Meeting Drilling Challenges in Shallow Extended Reach Wells in a Structurally Complex Field with Heavy Oil and Low Fracture Gradient*

Greg Stewart[1], Gunnar Holmes[1], Lee Stockwell[1], Jan-Henk Vankonijnenburg[1], Bruno Levy[2], Andrew Kenworthy[2], Fabricio Bezerra[3], and Santiago Zambrano[3]

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[1]Shell Brasil Ltda. Subsurface, Rio de Janeiro, Brazil (Greg.Stewart@shell.com)
[2]Shell Brasil Ltda. Drilling, Rio de Janeiro, Brazil
[3]Schlumberger D&M, Rio de Janeiro, Brazil

Abstract

Shell Brazil is developing a structurally complex Cretaceous heavy oil reservoir in a deepwater, shallow overburden setting, in offshore Brazil. The development plan called for completion of six 600 to 1000m long horizontal producers. Numerous challenges were encountered during development drilling. Integration of subsurface and drilling data was critical in overcoming the challenges.

Challenges encountered during development drilling depended on the hole section, the formations penetrated, drilling assembles used, and individual well path design.

- The shallow nature of the field (900 to 1000 m tvd below mudline) resulted in the need to start the build-up section near mud line.
- The 12 1/4” build-up section was drilled with Synthetic Based Mud (SBM). Induced fracturing, opening of minimum stress faults and the presence of high perm sands resulted in substantial SBM loss.
- The high net to gross (NtG) reservoir model predicted from the vertical well control and the need for gravel pack sand control led to a completion interval design with a straight near-horizontal well path.

As problems were identified, the subsurface team worked with the well engineers and directional drillers to optimize drilling parameters through the integration of drilling and subsurface data. As a result of the collaboration, many aspects of the drilling program were updated to improve drilling performance and well placement.

3D and 2D displays of seismic, with structural data, well bore lithology, and drilling data such as steering ratio, build rates, ROP, and WOB were used to better understand the relationship between geological formations and drilling behavior. Understanding the drilling behavior of

specific formations and lithologies at various depths helped in the re-design of BHA's, refinement of the steering program, and updating LWD requirements.

Mud weights were reduced, drilling fluids modified, BHA's and LWD tools changed to meet the drilling challenges. Recommendations for subsurface data collection from appraisal and development wells in order to reduce uncertainties and improve the drilling program were formulated. Even the basic well design and drilling philosophy was updated to include geo-steering in the reservoir and additional pilot wells in some areas of the field. Collaboration of subsurface and drilling teams led to significantly improved drilling performance and well placement.

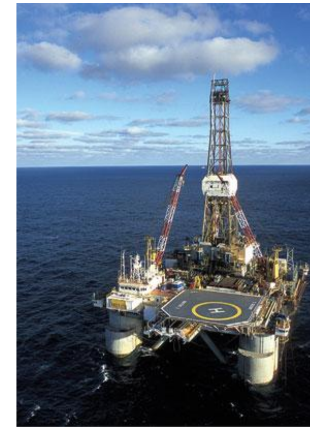
AAPG – Rio Paper #

TITLE: "Meeting drilling challenges with shallow extended reach wells in a structurally complex field with heavy oil and low fracture gradient"

Authors:

Shell Brasil Ltda. Subsurface:	Greg Stewart, Gunnar Holmes, Lee Stockwell, Jan-Henk Vankonijnenburg
Shell Brasil Ltda. Drilling:	Bruno Levy & Andrew Kenworthy
Schlumberger D&M:	Fabricio Bezerra & Santiago Zambrano

Subjects to cover :



Geologic Setting

Original Planning and Challenges

Initial Production Manifold 1 (PM)1 Drilling results

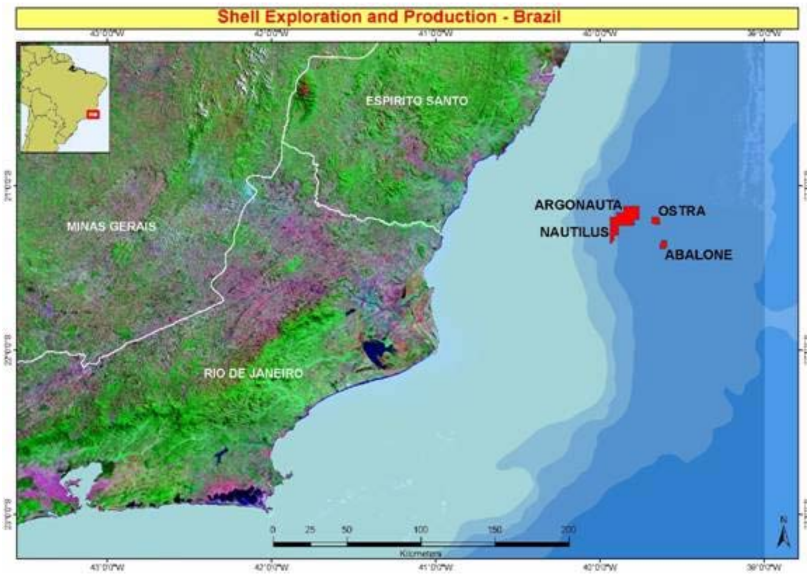
Integration of Subsurface, Drilling and Directional data

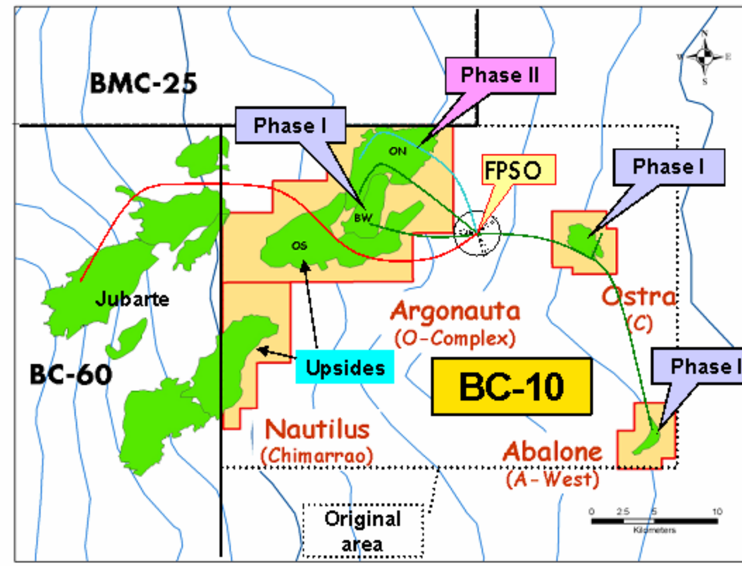
Changes made to meet challenges and deliver wells:

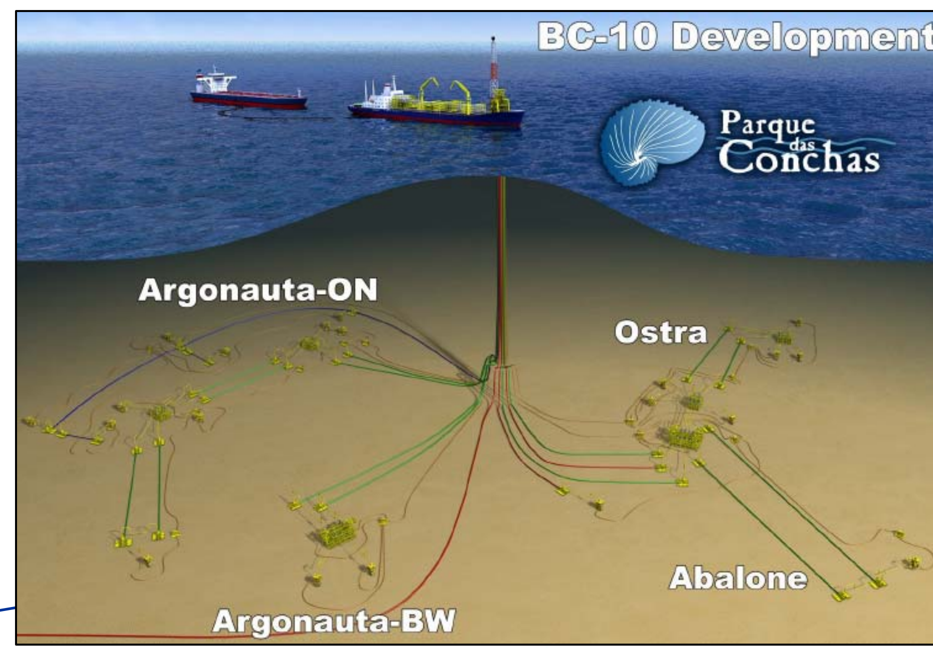
- Geologic Model
- Display Drilling and Geologic Data for Team Review
- Drilling Program,
- Directional Drilling program

