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THE POTENTIAL FOR SEABED CLASSIFICATION USING BACKSCATTER FROM SHALLOW WATER MULTIBEAM SONARS

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1. ABSTRACT

Large volumes of shallow-water (5-600m) bathymetry are currently being collected in Canada using multibeam sonars (Simrad EM100 and EM1000 systems). While the primary reason for data collection is safety of navigation, these instruments provide a measure of seafloor backscatter concurrent with the depth measurement. Although the acoustic imagery provided by these systems is of a lower spatial resolution than conventional towed sidescan sonars, it has three distinct advantages: the imagery is co-registered with 100% topography, the backscatter measurements are calibrated and the measurements can be made at speeds up to 18 knots.

Processing of the image data requires compilation of individual backscatter measurements from each of up to 60 beams to create across-track scans. The scan data are then geographically coregistered with a DTM derived from the bathymetric data providing a map of seafloor backscatter. The imagery and the topography can then be combined to provide local measurements of the variation of the backscatter strength as a function of incident grazing angle.

In order to use these backscatter measurements as a measure of remote sediment classification a "Hydrographic Ground Truthing" experiment was devised and is being implemented whereby the acoustic sensors are deployed over terrains of known roughness and sediment type. This has been achieved using the large tidal ranges within the Bay of Fundy (>15m) enabling direct sampling of the seabed (in the intertidal periods) to provide the basis for an empirical classification.

2. INTRODUCTION

Increasingly there is the need to understand the surficial geomorphology of the continental shelf region (Karl, [1]). To meet this need acoustic swath systems such as sidescan sonars are being used in a systematic manner in order to provide this knowledge (e.g. Danforth et al., [2]). With the recent development of shallow-water multibeam sonars one now has the necessary high-resolution bathymetric control needed to obtain quantitative backscatter measurements for use in seabed classification.

In order to use backscatter data in a quantitative manner, one requires a calibrated system, without the automatic gain controls so often built into the hardware of shallow water sidescans. Even then, if the calibrated echo level can be derived, one needs to know the local seafloor slope. Thus is is optimal to acquire high density bathymetric data long with the backscatter data. This can be done either from different vessels (e.g. Mitchell and Somers, [3]) or from a hybrid system such as a multibeam sonar from which echo amplitude data are extracted (e.g. De Moustier and Alexandrou, [4]).

Currently the Canadian Hydrographic Survey has four shallow water multibeam systems which have the potential to provide calibrated backscatter measurements at the same time as swath bathymetric data. The systems (Simrad EM100 (3) and EM1000 (1) multibeam sonars) have been used both on the Atlantic seaboard, and in the Gulf of St. Lawrence. They are being deployed on a variety of platforms including conventional displacement vessels, SWATH catamarans and robotic vehicles (Peyton, [5]). The data is collected for the purpose of safety of navigation, for which hydrographic data quality is the prime aim. Both sonar systems, however, have a secondary capability of providing information about the backscatter strength of the seafloor below the vessel. This paper outlines the nature of the backscatter data, the processing requirements, the potential for seafloor classification and the quality of the resulting imagery.

3. MEASUREMENT and CALIBRATION

Both the EM100 and EM1000 sonars use a frequency centred at 95 kHz. The two systems differ primarily in the swath width employed (Fig. 1) and their handling of the seabed echo strength data. The EM100 is an older system that was only designed to provide bathymetry. (Pohner, [6]). For each beam, however, a measure of the peak voltage present within the time window spanning the received echo was preserved. This value has had no time or angle varying gains applied to it, merely a series of linear gain steps used to maintain the echo level within the dynamic range of the digitiser (in order that the recieved echo phase could be preserved for split beam interferometry (Pohner, [7])). Originally no knowledge of the applied gains was preserved as the system was not intended to provide imaging data. However, as a result of a change in the data telegram, EM100 data logged subsequent to May 1992 now has the applied gains preserved. No absolute calibration level for the received voltage measurements is available so the data are strictly relative measurements.

