Pore Pressure Prediction Based on High Resolution Velocity Inversion in Carbonate Rocks, Offshore Sirte Basin - Libya*

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Abstract

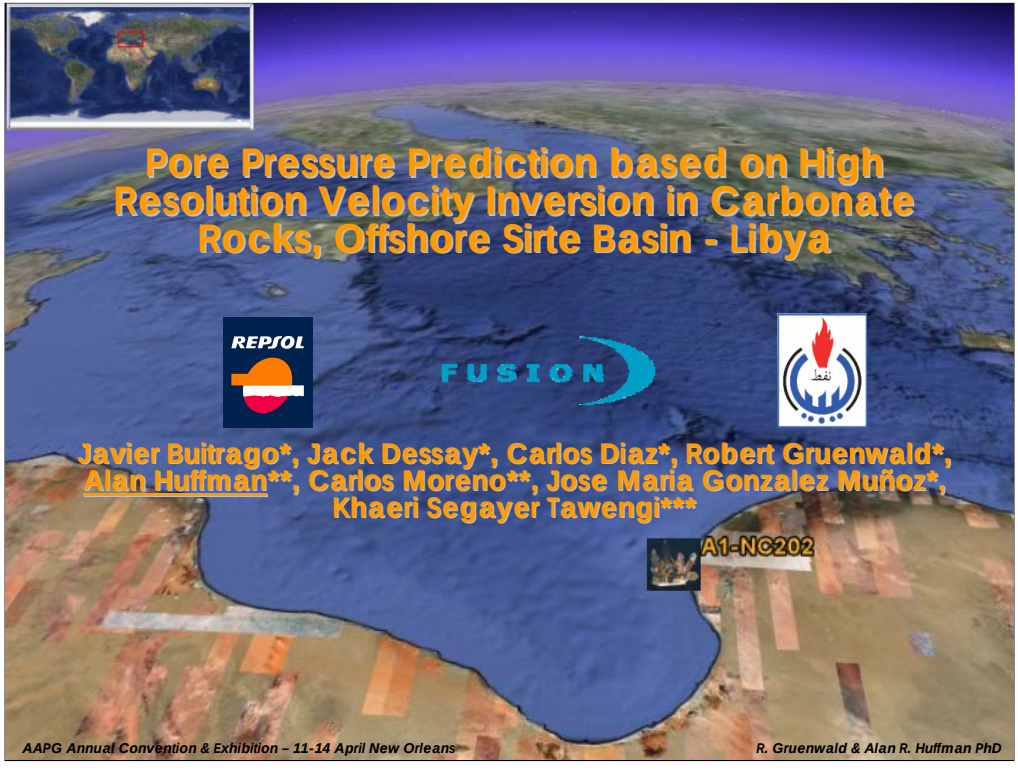
ResidualTM velocity analysis was employed to refine the input gathers and velocity field for pressure prediction in Cretaceous carbonates and further processed to produce an inverted velocity cube. From the acoustic inversion a shale velocity trend was generated and used for pressure calibration with the control wells to predict pressures in 3D. Attributes were generated for pore pressure (PP), pore pressure gradient (PPG), overburden pressure (OB), overburden gradient (OBG), fracture pressure (FP), fracture pressure gradient (FPG) and effective stress (ES).

Two reservoir-specific PP models with different saturating fluids were generated to account for buoyancy effects; Z Reservoir = FG at structural crest. From down dip pressures P-Max is calculated to a maximum extent of the possible fluid column to predict for pore fill columns using the local closure and spill points and pressure prediction at the penetration point for the reservoir assuming the existence of a centroid pressure point in a monoclinal structure. Fluid gradients used were; for brine 0.465 psi/ft, for light oil 0.3 psi/ft and for gas 0.1 psi/ft.

PPP results indicate a benign shallow section and then increases steadily below 11,500 ft to a maximum of 15.5 PPG at 15,100 ft and temperatures exceeding 300 deg F at TD.

Comparison of pre-drill prediction, based on seismic velocities, with LWD guided pressure monitoring, intermediate and final VSP data and final WL results show a high affinity with the prognosis. Space and resolution dependent PP Models can be generated from actual well data and seismic displaying the inherent velocity heterogeneity of seismic data versus high resolution of WL data.

Integration of regional knowledge, sound understanding of the basin specific structural setting and offset well data, PSTM and PSDM data, with real-time drilling parameter monitoring and a technology limited by the carbonate setting, provides valuable data for kick management and casing design in a HPHT environment.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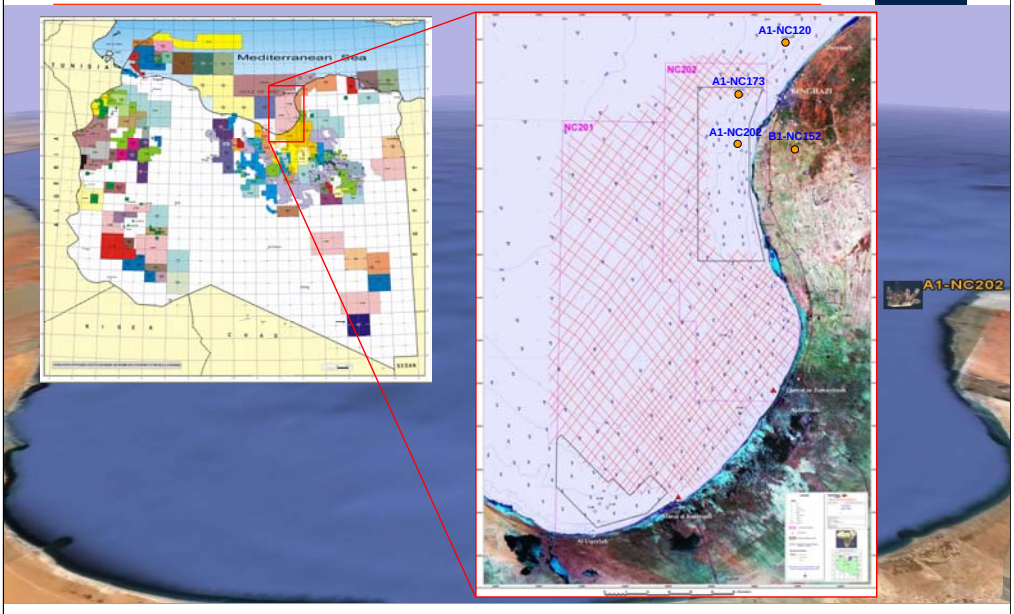
REPSOL
FUSION
Javier Buitrago*, Jack Dessay*, Carlos Diaz*, Robert Gruenwald*, Alan Huffman**, Carlos Moreno**, Jose Maria Gonzalez Muñoz*, Khaeri Segayer Tawengi***
A1-NC202
AAPG Annual Convention & Exhibition – 11-14 April New Orleans
R. Gruenwald & Alan R. Huffman PhD

