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title: **Heterogeneity characterization to identify hydrofacies in Barreiras Aquifer, Rio de Janeiro State, Brazil**

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ABSTRACT

The Barreiras Formation deposits, which occur on the northern coast of Rio de Janeiro- Brazil, in the onshore portion of the Campos Basin, are usually composed by tabular layers of sandstones, interbedded with mudstone lenses, associated to braided rivers deposits. The present study consisted of establishing a bridge between techniques for sedimentary and hydraulic characterization of the Barreiras granular aquifer, poorly studied, but widely used for urban and industrial water supply. In this study, sedimentological and permoporous tests were conducted in two outcrops, in order to characterize the heterogeneity, to define hydrofacies and to evaluate the quality of the Barreiras aquifer. As a result, it was recognized that the deposits are predominantly composed of muddy sandstone (labeled as lithofacies Aca and Am), and in minor proportion of sandy mudstones (lithofacies La). The sandstone lithofacies has low permeability, with hydraulic conductivity ranging between 10^{-4} to 10^{-5} cm/s, and is defined as hydrofacies 1, comprising the reservoir layers of the Barreiras aquifer. The mudstone lithofacies has a hydraulic conductivity between 10^{-5} and 10^{-8} cm/s, and is defined as hydrofacies 2, representing hydraulic barriers to the groundwater flow. According to these results, the Barreiras aquifer is characterized as a poor aquifer, with low permeability, differing from the typical braided stream deposits (recognized as good reservoirs) due to a high concentration of clay, possibly introduced by post-depositional processes such as mechanical infiltration of clays, feldspars weathering and bioturbation.

INTRODUCTION

Advances in the study of granular reservoirs, due to increased demand for exploitation of fluids, has led to the consolidation of a multidisciplinary approach. The stratigraphic and sedimentological studies applied to hydrogeology, based on techniques originally developed in the hydrocarbon industry, result in the concept of hydrofacies (Faccini et al., 1999), which are defined as sedimentary bodies interconnected with similar hydraulic properties (Anderson et al., 1999). The relationship of lithofacies and hydrofacies can be quantitatively assessed using outcrops accessible and good exposure, allowing detailed in situ mapping and laboratory measurements of the permoporous aspects of rock formations. Once a geological unit outcrop stratigraphical aspects and lithofacies are similar to the aquifer, it can be regarded as an analogue of this aquifer. It representsmaterials readily available for the study of 3D geometry and in situ measurements of hydraulic parameters on a detailed scale (Klingbeil et al., 1999).

The results of integrated studies aiming to characterize the hydrofacies allow the understanding of water groundwater flow, besides characterizing the heterogeneity of the aquifer. Such studies, besides providing an improvement in productivity, also offer important collaboration for the protection and remediation of groundwater resources due to contamination.

In this context, the present study consisted of establishing a bridge between techniques for sedimentary and hydraulic characterization of Barreiras Formation deposits, important source of freshwater for rural populations in the regions of occurrence. The Barreiras Formation deposits occur throughout more than 4000 km along the Brazilian coast, In the area of study, located in Rio de Janeiro State northern coast, emerse portion of Campos Sedimentary Basin (Fig. 1), are usually composed of tabular sandstone layers, interbedded with mudstone lenses, and are associated to braided rivers deposits.

Campos Sedimentary Basin comprehends low altitude tablelands; alluvial and coastal plains, corresponding to cenozoic sedimentary deposits, partially consolidated, and loose neocenozoic sediments.

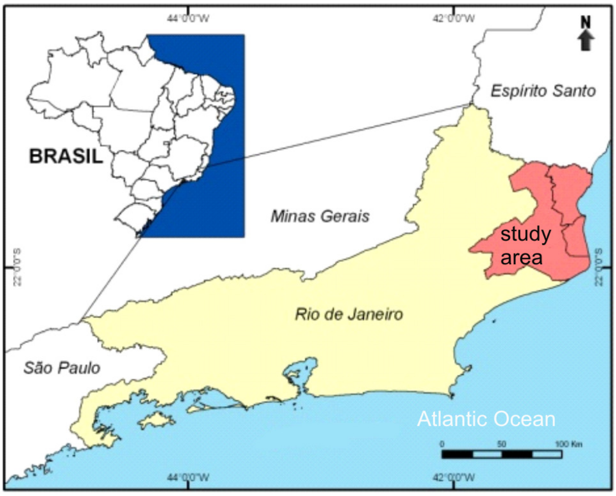

Figure 1. Location of study area in Rio de Janeiro State.

