New Processing and Seismic Interpretation for the Northern São Francisco Basin, Brazil — Part 2

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Abstract

The Brazilian regulatory agency ANP acquired eleven seismic lines and drilled a stratigraphic well on the northern São Francisco basin. The well data were inconsistent with the seismic image, so ANP requested Petrobras to reprocess the seismic data and examine the case. The preliminary results of the investigation were shown by Pereira et al. (2015).

We follow up that study by introducing elastic modeling to evaluate the existence of S-converted noise events on the original processed section. We are able to determine that the false event in the original image was generated by P-S-P mode conversion within the Cretaceous sandstone layer.

Introduction

The São Francisco Basin is located in the central-east portion of Brazil, covering an area of 382161.19 km^2, and extending over the states of Minas Gerais, Bahia, Tocantins and Goiás. This intracratonic basin is mostly comprised by Proterozoic sequences, followed by a Paleozoic sequence (Santa Fé group), and a Cretaceous sequence (mainly the Urucuia group) (Zalán & Silva, 2007).

In 2014, the Brazilian regulatory agency ANP (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis) contracted the acquisition of eleven 2D seismic lines (Figure 1) in the northern portion of the São Francisco basin. The processed seismic images suggested a thick column of sedimentary rocks and showed two strong reflections (Figure 2a). The top reflector was interpreted as the contact between the Cretaceous sandstone and the Neoproterozoic Bambuí formation. However, the stratigraphic well 2-ANP-3-BA showed a relatively thin column of Cretaceous sandstones overlying the Precambrian basement (Figure 3).

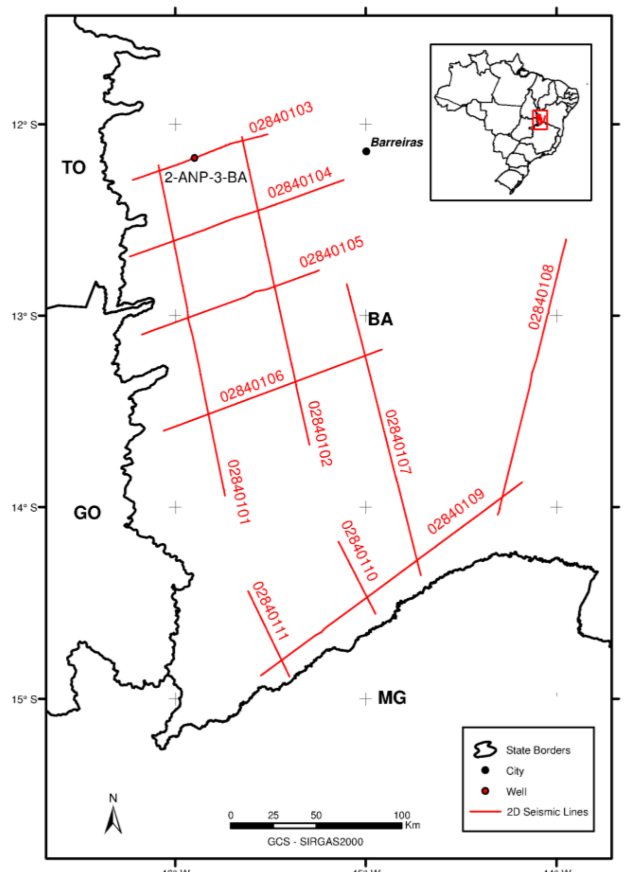


Figure 1 – *Map of the eleven 2D seismic lines and the 2-ANP-3-BA well.*

To clear this contradiction, ANP requested Petrobras to reprocess the seismic data and to investigate the issue. The new processing results showed that the bottom reflection is a false event created from stacked coherent noise. Pereira et al. (2015) raised a few hypotheses for the origin of that noise, but it was not possible at the time to establish its exact nature.

As a follow-up to that study, we will review the hypotheses, showing that most of them are not consistent with the seismic and the well data, and then use elastic synthetic data to prove that the spurious event could only have been generated by S-converted waves.