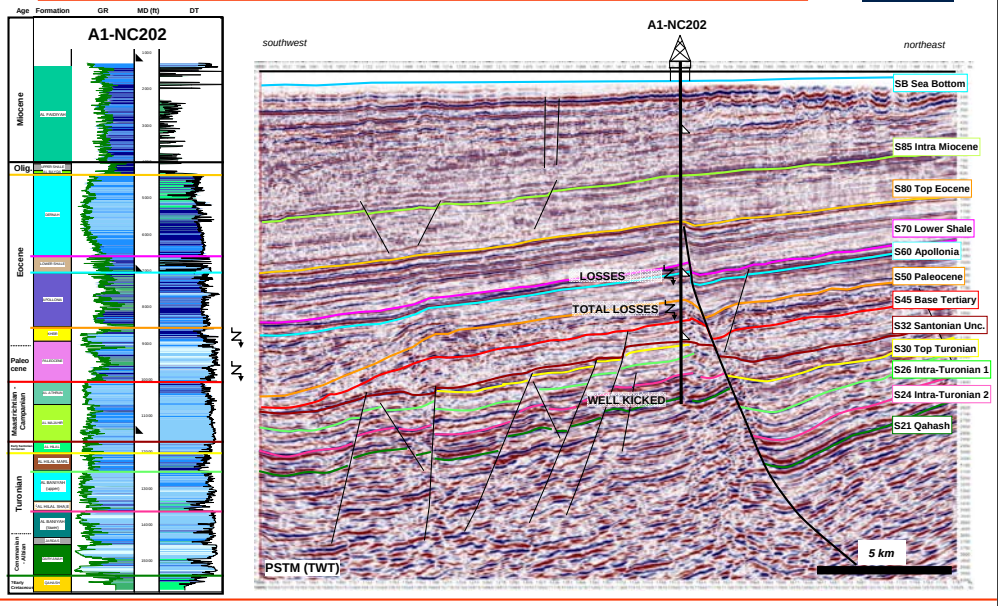
Draft Outline

- Geographical setting
- Offset Information
- Methodology
- Pre-Drill Prediction
- Well Monitoring
- Post Drill Analysis
- Conclusion

Cyrenaica - Libya



Drilled Stratigraphy – Geopressure Issues



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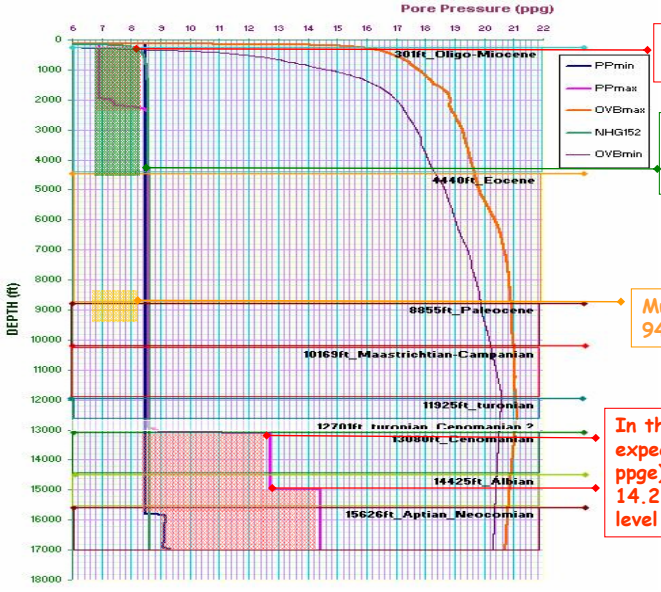
HP-HT well: Offset wells PP Comparison



Mud Losses encounter on the well B1NC152 at 371 ft

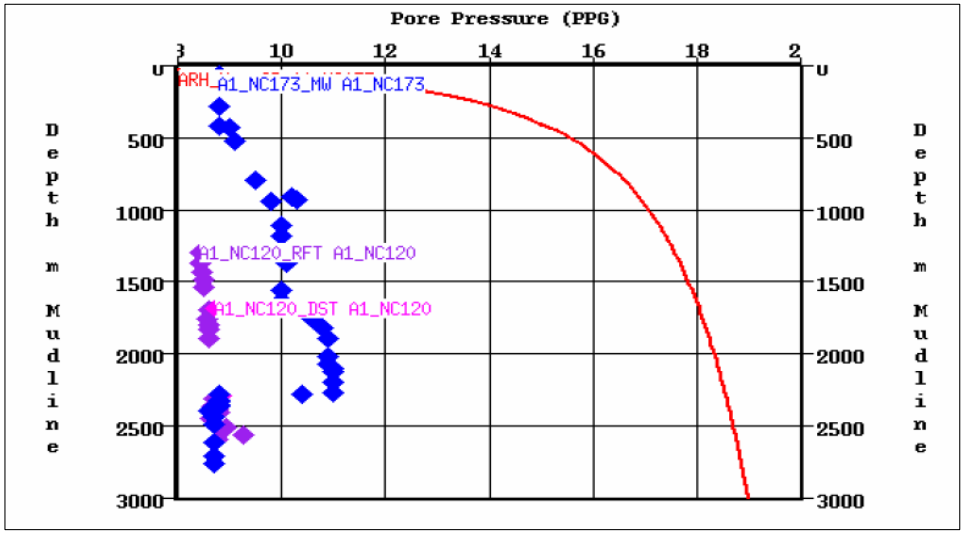
Mud Losses encounter on the well A1NC120 from 560 to 1369 feet

Mud Losses expected at 8800 to 9400 ft (corr with well A1NC173)

In the Cenomanian, PP Increase is expected at 13000 ft (PP= 12.1 ppge) and later at 15000 ft (PP = 14.2 ppge) in the Albian reservoir level (corr. with B1NC152)

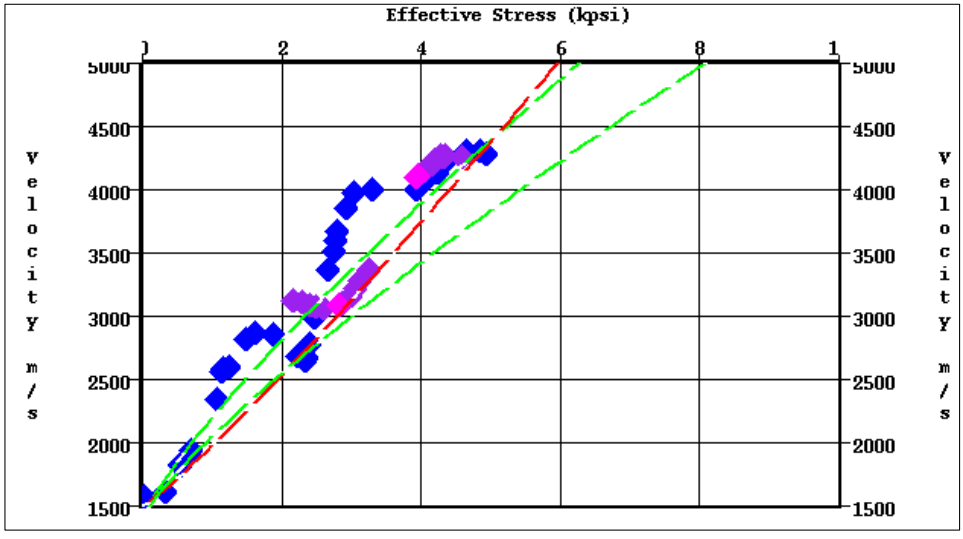
Presenter's Notes: Offset Well Information

Offset wells: Pressures from MW



Offset pressure data from the NC 120-A1 (purple and magenta) and NC 173-A1 (blue) wells that had seismic data support

Offset wells: Effective stress vs. Velocity



Velocity to effective stress calibration using a hybrid model (red curve) that moves from the minimum fluid pressure model at low effective stress to the maximum fluid pressure model at high effective stress.

