Framework for Modelling of Wireline Log Responses from Carbonate Outcrops

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Abstract

The foundation of reservoir modelling is the ability to integrate sparse and indirect data gathered at a variety of scales and generate models that can predict the behaviour of a reservoir under production. Recent oil discoveries in carbonate reservoirs (Pre-salt and Post-salt) in Brazil are complex and challenging to model.

Outcrop studies can help to understand what happens at the inter-well scale in the reservoir. This paper shows how outcrop data has been combined with a petrophysical model to create synthetic wireline logs, using petrographic and petrophysical information from samples retrieved in the Morro do Chaves Fm, Sergipe-Alagoas Basin. A pseudo-wellbore was created, with synthetic gamma ray and density logs. These synthetic wireline logs have the advantage of helping university students start to make the link between outcrop studies and subsurface petroleum-industry data sets.

This work is establishing a practical framework in advance of drilling several boreholes later this year where core will be retrieved and logs will be run, so that the integration of outcrop and log data can be accelerated.

Introduction

The major oil discoveries in the Brazilian Pre-salt over the last few years has increased the interest in carbonate reservoir studies in Brazil.

The Sergipe-Alagoas Basin is known in Brazil as a "Teaching Basin" because of the exceptionally good outcrops that include all the sections of the Brazilian Margin evolution. The Morro do Chaves Formation of Aptian (local Jiquiá) Age, is formed by reworked coquinas, formed from non-marine bivalves and ostracods with a variable percentage of siliciclastic material (Azambuja *et al*., 1998, Kinoshita, 2007, 2010). The Morro do Chaves Fm is exposed in excellent outcrops in the São Sebastião Quarry (former Atol Quarry) and this formation was chosen as a suitable analogue for potential offshore coquina reservoirs, and a series of rock samples were collected for the different rock types present.

Coquinas of the Morro do Chaves Fm have become the laboratory material of choice for much of the academic petrophysical community in Brazil. However, unlike the classic sandstones (such as the Berea and Bentheimer/Clashach/Lochabriggs sandstones used for studies in the USA and Europe) these carbonate rocks show a high-level of variability in pore type, size, geometry, distribution and connectivity. This will produce challenges in assessing petrophysical representivity and when comparing and applying the work of several different research groups.

Method

The methods followed to construct the synthetic logs, using stratigraphic, petrographic and petrophysical measurements include:

1) Facies description of the outcrop
2) Selection of different petrophysical rock types
3) Measurements taken in different rock types
4) Building the well bore rock type model
5) Modelling the synthetic wireline log responses
6) Calibration using real data
7) Iteration

A field trip to the São Sebastião Quarry was held in late 2012 with the objective to prepare a stratigraphic profile, to collect samples for petrography (40 hand-samples) and samples for petrophysical laboratory measurements (10 large blocks). A detailed facies description was acquired by zig-zagging up the section following the quarry roads and benches.

During the field trip, visual porosity and siliciclastic content quantification was described and recorded microscopically (10x hand lens). Facies analysis was carried out based on sedimentological attributes and a 60m vertical facies profile was prepared.

From the candidate petrotypes identified (the process of assigning and sampling rock types (Corbett and Potter, 2004; Corbett and Mousa, 2010) 10 blocks were collected and 53 plugs were drilled for petrophysical analysis. These are undergoing measurement for porosity, permeability and grain density. Microfacies and micro-CT analyses were performed. These data provide the basis for quantitative analysis of the Morro de Chaves Fm.

The pseudo-well bore model was built by combining the stratigraphic facies profile (converting the depths from the bottom up field log to the top down well log) with the petrophysical model (a simple equation discussed below) to produce synthetic log data. Although this process is somewhat subjective, a reasonable model was constructed using a spreadsheet and displaying the results in industry-standard logging format. This approach will be followed to derive synthetic acoustic logs. Properties that cannot be measured directly in the samples – such as hydrocarbon saturation – can be theoretically modelled from an understanding of the link between the petrophysical rock types and capillary pressure-derived saturation-height functions.

This set of synthetic wireline logs has been created by using the quarry outcrop, but later on this year boreholes will be drilled in the quarry, core will be retrieved and some logging tools will be run (GR, Resistivity, Density, Neutron, Sonic) which will enable calibration of the data sets. The aim is to use all this data to create 3-D geological models that can be used for a range of geoengineering (geophysical and engineering; mining and petroleum) purposes. Additional quarry-face profiles will help add to the 3D aspect of the data coverage.

