2D Anisotropic Depth Imaging of the Campos and Santos Basin using Spatially Unified Models: A Case History

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Abstract

This paper will examine the results of reprocessing a legacy 2D dataset. Imaging improvements will be shown to have been achieved both through the use of time domain signal enhancement techniques, as well as through the use of TTI anisotropic prestack depth migration. Furthermore detailed interpretation of the primary geologic interfaces that are associated with strong velocity contrasts was crucial in building an accurate velocity model. Anisotropic tomography at well locations in addition to extrapolation of the Thomson's parameters along 3D consistent geologic boundaries served to further improve the consistency of the resultant seismic images.

Introduction

The Campos basin in Brazil is one of the most active offshore oil and gas prospecting regions in the world.

Recent discoveries in Brazil recorded the world's highest number of oil and gas discoveries in 2011, the majority in its subsalt basins, in pre-salt formations.

The total oil and gas production from Brazil's Santos, Campos and Espirito Santo basins was about 730.5MMboe in 2010.

130,000 km of 2D data over Santos and Campos basins were acquired in 2000-2003. This data was first processed using time imaging techniques in 2003. The dataset was subsequently reprocessed in 2008. The 2008 reprocessing effort improved the structural imaging through the use of tomography and prestack depth migration.

To further improve the interpretability of this data another reprocessing effort was undertaken for lines in the Santos Basin. Multiple energy was a problem with the previous dataset. SRME as well as high resolution radon would be used to better attenuate this energy. The revised processing flow incorporated TTI anisotropic prestack depth migration. In addition to tying salt and carbonate interfaces at intersection points, an attempt was made to propagate the anisotropic parameters along lithological boundaries. The success of this work in the Santos Basin led to a similar reprocessing effort in the Campos Basin (2013).

Figure 1: Study Areas

Setting

Figure 1 shows the locations of the Campos and Santos basins of southern Brazil.

These basins are quite large but similar geologically. Some of the major imaging challenges are the presence of large sheets of halite often overlain with carbonates. The carbonates had velocities similar or higher than the underlying salt formations. Figure 2 shows the basic structures found in the Campos and Santos basins.

Large pre-salt discoveries have driven the interest in imaging these deeper targets. Accurate structural imaging is difficult because of the large lithological changes. These changes include irregular thickness of the salt formations, post-salt rafted Albian carbonates and anisotropy in post-salt clastics as well as in carbonates (H. Farmer et.al. 2011).

The top of the salt formations tend to be complex, especially in relation to the fairly flat base salt structures. Proper accounting for the salt and carbonate velocities, as well as for the anisotropic post-salt clastics removes the distortions of the base salt interface seen in conventional time imaging.

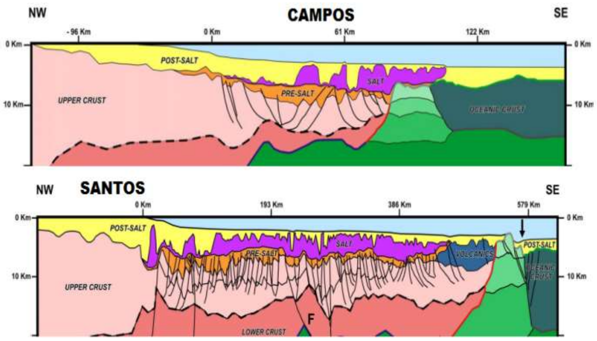

Figure 2: Geological Cartoon (P Zalan et. al.)

Method

Preprocessing

The primary goal of the reprocessing effort was to improve pre-salt structural imaging. This would be attained by a variety of imaging and modeling techniques, but improvements were also obtained via enhancement of the data input to the final depth imaging.

The uplift in the time domain data was achieved through a variety of means that included but were not limited to:

-- Debubble and zero-phase conversion

-- 2D SRME

-- High resolution radon

-- Spectral Enhancement

As multiples were quite evident in the 2003 processing, significant uplift was gained by the inclusion of SRME and high-res radon.

Initial Model Building

Accuracy in structural imaging is dependent upon accuracy in the models input into the imaging algorithms.

An initial velocity field was build using two passes of isotropic tomography in the pre-salt clastic section. Though the analysis was done on separate 2D lines, the velocities were in the end gridded to fill a 3D volume that would in a sense, unify the velocity field.

In order to improve the accuracy of the velocity model, checkshot information was used to calibrate the unified velocity field.

Figure 3 shows the location of the nine wells that were available. Of these only four were chosen to be used for calibration. The excluded wells either had not checkshot information or entered salt very shallow. It was decided to discard these locations from calibration.