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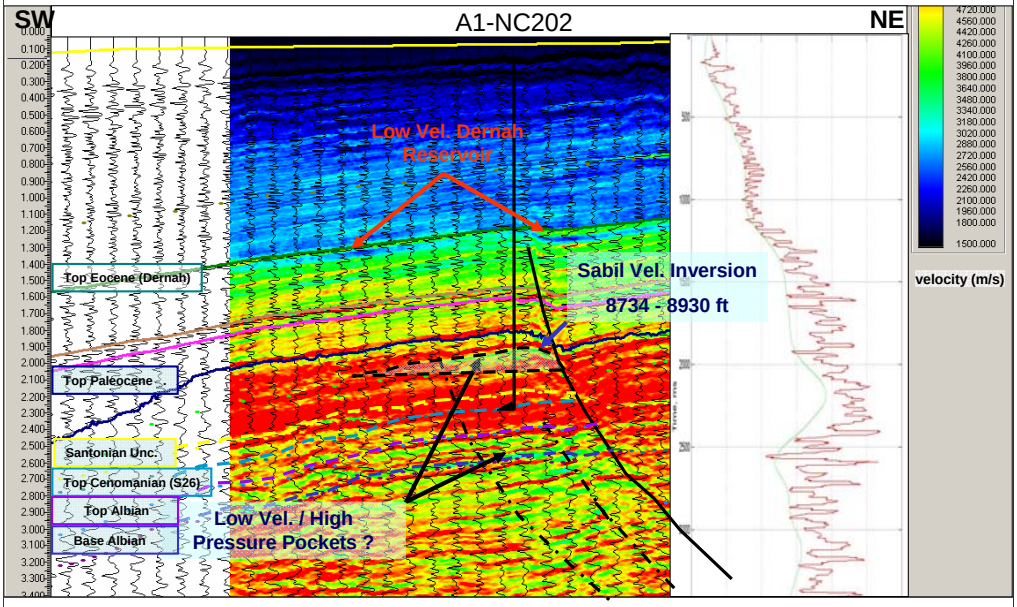
Methodology for Mixed Lithology Areas

- Perform traditional dense velocity analysis followed by residual velocity analysis
- Perform ThinMAN™ high-resolution inversion for reflectivity
- Use the residual velocities as a low frequency constraint to generate a calibrated acoustic inversion
- Extract the low velocity trend related to the interbedded shales
- Use the shale velocity trend for effective stress calibration and prediction
- Use the entire velocity field for time-depth conversion

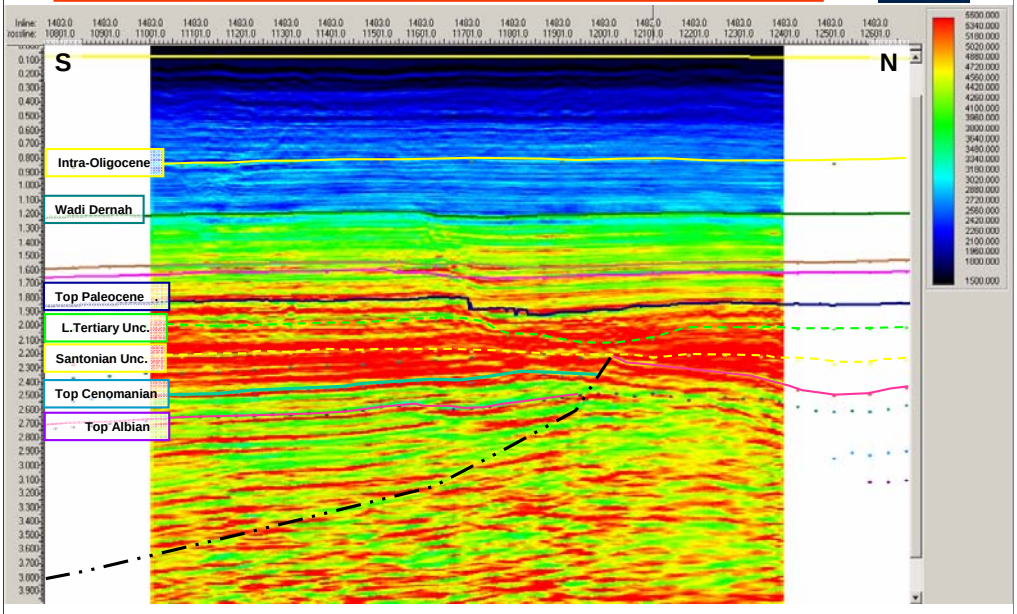
PPP Pre Drill A1-NC202



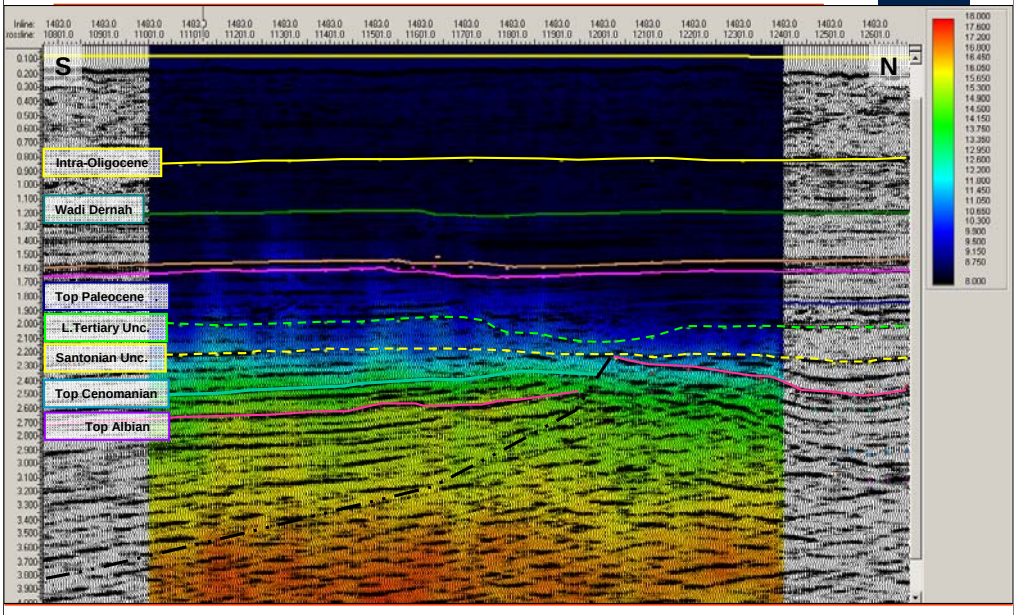
Vel. reversal is observed in Horizon S26 in Barracuda

