Bottom Classification in Very Shallow Water by High-Speed Data Acquisition

J.M. Preston and W.T. Collins

Quester Tangent Corporation, 99 – 9865 West Saanich Road, Sidney, BC Canada V8L 5Y8
Email: jpreston@questertangent.com
Web: www.questertangent.com

Abstract- **Bottom classification based on echo features and multivariate statistics is now a well established procedure for habitat studies and other purposes, over a depth range from about 5 m to over 1 km. Shallower depths are challenging for several reasons. To classify in depths of less than a metre, a system has been built that acquires echoes at up to 5 MHz and decimates according to the acoustic situation. The digital signal processing accurately maintains the echo spectrum, preventing aliasing of noise onto the signal and preserving its convolution spectral characteristics. Sonar characteristics determine the minimum depth from which quality echoes can be recorded. Trials have been done over sediments characterized visually and by grab samples, in water as shallow as 0.7 m.**

ACOUSTIC SEABED CLASSIFICATION

Introduction

Acoustic seabed classification is the organization of the sea floor and shallow subsurface sediment into seabed types or classes based on characteristics of an acoustic response.

This paper is concerned with acoustic classification using standard echo sounders. Sounder beamwidths are almost always wide enough to include the ray normal to the local bottom, and thus these echoes start with nadir specular reflection. Some history is presented, mostly pertinent to water deeper than about 10 m. Classification performance suffers in shallower water. Acquiring acoustic data at a very high rate addresses several of the issues that limit shallow-water performance. A new shallow-water system is presented, with survey results.

For many years, fishermen and others have been using echo sounders to classify the seabed manually. Some sounder display only the travel time of the echo from the sea floor translated into depth. Others display the echo intensity as an echogram; with these systems inferences on the nature of the seabed can been drawn from the echo character. This is possible because there is more information in the returning signal than just travel time. The details of the intensity and duration of the echo are measures of the acoustic backscatter, which is controlled by the character of the seabed. The second echo, which follows the path ship-bottom-surface-bottom-ship, has been found to be a useful indicator of surface character, when examined together with the first echo.

By the early 1970's, shipboard observations of the first and second echoes were used to provide real-time indications of bottom type and reflectivity. In the 1980's, dedicated seabed classification systems processed the analogue signals and generated values representing the acoustic response from specific seabed types. Currently, high-speed digital signal processors can extract many more features from the echo. By applying digital signal processing techniques to this backscatter information, accurate and repeatable acoustic classification of the seabed can be accomplished.

Sonar Waveforms

Fig. 1 shows two hypothetical seabeds and the associated echo traces, insonified by an echo sounder with a substantial beamwidth. From a smooth flat bottom, mud perhaps, the specular return from directly beneath the ship is directed back to the transducer, while returns from larger angles miss the ship. The result is an echo trace that has a short peak with no tail. Depending on the sonar frequency, the echo return from within the substrate is usually not large for mud. By comparison, the specular return to the ship from a rough complicated gravelly sea bottom is from a larger area
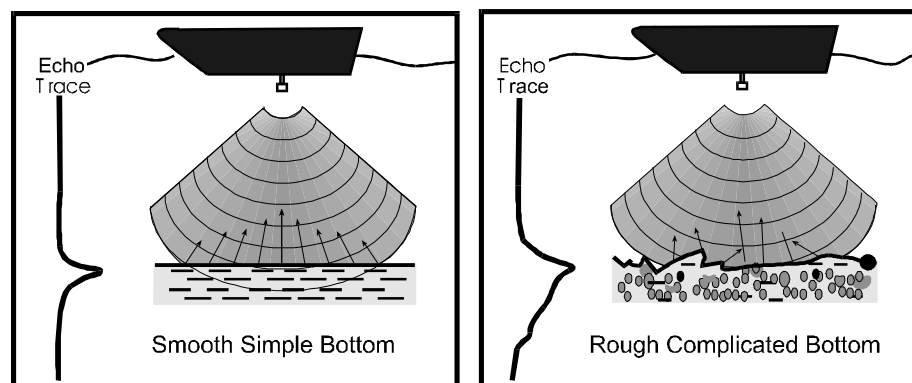

Fig. 1 Idealized echoes from two representative bottom types

because of the large number of facets at random orientations. More spreading time is taken to insonify a larger area, so these echo traces have long peaks and tails.

