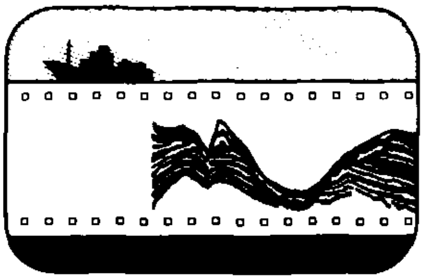

A Deep Tow High Resolution Seismic System for Continental Shelf Mapping

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Summary
Trials of a deep tow high resolution seismic system (DTS) intended for marine surficial geological mapping are described. The development of this equipment is the consequence of an engineering and scientific partnership between industry and government through implementation of various government policies intended to encourage Canadian Industry. The system is capable of penetrating acoustically "hard" bottoms to depths in excess of 33 m and "soft" bottoms to at least 100 m. Its high resolution (less than 0.3 m) and repeatable pulse shape make it an ideal source for identifying and mapping sea floor sediments. Sample records, accompanied by geological interpretations from areas of widely differing geology are included.

Sommaire
Description des essais d'un dispositif sismique à haute résolution remorqué en profondeur (DTS), destiné à la cartographie des dépôts surficiels sous-marins. La mise au point de cet appareil est le résultat d'une collaboration technique et scientifique entre l'industrie et le gouvernement, suite à la mise en oeuvre de diverses politiques gouvernementales visant à encourager l'industrie canadienne. L'appareil peut pénétrer les surfaces sous-marines à forte réflectivité acoustique (réflecteurs «durs») jusqu'à des profondeurs supérieures à 33 m, et les surfaces à faible réflectivité acoustique (réflecteurs «mous») à des profondeurs d'au moins 100 m. Son grand pouvoir de résolution (moins de 0.3 m) et la forme répétable de son impulsion font de l'appareil un instrument idéal pour l'identification et la mise sur carte des sédiments du fond marin. Sont inclus des échantillons de relevés, accompagnés d'interprétations géologiques se rapportant à des secteurs de géologie très différents.

Introduction
A new high resolution seismic survey system, the Deep Tow System (DTS) was evaluated by the Bedford Institute of Oceanography during the fall of 1974 (McKeown, 1975). The DTS employing a unique "boomer" type source (Hutchins, 1974) was designed and built by Huntec ('70) Limited as the first step in the development of a shipborne system to aid in geological mapping of the continental shelves.

In 1975, a modified version of the original prototype DTS operated from the CSS *Hudson* provided high quality graphic records and seabed acoustic reflectivity measurements of approximately 6500 km of ocean floor. The reflectivity data will be processed off-line by a computer to assist in classifying the different geological units shown on the graphic recordings. These data will be used to produce contour charts of reflection and attenuation coefficients and further aid in preparation of surficial geological maps.

In addition to its scientific merit, the project is of interest because it involves an industry-government partnership that is a practical implementation of the ocean policy statement (Office of the Minister of State - Science and Technology, 1973) and the contracting-out policy statement (Office of the Minister of State - Science and Technology, 1972). The favourable outcome of the 1974 trials with the prototype system (McKeown, 1975) resulted in *Seabed '75*, the first phase of a five-year research and development program, *Operation Seabed*, proposed by Huntec to perfect the mapping system referred to above. Funds for *Seabed '75* were provided by the Department of Supply and Services under its new bridge financing program (Dept. of Supply and Services, 1974), with field support services being provided by the Bedford Institute of Oceanography.

System Performance Objectives
Characteristics of prime importance in the design of a high resolution seismic system are the capability to penetrate seabed sediments known to be acoustically "hard" or difficult to penetrate and to define closely spaced subsurface geological events with adequate resolution. Seismic records obtained during the initial trials and discussed later in this report show that the system meets these criteria. Once special signal processing techniques have been applied to the received seismic signals, it should be possible to resolve reflection events to a precision of about 60 μs, which represents six to eight cm of sediment. The intensity of the acoustic pulse emitted by the DTS system is such that approximately 100 m of penetration in mud or 50 to 60 m of penetration in sand and glacial till can be expected.

