Statistical Characterization of Bathymetry and Stratigraphy on Continental Margins

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LONG-TERM GOAL

- Enable realistic interpolation of sparsely sampled bathymetric and stratigraphic data for use by the Navy in acoustic modeling.

OBJECTIVES

- Formulate statistical models of shelf and slope bathymetric roughness and for stratigraphic architecture.
- Develop methodology for interpolation of sparsely sampled bathymetric and stratigraphic data.

APPROACH

A "realistic" interpolation or extrapolation of bathymetry, i.e., one that honors both the statistical character and the deterministic constraints of the data, is referred to as a "conditional simulation." The first step in generating a conditional simulation is derivation of a statistical model for bathymetry. We typically employ the anisotropic von Kármán model (Goff and Jordan, 1988), which has proven appropriate for a wide variety of geophysical fields. However, refinements of this model have occasionally proven necessary in the shelf setting, including the shelf northern California shelf morphology (Goff et al., in press). In such cases, a superposition of two models (e.g., a Gaussian covariance at larger scales, and a von Kármán model at smaller scales) is usually satisfactory. Once an appropriate statistical model has been selected, a conditional simulation can is generated typically either Fourier simulation or sequential Gaussian simulation.

A conditional simulation of 3-D stratigraphic geometry requires several steps. First, stratigraphic horizons are derived from seismic reflection data. A statistical model is then derived for each stratigraphic horizon to be simulated, and the coherency function is derived for adjacent horizons. In situations where the seafloor is conformable with underlying strata, bathymetry can provide a strong constraint on stratal architecture through the coherency criteria. Successive strata can then be generated via a multi-staged procedure which conforms both to the both the statistical constraints and to any hard constraints such as seismic reflection or coring data.

The algorithm developed for generating a conditional simulation of stratigraphic architecture, dubbed "SimStrat", is shown schematically in Figure 1. Before simulation begins, several pre-processing steps are necessary: (1) a statistical model is obtained for bathymetry and the stratigraphic horizons which are to be simulated; (2) the coherence function is estimated for all adjacent horizons which are to be

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simulated; and (3) because it will serve as the basis for subsequent simulations, a "bathymetric model" must be generated - essentially a conditional simulation of bathymetry intended to remove artifacts and bridge data gaps, yet retain as much of the deterministic bathymetry as possible while adhering to the statistical model at all scales.

Simulation of the stratal architecture then proceeds from top to bottom, in each case using the nearest overlying horizon as a coherency condition, starting with the bathymetry model. First, however, we use a conditional simulation algorithm to expand and taper the overlying horizon in order to minimize edge effects, which can be severe for smoothly varying surfaces. An unconditional simulation is then generated which matches the coherency criteria (e.g., Gutjahr et al., 1997). This field is then conditioned to available hard constraints, both seismic and coring, using a differencing algorithm (e.g., Goff and Jennings, 1998). This simulated horizon then serves as the coherency condition for the simulation of the next stratal horizon in the sequence.

