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# Porosity Variations by Diagenesis in Reservoirs of the Bajo Barreal Formation, San Jorge Basin: Methodology of Evaluation With Logs

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## Abstract

This work is the result of the authors' several experiences in sandy reservoirs of clay minerals matrix in the San Jorge Basin. It is intended to highlight the advantages of the use of integrated reservoir models originated from the group of ordinary lithologic characteristics among reservoirs, their integration to sedimentary subambients inferred from logs, and high technology log data (spectral gamma ray and magnetic resonance).

The majority of the reservoirs of the Bajo Barreal formation are volcanoclastic sandstones with porosities modified and/or reduced with burial and as diagenesis grades increase. That decrease mainly takes place due to three processes: mechanic compaction, dissolution of grains by intergranular contacts, and pore cementation.

The quantization of the compaction is influenced by the abundance and type of lithic material. The use of technologies that make it possible to have a detailed estimate of the lithology (Spectral Gamma Rays, Lateral Impact and Rotated Cores) is of pre-eminent importance when evaluating that type of reservoirs.

The diagenetic conditions and processes directly affect porosity determination from conventional logs. This justifies the use of porosity tools that are independent from the type of material of the reservoir rock. However, the combination of porosity data obtained in the NMR together with lithologic determinations and appropriate logs results into an interesting alternative to improve the evaluation of sandy reservoirs.

Generally, it is considered that volcanoclastic sandstones have a poor potential as oil reservoirs, because of their low porosity and permeability due to compactational processes and precipitation of authigenic mineral, such as cement. But thanks to the high reactivity of their materials with fluids from the reservoir, secondary important porosities are developed making the reservoir a high quality one. For this reason, these processes can be used to indicate the quality of volcanoclastic sandstones.

The implementation of methodologies, as the ones in this work, endeavors to apply evaluation criteria of sandy reservoirs.

## Introduction

It is generally considered that volcanoclastic sandstones have a poor potential as oil reservoirs because of their poor porosity and permeability due to the action of diagenetic processes related to the sandstones burial. However, it is shown that some of these types of reservoirs develop secondary porosities which turn them into high quality potential reservoirs. For this reason, processes such as compaction, grain and cement dissolution are frequently used to determine the quality reservoir in volcanoclastic sandstones.

The main goal of this characterization methodology is to generate integrated reservoir models. These models are related to the processes mentioned above and they represent a generalization of the reservoir properties. These reservoir models are mainly generated from the use and integration of technologies such as lithological evaluation and mineralogical tools, conventional logs and data from nuclear magnetic resonance tools.

The integration of lithological description with data logs in a diagenetic context should be an important tool for sandstone reservoir characterization. The systematic use of this methodology would allow us to optimize operations related to the increase of production in developing oilfields.

## Geologic Context

The San Jorge basin is located in the center of Patagonia Argentina and covers a great area of Chubut and north of Santa Cruz provinces. Seen from above, it has an irregular shape and a marked east-west elongation.

It is situated between two high prints as the Massifs of Deseado and Nordpatagónico which control their south flank in Santa Cruz and the north one in Chubut province (Figure 1).

Within the levels of the Chubut Group, the Matasiete formation and its lateral equivalent D-129 Well, which is the main generating rock in the basin, are included. The main reservoirs are grouped in the formations of El Carmen Mine, Castillo and Bajo Barreal.

The inferior member of the Bajo Barreal formation contains equivalents of subsurface which vary their names according to their position in the basin. These formations are called Comodoro Rivadavia and Cañadón Seco in the north and south flanks respectively.

During the Tertiary, extensive episodes combined with eustatic oscillations determined a history of transgression and regression with an Atlantic inclination, which are represented by deposits from the formations Salamanca, Río Chico, Sarmiento, Patagonia and Santa Cruz [1-3].

## Diagenetic Processes of Reservoirs

The main reservoirs of the basin belong to the formation Bajo Barreal and their equivalents which change their names according to their position (formations Comodoro Rivadavia and Yacimiento El Trébol oilfield for the North flank and Cañadón Seco and Espinosa Table Mountain for the South flank respectively).

