Upper Cretaceous Sequence seismic and log facies of the of the Mundaú Sub-Basin: Impacts on the petroleum system

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Abstract

Over the last decade, new oil discoveries in the Guyana basins and West African Margin drew attention to the basins in the Brazilian Equatorial Margin, due the geological similarities between the new discoveries. In 2012, due the successfully oil discovery in the Pecém Well, in the deep waters of the Mundaú sub-basin, new opportunities of hydrocarbons accumulation in the area were speculated. In the Mundaú Sub-Basin, the Upper Cretaceous turbidities sandstones stands as an important play and recent studies has successfully mapped many sand-rich bodies in deep waters area and chronologic related to the Upper Cretaceous plays. However, these bodies have not been completely studied yet and they stratigraphic relationship and geometry still a matter of debate.This study used a 3D seismic cube, four wells and they respective density, gamma ray and porosity logs. In this study, five seismic facies and four log facies were mapped in the area, showing a tendency to accumulation of porous sand bodies in the deepest and upper levels of the area, while the shallowest areas presented a predominance hemipelagic deposits.

Introduction

The Brazilian Equatorial Margin (BEM) is a new exploration frontier, due recent discoveries of massive oil fields in the West African Margin and Guyana basins, that are geological correlated to the BEM. Between the BEM basins, the Ceará has shown to be a prolific one for new oil discoveries, due the successfully drilled wells in deep water. The Ceará basin (Figure 2) is divided in four sub-basins, which are grouped in compressive (Piauí-Camom, Acaraú and IcaraÍ Sub-Basin) and divergent (Mundaú Sub-Basin) with the exploration surveys and drilled campaigns focused in the last one. In the Mundaú sub-basin, the Upper Cretaceous turbidities sandstones, Upper Aptian fluvio-deltaic sandstones, Upper Aptian limestone and Lower Aptian fluvio-deltaic sandstone are the main plays exploited until now.

In this study, the Upper Cretaceous sequence is analyzed in the deep water of the Mundaú Sub-Basin, through seismic and wells data (Figure 2), this sequence is part of the transgressive drift sequence (Figure 1), associated to the wide opening of the Brazilian and African margins and composed by shales, siltstone and turbidities sandstones deposited in deep marine environments (Condé et al., 2007).

In deep waters sedimentary system, turbidities bodies have been source of massive oil discoveries over the world, being estimate that proximally 30BBOE (billions of barrel oil equivalent) were founded in turbidities reservoirs between 1995 to 2002 (Pettingill and Weimer, 2001). Turbidities system can present several depositional elements with different features and properties, for exempla turbidities system can present many geometries with different laterally and vertically connectivity (Silva et al., 2008), impacting directly in the reservoir and petroleum system. Among other factors, the composition and overlapping of turbidities bodies also play an important factor for oil accumulation. In this sense, the particularity of the turbidities systems in the Mundaú Sub-Basin and BEM still are poorly described and studied.

Recent study identified channel complex, point bars, feeder channels, dentritic lobes, smaller channels and distributaries in the deep water of Mundaú sub-basin, indicating important targets for oil explorations (Leopoldino Oliveira *et al.,* 2020). In this study, we aimed to clarify the stratigraphic relationship of the several deposition elements earlier mapped by Leopoldino Oliveira et al. (2020) in the Upper Cretaceous sequence in the deep water of the Mundaú sub- basin.

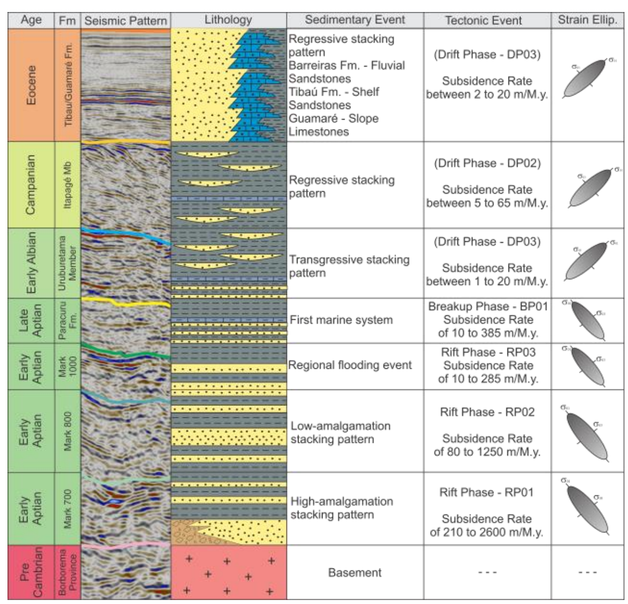


Figure 1 - Crono-stratigraphic chart of Ceará Basin (Cerdeira *et al.*, 2022 adapted from Condé *et al.*, 2007)

