A proposal for quantitative analysis of SeaMARC data

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A. Introduction

In the brief time since their inception, side-scan sonar devices like SeaMARC I and SeaMARC II have proved to be tremendously successful for imaging the ocean floor. Thus far, attention has been focused on the assessment of image greytone variations as a means of revealing and qualitatively describing a variety of submarine volcanic, tectonic and sedimentary features. A number of important characteristics of the SeaMARC acoustic images, however, strongly suggest that a quantitative analytical approach, employing statistical and digital image analysis techniques should be considered as well. Some of the pertinent characteristics of the SeaMARC data are listed below:

(1) The data collected by the SeaMARC systems are fully digital and have 8-bit (256 interval) dynamic range. This is 16 times greater than a Versatec plotter can resolve (16 greytones) and approximately 10 times better than the human eye can differentiate in a continuous tone image (~25 grey levels).

(2) The high spatial resolution, of the order of 10 m, allows oversampling of many surface units and features. A statistically significant number of samples can be acquired on a single ship-track for features with an along-track extent of the order of 100 m. Smaller features can be analysed by SeaMARC I or by multiple passes of SeaMARC II.

(3) The SeaMARC systems collect acoustic backscatter information over a broad range of incidence angles. This, coupled with the high across-track resolution, would allow the backscatter properties of various surfaces to be well-constrained.

(4) These acoustic data share many fundamental characteristics with other remotely acquired data, such as photography and radar images for which quantitative approaches have been developed. Photometry and radar scatterometry are primarily concerned with reconstructing such surface characteristics as texture (roughness) and attitude (local slope) from information obtained about how the surface reflects and scatters light as a function of incidence angle. As the theoretical basis for these methodologies is Fresnel's Reflection Coefficient, much of this work is also applicable to acoustic backscatter data.

(5) SeaMARC II collects bathymetry data and backscatter data simultaneously, thus providing two digitally registered independent (1 time delay, 1 normalized amplitude) data sets. These data sets, and others which can be derived from them, allow multivariate and discriminant analysis techniques to be employed to define a set of characteristics to assist in describing and automatically classifying geologically important surface units.

The sections that follow describe two projects which take advantage of these characteristics. In the first project SeaMARC data are examined for quantitative information on local slope variations and surface roughness characteristics. The second project combines these results with other information obtainable from SeaMARC and Seabeam data (e.g. local and regional bathymetry, local and regional slope, small scale roughness and topographic roughness) to establish criteria for distinguishing and geologically interpreting ocean floor surfaces and related features.

B. Backscatter properties of ocean floor surfaces.

Background The greytone variations within a SeaMARC II image are essentially recording variations in normalized backscatter. These variations are functions of the effective incidence angle, θ_e, surface roughness and acoustic impedence, $V\rho_2$. Effective incidence angle is, in turn, a function of the local across-track angle of the acoustic propagation vector, i.e. the local angle of acoustic impingement, θ determined by the instrument altitude and the across-track distance of the reflector within a swath, and the local slope of the reflecting surface. Thus, for a homogenous unit at the pixel scale, over which $V\rho_2$ does not vary significantly, information about surface roughness and local slope are contained in the backscatter data. Here, surface roughness corresponds to local undulations on the order of an acoustic wavelength (~10 cm). Local slope is equivalent to the weighted average surface tilt measured over a pixel-sized region. It is important to note that for side-looking instruments, local slope contains an across-track directional bias with no information gained for slopes with an along-track orientation.

Effective backscatter coefficient Several empirical and theoretical techniques have been used to separate the textural and slope information contained within remotely acquired backscatter data. The SeaMARC II images appear ideal for an analysis of the effective backscatter spectrum, $\sigma°(\theta)$. Calculating $\sigma°(\theta)$ from SeaMARC II brightness values involves range-dependent normalization to account for the fact that far-range surfaces receive a narrower 'slice' of the acoustic wavefront than do near-range surfaces. Other range effects such as attenuation have been removed automatically by SeaMARC II electronics. SeaMARC II data characteristics allow $\sigma°(\theta)$ to be constrained for a wide range of θ (~0° to ~80°).