In order to derive a measure of the seafloor backscatter strength one needs to follow a path similar to that described by de Moustier and Alexandrou [4]. A single measurement of backscatter strength (Sb) at a particular grazing angle (θ) can be obtained thus:

$$Sb(\theta) = 10\log((DN\,K)^2) - AGS - Tr - Rc + 40\log(R) + 2\alpha R - 10\log(A)$$

Where DN is the logged digital number (proportional to voltage) and K is the scaling factor to allow for A/D conversion. AGS is the sum of the applied gain steps as indicated in the logged data (which includes relative changes in source level). Tr and Rc are the transmit and receive beam patterns. R is the slant range from the source to the seafloor, α is the attenuation coefficent and A is the insonified area. Because K is unknown, one needs an external calibration step to scale the relative changes in backscatter strength to an absolute level. For our work we have attempted an empirical calibration by comparing the response of the EM100 with that of the EM1000 over similar lithologies.

The EM1000 represents a development of the EM100 based on the new EM12 system (Hammerstad, et al, [8]). For the EM1000, the time series of echo-strength data throughout the central 1 degree of the beam is preserved and is corrected for propagation losses, predicted beam patterns, source power variations and the insonified area (Simrad, [9]). The beam footprint over the pulse length is calculated assuming a flat seafloor at the beam point. Also, in order to reduce the dynamic range of the preserved data, a Lambertian model is used to modify the backscatter strength values according to the grazing angle derived assuming a flat bottom (Simrad, [9]).

Because of the system pre-processing very little manipulation of the data is required. The only post-acquisition correction that needs to be applied are to allow for the true seafloor slope away from a flat bottom at the beam location (measured using the complementary sounding data), correct for small variations in the transmit beam pattern and to remove the Lambertian correction. Thus one potentially has a measure of the seafloor backscatter strength that is independent of range (though not of grazing angle) that can be used as an input to a sediment classification model.

4. CORRECTION FOR SEABED SLOPES AND BEAM-PATTERN RESIDUALS

As a first order approximation, one may assume that the seafloor at the point of impact is flat. There are however three levels of correction that can be applied to produce an improved measurement of the impinging grazing angle:

- One may allow for the across-track slope derived by using the sounding data from the beams to port and starboard of the beam of interest. This is easy to apply real-time as the data is available irrespective of geographic context.
- The next correction is for the along-track slope. This is less simple as one only has the post and prior ping and strictly one needs to know the geographic location of these other swaths. This can be approximated in real-time by knowing the vessel velocity and azimuth for the three pings.
- Lastly for the case of the Simrad EM100 and EM1000 systems, one needs to allow for the pitch at time of transmission as the transmit beam pattern is not pitch stabilised. The pitch angle may be combined with the along-track slope.

While the gross beam pattern effect has been accounted for in the EM1000 data, there are small +/-2dB variations in the transmit beam pattern (Simrad, [9], p.16) not accounted for in the beam pattern removal algorythm. This fact comes out clearly in the sidescan imagery where ship parallel striping can be detected (e.g. Fig. 3b) which correspond to constant angular bearings from the vessel. It also shows up in the plots of backscatter angular response as short wavelength ripples in the angular response curves that are present for all seabed types and not mimicked from port to starboard. These signatures are unique to each particular transducer and must be removed in order to compare the angular response from one system to another.

5. POTENTIAL FOR CLASSIFICATION

Acoustic backscatter measurements of the ocean floor can provide a means for remote seafloor classification. To be useful, however, such measurements must be calibrated and their limitations recognised. A single measurement of backscatter strength (Sb(θ)) is valid only for the grazing angle (θ) considered. It varies significantly as a result of the angle at which the sound impinges on the ocean floor. Multibeam sonars provide an across-track profile of seafloor backscatter strength in which the grazing angle is continuously varying so that even for a single seafloor lithology, the across-track backscatter profile would not be flat. In order to provide an inherent property of the seabed, the full variation in backscatter strength as a function of grazing angle needs to be understood. Generally the greatest variability in Sb(θ) occurs as the grazing angle shift from vertical incidence (θ=90°) to high angle oblique incidence (θ=80-60°) and this is exactly the range of grazing angles covered with narrow or medium swath width ((40 to 60° sector) multibeam sonars.