São Sebastião Quarry Example

The São Sebastião Quarry near Maceio (Alagoas, NE Brazil, Fig.1) was used as an example for this approach. Other quarries in the same basin are undergoing the same type of analysis.

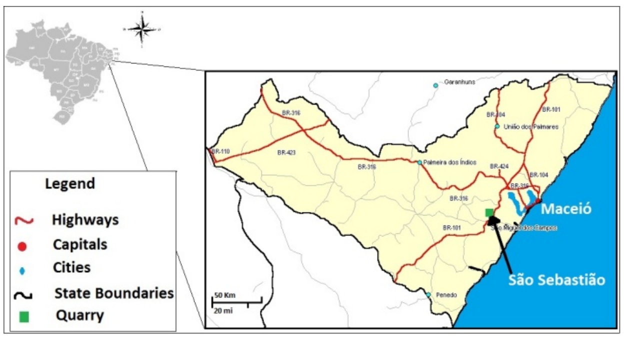

Fig 1: Location Map of the São Sebastião Quarry in S. Miguel dos Campos, near Maceio (Alagoas, NE Brasil).

A 60m profile was chosen for the facies and rock-type logging in the quarry. Due to access and safety, the log follows the easily accessible benches in the eastern face of the main quarry (Fig. 2)

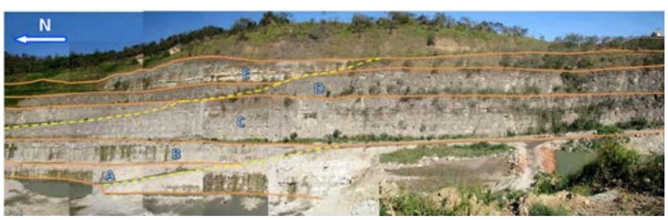

Fig 2: Photomosaic of the São Sebastião Quarry showing the zig-zag path of the logged profile.

A detailed facies analysis was undertaken (Fig. 3) and thin sections were made (Fig.4) for key samples. Larger block-samples were taken that were then plugged in the lab and porosity was measured (Fig. 5).

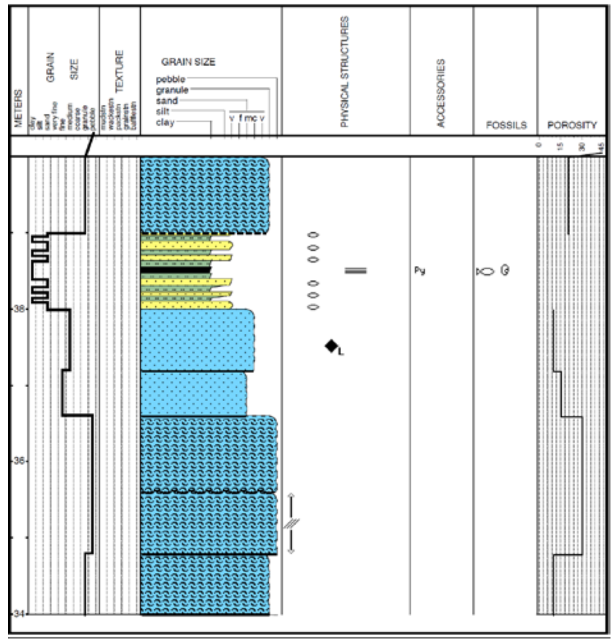

Fig 3: To show part (6m) of the stratigraphic profile logged at 1:40 scale. Coquina intervals in blue.

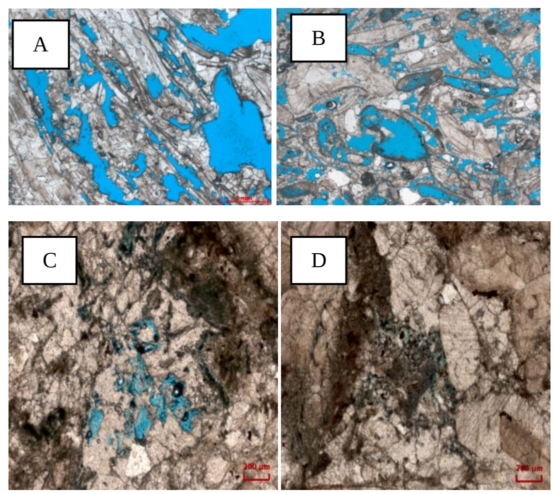

Fig 4: Photomicrographs from the Morro do Chaves Fm coquinas showing porosity (in blue). (A) high degree of corrosion porosity, (B) mouldic porosity, (C) low inter-crystalline porosity and (D) patchy micro-porosity.

