Impact of the Silica Content on the Porosity and Permeability in carbonates of the Barra Velha Formation, Santos Basin, and the response in the Acoustic Impedance.

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Abstract

Several researches have been performed in the last decade to understand the peculiarities for the development of carbonate reservoirs in the presalt of Brazil. This study aims to analyze the correlation between silica content, porosity, and permeability in the Barra Velha Formation, Santos Basin, using log data from two different wells. We observed that the higher the silica content, the lower the effective porosity and permeability. The acoustic impedance (IA) versus silica content crossplots showed a good correlation with the reservoir properties such as porosity and permeability, providing information to characterize the facies in reservoirs and non-reservoirs.

Introduction

More than a decade has passed since the discovery of reservoirs in the Brazilian Presalt province (Figure 1). The enormous hydrocarbon production potential has attracted worldwide attention and today this province has an average production of approximately 2500 Mboed/d (ANP, 2020). Many challenges have been overcome and many studies have been carried out to better understand the heterogeneity of the presalt carbonate reservoirs, such as the diagenetic processes that influence the permoporous conditions, impacting the development of these fields.

The Barra Velha Formation was established in the Post-Rift phase, substage Alagoas, in the Aptian. This formation was deposited in a lacustrine environment, that became shallower upward and finally been topped by an extraordinary thick dense evaporite section, named Ariri formation, during and after the breakout of the Gondwana Supercontinent.

Wrigth & Barnett (2015) proposed a facies deposition model based on 3 main facies: carbonate laminites, associated with periods of lake flooding with low salinity and alkalinity; spherulites, associated with pH increase, radial structures, and reworked depositional facies; and finally, shrubs associated with the reduction of Mg-clays precipitation and low lake level.

Studies have been carried out to establish correlations between the behavior of silica and the permoporosity of the presalt carbonate reservoirs. Pinto et al. (2017) stated that elements derived from hydrothermal fluids enriched in Si, Mg, and Ca, associated to igneous intrusions such as exerted a high influence in this restricted lake environment. Lima and De Ross (2019) showed that processes such as dolomitization and silicification are common in the Macabu Formation, Campos Basin (analog for the Barra Velha Formation). Wright & Barnett (2019) warned that a high intake of hydrothermal fluids rich in CO_2 would have led to the release of cations, influencing the alkalinity. Sartorato et al. (2020) characterized four silicification processes that can occur in the early or late diagenetic phase. Therefore, the megaquartz impacts more on the quality of the reservoir, interpreted as late diagenetic phase, probably linked to hydrothermalism and it is well identified in the ECS logs (Elemental Capture Spectroscopy).

The aim of this study is to identify the correlation behavior between silica, acoustic impedance and the reservoir properties, such as porosity and permeability, in the Barra Velha Formation in a presalt field of the Santos Basin.

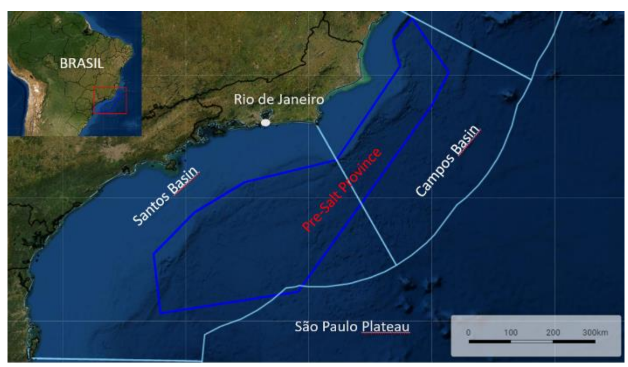

Figure 01: Presalt province in the Santos Basin. Illustration North-oriented and modified from geo.anp.bov.br/mapview.

Method

In this study, we used two wells from a presalt field, named Well A and Well B. Both wells are lithologically characterized as carbonate intervals in the Barra Velha Formation with Well B showing a 40 m interval of igneous rock (diabase) at the top of the formation. In our analysis, we considered the following well-logs: gamma-ray (GR_EDTC), Caliper (HCAL), acoustic impedance (AI), Elemental Capture Spectroscopy (ECS) for Calcium and

Silica dry weight logs, NMR effective porosity (CMRP_3MS), and permeability (KTIM). Porosity and permeability logs were correlated to laboratory analysis of side-wall samples and conventional cores.

