



Petrophysical, petrographic and mineralogical characterization of pre-salt analogue – Purbeck Group, UK

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Abstract

In this work, we characterized mineralogical, petrographic and petrophysically the Mupe Member from the Purbeck Group lower portion, located in southern England and northern France. These rocks mainly consist of limestones and can be considered as a partial analogue rock of the Brazilian pre-salt carbonate reservoirs.

The laboratory tests campaign to characterize these lithologies comprised of X-ray diffraction (XRD) tests and thin sections description, gas effective porosity and absolute permeability, nuclear magnetic resonance (NMR).

The results of XRD and thin sections indicated a mineralogy rich in low-magnesium calcite and the presence of different types of pores. The NMR T₂ distribution indicated that the plugs are very heterogeneous, having pore size distributions varying from bimodal to polymodal.

Introduction

The production of oil and gas from the Brazilian pre-salt is significant, accounting for over 70% of the national production (ANP, 2021). The pre-salt reservoir rocks are composed mainly of carbonates and present variable properties due to spatial heterogeneities.

In carbonate rocks, the generation of pore space networks and permeability evolution are strongly associated with complex physical chemical processes such as dissolution and precipitation reactions. They can induce the generation of secondary porosity due to the higher solubility of calcareous minerals, forming a complex pore structure in these rocks (Bagrintseva, 2015; Tiab e Donaldson, 2015).

It is of extreme importance to quantitatively determine the reservoir's petrophysical characteristics through laboratorial core analysis (McPhee et al., 2015). However, due to the high cost for obtaining rock cores samples from

offset wells, especially in deepwater wells, the usage of analogue reservoir rocks is common practice in the oil and gas industry.

The Mupe Member, composed of Upper Jurassic lacustrine microbialites, and associated facies formed in a semi-arid climate setting in an extensional basin, can be considered as a partial analogue for some aspects of the Brazilian pre-salt carbonate reservoirs. The deposits are approximately the same age, have a similar tectonic setting and basin evolution processes (both are pre-salt) and both have porous microbial mound facies" (Gallois & Bosence, 2017).

In this work, we characterized the mineralogy and petrography of the Mupe Member carbonates through X-ray diffraction (XRD) and thin sections, respectively. Routine core analysis (RCAL), including effective gas porosity and absolute permeability, and nuclear magnetic resonance (NMR) were used for the petrophysical analysis.

Method

From the blocks available for this study, two samples were selected to be analyzed by:

- **X-ray diffraction (XRD)** at the Mineral Technology Center (CETEM) at the Ministry of Science, Technology and Innovation using the D4 Endeavor equipment manufactured by Bruker-AXS. The Rietveld Method (Rietveld, 2014) was used to characterize the crystalline phases present;
- and two **petrographic thin sections** were made from two representative facies and described at the Geological Sample Processing Laboratory (LGPA) at the State University of Rio de Janeiro (UERJ).

Six plugs, with 1.5 inches in diameter (about 3.8 cm) and between 2 and 2.6 inches (about 5 to 6.7 cm) in length, were cored from three blocks (1, 3 and 6) with different facies identified visually.

Plugs were cleaned using the standard Hot Soxhlet extraction method with toluene and methanol circulation - for removal of residual oil and salts contained in the pore spaces – these were then dried in an oven.

The plugs were then analyzed using the following methods and equipment:

- **Helium effective porosity and nitrogen absolute permeability** using the gas porosimeter and permeameter model DV-4000, manufactured by Stratum Reservoir (Previous Weatherford Labs), available at the Enhanced Oil Recovery Laboratory (LRAP) at UFRJ;
- **Nuclear magnetic resonance (NMR), for liquid-filled porosity and transverse relaxation time (T₂) measurements.** The laboratory tests were conducted using the Maran 12MHz equipment manufactured by Oxford Instruments, available at the Geophysics and Petrophysics Laboratory (LAGEP) at UFRJ.
- **Pressure saturation.** For the NMR analysis, the samples were saturated at 1,000 psi of pressure with distilled water using the sample saturator from the manufacturer Vince instruments, available at the National Observatory's Petrophysics Laboratory (LabPetrON) and then weighed to verify the effectiveness of the saturation procedure. The saturation index was calculated from the following equations:

$$V_{\text{fluid}} = M_{\text{saturated}} - M_{\text{dry}} \times \rho_{\text{fluid}},$$

$$\text{Saturation index} = V_{\text{fluid}} / V_{\text{pores}}$$

where V_{fluid} is the volume of fluid saturating the porous space of the rock, $M_{\text{saturated}}$ is the mass of the saturated sample, M_{dry} is the dry mass of the sample, ρ_{fluid} is the saturating fluid density and V_p is the helium-measured pore volume.