SimStrat Flow Chart

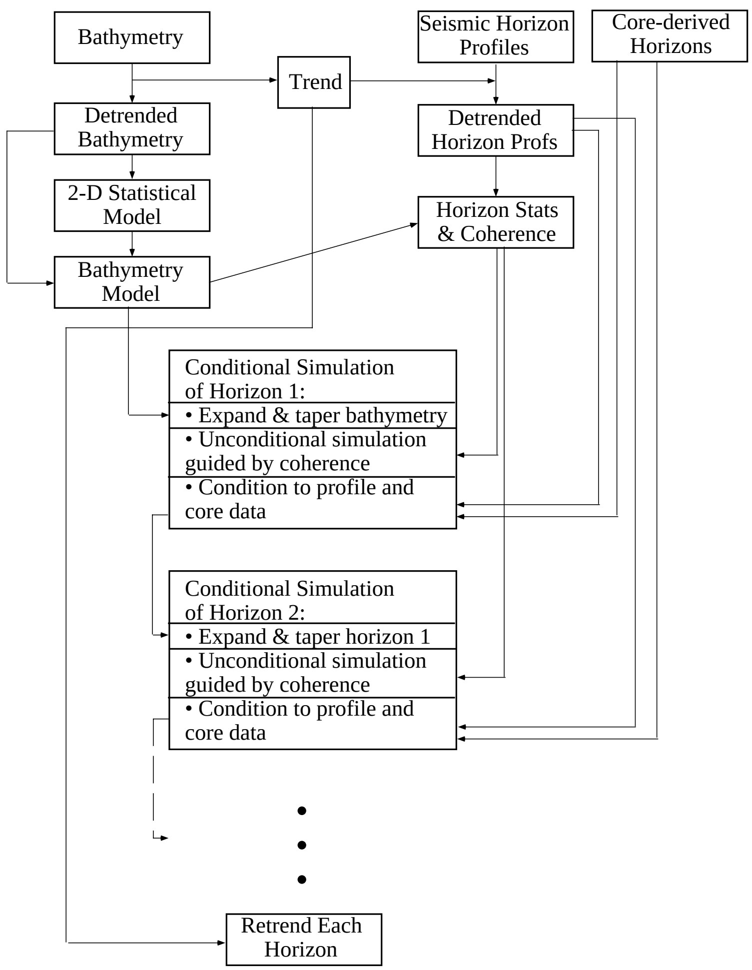

Figure 1. Schematic flow chart for SimStrat algorithm to generate a conditional simulation of stratigraphic architecture, based on inputs from bathymetry, interpreted seismic reflection horizons, and core-derived horizons.

WORK COMPLETED

Structural interpretation and statistical analysis of the northern California and New Jersey margin swath mapping surveys were covered in the PI's 1995 and 1996 progress reports. Preliminary results from the northern California survey were presented in Goff et al. (1997), and a more thorough analysis of the northern California shelf morphology is presented in Goff et al. (in press). Results from the New Jersey shelf survey are presented in Goff et al. (submitted.).

In collaboration with Dr. J. Jennings at the University of Texas Bureau of Economic Geology, a study has been completed which optimizes the Fourier methods of unconditional and conditional simulations (Goff and Jennings, in press). This study was described in the PI's 1997 progress report. Computer code has been developed for generating Fourier conditional simulations of two dimensional fields with arbitrary conditioning criteria, using and combination of anisotropic Gaussian and von Kármán model as a basis. This code is available for distribution from the PI.

The past year has seen two significant accomplishments, the results of which are described below. First, a working SimStrat algorithm has been completed both for two- and three dimensions. A manuscript describing SimStrat is the topic of a manuscript in preparation for the upcoming STRATAFORM modeling special issue of *Computers & Geoscience*. Second, in collaboration with Dr. N. Driscoll of Woods Hole Oceanographic Institution, an analysis of the statistical character of canyon systems on the US Atlantic continental slope was completed. This work was the subject of a presentation at the 1997 Fall AGU meeting (Goff and Driscoll, 1997), and is the topic of a manuscript in preparation.

RESULTS

***SimStrat*.** An example of a two dimensional output from the SimStrat algorithm is presented in Fig. 2. Prior running SimStrat, a simulated stratigraphic architecture was created under an assumed Gaussian covariance and power law coherence, where larger scales are strongly coherent and smaller scales are poorly coherent between adjacent horizons. This unconditional stratigraphic simulation served as "reality" for the subsequent conditional simulation: here we sampled 5 locations at each horizon (representing, for example, either a core or a seismic line crossing this profile line), and generated a conditional simulation constrained by those values as well as the known statistical character and coherency criteria. The conditional simulation deviates, as expected, from the "true" stratal architecture where not constrained by the conditions. However, the coherency criteria have helped to reproduce some of the larger-scale character even where no conditions exist - especially the larger hump between ~10 and 30 on the x-axis. Without the coherency criteria, that information would be lost at the first horizon below the seafloor.

