Advances in Reservoir Development Using Extra-Deep Azimuthal Resistivity*

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Abstract

Extra-deep reading propagation resistivity tools have been deployed in various reservoir settings around the world in recent years in an effort to further improve efficiencies in reservoir development. For many years, field development relied on standard and azimuthal propagation resistivity tools with depths of investigation up to approximately 5m for geosteering and well placement. While effective at geosteering against adjacent boundaries to maintain position in oil-bearing formation, deeper resistivity measurements enable a closer correlation with seismic models and provide more complete reservoir mapping.

The first extra-deep propagation resistivity tools were developed by employing lower frequency waves, increasing antenna spacing, and eventually adding lower frequency azimuthal signals. The new designs greatly increased the depth of detection and also added directional components. However, because of the greater volume of formation being investigated, the deeper readings bring extra complexity and uncertainty to the interpretation process so that innovative inversion software is required to support the tools and produce results that can be used in real-time.

The larger scale results of the extra-deep measurements have created an opportunity to compare seismic profiles with real-time data from the well bore. The comparison can be used to validate or correct the seismic model and to improve confidence in the use of seismic data during drilling.

This presentation shows the results of wells drilled using extra-deep resistivity tools on the Peregrino Field operated by Statoil Brazil. The reservoir comprises complex and channelized high-energy gravity flows with largely unmapped sands of limited lateral extent and thicknesses ranging from 2m to 25m. Originally developed to improve net sand drilled in the Peregrino heavy oil reservoir by enabling a more strategic approach to geosteering, the tool deployment brought additional benefits in reservoir understanding which impacts seismic model interpretation, future well planning, completion strategies, and pilot holes.

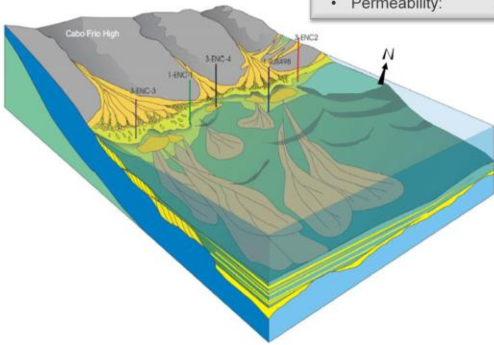
Presenter's notes: A technology that gave us a lot of contribution to optimize drilling/completion results and also increase sandstone exposure.

Peregrino Field | Overview

- Offshore Campos basin (shallow water)
- Statoil 60% (*Operator*), Sinochem 40%
- Start drilling: September 2010:
- 1st oil: April 2011
- Plateau production ~100.000 bpd

Reservoir

• Late Cretaceous sandstone	
• Gravity flow deposits in an open-marine setting	
• Oil gravity:	~14° API
• Oil viscosity:	150-350 cP
• Porosity:	25-30%
• Permeability:	Multi-Darcy



Presenter's notes: Here, a quick overview on our field that is called "Peregrino", which is already on the development phase.
Gravity flow deposits of Carapebus Fm. deposited over an irregular base that is constituted by carbonates (due to aerial exposed during million of years) of Macae Gp. Elements of delta/shoreface deposits may exist within the Carapebus Fm.

Peregrino Field | Geosteering Challenges

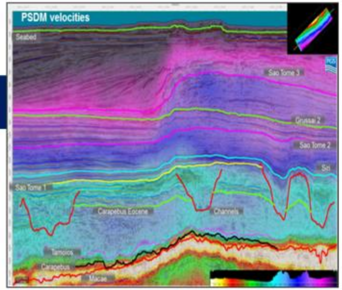
- Limited well coverage

- Seismic uncertainty
- Productive sandstones within the reservoir are not identified on seismic
- Canyons in overburden
- Some areas of reservoir Below Seismic Resolution

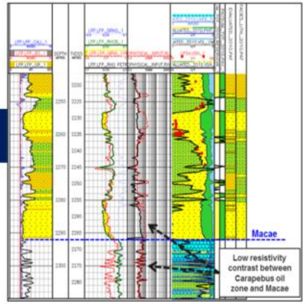
- Reservoir complexity
- Irregular reservoir base controls deposition
- Heterogenic, sandstone facies distribution and connectivity difficult to predict
- Lateral changes in lithology