The majority of these sandstone deposits which are potentially hydrocarbons reservoirs belong to a fluvial continental environment. They are land laid in the shape of channels, lobes or lens in a smaller proportion.

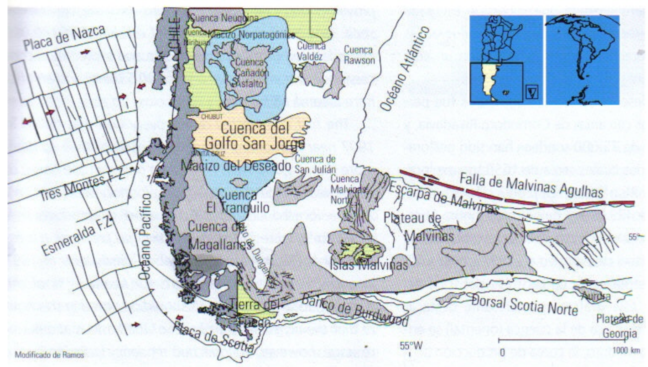


**Figure 1.** Location of San Jorge basin and its flanks (Figari *et al.* 1999)

The reservoirs of the Bajo Barreal formation are mainly volcanoclastic sandstones with reduced porosities because of burial and diagenesis increase. That decrease takes place due to three processes: mechanic compaction, dissolution of grains by intergranular contacts, and pore cementation [4].

The quantization of the compaction is influenced by the abundance and type of lithic material. Normally, the lithic volcanic grains turn into phylosilicates by weathering or diagenesis and are partially strained in the pseudomatrix. From a physical point of view, they are very ductile materials. The relation between the soft minerals (basic or intermediate volcanic lithics, micas or clay) and hard minerals (quartz and feldspars) seems to be the first indicator of the compactional behaviour of lithic materials. From this point of view, the use of technologies that provide us with detailed lithological data (Spectral Gamma Rays, Lateral Impact and Rotated Cores) is of pre-eminent importance when evaluating the reservoirs.

The mechanic compaction and the dissolution of grains by intergranular contact are compactional processes because they irreversibly reduce the intergranular volume of sandstone packing Fig.2. On the other hand, cementation obstructs but does not reduce the intergranular volume. The processes of mechanic and chemical compaction and cementation are important in the modification of the intergranular porosity of the reservoirs [5-6].

## Proposed Methodology

The proposal is based in the intergration of hightech logs with a detailed analysis of all types of subsurface samples (cuttings, cores and side wall cores either rotated or impact)

In a diagenetic process analysis context, the integration of logs for interpretation is proposed from the lithological characteristics which allow the grouping of different types of reservoirs. Tabla 1.

The use of conventional electric logs is intended to identify and describe electrofacies according to criteria stablished by Serra and Abott [7] in order to integrate them to lithological studies and logs which would allow us to estimate the diagenetic processes in the reservoirs (Figure 3).

It is then intended to group different indicators of reservoir quality from nuclear magnetic resonance data in order to relate them to electrofacies.

The understanding of a diagenesis model in an area provides a detailed evaluation of reservoirs as well as an excellent control to extrapolate the interpretations of the reservoir quality.

In this way, it is possible to define and group integrated models of reservoirs to generate operative applications for each reservoir.

## Electrofacies Analysis

The main goal of this analysis is to interpret the space distribution of shale layers by means of a geological model of sedimentation. The objective is to define an estimated paleoenvironmental model that provides the variation and distribution of its components.

The geological interpretation of electric logs takes into account certain characteristics such as spontaneous potential curve shape, types of contacts, permeable thicknesses and intercalation layer number.

If we applied the concept of elemental sequences to indicate the vertical combination of electrofacies genetically related, this would represent a part of a sedimentary environment.

All these inferences and interpretations can be corrected, completed and modified by means of other additional tools. It is the example of interpretations of cores or hightech logs of resistive image resolution or plunge log, etc. Figure 4.

## Lithologic Models of Reservoirs

The different lithologic models are determined by the lithological, mineralogical and textural characteristics in the clasts as well as in the fine interstitial materials in the matrix. They interact with the different fluids in the reservoirs.

