Petroleum System and Seismic Expression in the Campos Basin

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Abstract

The petroleum systems of the Campos Basin contains 60 billion barrels of discovered oil in place and 775 billion cubic meters of natural total gas in place, comprising one of the most prolific petroleum systems in South America. It is located in southeast Brazil covering about 100,000 km^2 with 44 oil fields, seven giants, holding up to 90% of total Brazilian oil reserves and 50% of total natural gas reserves.

The Campos Basin produces mostly from turbiditic sandstones of the Carapebus formation (Cretaceous-Tertiary), comprising the biggest part of the total production. Other important reservoirs are calcarenites of the Macaé formation (Albian), bioclastic lacustrine limestones of the Lagoa Feia formation (Barremian), and fractured basalts of the Cabiúnas formation (Neocomian).

The source rocks are saline-to-brackish lacustrine water shales of the Lagoa Feia formation (Barremian) containing 5% TOC average, an average thickness about 100m with a maximum of 500m in depocenters, covering approximately 50,000 km^2.

Trapping style is chiefly structural for the Cabiúnas formation; structural-stratigraphic for the coquinas (bioclastic limestones of the Lagoa Feia formation), where pinch-out of the coquinas is a common feature; strongly structural for the calcarenites of the Macaé formation (rollovers related to salt tectonics), and finally structural combined with sandstone pinch-out for Cretaceous and Tertiary turbidites of the Carapebus formation.

At the Corvina-Parati depocenter, thermal basin modeling suggests the onset of oil generation in late Albian, reaching its maximum during the Miocene and it is still going on to present days. The top of oil window is about 4,500m deep and transformation rate reaches up to 70%.

Seismically, the Campos Basin shows distinct response and characteristics according to lithologies and ages. The lowermost sequence (Lagoa Feia and Cabiúnas formations) is poor in seismic attributes; the geological model is more adequate for mapping reservoirs and defining best leads. From Middle Cretaceous up to Miocene, the seismic attributes, such as amplitude anomalies, instantaneous phase, instantaneous frequency, and AVO, have been used for defining reservoir geometry, and as good hydrocarbon indicators.

The events chart portrays the temporal relationship between elements and processes of the Lagoa Feia-Carapebus (!) petroleum system in the central area of the basin, accountable for the Marlim oil field charging.

The success for oil exploration in the Campos Basin stems from the presence of excellent source rocks and reservoirs, late migration, presence of internal structural highs, but mostly for the commitment to face deep water exploration challenges.

INTRODUCTION

The Campos Basin, a passive margin basin originated during the Gondwana break-up, is located in offshore Rio de Janeiro State, southeastern Brazil, covering an area about 100,000 km^2 from the coastline down to the 3,400m water depth (figure 1). Its Lagoa Feia-Carapebus (!) petroleum system is the most prolific petroleum system in Brazil. (Mello et al., 1994).

Based on litostratigraphic content the basin is subdivided into three large sequences: 1)**Continental Sequence,** 2)**Transitional Sequence**, and 3)**Marine Sequence** (Guardado, et al., 1989 ; Dias et al., 1990). The **Continental Sequence** is composed of (Neocomian – Barremian) volcanic rocks of the Cabiúnas formation, conglomerates, sandstones, limestones and shales of the Lagoa Feia formation. A severe extensional tectonic activity in the rift phase

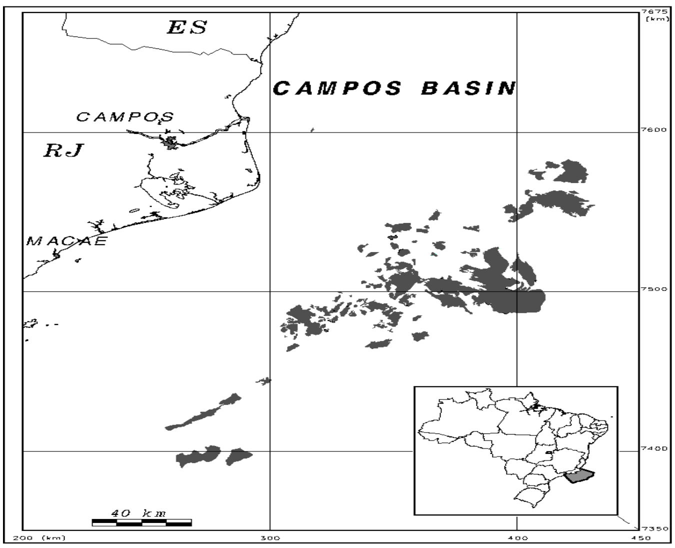

Figure 1 – Location map of Campos Basin.