- Low resistivity contrast at base reservoir against carbonate formation

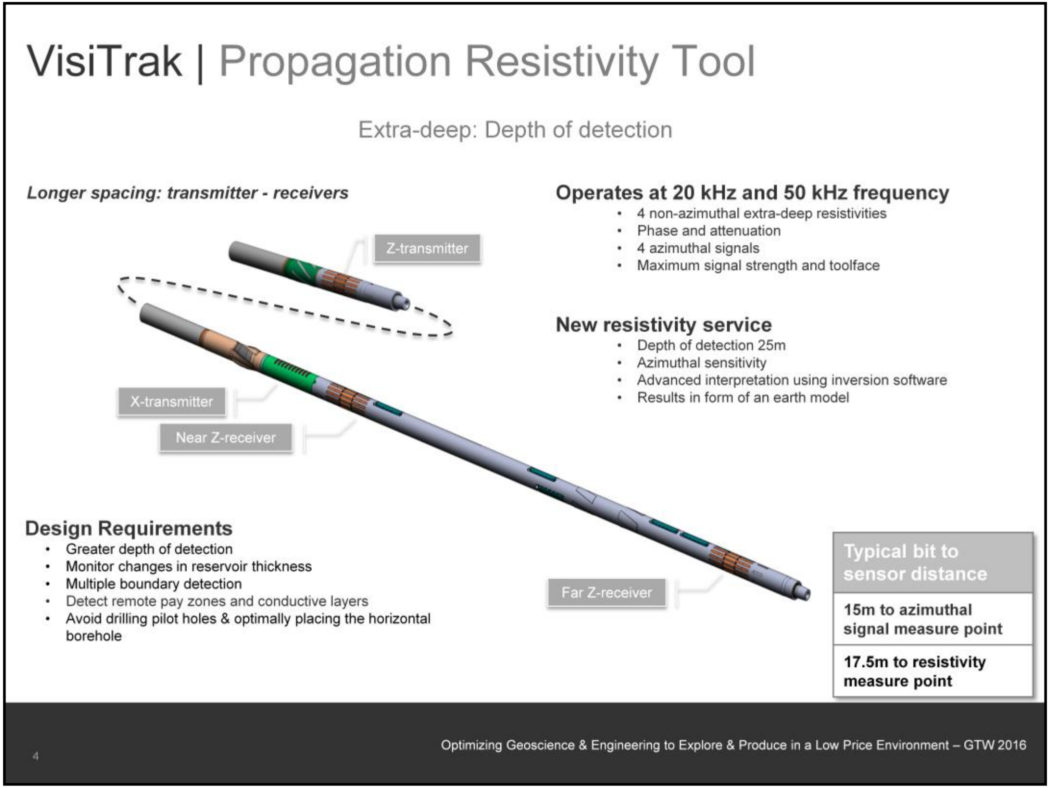
Canyons in the Overburden



Heterogenic reservoir with low contrast base

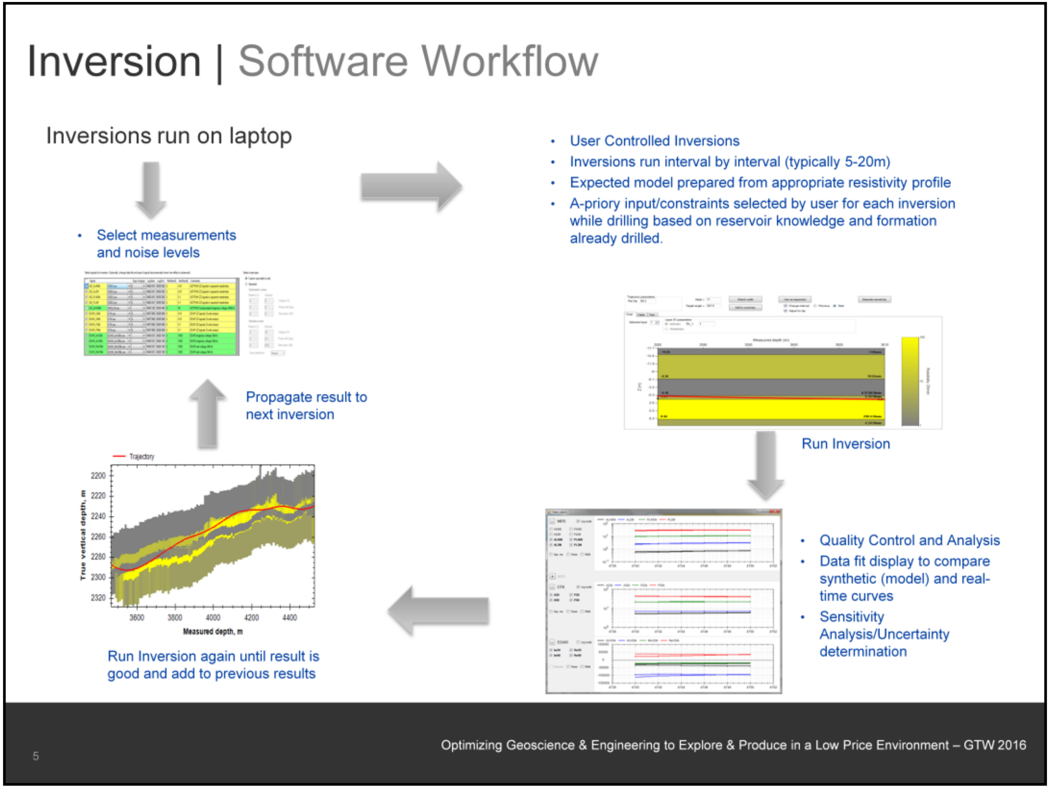


Presenter's notes: Besides issues regarding oil gravity and water production/injection management, we have some challenges that has a direct impact on the geosteering.



