ANALYSIS OF HIGH RESOLUTION SIDESCAN-SONAR: APPLICATIONS TO SEA FLOOR MAPPING AND RESOURCE EVALUATION

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1. INTRODUCTION

Remote sensing technologies provide a unique view of an area, and powerful analysis capabilities. Remote sensing of the sea floor using sidescan-sonar permits a systematic mapping of large areas of the sea floor; the entire deep water portion of the Exclusive Economic Zone of the United States has been imaged using sidescan-sonar [1]. Sidescan-sonar is most often used: (1) to create a map view of an area to guide an investigation for sampling, deploying current meters, or deep submersible dives, and (2) to qualitatively asses the geologic processes active in that area. In order to use the sidescan-sonar image for quantitative geologic analysis, the factors that control the level of acoustic backscatter need to be defined.

Sidescan-sonar imagery is a graphical representation of how sound interacts with the sea floor. The vast majority of backscattered sound received by a sidescan-sonar transducer is diffracted from the sea floor rather than directly reflected [2]. Accepted theory states that backscatter is a function of sea floor topography, surface roughness, sediment induration, frequency of the sonar, angle of incidence of the sound wave front, and acoustic impedance contrast between the water and the sea floor [3]. Few quantitative studies have been undertaken to test these theories due to the difficulty in acquiring the necessary geologic data to "ground-truth" the sonar data. Contemporary digital data acquisition, computerized image processing techniques, and improved navigational accuracy allow a more quantitative analysis of the causes of relative backscatter intensity than has been possible in the past; the limiting factor is the non-quantitative nature of sidescan-sonar systems presently in use.

Geophysical and geologic data were collected over a segment of the northern insular shelf of Puerto Rico to assess what properties of the sea floor control backscatter intensity variations over a relatively flat, sediment covered area of sea floor. Statistical parameters derived from the sidescan-sonar data and the associated sediment samples were used to link the imagery to the sea floor geology.

2. METHODOLOGY

2.1 Field Data Collection

As part of a systematic sea floor mapping program [4] of the insular shelf off Luquillo, Puerto Rico (Fig. 1), marine geologic surveys were conducted in April/May 1991 aboard the research vessel JEAN A. Data were collected using a 100 kHz Klein sidescan-sonar system, 3.5 kHz and Huntec Sea Otter Boomer seismic-reflection profilers, and a Shipek sediment grab sampler. Additional sediment

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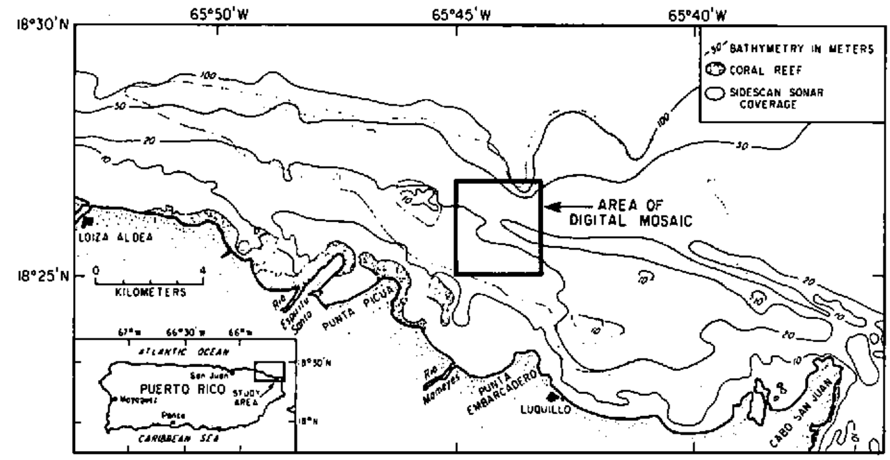

Fig. 1: Map showing location of survey area over the insular shelf off Luquillo, Puerto Rico. "Area of digital mosaic" is the portion of data used in this study (Fig. 2).

samples were collected in June 1992 using a Van Veen grab sampler aboard the R. V. BORIKEN.

The Klein sidescan-sonar system was used to obtain data at a rate of 7.5 pings per second which yielded a total swath width of 200 m per trackline. These data were logged digitally using a QMIPS data acquisition system [5] with a sampling scheme that resulted in a 0.1 m pixel size in the across-track direction. The seismic data were collected in analog form; trackline bathymetry was digitized from the seismic records.

During the 1991 cruise, ship navigation was conducted using a shore-based Miniranger Falcon IV transponder navigation system which resulted in a location accuracy of ±5 m for the ship tracklines, subbottom profiles, and sediment samples. The sidescan-sonar vehicle was towed behind the ship and was not navigated independently. This induced an additional maximum error of approximately 15 m in the sonar imagery location. Navigation on the 1992 sampling cruise was conducted using an Ashtec portable GPS unit with an accuracy of ±100 m.