The porosity log used were acquired using the NMR tool. As an essentially independent matrix, this tool is sensitive only to fluids in pores (Coates et al., 1999), resulting in a higher accuracy when correlated with laboratory rock measurements. The permeability of NMR records is obtained using a combination of theoretical and empirical relationships (Coates et., 1999).

After well data loading (logs and rock laboratory measurements) the quality control was made to assure the correct data depth adjustment considering drilling reports.

The acquisition of the log data occurs from different executions, so it was necessary to make some depth adjustments since the change of depth was a mandatory step in the development of this study. Other corrections such as removing spikes, merging data, interpolating short gap intervals, and checking the sample rate were also applied. The last part of the QC analysis was the verification of the Caliper to identify the compromised interval due to the washout.

The Al_2O_3 and SiO_2 logs were analyzed using crossplots. The crossplot allows us to establish direct correlations between the data analyzed. The crossplots were colored according to porosity and permeability logs. These criteria enable us to characterize the data analyzed in the formation according to the similarity in permoporous properties. This type of analysis permits extracting petrophysical information and/or identify depositional trends.

Results and Discussion

Figure 02 illustrates the logs of the Well A in Barra Velha Formation. The Caliper log presents a good response, except at the top of the formation where it showed some washouts. The GR log shows a spiky behavior that might indicate stormy weather, probably pointing to a shallow lake paleoenvironment (Rider, 2002). Near the top of the formation (xx15/xx40 m) it is possible to identify the Marco Lula (Lula Fingers), a feature found in some presalt wells (Wrigth & Barnett, 2015; Buckley et al., 2015; Neves et al., 2019). In this area, the calcium and silica logs behavior is similar to the GR log. In this work, we do not intend to discuss the silica genesis but highlight its relations with porosity and permeability. The acoustic impedance (AI) shows an increased upward log response. There is a remarkable correlation between NMR effective porosity and side core samples, which increases NMR log reliability. It is possible to observe a decrease in the response of the porosity log from the base to the top, which has a good correlation with the increase in the impedance acoustics. The permeability exhibits a response with a similar trend to the porosity logs and has a good correlation with side core samples.

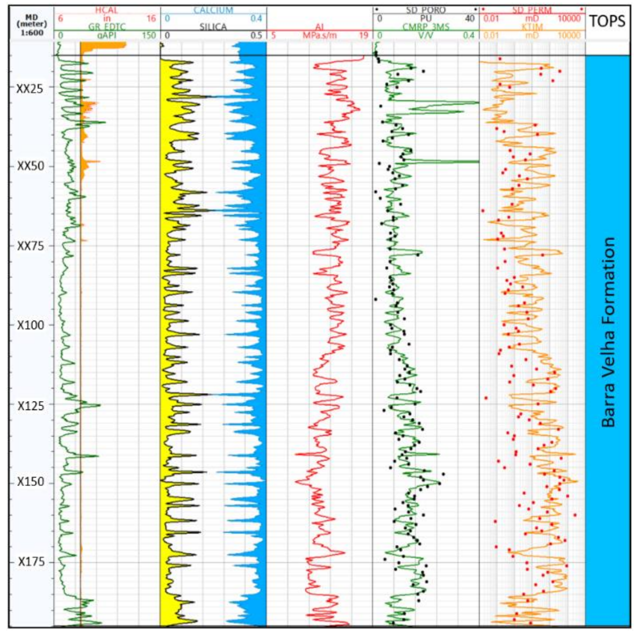

Figure 02: Well A logs. Tracks. 1- MD (meters); 2- Caliper (HCAL) (orange), Gamma Ray (GR_EDTC) (green); 3-Silica Dry Weight (SILICA) (yellow), Calcium Dry Weight (CALCIUM) (light blue); 4- Compressional Acoustic Impedance (AI) (red); 5- Effective porosity from NMR (CMRP_3MS) (green), Side-wall sample porosity (SD_PORO) (black dots); 6- Permeability (KTIM) (orange) and Side-core permeability (SD_PERM) (red dots); 7- Zones.

Figure 03 shows the logs of Well B, which is characterized by a low gamma-ray and an "on gauge" caliper. Silica and calcium logs do not repeat the spiky behavior over the entire interval as observed in Well A. In Well B an increase in silica content and a decrease in calcium from the base to the top is observed. The Al_2O_3 log shows an increase from the bottom to the top which corresponds to a reduction in the effective porosity. The lower part has the best permeability and porosity. At the top of the formation, it has a igneous intrusion (diabase) of 40 m thickness. It was possible to establish a correlation between the reduction of porosity and the increase of silica content and, according to the silica content, we divided the interval in three different ranges: 1- (X110/X125m); 2- (XX60/X110m); 3- (XX15/XX60m).

