# The Santos Basin Mega-depth Project: Rapid Large Scale Depth Imaging

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### Abstract

This paper reviews the 3D pre-stack depth model building and imaging workflow of the Santos Basin Mega-depth project. The Santos Basin Mega-depth project is located “up-dip” of the recent deepwater pre-salt discoveries, and covers over 20,000 square kilometers of the deepwater Santos Basin. Beam pre-stack depth migration, along with automatic 3D reflection tomography, was the primary tool used to build the depth velocity model.


### Introduction

The Santos Basin, offshore Brazil, encompasses approximately 340,000 square kilometers with a range of water depths from 0 to 3,000m below mean sea level. Approximately half (~170,000 sq. km) of this area lies in the deepwater portion (>1,000m). Less than half (~60,000 sq.km) of the deepwater portion has 3D seismic coverage with most having undergone pre-stack time migration (PSTM) reprocessing over the last several years.

Until recently, most of the exploration taking place in the Santos Basin was focused on post-salt targets between 2500-4500m below sea level in shallow water (50-1000m) using primarily PSTM migrated results from non-exclusive or proprietary 3D projects. Recent exploration successes, beginning with the Tupi discovery in 2004, have moved the exploration focus to the deepwater Santos Basin with pre-salt target depths between 5000-6500m. These deepwater pre-salt (various evaporites including anhydrite and salts) targets require pre-stack depth migration (PSDM) to accurately image structural syn-rift reservoirs.

The PSDM velocity model must take into account not only the interbedded salt layer, but also the isolated igneous intrusions (dikes and sills), fast carbonates above and below salt, and a myriad of multiples observed on PSTM and PSDM sections. These lithologic complexities create structural imaging problems in pre-salt PSTM sections as the strong lateral and vertical velocity variations cannot be imaged properly with PSTM technology. By accurately modeling the igneous intrusions, onlapping carbonate sequences and salt geometries, PSDM can accurately image the structure of the pre-salt syn-rifted reservoirs.

In late 2008 PGS embarked on one of the largest PSDM projects in company history, the Santos Mega-depth project (see Figure 1). This project combines six (6) overlapping 3D surveys, encompassing over 20,000 square kilometers, which were acquired using oth traditional and continuous long offset streamer geometries. It was apparent that the standard Kirchhoff and wave equation PSDM’s typically used for velocity depth model building would not be sufficient to produce a timely product. Consequently it was decided that beam PSDM would be used as the primary tool for velocity model bulding. Advantages of this technology include rapid migration turnaround (days instead of weeks), improved steep dip imaging of complex top salt, improved imaging in the poor signal to noise (S/N) pre-salt section, and additional tools for suppressing remnant multiples / artifacts in the depth domain.

In addition, all of the original 3D surveys were required to be reprocessed with a cascaded de-multiple sequence including 3D surface related multiple elimination (3D SRME) to address multiple energy most notably plaguing the base salt and pre-salt sections.

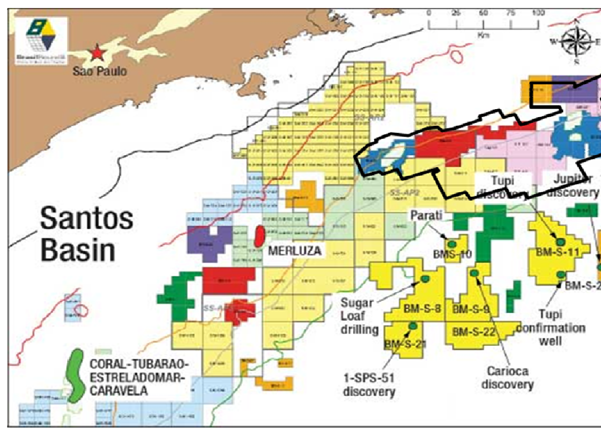


**Figure 1.** Map view of the 20,000 sq.km Santos Mega-depth project (black outline) in relationship to recent ultra-deepwater pre-salt discoveries

### Depth Imaging Technology

The primary tool used for the rapid model building and imaging was beam pre-stack depth migration (BPSDM) (Sherwood et al, 2008). The principal components of this process are:-

1) Decomposition (dipscan), using a multi-dimensional slant stack to break the data into a set of seismic wavelets.

