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Campos basin: review on the geology and its oil and natural gas exploration and production context

Bacia de campos: revisão sobre a geologia e seu contexto de exploração e produção de petróleo e gás natural

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Abstract: *This review and analysis work presents the Campos Basin, in its geological aspects, such as the tectonosedimentary evolution and its petroleum systems and exploratory plays, the history of exploration and production, in post-salt and pre-salt reservoirs, the panorama current production as well as future perspectives for production in the basin, in the context of national medium and long-term forecasts.*
Keywords: Campos Basin, Hydrocarbons Exploration, Brazilian Post-Salt and Pre-salt, Hydrocarbons Production, Production Forecasts.

Resumo: Este trabalho de revisão e análise, apresenta a Bacia de Campos, em seus aspectos geológicos, como a evolução tectonossedimentar e seus sistemas petrolíferos e plays exploratórios, o histórico de exploração e produção, em reservatórios do Pós-Sal e Pré-Sal, o panorama de produção atual bem como as perspectivas futuras de produção da bacia, no contexto das previsões nacionais de médio e longo prazo.
Palavras-chave: Bacia de Campos, Exploração de Hidrocarbonetos, Pós-sal e Pré-sal brasileiro, Produção de Hidrocarbonetos, Previsões de Produção.

1 Introduction

The time of the first onshore hydrocarbons discoveries in Brazil, in the late 1930s, the potential for reserves in the offshore basins was already emerging, however exploration and production activities in the Brazilian East Margin basins only began in the 1960s (Lucchesi, 1998; Mendonça et al., 2003), being the first discovery in the Garoupa Field in 1974 (Lucchesi, 1998; Piquet, 2011), that allowed the advance in the search for petroleum self-sufficiency (Lucchesi, 1998). The Campos Basin is located on the north coast of the state of Rio de Janeiro and south of Espírito Santo, in a sedimentary area of 173,331 km², limited to the North with the Espírito Santo Basin, by the Vitória High and to the South, with the Santos Basin through Alto de Cabo Frio High (ANP, 2015; EPE, 2019). It is a high potential basin and the most prolific with about 90% of Brazilian oil reserves until 2007 (Winter et al., 2007).

With the recent discoveries in the Pre-Salt Petroleum Province, in the Campos and Santos basins, since 2007, important structural changes have taken place in the country's economic and political context with a view to being among the world's largest reserves holders and major oil producers, with world-class assets (Piquet, 2011). Consisting of large accumulations of light oil, of excellent quality and with high commercial value, the pre-salt discoveries place Brazil in a strategic position in the face of the great energy demand for world (Petrobras, 2020).

According to ANP (2020a), in 2020 the Campos Basin ranked as second in production, with daily production of 1,016,021 (bbl/day) of oil, 19,005 (Mm³/d) of natural gas and 1,135,559 (boe/d) of total production with 35 wells, which represented about 32% national oil production and 14% national gas production. Currently, this basin remains in second place in production, despite the decrease in 2021 production, with daily production of 814,173 bbl/day of oil and 17,272 Mm³/day of natural gas, which represents about 28% national oil production and 13% national gas production, and a total daily production of 922,809 boe/day (barrel of oil equivalent), operating with 28 producing fields (ANP, 2021). In terms of royalties, which in March 2020 received R$ 486,079,769.30, of which 50% of the social fund being allocated to health and education, showing the impact that exploration in the basin has on public accounts, considering a potential for economic and financial leverage (Araújo, 2001. p. 260, ANP, 2020b). Petroleum activities also generate direct and indirect jobs, growth in local commerce and increased municipal and state tax revenue (Piquet, 2011).

Considering the above scenario, the importance of oil and natural gas exploration for the country, and the contribution of the Campos Basin, is highlighted in this sense. This review work aimed to describe the history of exploration and development of the main discoveries in the Campos Basin, as well as to understand the geological evolution and the petroleum potential of the Basin. To broaden the knowledge of the formation of the large accumulations of light oil of excellent quality and high commercial value, raising Brazil to third place among the world's oil producing countries.

The general objective is to understand the regional geology, onshore and offshore (mainly), stratigraphy and the potential and the history of petroleum development in the Campos Basin (Schaller, 1973; Rangel et al., 1994; Fonseca et al., 1998; Silva and Cunha, 2001; Winter et al., 2007). To achieve this main objective, the specific objectives are to analyze the geological characteristics of the Campos Basin, and the evolution of hydrocarbon exploration and production that highlight the basin in the national exploratory context. For this purpose, secondary data provided by the Oil, Natural Gas and Biofuels National Agency (ANP - Portuguese Acronym), Petrobras, Energy Research Office (EPE - Portuguese Acronym), in addition to a bibliographic review on the following topics: i) Tectonic-sedimentary evolution; ii) Description of the petroleum systems and main exploratory plays; iii) Exploratory historic; and iv) Oil and natural gas production forecasts. This article contributes to the discussion on the Campos Basin relevance to produce oil and natural gas in Brazil today and in the long-term horizon.

2 Methods and techniques

The development of this paper had as method the bibliographical and exploratory research according to the understandings of Lüdke and André (1986) and Gil (1995), addressing the geological aspects and the Campos Basin petroleum potential. This research had a descriptive-exploratory character (Gil, 1995), aiming to deepen the knowledge on the theme. Using the bibliographical and exploratory research method, exhaustive research was conducted for classic papers about the Campos Basin in terms of regional geology, as well as more recent works related to the discoveries, exploratory model, and forecasts of hydrocarbon production in the basin, in Portuguese and English.

The research was conducted through the "Google Academic (2020)" and "Researchgate (2020)" search engines, focusing on the period between the 1980s to 2021. The key words were Campos Basin, Hydrocarbons Exploration, Petroleum Potential, Brazilian Post-Salt and Pre-salt, Hydrocarbons Production and Production Forecasts. After this first stage, the documents were analyzed in terms of their relevance and update, and the information was synthesized and correlated, verifying the coherence between the concepts, definitions, and order of magnitude of the data.

