[PS]Geological Evolution of the Petroleum Systems of the Cabo Frio High Area

Eugenio V. dos Santos Neto[1], Ramsés Capilla[2], Davy R. Brandão[1], Ricardo Jahnert[1], Marco Brito[1], Luiz Felipe C. Coutinho[1], André Etienne P. P. D. Ferraz[1], and Luiz A. P. Gamboa[1]

Search and Discovery Article #42605 (2025)**
Posted November 11, 2025

*Adapted from extended abstract based on oral presentation given at AAPG International Conference and Exhibition (ICE) Rio de Janeiro, 30 September - 3 October, 2025.
 DOI:10.1306/42605Neto2025

[1]LAGEMAR/Universidade Federal Fluminense
[2]PETROBRAS/CENPES/PDIEP/Geoquímica

Abstract

The Cabo Frio High (CFH) is localized between Santos and Campos Basins, in a region characterized by intense tectonism and magmatism. The proximal CFH is an area of continental basement uplift, while its outer part can be followed into the oceanic crust. The CFH developed through a complex history involving pulses of uplift, intrusive, extrusive and explosive magmatism in the Upper Cretaceous, and extrusive magmatism in Eocene. It started to be uplifted during the Late Cretaceous, separating the margin in two basins (Santos and Campos). During the Eocene, the CFH experienced intense influence of magmatism and further uplift. Both of these basins are oil prone. Such complex evolution had significant effect on the petroleum systems in the CFH and its adjacent areas.

This study is an integrated interpretation of geochemical data of oils and natural gases, and geophysical information (seismic data, magnetic and gravimetric mapping) aiming to refine the knowledge about the influence of geological evolution of CFH on petroleum systems of that area.

Oils in the CFH area are found in pre- and post-salt reservoirs in the CFH and are correlated with source rocks deposited under lacustrine brackish to saline conditions during the Buracica local stage (Upper Barremian). However, oils found in shallower traps (post-salt reservoirs) were biodegraded in different intensities, showing a depletion in alkanes and relatively lower API degrees (mostly 10^0-16^0) compared to their counterparts of the pre-salt (24^0-26^0). In some cases, evidence of refreshing is suggested in part of the studied oils that have both the full range of n-alkanes (C15+) and 25 nor-hopane (demethylated hopane), and/or n-alkanes (C15+) in samples with UCM (unresolved complex mixture) observed in gas chromatograms. Such compositions indicate one initial pulse of oil that was biodegraded and one new charge of pristine oil, suggesting petroleum generation in pulses with dissimilar ages and, probably, increasing levels of thermal evolution.

Accumulations in the CFH area are generally scarce in CO_2 (<2%), except two pre-salt accumulations with 49.2% and 11.9%. Results of noble gas geochemistry have shown helium isotopes with relatively high $^3He/^4He$ ratio (R/Ra >3.0), indicating a strong signature from the mantle. H_2S in the oils vary between nil (most samples) to 300 ppm. Isotopic composition of sulfur in H_2S ($\delta^{34}S$ > +10‰) and VOSC (volatile organic

sulfur compounds) distribution suggest contribution of TSR (thermochemical sulfate reduction) and catagenetic processes of the kerogen, especially those VOSC of higher molecular weight.

The geological evolution of CFH influenced the petroleum systems in many ways. The intense magmatism, flux of deep hot fluids and uplift episodes altered the expected maturation development, producing multiple petroleum charges and different levels of oil preservation. In the same way, erosion or non-deposition of sedimentary layers, particularly salt, has been identified, and alterations of the original porosity and permeability in reservoir rocks are anticipated.

Understanding the complex geological evolution and the relative importance of each variable controlling the petroleum systems in the CFH is crucial for the most effective exploration of that area.

