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

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Introduction

As part of the exploration process for a prospective area in the Sirte Basin, offshore Libya, geopressure prediction was performed on 200 km^2 of 3D seismic data in two subsets of 100 km^2 each from the NC202 survey. Fluid and fracture pressure interpretation was based on well control and seismic interval velocities.
Offset well control included one well located within the seismic survey area. This well contained no RFT or MDT data, but did have mud weights (MW), leak-off tests and wireline logs. A second well near the survey was tied by a 2D seismic line. This well contained MDT and DST data.

Methodology

REVEL™ residual 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 (Figure 1). An acoustic inversion was used to isolate the shale velocities, and a shale velocity trend was calibrated to effective stress 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) (Figure 2).

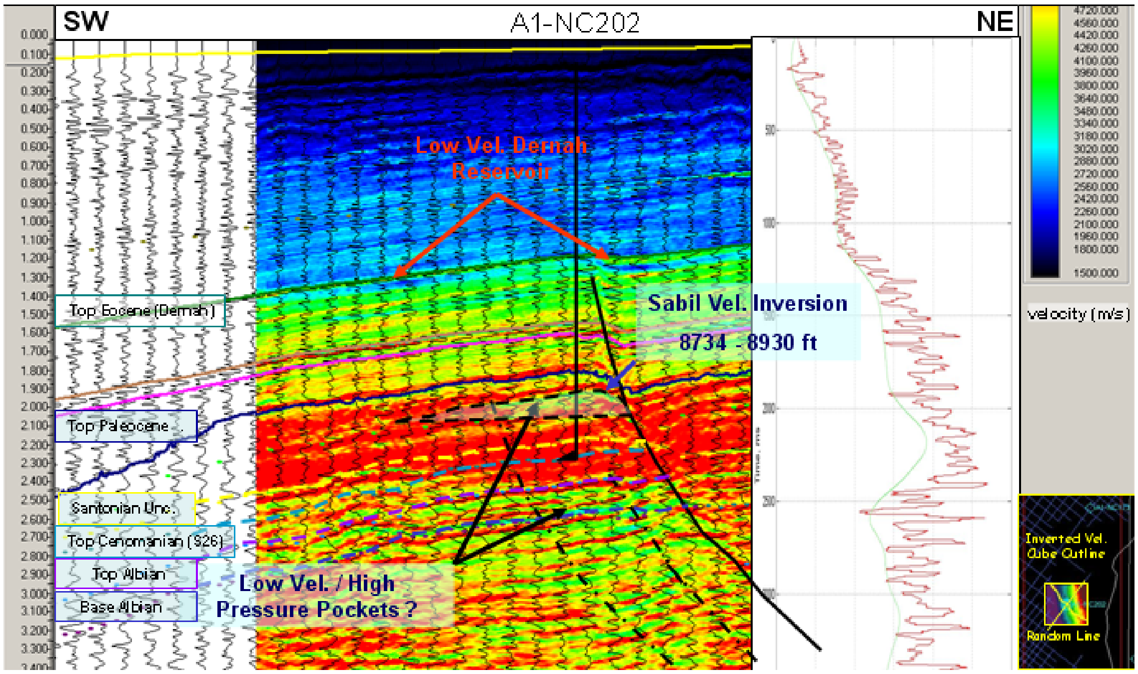

Figure 1: *Comparison of inverted Vp using the hybrid model and smoothed shale velocity shale trend generated from the inversion at the well location results for use in pore pressure prediction.*

Two reservoir-specific PP models with different saturating fluids were generated to account for buoyancy effects for prediction of reservoir pressure and seal failure. 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 equilibrium 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.