created a series of horsts and grabens controlling the deposition, of the Continental Sequence, which is up to 5,000 meters thick on the depocenters. The main reservoirs in the continental sequence are fractured basalts and bioclastic limestones (coquinas), commonly related to regional basement highs. The traps in coquinas and basalts are complex with a combination of structural basement highs and stratigraphic pinch-outs.

The **Transitional Sequence** (Aptian) is composed of evaporites (halite and anhydrite), besides conglomerates, sandstones, shales and limestones. The upper part of the Lagoa Feia formation is characterized by poor reservoir conditions. The Transitional Sequence is a period of quiescence in the tectonic activity of the basin (Guardado et al., 1997a , 1997b).

The **Marine Sequence** (Albian to Recent) is made up of shallow water carbonates of the Macaé formation, deep water sandstones and shales of the Carapebus and Ubatuba formations.

The Campos Basin has four potential source rock intervals. The marine potential source rocks are Turonian/Cenomanian shales 3% average TOC, and Albian shales and marls containing 6% TOC average. In the transitional sequence, the hipersaline shales (Aptian) occur in thin layers interbeded with limestones 2% TOC average. The main source rocks are the saline-to-brackish lacustrine shales (Barremian) 5% average organic carbon content. The oils and the organic extracts reveal an identical arrangement of biological marker, suggesting oils of non-marine origin.

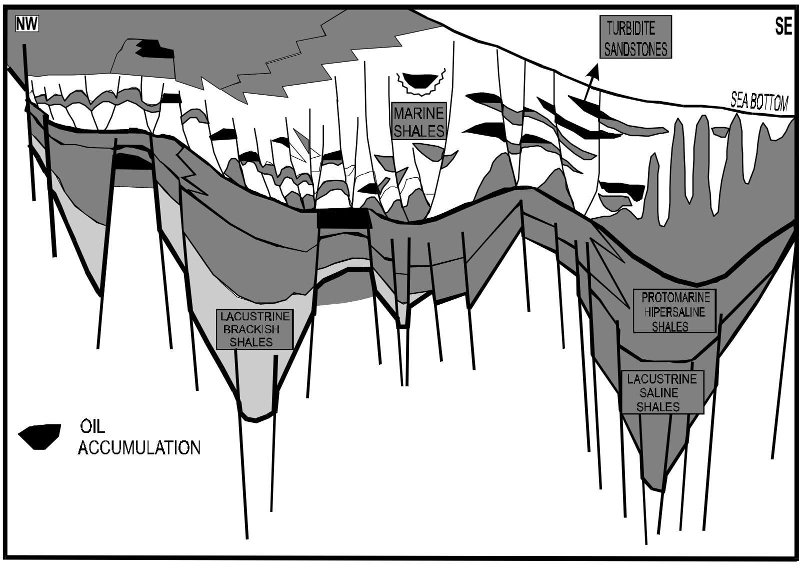

Figure 2 – NW-SE cross section portraying the regional framework, source rocks, reservoir distribution, and main trapping styles.

The geohistory evolution diagrams of the central pod of source rocks suggest the starting of oil generation in Albian-Santonian time, reaching peak of oil generation during Miocene, but still generating liquid hydrocarbons at the present days. The deposition of an expressive package of Oligo-Miocene sediments accelerated the process of oil generation/expulsion/migration in the lacustrine shales of the Lagoa Feia formation and created a thick seal over turbidite reservoirs.

The migration pattern includes oil movement through salt windows, normal and listric faults, and unconformities to reach and charge the reservoirs.