GEOLOGICAL EVOLUTION OF THE PETROLEUM SYSTEMS OF THE CABO FRIO HIGH AREA

Eugenio V. dos Santos Neto[1], Ramsés Capilla[2], Davy R. Brandão[1], Ricardo Jahnert[1], Marco Brito[1], Luiz Felipe C. Coutinho[1], André Etienne P.P. D. Ferraz[1], Cleverson G. Silva[1], Luiz A. P. Gamboa[1]

[1]LAGEMAR/Universidade Federal Fluminense, [2]PETROBRAS/CENPES/PDIEP/GEO/Geoquímica

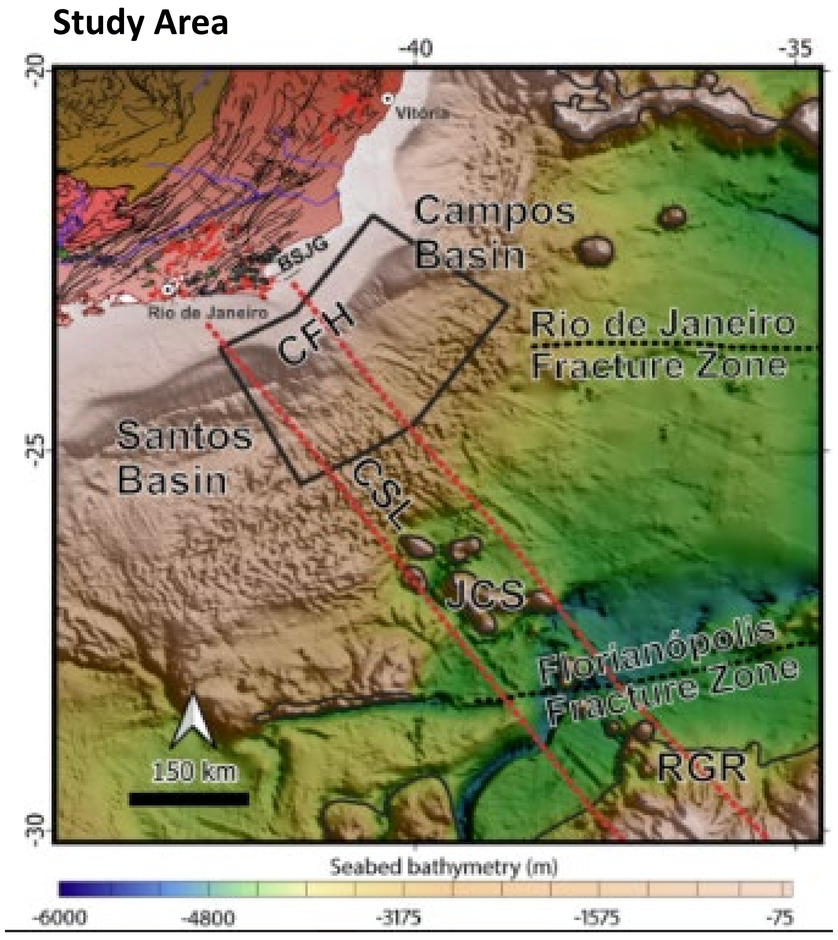
Introduction

The Cabo Frio High (CFH) is localized between Santos and Campos Basins, in a region characterized by intense tectonism and magmatism. The proximal CFH is an area of continental basement uplift, while its outer part can be followed into the oceanic crust. The CFH developed through a complex history involving pulses of uplift, intrusive, extrusive and explosive magmatism in the Upper Cretaceous, and extrusive magmatism in Eocene. It started to be uplifted during the Late Cretaceous, separating the margin in two basins (Santos and Campos). During the Eocene, the CFH experienced intense influence of magmatism and further uplift. Both basins are oil prone. Such complex evolution had significant effect on the petroleum systems in the CFH and its adjacent areas.