In general, various features of the seabed control the character of the returning echo trace. The two dominant influences are the roughness of the sea floor and the density and sound speed differences between the water and the sea floor material. Seabed roughness occurs on many scales, from the grain size of the material to bedforms that range up to metres in length. Density and sound speed differences determine the mismatch in acoustic impedance between water and sediment, and thus the echo amplitude. These differences can be substantial between, for example, very loose mud and bedrock.

Acoustic Classification Systems

Remote classification of the sea bottom requires an acoustic data acquisition system and a set of algorithms that analyze the data to determine the seabed acoustic class. Non-acoustic data, from direct sampling or observation, is usually used to relate the acoustic classes to the physical properties of the marine sediments.

Dedicated seabed classification systems consist of integrated hardware and software. The data processing relies on the extraction of characteristic features from the seabed echo. Classification implies some kind of ordination technique to group echoes with similar features. The two best-known systems on the market are QTC VIEW™ (Quester Tangent Corp.) and RoxAnn™ (Stenmar Micro Systems Ltd. of Aberdeen, Scotland). These systems take fundamentally different approaches.

The RoxAnn™ classification system [1,2] is based on the energy contained in the first and second echoes. The second echo refers to the bounce of the original sound pulse reflecting off the sea surface and then the seabed for the second time. The system uses two values derived by the analogue integration of the tail of the first echo and the full extent of the second echo. The two values, known as E1 and E2, constitute the feature set used for classification. The ordination technique is based on the pair of E values, by assigning domains to classes in a two-dimensional Cartesian plot.

The QTC VIEW™ system [3-5] uses digital techniques to acquire all sonar data from transmit to a maximum range. The window surrounding only the first echo is analyzed by a series of algorithms that derive 166 feature descriptors. Some of these features are based on echo shape, and others on spectral characteristics. With a fairly wide beam ($\approx 15°$ or so) echo shape is rich in sediment information with nadir echoes because backscatter coefficients and their variation with angle of incidence differ markedly between sediments near normal incidence. Principal components analysis (PCA) is used to reduce the information to three "Q" values representing linear combinations of the features most useful in distinguishing seabed types. Points defined by the triad of Q coordinates are plotted in 3-dimensional space for visual inspection of clustering. Class assignments are based on multivariate distances between Q-values of records to be classified and those of the cluster centers. In addition, a value is calculated for each record representing the confidence in choice of class.

This approach to acoustic bottom classification relies, at base, on the geological and biological diversity of the sea bottom being expressed in acoustic diversity of echoes. Exploiting this concept requires appropriate acoustic and data-acquisition equipment, to capture any echo details that carry bottom information. Just as important are suitable techniques for extracting features from the echoes, for setting aside features due to equipment and procedures, and for classifying echoes using those features that are rich in bottom information. To relate classes based on acoustic diversity to the biological or geological differences of interest, one must obtain appropriate samples, using divers, grab samplers, or the like. The acoustic classification is deemed successful if samples from several areas within the same acoustic class are distinct, in the required sense, from the samples taken from areas in other acoustic classes. When this is so, the acoustic classifications are both useful and valuable, because acoustic survey can systematically and efficiently cover large areas at a wide range of spatial resolutions. The user can confidently assign typical bottom characteristics of the point samples from any location in each acoustic class to the entire area within that class.

All these bottom-classification systems connect to almost any sounder without affecting its operation. The head amplifier is exposed to the transmit pulse, from which it derives a trigger, and to the echo, which is either analyzed in real time or recorded. Time since the trigger is used to generate a gain (TVG) that is applied to voltage-controlled amplifiers.

