The influence of fine grains in the Barra Velha Formation of 9-SEP-1-RJS well, Sepia Field, Santos Basin

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Abstract

The characterization of carbonate reservoirs presents challenges associated with the heterogeneity of the permoporous properties found in these rocks. Therefore, this paper proposes a petrophysical evaluation of the carbonate rocks to identify the best reservoir zones and, the verification of the influence of the presence of fine grains aiming to understand the impact on the quality of these rocks as reservoir in the Barra Velha Formation in 9-SEP-1-RJS well, Sepia Field, Santos Basin. The results show that the best reservoirs are associated with stromatolites with shrub and spherulitic structure, besides grainstones composed by fragments of spherulite and stromatolite. While in regions where there is the presence of fines, mainly, the porosity and permeability of these rocks are affected, negatively impacting and compromising the quality of the rocks as a reservoir in the Barra Velha Formation.

Introduction

The Santos Basin is the main oil producing basin in Brazil, accounting for 74% of total production. Its huge oil reserves correspond to the complex carbonate reservoirs of the pre-salt play. The characterization of these reservoirs presents challenges due to the faciologic complexities provided by vertical and lateral heterogeneities (Mohriak et al., 2015).

These carbonate rocks are affected by diagenetic processes that impair their quality as a reservoir (Lebre et al., 2021). Dissolution, cementation, and mineralogical replacement are among the most common processes. The worsening in the porosity and permeability of these reservoirs, due to diagenesis, occurs in several fields of the basin (Lima & De Ros, 2019). In addition, these accumulations are located below thick salt layers, often fractured and under the influence of hydrothermalism making their exploitation difficult.

The presence of fine grains that differ from conventional clays represents an additional challenge for production optimization in the Barra Velha formation (Herlinger et al., 2017). The presence of fine grains obstruct porous connections and impede fluid flow in reservoirs (Penington, 2000). Few studies evaluate how the presence of these fine grains affects the geophysical responses of well logs and negatively impacts the production of pre-salt reservoirs (Castro & Lupinacci, 2019).

The Sepia field is located in the central portion of the Santos Basin, about 280 km offshore and in water depths of 2,150 m. In December 2021, it made up the 2nd Bidding Round for the Surplus Volumes of the Onerous Assignment (Ribeiro et al., 2022). Its carbonatic reservoirs are intensely faulted and fractured, but with great thickness for oil accumulation. The Sepia field has an average total production of more than 178 Mboe/d (ANP/SDP, 2023), the 4th biggest producing field in the Pre-salt.

Barra Velha Formation

Deposited during the Aptian and belonging to the local floor Alagoas, the Barra Velha Fm. occurs on the sediments of the Itapema Fm. and is overlain by the Ariri Fm. It is limited in the base by the Pre-Alagoas discordance, in the top by the salt base, and divided inwardly by the Intra-Alagoas discordance. This discordance separates the carbonates deposited during the sag phase in its upper part, from those deposited during the rift-superior phase in its lower part (Buckley et al., 2015). Rocks composed of stromatolitic limestones, microbial laminites, carbonaceous shales, and microbialites rich in talc and magnesian clays (Moreira et al., 2007), are associated with a shallow, hyper-alkaline, evaporation-prone lacustrine environment (Wright & Barnett, 2015), with diagenetic facies commonly showing replacement/cementation by dolomite and quartz (Arienti et al., 2018).

Method

The flow chart below was employed to characterize the best reservoir zones and evaluate the influence of fine grains in the Barra Velha Formation in well 9-SEP-1-RJS (**Figure 1**). The data made available by ANP includes well geophysical logs, petrographic reports and slide images. The loading of the logs data and the interpretations developed were carried out using Interactive Petrophysics (IP) software, provided by Lloyd's Register.

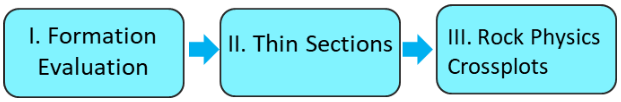

Figure 1 - Flowchart used to achieve the objectives.

(I) Formation Evaluation

In this step, the characterization of reservoir properties and net pay estimates were performed in 7 steps based on the workflow applied by Ribeiro et al., (2022): 1) Data import and quality control, 2) estimation of clay volume, 3) porosity determination, 4) fluid identification, 5) water saturation estimation, 6) cutoffs of reservoir properties, 7) net pay.

(II) Thin Sections

The description of the thin sections was carried out based on the petrographic reports described and provided by the ANP, as well as the slide images used. This step allowed an integrated analysis between the logs responses obtained in the formation evaluation with the characteristics seen on the slide and described in the reports.