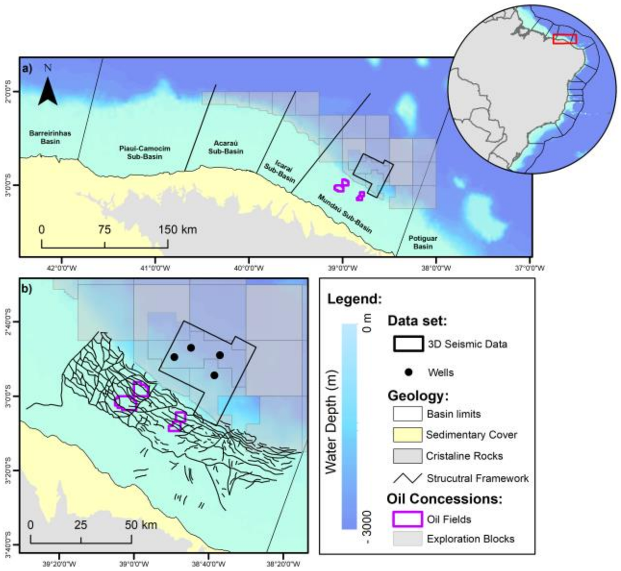


Figure 2 - Location map of the Mundaú Sub-Basin and the data used in this study.

Method

The data set consists of a 3D seismic cube, depth migrated, covering proximally 1,1 km^2 in the deep water of the Mundaú sub-basin and four wells and the Gamma Ray, Porosity and Density logs. In the first step, the top and base horizons of the Upper Cretaceous sequence were mapped and gridded to produces the respectively surfaces map (Figure 3b and 3c), in addition the seabed also were mapped to serve as reference (Figure 3a). Using the top and base surface maps, the thickness of the Upper Cretaceous sequence was calculated (Figure 3d). To highlighted the amplitude anomalies, the RMS Amplitude attribute was applied to the horizon top of the Upper Cretaceous sequence (Figure 4).

The seismic data were interpreted using Petrel software from Slb, the seismic patterns were interpreted considering the concepts proposed by Vall et al. (1977) and compilated for better understand the area (Figure 5).

The wells data were analyzed individually and porosity, density and gamma ray logs were combined in a three-dimensional plot (Figure 6), following the methodology proposed by Rieder (1998). Using the xyz crossplots, four log facies were interpreted and compilated to correlation of temporal occurrence of the facies (Figure 7).

Results

The study area (Figure 2b) is located in the deep waters zone of the Sub-Mundaú Basin, specifically in the marine slope transition, with depth ranging from 200 to 2300 meters (Figure 3a). In this area, the mapping of the top the Upper Cretaceous sequence shows a two channels' patterns in the western region and a relatively high region in the central zone of the area (Figure 3b), the deepest occur in the northeastern part of the area. The base of the Upper Cretaceous Sequence presents an elevated zone in the central part of the area without a clear pattern of sedimentary system geometries (Figure 3c), however it is possible to notice the pattern to increasing depth to the northeastern region of the area (Figure 3c), similar to the Upper Cretaceous Sequence top (Figure 3b). Using the surfaces described above, was possible calculated the thickness of the Upper Cretaceous Sequence (Figure 3d), with values ranging between 10 to 1000 meters, where the higher values (750 to 1000 meters) occur gather in four elongated bodies NW-SE oriented (Figure 3d), this bodies are surrounded by relatively thick zones (500 to 750 meters), with presents a pattern similar to the Upper Cretaceous Sequence top (Figure 3b), in which presents a geometry similar to channels that are separated by banks with the smallest values of the area (10 to 500 meters).

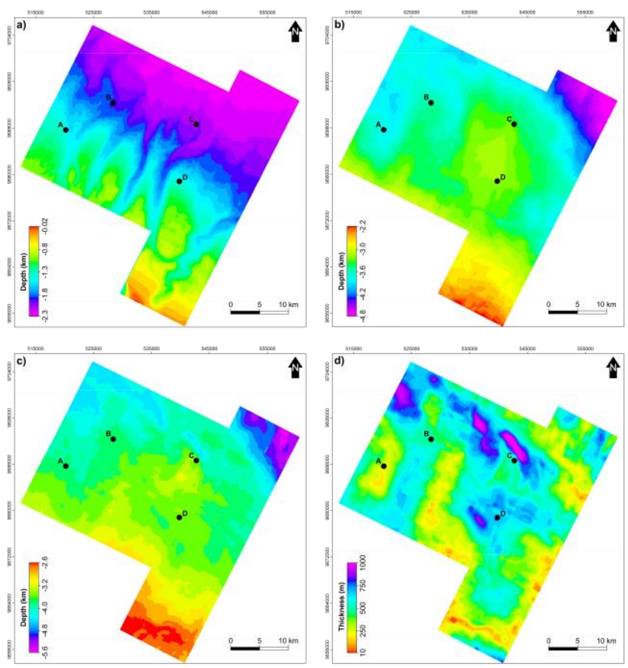


Figure 3 - Interpreted surface of the seabed (a), Upper Cretaceous Sequence top (b), Upper Cretaceous Sequence bottom (c) and thickness map of the Upper Cretaceous Sequence (d).

