spectrum of different disciplines are cooperating on an integrated basis, appropriate and effective organizational patterns must be developed, employed, studied, and evaluated.

In order to meet these objectives, the project was designed as a five-year effort of approximately 1.8 million dollars in total project costs, including the matching funds contributed from each institution. Both the scope and impact of the project were conceived very broadly. As stated in the original proposal, "The targets chosen for this study have ramifications that extend beyond the specific purposes that are stated in the proposal. It is evident that by-products in both research and technology will develop that touch almost every federal agency that deals with the ocean, most of the institutions involved in the Sea Grant Program, and many industrial activities. . . The gains to the nation from a successful program would be many. The development of the Continental Shelf will be greatly enhanced if one can remotely obtain a meaningful and inexpensive description of the physical properties and the load-bearing characteristics of marine sediments. Effective knowledge in these areas would have specific benefit and significant economic impact on many areas including:

- Determination of optimum pipeline and cable routes
- Identification of the volumetric extent and geological nature of aggregate fields
- Determination of the anchorage qualities of off-shore sediments for drilling rigs, off-shore terminals, vessels, power stations and habitats
- Location of buried pipelines
- Assessment of materials to be removed in dredging
- Marine foundation design requirements

In summary, the knowledge growing from this research can be applied to almost all situations where man exploits the sea floor as a resource, or as a base for structures.

To reach these objectives, specific goals were established for each of the programmed five years of this project as detailed in the original proposal (Figure 1).

A more detailed view of the first year's objectives, established milestones, and the individual task interrelationships is presented in Figure 2. These activities are summarized in the following individual goals:

1) To conduct pilot studies on at least two classes of sub-bottom types, established milestones, and the individual task to identify associations between sub-bottom constituents and acoustical descriptors.

2) To develop preliminary theoretical models of the ocean bottom toward improving our understanding of the correlation between acoustical descriptors and the physical properties of the sub-bottom in general.

3) To acquire and make operational equipment to secure sub-bottom physical and acoustical data.

4) To draw initial inferences from the pilot studies and the theoretical modeling which will provide direction to future research efforts concerning a more fundamental understanding of the interrelationships between physical sample measurements and acoustic profiling.

5) To improve understanding of multi-institutional research and development collaboration.

The original proposal requested funds in the amount of $182,000 from the NSF Sea Grant Program. An initial grant for this project of $90,000 was awarded on March 24, 1970 to begin work on the above stated first-year goals. A proposal addendum was subsequently prepared and submitted in September of 1970, which detailed the technical accomplishments of the first eight months' work, and requested additional funds in the amount of $40,000. Three additional goals were identified in the addendum:

1) To increase the speed of acoustical data reduction

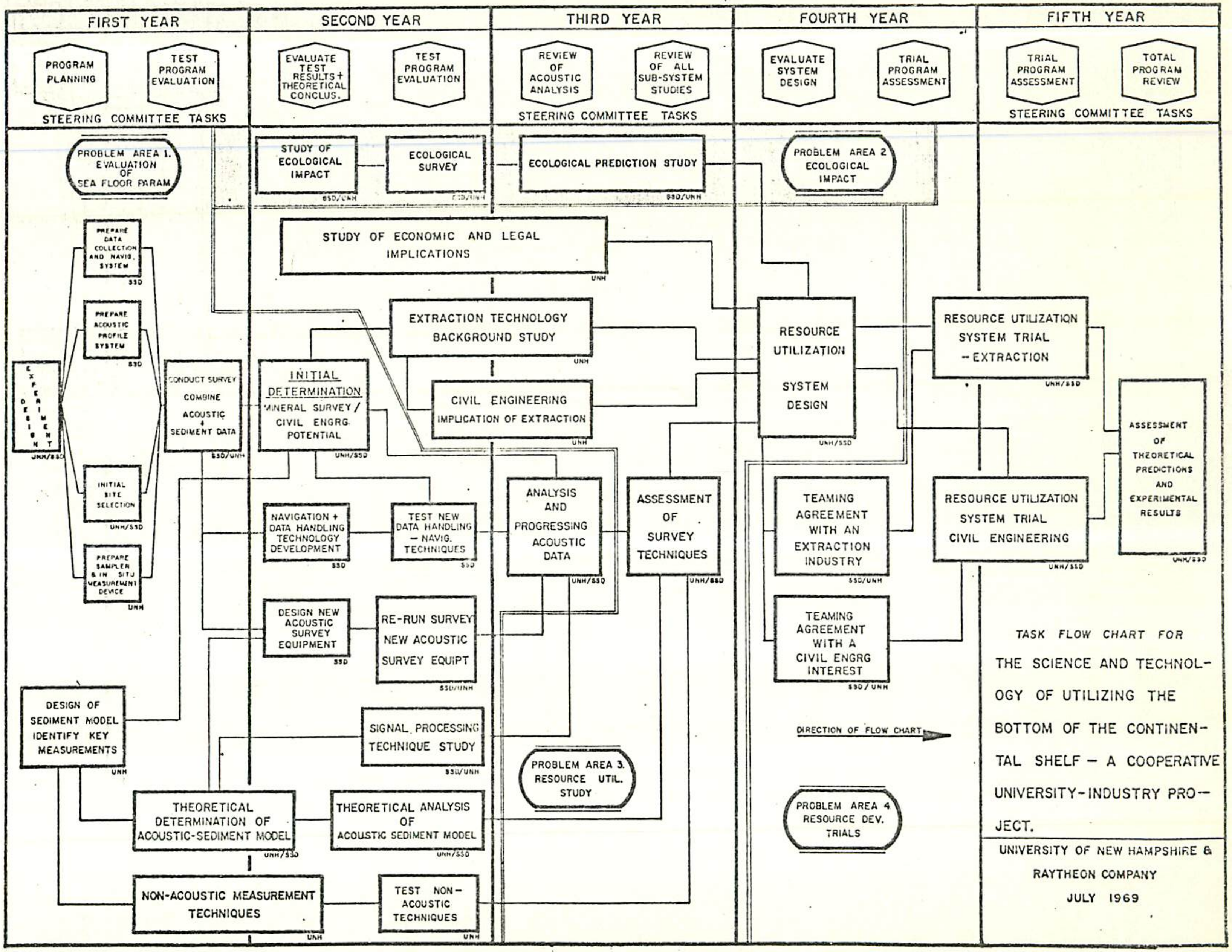
2) To perform experimental investigations to delineate the space and time effects in our acoustic data

3) To conduct more detailed physical sampling experiments on our selected ocean bottom test sites.

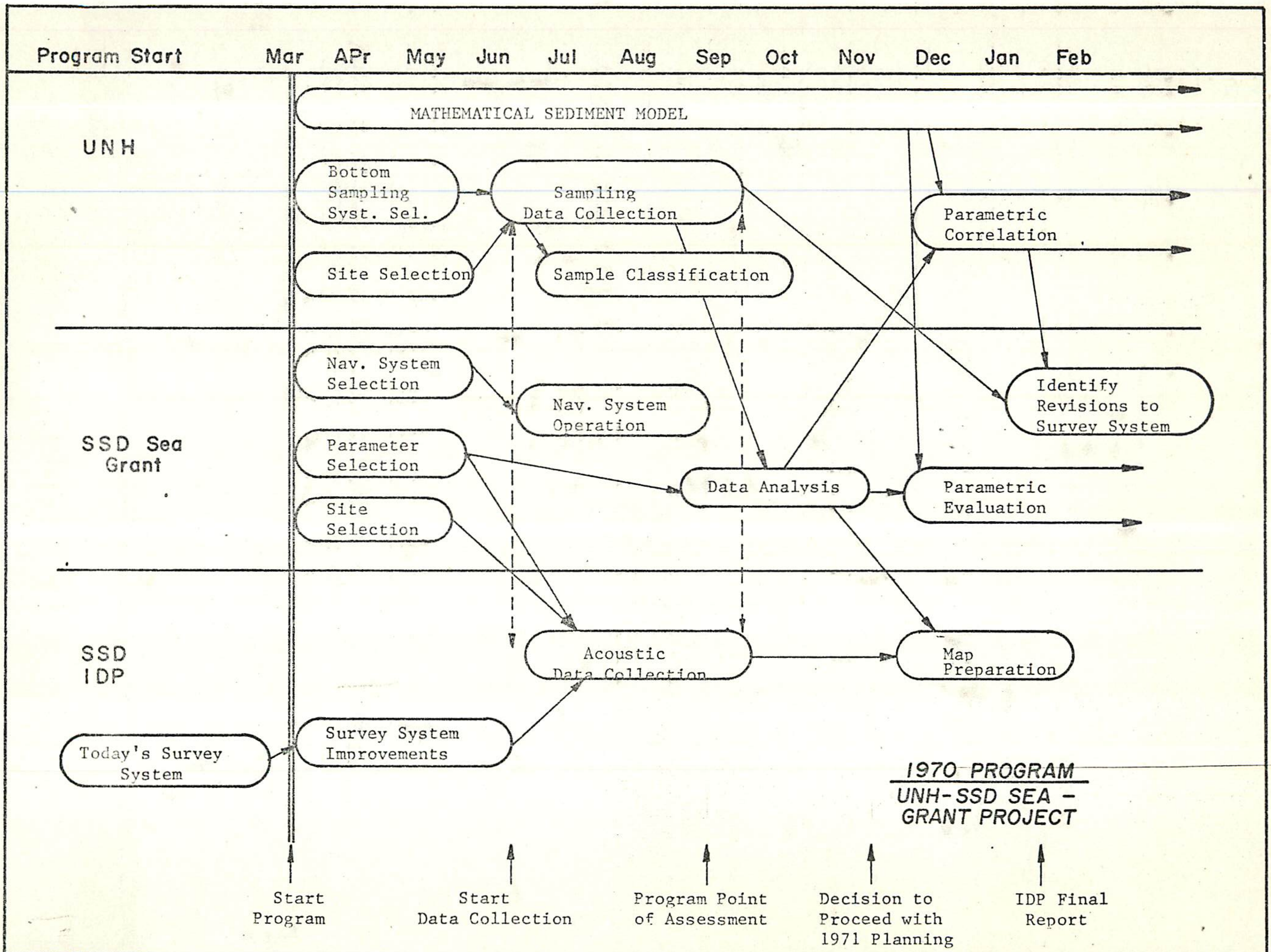
The "add-on" grant was awarded in April, 1971, to cover the November, 1970 - May, 1971 period. The funding date created a gap between the end of the original grant activities and the work to be accomplished under the "add-on". The break thus resulted in formal extension of the first-year scheduled activities through June, 1971

The report which follows contains a review of the accomplishments of the entire first-year award, including the add-on, and as such covers the time period of March, 1970 through June, 1971. It should be noted that the detailed results and status of this project eight months after initial funding have been previously presented in the add-on proposal submitted in September, 1970. This latter document has been drawn upon freely in the preparation of this first year summary report; however, the emphasis has been placed upon that work conducted under the subsequently received funding.

The second year of the project was funded on June 29, 1971, for the time period March 1, 1971 through February 29, 1972, in the amount of $199,500 from the National Sea Grant Program of the National Oceanographic and Atmospheric Administration. The major technical achievements at the mid-point of the second year will be summarized in the forthcoming proposal for third-year funding, and their magnitude will further demonstrate the critical importance of the fundamental groundwork which was accomplished during the first year of the project. While we are convinced that the first-year accomplishments satisfy the goals set down for that time period, the second-year accomplishments have more than met our expectations, particularly in view of the fact that



Task Flowchart



Program Start
Mar
APr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
UNH
MATHEMATICAL SEDIMENT MODEL
Bottom Sampling Syst. Sel.
Site Selection
Sampling Data Collection
Sample Classification
Parametric Correlation
SSD Sea Grant
Nav. System Selection
Nav. System Operation
Parameter Selection
Site Selection
Data Analysis
Parametric Evaluation
Identify Revisions to Survey System
SSD IDP
Today's Survey System
Survey System Improvements
Acoustic Data Collection
Map Preparation
1970 PROGRAM
UNH-SSD SEA – GRANT PROJECT
Start Program
Start Data Collection
Program Point of Assessment
Decision to Proceed with 1971 Planning
IDP Final Report

FIG 2

both the first and second years were funded at levels below those suggested in the original proposals.

In summary, although the following report can stand alone as a review of the technical and managerial accomplishments of the first year, it should also be viewed as a stepping stone toward the far greater progress which has been achieved during the second year.

II. MANAGEMENT OF THE PROGRAM

The original proposal for this program stated:

> "because of the different organizations involved, the structure of the project and the managerial framework which supports and sustains it must permit each of the organizations to operate in a style consistent with its own traditions and values. At the same time, it must provide a means for overall project coordination and direction, with a flexibility to modify specific project organization to take advantage of new information and/or staff. To meet these requirements we have designed a structure which will be self-refining to a continuing and explicit process of evaluation and modification."

The proposal further suggested a framework consisting of a program manager and a management team to coordinate the efforts of the two very different organizations involved in conducting the project. As was anticipated in the original proposal, the University of New Hampshire and the Submarine Signal Division of the Raytheon Company have different organizational structures, styles of operation, history, traditions and objectives.

Overall technical direction was provided by the co-principal investigators with frequent joint UNH/Raytheon meetings held to develop research priorities and experimental strategies. While the respective inter-institutional technical direction was satisfactory to achieve our individual program objectives, we understandably experienced some difficulty in both technical and managerial communication between the two organizations. In this regard, project management was a particularly supportive activity acting to increase the flow of information and aid the coherent progression of the technical efforts.

A. Effects of the Project Upon Educational Goals of UNH

While the potential project derived beneficial effects upon education were not fully realized during our first year, there were a significant number of positive accomplishments related to the collaborative nature of the inter-institutional project.

