The importance of geology-driven seismic processing and interpretation: a case study of the Proterozoic Sao Francisco Basin

Paulo Souza – PGEOF- GETA-UFBA – Salvador - Brazil
Danilo Cruz – Petrobras – Natal - Brazil
Estéban Sabogal - Universidad Industrial de Santander - Bucaramanga- Colombia
Luis Huerga Ándres – PPGEO-UFBA – Salvador - Brazil
Michael Holz – Geoscience Institute – GETA-UFBA – CNPq Researcher – Salvador - Brazil

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Abstract

GETA-UFBA carried out a P&D project in the northern region of the Proterozoic São Francisco Basin (in Bahia state) between 2012 and 2014. The available data set (well log data and 2D seismic lines) has led to a sequence stratigraphic framework with three first-order Proterozoic sequences, based on strata termination and seismic facies analysis. That interpretation has changed dramatically when ANP (the Brazilian Hydrocarbon Agency) made new well data available and took the group to reprocess seismic lines with a geology-driven workflow. This led to the conclusion that there are no Proterozoic sequences in that portion of the basin, and that the depocenter is much shallower than previous researches had appointed. This case study shows conclusively that interpretation and seismic processing must have constant and positive feedback from geologic knowledge.

Introduction

The São Francisco basin is a frontier basin, i.e., a basin with only short-term exploration activities and a relatively poor data set, hence with several challenges and controversies. This paper deals with the northern part of the São Francisco basin, located over the namesake craton (Fig.1) in Bahia State, with a focus on the northwestern region. The majority of studies were historically conducted in the southern part (Minas Gerais State), where Alkmin & Martins-Neto (2012) defined five 1st-order sequences: the Paleoproterozoic Minas-Itacolomi sequence; the Paleo/Mesoproterozoic Espinhaço I and II sequences; the Neoproterozoic Macaúbas sequence, and the Neoproterozoic Bambuí sequence. In the study area, the Neoproterozoic Macaúbas and Bambuí sequences are recorded (Fig.2). The youngest record is the Phanerozoic coverage of the craton known as the "Bacia Sanfranciscana", in Bahia State represented mostly by the sandstones of the Cretaceous Urucuia formation.

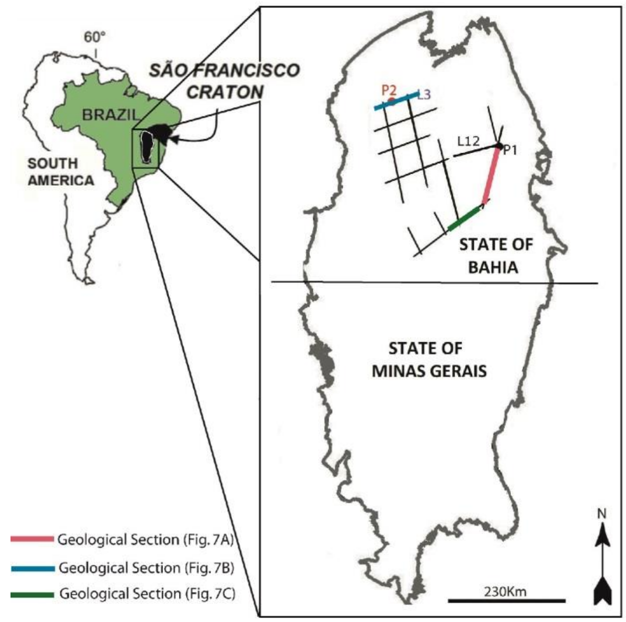

Figura 1 – Location map of the São Francisco basin. The lines represents the interpreted seismic sections. Three of them were used to elaborate the geological sections shown in figure 7. Well P1 was available since the beginning of the project in 2012 and was used to tie that well to seismic line L12. Well P2 was available much later (by the end of 2013) and induced a dramatic change to the prior seismic-stratigraphic interpretation.

The acquisition of 2D seismic data in the northern portion (Bahia State) dates 1997, and the post-stack data was made available in 2009. A P&D project sponsored by ANP (the Brazilian Hydrocarbon Agency) was carried out by research group GETA-UFBA in the northern region of the Proterozoic-Phanerozoic São Francisco Basin (in Bahia state, Fig.1) between 2012 and 2014, working with a relatively poor data volume, due to the large area of acquisition (around 100.000km²) and the 50 km spacing of the seismic lines. For this area only one seismic-well correlation was possible (P1 and L12 in Fig.1).
This study aims to discuss the importance of processing and interpretation of seismic data with constant and positive feedback from the geologic knowledge of the study area, since better knowledge of the geology can provide significant improvement in stratal definition (Sarkar, 2013).