Final Well Results

BC-10 OSTRA Field Location





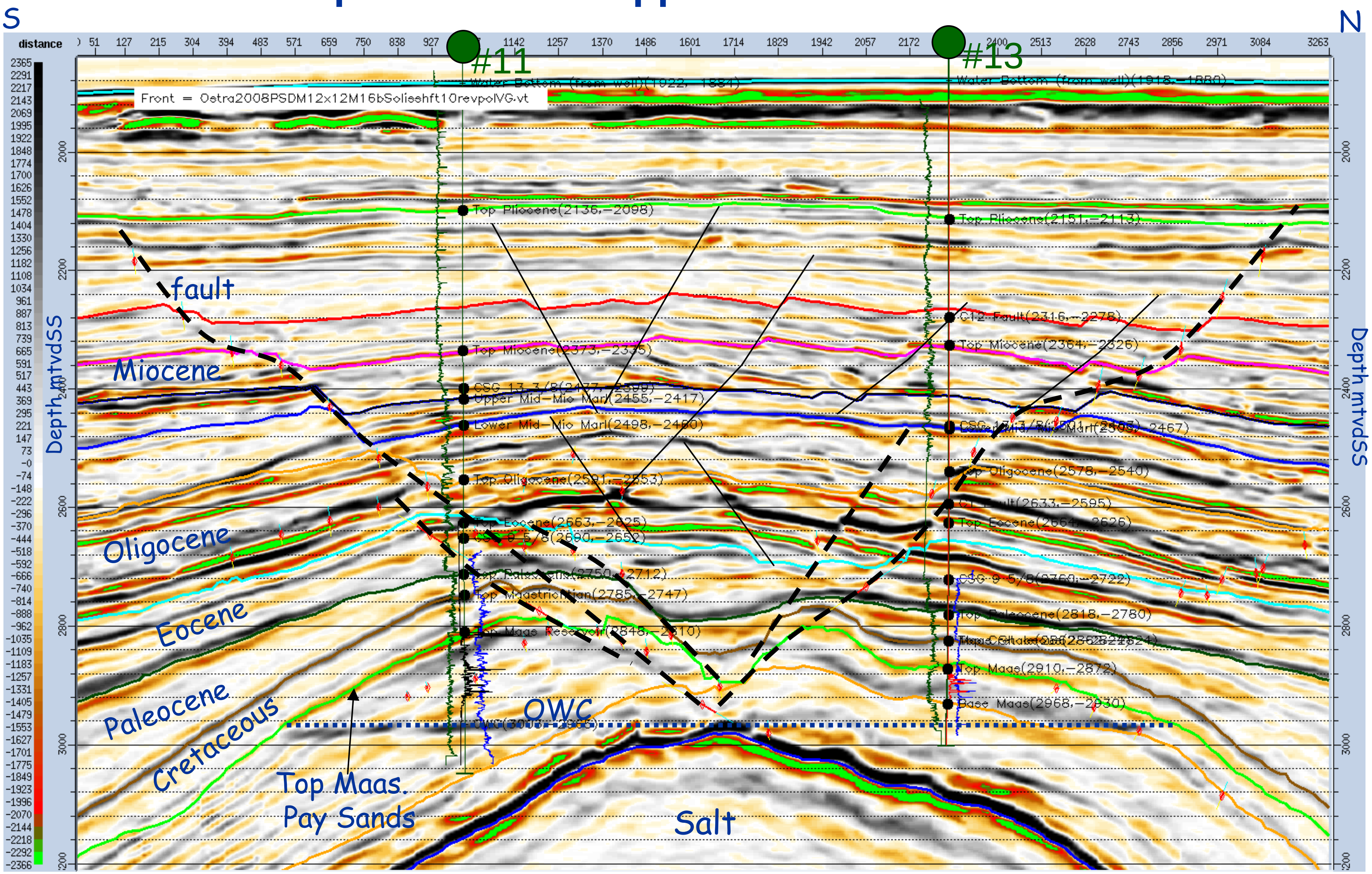


Joint Venture

- 50% Shell Brazil Ltda (Operator)
- 35% Petrobras
- 15% ONGC
- Northern Campos Basin120 km SE of Vitória offshore Brazil
- Ultra Deep1900 + m water depth

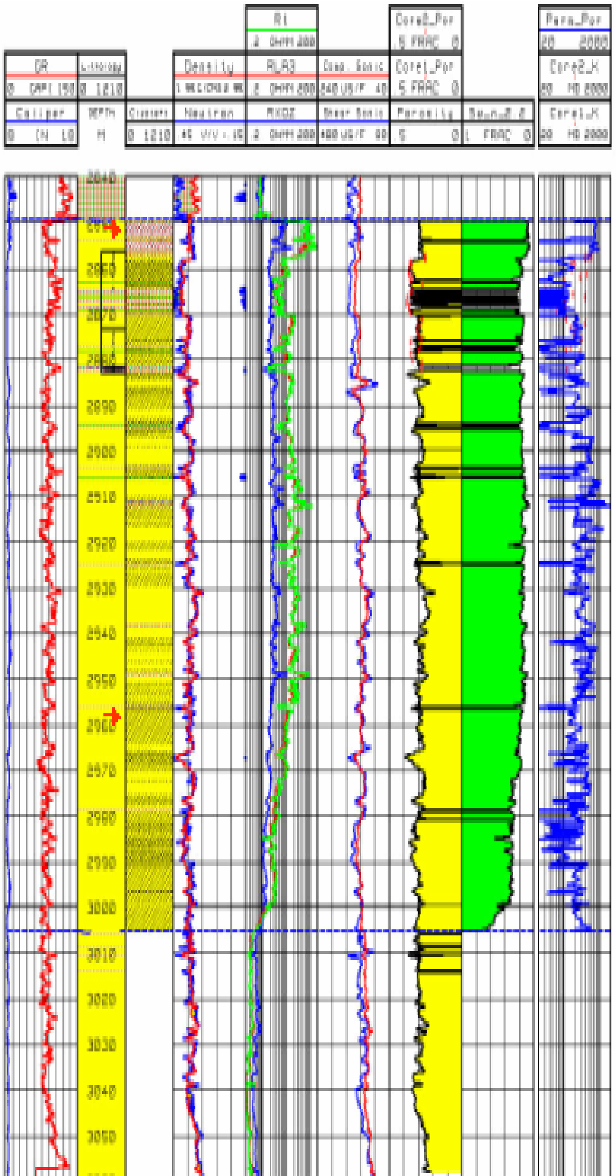
Original Planning Premise and Challenges

OSTRA Exploration and Appraisal Well Control for F.D.P.



OSTRA Well Control for Development Planning

High NtG Reservoir 80 to 95 % with much of non-reservoir Calc Streaks



#11 Maastrichtian KU1:
2849.5 – 3005.5 mbdf

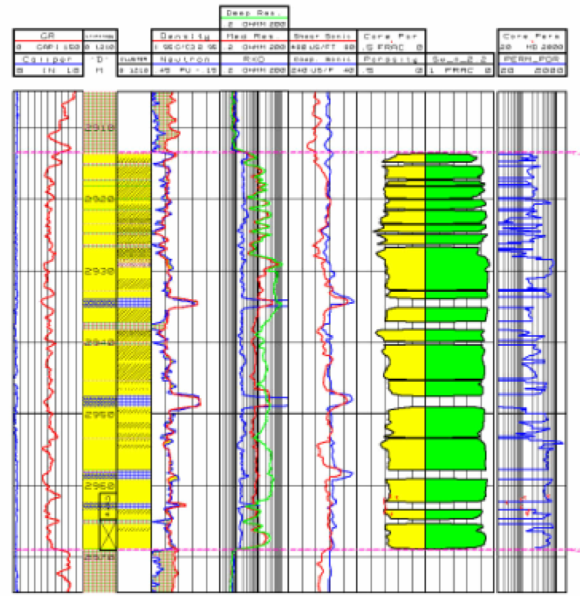
- Gross : 156 m
- Net : 149 m
- N:G : 0.95
- ϕ : 30%
- Sh : 79%
- Cut 27.3 m core, rec 25.5 or 93%
- Rec 56 of 60 SWC

MDT oil samples taken at:

2850.5 mbdf

2957.0 mbdf

TD in Sand



#13 Maastrichtian KU1:
2913 – 2969 mbdf

- Gross : 56 m
- Net : 45 m
- N:G : 0.81
- ϕ : 28 %
- Sh : 88 %
- Cut 8 m, rec 3.68m or 46%
- Rec 52 of 60 SWCs

MDT oil samples taken at:

2930.5 mbdf

2968.6 mbdf

Lower Maas KU2:
Penetrated all non-reservoir
Gross : 70.5 m

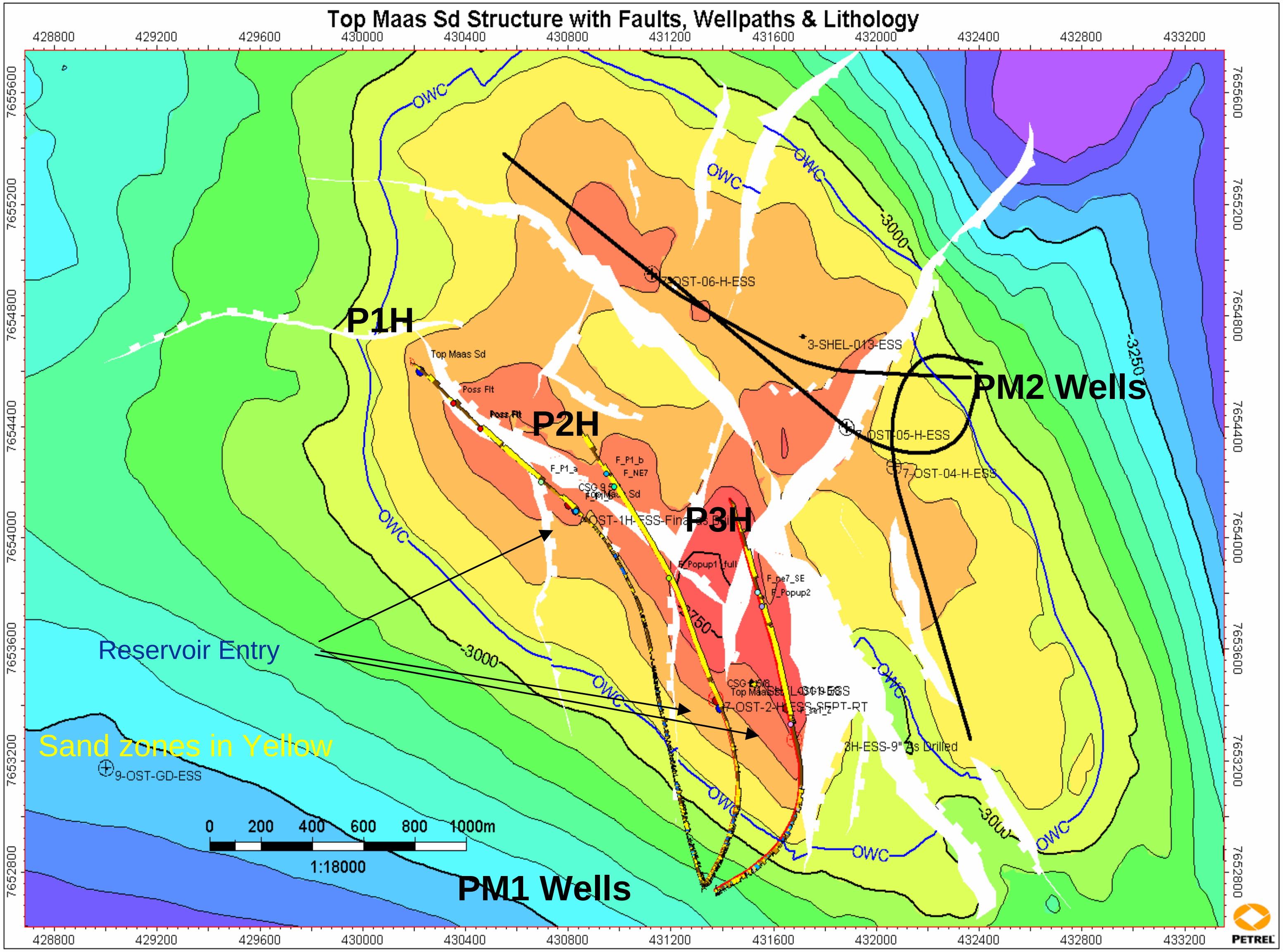
TD in Shale

Challenges:

1) Shallow (~900 m TVD below mudline)
2) Structurally complex
3) Relatively heavy and viscous Oil
4) Low fracture gradient

Results of PM1 Wells & Changes in Drilling program

Drilling Results – PM1 First 3 Horiz Prod



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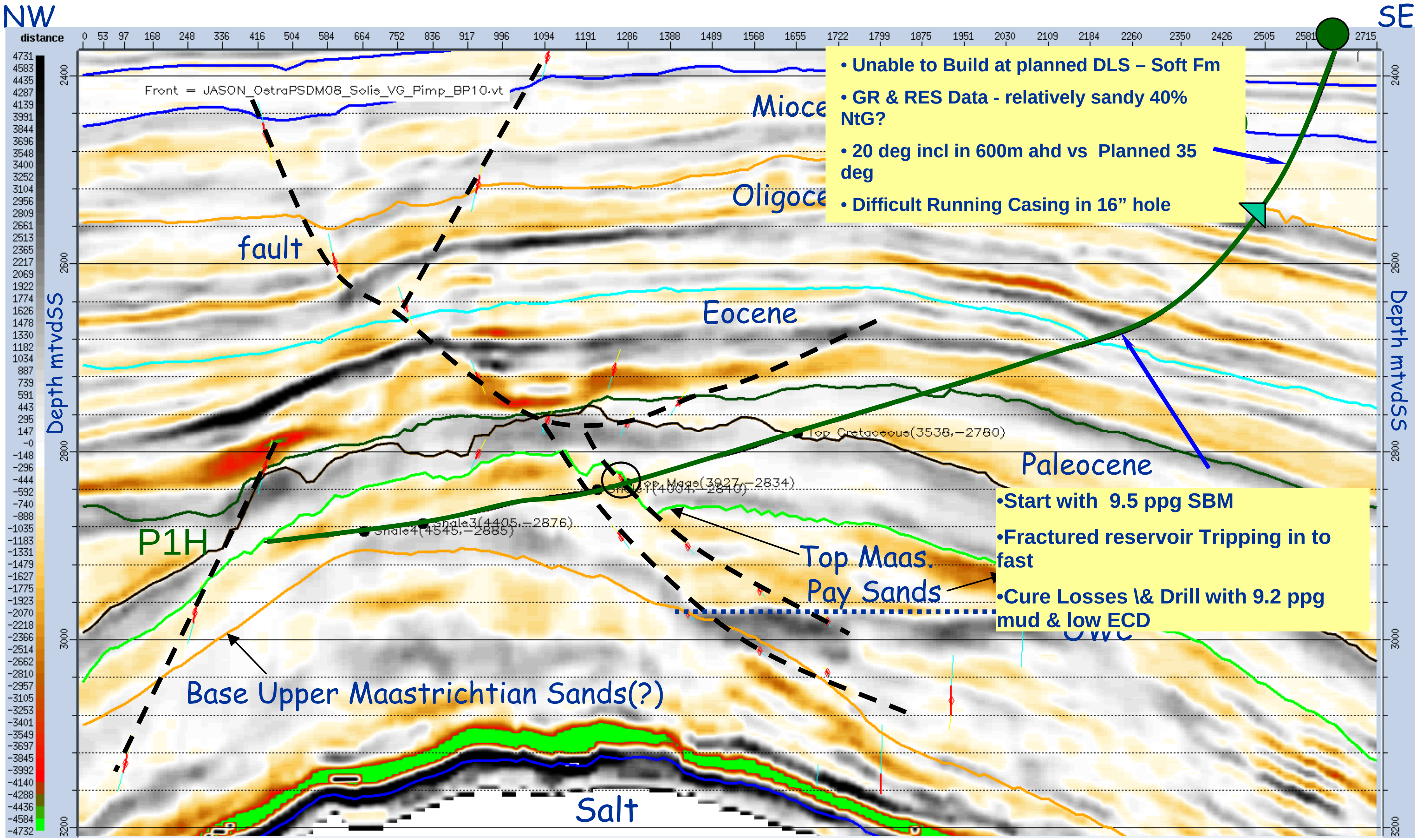
P1H Drilling Results - Top hole and Build-up Sections



OST-P1H (Reservoir) Well Section (p-impedance) in Depth showing Horizons, and faults