Publication of a map series on the surficial geology of the eastern Canadian continental shelf was begun in 1970 as a joint venture of the federal Departments of Energy, Mines and Resources and Environment (King, 1970; MacLean and King, 1971; Drapeau and King, 1972; Fader *et al.*, in press). *Operation Seabed* is expected to contribute to this program through the development of an automatic sediment recognition and charting system. This system will greatly reduce the amount of sampling data normally required to produce surficial maps. An important feature of such a system is an acoustic source with high repeatability, hence, emphasis was placed on examining the source fidelity during these trials (McKeown, 1975).

Surficial geology maps have many applications including the planning and design of seabed supported structures such as offshore oil rigs. The design of the foundations for such structures is strongly influenced by the properties of the first few metres of the sea floor. The seabed engineer seeks to determine overburden thickness to a precision of better than 0.3 m in many cases. At the same time, he needs to know the physical properties of the surficial sediments to a depth approximately equal to the horizontal extent of the planned structure (in the case of a gravity platform, about 100 m). This information can be obtained from the DTS provided the received acoustic signals can be related to the geotechnical properties of the sediments.

The relation between a number of important geotechnical parameters of geological materials and their acoustic properties has been extensively investigated (Akal, 1972; Hamilton, 1971; Taylor Smith, 1974). However, the difficulty of obtaining reliable quantitative measures of the acoustic parameters under operational conditions at sea, and the imprecise data generated by existing high resolution marine seismic systems have frustrated attempts to use acoustic data for routine seabed classification except under ideal conditions. An objective of *Operation Seabed* is to relate quantitative acoustic properties to various geotechnical parameters.

Existing seismic reflection systems do not have a sufficient penetration/resolution quotient under operational conditions to be effective in the selection of sites for bedrock sampling with a shallow drill. The DTS system can be employed to locate suitable drill sites for an electric drill with a six m drilling capability (Fowler and Kingston, in press). Our rate of sampling success has improved greatly since the DTS has been used in this function. The use of the DTS has resulted in a 40 per cent improvement in core recovery.

Description of the Deep Tow System

To satisfy the needs outlined above the acoustic source must possess: a high source intensity to penetrate acoustically "hard" bottom; a short pulse life to permit definition of closely spaced geological events; narrow beam width for spatial resolution; and a repeatable pulse shape to simplify the task of classifying seabed sediments by their acoustic characteristics. Furthermore, the system as a whole, must be towed well below the water surface to minimize the effect of wave action on the source and to reduce signal attenuation over the water path from source to sea floor. Deep towing substantially improves the signal-to-noise ratio of the received seismic signal. Towing the source close to the bottom also improves spatial resolution as a smaller area of the bottom is acoustically illuminated.

The DTS provided by Huntec in the late summer of 1974 is shown in Figure 1. The towed body contains a Huntec ED-10B electrodynamic or "boomer" type source, a Huntec M3 Energy Storage Unit, and an Atlantic Research type LC-32 hydrophone rigidly mounted within the body to maintain a fixed source-receiver geometry. A second hydrophone was trailed five m behind the body. Instrumentation to sense pitch, roll, and depth was installed temporarily for the initial trials. It has since been replaced with a unit that senses pitch, roll and vertical acceleration. The acceleration signal is integrated electronically to compensate the graphic record for heave of the ship. The towed body is about 1.6 m long, 1.0 m wide, and 0.6 m high. It weighs 270 kg in air and 115 kg in water.

The prototype DTS was towed on 150 m of 15 mm diameter armoured cable enclosed in a rigid plastic fairing to reduce drag. The fairing has a large bending radius and a large winch and sheave block are required aboard ship. The winch, shown in Figure 1, is about 1.5 m high and weighs 1600 kg including the armoured cable.

Towing System Performance. The low drag fairing on the cable permits the body to be towed at depth with minimum cable scope, but, because the wire angle is nearly vertical, there is strong coupling between heave of the ship and the towed body. To achieve higher resolution, heave compensation must be provided both electronically as described above and mechanically by decreasing coupling between the ship and towed body through the use of higher drag fairing.

The towed body pitched up to 12° during the initial towing trials but in calm water this pitch was reduced to 2°. As the pitch is twice the effective beam width of the source, the seismic record is degraded. Work is underway to correct this problem and indications are that the pitch can readily be reduced to 5° for heaves of seven m peak-to-peak. For a more detailed report of these trials see McKeown (1975).