For imaging purposes, the mean angular response of backscatter strength is derived and used to "normallise" the measurements. This "normallised" value and its spatial variance (texture) can be used as first-order classification tools. In addition, however, the difference in the angular response can be used as a tool which allows discrimination between lithologies that show similar mean backscatter strength values. In order to obtain the angular response, one has to include measurements at multiple grazing angles which, for the case of conventional single-pass surveys must therefore imply averaging measurements across a footprint approximately equal to the swath width thereby running the risk of crossing lithological boundaries.

6. IMAGE QUALITY

The backscatter data provided by both systems can be geographically registered into digital mosaics (Figs. 2 and 3). The spatial resolution of the EM100 imagery is the same as that of the bathymetry (generally about 10-15% of the water depth). Figure 2 provides an example of the nature of the data quality. The bathymetric data (Fig. 2a) can be sun-illuminated (Fig. 2b) in order to show short wavelength topographic relief that can aid in the interpretation of the seafloor. Bedrock outcrop patterns, relict glacial drumlins and draped seafloor are easily distinguished. What cannot be resolved is the nature of the sediment drape in topographically featureless regions. The complementary imagery (Fig. 2c) provides the ability to distinguish gravel lag (relict glacial deposits) and post glacial fine-grained sediment (sub-littoral sand bodies, dark regions). The EM1000 imagery can be used in much the same manner. In contrast to the EM100, however, it can provide much greater spatial resolution in the imagery (Fig. 3a) and is capable of resolving features down to a few metres in size (e.g. gravel dunes, Fig. 3b).

In presenting a geographically registered mosaic of seafloor backscatter measurements, one wishes to present the user with a map showing the spatial distribution of the various seafloor lithologies. The fact that one is not dealing with identical measurements because of the grazing angle variability is of little interest to the end user. If the shape of the angular variability was known and varied little from sediment to sediment then an angular function could be applied to "normalise" the backscatter measurements made across a multibeam swath. In reality, in order to remove the gross angular variability in the image one can empirically find the mean variation with grazing angle and reduce each measurement by this value. While this will remove the gross angular variability it will leave the signature of those sediment types whose angular response deviates significantly from the mean response.

To illustrate this point, a mosaic of EM100 backscatter is presented (Fig. 2c). The measurements have been reduced according to the mean angular response of the region (which extends beyond the viewed subregion). As the dominant lithology over which the average was calculated is bedrock outcrop and glacial till, the mean response shows only a weak angular variability with little difference in backscatter strength between vertical and oblique incidence (response (2), Fig 1). In contrast, the lower backscatter regions which are draped in mud have a much stronger angular response with a 10 dB drop from vertical to oblique incidence (response (5), Fig. 1) As a result a strong striping is visible in the low backscatter (dark) regions which is not a indication of seafloor variability.

Because the EM1000 is a wider swath sytem, the majority of the image data is dominated by grazing angles from 40 to 15^{o}, providing a less noticeable angular response overprint in the data. In the presented example (Fig. 3a) no correction has been made for angular response and the only noticeable artifact is the higher vertical incident measurement that is exhibited in the gravel lags to the east (response (1), Fig. 1) which is less apparent in the regions of bedrock outcrop (response (3), Fig. 1).

7. HYDROGRAPHIC GROUND-TRUTHING EXPERIMENT

In order to use the mean and angular response of backscatter strength as a tool for remote seafloor classification, one needs to identify the signature of the lithologies present and define a method for discriminating between those lithologies based on the differences in their acoustic character. A number of example responses are presented in Figure 1. In deriving these responses care must be exercised to ensure that the insonifying footprint does not extend to regions of other lithologies. By choosing small regions without apparent sediment boundaries within imagery, one can build up a library of characteristic response curves, which can be linked with co-registered ground truth data. In this manner one has the potential to build up a knowledge base that forms the basis for the classification scheme. To this end a 3 year NSERC Strategic Grant termed "Hydrographic Ground Truthing" has been put in place which is specifically aimed at examining both the hydrographic data quality and the potential for seafloor classification of the sonar systems currently utilised by the Canadian Hydrographic Service. Data presented herein are results from the first phase of the project. A more detailed overview of this experiment is presented by Mayer ([10]).