Although it is extremely difficult to quantify the direct influence a research project has on overall educational goals, we feel that the UNH/Raytheon Project has had substantial educational impact.

1) The research within the project has been carefully and thoroughly integrated into our educational programs. At least six courses have substantially utilized theory or information associated directly with the Project. Several courses are new and have been added because of the existence of this project.

   Additionally, two graduate theses have been written as a result of research on the project and several more are in progress. Potentially, even more importantly, the informal influences of the project upon students through seminars, example problems in courses, and the experience gained by students working in the field with engineers from Raytheon, cannot be overlooked as a significant contribution to the educational process.

2) As a secondary educational benefit, this project has created considerable enthusiasm among both graduate and undergraduate students. Its mix of theory and practice, research and at-sea data collection, academic and industrial environment, has stimulated interest in using the program for thesis subjects. Three students worked on the program without pay to partake of these benefits.

3) As a tertiary benefit, the project has continued the development of inter-disciplinary oceanographic research at UNH. The faculty and students within the project are from several departments. More importantly, a basis for integrating the marine biological, electrical engineering, and mechanical engineering department activities has been firmly established. Further, the continuing development of the relatively new interdisciplinary Engineering Ph.D. Program has been enhanced through the cooperative involvement of the associated University faculty and graduate students within the context of this research program. We thus believe this project has enabled us to understand more clearly the principles for establishing such interdisciplinary research products.

B. Effects of the Project Upon the Raytheon Company

Aside from the obvious benefits of the research itself, several important things have occurred at the Ocean Systems Center at Raytheon.

1) a new business direction has been established which is a direct outgrowth of the impacts of this project. Specifically, an acoustics surveying business related to the Gulf Coast pipeline surveys, drill rig anchoring, and physical structure surveys has been created since the beginning of this project.

2) this project is a major nucleus in developing a rational base for commercial business in what has historically been a military business. The project has brought a valuable emphasis on research and development to the center, and has permitted the building of a competent staff.

3) the Ocean Systems Center has acquired the business assets of an oceanographic research and development company to augment the new survey business and to support this Sea Grant Project.

4) more importantly, it has been demonstrated that the enlightened self-interest of a profit-directed industrial organization can be properly served through such a program. The association with a group of university-based scientists provides a stimulus through new ideas and the cross-fertilization of this joint program that results in new business developments. At a time when economic conditions in the electronic and ocean-oriented industries are universally gloomy, the Ocean Systems Center at Raytheon finds the wide range of exciting new business prospects, a new concept of the markets to be served, and a growing set of tools with which to serve it. It is important to note that much of this ferment stems from the thought processes engendered by this program.

C. Effects of the Collaborative Effort

Both the University and the Raytheon Company have gained extensive knowledge concerning the nature of inter-institutional collaboration. The University of New Hampshire and the Raytheon Company have now worked together for two years to develop this project and to conduct the first year's research. In the process, we have learned about and overcome many of the problems which university/industry collaborative efforts must first resolve. Personnel at both institutions are now enthusiastic about the productivity of the relationships which exist within the project believing that joint research teams can be created to conduct research that otherwise would be difficult or impossible for either of the institutions to accomplish separately.

D. Problem Areas

Several important institutional factors concerning the optimum matching of each organization's self-interests in order to provide a functioning research and development team, have also been examined. Throughout the proposal period and the first year of the project, personnel from the University's Whittemore School of Business and Economics worked with the project team members to help build a supportive management structure based upon full communication and the development of collaborative decision-making mechanisms.

As part of this effort, interviews were conducted with all project personnel during the summer of 1970; approximately three months after the initial funding of the project. At that time a number of issues were identified which needed attention and clarification to prevent them from growing into major problems. To resolve these issues, a series of ad hoc meetings were convened. These special working sessions led to a satisfying increase in the quantity and quality of the transfer of technical information between personnel at UNH and at Raytheon, as well as an improvement in managerial communication.

Early identification of these issues thus led to the resolution of a number of potential conflicts which could exist between an educational and an industrial organization. The technical memoranda prepared for the addendum proposal in September, 1970, and the second year proposal in January, 1971 reflect this improving quality of collaboration and information exchange between the two institutions.

It is, however, significant to note that the true measure of collaboration between UNH and Raytheon is reflected in the process of the project itself. The UNH/Raytheon team has successfully integrated experiment design and at-sea data collection activities with on-going advanced theoretical modeling and sophisticated computer aided data processing; all directed toward obtaining a more comprehensive understanding of coastal resources and their intersocietal impact.

III. TECHNICAL PROGRESS

A. Introduction

The overall technical objective of this program in the first year has been to lay the groundwork for the identification and classification of soil mechanics parameters by remote acoustic surveys. The success of such a program is dependent upon refining the proposed theoretical model so that the soil mechanics parameter can be properly described. Once these parameters are determined and quantified, advanced signal processing techniques can be applied to the real world acoustic data to extract the required sediment classification and civil engineering determination indices.

The program has concentrated on the following major areas of activity:

1) Model Development
2) Theoretical Soil Mechanics
3) Systems Engineering
4) Data Acquisition
5) Laboratory Analysis of Physical Samples
6) Signal Processing and Computer Operations
7) Development of Data Bank.

As in the second year proposal, a summary of technical progress is presented in a series of updated figures. The bar graph representations at the right hand side of the individual activity area descriptors present the June status. Again as in the second year proposal figures, the first and second phases of the technical study divide roughly into first and second year activities. Some overlap, however, does exist.

THEORETICAL MODELING	SECOND PHASE ACTIVITIES	NONLINEARITIES OF SUB-BOTTOM	
		DIFFUSIVE (non-sharp) BOUNDRY CONDITIONS	
		BOTTOM ROUGHNESS RANDOMNESS STUDY	
		DISTORTED SQUARE PULSE SHAPE AFTER FILTERING, AND RELATION OF DISTORTION TO LIQUID FLUCTUATION, LAME PARAMETERS AND EFFECTIVE DENSITIES	
		INCLUSION OF LIQUID FLUCTUATION, REVERBERATION EFFECTS ON THE LIQUID WAVE FORMALISM.	
		INCLUSION OF POROSITY, WATER CONTENT EFFECTS ON THE ANALYTICAL FORMALISM (PERTURBATION TECHNIQUES)	
	FIRST PHASE ACTIVITIES	SOLUTION BY ASSUMING LIQUID LAYER NON-FLUCTUATING, NO REVERBERATION	
		SOLUTION BY SHARP BOUNDRY CONDITIONS	
		COMPLETE SOLUTION OF ONE LAYER	ANALYTICAL FORM
			INVERSE ANALYSIS
		INVERSE PROBLEM OF ANALYTICAL FORM FOR n LAYERS	
		ANALYTICAL SOLUTION OF THE SYSTEM OF THE HELMHOLTZ EQUATIONS IN MATRIX FORM (BOUNDRY COUPLING) FOR n-LAYERS	
		CHOICE OF FIELD EQUATIONS IN LIQUID LAYER AND SUB-BOTTOM VISCOELASTIC LAYERS. . $(\nabla^2+k_a^2)\phi_a=0$ $(\nabla^2+k_{L,T}^2)\phi_{L,T}=0$	

FIG. 3

SOIL MECHANICS & GEOMORPHOLOGY	SECOND PHASE ACTIVITIES	EXPERIMENTAL	CORE SAMPLE DIRECT DATA ANALYSIS
			VIBRATORY TEST BY VELOCIMETERS OF CYLINDRICAL CORE SAMPLE
			CORE DATA SAMPLING (POSSIBLY RICHARDSON CORING)
		THEORETICAL	VIBRATION ANALYSIS OF CORE SAMPLE OF HETEROGENEOUS SUB-BOTTOM MATERIAL
			SAND, CLAY, GRAVEL, MINERAL SUB-BOTTOM SOIL IDENTIFCATION BY ACOUTIC SIGNATURES
			SAND, CLAY, GRAVEL, MINERAL, SUB-BOTTOM SOIL PARAMETERIZATION
			HETEROGENEOUS SUB-BOTTOM SOIL STUDIES (GENERAL)
			MICROSTRUCTURE STUDIES (GENERAL)
	FIRST PHASE ACTIVITIES	EXPERIMENTAL	DIRECT LAB TESTS FOR GRAIN SIZE WATER CONTENT, POROSITY, ETC. FROM CORE SAMPLES
			CORE DATA SAMPLING
		THEORETICAL	VIBRATION ANALYSIS OF CYLINDRICAL CORE SAMPLES
			ATTENUATION EFFECTS IN THE LAMÉ PARAMETERS
			RIGIDITY VERSUS GRAIN STRUCTURE RELATION IN LAME PARAMETERS λ, μ
			INCLUSION OF WATER CONTENT INTO THE FIELD EQUATIONS $\rho = \rho_0(1-\gamma) + \rho\gamma_L$
			INCLUSION OF POROSITY EFFECTS INTO THE FIELD EQUATION $\rho = \rho_0(1-\gamma)$
			CHOICE OF FIELD EQUATION IN THE SUB-BOTTOM LAYERS $\rho \frac{\partial^2 \vec{u}}{\partial t^2} - \mu \nabla^2 \vec{u} - (\lambda+\mu)\nabla(\nabla \cdot \vec{u}) = 0$

FIG. 4

SIGNAL PROCESSING	SECOND PHASE ACTIVITIES	INTERP. OF DATA	INTERPRETATION OF DISTORTED SQUARE PULSE SHAPE IN TERMS OF THEORETICAL MODEL
		DATA COLLECTION	DATA COLLECTION FOR SOURCE AND RECEIVER ON BOTTOM SURFACE
			DATA COLLECTION OF SQUARE PULSE SHAPE RESPONSES
		NUMERICAL ANAL. & COMPUTATION	COMPUTER ANALYSIS OF nth ORDER COUPLED EQUATIONS
			FAST FOURIER TRANSFORM TECHNIQUES
		THEORETICAL	ADAPTATION OF INPUT-OUTPUT RELATION INTO KALMAN FILTER OF n LAYERS
			ADAPTATION OF INPUT-OUTPUT RELATION INTO KALMAN FILTER OF ONE LAYER
			ADAPTING WIENER FILTER TO KALMAN FILTER
	FIRST PHASE ACTIVITIES	INTERP. OF DATA	PLANE WAVE REFLECTION COEFFICIENTS
		DATA COLLECTION	ACOUSTICAL PROFILING
			TIME RESPONSE TO MODULATED PULSE
		NUMERICAL ANALYSIS AND COMPUTATION	COMPUTER ANALYSIS OF THE SYSTEM NOISE FIELD
			INVERSION OF MATRIX OF ANALYTICAL FORM BY COMPUTER ANALYSIS
			INCLUSION OF NOISE FIELDS(REVERBERATION, BOTTOM ROUGHNESS, LIQUID INHOMOGENEITY, FLUCTUATION OF LIQUID ITSELF, SUB-BOTTOM
		THEORETICAL EFFORTS	STATISTICAL ANALYSIS
			INPUT-OUTPUT RELATION-ANALYTICAL FORM FOR n LAYERS IN MATRIX FORM
			INPUT-OUTPUT RELATION-ANALYTICAL FORM FOR ONE LAYER $\phi_{out}(\vec{k},\omega) = \frac{\Delta_1(\vec{k},\omega)}{\Delta(\vec{k},\omega)} \phi_{in}(\vec{k},\omega)$
			CHOICE OF OPTIMIZED FILTER (WIENER FILTER $\phi_{out} = \int h(t-T)\,\phi_{in}(T)\,dT$

