

Addressing Challenges in Deep Water Gulf of Mexico Depth Imaging Through Geologic Models and Acquisition Simulation - The Tempest Project

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Summary

This paper describes the framework for constructing a realistic deep water Gulf of Mexico geologic model, marine acquisition simulation using full offset wave equation, application of various depth migration tests using the known model, and comparison of the model data results to real data results. The main focus of our project was to construct a realistic geological model, to simulate seismic acquisition using typical marine acquisition geometry and parameters and to image the data using prestack depth migration algorithms that are used in routine production processing. The project results are a series of prestack depth migrated volumes generated using various Kirchhoff and wave equation algorithms. These volumes serve as an interpretation guide and aid our understanding of complex salt bodies and subsalt structures in real deep water Gulf of Mexico datasets.

Introduction

The exploration team at Devon Energy Corporation routinely interprets subsalt geology from data acquired in the Gulf of Mexico. Most of these datasets include areas of very poor signal. Over the years both seismic data as well as imaging algorithms have improved enabling better interpretation of subsalt data. However, there are still large areas where the image quality is not sufficient for accurate interpretation. In order to improve our ability to correctly interpret areas of low illumination and poor signal, we undertook a project to enhance our understanding of the limitations of subsalt seismic data as well as prestack depth migration algorithms. This was done by creating a typical deep water Gulf of Mexico geologic model and velocity dataset and comparing its imaging results to real data imaging results.

Over the past few years we increased our ability to simulate real data phenomena such as optimal acquisition geometry, optimal processing flows and selection of prestack depth migration algorithms. Since these above key technologies can be optimized only knowing the model (i.e. the answer), seismic simulation provide a practical way to take important decisions in all seismic data collection and imaging, leading to better understanding of the real data and more accurate interpretation of the real data.

The project presented in this paper demonstrates an important improvement in simulation work - the ability to

generate a complex three dimensional model and to simulate such model using wave equation algorithms. This technology is not new, but up to recently was not practically used due to its high cost and execution time. With the recent development in both computer hardware and software, complete full offset finite differences simulation projects are feasible, using appropriate key parameters such as large apertures and high frequency bandwidth and can be done in a timely manner so their results will be used as part of the exploration project.

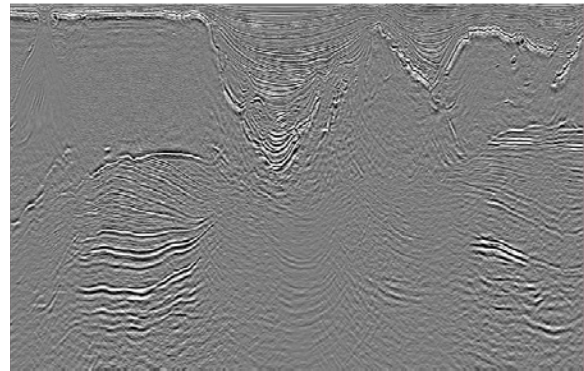


Figure 1a: Seismic example of imaging challenges in the sub salt Gulf of Mexico. Seismic data courtesy of CGGVeritas.

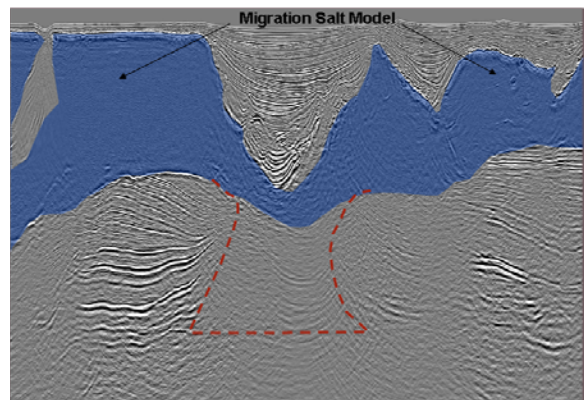


Figure 1b: Seismic example with migration salt model and alternative salt model. Seismic data courtesy of CGGVeritas.