METHODS

In the present study, sedimentological and permoporous tests were conducted in two outcrops according to Klingbeil *et al.* (1999), as shown in Figures 2 and 3. In both outcrops, section Barra de Itabapoana and section Córrego Sucupira, two sandstone lithofacies are identified: a sandstone with cross stratification (Aca) and a massive sandstone without apparent structures (Am), and a lutite-mudstone (La). The sandstone facies predominate in relation to the pelitic one. The most representative lithofacies is Am, which represents 63% of the deposits.

Laboratory and field tests were carried out in order to define porosity and hydraulic conductivity according to methods by Ezzy *et al.* (2006), Elrick *et al.*, (1989) and Fetter (2001) and textural aspects of Barreiras Formation sediments, to characterize heterogeneity and define hydrofacies (Anderson *et al.*, 1999; Anderson, 1989) and to evaluate the reservoir quality of the Barreiras aquifer (Dickinson, 1970; Folk, 1980).

RESULTS AND CONCLUSIONS

Sedimentary deposits are predominantly composed of muddy sandstone (lithofacies *Aca* and *Am*), and secondarily of sandy mudstones (lithofacies *La*). The muddy sandstones are quartzose and present about 30% of clay content, due to post-depositional processes that obliterated the primary porosity. The porosity is dominantly secondary, mainly by shrinkage of the clay material (Beard and Weyl, 1973).

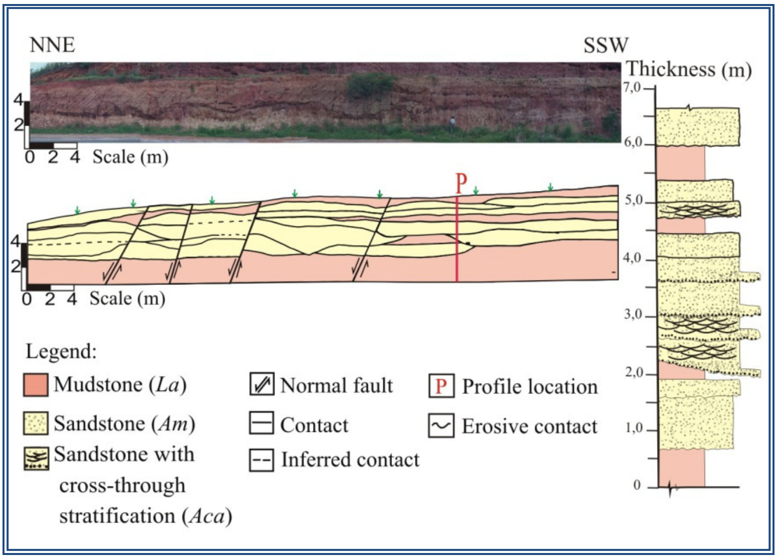

Figure 2. Photo mosaic interpreted and lateral facies of the section Córrego Sucupira.

The lutite sandy lithofacies present distinct sedimentary and hydraulic characteristics. In *Am* and *Aca* facies the values of hydraulic conductivity, porosity and concentration of clay were very similar, clearly distinguished from facies *La*, in general, with lower values of hydraulic conductivity and effective porosity and higher concentration of clay and greater total porosity (Fig. 4).

