VARIATION OF BACKSCATTER PDF IN SONAR IMAGERY AND SHADE CORRECTION BY HISTOGRAM TRANSFORMATION

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ABSTRACT

The variation of mean back-scatter with grazing angle and sediment type has been of theoretical interest for some time, and has also been proposed as a possible method of hydroacoustic sediment characterization. At the same time systematic shade variation with range, which is closely correlated with elevation angle and grazing angle, is a significant problem for the visualization of sidescan sonar data. This paper presents intensity histograms as a function of elevation angle for some representative seabed types, and shows that not just mean back-scatter but the shape of the histogram is dependant on grazing angle, due to a combination of specular reflection near nadir, and shadowing at shallow grazing angles. Nevertheless, for each seabed type, it is possible to provide excellent compensation for shade variation by a table look-up procedure which effectively transforms the histograms to a selected histogram at mid-range.

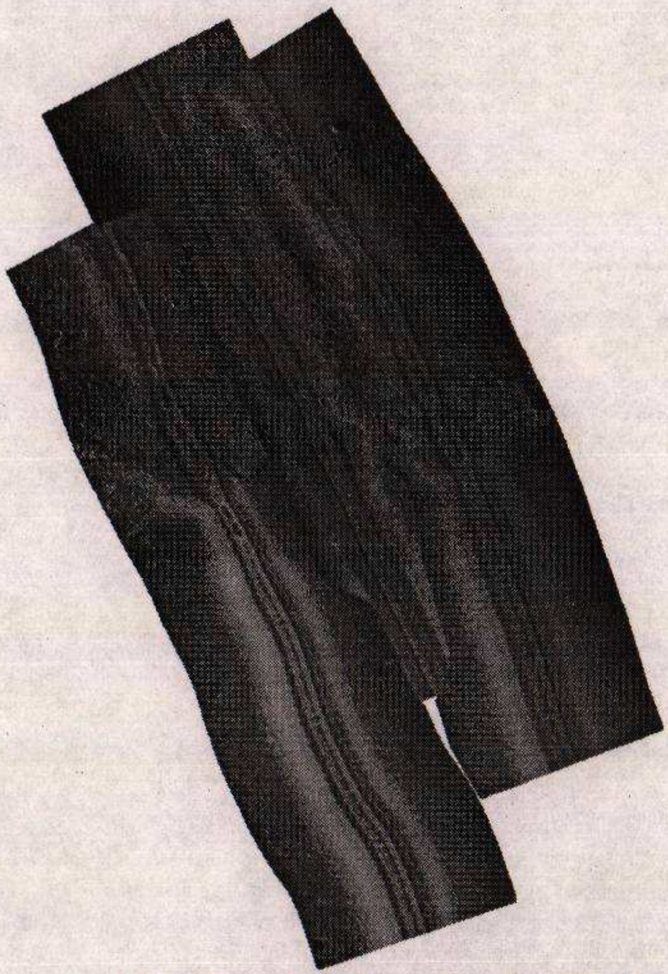
Shade-correction of complete records or mosaics covering a range of geology can either be achieved by pre-segmentation of the imagery, or with some degradation in quality, by ignoring the geology when calculating the set of histograms.

1. INTRODUCTION

"Shading" is a term used in image analysis to denote systematic intensity variation across an image due to instrumentation. Almost all raw sonar records are subject to intensity variation with range. This variation is so familiar that it often passes unnoticed on the individual chart record. However it can be a considerable disturbance to the eye and the interpreter when records are combined into a mosaic (Fig 1).

