Structural and halokinetic analysis of the Frade Field area, Campos Basin, Brazil.

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Abstract

Salt tectonics, basement fault reactivation, or continental margin instability can disturb post-rift sequences and form important controls of the structural and stratigraphic features found in the deep-water petroliferous region of the Campos Basin, offshore Brazil. 3D and 2D seismic data covering the Frade Field area in the north central portion of the Campos Basin have been used to characterize the salt structures and investigate their influence on the overlying strata, which contain the Oligocene-Miocene turbidite oil field reservoirs.

Seismic interpretation and isochron maps were integrated to enable the evaluation of the salt-sediment relationship and associated deformations, in particular, the halokinetic deformational events involving the Albian to Campanian sediments. Interpretation of the data revealed that two stratigraphic intervals, the Campanian-Albian (around the salt anticline) and the Albian-Aptian, are locally thicker in the study area than those of nearby fields, such as Roncador, where the Maastrichtian depositional sequence is thicker. A key structural control in the Frade Field area was the development of a shear zone with a dextral strike-slip component, which resulted in the formation of a rhomb-graben at the Albian level. Formation of this feature created accommodation space for a thick Campanian depositional sequence above the salt anticline. Conceptual restoration revealed that the salt-sediment relationship started with gravitational gliding during the deposition of the Lower Albian and later changed to active diapirism during the Campanian. This was a very import event, as the thicker Campanian sequence previously deposited in the rhomb-graben was inverted, which helped form the low-relief anticline structure of Frade Field and deformed the Miocene-Oligocene turbidites to geometries favoring hydrocarbon accumulation.

Introduction

Atlantic-type passive margins are considered tectonically quiescent environments during the thermal phase of subsidence, which starts at the transition from the rift phase to the drift phase of these basins. However, some sedimentary basins are further affected by tectonic processes due to halokinesis, reactivation of basement faults, or instability of the continental margin due to sediment progradation and differential overburdens, which disturb/deform previously formed structural and depositional features. This can lead to the formation of diverse halokinetic features, such as turtleback structures, anticlinal structures, mini-basins, rafts, normal listric faults, and reverse faults, among others. These tectonic movements are important controls for the genesis of structural and stratigraphic features encountered in the Campos Basin, particularly in the petroliferous deep-water region adjacent to Frade Field, where the study area of this work is located.

Remobilization of Late Aptian evaporites tends to alter the configuration of the overlying strata, particularly Early to Late Albian carbonates and Late Cretaceous siliciclastic sediments. Due to the viscous nature of salt and the fact that its density varies little with increasing pressure or depth, the weight of the overburden tends to expulse the salt towards the depositional surface as well as laterally, resulting in the deformation of the salt's overlying sedimentary layer (Jackson *et al*., 1994) and can influence the configuration of post-salt deposits. Analysis of the deformation and remobilization of salt bodies allows for a better understanding of their influence on overlying stratigraphic layers and, above all, the structural geometry of associated reservoirs.

Frade Field is located in the deep-water region of the continental slope of the Campos Basin, approximately 115 km from the northeastern coastline of Rio de Janeiro State (Figure 1). The field was discovered in 1986 after drilling the 1-RJS-366-RJ Petrobras pioneer well. The field has produced from Oligocene and Miocene turbidite sand reservoirs since 2009.

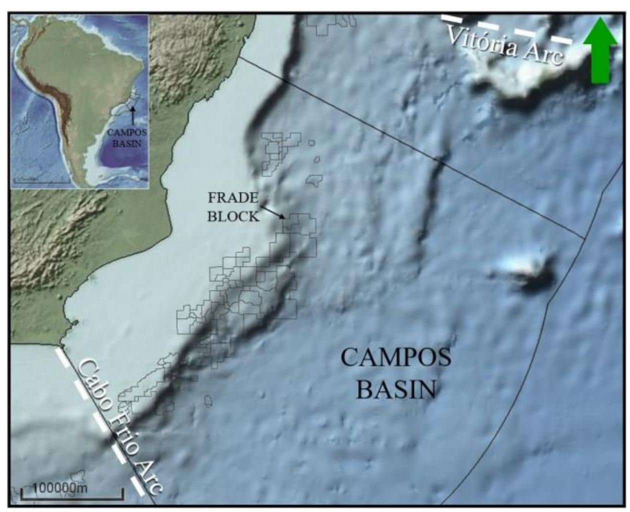

Figure 1: Location of the Frade Field study area including the political and geological limits of the Campos Basin.

Method

The study workflow used 2D and 3D post-stack migrated seismic data and electric logs from exploratory wells focusing on the area in and around Frade Field. Velocity model data used for the migration of the data was unavailable for this survey; hence, all measurements are in two-way time (TWT).