The Campos Basin is widely studied and presents a considerable number of primary and secondary sources, allowing the application of the indirect documentation technique (Gil, 1995; Oliveira, 2002), by means of the bibliographic survey in available national and international publications related to the theme, the most current works were selected, and the most relevant information compiled. Scientific articles, monographs, dissertations, theses, presentations, and official reports from government agencies were analyzed, among which the following stand out: the ANP Annual Bulletin; ANP Bidding Rounds Geological Summaries; Petrobrás Geoscience Bulletin; and EPE Reports and Technical Notes. The concept of Play used in this work is that of Magoon and Dow (1994), understanding as a set of genetically related prospects, from the petroleum systems point of view.

3 Geological context

The Campos Basin locates in Brazil southeastern, between Rio de Janeiro and Espírito Santo states in a sedimentary area of approximately 173,331 km² (ANP, 2015; EPE, 2019 – Figure *1*). The basin has an onshore and offshore area with its limits defined in the North with the Espírito Santo Basin, by the Vitória High, and in the South with the Santos Basin by the Cabo Frio High, in the West, in the onshore area, by the igneous and metamorphic rocks outcrops belonging to the Ribeira Belt that make up its Precambrian basement (Ministério de Minas e Energia, 1983; Fonseca et al., 1998; Silva and Cunha, 2001), and to the East by the sedimentation towards abyssal plain oceanic (ANP, 2015; Mohriak et al., 1989). The Cenozoic sedimentary cover is represented by the Barreiras Formation (Miocene) and the quaternary coastal deposits near the mouths of rivers such as Paraíba do Sul River (Brêda, 2012; Vilela et al., 2016; Carelli et al., 2019), however, as they are not of petrolific interest, these deposits will not be described in this paper.

3.1 Tectonic-sedimentary evolution

The Campos Basin has its origin and evolution related to the opening process of the South Atlantic, during the Gondwana paleocontinent fragmentation (Final Jurassic/Early Cretaceous), and the tectonic efforts in the basin generation process resulted in the basic stages classically described as: Rift, Post-Rift (Transitional) and Drift (Marine) (Castro and Picolini, 2014; Winter et al., 2007). The first stratigraphic chart was prepared by Schaller (1973), later updated by Rangel et al. (1994), both focusing on lithostratigraphy. Winter et al. (2007) developed a stratigraphic chart emphasizing the depositional sequences, this being the most recent Campos Basin stratigraphic chart (Figure *2*).

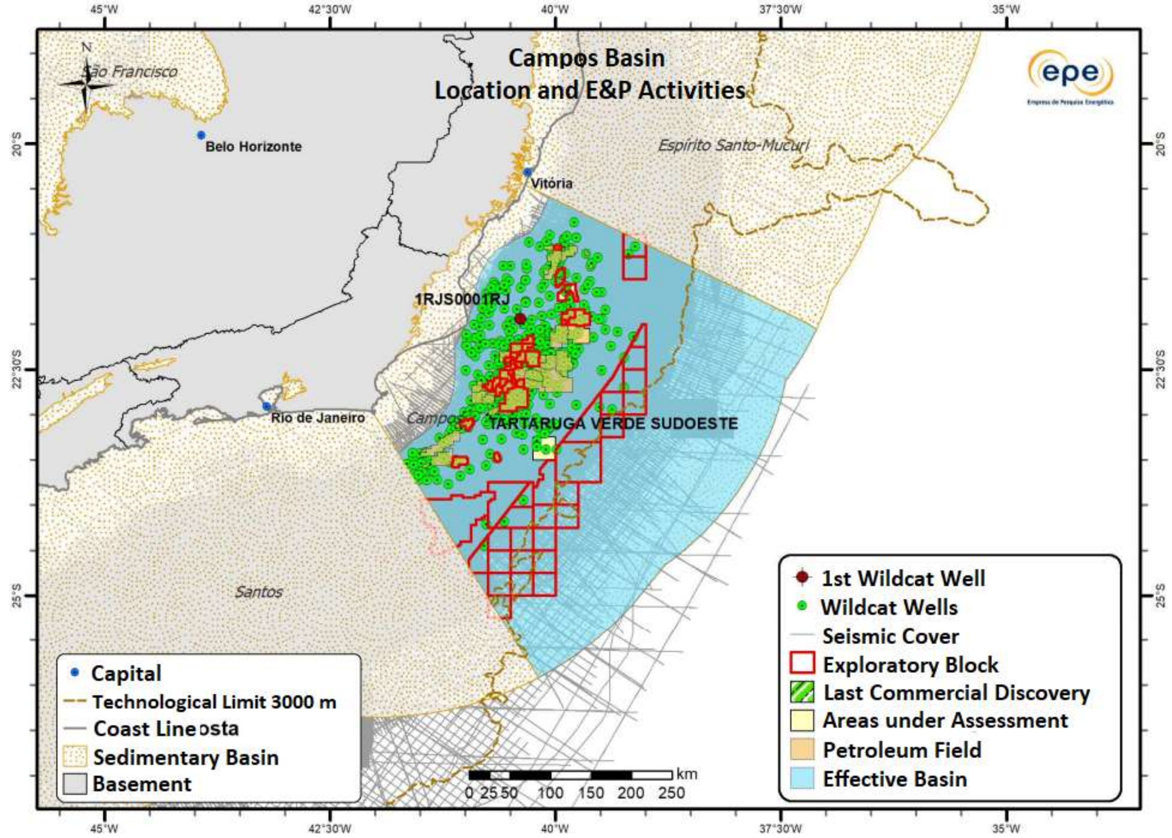

Figure 1. Campos Basin location and exploratory activities information's. Source: Modified and Translated from EPE (2019).

The Rift section (Hauterivian/Aptian), according to the mega sequences described by Winter et al. (2007) is subdivided into Sequences K20-K34, K36 and K38, and correspond to the Lagoa Feia Group continental sediments, deposited on the Cabiúnas Formation basalts. They are conglomerates, sandstones, siltstone, reddish shales, and lacustrine carbonates. In the onshore area, are described basic rocks dikes with NE-SW direction, correlated with the Cabiúnas magmatism (ANP, 2015). No deposits from the Sin-Rift I phase are found in Campos Basin, which may not have been preserved, with the Sin-Rift II and Sin-Rift III phases present (Chang et al. 1992; ANP, 2015). The Sin-Rift II phase started from the crustal distension that resulted in a series of half-grabens with intense volcanism (Cabiúnas Formation - correlated to the Serra Geral igneous event in the Paraná Basin) and with lacustrine deposits associated (Sequences K20-K34). Sandstones, siltstone, and conglomerates associated with successive basaltic spills are identified, with some occurring fractured and with vesicles, as they occur in the reservoirs from Badejo Field (Winter et al., 2007; ANP, 2015).

