A Realistic Deep Water Gulf of Mexico 3D Simulation and Imaging - The Tempest Simulation, Datasets and Imaging

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Summary

The Tempest 3D model and dataset were generated to test industry's ability to correctly image deep water Gulf of Mexico subsalt structures. The project included four steps: (a) design of a 3-dimensional model based on real Gulf of Mexico geology; (b) acquisition design that included narrow azimuth, mid (range) azimuth and wide azimuth geometries; (c) numerical simulation using two-way wave equation algorithm and construction of three synthetic datasets; (d) application of various prestack depth migration algorithms for testing of subsalt imaging quality.

The project parameters acquisition design and prestack depth migration algorithm parameters were all selected based on a single guideline: to be done as close as possible to field data acquisition and imaging. By following this guideline we obtained a dataset which realistically represents our ability to resolve subsalt imaging challenges. In this paper we present the project steps and demonstrate its main results.

Introduction

In late 2005 Devon Energy Corporation realized the need to have a Gulf of Mexico model based 3-dimensional synthetic dataset in order to quantify deep water subsalt interpretation concepts and how well current technology can imagine them. Several 2-dimensional synthetic datasets were generated over the years and became available to the industry. These include the Marmousi dataset (Versteeg R., 1994), the various SMAART JV datasets (i.e. Pluto and Sigsbee), and the recent BP dataset (Billette and Brandsberg, 2005). In 3 dimensions, only the SEG salt model synthetic dataset was produced by the industry (Aminzadeh et al., 1997).

Together with SeismicCity Inc., Devon Energy Corporation decided to develop a 3D model based on deep water Gulf of Mexico geology, simulate and acquire a marine synthetic dataset using the model, apply various prestack depth migration algorithms and compare the results to real data results.

The project and its derivatives were named - Tempest. Construction of the model and simulation of the synthetic datasets were done during 2006, and various depth migration algorithm tests were done during 2006 and 2007.

In this paper, we present the Tempest project. In the following sections we describe the construction of the 3D model, the design of the acquisition geometry, we explain the simulation process, and then the prestack depth migration algorithms that were implemented. We conclude with the major lessons learned from the project and our view of similar future projects.

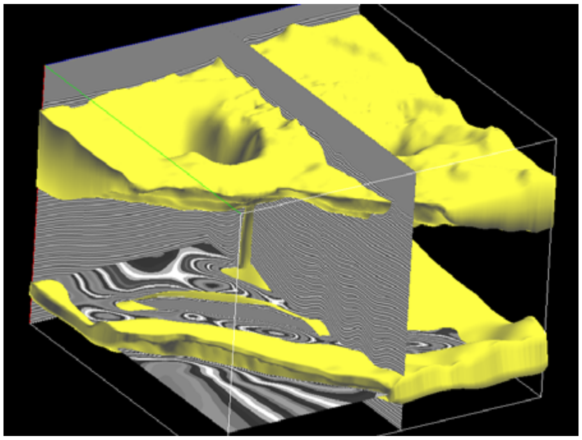

Figure 1: The tempest salt body consists of an allochthonous salt connected to an autochthonous salt through a vertical salt stock.

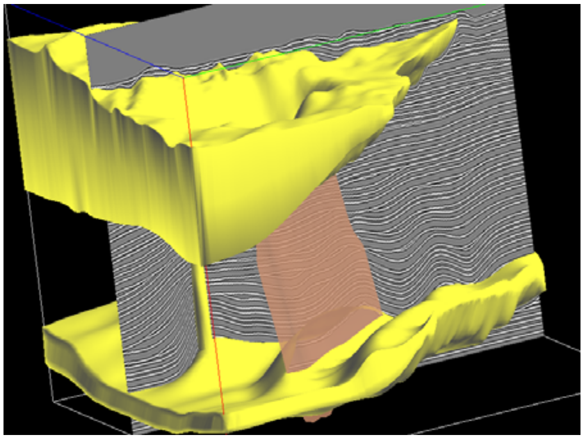

Figure 2: The tempest fault plane starts at the autochthonous salt and continues through the subsalt section to the base of the allochthonous salt.

Model Building

Model building of the Tempest project is based on real deep water GOM geology. The construction of the 3D model started with three 2D cross section drawings that included the main features of the 3D model: The water bottom geometry, the allochthonous and autochthonous salt bodies and the subsalt fault. From these three 2D cross sections a complete 3D model was developed (see figures 1 and 2).