The backscattered sonar echo is attenuated with increasing range, not only because of spreading losses, but because the incidence angle with the seabed normally decreases with increasing range. Hence all survey sonar instruments include some form of TVG (time-varying gain) to reduce the dynamic range of the signal before display. If a number of conditions are satisfied - the gain parameters in the sonar instrument are properly recorded, the elevation beam pattern is known, and the backscatter variation with incidence angle follows Lambert's Law - it is possible to make reasonable predictions about intensity variation with range, and to compute a TVG (time-varying gain) which will compensate [1]. However Lambert's Law is only an approximation to backscatter variation with incidence angle, which also depends on the nature of the seabed, see for example Jackson [2]. Hence, even in principle, seabed classification is required before an accurate TVG can be computed.

Unfortunately there is a related problem in classifying sediment from backscatter statistics because these statistics depend on grazing angle. One option is to restrict classification to "mid-range" data in order to minimize grazing angle effects. This is essentially the approach adopted by Pace ad Gao [3], and by Huseby [4] with multibeam data. The alternative proposed by Hughes-Clarke [5] is to use dependence on grazing angle as a classification feature.



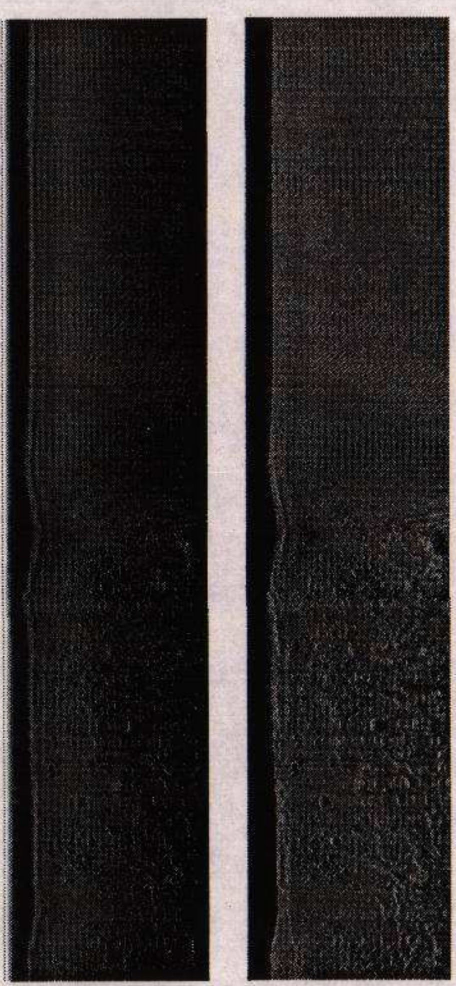


Fig 1 380 kHz sidescan sonar mosaic before shade correction

Fig 2a, b Sidescan sonar record before and after shade correction by transformation of histograms collected over whole record

The main purpose of this paper is to describe a strategy for shade correction by transformation of histograms collected from the data itself. The first step is to compensate each sidescan record for shade variation independently of seabed material, using range-related or elevation angle-related histograms. If this corrected record can be accurately classified, or at least segmented, into different geological types, the segmented record can then be used as a "context" to improve shade correction. The procedure will become clearer in the course of the paper. Section 2 is concerned with the variation of backscatter PDF using a set of histograms gathered from experimental data, and describes the basic method of shade-correction. Section 3 presents one result of segmenting the same sonar image, using both an uncorrected and a shade-corrected data. Section 4 discusses the application of the shading technique to sidescan sonar mosaiccing.

2. INTENSITY HISTOGRAMS

Fig 2a, b show a 200 m section of a sonar record from an SGU (Geological Survey of Sweden) survey of the Kattegat using a 380 kHz Klein side- scan sonar. The survey practice is to maintain the height of the towfish constant above the seabed as far as possible, so there is good correlation between incidence angle with the seabed and slant range, especially in areas offshore Sweden where bottom slopes quite gently. However grazing angle may be significantly less than elevation angle in these records, since the fish was flown close to the thermocline.

