Integration of Sedimentology and Stratigraphy in a 3D Static Model: Example from the Echinocyamus Formation in the Block X, Talara Basin, NW Perú*

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Two Key Questions

- Can we efficiently incorporate the Sedimentology and Stratigraphy in a 3D Static Model, considering the complexity of Talara Reservoirs?
- What is the best way to integrate the diagenetic complexity in these models?

Objectives

- Characterize the facies associations to interpret the depositional model;
- Create a stratigraphic framework for propagation of petrophysical properties;
- Assess the diagenetic impact in determining the reservoir quality distribution;
- Expected Results: optimization, risk and uncertainty reduction in EOR projects.

Conclusion

The integration of sedimentology and stratigraphy, combined with geostatistical tools, provided a better understanding of geometrical relationships and connectivity potential of the reservoirs within each stratigraphic unit.

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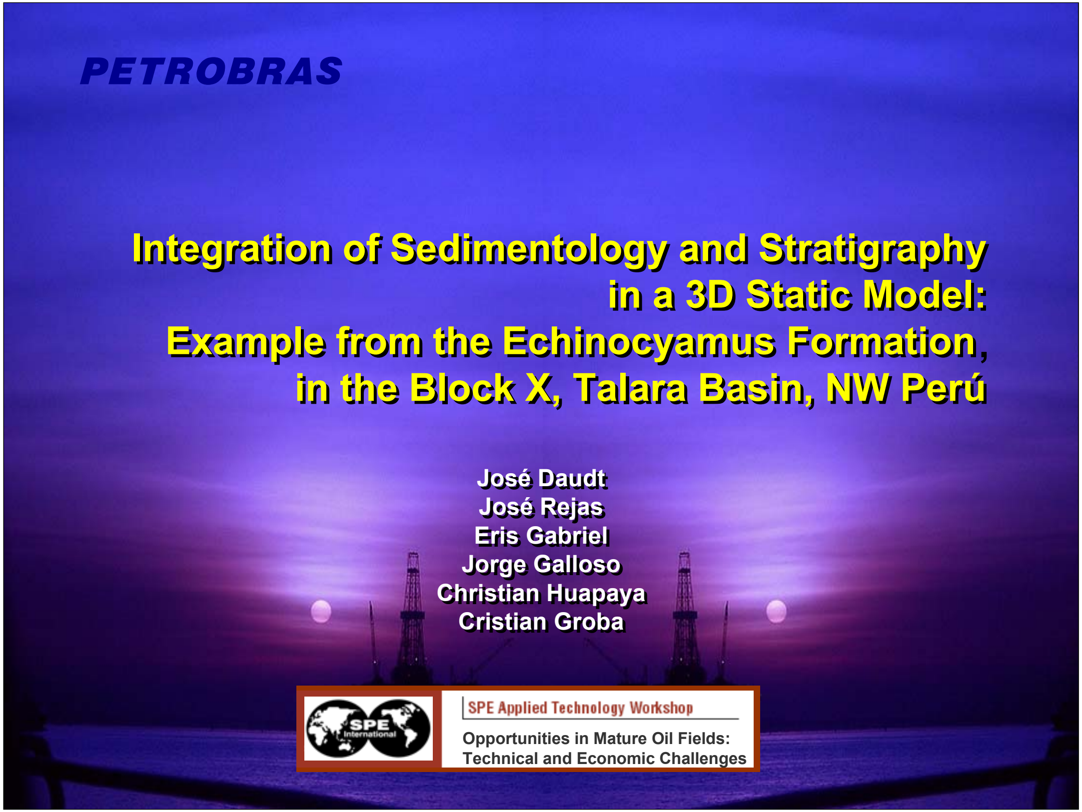
The stratigraphic framework defined new surface-based compartmentalization that is important to guide new strategies of stimulation and injection planning, resulting in an optimization of the project (better sweep efficiency);

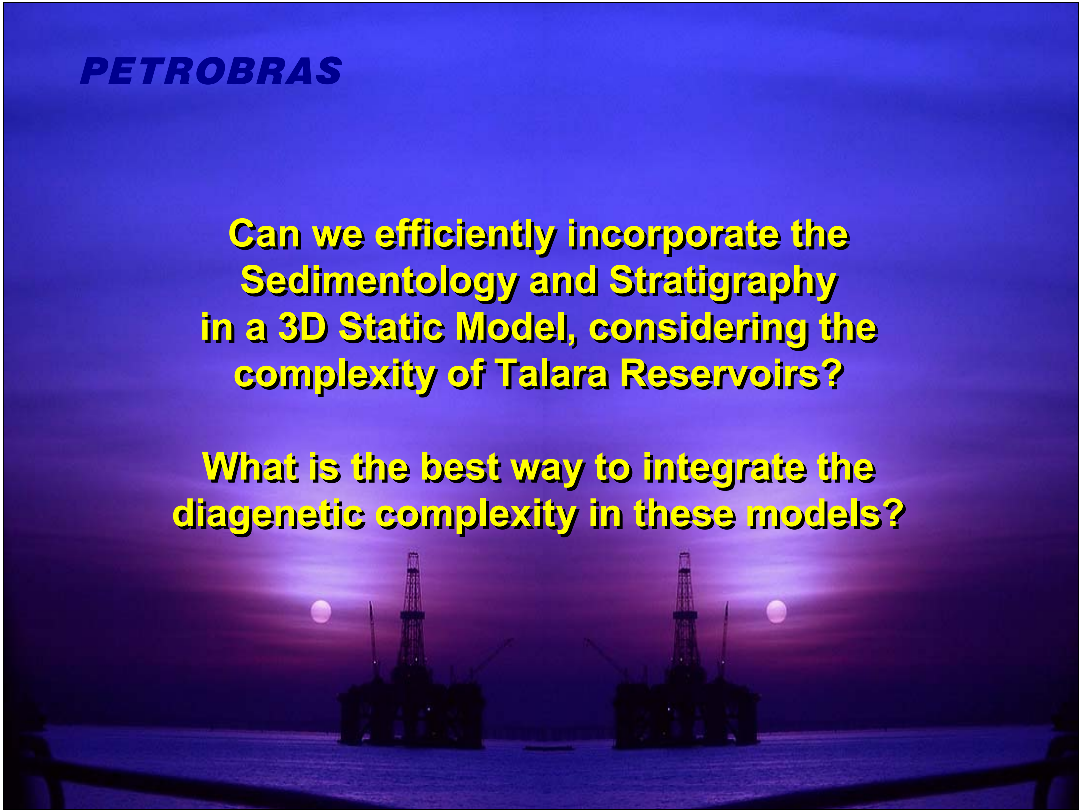
Diagenetic studies will provide a reservoir petrofacies model that may establish the link between the FZI and the stratigraphic framework.

Reference

Daudt, J., and C.M. Scherer, 2006, Facies architecture and depositional model of the fluvio-deltaic reservoirs of the Echinocyamus Formation (lower Eocene) in the Block X area, Talara Basin, NW Peru (written in Portuguese): Boletim de Geociências da Petrobras, v. 14, no. 1, p.27-45.



Presenter's Notes: This work presents an example of integration of sedimentological and stratigraphic concepts in a 3D static model in order to support secondary recovery projects.


PETROBRAS
Can we efficiently incorporate the Sedimentology and Stratigraphy in a 3D Static Model, considering the complexity of Talara Reservoirs?
What is the best way to integrate the diagenetic complexity in these models?

