SEABED '75 — OBJECTIVES AND ACHIEVEMENTS

P. G. Simpkin, D. R. Parrott, R. Hutchins, and D. I. Ross

Report Series/BI-R-76-15/December 1976
The Bedford Institute of Oceanography is a Government of Canada establishment whose staff undertake scientific research and surveys in the marine environment. It consists of three main units: (1) the Atlantic Oceanographic Laboratory, which is part of Fisheries and Marine Service, Department of the Environment, (2) the Marine Ecology Laboratory, also of Fisheries and Marine Service, Department of the Environment, and (3) the Atlantic Geoscience Centre of the Geological Survey of Canada, Department of Energy, Mines and Resources.

L'Institut oceano graphique de Bedford est un établissement du gouvernement du Canada, dont le personnel entreprend des travaux de recherche scientifique et des études se rapportant au milieu marin. Il comprend trois services principaux: (1) le Laboratoire océanographique de l'Atlantique, qui fait partie du Service des pêches et des sciences de la mer du ministère de l'Environnement, (2) le Laboratoire d'écologie marine, qui relève également du Service des pêches et des sciences de la mer du ministère de l'Environnement, et (3) le Centre géoscientifique de l'Atlantique de la Commission géologique du Canada, ministère de l'Energie, des Mines et des Ressources.
SEABED '75 - OBJECTIVES AND ACHIEVEMENTS

by

P.G. Simpkin, D.R. Parrott, and R. Hutchins

Huntec ('70) Limited
2F Howden Road
Scarborough, Ontario

and

D.I. Ross

Atlantic Geoscience Centre
Geological Survey of Canada
Department of Energy, Mines and Resources

December 1976

REPORT SERIES

BI-R-76-15
ABSTRACT

Seabed '75 was the first phase of a planned 5 year joint government-industry research program involving the Atlantic Geoscience Centre and Huntec '70 Ltd., a Canadian company involved in the development of both land and marine geophysical instrumentation. The research program can be divided into the data collection phase - where the Huntec Deep Tow Seismic system, along with more established geophysical methods, was intimately involved in the research cruises of Regional Reconnaissance Subdivision, and the data analysis phase - where a preliminary study of the seismic data to establish its suitability as a means of measuring certain geotechnical properties of sea floor sediments was undertaken.

The high resolution seismic data added significantly to the output from the research cruises and the indications from the data analysis show that modern signal theory can be used with the Huntec seismic data to obtain parameters which reflect bottom sediment characteristics. The parameters of the seismic signatures involved not only estimates based on bottom echo amplitude, but also on the shape of the individual echoes.

SOMMAIRE

Le Seabed '75 a constitué la première phase d'un programme conjoint du gouvernement de l'industrie prévu pour cinq ans et faisant appel à la participation du Centre géophysique de l'Atlantique et de Huntec '70 Ltd., une société canadienne travaillant à la mise au point d'instruments de recherche géophysique terrestre et marine. On peut diviser le programme de recherche en deux phases: la phase de cueillette des données au cours de laquelle le système sismique de remorquage en eau profonde et des méthodes géophysiques plus traditionnelles ont été utilisés pendant les croisières de recherche de la sousdivision des levés de reconnaissance régionaux, et la phase d'analyse des données au cours de laquelle on a entrepris une étude préliminaire des données sismiques en vue d'établir si elles constituent un moyen convenable de mesure de certaines propriétés géotechniques des sédiments du fond marin.

Les données sismiques à haute définition ont accru de façon significative les résultats des croisières de recherche, et les indications provenant de l'analyse des données montrent qu'il est possible d'utiliser la théorie moderne du signal de concert avec les données sismiques Huntec pour obtenir de paramètres qui indiquent les caractéristiques des sédiments de fond. Les paramètres des caractéristiques sismiques ne comprenaient pas uniquement des estimations fondées sur l'amplitude des échos de fond, mais également sur la forme des échos particuliers.
TABLE OF CONTENTS

I. INTRODUCTION
   1.0 Summary and Acknowledgements 1
   1.1 Objectives of the Seabed Project 2
   1.2 Goals of Seabed '75 2

II. EQUIPMENT DEVELOPMENT
   2.0 The Huntec Deep Tow Seismic System 4
   2.1 Field Evaluation 1974 6
   2.2 Field Program 1975 7
   2.3 System Development during 1975
      2.3.1 Towing and Mechanical Aspects 7
      2.3.2 Fish and Laboratory Instrumentation 8
      2.3.3 Boomer and Energy Storage Unit Development 9
      2.3.4 Sound Source Studies 9

III. DATA ACQUISITION ON A.G.C. PROJECTS
   3.0 Introduction 16
   3.1 Scotian Shelf - Hudson Cruise 75-007, April 11-24 17
   3.2 Grand Banks - Hudson Cruise 75-009, Phase I, April 25-May 29 17
   3.3 Northern Gulf of St. Lawrence - Northeast Newfoundland,
      Hudson Cruise 75-009, Phase III, July 21-August 20 19
   3.4 S.E. Baffin Island - Hudson Cruise 75-009, Phase V,
      September 14-October 12 24
   3.5 St. Margaret's Bay - Emerald Basin, Maxwell Cruise 75-030,
      November 14-December 5 25

IV. DATA ANALYSIS
   4.0 Introduction 28
   4.1 Digitization of Analogue Data 28
   4.2 Early Data Analysis 28
   4.3 Advanced Data Analysis
      4.3.1 Teknica Resources Development 32
      4.3.2 Bannister Technical Services "Bancques" System 33
      4.3.3 Features Extraction - J. Dodds 37
      4.3.4 Data Analysis at Bedford Institute of Oceanography 42
      4.3.5 Related Projects at Memorial University 44

V. CONCLUSIONS 45
LIST OF FIGURES

Figure No.

2.1  Schematic of the Huntec Deep Tow High Resolution Seismic System.

2.2  On-Axis acoustic pressure signatures for DT1 Boomer before and after 1975 field season, and the DT2 Boomer. Excitation voltage 6 kV.

2.3  Power spectra of the acoustic signatures shown in Figure 2.2.

2.4  Differences in DT1 power spectra over 1975 field season.

2.5  On-Axis peak intensity and impulse level for DT1 Boomer after field season and DT2.

2.6  Change in positive peak intensity with orientation of DT2 Boomer (Dec. 1975).

3.1  Seismic data obtained on a line on the Grand Banks of Newfoundland.

3.2  Huntec high resolution seismic reflection profile of cuestas forming the ridge between Mecatina Trough and Esquiman Trough, N.E. Gulf of St. Lawrence.

3.3  Location of seismic lines in White Bay.

3.4  Deep tow seismic record across the head of White Bay, northeast Newfoundland.

3.5  Deep tow record obtained nearer the mouth of White Bay.

3.6  Deep tow record across drill site # 4 off S.E. Baffin Island.

3.7  Deep tow record and bathymetry obtained in deep water in Davis Strait.

3.8  Deep tow profile across a sedimentary basin in St. Margaret's Bay.

4.1  Acoustic pulse and cumulative energy plot from sediment in Emerald Basin.

4.2  Location of ship's tracks across the Emerald Basin.
List of Figures (cont'd)

Figure No.  
4.3  E3 vs E1 ensemble medians labelled with the record number of the first record in the section of survey time.
4.4  One minute sections of digitized Deep Tow data over various bottom types encountered in the Emerald Basin.
4.5  Sonograms of shots obtained over La Have clay on top of Emerald Silt, and till on the Emerald Bank.
1. INTRODUCTION

1.0 Summary and Acknowledgements

This report summarizes the work carried out and the principal results obtained on the Huntec Seabed Project during 1975. The project was initiated as a five year joint government/industry research and development project in December 1974 as a result of the unsolicited proposal "Remote sensing of the geotechnical properties and geological classification of marine sediments from a ship underway" submitted to the Department of Supply and Services by Huntec '70 Ltd., in November 1974. The proposed research project to quantify vertically reflected acoustic energy in terms of geological parameters of the seafloor resulted from extensive theoretical and experimental studies on impulsive sound sources (Hutchins, 1974) and the development of a prototype deep towed boomer. The prototype deep tow system was evaluated in August-September 1974 (McKeown, 1975a) and proved to have the necessary fidelity and frequency response to warrant further development of both the system and methods of data analysis (Hutchins et al, 1976). We believe the results of the first phase of the five year project carried out during the period December 1974-March 1976 and summarized in this report fully justify the expectations outlined in the unsolicited proposal.

Progress in the Huntec Seabed Project is evaluated by a committee of scientists from the Bedford Institute of Oceanography and from Huntec '70 Ltd. (Appendix A). This committee has played a key role in the success of the project to date by providing a forum for frank discussion of problems arising and of new directions in which available funds should be allocated. We would like to acknowledge their input in the results presented in this report.

The deep tow system has been used to acquire data on five separate research cruises during 1975. In all cases the deep tow high resolution seismic system has added significantly to the scientific results of the cruise by providing new information not available from any other source. In many cases this has opened up new opportunities for research not previously recognized. Examples of data obtained directly related to on-going projects in the Atlantic Geoscience Centre at Bedford Institute of Oceanography are briefly reviewed in Section III and the reader is referred to more detailed accounts in the published literature. We are indebted to Chief Scientists on the various cruises (Appendix B) for their efforts to accept and utilize the deep tow system as a geological mapping tool, and through its evaluation on field operations, to provide input into the improvement of the system. Of particular importance to the success of these field projects was the efforts of the two Huntec field personnel, John Lewis and George Bika. Their dedication in trying to meet the varying requirements of different scientists throughout the four months of field use contributed significantly to the success of these projects. As a result of field experience gained, the equipment reached a high level of reliability and operational efficiency during the season.