The 3D model was constructed in two phases. First, a macro model consisting of about 15 layers was built. Second, a detailed model consisting of about 60 layers was build from the macro model (see figure 3). The reason for generation of the detailed model was to create the Gulf of Mexico velocity gradient by incrementing the velocity from one layer to another, and at the same time to have a model that when used for numerical simulation will result in seismic reflections in close proximity to one another, making the synthetic data closer in nature to field acquired data.

The final Tempest 3D model includes a large allochthonous salt body that is fairly easy to image and interpret, a subsalt fault and vertical salt stock that are difficult to image, and a deeper autochthonous salt that appears speared throughout the model. The subsalt section consists of a series of sedimentary layers with several key structures.

The model size is 36 OCS blocks (i.e. 900 sq. Km) and is 42,000 ft deep. The model was built on a 20m x 20m grid. The Tempest simulation was done using the acoustic wave equation and therefore the model consists of pressure velocity only.

Survey Design

The Tempest survey was designed to achieve two goals. The first goal was to create a narrow azimuth dataset that will be used to test the ability to correctly image subsalt structures. The second goal was to create a wide azimuth dataset that will be used to test the advantages of wide azimuth imaging. In order to test both narrow azimuth as well as wide azimuth acquisitions, three dataset were recorded. The first one was a narrow azimuth dataset, the second was a mid (range) azimuth where the streamer boat is located about 2Km away from the source boat, and a third, wide azimuth dataset where the streamer boat is located approximately 4Km away from the source boat. These three datasets can be combined to a single, wide azimuth dataset (see figure 4).

The streamer configuration was of 13 streamers for each boat, each streamer with 200 channels. This resulted with 2,600 channels for each recorded shot. The distance between receivers was 40m and the distance between streamers was 40m.

The simulation was done by shooting a total of 111 boat passes where at each boat pass 181 shots were simulated. The distance between two shots along a sail line is 160m and the distance between two sail lines is 260m. The above parameters resulted with constant surface fold of 25 for the near azimuth dataset.

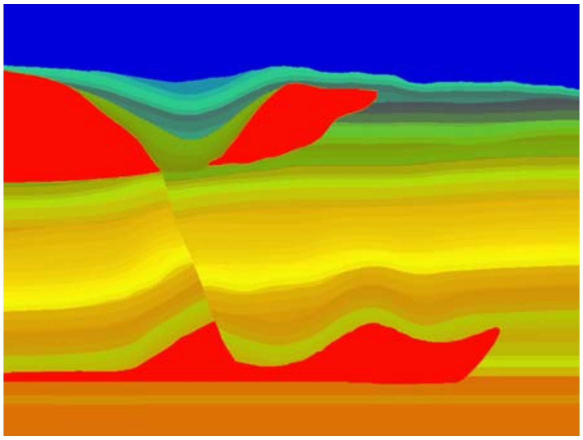

Figure 3: A profile from the tempest 3D velocity model.

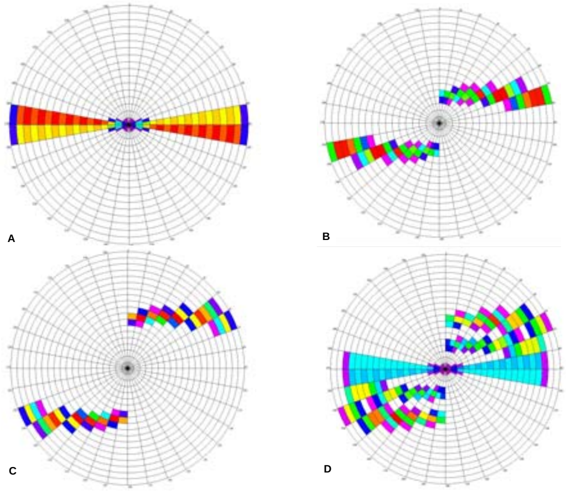

Figure 4: Azimuth distribution of the tempest datasets:
(A) Azimuth distribution of the narrow azimuth data set.
(B) Azimuth distribution of the mid (range) azimuth data set.
(C) Azimuth distribution of the wide azimuth data set.
(D) Azimuth distribution of the three combined data sets.