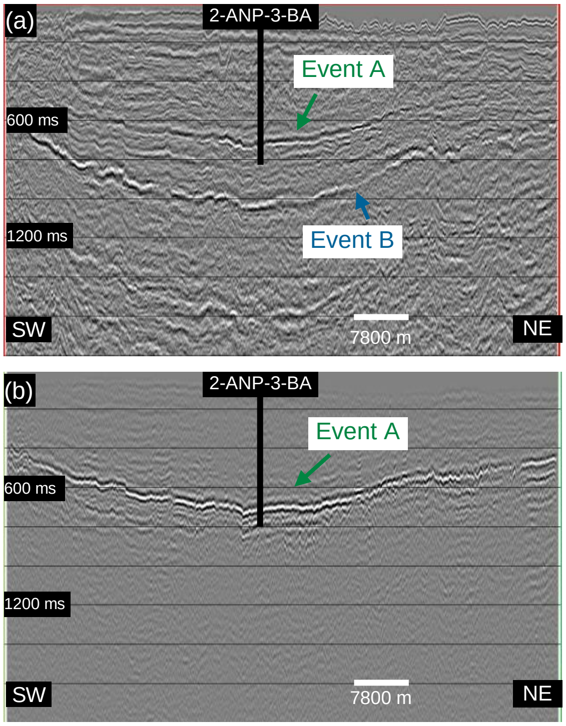


Figure 2 – *Seismic sections of line 284-0103, obtained from: (a) the original processing (year 2015), exhibiting two strong reflectors; (b) reprocessing by Petrobras (year 2017), exhibiting only one strong reflector.*

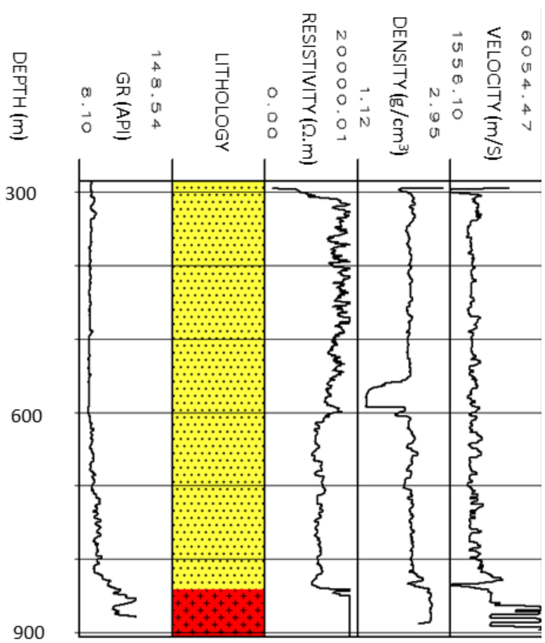


Figure 3 – *Results of 2-ANP-3-BA well: Cretaceous sandstone (2671 m/s, standard deviation 183 m/s) overlying the basement (6000 m/s; information comes from another well because the sonic log in this well has a large standard deviation).*

Method

The processing sequence used by Petrobras was very similar to the original sequence. However, the high level of coherent noise in the data allows for many possible velocity interpretations. Therefore, the main tools used by Pereira et al. to study the spurious events were Constant-Velocity Stack (CVS) sections and coherency (semblance) panels. Additionally, they employed 1.5D finite-difference *acoustic* modeling to create a controlled synthetic dataset, where the events could be accurately identified, and then correlated with those observed on the real data. The velocity field for modeling was a simplified representation with only three homogeneous layers: the weathering layer (velocity 800 m/s), the Cretaceous sandstone (velocity 3000 m/s), and the basement rock (velocity 6000 m/s).

In the present study, we employed 1.5D *elastic* modeling to investigate the possibility that S-converted waves generated spurious events. However, performing this step was complicated by the absence of S-wave information from well 2-ANP-3-BA and from neighboring wells. For that reason, we generated different scenarios by taking percentages of the P-wave velocity field, finding that 50% was a sufficiently good approximation for our purposes.

Possibilities

In the following paragraphs, we will review the six hypotheses (Figure 4) raised by the previous study (Pereira et al., 2015) to explain the existence of Event B in Figure 2a. The first four will be only briefly described, as they can still be easily proven wrong. The last two will require further discussion, to take into account new evidence obtained from elastic modeling.

