MEETINGS

Opportunities for 3-D Seismic Reflection in Geoscience Research

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You would think they were images of the Earth's surface made from an aircraft or satellite, or maybe high-resolution images of the seafloor, the sort made with modern multibeam echo sounders. There are hills and valleys, steep scarps and flat plains. Features like meandering river channels including levees and over-bank deposits are clearly defined, and great armadas of ripples like desert sand dunes appear as if seen from the window of a commercial aircraft. There are even impact craters made by meteorites with resolutions as clear as those seen on the Moon through telescopes.

You can fly around this terrain any direction you choose at any height and speed. You can stop, hover in one place, and look around before traveling on. Just when you might start to wonder why you haven't seen roads or towns or vegetation, you recall that this is not an image of today's land surface but that of an ancient terrain, deep below the surface of the Earth, revealed by three-dimensional (3-D) seismic reflection imaging.

Around 100 investigators met at a U.S. National Science Foundation (NSF)-sponsored workshop at the Lamont-Doherty Earth Observatory of Columbia University in early September to ogle tens of these startling images and deliberate on the transformative impact they might have on marine geoscience research in the academic community.

Volume Control

Properly executed (no small task, as was learned during the workshop), a 3-D seismic investigation images a 3-D volume rather than a two-dimensional (2-D) surface. Three-dimensional studies seismically illuminate the subsurface in a roughly cubic space with approximately equal resolution throughout the volume. The quality of information is almost equally high regardless of location within the volume or the direction of observation into the volume.

From this information, a 2-D image can be extracted in a vertical plane, giving the orientation of classic reflection imaging studies. The plane of section can be horizontal (a time or depth slice) or any orientation one chooses, and images will appear at the same resolution. There is no requirement to be confined to planar surfaces; it is possible to pick a nonplanar surface based on a particular attribute, such as the strength of the reflection from the subsurface, and obtain an image of that surface.

Yet the real power of these images comes from resisting the temptation to extract conventional 2-D slices or surfaces from the volume, even if they can be chosen in unconventional orientations. The great advantage of 3-D images is that they are indeed images of volumes, not planes or surfaces, and can be analyzed as such. The interpreter is not constrained to examine a surface, but can enter the volume and from a subsurface vantage point observe the environment in any direction. Ambiguous features that have always puzzled interpreters of 2-D sections readily resolve into faults, folds, reefs, basins, and so forth, based on their true characteristic shapes in 3-D.

Workshop participants saw from Mike Enachescu (Memorial University of Newfoundland), Henry Posamentier (Anadarko Petroleum Corporation, Houston, Texas), and Joe Cartwright (Cardiff University, Wales) numerous examples of data collected for commercial application in which 2-D interpretations from within the volume would have led to seriously incorrect interpretations. In addition, Bill Keach from Landmark Graphics (Houston, Texas), presented the latest in interpretation software, which exploits multiple seismic attributes to highlight chosen features within the volume.

In a half-day clinic, participants were schooled in the challenges of 3-D seismic acquisition procedures by Phil Fontana, an acquisition specialist from the software company Veritas (Cupertino, Calif.). He emphasized the requirements for ship navigation, location of the streamer hydrophone array towed behind a vessel, quality monitoring of multiple systems, and strategic planning in execution of surveys that are at least an order of magnitude more stringent than the requirements for academic 2-D surveys conducted in the past. These requirements become particularly demanding when the application envisages four-dimensional (4-D) applications.

