**Microporosity and Cementation Coefficient (m) Analysis of Coquinas in the Morro do Chaves Formation: Implications for Reservoir Quality Assessment**

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This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.

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# Abstract

**This study investigates the microporosity content and its correlation with the cementation coefficient (m) in the Coquinas of the Morro do Chaves Formation. Resistivity tests were conducted on 29 samples, and geometric parameters were extracted from petrographic images to analyze the pore characteristics. The results reveal two distinct porosity groups: Group 1, with lower porosity and complex pore geometries, including intercrystalline and micropores, and Group 2, with higher porosity and simpler pore structures, including vugular pores formed through dissolution processes. The cementation coefficient (m) shows varying relationships with pore types, suggesting the importance of considering pore complexity and diagenetic features. The findings highlight the significance of understanding microporosity characteristics for assessing reservoir quality in carbonate formations.**

**Introduction**

Bioclastic carbonate rocks, commonly known as coquinas, are sedimentary formations that have garnered significant scientific and industrial interest due to their unique characteristics and distinct electrical properties. In this article, we specifically concentrate on the electrical properties of coquinas from the Morro do Chaves Formation, which is chronostratigraphically correlated with Pre-salt bioclastic deposits.

Coquinas primarily consist of fragments of shells, skeletons, and other calcareous biogenic materials, cemented by calcium carbonate or other minerals. This composition and texture endow coquinas with significant porosity and permeability, making them important hydrocarbon reservoirs in many sedimentary basins.

A crucial parameter in characterizing the electrical properties of coquinas is the cementation exponent (m), which is obtained using the Archie equation. This equation relates the electrical resistivity of a rock to its effective porosity and cementation exponent. The cementation exponent serves as an indicator of the quality of pore connection present in coquinas, directly influencing their electrical conductivity. To better understand the response of cementation exponent (m), obtained using the Archie equation and porosity data, we also gather geometric parameters such as DomSize and Perimeter over Area.

Comparing the cementation exponent with porosity data and geometric parameters such as DomSize (size of the porous domains) and Perimeter over Area (the ratio of the perimeter of the cross-sectional area of the pores) can provide additional insights into the connectivity and distribution of pores in coquinas, aiding in the understanding of their electrical properties. Both geometric parameters are commonly used for velocity interpretation, but their physical meaning is applied here to gather more information about pore space. PoA describes how complex the porous system is independent of total porosity. Small values, in general, indicate a simple pore system. DomSize is an indicator of a dominant pore-size range.

Understanding the electrical properties of coquinas from the Morro do Chaves Formation concerning porosity, cementation exponent, and geometric parameters of the pores is essential for the accurate characterization these carbonate rocks as hydrocarbon reservoirs. Moreover, these studies can contribute to the development of permeability models and flow prediction in similar bioclastic carbonate rocks found in other sedimentary basins.

In this article, we present a detailed analysis of these electrical properties of coquinas from the Morro do Chaves Formation, specifically focusing on comparing the cementation exponent, porosity data, and geometric parameters of the pores.

**Method and Theory**

For the electrical resistivity test, the LCR Wayne Kerr model 4320 meter was used, an instrument used to measure electrical inductance (L), capacitance (C), and resistance (R) of components and circuits at various frequencies (CAMPBELL, 2019).

To perform the electrical resistivity measurement, each sample undergoes a drying process to remove any moisture it may have absorbed during the plug production process. After the drying period, the sample was immersed in a brine solution and placed in a vacuum desiccator for complete saturation, and after the saturation process, it was ready for the resistivity test. The brine used has 50000ppm of NaCl and a 1.0403 g/cm density.

According to Archie (1942), the conductivity of brine-saturated rock is proportional to the specific resistivity conductivity of water-saturated rock (R0), which is proportional to the specific electrical resistivity of brine (Rw). As a result of the proportionality in the case of brine-saturated rock, Archie introduced the resistivity formation factor (FRF), as shown in Equation 1 below.