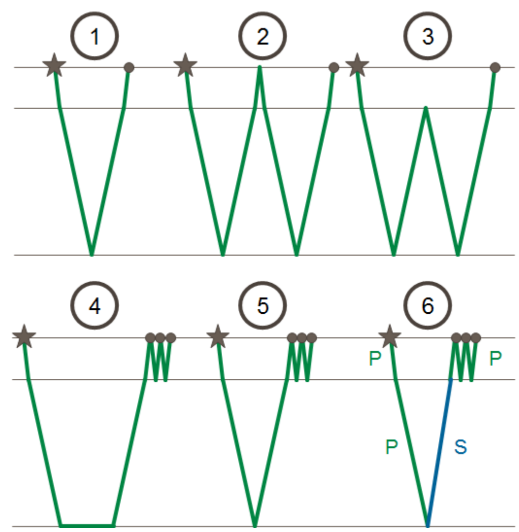
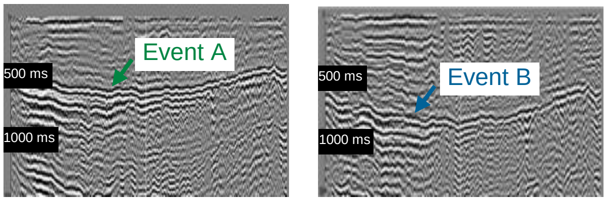


Figure 4 – *Illustration of the six hypotheses considered in this study for Event B. The top layer represents the weathering zone, while the bottom layer represents the Cretaceous sandstones.*

1. Event B is real. From our stratigraphic knowledge of the São Francisco basin and from the well data, we expect that the stacking velocity should increase with depth. However, the stacking velocity for the top event is around 2800 m/s (Figure 5a), while the stacking velocity for the bottom event is around 2100 m/s (Figure 5b). This velocity pair would also imply a non-physical negative interval velocity between the two interfaces.



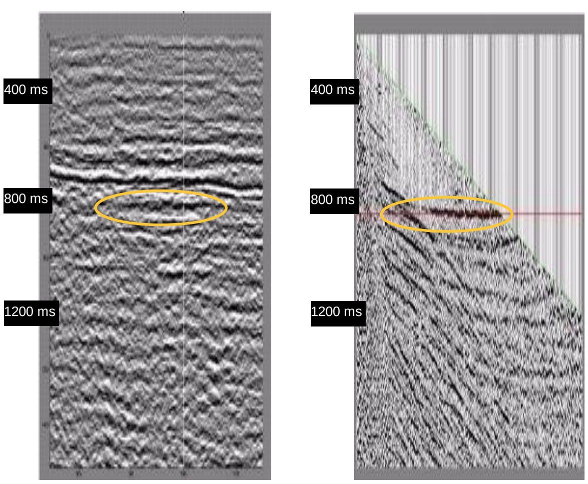
(a) (b)

Figure 5 – *CVS sections from line 284-0103, for stacking velocities (a) 2800 m/s and (b) 2100 m/s.*

2. Event B is a surface-related multiple. We clearly see in Figure 5 that the two events do not have an important feature of surface-related multiples: periodicity. They also do not appear to have reversed polarities, although it may be difficult to tell, due to interference with other events. Finally, their stacking velocities are not similar.

3. Event B is an internal multiple. The well data shows that the Cretaceous sandstone layer is essentially homogeneous, so the multiple-generating interface would have to be the weathering layer bottom. Therefore, the multiple event would obey the criteria of periodicity and reversed polarity, again contradicting what we see in Figure 5. Its stacking velocity would also be slightly greater than the primary event's, which is not the case.

4. Event B is a refraction. In Figure 6, we see that the basement refraction can be stacked into a rather strong event. However, the stacking velocity required for that is about 4000 m/s, which is much greater than the stacking velocity of Event B, shown in Figure 5b (2100 m/s).