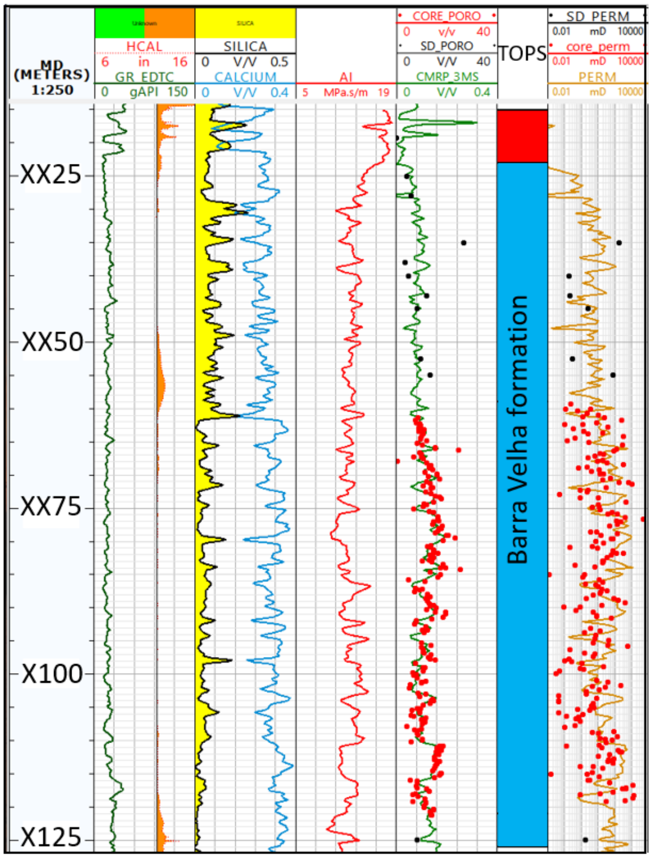

Figure 03: Well B logs. Tracks. 1- MD (meters); 2- Caliper (HCAL) (orange), Gamma ray (GR_EDTC) (green); 3- Silica Dry Weight (SILICA) (yellow), Calcium Dry Weight (CALCIUM) (light blue); 4- Compressional Acoustic Impedance (AI) (red); 5- Effective porosity from NMR (CMRP_3MS) (green), Side-wall sample porosity (SD_PORO) (black dots), Core porosity (Core_poro) (red dots); 6- Permeability (KTIM) (orange) and Side-core permeability (SD_PERM) (black dots), Core permeability (Core_perm) (red dots); 7- Zones.

Figures 04 and 05 show the crossplots of silica content versus acoustic impedance for Well A and Well B, respectively. We colored the data by porosity to facilitate the group characterization. Observing these crossplots it is possible to notice a correlation between the silica content and the acoustic impedance. Also, the best porosities correspond to the lowest values of acoustic impedance and silica content. Although Well A shows porosity data reaching values above 25%, this can be interpreted as anomalous information due to washout on the upper part of the formation, compromising NMR logs.

Figures 06 and 07 show the crossplots between silica content and acoustic impedance in Well A and Well B respectively. We colored the data from intervals of permeability to improve the analysis. Just like the porosity, it is possible to notice that the lower the values of silica content and acoustic impedance represents the highest permeability. It is important to mention that the diabase interval, identified in the red ellipsoid in Figures 5 and 7, presents high acoustic impedance and silica content, and low effective porosity and permeability.

Table 01 shows the average from logs used in crossplots analysis for Wells A and B. The average values of the silica content and acoustic impedance are higher, whereas the effective porosity and permeability are lower when comparing the Well B with the Well A. This can be due to silicification during the initial or late silica diagenesis process, which ended up it filling the porous space.

Table 1: Average values of silica content, acoustic impedance, porosity effective, and permeability logs of Wells A and B.