(III) Rock Physics Crossplots

The rock physics crossplots allow us to correlate elastic parameters to reservoir properties. In this way, it helps us to reduce uncertainties during formation evaluation. In this step, compressional (Vp) and shear (Vs) wave velocity curves and acoustic impedance (IP) were calculated.

Results

(I) Formation Evaluation

The caliper curve (HCAL) gives a good relationship of the measured values and the well wall. The oil-water contact (O/W) was estimated at 5.544m by interpreting the pressure gradient graph and the deep resistivity log (AT90). The gamma ray log (GR) shows an average value of 27 gAPI. While the photoelectric factor curve (PEFZ), around 4.95 b/e. Such patterns suggest low natural radioactivity and little mineralogical alteration, as expected in a clean, calcite-dominated carbonate section.

Significant changes in the responses of the NMR and acoustic impedance (IP) logs allowed the subdivision into five zones (D, E, F, G and H) interpreted above the oil-water (O/W) contact, according to the permo-porous characteristics and possible textural heterogeneities of each section. The analysis of zones A, B and C will not be the focus of this paper, as they are located below the O/W contact. **Table 1** shows the reservoir properties of these zones.

Table 1 - Comparison of reservoir properties between interpreted zones in the Barra Velha Formation

Properties/ Zones	H	G	F	E	D
Thickness	141 m	35 m	44 m	20 m	65 m
Vclay_LRV	9.5%	14.4%	21.0%	16.8%	8.0%
VCL	4.0%	12.5%	66.1%	11.6%	3.1%
TCMR	14.9%	6.0%	10.2%	5.3%	14.5%
CMRP_3MS	14.3%	5.3%	3.1%	4.7%	14.0%
CMFF	11.4%	3.0%	0.3%	2.7%	11.8%
KTIM	148.9mD	1.5mD	0.003mD	0.3mD	427.3mD
Swir_RMN	21.3%	46.7%	89.5%	43.7%	18.6%
SwArchie	4.0%	13.9%	71.6%	24.2%	7.5%

In zones D (5.478/5.544m) and H (5.238/5.379m) estimate the lowest clay volume (Vclay_LRV) of the formation with 8% and 13.5%. The highest percentages of effective porosity (14.0 and 14.3%) and free fluids (11.8% and 11.4%) are still seen, as well as permeability (KTIM) values susceptible to good reservoirs. The fine grain volume (VCL) with T2 log mean (T2LM) values of 250ms and 246m, suggests little microporosity. The low water saturation measurements (SwArchie and Swir) corroborate with the higher thicknsses for net pay (**Figure 4**).

In zones E (5.458/5.478m) and G (5.379/5.415m) there is a decrease in permo-porosity, possibly due to more intense cementation and clogging of pore throats making these carbonates more closed and configuring loss of reservoir quality. The clay content reaches 16.8% and 14.4%, respectively. The presence of fine grains also registers an increase in these regions, given by VCL values of 11.6% and 12.5%, in addition to T2LM measurements of 82ms and 98ms, respectively. The irreducible water saturation (Swir) shows relevant increases 43.7% and 46.7% in zones E and G, values higher than those observed in zones D and H.

In zone F (5.415/5.458m) a slight increase from GR to 35 gAPI and change in photoelectric factor (PEFZ) is observed, which suggests possible more clay matrix. The neutron log (NPHI) increases and sharp drops are observed in the density (RHOZ) and transit times logs, promoting a considerable impact on the acoustic impedance (IP). The deep resistivity curve (AT90) is also sharply reduced. The effective porosity, free fluids and permeability reduce significantly to the lowest values seen in Barra Velha Fm. (Table 1). However, the clay volume by NMR (VCL) indicates a considerable increase in fine grains estimated at 66.1% and suggests the presence of magnesian clays. The total porosity (TCMR) exhibits a slight increase compared to zones E and G, however, portraying an increase in microporosity. Therefore, the evaluation characterizes a non-reservoir behavior in this zone, corroborated with the absence of net pay (**Figure 4**).

(II) Thin Section

The thin blades used to integrate the rock data with the logs responses were provided and characterized in the ANP petrographic reports. **Figure 5** shows slides from the five main zones described during the formation evaluation step.

In Zone D, thin sections 1, 2 and 3 are described as stromatolites consisting of shrub, brecciated, fractured and spherulitic microfacies, with open and/or normal arrangement, in addition to the presence of dolomite cementation in rhombohedral habit.

