The Use of Seismic Inversion Results as an Input in a High Resolution Petroleum System Modeling in the Santos Basin, Brazil*

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Abstract

We show the application and results of a methodology for high resolution lithology definition in a petroleum system model of the Santos Basin, Brazil. More and more high resolution G&G data is collected during exploration campaigns. Seldom do we use all the data at this high resolution. The inversion of 3D and 2D seismic data allows us to define physical properties within the subsurface at very high resolution.

In Basin and Petroleum Systems Modeling (BPSM) we have historically focused on the low-resolution, regional scale. With advances in computing power, resolutions are increasing, demanding high resolution input data.

We present a workflow of the integration of G&G data to populate a BPS Model with high resolution facies properties. After building a standard petroleum system model, the seismic data, calibrated with petrophysical and geological well information (using empirical and theoretical rock physics), were employed to assign a high resolution facies distribution for the post-salt stratigraphic units of the Santos Basin. The goal of this study was to define an accurate, high resolution geologic input forming the basis for a more reliable assessment of the hydrocarbon charge risk.

Following a Bayesian Neural Network approach, the petrophysical data set and seismic attributes were used for a lithologic facies inference at the seismic volume. First the petrophysical data were utilized to create local probability density functions (fdps) associated to each facies at seismic attribute domains. Then 3D probability models for each facies were constructed using these fdps

together with the seismic attributes from seismic inversion of the seismic cube. The obtained probability models were employed as inputs for all inference work regarding the facies distribution.

The petroleum system model was initially built at standard resolution, making use of seismic interpretation data, regional facies distribution, and geochemical information. The boundary conditions were defined, and the model was calibrated with the available thermal and geochemical data. In order to upgrade the calibrated model to higher resolution, the model's layers were subdivided and the grid was refined to increase the vertical and horizontal resolution within the layers of interest. The resolution of the seismic inversion results is still too high to assign directly to the model. Therefore, the inversion data were upscaled to this new grid-resolution in order to redefine the facies distribution within the post-salt section at high resolution, based on the geophysical-petrophysical analysis of the seismic data.

Two key advantages result from the presented modeling approach:

1. The high resolution facies distribution allows for a high resolution fluid migration during simulation of this refined model. This is particularly important in areas where stratigraphic trapping mechanisms are important. Additionally this methodology will allow modeling of small hydrocarbon accumulations, such as satellites to known fields. In the standard low resolution models, small satellite fields will be too small to be predicted by the model.
2. Due to the very accurate lithologic predictions based on the seismic inversion data, we can much better predict any potential high-pressure zones in the area of any drilling prospects. The better prediction of formation pressure is not only important to drilling safety, but also to the volumetric prediction of any hydrocarbon accumulations, due to a better porosity modeling.

The presented methodology integrates well information, seismic attributes, and rock physics with the petroleum system model, enabling a better understanding of the dynamics between sediments and fluids, and provides an accurate tool to better evaluate the exploration risk.

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Agenda

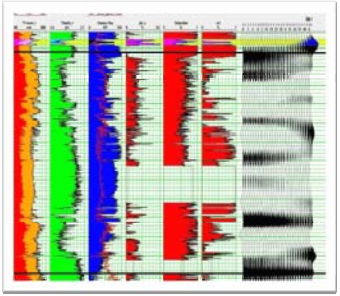
1. Introduction
   - Motivation
   - Workflow
2. Concepts
   - Facies Simulation
   - Seismic Inversion
   - Facies Refinement
3. Petroleum Systems Modeling
4. Final Remarks

Motivation

Large efforts are made to use and integrate

-Petrophysical data
-Seismic data
-Well data

In development and production exercises.



But …
we generally do not use the generated information for exploration, particularly in Petroleum Systems Modeling.

So …
we decided to use this already available work, and apply it to improve our PSM.

