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Foz do Amazonas Area: The last frontier for elephant hydrocarbon accumulations in the South Atlantic realm[1]

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In most areas of the South Atlantic, exploration is far from being mature since offshore ultra deep-water exploration has just begun. Geochemical data suggest that similar tectonic-stratigraphic evolution, organic-rich facies and oil types are found across the South Atlantic petroleum provinces, allowing the application of a unified model for hydrocarbon provenance in counterpart basins. Such similarities, when interpreted in a paleogeographic context, can help reveal details of unexplored petroleum systems.

This study, based in a integrated multidisciplinary approach and using technologies ranging from remote sensing to molecular geochemistry, suggests the Foz do Amazonas area, after the Campos basin, as one of the most promising oil/ gas-prone provinces in the Brazilian continental margin. Throughout the tectonic-stratigraphic framework, regional facies variations of Upper Cretaceous and Tertiary source rocks are consistent with a marine carbonate and marine deltaic model for source rock deposition. The origin of the hydrocarbons, in the area, is related to Upper Cretaceous anoxic global events (Cenomanian to Turonian), and a huge fluvial marine deltaic complex that was formed since Miocene. The Niger delta oil province is a comparable petroleum system analogue.

INTRODUCTION

As a result of the giant oil discoveries in deepwater reservoirs, in the Niger delta, over the past few years, most of the major oil companies are actively investigating the presence of similar petroleum systems in deepwater areas of the Amazon Delta. Although the Foz do Amazonas and Niger delta basins, which lie on opposed sides of the South Atlantic, are traditionally considered as independent entities, evolving geological knowledge is suggesting them to share structural, stratigraphic and geochemical elements, leading therefore to analog petroleum systems. The major uncertainty regarding its huge hydrocarbon potential is the presence or absence of prolific source rock systems in deep-water areas.

The Amazon delta is considered strategic, because it shows similar oil types and therefore, petroleum systems when compared with the most prolific deltaic basins in the world. Also, deep water exploration, in this basin, has practically not been accomplished. Added to this situation, the occurrence of several shallow water, sub-

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commercial accumulations of oil and gas together with, the appearance of natural oil seeps closely associated with listric and strike slip faults that reach the surface, indicate the presence of at least two active petroleum systems in the area.

The Foz do Amazonas basin is located in the northern area of Brazilian equatorial margin, and covers an area greater than 360,000 Km^2 landward of the 3,000 m isobath (Fig. 1). The basin is directly related to the rupture of the African and American plates during Aptian-Cenomanian times. This basin can be classified as a typical divergent, mature, Atlantic-type continental margin (Asmus and Ponte, 1973). This paper describes how a petroleum system approach, supported by multidisciplinary technology, involving seismic, geochemical and remote sensing data, are useful in the prediction and selection of future deepwater exploratory areas and directly impact the development of new hydrocarbon frontiers in the South Atlantic realm.

1. GENERAL GEOLOGY

The Foz do Amazonas province can be subdivided into several geological subprovinces. The most important are: Pará and Amapá platforms, Caciporé semi-grabens synthetic systems, Tertiary carbonate platform and the Amazon mouth system (Fig. 1). The tectono-sedimentary history of the basin started during the Triassic with the deposition, in the Caciporé area, of pre-rift siliciclastic sediments of the Calçoene formation (Brandão and Feijó, 1994; Fig. 2).

The rift siliciclastic stage was a direct result of the South Atlantic opening during Aptian-Cenomanian times (Fig. 2; e.g. Castro et al., 1978). The process was associated with a basement-involved block rotated faulting, with semi-grabens tilting towards southwest and associated with a regional unconformity that is overlain by the drift sequence. The rift sediments are composed of continental to marine shales and sandstones of the Caciporé formation deposited in semi-grabens with a maximum thickness of about 6,000m (Silva and Rodarte, 1989; Silva et al., 1999).

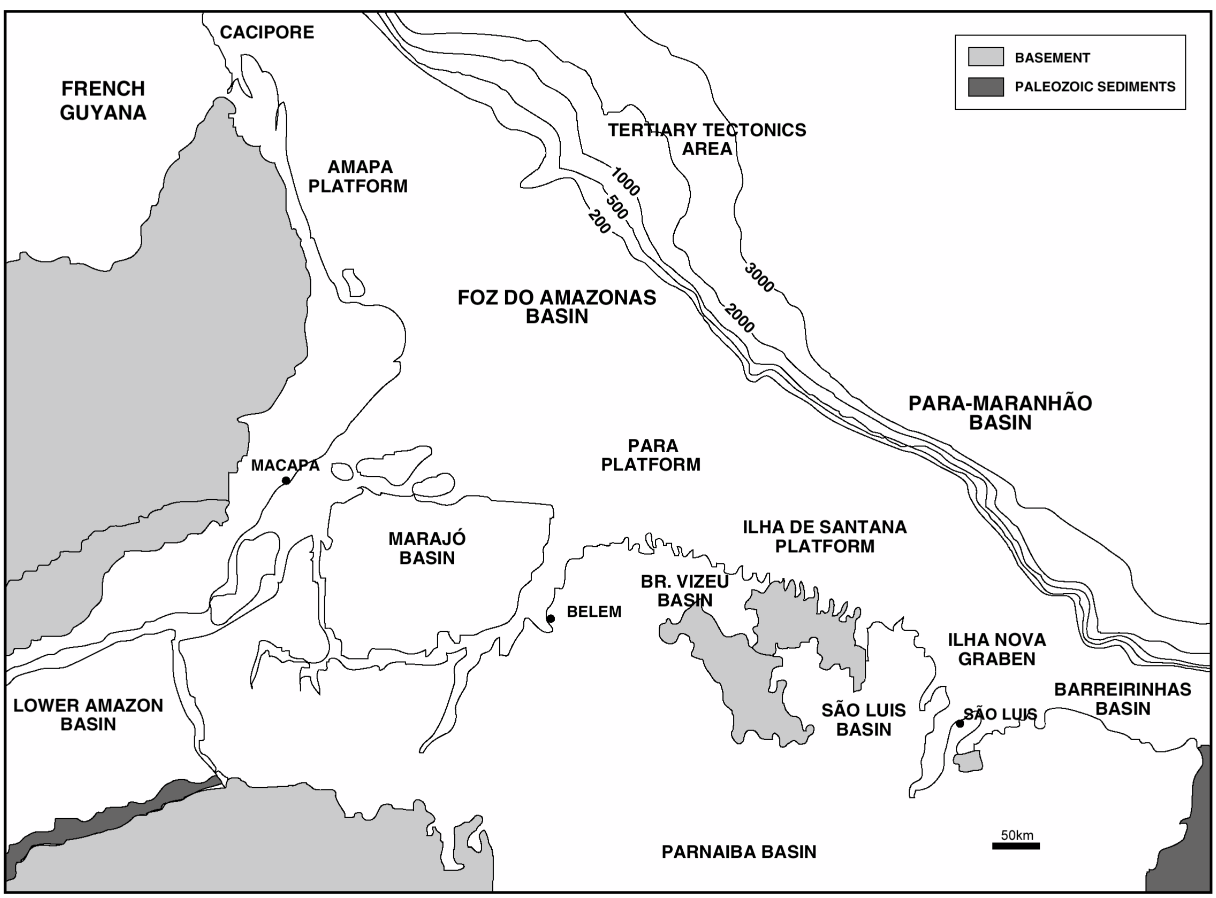


Fig. 1 Location map of the Foz do Amazonas area.