In Zone E, blades 4 and 5 are described by spherulites with laminated structure, micritic core and dolomite and quartz cementation. Blade 6 is stromatolite with a shrub structure composed of spherulites with very small to medium fraction and dolomite cementation.

In Zone F, slide 7 is described by stromatolite with shrub structure composed of spherulites, but with 15% clay matrix and dolomite cementation. Blades 8 and 9 are characterized by spherulites with a 30% clay matrix.

In Zone G, slide 10 comprises spherulites with presence of dolomite, clay and micritic core. The dolomite cementation reaches 15%. Slide 11 shows spherulites with laminated texture and presence of dolomite and cementation of pyrite and dawsonite. Slide 12 shows spherulites with shrub and laminated texture, indistinct matrix and cementation of dolomite, dawsonite, pyrite and quartz.

In Zone H, blades 13 and 14 are described by well-selected grainstone, normal packing and composed of fragments of spherulite and stromatolite. Cementation reaches 10 to 12%, composed of dolomite and quartz. Slide 15 is characterized by stromatolites with shrub structure, composed of spherulite, pelloid and open arrangement.

(III) Rock Physics Crossplots

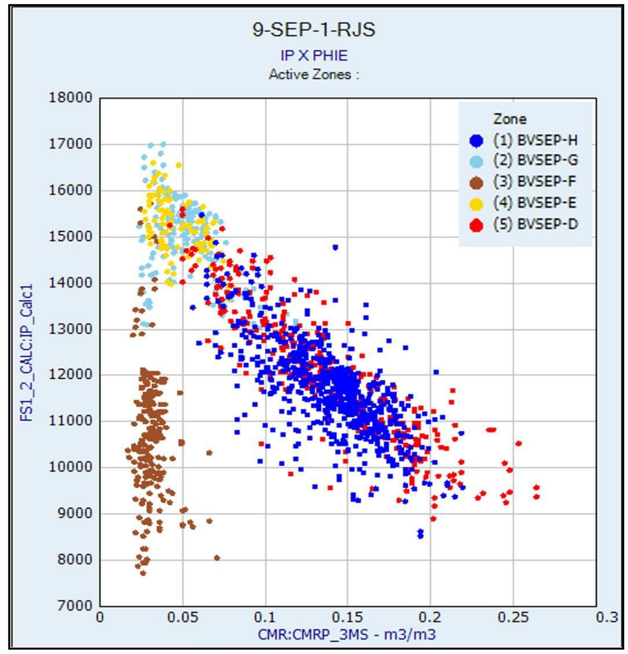

Figure 2 - IP *versus* PHIE Crossplots for zones.

The analysis of the crossplots assists in understanding the heterogeneities of Barra Velha Fm. The IP x PHIE crossplot (**Figure 2**) allowed us to identify two distinct trends. In the main, the increase in IP is related to the decrease in PHIE. And the best reservoirs (zones H and D) are associated with lower IP values between 10,000 and 14,500 g.m/cm3.s and medium to high porosity. Zones G and E represent the closed carbonates, with high acoustic impedance values and considerable decrease in porosity due to the strong influence of dolomite cementation. The secondary trend shows a variation of IP while the porosity changes little. This F zone is characterized by microporosity caused by a large volume of fines, observed in the formation evaluation.

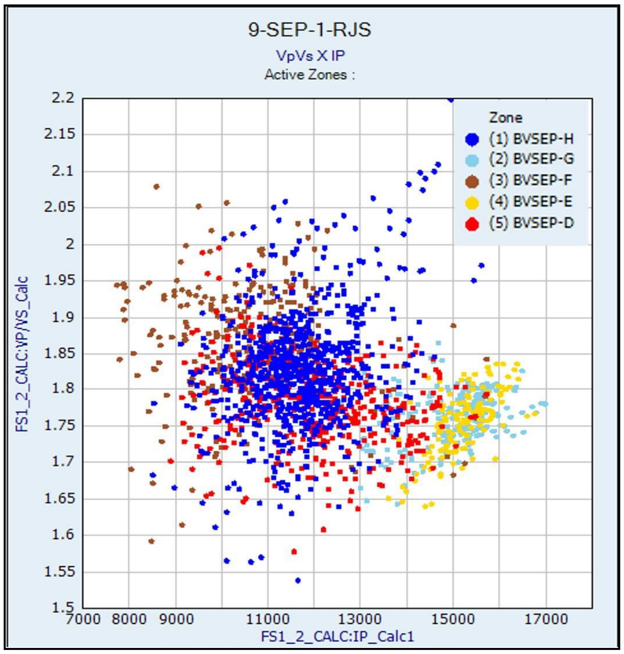

Figure 3 - Vp/Vs *versus* IP Crossplot for zones.