Interpretation of the geophysical project data was carried out in a systematic manner to characterize the structure and stratigraphy of the study area and the geometry of the salt bodies and their tectonic movements. The 2D seismic lines were used to give a regional view, while the 3D seismic cube allowed detailed assessment of the stratigraphic sequences and detailed 3D mapping of the main salt body. The chronostratigraphic markers interpreted in this study were chosen based on the stratigraphic chart for the Campos Basin proposed by Winter *et al.* (2007) in which eight (8) horizons with a focus on the Upper Cretaceous were used to interpret the 3D seismic, whereas six (6) horizons were used to interpret the 2D seismic lines in less detail for the Upper Cretaceous, but with the inclusion of the pre-rift and rift sequences (Figure 2).

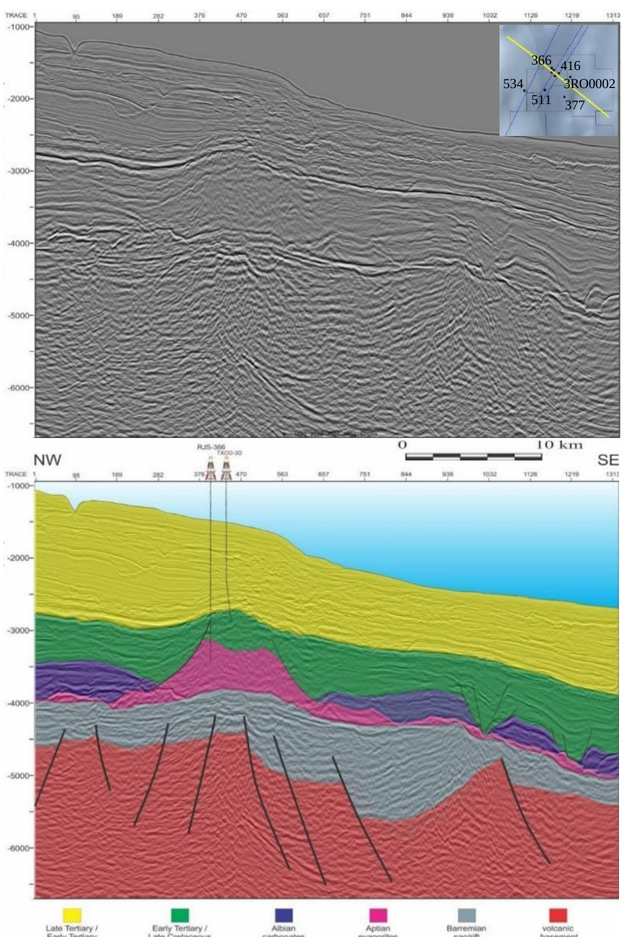

Figure 2: 2D line 228-0539 without and with interpretation. This line has an apparent strike orientation in respect to the main salt wall feature.

Isochron maps were generated for four (4) intervals of interest using the horizons interpreted for the structural maps and include the ages in which tectonic movements were identified previously from the seismic interpretations, which have also been recognized by several authors (Fetter, 2009; Meisling *et al.*, 2001, Mohriak & Fainstein, 2012, Rangel *et al.*, 2003; Waisman, 2009, among others). The interval thickness is measured in milliseconds and the maps have a vertical exaggeration of 2X.

Time slices were also analyzed and interpreted with the aid of seismic attributes such as TecVA (Bulhões & Amorim, 2005) and Variance.

Results

Interpretation of the 2D data characterizes the normal faulting of the rift sequence and the presence of a pre-salt structural high beneath Frade Field. Also, the anticlinal structure of the Miocene-Oligocene reservoirs (Silva, 2013) is associated with a salt body orientated WNW-ESE (Figure 2). This is an uncommon trend when compared with other salt structures previously mapped in the Campos Basin, which are generally oriented SW-NE (ANP, 2006).

Detailed 3D interpretation revealed the presence of a sigmoidal shaped feature separating four (4) Albian carbonate rafts by conjugate normal faults. This feature is clearly seen when mapped at the lower Albian horizon (Figure 3) and has a geometry similar to that of a rhomb-graben or pull-apart basin. As such, a transcurrent fault would be centrally localized within the feature with a dextral movement of the Albian rafts.

