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A workshop on Terrain Analysis and Quantitative Geomorphology was held at the Massachusetts Institute of Technology on April 5-7, 1988. The workshop was sponsored by the Office of Naval Research (ONR) and the Naval Oceanographic Research and Development Activity (NORDA). Its purpose was to assess methods for the quantification and analysis of seafloor morphology, to examine their application to acoustic scattering problems, and to evaluate future research directions and needs. A broader goal was to foster cooperation among investigators and minimize the redundancy in Navy-sponsored research projects. This report summarizes the results of the workshop and makes recommendations regarding future research.

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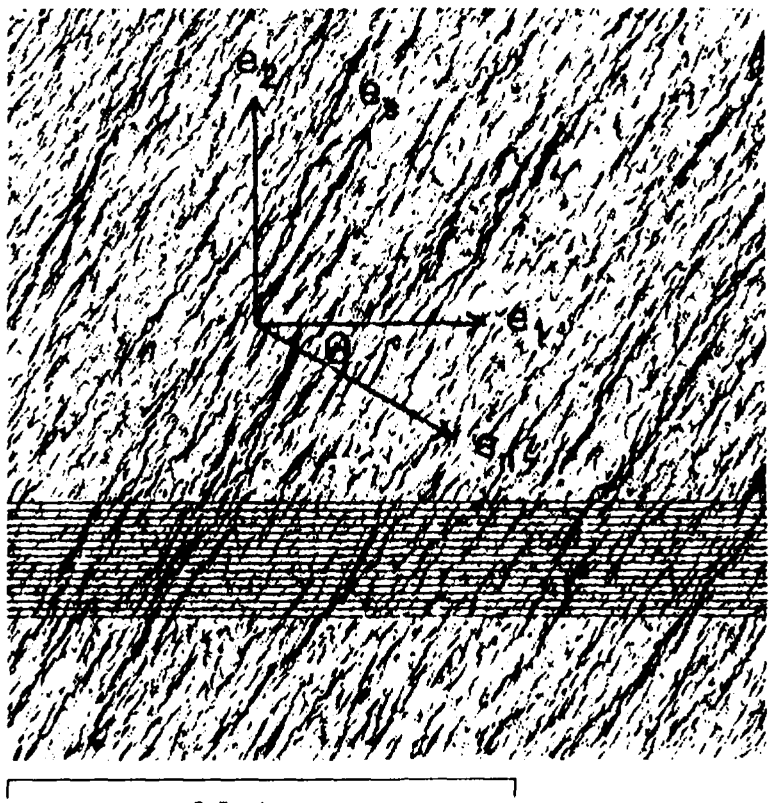
ONR/NORDA

Workshop on Terrain Analysis and Quantitative Geomorphology

Massachusetts Institute of Technology
April 5-7, 1988



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ONR/NORDA Workshop on Terrain Analysis and Quantitative Geomorphology

A workshop on Terrain Analysis and Quantitative Geomorphology was held at the Massachusetts Institute of Technology on April 5-7, 1988. The workshop was sponsored by the Office of Naval Research (ONR) and the Naval Oceanographic Research and Development Activity (NORDA). Its purpose was to assess methods for the quantification and analysis of seafloor morphology, to examine their application to acoustic scattering problems, and to evaluate future research directions and needs. A broader goal was to foster cooperation among investigators and minimize the redundancy in Navy-sponsored research projects. This report summarizes the results of the workshop and makes recommendations regarding future research.

Rationale for the Workshop

Marine geology has entered a new phase. The focus of research has shifted from the large-scale features described by plate tectonics to small-scale features generated by more local processes acting on the seafloor. This research is yielding quantitative descriptions of seafloor morphology ranging in horizontal scale length from tens of millimeters to tens of kilometers. Because such descriptions are critical to improving the understanding acoustic scattering and reverberation from the ocean bottom, marine geological research has taken on new relevance to the Navy.