In **Figure 2**, the medium to high porosity carbonates (zones H and D) present the same ranges of IP values observed in zone F. The crossplot Vp/Vs x IP (**Figure 3**) helps to understand this heterogeneity. For, acoustic impedance is sensitive to porosity and the Vp/Vs ratio is more influenced by mineralogy (Ribeiro, 2022). It is observed that zone F, dominated by fine grains, presents values between 1.82 and 1.97 of Vp/Vs ratio, higher compared to other regions. This behavior is associated with the beginning of the Lower Sag phase and may be related to the occurrence of magnesian clays, according to Castro (2019). Some intervals of the H zone exhibit an increase in irreducible water saturation that slightly decreases Vs and increases Vp/Vs. Thus, in these regions Vp/Vs values above 1.9 are observed.

Conclusions

The best reservoirs for hydrocarbon accumulation observed in the Barra Velha Formation in this well are zones H and D, composed by spherulites and stromatolites with good permophorosities. Zone F described by spherulites with clay matrix is characterized by the non-reservoir behavior, due to the significant presence of fine grains and the possible occurrence of magnesian clay composing the matrix of its framework. Finally, zones E and G correspond to spherulite intervals cemented by dolomite, quartz and micritic matrix.

Medium to high porosity carbonates and fine-grained dominated carbonates exhibit the same ranges of IP values. Therefore, low IP values derived from acoustic inversion may lead to misinterpretations about high porosity in the Lower Sag region in this well. This separation through IP represents a challenge for the characterization of pre-salt reservoirs. Therefore, using the crossplots (Vp/Vs x IP and IP x PHIE) together is essential to visualize the influence of magnesian clays and understand heterogeneities in the Barra Velha Fm.

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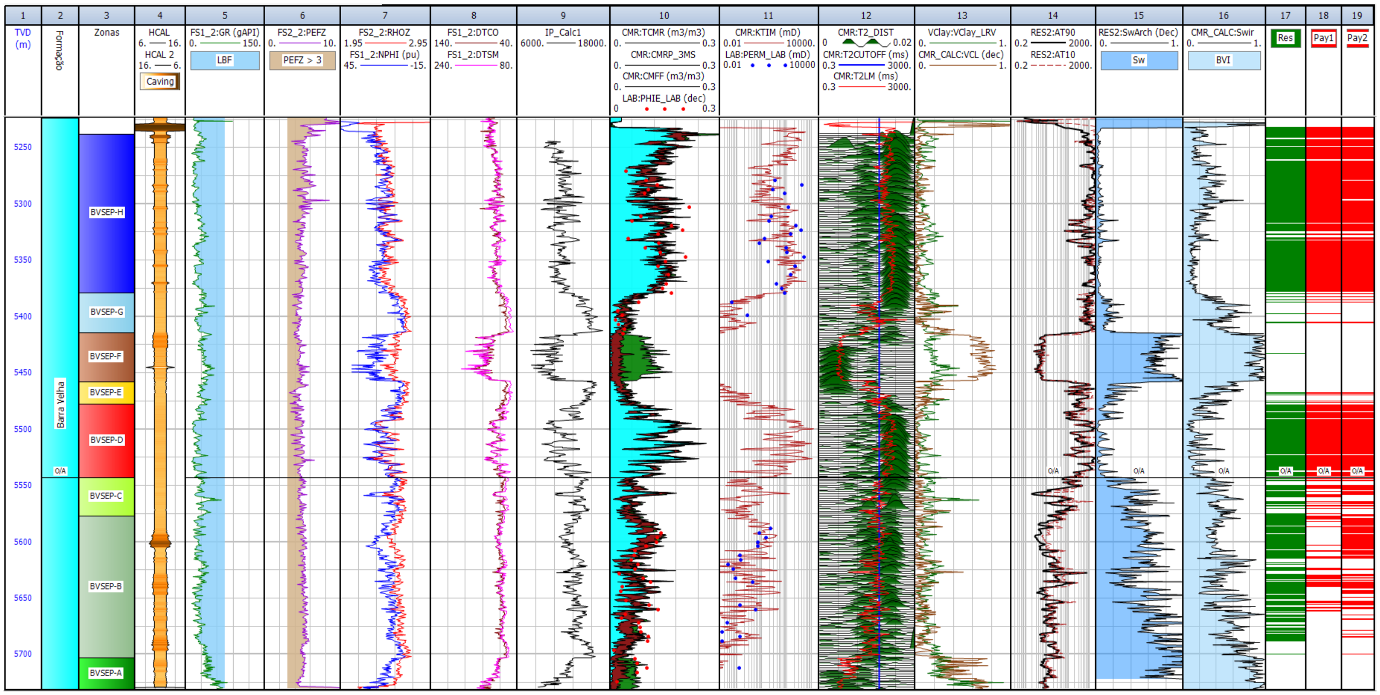

Figure 4 - Well log analysis for Sepia 9-SEP-1-RJS well.

