# Application of 3D interbed multiple attenuation in the Santos Basin, Brazil

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### Abstract

Imaging of pre-salt reservoirs in the Santos Basin can be significantly affected by the presence of strong interbed multiples in the data. These multiples can be predicted using a data-driven, true azimuth convolution method similar to surface-related multiple elimination (SRME), and removed using a suitably constrained subtraction technique. We discuss the application of this method to Santos Basin data, and present results on 2D synthetic data and 3D real data.

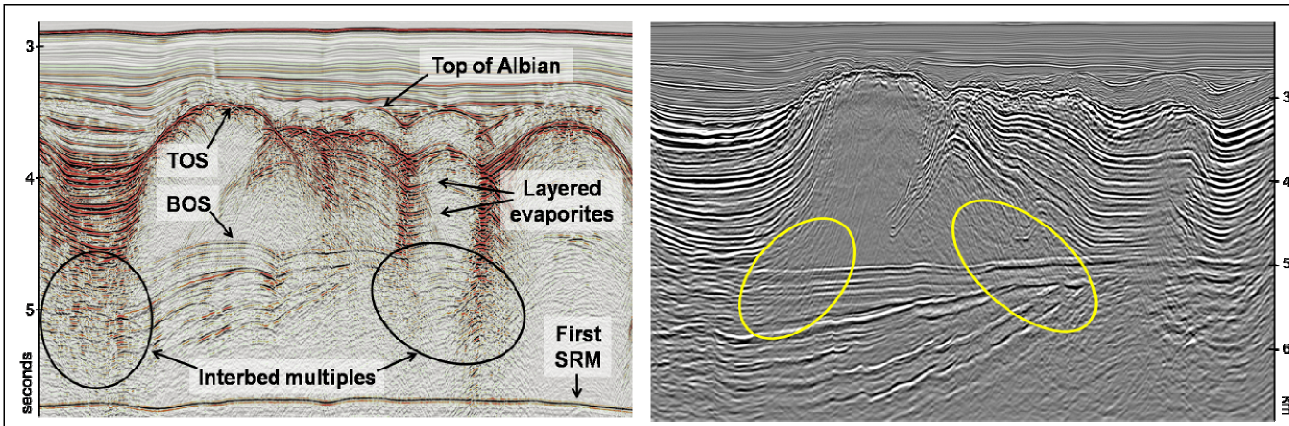
### Introduction

The Santos Basin, offshore Brazil, has emerged as one of the most exciting exploration prospects in recent years. The discovery of Tupi in 2006 confirmed the potential of the pre-salt play. Since then, new pre-salt discoveries have followed in quick succession: Sugarloaf in 2007, Jupiter and Iara in 2008, and Azulao and Iracema in 2009. Further test drilling after the initial discoveries at Tupi, Jupiter, and Iara have indicated billions of barrels of light sweet oil in each field. With reserves of this size, there is considerable interest in overcoming the unique challenges of imaging in this region.

One of the unique challenges to seismic imaging in the Santos Basin is the presence of strong interbed multiples. An example of these multiples can be seen in Figure 1, which shows near offset data from a line near the Tupi discovery. Note that the first surface-related multiple appears well below the pre-salt target. Strong interbed multiples, however, contaminate the pre-salt primaries. The interbed multiples are generated by a series of strong reflectors above the target. The water bottom, top of Albian layer, top of salt, and layered evaporites can all contribute towards generating strong interbed multiples. The strongest of these multiples appear below syncline structures in the top of salt and layered evaporites, due to a focusing effect that traps multiple energy in the minibasin (Pica and Delmas, 2008).

Migration of data with interbed multiples results in migration artifacts that cut across real events. A sample Kirchhoff migration result from this area is shown in Figure 1. Migration artifacts extend from beneath the layered evaporite sequences and across base of salt. In some areas, the artifacts can interfere with fault interpretation in the target.

Several methods have been proposed for attenuating interbed multiples. We review some of these methods, and discuss our own data-driven, true azimuth method. We then present examples of the application of our method to synthetic and real data from the Santos Basin.




