Geophysics Characterization of Oligocene Turbidites and its relationship with Synsedimentary Fault Systems in Marlim Oil Field - Campos Basin - Brazil: Seismic and Well Profile Analysis

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Abstract

Since the 1970's, it is known the hydrocarbon exploration in the post salt zone at Brazilian offshore basins. The Marlim oil field, discovered in 1985, is considered the most important oil source for the country, geologically at the Oligocene stratigraphic layer, it lies above the salt domes. However, latest studies carried out by petroleum companies showed that the oil production started to reduce, which indicates a mature stage of hydrocarbon extraction turning into a declining stage; it is important to improve the geological knowledge on this area in order to better decide about the economic future of Marlim.

The objective of this research is to comprehend the spatial distribution of the Carapebus Oligocene turbidites in the Marlim Field (Campos Basin), as well as characterize and interpret the main fault systems and its relation to the main turbidite boundaries.

The investigation was made based on geopshysical techniques such as seismic and well profiles correlations focused at the main Oligocene reflector (reservoir top and base). The research identified that Marlim Field contains potentially important turbidites bodies - classified as Marlim Turbidites - whose preferential orientation is from Northwest (NW) to Southeast (SE).

It was observed a big turbidite body in the Northeast portion, associated with a NE-SW normal fault system capable to restrict the turbidite development and acts as a way to oil migration from the pre-salt zone to the post-salt zone, more specifically in its uplifted side, transforming them in a highly interesting exploratory play, conditioned by structural traps.

Introduction

The Campos Basin (Figure 1), located in the Southeastern portion of Brazil, occupy an area of 100.000 Km² and it is considered the most important Brazilian hydrocarbon producer, representing approximately 60% of all country oil production (BASTOS & LUPARELLI, 2015). The basin is bordered by Alto de Vitória (North) and Alto de Cabo Frio (South), geological structures that separates it, respectively, from Espírito Santo and Santos Basins.

The giant Marlim Field is located in the northeastern portion of the Campos Basin, approximately 110 Km East from Cabo de São Tomé, in Rio de Janeiro State coast. The field was discovered in 1985 by Petrobras, and covers an estimated area of 257,6 Km². The production started in 1991 and Marlim quickly became the largest producing field with daily production of 610.000 barrels (JOHANN et al., 2009). In 2016, Marlim was considered the fifth largest producer with 150.000 barrels per day, which clearly demonstrate the dramatic decrease of oil production through the years, even when the field breaks the record of producer wells, totalizing 48 (DEPG, 2016). The oil has high gravity (17-21 degree API) and low content of sulfur and metals, which makes it environmentally attractive (D'ALMEIDA, 2002).

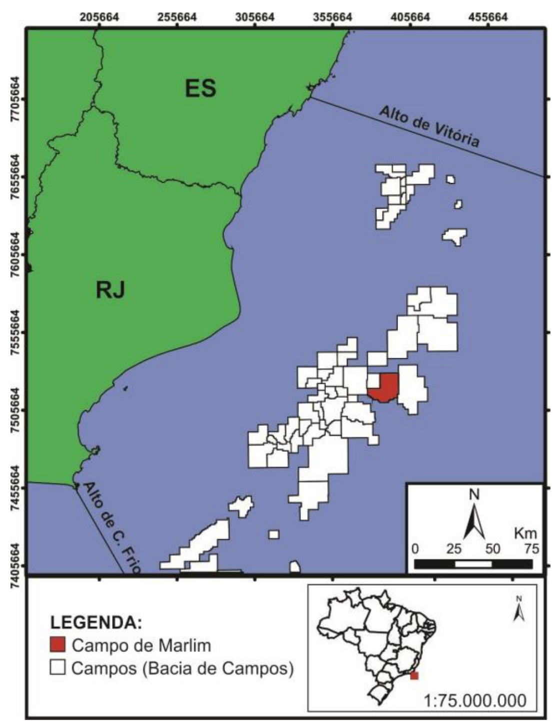

Figure 1 - Campos Basin location map emphasizing the Marlim Oil Field.