Presenter's Notes: Comparison of inverted Vp and smoothed shale Vp at Well A

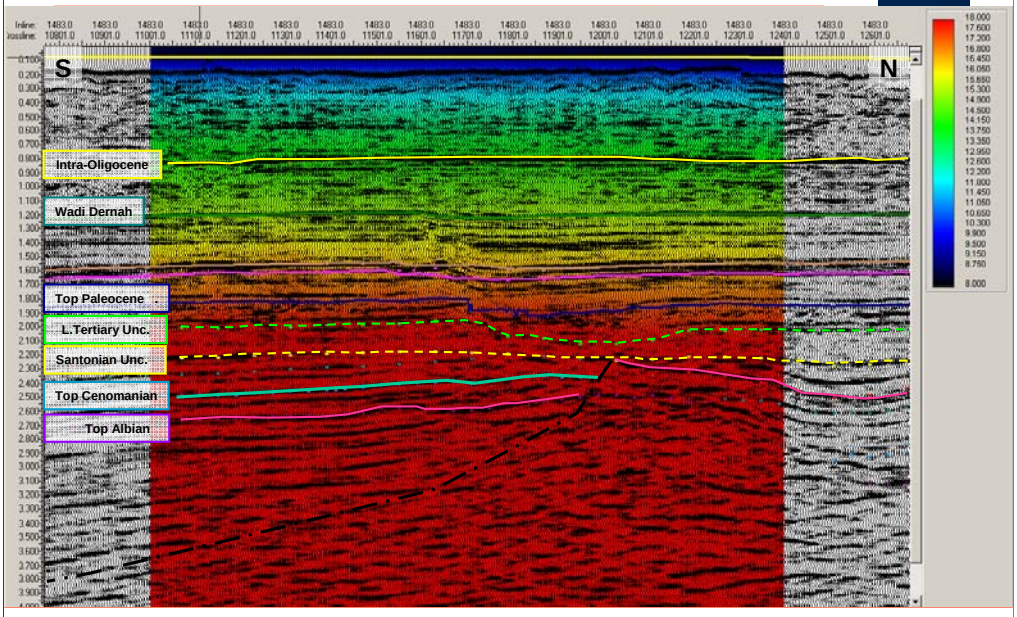
Inverted V_{int} section through prospect



Fluid P-gradient using pressure model (PPG/EMW)



Fracture P-gradient interpretation (PPG/EMW)



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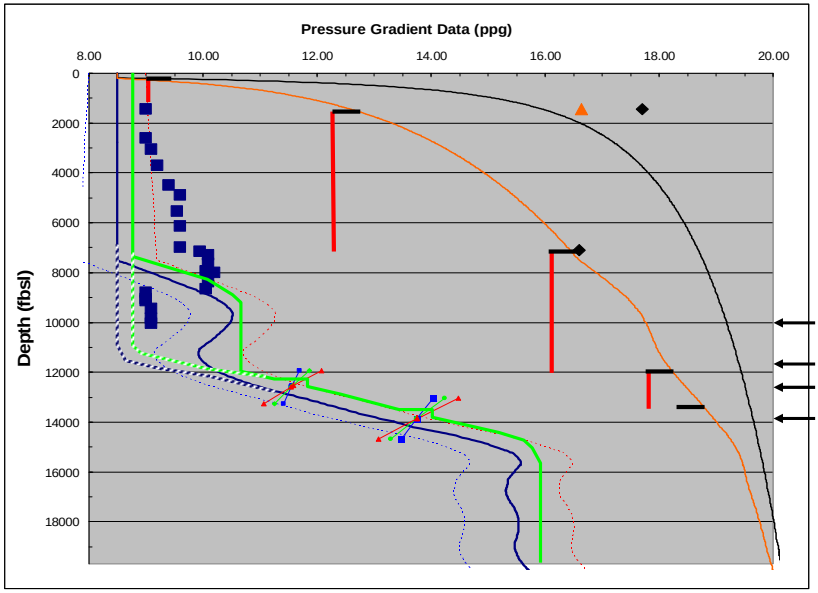
Pre-Drill Prediction vs. Drilling Calibration



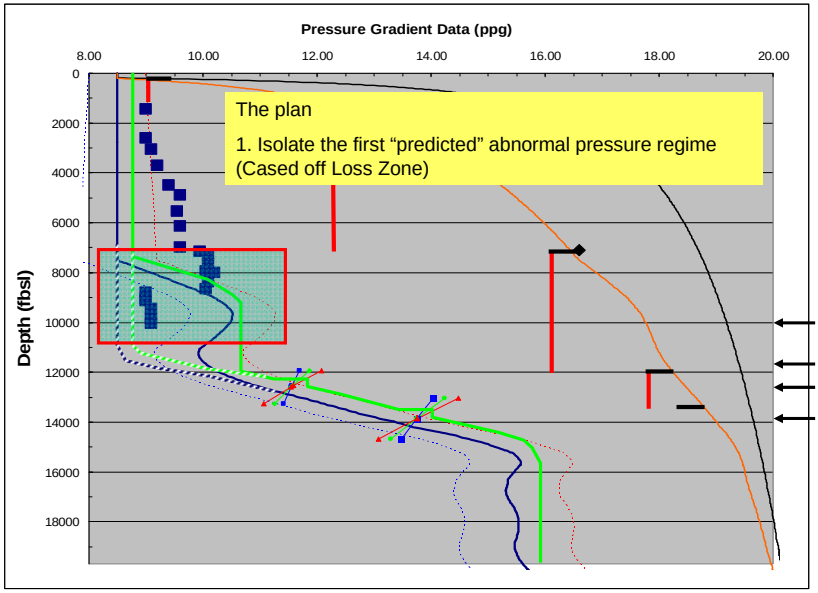
Revised prediction removal of initial pressure ramp, but honoring the major deep pressure ramp

Presenter's Notes: Plan was to predict first abnormal regime, result is lower pressure (losses).

