Enhanced Presalt Imaging Using Iterative Least-Squares Migration: A Case Study in Santos Basin, Brazil

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Summary

Imaging technologies such as Kirchhoff Migration and Reverse Time Migration (RTM) provide a level of seismic resolution that suit the industry's expectation of capturing hydrocarbon reservoirs and outlining prospects. Over the last few years, Least-Squares Migration (LSM) has become the new standard in high-end seismic imaging, providing a higher level of granularity necessary for prospect risk mitigation, reservoir characterization and well planning. In this case study, we present the advantages of using an iterative LSM for imaging and interpretation of presalt reservoirs of the Buzios Field in Santos Basin, offshore Brazil.

Introduction

Reservoir targets in the Santos Basin are mainly localized in presalt carbonate build-ups underneath the Layered Evaporite Sequences (LES) as shown in Figure 1. Major industry focus on such presalt hydrocarbon reservoirs requires accurate seismic imaging to mitigate exploration risk and to constrain uncertainties in reservoir characterization. To achieve this, as a first step, an understanding of LES (Salt) complexity and the differing character of the postsalt carbonate layers must be incorporated to obtain a good representation of the earth model, which are usually derived from Full Waveform Inversion (FWI).

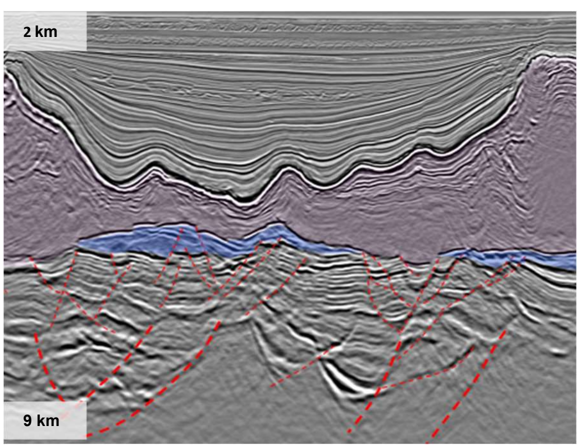

Figure 1: Typical carbonate build-ups (blue) underneath heterogeneous salt (purple)

Even with an accurate velocity model, a conventional depth migration produces an approximation of the earth's true reflectivity, as there is no compensation for acquisition limitations and variable illumination under complex overburden. The result is a seismic image with biased illumination and limited wavenumber content resulting in a compromise of seismic granularity, especially at presalt target depths.

Least-Squares Migration can overcome these limitations by posing imaging as an inversion problem (Nemeth et al., 1999), thereby resulting in an imaging estimate that is closer to the earth's reflectivity. An iterative, data-domain LSM has been used in this case study to obtain a high-resolution and accurate postsalt, LES and presalt reservoir sequence.

Methodology

Different implementations of LSM exist in the industry ranging from image-domain implementations with low-rank approximations (Guitton, 2004) and use of point spread functions (Valenciano, 2008, Valenciano et. al, 2015) to data-domain approaches. In this particular case study, an iterative, data-domain LSM (Lu et al., 2017) with a visco-acoustic, one-way wave-equation operator is used. Synthetic shots are created using Born modeling with an estimate of the earth's true reflectivity and a velocity model. A residual is estimated by minimizing the difference between the observed and the synthetic data and the image is updated in an iterative manner as shown in Figure 2.

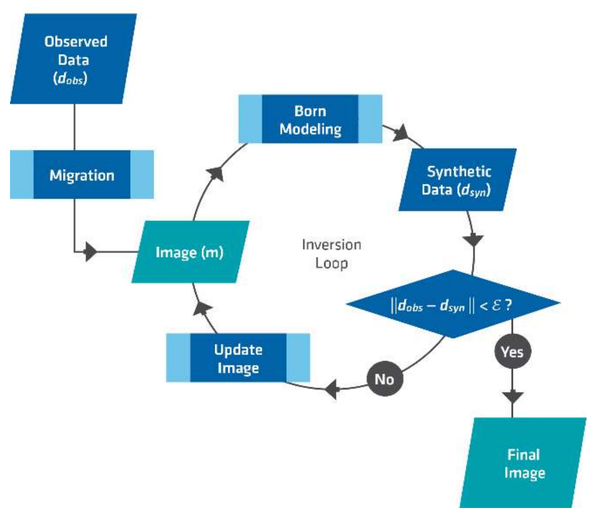

Figure 2: Iterative, data-domain Least-Squares Migration workflow

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Least-Squares Migration is a compute intensive process involving several iterations of modeling and migration. By using a one-way, wave-equation extrapolator, while being mindful of the limitations, a high-frequency estimate of the earth's reflectivity can be obtained more efficiently compared to LSM with a two-way extrapolator. In this study, there are no steep salt overhangs making LSM with a one-way extrapolator a suitable method to generate high-resolution images.