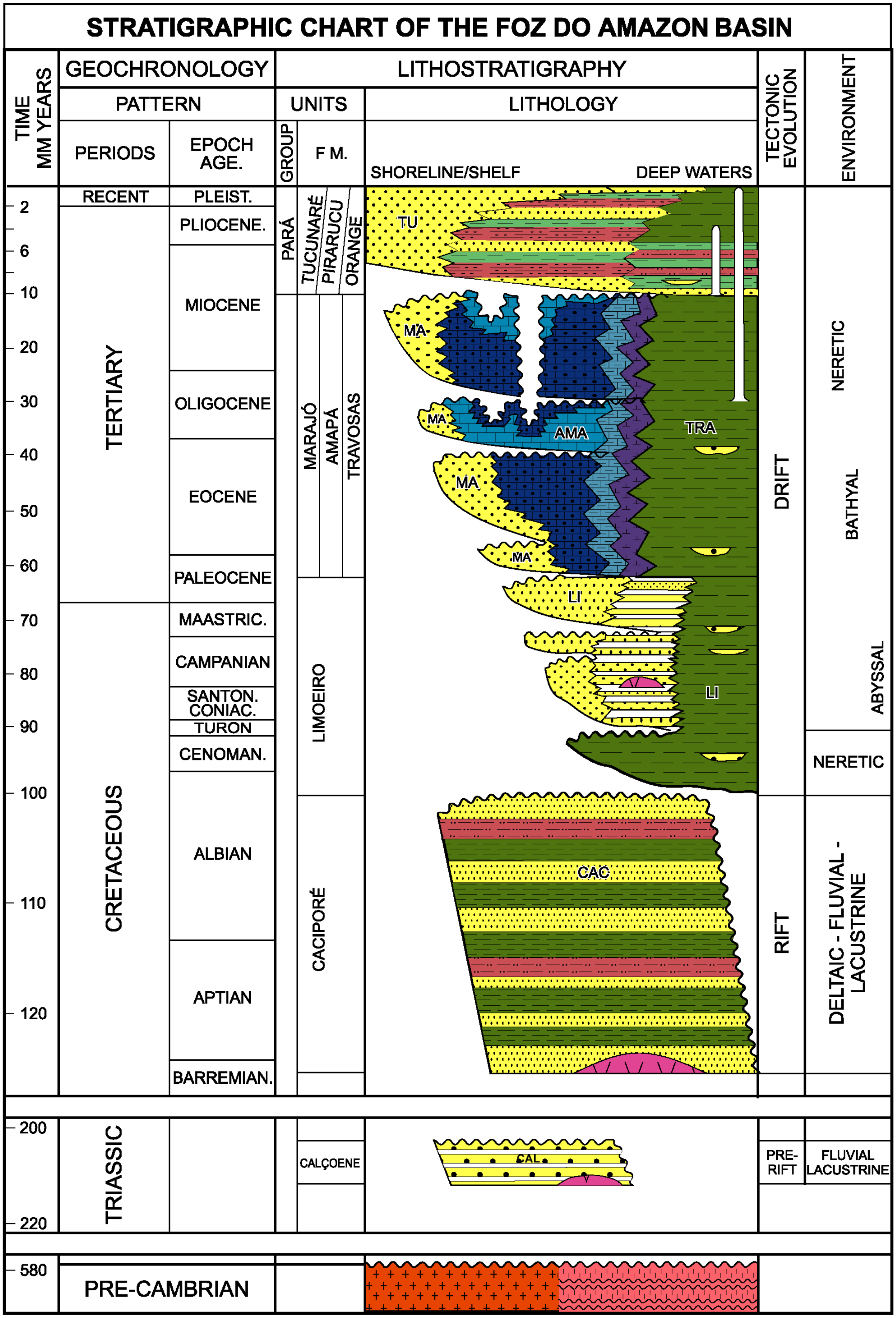


Fig. 2 Stratigraphic chart of the Foz do Amazonas basin (modified from Feijó et al., 1994).

The rift phase ceased once sea floor spreading started, with the succeeding drifting stage being characterized by flexural subsidence of the margin without conspicuous faulting. Three main drift sequences overlaid the rift sediments: a Upper Cretaceous dominantly prograding, siliciclastic continental to marine sequence; a Paleocene/Lower Miocene marine carbonate platform, and an Upper Miocene to Recent, very thick, prograding siliciclastic sequence related to Amazon river sedimentation (Fig. 2-4; e.g. (Silva and Rodarte, 1989; Silva et al., 1999).

The Upper Cretaceous, dominantly prograding siliciclastic, continental to marine sequence, represented by the Limoeiro formation, is composed of shales (basal transgressive unit), and a sandstones/ shales succession, with thickness ranging from 2,500 to 3,000m.

The Paleocene to Lower Miocene marine carbonate platform, represented by a dominantly transgressive sequence (65 to 10 my), is mainly composed of carbonates and marls of the Amapá formation (Fig. 2). This sequence is characterized by platform and slope carbonate sediments deposited in a neritic to upper bathyal environment. This carbonate succession appears to be linked with conditions of tectonic quiescence. Near the Tertiary shelf break, an adiastrophic tectonism is represented by listric detached faults soling out on the Upper Cretaceous regional unconformity (Silva et al., 1999).

Overlying the Paleocene to Lower Miocene marine carbonate platform, is a younger, very thick (up to 9,000m), prograding siliciclastic marine sequence, of the Tucunaré, Pirarucú and Orange formations (Pará Group), related to the Amazon River sedimentation (Silva et al., 1999; Fig. 4 e 5). A structural and seismic stratigraphic analysis shows that most of the basin, during this time, was affected by a very intense gravity tectonics, caused by the influence of the fast and thick siliciclastic sedimentation (e.g. Silva et al., 1999). Castro et al (1978), identifies the structural style of the basin as composed of growth faults and interpreted the compressional features as diapiric structures. Recently, Silva et al. (1999), based on new seismic data, identify the former diapirs as compressional structures (folds and thrust faults) and define new tectonic model for the area based on gravity gliding and spreading (Galloway, 1986).

2. PETROLEUM SYSTEM

In the last years, a multidisciplinary approach involving geochemical, geological, geophysical and micro-biostratigraphic research, has greatly enhanced the level of understanding of some of the most representative petroleum systems in the Brazilian sedimentary basins (Mello et al., 1991, 1994 and 1995).

The petroleum system concept shifts emphasis from the rock to the fluid system of discovered petroleum occurrences (Magoon et al., 1988). The petroleum system approach is the best method to evaluate exploration risk, even in unexplored provinces as deep water Foz do Amazonas basin. When exploration risk is evaluated in a sedimentary basin, it is mandatory to investigate three independent variables, which are “Hydrocarbon charge”, “Trap,” and “Timing”.

Hydrocarbon charge is the oil and gas fluid system that would be available to the trap, if it were present. Trap is the sedimentary rock that includes reservoir and seal rocks, and the trapping geometry formed by reservoir-seal interface. Timing is whether the trap formed before the hydrocarbon charge entered the trap (Magoon et al., 1988).

Because petroleum is proof of the presence of a system, this is the place to start an investigation. First, representative oil samples from Foz do Amazonas and Niger delta were analyzed. After a series of geochemical analysis, the data were used for oil-oil correlation to determine how many different oil types occur in the provinces. Generally, if only one type of hydrocarbon occurs in a petroleum province, there is at least one petroleum system. As a rule of thumb, there is at least as many petroleum systems as there are oil types, unless there is mixing or a change in organic facies within the active pod of source rock.

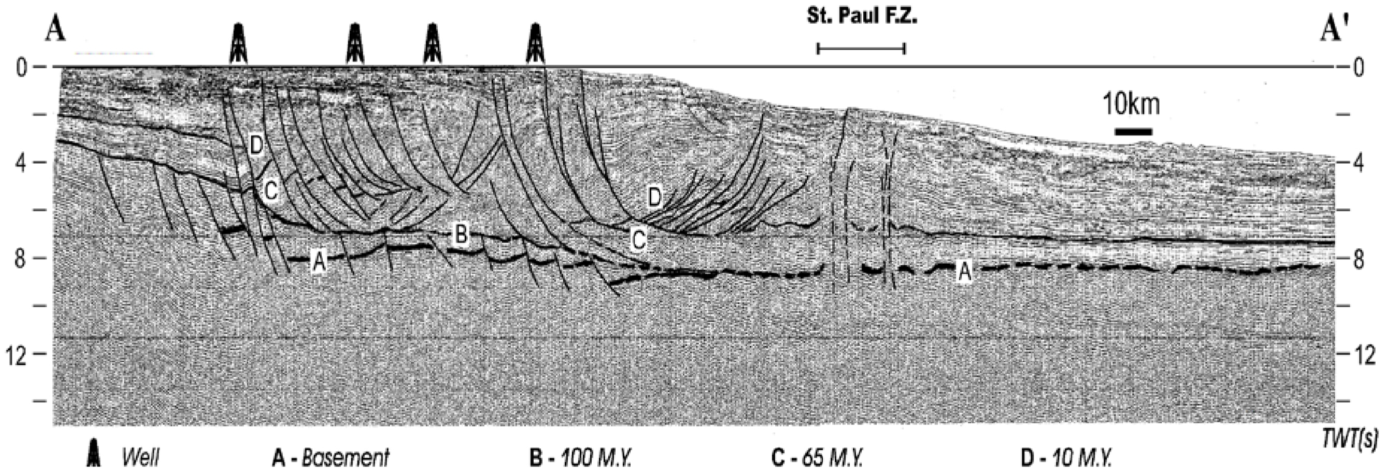


Fig. 3 Multichannel seismic section typical of the Foz do Amazonas basin illustrating the carbonate platform, growth faults along the shelf margin and thrust faults (Silva et al., 1999)

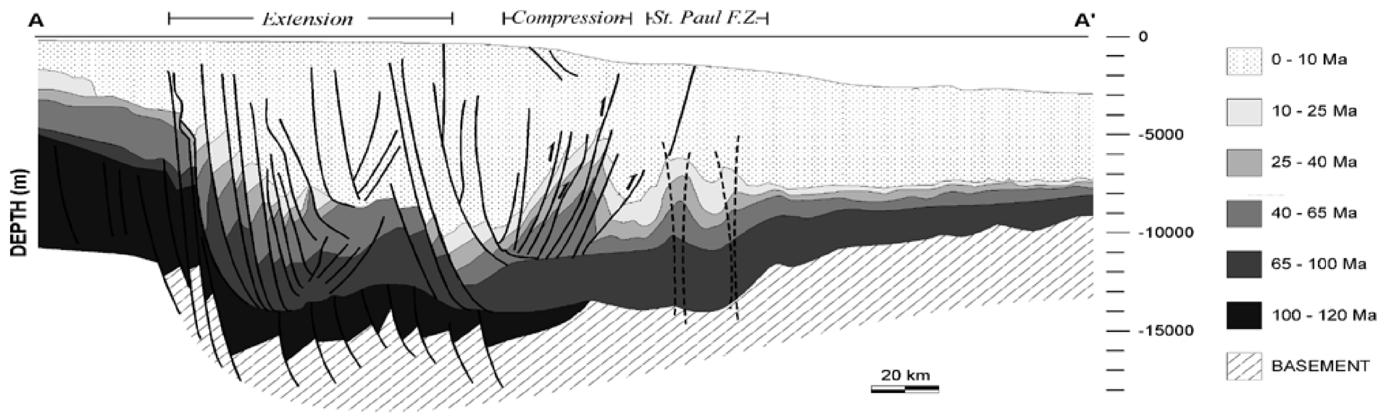


Fig. 4 Representative geological section of the central part of the Foz do Amazonas basin showing two areas of extension and compression (Silva et al., 1999)

The recognition of analog petroleum types in both Amazon and Niger deltas in the Brazilian and West Africa margins (Fig. 5) fosters the understanding of the hydrocarbon source potential in these areas, since the Niger delta oil province bears around 125 billion BBL of oil in place (Doust, H., and Omatsola, E., 1990; Mello et al., 1991), and the Foz do Amazonas only has thus far demonstrated subcommercial accumulations.