(a) (b)

Figure 6 – *Seismic data from line 284-0103, showing the basement refraction event: (a) segment of the 4000 m/s CVS section; (b) CMP gather after a 4000 m/s NMO correction.*

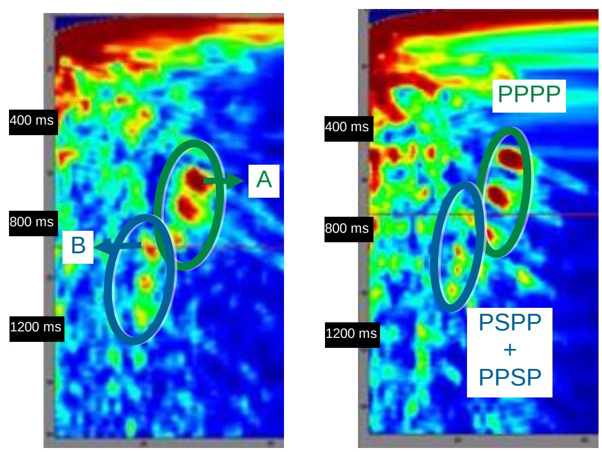
5. Event B is a shallow reverberation (peg-leg).

In this case, we expect that the reverberations should be periodic and have decreasing stacking velocities. The period would be the two-way traveltime in the weathering layer.

There is no direct way of estimating that traveltime in this case, as the weathering-layer bottom reflection is not visible on the seismic data. However, its refraction is very clear and has an intercept time of about 100 ms. The intercept time is always smaller than the zero-offset reflection time, and these two times are usually close, so the weathering layer two-way traveltime is expected to be somewhat larger than 100 ms.

Now, examining the green ellipse in Figure 7a, we see that, under the basement reflector (Event A), there is a trend of repeating events with a period of about 120 ms and slightly decreasing stacking velocities, which fit the expected behavior for the shallow reverberations. However, their period and stacking velocities (of about 2700 m/s) clearly do not match the characteristics of Event B. We must then reject this hypothesis.

We can use the modeled data for further confirmation. Comparing the coherency panels for the real data (Figure 7a) and the synthetic data (Figure 7b), we see a correspondence between the repeating patterns shown in the two images. Since the velocity model for the synthetic data is known, we calculated the exact traveltimes and velocities expected for the shallow reverberations, and they indeed match the characteristics of those event trends.



(a) (b)

Figure 7 – *Semblance panels for a CMP of line 284-0103, calculated from (a) the real data and (b) the modeled data.*

6. Event B is an S-converted wave.

After rejecting all the previous hypotheses, the only remaining possibility is to assume that mode conversion is responsible for the spurious event. To confirm that, we again correlate the coherency panels for the real and the synthetic data (Figure 7).

In Figure 7a, the trend that includes Event B in the real data is highlighted by a blue ellipse. Comparing the two coherency panels, we see that a similar trend of events exists for the synthetic data (Figure 7b). The repeating events have a period of about 120 ms, which simply means that, like Event A, Event B also generates shallow reverberations.

Again, since the velocity model for the synthetic data is known, we calculated the exact traveltimes and stacking velocities for all possible propagation modes of the basement reflection (PSPP, PSSP, PPSP, etc.). We found that only the PSPP and PPSP modes are consistent with the observed events.

Therefore, we conclude that Event B, shown in the original processed section, is not geologic, and that it was generated by erroneously stacking energy from the PSPP and PPSP wave modes of the basement reflection.

Conclusions

The main goal of the reprocessing sequence was to clarify the apparent inconsistencies between the well and the seismic data. By carefully studying the traveltimes and stacking velocities, we were able to assert that the suspicious event is not geologic. By employing acoustic and elastic modeling, it was also possible to establish that the event was generated by stacked S-converted energy, and specifically by the PSPP and PPSP propagation modes.

This case study shows that forward modeling can be used as an important tool for interpretation. The synthetic data is created in a controlled environment, so the modeled events can be compared with those on the real data to make it easier to distinguish noise from signal.

The São Francisco Basin is a frontier exploration area, since a very small amount of seismic and well data is available. The results of this study were crucial to develop knowledge about the northern portion of the basin. Being aware of the possibility of stacking S-converted waves in this area will also help to avoid mistakes in future seismic processing flows.

Acknowledgments

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