Case Study Details

The study area contains the Buzios field in the Santos Basin, offshore Brazil (Figure 3). The contributing survey is PGS' BS-500 acquired in the 2000. This narrow azimuth (NAZ) data was acquired with 10 cables, 100 m streamer separation and 8 km streamer length.

The inputs to the LSM workflow were: pre-processed shot gathers, a velocity model and a depth migrated stack, which come from a large-scale rejuvenation program (2016 - Present) of PGS' Santos Basin data library. More than 34,000 km^2 of seismic data from 11 separate streamer surveys were merged into a single, seamless, broadband dataset covering a large swath of the Santos Basin.

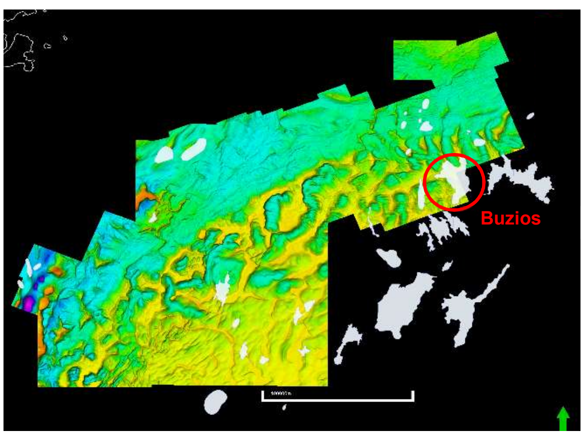

Figure 3: Structural map of Top Salt with the location of the Buzios field in the mini-basin domain

Velocity Model Building

In the LSM workflow, the velocity model remains unchanged. An accurate velocity model is required to avoid cycle skipping between the observed and the synthetic shots, which would results in a subsequent degradation of the updated image.

The postsalt sediment velocity model building workflow in the Santos Basin reprocessing project used a combination of traditional Tilted Transverse Isotropy (TTI) tomography and Full Waveform Inversion. A unique implementation of FWI (Ramos-Martinez et al., 2016), utilizing the full wavefield, was deployed to push the velocity updates down to presalt sections. The result of this workflow was a geologically consistent postsalt sediment velocity model accurately capturing the depth dependent velocity variability of the Albian carbonates and the mega-sequences of the Upper Cretaceous clastic sequences (Figure 4).

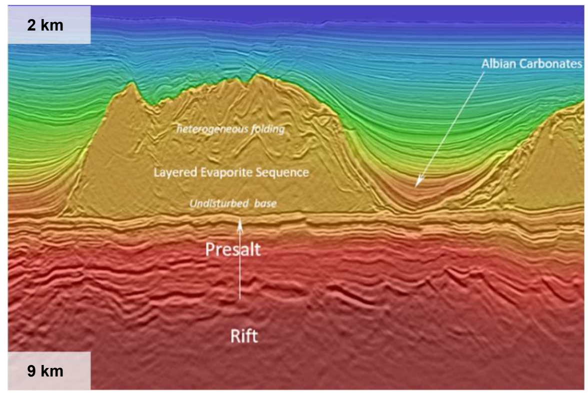

Figure 4: Seismic section with velocity overlay illustrating structural conformity of the model with subsurface geology

An example of the intrasalt velocity update using FWI is shown in Figure 5. A combination of FWI and reflection tomography resulted in a high-resolution velocity model from water bottom through presalt sections in the rejuvenation project. For this LSM study, a subset of the regional velocity model was used over the Buzios field.

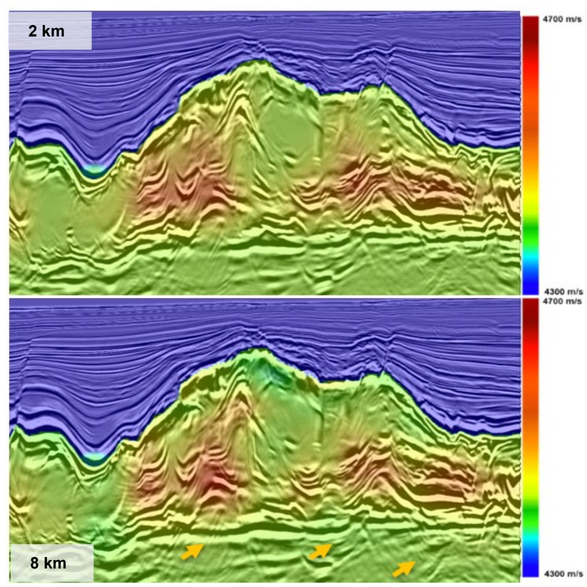

Figure 5: Base Salt and presalt events (indicated by arrows) are better imaged after FWI updates in the LES section

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Least-Squares Migration Results

Although the conventional migration results (Figure 6) from the recent Santos basin reprocessing showed a significant improvement over the legacy data, some improvement in resolution, especially in the presalt sections could aid further reservoir characterization. The objective of the LSM workflow in this study was to address presalt limitations and to enhance the resolution of the presalt carbonate build-ups and fault patterns beneath.