FIG. 5

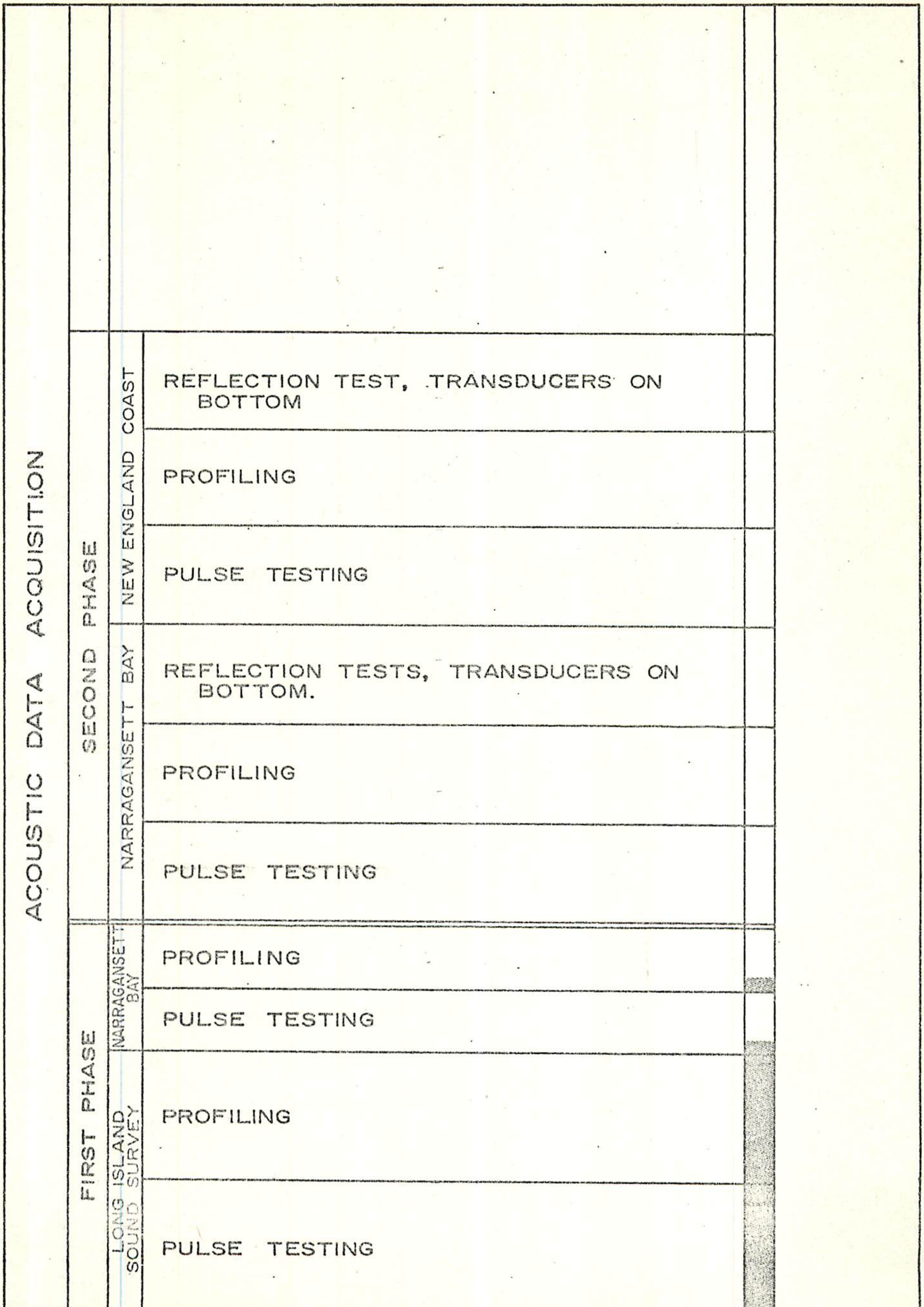

ACOUSTIC DATA ACQUISITION
SECOND PHASE
NEW ENGLAND COAST
REFLECTION TEST, TRANSDUCERS ON BOTTOM
PROFILING
PULSE TESTING
NARRAGANSETT BAY
REFLECTION TESTS, TRANSDUCERS ON BOTTOM.
PROFILING
PULSE TESTING
FIRST PHASE
NARRAGANSETT BAY
PROFILING
PULSE TESTING
LONG ISLAND SOUND SURVEY
PROFILING
PULSE TESTING

FIG. 6

B. Model Development

The identification and classification of sub-bottom soils and soil mechanics parameters by remote acoustic surveys requires a mathematical model of the ocean and the sub-bottom. The reliability and utility of the information extracted from the acoustical data depends on the accuracy and generality of the theoretical model. Therefore, a major initial effort of this study was the evaluation of existing models. Following the evaluation of several current models it was concluded that, while each possessed certain individual assets, no one model possessed sufficient sensitivity to establish the general bottom characteristics at the level required to yield a unique classification of sediment composition and civil engineering properties.

Having found current models somewhat limited, the development of a field theoretical model general enough to accommodate most aspects of acoustic scattering from the sub-bottom was undertaken. Complementing this effort, the development and implementation of a ray-acoustic, plane wave model has also been accomplished. This latter effort is discussed in a section following the field theoretical model description detailed below.

1. Field Theoretical Model

The field theoretical model is developed as one approach to predict the characteristics of the bottom and sub-bottom sediments based upon their impulse response when probed with acoustic energy.

The model assumes that the ocean is a semi-infinite liquid layer covering the sub-bottom which is assumed as a semi-infinite viscoelastic layer. The acoustic wave in each media is described by the Helmholtz equation with nonlinearities of the medium contained in the associated wave numbers. However, such non-linearities will be disregarded at first stage of our developments. Significantly, the present generalized model is best suited to account for the second order effects occurring in the propagation media.

As the liquid medium can support only compressional waves, only one Helmholtz equation is required to describe the wave motion. In contrast, the sub-bottom supports shear waves as well as compressional waves and thus two Helmholtz equations are required to describe the motion of the acoustic pulse in the viscoelastic representation of the bottom sediments. After using proper transformations the problem is reduced to a boundary value problem. Using widely accepted boundary conditions for the liquid-solid interface, an integral expression is obtained for the output signal in terms of the input signal. This is essentially unit impulse response function on the Green's function of the layered system under consideration.

The unit impulse response function (Green's Function) expression for a semi-infinite liquid layer on semi-infinite viscoelastic layer reads:

$$T(C_0, C_L, C_T, {}_0, {}_1, {}_0, {}_L, {}_T, , R, Z, H) = \text{Gain}\ e^{i\text{Phase}} =$$

$$\int_0^{\infty} \left(\frac{\rho_1\sqrt{x^2-k_0^2}\left[(2x^2-k_T^2)^2 - 4x^2\sqrt{x^2-k_L^2}\sqrt{x^2-k_T^2}\right] - \rho_0 k_T^4\sqrt{x^2-k_L^2}}{\rho_1\sqrt{x^2-k_0^2}\left[(2x^2-k_T^2)^2 - 4x^2\sqrt{x^2-k_L^2}\sqrt{x^2-k_T^2}\right] + \rho_0 k_T^4\sqrt{x^2-k_L^2}} \right) \frac{e^{-(Z+H)\sqrt{x^2-k_0^2}}}{\sqrt{x^2-k_0^2}} J_0(Rx)\ x\ dx$$

Where: $k_0 = \dfrac{\omega}{C_0(1+i\omega\varepsilon_0)}$, $k_L = \dfrac{\omega}{C_L(1+i\omega\varepsilon_L)}$, $k_T = \dfrac{\omega}{C_T(1+i\omega\varepsilon_T)}$

$\omega = 2\pi f$, f = frequency of carrier pulse-packet in Cycles per Second

$C_0 = 1501 \frac{\text{Meters}}{\text{Second}}$ = Sea Water Sound Velocity ε_0 = Sea Water Damping

C_L = Sediment Compressional Velocity ε_L = Compression Damping

C_T = Sediment Shear Wave Velocity ε_T = Shear Wave Damping

ρ_0 = Sea Water Density = $1.025 \frac{\text{Gm}}{\text{CM}^2}$ x = Integration Variable

ρ_1 = Sediment Density J_0 = Zero Order Bessel Function

Z = Height of Transmitter above Sea Bottom in Meters

H = Height of Receiver above Sea Bottom in Meters

R = Distance between Transmitter and Receiver in Meters

While exact analytical solution of the response integral is complicated, the long wavelength and the short wavelength approximations are currently being worked out. Computer solutions are also started.

The present approach takes into account the three-dimensional characteristics of the signal source modeled explicitly in the input-output relation. From the input-output relation one can infer information about attenuation in the sediments. Dispersion is taken into account, both due to the boundaries and the viscoelasticity of the sub-bottom sediments. Furthermore, shear wave velocities of the sub-bottom may be inferred from the output signal.

2. Plane Wave Model

As the majority of the acoustic sediment descriptors discussed in the literature have been computed employing ray-theory, plane wave models, the development of similar capabilities and investigate efforts within this program was considered warranted. More specifically, the development of a plane-wave reflection model allows the research team to compute the acoustic indicies of the sediments sampled on a comparable basis with values determined by previous researchers.

Several additional benefits accrue to the program through the development of these programs. First, the degree of agreement between the values computed for the Long Island Sound and Narragansett Bay sediments, when compared with reported values calculated for similar sediment types, will yield a measure of the representativeness of the sediments being sampled in this program. Second, processing the acoustic data employing the plane-wave model allows the assessment of data quality and consistency. And third, a direct comparison between acoustic indices calculated employing the plane-wave model and those values calculated using the developing field theoretical model will be possible. This latter capability should allow a direct assessment of the anticipated added sensitivity realized through employment of the field theoretical model.

Initial ray-acoustic modeling efforts have been directed toward the more simply implemented, normal incident case where the sea-floor is represented by a series of plane interfaces separating homogeneous fluids. A programmed second year goal expands this model to include oblique incidence and shear wave components.

In the existing plane wave model, acoustic reflectivity is parameterized (the assignment of a parameter or parameters of a simple model to represent a complex physical process) according to a specular, coherent reflection model. Absorption is considered to be present in each fluid media and is accounted for by making the respective layer-wave numbers complex. Based on experimental evidence, the phase velocities are assumed independent of frequency and the attenuation coefficient linearly proportional. Classical boundary conditions are assumed at each interface, and an iterrative process implemented to arrive at the composite layered bottom reflection coefficient.

In allowing the attenuation coefficient to be linearly proportional to frequency, the resulting reflection coefficient is interpreted to be the ocean bottom transfer function analogous to a linear, composite or cascaded filter. The result of this implementation is then transformed into the time-domain and the resulting expression interpreted as the impulse response. Working now with both the time-domain as well as the frequency-domain representations,the resulting response of the oceans bottom to any arbitrary incident waveform may be analyzed. Programs are being developed in this implementation to process both analytically assummed and experimentally monitored incidence waveforms.

Cross-correlation and convolution techniques also are presently being considered whereby assessments may be made between the actual transfer function of the bottom, as derived from experimentally obtained data, and those calculated employing the above transfer function simulation.

C. Theoretical Soil Mechanics

The integration of soil mechanics with wave mechanics is one of the central themes of this project. The first year's efforts have been centered around the search for reliable analytical and relevant experimental methods for the determination of Lamé parameters and effective densities of the sub-bottom layers.

A general review of the literature related to the identification of marine deposits by means of acoustical profiling reveals that the Hookean model (linear elastic material) adequately accounts for wave velocities in rocks and sediments, but does not provide an explanation of the wave-energy losses. The abundance of positive documentation related to the general problem of using a viscoelastic model to characterize marine sediments provides the following major conclusions:

1) The Gassman assumption of a "closed system" is valid because of the small stresses imposed by the sound waves.

2) The deviation from Hookean response is small and far less than the lateral and vertical variations in sediment properties.

3) The first order viscosity effects of the pore water can be neglected for sediments.

4) The first order dispersion is not a significant factor in the frequency regions of marine geophysics.

5) Viscoelastic concepts must be used to account for attenuation.

6) Attenuation appears to be a linear function of frequency for most marine sediments.

The significant parameter in the acoustic system, which is least understood and holds the most promising application for the classification of marine sediments, is the expected variation in attenuation of the acoustic wave as a function of both sediment type and probing frequency. More specifically a viscous model implies a dependance on the phase velocity of the acoustic signal so that the medium not only produces attenuation in amplitude, but dispersion in velocity of propagation as a function of frequency. This formalism thus differs from the approach adopted in the previously described plane wave modeling where the phase velocities have been assumed independent of, and attenuation coefficients linearly proportional to, frequency.

The adopted visous model further implies that consideratioh of the physical chemistry of the sediment is necessary as well as some consideration of the visous nature of pore water adjacent to the surface active particles as these parameters may be significant in mineral identification. A recent paper by Rosenquist shows that the broad definition of a "clay" could be more accurately specified by formation heats and physical chemical structures. One type of clay with small mineral deposits possesses a much different internal energy than one of high mineral content and doing a mechanical work on each system would give different responses from a thermodynamical viewpoint. In this context, the propagation of acoustic energy can be looked at as doing work on a system and we may thus have an important new research direction to aid in the classification of sediments by their internal energy.

Another important classification parameter for the soil mechanics model is porosity; a measure of the amount of voids expressed as a percentage of water volume per unit volume of saturated sediment. The porosity term has been related by Hamilton to the sediment dynamic bulk modulus. It also appears to be a major factor in the determination of sediment viscosity and attenuation as a function of frequency.

Building on this background, analytical methods that parallel and complement the experimental soil mechanics activities as conducted in the laboratory and aboard the sample-collecting vessel have been developed. Since each sub-bottom layer is assumed to obey the visco-elastic field equation, the soil mechanical properties such as porosity and liquid content can be properly included in the model developed through the density function by properly parameterizing porosity, water content, grain size distribution, and viscosity. Furthermore, the grain size distribution appears strongly related to complex Lamé parameters as the degree of acoustic penetration of the sub-bottom is related significantly to the grain size of the sediments being probed.

D. Experimental Soil Mechanics

During the first year of the project, we have developed a proven capability in the area of sub-bottom sampling. Cores in excess of 20 feet were acquired and analyzed in the UNH soils laboratory. It was hoped that experiments could be done in two identifiable divisions.

1) Soil cores are to be open to measure water content, porosity, and grain size. Since these soil cores are distributed for analysis we have maintained proper reservations about the evaluated results, particularly with respect to rigidity.

2) Vibratory tests to measure effective density and Lamé parameters have been developed. It was proposed to initiate a test capability in this area; however, funding problems have forced us to postpone this type of experimentation.

E. Systems Engineering

The companion UNH physical sampling program has successfully taken cores in excess of 20 feet but generally no more than 30 feet in common marine sediments. This depth equals a nominal 8 to 12 milliseconds of acoustic record.

In cores recovered by the project, minor physical interfaces are sometimes only inches apart, and major ones as close as a foot or two. The measurement system eployed in the year one Sea Grant experiments thus should possess sufficient resolving power to differentiate the

the expected physical variations and still yield minimum sub-bottom reflections to depths in excess of 25 feet.

One further consideration in the early months of the program was imposed as the procedures and computer facilities to machine process our acoustic data had not been formulated and our ability to extract soil classification information had to, for the most part, rely principally on the time domain (amplitude) characteristics of the echo. As a consequence, particular systems employed were chosen specifically for their linearity and wide dynamic range together with the consistency of amplitude, gain, and overall detection characteristics.