Calibration scalars were obtained that would match the unified velocity field to the checkshots. These scalars were then gridded to the 3D volume. Propagation of these scalars was done along five interpreted horizons that included water bottom and top salt.

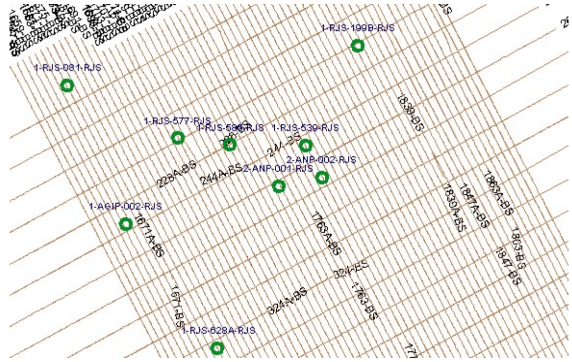

Figure 3: Santos Basin 2D survey map with well locations in green

Anisotropic Parameter Estimation

Isotropic prestack depth migration was performed using the well calibrated velocity model.

As with the calibration scalars, a unified 3D dip field was estimated from the 2D profiles.

When performing isotropic PSDM with a checkshot corrected velocity field one would generally expect that the resultant migrated gathers would not be optimally flattened. The residual curvature that existed in these gathers was used to obtain estimates of the anisotropic parameters epsilon and delta. These parameters were derived at the four locations where the checkshots were used for velocity calibration.
Epsilon and delta were simultaneously estimated though the use of a focusing analysis technique

Demigration of the migrated gathers was performed to get the correct focusing operator in time domain. The focusing operator will produce a resolution higher than picking travel times in time domain. The demigration approach thus improves the accuracy of the anisotropy parameter estimation. It also allows the initial model to be either isotropic or anisotropic. (Cai et. al., 2009).

The epsilon and delta functions thus derived were then used to build 3D volumes that encompassed the 2D survey. Figures 4 and 5 show the resulting unified epsilon and delta models.

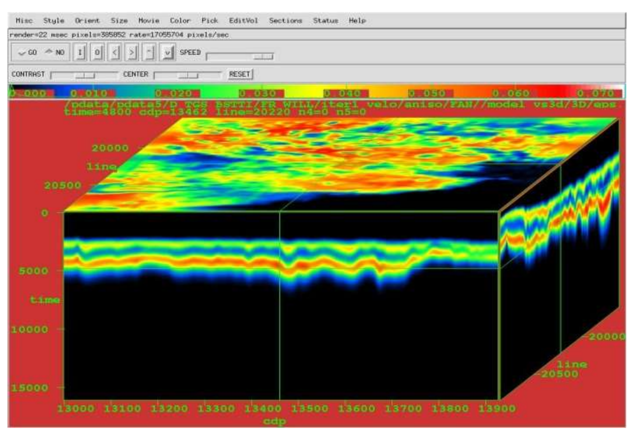
Figure 4 Unified epsilon model

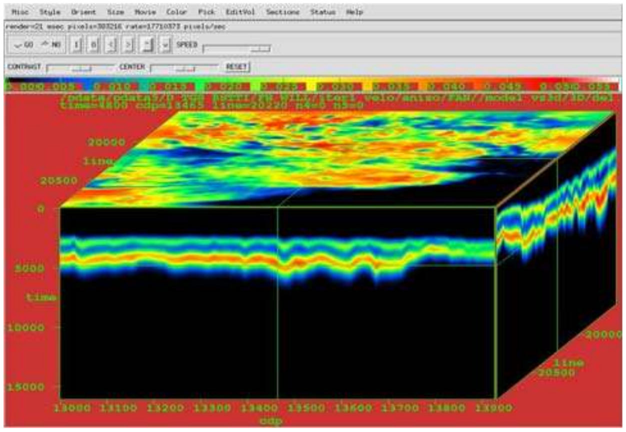

Figure 5 Unified delta model

Using this approach the maximum values of epsilon and delta were found to be approximately 9 and 7 percent respectively.

Pre-salt Velocity Model Refinement

It was not envisioned that the 3D unified velocity field would be used for the final migration.

Since 2D migrations cannot properly handle dips that are out of the plane of the section, certain adjustments must be made to obtain optimal flattening and imaging of the 2D sections. Dip lines will not necessarily image best with the same velocity field that would image strike lines in the presence of out of plane reflections.

