Geological Characterization and Modeling of an Aptian Carbonate Reservoir in the Santos Basin, Brazil*

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Abstract

The offshore of Santos Basin, in the Brazilian Southeastern continental margin, accommodates a huge hydrocarbon province. In the early 2000's, oil discoveries in deep and ultra-deep waters, located in the Barremian-Aptian carbonate section, brought a new economic interest to the area. In this work, we will focus on an Aptian carbonate platform, which composes one of the most prolific oil fields of this province. The work aims to present the geological context of the area and propose a workflow for the geological characterization and modeling to better understand the spatial distribution of the sedimentary facies and permo-porosity that can define preferential producing stratigraphic zones and flow paths. For this goal, the geological model represented by the structural, stratigraphic, facies, and permo-porosity models will be presented. Sedimentological studies identified five main carbonate facies in the studied sequence: grainstones, stromatolites/shrubs, spherulitites, laminites, and wackestones/mudstones. The cycles defined by facies successions allowed the interpretation of stratigraphic surfaces that can be correlated throughout the field and separate the section into five main zones. A stratigraphic-sedimentological forward facies model was constructed to reproduce the sedimentary stacking pattern observed from well data, based on the simulation and tests of different parameters that act in the depositional process of carbonate rocks: base level oscillations and carbonate depositional rate. The facies model is used to guide the permo-porosity distribution. The permeability distribution requires the definition of rock types, with different classes of permeability, and fracture zones. Based on 3D forward modeling, the best set of environmental conditions able to explain the pattern of carbonate deposition observed in the study area are a slow carbonate depositional rate and lake-level oscillations which were essentially induced by arid climatic conditions. In terms of reservoir quality, the better reservoir facies are stromatolites and grainstones. The higher permeabilities are a combination of the primary porosity connection, increased by dissolution and fractures. The integration of this work allows an understanding of the sedimentological processes acting in the platform, the facies and permo-porosity distribution between wells and helps in the improvement of the predictability of the production curves that can be confirmed by real production performance.

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ACE 101: Bridging Fundamentals and Innovation

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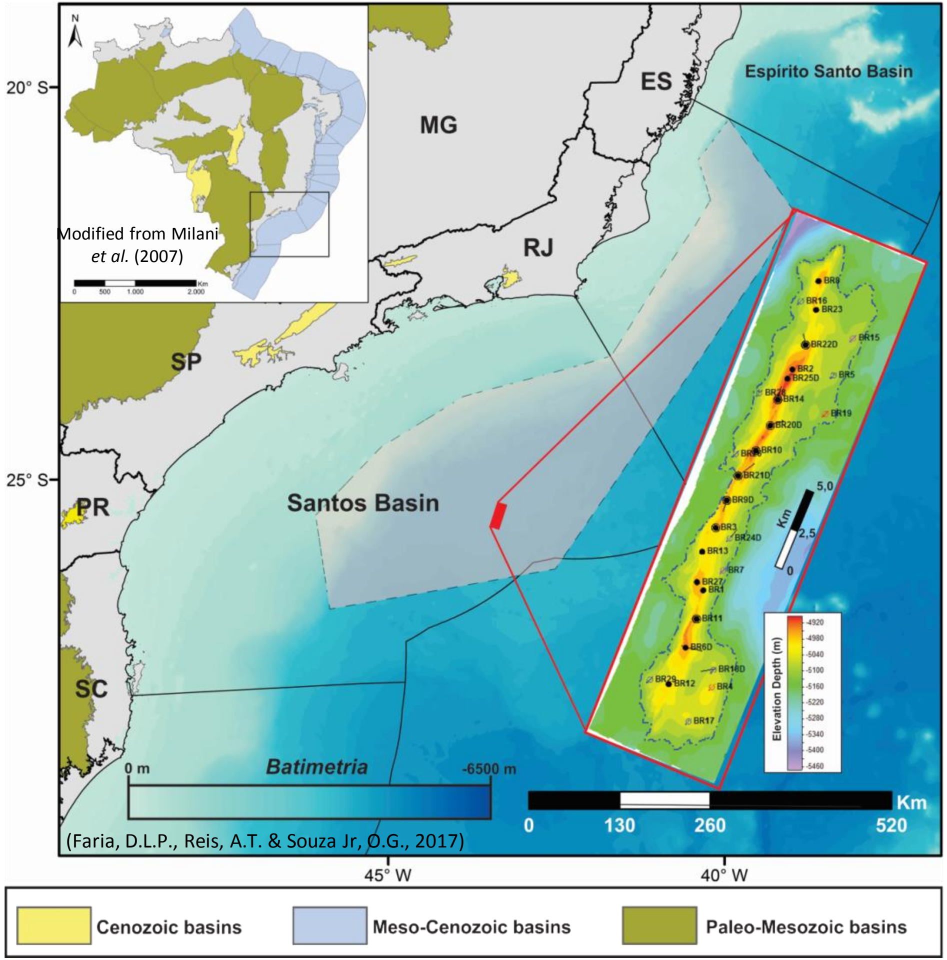
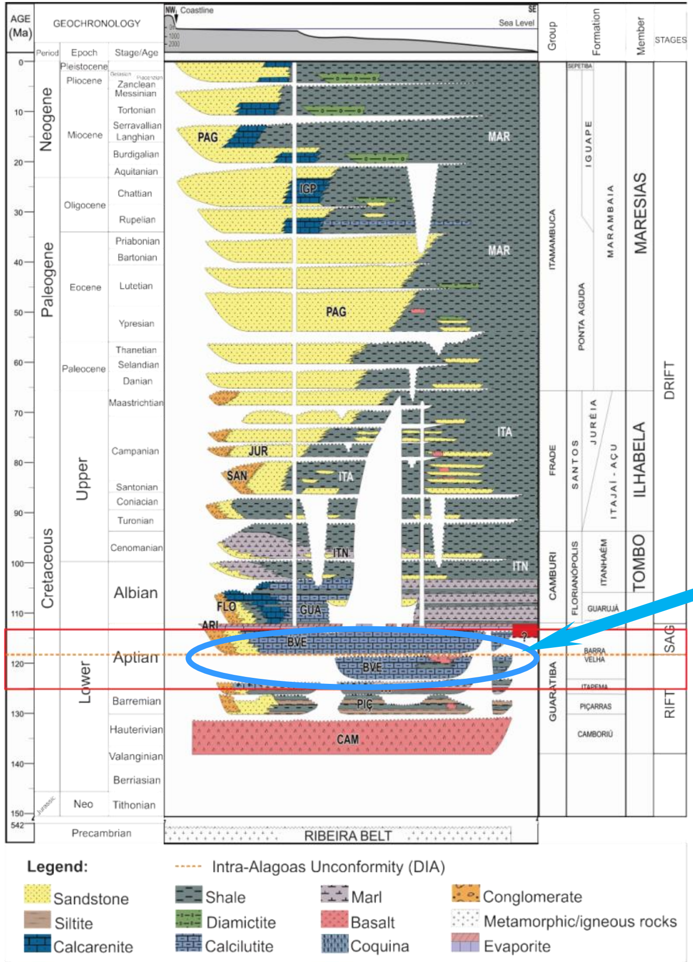
Location