The displayed record contains 1282 columns, or digital samples, extending out to a slant range of about 50m. The sonar signal was digitized with 12 bits precision. Fig. 3a, b, c show three homogeneous test regions selected from the same survey which appear to be made up of different seabed material. The three regions might be classified as "mud", "sand", and "rocks" respectively. There is a systematic shade variation across all these records. At short range, the variation follows the bottom return and is clearly a function of elevation angle, in fact a combination of the elevation beam pattern and the onset of specular reflection near nadir. At longer range, the variation could be ascribed to the TVG setting. With this instrument, the TVG function is chosen by the operator and not recorded, so the true variation of mean backscatter with range is not available, only the apparent variation in the recorded data.

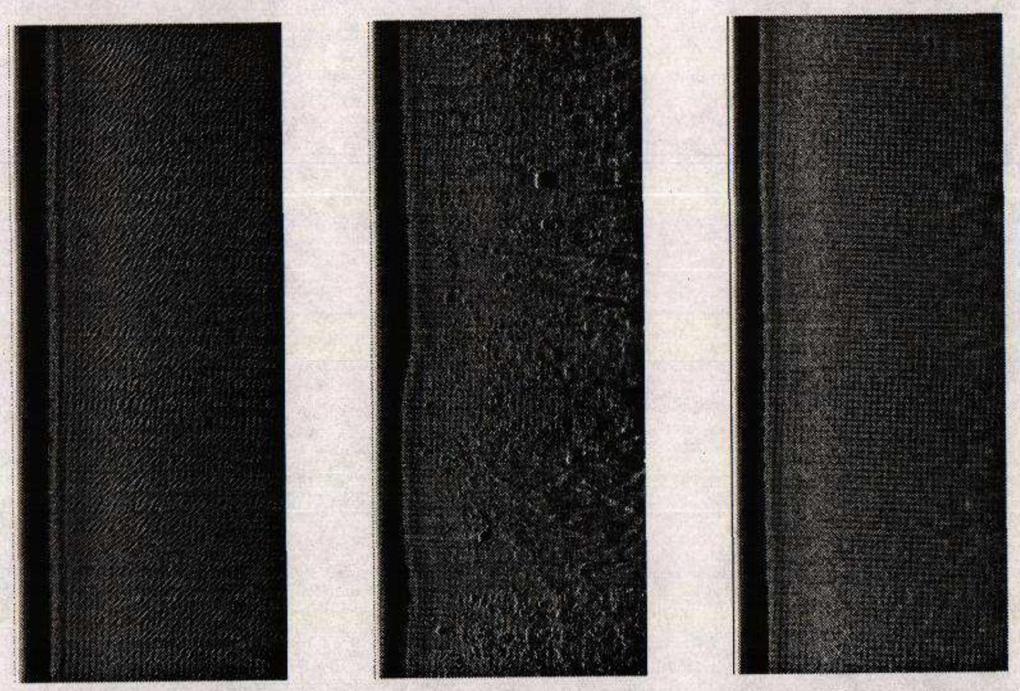


Fig 3 Homogeneous regions of seabed before shade correction: a) sand ripples b) scattered rocks c) mud or fine sand.

The variation of the backscatter PDF for different seabeds could be explored this by collecting histograms for different range intervals. However at short range the dependance on elevation angle is so clear that it seems better to collect histograms for intervals of cosΦ where Φ is the elevation angle (cosΦ is used rather than Φ to obtain more equal spacing across the record). In order to find this angle, the bottom return is first tracked carefully using an automatic tracking algorithm, giving the column number, botcol, for each ping or line of the record. Pixel intensity histograms can then be collected for equal intervals of cosΦ = botcol/col. Figs 4a, b, c show histograms 1, 8, 16, 24 and 31 for sand, rocks, and mud respectively. As the elevation angle reduces towards zero with increasing range, the approximately Gaussian shape of the histogram becomes modified by increasing shadow, leading to an almost bimodal character. The variation in the statistics can be seen by plotting variance/mean and skewness as a function of cosΦ (Figs 5a, b). Skewness is considerable at nadir, presumably because of the tail in the distribution from specular reflection. It drops sharply at a few degrees from nadir, and then climbs steadily out to maximum range. Skewness is greatest in the "rocks" image with the greatest shadow content, but is also present in the "mud" image which at first sight appears featureless.

