Wave-Equation Depth Imaging in an Integrated Regional Framework

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Summary

Regional geologic context is an important factor in the effective assessment of exploration risk in frontier areas such as the ultra-deep waters of the Gulf of Mexico. The use of regional frameworks has been reported during the prospect evaluation and discovery phases of several large deepwater fields in the Gulf of Mexico. This paper describes a new, fully integrated, region-wide seismic framework that addresses this need. The approach incorporates:

- Long offset, long record length, high resolution data acquisition
- Integrated, area-wide subsurface model-building incorporating salt interpretive experience, seismic velocity estimation, and guidance from 3-D gravity control
- Pre-stack depth imaging techniques.

A robust, integrated workflow with associated analytical tools has been designed to create a high quality seismic database that provides both regional scale and image detail in depth to support exploration understanding across this complex Gulf of Mexico geologic regime. We discuss the issues related to providing accurate seismic images in depth across this regionally consistent grid.

Introduction

In deepwater Gulf of Mexico, exploration prospects have moved from the amplitude-driven plays of the 1990's to less amplitude-sensitive, older stratigraphy frequently below highly complicated salt canopies. This has clearly shown the value of a regional petroleum systems framework to assess prospect risk. (Yeilding et al, 2002). This "source up" perspective has demonstrated its utility with the discovery of several giant fields where companies have performed sub-regional analyses and prospect maturation processes within a full geologic systems context.

The challenge has been to obtain both the regional scale and the subsurface information content in a timely and affordable fashion. For the largest companies, frameworks of large-scale 3-D programs and published well data have been helpful while conventional 2-D grids have traditionally provided only gross context. For industry, however, the challenge remains on how to achieve the necessary balance between scale and information content with acceptable time availability and budgetary objectives. With periodic OCS leasing turnover likely to provide significant acreage opportunities in 2006-2008, practical solutions to address region-wide context becomes especially important.

A seismic program concept is described that addresses this need. It achieves an integrated area-wide perspective with the detailed image quality in depth required to provide the proper geologic framework that will allow companies to make informed exploration decisions at the prospect level. A Gulf-wide, high-resolution 2-D seismic acquisition grid has been combined with geologic expertise in salt tectonics, 3-D gravity modeling, 3-D velocity model-building, and state-of-the-art depth imaging techniques. This has provided the first fully integrated, area-wide, high quality seismic database in depth across the Gulf of Mexico.

Program Concept and Acquisition

In designing a total program concept to address Gulf of Mexico frontier needs, four steps were considered important. Firstly, the program must be area-wide and internally consistent across the region. The program was developed as a series of integrated cellular modules each approximating 1000 OCS blocks with continuity between cells from west to east across the deepwater Gulf of Mexico. Secondly, the seismic acquisition must provide the data resolution below the salt canopy to image the deeper formations of interest including Paleogene and earlier formations. A 2 mile x 2 mile high-resolution 2-D seismic program with ongoing rigorous quality control was designed with very long offsets (10000m), long record length (13-14 seconds) and high-fold (133) to meet this requirement. Thirdly, to assure clear seismic imaging of the complex subsurface, as well as access to modern depth imaging tools, close collaboration is essential between the seismic interpreter with local knowledge of the area and its salt tectonic history and the depth imaging processing team. Fourthly, other independent geophysical measurements are used to guide the interpretation effort and corroborate results.

Systems Approach to Model-Building for Depth Imaging

The initial workflow developed to provide each cell's pre-stack depth migration (PSDM) results adopted the industry standard iterative salt flood approach. To maximize the imaging opportunity, wave equation PSDM was selected as the primary imaging tool. It is best equipped to address the multi-pathing associated with rugose salt surfaces and to minimize wavefront artifacting in the deeper parts of the section. The selected wave equation PSDM method also provides an effective migration aperture across the full length of the long seismic lines ensuring that steep dips are imaged both in the clastic section and the associated salt boundaries.

While the data are a 2-D grid, at all times a three-dimensional perspective was maintained to ensure the internal integrity of each cell. While building the salt model, an ordering of line interpretation was invoked to maintain spatial consistency as the salt surfaces were built up and all data across the cell were modeled as a unit before proceeding to the next iteration. Similarly, development of the velocity field at relevant stages was built on a cell-wide basis.

