High Resolution Imaging in the Campos Basin using Legacy Seismic Acquisition

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Summary

Many regulatory bodies (as well as sound engineering practice) require a shallow high-resolution survey prior to drilling or adding infrastructure. While there are acquisition methods specifically designed for high-resolution surveying, there is considerable value when a standard survey can be used for providing a high-resolution image. Here we will show a high-resolution depth image in the Campos Basin off the coast of Brazil, as well as a processing flow and technology that result in a higher bandwidth compared to a standard flow.

Introduction

Santos and Campos Basins are proven petroleum systems with over a decade of exploration and production, mostly inboard of the regional SW-NE external high (Zalan, 2020). Internal and external source kitchens have been delineated based on regional potential fields and 2D seismic data where primary reservoirs are carbonate platforms and buildups sealed by massive autochthonous salt bodies. The new 3D dataset we are working with covers outboard parts of the Campos basin, shows allochthonous salt geometries that interplay with different crustal domains, going from continental crust resistate over sediment-filled sag and back to oceanic crust and partially exhumed mantle. Besides Albian carbonates that are draping top of salt, the early Paleogene volcanics at variable depths, and usually small scale, are important to image well, as they are directly affecting seal integrity.

The shallow section is represented by deep marine sediment gravity flows that are predisposed by large salt bodies. Mass transport complexes can be mapped across different depth levels and vary in thickness from 50 m to 250 m. Active salt diapirs are generating slumps and slides in shallow as well as deeper faulting systems in between salt mini-basins.

During 2019-2020 a 3D NAZ survey in the Campos Basin was acquired in two phases using 10 and 12 streamers 10 km in length with a 100 m cable separation. Streamer depth was 15 m and 19 m with a source depth of 8 m. The flip-flop source interval was 50 m on the same source. The targeted midpoint spacing was 25 m x 6.25 m. The high-resolution product for this survey was required to have an image spatial sample interval of 6.25 m x 6.25 m and a vertical sample interval of 3 m. The required bandwidth was 60 Hz, defined as the portion of the spectrum where the amplitude is within 6 dB of the peak amplitude.

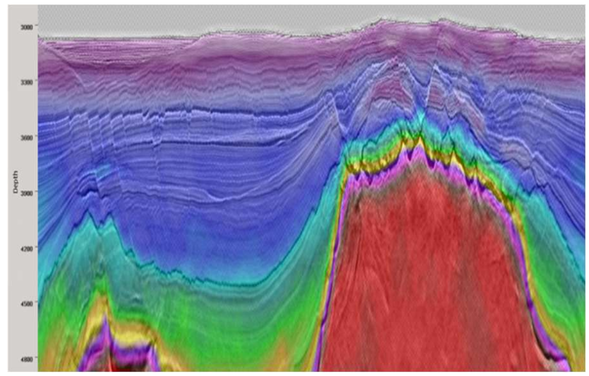

Figure 1. DM FWI velocity model overlayed on the high-resolution image in Campos Basin shows the complementary interplay of the detailed velocity model and image.

Method

To achieve the required resolution a 4 to 1 interpolation was required. In addition to the data density a higher resolution velocity model was also generated using Dynamic Matching FWI (DM FWI). It was very important that the interpolated data, the signal processing, the detailed velocity model and the resulting migration operators worked together to maximize the resulting image resolution.

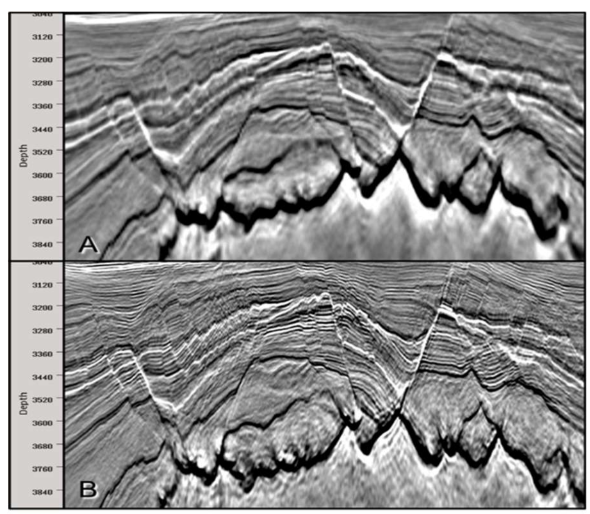

Figure 2. A close up of an inline with fault detail showing the improvement in resolution between the legacy (A) and the high-resolution image (B)