Figure 1
The DTS system aboard Survey Venture showing the winch, cable, crane, sheave block and towed body. The V-fin towed body in the background is associated with a Kelvin Hughes 26B echo sounder.

Acoustic Characteristics of Source. The acoustic characteristics of the source were examined. It was found that it produced a pressure wave (Fig. 2) with a peak amplitude corresponding approximately to that generated by 50 g of explosives. The source produces significant power over a wide band of frequencies from 800 Hz to 10 KHz to yield good penetration coupled with high resolution as indicated in Figure 3. It is anticipated that the source will be used in a sophisticated system capable of automatic sediment identification. This requirement can only be met if the acoustic pulses are highly repeatable in shape and level. Acoustic trials confirmed that the ED-10B transducer meets this requirement. These acoustic measurements have been described more fully elsewhere (McKeown 1975).

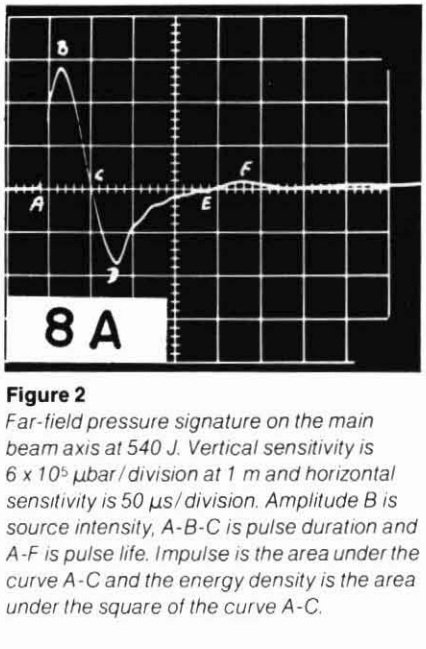

Figure 2
Far-field pressure signature on the main beam axis at 540 J. Vertical sensitivity is 6 x 10⁵ μbar/division at 1 m and horizontal sensitivity is 50 μs/division. Amplitude B is source intensity, A-B-C is pulse duration and A-F is pulse life. Impulse is the area under the curve A-C and the energy density is the area under the square of the curve A-C.

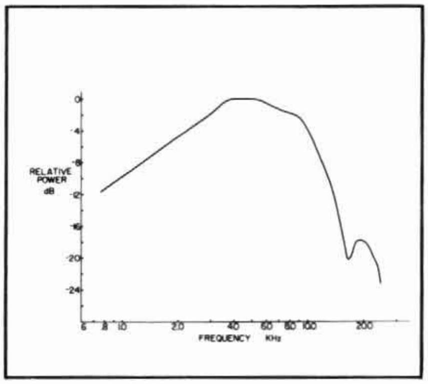

Figure 3
Power spectrum of the main beam axis pressure pulse signature of Figure 2 at 540 J.