1. Isolate the first "predicted" abnormal pressure regime (Cased off Loss Zone)
2. Drill safely the sharp pressure ramp towards the HP zone

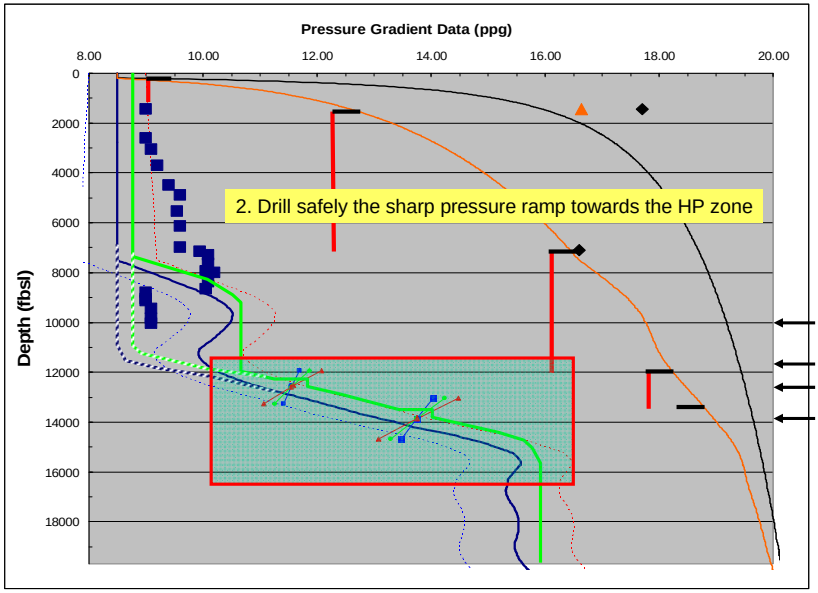
Here it has to be mentioned that 12772 MDT point was taken after killing the well at TD.

Pre-Drill Prediction vs. Drilling Calibration



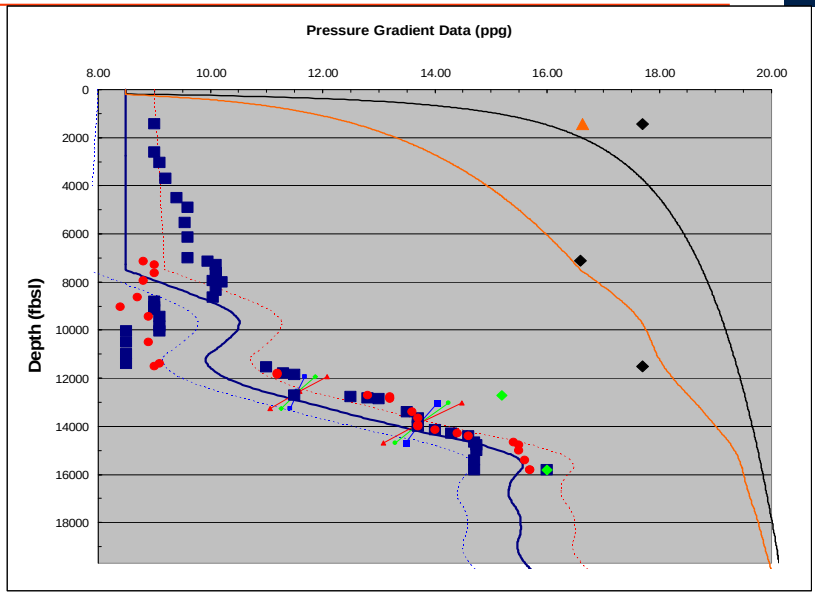
Revised prediction removal of initial pressure ramp, but honoring the major deep pressure ramp

Pre-Drill Prediction vs. Drilling Calibration



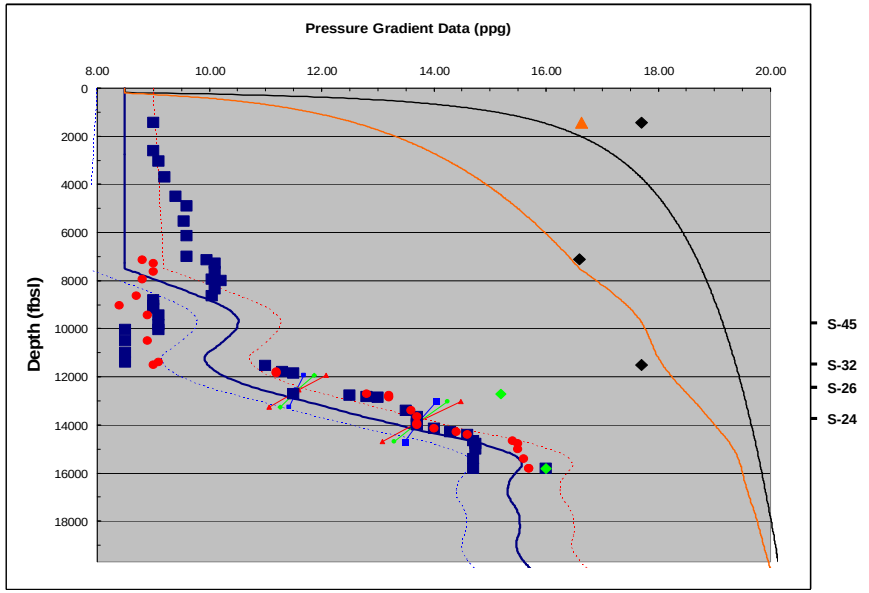
Revised prediction removal of initial pressure ramp, but honoring the major deep pressure ramp

Pre-Drill Prediction vs. Drilling Calibration

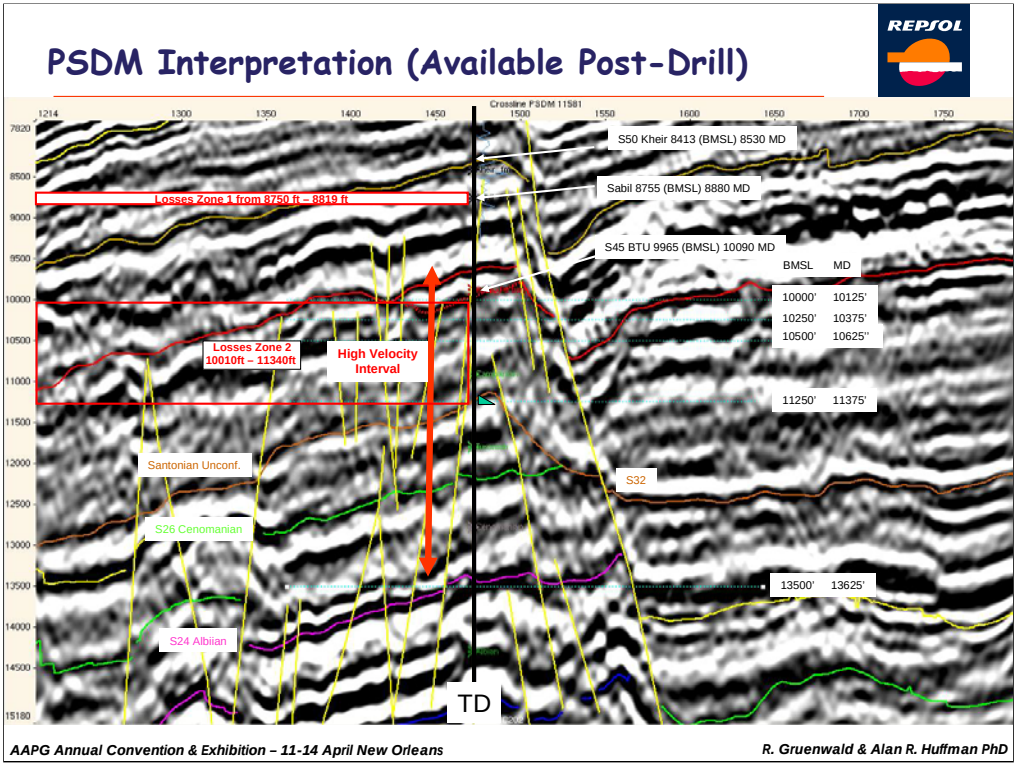


Pre-Drill Prognosis with drilled under / over pressure ramp

Pre-Drill Prediction vs. Drilling Calibration



Original prediction from pre-drill location with actual drilling data including drilled MW (blue), PreView data (red) and MDT data (green). The MDT at 12,772' is likely to be supercharged (SLB final)