In the Sin-Rift III phase (Sequences K36 and K38) there is a predominance of fluvio-deltaic, lacustrine and alluvial fan sedimentation, with the occurrence of clayey packages, deposited in a freshwater lake environment (Winter et al., 2007), sandstones, sin tectonic conglomerates and carbonate composed by shells of pelecypods (coquinas) in structural highs (Alto de Badejo, for example). A striking feature is the talc-stevensite clay minerals, which, according to Dias (2005), were precipitated in alkaline volcanic lakes. This mega sequence is represented by the Cabiúnas (volcanic), Atafona (siltstones and sandstones with talc-stevensite), Coqueiros ("coquinas" and shales) and Itabapoana (conglomerates) formations of the Lagoa Feia Group (Sequences K36 to K38 - Winter et al., 2007). The shales of the Atafona Formation are important source rocks - Buracica Shale, however, the shales of the Coqueiros Formation, are the main source of the basin - Jiquiá Shale. The "coquinas" (calcirrudites, calcarenites and bioclastic) of the Coqueiros Formation, are the main reservoirs in the Rift Sequence (Guardado et al., 1989).

The Post-Rift Phase, also called Transitional Evaporitic Mega Sequence (Sequences K46 and K48, and Sequence K50 - Winter et al. 2007), is separated from the Continental Mega Sequence by the Upper Pre-Aptian discordance (Dias, 2005), and refers to the Lagoa Feio Group upper portion, with deposition during Aptian (local Alagoas Stage), between 118 and 112 M.y. (Guardado et al., 1989; Castro and Picolini, 2014; ANP, 2015). It is a transitional phase between thermal and mechanical subsidence and tectonic stabilization (sag), with continental and marine deposition (Guardado et al., 1989; Dias, 2005). This Mega Sequence consists of the Itabapoana (conglomerates), Macabú (stromatolites and microbial laminites), Gargaú (marl and calcilutite) and Retiro (anhydrite, halite, carnallite and sylvinite) formations from Lagoa Feia Group (Mohriak et al., 2008; Castro and Picolini, 2014; ANP, 2015).

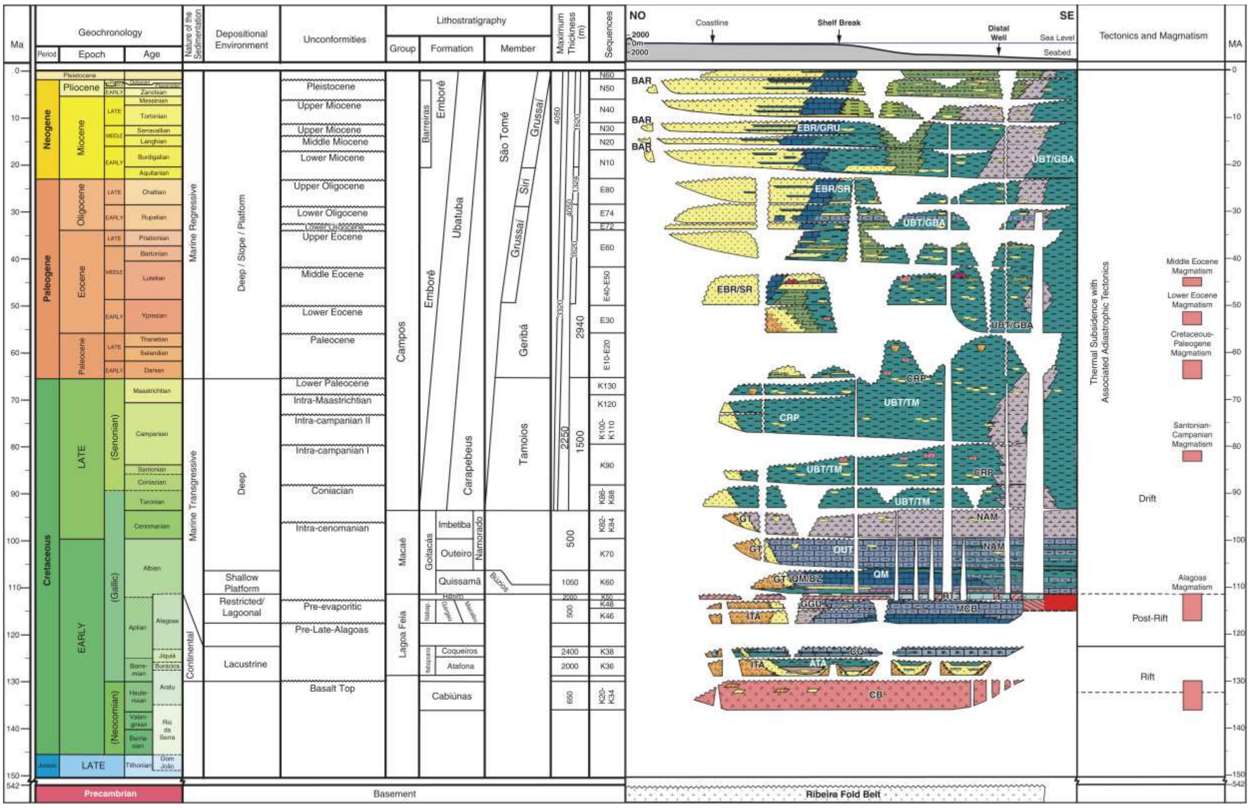

Figure 2. Stratigraphic Chart of the Campos Basin. Source: Winter et al. (2007).