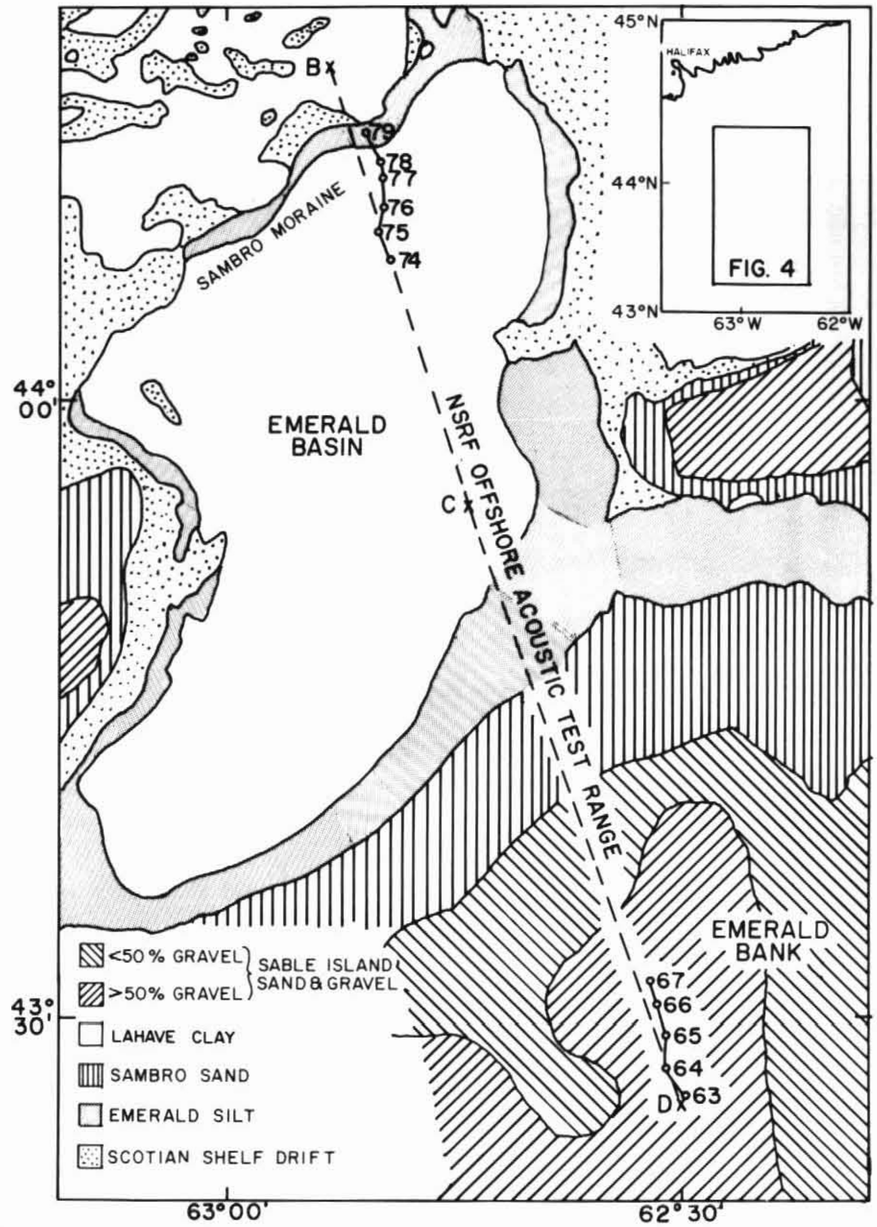

Figure 4
Surficial geology on the Nova Scotia Research Foundation (NSRF) Offshore Acoustic Test Range in the vicinity of the areas encompassed by the seismic profiles of Figures 5 and 6.

Geological Interpretation of Sample Records

Sample profiles, together with their geological interpretation, are shown in Figures 5, 6, and 7. Seismic records obtained with the DTS do not possess the "bubble pulse" common to seismic sources such as air guns: this permits the sub-bottom geology near the sea floor to be better defined. By towing well below the surface, the source and receiver are far removed from surface disturbances, the signal-to-noise ratio of the seismic signal is markedly improved, and spatial resolution is increased. However, some distortion of bottom topography occurs if the depth of the towed body is varied along the survey line.

Figure 5 is a seismic profile obtained with the prototype DTS. The profile crosses the southern flank of the Sambro Moraine (Fig. 4) and extends into the Emerald Basin for approximately three km, in water depths from 200 to 250 m. Approximately 60 m of penetration at water velocity was achieved through LeHave Clay, Emerald Silt, and Scotian Shelf Drift to the Cretaceous bedrock surface. Bedding is resolved in the Cretaceous unit to a true depth of approximately 20 m. The Scotian Shelf Drift overlies the beds of Cretaceous age and is most readily recognized by its undulating surface. The higher peaks on the till surface are defined by vertical dark areas at their flanks. These areas probably represent side echos from the peaks but they are not hyperbolic in shape because of the highly focused nature of the source. Some are due to smaller point sources on and below the till surface and these probably represent boulders. The Sambro Moraine is shown on the right of the illustration and the manner in which it is intertongued with the Emerald Silt is clearly portrayed. The relationship was probably established by advance and withdrawal of the continental ice front. The surface of the till forms the seabed across the top of the moraine but it is obscured on the record by unnecessarily high gain setting. The Emerald Silt is the most stratified unit in the basin, but the nature of its stratification is not understood. The unit is a poorly sorted proglacial deposit. The beds may represent lithologic changes or they may represent subtle changes in a geotechnical property. Some point sources are evident within this unit. The uppermost unit in the interpreted section, the LaHave Clay, was recognized from echograms. Differences between the LaHave Clay and the Emerald Silt are not evident on the record but should become evident when the data are expressed quantitatively as variations in reflection coefficient.

