Submission code: 9JVZK6NGJR

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Petrophysics and Mineralogy of Black Shales from the Araripe Basin – CE

Anne Beatrice Guedes Sobrinho (UFCG), José Agnelo Soares (UFCG), Juliana Targino Batista (UFCG), Mariana Laiane Soares Dutra (UFCG), Gabriel Ferreira Viana de Lima (UFCG), Jaquelynne Cássia De Amorim (UFCG)

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Abstract Summary

A new scenario for the expansion of the global energy matrix has been emerging with exploration and production of unconventional resources in rocks whose petrophysical characteristics do not allow extraction by traditional methods. Black shales are part of this type of reservoir and exhibit high hydrocarbon generation potential, although their characterization is complex. In this context, the objective of this study is to evaluate oil shale samples from Araripe Basin through basic and advanced petrophysical tests and material characterization techniques. The results indicate these rocks, rich in organic matter, are predominantly composed of calcite and quartz - a composition that favors hydraulic fracturing, an essential technique to enable the production of unconventional hydrocarbons. Although the samples show low permeability, their porosity is considerable. The analysis of petrophysical properties indicates a significant effect of organic matter and microporosity on elastic wave velocities.

Introduction

Unconventional reservoirs are characterized by their occurrence in low-permeability lithologies, such as shale. In these cases, the source rock itself also plays the roles of reservoir and seal (Ross & Bustin, 2007). Brazil has considerable potential for the research and exploration of unconventional reservoirs. Among regions exhibiting this type of occurrence is the Araripe Basin, which features multiple outcropping shale units (Assine, 2007).

Among the petrophysical properties, porosity stands out in reservoir engineering due to its direct relationship with the rock's fluid storage capacity. However, in shale-type lithologies, accurately determining porosity is particularly challenging due to the microscopic and complex nature of the pore network (Rosa, 2006). Determining permeability also presents specific challenges. For mineralogical characterization purposes, analytical techniques such as X-ray diffraction (XRD) and X-ray fluorescence spectrometry (XRF) are widely used. Therefore, the present study aims to characterize the black shales of the Araripe Basin, with an emphasis on their petrophysical and mineralogical properties, through laboratory analyses.

Method and/or Theory

The study area is located on the border between the municipalities of Nova Olinda and Santana do Cariri, in the state of Ceará, where rock samples were collected during field campaigns conducted at the Pedra Branca Mine. In this location, representative outcrops of the Araripe Basin are found (Figure 1).

Basic petrophysical tests were conducted using the Ultra-Poro/Perm 500 permeameter-porosimeter. The samples were initially subjected to surface cutting and polishing, followed by oven drying at 90°C for 24 hours. XRF analyses were performed using energy-dispersive spectrometry. XRD tests were carried out using a diffractometer with Cu-Kα radiation, operating at 40 kV and 30 mA, with an angular scan range from 5° to 60° (2θ) and a scanning rate of 2°/min. Quantitative analysis of the mineral phases was performed using the Rietveld refinement method, which enabled accurate determination of the proportions of the identified phases. Finally, ultrasonic velocity tests were carried out using the Autolab 500 system, which allows for the simultaneous acquisition of three waveforms: the compressional wave (P-wave) and two mutually orthogonal shear waves (S_1 and S_2).