The acoustic character of the deep ocean basins results from the generation and modification of the seafloor by a number of geological processes. The upper surface of the oceanic crust is initially created by the interplay of volcanism and tectonic deformation along the narrow and dynamic locus of the world-encircling mid-ocean ridge system, which gives rise to the distinctive terrain signature of ridges and valleys of variable relief and shape. This "abyssal hill" terrain is modified in time and space by off-axis volcanism, sedimentation, and post-depositional sediment transport as it moves away from the spreading centers. A major goal of the current phase of marine research is to understand the detailed nature of these geological processes.

To achieve this goal it is first necessary to quantify the geological descriptions of the seafloor across a broad spectrum of spatial scales. Swath-mapping systems such as Sea Beam and Sea Marc are beginning to provide the academic research community with large volumes of high-quality, two-dimensional data on the shape, form, and roughness of the seafloor. To handle this flood of data, new techniques for the deterministic and statistical analysis of fine-scale morphology are being rapidly developed. The type of information derived from the application of these analysis techniques to swath-mapping data is precisely what is needed to improve quantitative descriptions of acoustic interactions with the ocean bottom.

Scientific Questions

The recent confluence of interests of the geological and acoustic communities opens new opportunities for progress on problems of Navy importance. In formulating a research program to take advantage this confluence, it is necessary to identify the common ground between the two disciplines while recognizing the differences in their long-term research goals. Marine geological research is addressing the following basic questions:

- What are the fundamental processes that shape the seafloor during its generation at spreading centers? What is the nature, mechanism and time variation of the three-dimensional, small-scale constructional processes not accounted for by the steady-state spreading model? Are the abyssal hills generated within plate boundary zones formed primarily by faulting or vulcanism?

- How is small-scale topography affected by discordant zones along divergent plate boundaries? What is the fine-scale structure of transform faults and fracture zones? What is the nature of non-transform discordant zones? What are the topographic signatures generated by the evolution and migration of these discontinuities, and how can these signatures be used to understand the mechanisms that control their formation and along-axis propagation?

- How is the formation of seamounts on ridge crests related to speading-center dynamics? What controls the size and shape of a seamount? What governs the along-axis variations in the number of seamounts? How many of the seamounts observed on old crust are formed off-axis? Can seamount population statistics be related to the flux of magma through the oceanic lithosphere?

- What mechanisms are responsible for the vulcanism expressed in large island chains and some oceanic plateaus? How frequently do intraplate flood basalt episodes occur in the deep ocean basins, and how do they modify bottom morphology?

- How do sedimentation, erosion, and mass wasting modify the original volcano-tectonic terrain created at ridge crests? In what way can quantitative descriptions of fine-scale topography and bottom roughness be used to understand sedimentary processes and the mechanisms of post-depositional transport?

- What active relief forming and modifying processes occur on continental margins? How can the morphology of a continental magrin be used to constrain its tectonic and depositional history?

Quantitative morphology provides a framework for formulating and answering these questions. Although the methods and procedures vary widely, the analysis usually involves four separate steps: (1) parameterization of small-scale topography in terms of a mathematical model, (2) solution of a forward problem to predict the effect of a specified model on idealized echosounding data, (3) solution of an inverse problem to estimate model parameters from real echosounding data, and (4) use of the parameter estimates to constrain the nature of the relief forming processes.

Although the ocean acoustics community is not interested in the geological processes governing seafloor evolution per se, the mathematical representations resulting from steps (1)-(3) of a geomorphic analysis can be employed directly in predicting acoustic interactions with the ocean bottom. Scientific questions raised by the ocean acoustics community include:

- What bottom and sub-bottom scattering mechanisms (reflection, refraction, diffraction, or diffuse scattering) contribute to the ocean acoustic reverberation field? Under what conditions does each mechanism dominate?