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Gulf of Mexico Imaging Challenges

The regionally distributed and often geometrically complex allochthonous salt canopy in the Gulf of Mexico creates a challenging imaging environment. Advancements in computing hardware and development and optimization of depth migration algorithms has lead to better images of sub salt geology, yet many regions remain unclear and too difficult to interpret (see figure 1a). Is this due to acquisition parameters? Is it due to incorrect velocity models? (see figure 1b). Furthermore, what effect do complex salt geometries such as steep allochthonous salt flanks and a rugose base salt have on the ability to image the subsalt section? Can subsalt fault planes be imaged, and in more general, how do these challenges affect imaging potential exploration targets? These ongoing questions inspired us to design, simulate and image a typical deep water Gulf of Mexico model so we can try to gain a better understanding to the above questions. We named this project – Tempest.

Model Design Goals

At its inception, the Tempest geologic model’s purpose was to create an acoustic model that addresses 3D imaging challenges geoscientists encounter in their search for oil and gas in the salt province of the deep water Gulf of Mexico. Careful consideration through input from interpreters, was taken to ensure that the final product represented documented, reproducible Gulf of Mexico geology and ensured that it was not a model consisting of

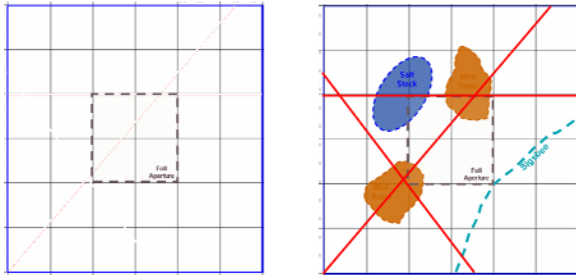


Figure 2: (a) Map covering the Tempest model input area consisting of 36 OCS blocks with each block measuring 3 miles per side. The 36 block input allows for full illumination of the four central blocks. (b) Tempest model input area with the distribution of salt features and the location for the 3 framework lines.

unrealistic structural and salt geometries that is aimed at testing algorithm deficiencies. Major features in the model

include: water bottom geometry, allochthonous and autochthonous salt bodies including salt roots, allochthonous mini-basins, subsalt faulting and deep target three-way and four-way structures. Conscientious thought was taken to ascertain that structural geometries and distribution of salt related features accurately represented common and documentable sub salt features observed in the deep water Gulf of Mexico.

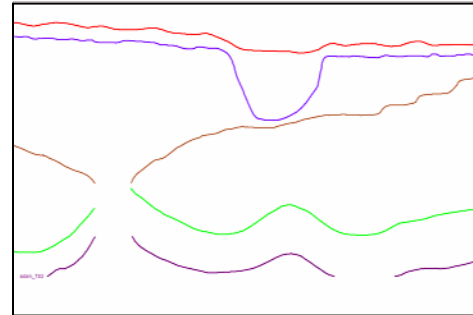


Figure 3a: Example of digitized cross section used to create the model framework.

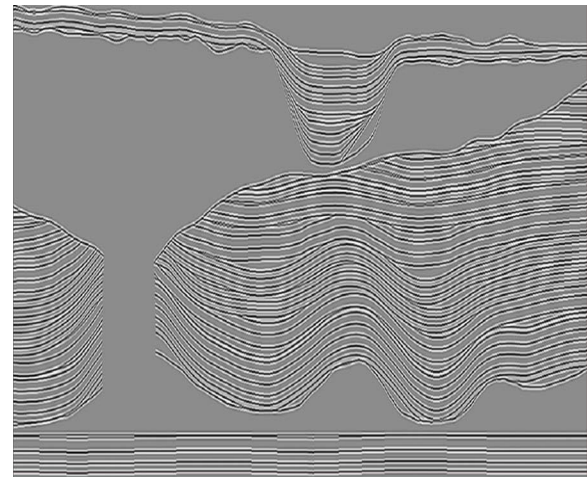


Figure 3b: Example of cross section convolved with a 25 Hz Ricker wavelet, demonstrating the progressing from conceptual work lines to seismic data.