Presenter's notes: Therefore, in order to minimize the challenges of not only this but other fields, it was required a technology that is able to attend some design requirements: Here is what is behind the extra deep azimuthal resistivity technology:

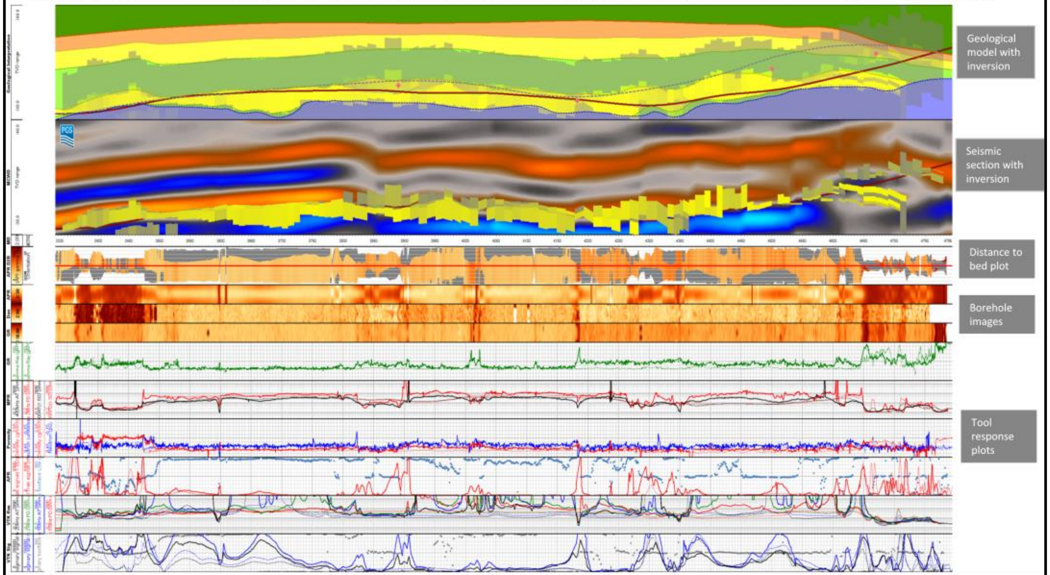
- Higher depth of detectection due to:
  - Low frequency
  - Higher distance between the transmitters and receivers
  - Pilot well



Presenter's notes: In addition to hardware improvements, it was required to develop a very robust software that integrates all the tool outputs and is able to deliver a proper and consistent model.

RT log | Reservoir Navigation Service

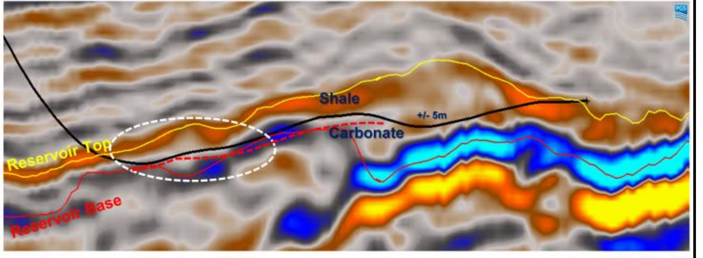
Inversion results are used in combination with conventional measurements and seismic model



Presenter's notes: In RT, lets see how is the integration of this technology with other LWD logs and seismic. (read the boxes)

Well A | Reservoir Mapping

- Casing set above target sandstone in Lower Carapebus, close to the carbonate base.
- Build at maximum DLS, unable to land in target.
- Second sandstone identified below well on top of carbonate.
- Target lower sandstone and abort after dip change.
- Build to intercept upper sandstone at second dip change.
- Drill out of base to second target.
- Sidetrack well.



Inversion result from well targeting sandstone towards base reservoir

Presenter's notes: Well A – BSR well (thinner and layered than expected)

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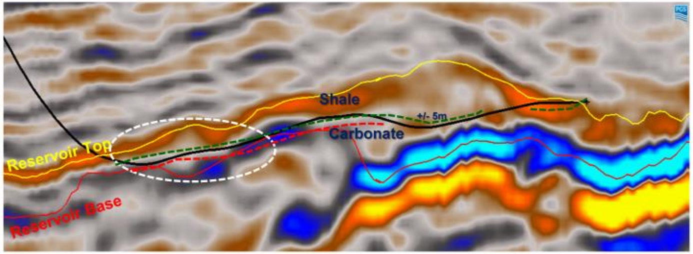

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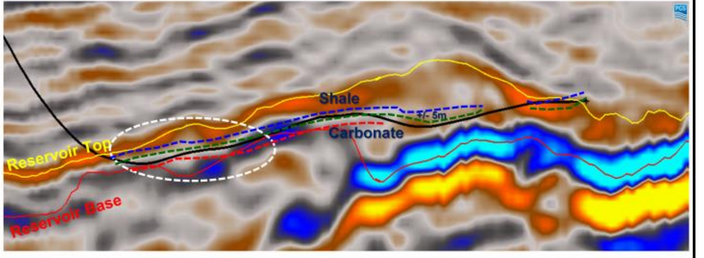

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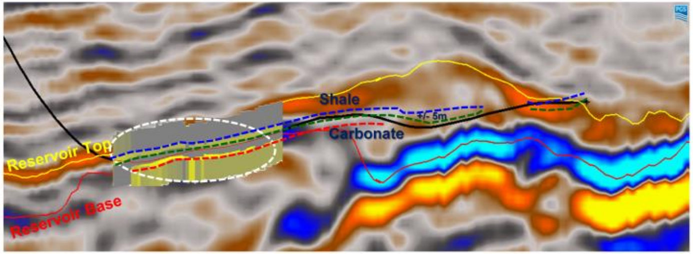