Numerous outside organizations and consultants have contributed to the project during the past 15 months through discussions or through formal participation under sub-contract (Appendix C). We are particularly indebted
to those who have given their time freely to discuss concepts and new
directions of research or to evaluate aspects of the work in progress. We
hope that this report will provide evidence of their influence on the work
undertaken.

1.1 Objectives of the Seabed Project

The objective of the Seabed Project is to develop and apply a new
methodology based on vertical incidence reflected acoustic data to the
production of marine geological maps. The acoustic data will be acquired
continuously from a ship on survey using the Huntec deep tow high resolution
seismic system. Through the application of quantitative processing and
interpretation techniques these data will be interpreted in terms of lithologic
variations of both consolidated and unconsolidated sediments on the seafloor
and at depth. Independent "ground truth" will be provided for this inter-
pretation through geological sampling and in situ measurements of the physical
parameters of the sediment being surveyed. The specific program objectives
are summarized in the original project proposal (Huntec '70 Ltd., 1974) as
follows:

1. To improve the cost effectiveness of the marine geological
mapping program of the Geological Survey of Canada by:

   a. Acquiring and interpreting quantitatively, high resolu-
tion seismic data in order to determine the lithologic
classifications and the geotechnical properties of the
geological units on and below the seafloor.

   b. Publication and distribution of the results in improved
presentation formats to end user groups.

2. To identify sonogram characteristics that correlate with
lithologic, chemical, biological, engineering and other pro-
perties of the geological units on and below the sea bed.

3. To publish an atlas of sonograms and of sonogram character-
istics in a systematic manner, according to the results
obtained in (2) above.

4. To design and build a prototype on-line data processing
system, which will compute and store in digital form the
signal parameters which are diagnostic of the properties
sought.

The project duration is for five years and is divided into five
one-year phases, each phase having specific goals to be achieved before the
next phase is initiated.

1.2 Goals of Seabed '75

Seabed '75 is the first phase of the five year program. The
specific goals of phase I were identified in the project proposal as follows:

1. To provide AGC with survey data relevant to the
objectives of the 1975 AGC CSS Hudson cruise plan.
(2) To assess the feasibility of utilizing normal incidence acoustic reflections to determine the geotechnical properties and lithologic classification of the sea bed. (Single layer problem).

(3) To identify other characteristics of the bottom reflected signal that contain useful information concerning the sea bed, as they relate to the spectral and directional characteristics of the source.

The work summarized in this report has shown the feasibility of using normal incidence reflection data to determine gross lithologic changes and has shown that the wide-band reflected signals contain information in detail of changes within the unconsolidated sediments that have in the past been masked or absent. The vertical resolution provided by the wide bandwidth of the source has highlighted problems in the analysis of the data of more importance than initially recognized. The extent to which the goals of the 1975 program have been achieved can be judged from the results that follow. The main conclusion from the work and plans for Seabed '76 are included in Section V.
II. EQUIPMENT DEVELOPMENT

2.0 The Huntex Deep Tow System

The Huntex Deep Tow Seismic (DTS) System was developed by Huntex ('70) Ltd. following a study of seismic source technology conducted by the company for the Atlantic Geoscience Centre (DSS OSR3-0121) in October 1973.

Heart of the system is an impulsively driven plane piston transducer of the boomer type, developed by the company following extensive theoretical and experimental investigations (Hutchins 1974) under cost sharing grants from the Defence Research Board of Canada (DIR E228, E190) and from the Department of Industry Trade and Commerce (PAIT EA-27).

The system was designed to give quantified acoustic reflectivity, improved resolution of near sub-surface reflections, penetrations to 300 metres in soft sediments, and be operable under heavy weather conditions for geological mapping of the continental shelf.

This type of source provides a high intensity (for penetration) broad frequency band (for resolution) acoustic pulse possessing unique directional characteristics, which makes it particularly suitable for the purpose intended.

The system employs an underwater towed body containing the sound source, a capacitor discharge system, hydrophones for receiving the seismic returns and an attitude sensor package (Fig. 2.1).

The seismic source is pressure compensated, so that the acoustic pressure pulse is constant with depth to 1000 feet. Fish roll, pitch, vertical acceleration and pressure (depth), from the attitude sensor package together with two channels of seismic information are transmitted up a double armoured cable to the surface, whilst the source trigger pulse, the high voltage DC supply for charging the capacitor, and low voltage DC supply for the fish electronics are sent down the cable from the surface.

The system achieves its high performance from:

(1) The narrow acoustic beam angle of the source.

(2) A constant spacing between receiving hydrophones and the source.

(3) Removal of the surface reflected ghost from the area of interest by adjustment of towing depth.

(4) Reduction of ship generated noise at large fish ship distances.

(5) Mechanical decoupling between the fish and the ship.

(6) Electronic compensation of residual fish motion by utilization of the accelerometer and pressure(depth) signals to retard the source trigger instant relative to the start of sweep pulse of the graphic recorder (Heave compensation).
Figure 2.1. Schematic of the Huntect Deep Tow High Resolution Seismic System.

(7) A low drag faired cable which gives good towing depth at survey speeds, and serves to dampen out cable strum, normally a bothersome source of noise.

These advantages come at the cost of increased complexity. In addition, the necessity to maintain a close source hydrophone separation results in direct interference between the source and the seismic signal. This interference arises in part from acoustic backscattering, and mechanical ringing of the fish structure and hydrophone support. This interference dies out with time, and is not significant beyond 50 milliseconds. Hydrophones, with less motion sensitivity will improve this condition.

The electronic heave compensation has been very effective in eliminating from the graphic recordings changes in fish depth, thus presenting a true contour of the seabed, even under heavy weather conditions. The principal effect of heavy seas, is the increase in ambient sea noise associated with high sea states; this noise is independent of fish depth.
The ship borne components of the system presently comprise:

(a) A high voltage Power Control Unit (PCU) for charging the energy storage capacitor in the fish.

(b) A signal processing unit and a graphic recorder for the production of seismic sections.

(c) A tape interface unit and a tape recorder for recording the seismic and other relevant signals.

(d) A fish attitude display unit which indicates the motion and position of the fish, and provides the heave compensation correction to the trigger pulse derived from the graphic recorder.

Items (c) and (d) resulted from initial trials conducted in 1974 (McKeown) by the Bedford Institute of Oceanography.

2.1 Field Evaluation 1974

A field evaluation of the first Huntic DTS system was undertaken by the Metrology Division of the Institute during July, August and September 1974 (McKeown, 1975). The main objectives were to determine:

(a) Towing characteristics of the towed body.

(b) Acoustic characteristics of the boomer sound source.

(c) System performance in an area of well defined geology.

Experiments at sea were conducted using a small research ship 'Survey Venture'. Towing trials within the confines of Bedford Basin and over the Nova Scotia Research Foundation offshore acoustic test range proved that the Huntic DTS system was capable of producing high resolution seismic information, however, it was suggested that before a major data collection program be undertaken, several modifications to the system be made. In addition to these trials, a comprehensive study of the boomer pressure pulse was made using the facilities of the Defence Research Establishment Atlantic located on the moored barge in Bedford Basin. These tests indicated that the excellent pulse to pulse repeatability of the Huntic boomer should be nearly ideal for quantitative measurements on the signal reflected from the sea floor.

The majority of the modifications involved the mechanical components of the system. Improvements to the winch, handling system and the fish body were considered essential if the system was to withstand long periods of continuous operation. Similarly, the addition of a telemetry system so that the towing characteristics of the fish could be observed on deck and a form of heave compensation system to reduce the effect of fish motion on the graphic profiles were thought necessary.

Prior to the start of the Seabed 75 field program, the majority of the recommendations were implemented. Solutions were found to most of the mechanical problems and a prototype heave compensation and attitude sensor system was incorporated.
2.2 **Field Program 1975**

The field program of Seabed '75 consisted of several cruises on CSS Hudson and one cruise on CSS Maxwell. On the Hudson cruises the DTS system formed an important part of the scientific effort in acquiring shallow seismic data for on-going A.G.C. projects. This work is described fully in Part III of this report. As can be expected in a development program of this nature, ideas for improving system performance occur continually. These are fully described in the individual cruise reports listed in Appendix D but are reported here in more general terms. On the Maxwell cruise a significant proportion of the time was spent in towing trials and in measuring the acoustic characteristics of the original DTS system and an entirely new system - DT2. This second system was also used to obtain acoustic data for later analysis (3.5).

2.3 **System Development During 1975**

2.3.1 **Towing and Mechanical Aspects**

For the entire data collection program on CSS Hudson few changes to the various mechanical components were made. One cause for concern early in the program was the difficulty in maintaining a stable fish trajectory through the water. After trying various remedies such as altering the weight distribution within the fish, trimming the fins, etc. with little success it was concluded that the very efficient 'Fathom' fairing, fitted to the tow cable to reduce drag through the water did not freely rotate on the cable thus applying a torque to the cable and causing instability which was more noticeable at higher towing speeds. The removal of several tens of metres of fairing from the fish end of the cable improved towing characteristics and it was also observed that with time the fairing gradually became less tight on the cable.

The effect of vertical motion of the tow point on the fish trajectory depends mainly on the amount of mechanical coupling that exists between the ship and the fish. Since an efficient fairing gives little or no decoupling, any movement of the tow point is translated directly to the fish. For optimum acoustic performance a constant fish depth is desirable; a virtual impossibility if cyclic forces due to ship motion are continuously applied to the tow point. An attempt to give a degree of mechanical decoupling using various types of accumulators at the tow point aboard the ship were not too successful due to severe forces that arise in very rough seas. Ultimately a system of electronically delaying the firing instant to correct the graphic record for vertical motion was introduced (2.3.2).