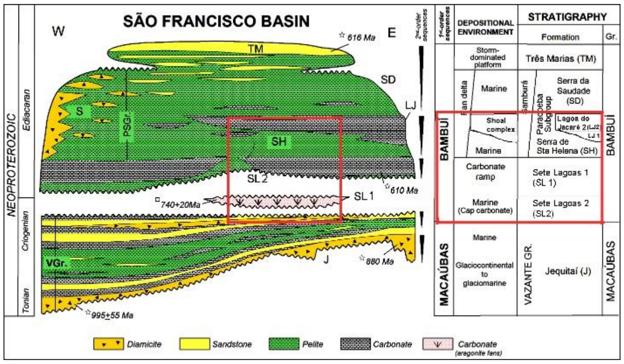

Figure 2 – Stratigraphic chart of the Macaúbas and Bambuí sequences in the São Francisco basin (Numbers marked with a square indicate deposition or intrusion ages; numbers marked with a star denote ages of the youngest detrital zircons found in the unit (modified from Alkmin & Martins-Neto, 2012). The red rectangles delimit the approx. time-space frame dealt with in the present paper.

This might be obvious, but as pointed out by Hart (2013), there has been little collaboration between sedimentary geologists and geophysicists in terms of understand the relationship between the sedimentary depositional processes and the seismic response. This may lead to misinterpretations such as reported in the present paper. The available seismic data, which "clearly" indicated a depth of about 3km for the basin and the presence of four megasequences, was actually misleading. New well data made available by ANP took the group to re-interpret the data and to reprocess seismic lines with a geology-driven workflow in order to find out how such a mistake in a seismic stratigraphic interpretation could occur, and to get answers that avoid such errors in future interpretation.

Method

Seismic reflection and well data were provided by ANP. Seismic data consists of thirteen 2D terrestrial seismic lines acquired by Petrobras and processed in 2009 by Geokinects. Depth conversion was made using interval velocities from sonic logs. Additional geological data was extracted from several well logs and from geological mapping.

Seisspace (Landmark) was the software used for processing seismic lines, including geometry analysis, mute stretch, static correction, velocity analysis and stacking. Migration was not done because the 2D seismic data shows sub-horizontals reflectors and absence of faults that did not require this step.

Interpretation was done using software Geographix (Landmark), with integration of geologic data obtained during the project, such as lithological and tectonic maps.

The seismic and well data were tied using information of the sonic and density log data. Sequences were defined by regional unconformities, using standard seismic stratigraphic interpretation procedure (mapping of reflector terminations) and seismic facies analysis based on amplitude, continuity, frequency and geometry of seismic reflectors (Payton, 1977; Posamentier and Kolla, 2003; Catuneanu et al., 2011).

Results

From the seismic analysis a sequence stratigraphic framework with three first-order Proterozoic sequences (Seq I to III) and one Phanerozoic sequence (Seq IV) emerged. Figure 3 shows a representative seismic line for the study area and the original interpretation.

This line, processed without any geologic input, "clearly" shows several reflector in depths up to 1.5s, leading to an interpretation of several Proterozoic sequences and to the conclusion that the basin has a depth of at least 2,5 to 3km in that area. Not only GETA-UFBA, but other interpreters outside the university, all with proven expertise, have shown a very similar interpretation and believed that the basin had a high maximum depth (e.g. Rugenski et al., 2012).

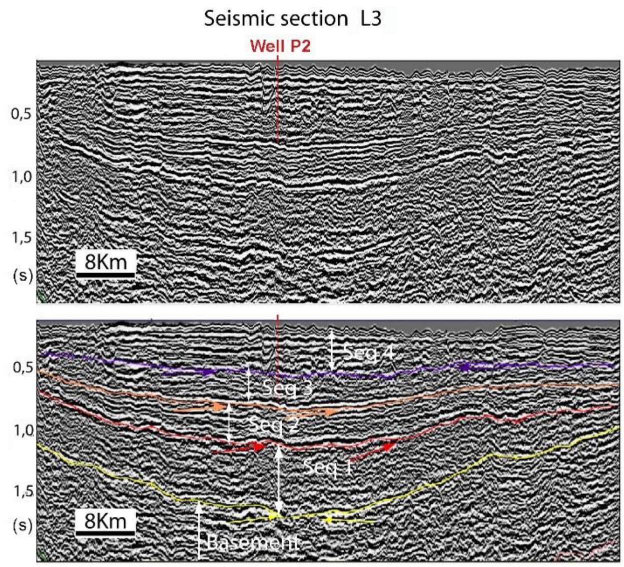

Figure 3- Above: seismic section L3 processed without geologic input (since well P2 was only made available long after this interpretation was done). Below: based only upon the seismic response and gravity data, four depositional sequences were interpreted (Seq 1 Seq 2, Seq 3 and Seq 4).