2) Migration, which performs a point to point mapping of each wavelet from the recorded data space to the migrated image space.

3) Reconstruction, which composites each wavelet in its local region of the migrated image space and outputs seismic depth traces.

Speed is achieved because the decomposition is independent of the model used for migration and so is only required prior to the initial migration. Subsequent iterations of migration only require the second and third steps of the process and these, together, require a fraction of the computational resources required by the decomposition step. Given the current state of the art hardware available for BPSDM it has become an “on demand”, if not quite “interactive”, process.

Other features of the BPSDM process that make it a very attractive tool are:-

1) Ability to image steep and overturned dips.
2) Ability to reject multiple energy and coherent noise.
3) Incorporation of anisotropy in the model.
4) Ability to apply 3D residual move-out corrections to the reconstructed seismic traces.

Automatic 3D reflection tomography was used to update the sediment velocity model following each iteration of BPSDM. The automatic tomography picks a dense set of residual depth delays from the BPSDM common image gathers and selects the statistically most reliable ones to perform the model update. This combination of processes allows for the complete updating of a model in a matter of hours compared to the days, or even weeks, required using traditional methods.

Interpretation of the data was a challenge due to the complexity of the structures and the presence of residual multiples on the legacy data used at the model building stage. BPSDM was used to test various interpretations of the carbonate and salt structures that were built into the model. Following salt interpretation and model building BPSDM, automatic reflection tomography was again used to update the pre salt velocity model.

**Depth Processing Workflow**

Build Sediment Overburden Model: A water flood migration was performed with a water velocity of 1490m/s. This water flood migration was then used to interpret the water bottom over the entire region. The PSTM velocity model was then converted to depth, smoothed, and used to migrate the dipscanned data. The sediment flood was then used to interpret a top “fast carbonate/salt” mask horizon that would be used to constrain the automatic reflection tomography iterations used to build the background sediment velocity model (see figure 2). Four (4) iterations of grid-based tomography were used to build the background sediment velocity model for the entire project area. After each tomographic iteration, full volume BSPDM images and offset gathers were created to QC the tomographic results.

Figures 3 through 6 illustrate the data at this stage of the model building and imaging sequence.

Anisotropic Evaluation: As the sediment overburden velocity model was constructed with an isotropic media assumption, it was decided after the final sediment model was constructed to evaluate the existence of vertical transverse isotropy (VTI). An analysis of the migrated output gathers showed no noticeable non-hyperbolic moveout, or the notorious “hockey sticking”, on the far offsets. In addition, over 20 well logs, within the project area, were selected for evaluation. The selection criteria required 1.) wells logs existed (i.e., they were public), 2.) wells were vertical, 3.) wells penetrated into the top salt or into a volcanic sill that could easily be tied to the seismic data. Upon tying many wells with these criteria to the sediment flood volume, it was determined that the delta shift from well log to seismic tie was less than 1.25% for all of the wells evaluated. As these delta values were determined to be relatively small, and that delta is approximately equal to epsilon in this region, anisotropic tomography would not be required and we would proceed building the carbonate/salt portions of the model building sequence.

Modeling the Fast Carbonate Layer: Upon completion of the sediment velocity model building iterations, in-house salt tectonic experts performed the detailed top “fast carbonate/salt” (TFC-1/TOS-1) horizon interpretation. The next procedure in the velocity depth model building sequence was to “flood” below the TFC-1 horizon with appropriate carbonate velocities that flatten the base fast carbonate (BFC-1). Upon completion of the TFC-flood-1, in-house interpretation staff interpreted the BFC-1 horizon, which was only required over isolated areas. In some isolated areas, the TFC-flood-1 with constant velocity was not adequate to image the BFC-1 horizon, and so horizon-based tomography was applied to build a lateral and vertical velocity model for these carbonate layers that allowed the migrated gathers for these regions to be flattened.

