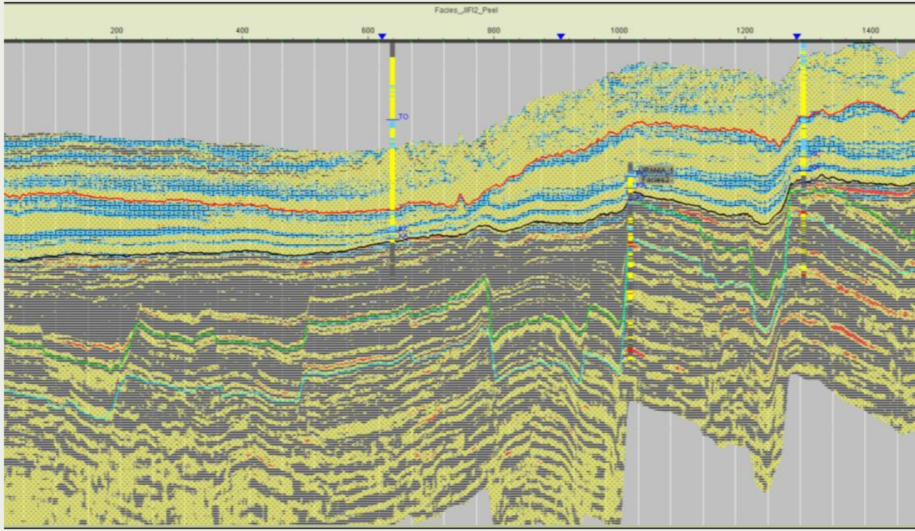
Robust Facies Modelling



Improving Geopressure Assessment during the E&P Cycle

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7th March, 2019

Executive Summary

Any pore pressure model should be developed early in the E&P cycle, and then refined as new data become available, when a prospective area becomes of exploration focus, and when field development is to be undertaken.

Pore pressure in sands, i.e., reservoir units, is controlled by the lateral and vertical connectivity of the sands and the associated geometries with respect to the bounding shales

- Isolated Lenses vs. Connected Channel/Fan Complexes
- Flat lying vs. Tilted Beds
- Fault Juxtaposed Sand-on-Sand vs. Fault Seal

The best practice workflow requires a full 3D understanding (via inversion) of the facies, their geometries, and the elastic properties in combination with well-based observations and a process-driven approach to build a coherent geologically-aware pressure model.