The petrographic studies and X ray diffraction allow us to group similar characteristics as regards the proportion of mineral clay, cement and matrix. This generates lithological models [8-9] which can be checked and corrected by lithological logs (gamma ray spectral)

There is an areal and vertical heterogeneity in the reservoirs of the basin. However, the observations carried out using this diagenetic analysis allow us to group characteristics into models of types of reservoirs.

## Integrated Models of Reservoirs

The radioactive elements in the clays send gamma rays with characteristic levels of energy. The tools which classify natural gamma rays in energy windows allow us to identify and quantify three main radioactive elements in the clays: Thorium, Uranium and Potassium. In other words, the level of energy of the radiation and the quantity of rays per second indicate the element involved.

On the other hand, the different minerals in clay are characterized by a ratio Thorium/ Potassium. According to this ratio, it is possible to quantify the presence of the minerals mentioned above.

In the reservoirs in San Jorge basin the feldsparic lithic sandstones (Figure 2) have natural radioactive levels similar to the the ones in clays. If the radioactive spectrum of sandstones is analysed with a model for clays, the results could be wrong.

For this reason, in the case of these logs care should be taken when considering the results and the type of clay should be interpreted in a geological context as a sedimentary diagenesis and depositional environment.

The acquisition of nuclear magnetic resonance provides the following petrophysics quality data rock:

- MPHS: Magnetic Total Porosity
- MPHE: Magnetic Effective Porosity
- MBVI: Magnetic Porosity Irreducible Volume
- MBVM: Magnetic Bulk Mobile Volume
- Kc: Coates Permeability index

The reservoirs in the formation Bajo Barreal have very different petrophysics characteristics (Figure 5). These variations are probably related to the internal structure of the reservoirs which is at the same time connected with the depositional processes in their diagenesis.

The poor porosities and the high occurence of small pores due to the clay matrix are typical characteristics in most reservoirs of the formation Bajo Barreal. Because of this, they contain high concentrations of irreducible water which decrease the effective pores of the reservoir. This type of reservoirs only produces fluids which are not sticked to the pore walls by capillarity forces. For this reason, there are effective porosity rocks with a high irreducible fluid volume that present a lower petrophysics quality than other with less effective porosity but lower fluid volume.

The types of clay in then interstitial fine part of this reservoir play an important role in the relation between porosity associated with irreducible fluids and clay.

It is difficult to characterize the reservoirs due to the occurence of multiple different reservoirs in each well column. However, this methodology provides a more concised characterization of reservoirs than the one from specific log data analysis.

## Conclusion

This methodology integrates lithological, mineralogical and hightech log data which allow us to estimate the location of better quality levels of reservoirs by means of an areal diagenetic model.

It is a predictive methodology because all the elements in a sedimentary environment can be identified by indirect subsurface methods such as electric log geological interpretations, well images and/or detailed description of lithological types.

The use of these lithological integrated models in order to understand the fluid-rock interaction system generates applications to optimize hydrocarbon recovery.