2.2 Image Processing
The sidescan data were initially processed following the methodology of Danforth and others [5]. This suite of software compressed the data to a 0.4 m per pixel size, corrected for geometric distortions, radiometrically enhanced the data, and merged the sonar and navigation data files. The resulting sonographs were output to a thermal printer for hard copy. These analog images were used to create a "field" mosaic of the study area which, in turn, was used to guide the sediment sampling strategy.

A portion of the sidescan-sonar data from the 1991 survey was selected to create a

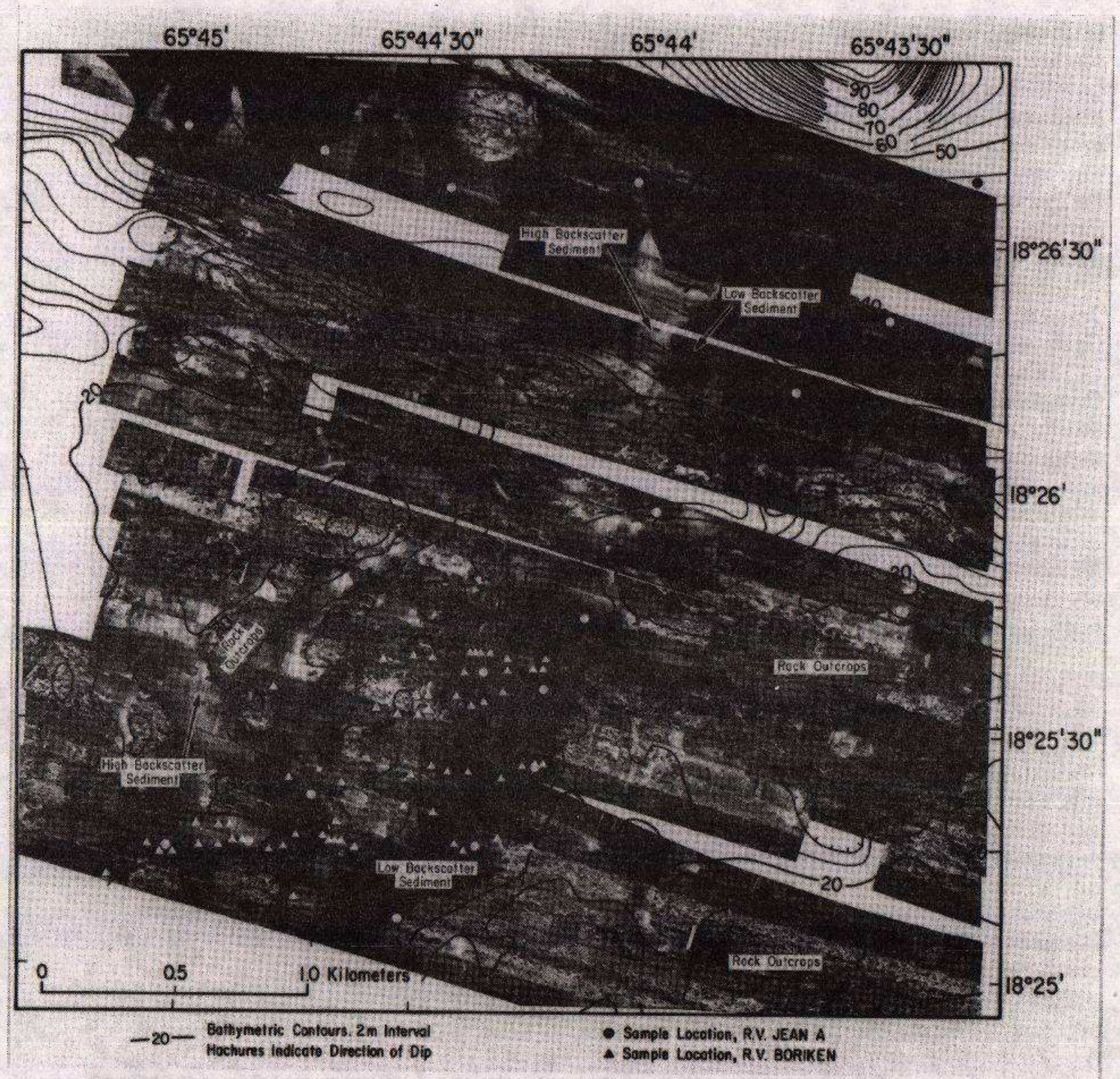

Fig. 2: Digitally processed and enhanced sidescan-sonar mosaic of a portion of the insular shelf off Luquillo showing bathymetry and sample locations.

composite digital mosaic (Fig. 2). This area was chosen due to its manageable size (13 km^2), because it contained a broad range of backscatter intensities which were representative of the entire survey area, and because sediment samples were located in many different backscatter regimes.