The geology features observed in Marlim Field is quite similar to the one found in Campos Basin (WINTER et al., 2007) (Figure 2), in which the Precambrian basement consists in migmatites, granulites and gneiss of Faixa Ribeira (TUPINAMBÁ et al., 2000). Between Berriasian (140 M.y.) and Aptian (120 M.y) a rifte sequence starts a continental lacustrine phase and, as a consequence, a main Aptin source rock was developed. The continuous process of Atlantic Ocean aperture culminates in deposition of large salt quantities, during the transitional phase. Finally, the passive margin phase started at 110 M.y with the deposition of carbonates and, as the transgression advances, carbonate platforms are gradually replaced by deep water marine sediments and occasionally turbidites, which represents, respectively, seal and reservoir rocks.

The Oligocene/Miocene Marlim Turbidites are considered a group of tabular sandstone bodies (PERES, 1993) with high levels of porosity - 30% - and permeability - 2000 mD - (LORENZATTO et al., 2004).

Vincentelli et al. (2016) describe tectonic reactivation of the rift system as the main responsible for the oil migration and consequent accumulation in the turbidites bodies. In this case, the hydrocarbons are sealed by the shale of Ubatuba Formation. Therefore, Marlim Turbidites are really considered an interesting exploratory play and its intimate relationship with the above mentioned fault systems must be deeply considered in the Marlim Field oil prospection.

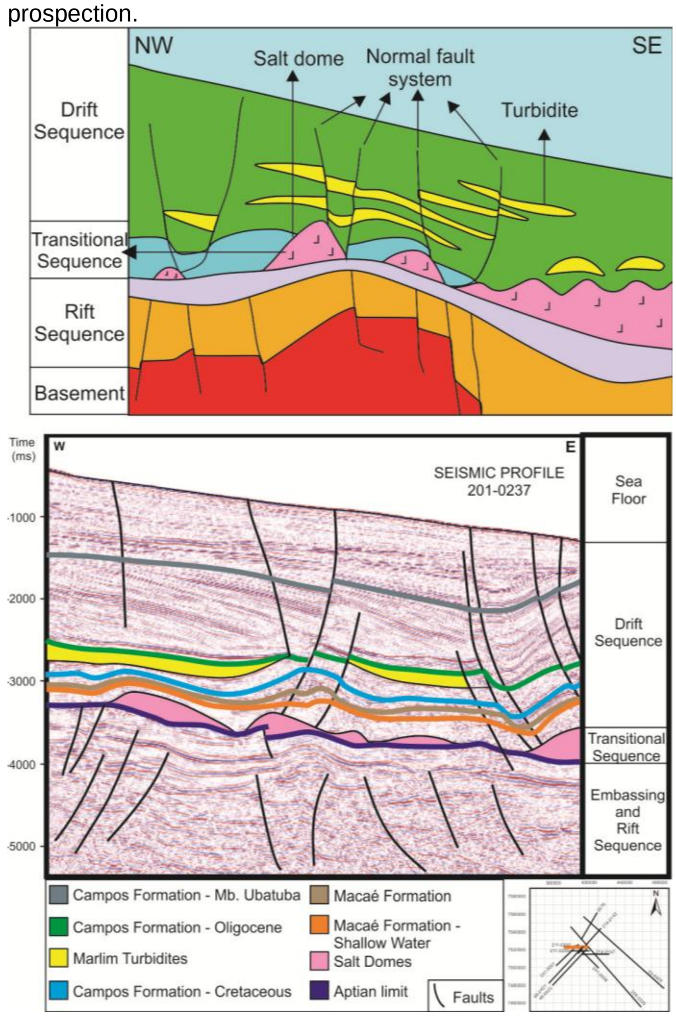

FIGURE 2 - *Schematic geological section from Campos Basin above (Modified from Rangel & Martins, 1998) compared to a seismic profile obtained from the research in the Marlim Field, below. In the lower right is the position of the selected seismic profile.*

The objective of this research is to comprehend the spatial distribution of the Marlim turbidites - Oligocene Campos Formation, Carapebus Member - in the Marlim Field (Campos Basin), as well as characterize and interpret the main fault systems and its relation to the turbidite boundaries using well correlation techniques and seismic data.

Method

The development project required the use of a database composed by wells and seismic lines provided by the Agência Nacional do Petróleo (ANP) as part of a policy to supply public data for university researches.

The project was divided in four main stages:

1) Studies compilation and database improvement: the first phase was characterized by systematic compilation of the most diverse bibliographical references regarding to Campos Basin and Marlim Field, which includes lithological, stratigraphic and structural settings, geological evolution and geophysical concepts and theories. Furthermore, the stage embraced the organization of 11 seismic profiles (578 Km of seismic lines) and 16 wells - 10 in Marlim Field, 3 in Garoupa Field and 3 in Albacora Field - with their respective composite logs and well folders (Figure 3).