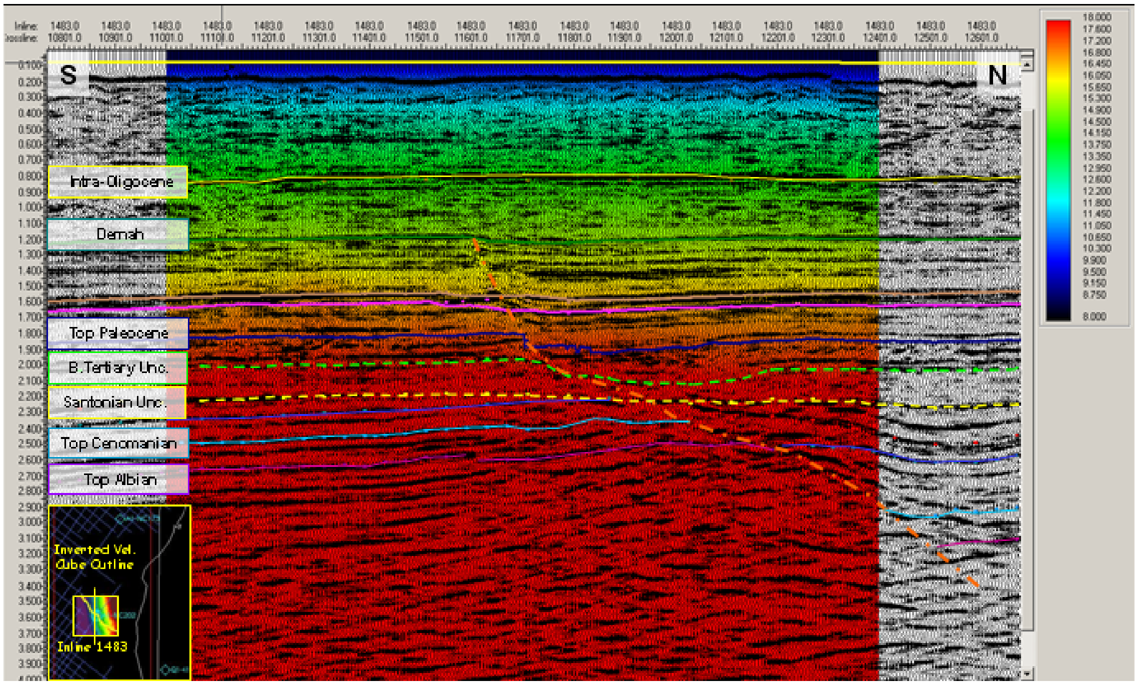

Figure 2. *Fracture pressure gradient interpretation for inline 1483 using the hybrid model. The Dernah horizon is shown in green. The well location is near the center of the line.*

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 300º F at TD (Figure 3).

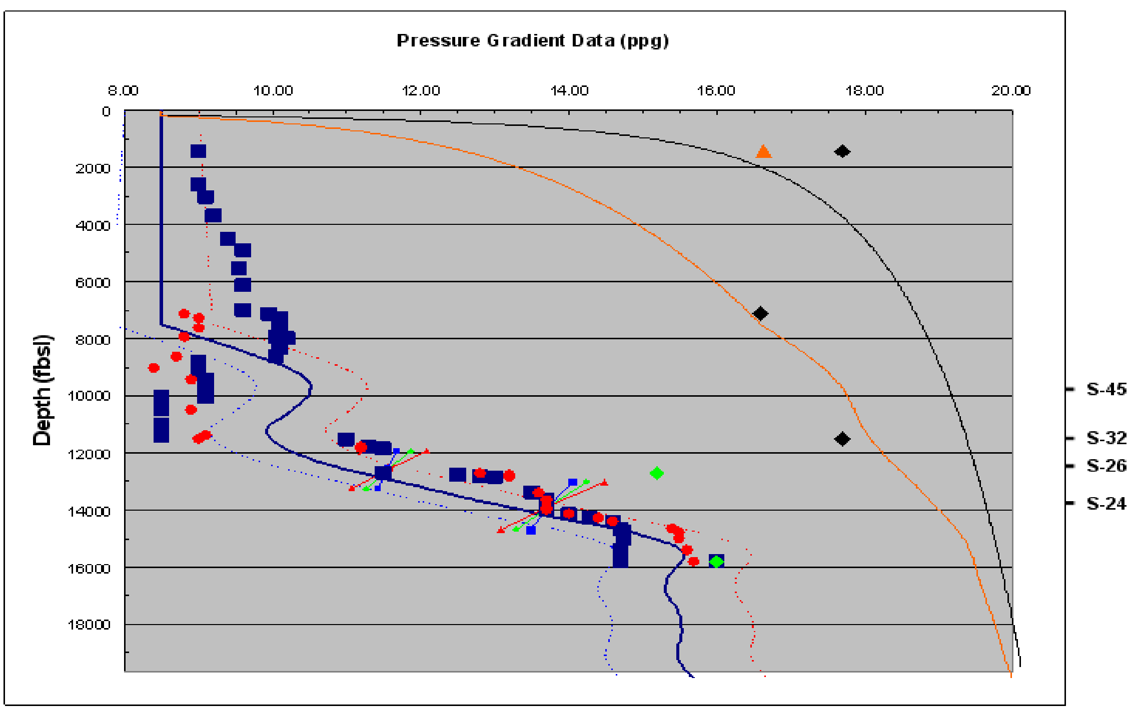

Figure 3. *Original prediction from pre-drill location with actual drilling data including drilled MW (blue), PreView data (red) and MDT data (green). The MDT point at 12,772 ft is likely to be supercharged due to well killing activity and exposure to the open hole section under high MW.*

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 but also variability with lateral offset (Figure 4). 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.