This subset of the sidescan data was further processed and digitally mosaicked using procedures developed by Chavez [6] and EEZ-SCAN Scientific Staff [7]. To allow analytic comparison between adjacent swaths of sidescan data, tone matching was critical. In tone matching, a histogram of the range of backscatter intensities for each swath of sidescan data was normalized to a designated "master" swath, thus equilibrating all swaths. The master swath was selected because it was most representative of the acoustic backscatter spectrum in the study area. Once tone matching had been completed, the swaths of imagery could be mosaicked together. This resultant composite digital image was then registered to the bathymetric contours to correct for any spatial distortion induced by the mosaicking process. In the final image (Fig. 2), low backscatter is dark, high backscatter is light, and pixel size has been further compressed to 1 m.

2.3 Laboratory Data Collection

Grain size analysis of the samples was conducted using a combination of wet sieve and Coulter Counter following the methodology of Poppe and others [8]. Compositional analysis was conducted through microscopic point counts of the sediment coarse fraction. Analysis of calcium carbonate content was conducted using methods described by Rodriguez and Trias [9].

Statistical parameters of the sidescan image were collected from the digital mosaic in 5 x 5, 11 x 11, and 21 x 21 m areas, centered around each 1991 sediment sample location. The 5 m digital "sample size" was suggested due to the navigational accuracy of the sediment sample locations ($\pm$ 5 m). The larger sample areas were suggested because of the possible 15 m error in image location.

3. ANALYSIS

Statistical parameters of digital number values (DN) in varied acoustic backscatter regimes were analytically compared with a suite of textural, compositional and geochemical properties of the associated sediment samples. The statistical parameters of the sonar data used in the analyses were: the mean, standard deviation, and skewness of the DN values in the sampled area. The sedimentologic variables used in the analyses were: the mean, median, standard deviation, skewness, and kurtosis of the sediment grain size distribution; mathematical combinations of the above; cumulative percentiles of single phi units; percent gravel, sand, silt, clay; percent calcium carbonate content; percent corraline algae, *Halimeda*, *Echinodermata*, coral fragments, *Porifera*, *Molluska*, *Gorgonia*, *Annelida*, *Bryozoa*, *Foraminifera*, unknown skeletal fragment, ooids, aggregates, peloids, quartz, feldspar, rock fragment, and unknown terrigenous fragments. Variables not used in the analyses included: sea floor topography and induration, because the data analyzed covered a relatively flat, sediment covered area; and subbottom penetration, because the high frequency signal used would not penetrate the sea floor surface.

A comparative graphical analysis of all variables yielded poor correlations throughout. The exponential relationship found between mean grain size and mean DN value had a poor correlation (R^2 = 0.37) when using the exact location of the sediment samples on the digital data. However, this relationship was pursued because a good correlation was observed in the field. The poor correlation found using the digitally mosaicked data was attributed to (1) the possible 15 m

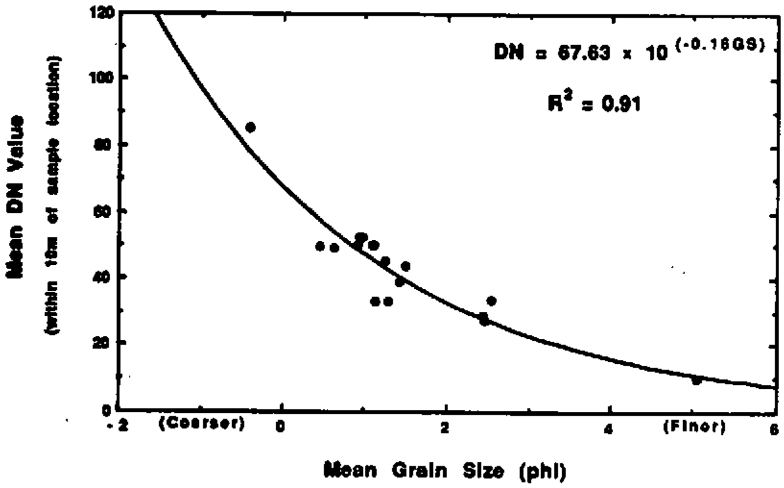

Fig. 3: Relation between relative acoustic backscatter intensity (DN) and sediment mean grain size (GS) using samples collected in 1991. R^2 is the correlation coefficient. 5 x 5 m digital sample size used.

navigational error in imagery location; and (2) limitations in image quality: some sediment sample locations plot on the nadir of the sonograph, an area of no data directly below the vehicle; some plot on stencil seams of the digital mosaic, an area of dubious data quality; and some plot in areas of low signal-to-noise ratio (far range of the swath). Eliminating the poor-quality digital data points (41%) from the analysis, reduced the range of the corresponding sedimentologic data such that no fine or coarse samples remained, only a cluster of sands. This did not improve the correlation.