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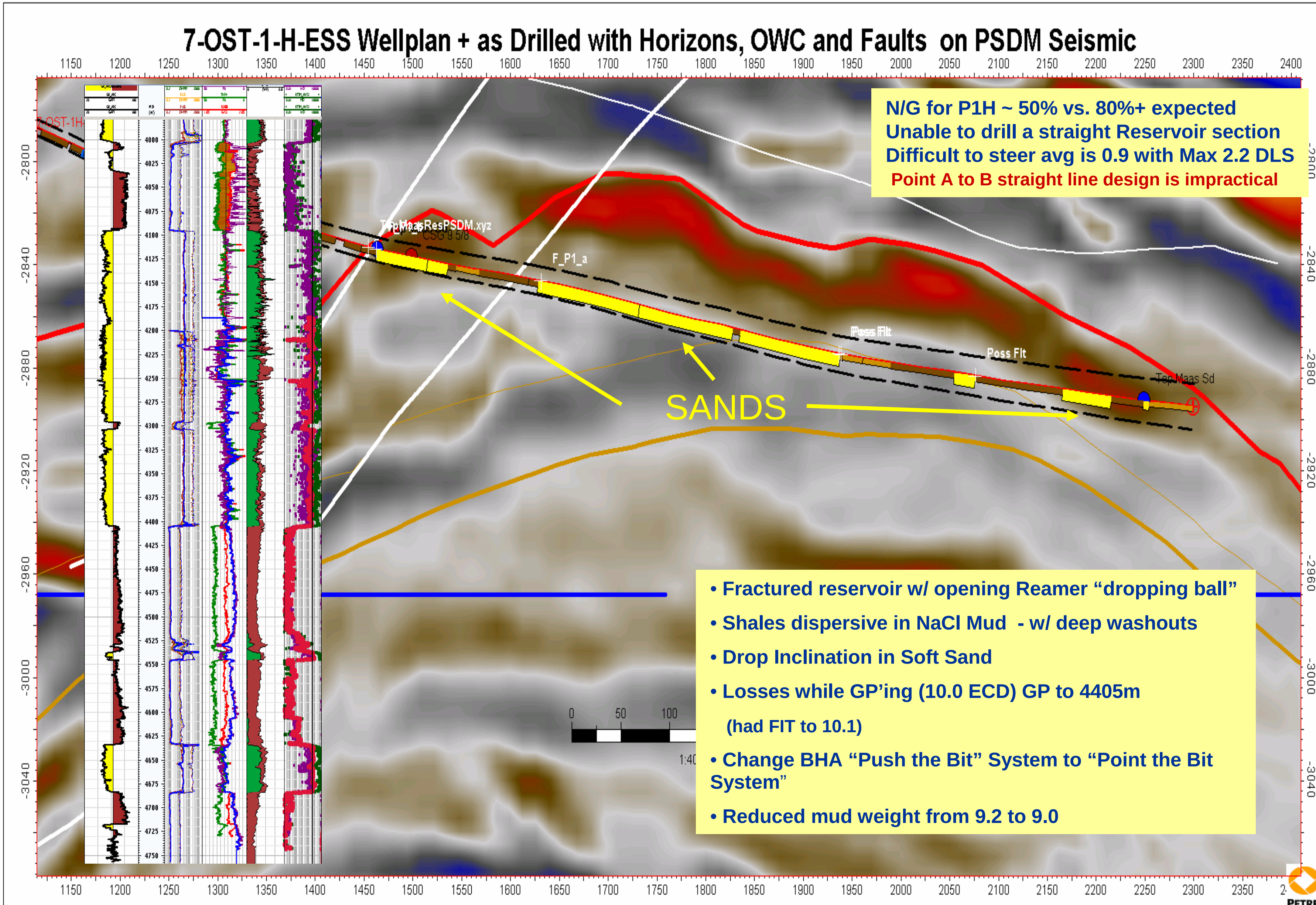

P1H – 8.5 bit X 9.5" Reamer Horizontal Section

Production Manifold 1 Subsurface Results vs. Prediction

- **Top reservoir intersection within 3m TVD (<80m AHD)**
- **Faults found within 20m of prediction:**
  - NS faults Cmt'ed seepage while drilling
  - No major losses associated while drilling faults
  - Some Mud Loss issues while completing P2
- **NtG for P1H and P3H ~ 50% vs 65-95% predicted. P2H NtG = 90%**

Evolution of Drilling Plans during PM1 Well execution

Top Hole : For PM1 Wells we changed Well Plans to less aggressive Build-Up Shallow

Build–Up : Increase DLS (Change in TopHole): ***Change BHA "Push the Bit" to "Point the Bit System";*** Reduce SBM Mud Wt from 9.5 to 9.2 ppg

•Reservoir Section:

•Use Point the bit steering system

•Change Reservoir profile from Straight line to modest "Build & Turn" to target sands

•Change Mud System to 3% KCl & drop WBM Wt from 9.2 to 9.0ppg

•Change LWD/MWD Tool : Battery life, Data Suite - Caliper behind Reamer

•Changed reamer Type and Drill-out Procedure

PM2 Wells

Working Together to Deliver Better Wells
Changes to Planning and execution Workflow

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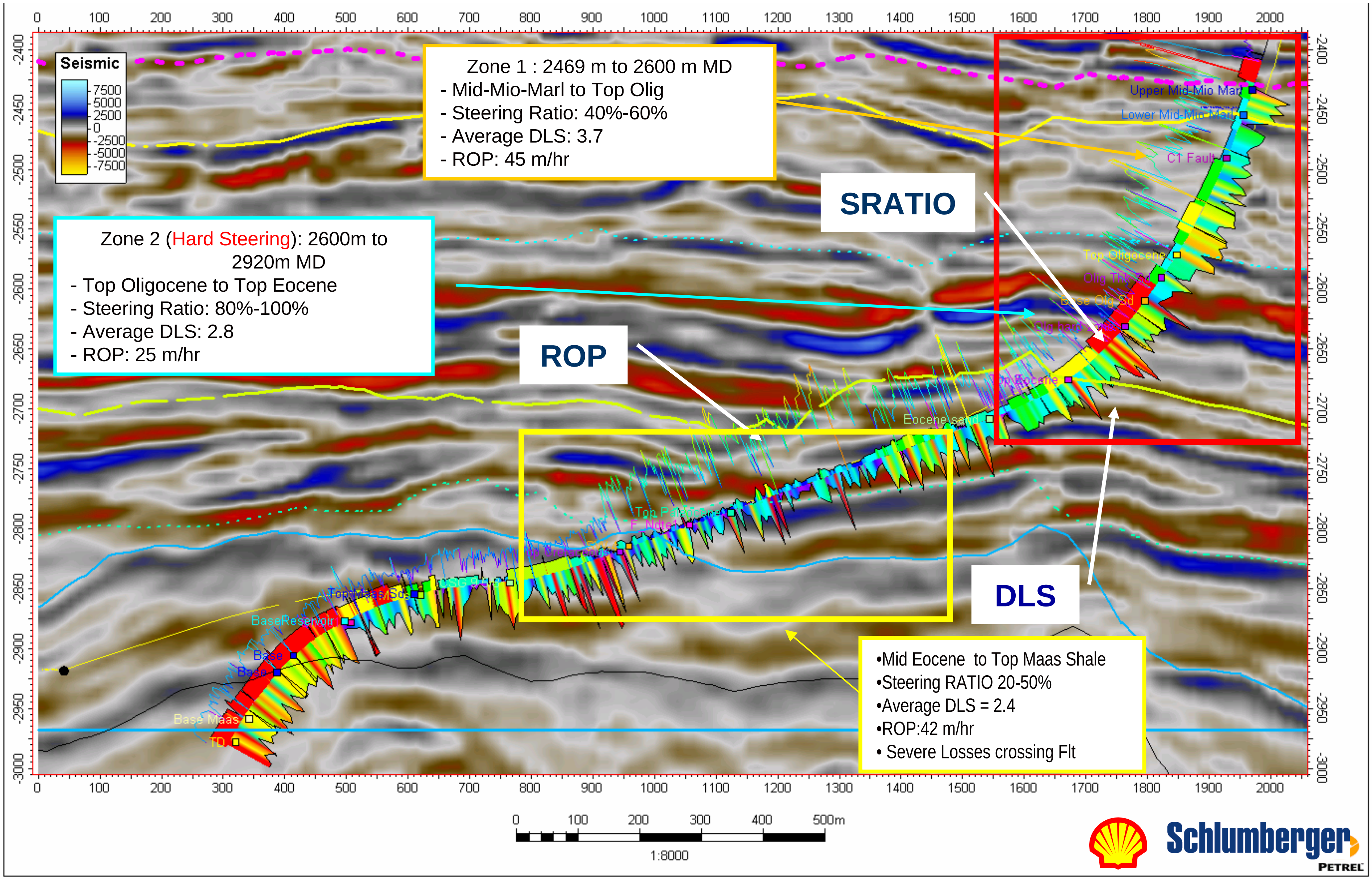
Top Hole and Build-up section – Integration of Drilling and Directional Data with Geology



Changes in Drilling Plans Resulting from Multi-Disciple review of Drilling & Directional Drilling performance against Subsurface data

Top Hole :

- *Change BHA for PM-2 wells from 16” bit to 12.25” bit w/17.5” Reamer*
- *Use Point the Bit system for Top-Hole Drilling*
- *Adjust DLS and steering parameters per Lithology, depth and Drilling behavior*

Build–Up :

- *Adjust DLS per Lithology, depth and Drilling behavior*

Reservoir Section:

- *Add Pilot Well in P4H Fault Block to reduce uncertainty*
- *Use Seismic data to Plan Reservoir well path (Impedance volumes and Body Extraction)*
- *Add geo-steering in Reservoir section*