 $R\_{0}=FRF x R\_{W} $ (1)

The resistivity formation factor expresses the relative resistivity magnitude to the conductive brine due to the presence of a non-conductive matrix, i.e., the formation. Since the pores are the only conductors, a correlation of the resistivity formation factor with porosity can be found as shown below in Equation 2:

$FRF=\frac{R\_{0}}{R\_{W}}=\frac{1}{∅\_{e}^{m}} $ (2)

Where **e is the effective porosity, the empirical exponent m is called the porosity exponent. Although the electrical resistivity was measured at different frequencies, we chose the value that regards to the frequency where the phase is closer to zero, to estimate the Archie’s m exponent. This approach is described by Worthington et al. (1990) and aims to avoid induced polarization effects.

Total porosity (ϕ) was measured by a helium gas porosimeter (Ultrapore 300).

The geometric characteristics, including DomSize, Perimeter over area (PoA), and microporosity, were derived from petrographic images using a transmitted light petrographic microscope connected to an AxioCam HRc camera and AxioVision software. The images were captured using a 5X objective lens with plane-polarized light (PPL), and the pore area resolution was set at 63.48 µm2, following the methodology outlined by Weger et al. (2009) and Lima Neto et al. (2015). Microporosity was estimated based on the geometric properties, employing a cutoff value of 500 µm2, equivalent to a diameter of 25 µm, corresponding to the specified limit for micropores proposed by Anselmetti et al. (1999). Furthermore, the identified pore types were characterized, and geological descriptions were provided.

**Results and Discussion**

Resistivity tests were conducted on a total of 29 samples. The first step was to validate cementation coefficient data compared with literature data to determine whether the obtained values were consistent or deviated from reality, as shown in Figure 1. For this comparison, we used Corbett *et al.* (2017) data, who have worked with the same bioclastic deposits from Morro do Chaves Formation.



Figure 1: Cementation exponent (m) and porosity plot for Morro do Chaves Coquinas: Blue dots are from this present work, and orange ones are from Corbett et al. (2017).

The dataset from Corbett et al. (2017) is subdivided into three coquina facies. Overall, it is safe to say that our data is similar to the literature. Although our samples show a lower cementation coefficient (m) than the data obtained by Corbett et al. (2017), the variation between them is not discrepant, and there is even some overlap in the data points, diluting possible uncertainties about the measured (m) values. The data from Corbett et al. (2017) that the author characterizes overlap with our samples (m values between 1.5 and 2.1) as bioclastic calcirudites (rudstones), with dense compaction, fractures and dissolution as the dominant pore type and the occurrence of siliciclastic material between 20 to 30%, with characteristics very similar to our dataset, both in terms of packing, texture and chemical content, corroborating the dataset and indicating a possible association of facies with the values found for "m."

With the cementation coefficient (m) data showing real values, we sought to understand the numerical relationships with geology. Usually, the cementation coefficient, as it is called, provides a good indication of cementation in sandstones (Montaron, 2008); however, this correlation is difficult in carbonates. Corbett et al. (2017) suggest adopting the term porosity exponent instead of the cementation coefficient when working with carbonates. Soto et al. (2012) suggest a reservoir classification methodology associated with the pore type based on the variation of the "m" coefficient, which was done for our dataset, as seen in Figure 2 below.



Figure 2: Cementation exponent (m) and porosity plot with pore type and Soto et al. (2012) ranges.

A large part of the dataset, when plotted, falls into the fields proposed by Soto et al. (2012) as "fracture/matrix" and "matrix." Most of the data is in the "fracture/matrix" range, which is consistent with what was observed by Corbett et al. (2017) for similar "m" values, where the author himself considers the dominant pore type to be fracture-like. From the pore classification, it is observed that none of the samples were classified as having fracture-type porosity, but there was an intense presence of diagenetic features in the dataset, with dissolution and chemical compaction features.

Figure 3 presents the main diagnostic graphic for property (m). In this chart, the dominant pore size (DomSize) was added to assess any correlation between the geometric parameter intrinsically linked to pore types in the sample set.

Figure 3: Cementation exponent (m) and porosity plot with pore type with DomSize at the color bar.