Modeling the Salt layer: Upon completion of the BFC-1 horizon interpretation, the next procedure for the velocity depth model building sequence was to “flood” below the BFC-1 horizon with a salt velocity of 4,500m/s. This velocity was confirmed by calibrating with several well logs within the project area. Upon flooding the BFC-1 horizon with salt velocity, in-house expert interpreters began interpreting the base salt horizon (BOS-1). At this stage the newly preprocessed seismic data, with 3D SRME appplied, became available and was used for the remainder of the BPSDM model building sequence. The in-house interpretation staff continued interpreting the BOS-1 horizon, reviewing and revising previous questionable picks that were previously masked by multiple reflection energy. It was observed that the 3DSRME processed data suppressed much of the multiple energy in the pre-salt section, and led to improvements in the BOS-1 interpretation.

Pre-salt sediment model update: As the 3D SRME input data significantly improved the pre-salt section by removing surface related multiples, it was decided that the pre-salt reflectivity was adequate enough to perform several iterations of pre-salt sediment tomography to further flatten the QC gathers and update he velocity model. In addition, application of the beam-based focus/defocus depth demultiple improved the overall image quality by removing additional multiples that the 3DSRME process did not (i.e, peg-leg multiples and mode converted energy with residual moveout).

Final Beam Migration: Upon completing the pre-salt sediment tomography, final beam migrated volumes and gathers were created at fine bin sizes. Post migration processing included near trace muting to improve the stack response, global scaling and filtering to improve the overall appearance, and 3D residual normal moveout was applied to flatten any non-hyperbolic moveout to improve the overall stack response.

**Velocity Model Building Challenges**

1) Anisotropy was not significant enough to be addressed.

2) Shallow volcanic (SV) or basalt sills and dikes were apparent after several iterations of the sediment overburden model building sequence. As most of the SV's were less than 150m in thickness, and testing with and without 150m thick SV did not improve the sub-SV image quality, it was determined not to model these lithologic features.

3) The fast carbonates above salt were generally well behaved and of constant velocity which allowed for a solution with grid-based tomography. However, isolated carbonates required additional layer-based tomography solutions to determine the lateral and vertically varying velocities within these bodies.

4) The top of salt in this region is dissimilar to that of the salt features found in the Gulf of Mexico and West Africa. Many of the salt bodies in the region exhibited internal reflections near the top salt which were not observed to be multiples as they were properly imaged with salt velocity.

5) Portions of the pre-salt region exhibited very little reflected energy and thus reflection tomography broke down in these regions. Pre-salt velocities for these regions were interpolated from surrounding regions.

**Conclusions**

We have demonstrated the value of BPSDM and automatic reflection tomography as tools for rapid depth velocity model building and imaging over a very large project area with very complex geologic problems. The opportunity for more detailed work on selected areas exists. The image quality demonstrates why exploration activity in the Santos Basin is high.

**Acknowledgments**

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**References**

**Sherwood, J.W.C., K.Sherwood, H.Tieman, K.Schleicher,** 2008, 3D Beam Prestack Depth Migration with Examples from Around the World, 70th EAGE Conference & Exhibition, Expanded Abstracts.