Presenter's Notes: PSDM Line across Well Location

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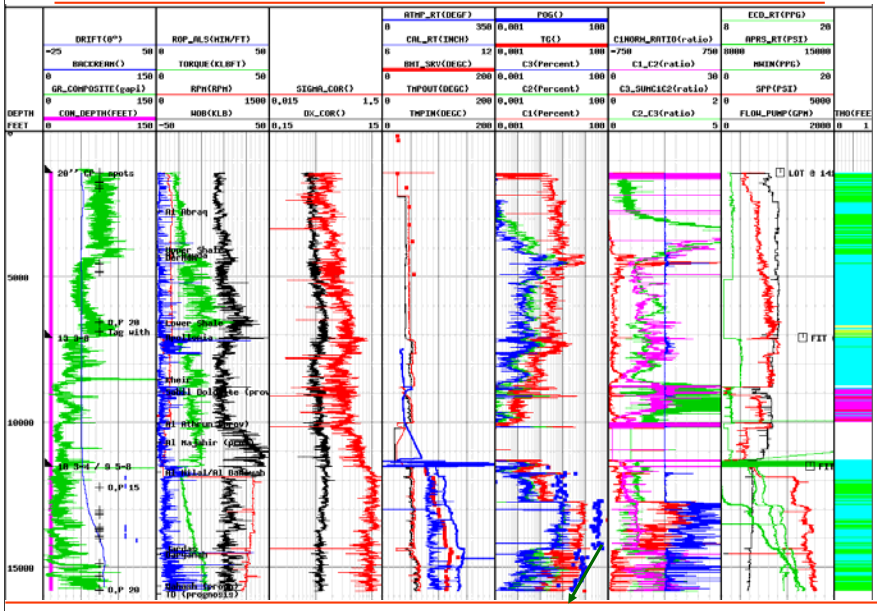
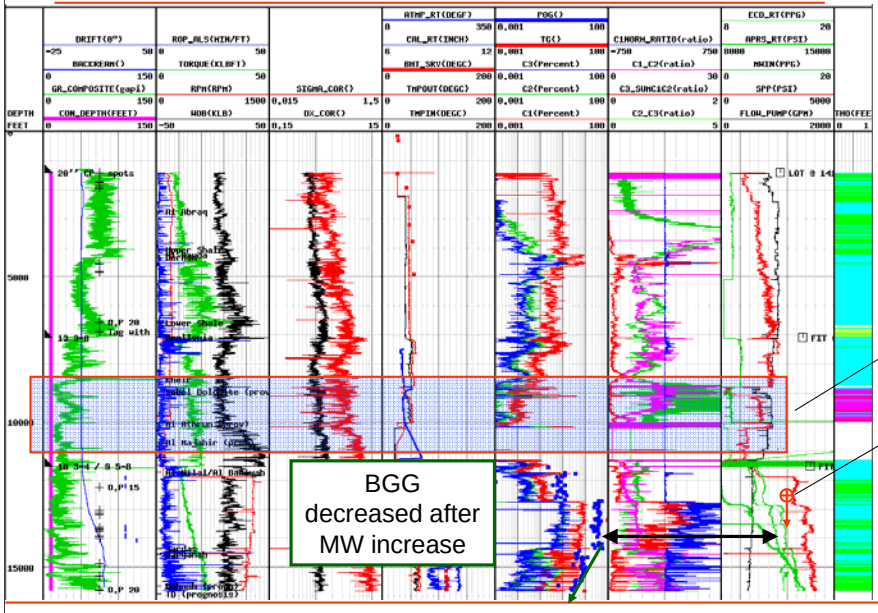
Lessons Learned Geopressure issues

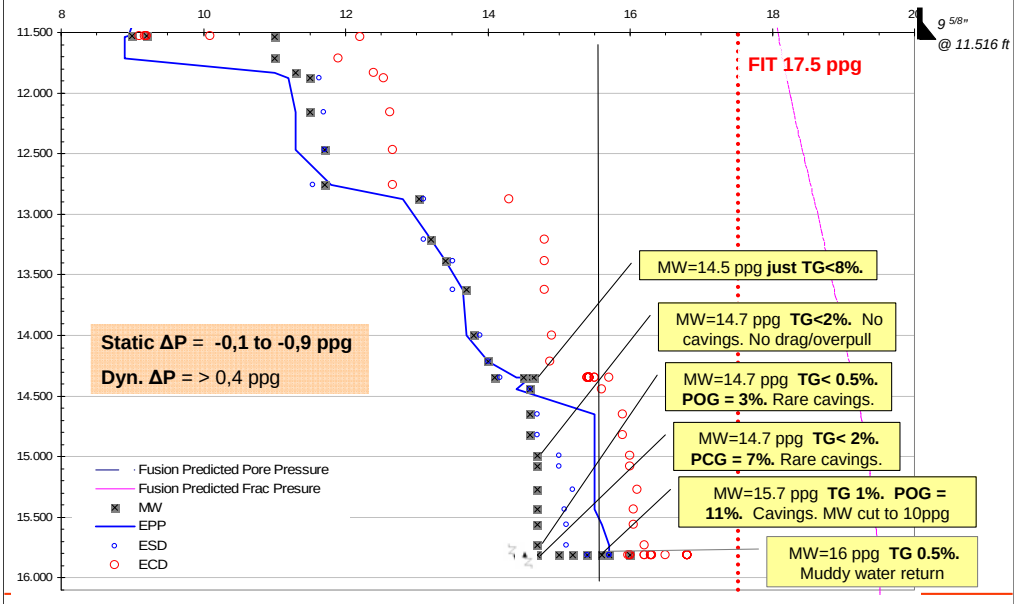


Presenter's Notes: The well did not kick at the 12772' MDT point because it is likely laterally connected to a reservoir **"isolated centroid",** or connected by fracture deeper part of the reservoir like a short circuit but **disconnected from shale behavior**