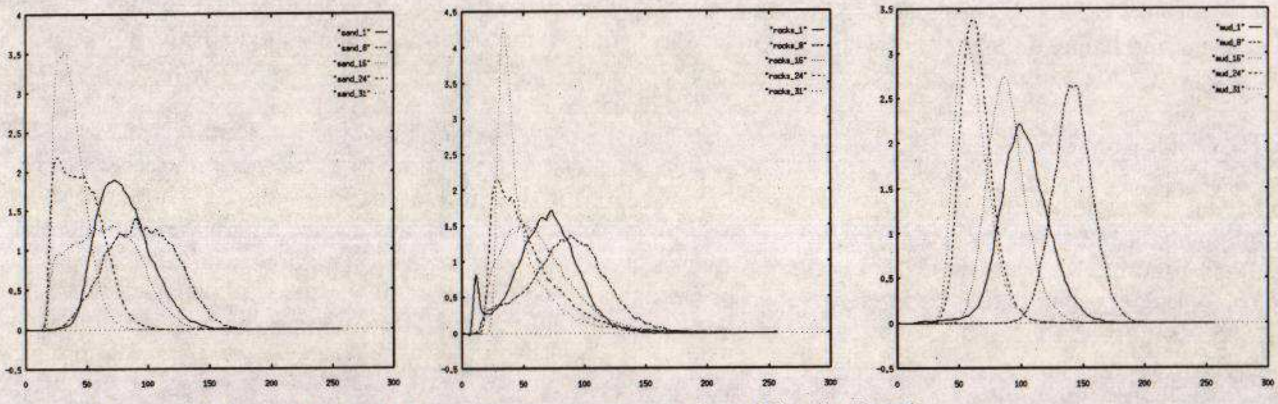


Fig 4 Sample histograms 1,8,16,24,31 from uncorrected records: a) sand b) rocks c) mud

The simplest method of automatic shade correction is to estimate mean pixel value over a long sequence of pings as a function of range, and then adjust gain with range in compensation. The result of carrying out this kind of procedure on Fig 2a is shown in Fig 2b. cosΦ is used rather than range, in order to achieve better short-range shade correction. The result is unsatisfactory, with evidence of excessive gain at longer ranges. Shadow content of the image at longer ranges depresses the estimated mean, leading to overcompensation.

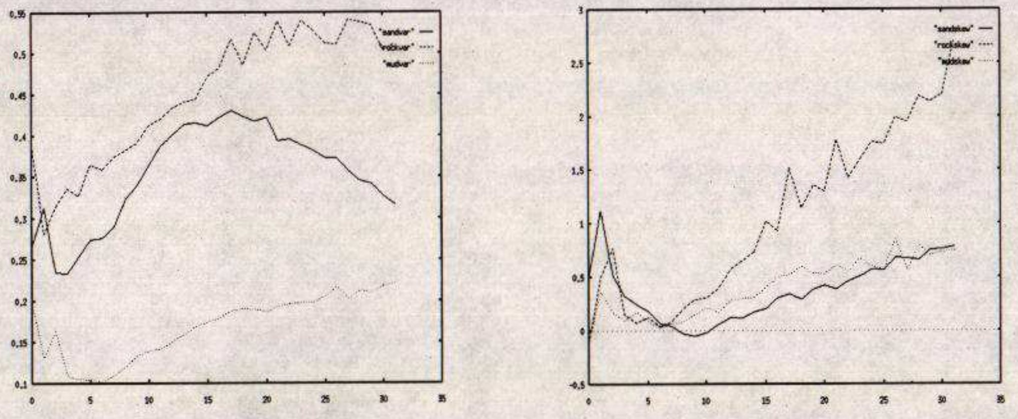


Fig 5 a) variance/mean of sand, rocks, and mud histograms versus cos Φ (elevation angle) b) skewness versus cos Φ.