DATA ACQUISITION FOR BOTTOM CLASSIFICATION IN VERY SHALLOW WATER

Bottom classification in water less than about 5 m deep is often in support of ecological or habitat surveys. Even if the bottom in all or part of the survey area could be classified visually, which is not always possible or practical, acoustic bottom classification may well be preferred so that the entire survey is systematic and consistent over a large area. In fact, the opportunity to classify visually, perhaps at low tide, can assist the acoustic results by providing ground truth over large areas for comparison with the acoustic results, rather than the usual sparse set of point samples.

To classify accurately in water shallower than 5 m or so, four issues must be addressed. 1. The sampling rate must be fast enough to capture the details in very short echoes. Shallow-water echoes are always kept brief, because the first and multipath echoes must not collide. 2. There is little time between the transmit pulse, the first echo, and
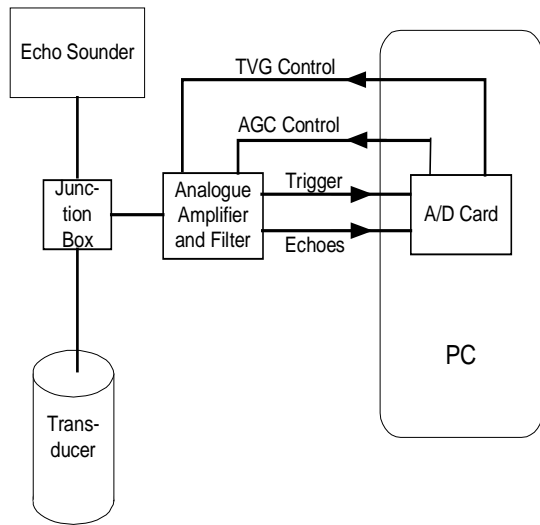
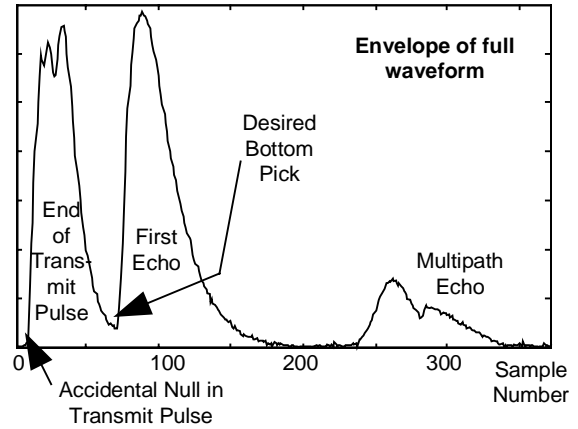Fig. 2: High-speed data acquisition system suitable for very shallow water.

Fig. 3: Echoes in very shallow water, illustrating issues with triggering when waveforms overlap.

multipath echoes. Classification requires that all but the desired signal always be excluded from the data to be processed. 3. Data acquisition systems for echoes are usually designed to capture echoes from depths of several hundred metres, at least. The amplitudes of echoes from less than a metre can be six orders of magnitude larger, so the acquisition system needs a remarkable dynamic range. Clipping usually has serious effects on classifications. 4. Echoes from identical sediments at different depths are different, and so are features from those echoes. In deep water, compensation for depth changes can be linear, but this is not true in shallow water.