8.SUMMARY

Backscatter measurements at 95kHz taken from the continental shelf provide useful acoustic signatures which may be correlated with seabed lithology. These measurements are co-registered with multibeam topography and thus the influence of variations in seafloor slopes may be minimised.

The geographic variations in mean backscatter strength may be used as a first order seafloor classification tool. In order to resolve lithologies with similar mean backscatter strength, the variation in backscatter strength as a function of grazing angle and the variance of the backscatter strength may be used as qualifiers. The angular response measurements need to be interpreted with caution as they are not point specific but must be derived along a transect and thus can be influenced by sediment boundaries.

Future progress will focus on the collection of seafloor physical property data in order to relate measured responses to the acoustic interaction with the seabed. In addition the inter-calibration of the EM100 and EM1000 instruments will be carried out to ensure the collection of equivalent data despite changing platforms.

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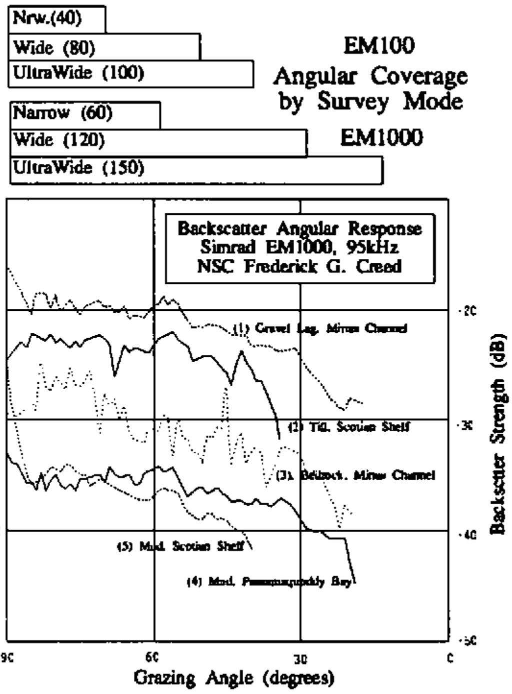


Figure 1: Composite figure showing:
(top) - Angular coverage of the EM100 and EM1000 multibeam sonars.
(bottom) - Angular response of backscatter for a representative selection of lithologies common on the Canadian Atlantic margin. Each curve represents an average of between 50 and 100 transmit pulses and represents an average of the port and starboard response. Samples were taken from regions without apparent geological boundaries.