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Objectives

- Characterize the facies associations to interpret the depositional model;

- Create a stratigraphic framework for propagation of petrophysical properties;

- Assess the diagenetic impact in determining the reservoir quality distribution;

- **Expected Results:** optimization, risk and uncertainty reduction in EOR projects.

Presenter's Notes:

The objectives:

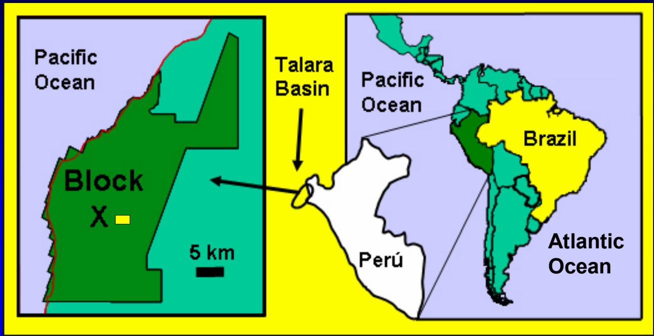
1- To build more robust and logical depositional models that better represent the reservoir geometry and connectivity. In our opinion, we need to put more depositional-model concepts in the 3D static models because this will be crucial for better geometric characterization.

2- To understand the stratigraphic evolution based on variations in the depositional model. The stratigraphic framework will be very important to the propagation of petrophysical properties, as the stratigraphic surfaces are the best constraint for it.

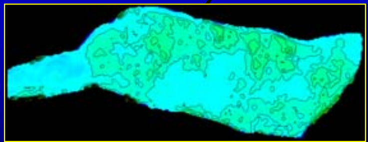
3- To create a methodological approach to incorporate diagenesis. This item is in progress; some some preliminary observation and ideas are presented.

The expected results are related to optimization, risk and uncertainty reduction, especially in secondary recovery projects. The optimization, with quite a wide array of concepts, may be represented by a series of different activities and plans to increase the oil recovery (from drilling new wells to be more precise in determining the best interval to stimulate, for instance).

Area Block X:
470 km^2



1 Km



Studied Area (B9-Ballena):
3.8 km x 1.1 km

Data Base (this study):
7 Cores (86 plugs), 400 m
Approx. 4,500 wells in the Block X
48 wells in the B9 Area
No seismic available

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What we “think” we know...

A <u>geological</u> “point of view”...

We may be able to explain the production trends, the HC distribution and its displacement by…

- **Tectonics:** syn - & post-depositional structural trends;
- **Sedimentology:**
  - a) facies architecture
  - b) facies architecture + Diagenesis
- **Stratigraphy:** stratigraphic framework

KEY WORD:
INTEGRATION

Presenter's Notes:

General ideas to explain the hydrocarbon distribution, considering different scales and kinds of reservoir compartmentalization. The structural approach has always been very important in Talara Basin. The tectonics, of course, plays a very important role in determining the first-order reservoir compartmentalization. However, for secondary recovery projects, Sedimentology and Stratigraphy begin to increase in importance--in characterizing smaller-scale heterogeneities. In any case, the integration of these three disciplines is vital for better models that aim to incorporate different scales of reservoir heterogeneities.

Example of Geological Characterization in the B9-Ballena Area, Block X, Talara Basin, Peru

Unit: Echinocyamus Formation (Lower Eocene)

Presenter's Notes: Presented is an example of static reservoir characterization of the B9, Ballena Area, Block X, Talara.

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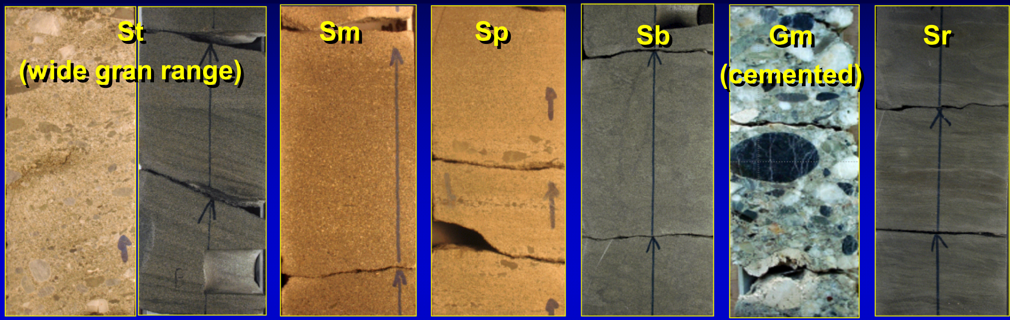
Facies Characterization



Decreasing Reservoir Quality →

Facies Associations

Depositional Domain	Sub-environment (MFA)	Facies Associations
FLUVIAL	Fluvial Indiviso (reservoir + flood plain)	Gm / Sp / St / Sm / Fm Cycles: Gm+St+Sp+Sm; St+Sp+Sm; St+Sp
DELTAIC	Delta Plain	Gm / Sp / St / Sm / Fm (difficult to separate from MFA Fluvial)
	Delta Front	Sb / Sr (subordinate: Sh / Fm / St / Sm)
	Prodelta	Ssl / Fm / Fms / Sb (subordinate: Sr / Sp)

Daudt & Scherer, 2006

Presenter's Notes:

The model was built after examination of almost 400 meters of core descriptions allowed us to identify 7 or 8 main lithofacies (some of them with different range in grain size). After this, these lithofacies were considered in an associated way, attempting to characterize sub-environments of deposition (or, what we called "Major Facies Associations"). Two main depositional domains were established: fluvial and the deltaic (the latter one was subdivided in smaller units according to the Major Facies Associations: delta plain, delta front and prodelta).

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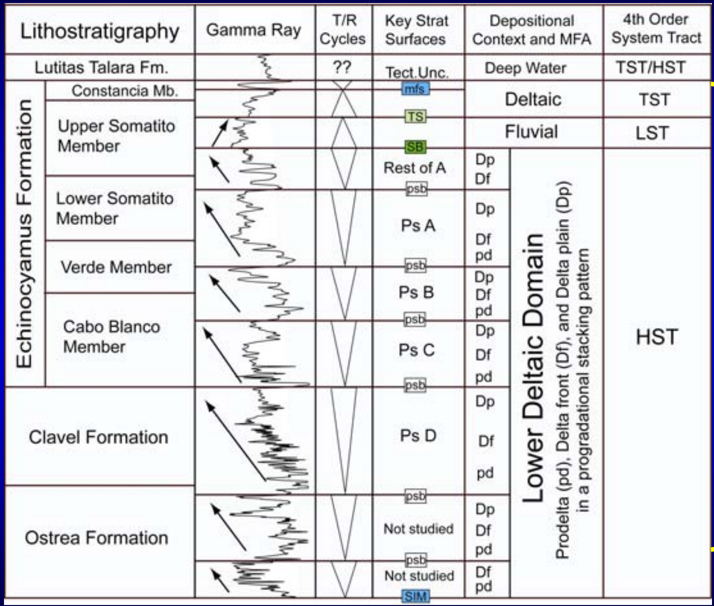
High Resolution Sequence Stratigraphy



Time Span: Aprox. 1.2 My (3rd order)
PSet: 25 a 55 m

Stratigraphic Model vs Eletrical Logs

↓

Predictive Model

Daudt & Scherer, 2006

Presenter's Notes:

The depositional model makes possible the generation of a new stratigraphic framework that shows an interplay between the marine-influenced section (the lowermost part, compound by a series of parasequence sets, each of which is about 100-130 ft, and a fluvial-prone interval that cuts the previous section. This is slightly different from the traditional lithostratigraphical approach. Allowing for a more detailed reservoir compartmentalization is very important in secondary recovery projects. The stratigraphic model was also correlated to the electrical logs what allowed us to build a predictive model for uncored wells.