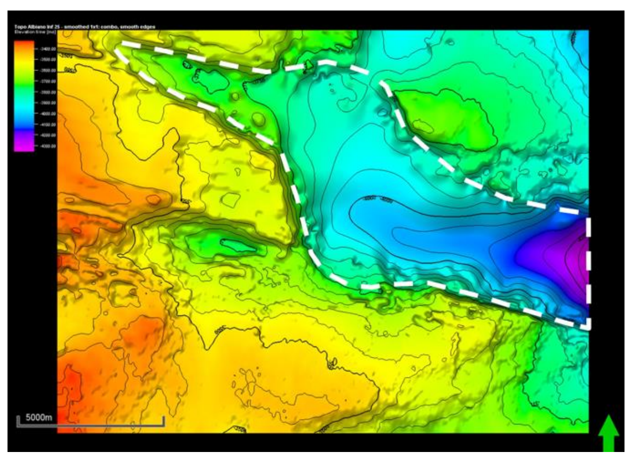

Figure 3: Structural map of the top of the Lower Albian. Observe the sigmoid-shaped feature highlighted with a white dashed line. Vertical exaggeration 1:1.

The underlying Frade salt structure was mapped in detail to capture the syn-depositional deformation imprinted from the Lower Albian due to salt flow. Undulations associated with the syn-depositional faults are observed on the top of the Albian evaporites and enable definition of the Albian raft boundaries. The Frade salt structure is more than 16 km in length and 5 km in width and exhibits the sigmoidal pattern observed in the Albian structural maps (Figure 4). A smaller evaporitic feature is located to the west with a more E-W orientation, but still roughly parallel to the trend of the main Frade salt structure.

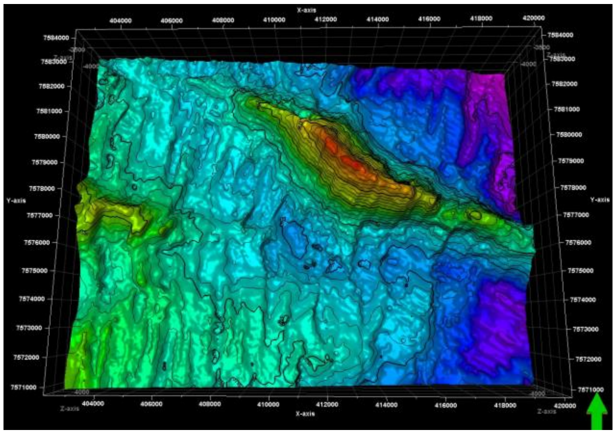

Figure 4: 3D structural map of the top of the Aptian Salt. Observe the undulations associated with syn-depositional faulting of the lower Albian sequence. Vertical exaggeration 1:1.

The Campanian-Albian interval represents the period in which a major portion of the halokinetic movement related to the Frade salt structure occurred. Interestingly, it also shows that the sigmoidal feature shown previously in the Lower Albian structure map behaves as a depocenter, which has been filled by Campanian-Albian aged sediments (Figure 5). The thickness of this sediment package is greater than 800 ms in the areas which are yellow-green. The purple area aligned at the center of the sigmoidal structure corresponds to the Frade salt structure and is characterized by little to no Campanian-Albian deposits where the salt pushed up into the depocenter syn-kinetically until the end of the Campanian period.

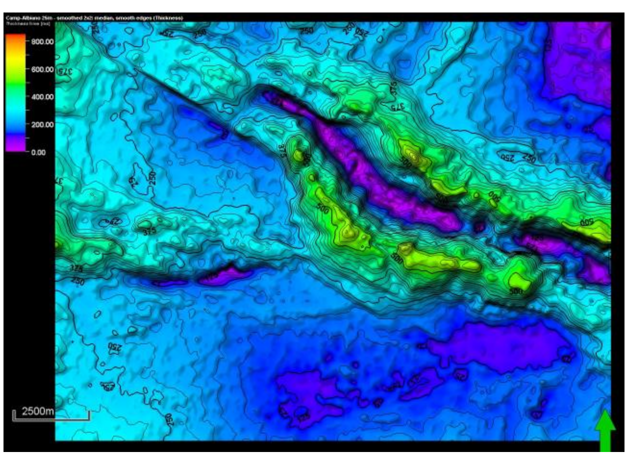

Figure 5: Isochron map of the stratigraphic package between the Campanian and Albian markers. Observe the thick deposits inside the sigmoid-shaped feature.

Interpretation of the Lower Albian faults (Figure 6) was extremely interesting as this interval represents deposits that are in direct contact with the Late Aptian evaporites, which undergoes extension as the evaporite layer flows basinward (toward the oceanic crust). Subsequently, these faults are syn-depositional and result from the gravitational gliding of the carbonate deposits on the evaporite layer. Most of these faults are limited by an erosional unconformity, with only a few that pass into the Upper Albian, probably due to localized reactivations.