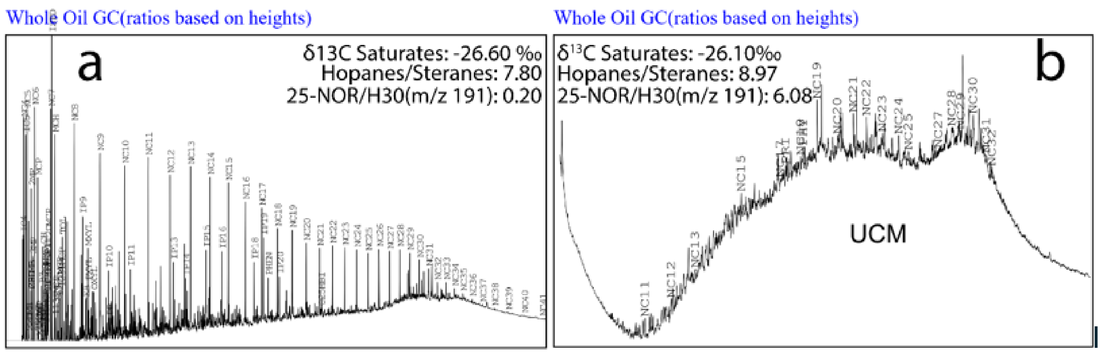
Objectives

This study is an integrated interpretation of geochemical data of oils and natural gases, fluid inclusions petrography, and geophysical information (seismic data, magnetic and gravimetric mapping) aiming to refine the knowledge about the influence of geological evolution of CFH on petroleum systems of that area.

Study Area



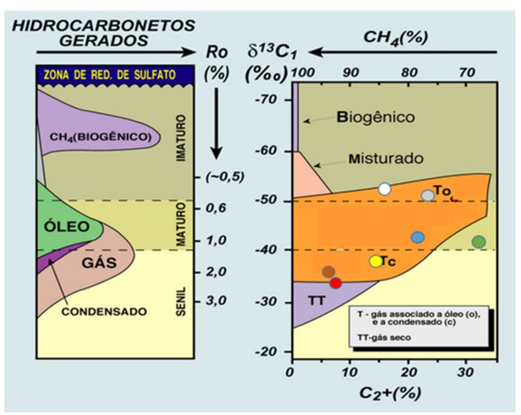
Oil Geochemistry



"*Refreshed*" oil (4-BRSA-380-RJS, 3005-3030m) (a)
Biodegraded oil (1-SHEL-4A-RJS, 2373m) (b)

OIL TYPE	n-ALKANES	DEMETILATED HOPANE	API °	EXPECTED RESERVOIR
Pristine/ Refreshing	Full range Present	Low abundance, or nil	25-27	Pre-salt
Biodegraded	Absent, or Relicts	High abundance	10-13	Post-salt

Gas Geochemistry



δ13C1 ‰	%C1	
-37,90	94,4	
-40,12	66,2	
-50,70	77,6	
-35,13	N.D.	
-38,58	86,03	
-52,34	84,8	
-41,98	79,8	

Pre-salt
Post-salt

Reservoir	CO_2 %	H_2S ppm	He (R/Ra)
Pre-salt	11.9 – 49.2	Up to 300	3.00 – 4.27
Post-salt	0 – 0.3	No data	No data