The purpose of the petroleum system study in the Foz do Amazonas province, among others, was to provide a picture of the analogy among the fluid system and tectonic and stratigraphic evolution of the deltaic basins along the South Atlantic margin. If we compare the Foz do Amazonas province with the Niger delta (West Africa; Figs 3-7 and Doust, H., and Omatsola, E., 1990; Mello et al., 1991) we can address not only the tectono-sedimentary evolution of the basins, but also, the similarities and differences between their petroleum systems.

3. TECTONO-STRATIGRAPHIC SETTING

The main reservoirs and traps present in the Foz do Amazonas province are Early to Mid Albian syntectonic clastic rocks of Caciporé formation, Paleocene to Miocene biocalcarenites of the carbonate platform of the Amapá formation and the turbiditic sandstones of the Upper Miocene/Recent Pirarucú Orange formations (e.g. Figs 2-4 and 6-7; Silva and Rodarte, 1989; Miranda et al., 1998). They are mapped in almost all the province (Figs 4-5; Silva et al., 1999).

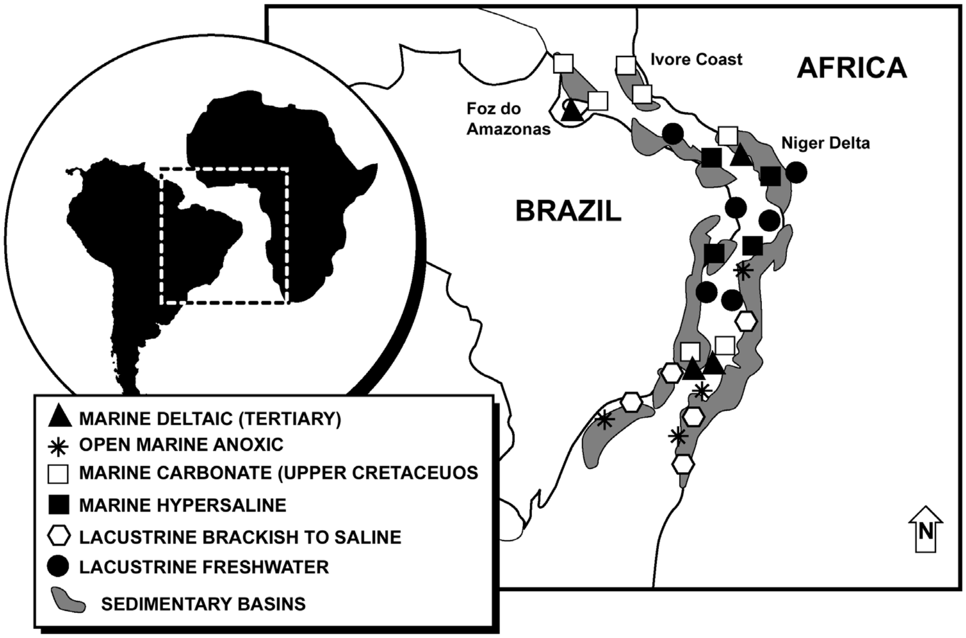


Fig. 5 Map showing oil type distribution across the South Atlantic realm (taken from Mello, 1990).

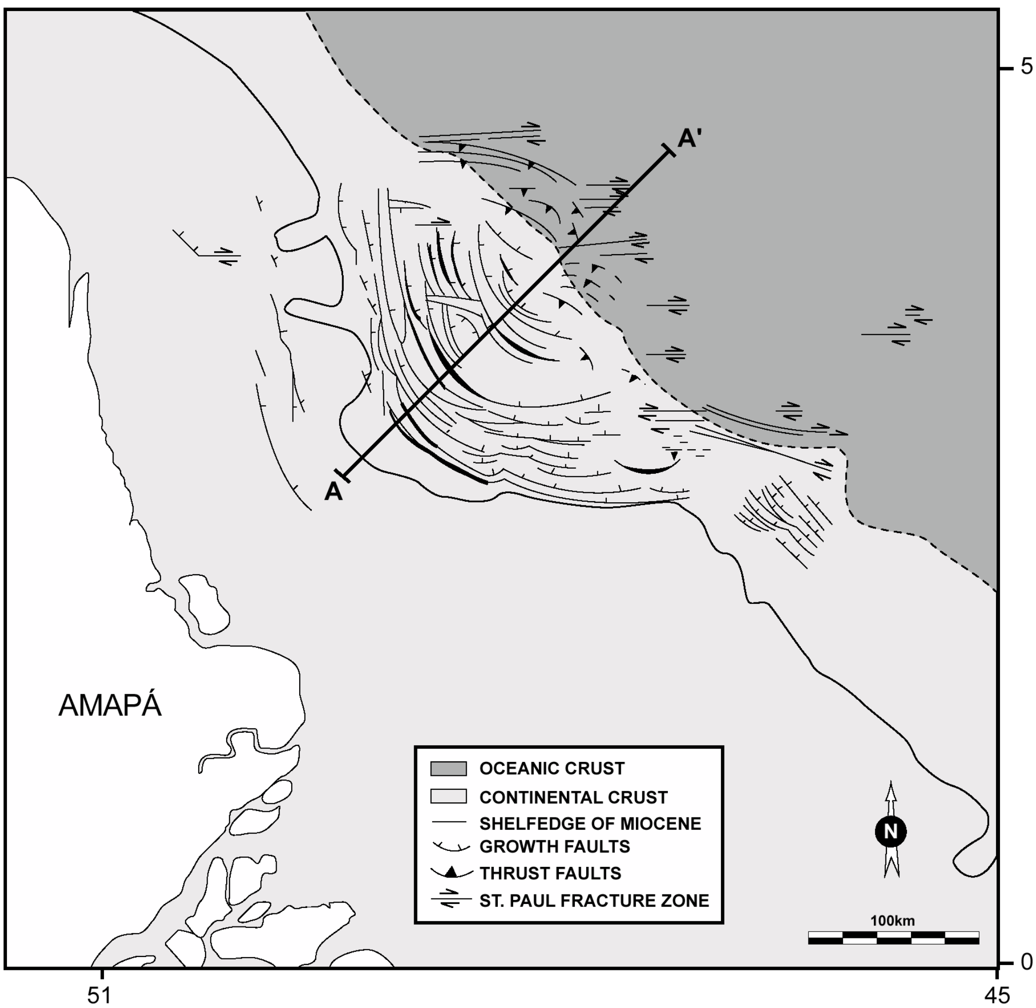


Fig. 6 Fault map of the Miocene showing the growth faults near the shelf edge, thrust faults in a northeastern direction together with interpreted natural oil slicks (taken from Silva et al., 1999 and Miranda et al., 1999)