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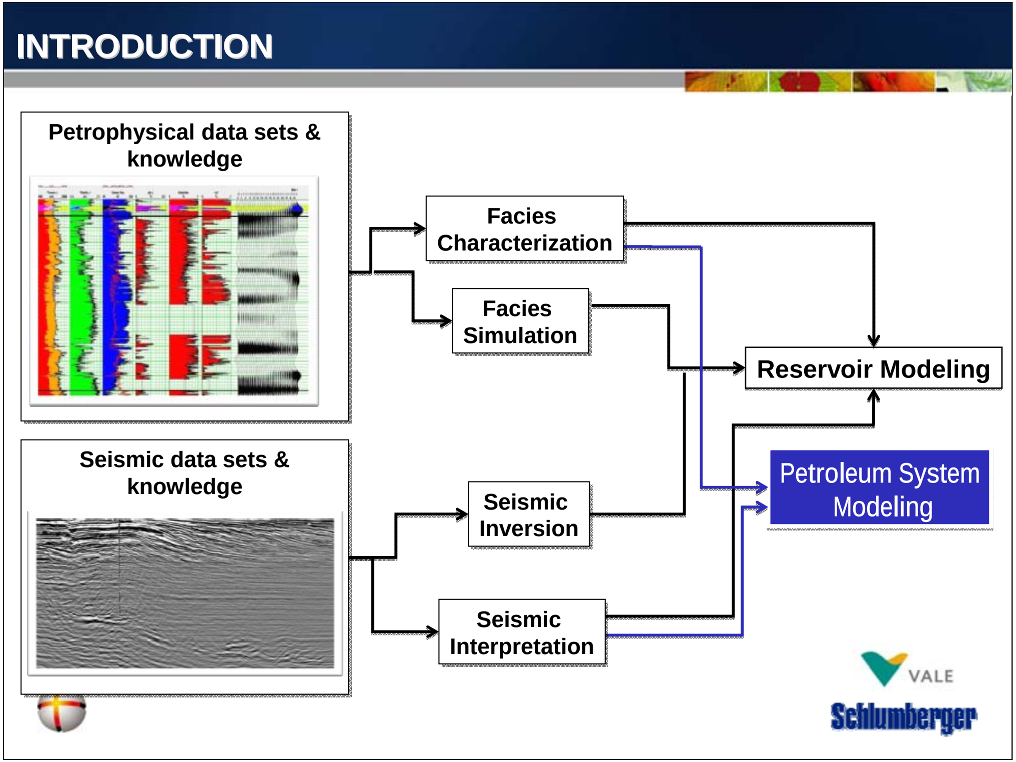


Presenter's Notes:

We have both petrophysical and seismic data and knowledge in our team, but we were only using part of this in our petroleum system model. But there are other products of the work done with these data that were already being used for the reservoir modeling. Thus, we decided to use this work, that was already available, and use it to improve our PSM.

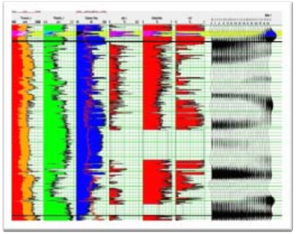
Work-flow for facies inference:

i- from well log data and using a Bayesian neural network, we infer the number of facies and classify these facies on the well log samples.

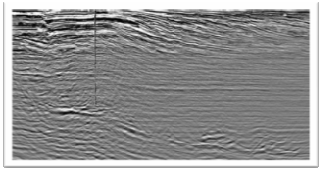
ii- With the facies inferred from well log data and elastic properties, computed from seismic inversion, we infer a facies model for the seismic volume. The output is a collection of cubes: for each facies will be a cube of probability forthe facies to occur. From these cubes of probabilities one can compute a likely 3D model of facies.

INTRODUCTION

Petrophysical data sets & knowledge



Seismic data sets & knowledge



Facies Characterization

Facies Simulation

Seismic Inversion

Seismic Interpretation

Petroleum System Modeling

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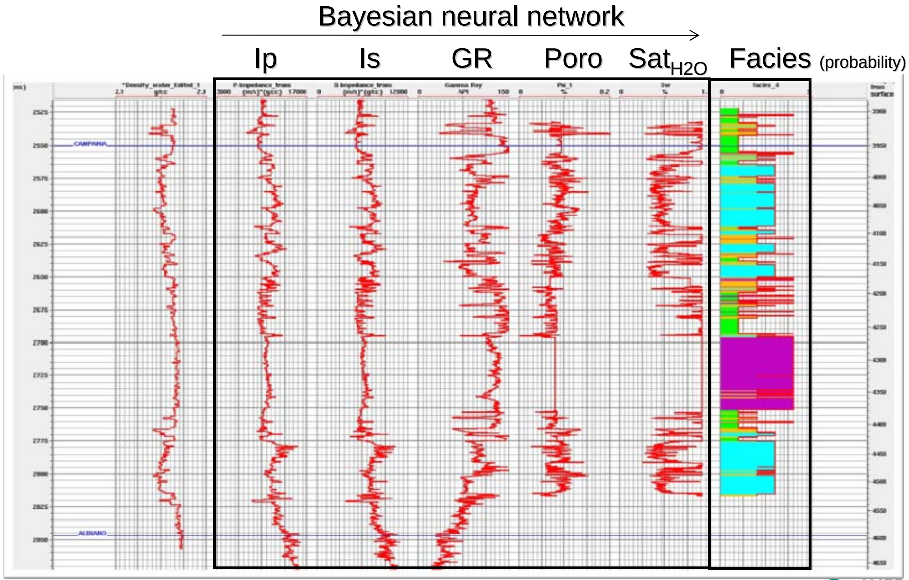
FACIES SIMULATION – Step 1



