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Basin Modeling of Thermal History and Biodegradation Alteration of Potiguar Reservoir Oils (Brazil)

The aim of this study was to attempt a complete reconstruction of the geological history of some reservoir oils in the Potiguar Basin (northeastern Brazil) in order to assess the extent of biodegradation that affected them on a regional scale. The Potiguar Basin was a rift formed during the Lower Cretaceous which later evolved to a marginal basin after the breakup of the South American and African continents. An integrated study using geochemical data from source rocks and oils, and basin modeling was carried out to understand the maturity evolution of the source rocks, as well as the compositional changes the generated fluids undergo during maturation and secondary migration.

A cross-section (Figure 1) along the Carnaubais Trend (ENE-WSW) was modeled using Temis2D. Most biodegraded reservoir oils are located in the western part of the section (onshore), within the Upper Cretaceous sandstones of the Açu units that occur at shallow depth (<1000 m) and low temperatures (<65°C). Deeper reservoirs, containing non-biodegraded but more mature oils, are located in the northeastern area of the transect. Gas chromatography and biomarker data allowed us to correlate these oils with the lacustrine shales of the Upanema Mb. and the limestones and shales deposited in a transitional environment of the PT beds, both part of the Alagamar Fm. (Aptian). Hence, the thermal maturation of these source rocks was reconstructed (Figure 2) together with the migration pathways and reservoir filling. For each selected reservoir, the chemical composition of the oils before biodegradation was calculated. For this, we used the compositional module of Temis2D, which enables to describe fluids into the following chemical classes: non-hydrocarbon gases (CO₂, H₂S), hydrocarbon gases (C₁-C₅), distillate Pi - 250°C (saturates and aromatics), residue 250+ (saturates, aromatics, resins and asphaltenes) and char. A new kinetic schema for oil cracking was established in order to improve that already published by Behar et al. (1991) and Vandenbroucke et al. (1999) and to better constrain the kinetic parameters of the NSO compounds generated in source rocks which constitute the major fraction of the S2 peak.

Indeed, results show that most of the heavy fraction generated in source rocks are degraded in the early stages of kerogen transformation before petroleum expulsion and consequently expelled fluids have a lower density and viscosity than those of the fluids generated directly by kerogens (Figure 3). Mixing of generated oils from the two source

rocks occurred before the main phase of secondary migration. Hence, reservoir oils have a relatively homogenous chemical composition. Oils migrated laterally updip along the Açu carrier beds to the onshore accumulations, with no substantial compositional changes during migration. The model predicts the correct chemical composition of the non-biodegraded oils in terms of GOR, distillate proportion and paraffin content (Table 1).

parameters	observed	modelled
C_6-C_{14}	36.7	29.3
C_{14} sat	43.4	45.3
C_{14} aro	10.3	13.3
NSO	9.6	12.1
(C_6-C_{14}/C_{14}) sat	0.85	0.65
(Sat/Aro) C_{14+}	4.2	3.4
(Aro/NSO) C_{14+}	1.1	1.1
GOR	100-120	110

Table 1 : Comparison of the chemical composition of the oil as observed in reservoirs with that predicted by modeling with Temis 2D.

A series of 3 non-biodegraded and 9 biodegraded oils were selected for geochemical analyses: the latter have reached at least the stage 4-5 on the biodegradation scale proposed by Peters and Moldowan (1993). The oils are located in different reservoirs, the present temperature of which varies between 40 and 65°C. Using the chemical alteration of the saturates and aromatics observed on biodegraded oils, the chemical composition of the biodegraded oils was renormalized, and later compared to the chemical composition of the non-biodegraded oils. Consequently, it was possible to estimate of minimum absolute losses for the light hydrocarbons (saturates and aromatics) and for the heavy fractions (C_{14+} saturates, aromatics, resins and asphaltenes).

well	C_{14-}	C_{14+} sat	C_{14+} ali	C_{14+} aro	total
initial	0.0	0.0	0.0	0.0	0.0
1	57.1	23.4	54.5	0.0	28.0
2	61.7	28.2	61.8	0.0	31.7
3	61.9	31.5	72.0	0.0	33.3
4	83.4	39.6	78.7	0.0	45.3
5	90.7	33.0	89.7	22.1	44.6
6	86.0	47.8	89.5	12.5	51.0
7	65.5	49.0	73.1	15.9	44.2
8	100.0	43.8	81.6	10.1	53.8
9	100.0	51.3	80.6	22.5	58.4