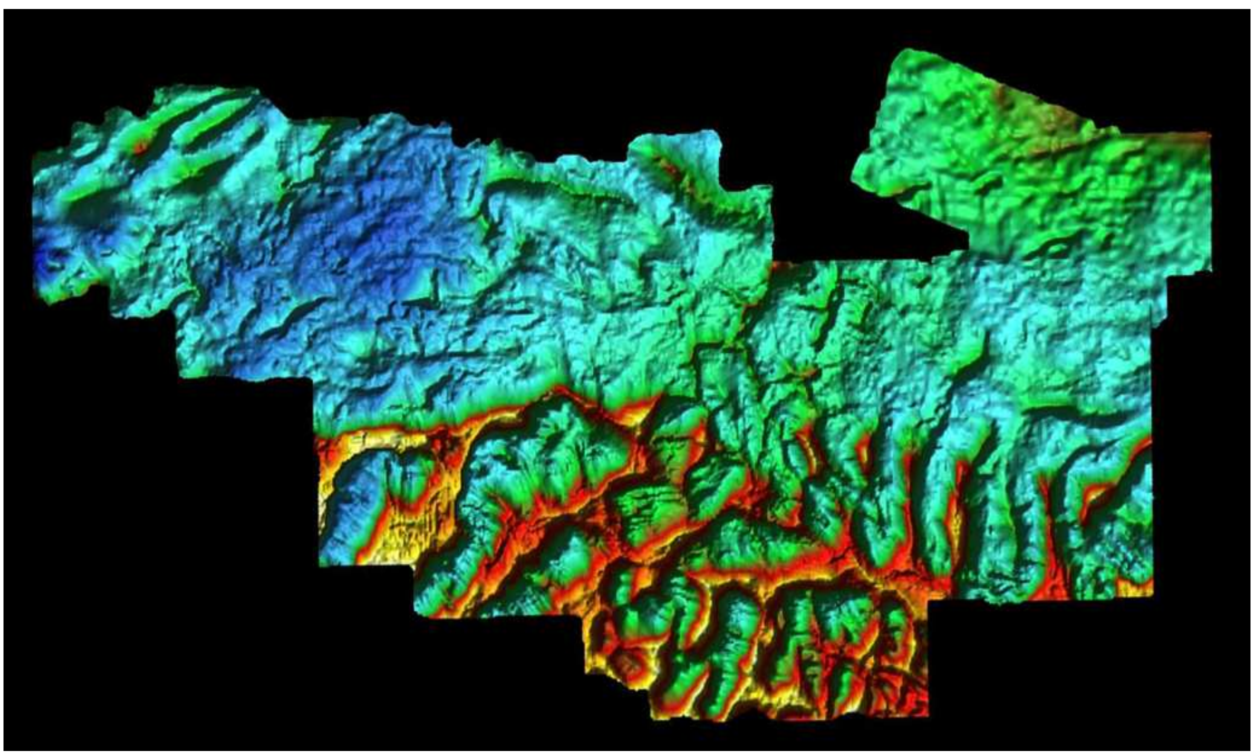

**Figure 2.** Top of fast carbonate / salt mask used to constrain the 3D reflection tomography for building the background sediment velocity model.

