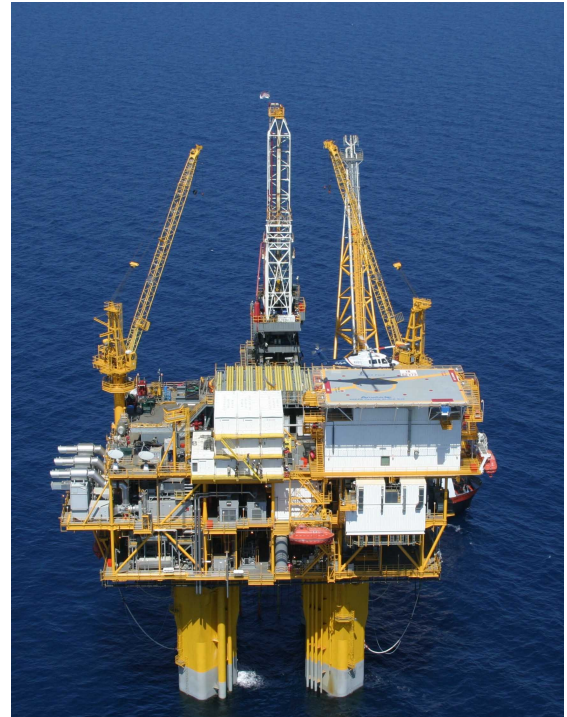


Anadarko's Marco Polo Field

A RockMod Success Story

Anadarko Petroleum is one of the world's largest independent oil and gas exploration and production companies. The deep waters of the Gulf of Mexico are a significant component of the company's growth strategy and its first discovery there was made in April 2000 in the Marco Polo field. This field is located on Green Canyon Block 608, about 160 miles south of New Orleans, Louisiana. The field is in 4300 feet of water and is being produced from the deepest tension leg platform in the world. The first well encountered 320 feet of oil sand from five different Miocene targets above salt. Field production began in July 2004.



In essence, RockMod is "knowledge-constrained" geologic model building. It uses Markov-Chain Monte Carlo simulation methods to build a series of high-resolution models of the reservoir zone that all agree with all of the input data, which includes (pre-stack) seismic amplitude data, well logs, petrophysical relationships, and geologic inferences about reservoir trends, shape, thickness, and lateral extent. The resulting models are plausibly detailed at vertical x lateral resolutions of 5 x 25m, yet also provide coherent interpretations at the seismic scale, and on up to the km scale.

The data set for the field was acquired and processed in the late 1990s. Since then, Anadarko has reprocessed the data several times using different methods. The most recent pre-stack time migration formed the basis of a new reservoir characterization technique performed by the University of Texas-Austin Research Consortium on Formation Evaluation (UT-Austin).

"We thought the new technique they were using could increase the resolution of the 3D seismic data," explained Tim Fasnacht, Senior Staff Geophysicist at Anadarko Petroleum. "This could give us a better handle on potential reservoir baffles or barriers, which could have a significant effect on connectivity, leading to a better understanding of well productivity."

A Team Effort

When Anadarko provided the data set to UT-Austin it was immediately obvious that it was well suited for a new technique called RockMod, developed by Fugro-Jason. "When I saw the data and did the quality control and the basic analysis, I realized that these data were a prime example for using the new Fugro-Jason software," commented Carlos Torres-Verdin, Associate Professor at UT-Austin. "I have a very good relationship with Fugro-Jason and have worked with them for a long time so I proposed that we work together."

A team was formed comprising Anadarko, UT-Austin and Fugro-Jason. Much of the early work was performed at Fugro-Jason's main facility, with software engineers and geoscientists working hand-in-hand.

Petrophysical Analysis

In this preliminary step, the team computed porosity, permeability and water saturation within the sands. They then determined if there was a correlation between elastic properties (p-wave impedance, s-wave impedance and density) and petrophysical properties (porosity, clay content, hydrocarbon saturation, and permeability).

"It was very clear how to differentiate between sands and shales in this field," said Torres-Verdin. "We also found that the combination of p-wave impedance and s-wave impedance allowed us to differentiate between gas, oil, and water."