The major part of the CSS Maxwell program was allocated to optimising towing characteristics of the fish under the direction of Mr. J.G. Dessureault of the Metrology Division. The second DTS system with a haired fairing was made available for this program. The haired fairing is less efficient that the Fathom fairing so that a far greater degree of natural decoupling exists. The main results of these towing trials were as follows:

(a) Balancing the fish in both air and water prior to any towing trial is essential.
(b) A towing bridle rather than a ball joint gives a smaller degree of roll.

(c) Even with a small ship in near gale conditions the haired fairing significantly reduces the amount of vertical motion experienced by the fish, resulting in improved seismic profiles.

(d) Because of the decoupling, mechanical strain on the fish, tow cable, handling system and winch is greatly reduced.

2.3.2 Fish and Laboratory Instrumentation

Electric Heave Compensation

Since some vertical motion of the fish will always be present, a form of heave compensation is necessary if the full potential of any high resolution system is to be realized. One method of performing this operation electronically is to delay the firing time of the boomer (with respect to the position of the stylus on the graphic recorder) an amount proportional to the vertical position of the fish. This technique therefore must have an input signal representing the vertical position of the fish and a convenient way to generate this 'heave' signal is by a double integration of the output from a single component accelerometer. A system using the above technique was available for most of the data acquisition phase of Seabed '75. In relatively calm conditions this system operated satisfactorily but several factors affected the performance in rough weather.

(a) The need to decouple any electronic integrator because of inherent dc drift in the output signal means that some phase shift will be present for ac signals. Since the heave signal is effectively a sinusoid with approximately a 6-second period, errors in compensation will result. The errors become significant when the heave motion is excessive.

(b) High level transients appear to be generated by the accelerometer when subject to either large rates of change in position, horizontal cross-coupling forces or rotary forces due to roll and pitch motions. The subsequent output from the dual integrators is effectively the impulse response which again causes errors in compensation. The effect is a cyclic change in the boomer firing time with a period of about 2 minutes.

Even with the above difficulties the improvement in record quality with the heave compensation system was significant.

Data Recording

The main problem associated with the data recording process involved the inferior recording characteristics of the analogue tape (3M type 177). Several reasons why this tape should not be used for recording seismic information were offered by the manufacturer.

(a) Non professional quality tape may cause excessive wear of the recording heads of instrumentation tape recorders resulting in a reduction of their expected lifetime.
(b) The tape recorder frequency response, particularly at the high frequency end, cannot be guaranteed.

(c) The noise level on playback will inevitably be significantly higher than for a better quality tape.

After a series of tests a slow speed 3M instrumentation tape, type 296, was found to satisfy the requirements of the recorder manufacture concerning headwear and was also found to give the necessary frequency response and noise levels on playback.

Since this tape was introduced, regular frequency response and noise tests have been conducted on the tape recorders to establish the effect of constant use. No measurable changes in performance have been detected over a period of 12 months.

2.3.3 Boomer and Energy Storage Unit Development

Essentially the entire acoustic system remained unchanged for the whole of the data acquisition phase on CSS Hudson. Apart from the need to clean and adjust the spark gap in the Energy Storage Unit at regular intervals no other maintenance of either system was necessary. However, further development of the ED10B boomer aimed at increasing the energy output level and increasing the width of the output pulse was carried out by Huntel '70 Ltd. Development of a Silicon Controlled Rectifier (SCR) firing circuit to replace the spark gap was also undertaken by Huntel. Several advantages that the SCR system will have over the spark gap system are:

(a) No maintenance whatever will be necessary.

(b) Assuming a boomer with constant physical characteristics no long term changes in output pulse shape will be observed.

(c) The unit will be acoustically silent in operation.

Item (b) is of significant importance where quantitative analysis of the seismic echoes is to be undertaken.

2.3.4 Sound Source Studies

The DTS system, DT1, used continuously on the data acquisition program onboard CSS Hudson during Seabed '75 contained the actual boomer unit previously evaluated by the Metrology Division during 1974 (McKeown, 1975a). Thus, the acoustic characteristics of the boomer and calibration information at the start of the season are well documented. From tests onboard the DREA barge during November 1975 similar characteristics and calibration details for DT1 were obtained permitting evaluation of a season's operation on performance. Similar tests on the boomer system DT2 provided for the CSS Maxwell cruise to Emerald Basin during November 1975 were also performed. The acoustic characteristics of DT2 were nominally identical to those of DT1. The results from these tests have been assessed in earlier Huntel reports (Parrott, 1976), (Simpkin, 1976) therefore only a brief review will be presented here.
After some 7 million firings of the DT1 boomer during 1975, the peak of the power spectra for the on-axis pressure signatures was found to have shifted to a higher frequency implying either a reduction in the low frequency or an increase in the high frequency content of the output pulse. A reduction in the peak amplitude and energy content of the pulse was also observed. Figure 2.2 shows the acoustic pressure pulses obtained from DT1 prior to and following the field season, and the new DT2 boomer. All the signatures were obtained with a nominal PCU excitation voltage of 6 kV and the hydrophone positioned as near as possible on the main geometrical axis of each boomer and in the far field region. Figure 2.3 shows the corresponding power spectra for the signatures of Figure 2.2. Errors in any particular observation may be present due to difficulties in maintaining a rigid geometry of the calibrating system; some movement of the test barge due to wave and wind action is possible. Different test equipment was also used in the two series of tests adding further unknowns. Figure 2.4 shows the differences between the two output pulses of DT1 over the field season. Neglecting frequencies above 10 kHz (which may be contaminated by the digitization procedure) little change in characteristics are observed for excitation voltages of 4 kV and 6 kV. Figure 2.5 shows on-axis positive peak intensity and impulse level for DT1 after the field season and DT2 plotted against excitation voltage and finally, Figure 2.6 shows the change in positive peak intensity of DT2 against orientation. Small differences between the clockwise and counterclockwise intensities indicate that a small zero offset may have been present, but here again the difficulty in keeping a fixed geometry between the boomer and the hydrophone may have introduced small errors.
Figure 2.2. On-Axis acoustic pressure signatures for DT1 Boomer before and after 1975 field season, and the DT2 Boomer. Excitation voltage 6kV. Vertical Axis - Hydrophone output, unscaled.
Figure 2.3. Power spectra of the acoustic signatures shown in Figure 2.2.
Figure 2.4. Differences in DT1 power spectra over 1975 field season.
Figure 2.5 On-axis peak intensity and impulse level for DT1 Boomer after field season, and DT2 Boomer.
Figure 2.6 Change in positive peak intensity with orientation of DT2 Boomer (Dec. 1975). (db rel.1μPa = db rel.1μbar +100)
III. DATA ACQUISITION ON A.G.C. PROJECTS

3.0 Introduction

The offshore geological mapping programs of the Atlantic Geoscience Centre have been significantly expanded with the use of the Huntex Deep Tow high resolution seismic system during 1975. The availability of seismic data with a vertical resolution of better than 1/4 m, combined with penetrations of 50 – 100 m in a wide variety of offshore environments, has opened up new possibilities in interpretation which previously were impossible. In surficial mapping, quantitative geological classification of the seabed by acoustic techniques with the requirement for only regional ground truth information provided by sample collection and analysis, has become a real possibility. In combination with sidescan sonar, the resolution provided by the Huntex system has provided information on recent sediment dynamics and highlighted processes of sediment dispersion and transport during the recent geological past. In bedrock geological studies, the new precision available has enabled shallow bedrock surfaces to be mapped in detail resulting in new information on the formation and modification of the bedrock surface. The precision with which the bedrock surface can now be mapped has enabled reliable bedrock sampling to be undertaken using shallow electric drill facilities capable of being operated from a standard oceanographic vessel (Fowler and Kingston, 1975).

Prior to the use of the Huntex Deep Tow system in 1975 this electric rock drill had been operated on a total of 83 lowerings on potential bedrock sites with core recovery being obtained on only 29 (35%) of these lowerings. In 1975 the drill was lowered on 78 bedrock targets selected from Huntex Deep Tow records with core recovering on 37 (or 47.5%) of these lowerings. The improvement in core recovery/lowering of 36% is largely attributed to the better definition of bedrock sites. More importantly the ability to identify and define targets precisely with the Huntex Deep Tow system has provided insight into deficiencies in the drill operation and led to improvements being undertaken by the Metrology Division at the Atlantic Oceanographic Laboratory.

The first goal of Seabed '75 was "to provide the Atlantic Geoscience Centre with survey data relevant to the objectives of the 1975 AGC CSS Hudson cruise plan" (Huntec, 1974). This section summarizes the work accomplished within the Seabed project towards meeting this goal.

The Deep Tow System was operated on four major cruises of CSS Hudson off the East Coast of Canada during 1975. Additional trial and evaluation work was carried out on CSS Maxwell at the end of the field season with new data being acquired in St. Margarets Bay and on the Scotian Shelf. In all cases the system became an essential tool of the work planned. The importance of the new capability provided by the Deep Tow system can only be judged from the scientific results obtained. Reference is made to preliminary publications resulting from the cruises so that the reader may judge for himself the immediate relevance of the improved resolution obtained on graphical records during the cruise.
3.1 Scotian Shelf - Hudson Cruise 75-007, April 11-24

For some years Dr. L.H. King of the Atlantic Geoscience Centre has been studying the surficial geology of the Scotian Shelf. One of the most interesting features of this area is the "pockmarks" or depressions encountered in the Emerald Basin (King and MacLean, 1970). These depressions are a few metres deep by upwards of 100 metres in diameter and are formed in the LaHave Clay overlying the Emerald Silt. The primary objective of the cruise of CSS Hudson to the Emerald Basin in April 1975 (McKeown, 1975b) was to examine a small area of the Basin where these pockmarks were known to occur in profusion utilizing the latest survey technology available, namely medium range sidescan sonar, high resolution seismic, and precision navigation.