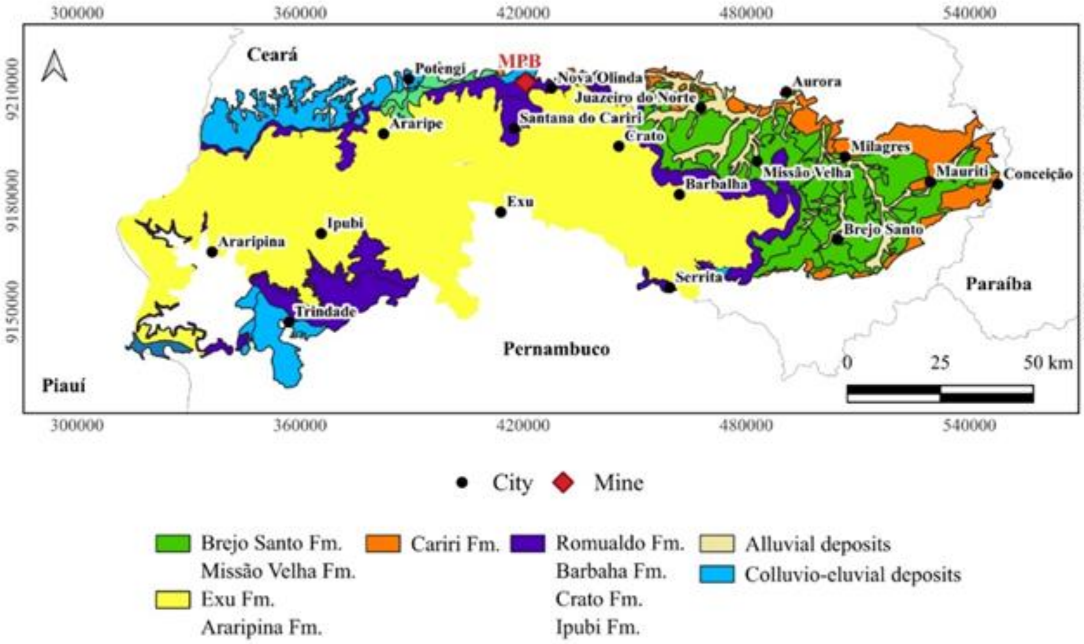

Figure 1: Location map of the study area (modified from Assine, 2007).

Results

Porosity values range from 2.3% to 31.3%. According to Chapman (1976), reservoir rocks have sufficient porosity to store hydrocarbons. Common porosity values in such rocks range from 5% to 35%, with highest concentrations between 15% and 30%. The porosity values measured in this study primarily represent macropores. Shales are expected to contain a significant proportion of micropores, which are not captured by the measured laboratory porosity.

Petrophysical test results indicated low permeability values. According to Amyx *et al*. (1960), permeabilities below 1 mD are considered low. Since all the results fall within this same order of magnitude, it can be concluded that permeability are low for all samples - which is consistent with the type of rock analyzed. For comparison, conventional compacted sandstone reservoirs typically have permeabilities ranging from 0.5 mD to 20 mD (King, 2012).

XRD analyses show that predominant phases in the samples are calcite and quartz. More precisely, Rietveld refinement revealed average contents of 32.6% and 4.5% for these phases, respectively. X-ray fluorescence tests revealed average proportions of 60% CaO and 17% SiO_2. In smaller concentrations, other mineral phases were identified, including illite, montmorillonite, nontronite, dolomite, anhydrite, muscovite, gypsum, and kaolinite.

Organic matter content of the analyzed samples ranged from 25.4% to 30.4%. Total organic carbon (TOC) values for shales of the Ipubi Formation indicated exceptionally high TOC, far exceeding the minimum threshold of 1% required for a potential hydrocarbon source. With an average of approximately 22.5%, the shales of the Ipubi Formation in the Araripe Basin demonstrate exceptional potential for hydrocarbon generation (Castro, 2015).

Mineralogical composition of shales plays a key role in the feasibility of oil and gas production, as it directly influences the mechanical behavior of the rock during hydraulic fracturing - a crucial operation in the exploitation of unconventional deposits. Shales with higher quartz and calcite content tend to respond better to fracturing due to the brittleness of these minerals, which promotes fracture generation (Gale *et al*., 2007). Considering the composition of the analyzed samples, it can be inferred this rock as well prone to hydraulic fracturing.

Figure 2 illustrates the relationship between P-wave velocity (VP) and the porosity of the samples. Previous studies involving different lithologies indicate an inversely proportional relationship between ultrasonic velocities and porosity (Garia *et al*., 2019). However, for the oil shale samples analyzed in this study, a generally opposite trend is observed - showing a directly proportional relationship between wave velocities and porosity.