The events chart (figure 3) summarizes the relationships between the elements and processes from the Lagoa Feia-Carapebus (!) petroleum system. The migration took place mainly in Tertiary, from the lacustrine source rocks to the turbiditic Oligocene reservoirs. Because oil migration is still going on, the critical moment is at present days.

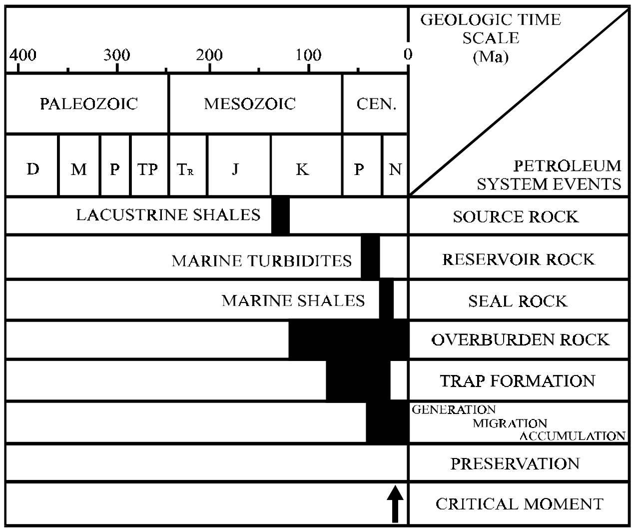

Figure 3 – Events chart for the Lagoa Feia-Carapebus petroleum system (!) (Mello et al., 1994).

SEISMIC RESPONSE

The seismic response in Campos Basin has many distinct aspects. The turbidites have quite distinct seismic responses, according to depths and geographical situations. The seismic attributes such as amplitudes, instantaneous phase, and AVO, are helpful tools in mapping turbiditic sandstones, and, occasionally, the presence of oil. All of the oils discovered so far in Campos Basin were sourced in shales of the Lagoa Feia formation. Seismically, it is also possible to identify the source rocks.

Source Rocks

The main source rock is the Lagoa Feia Shale (Barremian), interbeded with carbonate rocks and characterized by negative seismic amplitudes. Because of the strong velocity and density contrasts, between shales and carbonates, the amplitudes may be abnormally low in the Lagoa Feia Shale. Nevertheless, in most of the Campos Basin, the shales and carbonates originate parallel reflectors with strong seismic contrast, and negative and positive anomalies.

The reflectors associated with marine potential source rocks, mainly the Albian section, show an increase in the intensity of the negative amplitude in deep waters, probably related with the presence of oil.

Reservoirs

Basalts – Cabiúnas Formation

Basalts are non-conventional reservoirs. Oil is trapped either in fractures or vesicules. Seismically they show high velocities and positive amplitudes. However, the top of lava flows is commonly weathered and consequently generates negative amplitudes.
The Cabiúnas formation is deep in the geological section of Campos Basin – the main reason for the low frequency signals in the basalts. The proposal leads for basalts are based exclusively on fractured structural highs; the seismic attributes have little or no influence.

Coquinas – Lagoa Feia Formation

The coquinas deposited on, or nearby the basaltic basement structural highs, are fairly good reservoir rocks. The coquinas show positive reflection coefficient and, the seismic resolutions are very poor in the oil fields related to the low frequency. In some cases, the instantaneous phase is helpful when delimiting pinch out of coquinas bodies over basalts. The presence of strong positive amplitudes in structural highs has been associated with oil accumulation.

Carbonates - Macaé Formation (Quissamã Member)

The carbonates of the Quissamã Member are well identified in rollover closure structures created by halokinesis. Hydrocarbons have been discovered, and produced, in several of such rollover structures throughout the Campos Basin. The top of the Quissamã Member is seismically well defined by a positive contrast between high velocity calcilutites and porous, low-velocity shales above.
The Quissamã Member is characterized in the upper portion by a rhithmitic sequence formed by porous and non-porous carbonates. This produces an alternation between negative and positive contrasts in seismic data. The analysis of seismic amplitude, interval seismic velocities, and AVO are keys to the best results so far in the Macaé limestones.