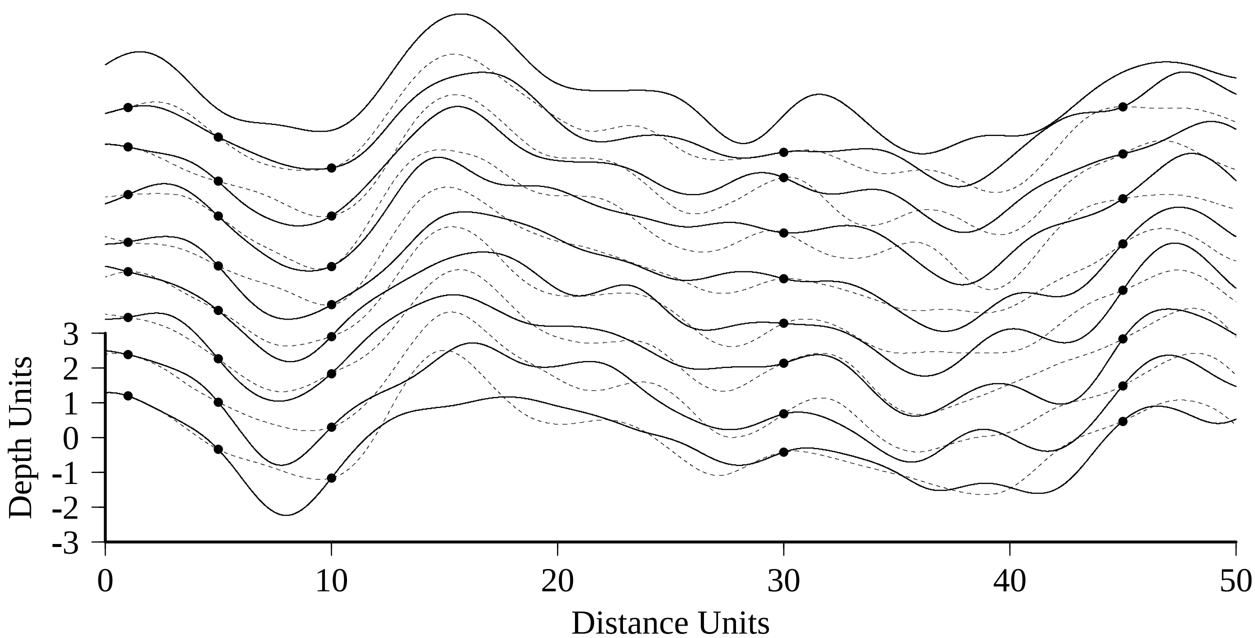

Figure 2. Example of SimStrat algorithm output for 2-D. Top profile and dashed represent an "unconditional" coherent simulation which served as reality for the SimStrat run. Five conditions, represented by dots, were sampled from each horizon. The conditional simulation horizons, based on these conditioning values, the known statistical character of each horizon and adjacent-horizon coherency criteria, are shown as solid curves.

*Canyon Morphology***.** Our hypothesis for slope failure on the US Atlantic margin purports that there are two dominant modes of failure: (1) smaller-scale failures that form canyons or occur within and are channeled by existing canyons systems and (2) larger-scale, catastrophic failures that undermine several canyon systems and effectively erase the pre-existing canyon morphology. This hypothesis predicts that the morphology of the associated slide deposits should also vary as a function of failure mode. That is, funneled, coalescing slide deposits reflect failures that form canyons or occur within canyon systems and their downslope morphology is affected by the evolving/pre-existing canyon relief. Conversely, large blocky slide deposits are caused by large slope failures that undermine several canyon systems. Furthermore, this hypothesis predicts that different portions of the US Atlantic continental slope will be in different stages of canyon evolution. Our hypothesis predicts that canyons in regions which have not experienced large-scale failure for long periods will have larger relief and width, lower average slopes, and greater shelf/slope break indentation. To investigate the morphology of these canyon systems more rigorously, we have estimated statistical properties of slope parallel profiles, progressing from the shelf/slope break to well past the slope/rise transition (Figure 3; Goff and Driscoll, 1997).

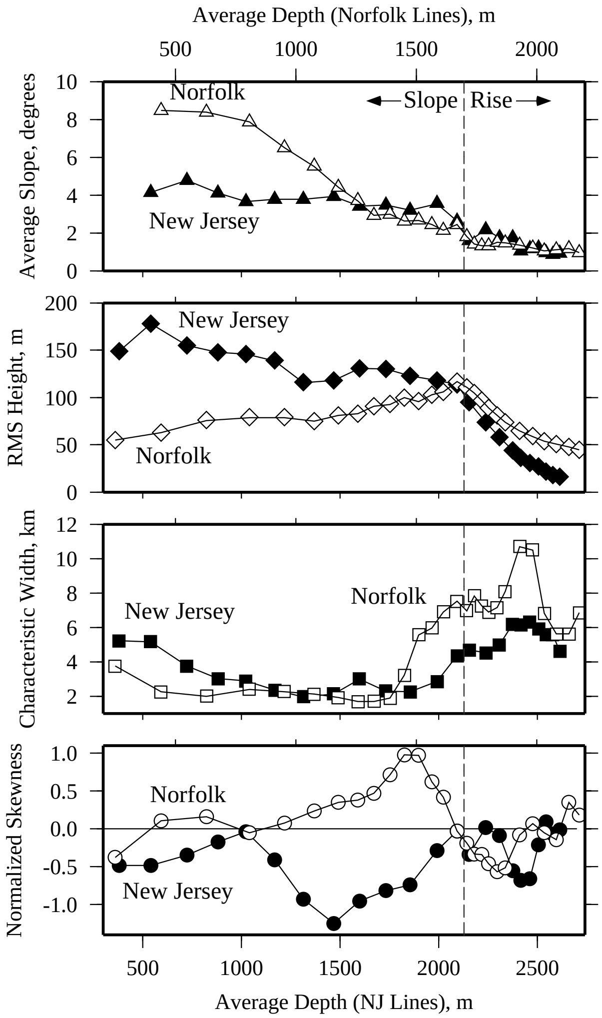

Figure 3. Downslope profile statistics of the New Jersey and Norfolk canyon systems. Parameter estimation follows the method of Goff and Jordan (1988) and Goff (1995). Parameters include:

• Average slope was computed by taking the tan-1 of the difference in mean depth over adjacent profiles divided by profile spacing.