This seismic stratigraphic interpretation changed dramatically when ANP (the Brazilian Hydrocarbon Agency) made new well data available. The new well P2, drilled over seismic line L3 (see location in figures 1 and 3) reached the crystalline basement at 840 meters (approx. 0.7s double travel time), indicating a relatively shallow basin and the inexistence of sequences 1,2 and 3. This is a new significant result concerning the basin´s stratigraphy in Bahia State. It decreased its hydrocarbon potential, and took the group to reprocess seismic lines with a geology-driven workflow in order to understand the existence and the physical nature of the "clearly" noticeable deeper reflectors. Seismic line L3 was re-processed twice, first for enhancing visibility of the reflectors (Fig. 4A), the second used sonic profile from well P2 to carry out more accurate velocity analysis (Fig.4B). Figure 4 shows the velocity analysis. Band-pass filtering has also been applied to time below 0.7s (Fig.6).

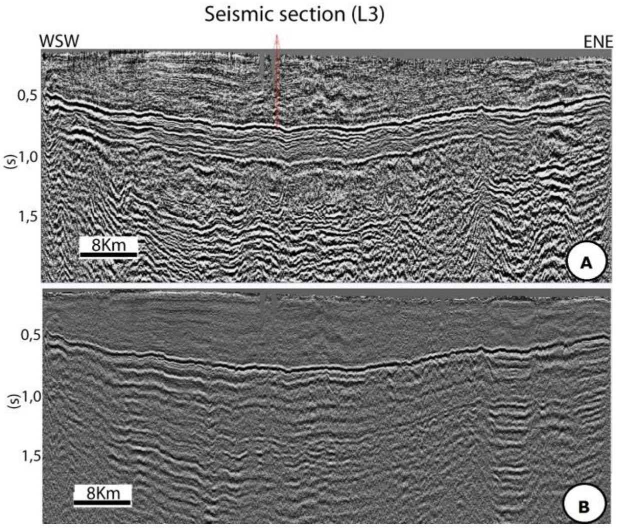

Figure 4 – Seismic line L3 with location of well P2 which reached the basement at a depth of ~840m. (A) Reprocessed line with average velocity analysis and without information from the well. B) Reprocessed line using information from the well. Note that deep reflectors have lost visibility and show a reverberation-like signature.

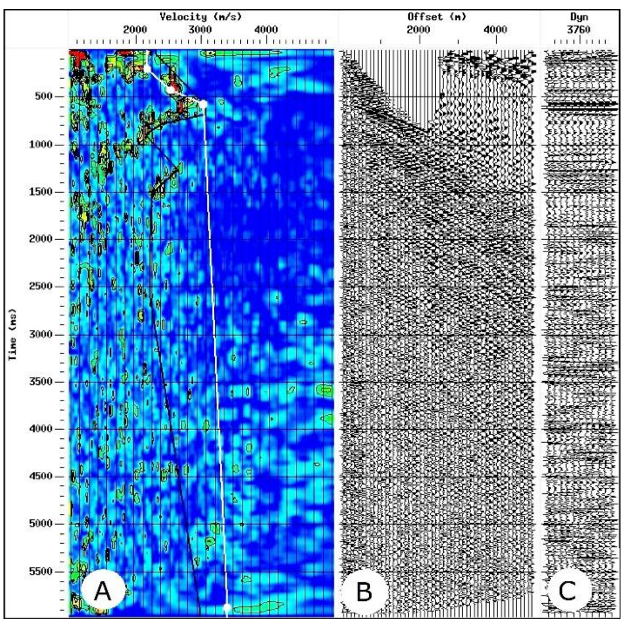

Figure 5 – Representation of the velocity analysis for seismic line L3. (A) VELAN by horizontal coherence (semblance), (B) CDP corrected by NMO, (C) representation of the lateral continuity of the CDP. The VELAN displays two velocity x time curves. The black curve represents the velocity analysis without any geologic input, while the white curve is the result of the analysis based upon geologic data acquired from well P2.