In an attempt to preserve the data spread, DN sample locations of the poor quality digital data points were modified. If the geology appeared uniform in the area local to the sample site, the 5 m DN boxcar was moved a maximum of 10 m from the correlative sediment sample location into areas of valid data. This manipulation of the data was acceptable due to the ±15 m image location error. Moving the DN sample locations into proximal areas of better digital data quality improved the correlation coefficient between the mean grain size and mean DN to 0.91 (Fig. 3). This improved correlation is expressed by:

$$DN=67.63 \times 10^{(-0.16GS)}$$

where DN is the relative backscatter intensity and GS is the mean grain size in phi-units. Note that the exponential relationship suggests that the DN values for finer grained sediments are less sensitive to changes in mean grain size than are those of coarser grained sediments (Fig. 3). The same analysis was performed using larger DN samples (11 x 11 m and 21 x 21 m), producing similar results. However, the correlation coefficients were lower than that found on Figure 3.

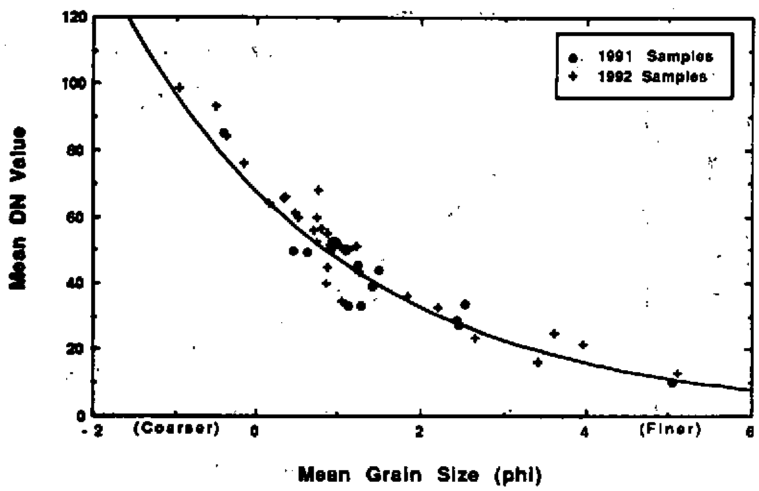

Fig. 4: Relation between relative acoustic backscatter intensity (DN) and mean grain size shown in figure 3, with samples collected in 1992 overlaid.

Although the Klein sidescan-sonar is a qualitative system, and navigational uncertainties exist, a strong correlation was found between the image and sedimentologic data. To test this relationship, additional sediment samples were collected in 1992, and analyzed using the same justifications as the 1991 data. Despite potential changes in the sediment distribution over the preceding year, and the reduced navigational accuracy, these additional data reinforced the validity of the original correlation: grain size is the dominant factor controlling relative backscatter intensity with the 100-kHz sidescan-sonar system in the study area (Fig. 4).

4. APPLICATIONS

Applications of the image analysis technique used in this study include sea-floor mapping and resource evaluation. This methodology enables the creation of sediment texture distribution maps which can be used to locate and evaluate natural resource potential. The spatial distribution of sedimentary facies can be mapped in much greater detail by adding sidescan-sonar data collection to conventional sampling schemes.

The correlation found between mean grain size and mean DN value (Figs. 3 and 4) can be used to false-color enhance the sidescan image in order to present the acoustic and grain-size data together in a single image. The resultant image reveals textural sedimentologic distributions of the sea floor. While rock outcrops are affected by the color enhancement, the ability to interpret the false-color image applies only to the flat, sediment covered areas analyzed in this study. Other techniques will need to be developed to characterize the areas of rock outcrop. A low-pass smoothing filter reduces the DN variance within a digital sidescan mosaic. Application of such a filter (31 x 31 pixel moving boxcar) to the digital mosaic prior to false-color enhancement reduces noise and converts the highly detailed nature of the imagery to more general trends, enabling improved interpretation of the large-scale sediment distribution.

False-color enhanced sidescan mosaics can be used to delineate the location of the desired size of sediment, and the associated subbottom profiles can be used to measure the thickness of the sediment deposit. Offshore mineral resources, especially sand, gravel, and limestone, are of major importance to island nations due to their limited and often depleted onshore sources for construction materials and beach replenishment. This analysis and enhancement methodology can be extremely useful to island nations which need to utilize their offshore resources.

5. ACKNOWLEDGMENTS

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