Results

XRD results are presented in **Table 1**. They indicate that the samples are composed almost entirely of low-magnesium calcite, with smaller quantities of quartz and barite.

Table 1. XRD results.

Phase Name	Sample 1	Sample 2
	Wt% Rietveld	Wt% Rietveld
Quartz	3.5	0.6
Magnesian Calcite	96.5	98.4
Barite	0	1
Total	100	100
Mg in calcite	0.001	0

In thin section 1 (facies similar to plugs 1X and 3Y), it was observed that the sample is rich in micritic matrix material with what Gallois (2016) interpreted as sparse chalcedony spherules, resulting from recrystallisation of the micritic matrix (**Figure 1**). In porous zones, sparry calcite has crystallized, probably due to the passage of calcitic fluid during burial (**Figure 5**). The carbonate rock can be classified as a mudstone to wackestone, according to the Dunham (1962) classification methodology. The main porosity types observed are vugular, intergranular, moldic and microporosity.

Thin section 2 (facies similar to plugs 3Z, 6X, 6Y and 6Z) presents a branched columnar stromatolitic structure made of pelloids, chalcedony spherules and micrite matrix vertically stacked with poorly marked laminations (**Figure 6**), occurring laterally with zones rich in peloids and sparry calcite cement. The sample also presents sparry calcite crystallized in the pore walls. The rock can be classified as a thrombolite to stromatolite, according to the Aitken (1967) classification methodology. The main porosity types observed are vugular, intergranular, growth-framework and microporosity.

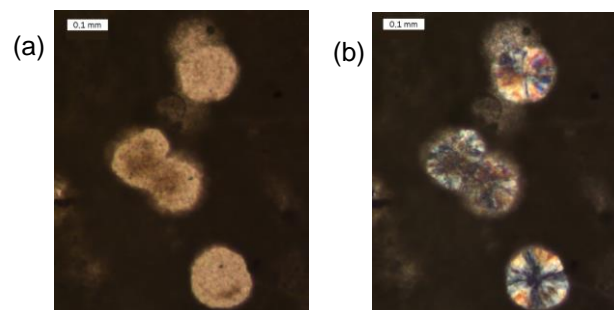


Figure 1. (a) Brownish nodular crystals under natural light and (b) radial extinction cross under polarized light in thin section 1, with a 10x magnification.

The results of tests on gas porosity and permeability, samples saturation index and porosity obtained by NMR are presented in **Table 2**, the comparison between the porosity results are shown in **Figure 2** and the comparison between gas porosity and permeability are shown in **Figure 3**. The correlation between the different results was very satisfactory, demonstrated by the high coefficient of determination $R^2 = 0.96$.

Table 2. Gas porosity and permeability, saturation index and porosity obtained by NMR.

Sample	Gas porosity (%)	Gas permeability (mD)	Saturation index (%)	NMR porosity (%)
1X	12.10	1820.53	84.09	11.48
3Y	12.50	1868.37	74.24	11.04
3Z	6.60	4.28	82.72	6.17
6X	6.40	0.26	94.85	7.11
6Y	8.14	0.83	91.22	8.34
6Z	7.62	2.13	93.9	7.54

Based on gas porosity and permeability results, the analyzed plugs can be separated into two groups (**Figure 3**): with higher porosity and extremely high permeability values (samples 1X and 3Y) and with lower porosity and low permeability values (samples 3Z, 6X, 6Y and 6Z).

The saturation values were satisfactory for plugs 6X, 6Y and 6Z and low for samples 1X, 3Y and 3Z. The low values of saturation are likely due to the large number of vugular pores, which can decrease the effectiveness of the saturation process because they fail to retain the saturation fluid (De Luna et al., 2016).