- Within a specified frequency band (e.g., 10-1000 Hz), what are the horizontal and vertical scales in topography, roughness, and elastic properties that control wavefield scattering? How should these variations be deterministically described for wavefield calculations? Can they be statistically described? If so, what statistical properties are most important in determining the scattering characteristics?

- Can scattering theory be combined with quantitative geological representations, either deterministic or statistical, to allow meaningful quantitative prediction of acoustic bottom reverberation?

Recommendations

Marine geological research is being invigorated by a new set scientific questions posed by new sources of high-resolution data. Considerable theoretical attention is being given to techniques for making more effective use of these data in solving geological and ocean acoustics problems. It was the consensus of the workshop participants that this research program would be substantially accelerated by implementing the following recommendations:

1. Several areas representing typical geological provinces should be identified as "natural laboratories" for future mapping and acoustic scattering experiments. These experiments should include:

    a. Detailed mapping of geological features and bottom properties on horizontal scales ranging from 10 mm to 100 km.
    b. Intercomparisons and ground-truthing of acoustic mapping systems.
    c. Intercomparisons of deterministic and statistical analysis techniques.
    d. Measurement of scattered acoustic wavefields over the frequency range 10 to 100,000 Hz and comparison with predictions from scattering theory and numerical models utilizing quantitative surface and sub-surface geological data.

2. The basic acquisition and equipment maintenence costs of existing academic Sea Beam systems should be block funded so as to insure that data are routinely collected during all underway operations, including transits, of Sea Beam equipped ships.

3. Hull-mounted and towed acoustic mapping systems currently employed by the academic fleet should be calibrated for far-field system response and noise. If necessary, new facilities for this purpose should be developed.

4. Facilities should be improved for the permanent archiving of digital bathymetric and acoustic-imaging data. Ways should be sought to make more effective use of existing swath-mapping and high-resolution acoustic imaging data, including data archived by the Navy, in characterizing small-scale geomorphic variations throughout the ocean basins.

5. Efforts to improve theories for acoustic wavefield interactions with the seafloor should be based on realistic geological models that incorporate the full range of variations in bottom topography, material properties, and sub-bottom heterogeneity.

6. The capabilities of existing acoustic mapping systems employed by the academic institutions should be improved. The upgrading of instrumentation should include:

   a. State-of-the-art digital and acoustic technology.
   b. Accurate ship navigation coupled to accurate ship-relative instrument navigation.
   c. Capability for interchanging transmit and receive functions in cross-fan beam acoustic geometries for enhanced refraction, mapping and reverberation experiments.

7. New instrumentation for mapping bottom morphology and material properties should be developed with the following capabilites:

   a. Imaging and ground-truthing of complex terrains with steep slopes at centimeter resolution.
   b. In-situ measurement of the geological and acoustic scattering properties of a common patch of seafloor.
   c. High-resolution, broadband sub-bottom profiling.
   d. Digital stereo optical imaging at centimeter resolution.

Workshop Agenda

Tuesday, April 5

0830	Registration	
0900	Introductory remarks	J. Kravitz, T. Jordan
0915	Short contributions *(5-10 min each)*	P. Lonsdale
		K. Macdonald
		A. Malinverno
		D. Hayes
		T. Reed
		J. Goff
		R. Tyce
		P. Johnson
		C. Clay
		V. Varadan
		E. Thorsos
		T. Stanton
1200	Lunch at the Marriott	
1330	Organization of working groups; appointment of chairmen	
1400	Working group meetings	
1600	Reports by group chairmen	
1800	Dinner on the town	

Wednesday, April 6

0830	Review of report outline
0900	Working group meetings
1200	Lunch at Marriott
1330	Reorganization of working groups
1400	Working group meetings
1700	Reports by group chairmen
1800	Reception at MIT Faculty Club
2000	Dinner on the town

Thursday, April 7

0830	Review of the report
0930	Discussion of recommendations for future research
1100	Final remarks; further writing assignments (if any)
1200	Adjournment

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