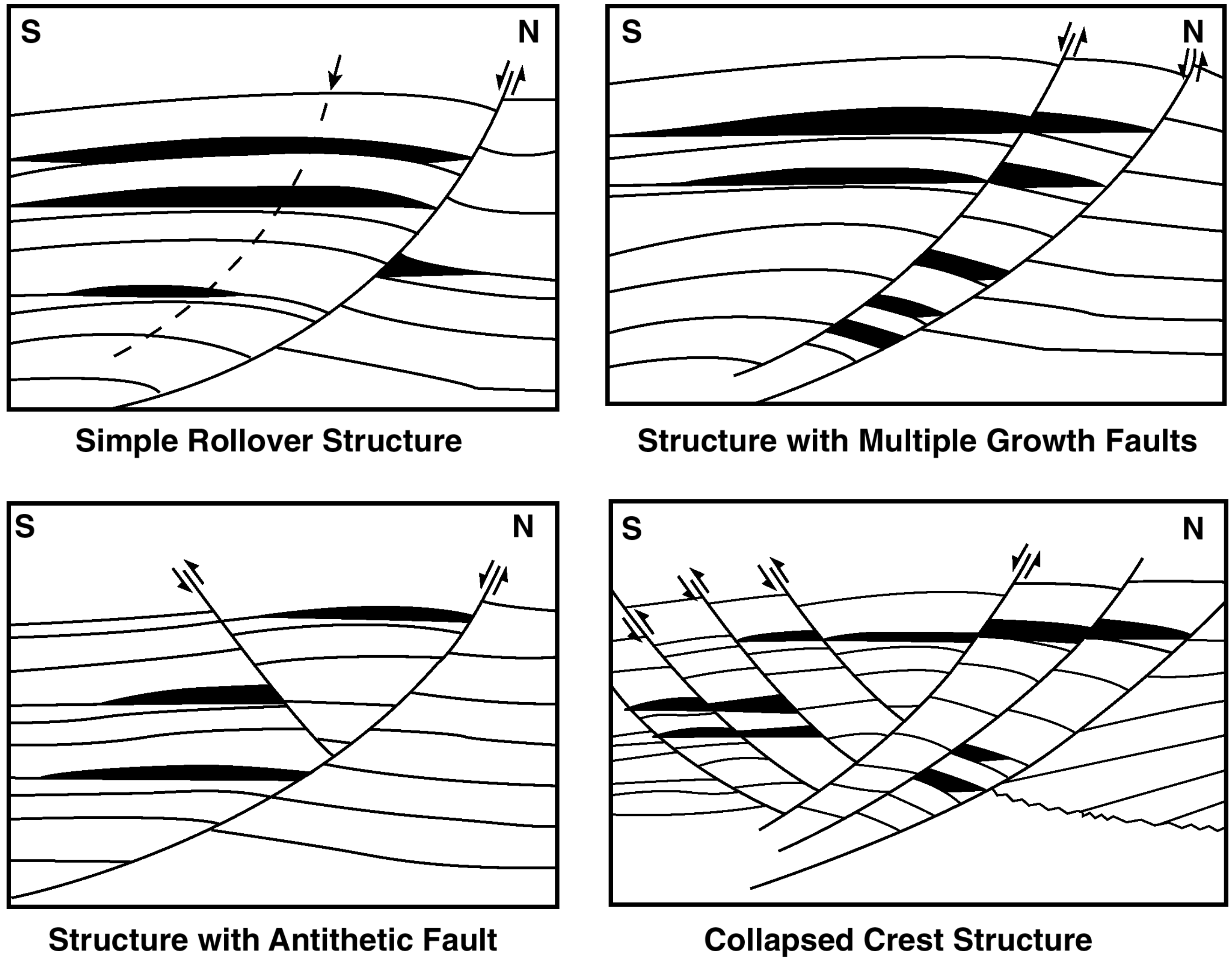


Fig. 7 Reservoir structural styles present in the Niger and Foz do Amazonas deltas (Requejo et al., 1995).

Structural and stratigraphic traps were created, as a result of the Cenozoic gravitational tectonics, which gave rise to listric normal, thrust and strike-slip faults that can affect the Cenomanian to Recent deposits. These faults are controlled by adiastrophic movements caused by the sedimentation loading of Upper Miocene/Recent sediments sliding over a general unconformity (Figs 4-5; Silva et al., 1998. As can be observed from a fault map of Miocene the growth faults are located near the shelf edge and thrust faults in a northeastern direction (Fig. 6; Silva et al., 1999).

A similar assemblage of gravity tectonic structures with their related traps are described in profiles across the Niger delta continental slope (Galloway, 1986; Doust and Omatsola, 1990). As can be observed in figures 3-4 and 6, the Foz do Amazonas province shows the same structural-stratigraphic features that are present in the Niger delta or any classic delta in the world, thus bearing similar structural and stratigraphic traps that make deltaic systems potential hydrocarbon provinces. The younger and fast sedimentary loading contributes to the suppression of the thermal evolution of the source rocks in deltaic area. Such fact allowed the basin to be oil prone no matter the depth of the source rocks.

The hydrocarbon accumulations expected in this type of environment are controlled by the lateral pinchout of sandstone turbidite reservoirs or by the regional dip eastward closing upward against listric faults, as observed in the Niger delta (Figs 3-4 and 7; Requejo et al., 1995).

4. HYDROCARBON CHARACTERIZATION AND SOURCE ROCKS

Detailed molecular geochemistry was applied to identify and characterize the oil types present in the Foz do Amazonas and correlate them with their Niger delta counterparts. One of the objectives was to assess the depositional paleoenvironments and the age of their putative source rocks and to perform the oil/source rock correlation in order to predict the existence of active prolific petroleum systems in deep waters of the Foz do Amazonas basin.

This approach was based mainly on the distributions and concentrations of biological markers aiming to assess age and depositional related biomarkers (Moldowan et al., 1990; 1994; Peters and Moldowan, 1993; Mello, 1988; Mello et al., 1988, 1988a, 1989, Mello et al., 1995).

Age and depositional related biomarkers are, as the name implies, compounds whose appearance in oils and source rock extracts are restricted to certain depositional environments and geological time periods. Thus, their presence in oils and source rock extracts can be of use to constrain, within limits, the depositional environments and age of their source rocks. Determination of the distributions of the age related biomarkers could only be achieved using sophisticated gas chromatography-mass spectrometry-mass spectrometry (GC-MS-MS) techniques (Peters and Moldowan, 1993;Mello et al., in press).

The use of the specific biomarkers such as C_{26} steranes, oleananes, 2 and 3-methyl steranes, dinosterane type steroids and C_{30} steranes have allowed geochemists to not only distinguish different origins related to specific organic facies for oils within one particular basin, but to also determine the approximate age of each organic facies (Moldowan et al., 1990, 1994; Mello, 1988, Mello et al., 1995, Mello et al., in press). This is of extreme importance when determining the petroleum systems that are active in each basin and of course, has profound impact on exploration strategies.

The application of this methodology was undertaken involving oil samples, pooled in reservoirs ranging in age, from Early Cretaceous to Tertiary, from Foz do Amazonas and Niger delta areas (Fig. 5). Such an approach gave scope to classify and correlate the oils and to determine the factors that control their composition (e.g. paleoenvironments of deposition and age of the source rocks, thermal evolution and geographic distribution).

The results of the biological marker investigation revealed similarities and differences among the oil samples studied. The data point out to an origin from two major types of hypoxic-anoxic environments (Figs 8-13; Mello et al., 1988, 1989, 1991, 1995) ranging in age from Late Cretaceous to Miocene (Figs. 2). The two types are: Upper Cretaceous marine carbonate, and Tertiary marine deltaic with either predominance of siliciclastic or carbonate lithology (Mello, 1988). Each oil type identified is discussed separately in the following sections.

Upper Cretaceous marine carbonate oil type

Oils from this group have been recovered from small size subcommercial accumulations in the Niger delta (Benue Through; Requejo et al., 1995), and Foz do Amazonas area (Caciporé to Pará-Maranhão, Mello, 1988; Mello et al., 1995; Fig. 5). They are derived from Upper Albian-Cenomanian marls and calcareous black shale source rocks deposited in a marine environment (e.g., Limoeiro formation in the Foz do Amazonas basin, and Upper Cretaceous in the Niger delta area; Mello, 1988; Requejo et al., 1995; Fig. 5). These oils, in Foz do Amazonas, are mainly pooled in Early to Mid Albian syntectonic clastic rocks of Caciporé formation and also Paleocene to Miocene biocalcarenites of the carbonate platform of the Amapá formation. The reservoirs start to be charged during Eocene from deep distant "oil kitchens" that present mainly lateral migration pathways, associated with regional unconformities, with major transform fault systems focusing towards different structural trends. These oils are characterized by naphtenic/ aromatic, middle sulfur hydrocarbon contents with low gas/oil ratios (Mello, 1988). As can be observed in figures 8-14, there is a good correlation between some of the oils from Foz do Amazonas and Benue through oil in the Niger delta.