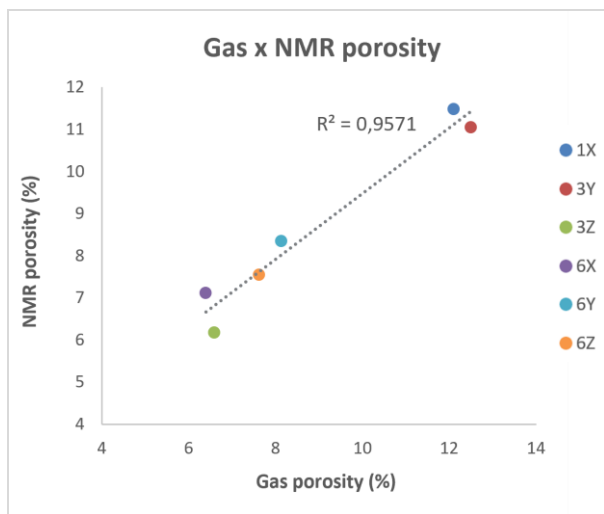


Figure 2. Correlation between helium porosity and NMR porosity.

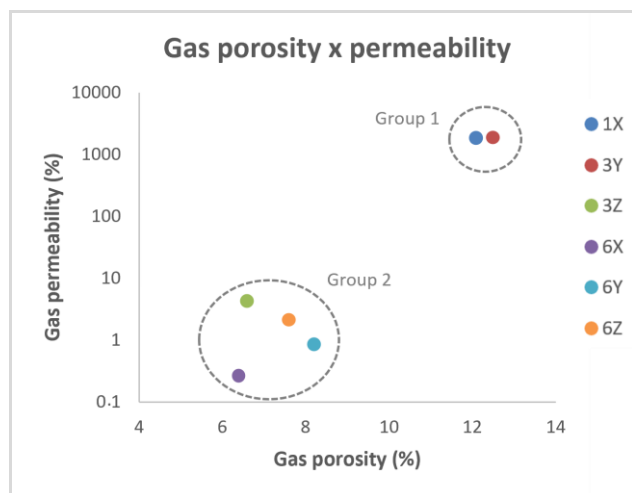


Figure 3. Correlation between gas porosity and gas permeability.

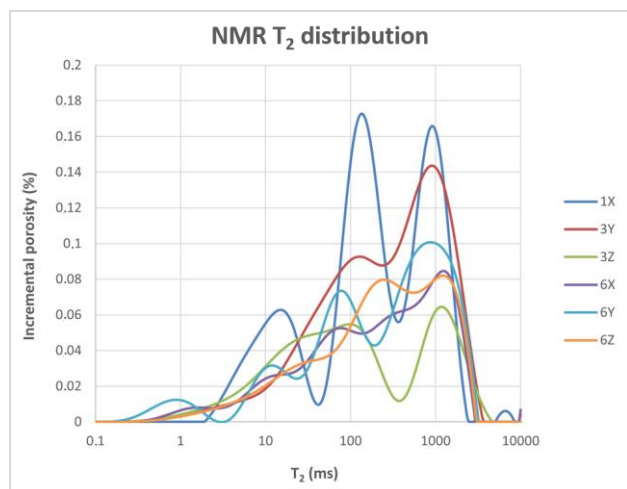


Figure 4. NMR T_2 distribution.

Conclusions

The results of XRD analysis and the description of the petrographic thin sections indicated that the mineralogy is rich in low-Mg calcite and also indicates the presence of different types of pores. Different facies were recognized having similar mineralogy but with different porosity and vastly different permeability characteristics.

Gas porosity and permeability results indicated two groups: with higher porosity and extremely high permeability values (samples 1X and 3Y) and with lower porosity and low permeability values (samples 3Z, 6X, 6Y and 6Z).

Despite the low saturation values for the samples with vugular pores (samples 1X, 3Y and 3Z), the porosity results obtained by routine core analysis and by NMR for all samples indicated a good correlation.

The T_2 distribution results indicate that the plugs are very heterogeneous, having pore size distributions varying from bimodal to polymodal.