Exploration in West Africa

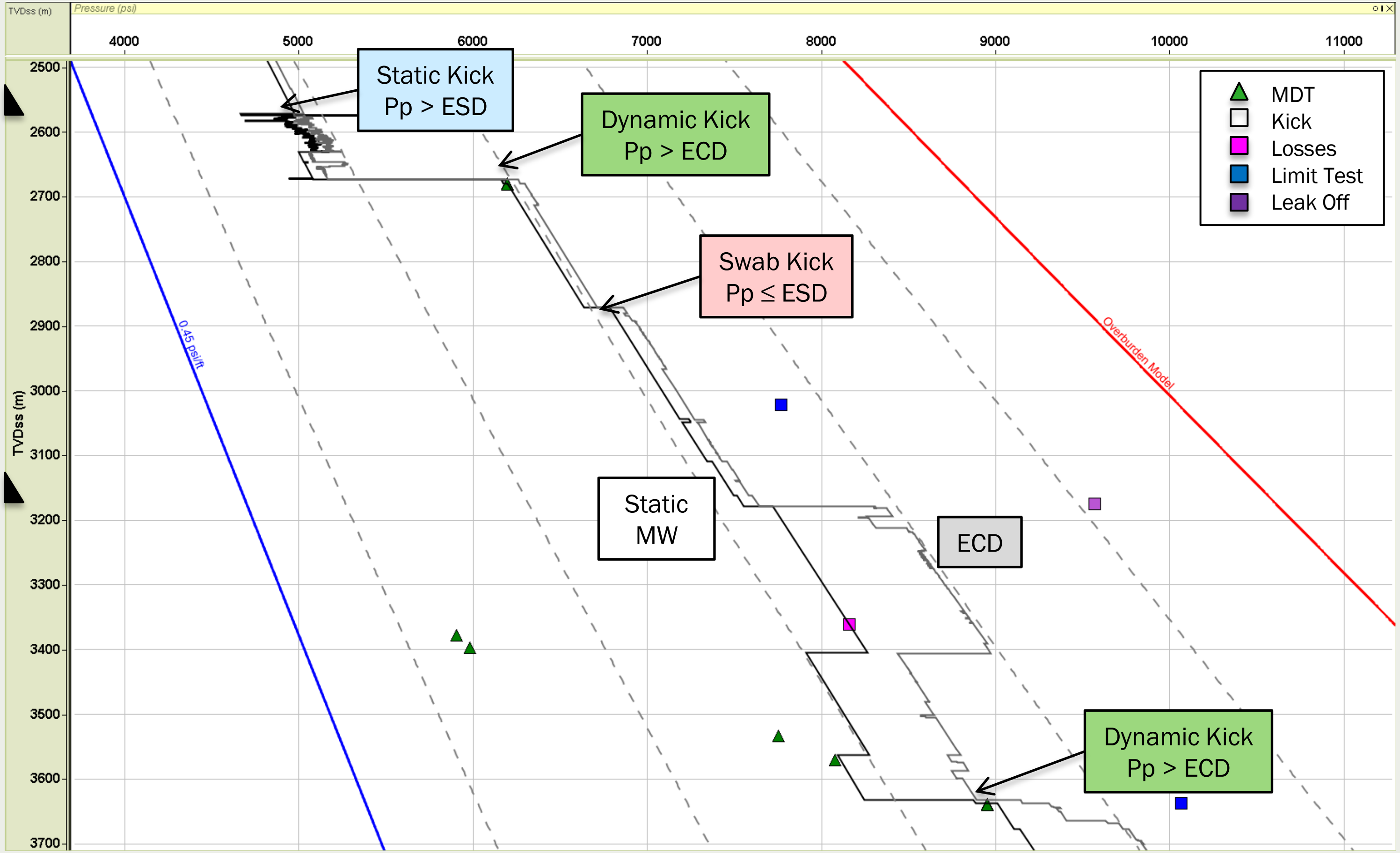
Exploration on the West African margin has gone through several distinct phases.

- Initial wells drilled on the shelf and shallow water targeted syn-rift and early post-rift plays.
- Followed by drilling in progressively deeper water with post-salt exploration in the basins from Angola to Gabon.
- Recent trends have been in the post-rift Cretaceous fan play on the transform margin typified by the Jubilee discovery in Ghana and the pre-salt plays of Angola and Gabon.
  - 100+ wells drilled since the Jubilee discovery in 2007.
- Further successes with discoveries such as SNE, Tortue leading the industry to chase increasingly frontier areas for exploration