To meet these requirements, program personnel considered three specific systems for the early surveys:

1) Matched Filter Correlation Detection

2) Finite Amplitude

3) Conventional "Short-Pulse"

1) Matched Filter Correlation Detection System

In brief, this system matches the returning echo against a replica of the transmitted signal and provides an output which is the time history of the cross-correlation. While the system works well, even in high noise environment, use of the system was eliminated because the process operates primarily in the frequency domain and as a consequence very little information as to amplitude dependencies could be extracted; a prime goal of these early exercises.

2) Finite Amplitude Data Acquisition System

This system employs the "finite amplitude effects," a corollary of the non-linear properties of the medium. Operationally, two high frequency signals are simultaneously launched from a special transducer which generates the low frequency waveform at the difference frequency. Beamwidths as narrow as 2 degrees with distinct suppression of side lobes are produced. The system provides outstanding bottom penetration and excellent resolution with transducers which are substantially smaller than the beam forming arrays required to produce equivalent directivity. One negative factor however, mitigates against obtaining quantitative data. Specifically, as the mixing phenomenon occurs in a physical volume of water and output signal levels are dependent on several variables, it has proven extremely difficult to calibrate this system in terms compatible with the analytical objectives of this program. The acquisition of "finite amplitude" data thus was postponed to a second year objective when our increased experience would allow use to be made of the new technology this system could bring to bear on the sediment assessment problem.

3) "Conventional" Short Pulse Sub-Bottom Profiling System

The needs for data collection during the early months of this program, were best served by a conventional short pulse sub-bottom profiling system. As it was desired to assess the frequency dependent attenuation of marine sediments and investigate several other expected frequency dependent acoustic parameters, a short pulse system allowing the generation of pulses at numbers of discrete frequencies between 2.0 and 20.0 kHz was designed. Initial system design criteria also included ease of calibration, greatest flexibility of output waveform, pulse stability (reproducibility), and the ability to generate acoustic pulses with sufficient energy to penetrate to a depth somewhat in excess of the expected physical sampling depth in all marine sediments (i.e., 25 feet).

Selection of a conventional short pulse system for the initial program tests was further justified as the existing data base created by previous researchers had been acquired employing similar systems. Thus the initial investigations of this Sea Grant Program could be most effectively correlated with the historical data if comparable systems were employed.

1. Data Acquisition System Design:

The initial, prime frequencies selected were 3.5, 8.0, and 12.0 kHz as these effectively covered the frequency band of interest. System flexibility also permitted the generation of pulses over the continuous range of 3.0 to 9.0 kHz. As discussed in the following data acquisition section, advantage was taken of this flexibility and selected additional sampling was conducted at 5.0, 6.0, and 7.0 kHz.

Following establishment of the generalized short-pulse source system criteria, the received system was examined to optimize the recording of all pertinent acoustic information contained in the reflected waveform. As a check on the acoustic source it was deemed advisable to have a continuous monitor hydrophone recording the actual source levels and waveforms produced by the transmitting transducer. A calibrated reference phone was positioned at a fixed distance (1 yard) from the source to provide these measurements.

In addition to the monitor hydrophone discussed above, two other receiver elements were employed in the year-one data acquisition system.

The first of these receivers was a second transducer; identical to the source. These two transducers thus allowed the acquisition of data analogous to conventional split-transducer sub-bottom profiling operations. The third receiver element was a second calibrated, omnidirectional hydrophone which was position adjacent to the source transducer at a lateral separation of one yard.

2. Laboratory Calibration:

Individual pieces of instrumentation together with both source and receiver acoustic elements were calibrated in the laboratory and in the Raytheon transducer test tank facility. Each component of the source and receiver system was calibrated for both frequency and amplitude response. Additional measurements were also made to ascertain the electronic noise level of all filters, attenuators, and amplifiers.

All electronic monitor and peripheral equipment including oscilloscopes, frequency counters and the time code generator were also calibrated, together with more extensive testing of the acoustic element of the system.

Hydrophones were calibrated for receiver beam patterns, frequency response, and sensitivity. Transducers in addition to the above three tests, were measured for transmit voltage response, impendence, and both their horizontal and vertical transmitted and received beam patterns at several frequencies bracketing each of the selected prime frequencies.

As one of the primary objectives of these data acquisition exercises was the acquisition of taped acoustical data, particular attention was paid to the actual record electronics. For these tests, an AMPEX FR-1300 analog recorder was selected and each channel calibrated

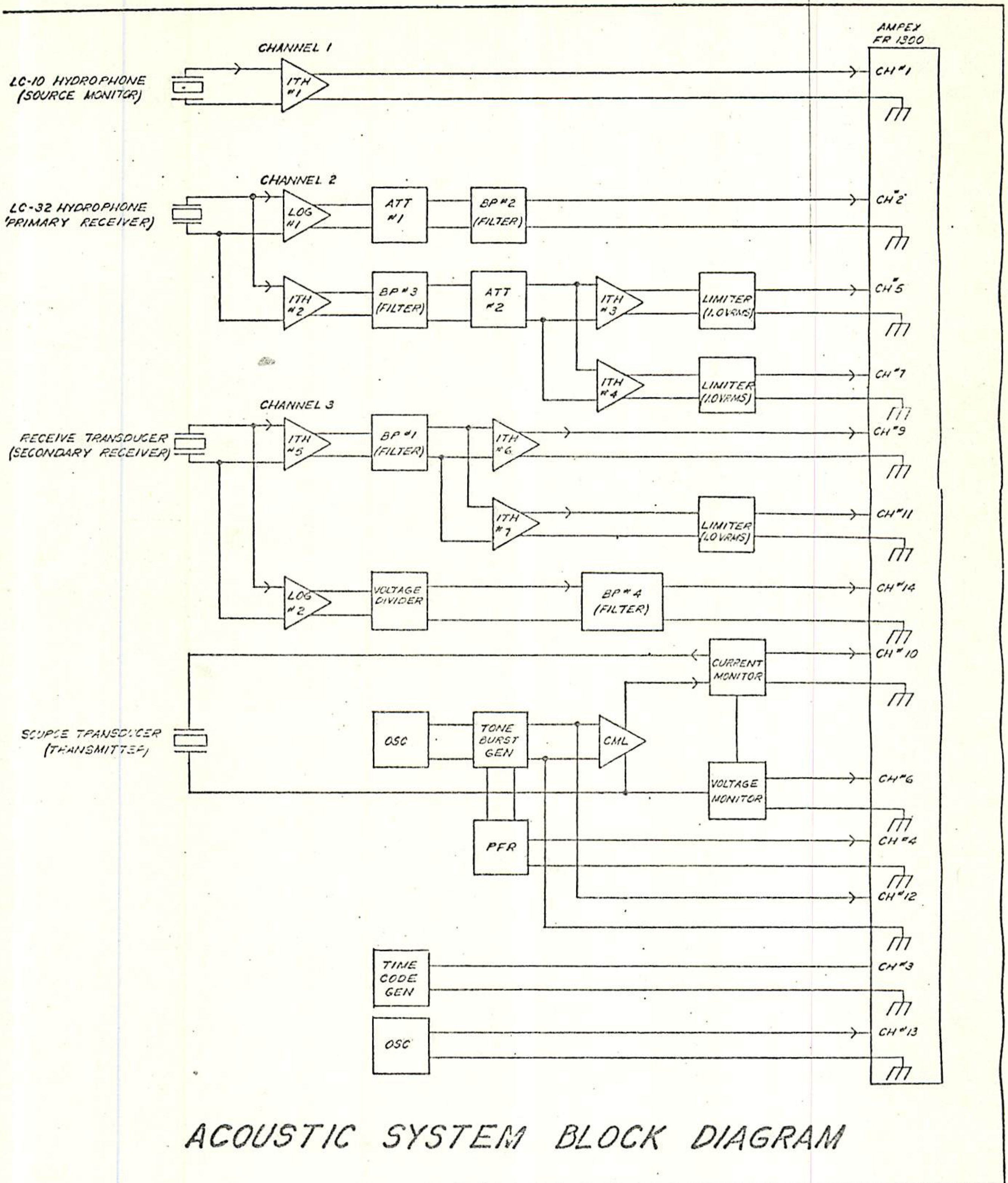

AMPEX FR 1300
CHANNEL 1
LC-10 HYDROPHONE (SOURCE MONITOR)
ITH #1
CH #1
CHANNEL 2
LC-32 HYDROPHONE (PRIMARY RECEIVER)
LOG #1
ATT #1
BP #2 (FILTER)
CH #2
ITH #2
BP #3 (FILTER)
ATT #2
ITH #3
LIMITER (1.0VRMS)
CH #5
ITH #4
LIMITER (1.0VRMS)
CH #7
CHANNEL 3
RECEIVE TRANSDUCER (SECONDARY RECEIVER)
ITH #5
BP #1 (FILTER)
ITH #6
CH #9
ITH #7
LIMITER (1.0VRMS)
CH #11
LOG #2
VOLTAGE DIVIDER
BP #4 (FILTER)
CH #14
CURRENT MONITOR
CH #10
SOURCE TRANSDUCER (TRANSMITTER)
OSC
TONE BURST GEN
CML
VOLTAGE MONITOR
CH #6
PFR
CH #4
CH #12
TIME CODE GEN
CH #3
OSC
CH #13
ACOUSTIC SYSTEM BLOCK DIAGRAM

FIG. 7

for both amplitude and frequency response. Additionally, measurements were made of the dynamic range available on each channel and data was recorded on those channels affording the greatest potential signal to noise (S/N) ratios.

A further factor considered in making the magnetic records was tape speed as this quantity essentially controls the bandwidth (Frequency response) attainable during recording. A tape speed of 7½ ips was selected although a slower speed would have been adequate to record our planned data (highest center frequency 12.0 kHz). The highest tape speed was dictated by the 36.0 kHz calibration tone (nominally, three times the highest data frequency) employed as a control on tape speed and for post operation computer digitizing. In addition to the analog channels discussed, an FM channel was included to record the 60 Hz reference tone from the PFR which allows post-operation play back on a graphic recorder.

Following the above measurements, the resulting calibration data was analyzed and a final system block diagram was generated. (Figure 7).

3. Dockside Calibration

The source and receiversystem outlined in the previous section was installed aboard the Raytheon reserach vessel, M/V ALAN several days prior to the commencement of acoustic data acquisition. In addition to the normal system checkout to assure proper operation, a series of system calibration were conducted. In these preoperation tests, each receiverline was calibrated to ascertain its frequency and amplitude response over the frequency range of 0.5 to 15.0 kHz at 0.5 kHz intervals. This data was both recorded in the field logs and on magnetic tape.

F. Data Acquisition Program

1. Introduction

An early awareness of the complexity of attempting the remote classification and identification of marine sediments through acoustical means dictated the necessity for a number of field data exercises and preliminary site surveys. The objectives for these initial exercises and surveys were threefold. First, to provide as early as possible within the total time framework of this project, actual field experience and team familiarization with the difficulties and constraints commonly imposed by oceanographic research operations. Secondly, to provide both the theoretical and experimental efforts at the University of New Hampshire and Raytheon with a working base of field data from which concurrent efforts could draw on and progress, and thirdly, to begin gathering information for subsequent studies through surveying both physically and acoustically a number of specific ocean bottom areas.

During the first year of the program, a series of four separate sampling programs were conducted. Initially, an attempt was made to acquire acoustics over fourteen (14) sites in Long Island Sound which had been cored the previous year by the United Aircraft Research Laboratories (UARL) under contract to the Connecticut Resources Commission. (Reference 1968).

In the Sea Grant data acquisition program, sampling at these sites consisted of both graphic display and magnetically recorded (taped) acoustics together with a surface sediment sampling program to correlate

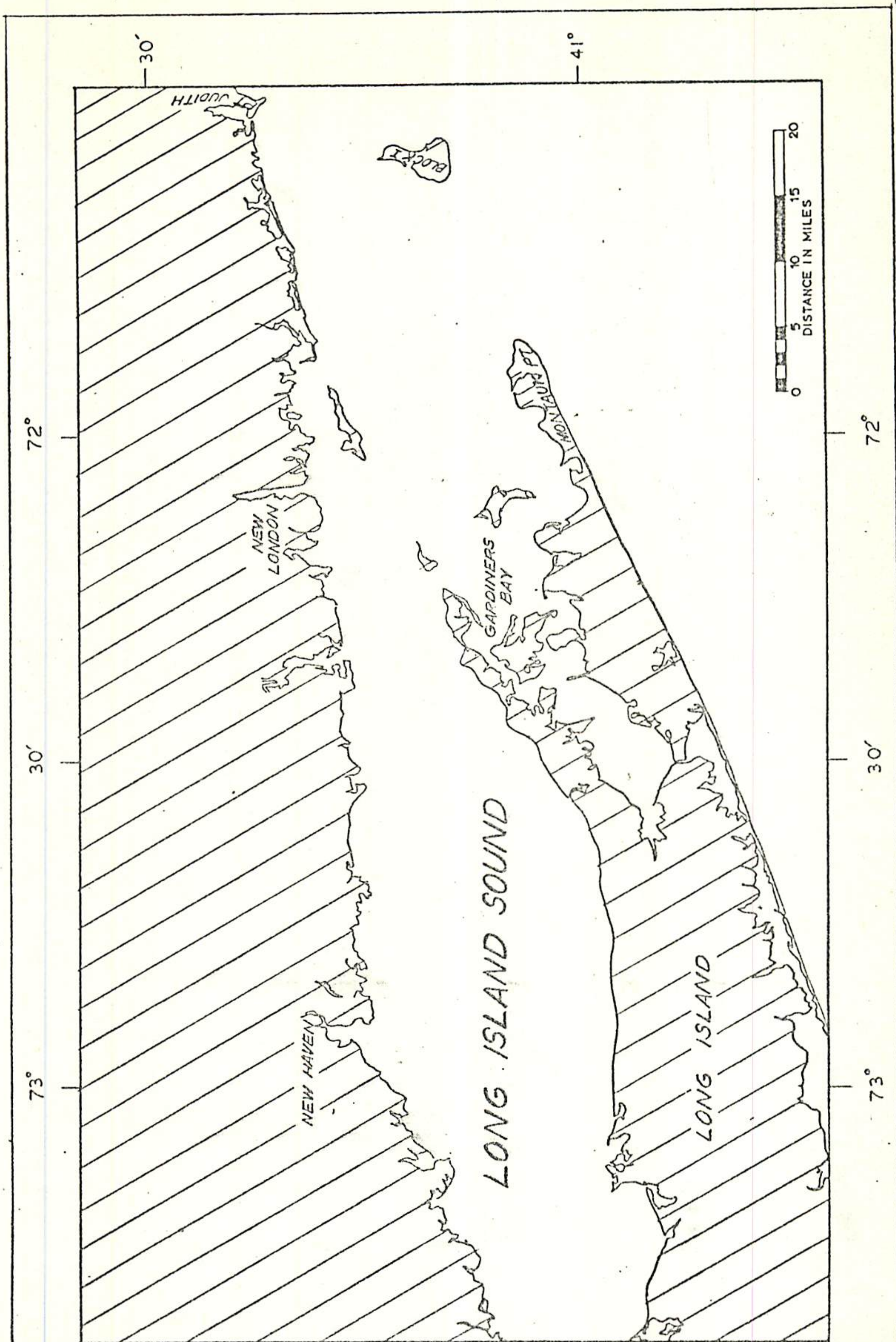

PT JUDITH
BLOCK I
MONTAUK PT
GARDINERS BAY
NEW LONDON
NEW HAVEN
LONG ISLAND SOUND
LONG ISLAND
0 5 10 15 20
DISTANCE IN MILES
30'
41°
72°
30'
73°
30'
41°
72°
30'
73°

