ABSTRACT

In recent years, the development of satellite altimetry has opened previously unexplored regions of the world's oceans to exploration by marine geoscientists. By correlating sea surface gravity with seafloor depth, researchers gain insight into the kinematics of seafloor spreading and the physical mechanisms by which the seafloor is formed and deformed. Given that the ocean comprises two thirds of the earth's surface, under which lies a vastly unexplored domain, visualization holds the key in isolating regions of exploration and providing an encompassing perspective that can not be achieved in nature. This case study describes the process of seafloor spreading and discusses some of the concerns with visualizing gravitational acceleration.

I. OVERVIEW OF DOMAIN

1. History

Although man has studied the earth throughout history, it is only in the past 40 years that we have developed a coherent understanding of the formation and evolution of the planet. The development of sonar during World War II made it possible to map the topography of the seafloor and subsequently revealed that it is not the vast, featureless plain that it had been imagined to be. It was the intensive study of the ocean basins in the 1950's and 1960's that provided the crucial pieces of information necessary to develop the hypothesis of plate tectonics thereby explaining workings of the earth.

2. Seafloor Spreading

One of the fundamental tenets of plate tectonics is the process of seafloor spreading. It is now known that two thirds of the earth's surface is formed by a continuous chain of submarine volcanoes that make up the global midocean ridge system. The oceanic crust, which comprises most of the seafloor and is formed from magma at the midocean ridge, subsides as it moves away from the ridge and eventually sinks back into the earth at deep trenches. The rate the seafloor spreads away from the ridge axis varies geographically from 10 to 180 kilometers per million years. The structure of the ridge axis is determined primarily by the spreading rate.

Slow spreading ridges, such as those in the Atlantic and western Indian oceans, are usually marked by rugged flanking topography and a one to three kilometer deep, 20 to 40 kilometer wide, axial valley. Fast spreading ridges, such as those in the Pacific and eastern Indian oceans, are characterized by smoother flanking topography and a continuous axial ridge which is usually less than one kilometer high. The ridge system is composed of ridge segments, 10 to 500 kilometers long, which are offset by perpendicular features called transform faults. Transform faults create deep valleys on the seafloor called fracture zones which preserve a record of the offset of the ridge and the motions of continents as they move about the earth's surface. The presence of these transform offsets also seems to be related to spreading rate. Slow spreading ridges usually have shorter ridge segments with more transform offsets while fast spreading ridges are more continuous.

3. Problem

Although the kinematics of seafloor spreading are very well understood, the dynamics are the subject of a great deal of current research in marine geophysics. The physical mechanism by which the seafloor is formed, deformed and carried away from the ridge axis is not
understood. In particular, we do not know why slow spreading ridges have discontinuous axial valleys and fast spreading ridges have more continuous axial highs. Because ridges which spread at intermediate rates are located in the largely unexplored southern oceans, the nature of the transition from an axial valley to an axial ridge structure has not been thoroughly studied.

These studies can be greatly enhanced through the support of the Advanced Scientific Visualization Laboratory, a small facility within the San Diego Supercomputer Center, that specializes in Scientific Visualization. The San Diego Supercomputer Center not only provides computational power, from a CRAY Y-MP and the Intel IPSC/860 and nCUBE 2 parallel machines, but also supports visualization efforts within many scientific, industrial, and commercial fields. Through commercial and internal visualization software running on high powered workstations in the visualization laboratory, traditional analysis of problems, such as the dynamics of seafloor spreading, can be extended through more informative and revealing visual simulations.

4. Satellite Altimetry

In recent years, the development of satellite altimetry has opened previously unexplored regions of the world's oceans to exploration by marine geoscientists. Satellite altimeters use microwave radar to make extremely detailed maps of the height of the sea surface. In addition to oceanographic effects, such as waves, tides and currents, the shape of the sea surface is determined by the gravitational attraction of structures on and beneath the seafloor. For example, the added mass of a seamount causes water to accumulate around it and form a "bump" on the sea surface above. Because oceanographic effects have longer wavelengths than most topographic features, these effects may be removed by filtering.

The processing and interpretation of these gravity measurements have been used extensively by Prof. David Sandwell at the Scripps Institution of Oceanography. His research team, which includes graduate students, leads one of many investigations within this oceanographic facility located next to the main campus of the University of California, San Diego. From the analysis of large amounts of computational and observational data, Scripps not only can locate uncharted seamounts and map fracture zones related to the breakup and movement of continents, but also search for explanations of physical events on a global scale.