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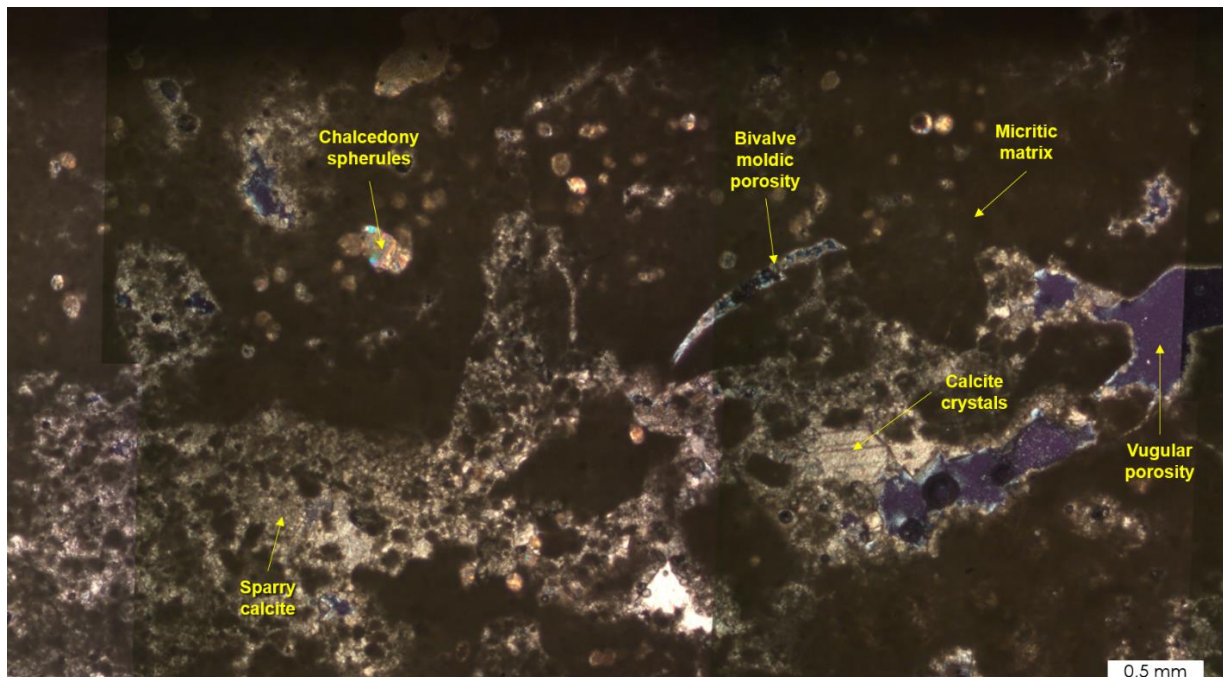
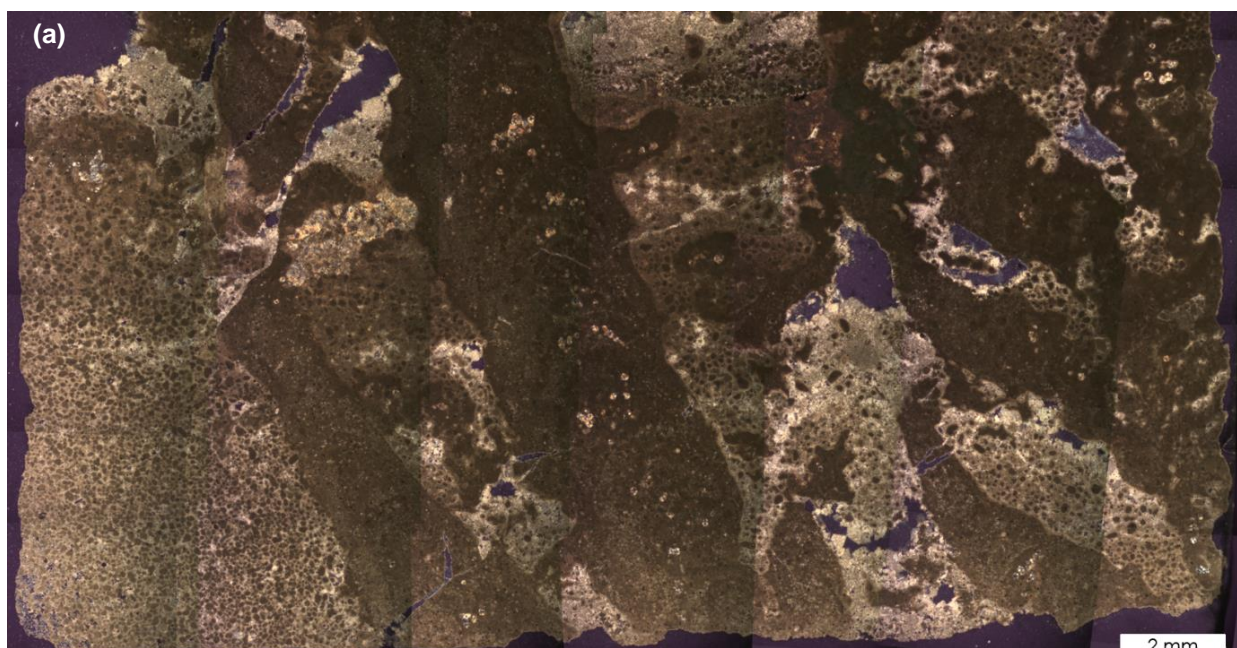