The first requirement for phase I of the Huntex Seabed contract was the collection of seismic data in an area of well defined geology to establish suitable signal processing and data display techniques. The April cruise on Hudson therefore had as a secondary goal, the collection of the required seismic data on magnetic tape for later processing.

The cruise also served as an evaluation of modifications that had been built into the deep tow subsequent to its preliminary trials in August-September 1974 (McKeown, 1975a). Results of equipment evaluation during this and subsequent cruises are summarized in the preceding section on equipment development. While the data recorded during this cruise was useful for setting up digital analysis procedures and assessing associated equipment requirements, the quality of data was such that it could not be used for quantitative analysis of geological parameters. Additional surficial geological information was obtained which will be of value in providing better control for the analysis of acoustic data acquired later in the year.

3.2 Grand Banks - Hudson Cruise 75-009, Phase I, April 25 - May 29

The purpose of this cruise (Fader, 1975) was "to continue the study of the surficial and bedrock geology of the Grand Banks and adjacent areas; to obtain a better understanding of the Appalachian geology of the Avalon Platform and Flemish Cap; to obtain further information on the broad structural framework of the area; and to develop an integrated survey concept for mapping surficial geology and quantifying high resolution seismic data in terms of surface and near-surface sediment properties". The Huntex Deep Tow System formed an essential part of the integrated survey concept for the surficial studies as well as providing the prime information on near surface bedrock features which it was hoped to sample with the Bedford Institute rock core drill.

This cruise was the first attempt to use the Huntex Deep Tow on an operational survey. Integration of the system with other standard shallow seismic reflection equipment, sidescan sonar, magnetic and bathymetric systems was essential. As expected, some initial difficulties were experienced in avoiding interference between the different measurement systems but this cruise definitely established the practicality of the multisensor survey concept for offshore geological mapping programs. Figure 3.1 from King and Fader (1976) demonstrates the value of the different acoustic techniques in interpreting the detailed geology of the bedrock and overlying unconsolidated
Figure 3.1. Seismic data obtained on a line over the Grand Banks of Newfoundland. (A) echogram; (B) Huntic Deep TOW (D.T.S.) profile; (C) air gun seismic profile; (D) and (E) enlarged areas of D.T.S. profile (B); (F) composite stratigraphic interpretation using (B) and (C) above. From King and Fader (1976).
sediments. King and Fader (1976) report as follows: "The high resolution capability of the system is well illustrated by the fine bedding of the mud and sand units. Seismic records obtained with the DTS do not have the "bubble pulse" common to seismic sources such as air guns; thus, it is possible to resolve reflection events to a precision of about 0.3 m. In the central area of the depression, penetration is inhibited by diffused gas (acoustic mask) in the mud and sand, but full penetration to bedrock was possible between the 4.4 to 5.1 km marks because there was no diffused gas (acoustic window). Adjacent profiles showed the acoustic mask close to the seabed and analysis of a vibracore sample from the gas-bearing layer indicated the occurrence of methane".

This cruise was also the first cruise to prove the effectiveness of the Huntec Deep Tow in identifying shallow bedrock sites capable of being sampled by the rock core drill. Not only did the Huntec system prove effective in locating drill sites where the bedrock was within reach of the 6 m extension of the drill, it also provided for the first time additional information on the type of overburden or bedrock into which the drill was penetrating. This information is of considerable value in monitoring the drill behaviour. As a result, a number of improvements to the drill system have been initiated to enable better core recovery in soft bedrock and improved performance in penetrating glacial overburden.

In regions of shallow bedrock significant penetration into the bedrock is obtained with the Deep Tow system. The high resolution available then provides excellent information on bedding within the near surface bedrock units (King and Fader, 1976).

A total of 3500 line kilometres of deep tow high resolution profiling was completed during the cruise.

3.3 Northern Gulf of St. Lawrence - Northeast Newfoundland - Hudson Cruise 75-009, Phase III, July 21 - August 20

The primary objectives of this cruise were twofold (Haworth, 1975).

(1) In the northeastern Gulf of St. Lawrence to delineate areas of shallow or outcropping bedrock with high resolution seismic data and to obtain bedrock samples using the Bedford Institute rock core drill for control in the preparation of a geological map of the area.

(2) In the northeast of Newfoundland to carry out a geophysical survey of the triangular area inshore of a line joining Cape Bauld and Fogo Islands, to map the offshore extension of the Appalachian system and to obtain wherever possible, bedrock samples using the Bedford Institute rock core drill to control the interpretation of the survey.

Reports of the work completed and preliminary geological maps prepared on the basis of the results obtained have been published by Haworth and Sanford (1976) and Haworth et al. (1976). These reports indicate the new detail obtained with the Huntec Deep Tow high resolution seismic system and again emphasize its importance in identifying drill sites where the bedrock surface
is accessible for sampling with the rock core drill. Haworth and Sanford (1976) state "A series of Huntex profiles across morphological units provided a good indication of potential drilling sites and revealed more clearly than ever before the cuestas that are characteristic of this area. Whereas bathymetric profiles only provide a general indication of this character except where a cuesta has a high and steep scarp face, the Huntex profile is able to see through the surficial material and reveal the clarity in shape of the small cuestas".

Figure 3.2 from this report shows the cuestas referred to and emphasizes the small areal extent of bedrock targets with less than 6 m of surficial cover. The importance in being able to clearly identify this cover, normally masked in the bubble pulse of a small air gun, before selecting drilling sites is obvious.

Although the prime aim of the cruise was to obtain information on bedrock geology, much additional information was obtained on the surficial sediments on the Huntex records. Figure 3.3 shows the location of three seismic lines across White Bay and Figure 3.4 shows the section obtained across the head of the Bay. Near the head of the Bay two separate channels which apparently merge to the north and south seem to have very different levels and sedimentary regimes. Towards the mouth of the Bay (Figure 3.5) the main channel widens significantly and the thickness of the acoustically transparent "mud" layer increases substantially. Some stratification can be seen within this layer and it is underlain by strongly stratified sediments which also thicken towards the mouth of the Bay. While this record rather dramatically exhibits the precision with which sediments having different
Figure 3.3. Location of seismic lines in White Bay. Deep Tow seismic sections for lines across the head of the Bay and towards the mouth are shown in Figures 3.4 and 3.5.
Figure 3.4. Deep tow seismic record obtained across the head of White Bay northeast Newfoundland. Note the clear identification of the upper surface of the acoustically transparent layer overlying the stratified sediments in the wider channel.
Figure 3.5. Deep Tow record obtained nearer the mouth of White Bay. The valley has widened considerably and the thickness of sediment increased. Some stratification is now seen in the acoustically transparent layer.
reflective properties can be mapped with the Huntec system, it also emphasizes the potential that the sound source has on account of its broad frequency spectrum for highlighting small scale variations of this type through the automatic processing of recorded data.

A total of 4850 line kilometres of Huntec data were obtained during this cruise. To date only the analogue records recorded at sea have been used for interpretation purposes and no computer analysis of the data has been attempted.

3.4 S.E. Baffin Island - Hudson Cruise 75-009, Phase V, September 14 - October 12

Bedrock drilling with the Bedford Institute electric rock core drill on the southeast Baffin Island Shelf was attempted from CSS Hudson in 1974 (Srivastava, 1974). The record of core recovery at that time (one 18 cm bedrock core in 12 lowerings) was disappointing and, although some of this was a result of mechanical difficulties experienced in drilling in a sub-Arctic environment, a major factor was a result of inadequate definition of drill sites with existing shallow seismic systems.

The improvement in drill site location provided by the Huntec system and the resulting improvement in core recovery obtained during the earlier part of the summer led to late modifications of this portion of the Hudson 750009 cruise to include five days to attempt additional bedrock drilling off southeastern Baffin Island (Srivastava, 1975). Information of this type is of considerable importance for stratigraphic correlation purposes since released sample data from commercial drilling is not available off the east coast of Canada, north of the Eastcan et al., Bjarni H-81 well on the Labrador Shelf 520 km south of Hudson Strait. The results of the drilling program have been reported by MacLean and Srivastava (1976) and of the core analysis by Jansa (1976) and MacLean et al., (in press). Fifteen drill lowerings at nine locations were attempted and six cores totalling 544 cm in length were recovered from four locations. Again, a major factor in the increased success can be attributed to the better definition of potential drill sites provided by the Huntec system although in this area perhaps more than in other areas drilled this summer, air gun records obtained concurrently with the deep tow records were important in identifying the bedrock surface. MacLean and Srivastava (1976) conclude: "The shallow seismic and high resolution systems, despite individual limitations, form a combination that is essential for the location of drill sites". Figure 3.6 shows a high resolution record obtained over drill site # 4 indicating 3 m of surficial cover overlying the bedrock. The drilling record at site 4 shows that the drill penetrated 3 m of unconsolidated material before entering the underlying limestone. A total of 1.37 m of limestone core was recovered. A grab sample at the same location showed the unconsolidated overburden to be approximately 90% sand and 10% silt.

On this cruise the Huntec deep tow was operated in the deepest water to date (1356 m) and Figure 3.7 shows the record obtained. Significant penetration was obtained and subsequent improvements in the seismic effectiveness of the boomer through new design theory which has been experimentally confirmed by Huntec '70 Ltd., should further improve this performance in deep water.
Figure 3.6. Deep tow record across drill site #4 off S.E. Baffin Island showing the bedrock (limestone) at a depth of 3 m below the surficial sand deposits.

A total of 650 line kilometres of Deep Tow high resolution seismic data was obtained on the cruise.