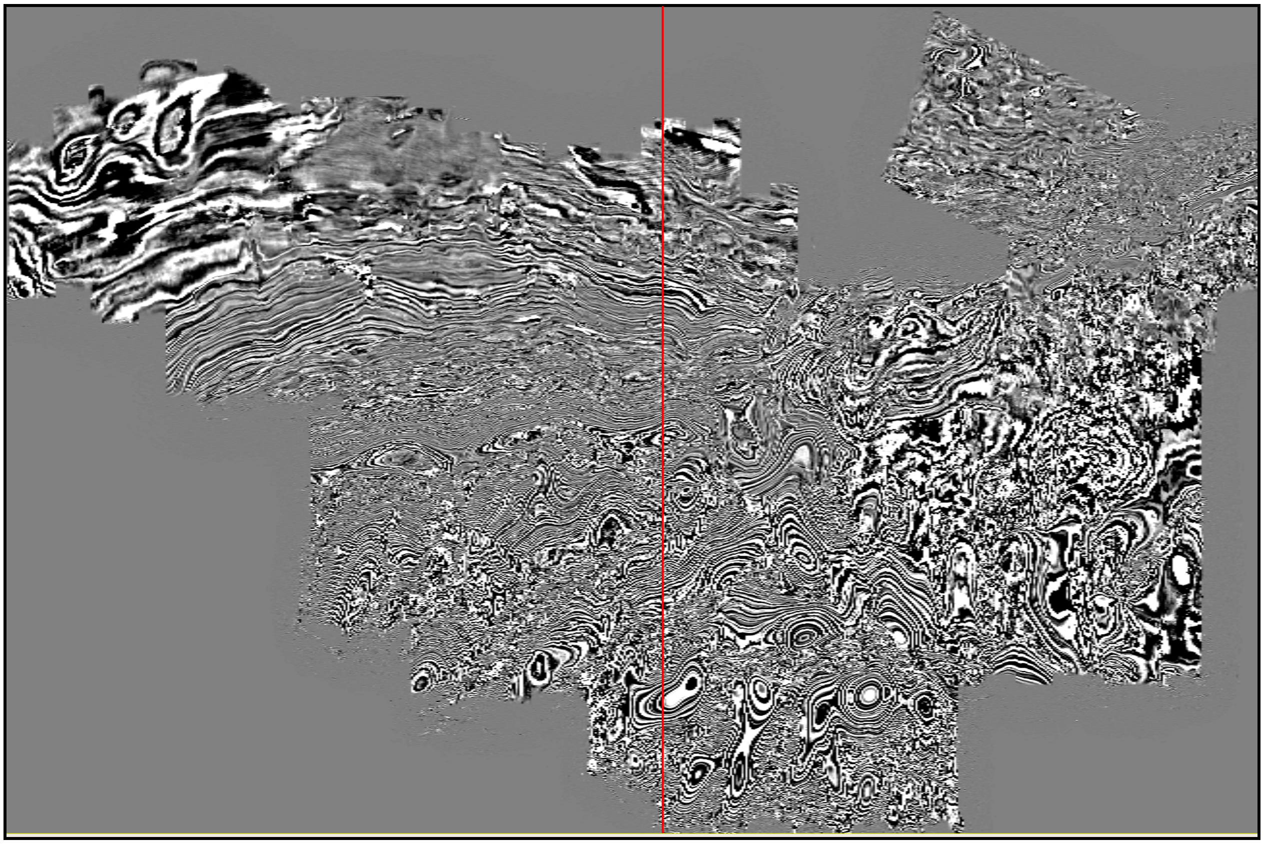

**Figure 3.** Depth slice at 3km of the Santos Mega-depth project, covering nearly 20,000 square kilometers, at the final sediment flood model stage.

