A fluid inclusion outlook on the petroleum migration of the Cretaceous Potiguar Basin, Brazilian Equatorial Margin

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Fluid inclusions have long been a recurring tool in the petroleum industry, providing relevant information on the timing, temperature, pressure, and compositional constrains of petroleum systems (see Volk and George, 2019 and references therein). Its application serves both green fields and mature proliferous provinces alike, such as the case of the Potiguar Basin – a historical petroleum province located in the Brazilian Equatorial Margin (BEM) and the subject of this study (Fig. 1).

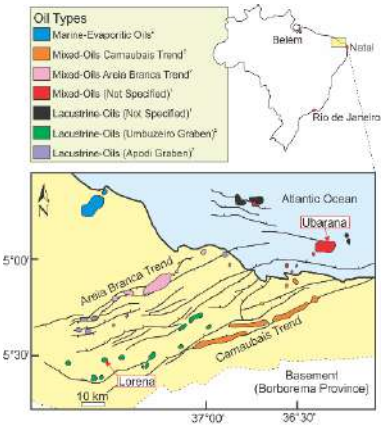

Figure 1. Potiguar Basin map: major rift structures, oil types, and the location of Lorena and Ubarana fields (Pestilho et al. 2018b and references therein).

The Potiguar Basin encompasses about 6 km thick sedimentary cover deposited during Cretaceous as a result of the tectonic break-up of the Western Gondwana (Pestilho, 2018 and references therein). The petroleum systems of the Potiguar Basin display a complex evolution, which includes long-range migration, mixed lacustrine-marine source-rocks, and biodegradation (Trindade et al., 1992). The reservoirs within the Potiguar Basin were chiefly charged by two source-rock units: (i) the Neocominian Pendência Formation, deposited in lacustrine settings; and (ii) the Aptian Alagamar Formation, that was deposited in the transition of continental to marine sedimentary settings (Trindade et al., 1992). The lacustrine oils sourced by the Pendência shales charged the Pendência sandstones in the southern section of the basin, while the Alagamar marine to mixed-source oils were mainly responsible by the accumulations found in the fluvial to deltaic clastic deposits of the Albian-Cenomanian Açu Formation located in both offshore and onshore (Trindade et al., 1992). Partial information on the onset of oil charge of these reservoirs were available at the time of this study, with estimation mostly derived from basin modelling studies. The complexity of the petroleum systems of the Potiguar Basin, and the renewed interest in the exploration within the BEM (Silva et al., 2021) provided an opportunity for the application of fluid inclusions in the understanding of the timing and the physical constraints involved in the charge history of the petroleum traps. The information provided by the reconstruction of the charge history of the Potiguar Basin may serve as an analogue to understand similar petroleum systems in the adjacent sedimentary basins at the BEM (Silva et al., 2021).

Here we summarize the main results and insights provided by the first systematic research using fluid inclusions (Pestilho, 2018; Pestilho et al., 2018a, 2018b, 2021) to address the major petroleum systems of the Potiguar Basin, using several tools: epifluorescence petrography, oil fluorescence spectrophotometry, petroleum biomarkers, confocal scanning laser microscopy, basin modelling, and PVT modelling of fluid inclusions. The major goal of this study was to constrain the early petroleum migration and address its association with the diagenetic environment at the onset of the oil charge history. With that major goal, two oilfields were chosen to as target areas: (1) the onshore Lorena (reservoir: Pendência Formation), and (2) the offshore – Ubarana (reservoir: Açu Formation; and the adjacent carbonates from the Ponta do Mel Formation) oilfields.

In the Lorena oilfield, fluid inclusion assemblages consisted of two-phase (liquid plus vapor or L-V) petroleum inclusions entrapped during the mesodiagenesis of the arkose hyperpycnites of the Pendência Formation: (I) in quartz, as both primary inclusions in syntaxial cement and secondary inclusions in detrital grains, and (II) in albite intragranular cement as primary inclusion. As for the Ubarana area, in the Açu Formation two-phase (L-V) secondary petroleum inclusion were trapped in quartz pebbles of fan-delta conglomerate pebbles during the late

mesodiagenesis, whilst in Ponta do Mel Formation shallow shelf carbonates, two-phase (L-V) petroleum and aqueous inclusions are hosted in saddle dolomite veins originated during late mesodiagenesis.