Sandstones - Namorado Sandstones – Macaé Formation

The Namorado Sandstones are Albian-Cenomanian turbidites, quite often with excellent porosities. Seismically, they show negative reflection coefficients, strongly enhanced, if oil bearing. The Namorado Sandstones, in the Namorado and Cherne oil fields were deposited in deep troughs adjacent to salt walls. Latter, during halokinesis, these troughs were uplifted and placed high in structural closures. Otherwise, in the Albacora field, the Namorado Sandstones are widespread and the structures are not so evident as in the Namorado and Cherne fields. The amplitude analysis is important on mapping sand distribution, as well as determing the presence of oil.

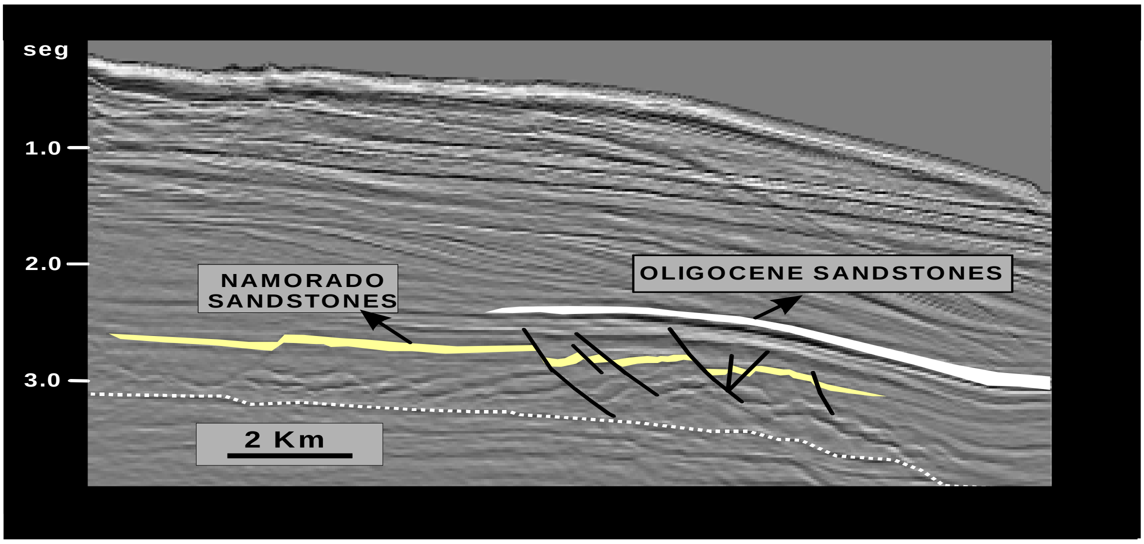

Figure 4 – Seismic line from Albacora field showing the strong influence of the halokinesis in the namorado sandstones and the stratigraphic main influence on the Oligocene turbidite sandstones.

Sandstones - Carapebus Formation (Turonian/Santonian/Maastrichtian)

The turbidites of the Carapebus formation (Cretaceous) are thick, widespread and rather important reservoirs in Campos Basin. Seismically, they can be either, positive, or negative reflectors, depending on both, internal geological features, and adjacent rock properties. Multiple unconformities have been pointed out as the main cause for the positive/negative interchanging reflections - different types of rocks are deposited on top of the unconformities. The seismic attributes,

such as amplitude, intervalar velocity, instantaneous phase, instantaneous frequency, and AVO, are important for defining geometry, mapping reservoir distribution, and, even outlining oil accumulations.
In shallow waters of northern Campos Basin the Cretaceous turbidites have positive reflection coefficients and low-amplitude; in deeper water, the uppermost turbidites have negative coefficient, and, occasionally, anomalous amplitudes; whereas, lower turbidites show no contrast at all.