Continental deposition predominated in Eoalagoas, in alluvial, lacustrine, and fluvial fan systems. In Neoalagoas there is a transition between restricted and continental epicontinental sea environments. On the coast, the marine incursion into extensive shallow regions resulted in the concentration of hypersaline waters that led to the construction of microbials (ANP, 2015). At the end, evaporite deposition occurs in a restricted environment, with little water circulation, limited to the south by a volcanic chain of EW direction, called Dorsal de São Paulo (ANP, 2015). The K46 Sequence is composed of conglomerates and sandstones at the edge of Itapaboana Formation; and carbonates, marl, and sandstones from shallow transitional environment of the Gargaú and Macabu formations. In the distal microbial laminite portions and exposure features in Macabu Formation they are frequent in comparison with proximal portions, indicating the passage of the K46 to K48 sequence in an interval of 115 M.y. (Winter et al., 2007).

Representing K50 Sequence, Retiro Formation was deposited during the Lower Albian, being composed of chemical sediments that register an environment with association of lagoons and sabkha plains, in a period of about 112 M.y. between the beginning and the end of deposition. Variations in the mineralogy of the proximal, median, and distal areas are observed, occurring, respectively, anhydrite,

anhydrite/halite and anhydrite/halite/carnallite/sylvite minerals (Mohriak et al., 2008). The halo kinesis developed in this sequence allowed to modify the Campos Basin structuring, creating favorable conduits and depocenters for the Upper Cretaceous turbidites deposition (Winter et al., 2007), between 118 and 112 M.y. (Guardado et al., 1989; Castro and Picolini, 2014; ANP, 2015).

The Drifte Phase (Albian to Recent) comprises marine sediments deposited in a regime of thermal subsidence associated with adiastrophic tectonism (halokinesis). In this Super Sequence, sediments from shallow platform environments to deep seas are deposited in transgressive and regressive episodes, whereas in the Cenozoic, the trend was predominantly regressive (Winter et al., 2007). This phase constitutes the deposits of the Macaé and Campos groups (Ubatuba, Carapebus and Emborê formations), aged between Albian and Holocene (Winter et al., 2007). The Shallow Platform Carbonate Mega Sequence was deposited in an open marine environment in Albian, with alternating successions of highstand system tracts (HST) with high energy carbonate deposition (packstones/grainstones) and transgressive system tracts with low energy carbonate deposition (wackestones/mudstones), represented mainly by Quissamã Formation from Macaé Group (ANP, 2015).

In the Transgressive Marine Mega Sequence, there was a progressive sinking of the basin and the global rise in sea level, resulting in the drowning of the carbonate platform and consequent deposition of low-energy sediments such as shales, marl and calcilutites (Chang et al., 1992). This Mega Sequence comprises the formations Outeiro (calcilutitos and shales), Imbetiba (calcilutitos) and Namorado (sandstone) from Macaé Group, the Tamoios Member from Ubatuba Formation (shales) and Carapebus Formation (sandstones) (ANP, 2015a). The Regressive Marine Mega Sequence is composed in predominance by successive fluvio-deltaic sequences, with the occurrence of delta fans, siliciclastic platforms and turbidites in deeper waters. This Mega Sequence is represented by the Ubatuba (shale), Carapebus (sandstone) and Emborê (carbonate) formations (ANP, 2015).

Macaé Group has a concordant occurrence aboveRetiro Formation evaporites, consisting of the Goitacás, Quissamã, Imbetiba and Outeiro formations. Goitacás Formation represents the proximal environments characterized by the association of alluvial fans, fan deltas, lagoons, and beaches (Castro and Picolini, 2014). The Quissamã Formation records a carbonate system with low and high energy facies, with the proximal area characterized by siliciclastic-carbonate facies and the distal area with typically carbonate facies (Castro and Picolini, 2014). The main reservoirs are oolitic and oncolitic calcarenites, deposited in shallow water banks, related to carbonate and inter-bar systems. In the most distal portion, shales and marl occur (Castro and Picolini, 2014).

4 Exploration and production history in Brazil and in the Campos Basin

From the end of the 19th century to the middle of the 20th century, the exploration of Brazilian oil and gas was concentrated in terrestrial basins, with the first efforts in the Recôncavo Baiano and in the Paleozoic basins (Lucchesi, 1998; Morais, 2013; Mendonça, Spadini and Milani, 2003). Institutions were created seeking to organize these exploratory efforts such as the National Department of Mineral Production (DNPM - Portuguese Acronym) in 1933, and the National Petroleum Council (CNP - Portuguese Acronym) in April 1939. Commercial production started in 1941, and in 1963 there was a discovery from Carmópolis Field, main producer at the time in the Recôncavo Basin, reaching the peak of national production in the 1970s (Bacoccoli, 1986; Lucchesi, 1998; Mendonça, Spadini and Milani, 2003; Morais, 2013).

With the creation of Petróleo Brasileiro S. A. (Petrobras), in 1953, the Union began to exercise a monopoly on the exploration, production, refining and transportation of oil and oil products, organizing national exploratory research (Mendonça, Spadini and Milani, 2004; Morais, 2013). The excessive costs need for technology and logistical difficulties motivated the migration of the exploratory process from onshore basins to the Brazilian platform, under risk contracts, increasing investments in the acquisition of geological-geophysical data in shallow waters. As a result, a series of discoveries between the 70s and 80s on the Brazilian East Margin increased production to 500,000 bbl/day at the end of 1984 (Bacoccoli, 1986; Morais, 2013; ANP, 2015).

The Campos Basin was the protagonist with the discovery of the Garoupa field in 1974, in Albian carbonates by well 1-RJS-9A-RJ. Several fields were discovered in the shallow waters of the Campos Basin in different exploratory plays, such as the fields of Badejo in “coquinas” of the lower Aptiano (rift phase), Enchova in Eocene sandstones and the first giant field in Brazil that was the Namorado field discovered in Cenomanian turbidites (ANP, 2015). The seismic acquisitions in deep waters, in the 1980s, and the exploratory campaign that followed led to the discovery of giant fields in turbiditic plays, among them Albacora (Miocene) and Marlim (Oligo-Mioceno). Between the 80s and 90s, the development of 3D seismic, and the advance in the use of seismic attributes, led to the discovery of Barracuda giant field in Oligocene to Eocene turbiditic sandstones (ANP, 2015).