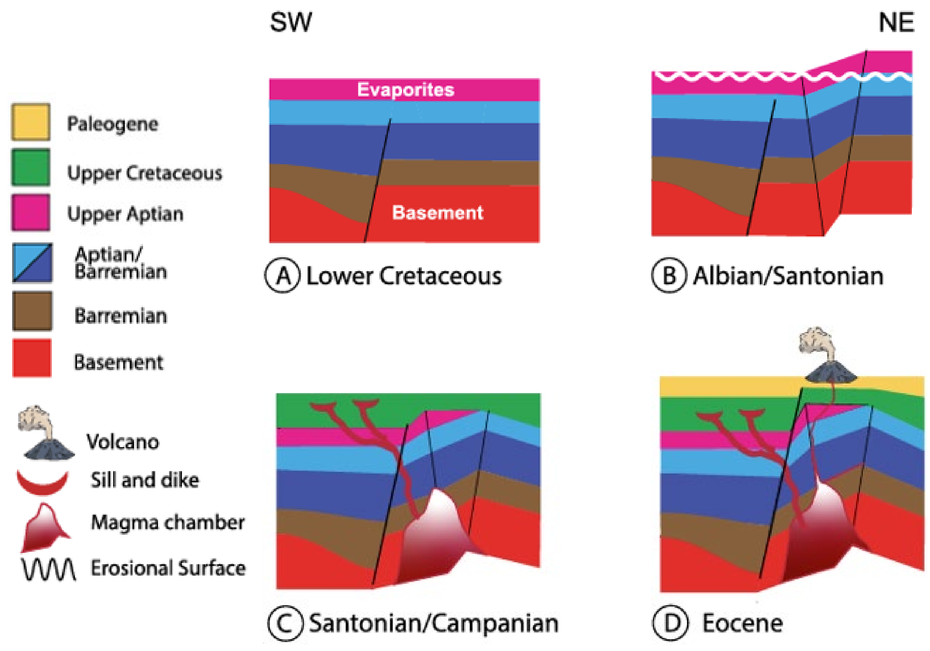
Paragenetic Sequence and Fluid Inclusions in the Barra Velha Fm.

Minerals and fluid inclusions (FI)	Syngenesis	Eodiagenesis	Mesodiagenesis
Shrub Calcite	———		
Dolomite		- - - - - - - - -	
Microquartz		- - - - - - - - -	
Megaquartz			- - - - - - - - -
Anhydrite			- - - -
Primary CO_2 FI	———	———	———
Primary H_2O FI	———	———	———

Fluid inclusions rich in CO_2 and mineral assembly in the pre-salt rocks evidence hydrothermal activity associated with Hauterivian-Aptian and post-Aptian magmatism.

Geological Evolution

The intense tectonism and coeval magmatism uplifted the sedimentary section, producing structures and erosion, or non-deposition, of sedimentary layers, particularly salt. Nevertheless, rocks preserved porosity for holding petroleum accumulations. Extra heat from the flux of deep hot fluids and of magmatism altered the maturation profile, generating pulses of petroleum charges that sequentially were trapped in post-salt reservoirs. According to the mixing proportion of pristine and former biodegraded oil, petroleum accumulations may show characteristics of "refreshing" or biodegradation.



Conclusions

- Intense structural activity in the CFH generated faults as natural migration avenues for hydrocarbons and other fluids (CO_2).
- Faults can open windows in the evaporites allowing oil and gas reach post-salt reservoirs, thus, subject to biodegradation process.
- The intense magmatism may have altered the expected thermal evolution of the source rocks influencing the petroleum generation and its composition.
- Fluid inclusions and mineral assembly in the pre-salt rocks suggest hydrothermal activity associated with Hauterivian-Aptian and post-Aptian magmatism.
- Hydrocarbons trapped in pre-salt reservoirs can have a wide range of thermal maturities (black to light oils, condensate and gas).
- Evidence of *refreshing* is found in oils having the entire range of n-alkanes, 25-norhopane and UCM, corroborating to the complex thermal/structural history in the Cabo Frio High area.
- CO_2, $^3He/^4He$ → Mantle; H_2S ($\delta^{34}S$ > +10‰) and VOSC (volatile organic sulfur compounds) distribution →TSR (thermochemical sulfate reduction) + catagenetic processes of the kerogen.

Acknowledgements

The authors thank PETROBRAS/CENPES for the sponsorship (Process 2022/00194-9; PT-200.20.10003) and the National Agency of Petroleum, Gas and Biofuels – ANP (Agência Nacional de Petróleo, Gás e Biocombustíveis) for the seismic and well data, NAB (Núcleo de Estudos em Biomassa e Gerenciamento de Água) and Physics Institute of the Universidade Federal Fluminense for analysis SEM-EDS.