The method proposed in this paper is to use, not just the mean value, but the whole histogram as a basis for shade correction. To do this, a mid-range histogram is chosen as reference, and look-up tables are constructed as a function of range, or cosΦ, which transform the measured histograms into the reference histogram. This procedure requires two passes of the data, one for histogram collection, and one to transform the image on the basis of the computed look-up tables. The result of carrying out this operation on Fig. 2a and Figs.3a, b, c is shown in Fig. 2b and Figs. 6a, b, c respectively. Shade correction carried out on the homogeneous regions is very successful in equalizing shading across the image. Figs. 7a, b, c show the corrected histograms corresponding to Figs. 4a, b, c. Shade correction in Fig. 2b is also comparatively successful.

Some implementation details may be noted. The measured histograms are smoothed before computing the look-up tables in order to reduce sampling effects. The original imagery has 12 bits precision, whereas the histograms are only collected for 256 grey levels. Hence the look-up tables compute a transformation from 12 to 8 bits. The look-up tables are then interpolated during the transformation operation in order to reduce quantization effects, which also restores 12 bits precision to the transformed image.

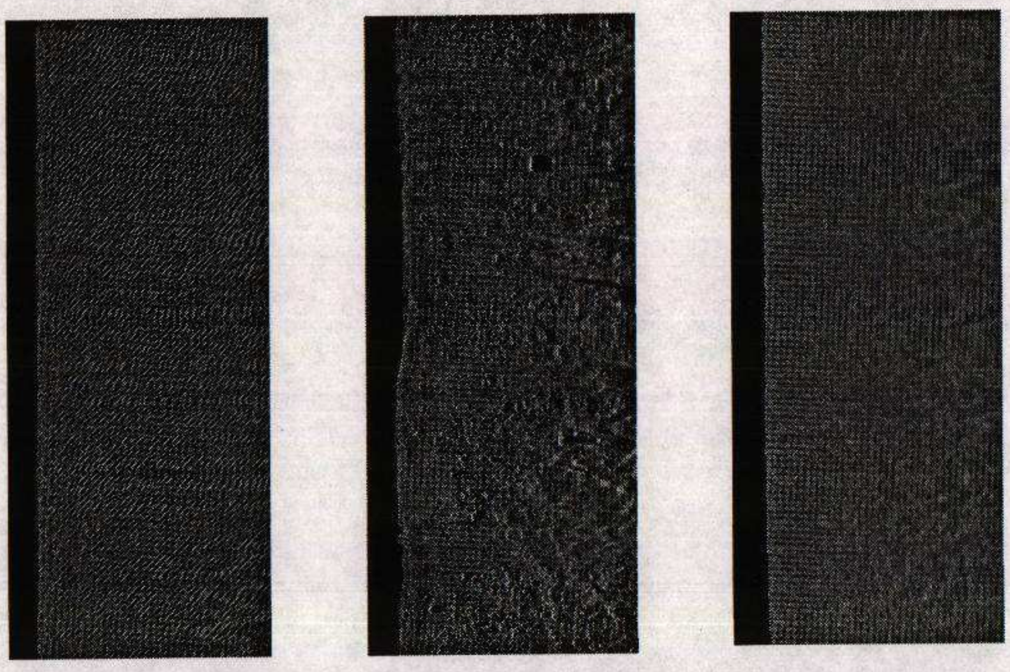


Fig 6 Homogeneous regions after shade correction by histogram transformation: a) sand ripples b) rocks c) mud