The total number of simulated shots was 20,000. The recording time for each shot was 12 sec with 4 msec sample interval.

The number of shots per block is lower than what usually is done in field acquisition, but one of our goals was to produce a dataset which is not too large, so different groups will be able to process it in the future.

Numerical Simulation

One of the main selections of tools for the Tempest project was to use a wave equation algorithm for the simulation of the shot gathers. The other option was to use ray trace simulation methods. Wave equation simulation however is much more appropriate for generation of synthetic seismic data that can then be used for processing and imaging.

Full offset, multi shot 3D wave equation simulation is a computer intensive process. In order to complete the generation of the 20,000 shots in a timely manner, a series of multi node computer clusters were dedicated for the simulation of the shots. The algorithm that was used for the simulation is a 4th order finite difference algorithm. Finite differences are used both for approximation of spatial derivatives as well as for time integration. The 4th order finite differences scheme was selected as the best compromise to achieve both the data quality requested in order to evaluate subsalt imaging quality but at the same time maintain a reasonable cost for the execution of the project. Since, the main objective is to investigate subsalt imaging quality we used an acoustic wave equation scheme with constant density.

Prior to the simulation of the complete 3D survey, test shots were calculated in order to QC the quality of the synthetic data generated (see figure 5). Having the final simulation parameters, the simulation of the complete 3D survey was executed. The resulting computer generated data was written in SEGY format and stored as a regular 3D field data set. In order to QC the generated dataset, a basic time processing flow was done resulting with an NMO stack volume (see figure 6).

Since testing of both narrow azimuth as well as wide azimuth imaging were the objective of the project, the narrow azimuth, a mid (range) azimuth and the third, wide azimuth dataset were all recorded .

The two main objectives of the simulation project were to generate synthetic data for testing of imaging algorithms and of various acquisition designs. The simulation was therefore done using an absorbing free surface condition.

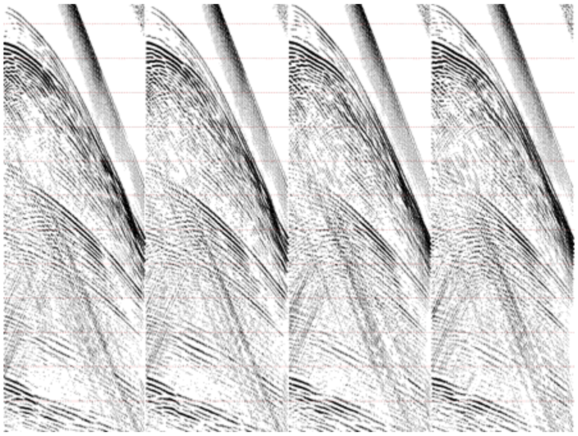

Figure 5: A series of simulated shot gathers.

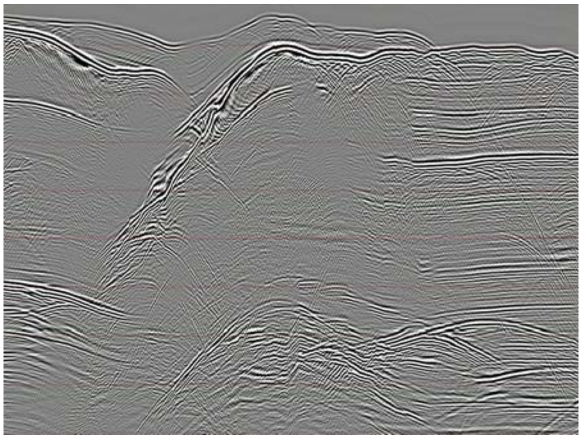

Figure 6: A cross section from the NMO stack volume.

The last simulation parameter to select was the recording time. The recording time was selected to be 12 seconds. This length of recording time is typical to large volumes of seismic data sets recorded at the Gulf of Mexico prior to the more recent wide azimuth acquisition.

The resulting data set includes inner-bed multiples, but is free of free-surface multiples and therefore can be used as input for prestack depth migration with little or no pre-processing.

Depth Imaging

Three objectives were set for the last step of the Tempest simulation project. The first was to test differences between two major depth imaging technologies – Kirchhoff summation prestack depth migration and downward extrapolation wave equation prestack depth migration. The second was to compare depth imaging resulting from narrow azimuth acquisition to depth imaging resulting from wide azimuth acquisition. The last and most important objective was to compare the synthetic data results to real data results and with that to build guidelines for interpretation of real subsalt data.