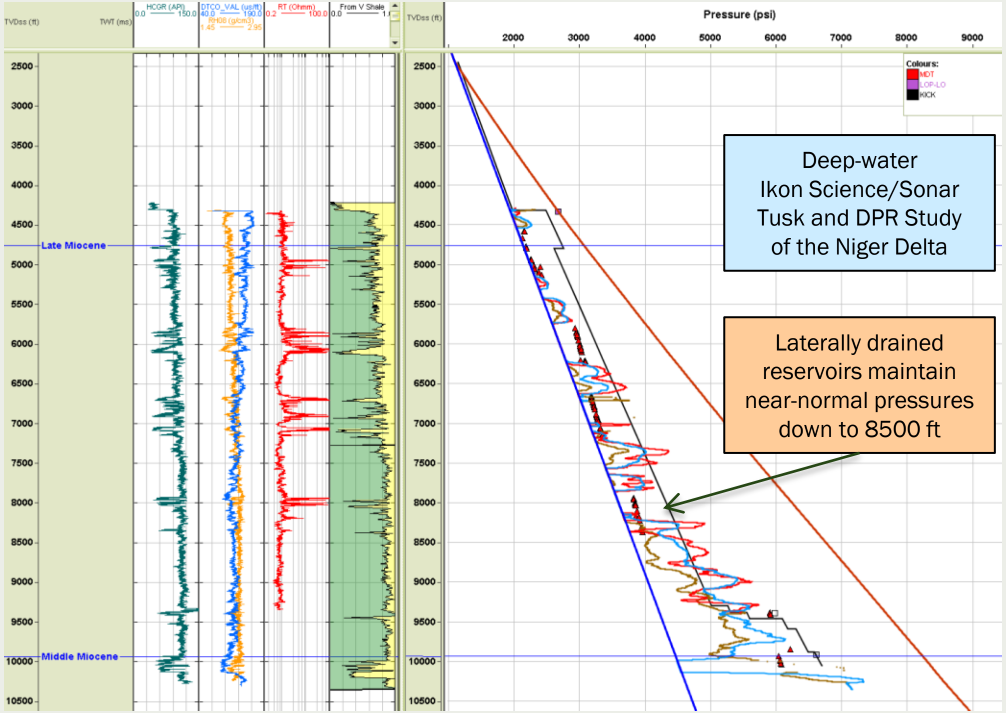
Geological challenges include thin turbidite deposits, sinuous channel systems, deep-water fan complexes, and pre-salt targets

Question – what can industry do to improve this success rate? Can understanding pressure help?

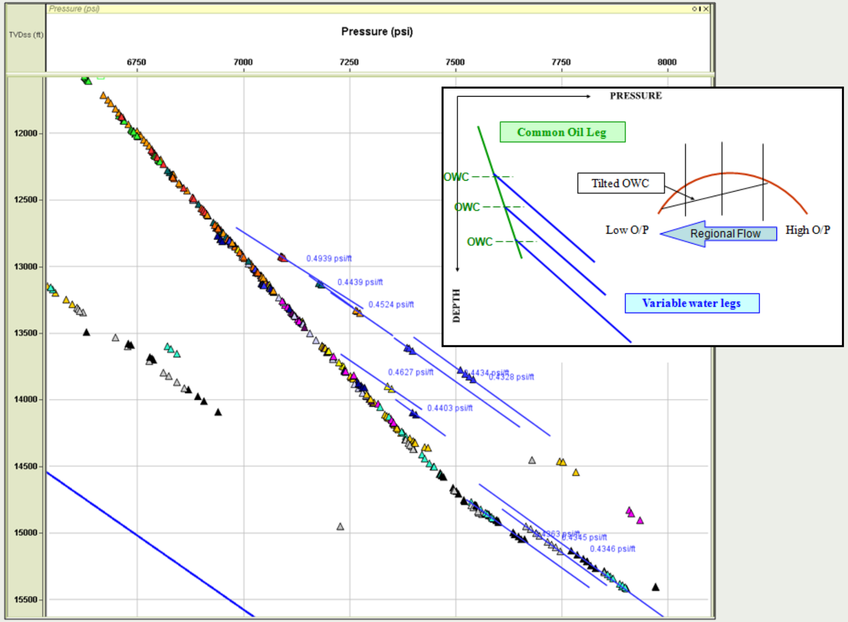
Challenging Drilling Environment: Cameroon