• RMS height, the square root of the variance, measures average variability about the mean value. Peak-to-peak variations are typically ~twice the rms.

• Characteristic width, measured by the width of the profile autocorrelation function, measures the average width of main features (i.e., canyons).

• Normalized skewness measures the vertical asymmetry of the profile. Skewness can provide information on canyon spacing. For example, if canyons are closely spaced, i.e., on the order of their widths, then profile skewness will be close to zero, whereas if canyons are widely spaced with little

The canyon system on the New Jersey margin south of the Hudson Apron has larger rms heights and characteristic widths, consistently negative skewnesses (implying well-isolated canyons), a nearly constant average slope (~3-4°) versus depth profile, and displays decreasing rms height with increasing depth (implying dominance of headward growth in canyon development). In contrast, the canyons system south of Norfolk Canyon have lower rms height and characteristic width, generally positive skewness (implying tightly packed canyons), a strongly decreasing average slope with depth (from ~8° at slope break to ~2° at slope-to-rise transition), and display increasing rms height with increasing depth. We also note that the NJ canyons appear dominated by headward growth, whereas the Norfolk canyons increase in size downslope. And finally, as evidenced by the skewness, material appears to be piling at the base of the Norfolk slopes, which may be evidence for frequent debris flows through these canyons.

IMPACT/APPLICATIONS

Conditional simulation of bathymetry and stratigraphic geometry will enable acoustic modelers to generate a realistic model of the seabed environment with limited data input.

TRANSITIONS

It is expected that the software and expertise developed under this grant will be utilized by researchers in the Shallow Water Acoustics program.

RELATED PROJECTS

In collaboration with Drs. H. Olson, N. Driscoll, J. Austin and R. Flood, the PI has recently been funded by JOI Site Survey Augmentation award to collect sediment grab samples and chirp sonar reflection data within the New Jersey STRATAFORM swath sonar survey. The grab samples are intended primarily to help ground truth the swath data, and the chirp data are intended to probe the internal structure of primary bedforms (sand ridges) observed in that data set. JOI funding is justified by the location of proposed Mid-Atlantic Transect drill sites 1-3 within the STRATAFORM swath survey. These sites are water depths that are too shallow for operation of the R/V *Joides Resolution*, and will require jack-up drill rigs instead. The contractors have stressed the need for geotechnical information at the proposed jack-up sites, including grain size analysis.

REFERENCES

Goff, J. A., Quantitative analysis of sea-ice draft I: Methods for stochastic modeling, *J. Geophys. Res.*, *100*, 6993-7004, 1995.

Goff, J. A., and T. H. Jordan, Stochastic Modeling of Seafloor Morphology: Inversion of Sea Beam data for second-order statistics, *J. Geophys. Res.*, *93*, 13,589-13,608, 1988.

Goff, J. A., and N. Driscoll, Statistical analysis of continental slope bathymetry on the US Atlantic margin: The evolution of canyon systems, *Eos Trans. AGU*, *78*< F350, 1997.

Goff,. J. A., L. A. Mayer, J. Hughes-Clarke, and L. F. Pratson, Swath mapping on the continental shelf and slope: The Eel River basin, northern California, *Oceanography*, *9*, 178-182, 1996.

Gutjahr, A., Bullard, B., and Hatch, S., 1997, General joint conditional simulations using a fast Fourier transform method: Math. Geology, v. 29, no. 3, p. 361-389.

PUBLICATIONS SINCE LAST REPORT

Goff, J. A., D. L. Orange, L. A. Mayer, and J. E. Hughes-Clarke, Detailed investigation of continental shelf morphology using a high-resolution swath sonar survey: The Eel margin, northern California, *Mar. Geol.*, in press, 1998.

Goff, J. A., and J. W. Jennings, Jr., Improvement of Fourier-based unconditional and conditional simulations for band limited fractal (von Kármán) statistical models, *Math. Geol.*, in press, 1998.

Goff, J. A., D. J. P. Swift, C. L. Schuur, L. A. Mayer, and J. Hughes-Clarke, High resolution swath sonar investigation of sand ridge and sand ribbon morphology in the offshore environment of the New Jersey Margin, submitted to *Mar. Geol.*