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Presenter's Notes:

With the petrophysical logs, the facies were inferred, and then related to the inverted seismic attributes in order to be able to define the facies at each cell from the seismic volume, given a couple of seismic attributes.

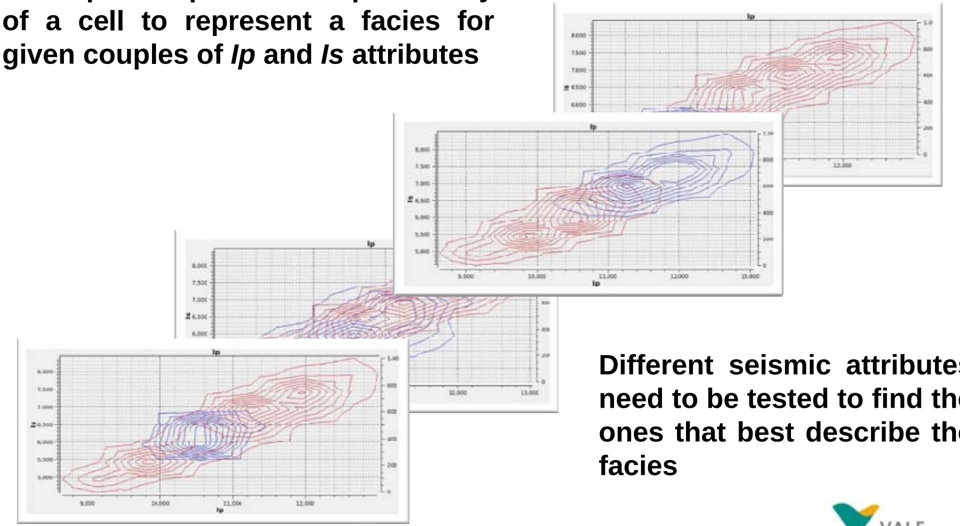
These logs are density, P-impedance (Ip), S-impedance (Is), Gamma-ray, porosity, water saturation and facies.

Four facies was inferred from well logs: 1- green (shale), 2 - orange (dirty sand), 3 - cyan (clean sand), and 4 - purple (shale).

The facies was inferred from gamma ray and porosity. These facies was classified at the Ip and Is domain.

FACIES SIMULATION – Step 2

cross-plots represent the probability of a cell to represent a facies for given couples of *Ip* and *Is* attributes



Different seismic attributes need to be tested to find the ones that best describe the facies

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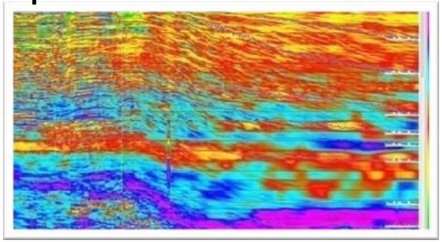
Presenter's Notes:

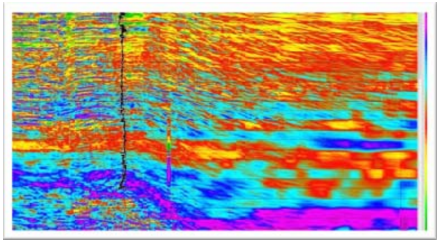
These cross-plots represent the probability of a cell to correspond to different facies given the two attributes Ip and Is. Other cross-plots are made, with different attributes, in order to determine the ones that better describes the facies, and then they are used to obtain the probability of a cell to be each defined facies.