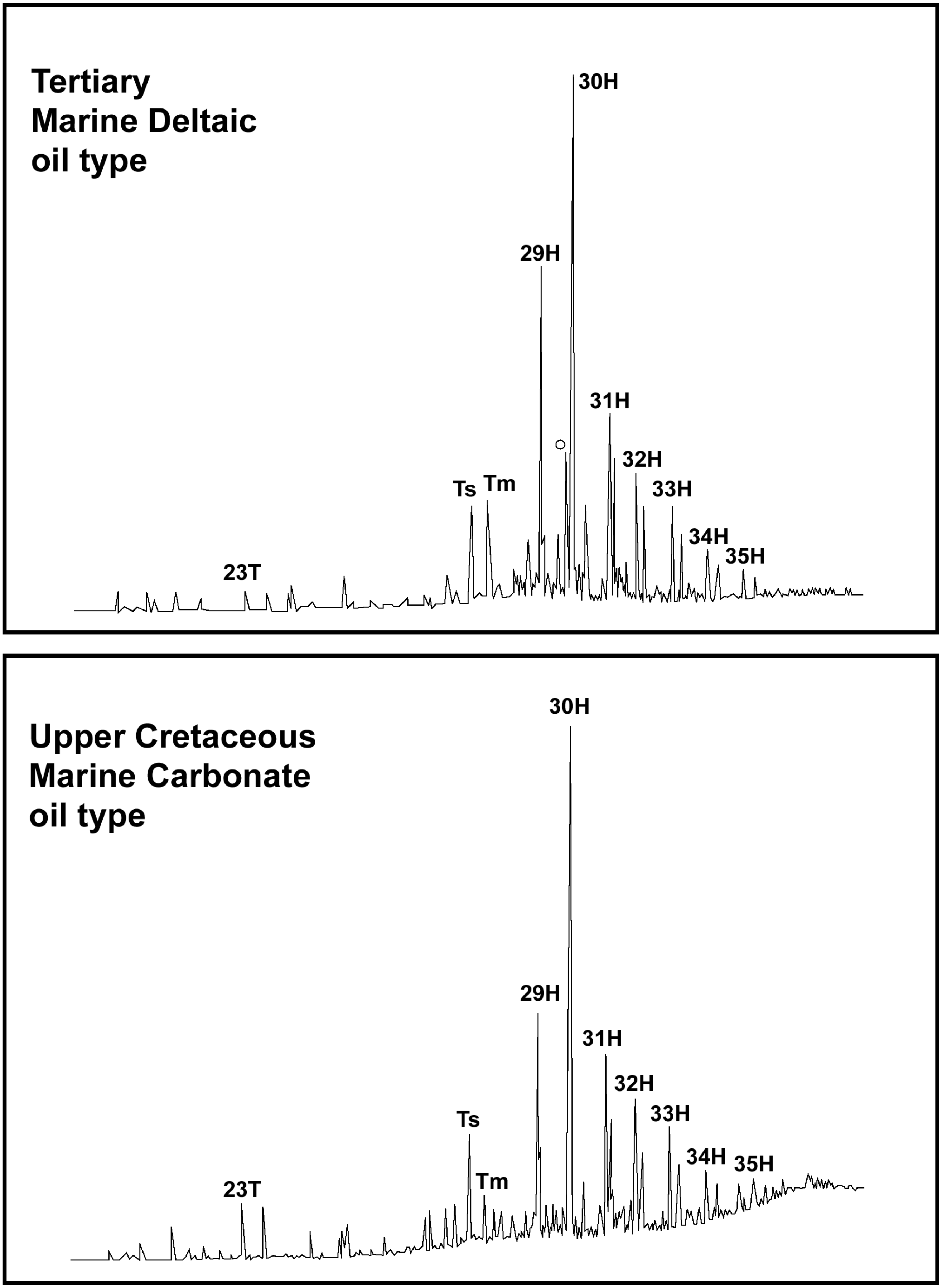
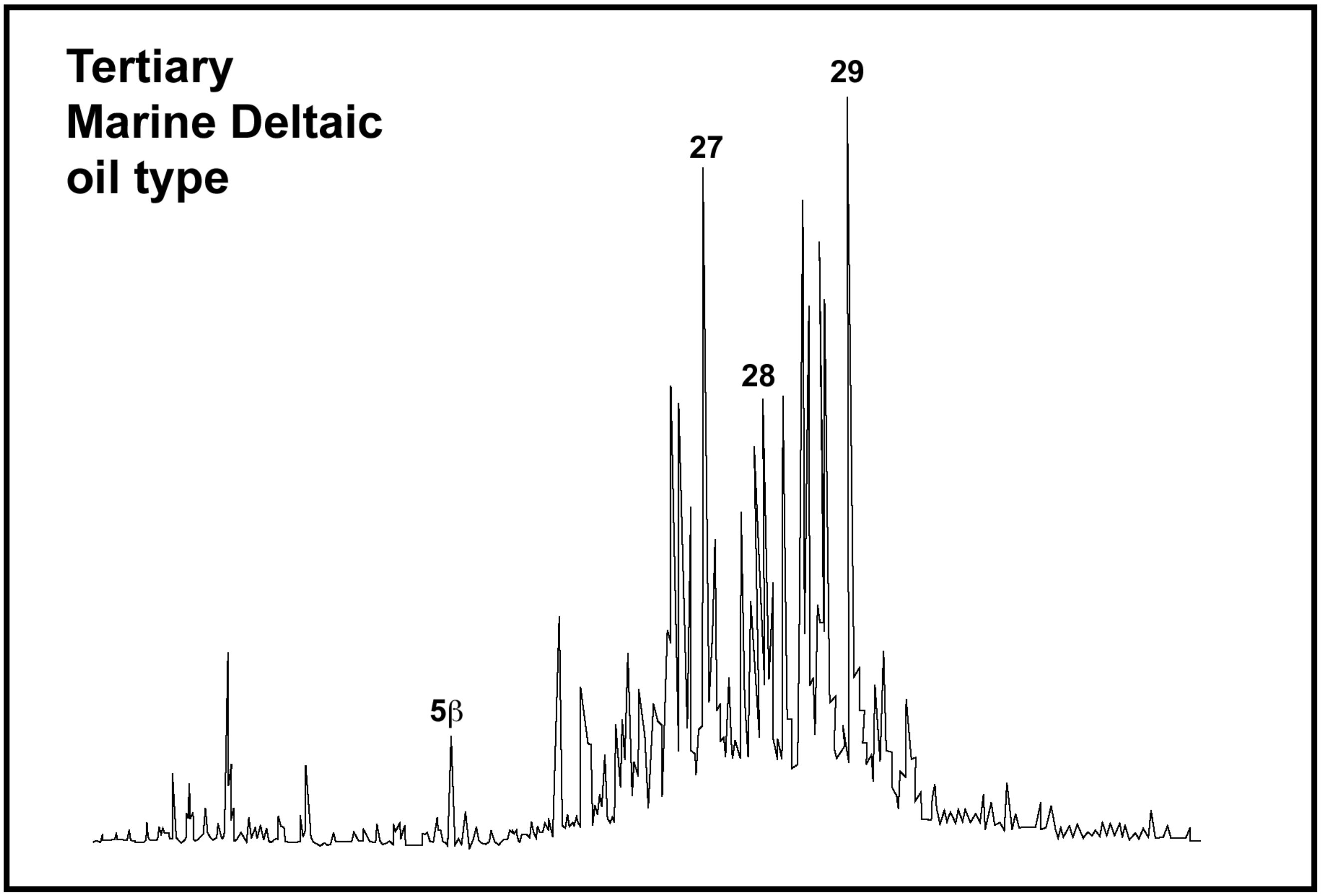


Fig. 8 Mass chromatograms of m/z 191 showing representative sterane distribution in Niger Delta oil type (Requejo et al., 1995).



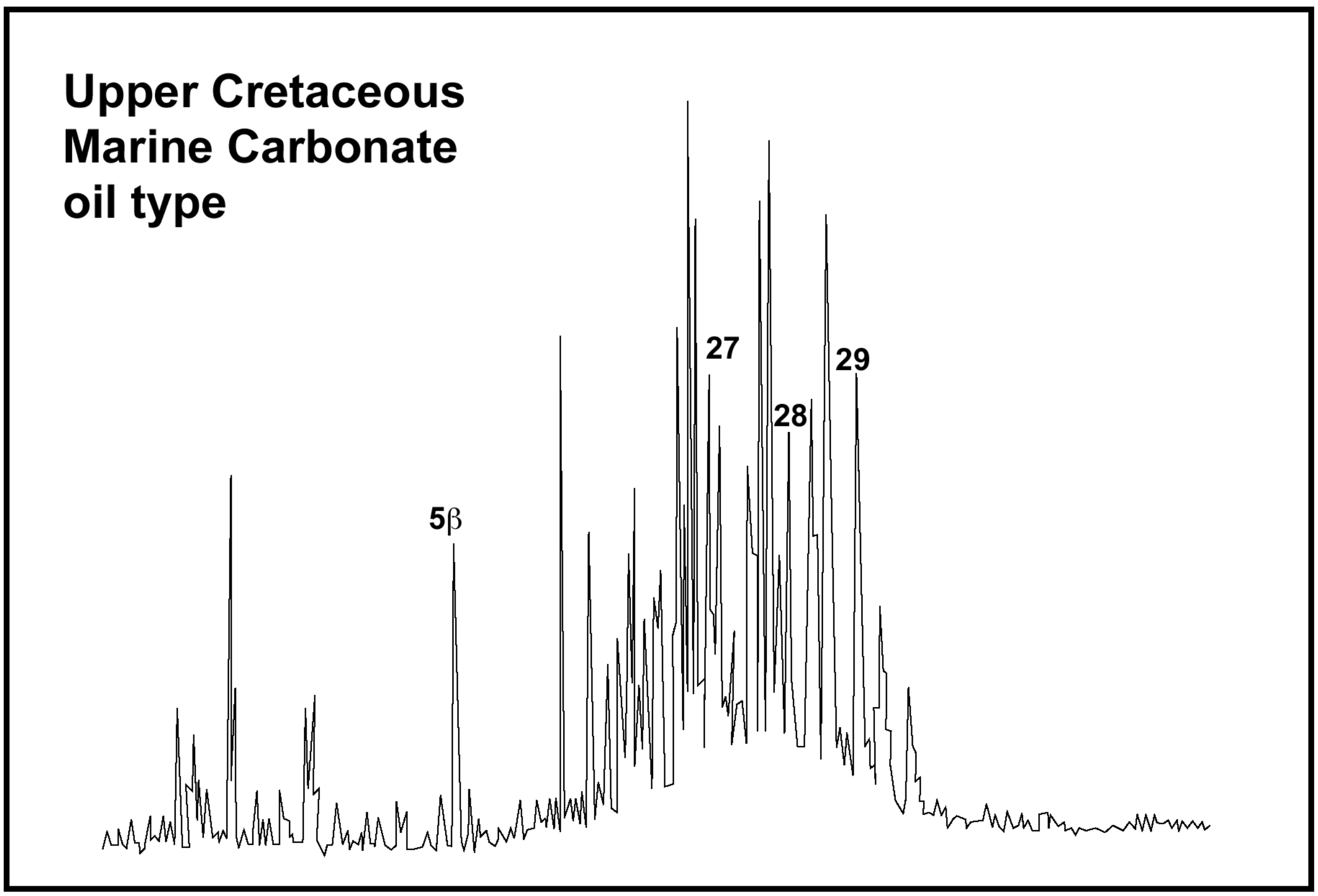


Fig. 9 Mass chromatograms of m/z 217 showing representative sterane distribution in Niger Delta oil type (Requejo et al., 1995).