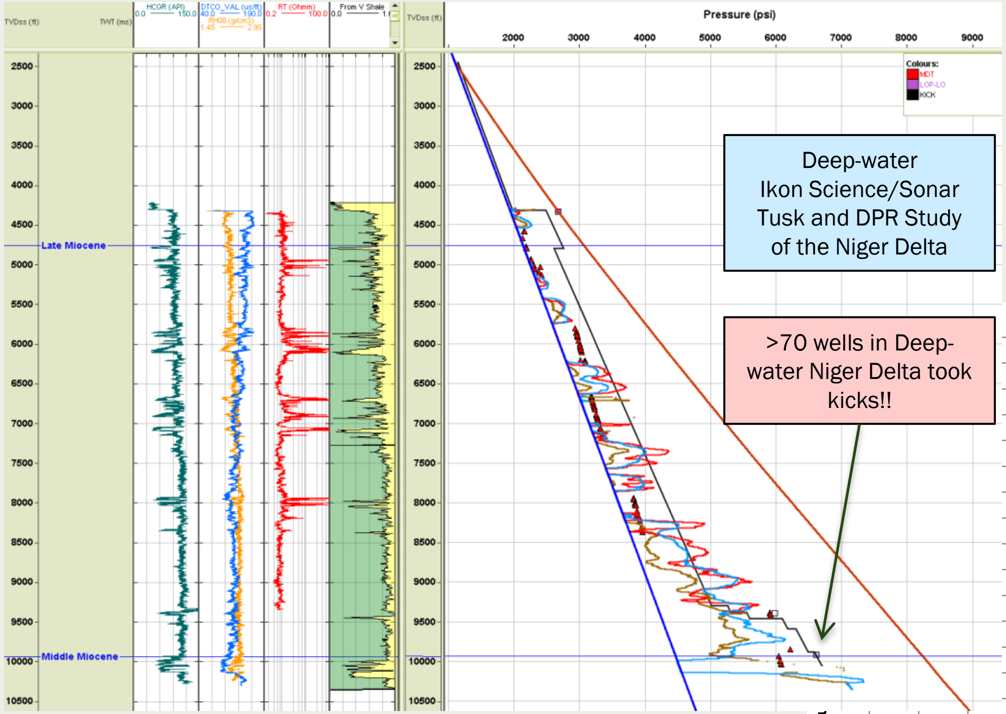
Is Predicting Pore Pressure a Challenge?



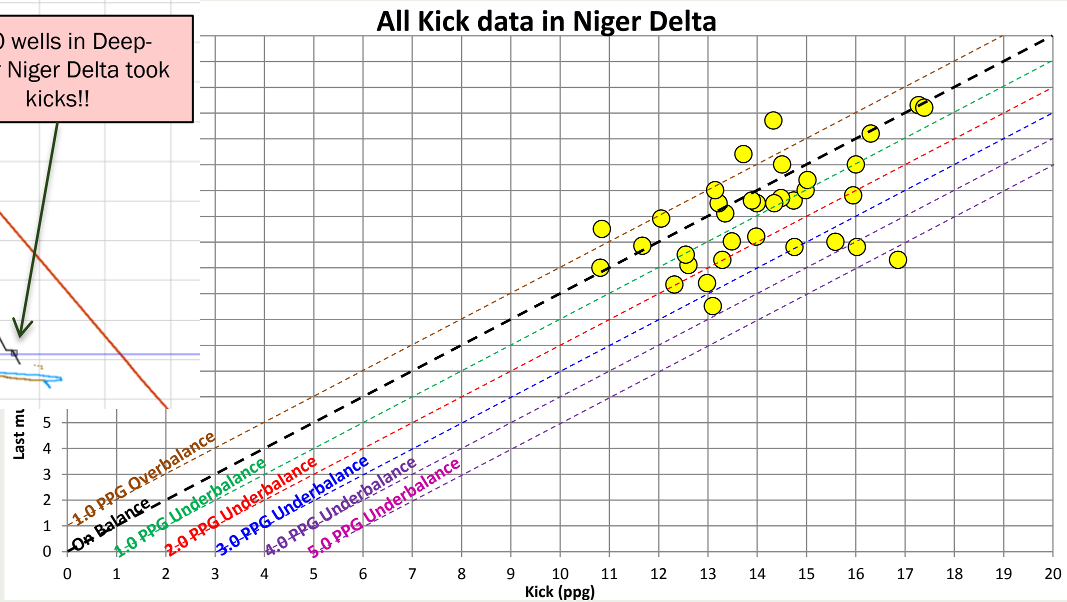
Regional evidence for laterally drained sands, providing the potential for mis-calibration of shale pressure models, as well as enhanced sealing characteristics and hydrodynamic reservoirs



Is Predicting Pore Pressure a Challenge?