SEISMIC INVERSION

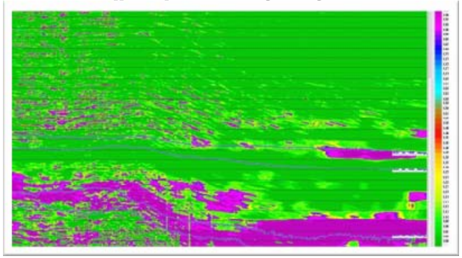
Ip



Is



Probability of Facies 3 (clean sands) to occur (purple = high; green = low)



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Presenter's Notes:

Then, after choosing the two attributes that describe each facies, we compute the probability of each facies to occur.
Here the Ip and Is seismic attributes are represented and on the right the probability of occurrence of facies 3, that is the clean sands.

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   - Modeling results
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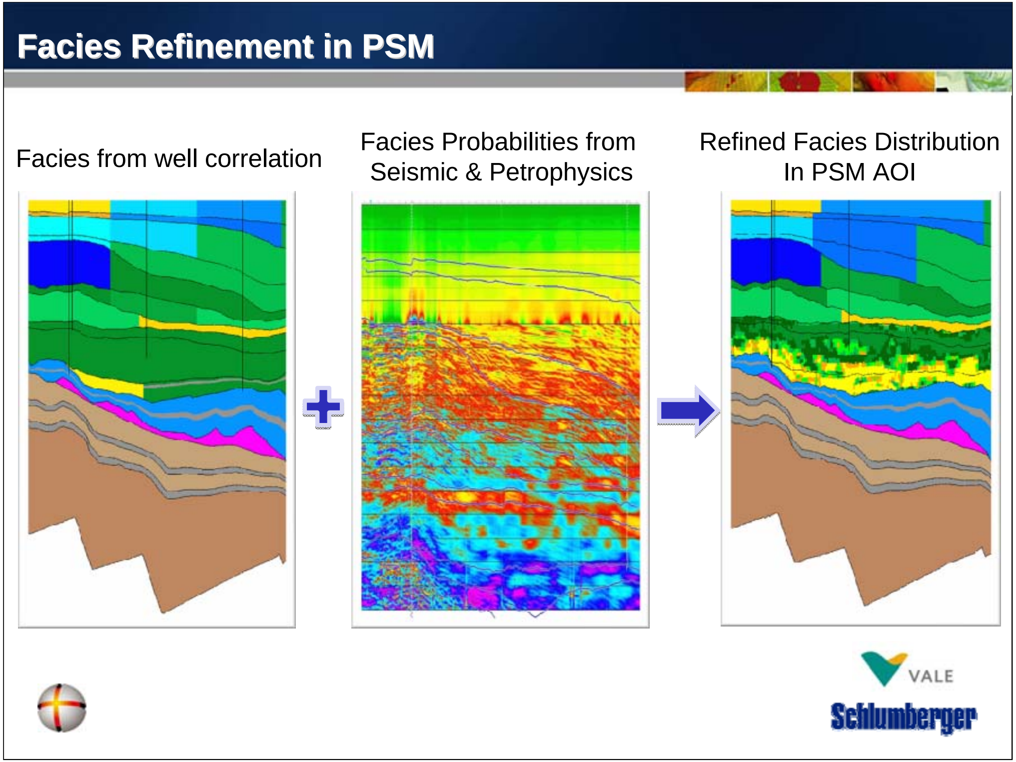
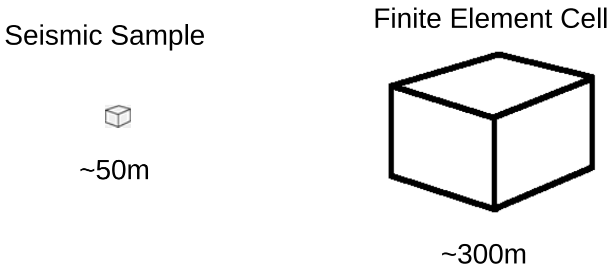


Presenter's Notes:
For the first try, we decided to use a 2D PSM that had been built in a traditional way, and incorporate facies probability obtained from seismic inversion, in order to achieve a more refined facies distribution.