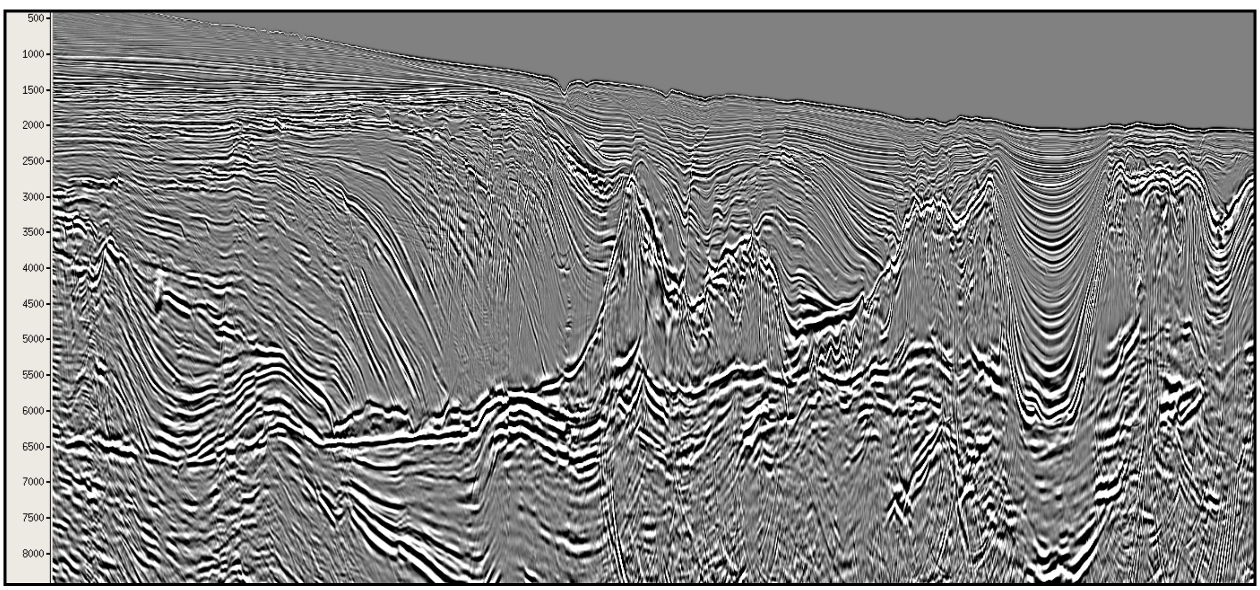


**Figure 4.** North-South profile through the final (4th iteration) sediment flood model of the Santos Mega-depth project. Velocity updates to the fast carbonate, evaporites and pre-salt section have not been applied on this image.

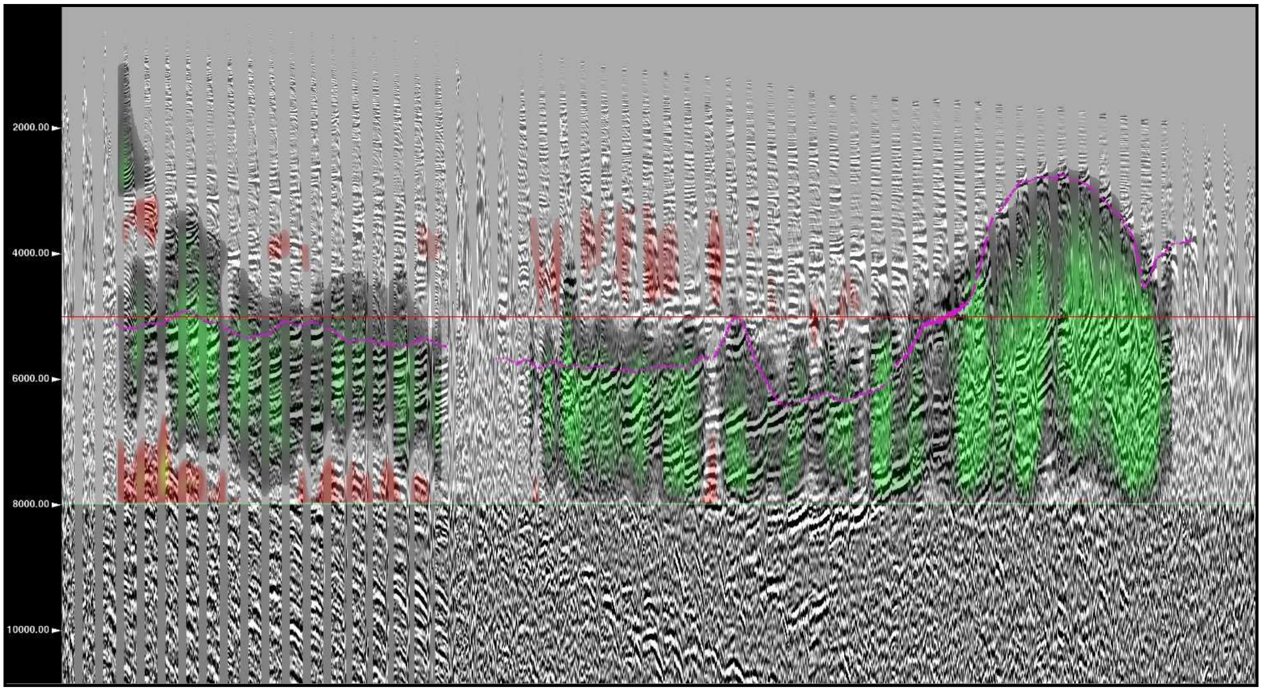


**Figure 5.** Gamma plot illustrating residual moveout calculated after the 4th iteration sediment tomography. Red indicates velocity model is greater 2.5 to 5.0 percent too fast while black indicates the velocity model is 2.5 to 5.0 percent too slow. Gray indicates the velocity model is less than 2.5 percent too fast or too slow. Green indicates the velocity model is greater than 5 percent to slow (i.e, salt).