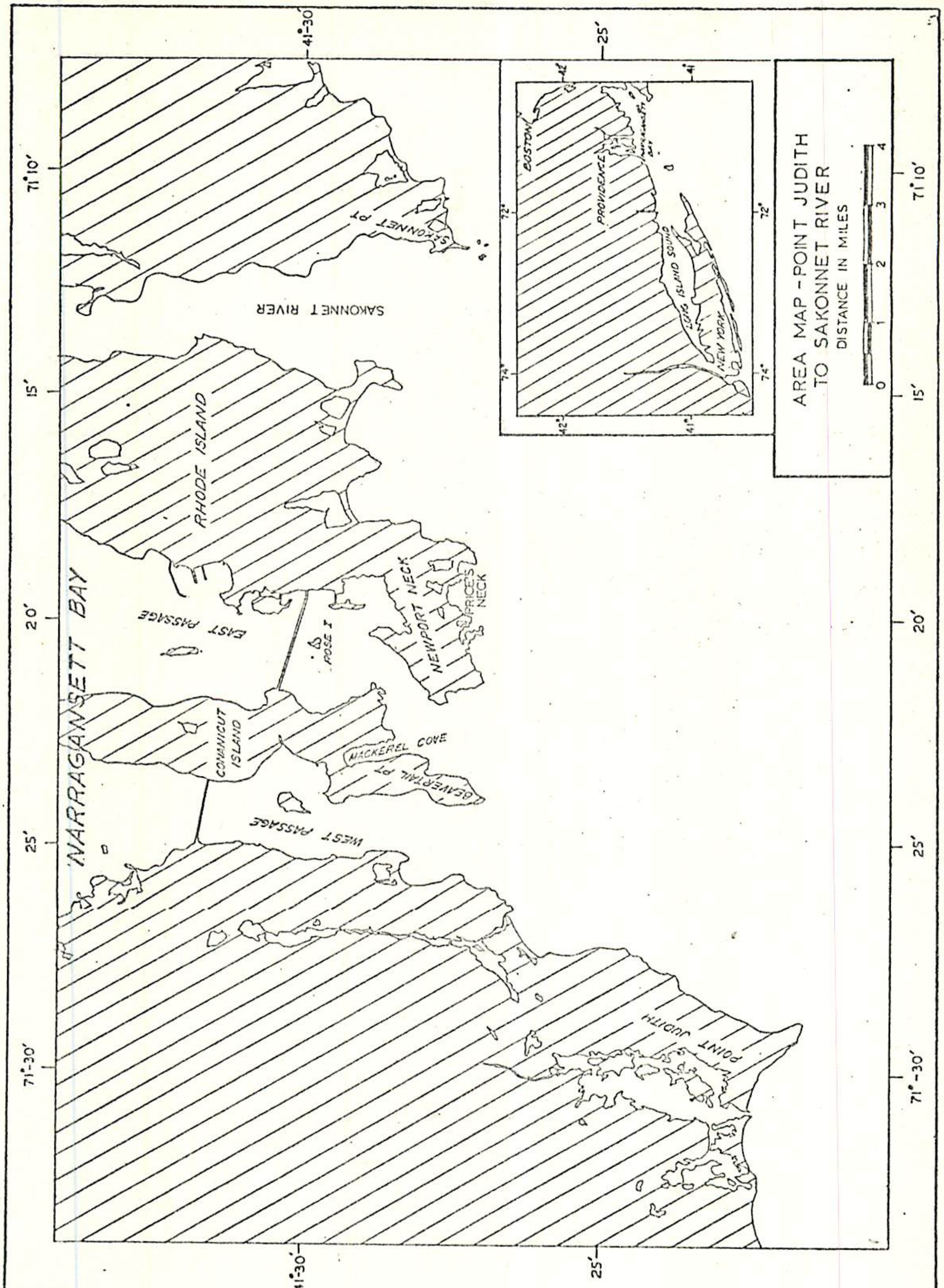
FIG. 8

with the sediment analysis of cores taken by UARL. The scope and initial results of these data collection exercises have been previously reported in considerable detail in Technical Memo VI and the progress report dated November 5, 1970 to the Sea Grant Program Office. Interested readers are directed to these documents for a more complete discussion of results than is contained in this summary report.

A second, more extensive sampling project was also undertaken the first summer. These efforts were directed toward finding at least two areas within the Narragansett Bay System possessing distinctly different sediments, preferably a gravelly-sand and a silty-sand (Figure 9). Ideally, these sites would have horizontally oriented beds four to six feet in vertical extent in an area of low bottom relief overlying a thick homogeneous sediment of markedly different physical properties (e.g., a clay). "Ideal" sites were not found but based upon further literature search and physical sampling, several sites were identified where the sediment exhibited a large variation in both acoustical and physical properties of the individual layers.

Following preliminary sub-bottom acoustic traverses through the areas, sites were selected for the physical sampling employing the POGO-STICK, a vibratory corere developed by UNH as one task under the overall Sea Grant Program. Significantly, cores in excess of twenty feet were obtained from multiple sites in each the Mackeral Cove and West Passage areas of Narragansett Bay.

Following the coring activities, a series of closely spaced acoustic survey lines were run using a conventional 3.5 kHz sub-bottom profiler to assess the detailed sediment structure at and between the core sites. The data collected during this period consisted



AREA MAP - POINT JUDITH
TO SAKONNET RIVER
DISTANCE IN MILES
0
1
2
3
4
NARRAGANSETT BAY
RHODE ISLAND
SAKONNET RIVER
SAKONNET PT
EAST PASSAGE
WEST PASSAGE
CONANICUT ISLAND
MACKEREL COVE
BEAVERTAIL PT
NEWPORT NECK
PRICES NECK
ROSE I
POINT JUDITH
BOSTON
PROVIDENCE
LONG ISLAND SOUND
NEW YORK
71°10'
15'
20'
25'
71°-30'
41°30'
25'
42°
41°
72°
74°

FIG. 9

of graphic records which were then analyzed to produce a series of bathymetric and sub-bottom sediment interface maps. The generation of these topographical maps and their significance in the context of this program Sea Grant objectives is discussed in detail in a Technical Memo presently in preparation.

To summarize, however, this series of maps present a comprehensive picture of the bottom and sub-bottom structure which, in addition to expanding the physical-acoustic data bank, allowed the design of specialized at-sea experiments to assess particular geotechnical properties of these sediments. For example, in year two operations acoustic data will be acquired at map indicated geographical positions where the second sub-bottom layer has constant thickness and underlies the uppermost layer of bottom sediments which progressively become thinner. Under these conditions, acoustic wave attenuations with depth may be found in the uppermost layer by direct comparison. By reversing this procedure, attenuation rates may be computed for the lower most layers in successive order. In addition to providing data on various sediment type attenuation coefficients, knowledge of attenuation within these layers will allow the calculation of internal reflection coefficients for the underlying of sub-structures.

The fourth series of field data was acquired under the add-on funding received late in the program's first year. Based upon the experience gained during our previous operations and the learning acquired during initial analysis of the Long Island Sound and Narragansett Bay data, several additional factors were considered.

First, computer aided data reduction and processing of the voluminous acoustic data collected was strongly indicated. Second, interpretation of the Precision Fathometer Recorder (PFR) traces from several of the initial survey sites indicated noticeable lateral variation in the apparent composition of the bottom and sub-bottom layers. And third, as a result of the variation noted above, the necessity for either simultaneous conduct of both physical and acoustic sampling or employment of a precise navigation system for reoccupation of the physical sampling stations was required.

2. Physical Data Acquisition

A Program of Continental Shelf bottom and sub-bottom material sampling was undertaken by Sea Grant project personnel during the summer of 1970. The objective of this program was to provide soil information for later correlation with acoustic data. Two basic types of samples were desired.

1) Surficial bottom samples over a very large area to aid in selection of a variety of sub-bottom types.

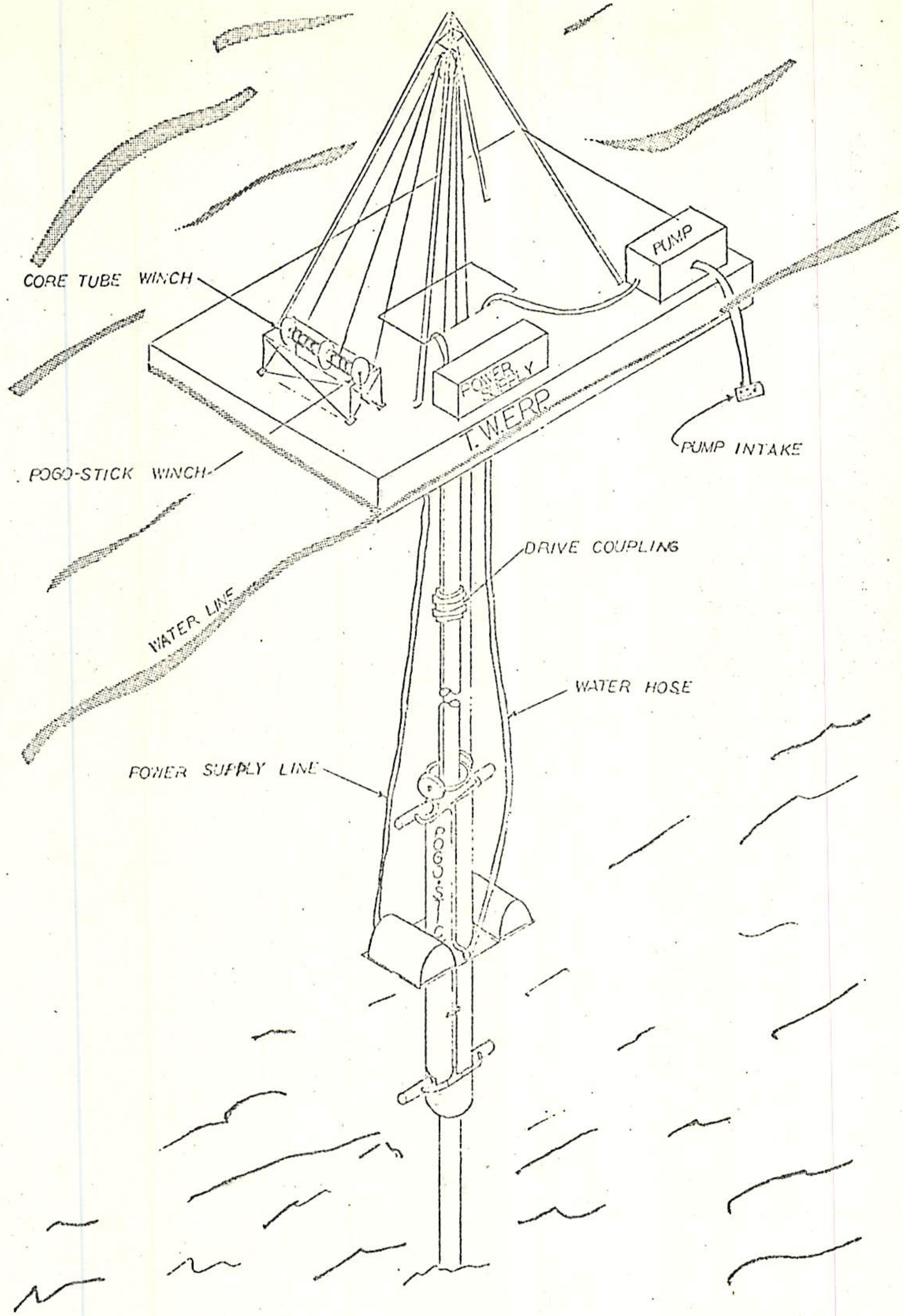
2) Sub-bottom samples from depths to 20 feet or more from a smaller number of sites each having its own specific stratigraphy.