3.5 St. Margaret's Bay-Emerald Basin – Maxwell Cruise 75, November 14 – December 5

This cruise was initiated to (1) study the effect of ship's motion on the behaviour of the Deep Tow fish, (2) to test and evaluate the second Huntex Deep Tow System built by Huntex earlier in the summer, (3) to acquire good quality data in St. Margaret's Bay and over the acoustic test range in Emerald Basin, and (4) to obtain comparative records of the acoustic pressure signatures of the two systems.

Although the prime objectives of the cruise were oriented towards further equipment development and evaluation and only 150 line kilometres of data were acquired towards meeting the third objective, a summary of the cruise as related to other geological studies is included here for completeness. The results of the equipment trials are summarized elsewhere in this report and in the cruise report (Simpkin et al., 1976).

The main data obtained on the cruise consisted of 40 km of data in St. Margaret's Bay and 113 km of data along the Nova Scotia Research Foundation acoustic test range in Emerald Basin. This latter data was acquired specifically to provide good quality data for developing quantitative
Figure 3.7. Deep tow record (a) and Bathymetry (b) obtained in deep water in Davis Strait. The vertical bars are caused by interference from a 1000 cu. in. air gun being operated at the same time.
analysis procedures in an area of known geology. It is the prime data base used for the signal analysis carried out during Seabed '75 and is summarized in Section IV of this report.

The data recorded in St. Margaret's Bay was obtained to complement other information acquired as part of the project on Pleistocene-Holocene marine basin sedimentation being undertaken in the Atlantic Geoscience Centre. This project includes detailed sedimentary studies of a number of coastal bays and sedimentary basins including St. Margaret's Bay.

The Huntex Deep Tow data recorded in St. Margaret's Bay defines the surface of the impenetrable reflector of Keen and Piper (1976) observed on earlier sounding and sparker records. Figure 3.8 from Vilks and Rashid (in press) shows a profile across the basin in St. Margaret's Bay. At both ends of the profile a ledge of bedrock crops out on the sea floor. The centre of the basin is infilled by fine sediments. Approximately 40 metres from each outcrop the penetration of the acoustic signal was arrested by a discontinuity in the sediment. The surface of the acoustic discontinuity extends across the basin at approximately 1.5 m below the sediment-water interface, masking the detection of any structure in the sediment below this level. Vilks and Rashid report that in core 104 the surface of the acoustic layer coincides with a 7500 ppm methane concentration, suggesting that the acoustic mask is methane and that a large fraction of the gas is in bubble form. The high concentrations of methane in the core is the only parameter studied in the sediment that could be correlated with the acoustic discontinuity.

![Figure 3.8](image-url)

Figure 3.8. Deep tow profile across a sedimentary basin in St. Margaret's Bay showing the near surface acoustic mask caused by the presence of methane gas in the sediments.
IV. DATA ANALYSIS

4.0 Introduction

The two phase I project objectives related to data analysis were:

(1) to assess the feasibility of utilizing normal incidence acoustic reflection data to determine the geotechnical properties and lithologic classification of the sea bed.

(2) to identify other characteristics of the bottom reflected signal that contain useful information concerning the sea bed, as they relate to spectral and directional characteristics of the source. (This section of the report describes the analyses initiated during 1975 and the results obtained towards achieving these objectives.)

4.1 Digitization of Analogue Data

The first step in initiating quantitative analysis of the acoustic data from the deep tow system, available on magnetic tape as analogue records, was to digitize the data in a form compatible with the computers available at Bedford Institute of Oceanography.

A Tape Replay Unit (Progress Note # 75/2) designed to gate a selected portion of sequential seismic signatures was constructed. The resulting analogue signals representing the acoustic pressure pulse reflected from the water/sediment interface could then be digitized and stored on digital magnetic tape. A HP2100 computer with an analogue/digital interface and made available by the Metrology Division of the Atlantic Oceanographic Laboratory was used to digitize the acoustic signals and to record them as a time series. An information header containing the shot number, file code number and the elapsed time from the fire instant to the start of digitization was also included on the tape. Mr. G. Dubois built the digitization unit used for this work and Dr. A.S. Bennet provided much of the software for the HP2100 computer.

A sampling rate of 25 µs giving a practical upper frequency limit of 20 kHz was used in the digitization process

4.2 Early Data Analysis

Initial data analysis consisted of visual examination of the replayed digital seismic signals reflected from various types of seafloor sediment to identify characteristics within the pressure/time series that could possibly be used for sediment classification. In addition the variability in signal amplitude and envelope shape was to be investigated.

The DTS Emerald Basin data collected at the start of the 1975 field season (Hudson Cruise 75-007) was used in this instance because of the amount of surficial geologic control available (King, 1970). Subsequently improved quality data was obtained in November on Maxwell Cruise 75-030. This latter data, digitized in the same way, was used on all the subsequent data analysis.
The first attempt at processing the digitized data made use of the CDC 3150 computer, the main computing facility at B.I.O. This work utilized standard library programs where necessary; of immediate interest were the range of Fourier analysis programs written originally by Dymaxion Ltd., for the Air-Sea Interaction Group (see Appendix E). Due to the quantity of the Huntec data involved, and the stage of development of the project, this work was not successful. The inflexibility of a batch type computing system does not lend itself to an analysis of this nature. It was therefore decided to rely entirely on the small computers within B.I.O.; initially the HP2100 series owned by the Atlantic Oceanographic Laboratory and later the PDP 11 owned by the Atlantic Geoscience Centre.

Using the HP2100, a time series of analogue filtered signals reflected from various types of seafloor sediment were reproduced graphically together with the integral square of the time series (Figure 4.1a and b). This latter parameter is indicative of the cumulative total energy received against time. The approximate locations in Emerald Basin where this data was obtained are shown in Figure 4.2.

As can be expected, both the peak amplitude and total energy of the reflected signals increase as the harder and coarser sediments of the Emerald Bank are traversed. A simple explanation of this phenomena is that for plane waves the reflection coefficient varies as a function of the acoustic impedance contrast between the sediment and the water as follows:

\[ R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \]

Where \( R \) = Rayleigh reflection coefficient

\( Z_1 \) = acoustic impedance of the water and

\( Z_2 \) = acoustic impedance of the sediment.

This relationship applies in a qualitative way to spherical waves as well. Since the acoustic impedance of the sediment is a product of the speed of sound in the sediment and its bulk density, and since both of these parameters increase with increasing grain size, an increase in bottom reflectivity can be expected.

The series of signals from the clay region show a slow rise in the cumulative total energy of the reflected signal with depth compared with the other sediments. This is rather interesting since a smooth surface would be expected to present a sharp initial coherent signal with little subsequent reflected energy due to a relatively small scattering term. The significant reflected energy immediately following the small coherent signal shown in Figure 4.1a and b can be postulated as due to volume scattering rather than surface scattering, however, without a more detailed examination this suggestion cannot be qualified. A degree of variation in both peak pressure and total energy is observed in all sets of data. In some cases a vague correlation with arrival time existed indicating that geometrical factors such as changes in the angle of the incident pressure wave due to fish motion are responsible. However, in some individual cases more drastic, though local changes occur. It can be inferred that such changes may be due to local variations in acoustic reflectivity or topographical features on a scale of the order of the wavelength of the boomer pulse, that is a few tens of centimeters.
Figure 4.1. Acoustic pulse and cumulative energy plot from sediment in Emerald Basin. Data collected over (a) LaHave Clay overlying Emerald Silt and (b) till.
Figure 4.2. Location of ship's tracks across the Emerald Basin, Nova Scotia Shelf on which data for the digital analysis for Seabed '75 was collected. The surficial sediment classification is from King (1970).
From this initial study the following conclusions were drawn:

1. Both peak pressure amplitude and total energy are in some way indicative of sediment type.

2. Cyclic changes in amplitude are probably due to fish motion.

3. More random changes could be due to local variations in sediment distribution or topographic features.

4. Changes in reflected signal amplitude are far greater than measured shot to shot variation in boomer output level, thus in future analysis the boomer output pulse can be assumed to be statistically stationary.

5. Some form of signal filtering could be effective in reducing acoustic noise.

These conclusions showed that significant information related to sediment type could be extracted from the Deep Tow data. In order to proceed further, a more thorough study of the pressure signatures was necessary and as funds had been allocated in the original contract for external professional support, several parties were approached with a view to participating in this analysis.

4.3 Advanced Data Analysis

The following consultants in the field of geophysical data analysis were approached with proposals to analyze typical Deep Tow high resolution data:

1. Teknica Resources Development Ltd., Calgary.

2. Bannister Technical Services, Edmonton.

3. J. Dodds, Data Analysis, Toronto.

4. D. Dunsiger, Memorial University of Newfoundland, St. John's.

4.3.1 Teknica Resources Development

Discussions were held with Roy Lindseth, President of Teknica Resources Development Ltd., of Calgary, a firm of consultants well founded in the seismic processing techniques applicable to the oil industry. There are several differences between shallow seismic data of use for surficial geological mapping and deep seismic data oriented towards the definition of structures associated with oil accumulation.

1. The oil industry is usually involved in a very detailed analysis of a relatively small amount of data.

2. Deep seismic data consists of reflections from horizons between layers of greatly differing acoustic characteristics, a phenomena not necessarily found in surficial seafloor studies.
(3) Borehole control, e.g. acoustic logs, is often available, particularly on land seismic surveys.

(4) In conventional seismic surveys the form of the outgoing acoustic pulse is not known to any great accuracy nor is there any high degree of consistency in pulse signature from shot to shot.

(5) In conventional exploration seismic shooting a degree of redundancy exists due to the multiplicity of data channels from a single shot. This information is used in interpretation of the data.