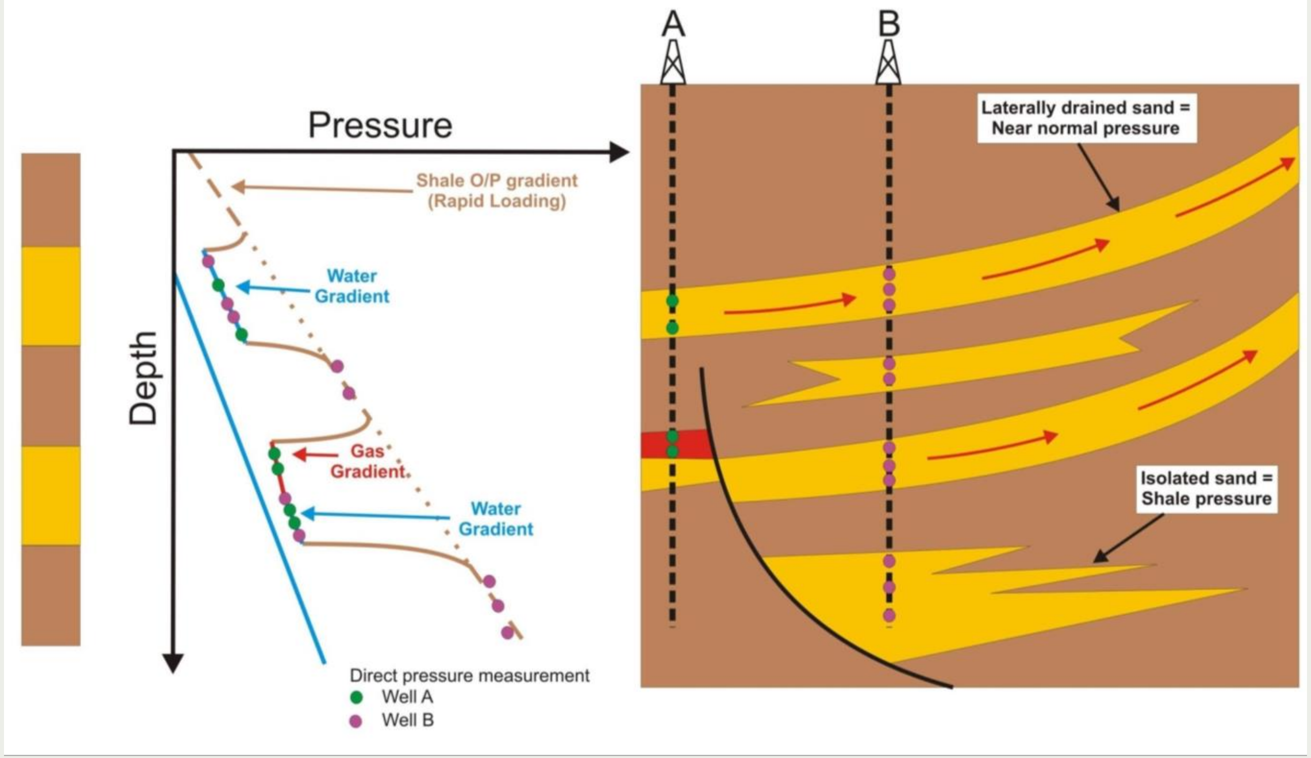


Regional evidence for under-balanced drilling highlighting the need for an robust facies model to risk the chance of taking a Kick