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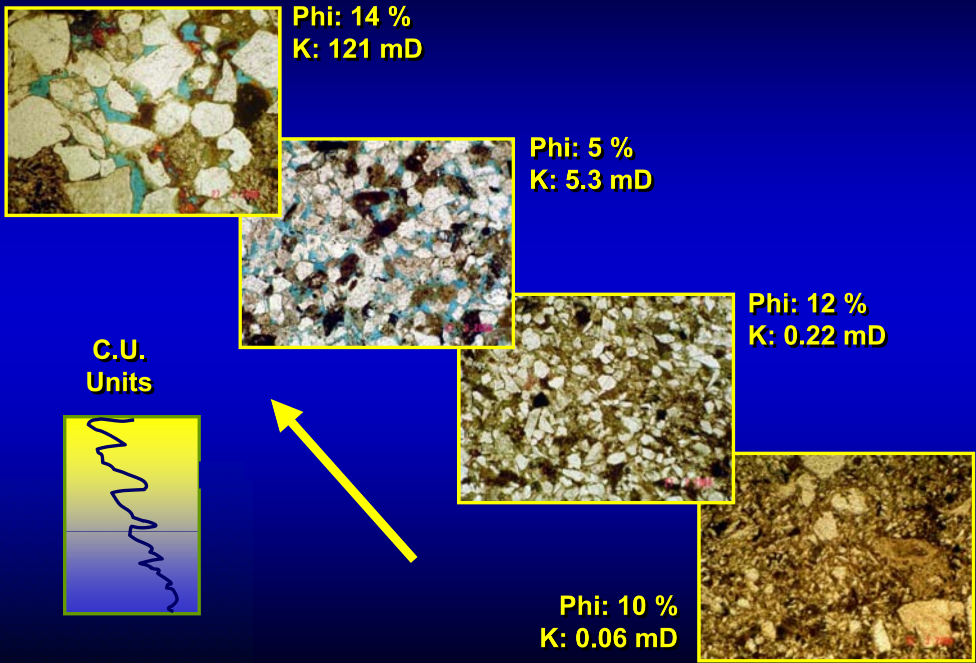
A Deltaic Parasequence Set



Presenter's Notes:

This view shows a typical parasequence set in the studied area, in the marine-influenced interval (parasequence sets). Observe that there is not a direct relationship between porosity and permeability, probably due to the diagenetic influence. Regarding the porosity, it is possible that the presence of authigenic minerals increased the storage capacity due to the high amount of microporosity.

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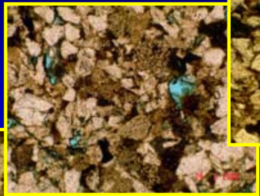
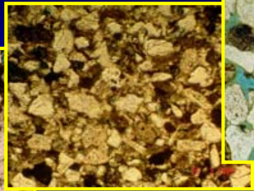
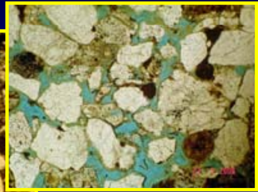
The Fluvial Facies Architecture

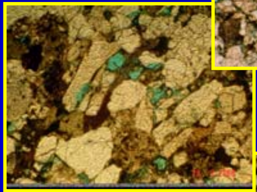
Phi: 12 %
K: 0.41 mD





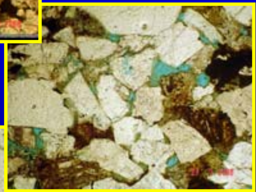


Phi: 11%
K: 0.6 mD

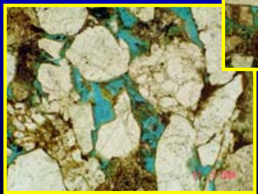


Phi: 12%
K: 0.14 mD

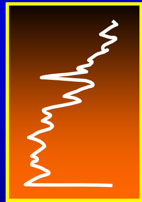
Phi: 17.1 %
K: 34.3 mD



Phi: 16 %
K: 0.55 mD



Phi: 17.5 %
K: 1.13 mD



F.U. Units
High frequency cyclicity;
High % of volc frag
and high % of Diagenetic
Smectite

Presenter's Notes:

This view shows a typical fluvial interval (in thin section). Observe that the fining-upward general trend is in some cases cut by higher frequency small cycles of coarser-grained sandstones which present better petrophysical properties. High proportion of volcanic fragments enhanced the formation of authigenic smectite. Again, there is no direct relationship between porosity and permeability, probably due to diagenetic imprint. It is possible that the higher permeability layers had its original porosity preserved due to the very early mechanical infiltration of smectite. The general grain size is fine to medium.

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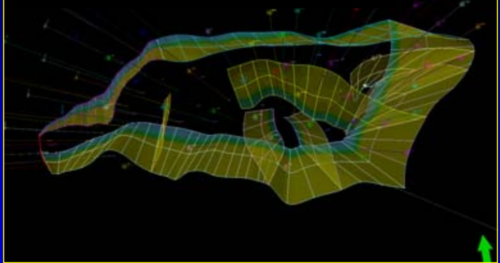
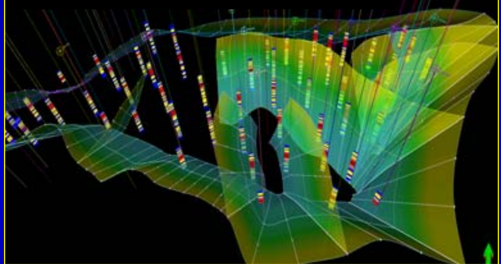
Methodological Steps

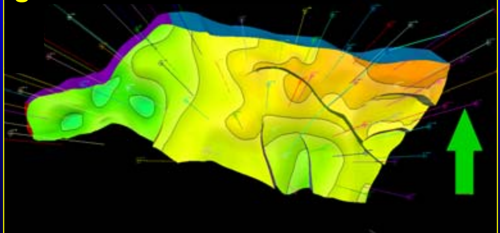
1 - Structural Framework



2 – MFA correlation in wells



3 – Stratigraphic surface generation



"Surface-Based Modelling"

Presenter’s Notes:

The methodological steps after the initial phase of sedimentological characterization. The first-order reservoir heterogeneity is defined by the structural framework. After this, an important and very time-demanding step is the MFA correlation of each well, based on electrical-log patterns. This approach is known as “surface-based modelling” where the surfaces are created, considering the shifts between the depositional systems (in other words, modelling strong influenced by the sequence stratigraphic interpretation).

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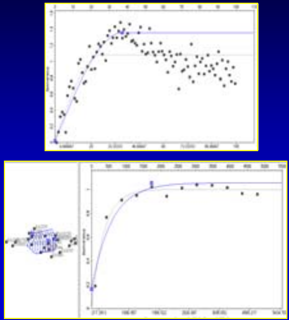
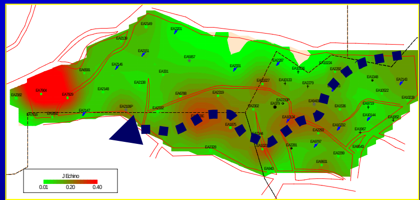
Geostatistical Analysis and 3D Mapping

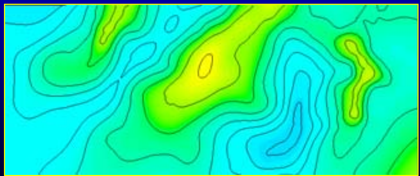


Variograms: Vertical/Horizontal

V.P.C. for each unit

"Soft" Trend for K: Productivity Index map (general)





"Soft" Trends for Phi: HC shows in cuttings for each genetic unit

Presenter’s Notes:

Basic geostatistical tools: Vertical Proportion Curves (V.P.C.) and vertical/horizontal variograms allow assessment of reservoir heterogeneity. The “soft” trends used for modelling include the productivity index map (Q/Pressure drawdown) for K propagation and the thickness of HC shows observed in cuttings (made for each genetic unit) for Phi propagation.