Depth imaging of the Tempest dataset was done using the exact model. We started by using both Kirchhoff algorithm as well as wave equation algorithm to migrate the narrow azimuth dataset. The Kirchhoff prestack depth migration produced a very clear allochthonous salt image and the wave equation prestack depth migration produced a better quality subsalt section image. None of the algorithms was able to image the vertical salt stock. However, the subsalt fault included in the model can be identified on the wave equation image.

Next, both the mid (range) azimuth and the wide azimuth datasets were migrated using both Kirchhoff summation algorithm and downward propagation algorithm. The mid (range) azimuth dataset was merged with the narrow azimuth dataset to obtain a typical "exploration" wide azimuth prestack depth migrated volume (i.e. with 2Km boat separation) and the wide azimuth dataset was merged with the mid and narrow azimuth datasets to obtain a typical "exploration" wide azimuth prestack depth migrated volume (i.e. with 4Km boat separation). Figures 7 and 8 show sections from the wide azimuth prestack depth migrated volumes.

The last step of the depth imaging part was to compare the imaging results of the synthetic Tempest dataset to prestack depth migration imaging of real data. The focus was the Tempest subsalt section and its four main exploration objectives: a four-way closure located at about 26000 ft, the ability to image a vertical salt stock connecting the allochthonous salt to the autochthonous salt, the ability to image a major subsalt fault, and the ability to image a three-way closure against the subsalt fault. The results of these comparisons were that we are able to image and interpret the subsalt structures, but at the same time it is almost impossible to identify steep dip features such the salt stock and the subsalt fault. Another feature that was analyzed and studied was the different noise artifacts produced in the lower illumination subsalt section. These noise artifacts are very important to be identified as they are commonly seen on real data subsalt prestack depth migrated volumes.

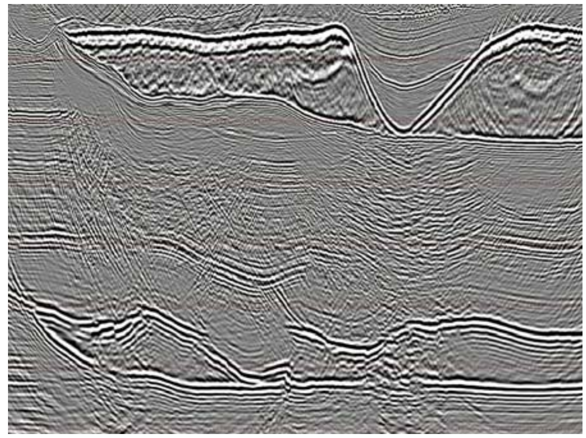

Figure 7: An inline section from the Kirchhoff summation wide azimuth prestack depth migrated volume.

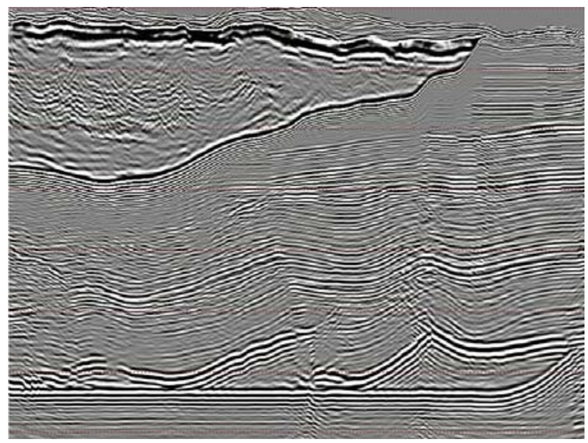

Figure 8: A cross line section from the wave equation wide azimuth prestack depth migrated volume.

Conclusions

We presented in this paper the various steps of the Tempest project. The objective of the project was to create a Gulf of Mexico model and synthetic data set that its depth imaging results could be compared to real data prestack depth migration results. Our main focus was to create a realistic model and dataset so its results can be used during routine Gulf of Mexico subsalt interpretation of real datasets. The observations from the synthetic dataset and depth imaging are assisting us in interpretation of real subsalt data. We demonstrated in this study that construction of a detailed geological model following by full offset wave equation simulation and various prestack depth migrations are feasible and can be done in a timely manner.

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.

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