Research vessel support for the program was provided by Southeastern Massachusetts University's R/V CORSAIR. During the Narragansett Bay sampling activity, the University of Rhode Island (a Sea Grant College) generously made available their docking and storage facilities at the Narragansett Campus.

Since the Program objective was to provide soil data on a variety of bottom and sub-bottom types, surficial bottom sampling was done over a large portion of Narragansett Bay starting at the mouth of the Sakonnett River in the East and ending near Narragansett Beach at the western end of the bay (Figure 9). For rapid surficial sampling, a Shipek snapper grab was most frequently used. This provides very positive sampling in all but the coarsest of bottom materials and has the advantage that sample washout is minimized. Where larger samples were required or when difficult materials were encountered, sampling was done with pipe dredges designed and constructed by project personnel.

For immediate sub-bottom sampling, a small gravity corer was obtained. As this corer was not expected to obtain cores much over 5 feet in length, it was decided to continue development under this project of a vibratory corer (Pogo Stick) originally designed and constructed as part of a previous Sea Grant funded research project. This electrically powered corer is designed to take 2 inch diameter cores in excess of 20 feet in length, and avoid the problem of core barrel length limitations commonly imposed on most conventional designs (Figure 10).

The reconnaissance investigations indicated that a variety of bottom types was in fact available. These ranged from clean, coarse sands to fine muds and included scattered sites with rocky and till derived bottoms. Following the initial surveys, gravity coring was conducted at three sites - one in East Passage near Rose Island - one in Mackerel Cove and another in West Passage near Beaver Neck. These sites were attractive for a number of reasons: a large amount of information was already available; they were close to shore-side facilities; they were sheltered from inclement weather and sea state; and a number of shore-based, charted points were visible for navigation purposes.



POGO STICK CORER

FIG. 10

Major activities were concentrated in West Passage and Mackerel Cove as there were WHOI refraction profiles available for these sites (Hersey, et al, 196). This latter information indicated significant acoustic zones in the first 20 to 25 feet beneath interface.

The Pogo Stick corer proved to be highly effective in these materials which consisted on multiple layers of muddy sands and gravels overlying a considerable thickness of blue marine clay. Several cores 20 feet or longer were taken from each of these two sites and these provide the initial basis for correlation with acoustic data acquired during the first year. To minimize station position error, the location of these cores was precisely determined using sextant observations to charted shore-based landmarks and navigation aids.

3. Acoustic Data Acquisition

i. Operations

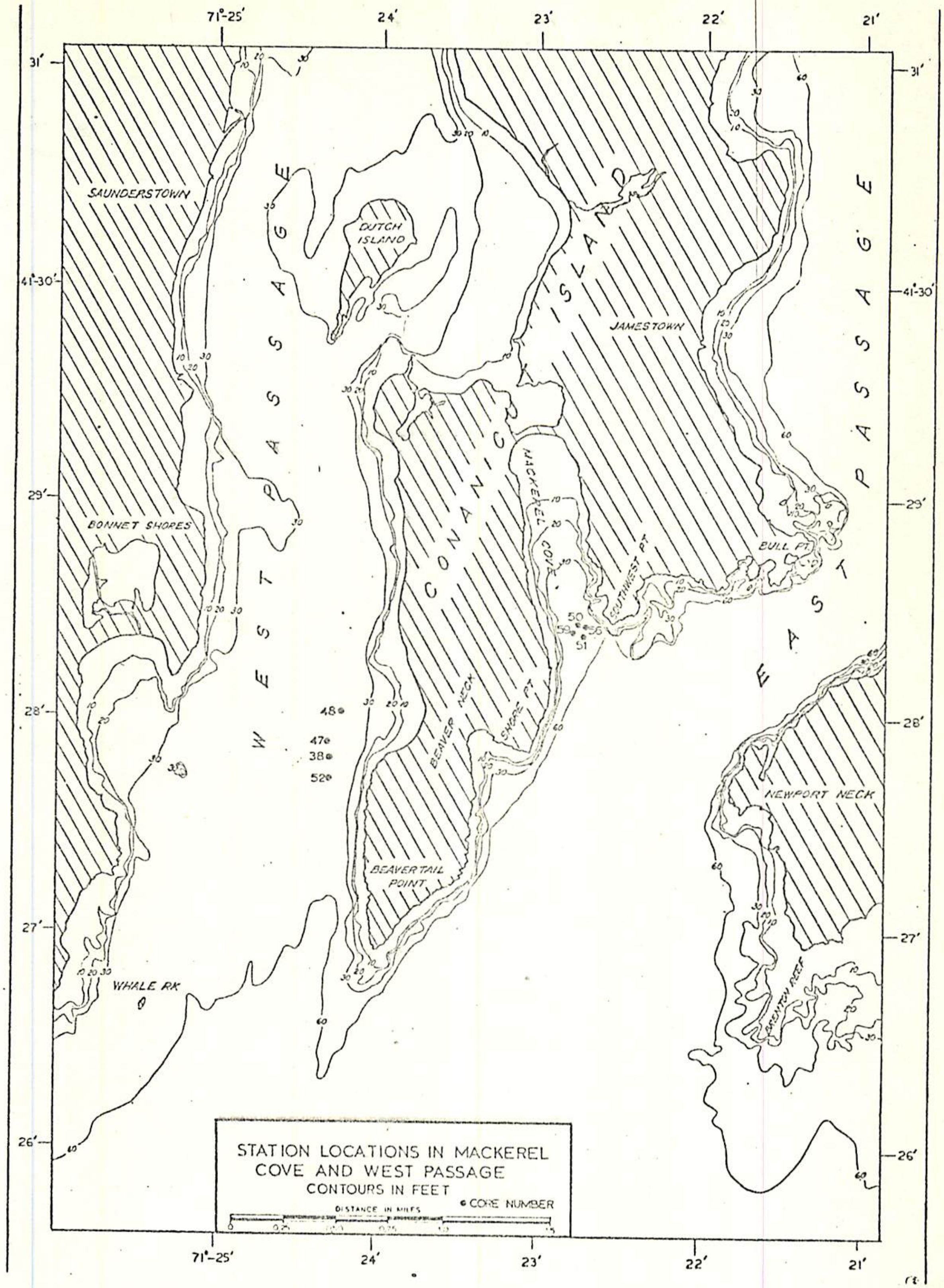
Six of the previously core sampled sites from within Narragansett Bay were selected for an expanded acoustic data acquisition effort. Rather than attempt to acquire acoustic data along a traverse which both passed through a previously cored sample site and which displayed no change in layer response, it was decided to anchor over the previously cored sites during conduct of the acoustic data acquisition activities.

It was anticipated that establishing the survey vessel at anchor would afford an opportunity for increased correlation between the various acoustic measurements as spatial variation observed during the previous tests in the sediments would be avoided. In order to accomplish these goals, at each station a sequence of acoustic sampling was planned which involved the acquisition of data at several center frequencies and geometric configurations.

Both the original position and reoccupation of these sites was accomplished through triangulation employing sextants for azimuth angle measurement, together with marker buoys to assist in determing the specific site location to be reoccupied. Based upon the angular resolution of these instruments and the chartered distances involved, the calculated error of the original and the reoccupied station position is computed as $\pm$ 25 feet. The station positions occupied during the sequence of acoustic data acquisition are presented in Figure 11.

At each of the six sites, the M/V ALAN executed a two-point mooring with subsequent anchor line adjustment to achieve the minimum practical displacement from the recorded physical sample coordinants. Test operations commenced as the M/V ALAN approached the designated station. At a point approximately 100 yards from the station position, sub-bottom profiling was initiated to ascertain the physical structure and continuity of the sub-bottom reflectors in the core area. Following position establishment, an on-station acoustic calibration program was conducted prior to the commencement of acoustic data recording.

While the major system calibrations were performed at dock-side, specific on-site calibrations involving the measurement of background noise and magnetic tape response were conducted to further insure data quality. Following these tests, the acoustic pulse generation system was activated with the transmitting voltagegradually increased from its minimum position until 20 milliseconds of sub-bottom information was displayed on the graphic recorder. The returning waveform was simul-



STATION LOCATIONS IN MACKEREL COVE AND WEST PASSAGE
CONTOURS IN FEET
CORE NUMBER
DISTANCE IN MILES
71°-25'
24'
23'
22'
21'
31'
41°-30'
29'
28'
27'
26'
SAUNDERSTOWN
DUTCH ISLAND
JAMESTOWN
BONNET SHORES
WEST PASSAGE
CONANICUT ISLAND
EAST PASSAGE
MACKEREL COVE
SOUTHWEST PT.
BULL PT.
BEAVER NECK
SHORE PT.
NEWPORT NECK
BEAVERTAIL POINT
WHALE RK
BRENTON REEF

FIG. 11

taneously examined on an oscilloscope and transmit voltage increased further if a satisfactory signal-to-noise ratio did not exist.

Concurrent with these operations, the vertical distribution (profile) of temperature and salinity were measured to allow an accurate calculation of sea watch density and sound speed. This latter information is employed in the data analysis calculations of expected Rayleigh reflection coefficients.

Two final checks were performed prior to commencing to record acoustic data. First, a system check was made to ascertain if the source levels being monitored at one yard and calculated based upon the transmit voltage response and measured input voltage agreed. Secondly, the amount of bottom loss was calculated based upon the oscilloscope presentation. A decision criteria was established in that if the calculated bottom loss exceeded 20 dB, the entire system was reexamined prior to actual acoustic data recording. Assuming this last test was satisfied, the recording of acoustic data commenced.

ii. Acoustic Data

Acoustic data was collected at three (3) center frequencies and from three (3) separate depths during these tests. The primary center frequencies employed for sampling during the at-sea data acquisition period were 3.5 kHz, 8.0 kHz, and 12.0 kHz. Three "standard" depths were selected . These depths 1) simulated standard underway sub-bottom profiling operations with the transducer a nominal five feet below the surface, 2) involved a bottom coupled mode with both transducers resting directly upon the bottom sediments, and 3) an "Optimum depth" configuration designed to allow acquisition of the returning acoustic signal from the bottom and sub-bottom prior to the arrival of the surface reflection. In this context "Optimum depth" operation; d is defined as:

$$D - \frac{d}{2} \leq d_{\emptyset} \leq \frac{D + d_s + d_{\emptyset}}{2}$$

Where: D = water depth

$d_{\emptyset}$ = depth of operations

d_s = depth of interest in sediments

d = pulse length in water

Generally, a one-millisecond (1 ms) pulse length was employed during the normal sequence of acoustic data acquisition at each station. In addition to the standard sequence of three positions, three frequency data, the planned operating schedule also allowed time for sampling at other frequencies, geometry, and/or pulse lengths. When not consumed by operational contingencies, additional data was acquired at several other center frequencies and at 0.5 mx pulse lengths. The additional center frequencies employed were 5.0 kHz, and 7.0 kHz.

G. Signal Processing and Computer Operations:

There are essentially two sets of acoustic data which were recorded on magnetic tape during the year one Sea Grant project. These data were acquired in Long Island Sound and in Narragansett Bay, respectively. Initial signal processing efforts began with manual procedures using a Sanborn Visacorder for chart printout of Long Island Sound data. Principal efforts in this area centered on the calculation of Rayleigh reflection coefficients and subsequently, bottom losses as a function of both frequency and bottom type. Having determined reflection coefficient and bottom loss values, these experimental values were then compared to published findings for similar sediments. Technical Memo VI discusses these results and the inter-relationships observed between acoustic and physical properties.

While the bulk of the data recorded in Long Island Sound will have to await completion of the machine processing efforts discussed below, some initial results can be derived from the manual processing studies already completed. Significantly, as reported in the Technical Memo VI, the data acquired at all the geographical sites examined displayed a high degree of correlation between physical property changes within the sediments and acoustically indicated reflection coefficients, bottom losses, and sub-bottom interface positions.

In addition, at a number of these physical sites, the use of various frequencies resulted in increased definition of sediment variations. From a quantitative point of view, the bottom loss values calculated were found to correlate quite closely with those observed by other researchers.

H. Computer Aided Processing:

Rather than continue to manually process the rapidly increasing amount of data, efforts were started to allow machine (computer) processing of the recorded acoustic data. Development of these programs was directed towards two objectives; first, the creation of the ability to process the Long Island Sound data and secondly, to develop programs which interface with on-going data acquisition permitting continuous digitization of recorded data. This latter effort was also aimed at establishing criteria to permit acquiring the acoustic data in the most advantageous format for post-operation processing.

In order to be able to handle both the Long Island Sound data and subsequently recorded Narragansett Bay data, two separate sets of analog-to-digital conversion programs were generated. The first digitizing programs allow selected series of pulses occuring within a fixed time segment, nominally 500 ms, to be digitized. Any number of these series or trains of pulses can be digitized, sequentially. The digitization procedure is particularly useful for data recorded during underway acoustic sampling where high pulse repetition rates are desired to achieve greater sampling densities.

A second set of digitizing programs also were generated to allow continuous digitization of extended series of pulses. The time interval between pulses however, is critical as there must be sufficient time (approximately 500 milliseconds) for machine operations between individual pulse digitizations. These latter programs were developed to process the acoustic data gathered from anchor stations in Narragansett Bay where a high sample rate during acquisition was not mandatory.