- Santos basin
- 310 km from coast
- Aptian isolated carbonate platform (Tucker & Wrigth, 1990)

Stratigraphic context

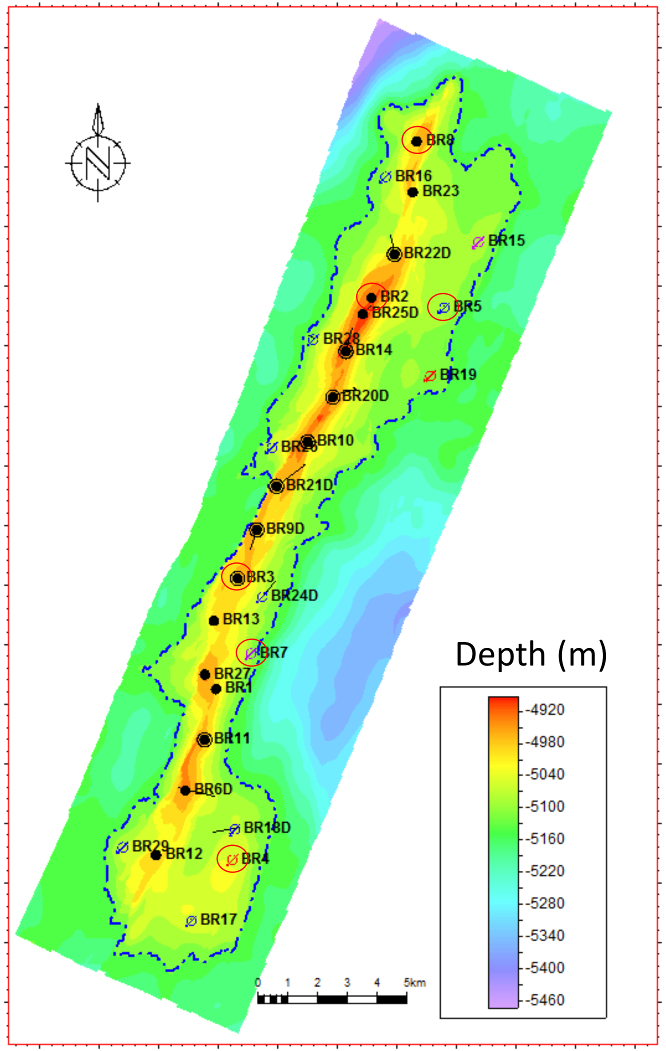


Reservoir:
Barra Velha Fm.
carbonates

Modified from Moreira *et al.* (2007)

Field

1° oil: jan/2013



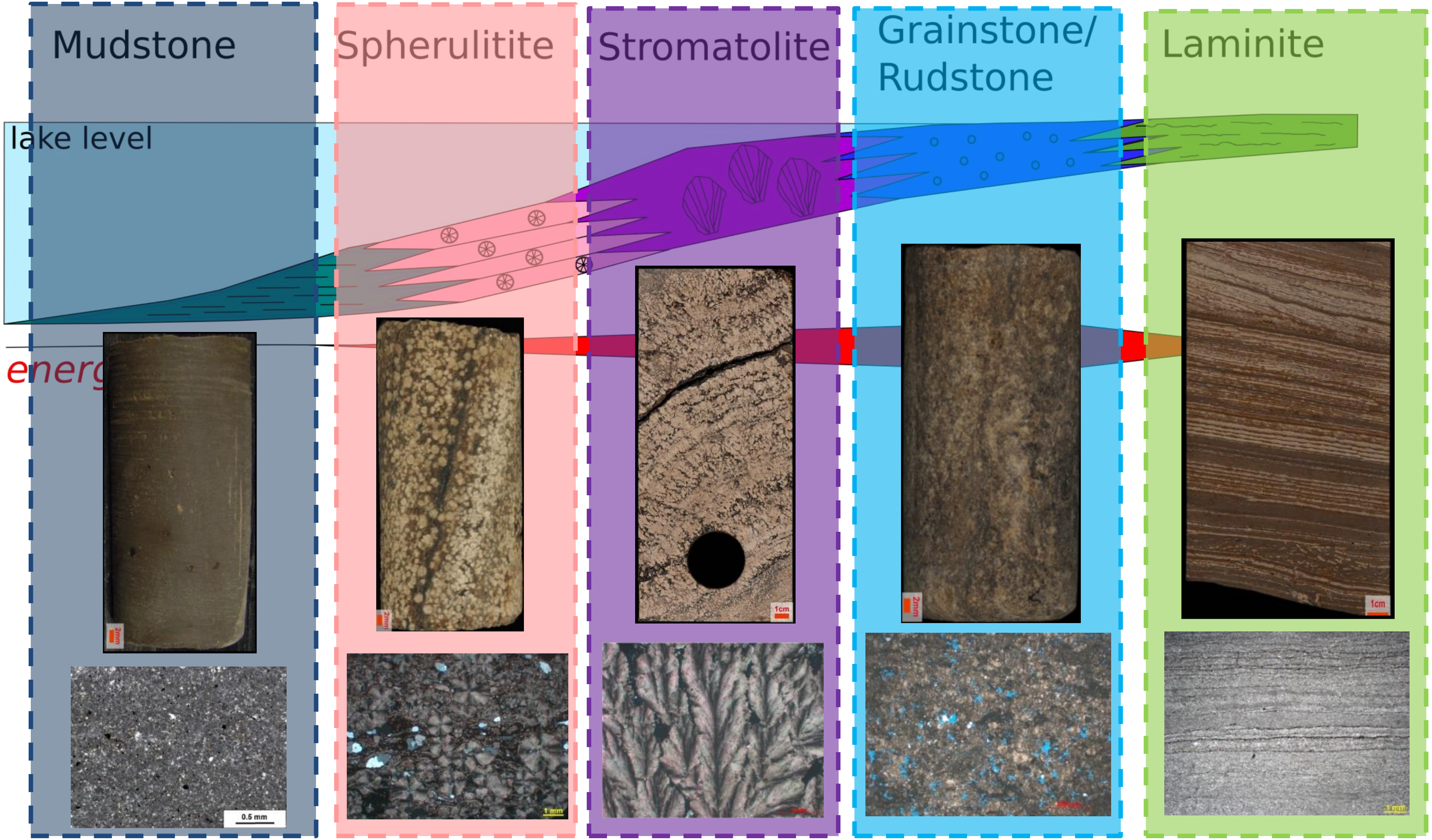
Drilled wells: 29

- 17 producers — simple completion / dual completion
- 8 water injectors
- 2 gas injectors
- 2 wags
- 6 cored wells (~390 m)
- 1879 side samples (24 wells)