This enabled the model to be used not only for imaging, but as a diagnostic tool to identify potential interpretation pitfalls, validate salt related structural model concepts as well as comparisons of migrations with a known velocity model and industry acquired speculative data.

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Model Framework

Taking into account the imaging challenges previously mentioned and using direct examples from industry data (see figure 1a), the construction of the 3D Tempest model began with a base map of the input area, consisting of 36 OCS blocks (6x6 blocks, 3 miles to a side). The project base map is shown in figure 2a. This input area has full illumination in the four central blocks. The challenge in building the model was distributing common salt features responsible for imaging challenges in a small region, roughly four OCS blocks, while ensuring reproduction of plausible geology (see figure 2b). Model construction began using the based map for orientation of structural and salt features.

Four common salt features, a salt root connecting the autochthonous to allochthonous salt, a welded mini basin, a salt floored mini basin and a representation of the Sigsbee escarpment were placed and used as the first guidance for the model. It progressed with three, hand drawn 2D cross sections that intercepted these features, creating the basic model framework. While additional structural geometries occur in the Gulf of Mexico salt provenance, including all such features in a limited area would create an unrealistic geologic model that could not be reproduced in the real world.

The 3D model evolved by moving from paper to the digital realm by digitizing the three hand drawn cross sections (see figure 3a), input into three dimensional space and used to guide further model development. Generation of the salt geometries and sub salt structures throughout the model was an iterative process between the interpreters and model builders, ensuring that accurate and realistic features were represented, and guided by the cross sections. The macro layered geologic model was convolved with a 25Hz Ricker wavelet (see figure 3b) for evaluation and final validation. The final product is a three dimensional model that emulates the geologic environment of interest (shown in figures 4a and 4b).

Depth Imaging Results and Interpretation Conclusions

From the final three dimensional Tempest geologic model, an acoustic velocity model (i.e. consists of pressure velocity field) was constructed. Using a marine acquisition design, an acoustic finite difference wave equation modeling program was used, generating a shot sorted set of field records as primary output. Following simulation, reference prestack depth migrated volumes were created by migrating the data set with the known velocity model. Both Kirchhoff summation and common shot wave equation algorithm were used to migrate the narrow azimuth and wide azimuth datasets. Free surface multiples were not

included in the acquisition following the goal of the projects focus as a strict imaging exercise.

While the Tempest model's overall complexity is relatively benign, the migration results using the known velocity model were demonstrative and very instructive because the model represents real geology that can be directly related to the geology in the Gulf of Mexico. Because the modeled complexities are discrete events, we can analyze and hypothesize the origins of lack of illumination without being biased by unrealistic, overriding complexity.

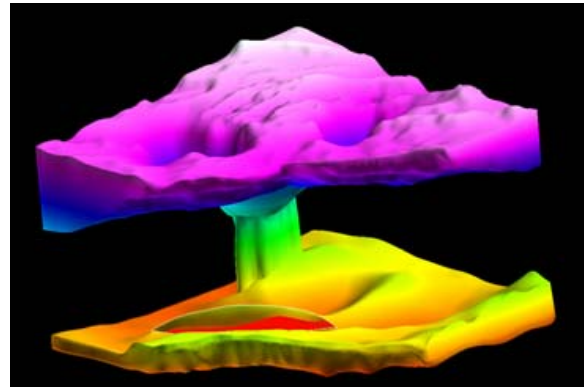


Figure 4a: 3D view of the Tempest model autochthonous and allochthonous salt.

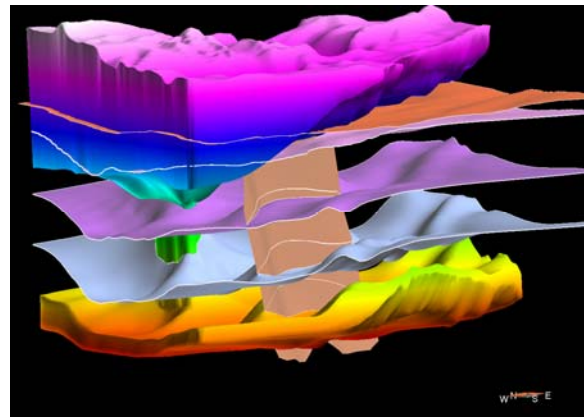


Figure 4b: 3D view of the Tempest model autochthonous and allochthonous salt, fault and surfaces.