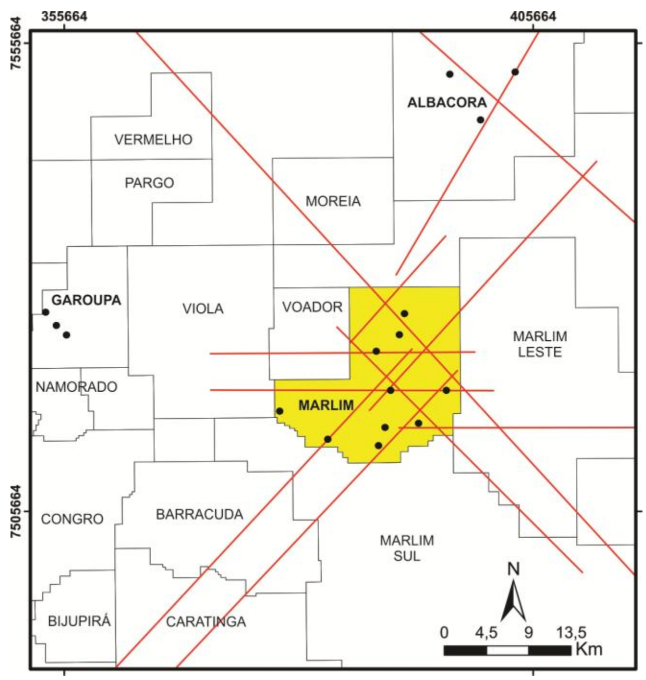

FIGURE 3 - *Map containing all the 16 wells - black points - and 11 seismic lines - red lines - used in the research.*

2) Well profile and seismic horizon identification: the second phase consisted in the construction of 16 well profiles containing relevant data for the research, as well as, gamma ray (GR - API), density (RHOB - g/cm³), resistivity (ILD - Ohm.m) and sonic (DT - µs/f) values. The well reports provided stratigraphic information regarding to the depths of each geological unit described at the basin. Subsequently, the sonic profile allowed to calculate the units interval velocity (Figure 4).

3) Seismic profile interpretation (Figure 5): the third phase consisted to calibrate the 1RJS-0305-RJ well profile information with the 0067-0576 seismic profile using the

interval velocity of 4 main geological formations or members: Campos Formation - (i) Ubatuba Member (2345 m/s) and (ii) Oligocene (3048 m/s); (iii) Macaé Formation (3650 m/s) and (iv) Macaé Formation – Shallow Water (3850 m/s). In this situation, the velocity data and the seismic time allowed to identify the depth in milliseconds of each interest formation in the seismic profile and, consequently, identify the reflector that belong to each one.

The interpretation and combination between all the seismic lines resulted in a solid database and subsequently allowed the map´s construction.

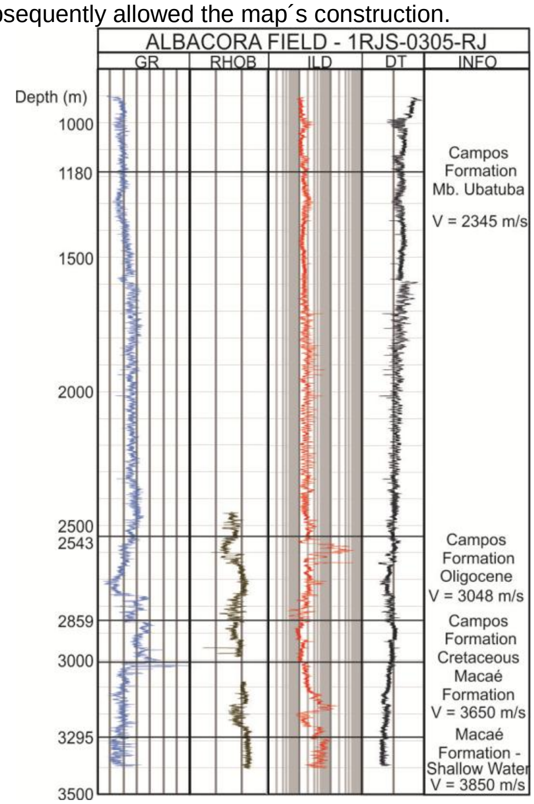

Figure 4 - *1RJS - 0305-RJ well profile from Albacora Field used to calculate the interval velocity of geological formation.*