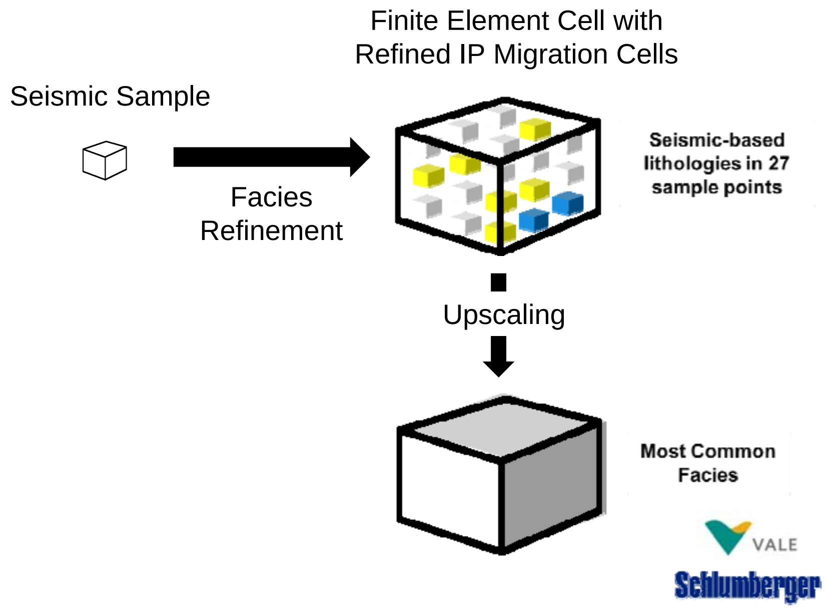
Seismic X PSM Resolution



Presenter's Notes:

The resolution of the seismic data is much more precise than the one of our PSM.

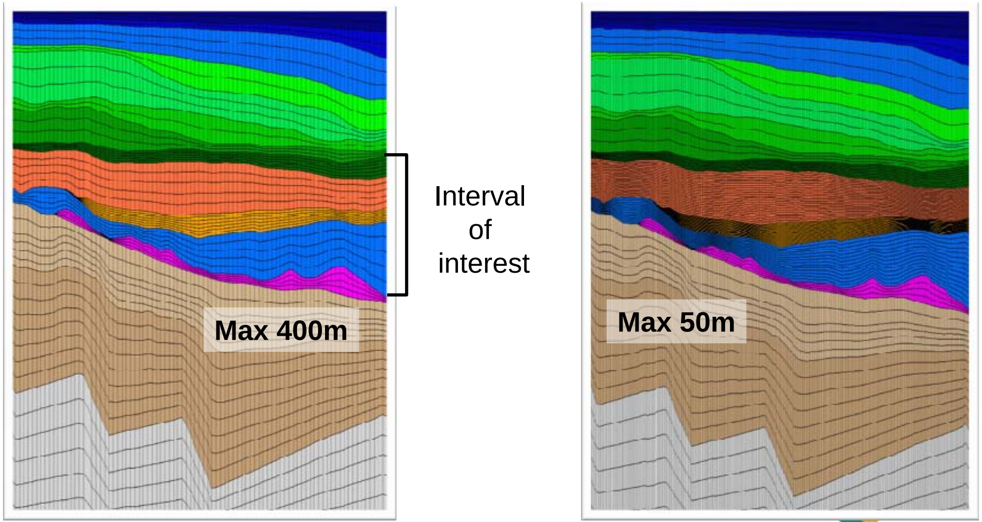
Facies Refinement Tool



Presenter's Notes:
The way we used to bring the information from the seismic sample to our fine element cell was through the upscaled option of the facies refinement tool, from Petromod, where the facies is defined in 27 sample-points within our PSM finite element cell, and then the most common facies is applied to the entire cell.

PETROLEUM SYSTEM MODELING

Change finite element resolution of Interval of Interest



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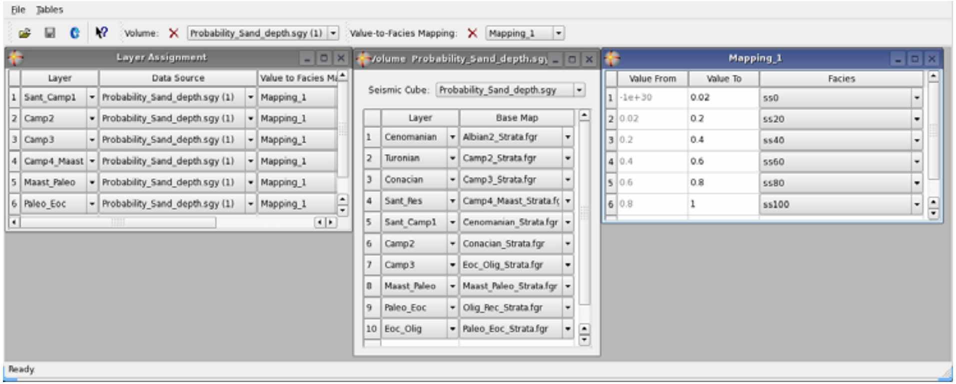
Presenter's Notes:

In order to better represent the facies distribution, the first thing that was done was to refine our model, vertically and horizontally.

PETROLEUM SYSTEM MODELING

PetroMod© Facies Refinement Tool



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Presenter's Notes:

Then, in the facies refinement tool of Petromod, we selected the seismic cube that were to be used, then defined which values would represent pre-defined facies, and applied it for the layers that would be refined.

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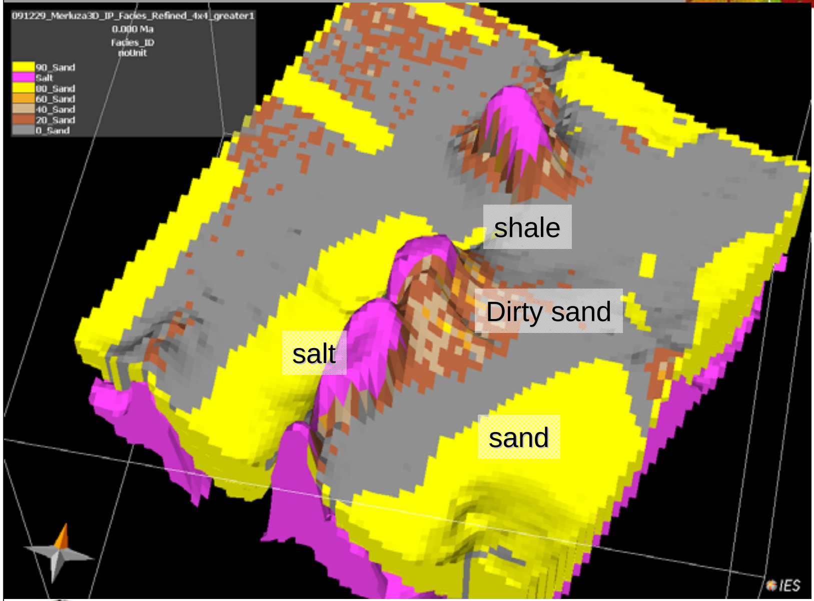
PETROLEUM SYSTEM MODELING



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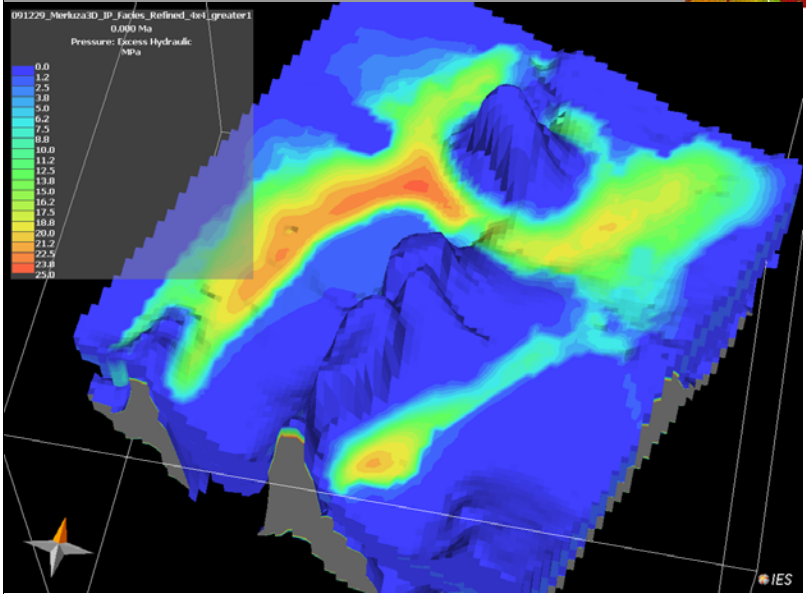
PETROLEUM SYSTEM MODELING