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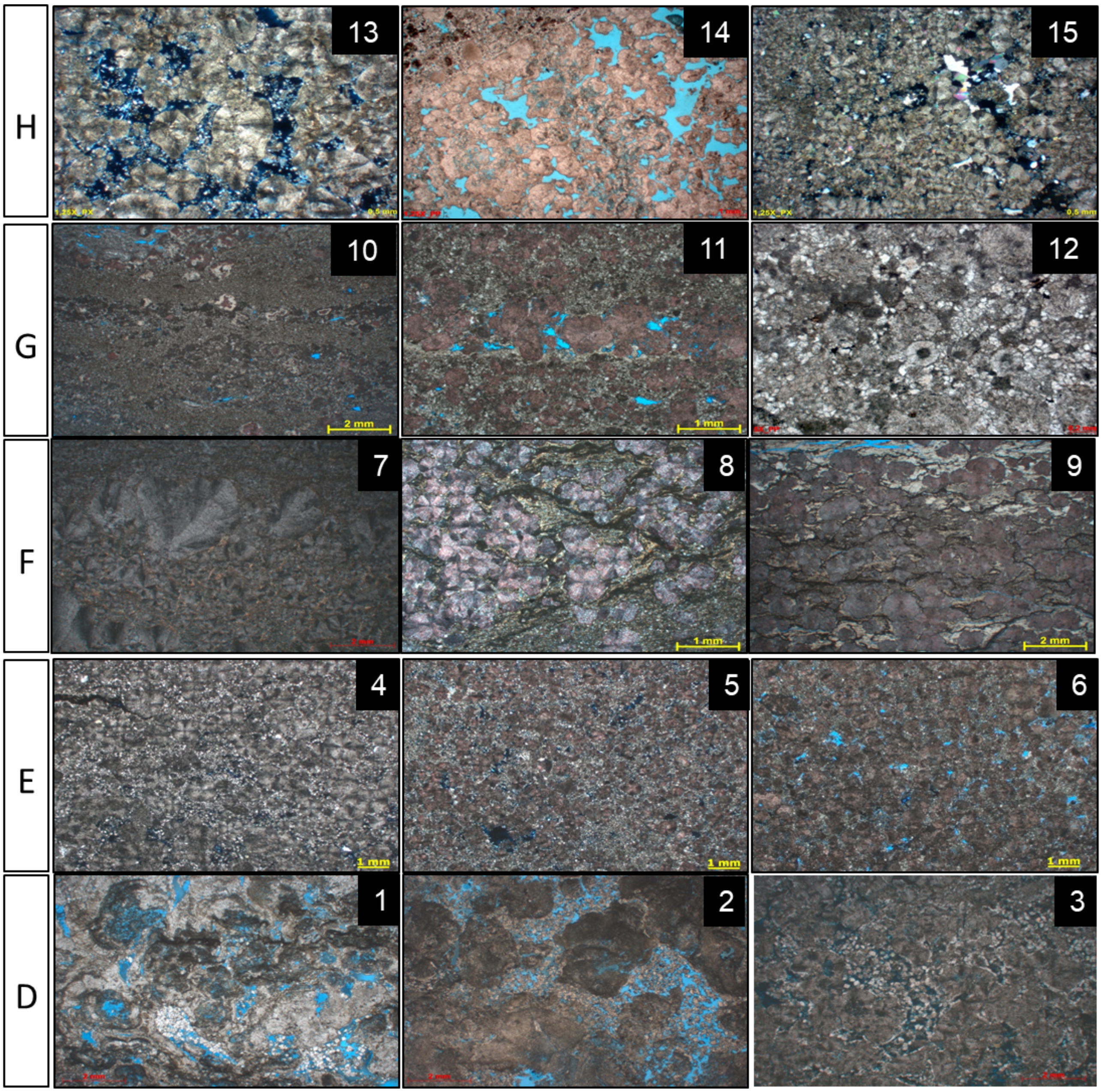

Figure 5 - Thin section from Sepia 9-SEP-1-RJS well.