Despite the oil crisis between 1970 and 1980, Campos Basin maintained exploratory progress and the production of its fields, and between 1974 and 1983, 345 exploratory wells were drilled, and 22 oil fields were discovered. Between 1977 and 1985 the daily production in water depths between 90 and 383 meters increased from 160,800 barrels in 1977 to 546,300 barrels in 1985. During this period, Petrobras increased its investments in the basin, which increased from US $ 877 million, in 1970-1974, to US $ 5.4 billion, in 1980-1984, and the costs of exploration and production activities reflected 45% of the total amount invested by the Company between 1975 and 1979, and 84% between 1980-1989 (ANP, 2015; Bacoccoli, 1986; Lucchesi, 1998; Mendonça, Spadini and Milani, 2003; Morais, 2013).

Advancing to drilling in deep waters, 400 to 1,000 meters of water depth, the discoveries of Albacora (1984) and Marlim (1985) stand out. In the 90s, with exploration in water depths between 2000 and 3000 meters, discoveries were made in turbiditic sandstones such as the Marlim Sul (well 1-RJS-0460-RJ) and Roncador (well 1-RJS-0436A- RJ) in Maastrichtian sandstones with approximately 9 billion barrels of oil in place (ANP, 2015; Mendonça, Spadini and Milani 2004).

In 1997, the New Petroleum Law (Law 9,478/97) broke the Union's monopoly, allowing the entry of private operators, operating on a concession basis through bidding rounds conducted by the ANP (Mendonça, Spadini, Milani and 2004). This time, the petroleum exploration phase began in deep and ultra-deep waters in the Campos Basin. Noteworthy are the accumulations of Maromba, Papa Terra, Peregrino, Xerelete and Parque das Conchas (Shell Park), as well as the discoveries of the Parque das Baleias (Whale Park), and the discovery of reservoirs in aptian pre-salt microbial carbonates previously to the Santos Basin pre-salt discoveries (ANP, 2015). The Figure 3 below summarizes the exploratory evolution of the Campos Basin, with the number of wells drilled and the main discoveries in shallow, deep and ultra-deep waters, according to the ANP Technical Seminar (ANP, 2018).

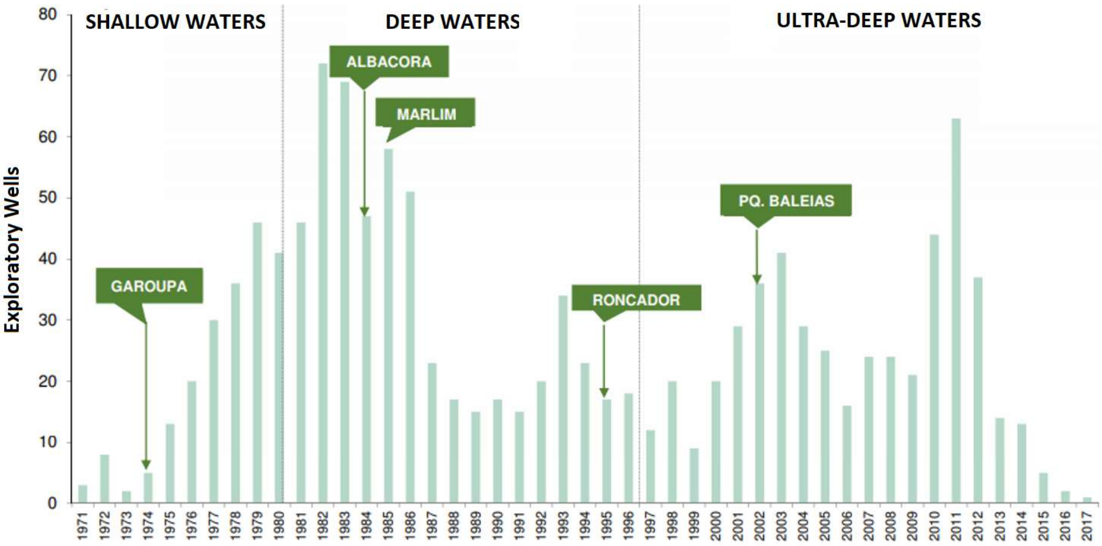

Figure 3. Campos Basin Exploratory History from 1971 to 2017. Source: Modified and Translated from ANP (2018).

Important challenges were overcome to allow exploration in deep and ultra-deep waters, such as unfavorable climatic and oceanographic conditions for the handling of offshore equipment, the hydrostatic pressures resulting from the water column, the low temperatures on the seabed, the conditions of the seabed, and more recently the difficulty in drilling the salt layer (Morais, 2013). Due to the distance between the platform and the well (up to 13,000 m), it was necessary to resize drilling columns, flow lines and risers that could withstand the great pressures imposed. Another challenge was the distance between the oil production or storage platforms to the coast (above 300 km). Additionally, the presence of impurities such as hydrogen sulfide and carbon dioxide in the reservoirs are still challenging in the exploratory process, as depending on their concentration they can cause corrosion in materials and equipment, such as Christmas tree, risers, putting the lives of workers at risk, and the change in oil viscosity can make extraction difficult, making the project unfeasible (Morais, 2013; D'Almeida et al., 2018).

The Campos Basin is the second main hydrocarbon producing basin in Brazil, responsible for national 28% oil production and 13% natural gas production (ANP, 2021; EPE, 2020a), being highlighted in the main ANP bidding rounds. Recently, during the 14th and 15th Bidding Rounds of the ANP, 19 exploratory blocks were offered under concession, 17 of which were auctioned (ANP, 2018). In the 3rd, 4th, and 5th Production Sharing Rounds of the 4 exploratory blocks offered, 3 were auctioned off. During the 16th Bidding Round (October 2019), 13 blocks were placed on offer in ultra-deep waters, 10 of which were auctioned (EPE, 2019).