Numerous analyses of radar imagery have shown that the shape of the $\sigma°$ vs θ curves for units with differing roughness and slope properties are distinct. Futhermore, the curves consist of different angular regions in which the scattering process varies. The near-vertical incidence region is the quasi-specular region, where for smooth surfaces $\sigma°$ can be quite large. Scattering in this region, where θ is between 0° and 30°, is dominated by specular reflection from surface facets oriented normally to the direction of incident radiation. For mid-range angles ($\theta \sim 30$ to $\sim 60°$), the typical curve is characterized by a "plateau" or diffuse region, which slowly decreases with angle. This region is dominated by small-scale roughness or Bragg scattering. From 60° upwards, roughness is still dominant but the effect of shadows due to macro-relief becomes increasingly important, thus causing a sharp fall off in $\sigma°$ toward 90°. Thus for each surface unit, for which $\sigma°(\theta)$ can be sufficiently well constrained, relative roughness and local slope information can be inferred. If, in addition, a reference unit can be established for which $\sigma°(\theta)$ is constrained and surface properties are well constrained by ancillary data (photography, samples, etc) absolute roughness and slope information can be inferred for other surface units.

<u>Technique</u> Determination of local slope and roughness information from SeaMARC II backscatter data can be obtained as follows:

(1) Locate and define lithological units on the basis of image data. Image enhancement techniques can be used to search for and delineate unit boundaries.

(2) Normalize backscatter data to account for range effects discussed above.

(3) Calculate and plot $\sigma°(\theta)$ for each unit using total unit sample population, determine best-fit curved for each unit.

(4) Relative roughness can be ascertained from analysis of the diffuse region of $\sigma°(\theta)$.

(5) The magnitude of the distance from the unit curve of an individual pixel may be indicative of the local slope of that surface element, i.e., between 30° and 60°, pixels with higher than average $\sigma°$ can be inferred to be oriented toward the receiver. By projecting the magnitude to the left so as to intersect the curve, θ_e and the local slope can be deduced.

(6) Following this routine, assign roughness values and local slope variation characteristics to all applicable units.

(7) Compare and interpret units using a reference area, with ancillary available data.

Data requirements and research cruise considerations To successfully extract quantitative slope and roughness information from SeaMARC II data requires precise monitoring of such instrument parameters as tow speed, altitude and gain. A more complete understanding of the backscatter data could be gained by establishing a test area in the region covered by the research cruise this August. This area should have as many of the following characteristics as possible:

(1) should be several swath widths in lateral extent

(2) should sample several bottom units (based on distinct brightness variations)

(3) should contain variations in macro-relief and regional slope

(4) should include dredge samples, cores, bottom photography and other data sets to constrain bottom unit geology.

Within this test area, the seafloor could be sampled at a range of tow speeds, altitudes and gain levels. The effects of these changes on σ° could then be assessed. The effects of regional slope on the backscatter curves could also be examined and methods to remove these effects could be developed. Ship tracks should be closely-spaced so as to provide tightly overlapping data swaths. In this way, reflectors could be sampled at various slant ranges to construct model σ° vs. θ curves and seafloor anisotropy could be studied by varying the tow direction. Information gleaned from this test area would be fundamental to understanding the data collected during other parts of the cruise as well as the data previously collected in the Juan de Fuca Ridge region.

C. Ocean floor characterization and unit classification

Characterization of surface features and discrimination of units are first order mapping objectives. Unit definition and classification, when combined with ground truth, can assist in the interpretation of the mapped region. Mapping with SeaMARC acoustic images, however, is faced with two fundamental problems: The first is that little ground truth (dredge and core samples, photographs, etc) exists, thus, units must be precisely defined on the basis of acoustic properties. Second, the mapping scheme must result in geologically meaningful units based, for example, on lithology, porosity or age rather than other variations introduced by depth changes or regional slope variations. Quantitative unit definition can be enhanced by establishing a set of numerical values, each of which translates into an independent surface attribute for every unit subsection. For SeaMARC II backscatter data, these could include average backscatter, surface roughness, roughness variability within each subsection and local slope variability within each subsection. Larger textural variations can be quantified by spatial filtering techniques. SeaMARC II bathymetry would also add larger-scale information: local relief, regional slope, concavity, topographic roughness and anisotropy. Including Seabeam data would allow the list of parameters to be extended to even larger scales to differentiate regional features with distinct topographic expression.

Given such a set of parameters for each unit subsection, several classification schemes may be implemented. A straight forward approach would be to determine the parameter values for those known units in the test area, establish which parameters are the most sensitive unit indicators and use these values to map units in other areas. This approach only results in differentiation of those units for which ground truth exists, either within the test area or elsewhere. Nonetheless, it is extremely important to locate all surfaces with similar characteristics to those which have been sampled.

Multivariate techniques can be employed to differentiate unsampled units. Principal component analysis can produce a subset of basis vectors which are sensitive to unit variations. These basis vectors can be correlated, and statistical units developed by clustering techniques. The unit parameters can be "tuned" for geological relevance by applying the method to test area data. When this process is complete, mapped surfaces can be automatically classified. Sampled units can then be interpreted and differentiated unsampled units targeted for future sampling.