Lessons Learned Geopressure issues



Geopressure Monitoring 8.5"OH Section



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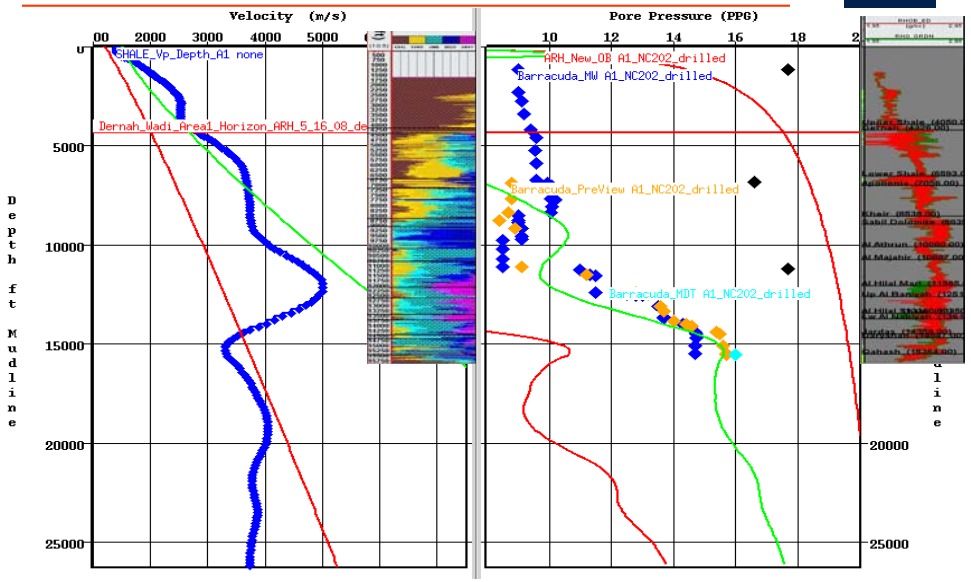
"Original Location" Geopressures – Post drilling



Calibration panel (right) showing the actual MW data (blue), the SLB PreView data (orange) and the MDT data (cyan) for the well and the original predicted pressure gradient (green curve). The left panel is the seismic shale velocities. These are for the original predicted location. Datum is mudline.

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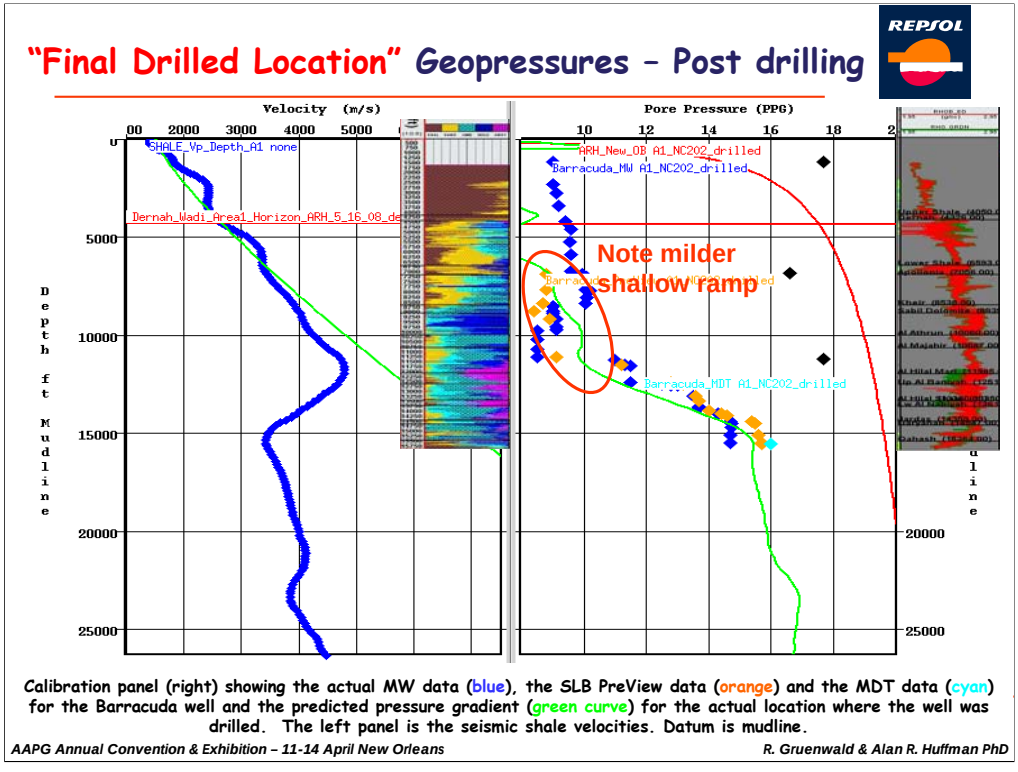
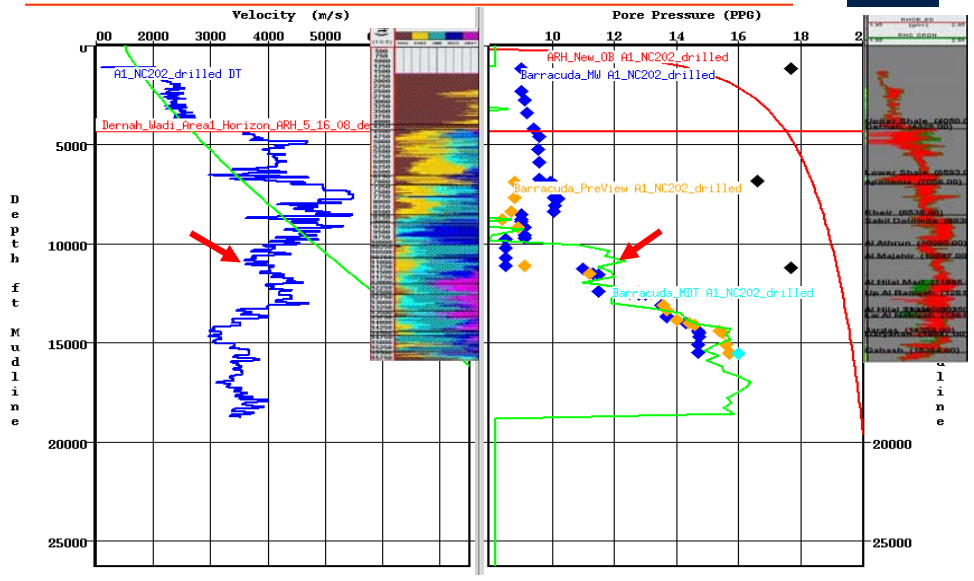


Calibration panel (right) showing the actual MW data (blue), the SLB PreView data (orange) and the MDT data (cyan) for the Barracuda well and the predicted pressure gradient (green curve) for the actual location where the well was drilled. The left panel is the seismic shale velocities. Datum is mudline.