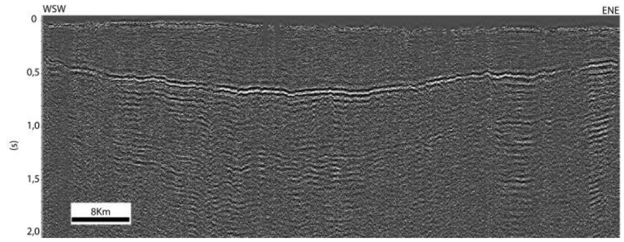

Figure 6 – Final reprocessed version of seismic line L3, which resulted from a more accurate velocity analysis and band-pass filtering. Note there is no more evidence of sequences 1,2 and 3 as interpreted from the original seismic line shown in figure 3.

Comparing the original seismic line (Fig.3) to the reprocessed line shown in figure 3B it becomes clear that the deeper reflectors were actually multiple reflections. Sequences 1, 2 and 3, which were though to record the Bambui supersequence and a Phanerozoic sequence, actually do not exist (Fig.6).

So what happened? What factors led to that erroneous interpretation?

Analyzing the history of the interpretation process, it is clear now that a number of factors led to this erroneous interpretation, namely:

1. The Bouguer map of the basin indicating low gravity (hence deep basement) for the region (Fig.7);
2. The reflectors in the seismic visibility that actually do not exist (reverberations);
3. Lack of direct information on the area (wells).
4. The representativity of megasequence Bambui for much of the basin, as in Minas Gerais state and eastern portion of Bahia state, inducing the interpretation that this group would also be expressively recorded in the western Bahia portion of the basin.

Gravimetric data indicate lower values in the western region due to the difference in density between sandstones of the Urucuia Formation and carbonates of supersequence Bambuí. This lithological difference results in a density difference and was measured via both wells using density profile (RHOB). Carbonates shows the density around 2.4 g / cm³ while the sandstones range from 2.1 g / cm³ and 2.2g / cm³ explaining the low gravity.

In order to depicture the lateral variation of the stratigraphic record of the São Francisco basin in Bahia, three geological sections were constructed (Fig.8), using reprocessed seismic data where the velocity obtained through the sonic log, showing that in the northwestern region the São Francisco basin´s sedimentary record is absent and the Cretaceous Urucuia Sandstones cover the crystalline basement .

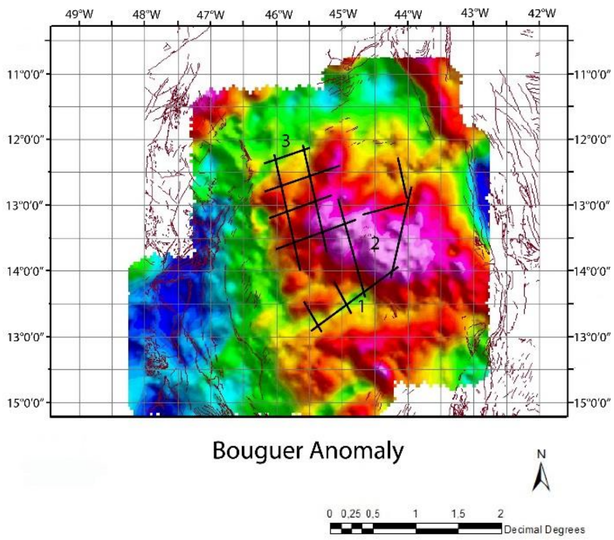

Figura 7: Gravimetric map (Bouguer Anomaly) with the main structures: 1- Cocos Low ; 2- Correntina's High, 3- Trough zone over which seismic line L3 is located. According to the gravity data, the basement of the region crossed by line L3 should be relatively deep.