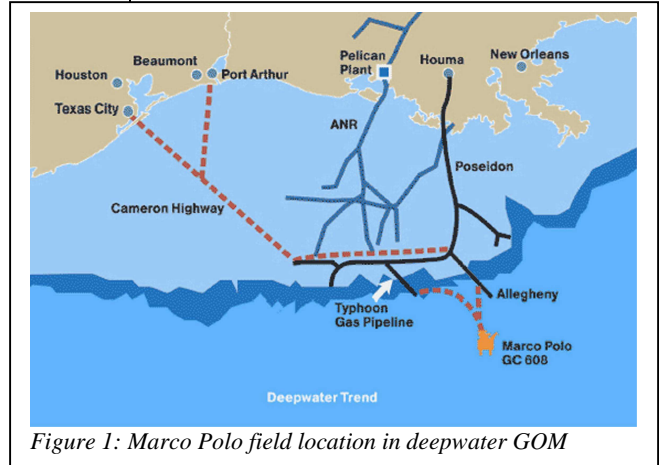


Figure 1: Marco Polo field location in deepwater GOM

Post-stack seismic amplitude data mainly detects p-wave impedance, while pre-stack data also incorporates s-wave impedance with the potential to output density. This offers additional degrees of freedom, making it easier to differentiate between lithology units, types of lithology, amount of porosity, volume of shale and pore fluid type. Additionally, stochastic inversion enables the quantitative integration of seismic measurements (laterally dense) with well log data (vertically dense).

Pre-Stack Stochastic Inversion estimates the elastic properties using a statistical method that ensures that results honor the well log data. In other words, the wells are used as controls to ensure that the elastic properties estimated match both seismic amplitude data and down-hole measurements.

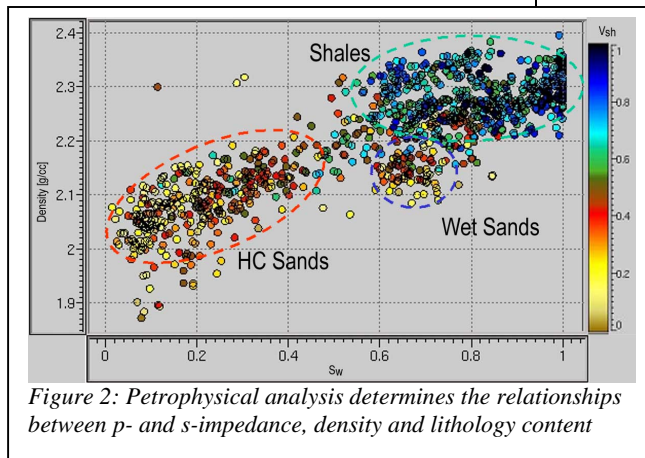


Figure 2: Petrophysical analysis determines the relationships between p- and s-impedance, density and lithology content

Pre-Stack Stochastic Inversion

With the preliminary analysis complete, the team moved on to performing the inversion. One of the features of RockMod that makes it distinct from other geostatistical techniques is that it works with pre-stack rather than post-stack seismic amplitude data. This fundamental difference enables the use of multivariate statistics, which in turn enables greater flexibility in the analysis phase.

"The most important and unique aspect of RockMod is that it combines the high resolution of well logs with the relatively dense lateral coverage of 3D seismic amplitude measurements," commented Torres-Verdin. "We found that by forcing the results to honor the well logs, we could increase the vertical resolution of the results. By combining the seismic amplitude data with the well logs, we could increase the resolution to about five meters."

"We were very excited to see the high resolution in terms of both lateral and vertical detail," said Fasnacht.

"When we mapped the attributes on different horizons, the shapes we saw for the anomalies were the way you would expect. The geomorphology looked correct and we obtained much more detail than what we were getting previously."

—Tim Fasnacht

Co-Sim of Geologic Bodies

Following inversion, the team applied the correlations of elastic properties to petrophysical properties with the intent of modeling petrophysical properties. The result was a high-resolution model that could easily be fed into a simulator for production flow simulation.

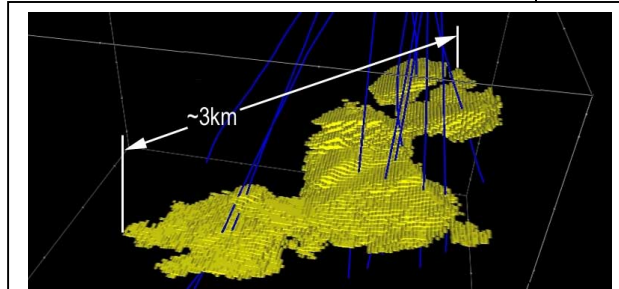


Figure 3: 3D View of the predicted geomorphology of the M10 sand

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Testing the Results

As a final step, the team ran a series of tests to determine the impact of the assumptions made during the analysis. Sensitivity analysis showed that the results were statistically correct.