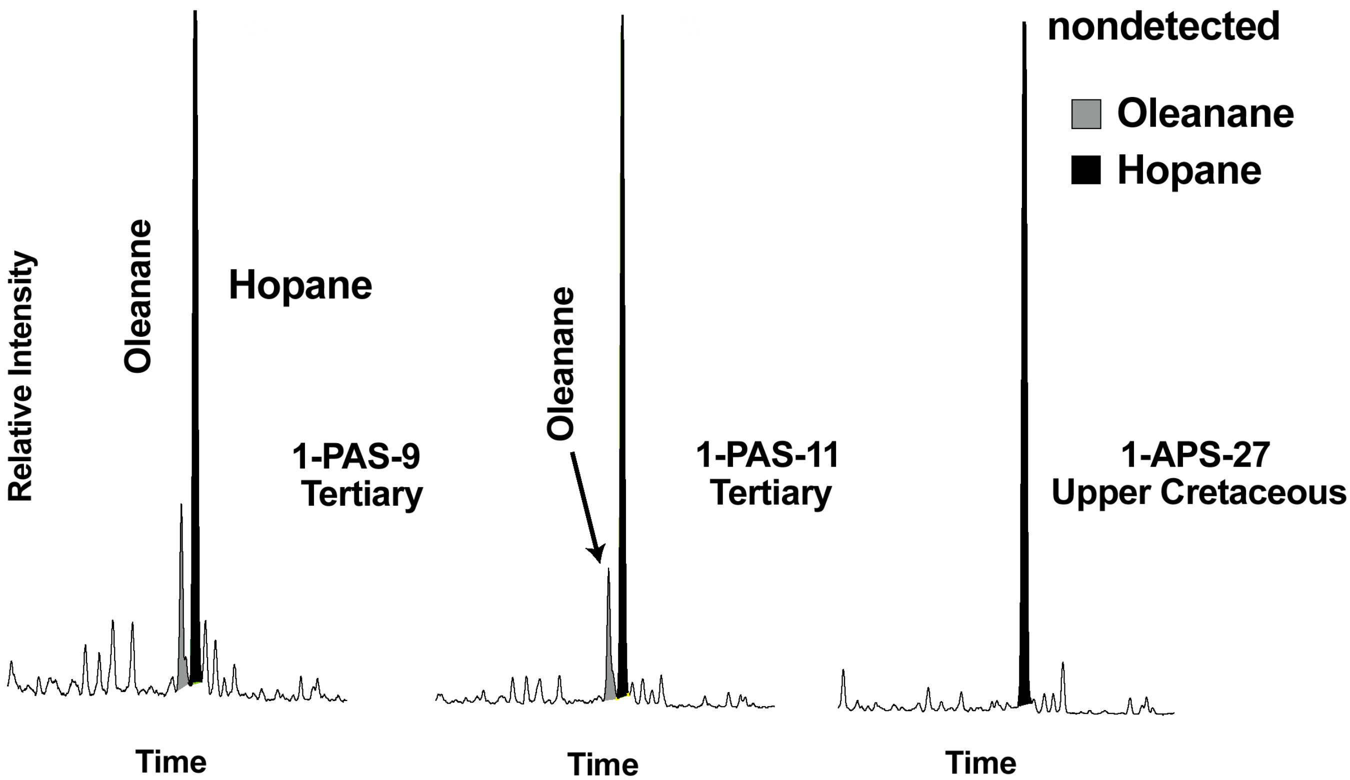


Fig. 10 GC-MS-MS (m/z 412-191) traces showing representative age related oleanane distribution in Foz do Amazonas oil types (Mello, 1988)

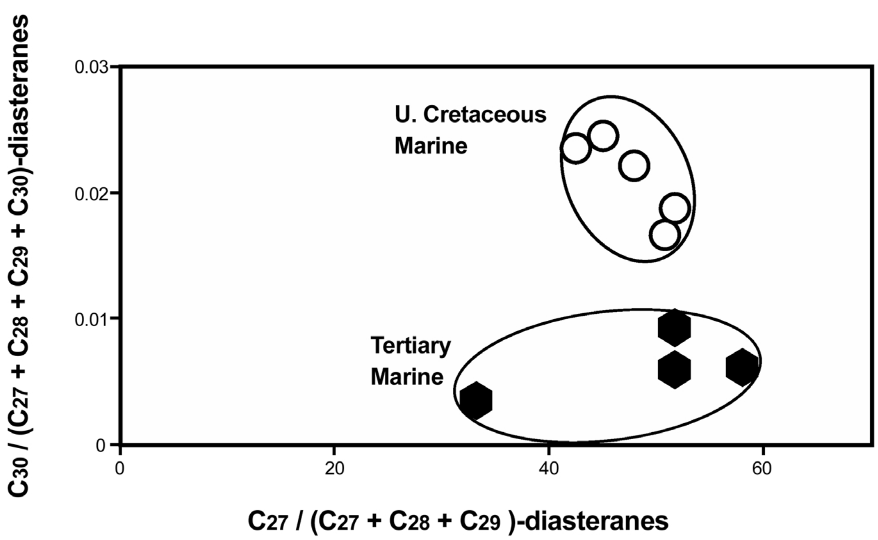


Fig. 11 Crossplot of diasteranes biomarkers from Foz do Amazonas oil types (Mello, 1988).

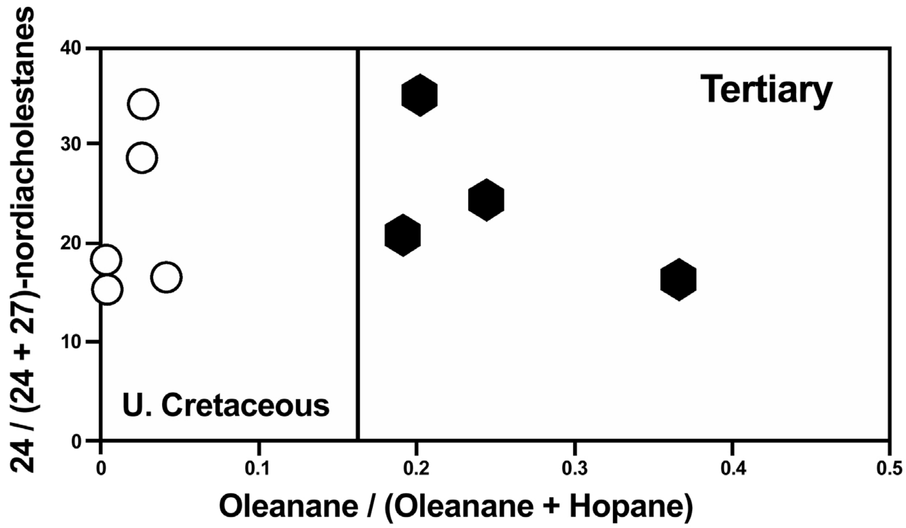


Fig. 12 Crossplot of nordiacholestanes ratios versus Oleanane / Oleanane + hopane content for Niger Delta and Foz do Amazonas oil types

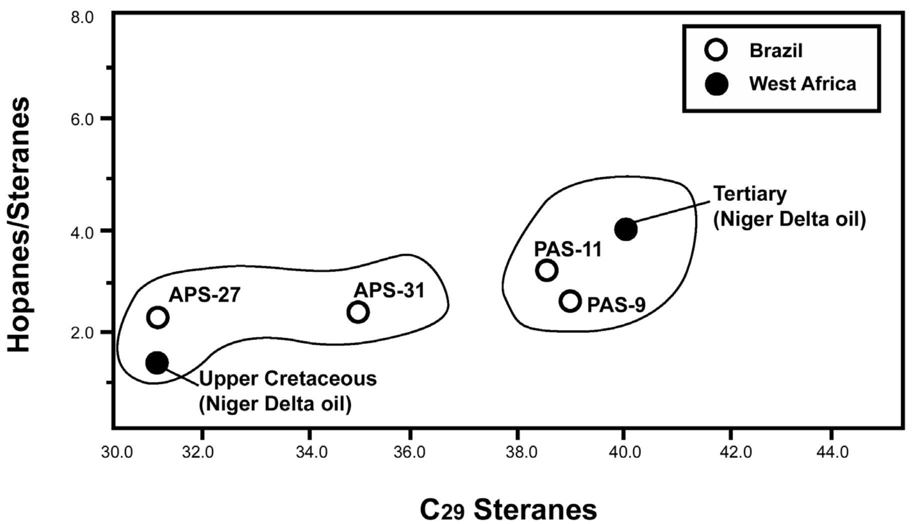


Fig. 13 Crossplot of hopane/sterane ratios versus C_{29} sterane content for Niger Delta and Foz do Amazonas oil types

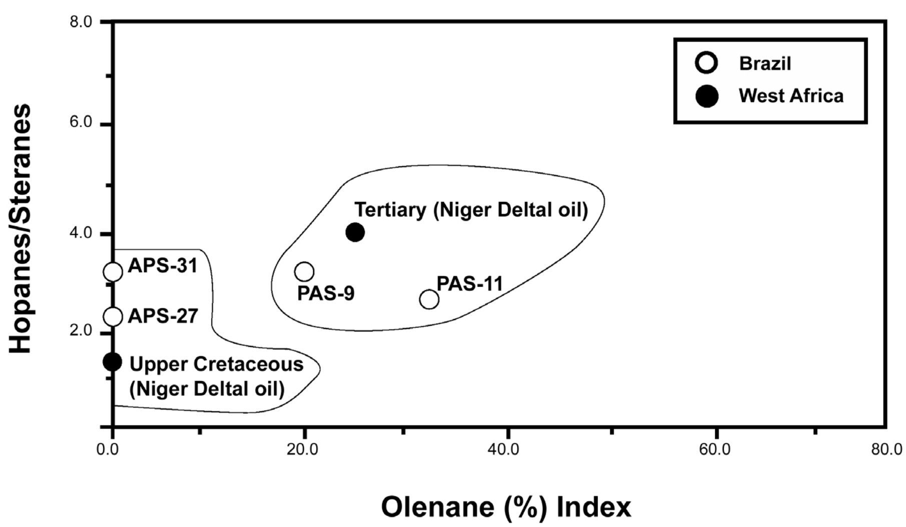


Fig. 14 Crossplot of Oleanane index versus C_{29} sterane content for Niger Delta and Foz do Amazonas oil types types

The source rock of the Upper Cretaceous marine carbonate oil type was identified in the Limoeiro formation comprising around 50-150m of fine, well-laminated, Albian to Turonian calcareous dark gray shales ($CaCO_3$ as high as 18%, Mello, 1988; Mello et al., 1988a). Total organic carbon (TOC) average from 2-5% and locally as much as 4% (Mello, 1988; Mello et al., 1988a). The hydrogen index, consistent with a type II kerogen, present values up to 600 g Hc/ mg of organic carbon. The organic petrology shows the predominance of lipid-rich material mainly of algal and bacterial origin (average 70% of amorphous organic matter; Mello, 1988; Mello et al., 1988a). Although the published data show an immature stage of thermal evolution for these sediments, the good hydrocarbon source potential of the rocks (as high as 30 kg Hc/tone of rock; Mello, 1988), combined with appropriate thermal history, provided by deeper burial, from pods situated far offshore, was sufficient to yield the oils present in the area.