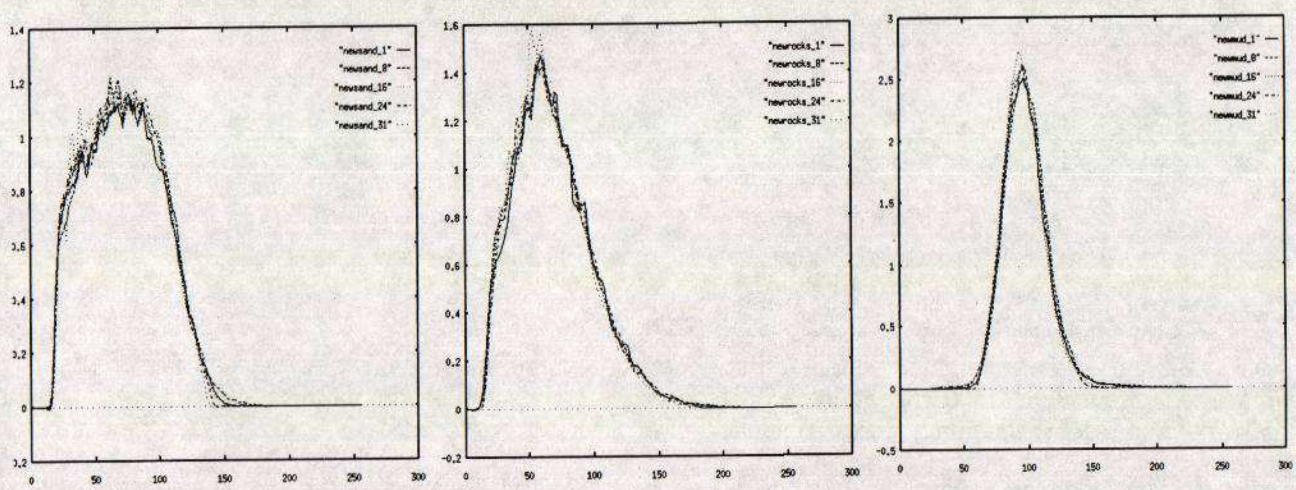


Fig 7 Sample histograms 1,8,16,24,31 from shade-corrected records a) sand b) rocks c) mud

One significant problem is to separate out dependency on elevation angle from dependency on range, since there is generally not enough statistical data to make good estimates. Hence the following heuristic procedure is used. It is assumed that at short range intensity mainly varies with elevation angle. In the first step, histograms are collected as a function of $\cos\Phi$, and the intensity is corrected out to $\Phi = 60^{\circ}$. In the second step, histograms are collected as a function of slant range, and the intensity is corrected over the full range of the image. This pair of operations can be iterated as required. The procedure could undoubtedly be simplified if some calibration information was available such as applied TVG, or elevation beam pattern.

3. A SEGMENTATION EXPERIMENT

An experiment was carried out together with Heriot-Watt University using a fractal-based sonar segmentation program [6]. Fig 2a was segmented into four classes, which might again be called "rocks","sand", and "mud", plus the water column as a fourth class. Segmentation is carried out with a Bayesian classifier using features derived from manually-defined training areas. Fig 8a shows the result of segmenting the original image, Fig 2a, while Fig 8b was obtained by segmenting the shade-corrected image, Fig 2b. The same training areas in the mid-range area were used in both cases.