With this in mind refinement of the sediment velocity field was done on a line by line basis. However, starting with a unified velocity field should help with the overall consistency of the final model.

Checkshot information was sparse and it was not felt that updates to the unified epsilon and delta models would be beneficial. Keeping a unified epsilon and delta models should also help with overall consistency of the resulting images.

The pre-salt and pre-carbonate velocity fields were updated using two passes of grid tomography.

For the above tomography runs carbonate and/or salt body masks were interpreted to exclude making velocity updates in those areas which contained salt or carbonate. It was not felt that tomography could capture the detailed structure and large velocity contrasts that occur at the sediment/salt interface.

Carbonate Modeling and Tomography

The carbonate modeling step is a branch point in the processing sequence.

In the Santos Basin there is usually a distinct carbonate layer, which is above the salt layer.

In the Campos and Espiritu Santo basins, the carbonate layer is either indistinct or non-existent. The salt geometries however are generally more complex in the Campos and Espiritu Santo basins. This often requires more iterations of prestack depth migrations to correctly model the salt boundaries.

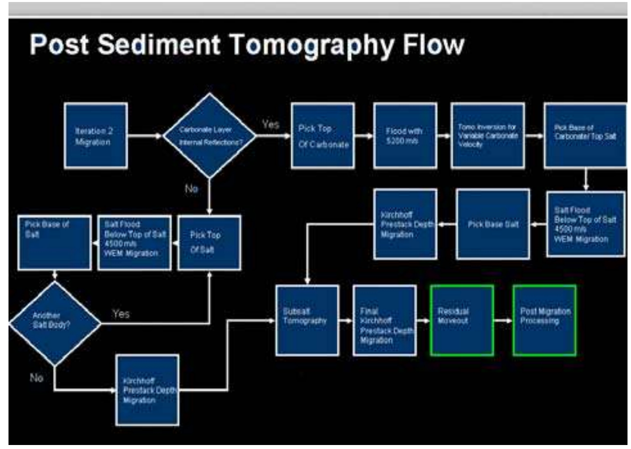

Figure 6 Post sediment tomograpy workflow

Figure 6 above shows the general workflow for these two steps.

If carbonate is present, the top of the carbonate layer is interpreted. The sediment velocity below this horizon is filled with a constant of 5200m/s. Carbonate velocities in this region are faster than salt velocities, but are not as homogenous. 5200m/s is used to get the velocity field closer to the velocity of the carbonate layer. Residual moveout picked from reflector off the base of the carbonate and internal reflectors within the carbonate layer were used to derive a tomographic update for the velocities of the carbonate layer.

Interpretation of the base of the carbonate section (which in this case was the top of the salt layer) was the final stage of modeling the carbonate layer. An attempt was made to tie horizons interpreted on dip lines to those interpreted on strike lines. This is not always possible as 2D migration limits how well the tie points can be made, especially in the presence of out of plane dip.

Salt Modeling

If there was a carbonate layer interpreted, the base of carbonate, which in general is the top of the salt layer, is used to define the region of the velocity model to be flooded with a constant 4500m/s.

If there was not carbonate layer present, top of salt was interpreted from the final sediment migration.

After flooding with 4500m/s below the top of salt, a prestack depth migration was run.

The resulting image was used to pick the base of salt. Sediment velocities were restored below the base of salt, and another iteration of prestack depth migration was run.

If the salt was sufficiently complex to warrant the interpretation of overhang structures, the process was repeated until the salt geometry was completely defined.

Sub-Salt Tomography

Once the carbonate and salt structures were defined, the velocities beneath were updated. This update was achieved though one or two iterations of sub-salt tomography and concluded the velocity modeling stage. The final velocity model was built and final anisotropic prestack depth migration run