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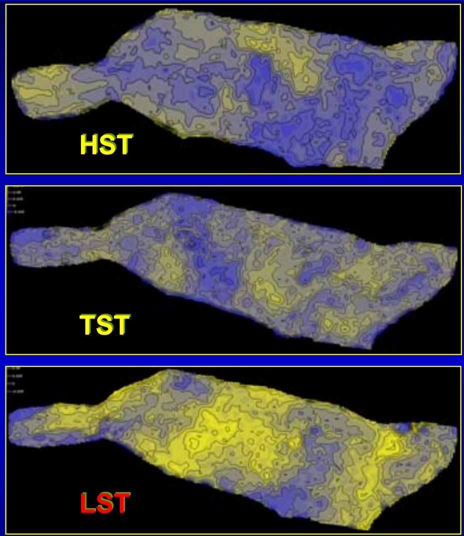
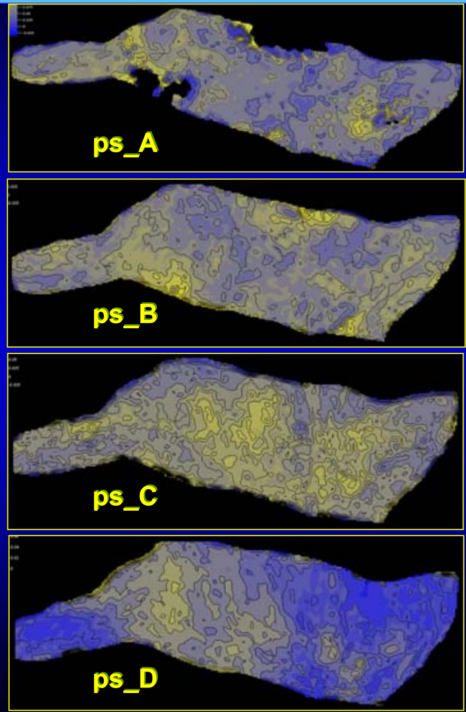
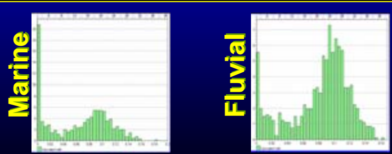
3D Properties Mapping: Average PHI







Presenter's Notes:

The result of the propagation of Phi in the block 9 of Ballena (average map of Phi for each stratigraphic interval). It is possible that some reservoir geometries show definitive patterns, as in the LST, TST and ps_C. Some parasequences do not show well defined geometries (e.g., ps_A), probably due to the erosion by the overlying genetic unit (in this case, the fluvial part of the LST).

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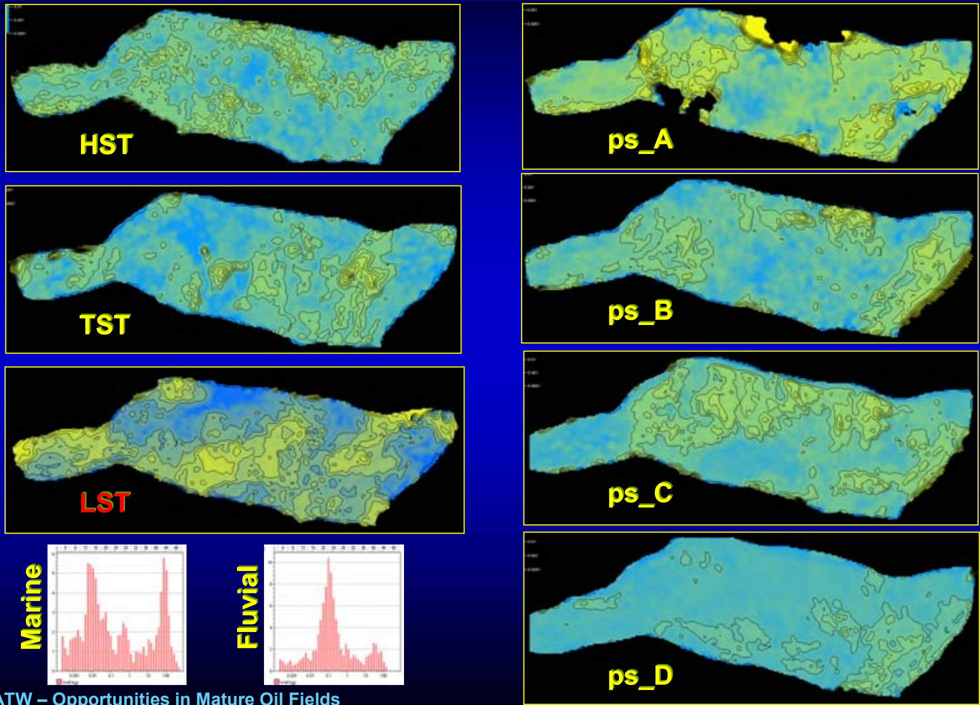
3D Properties Mapping: Average K



Presenter's Notes:

The result of the propagation of K in the block 9 of Ballena (average map of K for each stratigraphic interval). Observe that the general distribution of K is different in the marine and in the fluvial intervals. Both intervals allow us to predict at least 3 different qualities in reservoir performance (flow units?) for each main domain (marine and fluvial). It is also observed that in the fluvial interval the number of samples of higher permeability is small. The preliminary petrographic analysis suggests that this is the result of the presence of very thin layers, probably of great horizontal continuity.

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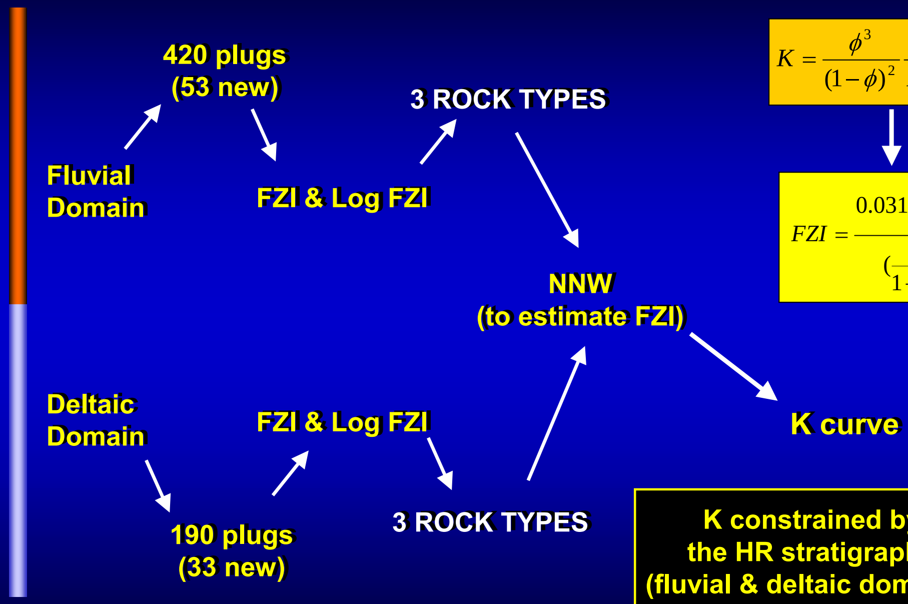
Workflow for K Estimation



$$K = \frac{\phi^3}{(1-\phi)^2}\frac{1014}{F_s \tau^2 S_{gv}}$$

$$FZI = \frac{0.0314\sqrt{K/\phi}}{\left(\frac{\phi}{1-\phi}\right)}$$

K constrained by the HR stratigraphy (fluvial & deltaic domains)

Presenter’s Notes:

Workflow that was followed for K estimation, based on the Flow-Zone-Indicator Methodology (FZI), associated with NNW (Neural NetWorks). The input data (basic petrophysical analysis) were initially constrained by the stratigraphic model. The flow zone indicator methodology is based on the Kozeny-Carman equation for K estimation. This methodology made it possible to constrain the K distribution within the stratigraphic model.