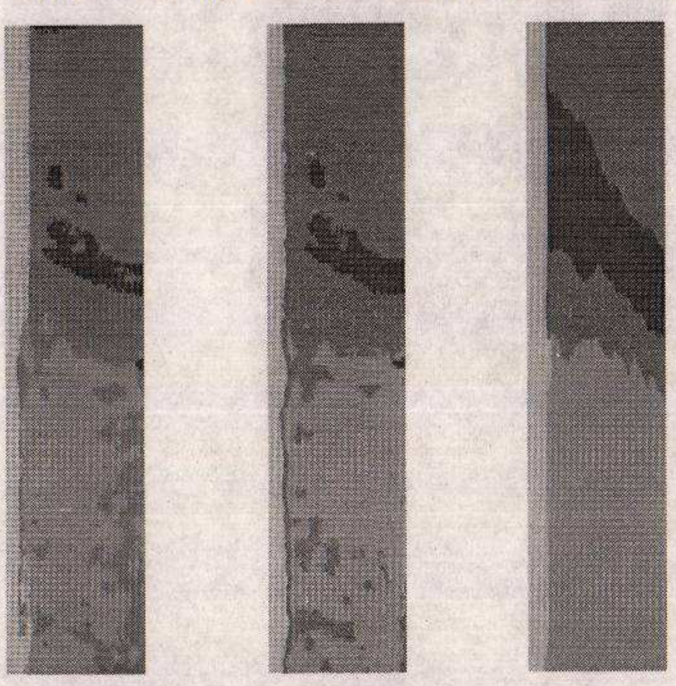
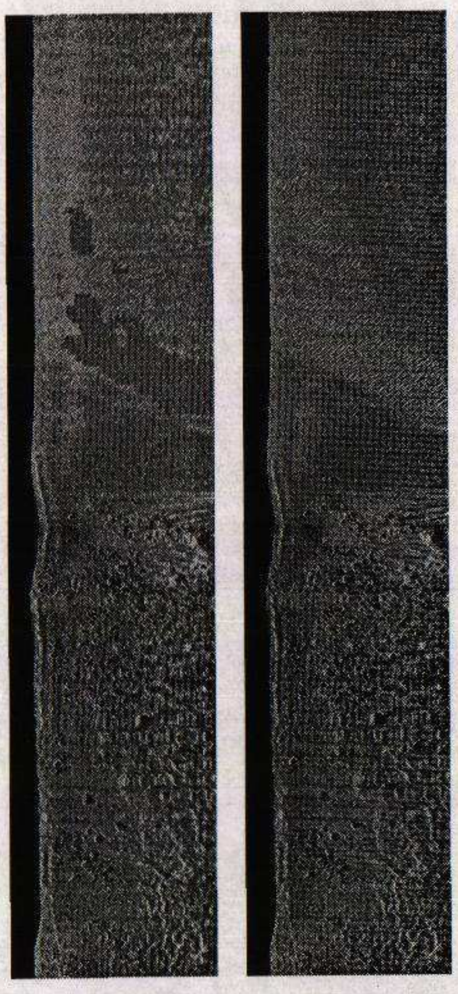


Fig 8 segmentations of (Fig 2) a) fractal segmentation of uncorrected record (in Fig 2a)

b) fractal segmentation of shade-corrected record (in Fig. 2b) c) Manual segmentation

As expected, there is little difference between the two segmentations at medium range. At short range, there is confusion between the mud and water classes in Fig 8a, but not in Fig 8b. At long range, the segmentation in Fig 8a. becomes fragmented, whereas the segmentation in Fig 8b remains consistent. Fig 8c shows a manual segmentation of Fig 2a, and there is no doubt that the segmentation of the shade-corrected image is superior to the segmentation of the raw image.

The segmented image can be used as a context for selective shade correction in the following way. Histograms are collected from the record as a function of cosΦ and range according to segmentation class. A reference histogram is then selected for each class, and look-up tables also computed by segmentation class. In the image transformation, look-up table is selected according to the class of the pixel in the context image. This procedure was carried out on Fig 2a using both the fractal segmentation Fig 8b, and the manual segmentation, Fig 8c as context. Figs 9a, b show the results. Although the result using the fractal classification is generally good, artefacts due to occasional misclassification are apparent.