Examples

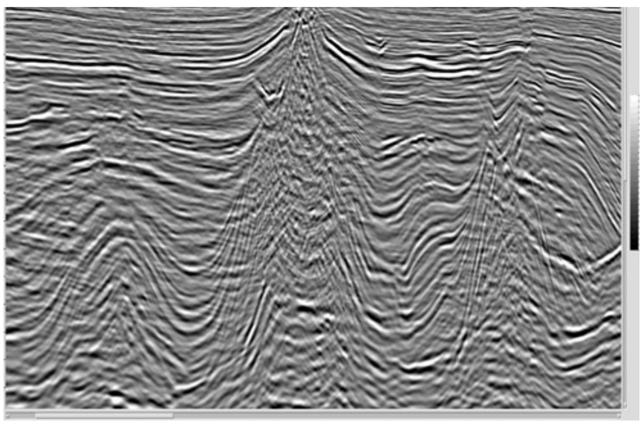

Figure 7 : Previous PSDM Migration

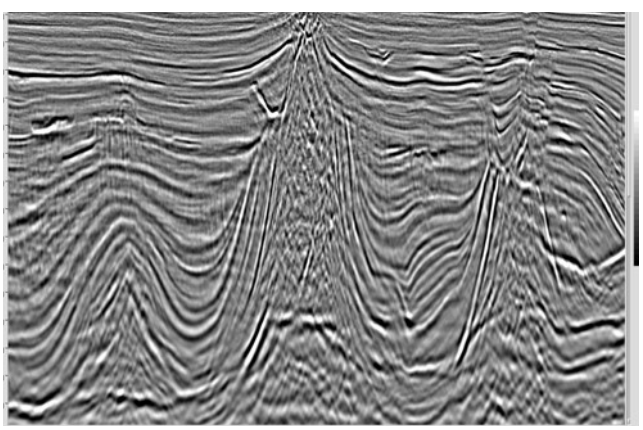

Figure 8 : Reprocessed TTI PSDM Migration

Figure 7 above is the result for the 2007 processing effort. Figure 8 shows the results after reprocessing with the flow described above. Note that the image of the salt has greatly improved. Both top of salt and steeply dipping reflectors against the salt have been dramatically improved. Additionally, the improvement in the preprocessing can clearly be seen in the reduction of the multiples that contaminate the sediment section.

Figures 9 and 10 show a larger portion of a line. Similar improvements are seen here. The continuity of the deeper structures is enhanced. Also the base of salt event (strong even on the right 1/3, mid depth) is shown to have fewer undulations simpler and thus more geologically plausible.

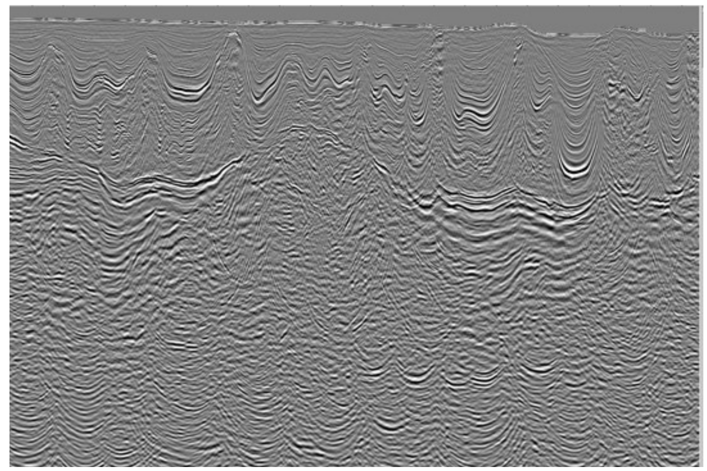

Figure 9 Previous PSDM Migration

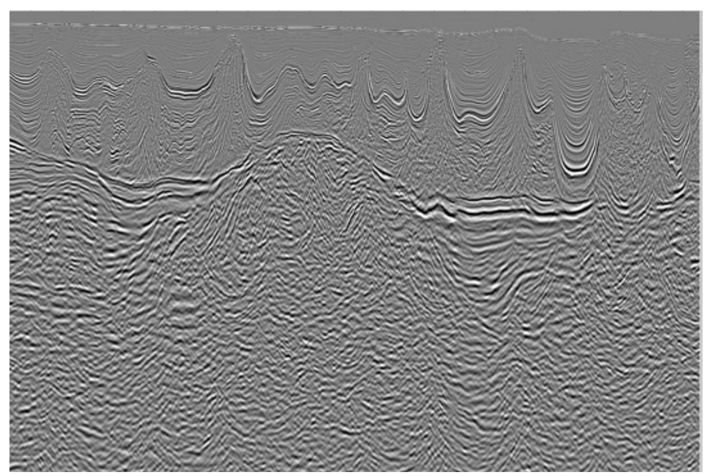

Figure 10: Reprocessed TTI PSDM Migration

Conclusions

Reprocessing of the Campos and Santos datasets with a workflow included:

SRME

Hi-Resolution Radon

3D Structurally consistent TTI anisotropic model

Detailed Carbonate and Salt Modeling

Incorporating the above elements into the processing flow resulted in a product that proved to be a significantly improved dataset. The final images were felt to be more geologically plausible and gave better structural continuity.

Acknowledgments

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Data examples courtesy of the WesternGeco/TGS Brazil 2D Data Alliance.

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