5 Petroleum systems and exploratory plays

The main petroleum systems and plays are indicated in ANP geological summaries (ANP, 2015, 2017, 2018): Lagoa Feia-Carapebus (!), Lagoa Feia-Lagoa Feia (!), Lagoa Feia-Namorado (!) And Lagoa Feia - Quissamã (!). The 14th ANP Production Sharing Bidding Round and the 15th ANP Concession Bidding Round (ANP, 2017, 2018) also presented the petroleum systems: Lagoa Feia - Macabú (!), Lagoa Feia - Coqueiros (!), Macaé - Carapebus (!). Campos Basin is a High Potential Basin, with Lagoa Feia-Carapebus (!) being the main petroleum system, and the predominant exploratory status is Established (sensu EPE, 2019b), with only Play Siri indicated as Immature. It has a sedimentary area of 173,331 km² and the Effective Basin area of 159,513 km² (EPE, 2019) - Figure *4*.

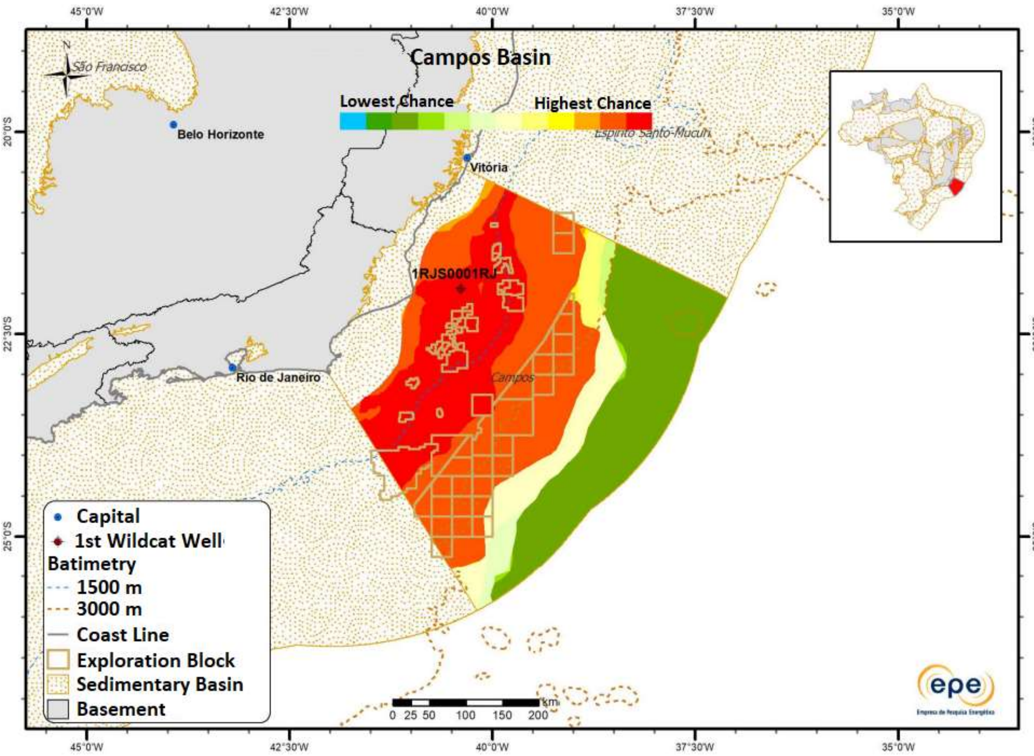

Figure 4. Map of the Probabilistic Effective Basin of Campos, indicating the chances of discoveries in the basin. Source: Modified and Translated from EPE (2019).

The turbiditic reservoirs of the Upper Cretaceous and Paleogene are responsible for most of the oil produced in the basin (ANP, 2017; EPE, 2019). Migration is predominant in salt windows, where listric faults take oil from the rift phase to different reservoirs in drift phase (post-salt). The main seals are shales, and the expected traps are structural, stratigraphic, and mixed, related to the distensive tectonics and halo kinesis (ANP, 2017; EPE, 2019). In the next item will be described the Campos Basin exploratory plays with their main elements and processes, in accordance with the ANP (2015, 2017, 2018) and EPE (2019) classifications. The source rocks are shown in the geological section in Figure *5*.

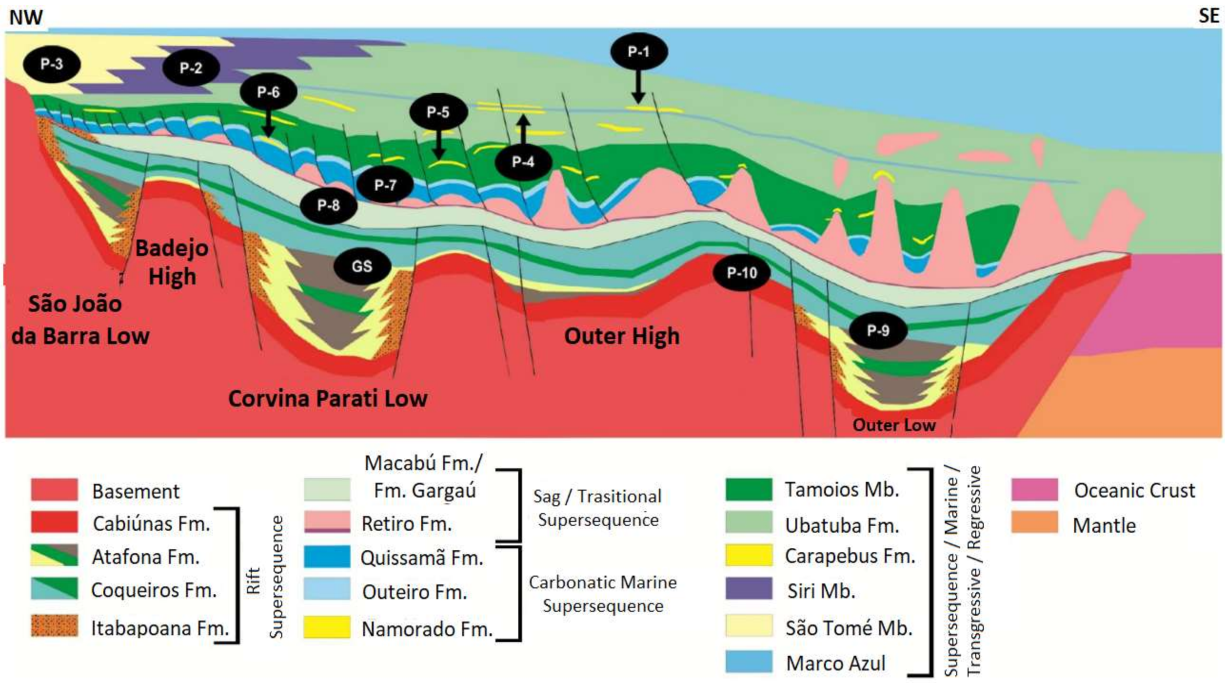

Figure 5. Campos Basin geological section with indication of the main petroleum system source rock (GS) and exploratory plays (P). Source: Adapted from ANP (2015) and EPE (2019b).