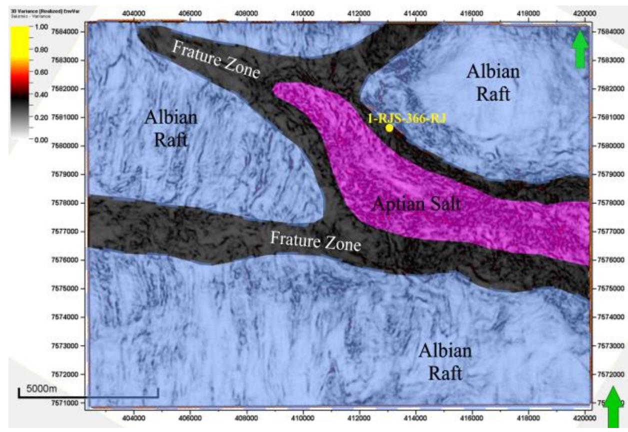

Figure 6: Tectonic interpretation of the -3750 ms time slice with the Variance attribute applied. Fault trends of the Albian rafts are visible with the western raft having a NE-SW trend and the southern raft having a N-S trend. Note the S pattern faults in the western raft.

Conclusions

The Frade Field area is geologically complex and represents various tectonic components which include a main phase of extensional rifting in the Early Cretaceous, halokinesis following salt deposition in the Late Aptian, local fault reactivations (both extensional and compressional regimes) in the Late Cretaceous to Miocene, and a rhomb-graben/pull-apart basin feature that is possibly associated with transcurrent faulting related to the salt flow and movement of the Albian carbonate blocks during halokinesis.

Movement related to salt tectonics began during the deposition of the Lower Albian with gravitational gliding of incipient carbonate deposits. A new phase soon followed associated with the Albian carbonate blocks and characterize movements with different relative velocities which culminated in an E-W extensional direction for the dextral shear couple.

In addition to halokinesis, reactivation of pre-existing basement faults may have contributed to the geometry of the salt structures, location of the incipient fracture zones and/or the diapiric growth phases of the Frade Field salt anticline.

Acknowledgments

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References

ANP. 2006. Interpretação e mapeamento dos sistemas petrolíferos da Bacia de Campos. Relatório ANP/UNESP/LEBAC, Tomo 1, 215 p.

BULHÔES, E. M. & AMORIM, W. N. 2005. Princípio da sismocamada elementar e sua aplicação a técnica volume de amplitude (tecva). Ninth International Congress of the Brazilian Geophysical Society. Extended Abstracts, Sociedade Brasileira de Geofisica, Salvador, Bahia State, Brazil, p. 1-6.

FETTER, M. 2009. The role of basement tectonic reactivation on the structural evolution of Campos Basin, offshore Brazil: Evidence from 3D seismic analysis and section restoration. Marine and Petroleum Geology, 26, p. 873-886.

JACKSON, M.P.A., VENDEVILLE, B.C. & SCHULTZ-ELA, D.D. 1994. Structural Dynamics of Salt Systems. Annual Review of Earth and Planetary Sciences, 22, 93-117p.

MEISLING, K.E., COBBOLD, P.R., MOUNT, V.S. 2001. Segmentation of an obliquely rifted margin, Campos and Santos basins, southeastern Brazil. AAPG Bulletin, 85, 11, p. 1903-1924.

MOHRIAK, W.U. & FAINSTEIN, R. 2012. Phanerozoic regional geology of the eastern Brazilian margin. In: Regional Geology and Tectonics: Phanerozoic Passive Margins, Cratonic Basins and Global Tectonic Maps. [s.l: s.n.]. p. 222–282.

RANGEL, H.D., GUIMARÃES, P.T., SPADINI, A.R. 2003. Barracuda and Roncador giant oil fields, deep-water Campos Basin, Brazil, in M. T. Halbouty, ed., Giant oil and gas fields of the decade 1990-1999, AAPG Memoir 78, p. 123-137.

SILVA, P. 2013. Caracterização faciológica e estratigráfica dos depósitos de águas profundas do Campo de Frade, Bacia de Campos, RJ. Dissertação (Mestrado em Geologia) - Instituto de Geociências, UFRJ, 125p.

WAISMAN, G. 2008. Tectônica de Sal da Bacia de Campos. In: Beca/Ball Edições (Ed.). Sal: Geologia e Tectônica. 2. ed. [s.l: s.n.]. p. 317-341.

WINTER, W.R., JAHNERT, R.J., FRANÇA, A.B. 2007. Bacia de Campos. Boletim de Geociências da Petrobras, v. 15, n. 2, p. 511-529.