The Future of 4-D Reservoir Monitoring: Advances in Technology for Large Oil and Gas Fields

by Roger N. Anderson, Lamont-Doherty Earth Observatory.

Getting more oil out of old fields is the payout of 4-D seismic reservoir monitoring. 4-D combines the analysis of seismic acoustic changes occurring over time with other borehole and surface measurements. 4-D analysis has the ability to track time-dependent changes such as pressure changes and production histories. The result is a coupled model of oil and gas drainage and a more accurate simulation of future production.

Evaluating the Subsurface over Time Using Time-Lapse Seismic

The tools and techniques required to interpret past acoustic changes that have occurred in oil and gas fields perform two essential tasks: 1) normalization of the seismic images between snapshots taken at different times, using different equipment and different geometries of acquisition and then processed differently at the computer center, and 2) interpretation of the similarities and differences in the acoustic signature of oil, gas, and water in the reservoir as they change over time.

More than twenty oil and gas fields from (fig. 1, 2) the Gulf of Mexico and the North Sea are the proving ground for new 4-D technology developments. These fields provide contrasts in acoustic response and seismic signal-to-noise, often between reservoirs within the same field, that point to important lessons for the planning of future 4-D reservoir monitoring projects. Conclusions to date are 1) pressure history often affects seismic responses as significantly as oil/gas/water mix changes and 2) volumetric "region-growing" is a method to scan multiple 3-D data sets for changes at a fast enough computational rate to satisfy engineers in charge of production. Region-growing is a signal analysis technique developed for the detection of differences in MRIs, CAT and PET scans, and in anti-submarine warfare. Region-growing is also very useful for the isolation of 4-D seismic differences that are meaningful in reservoirs.

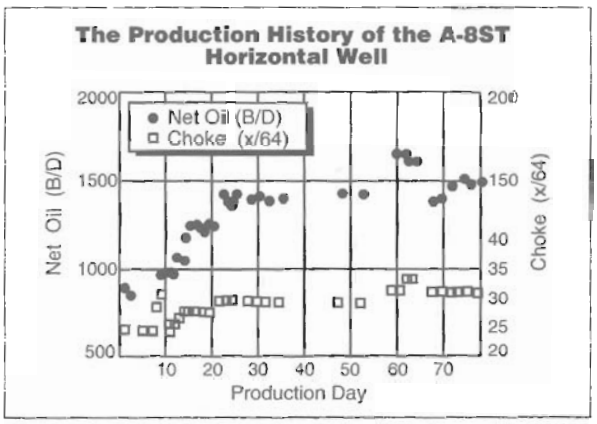

Figure 1: Production from a Gulf of Mexico well drilled after 4-D evaluation.

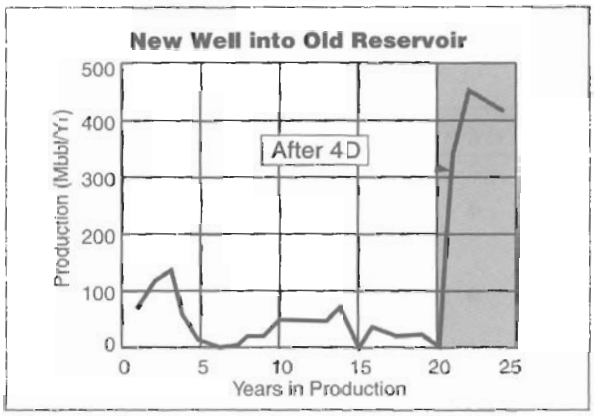

Figure 2:The field has added reserves after drilling wells based on 4-D.

Better understanding of the pattern of drainage to the surface will allow for better planning and execution of recovery programs in the future. Four-D provides the "killer app" for impedance inversions, which are the most likely seismic attributes that can detect change over time in reservoirs. As we get better at 4-D monitoring, more original oil-in-place will be extracted from producing reservoirs.

The 4-D Seismic Reservoir Simulation Loop

Seismic inversions will be routinely used on time-lapse seismic data sets to produce impedance differences. These become geostatistical reservoir characterizations and reservoir simulator data to quantify the variations in fluid saturations with time. New 3-D finite element models will be developed to compute synthetic seismic responses to differences detected by the real observations. Seismic-to-petrophysical iterations are added to the simulation loop. The continual updating of the loop forms a planning tool for predicting new drilling targets for recovery of bypassed oil and gas. Repeated looping of information leads to planning the time, spacing, types of receivers and borehole arrays that will be needed to successfully monitor the oil and gas fields of the future.

Biographical Sketch

Roger N. Anderson is director of Petroleum Technology Research at the Lamont-Doherty Earth Observatory of Columbia University in New York, where he has been for the last 24 years. He has a Ph.D in Earth Sciences from the Scripps Institution of Oceanography, University of California, San Diego. He spent the last 8 summers with oil and service companies in Houston, most recently at Western Geophysical. He is the author of more than 150 peer-reviewed scientific and technical papers. He has written a marine geology textbook and holds 7 U.S. patents. Anderson is on the board of directors of Bell Geospace, Inc. and 4-D Systems, LLC. His address is Lamont-Doherty Earth Observatory, Columbia University, Torrey Cliffs Road and Rt 9W, Palisades, New York 10964, Email: anderson@ideo.columbia.edu. *Note: The reservation code for this meeting is 5-0-1*

Future Applications of 4-D Seismic