Refining the Salt

Successful imaging of the pre-salt section depended on the accurate definition of the salt bodies. As the workflow evolved during the project, two key features emerged as important in reducing the ambiguity possible in salt thickness and shape, especially the more difficult base salt reflector. First, the availability of a two mile x two mile 3-D gravity database throughout the area allowed forward gravity modeling for comparison with the processed 3-D gravity data. This significantly aided the uncertainty reduction in the salt body interpretation. Second, to rapidly examine possible base salt scenarios, an interactive tool (SABER = SAlt Base Evaluation and Refinement) was developed that rapidly provided the interpreter with the PSDM result of the salt scenario allowing quick testing of different base salt configurations and their effects on pre-salt sediment interfaces. The SABER tool proved very effective in providing timely convergence on the best-fit salt shape prior to, and during, sub-salt iterations. An additional aid in assessing the validity of the model was availability of depth-migrated angle-based common image gathers. These were regularly examined for residual curvature that may reflect an inadequately designed model.

Imaging the Deep Section

Following the salt shape refinement, an area-wide salt body volume was available to activate PSDM iterations and allow deep pre-salt reflectivity to come into focus. Figures 1 and 2 show this integration of salt body interpretation with the areally developed velocity model. Figure 3 demonstrates the value of this workflow approach with a well-defined structural image available following the integrated PSDM methodology Both Paleocene and Cretaceous unconformity detail clearly emerged throughout the program area supporting the validity of the collaborative efforts that defined the salt canopy. In certain areas where salt body definition was defined with high confidence, velocity updating using tomography provided further refinement of the velocity model and improved imaging continuity of the deep reflectors.

As the project progressed, it was noted that, while wave equation generally gave excellent imaging across both depth and space, there were some areas where Kirchhoff PSDM provided different degrees of continuity especially at depth. Analyses of the data sets with common velocity models suggest that this reflects different algorithm responses to the specific subsurface characteristics. In many areas, especially deep, the wavefronting typically associated with Kirchhoff obscures image quality. However, to assure that the best available image is available at all points within the program, a Kirchhoff PSDM was included in the workflow as a complementary product. With the addition of quality assurance tools to provide 3-D velocity perspectives and to assess well tie quality, the workflow continues to evolve as additional improvements are identified for inclusion.

Conclusions

From design to execution, the program represents a significant industry advance in delivering fully integrated, regional seismic programs that can provide reliable geologic context in depth. The convergence of quality high resolution acquisition with tightly integrated collaboration of interpretation, velocity modeling and depth processing is demonstrated to be fundamental to the successful delivery of new fully integrated regional scale with exceptional local detail in the Gulf of Mexico deepwater. The major innovation is not the application of a specific technology but the disciplined, systematic approach that links leading-edge tools, technologies, and collaborative industry expertise within an internally consistent region-wide framework. Of particular value to successful execution were:

- Integrated cellular approach to building the program.
- Close linkage at all times of interpreter expertise and processing team.
- Development of interactive support tools to support interpreter effectiveness.
- Use of independent geophysical measurements to guide the interpretive effort.

Availability of consistent, integrated regional scale adds value to the understanding of petroleum systems mechanisms that are recognized to reduce exploration risk in this complex subsurface regime.

References

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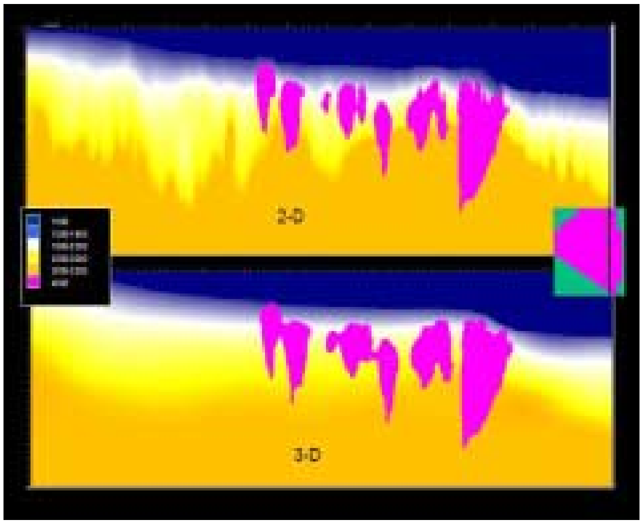

Figure 1: Line profile before and after 3-D smoothing.