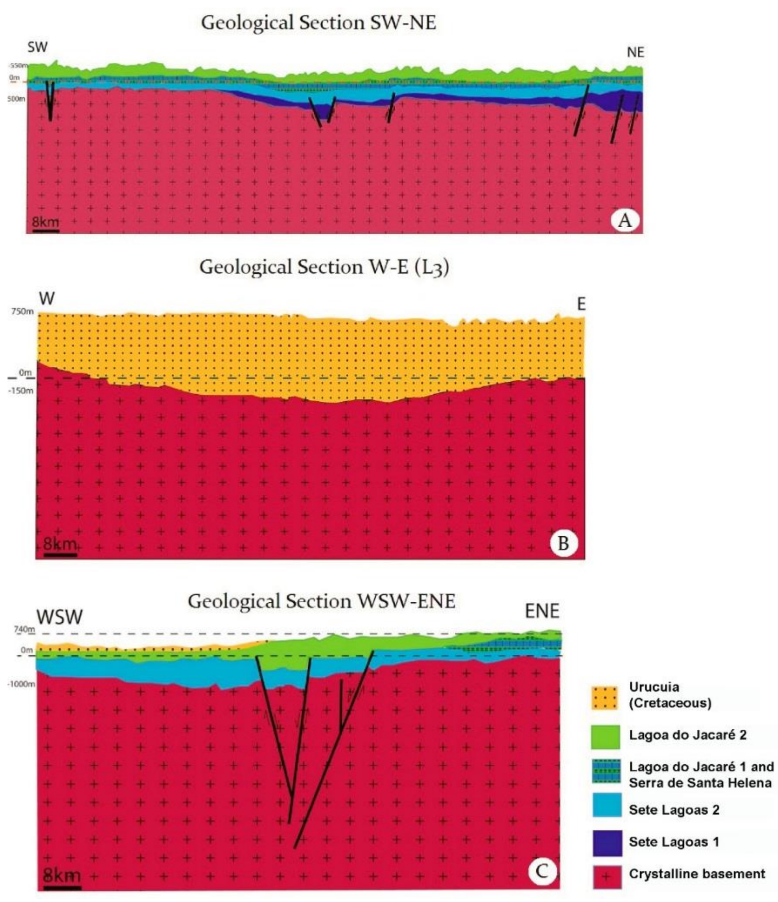

Figure 8: Geologic sections of three areas of the São Francisco Basin in Bahia State, enhancing the lithostratigraphic units. For stratigraphic reference, see also the stratigraphic chart in figure 2. (A) Eastern section, where well P1 is located, recording Sete Lagoas 1 and 2; plus Serra de Santa Helena and Lagoa do Jacaré 1 e 2 formations. (B) Geologic section in the northwestern region of Bahia, showing the Phanerozoic coverage (Urucuia Formation). This section is based upon the re-processed seismic line L3, where well P2 is located. (C) Section located at the region of the Cocos Low (see figure 7) where the almost complete transition from Neoproterozoic rocks (Sete Lagoas, Serrra de Santa Helena and Lagoa do Jacaré formations forming Supersequence Bambuí) to the Phanerozoic coverage (Urucuia Formation) is recorded.

Conclusions

It is very important to use direct geologic data during seismic processing and interpretation, especially in frontier basins such as the São Francisco. Such regions require more caution in every methodological step. Different kind of geologic data helps to correlate and brings credibility to the result. Processing of seismic data should have constant geological input to preclude misinterpretations. Wrong velocity analysis can valorize multiples reflection.
Different information helps to base the hypothesis created. Field data, well, seismic and gravimetric must be analyzed in an integrative manner and constantly tested during the interpretation process.

Specific conclusions are:

- The verification of the depth of the basement obtained by the well P2, was important because it provided the most detailed study of deeper reflectors and allowed the creation of a hypothesis for the seismogram has presented those answers.

- The depocenter of the São Francisco Basin in Bahia is not in the line L3 region, as expected. It is expected that the deepest region reach around 1400m in Cocos Low (Figure 7).

- The Bambuí sequence as recorded in Minas Gerais State has not been identified in the seismic lines of the western region of Bahia, although it has been identified in the eastern region.

- In the studied region, the absence of the Bambui supersequence, with the Cretaceous Urucuia sandstone covering the crystalline basement totally decreases the hydrocarbon potential of that region.

Acknowledgments

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References

Alkmin, F.F. & Martins-Neto, M.A. 2012 Proterozoic first-order sedimentary sequences of the São Francisco craton, eastern Brazil. Marine and Petroleum Geology 33:127-139.

Catuneanu, O., Galloway, W.E., Kendall, C. G. St. C., Miall, A.,D., Posamentier, H.W., Strasser, A., Tucker, M.E., 2011. Sequence stratigraphy: methodology and nomenclature. Newsl. Stratigr. 44 (3). Gebrüder Borntraeger, Stuttgart.

Hart, B. S. 2013. Whiter seismic stratigraphy? Interpretation – A journal of subsurface characterization. Vol.1, No. 1, p. SA17.

Payton, C.E. (Ed.), 1977. Seismic Stratigraphy e Applications to Hydrocarbon Exploration. American Association of Petroleum Geologists Memoir, vol. 26, p. 516.

Posamentier, H.W., Kolla, V., 2003. Seismic geomorphology and stratigraphy of depositional elements in deep-water settings. J. Sediment. Res. 73 (3),

Rugenski, A., Dyuarte, K.S.; Ranna, R.T.2012. Bacia São Francisco Norte- qual a espessura sedimentar? Congresso brasileiro de Geologia, Santos, 2012.

Sarkar, S. 2013. Geological Input Valuable in Seismic Velocity Analysis. AAPG Search and Discovery Article #41118.