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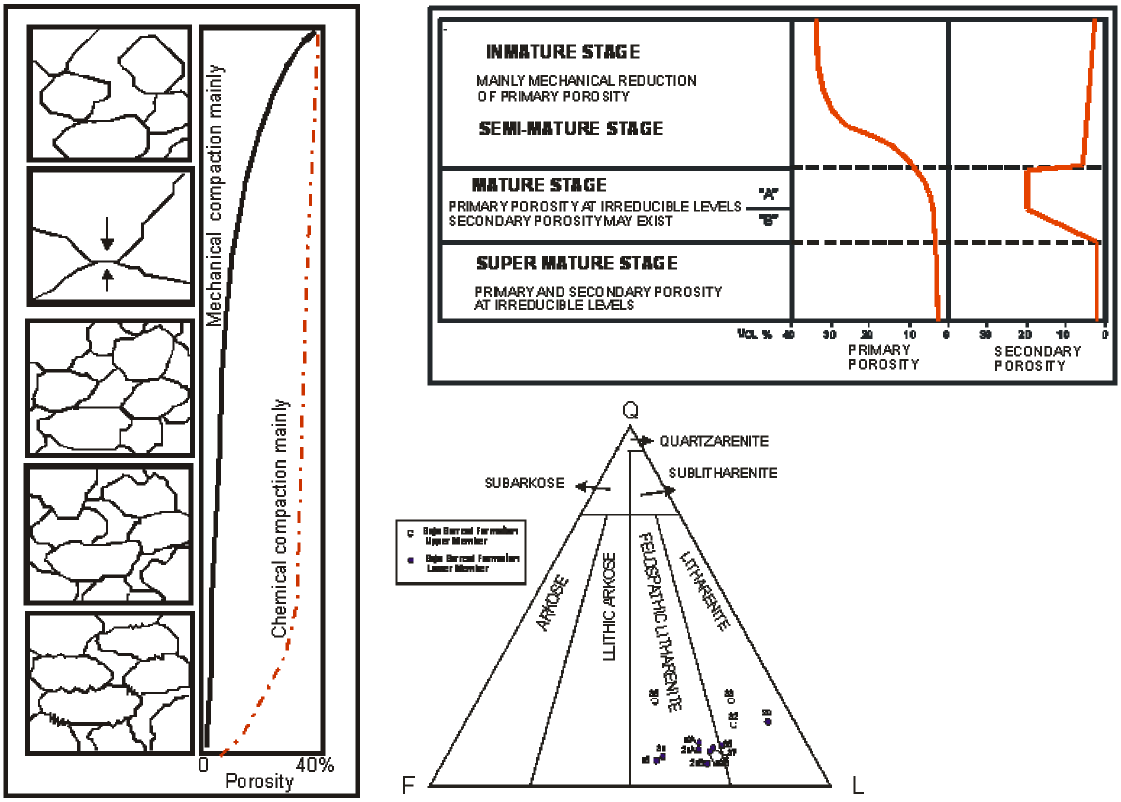


Figure 2. Textural stage of mesodiagenesis of sandstone shaly (modified Smith y McDonalds, 1978; Estrada, 2006)

| MODELS | CLASTIC FRACTION | MATRIX | ACCESORIES | SUBJECT | INTERPRETATION |
|---|---|---|---|---|---|
| ARN 1 | Quartz, glass, lithic rare | Clay matrix regular | Micaceous fragment and pyrite presence | Visual Porosity Regular | Abandoned channel and Bar-Finger Sands |
| ARN 2 | Quartz, glass, lithic rare | Clay matrix abundant | Micaceous fragment and pyrite presence | Infiltrated Mechanical Clay Texture. Visual Porosity Low. Interbedded sand and shale | Crevasse splay and flood plain |
| ARN 3 | Quartz, lithic, glass rare | Clay matrix rare | micaceous fragment isolate | Visual Porosity Regular to Good | Channel and amalgamated channel |

Tabla 1. Lithologic models and associated facies interpretation (Acosta y Estrada, 2005)