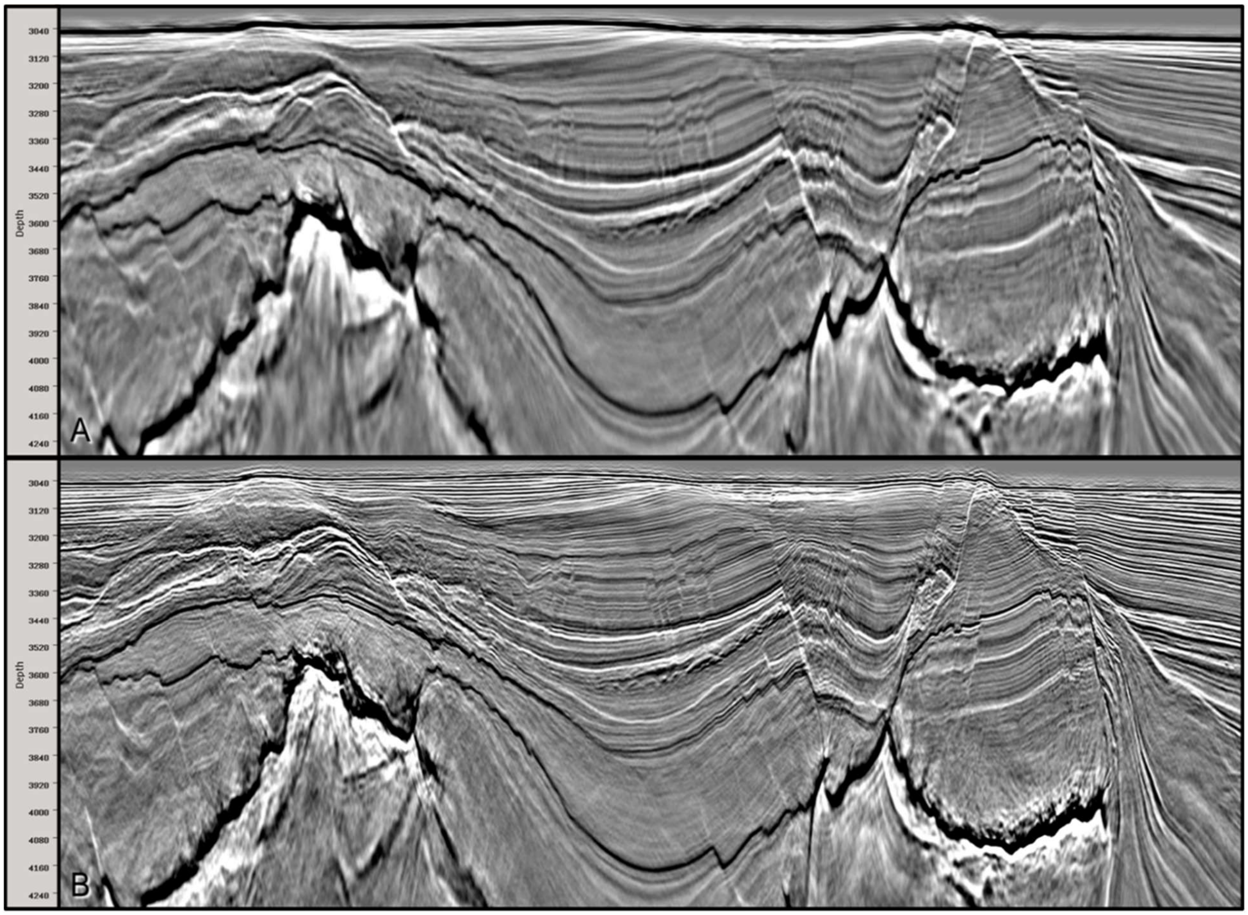

Figure 3. A Crossline comparing the legacy image (A) to the high-resolution Image (B)

The acquired crossline sampling of 25 m begins to have spatial aliasing at 15 Hz and the interpolation to 6.25 m pushes that to 60 Hz. The shallow geology in this survey is rife with shallow faults and small hazards, so the preservation of that bandwidth is paramount. To meet the challenge posed by this high ratio interpolation, we used a variation on Projection Onto Convex Sets (POCS) regularization. POCS interpolation is well known (Abma, 2006). The variation, which we call Dip-POCS, selects the full frequency range for a given dip at each iteration in contrast to the conventional POCS method that uses a single frequency-wavenumber combination. Dip-POCS can produce data that are not significantly aliased in the output geometry while still producing data which maintains a high resolution after imaging. The high order interpolation was a challenge. A sparse Anti-Leakage Fourier Transform (ALFT) (Xu, 2005) interpolation method was originally used on this data. While the ALFT can interpolate data at this ratio without serious aliasing, the sparsity constraint required removes desired discontinuities in the data. Some discontinuities are important, for example, discontinuities in fault diffractions due to the shot move up in a partially moved out common offset section, or the azimuth discontinuity at the boundary of two sail lines. If these discontinuities aren't preserved, it leads to a disconnect between the interpolated coordinates (and therefore the migration operators) and the kinematics present on the interpolated data. It is therefore possible to produce what appears to be high resolution time domain data that cannot be migrated to a high-resolution image. The Dip-POCS algorithm produces data with less aliasing while preserving the desired discontinuities, giving a higher resolution image.