The techniques used by Teknica Resources Development in analyzing seismic data involve a large amount of computation (Lindseth, 1968). Basically an attempt to model the deep geological strata is made such that the synthetic seismogram calculated for the model approximates that of the actual seismograms observed. Normally, this is accomplished using acoustic impedance differences between the layers with the addition of data concerning rock type and acoustic characteristics from borehole logs.

Differences that still exist after the inclusion of the acoustic parameters may be indicative of relevant features such as gas/water/oil interfaces, etc. The relative importance to the oil industry of this type of exploration justifies detailed analysis of the field data and critical examination of individual seismograms. The aims of both deep and shallow seismic studies in delineating layers of differing material are identical, only the scale is different. However, further steps in this direction were not undertaken at this time because it was felt that without first examining the quality of the Huntec data critically such a sophisticated analysis might be misleading. Nevertheless, future analysis of this type when good quality 'typical' seismograms can be selected could prove valuable.

4.3.2 Bannister Technical Services "Bancques" System

Over the past several years Bannister Technical Services has developed an acoustic profiling system for through the ice measurement of bathymetry and sub-bottom sediment classification. The system, which uses a conventional narrow bandwidth medium frequency acoustic transducer as a sound source, has been used to obtain acoustic impedance information in the Arctic and analysis of the data has resulted in some success in predicting geological classification of marine sediments (Caulfield et al., 1976). Discussions were held with Bannister Technical Services on the possibility of using the Bancques system to analyze data recorded with the Huntec Deep Tow system. As a result, a contract was drawn up with the following requirements:

(1) To carry out signal-to-noise analysis over the frequency range of 2 - 6 kHz on observations obtained with the Deep Tow system at 10 different locations.

(2) To use the Bancques analysis system to determine predictions of bottom and sub-bottom sediment properties on the basis of the recorded acoustic data at these 10 locations.
The control for the analysis was the surficial geology map by King (1970), and the data was selected from ten sites covering the various sedimentary units present in the Emerald Basin.

The results from this analysis (B.T.S. 1976) indicated that the Bancques system, originally designed for narrow band signals, could be used without any significant modification for the similar analysis of data obtained with the broad band Huntec Boomer. However, a noise problem reduced the confidence level in the prediction of sedimentary layers below 20 metres. This noise, a combination of coherent signals at 4 kHz and 5.3 kHz, was first observed during the data collection program when traversing the La Have Clay. Because of the relatively low reflectivity and the depth of the seafloor in the region the signal level was sufficiently small to enable the noise to be observed. It was thought that the 4 kHz signal was due to crosstalk within the tape recording system and that the 5.3 kHz signal was due to power supply regulation in the fish; modifications to eliminate these effects could not be implemented during the cruise due to insufficient time and lack of facilities. It is unfortunate that the noise had a frequency range within the power band of the boomer as steps to remove it by filtering would have altered the acoustic information contained in the signatures.

Several aspects of the Bancques analysis deserve comment:

(1) The analysis of a sequence of shots from a fixed transducer insonifying a fixed area of the seafloor such as was the case in tests of the Bancques system near Tuktoyaktuk (B.T.S. 1975) results in substantial spread in calculated acoustic impedances for the sedimentary layers. The Bancques system is designed to calculate a mean impedance over specific depth ranges and by comparing these mean impedance values with measured impedance ranges (e.g. Table 2) for specific sediment types deduce a classification for the sediment type. In the analysis of the Deep Tow data provided the surficial geological classifications predicted by the Bancques analysis agreed with the general classifications as identified by King (1970) except for three locations. In these three locations B.T.S. state that the presence of energy from the direct sea surface reflection within the time period of analysis of the bottom reflection affects the calculation of impedance for the bottom returns. The predicted impedance value is then likely to be too high as is in fact the case.

While the general classification of sediment type is a necessary first step in the use of acoustic data as a tool in studying the properties of marine sediments, this type of analysis essentially removes all variability in the successive acoustic signatures as noise. While some of this "noise" is system induced and therefore of no value in the analysis much of the variability observed in the acoustic data is felt to be associated with real variations in geology. This variability itself may be an important criteria in determining sediment properties.
<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ACOUSTIC IMPEDANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>((x \times 10^2 \text{ g}))</td>
</tr>
<tr>
<td></td>
<td>((\text{cm}^2 \times \text{s}))</td>
</tr>
<tr>
<td>Ice</td>
<td>8000</td>
</tr>
<tr>
<td>Water</td>
<td>1528</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>2157</td>
</tr>
<tr>
<td>Clayey Silt</td>
<td>2631</td>
</tr>
<tr>
<td>Silty Sand</td>
<td>3063</td>
</tr>
<tr>
<td>Very Fine Sand</td>
<td>3264</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>3443</td>
</tr>
<tr>
<td>Medium Sand</td>
<td>3509</td>
</tr>
<tr>
<td>Coarse Sand</td>
<td>3735</td>
</tr>
<tr>
<td>Gravelly Sand</td>
<td>3900</td>
</tr>
<tr>
<td>Sandy Gravel</td>
<td>4150</td>
</tr>
<tr>
<td>Gravel</td>
<td>4200–5000</td>
</tr>
<tr>
<td>Till</td>
<td>5000–8000</td>
</tr>
</tbody>
</table>

Acoustic impedance versus soil classification from Caulfield et al, 1976.
(2) The interference due to the direct sea surface reflection seen in the data collected from the harder sediments on the shallow Emerald Bank must be accommodated in some way. While this reflection may, in most cases, be eliminated for data analysis, its separation from the seabed reflection is not always possible in the field, particularly in areas of rapidly changing bathymetry. The need to allow a conservative safety factor in the depth of water beneath the fish, especially in uncharted regions, must be stressed. Thus, in some cases, until a preliminary survey has been performed this form of contamination can occasionally be expected.

(3) A stacking process using various length ensembles of consecutive signatures was not successful in improving signal to noise ratio because of the coherency of the contaminating signal. However, it is felt that this process would have highlighted changes in signal level due to causes other than local variations in sediment distribution. Surface roughness and seafloor undulations could effect signal amplitude even though the sediment is of the same classification. Surface roughness effectively scatters the incident energy and prolongs the bottom echo. This may not effect the Banques predictions because of the nature of the averaging along the record length inherent in the process. However, undulations in the seafloor could cause focussing and defocussing of the sound energy resulting in spatial changes in signal amplitude. The time averaging process used on this particular set of data was 0.752 ms. This represents approximately 3 1/2 pulse widths of the boomer pressure signature. To maintain the resolvability of the Hunttec boomer it is felt that this averaging time should be reduced to the order of one pulse length.

(4) The acoustic impedance of a sediment is equal to the product of density of the sediment and the velocity of sound in the material. If an empirical relationship between density and velocity of sound is known from independent measurements, this relationship can then be used to deduce the velocity and density from the impedance measurement. Other relationships between geotechnical properties can then be used to deduce porosity, bulk modulus, shear modulus, etc. (e.g. Hamilton, 1970). The B.T.S. analysis calculated values for these parameters as requested using an empirical relationship for density and acoustic velocity based on measured values for sediments in the Arctic. Geological sample control is not presently available to assess the validity of these predictions of the physical parameters of the sediments in the Emerald Basin.

In summary the Banques analysis on the Deep Tow data showed that the routine calculation of acoustic impedance, using Banques software, enabled a general classification of sediment type to be obtained and that such a classification was consistent with known surficial geology in the majority of cases.
4.3.3 Pattern Recognition - J. Dodds

An entirely different approach to sediment classification was attempted by Mr. J. Dodds, a geophysical consultant and computer analyst from Toronto. This analysis entailed identification of parameters within the bottom echo that could possibly be used for sediment classification using features extraction techniques as applied in the field of pattern recognition. In discussions with Mr. Dodds the following points were identified as considerations in initiating development of software for features extraction (Dodds, 1976).

1. The shape, energy and other characteristics of the bottom reflected signal are variable from one record to the next (see Section 4.2), thus a method of obtaining stable measurements from an ensemble of reflections should be developed. In addition concurrent statistical analysis is needed in determining the cause of this variability, and in deciding whether stacking or averaging would be useful in its removal.

2. The correlation between sediment properties and normal reflectivity is well documented (Akal, 1974). The acoustic reflectivity at normal incidence is strongly correlated with porosity, but correlations with some other significant properties (notably mean grain size) are poor. Furthermore, many of these correlations are based on theoretical calculations of acoustic impedance, which may not hold in practice. Characteristics of the reflected signal in addition to reflection coefficient must be measured if different sediment types are to be recognized.

3. The acoustic pulse emitted by the DTS source, as modified by the impulse response of the recording system, has positive and negative lobes, and must be deconvolved in order to obtain maximum resolution. To minimize computation time it would be advantageous to incorporate bandpass filtering into the deconvolution process.

4. Some noise is present in the DTS system as it was used in the 1975 season (see Section 4.3.2). It will be necessary therefore, to discriminate against this noise.

The acoustic reflectivity of a plane interface between two elastic, homogeneous, isotropic media is determined by the acoustic impedance contrast at the boundary. In this situation the reflected signal is identical in shape to the incident waveform. Examination of actual reflection signatures obtained with the DTS show that this is sometimes approximately true, but often the reflection is far removed from the shape of the source pulse emitted by the boomer. A number of possible departures from the ideal model may be responsible for the complexity of the reflected signal (Sheriff, 1975; Hilterman, 1975). Roughness of the sea bottom would cause surface scattering. Lack of homogeneity in the material of the sea bottom could likewise cause volume scattering (i.e. from within the volume of the reflector). At 10 kHz (which is within the usable spectrum of the source), a half-wavelength is 4 centimeters. Pebbles, roughness, or homogeneity on this scale would
drastically modify the reflected waveform. If the boundary between the water
and the sea bottom is not abrupt, there may be a continuous change of acoustic
impedance which will reduce the amplitude of reflections at shorter wave-
lengths.