5.1 Exploratory plays

The Fractured Basement Play (P10), corresponds to reservoirs in fractured basalts of Cabiúnas Formation (Hauterivian), the generation of hydrocarbons coming from Lagoa Feia Group (Barremian/Aptian) shales, and these migrated by direct contact and by normal faults. These reservoirs are sealed by shales and carbonates from Lagoa Feia Group (Barremian-Aptian) and the trapping is structural (EPE, 2019).

EPE (2019) subdivides the pre-salt reservoirs in two plays: Microbialites Pre-Salt (P8) and “Coquinas” Pre-Salt (P9). In both plays the generation occurs in Lagoa Feia Group (Barremian/Aptian) shales and the migration occurs in normal faults and carrier beds. In P8 the reservoirs are microbialites (Aptian) from Macabu Formation, sealed by evaporites from Retiro Formation, and the traps are structural type. In P9 the reservoirs are “coquinas” (Barremian/Aptian) of Coqueiros Formation, sealed by shales and carbonates from Lagoa Feia Group, with stratigraphic traps.

The post-salt carbonate reservoirs are represented by the plays Siri (P2) and Quissamã (P7). The generation occurs, for both plays, in the shales of the Lagoa Feia Group (Barremian/Aptian), with the migration in listric faults and/or salt windows. At Play Quissamã (P7) the reservoirs are shallow platform marine carbonates (Albian) from the Quissamã Formation, sealed by marl, shales and calcilutites from the Quissamã and Outeiro formations (Albian-Cenomanian). At Play Siri (P2), the reservoirs are platform carbonates (Oligocene) of the Siri Member of the Emborê Formation, sealed by shales from the Carapebus and Ubatuba formations (Eocene-Miocene). The traps for both plays are mixed (EPE, 2019).

Characterized by the generation in lacustrine shales of the Lagoa Feia Group and possibly marine shales (Albian/Turonian/Cenomanian), the plays Carapebus Cretaceous-Superior (P5), Carapebus Paleocene - Eocene (P4) and Carapebus Oligo-Miocene (P1) have as reservoirs turbiditic sandstones of Outeiro, Imbetiba and Carapebus formations, at different stratigraphic levels/ages. The migration in these plays occurs in listric faults and/or salt windows, being sealed by shales from the Carapebus and Ubatuba formations (Eocene-Miocene), with mixed-type traps (EPE, 2019).

6 Current production and production forecasts for medium and long term

According to ANP (2020a), the Campos Basin is the second largest oil and natural gas producer (Figure *6*), second only to the Santos Basin. In 2020, the Campos Basin recorded the production of 1,016,021 (bbl /day) of oil, 19,005 (Mm³/d) of natural gas and 1,135,559 (boe/d) of total production with 35 wells. Thus, the Campos Basin contributed with national 32% of oil production and with 14% natural gas production. The pre-salt layers in the Campos Basin are responsible for generating approximately 300,000 boe/day, part of this production comes from the fields of Badejo, Marlim, Voador and Jubarte (ANP, 2020a). In

April 2020, Petrobras identified the presence of oil in the exploratory well of the Southeast block of Tartaruga Verde, acquired in the 5th Production Sharing Bidding Round, in September 2018, with the entire area being explored and operated by Petrobras (EPE, 2020a).

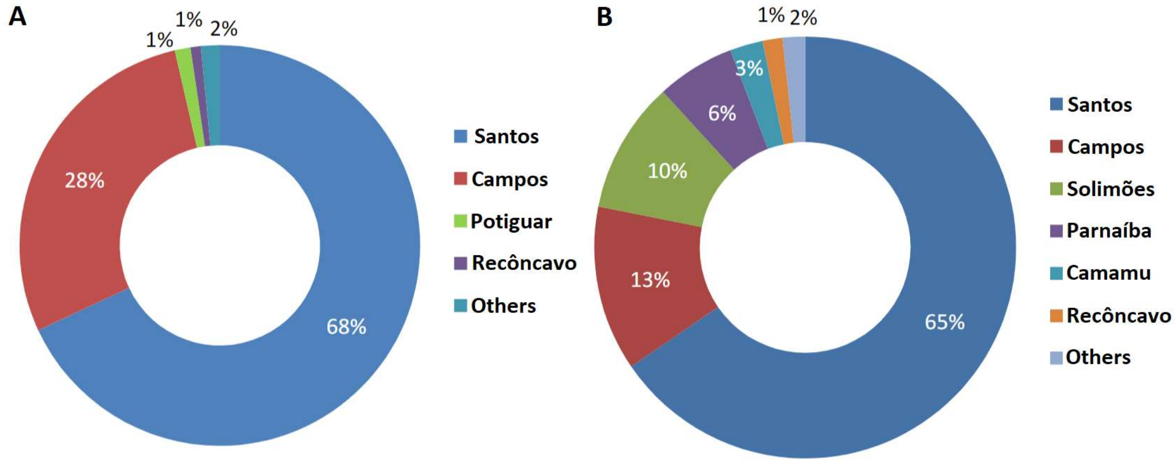

Figure 6. a) Distribution of oil production; and b) Distribution of natural gas production by basin (ANP, 2021).

Currently, this basin remains in second place in production, despite the decrease in 2021 production, with daily production of 814,173 bbl/day of oil and 17,272 Mm³/day of natural gas, which represents about 28% national oil production and 13% national gas production, and a total daily production of 922,809 boe/day (barrel of oil equivalent), operating with 28 producing fields (ANP, 2021).