Figure 6 is a profile across the gravel facies of the Sable Island Sand and Gravel on Emerald Bank, which is approximately 90 m deep. The interpretation is uncertain because of the local nature of the survey and the absence of significant horizons. Nonetheless, the important aspect of the record is that it demonstrates the

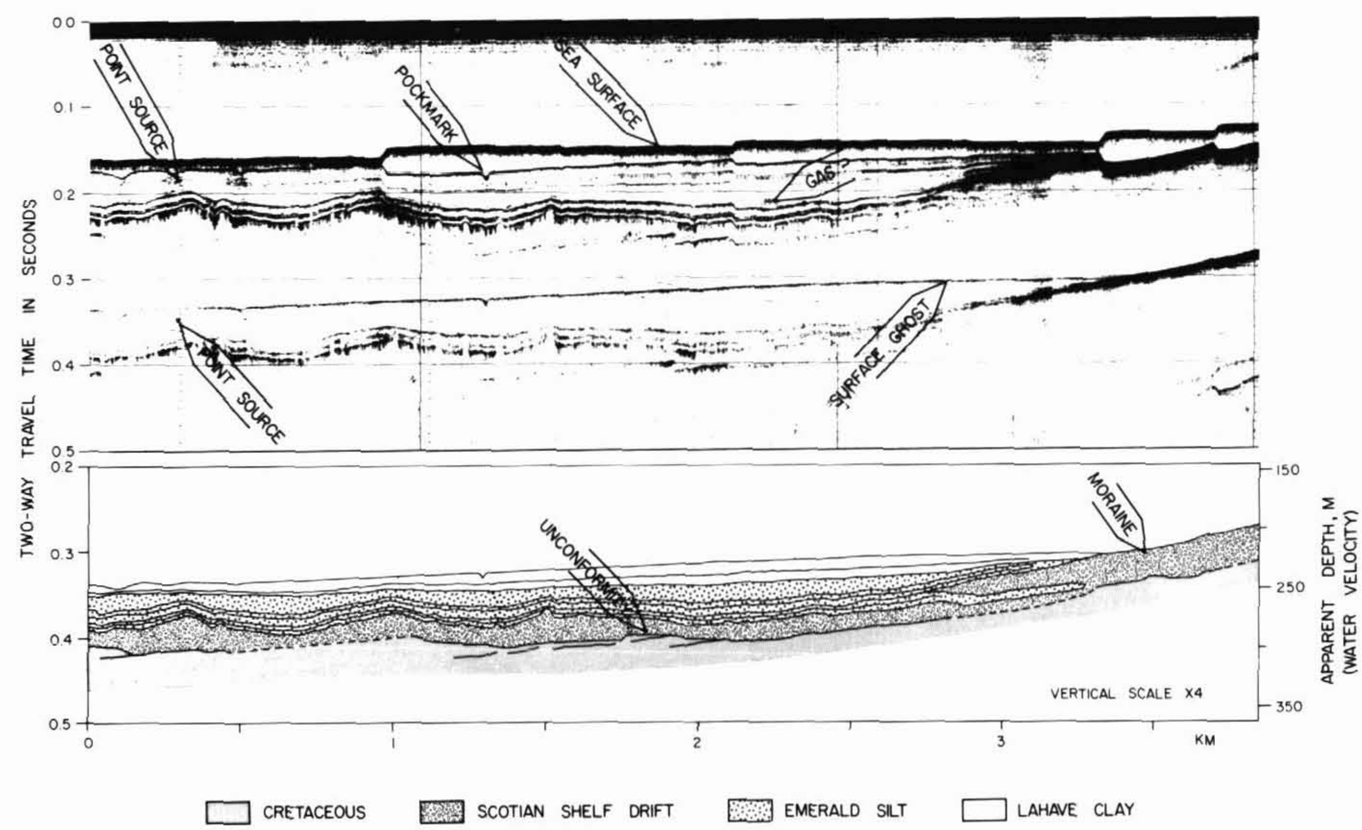

Figure 5

Seismic profile across the southern flank of the Sambro Moraine and extending out into Emerald Basin for approximately three km between fixes 75 and 78 of Figure 4.

capability of the system to achieve penetration to a depth of 33 m over a highly-reflective gravel bottom. The inset photograph shows typical appearance of the seabed along this profile. The channel surface and horizontal bed or possible Tertiary bedrock surface are clearly defined. The seabed is represented by an unusually dark, broad pulse which appears to be caused by saturation in the amplifiers by a highly reflective bottom. Heave of the towed body perturbs the seismic record but this difficulty has now been overcome through the installation of a heave compensator.