Table 2 : Estimation of the losses due to biodegradation of the total oil and its corresponding fractions

Based on results from migration modelling, estimations of residence time and biodegradation losses through time, for each petroleum accumulation, have been calculated and then, correlated with the regional water flow (Table 3).

well	C ₁₄	C ₁₄₊ sat	C ₁₄₊ ali	C ₁₄₊ aro	total	Rel. water flux
1	3.0	1.4	2.9	0.0	1.5	1.0
2	4.4	2.2	4.4	0.0	2.3	1.2
3	5.2	2.8	6.0	0.0	2.8	1.4
4	8.3	4.2	7.9	0.0	4.5	1.7
5	10.1	5.9	10.5	1.5	6.0	1.6
6	8.7	6.8	9.7	2.1	5.9	2.6
7	15.4	7.1	12.6	1.6	8.3	3.5
8	28.6	15.1	23.0	6.4	16.7	7.0

Table 3 : Estimation of the biodegradation rate of the Potiguar reservoir oils (%/Ma)

In conclusion, modeling of petroleum generation and migration in the eastern part of the Potiguar Basin allowed us to predict the chemical composition of the oils before biodegradation for the first time and thus, to clearly distinguish chemical changes of the oils between thermal maturity and biodegradation.

References

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Vandenbroucke M., Behar F., Rudkiewicz J.L. (1999). Kinetic modelling of petroleum formation and cracking : implications from the high pressure/high temperature Elgin Field (UK, North Sea). *Org. Geochem.*, 30, 1105-1125.

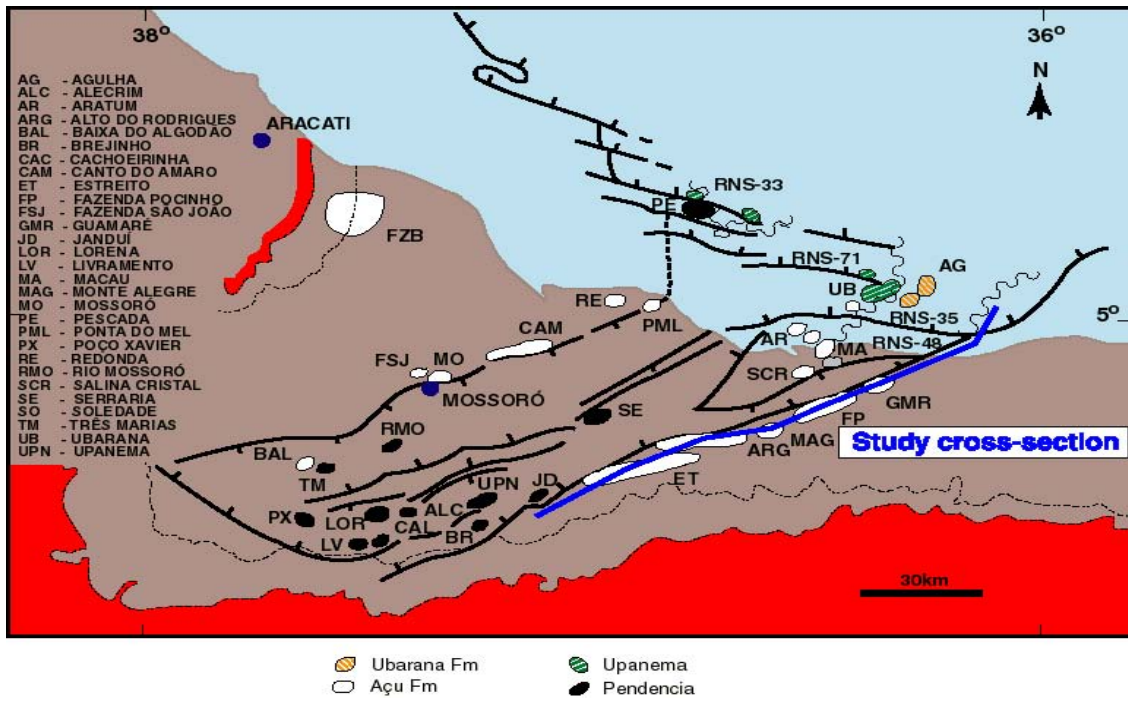


Figure 1 : 2D cross section in the Potiguar Basin (Brazil) selected for the present study.