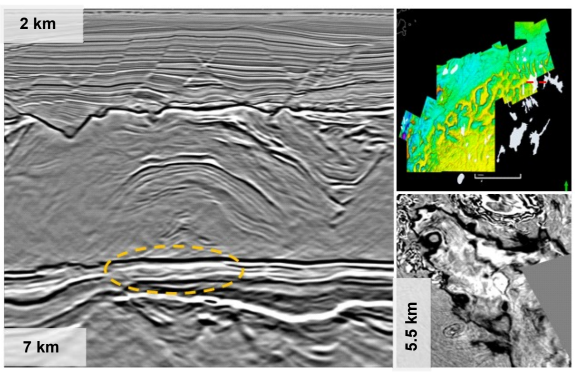

Figure 6: Conventional migration image showing potential for resolution improvement at target depth

The interpretation objectives of this study were to generate seismic images that help to delineate variation of reservoir facies and attribute volumes that highlight potential sweet spots. To achieve these objectives, LSM was performed up to 55 Hz, and the resulting images are shown in Figures 7a & 7b.

The comparison between the conventional migration and LSM results clearly indicate uplift throughout the section with improved postsalt imaging of faults and cap rocks, better imaging of internal salt structures and improved imaging of reservoir sequence in the presalt section. Figures 8a & 8b show the Root Mean Square (RMS) amplitude map extracted in the reservoir section below the Base Salt. Improved spatial resolution of fault patterns is clear after LSM. Furthermore, the amplitudes are more balanced in the presalt section with potential indicators of hot spots for reservoirs visible on the LSM image.

With the enhanced seismic images from LSM, better seismic stratigraphy to characterize reservoir facies changes in the presalt section is now possible (Figure 9). This helps in de-risking field development and production.

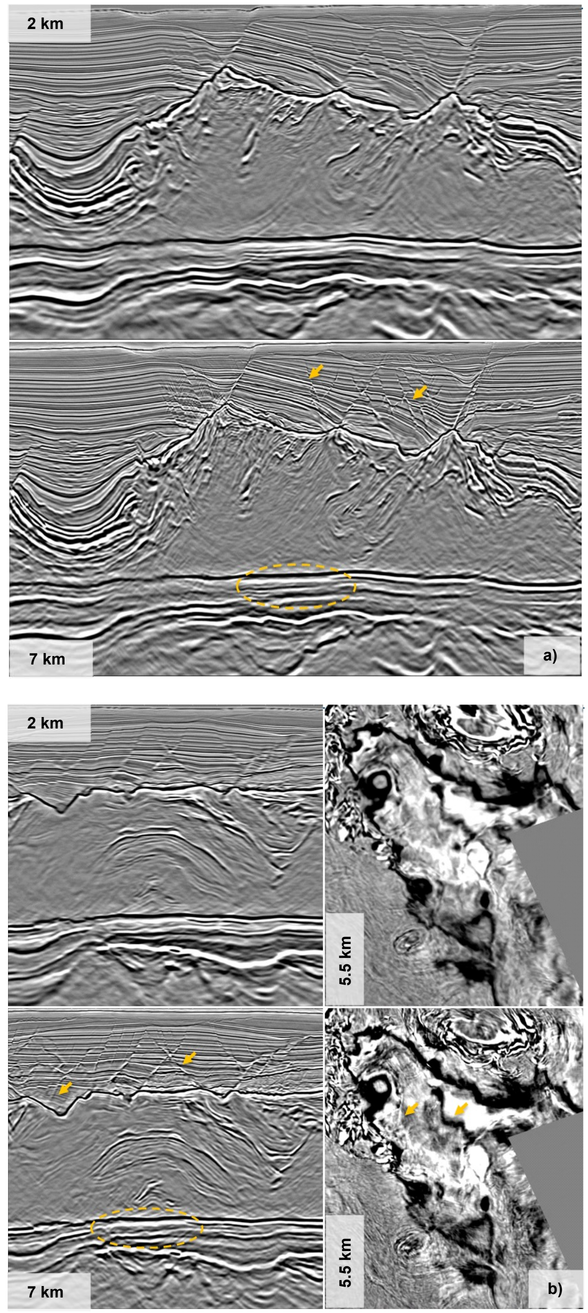

Figure 7: Comparison of conventional migration vs. LSM (55 Hz) a) N-S line b) E-W line and depth slices. The LSM images clearly shown an enhancement in postsalt imaging (faults and cap rocks), imaging of internal salt structures and presalt reservoir sequence.