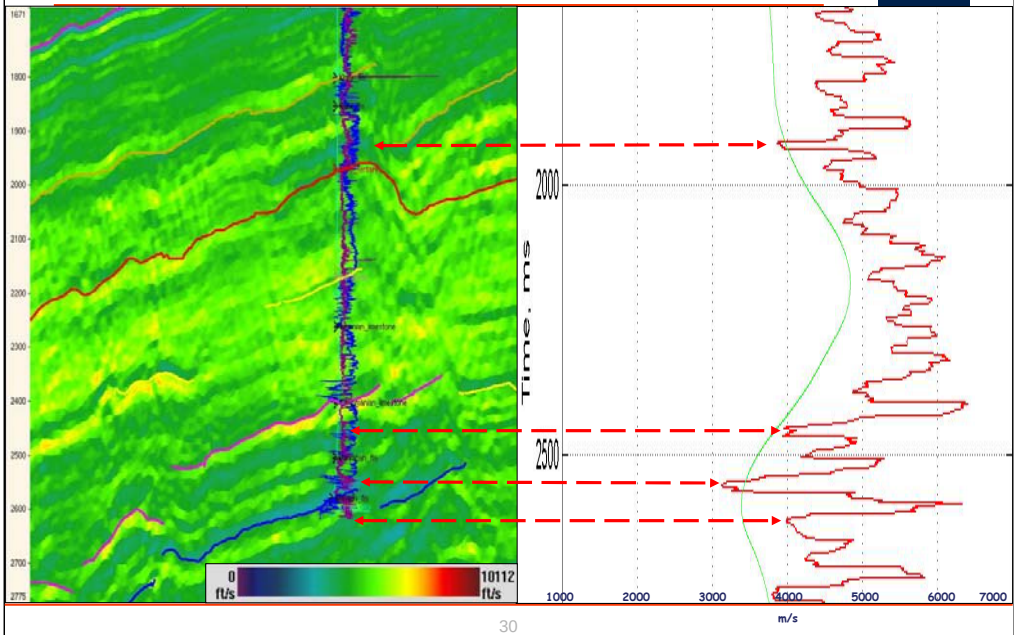
Presenter's Notes: This is the velocity function from the actual drilled location, which is 250 meters from the original prediction location. Note the decreased shallow ramp behavior. This velocity function predicts a lower pressure at 9,000 to 10,000 feet than the original location. Green curve on right with half ppg error bar final location prediction

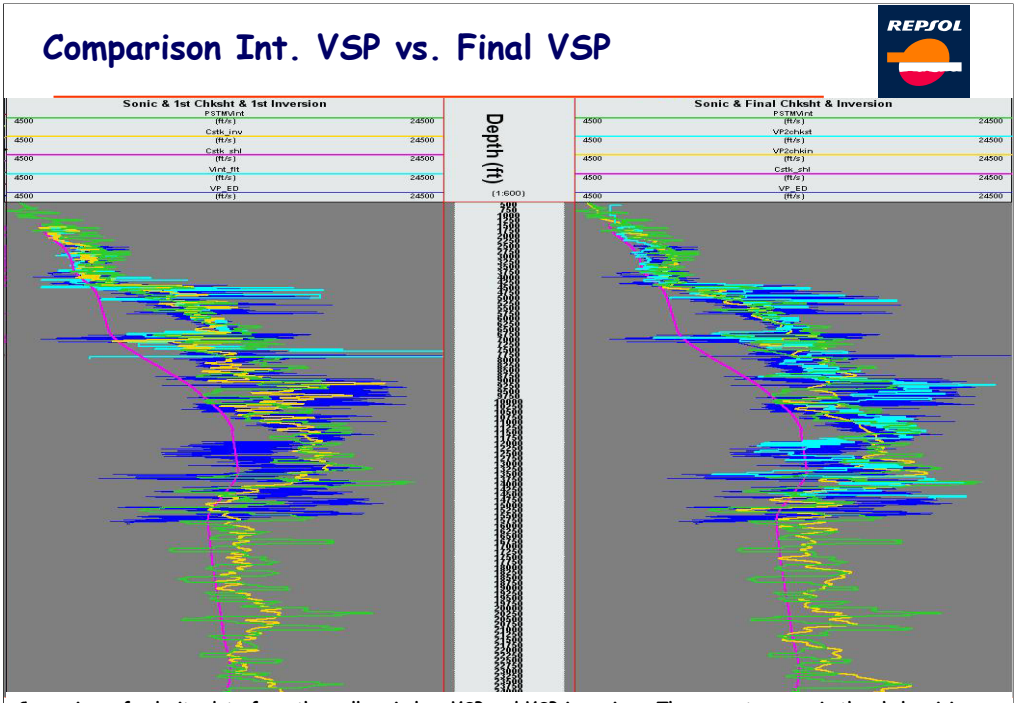
"Final VSP" Geopressures – Post drilling



Calibration panel (right) showing the actual MW data (blue), the SLB PreView data (orange) and the MDT data (cyan) for the well and the predicted pressure gradient (green curve). The left panel is the Vp from the VSP inversion. The minima on the sonic curve are the shaley zones. Datum is mudline.

Inverted Vp at Well – Cretaceous Section





Presenter's Notes: Mnemonic naming description;

1st TRACK

Cstk_inv = Corridor stack inversion from the intermediated (1st) run checkshot

Cstk_shl= Low frequency shale trend velocity

Vint_flt= Checkshot interval velocity

VP_ED= Velocity derived from the sonic log

PSTMVint= inverted velocity constrained by ThinMAN

2nd TRACK

Measured Depth

3rd TRACK

VP_ED= Velocity derived from the sonic log

PSTMVint=inverted velocity constrained by ThinMAN

VP2chkin=Corridor stack inversion from the final (TD) run checkshot

VP2chkst=Checkshot interval velocity from the final (TD) run checkshot

PSTMVint= inverted velocity constrained by ThinMAN

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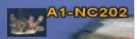

Conclusion

- Integration of regional knowledge, sound understanding of the basin specific structural setting and offset well data, PSTM and PSDM data, with real-time drilling parameter monitoring and a technology limited by the carbonate setting, provides valuable data for kick management and casing design in a HPHT environment.
- Pressure Prediction Can Be Performed In Complex Geologic Environments Under The Right Conditions
- Successful Predictions Require The Following:
  - Robust Velocities That Can Be Relied Upon To Indicate Presence of Pressure Anomalies
  - Investigate Thoroughly The Effects of Lithology on Velocity
  - Good Understanding Of Lithological and Depositional Variability
  - Sufficient Offset Well Calibration To Determine Which Pressure Mechanisms Are Active In A Study Area
  - Routine to Distinguish Poor Offset Well Data Adding Negative Bias (A1-NC173) from Valid Offset Well Data
  - Appropriate Seismic Methods Designed To Resolve Changes in Velocity Related To Pore Pressure
  - Ability to Detect Velocity Variations in Complex Lithological Settings
  - Full Integration of Structural, Stratigraphic and Geophysical Inputs
- Pre-Drill Predictions are designed to predict shale pressures ahead of the bit. Open fracture systems can cause the pre-drill prediction to be in error because of vertical fluid migration across formations. Wide-azimuth data are required to detect these fracture systems pre-drill.