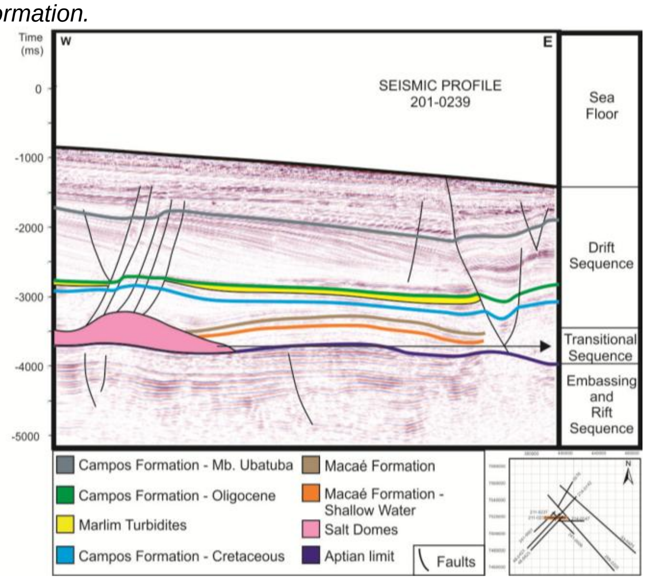

Figure 5 - *Example of seismic profile interpretation.*

4) Maps: the last step was to build in the software Surfer 13 the structural contour map for all the identified horizons, and its most relevant fault systems. It is necessary to mention that it was possible to show the contour structural maps in milliseconds because the water layer seemed to be uniform along the Marlim Field.

Furthermore, an isopach map was made using the Marlim Turbidites top and bottom limits. These maps were crucial to comprehend how the Marlim Field faults could control the turbidites distribution and oil migration.

Results

The integrated analysis of the information contained in the 11 seismic lines and 16 well profiles for the Marlim Field allowed to build a structural contour map (Figure 6), in miliseconds (ms), which chronologically represents the Oligocene limit and, stratigraphically, the top of both Carapebus Member - Campos Formation - and Marlim Turbidites.

As observed, the isochrones values denotes a gradual decrease from the Northwest (NW) region to the Southeast (SE), as a consequence of the natural platform deepening from the coastline to the ocean.

In the extreme right in the map occurs a relative increase in the isochrones values which, combined with the proximal seismic lines observation, indicates an Oligocene surface uplift, as a result of the occurrence of large salt domes.

Furthermore, the structural contour map exhibits zones characterized by isochrones disturbances, which represents discontinuities along the mapped surface. In other words, the observed perturbation points to a large normal fault system whose the preferential orientation is NW-SE in the Central and Northwest map regions - highlighted by the red line.

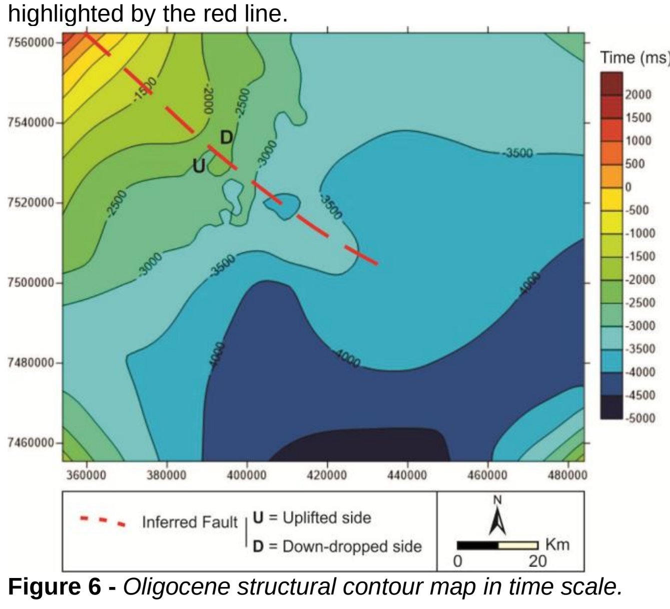

Figure 6 - *Oligocene structural contour map in time scale.*

In order to elucidate the probable relation between the normal fault system, identified in the figure 6, and the potential hydrocarbon reservoirs described in the area, such as Marlim Turbidites, an isopach map was made (Figure 7).