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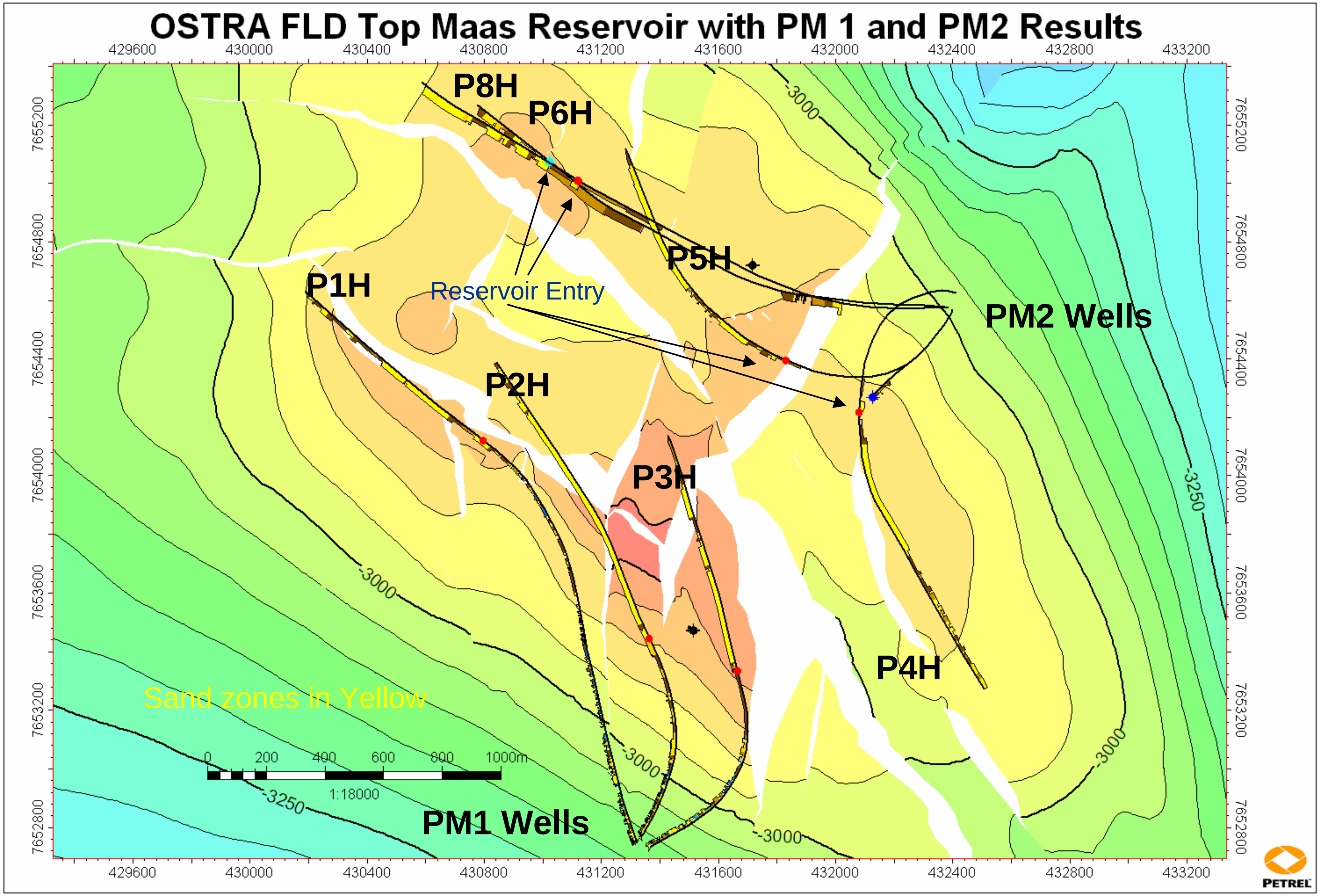
Drilling Results – PM2 Horizontal Producers



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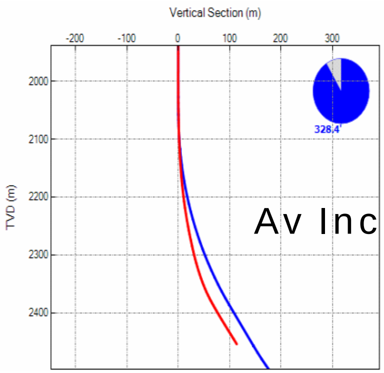
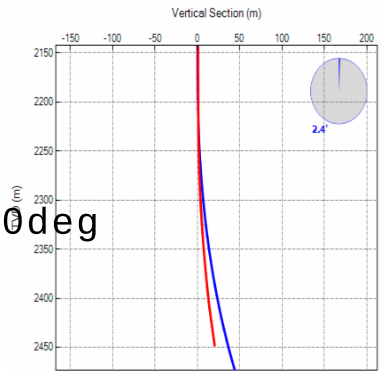
Top Hole Results

PM-1

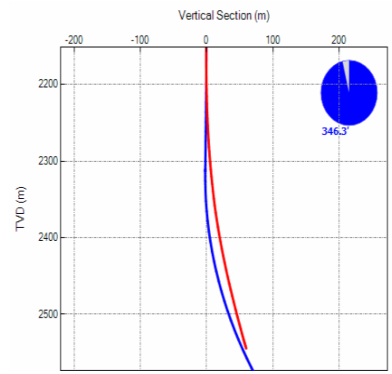


Av Inc 20deg

Ostra P1P

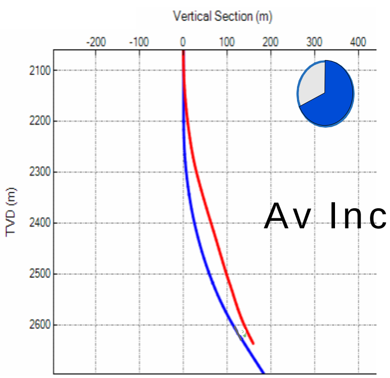


Ostra P3H



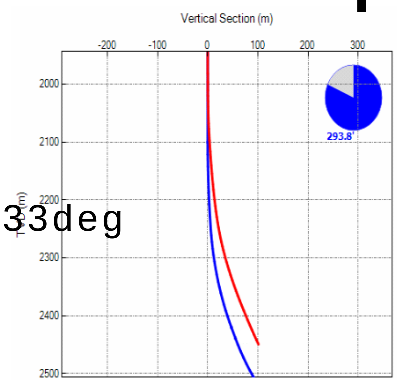
Ostra P2H

PM-2

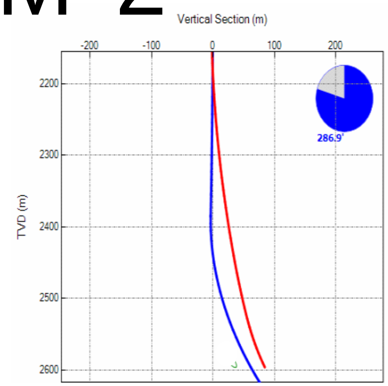


Av Inc 33deg

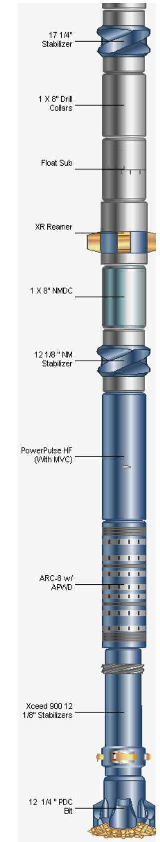
Ostra P4H



Ostra P6H



Ostra P5H



17 ¼” Stabilizer

Reamer 12 ¼” x 17 ½”

12 1/8” Stabilizer

Blue = Plan

RED = as Drilled

12 ¼” x 17 ½”

Use $12^{1/4}$” bit with $17^{1/2}$” reamer for top hole

Reduce drilling time by 50%

Proved DD capabilities of BHA in demanding wells w/ excellent DLS performance in soft Fm.

Drawbacks

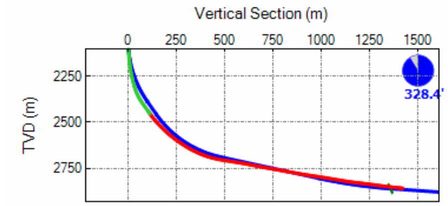
Need to drill 70 m past casing point for reamer to open hole

More moving parts

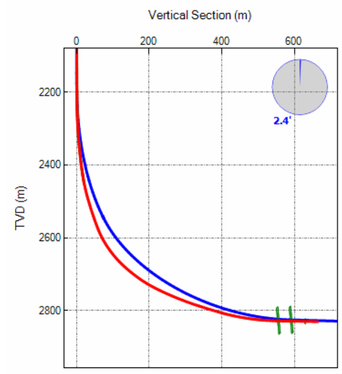
Landing in the correct spot

Production Manifold 1

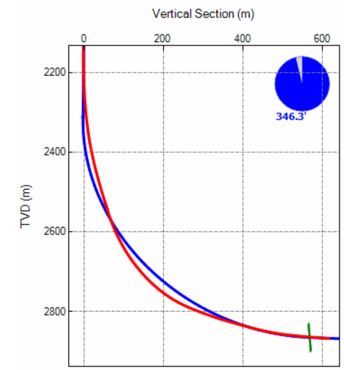
- P1H easy profile landing in the reservoir +/- 1m on plan
- P2H more aggressive profile – Res. came early 50m ahd
- P3H most aggressive plan in PM-1 Build and turn with a required DLS average 4.0°/30m – Land 3 m tvd deeper to Plan (80 m AHD)