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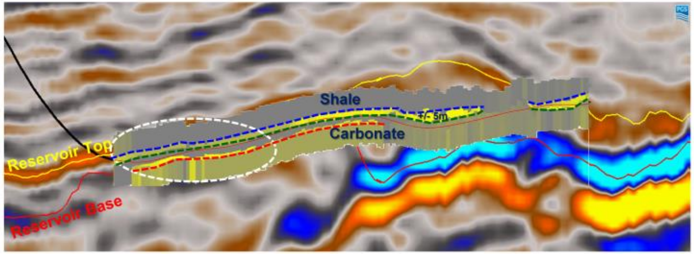

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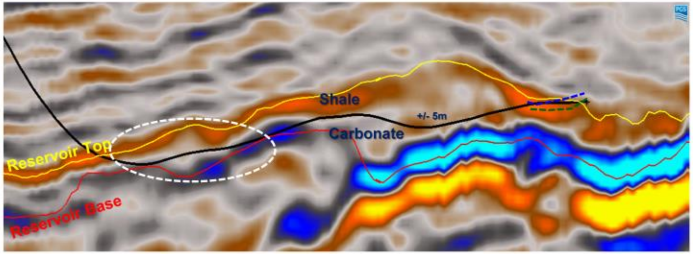
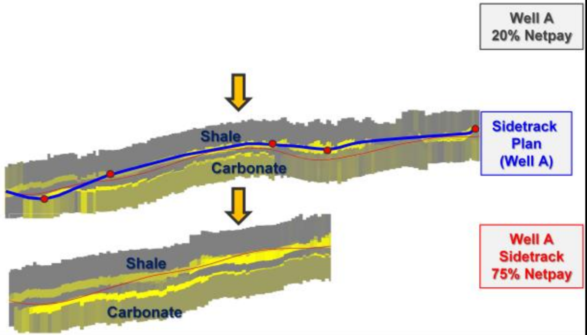
- Sidetrack planned based on inversion results from original well.
- Build section will target lower sandstone, but avoid carbonate below.
- Sidetrack planned along same azimuth

- Drilled 621m of upper sandstone
- Resistivity increased on structural high as on original hole
- Initial inversion results confirmed





Plan sidetrack using inversion results from original well

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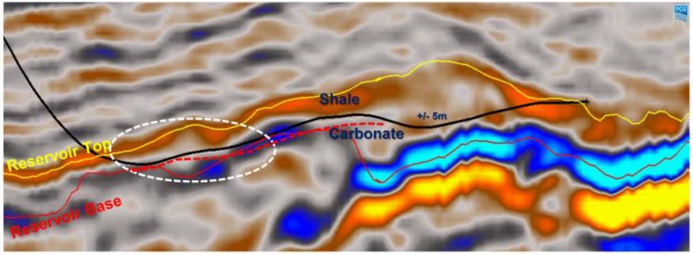

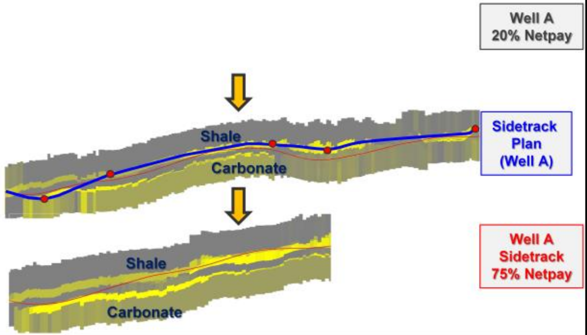

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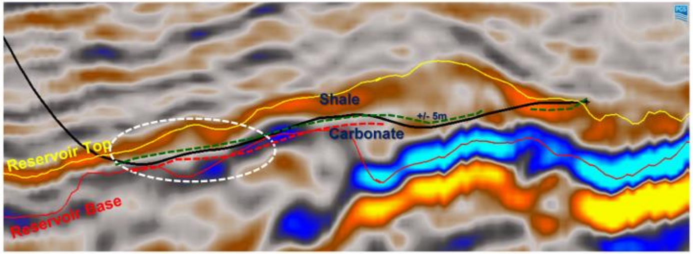

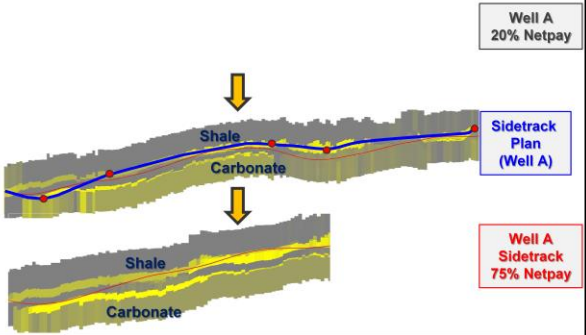

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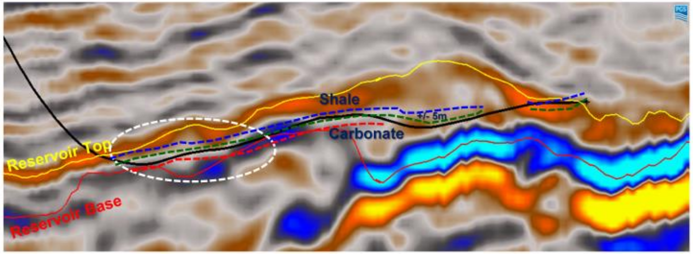