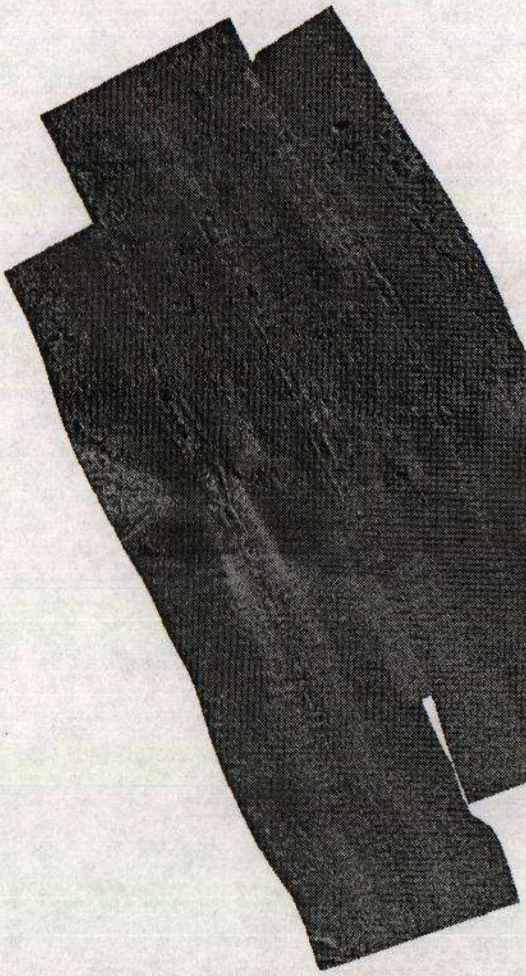


Fig 9 Shade correction of (Fig 2a) by selective histogram transformation using a) (Fig 8b) and b) (Fig 8c)
Fig 10 Sidescan mosaic (Fig 1) after shade correction by histogram transformation.

4. MOSAICCING EXPERIMENTS

Mosaiccing of the three adjacent survey lines shown in Fig 1 was carried out using the Chalmers GISMO software. The shade-correction procedure for a mosaic is identical with the procedure for an individual record, except that a common reference histogram, or set of reference histograms, is used to compute the look-up tables for each record. This has the advantage of equalizing shading over the whole mosaic, and reducing shade discontinuities at the boundaries between records. If required, contrast stretching can be carried out at the same time, simply by contrast stretching the reference histogram(s). Fig 10 shows a mosaic corresponding to Fig 1 after shade-correction independent of seabed type

5 DISCUSSION

5.1 Backscatter Statistics.

Results given here show that the shape of the backsctter PDF can vary considerably over the whole range of grazing angles from nadir to near horizontal. Variation with grazing angle appears to be greater for coarse than for finer sediments because of the greater shadow content at shallow grazing angles. Since the contrast between trailing and facing slopes depends on bottom topography, it would require systematic investigation to determine the likely extent of variation for different seabed sediments. However on the evidence, experimental results concerning variation of mean backscatter with grazing angle and sediment type need to be examined carefully for effects of bottom topography.

5.2 Sediment Classification from Sidescan Data.

Many proposed techniques depend implicitly on stationary statistics across a large part of the record. The shade correction technique proposed here should go some way towards reducing the dependance of the statistics on range and grazing angle. Intrinsic PDF information which could be used for classification is not destroyed, as it would be using a histogram equalization procedure [7]. This claim was verified to a limited extent with the Heriot-Watt fractal segmentation technique, and it would be interesting to investigate the effect with other classification features such as Pace and Gao power spectra [3].

5.3 Shade Correction.

The shade correction technique presented here not only improves the appearance of mosaics, but potentially extends the useful area of individual survey records. Two methods have been presented, the first one using histogram statistics derived from each record as a whole, and the second after each record has been segmented into homogeneous regions. The simpler method appears to give good results, and the risk of introducing artefacts is small. Further improvement can be obtained if the record can be successfully egmented into homogeneous regions and the shade-correction procedure repeated. Unfortunately misclassification between different classes introduces disturbing artefacts, so the technique must be used with caution.

It should be stressed that the given method depends on good correlation between slant range and grazing angle, which in turn depends on flying the towfish at a constant height over a fairly flat seabed.

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