In addition to the above digitization programs, several other programs have been developed. The first of these computer routines allows generation of computer driven plots of the digitized data. A typical plot detailing the time series of a normally incident 3.5 kHz acoustic pulse is presented in Figure 12. A second program accepts the output of the digitization programs and reformats the information on

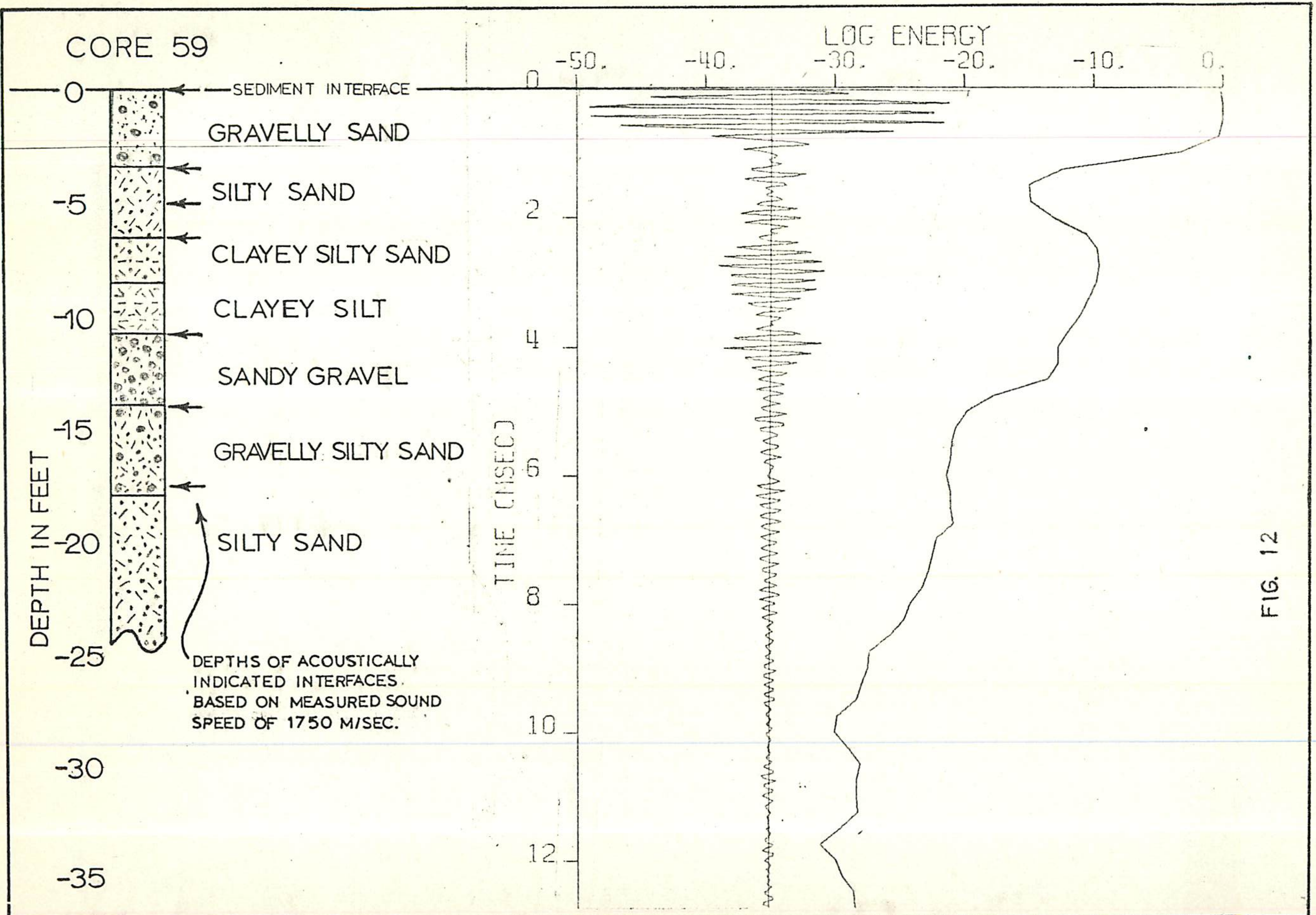

CORE 59
DEPTH IN FEET
0
-5
-10
-15
-20
-25
-30
-35
SEDIMENT INTERFACE
GRAVELLY SAND
SILTY SAND
CLAYEY SILTY SAND
CLAYEY SILT
SANDY GRAVEL
GRAVELLY SILTY SAND
SILTY SAND
DEPTHS OF ACOUSTICALLY INDICATED INTERFACES BASED ON MEASURED SOUND SPEED OF 1750 M/SEC.
LOG ENERGY
-50.
-40.
-30.
-20.
-10.
0.
TIME (MSEC)
0
2
4
6
8
10
12

FIG. 12

the original digital tapes into a second format compatible with computer input requirements of the researchers at the University of New Hampshire.

Yet another computer programming effort undertaken during the first year was the generation of programs to calculate the reflected waveform of a normally incident acoustic pulse under conditions of known outgoing pulse waveform and situation geometry together with water mass and sediment properties. These programs thus represent the computer processing implementation of the plane wave model discussed previously.

Further development of these programs is presently underway to allow calculation of expected sediment properties if the other criteria are defined. Operationally, as the outgoing pulse waveform can be monitored, the test geometry and water mass properties are generally known, and the reflected waveform can be recorded; peturbation of the values describing sediment physical properties to maximize the cross-correlation function between the actual reflected waveform and that calculated by the model should yield a set of values approximating those of the actual sediment. The output, thus is a remote assessment of sediment properties based upon the discussed plane wave - ray acoustic model.

As a second portion of the signal processing effort, in parallel with the work described above there was considerable effort spent in activities related to utilization of the results of the experimental program in verifying the field theoretical model which was being developed.

Because a vast amount of theoretical and experimental work has been done in the past which relates to the signal processing aspects of this project, an extensive literature survey was initiated early in the program. This survey provided the baseline of knowledge and understanding from which to approach the problem of processing experimental data to accurately detail sediment properties. The literature survey also resulted in a large list of articles related either directly or indirectly to the problem of determining the ocean subbottom structure with special discussions treating several of the more significant papers. These discussions additionally helped to formulate a list of sediment parameters and understand the inter-relationships between these parameters.

The task of data processing and signal treatment to enhance the field theoretical model indicated sediment indices was aided and integrated through approximately semi-weekly discussions in which it was attempted to relate experimental data. This aspect of the signal processing task was further expedited by the ability to participate in planning the experimental program. Such topics as the measurements to be made and recorded, the type of experimental equipment used, the equipment configuration and the amount of data were discussed with regard to data type and quality. Additionally, the amount of data to be acquired at each site was examined as this influenced the confidence factor in the statistical analysis done with regard to signal processing.

Because of the large amount of data acquired, the complexity of the proposed signal processing procedure, and the goal of eventually producing a complete on-line processing unit it became clear that computer processing of the data would be required. As a result, immediately following the availability of funds provided by the add-on effort, the UNH computer compatible with digital tapes of the raw data were made following initial successful test verification. Significantly the ability to process the raw acoustic data at both institutions has allowed more rapid transfer of newly acquired experimental data to the UNH Signal Processing investigators.

As an expansion of the efforts previously discussed, more specific literature surveys were initiated to determine the state of the art in digital signal processing; especially techniques related to the determination of signal statistics in the presence of noise. As one effort undertaken in this area, fast Fourier transform techniques were investigated. Programs presently have been written to employ FFT analysis in determining the onset of the bottom-reflected return pulse and for determination of the source transmit frequency. In this regard, Kalman filtering also has been investigated, specifically directed towards sophisticated noise suppression routines. The unpredictability of ocean noise, however, is a question mark and limits the free powers of Kalman filtering . Further investigation of this aspect of the signal processing task is programmed for the second year activities.

Initial computer programming has been aimed at determining the leading edge of the return pulse as boat and transducer motion in first year data manifests itself as time domain variability of the return reflections. Since the variation in time of arrival of the return pulses is large with respect to the period of the acoustic wave, statistical measures of pulse characteristics are extremely distorted. Pulse to pulse phase considerations have been postponed until stabilized time series data can be acquired.

In summary, the signal processing effort has focused on both the theoretical and experimental work in an effort to combine the results of each into a process which will lead to the expressed goal of remotely sensing the characteristics of ocean bottom sediments. Importantly, the concomitant signal processing associated with the two models being employed/developed by researchers in this project is proceeding as parallel efforts with extensive cross-fertilization between the two involved institutions.

I. Laboratory Analysis of Physical Samples

One of the primary goals of this program is the development of remote acoustic assessment methods to evaluate both the physical and civil engineering properties of coastal marine soils. Well taken and carefully analyzed cores and other physical samples thus form the cornerstone of this research from which develops an understanding of the correlation between the sensible acoustic parameters and the physical environment.

As one phase of the overall program, a series of samples were taken in Narragansett Bay and adjacent waters. These samples consisted of grab dredge, gravity core, and vibratory core samples. The grab and dredge samples, of course, represent only the surface sediment distribution, whereas the two types of cores yield not only a real knowledge, but information in the third dimension; depth.

Laboratory Processing

The dredge and grab samples were washed in fresh water to remove salt, then dried in an oven. Both hydrometer and wet sieve analyses were performed to determine grain size distribution. In addition, an average value of soil solid specific gravity was determined, and soil porosity was calculated.

Cores were split longtudinally with one half being divided into four inch long segments and retained for further analysis. The other half was visually divided into segments of obviously varying materials. Each of these different layers was treated as a separate sample and analyzed to determine grain size distribution and specific gravity of soil solids. In the event that the layers which appear to visibly differ do not appear to be acoustically different, the small samples from the other half of the core will be analyzed to try to establish a basis for an acoustic correlation.

The following parameters were determined for each sample:

1) D_{10} and D_{60} - These are particle diameters corresponding to different points in the grain size distribution. They are used by soils engineers to estimate porosity, permeability, and consolidation characteristics.

2) υ , coefficient of uniformity - This is the ratio D_{60}/D_{10} and is used as an estimator of the grading of samples.

3) Percent Gravel - This represents the percentage of the total sample which is larger than 2 millimeters in diameter.

4) Percent Sand - This represents the portion of the sample whose size ranges from 2 millimeters down to 0.062 millimeters.

5) Percent SaoC - This represents the portion of the sample which is silt and/or clay and consists of particles smaller than 0.062 millimeters in diameter. In this sample analysis no attempt has been made to distinguish between clays and silts. If this distinction proves to be important for acoustic correlation, further analytical techniques can be employed.

6) Specific Gravity of Soil Solids - This parameter, has proven difficult to determine because the presence of organic matter frequently leads to low values.

7) Porosity (calculated) - Porosity is the ratio of volume of voids to total soil volume. It could not be measured directly because of sample disturbance, but an estimate was made based on empirical relations developed by Hough.

In addition to the seven parameters cited above and the original grain size distribution, per se, each sample was classified according to the various percentages of gravel, sand, and SaoC, and further identified by a number locating it on a trilinear classification chart. This classification is not precise since different samples will frequently plot in the same zone. For this reason, the additional diameter and uniformity information has been included to give a more comprehensive mechanical description of the soil.

To demonstrate the general form, data from core #51 is presented below.

CORE # 51

Location: Mackeral Cove
N 41° 28' 22"
W 71° 22' 45"

Depth in Feet	General Information
0-1/2	Classification: α-SaoC-Sand - 5α
	Gradation: D_{10} = .05, D_{60} = .15, υ = 3.0
	S. G. Solids: 2.69
	% Gravel: 0 % Sand: 75 % SaoC: 25
1/2-1 1/2	Classification: α-Gravelly-Sand - 10α
	Gradation: D_{10} = .07, D_{60} = .60, υ = 8.6
	S. G. Solids: 2.67
	% Gravel: 10 % Sand: 85 % SaoC: 5
1 1/2 - 5	Classification: α-SaoC-Sand 5α
	Gradation: D_{10} = .025, D_{60} = .20, υ = 8.0
	S. G. Solids: 2.62
	% Gravel: 8 % Sand: 72 % SaoC: 20

Depth in Feet	General Information
5 - 5 1/2	Classification: β-SaoC-Sand - 5β Gradation: D_{10} = .035 D_{60} = .20 υ = 5.7 S. G. Solids: 2.52 % Gravel: 7 % Sand: 66 % SaoC: 27
5 1/2 - 6	Classification: β-SaoC-Sand - 5β Gradation: D_{10} = .015 D_{60} = .10 υ = 6.6 S. G. Solids: 2.68 % Gravel: 0 % Sand: 65 % SaoC: 35
6 - 9	Classification: β-SaoC-Sand 5β Gradation: D_{10} = .03 D_{60} = .10 υ = 3.3 S. G. Solids: 2.62 % Gravel: 5 % Sand: 65 % SaoC: 30
9 - 11	Classification: α-Sand-SaoC - 2α Gradation: D_{10} = .002 D_{60} = .03 υ = 15.0 S. G. Solids: 2.65 % Gravel: 0 % Sand: 25 % SaoC: 75

Depth in Feet	General Information
11 - 11 1/2	Classification: SaoC-Gravelly-Sand 6β Gradation: D_{10} = .02, D_{60} = .35, υ = 17.5 S. G. Solids: 2.73 % Gravel: 25 % Sand: 60 % SaoC: 15
11 1/2 - 17	Classification: Gravelly-SaoC-Sand 6α Gradation: D_{10} = .01, D_{60} = .40, υ = 40.0 S. G. Solids: 2.67 % Gravel: 20 % Sand: 55 % SaoC: 25
17 - 23	Classification: β-SaoC-Sand 5β Gradation: D_{10} = .006, D_{60} = .20, υ = 33.0 S. G. Solids: 2.72 % Gravel: 5 % Sand: 50 % SaoC: 45
23 - 24	Classification: α-SaoC-Sand 5α Gradation: D_{10} = .0075, D_{60} = .25, υ = 33.3 S. G. Solids: 2.54 % Gravel: 0 % Sand: 70 % SaoC: 30

J. Data Bank

One of the principal project sub-tasks is concerned with the acquisition of base-line data at a series of oceanographic stations covering a wide range of physical sediment properties. In order to locate sites for testing, an extensive literature search was first conducted from which several potential areas were selected for reconnaisance sampling. At the conclusion of this initial sampling and the attendant analysis period, a series of approximately 20 specific stations in Long Island Sound and the Narragansett Bay area were identified. Sediments occurring at these stations covered the spectrum of commonly encountered Continental Shelf sediments, ranging from marine clays to coarse glacially-derived sandy gravel.