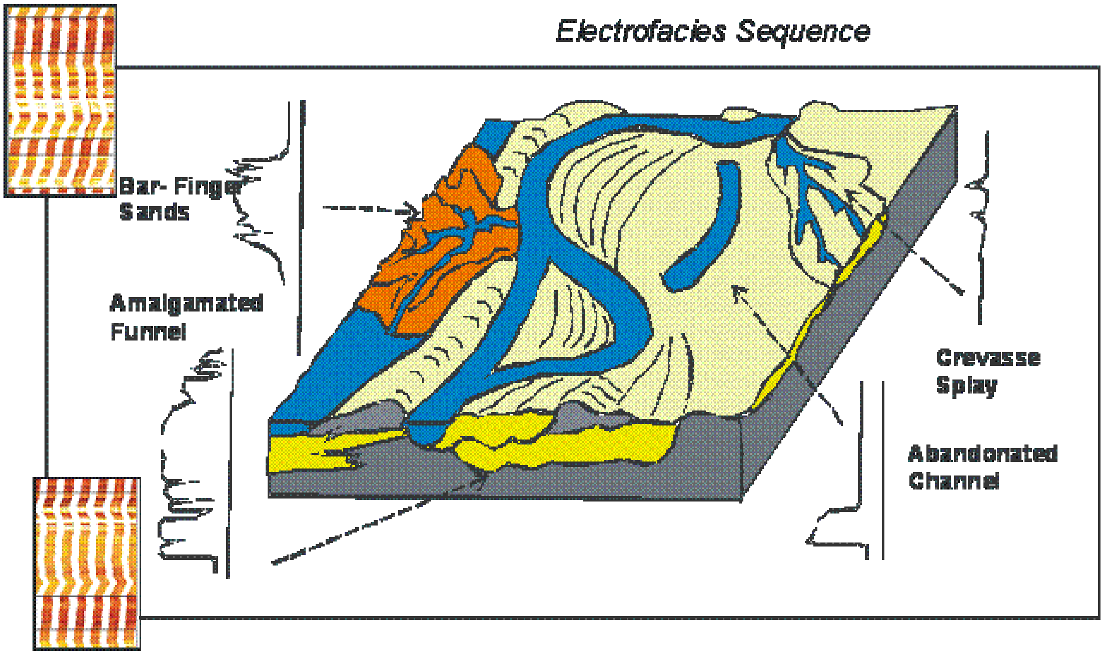


Figure 3. Electrofacies sequences (modified Acosta y Estrada, 2005)

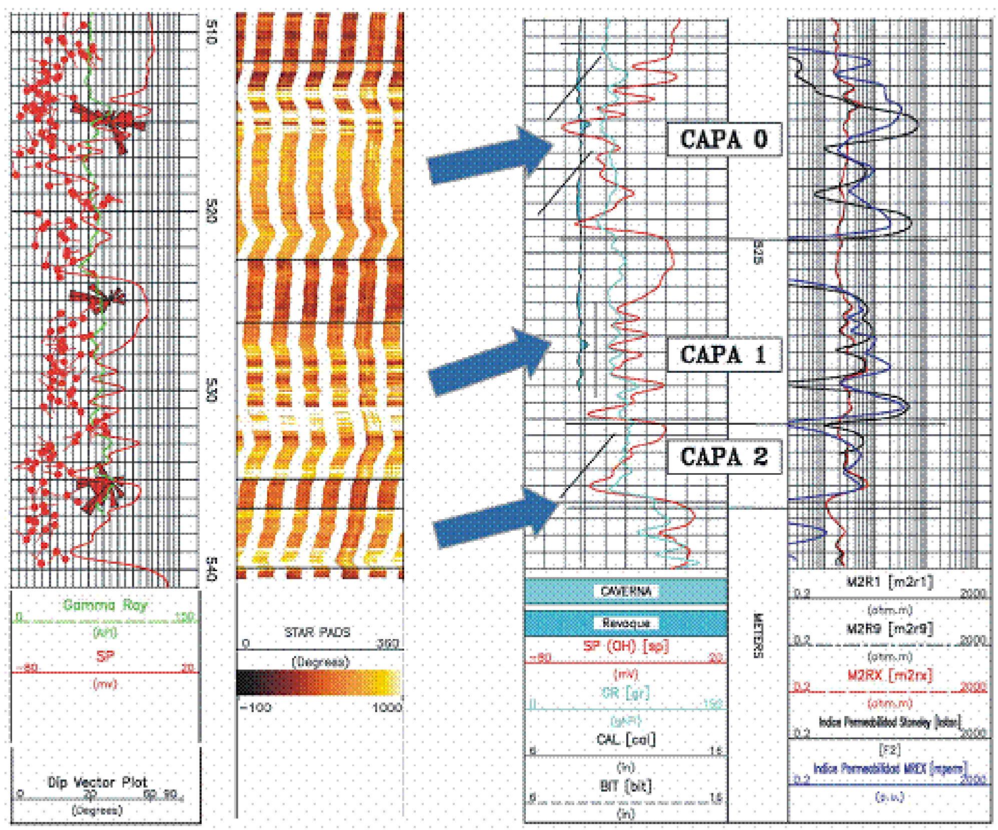


Figure 4. Image Log showed different fining upward sequence (Acosta y D'Onofrio, 2005)