LOG	AVG (WELL A)	AVG (WELL B)
SILICA	0.07 V/V	0.09 V/V
ACOUSTIC IMPEDANCE (AI)	11 MPa.s/m	13 MPa.s/m
POROSITY	12%	9.6%
PERMEABILITY	104.26 mD	73.37 mD

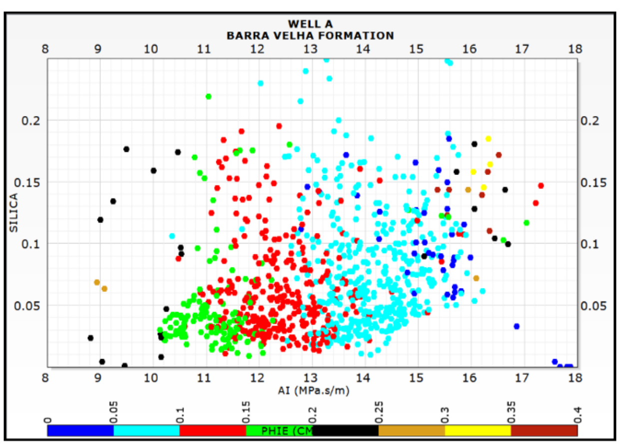

Figure 04: Crossplot of silica content versus acoustic impedance (AI) in Well A. Data colored according to effective porosity (PHIE).

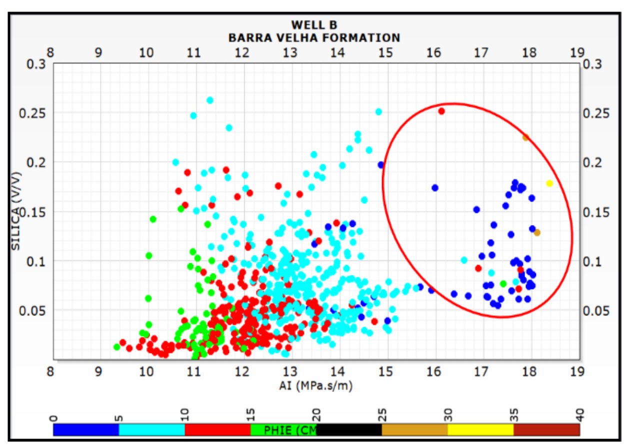

Figure 05: Crossplot of silica content versus acoustic impedance (AI) in Well B. Data colored according to effective porosity (PHIE). The red ellipsis indicates the igneous data.

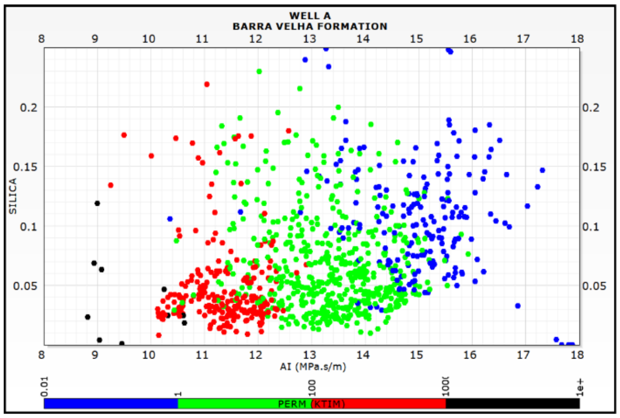

Figure 06: Crossplot of silica versus acoustic impedance (AI) in Well A. Data colored according to permeability (PERM).

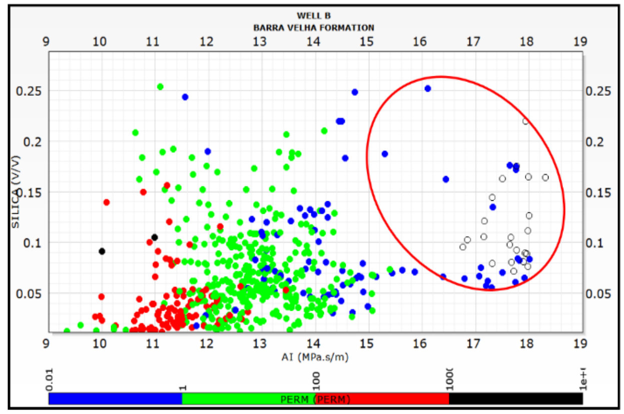

Figure 07: Crossplot of silica versus acoustic impedance (AI) in Well B. Data colored according to effective porosity (PERM). The red ellipsis indicates the igneous.

Conclusions

The silica content in the Barra Velha Formation plays a significant role in the presalt carbonate reservoir. In both wells analyzed, the silica content increases upwards while the calcium reduces proportionally. Silica content and acoustic impedance proved to be excellent parameters to characterize permeability and porosity. Well B shows more silica content than well A, probably due to hydrothermalism from diabase intrusion.

Acknowledgments

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