Figure 7 shows two short profiles from the Bedford Basin, Nova Scotia. An acoustic mask occurs over much of the central area of the basin and is illustrated on both records although stratification can be seen clearly elsewhere (Fig. 7). The mask is thought to represent free gas (probably methane) in the mud layer. In Figure 7(b) normal penetration is only achieved along a short section of the record over a subsurface peak, which is designated an acoustic window. The original source bed for the gas was possibly deposited below the level of the peak. This gas migrates upwards bracketing the peak without masking it.

Conclusions

The DTS described above has been tested over areas of well-defined surficial geology and the characteristics of the acoustic source have been determined. The source produces significant energy in the band 800 Hz to 10 KHz in a very narrow (11°) beam. Its short pulse duration (63 μs) and the absence of any "bubble pulse" permit high resolution and definition of near surface sea floor sedimentary layers. The high degree of repeatability from pulse to pulse greatly simplifies the development of signal processing techniques for automatically classifying and mapping sea floor sediments. Trials have shown that the system is capable of penetrating a highly reflective gravel bottom to a depth of 33 m and softer bottoms to a depth of at least 100 m. Its deep tow capability removes the source and receiver from surface disturbances and reduces signal attenuation over the water path. This capability greatly improves the signal-to-noise ratio of the seismic signal. It also improves spatial resolution by reducing the area of the sea floor insonified by the source.

Seabed '75 has already produced significant geological information and greatly improved sample recovery with a sea floor electric drill. The joint venture will yield an operational system for remote sensing and classification of near surface sediments.

