3D GPR modeling of carbonates reservoir analogues applying geometric attributes: Coqueiro Seco Formation, Sergipe-Alagoas Basin – Brazil

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Abstract (Font: Arial Bold, 9)

Recent petroleum reserves discoveries in carbonates reservoirs have increased the interest in this kind of reservoir. Usually this kind of reservoirs is very complex, mainly in terms of distribution of porosity/permeabilty and reservoir geometry which have strong influence on petroleum reserves and production. To promote a better understanding of the scenario it is necessary new detailed studies in modeling the internal and external architecture of carbonate reservoirs.

The purpose of present work is to interpret a 3D GPR dataset at Morro do Chaves Member (Coqueiro Seco Formation). These rocks are considered reservoir analogues to Lagoa Feia Formation (carbonate reservoirs), located in Campos Basin, Brazil. Our interpretation is enhanced through use of geometric attributes that are usually employed to interpret seismic data.

Introduction

Modeling of porous system architecture has been very useful in several areas of petroleum industry; due to through modeling it is possible to define important parameters, such as porosity values and reservoirs geometries, which have influence on reservoir management and oil production.

The majority of Brazilian reservoirs are associated to turbidities. However, recent subsalt discoveries have boost the interest in carbonate environment. One example is West African oil field composed by coquinas. In Brazil, expressive oil production has been obtained from Lagoa Feia coquinas (Campos Basin). Otherwise, due to heterogeneity of porous system, these kinds of reservoirs show many difficulties to hydrocarbon production. To solve these problems, modeling studies through geological and seismic data have been realized (Hardage et. al., 1998; Wang *et. al*., 1998b). The major problem about these studies is that they are not able to deal with subseismic features. To provide that understanding it is necessary to study reservoir analogues.

The purpose of the present work is to perform a 3D GPR interpretation at carbonate outcrops located in Sergipe-Alagoas Basin. The studied unit, Morro do Chaves Member, Coqueiro Seco Formation (Feijó, 1994) is composed by coquinas that are correlated to West African and Campos Basin carbonate reservoirs. Moreover, we show the advantages of applying geometric attributes (commonly used in seismic method) to GPR data interpretation.

Survey Area

Survey was acquired at Sergipe-Alagoas Basin, in Atol quary, located about 60km of Maceió (Figure 1). The GPR data (cube with 45 x 45 m sides, see the blue square in Fig. 1) was acquired in fixed offset mode (antennae separation of 0.8 m) and CMP modes with a Pulse Ekko 100, with 100 MHz unshielded antennae in broadside-perpendicular configuration and a pulse of 1000 V. All GPR profiles were done in a stop-and-go triggering mode for a maximum coupling with the ground. The CMP profiles reveal and area of relatively low velocity of v = 0.08 m/ns, while penetration depths are restricted to about 12 m in the fixed offset profiles. More details about the data processing can be found elsewhere (Menezes et al., 2005).

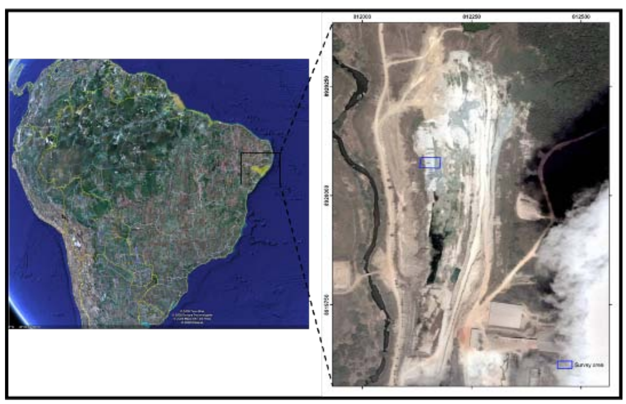

Figure 1: Location of Sergipe-Alagoas Basin in Brazil (yellow polygon), and survey area of this work on the right (blue polygon).

Overview of Sergipe-Alagoas Basin - Coqueiro Seco Formation

Tectonic-Sedimentary evolution of this basin began after Jurassic Period, when started events related to Gondwana breakup. Results of this event, normal faults can be found in a lot of seismic sections. More expressive heaves have N45E, N-S and ENE orientation. Older N-S faults are disposed en echelon to N45E orientation, and suggest lateral movement. These structures suggest existence of sinistral transtensional strength during Gondwana breakup (Lana, 1990).

During rift phase, lower areas were occupied by huge deep lagoons to where several rivers streamed into. Sediments carried by these rivers formed Barra de Itiuba Formation, Penedo Formation and Rio Pitanga Formation. In Lower Aptian began Coqueiro Seco Formation sedimentation. This system is composed by lagoon in which shells were deposited in its margins. This shells accumulation formed coquinas of Morro do Chaves Member.