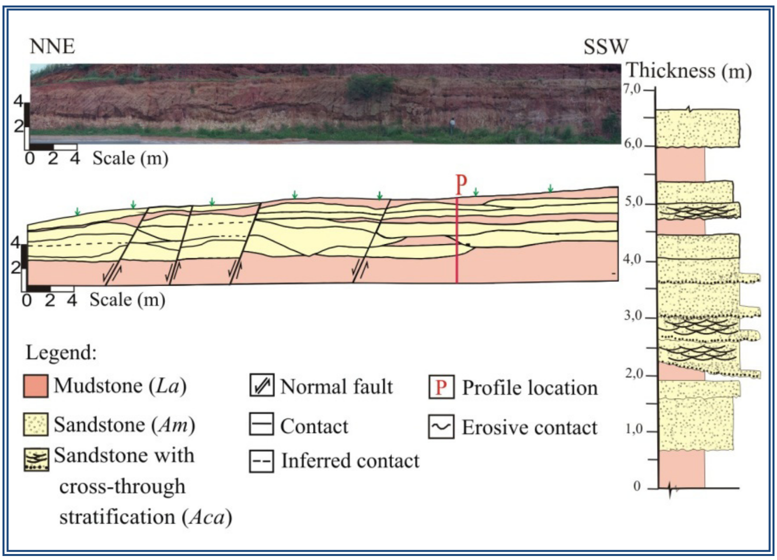

Figure 3. Photo mosaic interpreted and lateral facies of the section Barra Itabapoana.

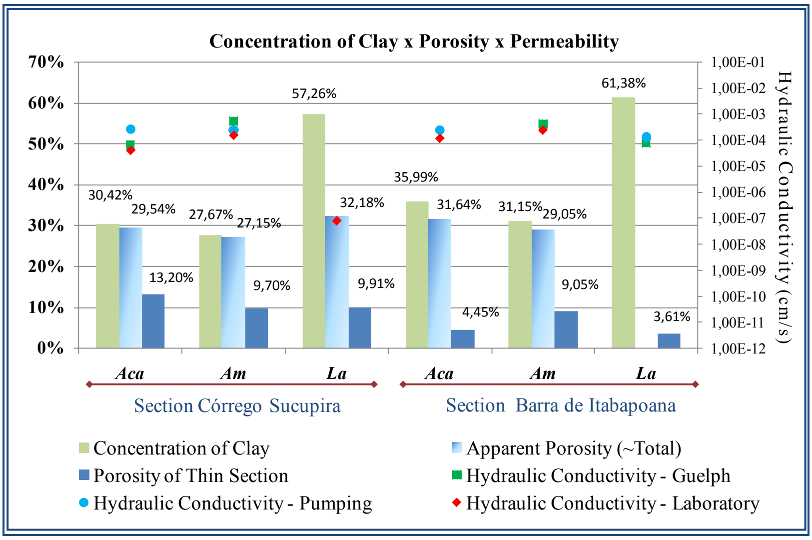

Figure 4. Bar graph with the concentration of clay and porosity (~ total) and dots with the values of hydraulic conductivities obtained with laboratory (variable head permeameter) and field (Guelph permeameter and pumping) tests.

The average values of hydraulic conductivity of each facies were calculated from the averaged values of laboratory tests (X axis), infiltration and pumping tests, as shown in Table 1.

From the characterization of porosity and permeability of lithofacies it was possible to define two hydrofacies in both sections of the aquifer Barriers, hidrofácies 1 and 2, as Table 2 and Figure 5.

Table 1. The mean values of hydraulic conductivity (K) of facies Aca, Am and La.

Facies	Variable Head Permeameter K (cm /s)	Infiltration Tests (Guelph) K (cm /s)	Pumping Tests K(cm /s)	K (cm/s)
Aca*	6.75×10^{-4}	6.54×10^{-5}	2.49×10^{-4}	3.30×10^{-4}
Am**	1.45×10^{-4}	2.37×10^{-4}	2.41×10^{-4}	2.08×10^{-4}
La***	7.61×10^{-8}	7.76×10^{-5}	1.30×10^{-5}	3.02×10^{-5}
Relationship of facies	Am ≥ Aca >La	Am>Aca≥La	Am ≥ Aca≥La	Am ≥ Aca>La

* Aca (sandstone with cross stratification);
** Am (sandstone massive);
*** La (mudstone massive).