(a) Near offset data. (b) Kirchhoff migration

***Figure 1:*** *Interbed multiples in data from the Santos Basin. Note the strong interbed multiples obscuring the pre-salt target in the near-offset data. The first surface-related multiple appears at the bottom of the figure, below the target. The migrated image shows migration artifacts crossing the base of salt and interfering with fault interpretation in the target.*

**Methodology**

Interbed multiple attenuation methods include model-based and data-driven approaches. The simplest of the model-based methods is move-out discrimination. This method attenuates events whose move-out on CMP gathers is not consistent with the local velocity model. This fails in areas with complex structure, as well as when multiples and primaries have similar move-out (El-Emam et al, 2005). More sophisticated model-based methods include wave extrapolation and illumination inside a migrated volume to generate a multiple model (Pica and Delmas, 2008). The success of any model-based method, however, depends on accurate information about the subsurface. This is the motivation behind the search for a data-driven interbed multiple prediction procedure.

SRME works well because a dense sampling of the surface wavefield can be easily obtained from the recorded data. For interbed multiple prediction, however, the wavefield at the downward reflector is not directly recorded. Berkhout and Verschuur (1997) approached this problem by using common-focus-point (CFP) operators to downward-continue the data to the multiple generating horizon. Multiple prediction in the downward-continued data is then a simple SRME-like convolution. The drawback to this method is the dependence on exact CFP operators. Jakubowicz (1998) removed this dependence by introducing an intermediate cross-correlation with the downward reflecting primary. With Jakubowicz' method, interbed multiples can be modeled directly from the data recorded at the surface.

The method we used is similar to the one described by Jakubowicz, as illustrated in Figure 2. A horizon is interpreted to separate the multiple generating events. The interbed multiple prediction is then given by equation 1, following Jakubowicz (1998).

$$P_{213} = P_2 P_1^* P_3 \qquad (1)$$

Where P refers to the wavefields from horizons 1, 2, and 3, and P* refers to the complex conjugate of P. Equation 1 neglects the source terms which can be compensated for using a least squares matching filter during the subtraction stage. It also includes both primary and higher order contributions to the interbed multiple prediction.

Some of the challenges of this method include computational cost and aperture definition. The required aperture must capture both the secondary source and receiver locations corresponding to the primary $P_1$ in Figure 2. It also needs to be carefully constrained as aperture definition is critical for accurate, alias free prediction.