Both source and maturity parameters from biomarkers indicate that the Pendência and Açu inclusion oils correlate with reservoir oil extracts. The Pendência inclusion oils are similar to the lacustrine oils sourced by the Pendência Formation (ex., low C_{24}-tetracyclic terpane/C_{23}-tricyclic terpane ratio and, low gammacerane/C_{30}-hopane ratio), whereas the Açu inclusion oil displays closer biomarker signature to that of the Alagamar Formation mixed oils (ex., low tricyclic terpanes/total hopanes ratio, intermediate gammacerane/C_{30}-hopane ratio). However, the oil from fluid inclusions of the Ponta do Mel has characteristics of the Alagamar Formation lacustrine organic facies (ex., high tricyclic terpanes/total hopanes ratio, low gammacerane/C_{30}-hopane ratio). The absence of mixed oils in the Ponta do Mel suggests an earlier lacustrine oil migration through the carbonate fractures prior to the main infill of mixed-oils in the Ubarana oilfield.

Fluid inclusion microthermometry, confocal scanning laser microscopy and basin modelling suggest that the initial filling of the Lorena reservoir occurred during the late rifting stage (Barremian and Early Aptian; ca. 129–124 Ma) at 62.7–80.6 °C (11–16.8 MPa) (Fig. 2). In the Ubarana oilfield, hydrothermal fluids migrated with the petroleum during the reservoir initial filling. The total homogenization temperatures for both Açu (Th_{mode} = 124–128 °C) and Ponta do Mel (Th_{mode} = 115–130 °C) are higher than the past and present-day reservoir temperature (present-day reservoir temperature = 110 °C) (Fig. 2).

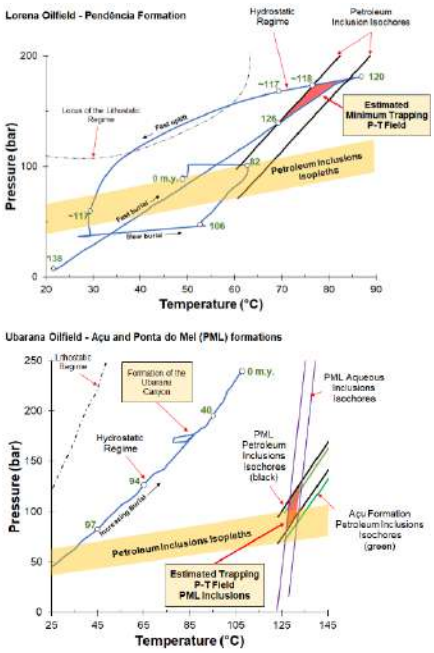

Figure 2. P-T diagrams comparing thermal histories, and fluid inclusions isochores for the Lorena and Ubarana oilfields (Pestilho et al. 2021).

Isochoric modelling of saddle dolomite-hosted fluid inclusions from the Ponta do Mel Formation indicates trapping temperatures between 128.9 and 133.1 °C and pressures between 10.6 and 12.9 MPa. Temperatures and equivalent salinities (mode interval between 16 and 20 mass % equivalent in $NaCl+CaCl_2$) of aqueous inclusions hosted in saddle dolomite are alike the fluid inclusions trapped in hydrothermal minerals in Pb-Zn Mississippi Valley-Type deposits. Finally, no specific timing can be suggested for the hydrothermal event in Ubarana Oilfield. However, this atypical (hydrothermal) petroleum system could be linked to two possible scenarios: (i) the onset of petroleum migration of the Alagamar Formation during the Cenozoic Macau (ca. 48–8.8 Ma) magmatic event; or (ii) an earlier activity of the petroleum system, prior to the peak oil generation (50–10 Ma).

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