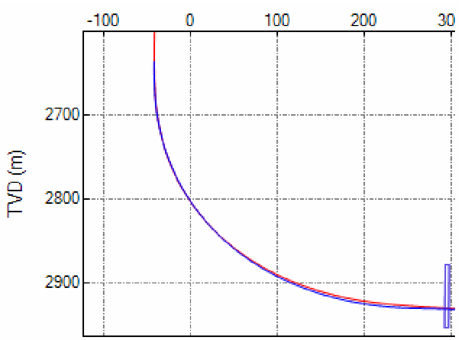
Ostra P1P



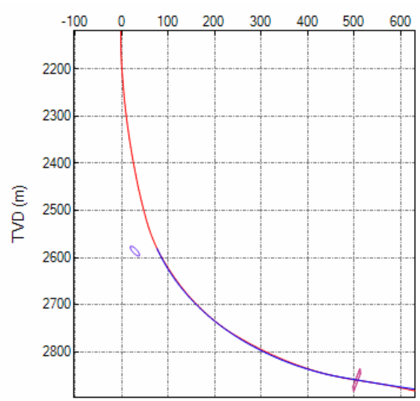
Ostra P3H



Ostra P2H



Ostra P4H



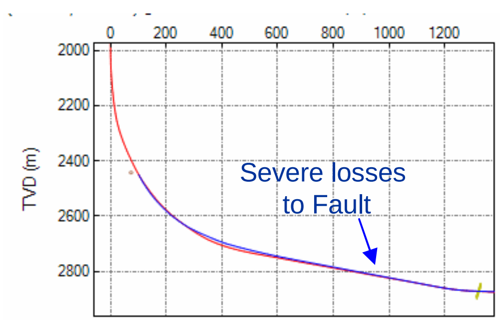
Ostra P5H

Production Manifold 2

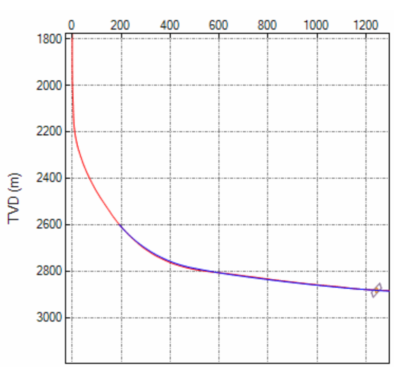
- P6H easy profile,

  Had Losses, magnetic interference = Survey error and Seismic Velocity mistie. Lost 150 m Reservoir section & turned well into Pilot
- P5H aggressive profile landing in the reservoir 80 m ahd late
- P4H most aggressive 3D profile, DLS constant 4.3 deg/30m

  Meet target using less than 100% of steering capabilities
- P8H (replace P6H) easy profile, landing in the reservoir +/- 1m on plan



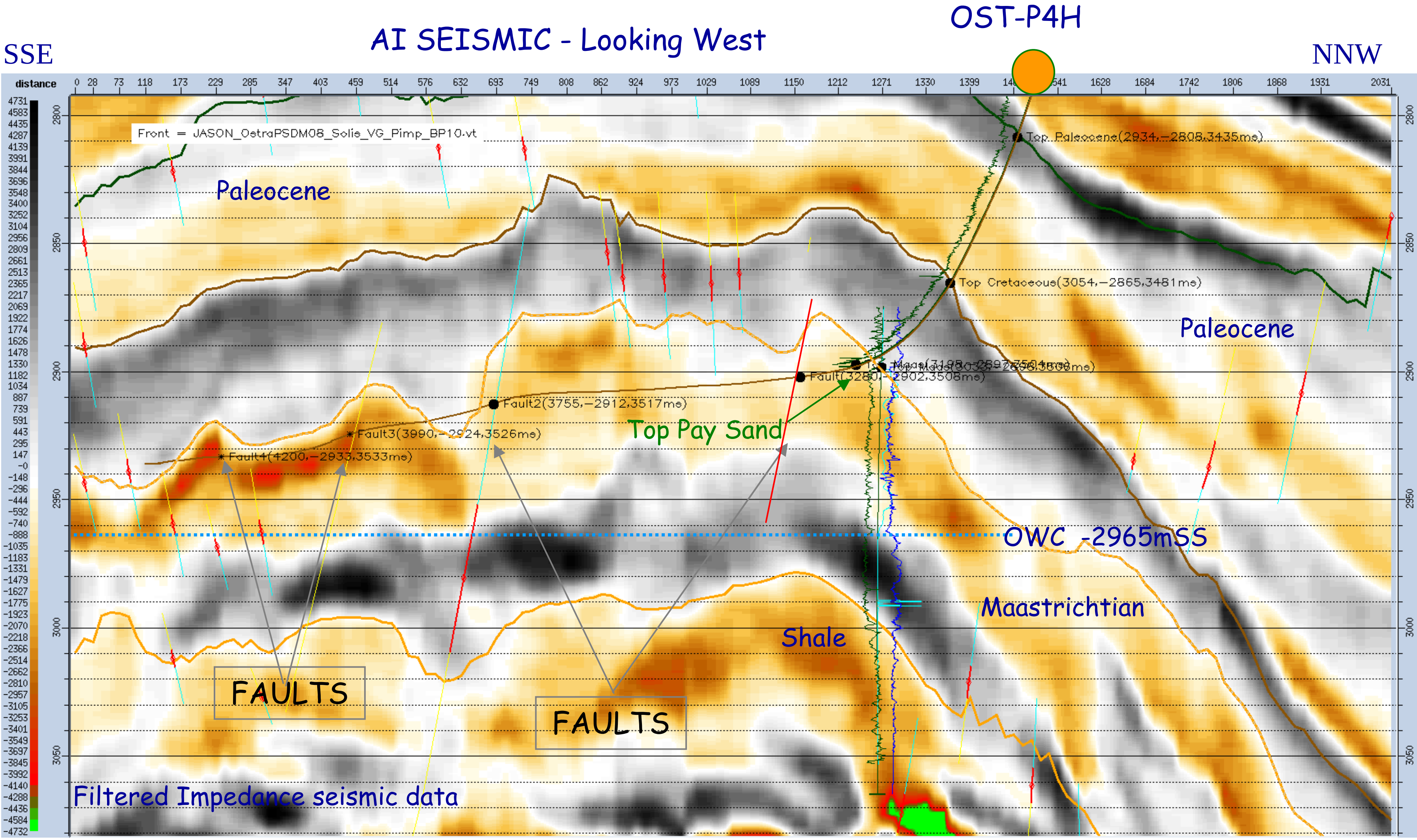
Ostra P6H



Ostra P8H

Ostra Field
Reservoir Section
Well Planning and Geo-steering
P4H Example

P4H Well Path Plan with P4 Pilot well and Mapped Faults

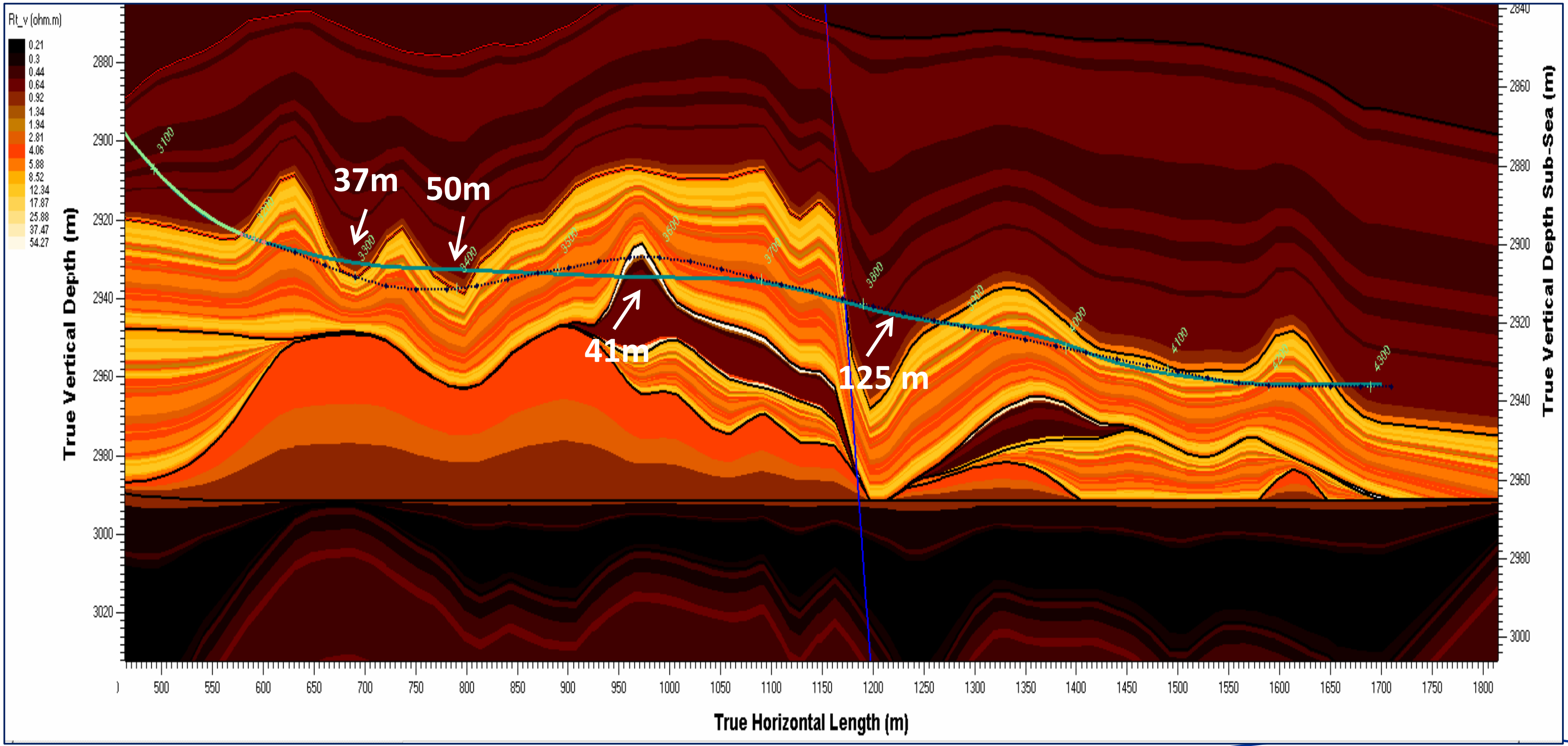


Fault Cuts (approx): 3280, 3755, 3990, 4200mMD
Fault Near 3280-3400mMD

2D Resistivity Layer Model of P4H Planned Well path

Use to Predict Geo-Steering tool behavior and reduce reaction time to changes in geology while drilling.