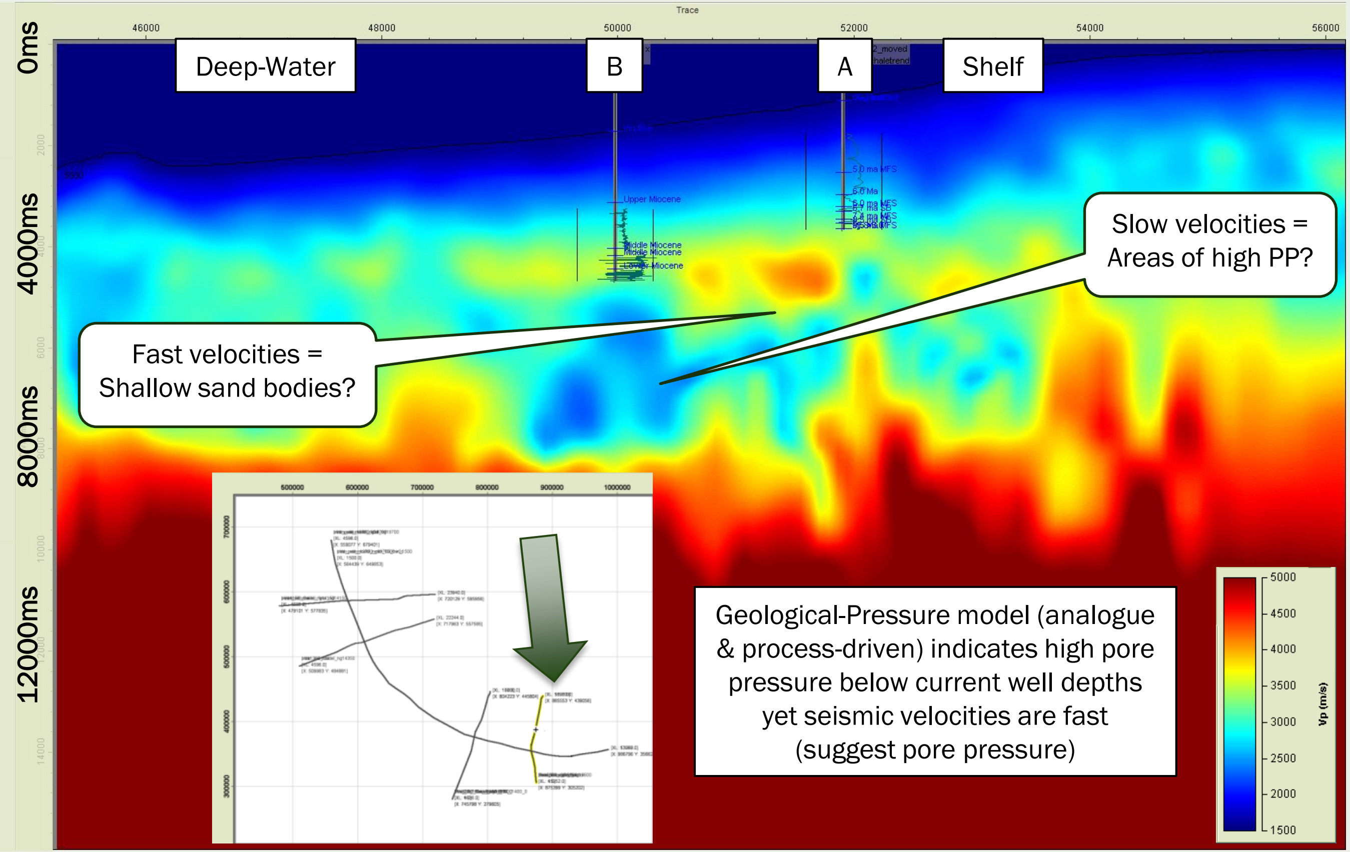


Sand vs. Shale Pressures: Lateral Drainage

How do we image the 3D geometry of the sands and risk to likelihood of isolated vs. connected reservoir units?

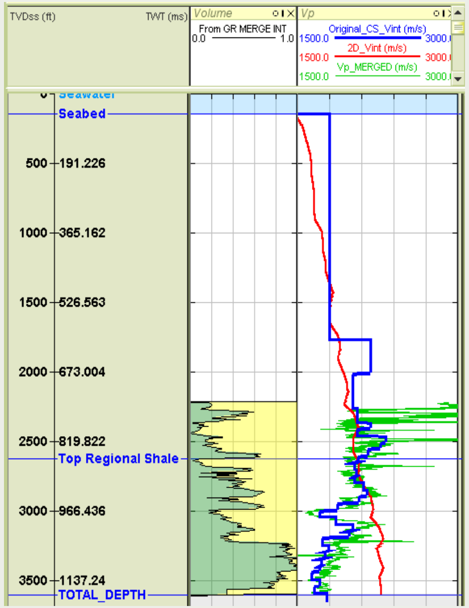


Should we rely on Seismic Velocities?