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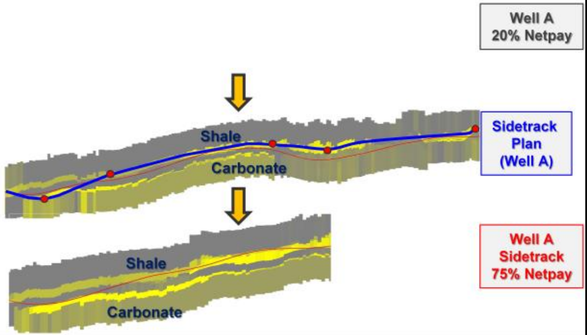

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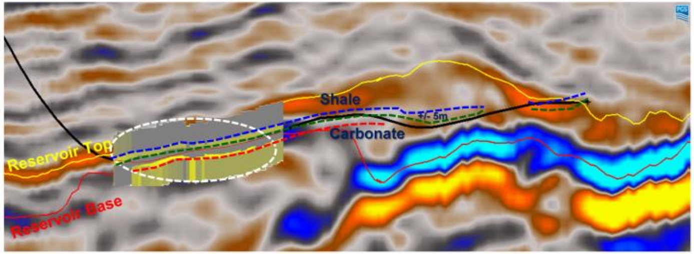

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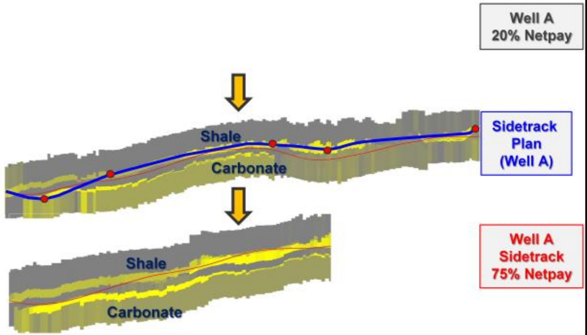

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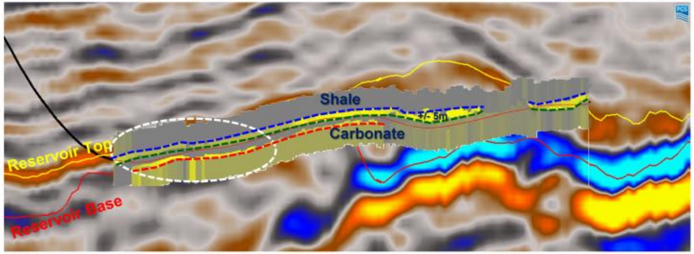
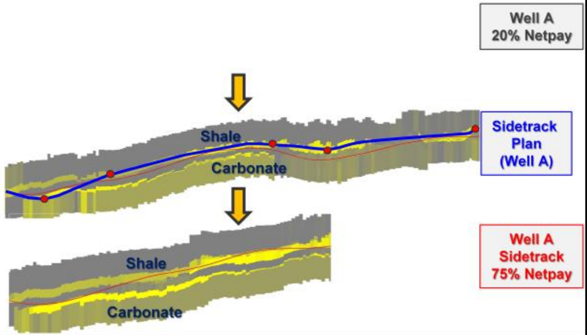
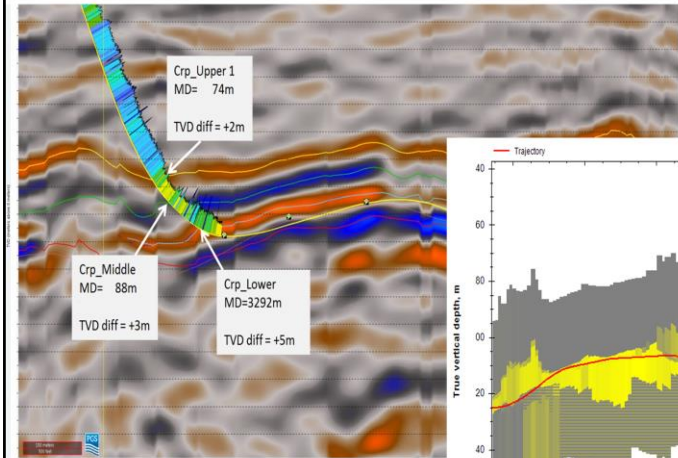




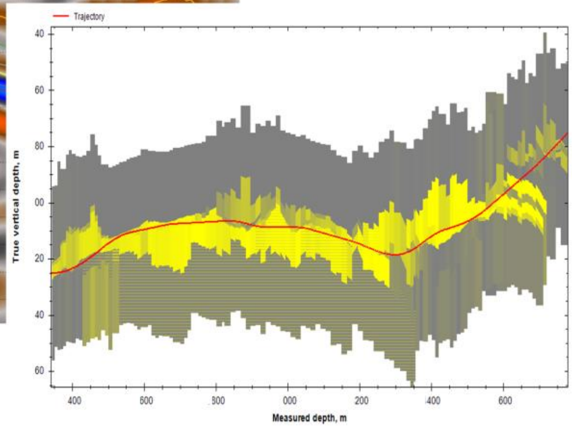
Plan sidetrack using inversion results from original well

Well B | Seismic Correlation

Extra-deep tools bridge the resolution gap between conventional LWD tools and seismic and can be compared directly with inversion results.