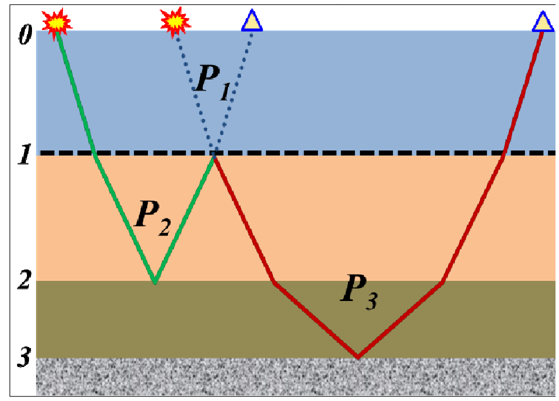


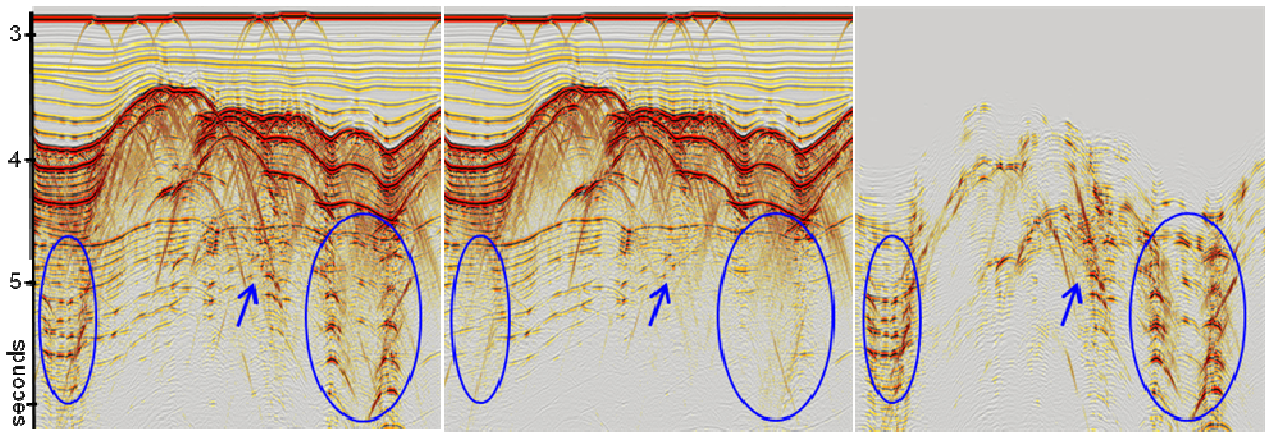

***Figure 2:*** *Prediction of multiples reflecting downward from horizon 1.*

**Synthetic data example**

A 2D synthetic dataset was created to mimic a line through the Tupi discovery. This dataset was generated by acoustic modeling using a velocity taken from the real data model-building result. The initial density model was derived from this velocity via Gardner's equation. The density was then iteratively updated until the synthetic data closely resembled the real data.

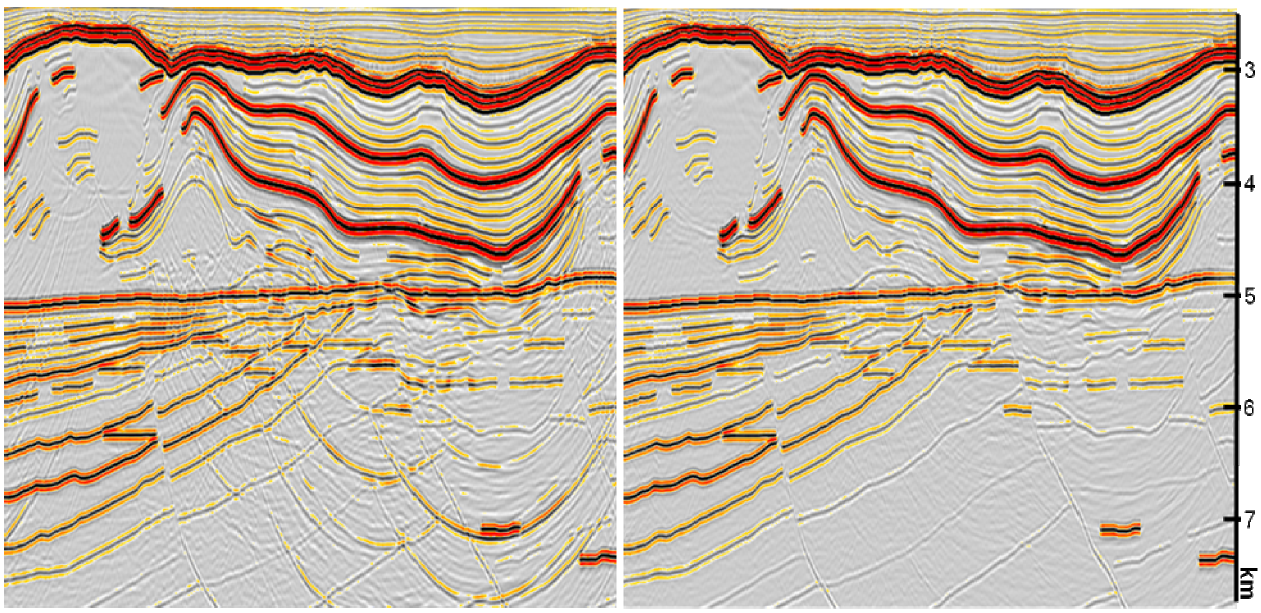
Two iterations of interbed multiple attenuation (IMA) were performed in this dataset, to attenuate multiples reflecting downward from both the water bottom and top of salt. The cumulative result of both passes is presented in Figure 3. The strong focusing-effect multiples below TOS synclines are well attenuated.

To test the effect of interbed multiple attenuation on the final image, migration comparisons were run. Figures 4 compares reverse time migrated (RTM) stacks on the synthetic data. Migration of the input data leaves several strong migration artifacts in deep data, along with a series of weaker migration artifacts that cross base of salt. After interbed multiple attenuation, the image is much cleaner, with good removal of both long and short-period multiples.