Quester Tangent's new acquisition system, QTC VIEW™ for shallow water, addresses these issues. The sampling rate is extremely high, far higher than needed for
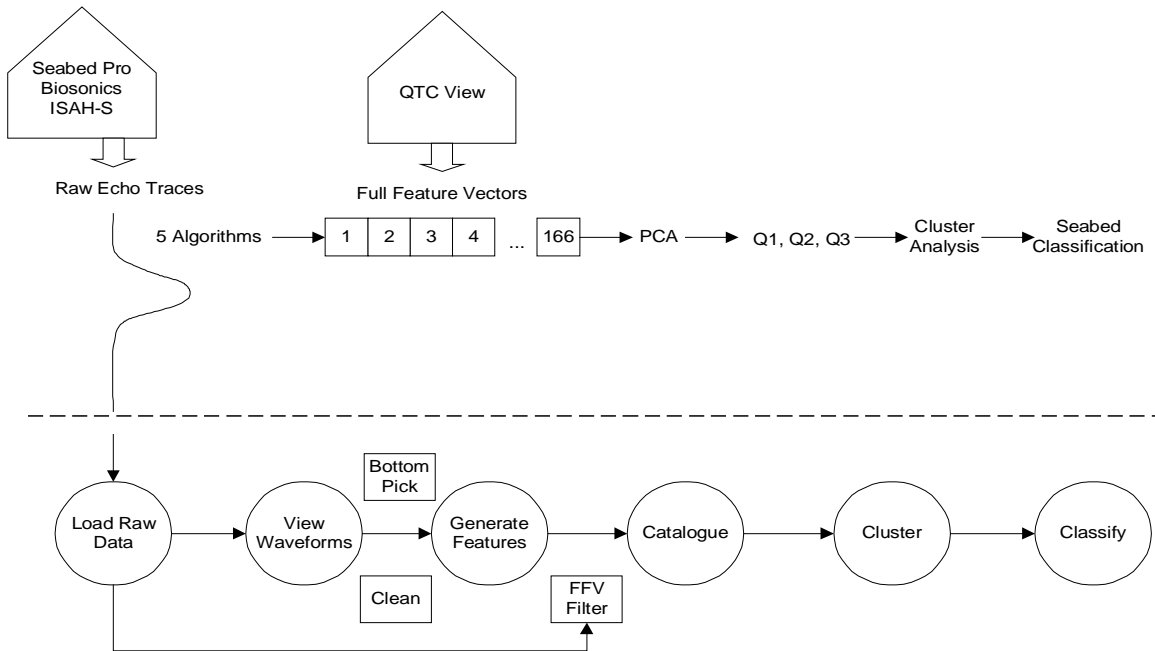

Fig 4. Process flow in IMPACT. The data set to be classified can consist of raw echo traces, from which 166 features are generated after bottom picking and cleaning. Alternatively, and not for the work described here, Full Feature Vectors (FFV) generated in real time by QTC VIEW™ can be input. FFV filtering is another important quality assurance step. IMPACT is oriented to unsupervised classification in which a catalogue is generated as part of the cluster process. The final result is classification of the input data set according to its acoustic diversity.

even the briefest echoes. The resulting data are decimated down to the appropriate rate for the sonar situation. This approach, besides easily adapting as the sonar situation evolves, includes sophisticated digital filtering tailored to the characteristics of echo sounder echoes. Fig. 2 is a block diagram of this system, showing that it operates in the same "eavesdrop" mode as other QTC systems. In particular, as shown in Fig. 2, the analogue echo waveform is bandpass filtered and TVG is applied before digital conversion by a card in an expansion slot of a desktop PC with a PCI bus. The A/D card samples to 12 bits at 5 MHz in shallow water, slowed to 2.5 MHz or 1.125 MHz in deeper water to avoid very large buffers. The TVG is under software control through a D/A output and voltage-controlled op-amps. To ensure that the signal amplitude is appropriate, and to relieve the user of the need to set a gain manually, ping-to-ping gain is software controlled (AGC) based on a running average of peak amplitudes.

In less than a metre of water, the transmit pulse may not be complete when the echo starts to arrive, particularly with sounders with poorly controlled ring-down. Obtaining reliable bottom picks and uncontaminated echoes may require some care, and the ring-down characteristics may determine the minimum workable depth. This system uses a blanking period after the trigger. The bottom pick is the first sample after the blanking period that satisfies the pick criteria. The transmit pulse length must be very consistent if its rising edge is used as the trigger; this is usually the preferred choice. If the trailing edge is used, sporadic

notches may cause premature triggers, as shown in Fig. 3. This figure also illustrates the challenges of identifying the start and end of first and second echoes in very shallow water. The QTC classification approach, based on only the first echo, is workable in these situations, particularly if assisted by off-line quality control based on bottom picks. Techniques based on identifying first and second echoes, such as RoxAnn, face the additional challenge of identifying the second echo, whose location depends on both depth and draft.