Deposition controlled by underlying carbonate topography. Dip changes expected.



Presenter’s notes: Well B: LWD logs and seismic compared with inversion results

Well B | Seismic Correlation

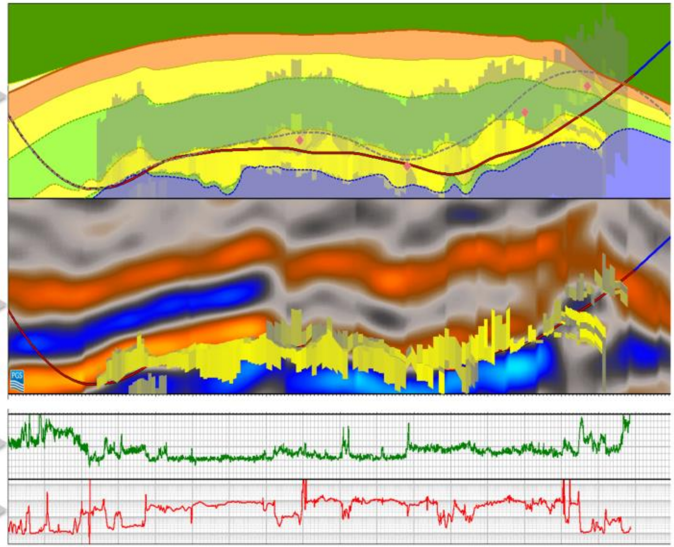
Inversion and seismic section in modeling software

Geological model with inversion result

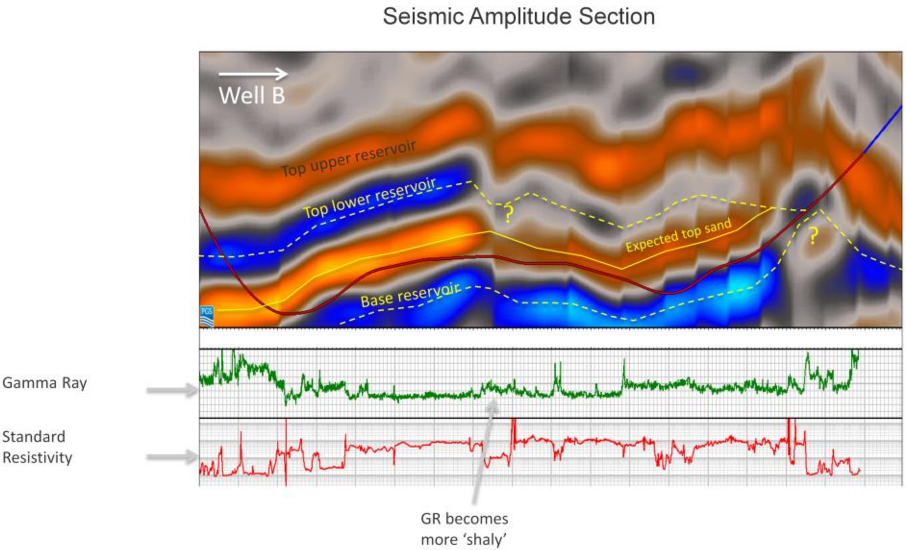
Seismic model with inversion result

Gamma Ray

Standard Resistivity



Well B | Seismic Correlation



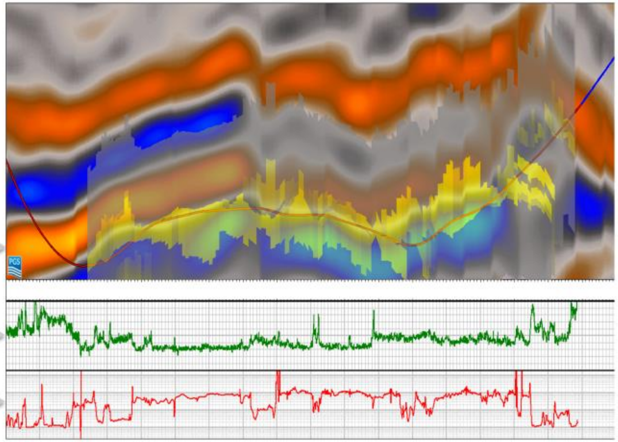
Presenter's notes: Well B: LWD logs and seismic compared with inversion results.

- Possible to deliniate top and base of the reservoir.