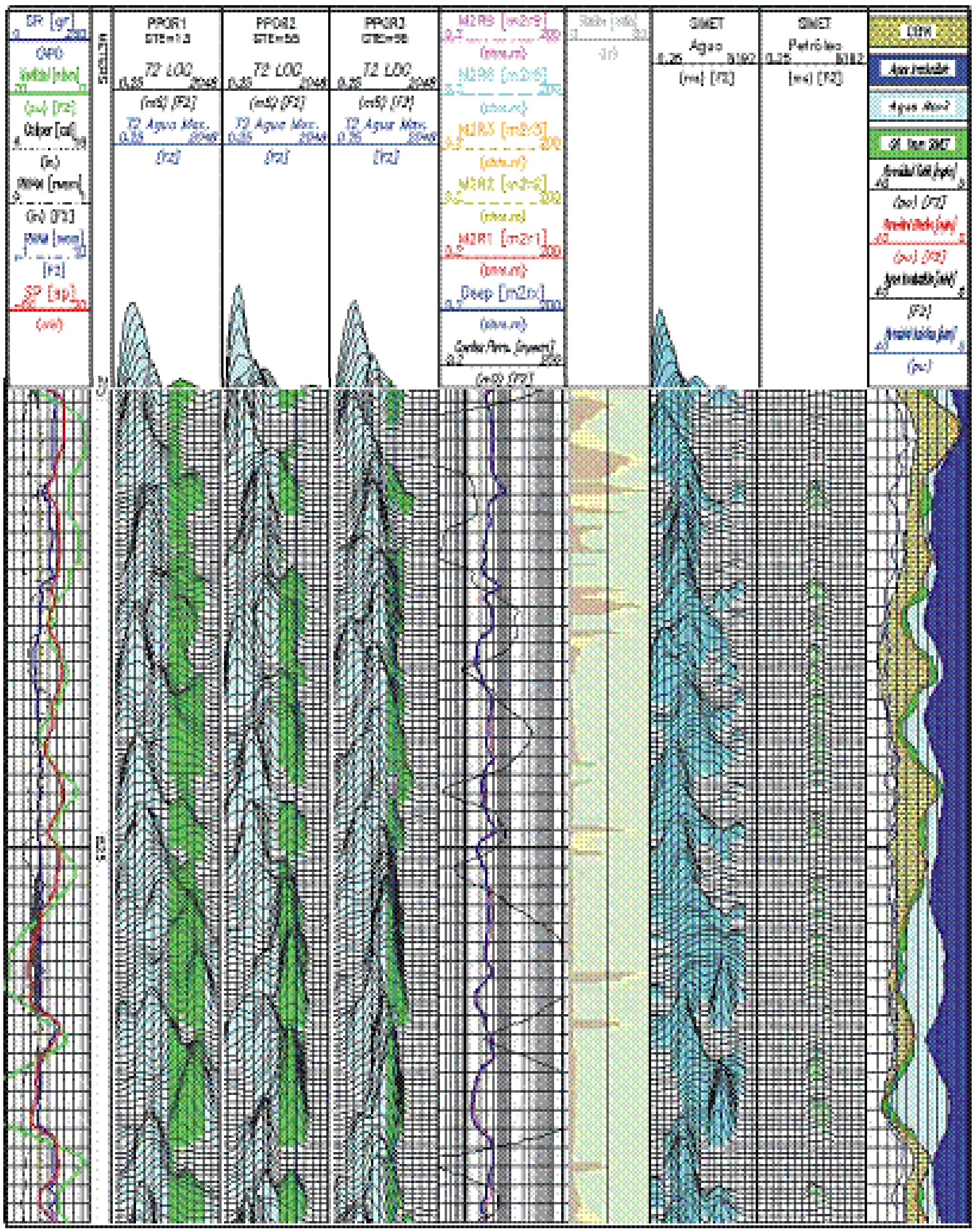


Figure 5. Log NMR showed reservoirs integrated models (modified Dominguez, et al., 2005, Estrada, 2006)