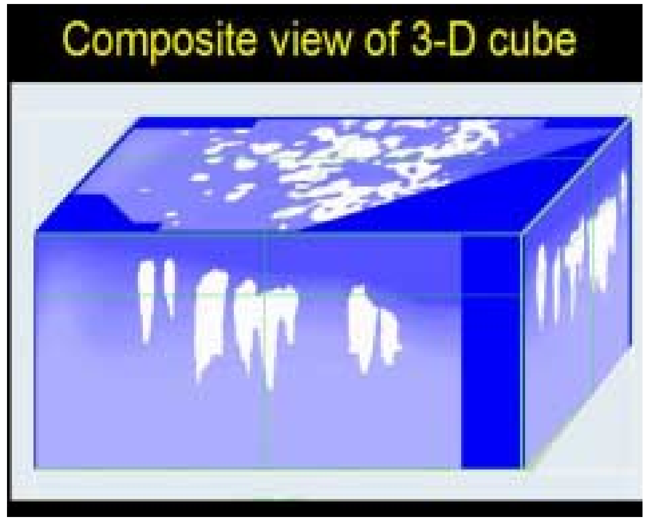

Figure 2: Composite Cube – Velocity and Salt bodies.

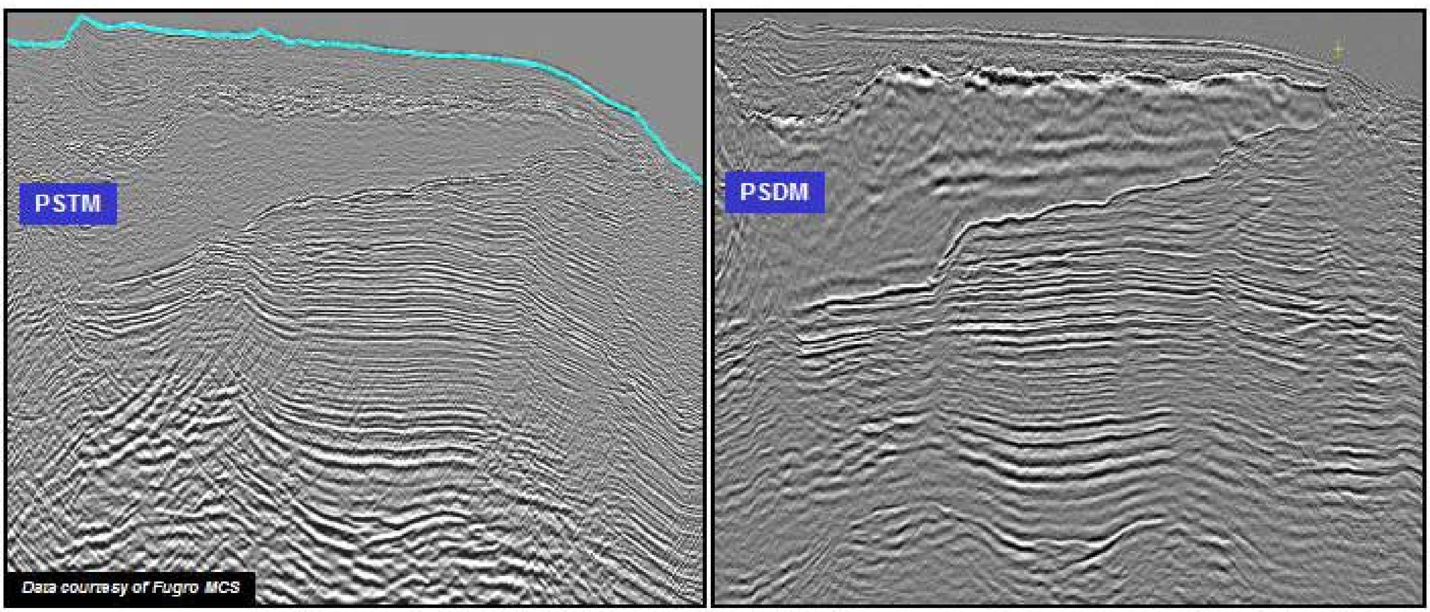

Figure 3: Improved structural positioning with PSDM. Left: prestack time migration. Right: Wave-equation depth migration.