The theoretical calculation of the effects described above is
difficult or intractable. (e.g. see Clay and Leong, 1974, for treatment of
the effect of surface scattering.) But, the effects in themselves contain
information about sediment type and properties. Surface scattering is de-
pendent upon surface roughness. The scale and amplitude of this roughness
will be affected by the plasticity and rigidity of the material of the sea
bottom. A material which is nearly fluid will not support much surface rough-
ness; a gravel will. Volume scattering will likely be stronger in a gravel
than a silt, due to the presence of pebbles. Poorly compacted, silty sediments
are most likely to exhibit a continuous change of acoustic impedance across
the water-sediment boundary. These effects may vary by orders of magnitude,
making errors due to topography and the like less important than in the
measurement of a simple reflection coefficient.

Information of this type is often of prime importance to the
engineer. Analysis of acoustic data in terms of average reflectivity normally
treats the variability in reflected signal resulting from such real geological
effects as noise reducing the information from a sequence of shots to an
average number which can be correlated with an average geological classification.

The techniques of pattern recognition, however, are well suited to
dealing with the empirical relationships which must result from the effects
described above. The general approach of pattern recognition is to classify
inputs or signals in a two-step process. The first step is to measure a small
number of significant features from a complicated input. The vector of features
is then mapped into one of a set of possible classes. The problem of using
pattern recognition in a particular application is essentially the problem of
finding features which can distinguish between signals of the various classes
with acceptable accuracy. In this search for features, it is not necessary to
know why particular values of a feature are typical of a class. Effects which
are known to exist but which cannot be calculated from theory may prove very
useful.

Initially four features of the bottom reflected pulse have been -- studied. These are the arrival time and the total energy contained in three
windows of variable length centered on the time of the peak amplitude. The
detection of the exact time of arrival of the bottom pulse presents a problem
and to minimize errors, an optimum filter using the source pulse and the noise
characteristics prior to the bottom arrival was used. Nevertheless, a decision
concerning the arrival time of a pulse has to be made, a process inherently
less reliable for small signals. Even so, tests carried out on the Emerald
Basin data collected in December 1975, Maxwell Cruise 75-030, indicates the use-
fulness of this approach. Figure 4.3 shows the average normalized reflectivity
coefficient using data windows of 0.2 ms (E1) and 3.2 ms (E3) for various en-
sembles of signals from different materials. On this type of display a
significant scattering term would reduce the value of the reflection coefficient
obtained for a short window, thus the distance a point is removed from the line
of equality, is indicative of the amount of scattering. Two groups with low
reflectivity coefficients are completely isolated from the majority of the data.
Figure 4.3. $E_3$ vs $E_1$ (see text) ensemble medians labelled with the record number of the first record in the section of survey line. Solid lines connect neighbouring ensembles in areas of apparently homogeneous sediment type. Broken lines connect neighbouring ensembles in areas of apparently variable sediment type.

These are for areas of soft sediments which by inspection of the graphic record only, appear similar in nature to each other. However, when displayed as above, their reflection coefficients are quite different.

The majority of the data analyzed, when grouped together in localities exhibit a large range of reflection coefficients but the grouping tends to be parallel to the line of equality. This poses the question, "Are the changes due to factors not considered in the analysis (e.g. fish motion) or are they due to natural causes?". A solution may be found by involving other characteristics in the analysis.

In summary this first attempt to identify characteristics of the acoustic signal which were related to sediment type resulted in some success in relating the total energy of the reflected signal in different time windows straddling the peak power point of the signal to different sediment types by
Figure 4.4. One minute sections of digitized Deep Tow data over various bottom types encountered in the Emerald Basin. The bottom section shows the complete original record, the middle sections two expanded portions of the record and the top section the replayed digitized one minute portions used for analysis.
effectively comparing the scattered component of the signal to the coherent reflection. The analysis identified the need for good geological control to allow "calibration" of a pattern recognition system and the potential of measuring the frequency dependence of the energy reflectivity in aiding the discrimination of sediment types. The analysis also pointed out the apparent lack of correlation in the incoherent reflections from shot to shot and the need for more study of the mechanisms causing these variations.

4.3.4 Data Analysis at Bedford Institute of Oceanography

Investigations at B.I.O. have concentrated on developing methods of handling the large amount of Huntex DTS data acquired during the year and presenting the data so that the full potential of the Deep Tow as a high resolution instrument can be realized. Of importance here were:

(1) Using the EPC graphic recorder and HP2100 computer to produce expanded seismic sections.

(2) Using the HP2100 computer to generate sonograms of individual seismic traces.

Early tests using the EPC graphic recorder indicated an effective maximum line density of 32 lines/cm representing an input signal bandwidth of 3.2 kHz at a sweep speed of 0.5 sec. It was felt that the full potential of the DTS system could not be faithfully reproduced within a normal operating time scale, so methods of implementing unreal time scales involving playback of the digitized time series were developed. Figure 4.4 shows several 1 minute sections of digitized data from the Emerald Basin after time expansion. In this case the data was filtered by bandpass filter with an approximate Q of 5 centered on 2.75 kHz. On this scale the individual components of the acoustic pulses can clearly be seen and bottom undulations of the order of 10 cm either caused by fish movement or of topographic origin can be detected. The flexibility of this system enables frequencies of 10 kHz to be observed, although theoretically the limit is governed by the data sampling interval. Inspection of the expanded records from the Emerald Silt and La Have Clay showed that a filter with a particular centre frequency could be chosen to enhance the detailed layering of selected stratigraphic sequences. Again no quantitative measurements have yet been made, but this type of analysis may prove useful in future sub-bottom classification.

Finally, sonograms of several seismic signatures were obtained. A sonogram effectively shows the distribution of energy in a time series and is a 3 dimensional representation of a seismic pulse, the three dimensions being time, amplitude and frequency. Ideally a two-dimensional representation of a sonogram would show contours of amplitude but initially the filtered time series were arranged as an ensemble. Figures 4.5a and b show sonograms obtained from till and silty clay regions of Emerald Basin. A full appreciation of the sonograms has not yet been made but certain features are immediately obvious.

(1) Energy is present in the signatures beyond the upper and lower limits of 1 kHz and 9 kHz.
Figure 4.5 Sonograms of shots obtained over: (a) La Have clay on top of Emerald Silt and (b) till on the Emerald Bank. The shots correspond to one of those in the digitized first and sixth sequence of Figure 4.4 respectively.
(2) The mid frequency band from the till contains its maximum energy several milliseconds after the seafloor reflection, whereas at high frequency the maximum energy is that of the seafloor reflection.

(3) Using a constant Q filter, resolution appears to be frequency independent.

(4) Features that are present at a given time and over a certain frequency range may be undetectable over a different frequency range.

On the basis of a single seismic signature with an unsophisticated filter no definite conclusions can be drawn. However, this technique shows promise in highlighting features that could possibly be used for identification of sediment types and topographical effects. The computer programs developed for the above analysis are described in Appendix E. Software developed under contract by outside consultants is fully described in the appropriate reports resulting from the sub-contracts.

4.3.5 Related Projects at Memorial University

Analogue data tapes were sent to Dr. A.D. Dunsiger of Memorial University of Newfoundland for analysis on the HP 5451B Fourier Analyzer System. Two of the tapes were copies of the original tapes recorded during the April cruise of CSS Hudson and were processed by a 1 kHz bandwidth filter centered on 4 kHz. These tapes were found to be unsatisfactory for comprehensive analysis due to the poor recording characteristics of the tape (see 2.3.2).

Subsequently an original data tape from the CSS Maxwell cruise to Emerald Basin was loaned to the University. Initial processing performed on these tapes included:

(1) Matched filtering using the replica transmitted pulse.

(2) Average power spectra over 50 echoes.

(3) Various methods of display, e.g. stacking of matched filtered echoes; stacking of magnitude squared echoes.

The purpose of this initial processing was to gain familiarity with data from the Huntec source and with the Memorial University's HP 5451B Fourier Analyzer System which is based on a HP 2100S mini-computer. This work is continuing as a post-graduate research project.
V. CONCLUSIONS

Seabed '75 has demonstrated that the DTS system even in its present form, has added significantly to the scientific data collected during the 1975 AGC Regional Reconnaissance program.

The use of the system in support of the BIO rock drilling program resulted in a substantial improvement over that of previous years in the amount of core recovered.

The system has demonstrated its ability to obtain high quality graphic records in water depths to 1500 metres under heavy weather conditions, yielding a resolution of the near sub-surface of the order of .25 milliseconds or 0.2 meter, and penetrations to better than 100 metres.

The system is compatible with magnetics, side scan sonar, air guns, echo sounders and gravity - and may be operated under heavy sea conditions.

The system with heave compensation, and high pass filtering of the received signals, has an effective beam angle of only a few degrees (±5°) and therefore should eliminate the need for a precision echo sounder to provide bathymetry.

The system has considerable potential for further development, in particular, the system noise can be substantially reduced by improved hydrophones and hydrophone supports, by improved fish structure, through improved fish stability, and better fairing to reduce cable strum at high towing speeds.

Digitization and analysis of selected portions of the data acquired during 1975 is now proceeding. It is expected that close examination of this data may reveal the need for further refinements to reduce system noise, or variability in the reflected energy due to fish motion and other causes associated with the system.