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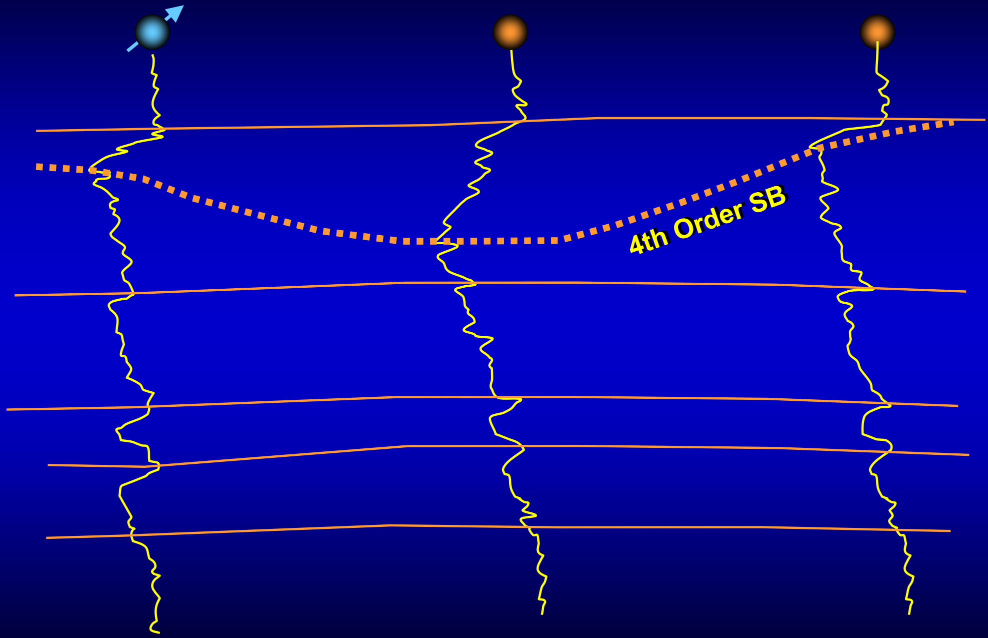
Diagenesis vs. Stratigraphic Model

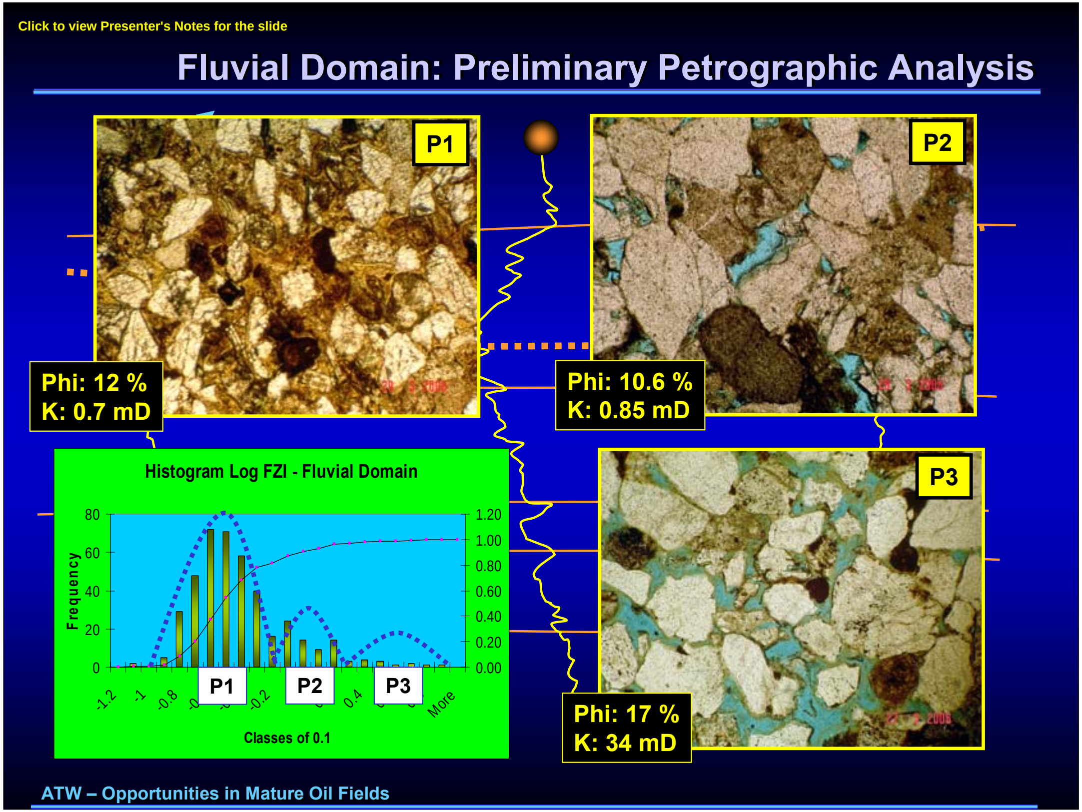


Presenter's Notes:

This analysis is incomplete, but we present some preliminary observations. This figure shows the traditional lithostratigraphy and the high-frequency sequence stratigraphy that predict the existence of a 4^{th}-order sequence boundary in the reservoir.

The lowermost part of the figure (the marine-influenced interval, composed of 4 parasequence sets) shows its boundaries approximately coincident (but not always coincident) with the lithostratigraphy.

However, what is the diagenetic behavior of each compartment?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Fluvial Domain: Preliminary Petrographic Analysis
P1
Phi: 12 %
K: 0.7 mD
P2
Phi: 10.6 %
K: 0.85 mD
P3
Phi: 17 %
K: 34 mD
Histogram Log FZI - Fluvial Domain
Frequency
0
20
40
60
80
0.00
0.20
0.40
0.60
0.80
1.00
1.20
-1.2
-1
-0.8
-0.2
0.4
More
P1
P2
P3
Classes of 0.1
ATW – Opportunities in Mature Oil Fields

Presenter's Notes:

The fluvial domain was analyzed using the Flow-Zone-Indicator Methodology (FZI). It has been possible to identify three different populations in the LOG FZI chart (three different FLOW UNITS [of reservoir quality]). The worst, P1, is more abundant and has a high proportion of authigenic minerals (mainly smectite). The best one, P3, is the least common, showing the least amount of authigenic clays (mainly mechanically infiltrated smectite that probably has preserved some depositional characteristics).