oil/water contact

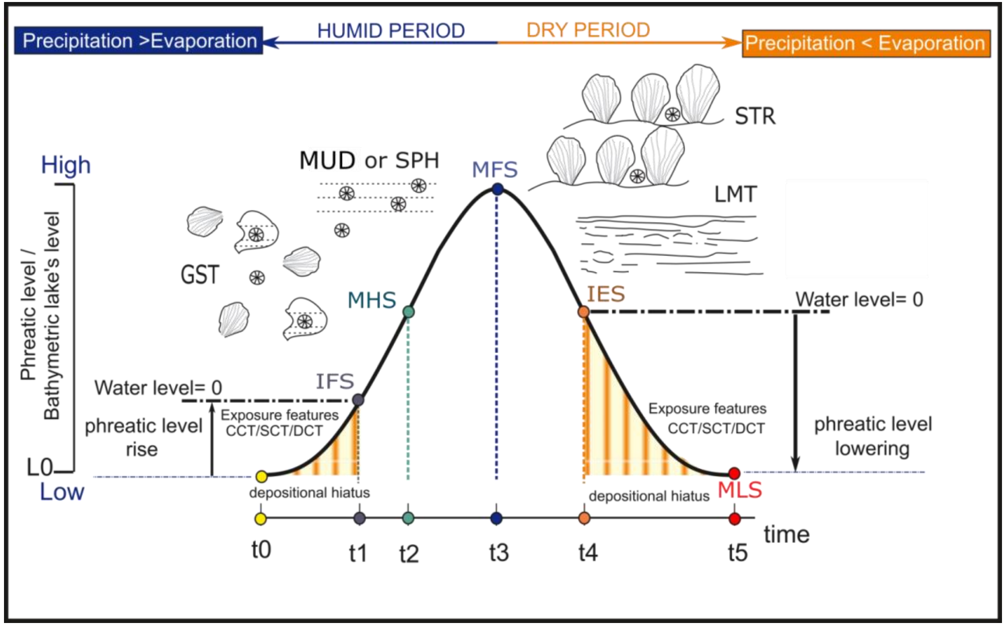
- Pretests (29 wells)

Depositional model



Ciclicity analysis

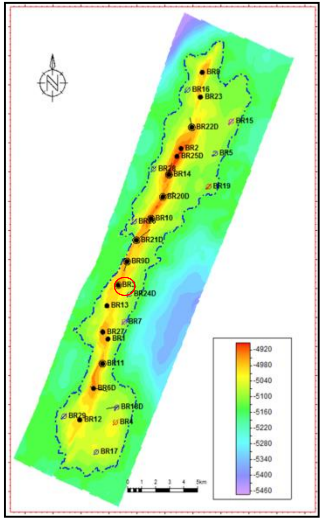
- Spectral GR (U-Th-K) and total GR
- Stacking pattern GST-SPH-STR-LMT



Modified from Bento Freire, 2012

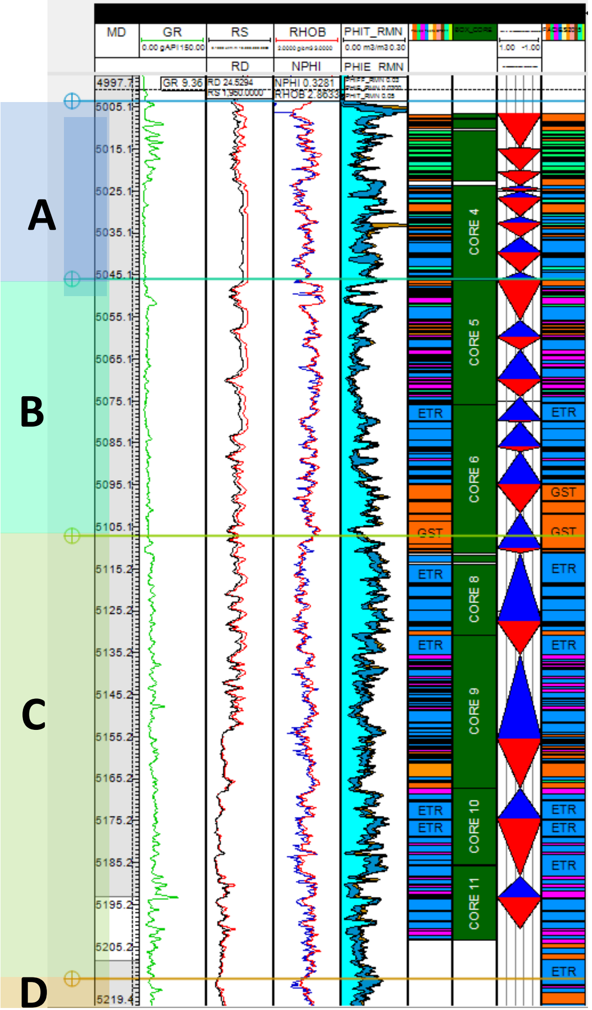
IFS – initial flooding surface
MHS - maximum humidity surface
MFS – maximum flooding surface
IES – initial exposure surface
MLS - maximum lowering surface

