The Eocene Santos Basin: Sequence Stratigraphy Interpretation and 3D Stratigraphic Modelling

[1]PINHEIRO-MOREIRA, Jobel, [2]JOSEPH, Philippe, [3]NALPAS, Thierry, and [2]GRANJEON, Didier [1]Petrobras (Rio de Janeiro, Brazil); [2]Institut Français du Pétrole (Rueil-Malmaison, France); [3]Rennes University (Rennes, France).

INTRODUCTION

The Santos Basin is a passive margin basin located at the south of the Brazilian continental shelf. It is bounded Northwards by the Cabo Frio structural high that separates it from the Campos Basin, and Southwards by the Florianópolis platform, which separates it from the Pelotas Basin. Four main depositional sequences compose the sedimentary package of the Santos basin: the continental sequence, the transitional sequence, the carbonate marine sequence and the siliciclastic marine sequence. A period of progradation of the siliciclastic marine sequence, which is the object of this study, took place during the Eocene.

A detailed sequence stratigraphy interpretation was performed at a regional scale, based on well and seismic data. Seismic facies analysis, picking of the unconformities and transgressive surfaces, and evolution through time of the offlap-break testify of changes in the subsidence pattern, eustatic sea level and sediment supply. This paper proposes a depositional sequence model and discusses the timing of gravity deposits during a cycle of relative sea level variation. This sequence stratigraphic interpretation had been tested using 3D stratigraphic modelling.

EOCENE DEPOSITIONAL SEQUENCES

The depositional sequences of the Middle Eocene (ES1 and ES2) are composed of 3 seismic facies: oblique-sigmoid facies, parallel facies and chaotic facies (Fig. 1).

The oblique-sigmoid facies displays a wedge geometry and its internal reflection configuration is an oblique-sigmoid complex. It corresponds to a slope front fill that took place during a relative sea level fall. The seaward offlap-break migration confirms the relative sea level fall and consequently, this prism corresponds to a lowstand system tract (LSW). A progradational coastal plain/shoreface/offshore depositional system is proposed.

A bank external form and parallel internal reflection configurations compose the parallel facies. This seismic facies shows an aggradational stacking pattern, which is established during a relative sea level rise and highstand. The aggradation pattern of the offlap-break confirms this sea level rise. In this case the shoreface/offshore system aggrades on the platform and these deposits represent the transgressive/highstand systems tracts (TST/HST). Because of this aggradation pattern, the TST/HST overlays the LST (Fig. 2) and, consequently there is no a significant backstepping of the deposits in the landward direction as in the classic models of sequence stratigraphy (EXXON, 1988 and Galloway, 1989).

The chaotic facies is located at the slope base and shows free and discontinuous reflections. Its geometry is controlled by the irregular paleo-topography created by halokinesis and it is distributed along the slope base. This seismic facies corresponds to gravity deposits produced by turbidity currents and represents a basin floor turbidite system (BFTS). Two possible origins have been discussed for the formation of these gravity deposits. The borders of the parasequences of the TST/HST are frequently eroded, indicating that sediments bypass the shoreface/offshore break and form the gravity deposits basinward. During the aggradation of the shoreface/offshore system, the slope becomes steeper. The deposits destabilize and can generate the mass flows or turbidity currents to form the gravity deposits (Fig 2). The formation of gravity deposits may also occurred during the relative sea level fall, but the more important volume of turbidite sedimentation is set up during the relative sea level rise. Consequently the sequence boundary is located inside these BFTS deposits in deep-water environments. The downlap surfaces on the top of gravity deposits, interpreted as sequence boundary, represent rather a diachronic surface (Fig. 1).

Fluvial system is absent in our model because incised valleys and canyons were not recognized, and a prograding and aggrading shoreface-offshore system was therefore proposed. This fluvial system can however exist outside of the studied zone. The physiography on which the system tracts of the sequences took place, is represented by a coastal plain-littoral-slope system. In this case the offlap-break represents the shelf-break and the depositional profile shows thus a narrow platform. Figure 2 is a 3D geologic model showing the shoreface-offshore system evolution during a cycle of sea level relative variation.

The transgressive surface is the most obvious to identify, especially on the zone where the LST and TST/HST are superimposed. Landward, the transgressive surface almost coincides with the sequence boundary. In the seismic data, the MFS is very difficult to identify because a downlap surface cannot be traced between the TST and HST. However, the SAN-2 well is located on the coastal plain and shoreface depositional environments. Consequently, the MFS were positioned on the maximum of sandy corresponding to the maximum landward-shift of the shoreface sandy facies. In the opposite, the transgressive surface was placed on the maximum of shalyness, equivalent to the maximum seaward-shift of the coastal plain shales.