ECHO PROCESSING WITH QTC IMPACT

Echoes, recorded as described above using the QTC VIEW™ for shallow water, were analyzed in QTC IMPACT (Quester Tangent Corp). This suite of programs calculates the 166 feature descriptors, performs principal components analysis, and clusters the records in Q-space, as described in the first section of this paper. IMPACT has extensive capabilities for quality assurance, and also accepts and processes navigational data, allowing classes to be plotted geographically. Data flow in IMPACT is shown in Fig. 4.

In survey after survey, it has been found that quality assurance is essential to achieving accurate sediment classifications. When the data set that was recorded is actual echoes, as in the work described here, the bottom picks can be reviewed, redone with different gates and thresholds, and then repaired manually, using the tool shown in Fig. 5. Accurate bottom picking is extremely important
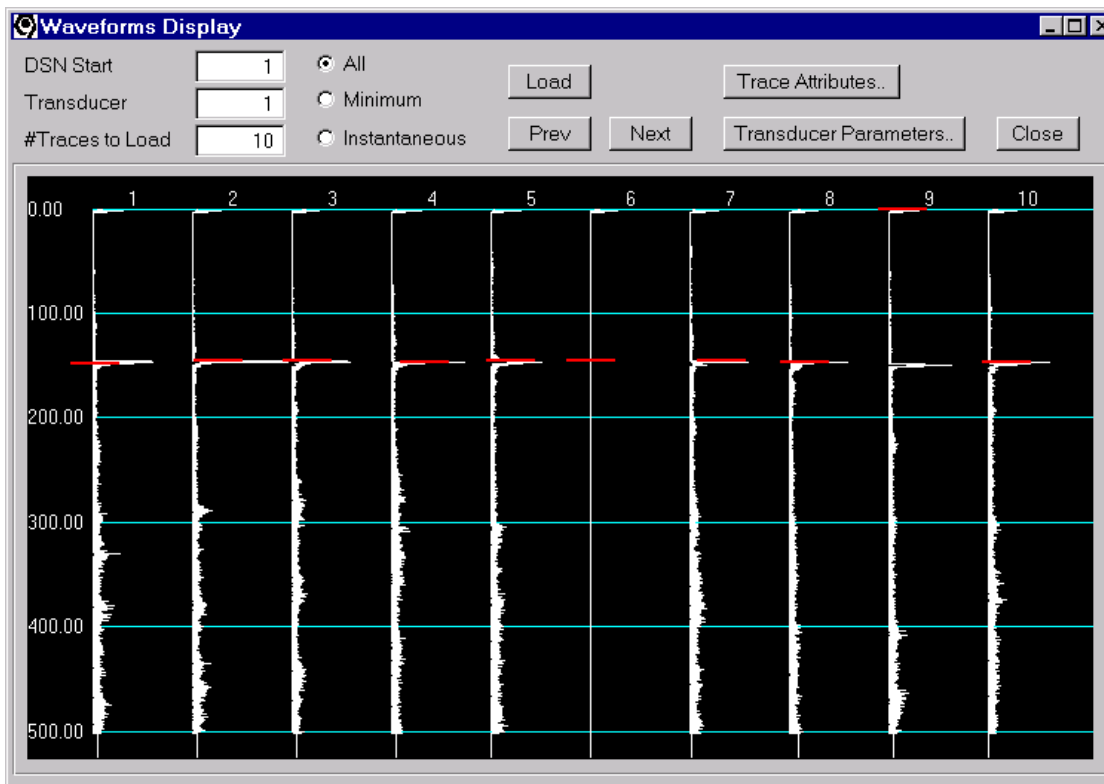

Fig. 5. Waveview display, used within IMPACT, showing ten deep-water pings plotted against depth. Pings can be inspected for adequate amplitude and clipping. Bottom picks, which are indicated by horizontal bars, can be revised. Manual adjustments are also possible, for example ping 6 can be unpicked and thereafter ignored. Accurate bottom picks are essential for accurate sediment classification.

because the windows of data on which the classifications are based are selected based on the bottom pick. Erroneous picks, on fish or artifacts for example, lead to data windows that are very different from actual bottom returns and can then dominate PCA. The Waveview window, Fig. 5, can also be used to identify insufficient signal-to-noise ratios and clipping.