Applying the RMS Amplitude attribute in the Upper Cretaceous Sequence top, it was possible highlight the amplitude anomalies in the area. The RMS Amplitude map shows a clear channel geometry in the western region with apparently point bars (Figure 4), while in the eastern region an elongated NE-SW oriented geometry occur, however without a clear geological pattern. To better investigate and understand the sedimentary dynamics and evolution of the area, a seismic facies analysis was made (Figure 5), the location of the seismic facies described are highlighted in the RMS Amplitude map (Figure 4).

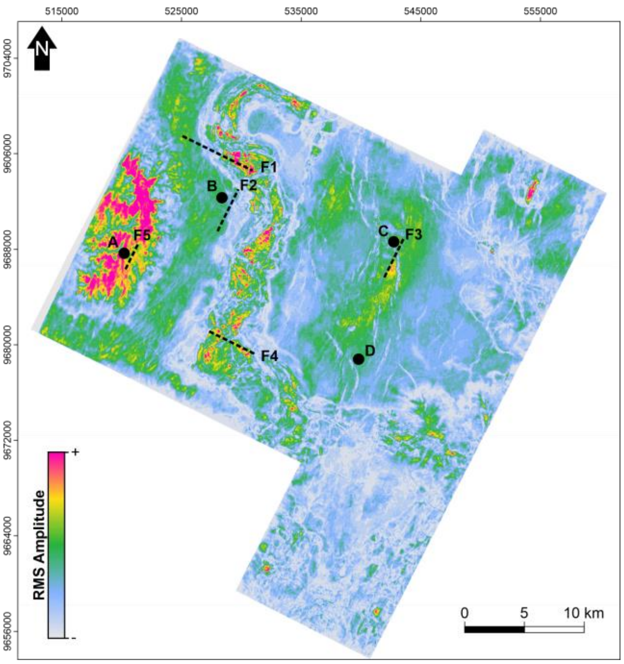


Figure 4 - The RMS amplitude attribute from the Upper Cretaceous Sequence top.

Five seismic facies (F1 to F5) were interpreted and described (Figure 5). The first seismic facies (F1) present a succession of wavy reflectors with low to high amplitude, similar to erosive channels succession, apparently migrating to west, laterally sub-parallel reflectors with very high to low amplitude without horizontal continuity, apparently associated to point and sand bars (Figure 5). The F2 presents a pattern an inclinated plan-parallel reflector with low to high amplitude and onlap termination (Figure 5). The third seismic facies (F3) are divided in two groups separated by unconformity, the bottom reflectors present high to low amplitude with plan-parallel geometry, while the top reflectors present low to moderate amplitude with plan-parallel truncating the bottom reflectors (Figure 5). The F4 presents wavy reflectors with high to low amplitude and erosive features (Figure 5). The F5 presents a very high amplitude and horizontally continuous reflector in the top and sub-parallel reflectors in the bottom (Figure 5).

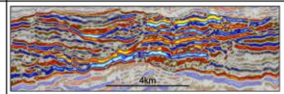
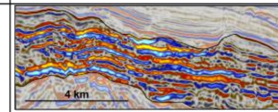
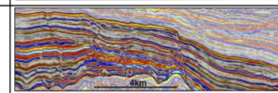
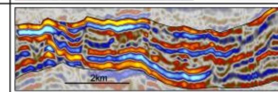
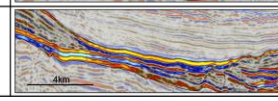
FACIES	SEISMIC PATTERN	FACIES DESCRIPTION
F1		Erosive channels features with low to high amplitude sub-parallel reflectors.
F2		Inclinated plane-parallel reflectores with low to high amplitude and onlap termination.
F3		Plane-parallel reflectores, top reflectores presents moderate to low amplitude and bottom reflectores presents high to moderate amplitude.
F4		Wavy reflectores with high to low amplitude and erosive features
F5		Erosive features and laterally continous reflectores with very high to low amplitude

Figure 5 - Summary chart of main seismic facies observed within the Upper Cretaceous Sequence.