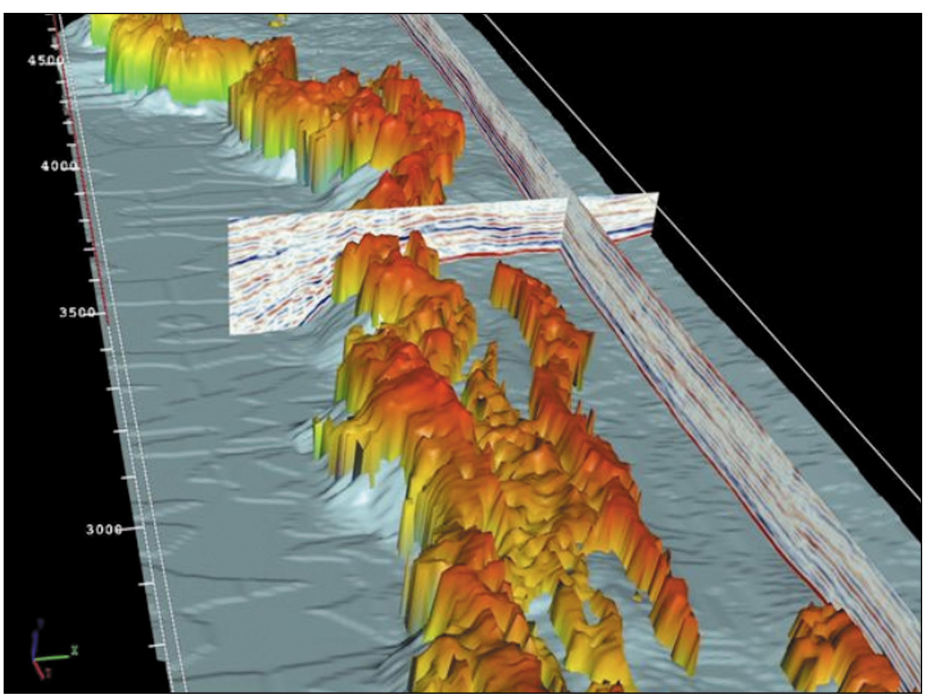

Fig. 1. Reef front revealed by 3-D reflection imaging. Individual 2-D sections (along the right side and through the center) give little hint of the complexity of the structure. [Image shown by Michael E. Enachescu at the 3-D Seismic Workshop].

3-D Movies to Track Volume Changes

The current frontier in industry seismic work is 4-D, in which successive 3-D surveys are used to determine the time evolution of features in the volume imaged. In industry applications, this mainly means the movement of fluids as a reservoir is drained. However, in academic applications this can mean movement or change in properties such as crystal fraction of magma in a mid-ocean ridge magma chamber or change in fluid pressure on faults that might signal an impending earthquake.

Participants heard a fascinating account from Paul Hatchell of Shell International Exploration and Production (Rijswijk, Netherlands) on how stress changes associated with fluid extraction in a reservoir can be imaged using 4-D approaches. His account was tempered by a sobering analysis of the extraordinarily rigorous acquisition requirements needed to ensure that meaningful information can be extracted from these 4-D data sets.

Three-dimensional acquisition revolutionized the hydrocarbon industry many years ago, and 4-D breakthroughs came more recently. These developments have led to a major enhancement in both oil field discovery and recovery rates. Exploration fleets run by commercial operators today tow multiple source arrays and routinely operate with 10 or more solid state streamers collecting data in swaths, Zamboni style, with each pass collecting several lines of data.

Acquisition costs run in the millions of dollars per project with acquisition accounting for a relatively small fraction of time at sea as the vessels wait on weather, make repairs, or simply make turns from one swath to the next. Parts of the survey are reshot if onboard analysis shows that acquisition has been incomplete in certain places. The project is not considered accomplished until all the data are collected at a suitably high quality standard.

However, academic geoscience research based on seismic reflection imaging has not yet fully benefited from the advances in 3-D imaging that have been led by the commercial sector. The primary academic experience has been in 2-D acquisition obtained using commercial acquisition equipment (current or near-to-current technology at the time of purchase) installed on vessels not built for seismic acquisition. The rate of upgrade has been slow, and academic capability has often fallen well behind industry standards. A major upgrade in capacity took place when Lamont-Doherty began operating the research vessel (R/V) *Maurice Ewing*, a purpose-built seismic vessel formerly operated by PetroCanada as *Bernier.*

The *Ewing* has been used to perform NSF-supported 3-D seismic surveys in two distinct settings: the East Pacific Rise, presented at the workshop by Graham Kent (Scripps Institute of Oceanography, University of California, San Diego), and in accretionary prisms at several locations, presented by Nathan Bangs (University of Texas at Austin, Institute for Geophysics). This method of 3-D acquisition is the least efficient and most trouble-prone approach, and it has been long out of use in the industry.

Ewing deploys a single streamer, so acquisition must be achieved by numerous closely spaced passes through the area, each acquiring only one line of data. This makes data quality especially vulnerable to streamer feathering by ocean currents, source dropouts, streamer noise, and other common acquisition problems that investigators have come to tolerate in 2-D work but which severely compromise quality in 3-D seismic imaging. Bangs, Kent, and others at the workshop with direct experience in acquisition on *Ewing* agreed that the greatest impediment they had to obtaining good 3-D images lay in acquisition shortcomings, not in subsequent data processing.