Morro do Chaves Member sedimentation occurred predominately in the beginning of transgressive stage and black shales were deposited during regressive periods. In this time, it is possible that lakes had a negative hydro balance, and consequent anoxic environment (Azambuja Filho & Mello, 1992).

Interpretation of GPR Data – Characterization of Sequences

Interpretation of GPR data was realized throughout identification of characteristics of individual facies, like deposition pattern, continuity, frequency and amplitude, and integration of sequence stratigraphy concepts.

All software's used on this activity were PostStack, to load 2d GPR data in 3D GPR Volume, SeisWorks 3D and Geoprobe (Landmark Graphics suite) to interpret.

At Figure 2 is possible to identify six interpreted sequence. All these sequences were individualized by their geophysics characteristics, as well as depositional pattern and integration of outcrop data (Kinoshita, 2007), and published information.

Carbonate Mound Sequence was characterized by their high amplitude contrast reflectors, continuous, apparently without unconformities patterns.
Packstone Sequence showed downlap reflectors and sigmoidal progradation.
Grainstone Sequence was characterized by downlap reflectors, continuous, low dip angle.

The association composed by these upper three sequences could be deposited in a trangressive system tract – catch-up stage (Figure 3) (carbonate mound formation) through keep-up stage – and units progradation caused by high stand sea level and high environment energy. These facts characterize shoaling-upward environment.

Black Shales Sequence: low amplitude contrast and plan-parallel reflectors. These shales were mapped through almost whole area. Therefore, high stand sea level can contribute to this deposition, where light zone decrease, turn impossible carbonates deposition.
Pack/Grainstone Sequence: downlap sigmoid reflectors.
Wackestone Sequence: plan-parallel reflectors, low amplitude contrast and cut-filling pattern.
Upper *Grainstone Sequence*: unconformities delimited by downlap and sigmoidal reflectors showing high dip angle.

The association composed by these three sequences above show progradational sigmoid morphology, typical of transgressive to high stand sea level, also characterizing shoaling-upward environment.

Then, facies modeling proposed in this article is defined by about seven meters thickness coquinas packages, composed by packstones and grainstones sequences and sigmoidal geometry deposited during high frequency shoaling-upward sequences, interlayer by thinner sequences, and about one meter thickness black shale (Figure 4).

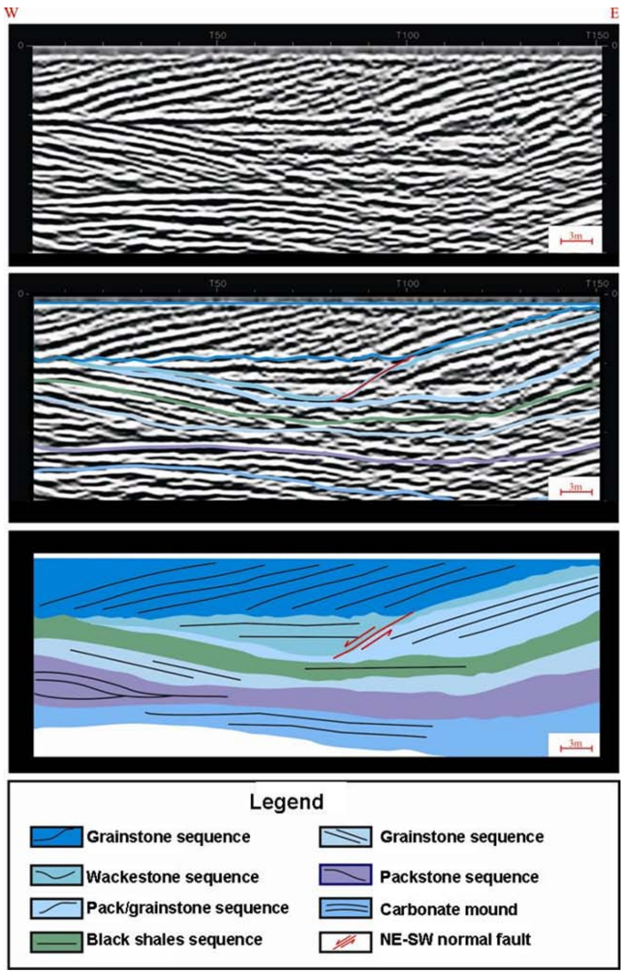

Figure 2: Uninterpreted section (upper), radar stratigraphy interpreted (middle) and illustrated as a cartoon (bottom) to better identify determinants features.