Table 2. Hydrofacies defined according to and lithofacies and hydraulic conductivities and their variation, compared with Zappa et al. (2006).

Hydrofacies	Description	Associated facies	Mean K (cm/s)	Range K (cm/s)	Zappa et al., (2006) K (cm/s)
1	muddy sandstone *laminated or without apparent structure*	Aca e Am	2.69×10^{-4}	$10^{-4} – 10^{-5}$	$10^{-1} – 10^{-2}$
2	sandy mudstones	La	3.02×10^{-5}	$10^{-5} – 10^{-8}$	***

*** Without reference.

The hydrofacies 1 consists of the lithofacies Aca and Am formed by poorly sorted argillaceous sandstone, quartz, with or without cross bedded apparent structure. It consists of layers with extensive sub-tabular lenses, with good connection between the sandy strata. It has a mean hydraulic conductivity of 1.53 $\times10^{-4}$ cm/s, ranging from 10^{-4} to 10^{-5} cm/s, and average porosity of 29.35%, consisting generally of secondary porosity, with pores randomly distributed. This hydrofacies relates to the reservoir layers of the Barreiras Formation.

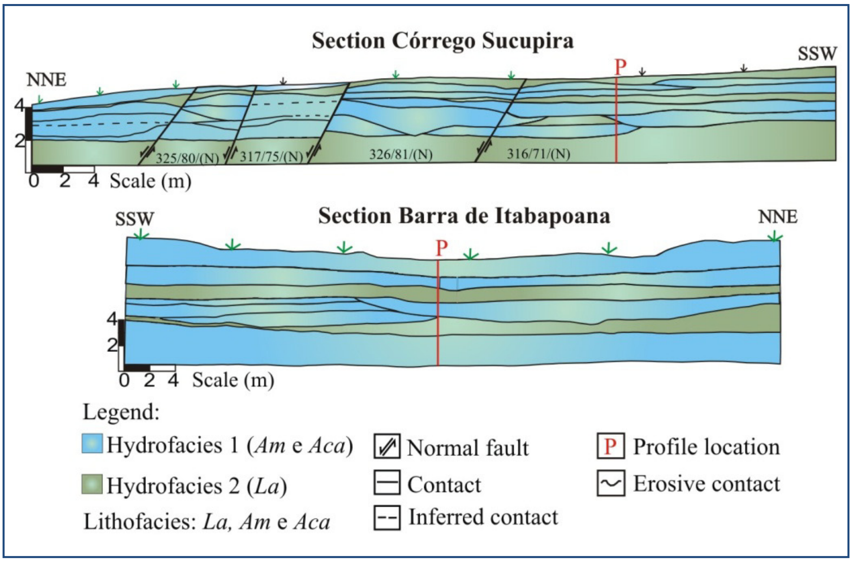

Figure 5. Hydrogeological sections of the sections Córrego Sucupira and Barra Itabapoana, with their hidrofacies.

The hydrofacies 2 consists of the facies La, formed by sandy mudstones, with 70% clay content, less permeable than hidrofácies 1, since mean hydraulic conductivity is equal to 6.92 x10-5cm/s ranging from 10^{-5} to 10^{-8} cm/s. Occurs in areas with lower degree of bioturbation and without the influence of faulting. The hydrofacies 2 can be considered as layers that behave as aquitards, acting as hydraulic barriers in Barreiras Formation.

The results of hydraulic conductivity obtained in a hidrofácies 1 differ from those obtained in similar hydrofacies in braided fluvial deposits, up to two orders of magnitude (Table 2). According to these results, the Barreiras aquifer is characterized as a poor aquifer, with a low permeability, differing from the typical braided stream deposits, generally recognized as good reservoirs (Zappa *et al.*, 2006), due to a high concentration of clay, introduced by post-depositional processes such as chemical weathering of feldspars, mechanical infiltration of clays and bioturbation, typical of tropical climates.

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