The signal processing also needs to support the desired resolution. Deghosting was done using a sparse 3D tau-p transform based method, followed by the application of a designature filter to flatten the low-frequency biased deghosted airgun signature. Finally, even though the target

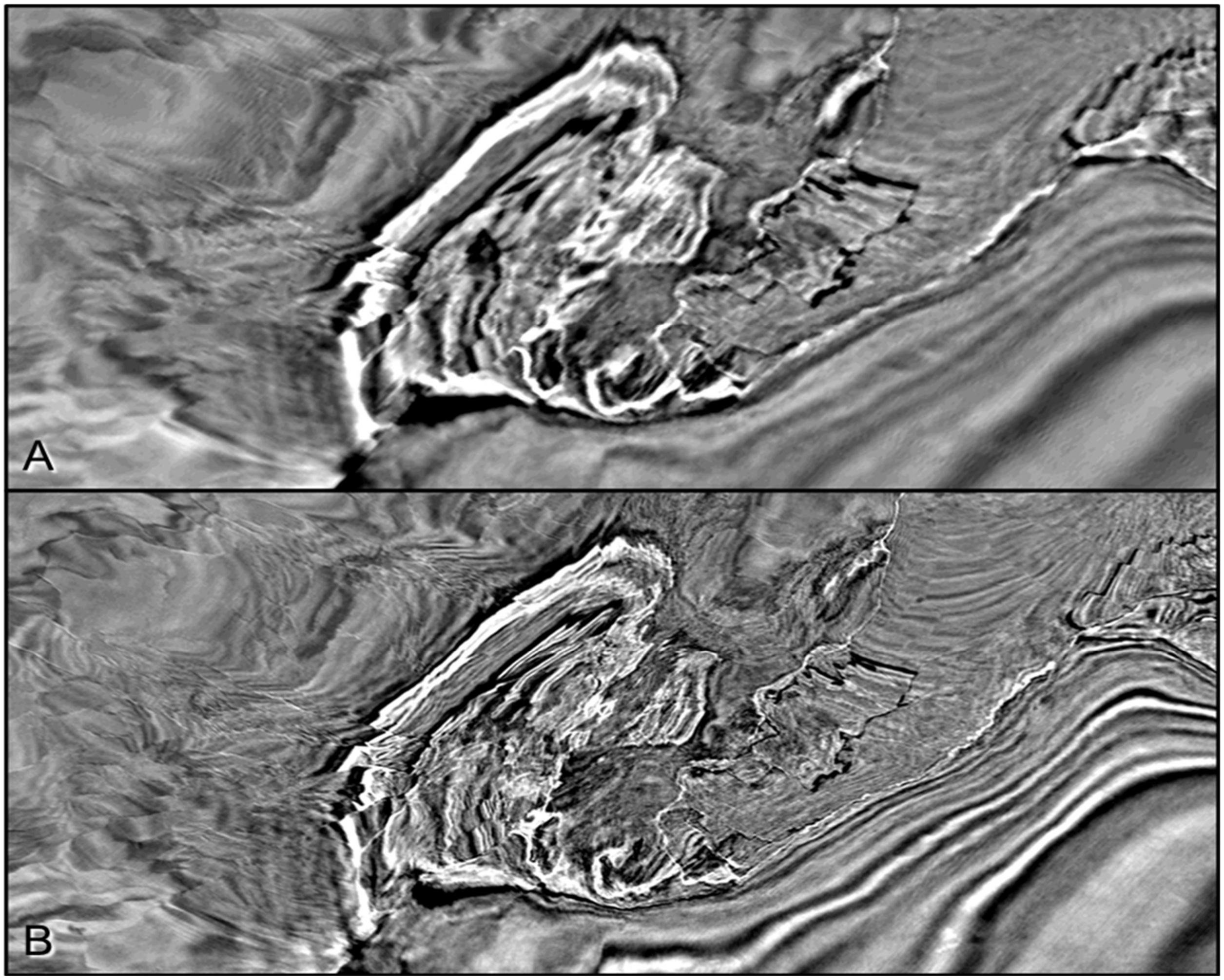

Figure 4. A depth slice comparing the legacy (A) to the high-resolution survey (B)

for the high-resolution survey was fairly shallow at 3 seconds or less below the water bottom, amplitude and phase Q correction were applied. While we may think of Q-correction mainly as a tool for deeper hydrocarbon targets, even within the first second of data, Q-correction can have an important impact on the image resolution.

The velocity model was updated using Dynamic Matching Full Wave Inversion (DM FWI) to accurately capture the details in the shallow sections. DM FWI uses both reflected and refracted arrivals to produce high-resolution velocity models (Mao, 2020). Having a velocity model that matches the level of detail desired in the image was valuable.

Results

The high-resolution image provided significant improvements in details compared to the legacy data. Figure 1 shows the valuable combination of the detailed velocity model and the high-resolution image. Figures 2 and 3 show lines with clear improvement in fault plane and shallow event definition. The desired bandwidth and spatial resolution goals were achieved. Figure 4 shows a depth slice with a substantial increase in lateral resolution. Faults that are difficult to see on the legacy data become visible in depth slices from the high resolution volume.

Conclusions

We successfully produced a high-resolution image from the legacy acquisition. The workflow comprised of Dip-POCS interpolation, careful signal processing, DMFWI and Kirchhoff migration produced an image suitable for regulatory and engineering requirements, nicely displaying the faults and shallow hazards in this are of the Campos Basin.

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Acknowledgments

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