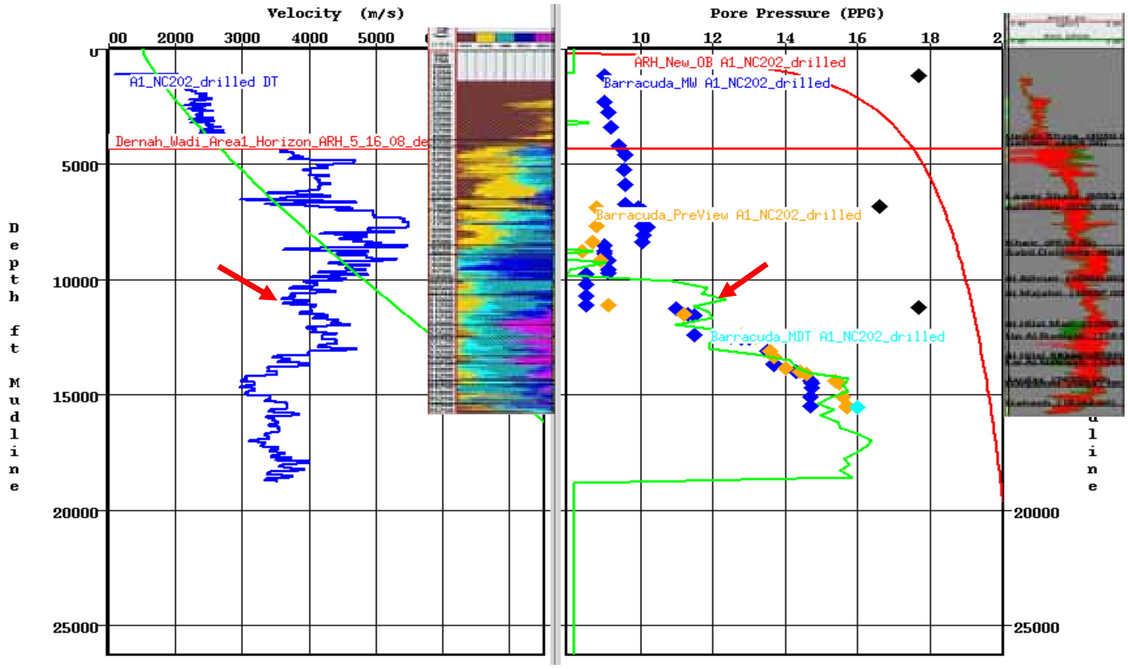

Figure 4 Final VSP PPP update. *Calibration panel (right) showing the actual MW data (blue), the SLB PreView data (orange) and the MDT data (cyan) for the well and the predicted pressure gradient using the shale points from the VSP (green curve). The left panel is the Vp from the VSP inversion. The minima on the sonic curve are the shaley zones. Datum is mudline.*

Well Monitoring and Post Well Review

Comparison between Eaton's Method, originally developed and applicable for the Gulf of Mexico, shows that this method can not be applied in the present carbonate dominated environment, while Bowers method seems more suitable to predict PP (Figure 5). During well monitoring this creates uncertainty, as the available methods, Eaton and D-exponent, are strongly dependent on shale compaction data available from LWD, these can not be reliably calibrated in the present carbonate setting. In the Pre-drill model it is significant to account for lithology changes and related velocity changes[1], therefore it has to be born in mind that apparent velocity inversion might not necessarily be related to unloading but also may host potential zones of under pressure responsible for losses as in the present example at depths shallower than 12,000 ft.

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.

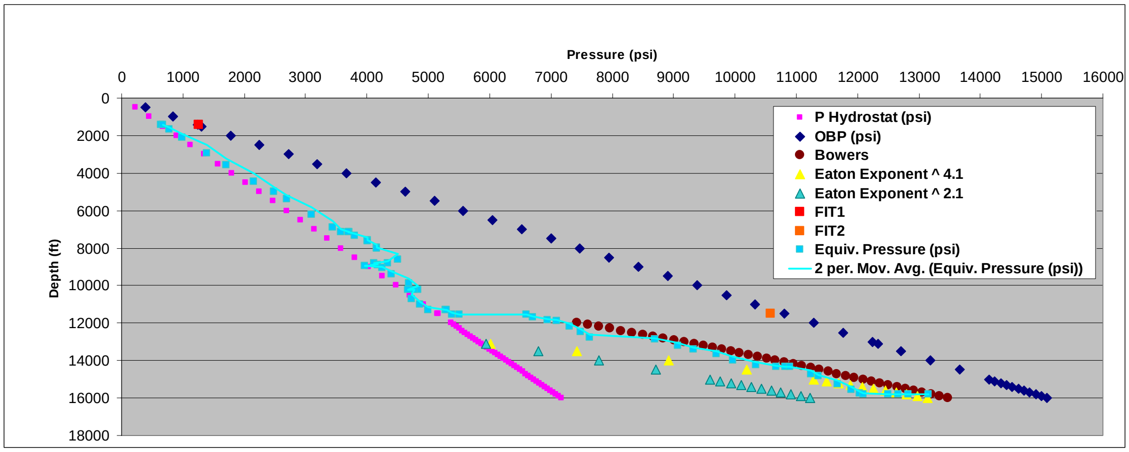

Figure 5. *Comparison between Eaton's and Bowers Method. Instantaneous velocities derived from WL DT shale velocities (GR > 80 API).*

Conclusions

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 Lithologic and Depositional Variability.
- Sufficient Offset Well Calibration To Determine Which Pressure Mechanisms Are Active In A Study Area.
- Appropriate Seismic Methods Designed To Resolve Changes in Velocity Related To Pore Pressure.
- Ability to Detect Velocity Variations in Complex Lithologic 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.

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