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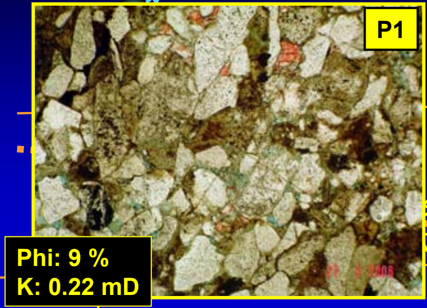
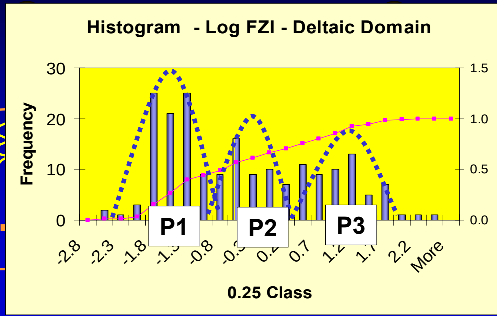
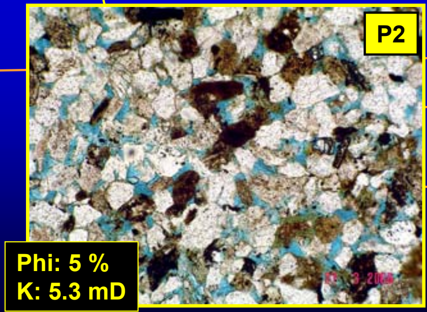
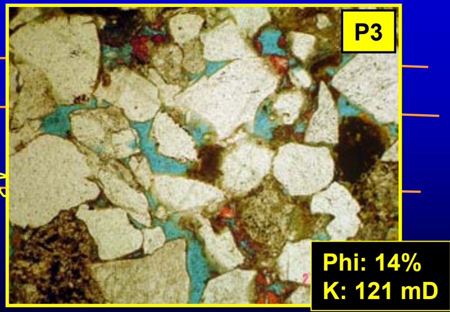
Deltaic Domain: Preliminary Petrographic Analysis



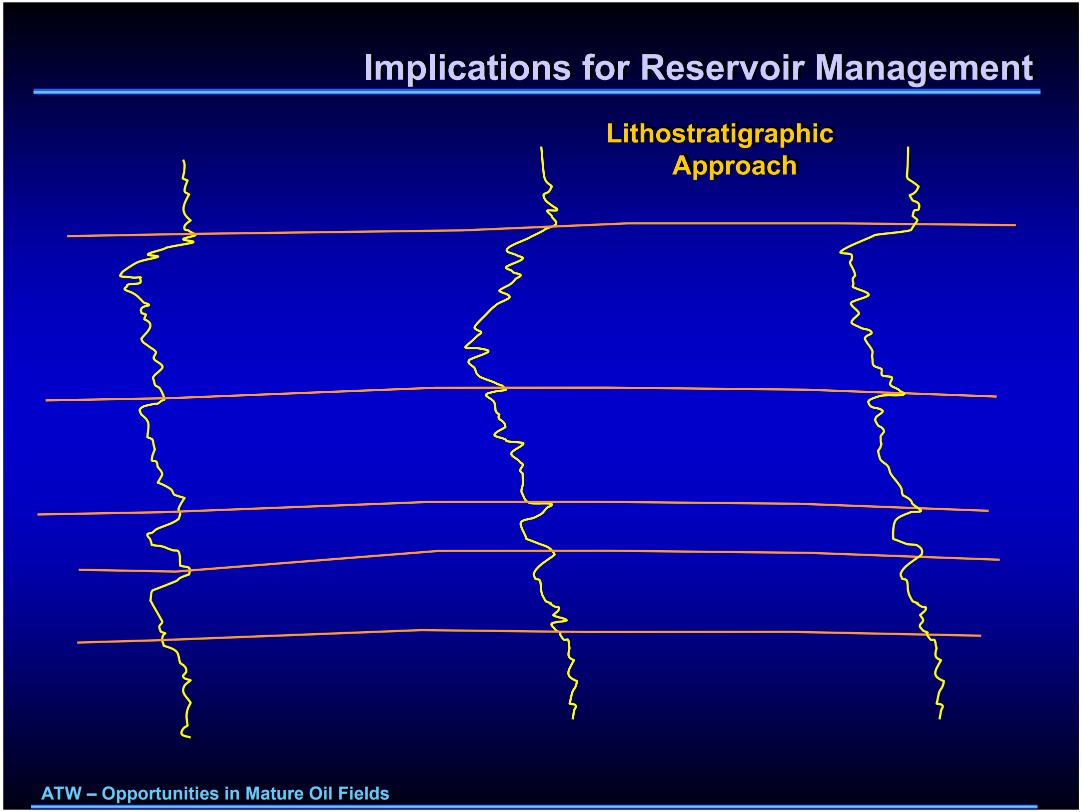






Presenter's Notes:

Following the Flow Zone Indicator Methodology, the deltaic domain presents three different populations in the LOG FZI chart (a fourth population may be predicted, but it is not so clear). More detailed study of the habit, distribution and volumes of the authigenic clay minerals may determine the correct relationship between the reservoir petrofacies and this methodology.



Presenter's Notes: This view shows the traditional lithostratigraphic compartmentalization of the Echynocyamus Formation.

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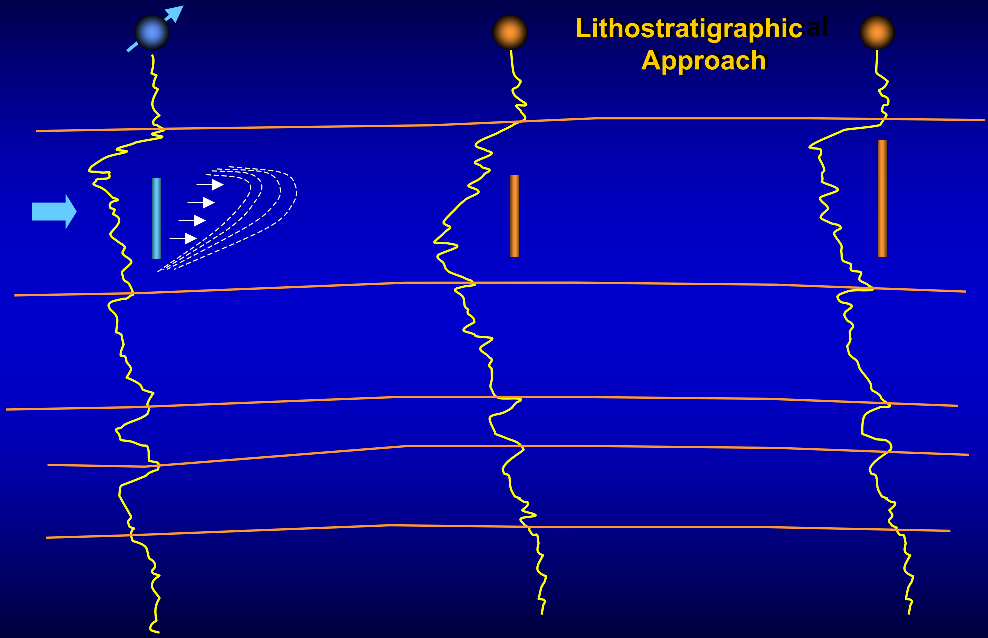
Assuming good continuity...



Presenter's Notes:

Assuming that the lithostratigraphy is known with accuracy, we would expect good continuity and good horizontal connection and a relatively high-sweep efficiency. In this case, the reserves estimated for this secondary recovery project would be consistent with this lateral and vertical sweep efficiency.