Notwithstanding the effects of further system improvements of this kind, there is good reason to believe that reliable estimates of seabed reflectivity can be made from the existing recorded data, and further, that this data will correlate with broad sediment classes and types.
REFERENCES


APPENDIX A

HUNTEC EVALUATION COMMITTEE

D.I. Ross, Atlantic Geoscience Centre Scientific Authority

*C.S. Mason, Metrology, Atlantic Oceanographic Laboratory

D.L. McKeown, Metrology, Atlantic Oceanographic Laboratory

L.H. King, Regional Reconnaissance, Atlantic Geoscience Centre

**G. Vilks, Environmental Marine Geology, Atlantic Geoscience Centre

**D. Heffler, Program Support, Atlantic Geoscience Centre

P.G. Simpkin, Principal Investigator, Huntec ('70) Ltd.

R.W. Hutchins, Technical Director, Huntec ('70) Ltd.

A. Brazeau, Contract Manager, Department of Supply and Services, Ottawa

*Up to November 10, 1975

**From November 10, 1975
### APPENDIX B

1975 Field Projects on which Huntec Deep Tow System was operated.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Ship</th>
<th>Area</th>
<th>Chief Scientist</th>
<th>Huntec Field Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 11-24</td>
<td>CSS Hudson</td>
<td>Emerald Basin</td>
<td>D.L. McKeown</td>
<td>R. Hutchins</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>T. Orton</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Tibinsky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Bika</td>
</tr>
<tr>
<td>April 25 - May 9</td>
<td>CSS Hudson</td>
<td>Grand Banks of Newfoundland</td>
<td>G.B. Fader</td>
<td>R. Hutchins (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>J. Lewis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Bika</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P. Simpkin (2)</td>
</tr>
<tr>
<td>July 21 - August 20</td>
<td>CSS Hudson</td>
<td>Northeast Gulf of St. Lawrence and northeast of Newfoundland</td>
<td>R.T. Haworth</td>
<td>J. Lewis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Bika</td>
</tr>
<tr>
<td>September 14 - October 12</td>
<td>CSS Hudson</td>
<td>Labrador Sea and Davis Strait</td>
<td>S.P. Srivastava</td>
<td>J. Lewis (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Bika</td>
</tr>
<tr>
<td>November 14 - December 5</td>
<td>CSS Maxwell</td>
<td>St. Margarets Bay and Emerald Basin</td>
<td>P.G. Simpkin</td>
<td>R. Parrott</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>T. Kerr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>G. Bika</td>
</tr>
</tbody>
</table>

(1) April 25 - May 9
(2) May 9 - May 29
(3) September 14 - September 24
APPENDIX C

List of contributors not directly associated with the Seabed '75 project team or associated field projects during 1975.

Mr. R. Brown, Dymaxion Ltd., Halifax
Mr. G. Dubois, Metrology, Atlantic Oceanographic Laboratory
Dr. A. Bennett, Metrology, Atlantic Oceanographic Laboratory
Mr. J.G. Dessureault, Metrology, Atlantic Oceanographic Laboratory
Dr. A.D. Dunsiger, Memorial University, Newfoundland
Mr. D. Caulfield, Banister Technical Services, Edmonton
Mr. R. Lindseth, Teknica Ltd., Calgary
Mr. J. Dodds, Toronto
APPENDIX D

List of Hunttec reports resulting from seabed contract

1. Field Report - April 3-25, 1975 - CSS Hudson Cruise No.'75-007 by T. Orton.


8. Operation Seabed 75, A Study of and Possible Solutions to the Computational Requirements for Processing the Hunttec Deep Tow Seismic Data by P.G. Simpkin.


APPENDIX E

Computer data processing carried out at Bedford Institute of Oceanography

Dymaxion

Dymaxion Ltd., of Halifax, were contracted for some of the initial software development for the Seabed Project. Existing software packages for performing Fourier analysis on data collected by the Air-Sea Interaction Studies group of Bedford Institute of Oceanography were modified to accept the Huntec seismic data, and routines to extract further information from the seismic signals were developed.

A sequence of programs was used to convert the data digitized on the HP 2100 computer to a format compatible with that used on the main computing facility at Bedford Institute of Oceanography, a CDC 3150 computer. Other programs to perform the analysis and to output the results to a Calcomp plotter were written. The large quantity of Huntec data and the rigid structure imposed on the programs by the batch processing system used on the CDC computer severely limited data analysis at this stage.

Output from the Dymaxion programs consisted of:

1. A plot of the digitized seismic signal.
2. The integral of the signal energy.
3. The power spectra of the signal.
4. The square root of the power spectra of the signal.

Subsequent Analysis Performed by Huntec

After the experience with the batch system of computing it was decided to rely on the minicomputers available at Bedford Institute of Oceanography for processing of the Huntec seismic data. The first concern was to develop more efficient programs to record the analogue data in digital form on conventional computer magnetic tape. Next, programs were developed to obtain information on the frequency of the seismic data and to determine if the classification of sediments using a computer based scheme was feasible. An HP 2100 series computer was made available by the Metrology division of Atlantic Oceanographic Laboratory and a PDP-11/20 computer by Atlantic Geoscience Centre.

The PDP-11/20 was used to output data to both graphic and fibre optic recorders via a digital-analogue interface unit. The computer was programmed to address a peripheral as a memory location thus simplifying input and output operations. In the future the PDP-11/20 will be used for the majority of the digitization and playback of the seismic data.

Most of the data processing has been executed on an HP 2100 series computer. This computer is equipped with a disc, has a Fast Fortran Processor and floating point arithmetic which makes it more suitable than the PDP-11 for data processing. In order to process the data recorded on the 9-track
magnetic tape drive of the PDP-11, an HP 12970A 9-track magnetic tape drive was purchased. Use of the two tape drives has proven that different formats are used to write the data on tape. In order to standardize on one system for the tapes all data will be recorded in HP compatible format. This will require the use of an algorithm to transpose data generated by the PDP-11 computer before they are written on tape, and a similar routine to read tapes that have been written on the HP computer. Such an algorithm has been written and tested. The routine takes approximately 10 ms for 1000 data points so that its use will not add significantly to the amount of time required for the input or output of data from 9-track magnetic tape.

Digitization Programs on the HP 2100

Acoustic signatures derived by replaying the analogue tapes of the recorded seismic data were digitized at a sample rate of 25 μsec on an HP 2100 series computer. A digitization window of 1024 points (approximately 26 msec) was used. An assembler language routine was developed to accept and store the digital values output by the A/D converter. These stored values were then processed by a FORTRAN language main program to record the edited portions of the data. The following options are available:

- **DIGIT**: Every digitized pulse is written to magnetic tape. Used to record an entire analogue tape on digital tape.
- **DIG1**: Record only 1 minute out of every 5. Records approximately 1 minute of data in digital form on magnetic tape and then waits for 4 minutes before recording the next 1 minute sequence. Used to provide a cross-section of the analogue data.
- **DIG2**: Record the incoming data only when enabled through the consol switch register. Used to digitize features of interest from the analogue tape.

Frequency Analysis Programs

In order to allow a comprehensive analysis of the response of different sediment types to acoustic pulses it is necessary to know the frequency content of the transmitted signal and then study the return signal to determine the changes that have occurred. It is also necessary to know the frequencies at which the data has the highest energy content in order to optimize the information obtained from the data. The cause of noise in the system is more easily determined if its frequency range is known.

The following programs are available for frequency analysis:

- **POWER**: Written to analyze the acoustic pulses, recorded at the DREA test facilities in Bedford Basin (of the Huntec DTS Boomer). Calculates the power spectrum of the digitized acoustic pulses and plots the spectrum on a Calcomp plotter. The data are corrected to a reference distance of 1 meter and the resulting data Fourier transformed to the frequency domain and
operated upon to produce the power spectrum. This program was also used to evaluate the effectiveness of the SCR firing circuit developed for the DTS Boomer.

**CROSS** Provides further information on the frequency content of the acoustic pulses. The program calculates the power spectra, difference in power spectra and the cross power spectra of two input pulses, and plots the results on a Calcomp plotter. The plotted results allow a quick check of any differences in the frequency content of the two input signals and is very useful in the comparison of two similar pulse sources. The plotted cross spectra allow a quick visual correlation of the similarity of two input pulses.

**FIELD** Used to analyze the frequency content of a portion of a digitized field record. Reads a time series from a binary format magnetic tape and plots its power spectra. Useful in determining the frequency content of a time series to help localize any interfering noise.

**SONO** Used to calculate the sonogram of a digitized seismic pulse and output the results to either a Calcomp plotter or to a fiber-optic graphic recorder. The program applies a recursive bank of filters to the recorded signal and outputs the filtered data to a plotter. In this way it is possible to study the effects that different filters will have on a signal, and to observe the variations in each signal that are evident only when filtered to enhance the desired portion of the frequency spectrum.

**Utility Programs**

In order to handle the magnetic tapes and plot the data, it was necessary to develop a series of utility programs. The following programs were written for this purpose, and where necessary converted to callable subroutines to be used with other programs.

**POSIT** Positions the magnetic tape at the shot number that is input through the teletype keyboard. The routine also opens the file for data transfer, obtains the internal channel required and transforms the data to the format required by the computer.

**POST1** Similar to POSIT, but for use on newer tapes which have a sequence number as well as a shot number in the header.

**COPY** Copies one magnetic tape onto another in the same format. Provision is made to change the label number that occurs at the first of every recorded shot.
COPY1 Copies a 7-track magnetic tape unto a 9-track magnetic tape in the same manner as COPY.

PLOT Reads a record from binary tape and plots it along the x-axis of the Calcomp plotter.

PLOTA Similar to PLOT but plots a series of shots along the y-axis. Used to study the continuity of bedding interfaces and correlate from one shot to another.

PLOTB Similar to PLOTA. Plots portion of signal at large scale, for visual examination of the frequency content, and signal to noise ratios.