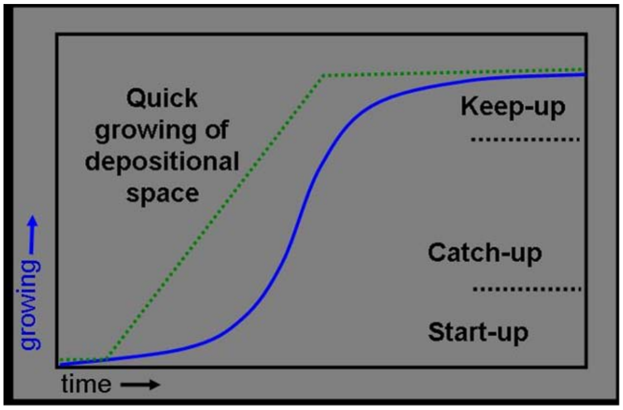

Figure 3: Carbonate growing through time, showing start-up, catch-up and keep-up stages. Adapted from Newman & MacIntyre, 1985.

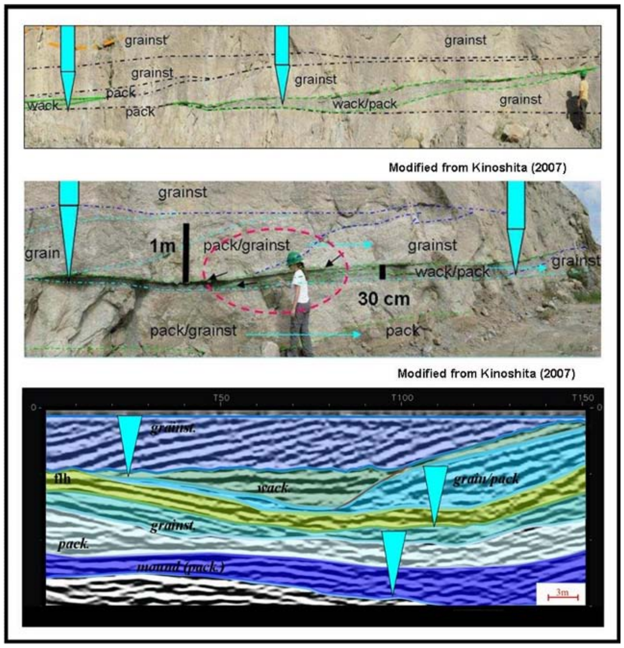

Figure 4: Example of images where information was used to build analogies between sequences characterized in outcrops and interpreted on GPR's volume.

Geometric Attributes Application

1- Dip

Dip Volume is a valuable attribute to help in geologic interpretation. Currently, the main application is to determine a local reflector surface upon which has an estimative of a discontinuity, or conversely, along which is possible to filter the data to extract their continuous component.

Dip Volume was calculated on this work using just GPR data, with no contribution of horizon interpretation. The intention was avoid eventual mistakes or bias caused by erroneous interpretation.

The method applied requires: (1) aligning the phase derived from complex-trace analysis, (2) discretely scanning for the most coherence planar reflector, or (3) cross correlating the gradient of the data and forming a gradient structure tensor, and is called by Dip Scan (Marfurt, et. al. 2007).

The process is developed in successive steps: initially the algorithm estimates coherence using semblance, variance, principal component, or some other statistical measure along a discrete number of candidate dips. Next, the algorithm passes an interpolation curve trough the coherence measures estimated by the peak value and two or more neighboring dips. The peak value of this curve gives an estimate of coherence, whereas the dip value of this peak gives an estimate of instantaneous dip. Figure 5 demonstrates DIP volume calculated using this method in GPR data, and illustrated how this attribute helped in sequence delimitation.

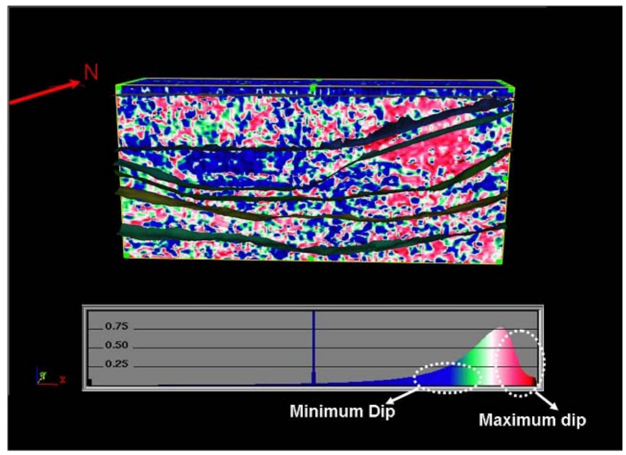

Figure 5: DIP Volume calculated through initial volume. Valuable maximum and minimum dip values between first and third sequences.

2- Coherence

Coherence is a measure of similarity between waveforms or traces. When seen on a processed section, the seismic waveform is a response of the seismic wavelet convolved with geology of the subsurface. That response changes in terms of amplitude, frequency, and phase, depending in the acoustic-impedance contrast and thickness of the layers above and below the reflecting boundary. In turn, acoustic impedance is affected by lithology, porosity, density, and fluid type of the subsurface layers.