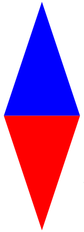
High resolution stratigraphy



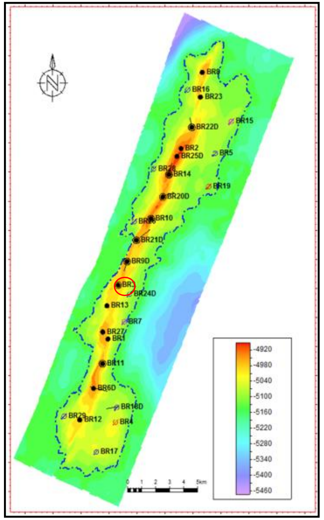
GRAINSTONE
LAMINITE
SPHERULITITE
STROMATOLITE

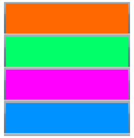
Well BR-3



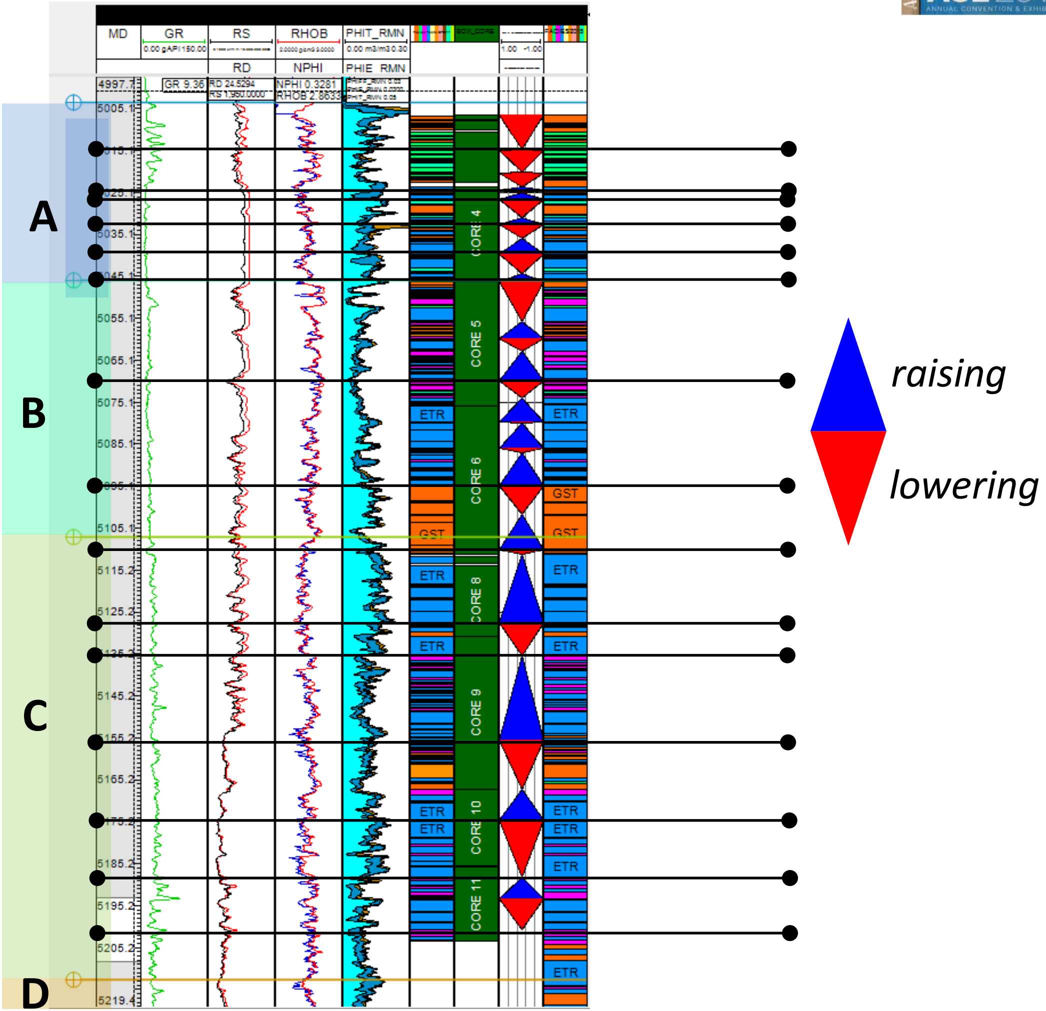


High resolution stratigraphy

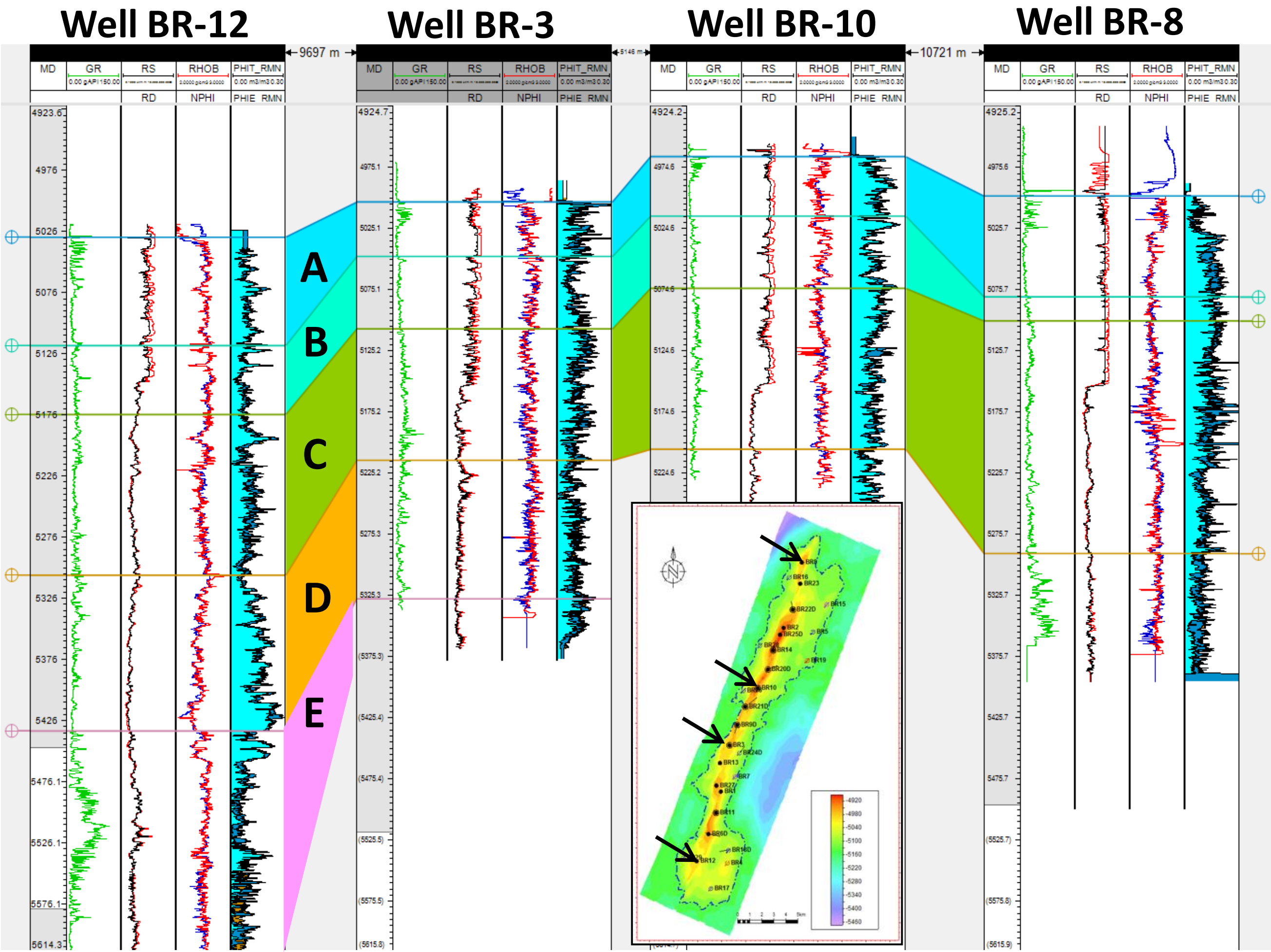




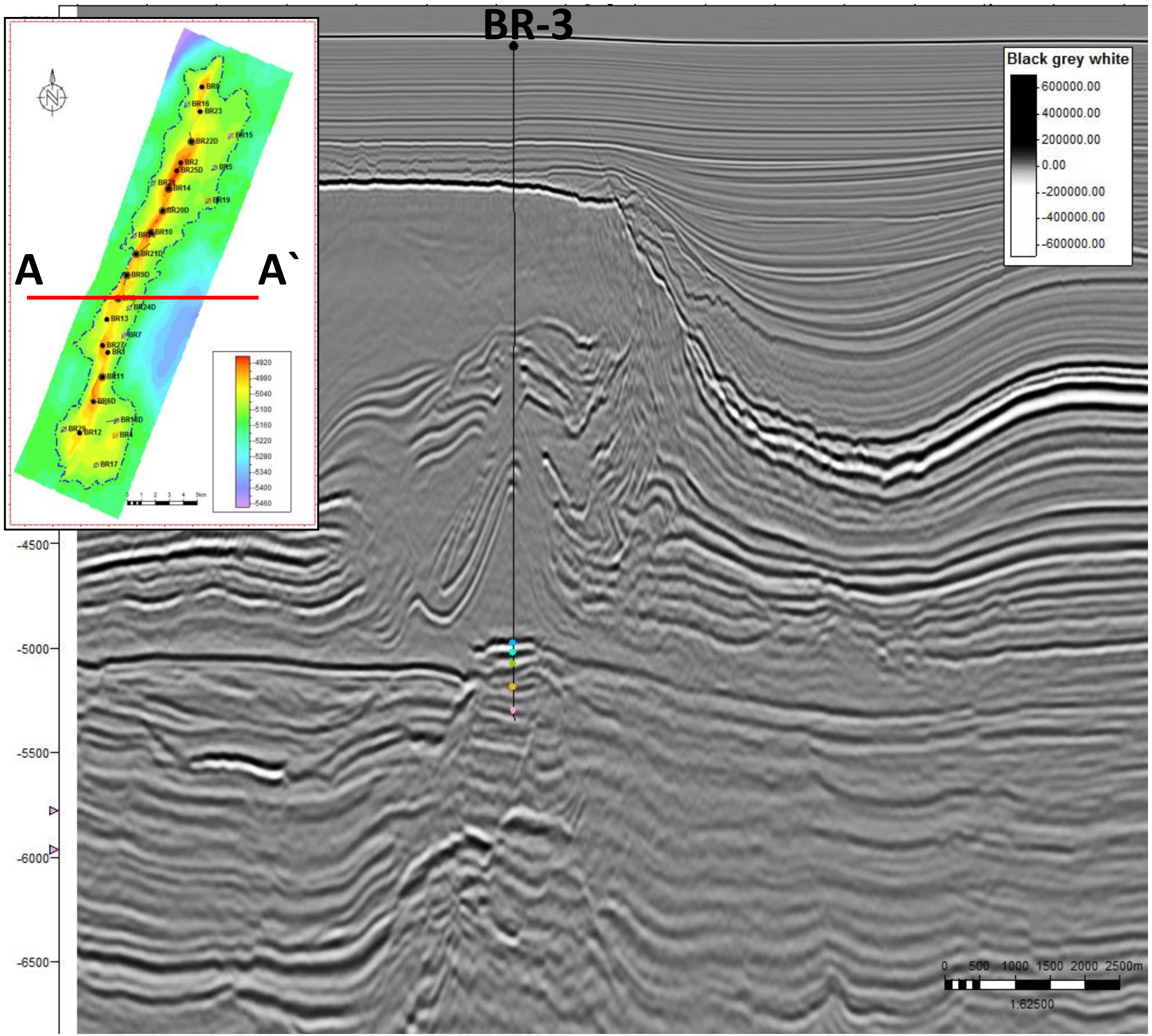
Well BR-3



Reservoir Zonation