Each Full Feature Vector (FFV) has an associated depth. FFV records can be filtered in IMPACT based on depth, location, time, and other variables to exclude outliers or to concentrate the analysis in the desired depth range, or area. This is often used to exclude foreshore in traditional surveys in moderate and deep water.
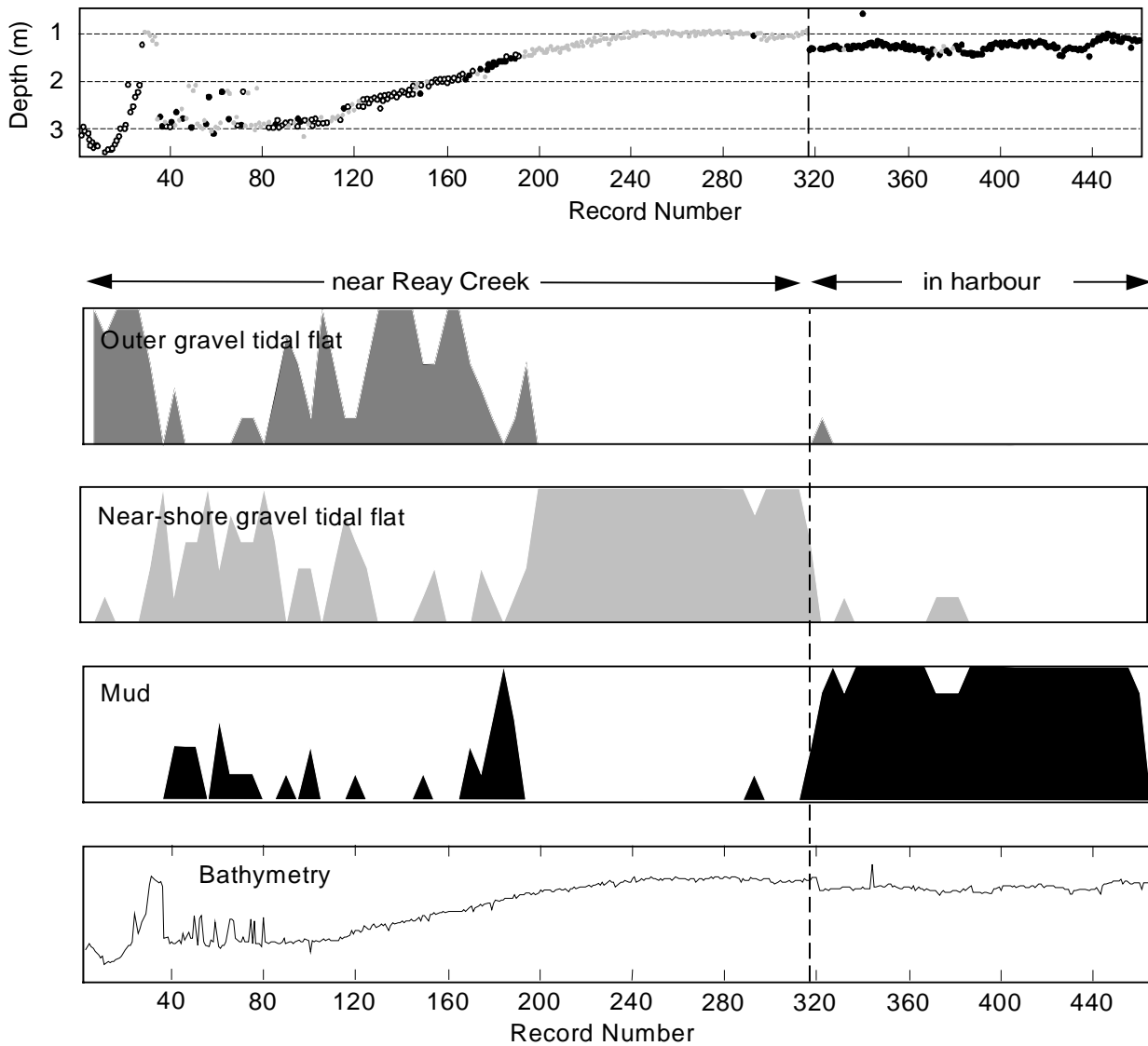