A study conducted by EPE, showed that the effects of the COVID-19 pandemic had an impact on the reduction in oil prices, due to the paralysis or decrease in some services, due to social distance (EPE, 2020b). The leadership disputed by Saudi Arabia and Russia, resulted in a fall below the level of 2004, which could significantly affect demand in the short term. As a result, new strategies were needed in production, refining and investment plans to meet world market demand (EPE, 2020b).

Petrobras reported the decrease in oil production to 100 thousand bbl/day, due to the oversupply of the foreign market and the demand crisis. The COVID-19 pandemic caused oil activities to be extended so that the state-owned company would cut about US $ 3.5 billion in investments scheduled for 2020, resulting in a final amount of US $ 8.5 billion, the devaluation of the real against the US dollar contributed to this event. The temporary deactivation of platforms that operate in shallow water and interventions in wells provide a reduction in production logistics that promotes about US $ 2 billion in reduction of operating expenses (EPE, 2020b). Even in times of crisis, Yinson signed a contract with Petrobras, where it will be able to operate in deep waters in the Marlim Field, in the Campos Basin for 25 years. The project of this contract foresees the drilling of 10 new wells, the unit will have the capacity to produce 70 thousand barrels of oil per day and compress 4 million m³/day of natural gas (EPE, 2020c).

In the context of national production projections, the 10-year Energy Expansion Plan 2029 (EPE, 2020a), predicts that national production, based only on resources in the reserve category, should reach the highest volumes in 2027, maintaining a level around 4 million bbl/day, mainly with the contribution of the Buzios, Lula, Mero, Sépia and Atapu fields, representing about 69% of the oil production forecast at the end of the period (EPE, 2020a).

Oil production in 2029 is expected to be about 111% higher than in 2018 (2.6 million bbl/day), with production in ultra-deep waters accounting for about 82% of national production (EPE, 2020a). The pre-salt share tends to increase with the prioritization of exploration and production due to the large volumes and high commercial value (Figure 7A). The start-up of the production modules of the Transfer of Rights ("Cessão Onerosa") and Mero will significantly influence, and the pre-salt will account for around 77% of the national oil production at the end of the decade, with a strong participation of the Santos Basin (EPE, 2020a).

The production of natural gas reserves will reach the highest volumes in 2028, with an expected peak in production of 155 million m3/day, with a slight decline until the end of the period, which may be offset by contingent and undiscovered resources. The Santos, Campos, Solimões and Parnaíba basins stand out in natural gas production (EPE, 2020a). The Campos and Santos basins account for approximately 84% of the total associated gas forecast for 2029 (EPE, 2020a). Pre-salt production reaches about 67% of the total in 2029 (Figure 7B), with accelerated growth from 2025, influenced mainly by the contribution of the extra pre-salt, about 28% of the total in 2029, where the contributions of non-associated gas producing units (EPE, 2020a).

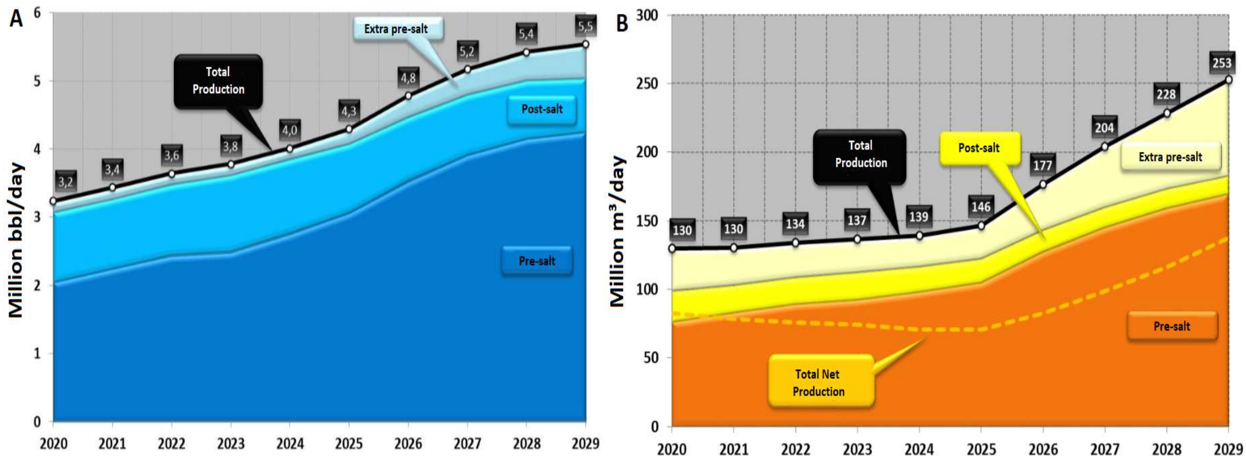

Figure 7. Forecasts of national A) oil and B) gross natural gas production for pre-salt, post-salt, and extra-pre-salt. Source: Modified and Translated from EPE (2020a).

7 Final Remarks

Petroleum activities in Brazil, especially in the Campos and Santos basins are extremely relevant for national development, and the recent discoveries in the pre-salt deposits have contributed to achieving self-sufficiency. This review work presented the state of the art regarding the geology of the Campos Basin, characterization of the petroleum systems and exploratory plays of the pre-salt and post-salt, which reflect in the production obtained in the main fields of this basin.

Several challenges were faced for production in ultra-deep waters, such as unfavorable climatic and oceanographic conditions and low temperatures. The presence of hydrogen sulfide gas and carbon dioxide in important fields are still undesirable characteristics, but the technological evolution obtained in the areas of geophysics, geology and engineering in general has allowed operations in deep and ultra-deep waters. Technologies have also been developed for the separation of these toxic gases and allowing for greater recovery of oil and/or natural gas in the pre-salt reservoirs.

Recently, during the global crisis related to the COVID-19 pandemic, the Campos Basin stood out for maintaining production in all existing fields. Even at a time when companies avoid making investments, there were contract renewals for exploration and production in the basin. The new discovery of the presence of oil in the exploratory well of the southeast block of Tartaruga Verde confirms the relevance of the Campos Basin in the national petroleum context.

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