Multiple realizations were constructed



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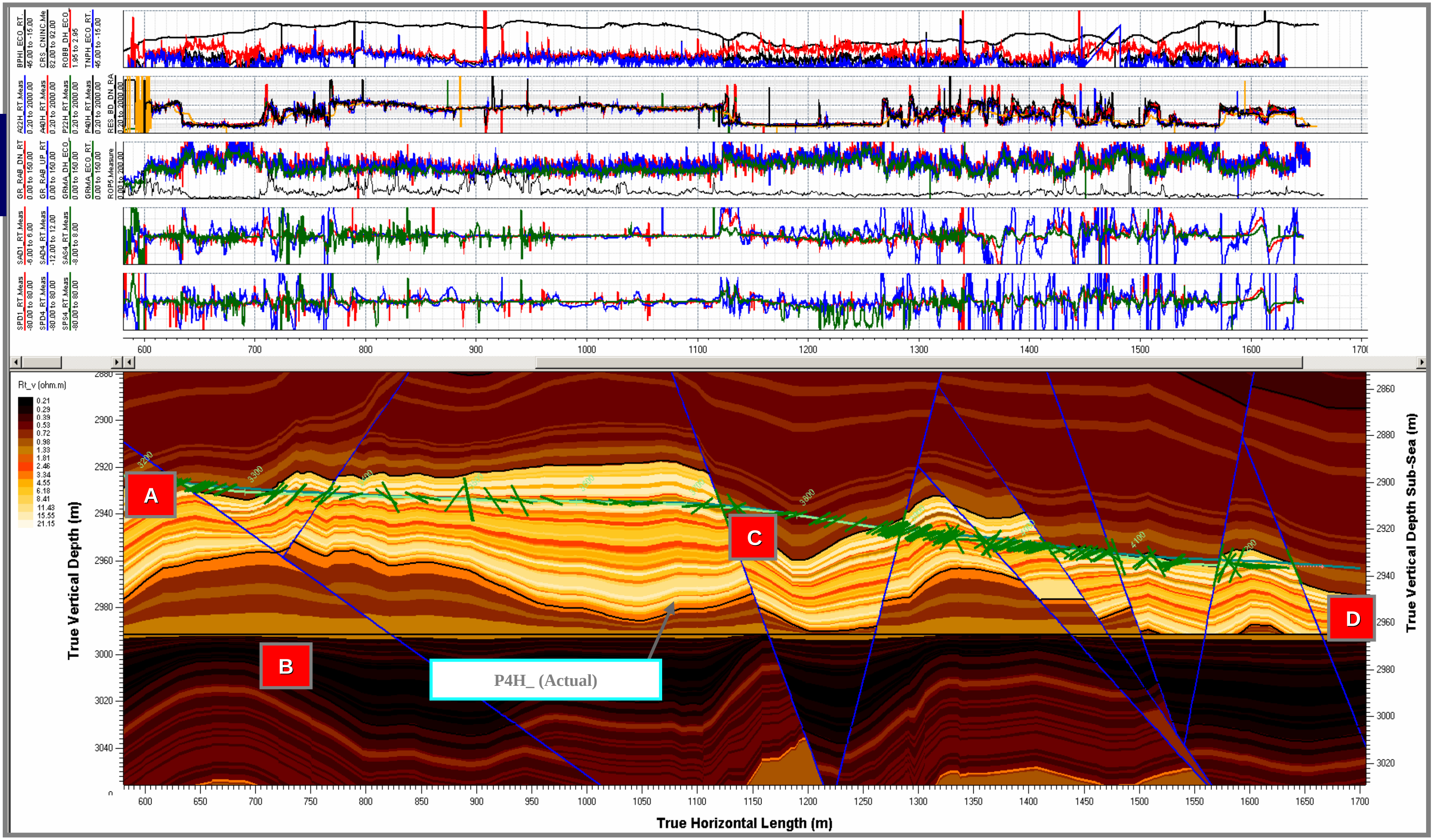
RTGS Model – Final Curtain SectionAs interpreted from Drilling Results



RTGS

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Ostra Field

Integration of Subsurface and Drilling data
to deliver better Wells

Summary

Ostra Phase 1 Drilling Improvement Results Summary

Top Hole Section: 16" changed to 17.5" hole

- **12.25" bit w/17.5" Reamer with Point the Bit system** + used learnings from Integrating Drilling & DD Behavior with Geology and increased team interaction resulted in:
- Increasing Avg Casing point Inclination from 20 degs to 33 degs
- Reduce drilling time by 50%
- No Problems encountered Running and Cementing 13.5/8" casing

Build–Up Section:12.25" Hole

- P1H and P2H landed within 1 to 2 m of plan (tvd) with simple Well profiles
- P3H landed > 4m deep to Plan - DLS average 4.0°/30m
- For P4H, P5H, P6H and P8H were Drilled within 1 to 2 m of Plan.
- P4H Average DLS 4.3 deg/30m with Steering Ratio < 100%
- P5H and P6H come in late due to changes in Velocity and Survey error in NE part of the field
- P6H was turned into a Pilot well, had Severe losses crossing a fault and was replaced by P8H

Reservoir Section: 8.5" hole

- Use Seismic data to Plan Reservoir well path
- No Longer Drilled "straight Point A to B Wells" - targeted zone with stronger Seismic Sd indications
- Able to enter Reservoir higher & add 150 m more exposure to Reservoir at the heel of the well
- Add geo-steering in Reservoir section and add additional sand despite restriction on DLS for GP
- Successfully Gravel Packed P4H with DLS up to 6 deg/30 m in the reservoir.

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Acknowledgements

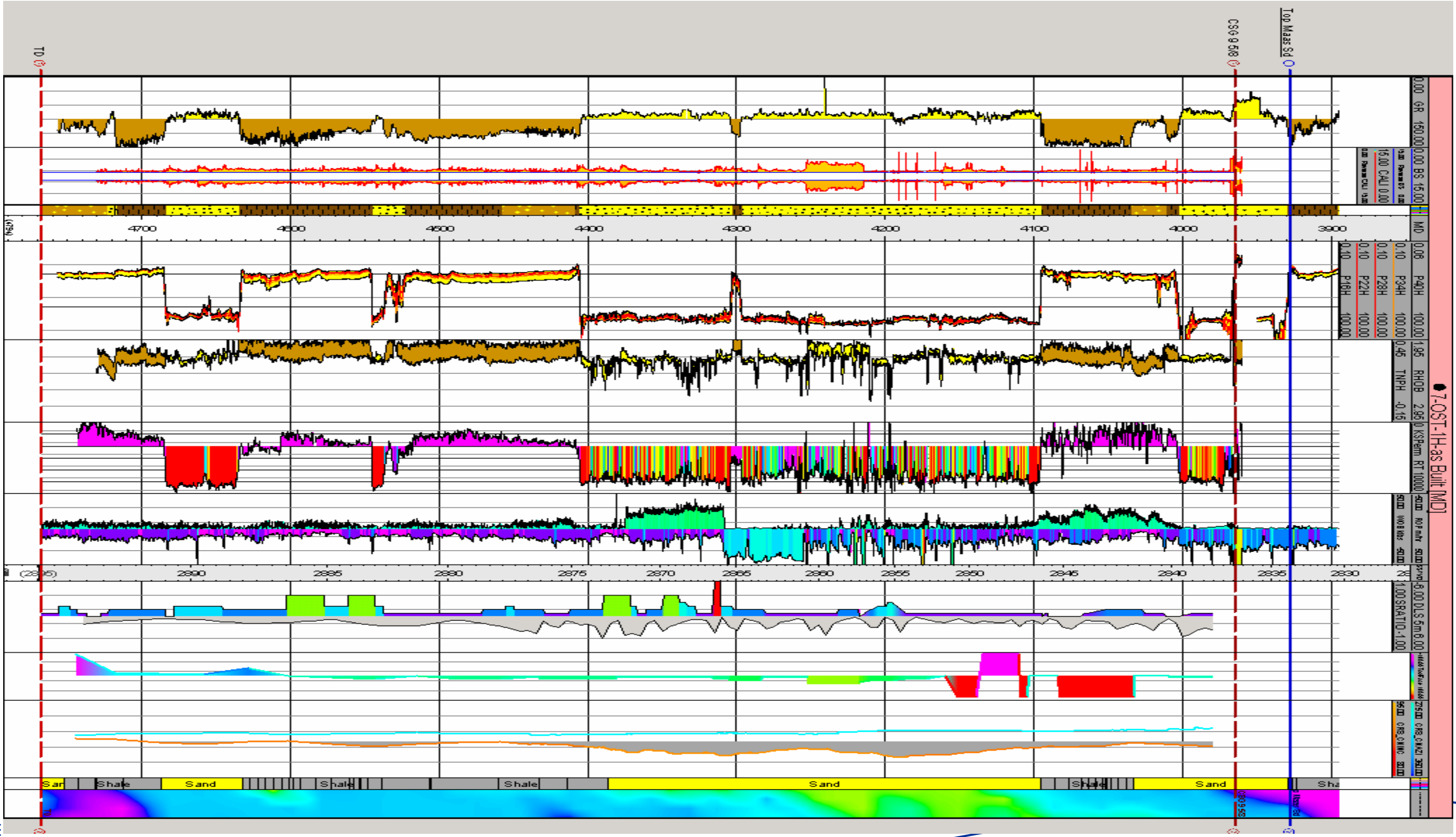
Schlumberger-Western Geco (Seismic)
Schlumberger D & M / Well Placement-Geosteering