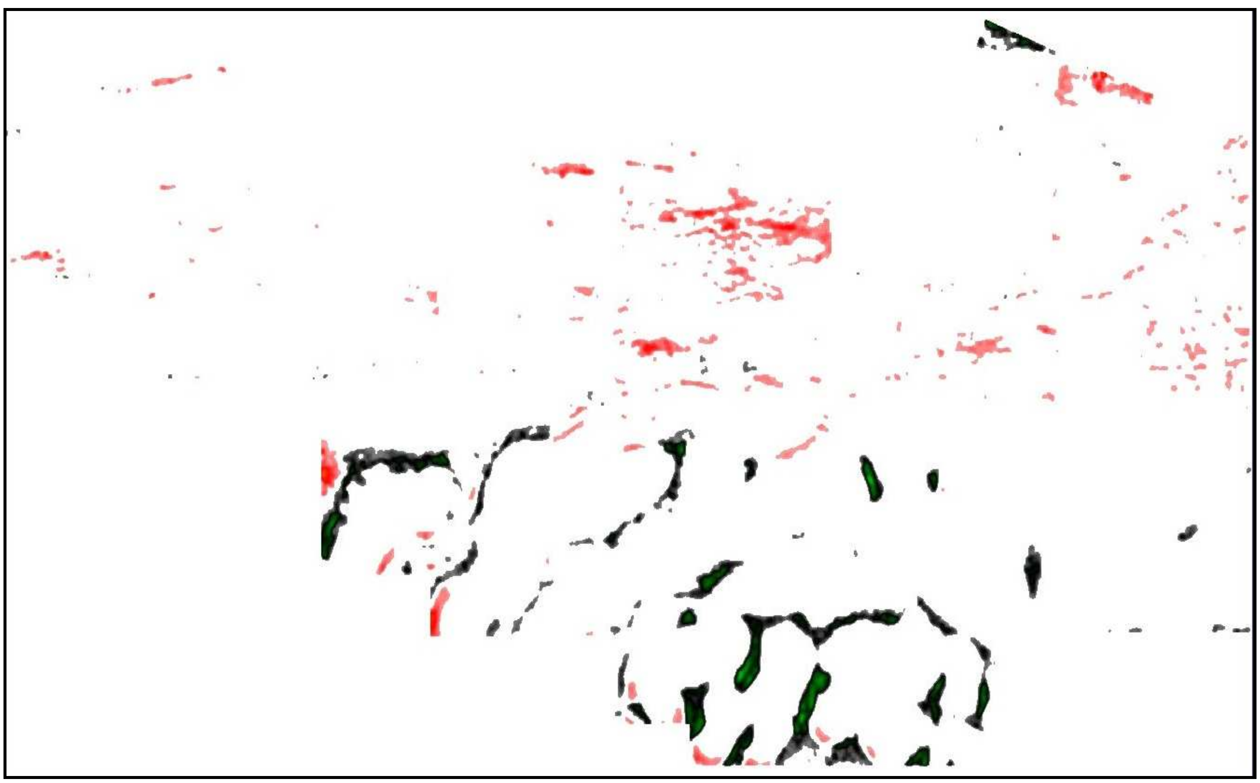

**Figure 6.** Depth slice at 3km of a gamma plot illustrating residual moveout calculated after the 4th iteration sediment tomography. Red indicates velocity model is greater 2.5 to 5.0 percent too fast while black indicates the velocity model is 2.5 to 5.0 percent too slow. Gray indicates the velocity model is less than 2.5 percent too fast or too slow. Green indicates the velocity model is greater than 5 percent to slow (i.e, salt).