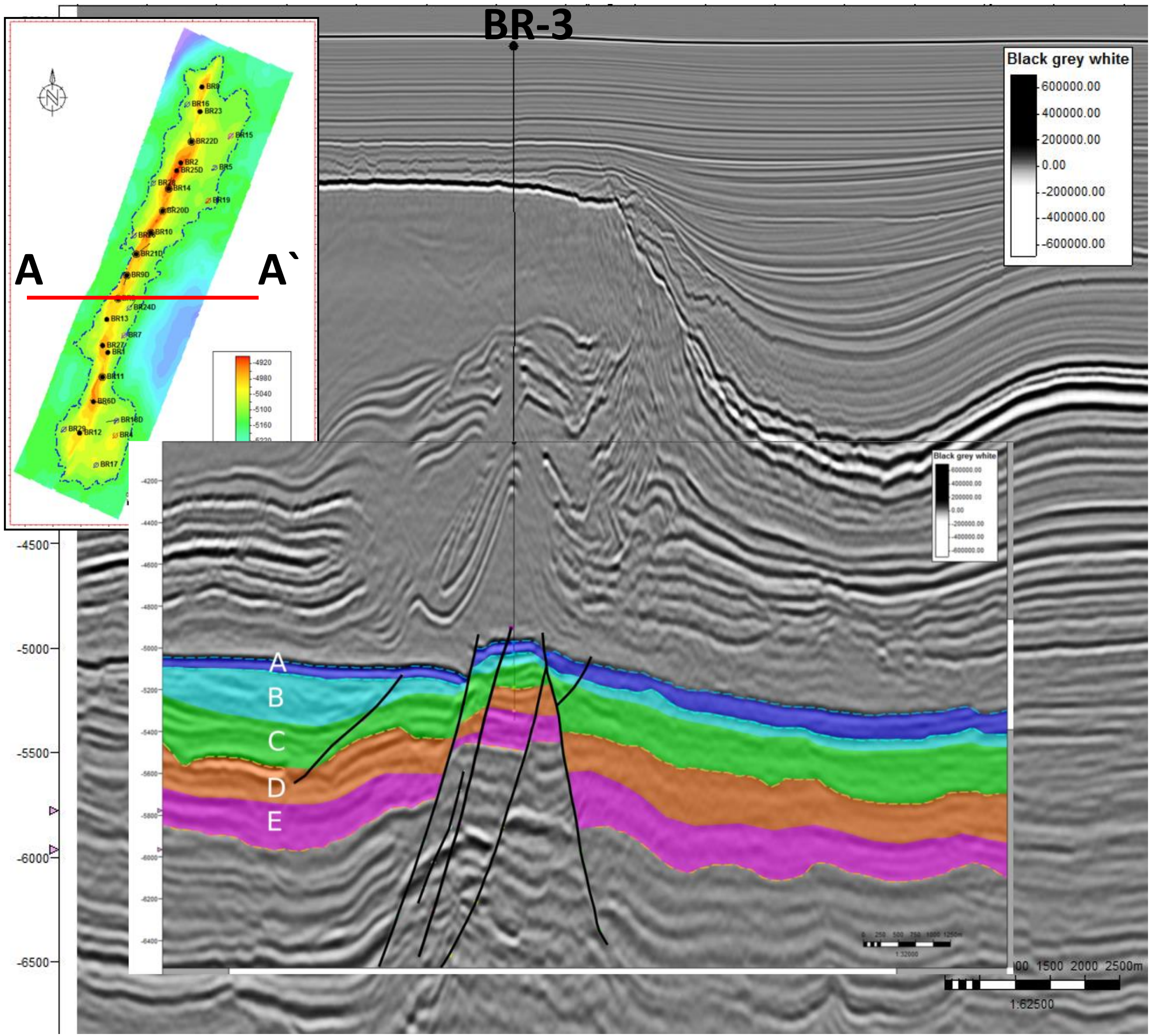


Zones on seismic



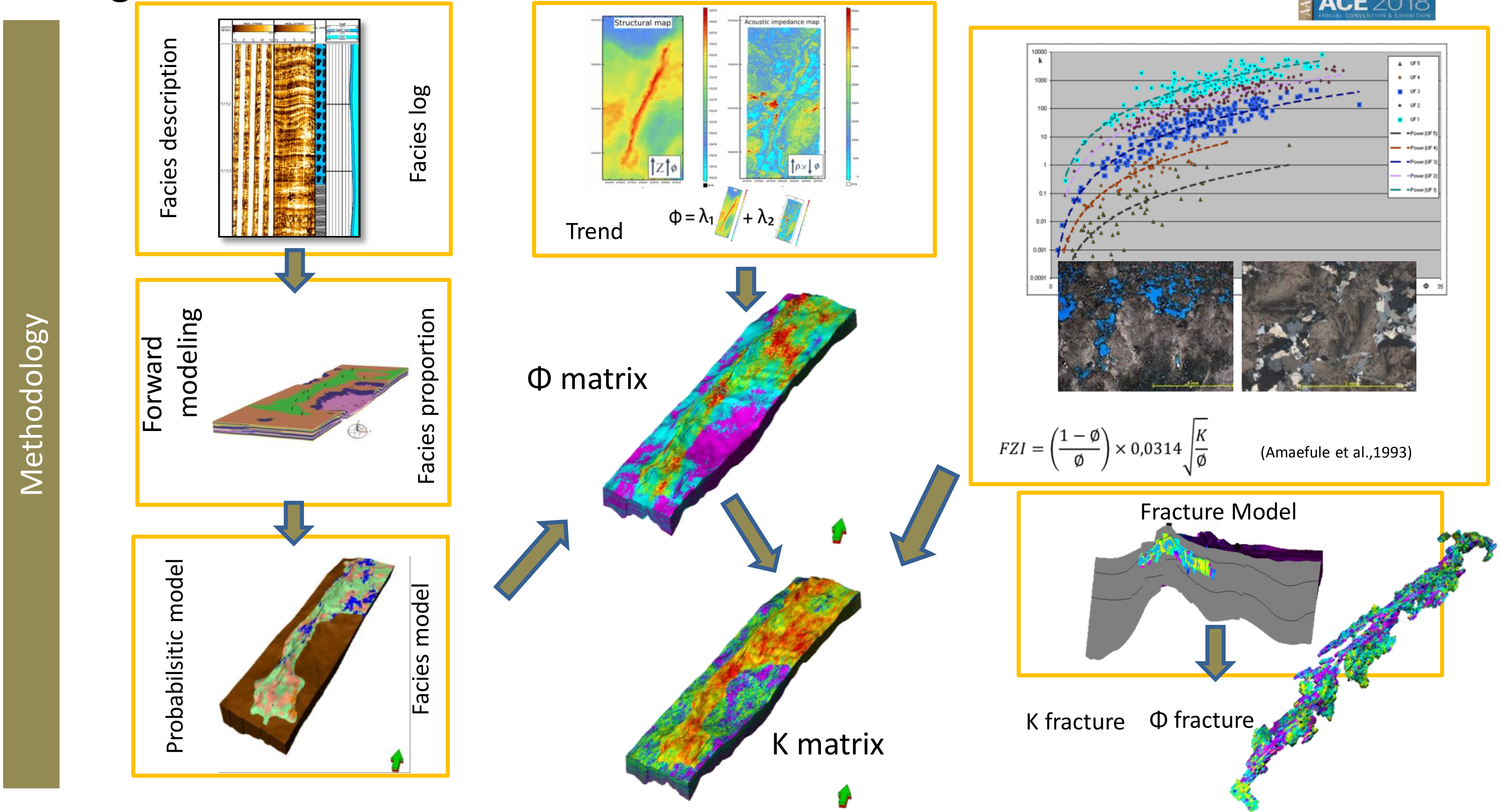
vertical exaggeration = 3x

Zones on seismic

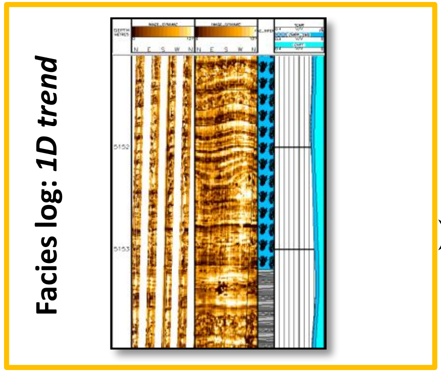


vertical exaggeration = 3x

Geological model workflow



Facies model



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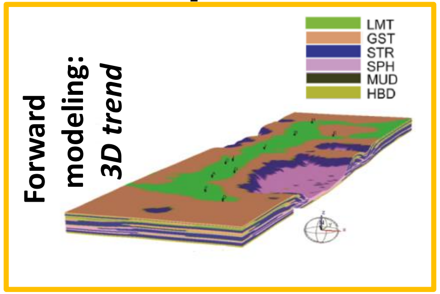

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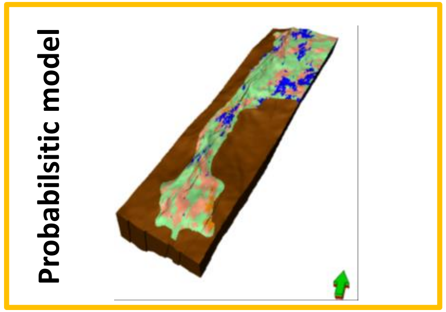