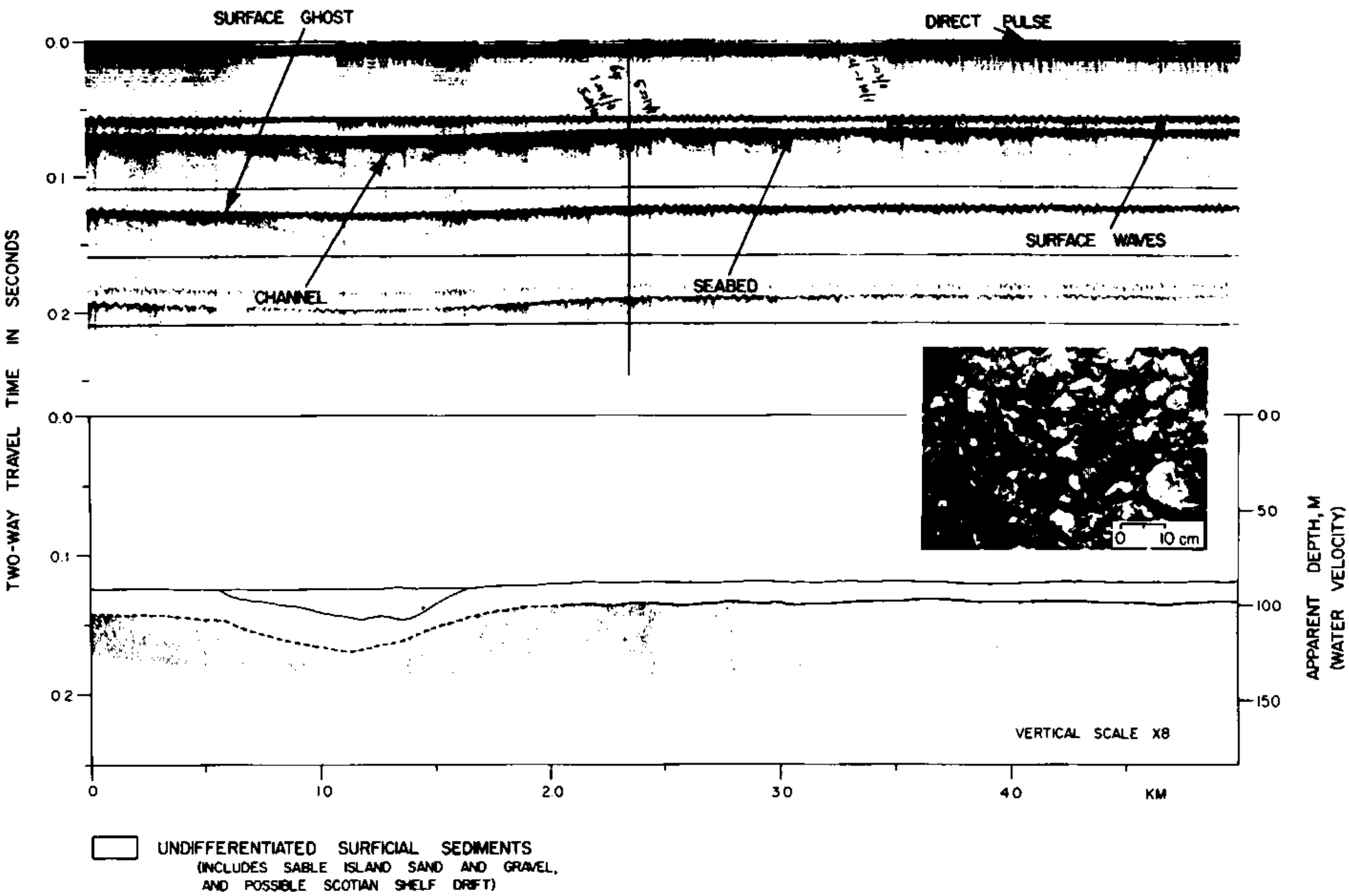

Figure 6

Seismic profile across the gravel facies (see inset) of the Sable Island sand and gravel on Emerald Bank between fixes 63 and 65 of Figure 4.

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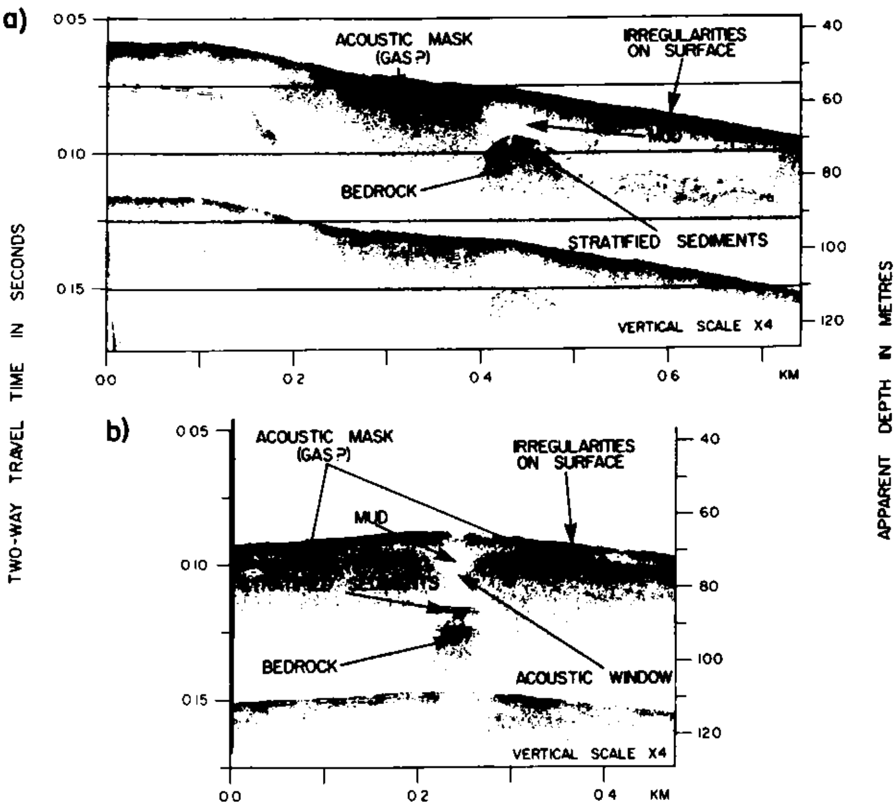

Figure 7
Seismic profile of two portions of Bedford Basin showing penetration through stratified sediments to bedrock at gaps in the acoustic mask. These sedimentary layers are about 30 cm thick.