The programmed sampling activity for these sites, including the reconnaissance survey and the addendum-funded sea-tests, involved a series of four at-sea operations. The resulting data includes, first, physical samples and the analyses of individual grabs, gravity cores, and vibratory core samples; second, acoustic data stored on both graphic records and on magnetic tapes; and third, measured temperature/ salinity profiles for computation of sound speed in the water column. The above data base is further augmented by the set of curves resulting from the calibration of each active and passive acoustic element employed for the at-sea data acquisition program. These later curves detail the parameters of transmitted and received beam patterns, hydrophone receiver sensitivities, and source transmitter voltage responses.

While the bulk of the data included in the present data base details essentially static conditions (e.g., the description of the cores, data sheets describing each test configuration, annotated graphic records from acoustic profiling, salinity/temperature profiles, and calibration curves of the acoustic sensors), the volume of acoustic data recorded on magnetic tape is a somewhat more dynamic resource.

In contrast to the previously mentioned information, the value of the tapes lies in the information they contain rather than in that which is presented. In order that this resource may be fully employed, it is mandatory that the data contained on these tapes be inventoried, organized, and processed.

The computer processing involved in the acoustic data reduction and analysis sequence has been previously discussed. The techniques being employed in data bank accounting however should be examined further. As the acoustic data is originally recorded on analog tape, the first requirement is an inventory of the information contained on these records. Data sheets to fill this requirement and simultaneously allowing the continual update of acoustic data bank status have been designed. As an example, the data acquired during the add-on period sea test is presented in the following sheets.

The specific information contained in each column is explained below.

Column heading	Description of information in column
Data Sheet	Number of the field log page(s) containing the information recorded during the actual at-sea operations period.
Site Number	Station number of the geographic position where the acoustic and physical data was acquired. These are the same numbers as those which appear on the area maps.
Geometry	This column contains a coded symbol detailing acoustic source-receiver confirguration and position. In this data sequence only three symbols appear: 1) S - Surface operations simulating conventional underway sub-bottom profiling. Source and receiver located approximately five feet below the surface. 2) Ø - Optimum depth operations. In this position, the bottom and sub-bottom reflections return to the receive hydrophone prior to the arrival of the surface (air-water reflection. 3) B - Bottom operations with both the source and receiver elements in direct contact with the sediments.
Center Frequency	Center frequency of the outgoing pulse in kHz.

Pulse Length	Duration of the outgoing acoustic pulse in milliseconds (msec.)
IRIG 'B' Time Code	A coded, time-referenced frequency signal recorded on the analog tapes during data acquisition to afford positive data identification and allow precise digitization of selected pulse sequences.
Analog Tape Number	Self Explanatory
Digital Tape Number	Self Explanatory
Digital Tape File Numbers	These numbers indicate the position of the four channels of acoustic data which were digitized. Specific file numbers are indicated in each labled column.
IRIG 'B' Time Code (Start)	The time code indicated in this column represents the initiation of digitization. In operation, at this exact time instant, a pulse was sent by the time code translator (reader) to the computer which then commenced actual digitization of the data.
Amount of Data	In this column is recorded the number of pulses which were digitized rather than the amount of data recorded on the analog tapes. On the analog tapes, a nominal 5 minutes of data were recorded which consists of approximately 300 pulses at a one pulse per second rate.
Station Location	Identification of the general geographical area from which the data acquired.

In summary, the data bank, at the close of the first year activities through and including those efforts funded under the year one addendum, comprises a large body of both physical and acoustical data, together with extensive component and system calibration curves. In addition to the intensive effort undertaken to process and analyze both data sets, attention has also been directed towards maintaining representative samples of the original material for reference and for utilization by other interested researchers. In this regard, splits of the physical samples have been inventoried and achieved. The acoustical data, of course, are available on the original analog magnetic tapes for either re-examination or subsequent special investigations.

Importantly, the first year efforts involving literature searches, reconnaissance surveys, and at-sea sampling programs have identified, located, and sampled naturally-occurring marine sediments ranging from fine grained clays to coarse, glacially derived sandy gravels. As the companion acoustical sampling was conducted covering a wide range of source-center frequencies, the total acquired data thus established an extensive base of physical and acoustical data for examination of the inter-relationships between acoustic energy propagation in and the physical properties of Continental Shelf sediments.

The sampling programs conducted during the first year also have delineated several sites with unique depositional geometry affording the opportunity to process the resulting differential path length acoustics for several additional sediment descriptive parameters. It should also be noted that the first year's activities were of further importance in that the learning gained has provided substantial direction to both the physical and acoustical sampling efforts under-taken in present second year program.

DATA SHEET	SITE NO.	GEOMETRY	CENTER FREQUENCY	PULSE LENGTH (M/SEC)	IRIG "B" TIME CODE	ANALOG TAPE NO.	DIGITAL TAPE NO.	DIGITAL TAPE FILE NUMBERS: LC-10	LC-32 (LOW)	LC-32 (MED)	LC-32 (LOG)	IRIG "B" TIME CODE (START)	AMOUNT OF DATA			STATION LOCATION
1	5	φ	3.5	1.0	169 12/54/20 13/02/07	1	9	1	2			169 12/58/00	20			MACKERAL COVE
2	5	S	3.5	1.0	14/05/57 14/13/00	1										
3	5	B	3.5	1.0	14/21/09 14/27/08	1	11		2		1	169 13/03/08	20			
4	6	S	3.5	1.0	172 10/54/17 11/00/11	1										MACKERAL COVE
5	6	φ	3.5	1.0	11/10/20 11/17/12	1										
6	6	B	3.5	1.0	11/29/00 11/33/07	1										
7	6	S	12.0	0.75	12/21/00 12/38/00	1										
8	6	φ	12.0	0.75	12/42/00 12/48/00	1										
9	6	S	8.0	1.0	175 11/17/00 11/26/00	1										
10	6	φ	8.0	1.0	11/33/30 11/40/00	1	11	3	4			175 11/33/30	60			
11	6	B	8.0	1.0	11/48/00 11/53/00	1	11		6		5	175 11/48/00	60			
12	6	S	12.0	0.75	12/44/02 12/52/04	2										
13	6	φ	12.0	0.75	12/56/00 13/02/02	2	9	4	3			175 13/00/00	20			
14	6	S	3.5	1.0	175 14/05/42 14/12/20	2										MACKERAL COVE

DATA SHEET	SITE NO.	GEOMETRY	CENTER FREQUENCY	PULSE LENGTH (M/SEC)	IRIG "B" TIME CODE	ANALOG TAPE NO.	DIGITAL TAPE NO.	DIGITAL TAPE FILE NUMBERS LC-10	LC-32 (LOW)	LC-32 (MED)	LC-32 (LOG)	IRIG "B" TIME CODE (START)	AMOUNT OF DATA			STATION LOCATION
15	6	ϕ	3.5	1.0	175 14/31/28 14/36/45	2	9	5	6			175 14/33/00	20			MACKERAL COVE
16	6	B	3.5	1.0	14/47/54 14/53/31	2										
17	4	S	3.5	1.6	176 11/48/05 11/55/15	2										WEST PASSAGE
18	4	ϕ	3.5	1.6	12/06/56 12/14/07	2	9	19	20			176 12/10/00	20			
19	4	B	3.5	1.6	12/21/20 12/27/19	2	10		5		6	176 12/21/30	20			
20	4	S	12.0	1.0	13/15/00 13/22/00	2										
21	4	ϕ	12.0	1.0	13/25/50 13/32/47	2	10	17	18			176 13/25/30	180			
22	4	S	8.0	1.0	14/01/50 14/08/08	2										
23	4	ϕ	8.0	1.0	14/19/00 14/25/40	2	9	21	22			176 14/22/00	20			
24	4	ϕ	7.0	1.0	14/29/50 14/31/00	2										
25	4	ϕ	7.0	1.0	14/32/38 14/38/18	2	10	19	20			176 14/32/38	180			
26	4	ϕ	6.0	1.0	14/49/10 14/55/48	3	1 / 8	1	3	5	4	176 14/49/00	300			
27	4	B	8.0	1.0	15/11/17 15/17/00	3	2	NO DATA	3	4	2	176 15/11/17	280			
28	2	S	8.0	0.8	179 08/43/43 08/51/30	3										WEST PASSAGE

DATA SHEET	SITE NO.	GEOMETRY	CENTER FREQUENCY	PULSE LENGTH (M/SEC)	IRIG "B" TIME CODE	ANALOG TAPE NO.	DIGITAL TAPE NO.	DIGITAL TAPE FILE NUMBERS LC-10	LC-32 (LOW)	LC-32 (MED)	LC-32 (LOG)	IRIG "B" TIME CODE (START)	AMOUNT OF DATA			STATION LOCATION
29	2	ϕ	8.0	1.0	179 09/05/15 09/13/30	3	2/3	5/—	—/2	—/3	—/1	179 09/05/15	300			WEST PASSAGE
30	2	B	8.0	1.0	09/26/54 09/33/44	3	3/4	NO DATA	—/1	—/2	5/—	179 09/26/54	300			
31	2	ϕ	7.0	1.0	10/11/23 10/17/00	3	4/5	3/—	5/—	—/1	4/—	179 10/11/23	300			
32	2	ϕ	6.0	1.0	10/24/52 10/30/51	3	5	2	4	5	3	179 10/24/52	300			
33	2	S	12.0	0.8	11/18/30 11/28/35	3										
34	2	ϕ	12.0	1.0	11/37/05 11/44/20	3	6	1	2	3	NO DATA	179 11/37/05	300			
35	2	S	3.5	1.0	12/24/35 12/31/25	4										
36	2	ϕ	3.5	1.0	12/42/00 12/53/30	4	6/7	—/4	1/—	2/—	5/—	179 12/42/00	280			
37	2	B	3.5	1.0	13/05/25 13/11/25	4	7	NO DATA	5	6	4	179 13/05/25	120			
38	3	S	12.0	0.8	180 09/19/23 09/26/25	4										WEST PASSAGE
39	3	ϕ	12.0	0.8	09/36/16 09/43/35	4	10	10	11			180 09/36/20	180			
40	3	S	8.0	1.0	10/58/00 11/05/50	4										
41	3	S	5.0	1.0	11/53/00 11/59/20	4										
42	3	S	6.0	1.0	12/03/00 12/10/00	4										
43	3	S	7.0	1.0	12/15/16 12/23/48	4										WEST PASSAGE

DATA SHEET	44	45	46	47	48
SITE NO.	3	3	3	3	3
GEOMETRY	φ	φ	φ	φ	φ
CENTER FREQUENCY	7.0	8.0	6.0	5.0	5.0
PULSE LENGTH (M/SEC)	1.0	1.0	1.0	1.0	0.5
IRIG "B" TIME CODE	180 12/31/05 12/38/45	12/42/45 12/48/30	12/59/00 13/06/20	13/10/00 13/17/25	180 13/22/32 13/27/30
ANALOG TAPE NO.	4	4	5	5	5
DIGITAL TAPE NO.	10	9	9	9	9
DIGITAL TAPE FILE NUMBERS: LC-10	12	12	13	15	17
DIGITAL TAPE FILE NUMBERS: LC-32 (LOW)	13	11	14	16	18
DIGITAL TAPE FILE NUMBERS: LC-32 (MED)					
DIGITAL TAPE FILE NUMBERS: LC-32 (LOG)					
IRIG "B" TIME CODE (START)	12/45/00 180	12/45/00 480	13/02/00 480	13/40/00 180	13/22/35 180
AMOUNT OF DATA	180	20	20	180	180
STATION LOCATION	WEST PASSAGE				WEST PASSAGE

IV. CONCLUSIONS AND ACCOMPLISHMENTS

Listed below is a summary of some of the accomplishments of the first year of this program. During the first year, we:

1. Located off-shore sites in Narragansett Bay with desired geological characteristics
2. Developed a successful coring system
3. Acquired long cores from several of the sites
4. Developed acoustic data collection system
5. Collected acoustic data from sites cored under Connecticut Research Commission study.
6. Collected acoustic data from selected sites which were cored in Narragansett Bay
7. Conducted pilot studies on wide range of bottom sediments for acoustic physical relationships
8. Generated design criteria for basic redesign of the acoustic systems and the data collection experiments
9. Conducted a broadly theoretical study of the acoustical - soil mechanics interactions as a basis for mathematical model.
10. Developed a single layer acoustic sediment model
11. Programmed the computer to accept this model
12. Obtained continuing Raytheon funding support into the third year of the program.
13. Contributed to strengthening the academic program of the University.

14. Contributed a technical base to new business development at Raytheon

It is necessary to note that not all our efforts were fully successful as we wished.

We had to struggle vigorously to create a truly collaborative university-industry team, and it was not always a successful effort. We became more communicative as the program progressed, ending the first year with considerable mutual respect.

It has been extremely difficult to find and maintain a high level of leadership in all phases of this program. Several major changes in manpower assignments resulted.

We had hopes of achieving a major amount of correlation between acoustics and physical samples at the end of the first year. The problems of developing the bridging technology, while collecting and reducing an extraordinary amount of data proved that our original aspirations were naive. It is not until well into the second year of the program that these hopes were being achieved.

The progress in theoretical modeling proceeded slowly. Initial emphasis was maintained on the single layer problem, with attention to the N layer being delayed.

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