It is possible to notice that the cementation coefficient value for most samples falls between 1.3 and 2.3, clustering the samples. However, samples with close "m" values have very different porosities. Furthermore, the types of pores do not show any clear pattern, with interparticle porosity associated with the highest and lowest "m" values. However, when interpreting the charts shown in Figures 3 and 4 (below), the geological, electrical, and petrophysical characteristics are better understood.



B

Figure 4: Cementation exponent (m) and porosity plot with pore type with Perimeter over Area at the color bar.

Despite the data set clustering in a cementation coefficient range, it is noted that the samples are divided into two groups. One group with porosity below 10% (group 1) and another group with porosity above 10% (group 2).

Group 1 generally presents low DomSize and higher PoA values, indicating small pores with complex geometry. Only two samples, one microporous and one moldic, do not exhibit this behavior, with DomSize values greater than 200 microns. However, despite having a higher parameter value, these pores may be reflecting large and isolated pores that makeup virtually all the sample's porosity. The microporous sample also showed fracture-type porosities, which may explain the M coefficient value and higher DomSize value. In addition to low DomSize values, group 1 concentrates samples with intercrystalline and micropores. The concentration of both pore types in this group could be an indication that porosity in these samples was initially low or underwent diagenetic alteration that caused the reduction of intercrystalline porosity), generally having a cementation coefficient like group 2 but with a smaller porous volume and generally smaller pores.

In contrast, group 2 presents higher DomSize values, a simpler pore geometry (PoA <200mm-1) and more occurrences of vugular pores, a type of secondary porosity generated by dissolution. Group 2 clusters interparticle, moldic and vugular pores. Diagenesis in this group acted to increase porosity without altering electrical properties. Figure 5 presents the cementation exponent with the microporosity range for each sample. 

A

Figure 5: Cementation exponent (m) and porosity plot with pore type with microporosity at the color bar (5A) and with permeability (5B).

Figure 5A illustrates the relationship between the cementation exponent and the microporosity range for each sample, further highlighting the differences between the two groups. The prevalence of increased microporosity is observed in group 1, characterized by smaller pores and more complex pore geometries, whereas group 2 exhibits lower microporosity content associated with simpler pore structures and the presence of vugular pores resulting from dissolution processes. Figure 5B presents permeability relationships, with higher values occurring at low complex pore space but without any proper correlation with "m".

From Figures 3, 4, and 5 possible to infer that "m" values do not match with a proper pore occurrence. It is noteworthy that different pore geometries, microporosity values, and permeabilities can be linked to the same cementation exponent. However, medium pores with low pore complexity shapes are linked to better reservoir conditions, with high porosity and high permeability.

**Conclusions**

In conclusion, the resistivity tests conducted on the samples from the Morro do Chaves Coquinas provide insights into the microporosity content and its relation to the cementation coefficient (m). The dataset can be divided into two distinct groups based on porosity: group 1 with porosity below 10% and group 2 with porosity above 10%. Group 1 exhibits smaller pores with complex geometries, including intercrystalline and micropores, suggesting low initial porosity or diagenetic alterations. In contrast, group 2 displays higher porosity with simpler pore structures, including vugular pores resulting from dissolution processes. Diagenesis in group 2 has increased porosity without significant changes in electrical properties.

The analysis of the cementation coefficient (m) reveals that different pore geometries, microporosity values, and permeabilities can be associated with the same m value. However, medium-sized pores with low complexity shapes are linked to better reservoir conditions, characterized by higher porosity and permeability. The findings emphasize the importance of considering pore types, geometries, and diagenetic features when assessing reservoir quality and conducting petrophysical analyses in carbonate rocks. Understanding these relationships contributes to a better understanding of microporosity characteristics and aids in the evaluation of reservoir potential in carbonate formations like the Coquinas of the Morro do Chaves Formation.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001 and Petrobras (Process 2017/00067-9). In addition, MC and RM thank INCT/Geofisica for financial support and CNPq for their Research Grants of Productivity in Technological Development and Innovation – DT II.

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