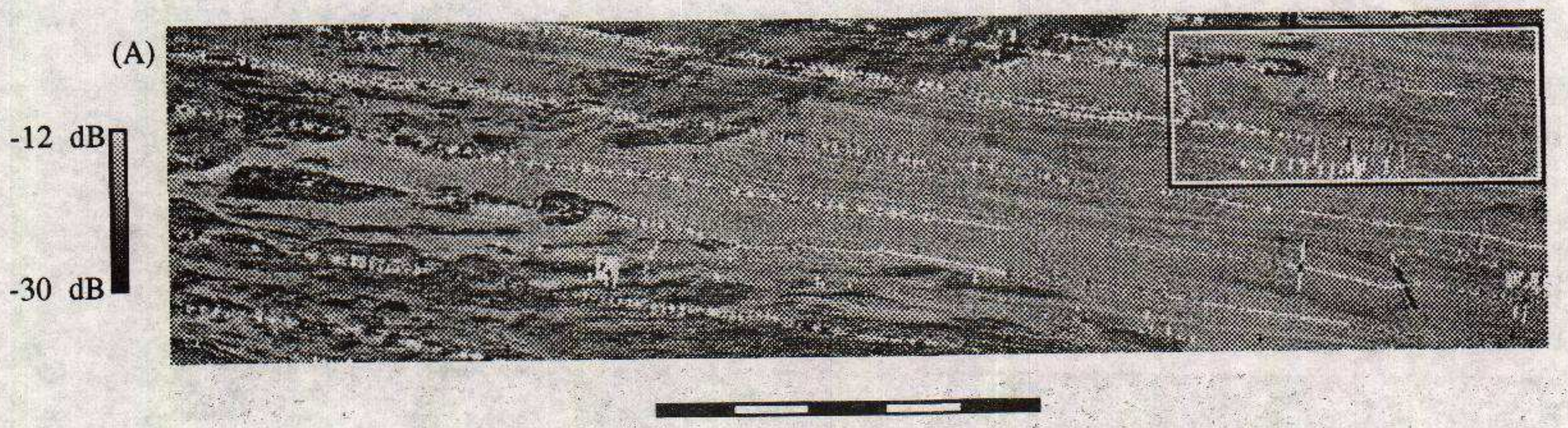
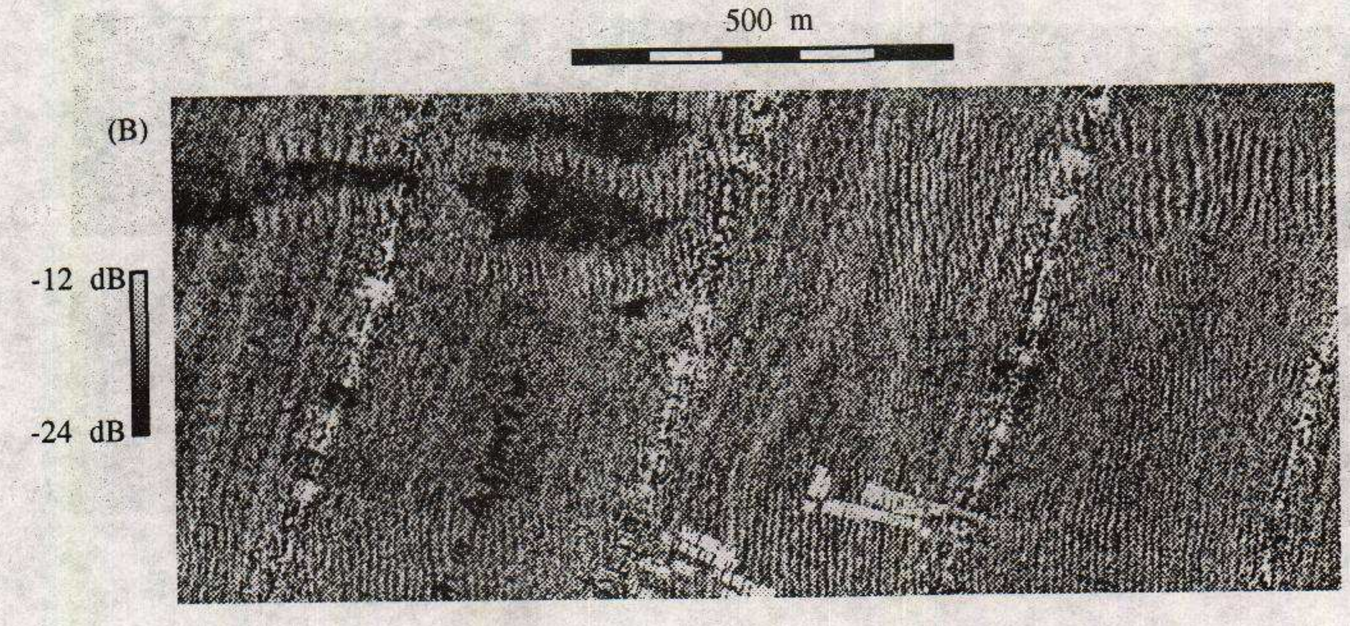


Figure 3: Example of imagery derived from EM1000 sonar
(3.6 x 0.9 km area, Minas Channel, Bay of Fundy)
(A) - imagery showing bedrock outcrop to west and gravel lag to east
(B) - close up of gravel lag showing 4-16m wavelength dune fields