- facies log using the rock descriptions and image log
- 3D facies proportion matrix using depositional processes modeling
- facies geostatistical simulation to honor well data

Stratigraphic-sedimentological forward modeling

➢ can be used to test and quantify concepts about the evolution of the carbonate platform.

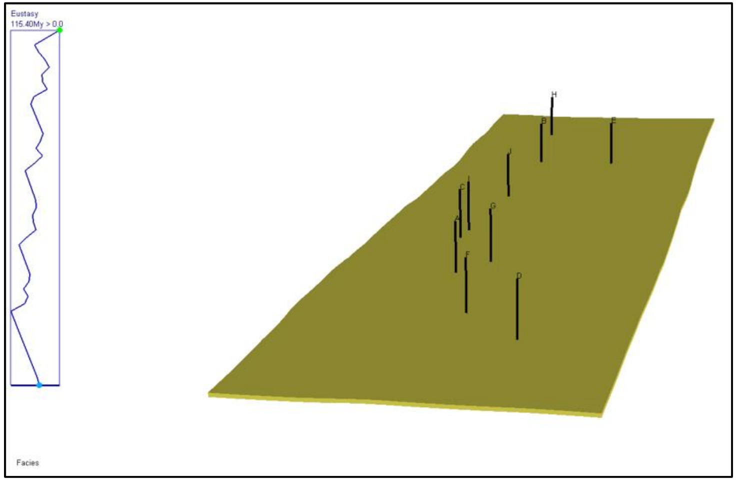
For each time step chosen, 3 main processes are considered:

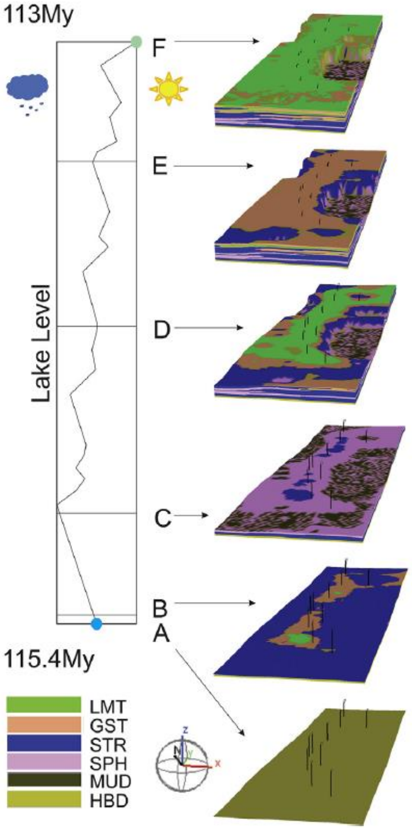
i) Accomodation space (subsidence + △ lake level)

ii) Production of carbonate facies by time (m/My)

iii) Coefficient *of* carbonate facies productivity by bathymetric range

Subsidence = 0.05mm/y
Deposition = 0.08mm/y

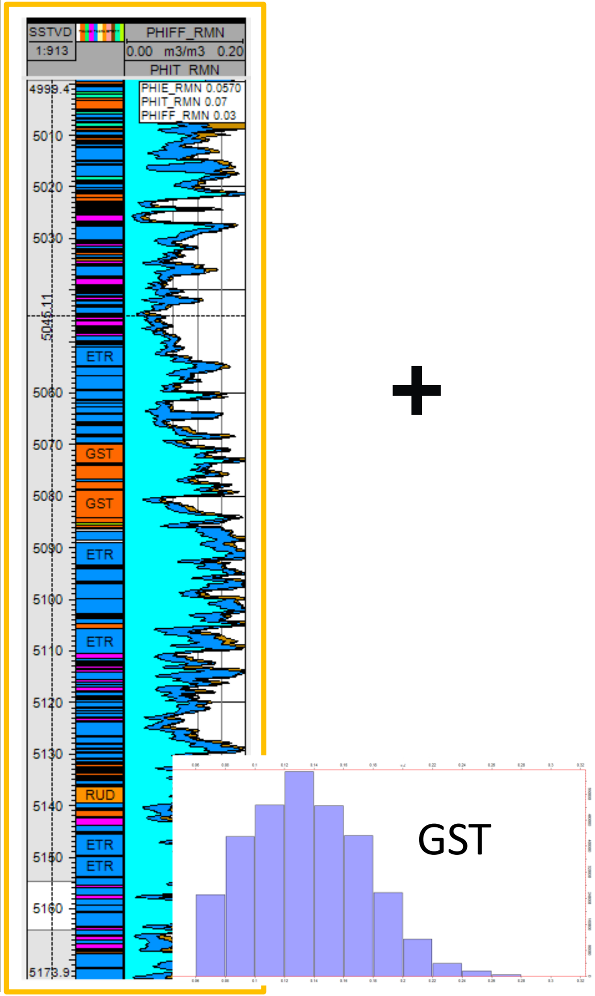




(Faria, D.L.P., Reis, A.T. & Souza Jr, O.G., 2017)

Porosity model

1D data



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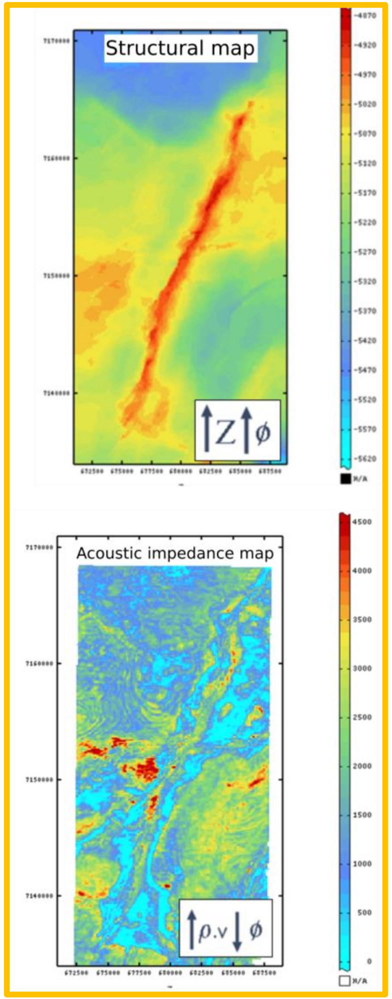
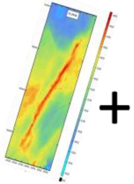
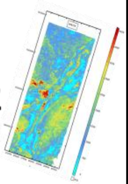
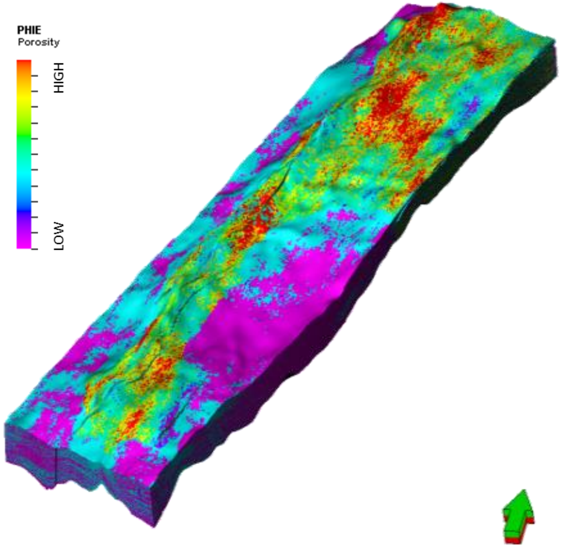
2D trend for each zone