By migrating the data using both Kirchhoff and wave equation algorithms, a comparison highlighting their strengths, weakness and more importantly how they complement each other was achieved. While the wave equation prestack depth migration generally produces a cleaner and better resolved sub salt image,

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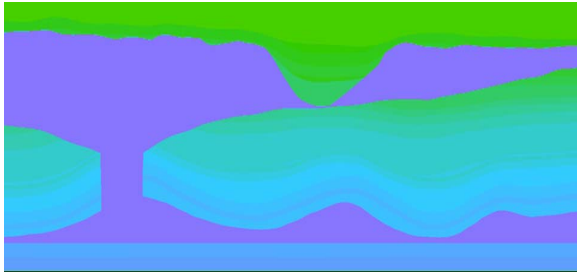


Figure 5a: Known velocity model input for depth migrations.

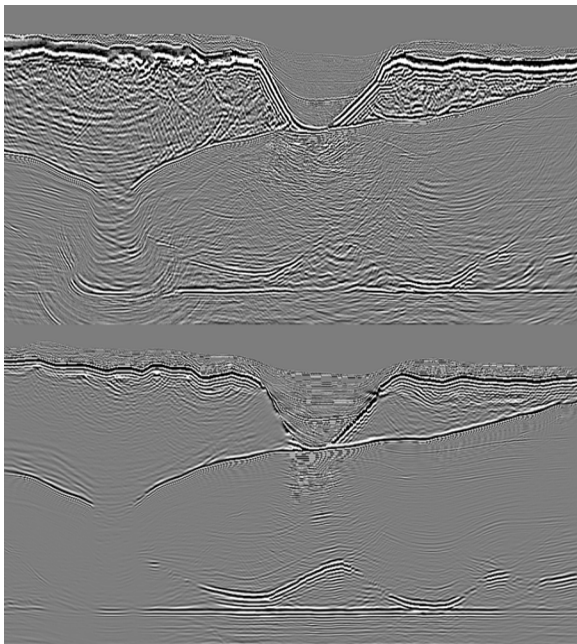


Figure 5b: Migration examples using the known velocity model. Top is Kirchhoff summation, bottom is common shot wave equation. Note how the Kirchhoff produces a crisper steep dipping top salt image and a cleaner basin and weld image. The wave equation produces a better sub salt image with less migration noise. Notice that both algorithms were challenged by the right side of the salt pillow and beneath the welded mini basin. Also, observe the migration noise and multiple generated by other interfaces aside from the free surface.

the Kirchhoff summation algorithm better captured the top allochthonous salt steep dips and salt flanks in the deep mini basins.

Both migrations were not able to resolve the vertical root, yet both wave equation and Kirchhoff algorithms did place basement reflectors in the proper place below the root. This result can be used as an analog for real data,

supporting interpretation models of salt roots where no structures are resolved in real data. Other results show that fault planes are still difficult to resolve, yet the wave equation produces a better image than the Kirchhoff summation algorithm. As important, another result from the migration was the ability to document the migration noise and multiples produced that are not a result of the free surface.

Conclusions

Guided by analogs representing real imaging challenges in the sub salt provenance of the Gulf of Mexico, a geologically realistic, 3D model was created. The full 3D model generation was a combination of geologic guidance from interpreters working in the Gulf of Mexico and an iterative model building process between the interpreters and model builders. Migration results using the known velocity model from the Tempest project enable the comparison of different depth migration algorithms, highlighting their positive and negative attributes and most importantly, how they complement each other. Tempest has helped Devon understand seismic expressions of complex geometries and since the model was designed based on real data images, the analysis of its results can directly be used in comparisons to real data.

Acknowledgments

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2008 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

No references