Due the small vertical seismic resolution, four wells were used in this study to improve the understand of sedimentary facies interpreted in the area (Figure 6 and 7). Through the density, porosity and gamma ray logs, four facies were grouped. The LF1 and LF2 both presents low gamma ray values, while the first one presents high density and low porosity values, the second presents low porosity and high density. The LF3 also present low gamma ray values and high porosity, similar to LF2, however, the density values are intermediary (Figure 6). The LF4 presents high gamma ray values, high density and intermediary porosity (Figure 6).

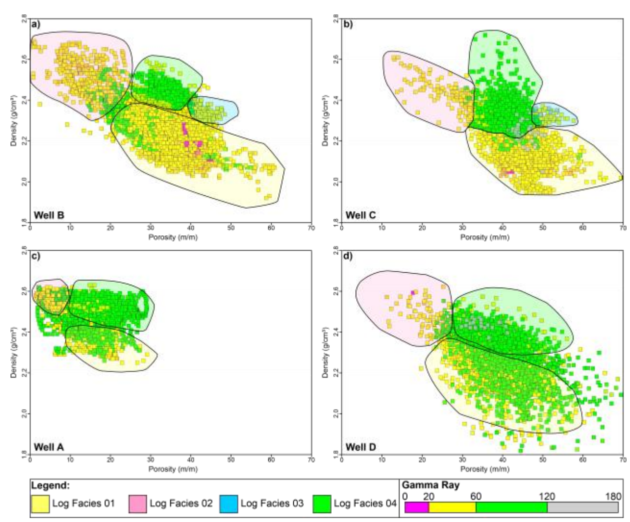


Figure 6 - Porosity (Neutron), density (RHOB) and Gamma Ray crossplots of the Upper Cretaceous Sequence for Well B (a), Well C (b), Well A (c) and Well D (d), see location of the wells in Figure 4.

The LF01 are present in al wells and occur mainly in the upper levels, specifically in the wells B and C the LF01 presents the thicker layers (Figure 7). The LF02 also are present in all wells, however are thinner than LF01 and are more common in bottom levels of the wells, in the well C also occur in the upper levels (Figure 7). The LF03 only occur in the wells C and B in different stratigraphic levels (Figure 7). The LF04 are present in all wells, in the wells A and B occur over all stratigraphic level, while in the wells C and B, the occurrence of the facies is limited to the bottom levels (Figure 7).

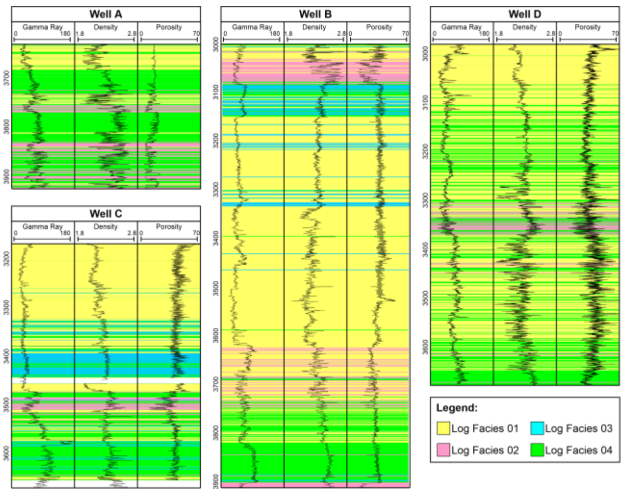


Figure 7 - Gamma Ray, density (RHOB) and porosity (NPHI) logs and the facies interpreted from crossplots (Figure 6) from Well A, B, C and D (See wells locations in the Figure 4).

The seismic analysis indicates the occurrence of large erosive channels in the western region of the study area and sand bars in the deepest region (Figure 4), the F4 and F5 shows erosive features occurring in the shallow areas, while the F1 indicates a sand bar occurrence, although associated to channel erosion (Figure 5). The LF1 can be associated to porous sand bodies, while the LF2 can be associated to amalgamated sand deposits. The LF3 also is interpreted as sand bodies in this study, however is related in this study to crevasse deposits, due the high-density values in the samples. The LF4 log in this study is interpreted as pelagic and hemipelagic deposit.

The LF analysis in the wells, shows an intercalation of deep-water shale and channel complex deposition, also can be observed the prolific development of sand deposits, related to channel complex, in the wells drilled in the deepest water level, while in the shallowest is predominant the deposition of shale, except by the occurrence of thin crevasse layers.

Conclusions

This study aimed better understand the stratigraphic relationship of the depositional elements in the Upper Cretaceous sequence of the Mundaú sub basin deep waters, for this, interpreted four seismic facies and four log facies. The results suggest a tendency of pelagic and hemi-pelagic deposit in the shallowest parts of the study area, while the sand-rich bodies occur in the deepest areas. Stratigraphically, the porous sand bodies occur more often in the upper levels in the wells. Expressive erosive channel expression also was interpreted in the area, mostly in the western region of the study area.

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