Sandstones - Carapebus Formation (Eocene)

Similar to the Cretaceous turbidites, the seismic expression of Eocene sandstones change as water depth changes. In shallow waters of the shelf area, predominates positive reflection coefficients (Parati and Anequim fields), however, in shallow waters of southern Campos Basin (Bicudo and Corvina/Malhado fields), the reflection coefficient is negative and the seismic attributes are excellent as oil zone indicators(Rosa, et al., 1985, Varela, et al., 1990). In deeper waters, all the Eocene turbidites show negative reflection coefficients and their seismic attributes are key factors on mapping reservoirs and hydrocarbon occurrences.

Sandstones - Carapebus Formation (Oligocene/Miocene)

The Oligo/Miocene sandstones are mostly non confined basin-floor turbidites bounded by thick shales. The giant oil fields in Oligo/Miocene sandstones present combined structural closures and stratigraphic pinch out of turbidites. Seismically, they always show negative reflection coefficient, and occasionaly amplitude anomaly, and bright-spots, whenever gas is present. Their seismic expression help the identification of oil zone and reservoirs (Rosa, 1987; Varela, et al., 1992)

CONCLUSIONS

The Lagoa Feia - Carapebus (!) petroleum system in central Campos Basin is a good example of perfect timing for oil generation, migration, and trapping. Oil was generated in the lacustrine shales of the Lagoa Feia formation, with its maximum during the Miocene time, when sedimentation rate was very high. Oil Migration, through faults and salt windows, charged exuberant Cretaceous and Tertiary turbidites of the Carapebus formation, a process that is still going on today.
The seismic attributes, such as amplitude, instantaneous phase, instantaneous frequency and AVO, have successfully been applied in oil exploration in Albian and younger rocks in Campos Basin, either, discovering hydrocarbons, or outlining reservoirs. For the older rocks of the Lagoa Feia and Cabiúnas formations the geological model predominates over seismic attributes.

REFERENCES

Dias, J. L., Carminatti, M., Scarton, J. C., Guardado, L. R. and Esteves, F. R.,1990, Aspectos da Evolução Tectono-Sedimentar e a ocorrência de hidrocarbonetos na Bacia de Campos.Origem e Evolução de Bacias Sedimentares. Petrobras.

Guardado, L. R., Gamboa, L. A. P., Lucchesi, C. F., 1989, Petroleum geology of the Campos Basin, Brazil, a model for a producing Atlantic type basin, In: Edwards, J. D., and Santogrossi, P. A., – Divergent Passive Margin Basins, AAPG Memoir 48.

Guardado, L. R., Wolff, B. and Brandão, J. S. L., 1997,a) Campos Basin, Brazil, a model for a producing Atlantic basins. Offshore Technology Conference, Houston, Texas. Abstract.

Guardado, L. R., Spadini, R. A., Mello, M. R. and Brandão, J. S. L., 1997,b) Petroleum Systems of the Campos Basin, Brazil. Hedberg Research Symposium Abstracts, Rio de Janeiro, Brazil.

Mello, M. R., Mohriak, W. U., Koutsoukos, E. A. M., and Bacoccoli, G. 1994, Selected Petroleum Systems in Brazil. In: Magoon, L. B., Dow, W. G., - The Petroleum System-From Source to Trap. AAPG Memoir 60.

Rosa, A. L. R., Arso, L. R., and Jaegher, R., 1985, Mapeamento do contato óleo-água com dados sísmicos na área de Bicudo, Bacia de Campos. Informe geofísico 62, Petrobras, Rio de Janeiro, Brazil.

Rosa, A. L. R., 1987, Albacora field : A case – history of seismic amplitude mapping. Exploration Geophysicists. International Meeting 57, New Orleans, EUA.

Varela, C. L. and Esteves, F. R., 1990, Mapeamento de amplitude na delimitação dos campos de Corvina e Malhado. Boletim de Geociências da Petrobras, V.4, n.3, Rio de Janeirob Brazil.

Varela, C. L., Castellani, R. T., and Rangel, H. D., 1992, Utilização de levantamento sísmico tridimensional (3D) no reconhecimento de depósitos turbidíticos Miocênicos da Bacia de Campos. Congresso Brasileiro de Geologia n.32, São Paulo, Brazil.

Sixth International Congress of the Brazilian Geophysical Society