Tertiary marine deltaic oil type with either predominance of siliciclastic or carbonate lithology

Oils from this group have been recovered in the Pará-Maranhão area, in the Foz do Amazonas province, and in the Niger Delta basin, in equatorial West Africa (Fig. 5; Mello et al., 1991). They are correlated with Lower Tertiary dark-grey shale potential source rocks deposited in marine environments (Travosas and Agbada and Akata Formations, Amazonas and Niger delta basins respectively; Fig. 5; Mello et al., 1988a, 1991; Doust, H., and Omatsola, E., 1990; Requejo et al., 1995). The oils are pooled in reservoirs ranging in age from Eocene to Miocene, charged during Late Miocene from deep distant "oil kitchens" that present mainly lateral migration pathways, associated with regional unconformities (Mello, 1988; Doust, H., and Omatsola, E., 1990). These oils are characterized by high paraffinic content, low sulfur, very high API degree (44 to 46), and high gas/oil ratios (Mello, 1988).

The Tertiary marine deltaic oil source rocks have not been drilled up to now. Mello, (1988) identified in the Amapá formation a very thin Oligocene organic-rich interval, composed of fine, well-laminated, marls ($CaCO_3$ as high as 54%; Fig. 15; Mello, 1988; Mello et al., 1995). Total organic carbon (TOC) average around 3% (Fig. 16; Mello, 1988). The hydrogen index, consistent with a type II kerogen, present values up to 400 g Hc/ mg of organic carbon (Mello, 1988; Mello et al., 1995). Although the interval shows an immature stage of thermal evolution, its proximal position together with its good correlation with the Tertiary identified oil (Mello, 1988; Mello et al., 1995), suggests that this facies, if buried deep offshore, as much as 6,000 meters, can have the appropriate thermal history, to yield the Tertiary oils.

In summary, the hydrocarbons sourced by the Upper Cretaceous marine carbonate and Tertiary marine deltaic petroleum systems in the Foz do Amazonas basin, indicate the presence of, at least, two active petroleum systems, with their respective pods located deep offshore in the area. Due to a fast Upper Miocene/Recent sedimentary loading in the basin, the oils, probably, were expelled only during the Miocene time, when they charged Early to Mid Albian syntectonic clastic rocks of Caciporé formation, Paleocene to Miocene biocalcarenites of the carbonate platform of the Amapá formation and the giant Tertiary turbiditic sandstones of the Upper Miocene/Recent Orange formation. The structural and stratigraphic traps were created, as a result of the Cenozoic gravitational tectonics, which gave rise to listric normal, thrust and strike-slip faults. The listric fault system associated with several regional unconformities acted as migration pathway for the hydrocarbons generated in the Tertiary and Upper Cretaceous sequences. The presence of biodegraded marine carbonate oils, in the Foz do Amazonas basin, with different thermal evolution profiles, indicates the occurrence of more than one migration and biodegradation event during the successive stages of reservoirs infilling (Mello, 1988). Such episodes appear to have been related to major sea level changes, which would have controlled the influx/ reflux cycles of meteoric waters in the reservoirs (Soldan et al., 1995). On the other hand, the marine deltaic oils did not present any signs of biodegradation (Mello, 1988).

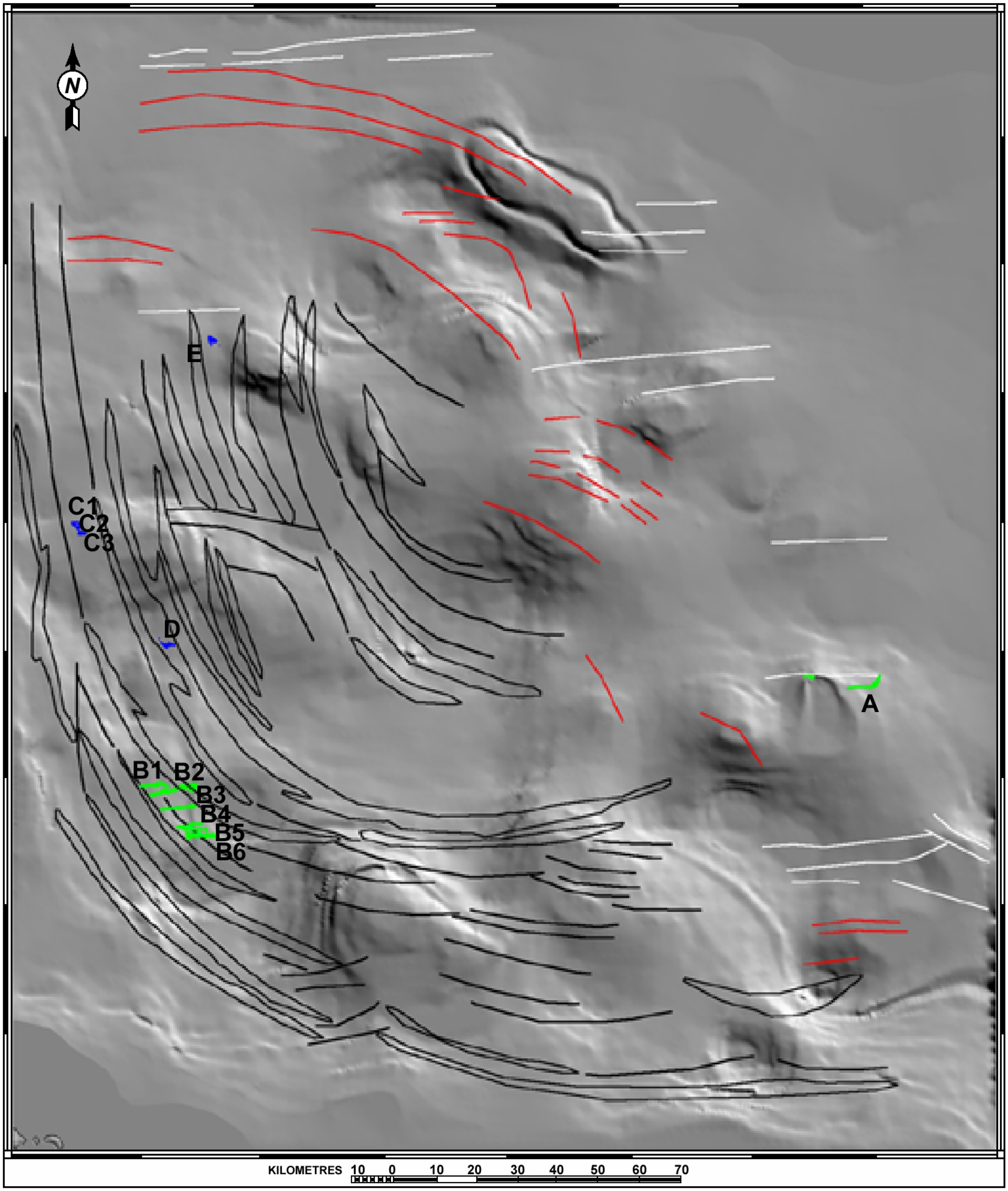


Fig. 15 Fault map of the Miocene showing the growth faults near the shelf edge, thrust faults in a northeastern direction together with interpreted natural oil slicks (taken from Miranda et al., 1999)

5. REMOTE SENSING APPLIED TO DETECTION OF NATURAL OIL SEEP

Natural oil seeps have historically provided valuable information about petroleum systems. Foremost, they indicate the presence of an active pod of hydrocarbon source rocks in the area, without which there can be no petroleum accumulations. The high cost of deep offshore exploration has made the identification of oil seeps an well-accepted risk assessment methodology (Miranda et al., 1998).

In the vast continental margin of the Foz do Amazonas area, Brazil, the identification of sea surface hydrocarbon slicks using RADARSAT-1 imagery was undertaken to predict the presence of active petroleum generation in the area. The significance of the natural oil seeps linked to structural features such as normal (listric) and strike-slip faults, in the deepwater mouth of the Amazon River, offshore Pará and Amapá states, also emphasize the importance of the Miocene adiastrophic tectonism as migration pathways in the area (Fig. 6; Miranda et al., 1998).

In part of the Foz do Amazonas area, RADARSAT-1 images were acquired over a period of one year. The methodology (Miranda et al., 1998), proved effective, as it showed that thin, elongated patches of smooth surface texture interpreted as natural oil seeps were closely associated with normal (listric) and strike-slip faults.