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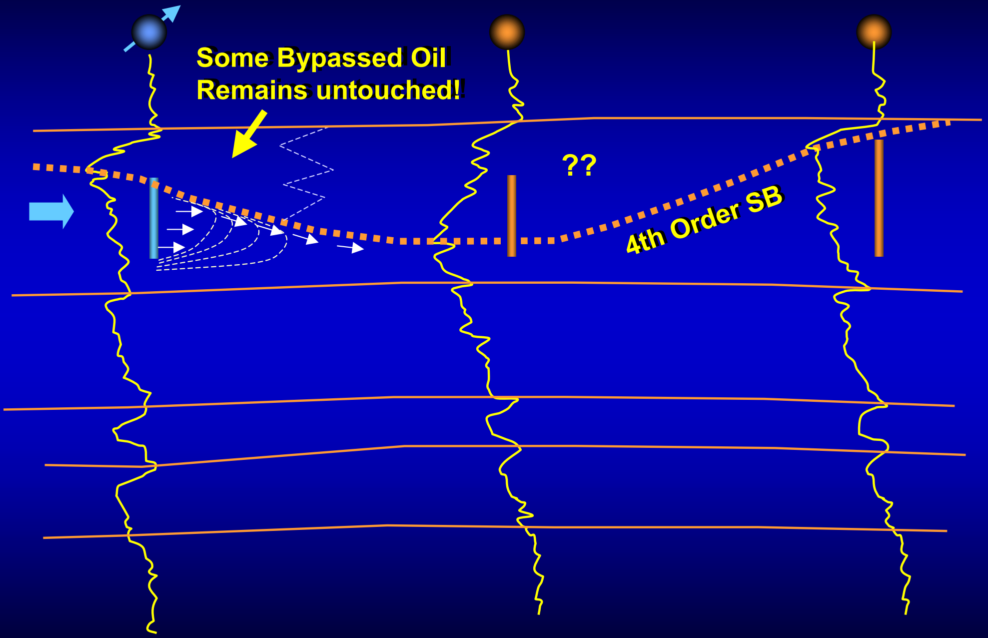
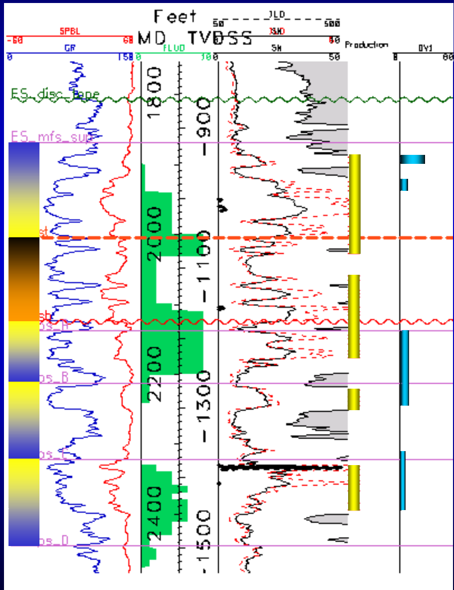
If we consider the HRSS



Presenter's Notes:

Considering High-Resolution Sequence Stratigraphy (HRSS), we may expect a different behavior in the flooding pattern, assuming that the 4^{th}-order sequence boundary (4^{th}-order SB) is a surface that is potentially a flow barrier. It is possible that some amount of hydrocarbons within the reservoir will never be efficiently swept by the water flooding, resulting in some bypassing of oil. This will cause an impact in the horizontal- and vertical-sweep efficiency that will, in turn, affect the secondary reserve estimate.

Radioactivity Tool Log in an Injector Well



75% of the injected water goes here

Nothing is "drunk" here!

20% of the injected water goes here

5% of the injected water goes here

Presenter's Notes:

This view shows some preliminary observations in the radioactivity tool log that delivers some clues about the reservoir quality in terms of permeability. It is possible to observe that the fluvial interval (higher % of smectite, lower permeability in general but with higher-permeability thin layers) has a lower injectivity than the marine-influenced interval. This is important to guide the stimulation strategy for optimization.

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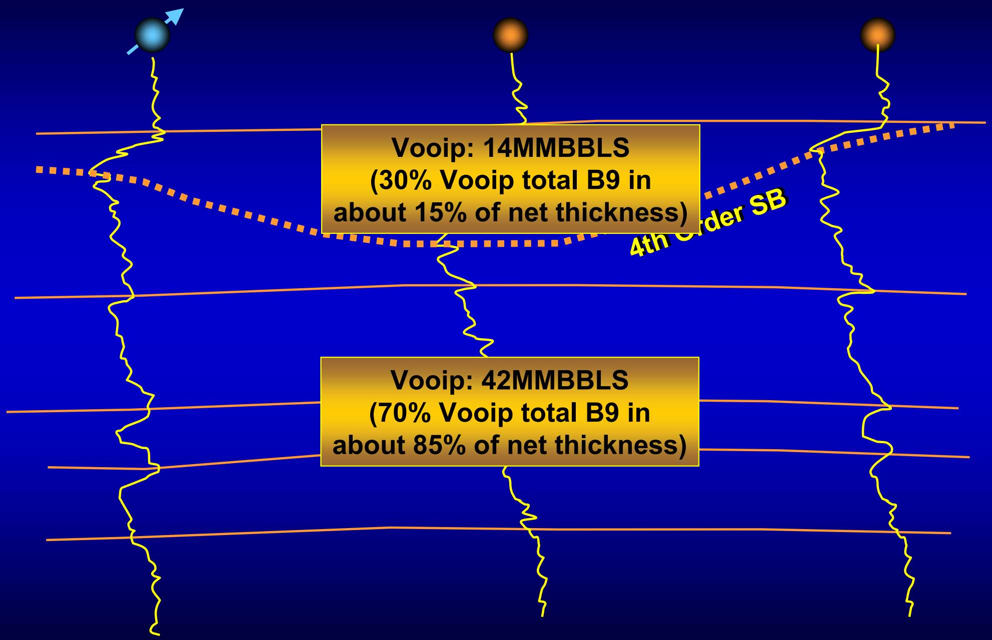
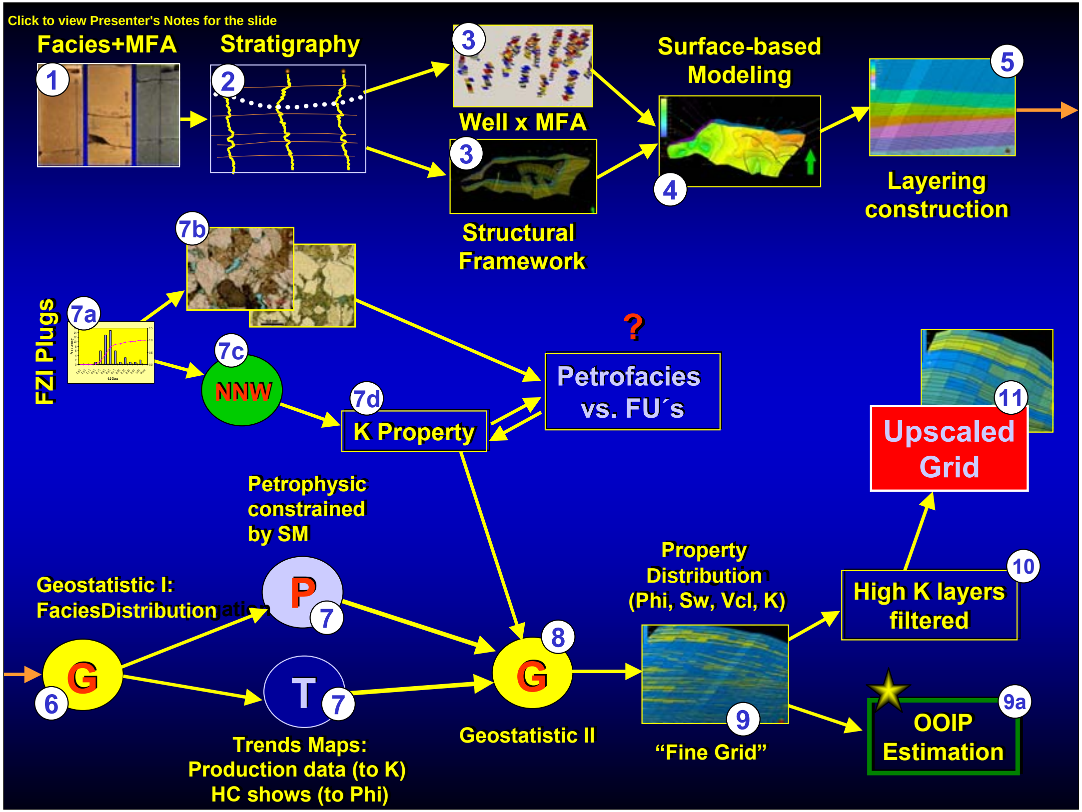
Relative Importance of Each Compartment