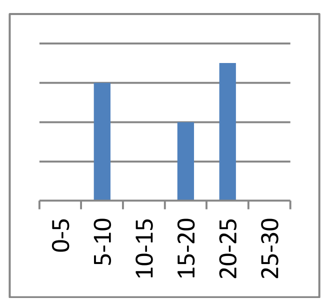

Fig 5: Histogram of core plug porosity data (%) measured in the lab (volume/weight method) for the selected petrophysical samples. Vertical axis shows relative proportions of samples.

Results

Fifteen lithofacies (facies) have been identified along the 60m vertical profile using sedimentological attributes such as lithology, major sedimentary structures, nature of siliciclastic content, accessories and fossil content. A facies and visible porosity profile was created. Clay, "terrigeneous" (undifferentiated sand, silt and clay) and limestone content are estimated for each hand sample along with the visible porosity. The percentages of these components were used to develop a weighted average clay content which serves as proxy for the GR curve (Fig. 6) and the visible porosity estimation combined with estimate of grain density to give a synthetic density log.

Initially using a qualitative (visual) estimate of porosity and a single limestone matrix density (of 2.71g/cc), the synthetic log will be 'improved' by iterating with laboratory data as it becomes available. This iterative process will continue as more data is collected and the framework established will help drive the data collection in the field.

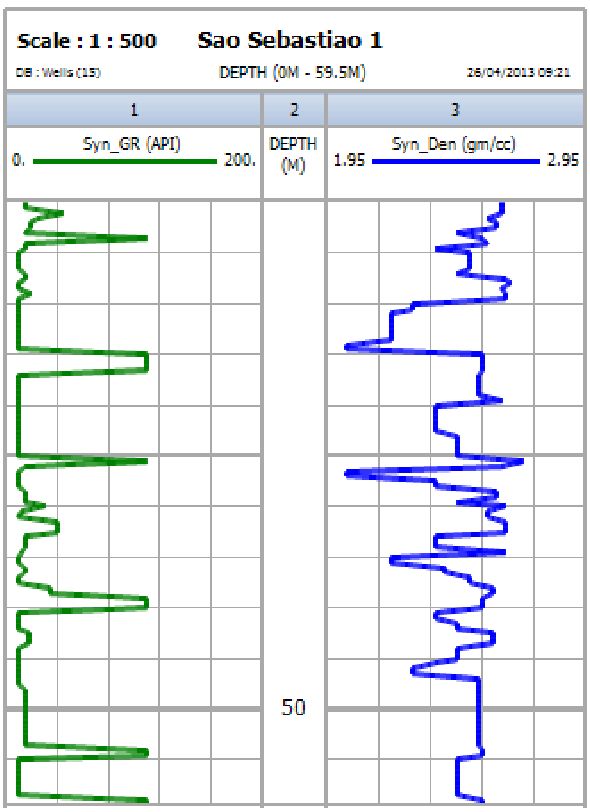

Fig 6: Example synthetic wireline log (at 1:200 scale) for the 60m measured section of Morro do Chaves Fm in the São Sebastião Quarry – with synthetic gamma ray (syn-GR) and density (syn-Den) as estimated from hand specimens.

As can be seen from the synthetic logs (Fig. 6) there is an apparent lack of any correlation between clay content (syn-GR) and the density (syn-Den) within the carbonate intervals. Some of the high porosity zones observed in the hand specimens were unconsolidated and it was therefore not possible to sample (plug) them for petrophysical analysis.

Conclusions and Recommendations

A framework has been established for the comparison of outcrop data with borehole data. In the absence of borehole data in onshore outcrops numerical models of logs can go a long way to helping understand potential petrophysical characteristics.

Pre-modelling of wireline log data prepares the way for improved log data analysis when actual logs are acquired and this technique can be applied to other outcrop studies. Building models from further profiles and drilling a number of wells will help to establish a 3-D framework for reservoir modeling studies.

The next important step in this study, is the calibration with wireline logging that is planned when the boreholes are cored and logged later this year. Geomechanical lab measurements will be taken as part of this project, which will help in the prediction of geomechanical responses, which is of interest to both mining, quarrying and petroleum industries alike.

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