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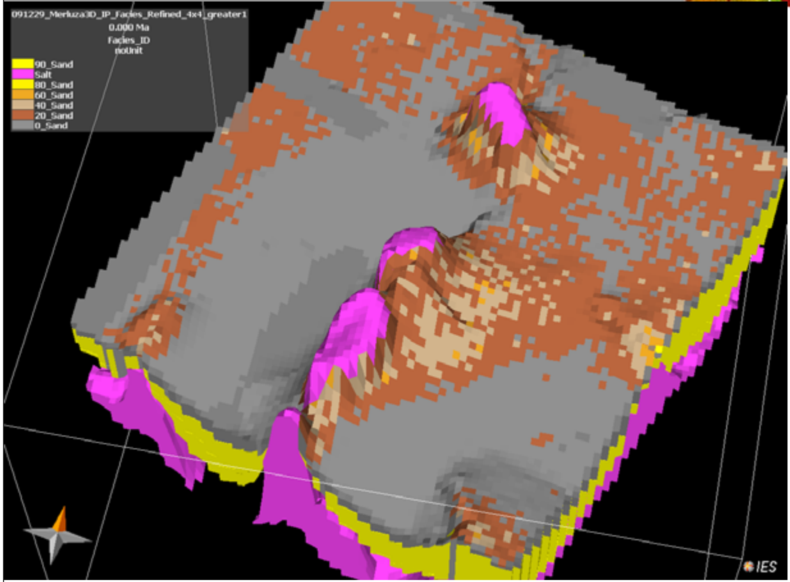
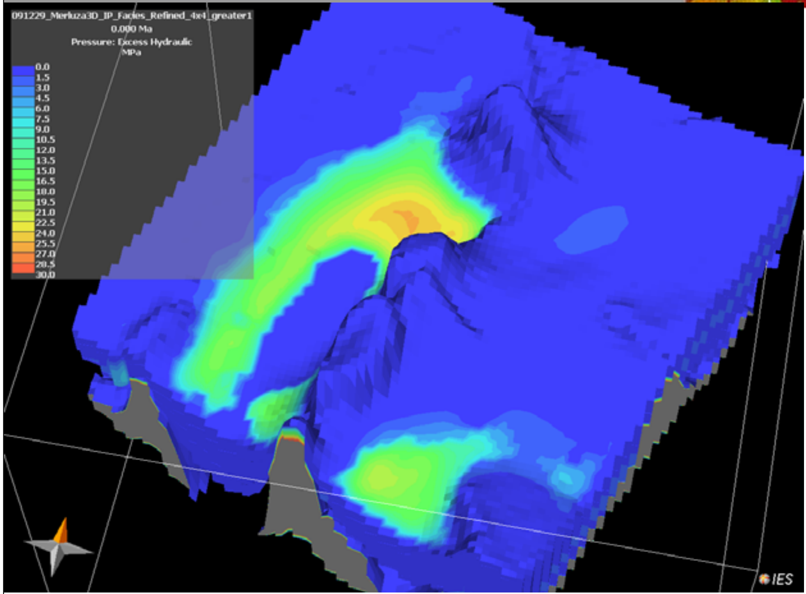
PETROLEUM SYSTEM MODELING