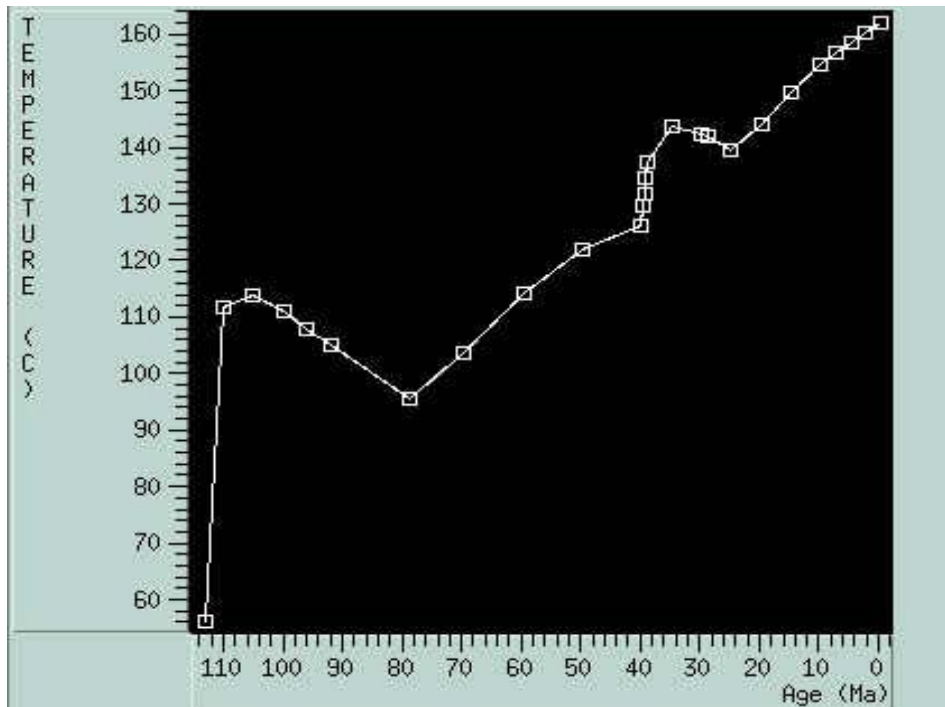


Figure 2 : Thermal history of the PT source rocks (Potiguar Basin, Brazil)

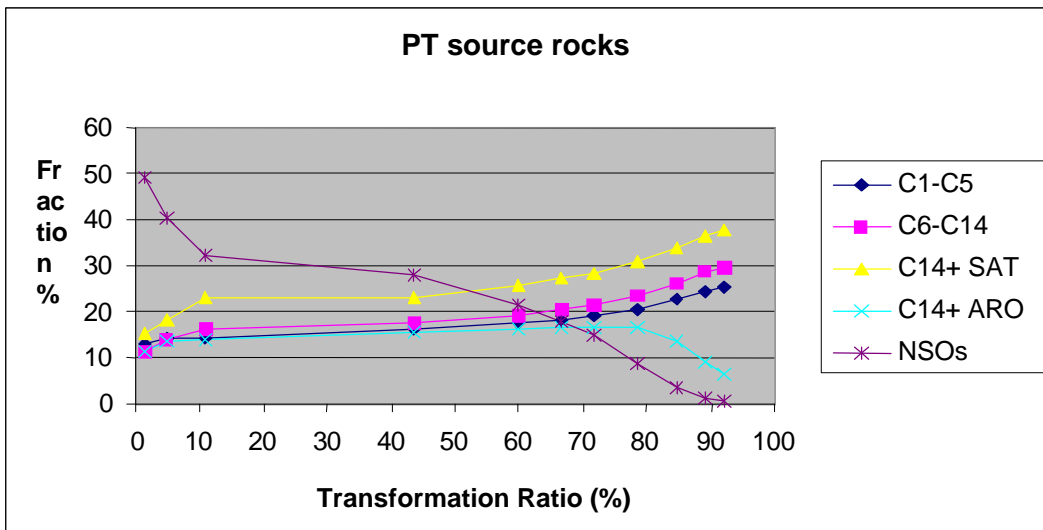


Figure 3 : Evolution of the chemical composition of the generated fluid in the PT source rocks.