II. RESULTS

1. Motivation

Early satellite altimeter missions were limited by a wide track spacing. This imposed a resolution limit on the data geoscientists could obtain for study. However, in 1985, the U. S. Navy launched the Geosat satellite altimeter which collected very high resolution data with a very dense track spacing. The Geosat mission accomplished a complete mapping of the marine gravity field with an approximate resolution of 10 kilometers. Unfortunately, only data south of 60° has been declassified. We are working with a subset of this data located between New Zealand and Antarctica. This is one of the previously unexplored segments of the midocean ridge system where an abrupt transition from an axial ridge to an axial valley structure has been discovered.

2. Method

Previously, marine geoscientists color mapped satellite altimetry data to produce a two dimensional representation of the gravitational acceleration associated with the Antarctic seafloor. However, by utilizing computer modeling and animation software, such as Wavefront Technology's Advanced Visualizer, a simulated seafloor environment could be produced in which researchers could interactively probe the data set as if they were exploring the ocean depths aboard a submarine.

This oceanfloor model was designed by first transforming the gravity data into extrusion levels. Next, a color library of materials was generated by sampling the

Figure 1: The Curvature of Fracture Zones

(See color plates, p. CP-43.)
ambient, diffuse, and spectral elements of the color table from the two dimensional pixelmap. The extrusion data values were then applied to a gridded plane, and by utilizing custom software from the San Diego Supercomputer Center, the three dimensional definition of the topology was written to the Wavefront object format with each vertex assigned a height dependent color from the material library. Smooth shading of the topology was generated from surface normals at each vertex, and blended coloring was achieved through color interpolation algorithms within Wavefront.

3. Visualization

The images shown (Figure 1 and 2) are part of a simulated, animated "swim through" of the portion of the Geosat data and were generated on a Silicon Graphics 4D/320 VGX using Wavefront Technology's Image renderer. This area is one of the previously unexplored segments of the midocean ridge system where an abrupt transition from an axial ridge to an axial valley structure has been discovered. The long, linear features are fracture zones, and a seamount is visible on the right side (see Figure 1). Also depicted is a closer look down one of the fracture zones (see Figure 2).

The motion for the "swim through" was initially scripted from the two dimensional aerial view of the region. Utilizing Wavefront's Preview animation capabilities, critical regions were isolated by specifying "key frames" or preferred camera positions. The motion was obtained by performing a spline interpolation between the translational and rotational information stored at each "key frame". The addition of a second camera parented to the "submarine" view provided valuable orientation information during the refinement of the motion. Finally, the motion was recorded to a laser videodisk recorder, Sony LVR-5000, and edited onto videotape.

III. FUTURE

1. Limitations

The integration of advanced visualization techniques with marine geoscience, such as the one outlined here, has only recently developed, and given the scale of global research performed by the Scripps Institution of Oceanography and other facilities, the reliance on technology will only increase. Therefore, the limiting factors of technology in terms of total resources and accuracy must always be considered.

For example, one of the limitations of this visualization technique involved the sheer size and high resolution of the data set. Due to memory considerations and rendering constraints, programs needed to be developed to selectively import filtered, low resolution data sections or subsets of the data in order to achieve a tolerable level of user interaction. Although these limitations were conquered, potentially, the management techniques will need to accommodate much more information should further data become available.

Also, in terms of accuracy, it is important to clarify that the surface shown in the generated images is not actually the seafloor but rather a surface of equal gravitational acceleration. The topography of this surface is approximately equivalent to the topography of the seafloor with one important difference. The gravity data also contains information about the subsurface structure in this area. The longer wavelength components of this image are related not only to the seafloor topography but also to density contrasts from structures several kilometers below the seafloor. This image appears smoother than the actual seafloor because the signal from the short wavelength features on the seafloor is attenuated by the water depth - approximately three kilometers in this area.

2. Conclusion

The relationship between gravity and topography has been used to study subseafloor structures in many parts of the world's oceans and is an important area of marine geophysical research. Although scientists need to be aware

(See color plates, p. CP-43.)
of the limitations of technology, the integration of visualization into this field has great potential. From an utilized in this project can be used for planning expeditions to remote oceanographic areas. Furthermore, the new perspective this visualization provides to the Scripps Institution of Oceanography reveals the broader relationship of midocean ridges. This helps the world understand how oceanic crust is created, as well as why spreading ridges have such different structures, thereby eliminating some of life's mysteries.

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REFERENCES