PETROLEUM SYSTEM MODELING



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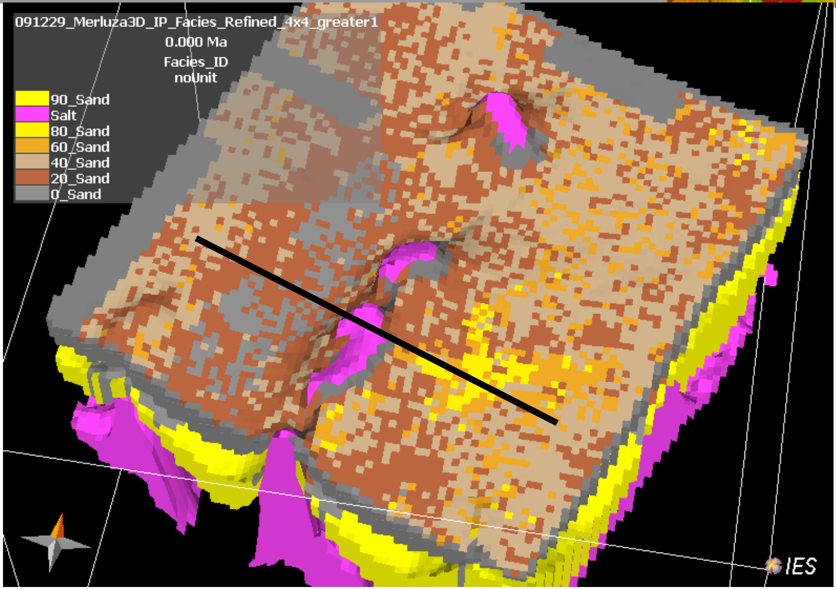
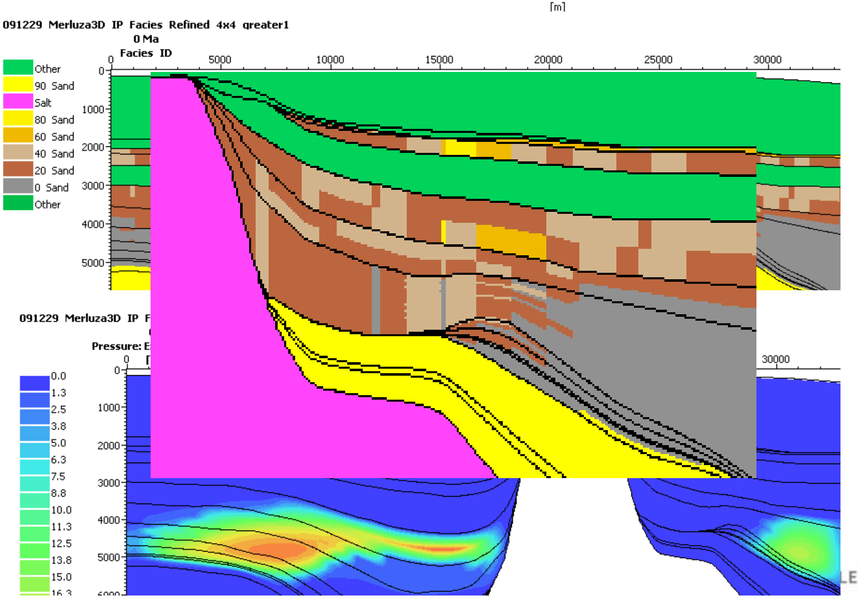
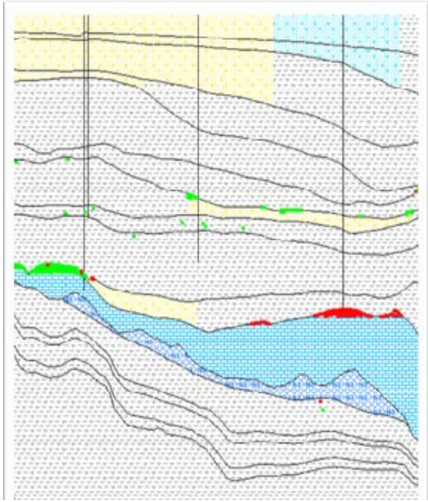
PETROLEUM SYSTEM MODELING

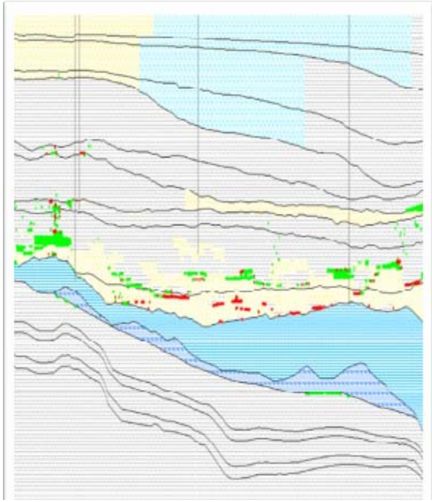


PETROLEUM SYSTEM MODELING



PETROLEUM SYSTEM MODELING





Presenter's Notes:

Petroleum saturation obtained with Darcy simulation with and without the facies refinement.

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FINAL REMARKS

- Use of real seismic data to populate a Petroleum systems model at high resolution
- Full Integration of Petrophysics, Geophysics and PSM
- High Resolution Model
- More realistic, High Resolution Simulation Results from Compaction (OP) to HC Migration (IP)

Acknowledgment

- **Vale**
- **Schlumberger**

Thank you