Well B | Seismic Correlation

Seismic Amplitude Section with Inversion Result

Inversion off depth at zero crossing

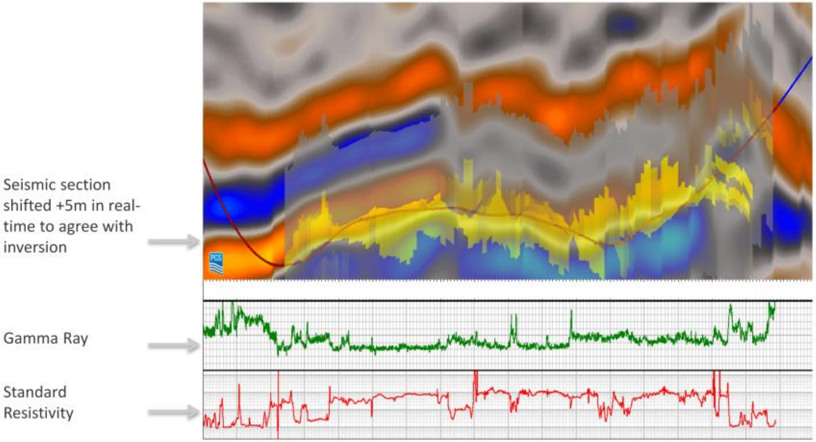


Gamma Ray

Standard Resistivity

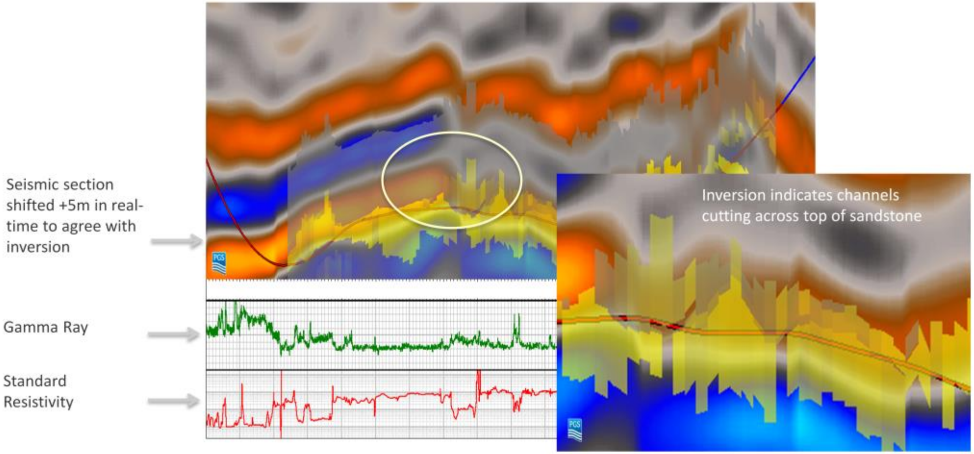
Well B | Seismic Correlation

Seismic Amplitude Section with Inversion Result



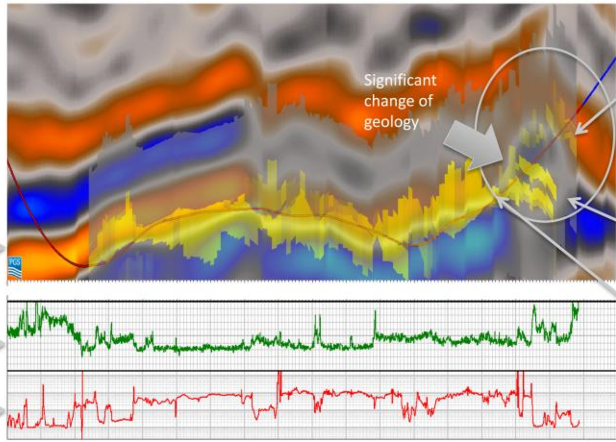
Well B | Seismic Correlation

Seismic Amplitude Section with Inversion Result



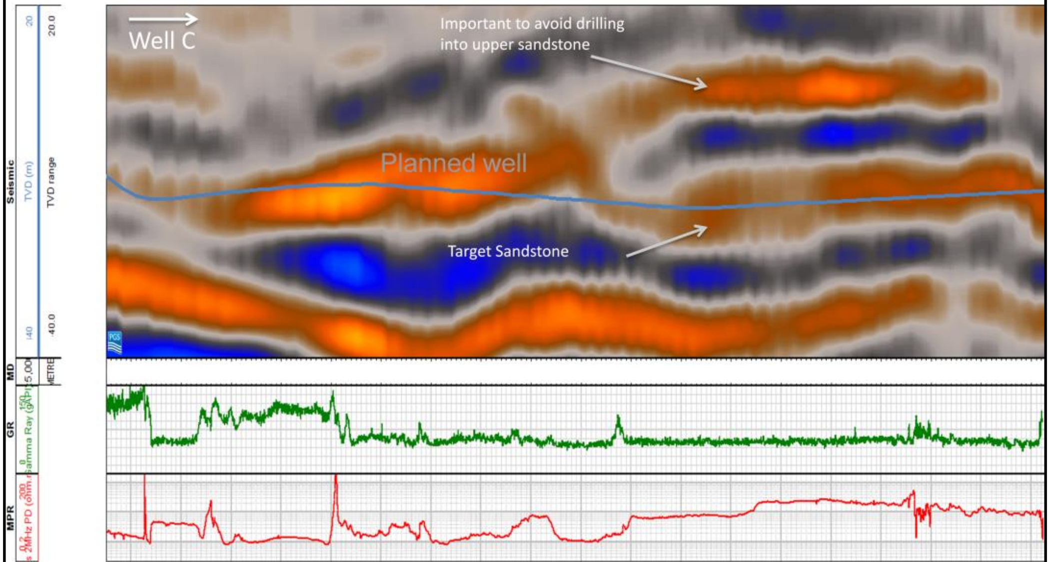
Well B | Seismic Correlation

Seismic Amplitude Section with Inversion Result

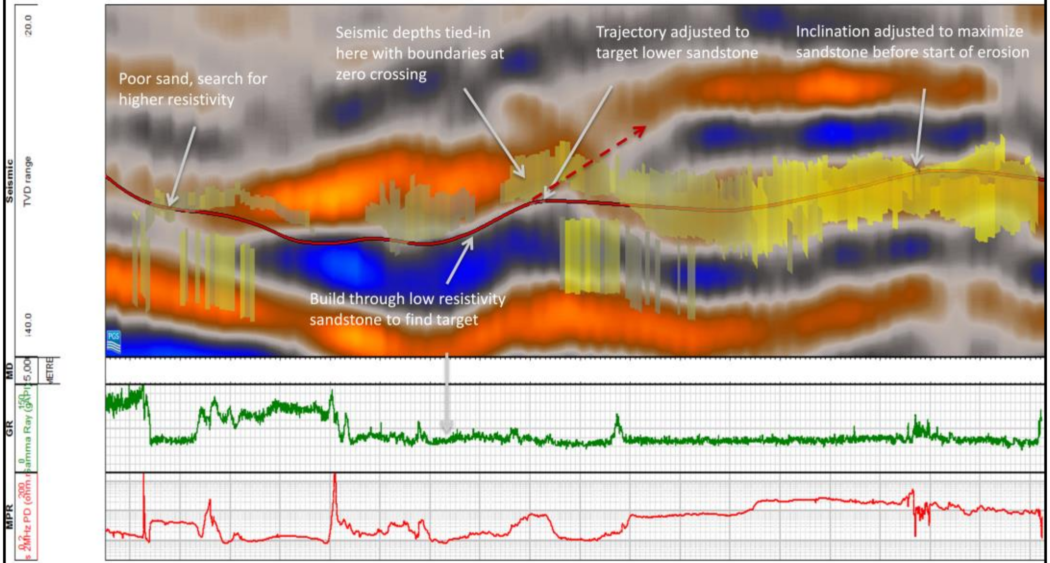


The correlation of inversion results with seismic is improving understanding of the reservoir and the ability to anticipate the validity of the seismic model ahead of the bit

Well C | Seismic Correlation (Objective)



Well B | Seismic Correlation (Result)



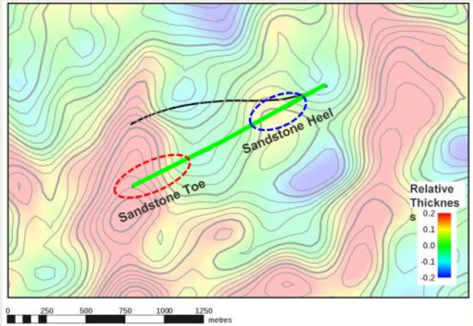
Confirmation of seismic depth by tying-in with inversion results enables steering decisions to be made with greater confidence

Summary

- **Extra-deep azimuthal resistivity and new inversion techniques have brought tangible improvements to reservoir development:**
  - Reservoir Characterization
    - Mapping reservoir while drilling