Consequently, the seismic waveforms that we see on a processed section differ in a lateral character – that is, strong lateral changes in impedance contrasts give rise to strong lateral changes in waveform character (Marfurt et. al., 2007).

In terms of geology, high coherence in waveforms indicates laterally similar lithology. Abrupt changes in waveforms can indicate fault or fractures in the rocks.

Therefore, extraction of coherence attribute from data is a reasonable tool that can help to identify geological boundaries, like faults and stratigraphic contacts. This attribute also helps to faster structural interpretation of huge data sets, besides turn easier to identify stratigrafic information.

Coherence can be calculated using some algorithms, (1) Cross-correlation, (2) Semblance, Variance and Manhattan distance, (3) Eigenstructure and (4) Gradient Structural Tensors (GST).

To calculate in this work, Eigenstructure method was applied using PostStack software. This method is sensitive not only to waveform but also to lateral changes in seismic amplitude.

First of all, we estimate dip and azimuth measure. Graphically, the Eigenstructure method analyzes a window of traces and determines which wavelet best represents the waveform variability. Then this wavelet is scaled to fit to each input trace, providing what we call the coherent component of the data within the analysis window. Eigenstructure coherence is simply the ration of the energy of the coherent component of the data to the energy of the original traces within the analysis window. For 3D data, the analysis window includes a suite of traces centered on the analysis point.

Parameters, 9 inlines x 9 crosslines x 50 samples, had chosen to calculate coherence on this work. These values were used because faults and fractures identified by Kinoshita (2007) were of small dimensions. Therefore GPR method can offer more details than Seismic method.

Figure 6 shows the results obtained calculating Eigenstructure coherence in GPR data (right panel in Fig. 6). In the coherence cube it is possible to identify a set of N-S and NE-SW normal faults/fractures. These orientations are parallel to the major regional fault system trend in the area. We assume that this regional system was still active at the time of the deposition Coqueiro Seco Member.

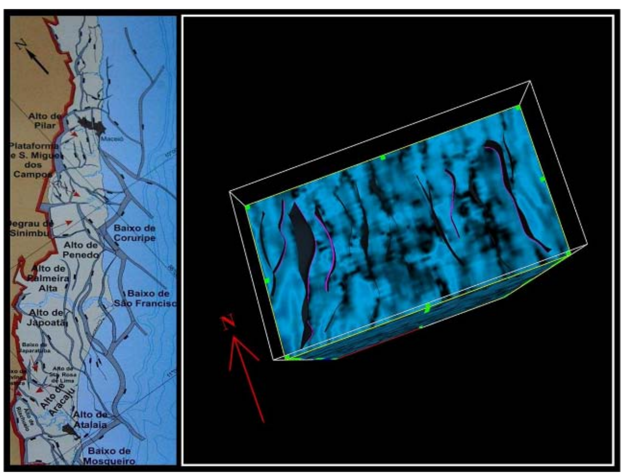

Figure 6: Structural similarities between regional framework (left panel) (modified by Lana, 1990) and Coqueiro Seco Member interpretation (right panel).

Discussion of Geophysical Modeling and Conclusions

In this section, we discuss important parameters, such as porosity, permeability and reservoir geometries. Carbonate lakes are dynamic systems and sensitive to clime variations and tectonics environment. Therefore, there are not trust rules to recognize these lacustrine deposits.

Then, all the data interpreted above were integrated became able collecting some data, which are important to modeling a production reservoir, waiting for just saturation fluid information. The use of geometric attributes in GPR interpretation allowed the recognition of several features that were not seen or poorly defined from the interpretation of the amplitude attribute only.

First of all, about lithology, trough facies characterization were possible identify each kind of rock. Using this data, it is possible to estimate porosity rate of each sequence, because this is an intrinsic property of rocks, and depends of compositional material (grains and matrix).

Then, following Dunham classification and outcrop data, it is possible to suppose that these units composed by packstones and grainstones are more porous than that composed by wackestones.

Permeability estimative depends of matrix's permeability and existence of faults and/or fractures. Unfortunately, measure of matrix's permeability is possible just using well core, and we did not have such kind of data. Then, we were restricting to modeling using only information from structural geology.

Therefore, it is important understanding about basin formation, because its structural deformation was responsible to coquinas sedimentation. This purpose is possible to be done because similarity orientation of regional and local faults, and some sequences were deformed/controlled by these structures, and could be used to hydrocarbon migration. Studies to better understand faults architecture are important to develop a reservoir, helping to locate wells, such as pioneer, production or injection, during several life steps of a reservoir.

Acknowledgments

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