"We did this through multiple blind well tests, where we removed one well and produced estimates along its trajectory," explained Arturo Contreras, UT-Austin. "When we plotted the results along the well and compared them to the actual well data we showed an extremely high correlation."

Uncertainty was also tested by analyzing the statistical properties of a set of solutions. The team found that the degree of variation was much less than 5 meters, which was within the noise level of the measurements.

Conclusions

The Marco Polo field was an excellent test case for RockMod because the data set was rich and of high quality. As a result, the team was able to prove the usefulness and accuracy of the new technique at the same time they built a greatly enhanced model of the reservoir.

The two criteria for using the technique were met: a correlation between elastic and petrophysical properties and a thickness of flow units and lithology units that can be differentiated by the seismic amplitude variations.

"This technique opens a whole new window of opportunity in reservoir characterization," stated Torres-Verdin. "I expect that this technique will change

the way we process seismic amplitude data, moving toward a more direct connection between seismic data and petrophysical properties through inversion."

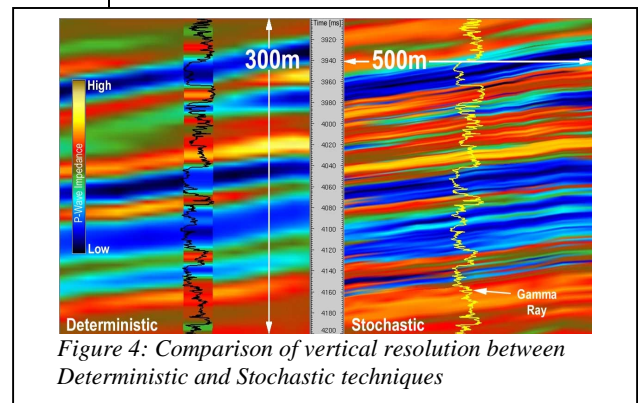


Figure 4: Comparison of vertical resolution between Deterministic and Stochastic techniques

RockMod can be widely applied in clastic depositional systems and carbonate depositional systems where elastic properties of carbonate facies are distinct. Using the technique, Anadarko and other companies will have better information for optimum well placement, how to produce, and even the field's economic viability.

For Anadarko, RockMod benefits can extend beyond the Marco Polo field to many other holdings. "To me, that's the biggest plus," said Fasnacht. "I'm really excited about using this technique in future field development."

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—Carlos Torres-Verdin

Acknowledgements

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About Fugro-Jason

Fugro-Jason is the leading provider of seismic reservoir characterization solutions, integrating geology, petrophysics, geophysics, and engineering to construct the most accurate and detailed descriptions of your reservoir. As a result, you can produce reservoirs with fewer, more productive wells and thereby increase your profitability.

More than 15 years ago we set off as Jason and the Argonauts did in search of the Golden Fleece—in our case, a better way to get More Oil with Less Toil. We knew that a wealth of data was available to geologists, geophysicists and engineers searching for and developing reservoirs, but that its true value would only be revealed if they could work together with common data. We dedicated ourselves to making that possible.

About RockMod

Our approach to Reservoir Characterization has always been to combine as much data and information about the reservoir as possible into a single model of the earth. RockMod combines Simultaneous AVA and Geostatistical Inversion, giving producing a model of the reservoir unparalleled in accuracy and detail.

RockMod Service deliverables can include:

- **Reservoir Identification** - maps or models of lithofacies at fine-scale detail
- **Reservoir Property Determination** - lithology, velocity, permeability
- **Reservoir Quality Indication** - maps and models of reservoir porosity, Net-to-Gross ratio maps, Net Pay thickness maps
- **Economic Risk Assessment** - probability models (P10, P50, P90, for example) based on multiple realization modeling

For More Information

Fugro-Jason has offices around the world, including:

Beijing • Dubai • Houston • Kuala Lumpur • Moscow • Paris

To contact us, visit www.fugro-jason.com.

RockMod combines geologic information with AVA sensitivity analysis techniques and pre-stack stochastic inversion, making it possible to substantially reduce development risk associated with conventional and non-conventional reservoirs. With RockMod, Fugro-Jason remains at the forefront of new reservoir modeling technologies."
— Carlos Torres-Verdin