Despite the arduous process needed to obtain them, the images provided by Bangs and Kent proved the value of 3-D seismic imaging. With a spatial scale irresolvable in 2-D work, Kent described the magma chamber structure of the East Pacific Rise that included tiny en echelon bodies whose individual segments seem to make stepping stones along the trend of the ridge and deepen beneath one limb of the overlapping spreading ridge. Bangs described details of décollement surfaces and the complexities of thrust faulting in accretionary prisms that completely eluded description from 2-D studies.

R/V Langseth: *The Future of 3-D Seismics*

Just as the introduction of 3-D imaging into the exploration industry revolutionized the search and recovery of hydrocarbons, the introduction of 3-D seismic imaging into the academic community is sure to revolutionize the understanding of fundamental Earth processes at ridges and margins.

The vehicle that will launch this new era is the research vessel *Marcus G. Langseth*, acquired by Columbia University from WesternGeco where it operated as the *Western Legend*. This vessel was purpose-built for 3-D seismic acquisition, and it is presently being refit for operation with four streamers and two sound source strings by Lamont-Doherty for the U.S. academic community. Users will include individual investigators and groups funded primarily by NSF.

International Ocean Drilling Program (IODP) site surveys will be an important part of the mission for the *Langseth*, as all studies that plan to use the riser capability of *Chikyu* (the Japanese-built ocean drilling vessel that will be used by IODP), as well as many nonriser holes, demand 3-D seismic studies for adequate site location.

The *Langseth* also will be available to users funded by others. Because the *Langseth* will be the only 3-D vessel dedicated for use by academic scientists in the world, collaborative programs with non-U.S. scientists are expected to be important.

Just how the vessel should operate was a matter of debate at the workshop. Many participants were convinced that the current mode of individual principle investigator-based studies would not allow a body of experience to be acquired that would ensure that consistent, high-quality data are collected at a reasonable rate. A mode of operation more like IODP or the Incorporated Research Institutes for Seismology in which data from programs on the vessel became rapidly available to the community, might be appropriate to ensure wide and equitable benefit from this unique and costly resource.

The workshop participants came to no conclusion on the operating mode for the *Langseth*, but the issue generated a discussion that now moves to the broader community and involves the University-National Oceanographic Laboratory System, NSF, and Lamont-Doherty as operator.

The "Symposium on 3-D Seismic Reflection Imaging: A New Opportunity for Marine Geoscience Research" was held 8–10 September at Lamont-Doherty-Doherty Earth Observatory in Palisades, N.Y. Workshop proceedings, including a list of attendees, speaker bios, and dozens of images from many of the presentations, are available at http://www.ldeo.columbia.edu/events/workshops/3Dseismic/index.html

—JOHN C MUTTER, Columbia University, Palisades, N.Y., and GREGORY MOORE, University of Hawaii, Honolulu, on behalf of the workshop steering committee.

A town hall meeting to discuss operations of the R/V *Marcus G. Langseth* will be held at the AGU fall meeting on Thursday, 8 December at 6 p.m. in the Marriott Hotel Golden Gate, Room A3, in San Francisco, Calif.

Global Impacts of Arctic Climate Processes

The polar regions are experiencing major climate and environmental changes due to the combined effects of natural variability and global warming. To address regional Arctic climate processes and their global feedbacks, 53 experts from the United States, Canada, Europe, and Russia gathered for a recent workshop at the Alfred Wegener Institute for Polar and Marine Research, in Potsdam, Germany.

The workshop, which was organized by Klaus Dethloff and Annette Rinke, focused on the use of regional models of the Arctic, global coupled climate models, and Arctic impact studies. This article summarizes the main advances and outstanding issues in Arctic modeling that were presented and discussed during the workshop.

Regional Models of the Arctic Atmosphere

The Arctic Regional Climate Model Intercomparison Project (ARCMIP, http:// curry.eas.gatech.edu/ARCMIP/) seeks to improve the simulation of Arctic climate in numerical models through the coordinated validation and intercomparison of various regional and global atmospheric models.

The first phase of ARCMIP focused on simulations with eight different models using data from the Surface Heat Budget of the Arctic Ocean (SHEBA) field experiment 1997/98. The seasonal, large-scale atmospheric flow patterns (e. g., of the mean sea level pressure) are reproduced remarkably well by the model ensemble. An interesting feature is that the bias of the geopotential—which approximates the actual height of a pressure surface above mean sea level—has the same pattern over the Beaufort/Chukchi seas in all models: the models underestimate this height when compared with the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis. In addition,