Figure 5. Thin section 1, highlighting the parts rich in micritic matrix with sparse chalcidony spherules and the porous regions with sparry calcite with well-formed calcite crystals on the walls of the vugular pores, in addition to the presence of moldic pores generated by the dissolution of fossil shell (likely bivalve).



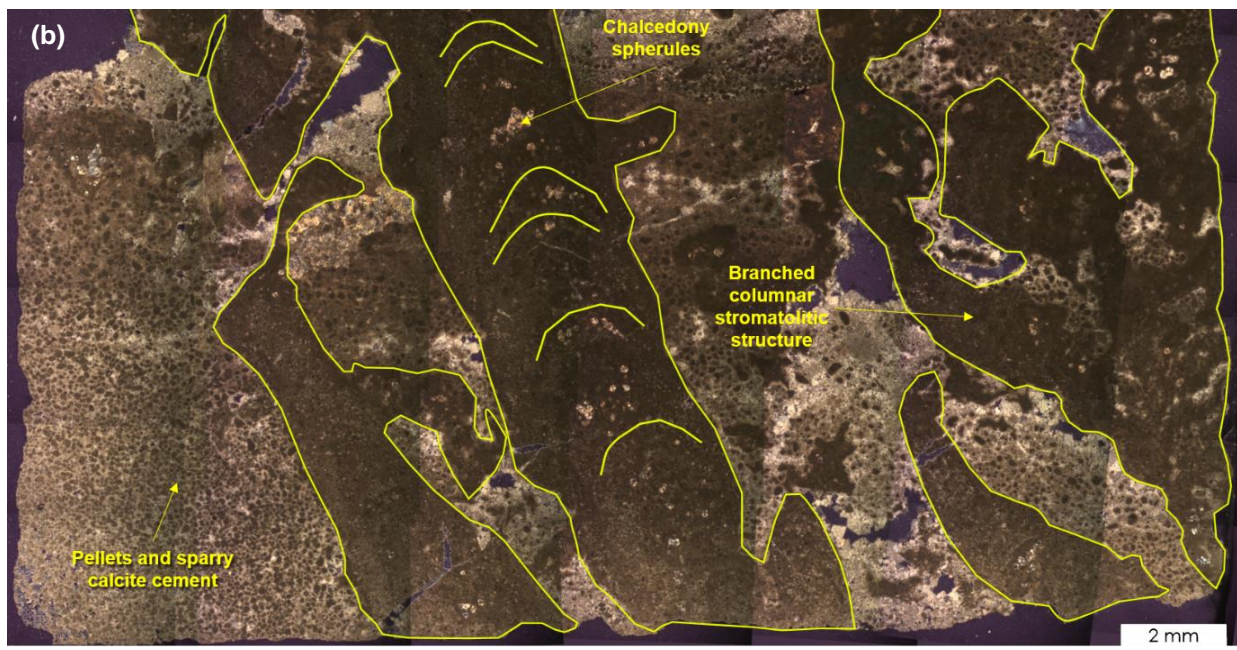


Figure 6. (a) Thin section 2 and (b) the same image highlighting the branched columnar stromatolitic structure with poorly marked laminations.