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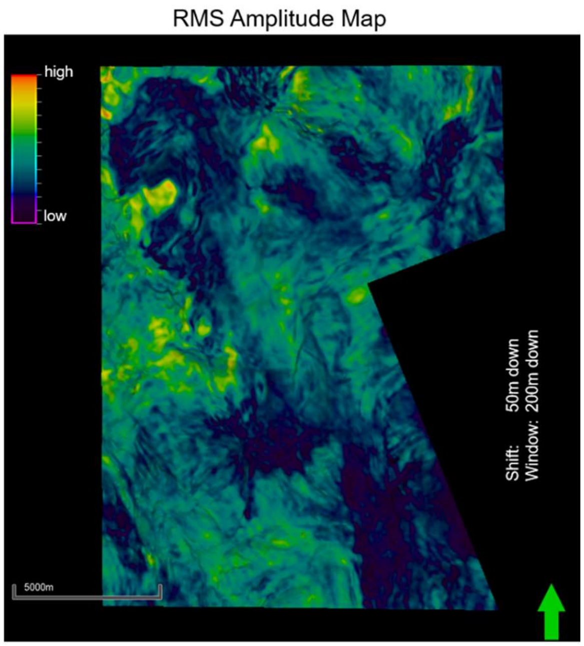

Figure 8a: RMS amplitude extraction from conventional migration within the presalt reservoir sequence below Base Salt. Hot colors indicate high RMS values.

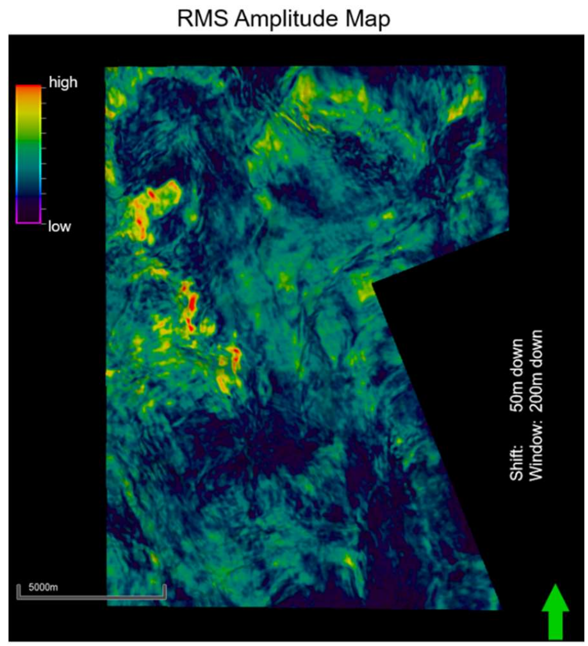

Figure 8b: RMS amplitude extraction from LSM (55 Hz) within the presalt reservoir sequence below Base Salt. Hot colors indicate high RMS values. Note the improved spatial resolution of structures and amplitude extraction with LSM.

Conclusions

The advantages of using Least-Squares Migration in presalt settings are demonstrated in this case study. Using an accurate velocity model for modeling and migration enables robust high frequency inversions.

Improved imaging of postsalt sedimentary geometries and higher resolution of fault patterns in the presalt section have been achieved with LSM. These enhanced images help mitigate reservoir compartmentalization risk, provide a better definition of sweet spots for drilling and allows high-resolution inversion technology for fluid prediction and reservoir estimates.

Acknowledgements

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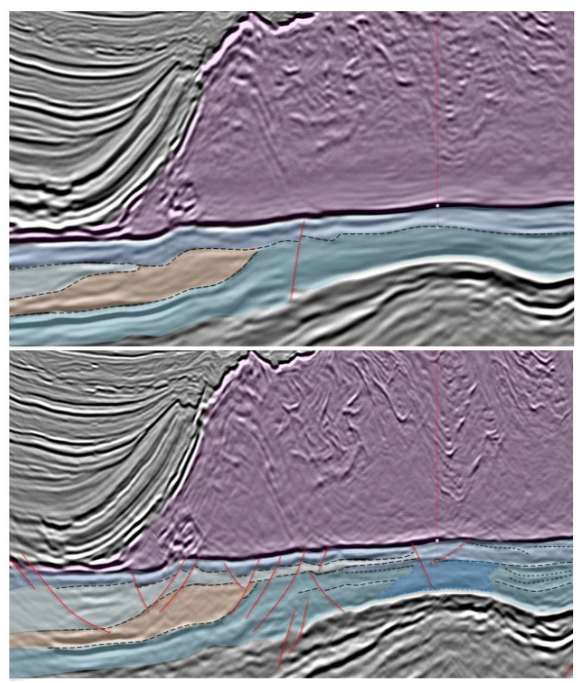

Figure 9: Use of LSM (below) enables better seismic stratigraphy

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