STRATIGRAPHIC MODELLING

A stratigraphic model, named Dionisos, has been developed to simulate the sedimentary basin stratigraphic architecture in 3D at a basin scale. This stratigraphic model is based on the reconstruction of geological processes such as subsidence, eustasy and sediment transport. To obtain this stratigraphic reconstruction, the model needs:

- The available space for the sedimentation, or accommodation. The accommodation maps were acquired using backstripping techniques;
- The sediment supply rate at the boundary of the simulated area. This parameter was estimated by dividing the decompacted thickness by the duration of each system tract;
- For each lithology, sand and shale, a transport parameter is used to quantify the amount of sediment which flows at the basin surface. Sediment transport is simulated by a diffusion equation linking the sediment supply rate with surface gradient.

The evolution through time of the coastal plain/shoreface/offshore system was correctly restored during the eustatic sea level fall and rise and, consequently the stacking pattern was also restored. Simulations reproduce very well the coastal plain/littoral/slope physiography with a narrow shelf, a linear character and the location of the shoreface through time (Fig. 3).

In seismic data, the slope measures 3° during the progradation periods and 7° during the aggradation periods. Simulations showed that as soon as the slope reaches more than 3°, sediments become unstable on the shoreface-offshore zones and they were transported by gravitational flows to form the BFTS at the slope base (Fig.4). Thus, the gravity sediments were mainly produced during the eustatic sea level rise. A small volume was produced during lowstand sea level, associated with the clinoform toes. The BFTS is located and distributed along the slope base**.**

CONCLUSION

The stratigraphic architecture of the system tracts is a striking characteristic of the Middle Eocene depositional sequences of the Santos Basin. In these depositional sequences, the TST/HST directly overlies the LST without presenting a noticeable backstepping as showed by classic models. This case corresponds to a perfect balance between the accommodation and sediment supply during sea level rise. In reality, the various possibilities of geometrical arrangement of systems tracts in a sequence depend exclusively of the interaction between the three factors which govern sedimentary filling in a basin: subsidence, eustasy and sediment supply.

Gravity deposits took place mainly during the eustatic rise/highstand of sea level. During the sea level rise, the shoreface-offshore zone aggrades on the shelf and the slope becomes steeper and steeper. Consequently, these deposits destabilize and can generate mass flows or turbidity currents to form gravity deposits of the slope base. Simulations illustrate that the sediments destabilize when the slope exceeds 3°.

REFERENCES

GALLOWAY, W.E., 1989. Genetic stratigraphic sequences in basin analysis I: Architecture and genesis of flooding-surface bounded depositional units. *AAPG Bulletin*, v.73, n.2, p. 125-142.

GRANJEON, D. & JOSEPH, P., 1999. Concepts and applications of a 3-D multiple lithology, diffusive model in stratigraphic modeling. In *Numerical experiments in stratigraphy: Recent advances in stratigraphic and sedimentologic computer simulations*, SEPM, n. .62, p.197-210.

MITCHUM, R.M., VAIL, P. & SANGREE, J.B., 1977. Seismic stratigraphy and global changes of sea level, part 6-Stratigraphic interpretation of seismic reflection patterns in depositional sequences. In *Seismic stratigraphy- application to hidrocarbon exploration,* C.E Payton (ed). AAPG, memoir 26, p. 117-134, Tulsa.

MITCHUM, R.M., SANGREE, J.B., VAIL, P. & WORNARDT, W.W., 1993. Recognizing sequences and systems tracts from well logs, seismic data, and biostratigraphy: Examples from the Late Cenozoic of the Gulf of Mexico. In *Siliciclastic sequence stratigraphy-recent development and applications,* P. Weimer & H.W. Posamentier (eds). AAPG, memoir 58, p. 163-197, Tulsa.

MOREIRA, J.L.P., 2000. Stratigraphie sismique et modélisation stratigraphique des dépôts de l'Éocène du Bassin de Santos (marge brésilienne). *Thèse de doctorat*, Université de Rennes 1, n. 2319.

POSAMENTIER, H.W. & VAIL, P., 1988. Eustatic controls on clastic deposition II-sequence and systems tract models. In *Sea level changes-An integrated approach,* C.K. Wilgus, B.S. Hastings, C.G.C. Kendall, H.W. Posamentier, C.A. Ross & J.C. Van Wagoner (eds). SEPM, memoir 42, p. 125-154, Tulsa.