The isopach map does not clearly represents the canyon morphology whose turbidites are associated, however, the map points to the turbidites general orientation from Northwest (NW), where the thickness is more representative and can reach 280 meters, to Southeast (SE), where the bodies become increasingly rare and its thickness does not exceeds a few meters. It is crucial to mention that, despite the preponderance of the NW-SE orientation, there are important lobes following the Southwest (SW) direction.

In a diametrically opposite situation, there are few lobes developed to the Northeast (NE), and they are usually very unrepresentative. The interpretation for this fact is based on the presence of the previous mentioned NW-SE normal fault system, capable to restrict the turbidite development.

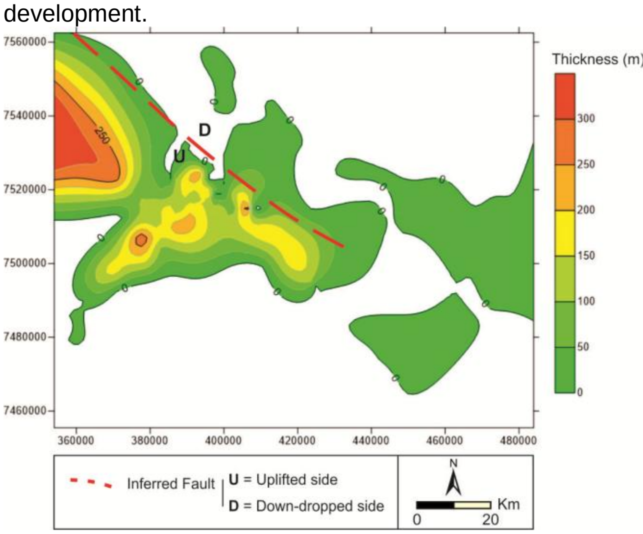

Figure 7 - *Marlim turbidite isopach map.*

The figure 8 illustrates one of the seismic lines that cross the mentioned fault system. It is observed, in this case, that the turbidite lobe is submitted to a normal fault that affects not only rift rocks but also Quaternary drift rocks. Such structural context for the Marlim Field has already been identified and described by Vincentelli (2016).

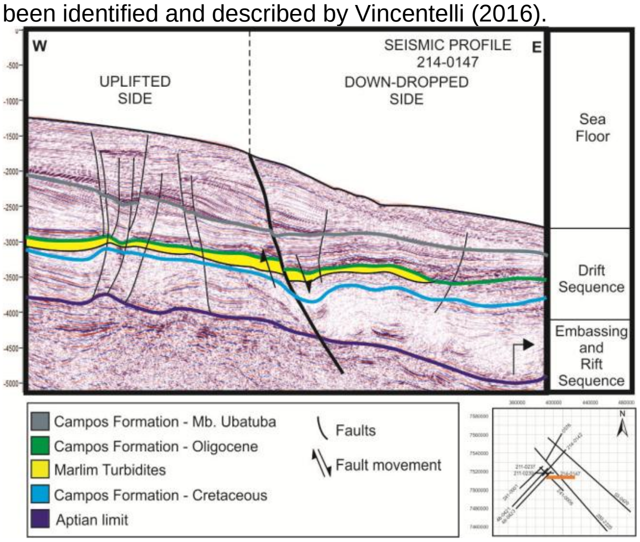

Figure 8 - *Seismic line 214-0147 showing the turbidite lobe being affected by normal fault.*

In this case, the normal fault is the result of the rift system reactivation, affecting all the superimposed sedimentary packages until reaches the most recent sediments from Holocene (Quaternary), not deformed.

To better comprehend the tectonic and stratigraphic evolution features presented in the area, the events was subdivided in 3 main stages, summarized and illustrated in figure 9.