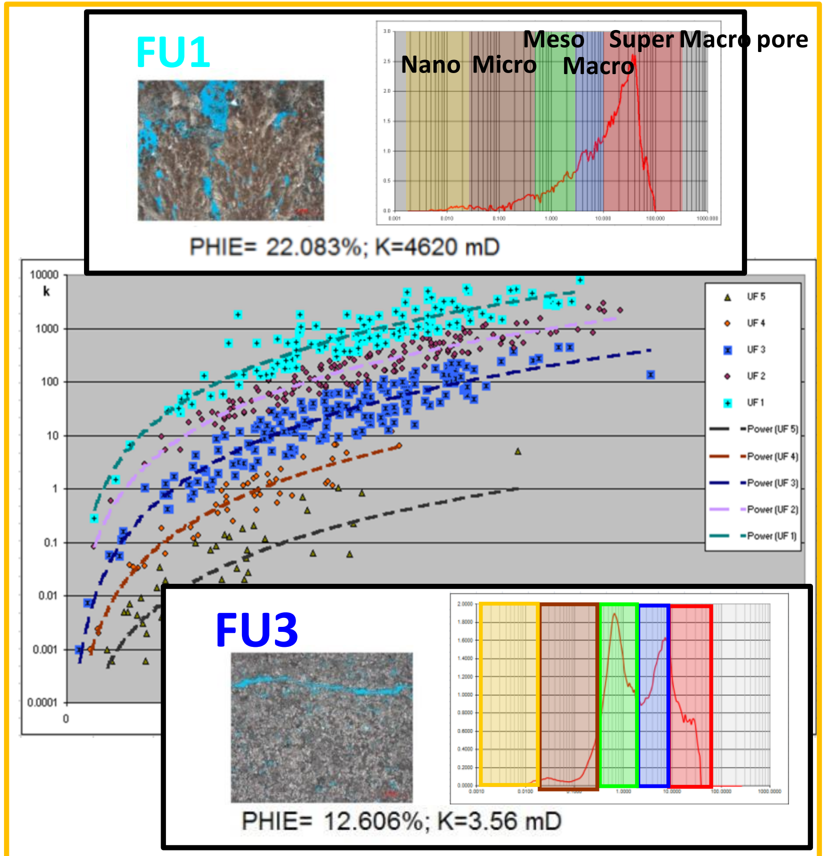


$\Phi = \lambda_1$  $+ \lambda_2$ 

=Φ matrix



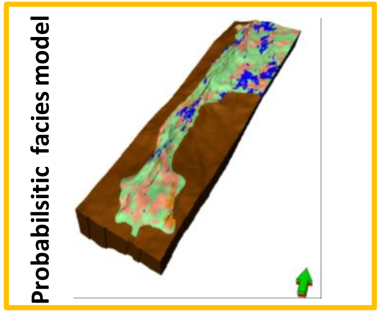
Permeability model



$$FZI = \left(\frac{1-\emptyset}{\emptyset}\right) \times 0{,}0314\sqrt{\frac{K}{\emptyset}}$$

(Amaefule et al.,1993)

- For a facies, the same porosity may have different permeability values
- Different types of rocks can have similar flow properties



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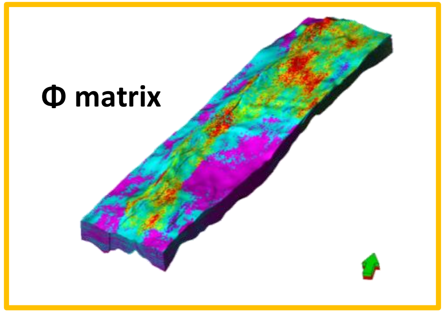
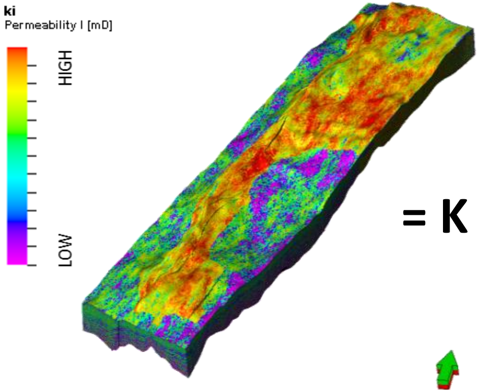




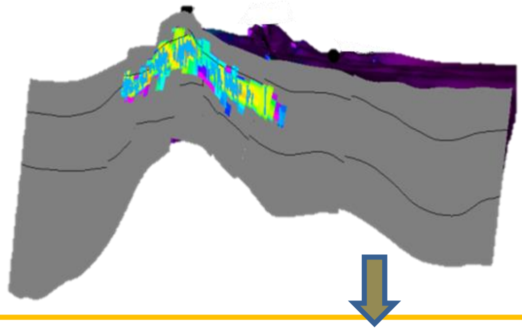
= K matrix

Fracture model

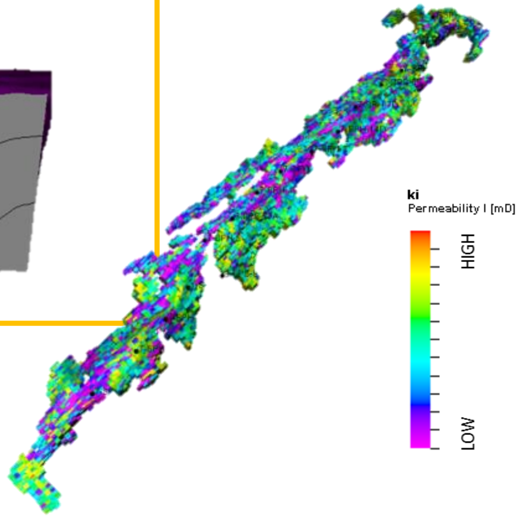
Discrete Fracture Network

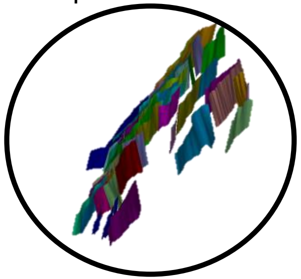
(DFN)

Fracture Model

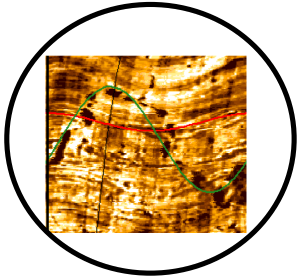


K fracture Φ fracture

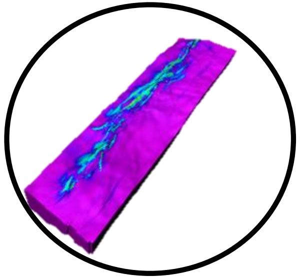




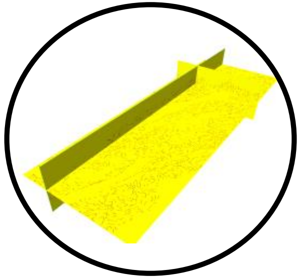
Faults: Seismic



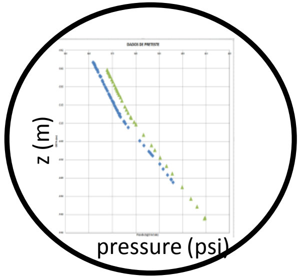
Fractures:Well



Strain



Vector-azimuth



Pre-test

Attributes

Conclusions

- The forward stratigraphic-sedimentological model was able to build a 3D facies distribution matrix to be used as a trend in the facies probabilistic model;

- The combination of impedance and structural maps as a 2D trend in the porosity model seems to be realistic when compared to well data;

- The permeability model, based on FZI concept and controlled by facies and porosity, can characterize the permeability generated by the diagenesis of the rocks, which impacts directly on the reservoir quality;

- The 2ϕ2k model indicates the permeability anisotropies and was the most suitable configuration for the history match;

- This workflow allowed us to build a geological model that represents most of the reservoir’s facies and permo-porosity heterogeneities. This is fundamental for the history match and production prediction, to improve the field management and to generate more accurate production curves;

- Co-working learning and experience exchange are essential for the constant improvement of the techniques shown in this workflow.

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