    - Future well planning
  - Understanding Seismic
    - Seismic depth tie-in
    - Filling in the resolution gaps
    - Understanding any shortcomings in seismic interpretation
  - Geosteering
    - Map sand thickness
    - Detect remote sandstone bodies
    - More strategic decision making in complex reservoirs

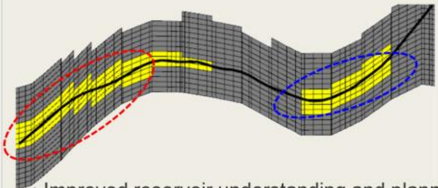
Presenter’s notes: Based on what it was discussed, the contributions from VisiTrak are various, such as follows:

VisiTrak Inversion

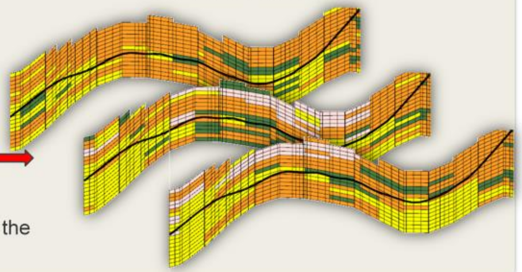


- VisiTrak serve as input for the reservoir characterization.

Input to Geomodel



Geomodel Realizations



- Improved reservoir understanding and planning of upcoming wells – proactive geosteering decisions in the complex heterogeneous Peregrino reservoir.

Presenter’s notes: We use the data as a guiding input for the geomodel

Ackowledgments

- The authors are grateful to:
  - The Peregrino license owners for allowing this data to be shown:
    - Statoil Brasil Óleo e Gás Ltda   Sinochem Petróleo Brasil Ltda
  - Baker Hughes do Brasil
- The seismic data shown is proprietary to PGS Investigação Petrolífera Limitada

There's never been a better time for good ideas

Obrigado!