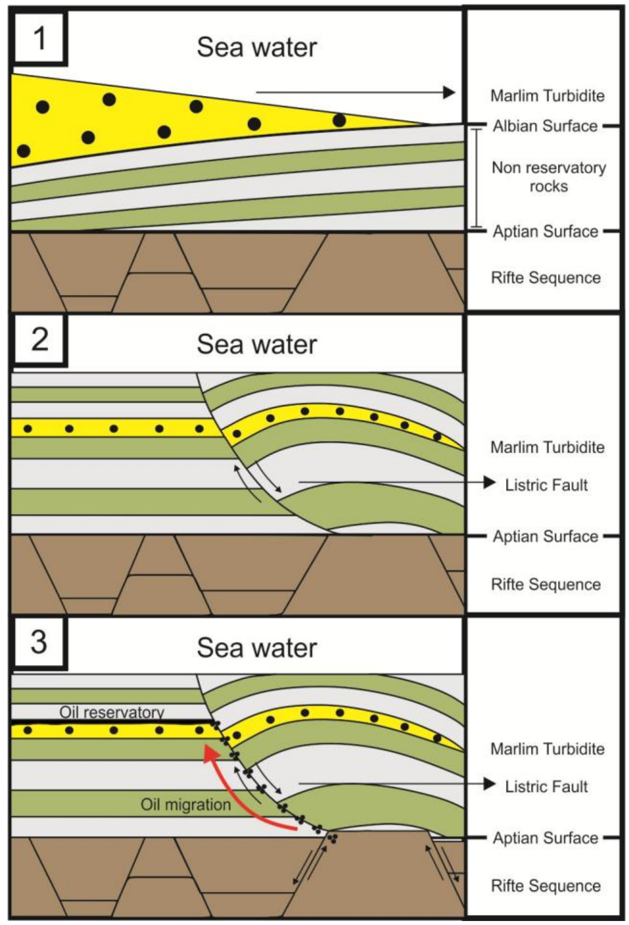

Figure 9 - *Marlim turbidites history, fault system and hydrocarbon migration. (1) Stability phase; (2) Activation Phase and (3) Reactivation phase.*

1) Stability phase: the first stage includes the period between the basin installation - rift phase - in the context of the Atlantic Ocean aperture, to the passive margin development stage, during the Oligocene-Miocene. It happened in a relatively stable tectonic epoch, where the faults of the drift sedimentary sequence did not exist or were little pronounced, in the way to not affect Marlim turbidites.

2) Activation phase: the second stage, occurred at the Oligocene-Miocene Epoch (approximately 15 M.y), is identified by normal listric faults with the lower portion positioned at the top of the Aptian. These fault systems were capable to deform the Marlim Turbidites. However, listric faults usually acts as sealant structures preventing, at first, migration of both gas and oil. Subsequently in the geological time, the basin became stable again, subjected to a retrogradation and consequent sea level rising.

3) Reactivation phase: the last phase, occurred after 15 M.y, was based on the reactivation of the rift system faults and it affects all the sequences between the Middle Miocene to the Quaternary. In the situations when these faults connect directly to the Marlim turbidites or to its associated faults, there is hydrocarbon migration from the pre-salt zone to the post-salt zone and, as a consequence, the oil accumulates in the Marlim turbidites, once they have high porosity and permeability parameters, and at the same time, they are capped by poorly porous and permeable shales, which confine the oil inside the turbidites and transform them in a higly interesting exploratory play (CARMINATTI, 1987).

In this way, the NW-SE fault system described in the present research can act as a migration route for hydrocarbons, in order to make the Marlim turbidites a strategic exploratory play. It is also worth to mention that the turbidites found in the fault uplifted side have greater potential to contain hydrocarbons, once the oil general tendency is to migrate to lower pressure regions. Finally, could be understood that the possible exploratory play described in this research is characterized by oil traps conditioned by structural aspects.

Conclusions

The integrated analysis of the all seismic lines and well profiles allowed to conclude that the Marlim Field has potentially important turbidites bodies - classified as Marlim Turbidites - whose orientation is from Northwest (NW), with more representative thickness to Southeast (SE), where the bodies thickness does not exceeds a few meters, although some turbidite lobes follow the Southwest (SW) direction.

The turbidite lobes in the Northeast portion is directly related to an important NE-SW normal fault system that are capable to restrict the turbidite development and could acts as a way to oil migration. These faults were submitted to tectonic reactivation and caused deformation in sedimentary sequences since the Lower Cretaceous up to Holocene. In the case when the faults connect directly to the Marlim turbidites or to its associated faults, there is hydrocarbon migration from the pre-salt zone to the post-salt zone and, as a consequence, the oil accumulates in the Marlim turbidites, more specifically in its uplifted side, transforming them in a higly interesting exploratory play, conditioned by structural traps.

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