Have the velocities been picked for pore pressure prediction in the first place?

Have the rocks changed too much via diagenesis to correlate pore pressure with velocity magnitude?



West Africa example: With permission from Afren

Building a 3D Geological-Pressure Model

Pore pressure in shales is pre-dominantly controlled by geological processes and is predicted in 1D using wireline data, e.g., Vp, Vs, Rho, Resistivity, Neutron and then these models are applied in 3D using seismic velocities.

- Given the limitations of using processing-based seismic velocities can we generate more meaningful elastic properties through a rock physics-driven inversion process?

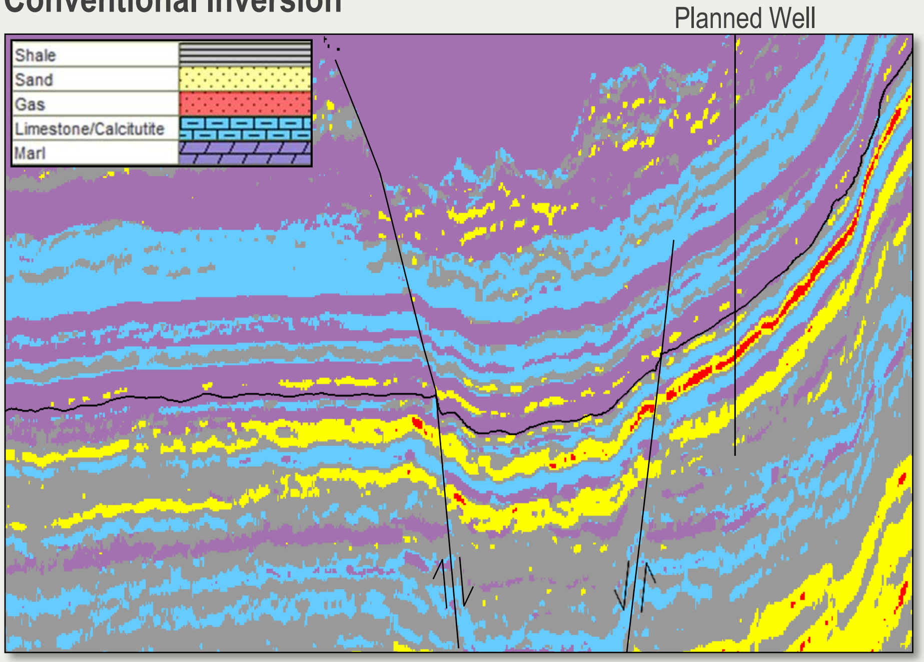
Pore pressure in sands, i.e., reservoir units, is controlled by the lateral and vertical connectivity of the sands and the associated geometries with respect to the bounding shales

- Can we understand the 3D distribution of the sands such that we can integrate a geologically-driven pressure model with the elastic property-driven pressure model in the shales (assuming no diagenetic effects are present in the shales)?

The best practice workflow requires a full 3D understanding of the facies, their geometries, and the elastic properties in combination with well-based observations and a process-driven approach to build a coherent geologically-aware pressure model.

Challenge: Add Geology into the Inversion

Conventional Inversion



In a conventional approach, a single Low Frequency Model (LFM) is constructed for the entire inversion which fails to take into account facies variations, therefore, limiting the detail that can be extracted from a conventional AVO inversion.