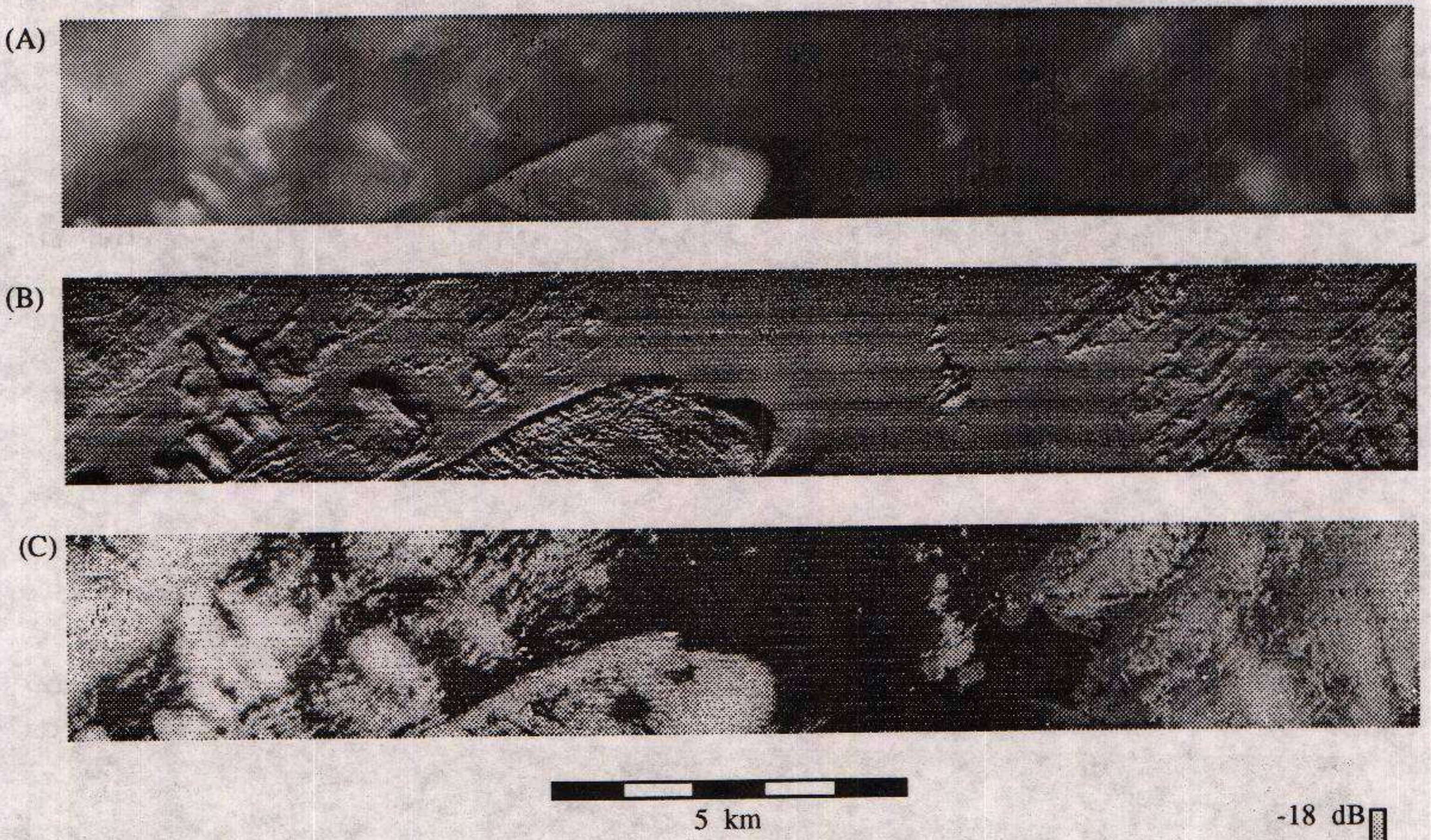


Figure 2: Example of EM100 sonar data
(19.0 x 2.9 km area, Scotian Shelf)
(A) - bathymetry (60-130m)
(B) - sun-illuminated topography (sun to south)
(C) - imagery derived from backscatter measurements