Fig. 6. Sediment classification near Sidney, BC. Records 1-317 were recorded over well-washed gravel and cobble, interspersed with mud, on an exposed tidal flat. Records 318-462 were recorded over mud in a nearby harbor. Top plot shows bathymetry and seabed class, with open circles designating outer tidal flat, gray circles near-shore tidal flat, and black circles mud. Echoes were recorded over outer, near-shore, outer, and then near-shore tidal flat and, to the right of the dashed line, over mud. The three middle figures are the proportional composition of groups of five records. The apparent jumps in depth after records 37 and 317 are where logging was paused and the boat moved. The erratic depth values between records 45 and 80 were due to triggering issues similar to those shown in Fig. 3.

SHALLOW-WATER RESULTS

Fig. 6 shows results of a recent survey in our local area. These results were produced from a data set recorded as described in the first part of this paper before processing in IMPACT. Of the 462 records in this local survey, the first 317 were recorded while drifting over well-washed aggregate, near a local beach open to winter storms. Since the depths ranged from 1–3 m, the gravel could be observed and its size estimated. Mud was seen between rocks in parts of this tidal flat. In particular, records 1-37 and 81-195 were recorded over the outer part of the tidal flat, with the rest of this group near shore. The outer portion had a larger mean gravel size. The last third of the records, 318–462, was recorded in a different location, in a harbor with a mud bottom. The top plot of Fig. 6 shows the three logical acoustic classes for the complete data set as determined by IMPACT. One can never be certain that water depth is not influencing acoustic classification, so it is reassuring to see accurate and consistent classes that are mingled in depth, as the two gravel classes are here. The proportional composition plots, the middle three plots of Fig. 6, show the fractions of boxcars of five records that are in each class. The records over the outer tidal flat are predominately in their own distinct class, while those recorded over the near-shore sections of the flat and over mud are almost completely separated, both from each other and from the outer-flat class. This demonstrates reliable and useful sediment classification in water as shallow as 0.9 m.

CONCLUSIONS

Accurate reliable sediment classification in shallow water poses several challenges. These have been addressed in the system described here. Key elements are a variable high sampling rate to ensure sufficient echo detail is captured and digital multirate processing to maintain spectral fidelity of echoes at optimal signal-to-noise ratios. The system has been proven to be useful and reliable by survey results in water as shallow as 0.9 m.

REFERENCES

[1] M.B. Collins, and G. Voulgaris, "Empirical field and laboratory evaluation of a real-time acoustic sea bed surveying system," *Proc. Inst. of Acoustics* 15, pp. 343-351, 1993.

[2] C. Dyer, K. Murphy, G. Heald, and N.G. Pace, "An experimental study of sediment discrimination using 1st and 2nd echoes," in *High Frequency Acoustics in Shallow Water* La Spezia, pp. 139-146, 1997.

[3] B.D. Bornhold, W.T. Collins, and L. Yamanaka, "Comparison of seabed classification using sidescan sonar and acoustic classification techniques," in Canadian Coastal Conference, 1999.

[4] W.T. Collins, and J.L. Galloway, "Dual-frequency acoustic classification of seafloor habitat using the QTC VIEW," in *Proc. Oceans 98*, Nice, 1998.

[5] L.J. Hamilton, P.J. Mulhearn, and R. Poeckert, "Comparison of RoxAnn and QTC VIEW acoustic bottom classification system performance for the Cairns area, Great Barrier Reef, Australia," *Continental Shelf Research* 16, pp.1577-1597, 1999.

[6] J.M. Preston, A. Rosenberger, and W.T. Collins, "Bottom Classification in Very Shallow Water," in *Proc. Oceans 00*, Newport, 2000.