To the many Shell employees who worked to bring BC-10 on Production

Our joint venture partners:
Petrobras, & ONGC
and the ANP

Back-up

P1H Reservoir section drilling Results and Reservoir drilling behavior



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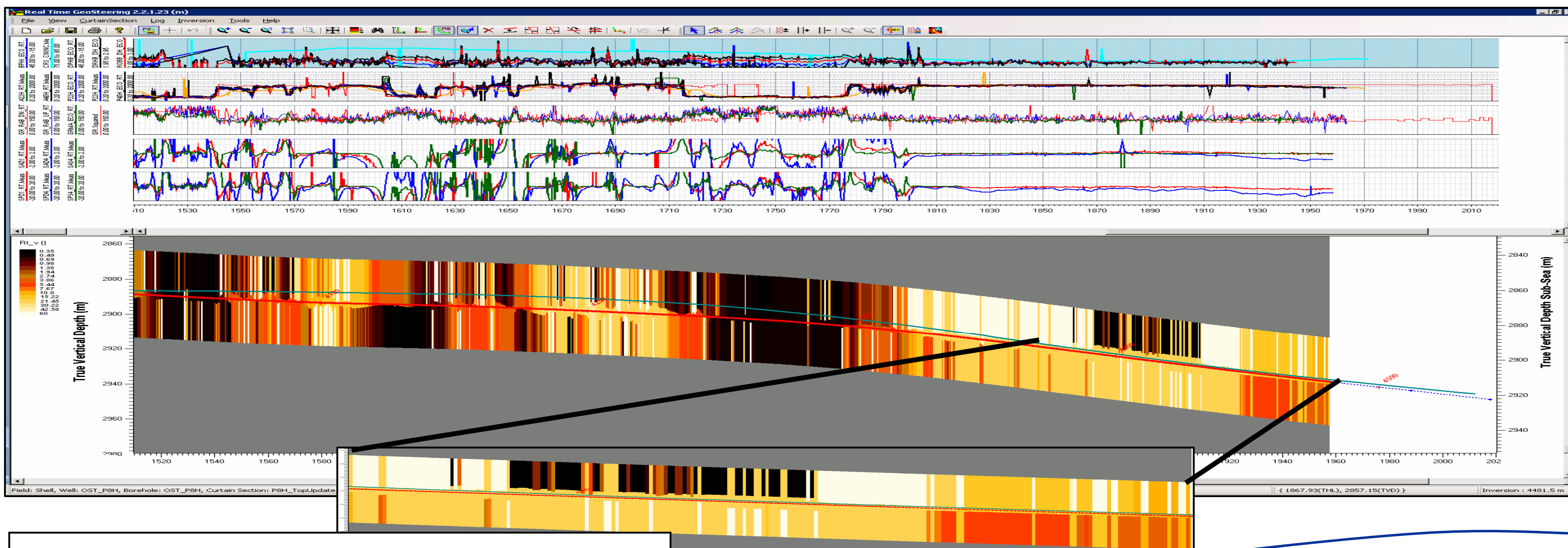
Geosteering / Execution

Execution

- Final Net Gross above the minimum expected (60%) in all 3 horizontal sections
- Unexpected Shale after the casing shoe (Seismic uncertainties)
- Due to accurate pre-modeling and risk management, use of Geo-steering tools for RT decision making was minimized in the P4H Well, but well used in P8H and P5H
- LWD data was effective in determining the Reservoir characteristics (image helped to understand the formation dips, Lithology, probably depositional environment and Fault distribution). Expected Shale intervals defined by low amplitude (Seismic) match with RT data
- Directional Guidelines provided by town proved extremely useful on rig site



P-15 stats to map the top of reservoir from 4391m to 4432m with 4.5m of distance. At 4448m P-15 inversion shows a minor conductive lamination below the trajectory which Rbit responds with a sensitive decrease

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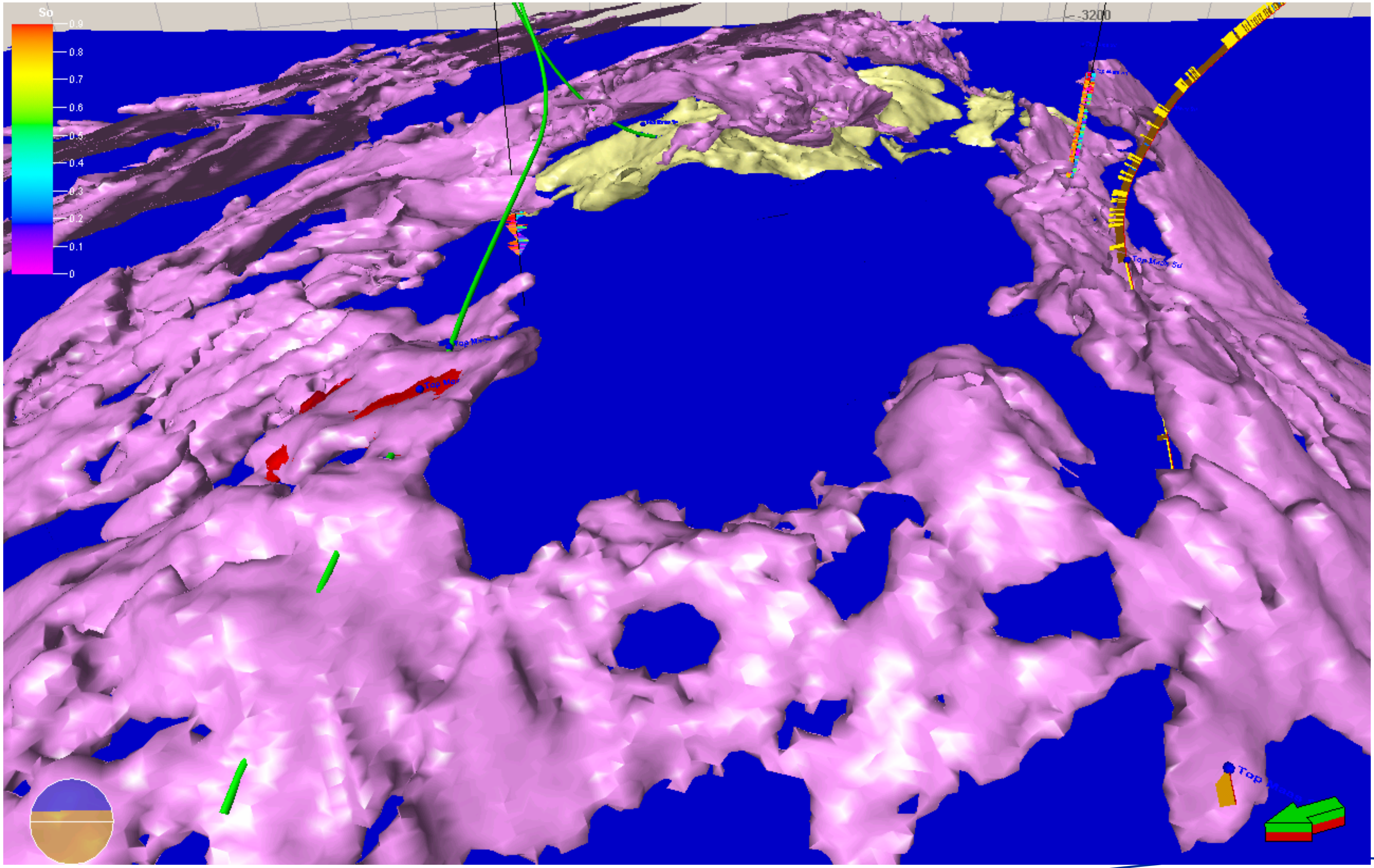
Use of extracted Seismic Volumes to plan reservoir Path



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