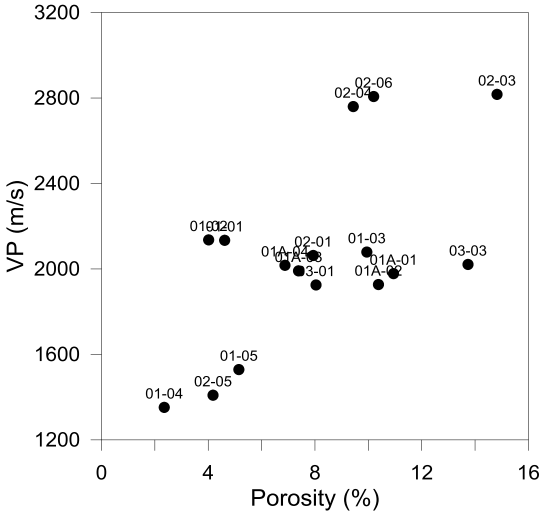

Figure 2: P-wave velocity versus porosity.

In shales, porosity is often controlled by nanometer-scale pores associated with clay minerals and organic matter. Microporosity significantly reduces the velocities of elastic waves in rocks (Eberli *et al*., 2003). Samples with lower porosity measured in the laboratory tend to be those in which organic matter or clay minerals fill the macropores, resulting in a higher proportion of microporosity. Figure 3 shows an inverse relationship between average grain density and volumetric fraction of organic matter for some oil shale samples, while figure 4 shows a direct relationship between grain density and macroporosity. This combined mechanism helps explain why the shales of the Ipubi Formation, characterized by high organic matter content, exhibit a directly proportional relationship between elastic wave velocities and macroporosity.

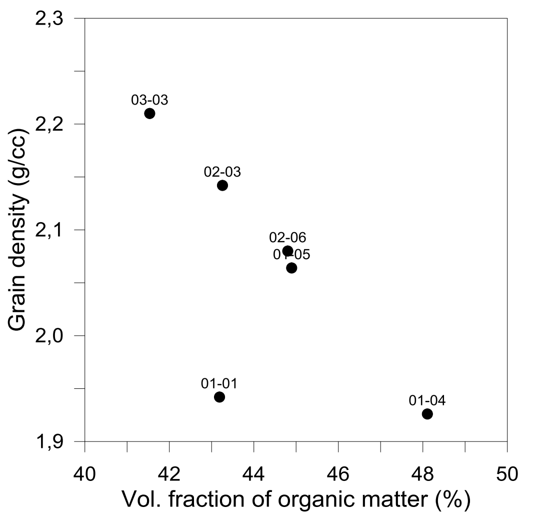

Figure 3: Grain density versus organic matter content for black shales of Araripe Basin.

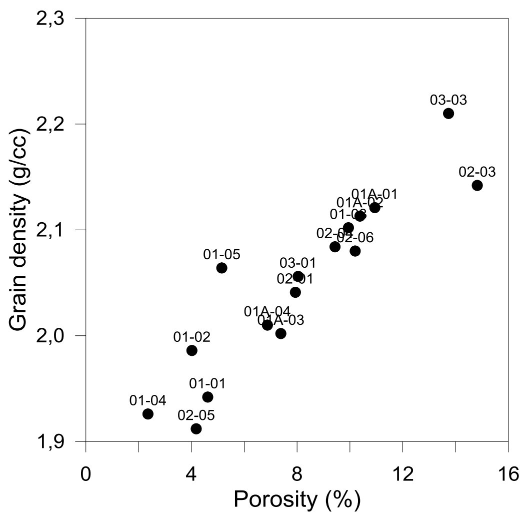

Figure 4: Grain density versus macroporosity for black shales of Araripe Basin.

Conclusions

The black shales of Araripe Basin studied here exhibit characteristics favorable to the formation of induced fractures - an essential technique for enhancing productivity in this type of reservoir. The characterization of these rocks indicated a predominance of minerals such as calcite and quartz, along with a significant presence of organic matter. Despite low permeability, the samples showed reasonable laboratory porosity values, while microporosity proved to be a key factor in the relatively low elastic wave velocities observed in these rocks.

Acknowledgments

We thank the Brazilian Funding Authority for Studies and Projects (FINEP) for the financial support provided through the research project "Nanoxisto," carried out by the Petrophysics Laboratory at UFCG.

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