The physical mechanism that allows detection of oil seeps is the dampening of capillary waves present on the ocean surface. These capillary waves, which are only a few centimeters in wavelength, produce backscattering of the incident radar pulse due to a Bragg scattering mechanism (Johannessen et al., 1994). As a result, ocean regions containing oil are dark in contrast with the background radar signal. However, with regard to radar imaging, the suppression of the wave backscatter is unfortunately not unique to the presence of oil. False targets include wind shadow, biological surfactants, local upwelling, shallow marine vegetation, and areas of heavy rainfall. Our proposed approach circumvents these pitfalls by using the textural classification algorithm USTC (Unsupervised Semivariogram Textural Classifier; Miranda et al., 1998) that enhances areas of smooth texture on RADARSAT-1 images. Oceanic databases and modeling results for winds, waves and tidal elevation where used to provide information about the environmental conditions at the time of RADARSAT-1 data acquisition. This information is crucial to select smooth texture areas interpreted as natural oil slicks. The seeps identified are then combined with seismic and bathymetry data in order to identify geologic controls on natural hydrocarbon seepage (Miranda et al., 1998).

Raster polygons defining smooth texture regions on USTC-classified RADARSAT-1 images were merged with geophysical and bathymetric data. A total of seven surface slicks were identified on the RADARSAT-1 (Fig. 6). The slicks range in length from 4.6 to 11.3 km; they have a mean value of 7.1 km and standard deviation of 2.04 km (Fig. 6)

The remote sensing method was effective in defining distinct and elongated smooth textural features interpreted as natural oil slicks on RADARSAT-1 images. Environmental conditions (ocean winds and waves) at the time of data acquisition were suitable for oil slick detection. Spatial coincidence of surface slicks and geologic structure at the top of Travosas Formation allowed inferences about the control of Cenozoic gravitational tectonics on natural seepage (Figs 13-14). Most of surface slicks originated in the extensional domain from sources near listric normal faults (Fig. 6). Only one surface oil slick was found in the compressional domain at greater water depths.
These results may be used for identifying the most promising acreage for oil exploration. They also indicate potential locations for collection of sea bottom cores for geochemical analysis.

6. CONCLUSIONS

An integration of oil molecular geochemistry, structural-stratigraphic and remote sensing data allowed to construct the model for two petroleum systems in the Foz do Amazonas area. Also, it has shown the occurrence of identical petroleum systems when compared with the Niger delta oil province (West Africa).
The hydrocarbons sourced by the Upper Cretaceous marine carbonate and Tertiary marine deltaic petroleum systems in the Foz do Amazonas basin indicate the presence of, at least, two active petroleum systems, with their respective pods located deep offshore in the area. Such fact, together with the presence, in the Foz do Amazonas area, of a similar assemblage, as observed in Niger delta, of gravity tectonic structures with their related traps, indicate that the Foz do Amazonas area can bear one of the most prolific petroleum provinces in the South Atlantic realm.

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REFERENCE

Asmus H.E. e Ponte F.C.,1973 ,The Brazilian marginal basins, In: Nair ,A.E. e Stehli , F.G., eds., The ocean basins and margins: v.1,The South Atlantic,Plenum Press, New york,p.87-132.

Brandão, J.A.S., and Feijó, F.J.,1994, Bacia da Foz do Amazonas. Boletim de Geociências da PETROBRAS, 8, 91-99.

Castro, J.C., Miura, K., and Braga, J.A.E., 1978. Stratigraphic and structural framework of the Foz do Amazonas Basin, 10Th. Annual Offshore Technology Conference, Houston, Texas, 1843-1847.

Doust, H., and Omatsola, E., 1990. Niger Delta. Divergent/Passive Margin Basins, Eds. J.D. Edwards and P.A. Santogrossi. AAPG Memoir 48, p. 201-252.

Galloway, W.E. 1986. Growth faults and fault-related structures of prograding terrigenous clastic continental margins. Gulf Coast Association of Geological Societies Transactions 36. 121-128.

Johannessen, J.A., Digranes, G., Espedal, H., Johannessen, O.M., Samuel, P., Browne, D., and Vachon, P.,1994, SAR Ocean Feature Catalogue. ESA SP-1174, 106 p.

Magoon, L.B., 1990. He petroleum systems-a classification scheme for research, exploration, resource assessment. In L.B. Magoon, ed., Petroleum Systems of the United States; Geological Survey Bulletin, 1912p. 2-10.

Mello, M.R. 1988. Geochemical and molecular studies of the depositional environments of source rocks and their derived oils from the Brazilian marginal basins. Ph.D. Thesis, Bristol University, 240pp.

Mello, M.R., Telnaes, N., Gaglianone, P.C., Chicarelli, M.I., Brassel, S.C. & Maxwell, J.R. 1988. Organic geochemical characterisation of depositional palaeoenvironments of source rocks and oils in Brazilian marginal basins. *In:* L. Mattavelli & L. Novelli (eds) *Advances in Organic Geochemistry 1987*, Pergamon Press, Oxford, 31-45.

Mello, M.R., Gaglianone, P.C., Brassell, S.C. & Maxwell, J.R. 1988a Geochemical and biologicalmarker assessment of depositional environment using Brazilian offshore oils. *Marine and Petroleum Geology 5(3),* 205-223.

Mello, M.R., Koutsoukos, E.A.M., Hart, M.B., Brassell, S.C. & Maxwell, J.R. 1989. Late Cretaceous anoxic events in Brazilian continental margin. *Organic Geochemistry 14(5)*, 529-542.

Mello, M.R., Mohriak, W.U., Koutsoukos, E.A.M., and Figueira, J.C.A. (1991) Brazilian and West African Oils: Generation, Migration, Accumulation and Correlation. *Proceedings of the Thirteenth World Petroleum Congress*, 153-164.

Mello, M.R. (1993) The Hydrocarbon Source Potential of Brazil and West Africa Marginal Basins. 3rd International Congress of the Brazilian Geophysical Society, *Expanded Abstracts*, 2, 1306-1307.

Mello, M.R., Mohriak, W.U., Koutsoukos, E.A.M., and Bacoccoli, G. (1994) Selected petroleum Systems in Brazil. in Magoon, L. B. and Dow, W. G., eds, The Petroleum System-from Source to Trap, *AAPG memoir* 60, 499-512.

Mello, M.R.; Telnaes, N & Maxwell, J.R. 1995. The Hydrocarbon Source Potential in the Brazilian Marginal Basins: A Geochemical and Paleoenvironmental Assessment. *Paleogeographiy, Paleoclimate and Source Rocks, AAPG Studies in Geology # 40, 233-272.*

Mello, M.R., Moldowan, J.M., Dahl, J., and Requejo, R. in press. Biological markers applied to the petroleum system approach. Petroleum systems of the South Atlantic, ed. Mello, M.R. and Katz, B. AAPG Memoir, in press.

Moldowan, J.M., Fago, F.J., Lee, C.Y., Jacobson, S.R., Watt, D.S., Slougui, N.E., Jeganathan, A. & Young, D.C. 1990. Sedimentary 24-*n*-propylcholestanes, molecular fossils diagnostic of marine algae. *Science 247*, 309-312.

Moldowan, J.M., Dahl, J., Huizinga, B.J., Fago, F.J., Hickey, L.J., Peakman, T.M., and Taylor, D.W. 1994. The molecular fossil record of Oleanane and its relation to Angiosperms. *Science 265*, 768-771.

Miranda, F.P., Fonseca, L.E.N., Beisl, C.H., Rosenqvist, A., and Figueiredo, M.D.M.A.M., 1997, Seasonal mapping of flooding extent in the vicinity of the Balbina Dam (Central Amazonia) using RADARSAT-1 and JERS-1 SAR data. Proceedings of the International Symposium Geomatics in the Era of RADARSAT (GER'97), Ottawa, Canada, May 1997.

Miranda, F.P., Bentz, C.M., Beisl, C.H., Lorenzzetti, J.A., Araújo, C.E.S., and Silva, Jr., C.L., 1998, Application of Unsupervised Semivariogram Textural Classification of RADARSAT-1 data for the detection of natural oil seeps offshore the Amazon Mouth: proceedings of the RADARSAT ADRO Symposium, CD-ROM format.

Peters, K and Moldowan, J.M. 1993. The biomarker guide: Prentice Hall, Englewood Cliffs, New Jersey, 363p.

Requejo, G., Sassen, R., Ukpabio, E., Kennicutt II, M.C., McDonald, T., Denous, M.C, and Brooks, J.M, 1995. Hidrocarbon source facies in the Niger Delta petroleum province as indicated by the molecular characteristics of oil. Book Book of Abstracts, 1995 International Chemical Congress of Pacific Basins Societies. Honolulu, Hawaii, December 17-22, Inor.7, 180.

Silva, S.R.P and Rodarte, J.B.M. 1989. Bacias da Foz do Amazonas e Pará-Maranhão (águas profundas): Uma Analise sismoestratigrafica, tectono-sedimentar e termica. Annais I Congresso Sociedade Brasileira de Geofísica. 2:843-852.

Silva, S.R.P., Maciel, R.R. 1998. Foz do Amazonas hydrocarbon systems. 1998 AAPG International Conference & Exhibition. Extended Abstracts Volume. Ed. Mello, M.R. and Yilmaz, P.O. Rio de Janeiro. P. 480-481.

Silva, S.R.P., Maciel, R.R. and Severino, M.C.G. 1999. Cenozoic tectonics of Amazon Mouth Basin. Geo-Marine letters, Springer-Verlag, 18. 256-262.

Soldan, A. L., Cerqueira, J. R., Ferreira, J. C., Trindade, L. A. F., Scarton, J. C. and Corá, C. A. G., (1995) Giant Deep Water Oil Fields in Campos Basin Brazil: A Geochemical Approach: in Z. C. Correa da Silva, ed., *Revista Latino-Americana de Geoquímica Orgânica*, 1 (1), 14-27.