Presenter's Notes:

Another impact is a better characterization of the reserve distribution. The relative importance of each compartment is shown in this figure. Observe that the fluvial interval, despite its smaller net thickness and higher % of smectite, presents an important hydrocarbon volume (high microporosity). Of course, all the marine interval, when considered in general, presents a much higher hydrocarbon volume due to its greater thickness.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Facies+MFA
1
Stratigraphy
2
3
Well x MFA
3
Structural Framework
Surface-based Modeling
4
5
Layering construction
FZI Plugs
7a
7b
7c
NNW
7d
K Property
?
Petrofacies vs. FU´s
11
Upscaled Grid
Petrophysic constrained by SM
Geostatistic I: FaciesDistribution
P
7
G
6
T
7
Trends Maps: Production data (to K) HC shows (to Phi)
G
8
Geostatistic II
Property Distribution (Phi, Sw, Vcl, K)
9
"Fine Grid"
High K layers filtered
10
OOIP Estimation
9a

Presenter's Notes:

Intention of this view intends to show a general workflow for this kind of approach, where sedimentology and stratigraphy play an important role in the very beginning. This allows one to build a coherent stratigraphic framework in which all the properties will be constrained. The main question in this workflow is how to deal with the petrofacies model, how to integrate it in the workflow and how to use it to predict diagenesis behavior in uncored wells. This work proposes the use of the FZI (Flow Zone Indicator) methodology associated with neural networks, correlating the petrofacies model with the different flow units identified with the FZI. We have not concluded this study because the petrographic analysis is currently being processed.

Final Comments

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Final Comments

-The integration of Sedimentology and Stratigraphy, combined with Geostatistical tools, provided a better understanding of geometrical relationships and connectivity potential of the reservoirs within each stratigraphic unit;

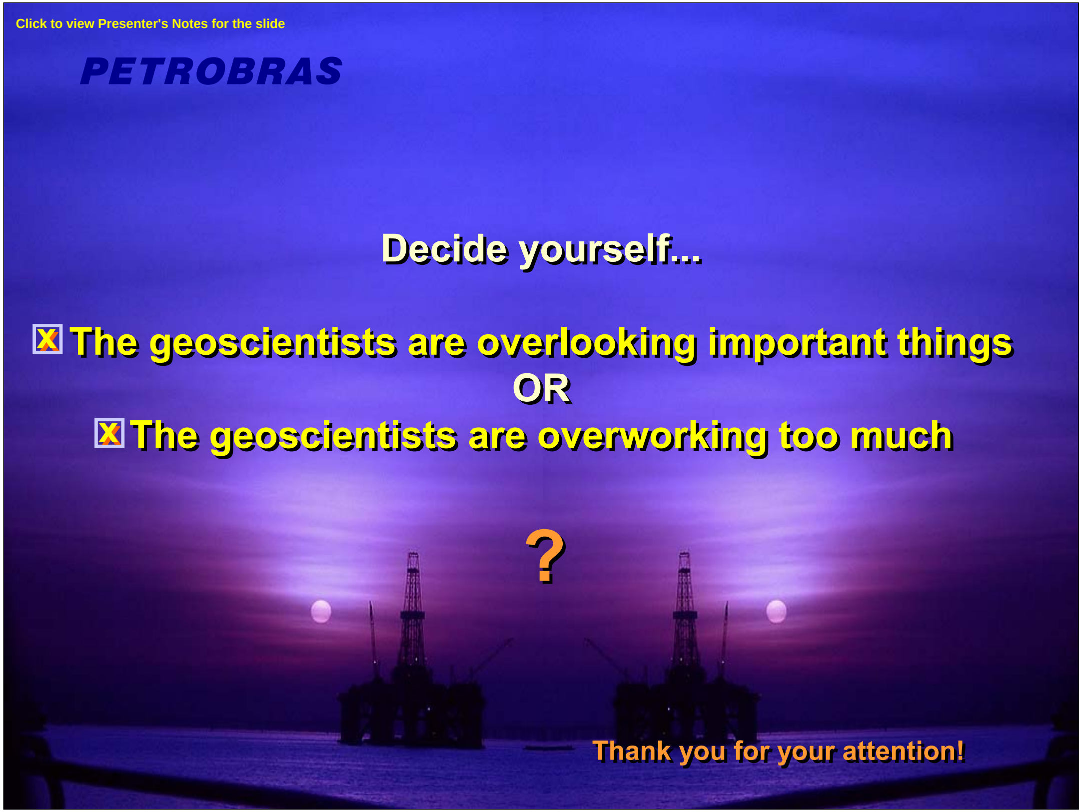
-The stratigraphic framework defined new surface-based compartmentalization that is important to guide new strategies of stimulation and injection planning, resulting in an optimization of the project (better sweep efficiency);

-Diagenetic studies will provide a reservoir petrofacies model that may establish the link between the FZI and the stratigraphic framework.

Presenter's Notes:

The integration of sedimentology and stratigraphy is important to better understand the geometry and connectivity of the reservoir bodies within each stratigraphic unit. This methodology is necessary to get more reliable reservoir geometries, as it incorporates more and more depositional-model concepts. The stratigraphic model allowed reduction in the risks in reserve estimation, especially because of a better characterization of where the HC is located. Also, the sweep efficiency may be improved as we have a much better understanding of the reserve distribution.

Diagenesis is still an open point. A reservoir petrofacies model will be correlated to the FZI. The type, habit and volume distribution of the different authigenic minerals will provide a better understanding of the relationship between the petrophysical properties and the Flow-Zone-Indicator Methodology. The final objective is to create a predictive model that integrates sedimentology, stratigraphy and diagenesis to reduce uncertainties in secondary recovery projects.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PETROBRAS
Decide yourself...
☒ The geoscientists are overlooking important things
OR
☒ The geoscientists are overworking too much
?
Thank you for your attention!

Presenter’s Notes:

Are we going in the right direction? This question is presented here as a brainstorm: do we always need to spend a lot of time in highly detailed reservoir characterization? Probably no, but we need to be make sure that each case is considered as an individual case. In highly complex basins (such as Talara) where reservoir-quality distribution (and even the geology) is still poorly understood, detailed reservoir characterization is the best approach to be used.