(a) Input (b) Subtraction (c) Difference

***Figure 3:*** *2D IMA in synthetic data*



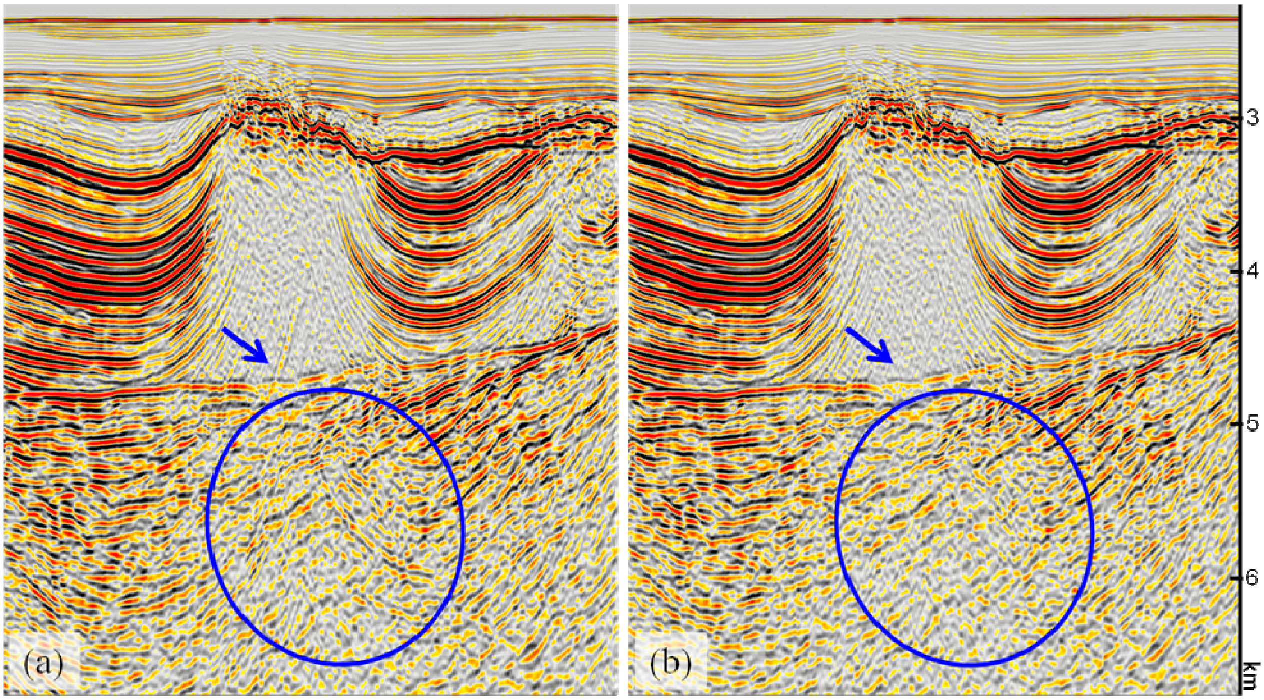

(a) Before (b) After

***Figure 4:*** *RTM comparison in synthetic data*

**Real data example**

In real data from the Santos Basin, true-azimuth 3D interbed multiple predictions were necessary for accurate prediction of multiples reflecting from the complex salt horizons. The complexity of this data is illustrated by the sample migrated line in Figure 5(a). A highly rugose top of salt is flanked by two syncline structures. The focusing effect of the synclines produces strong interbed multiples that cut across low-amplitude pre-salt events, especially in the poorly illuminated area below the rugose TOS.

A single iteration of interbed multiple prediction and subtraction was run to attenuate multiples reflecting downward from the water bottom. Figure 5(b) displays the migration result after 3D IMA. Most of the conflicting dips in the deeper pre-salt data are well removed. Some multiple-related artifacts are still visible, cutting across the base of salt. The shorter period of these multiples suggests that they are generated by downward reflection from the closely-spaced evaporite layers. Further iterations of IMA are required to remove these multiples.




(a) Before 3D IMA (b) After 3D IMA

***Figure 5:*** *Kirchhoff PSDM comparison in real data*

## Conclusions

In this paper, we demonstrated the impact of interbed multiples on the imaging of pre-salt reservoirs in the Santos Basin. We then reviewed some of the available attenuation methods, and discussed the application of a data-driven, 3D, true azimuth method to Santos Basin data. Results were presented in both synthetic and real data from the Santos Basin, demonstrating a significant improvement to the final pre-salt image.

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