Problem:

The LFM will be inaccurate as a single model cannot capture the range of facies present in the sub-surface

Solution:

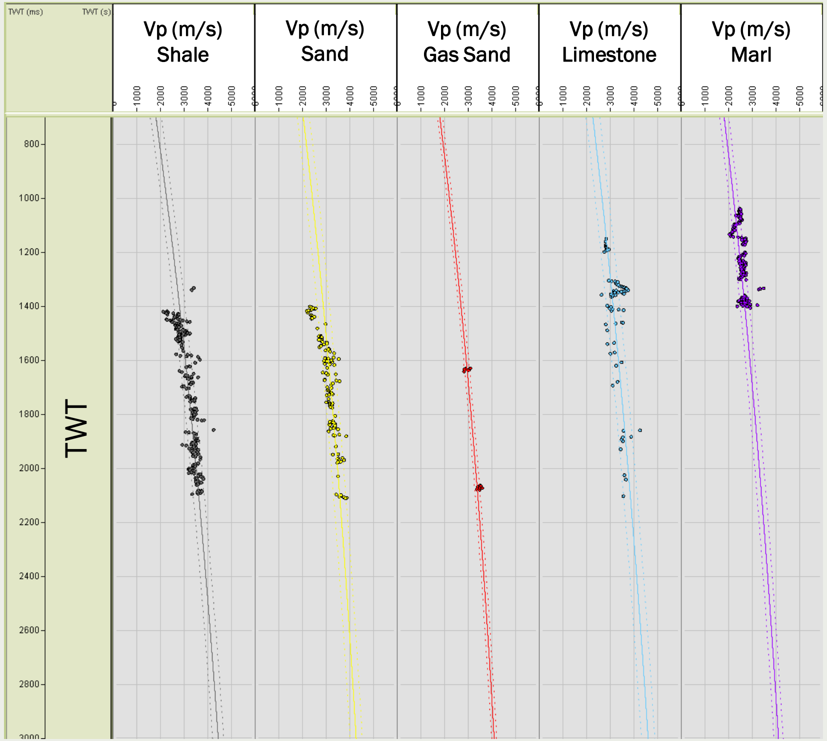
Use Facies-aware inversion, inputting multiple LFM's; one for each facies expected

Result:

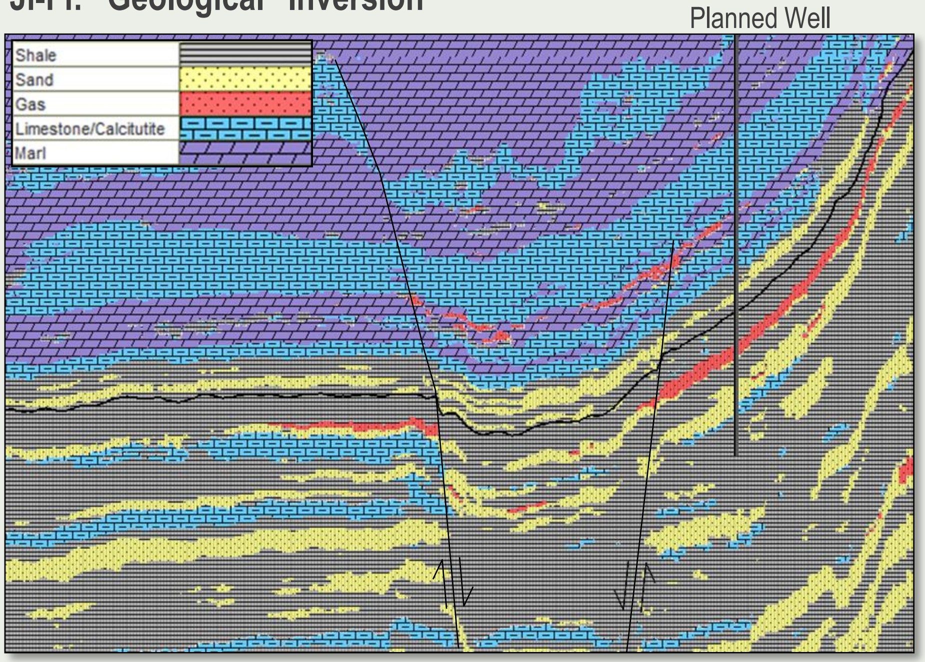
A better facies model combined with the optimum LFM

Solution: JiFi, Facies-based Inversion

Use geologically valid rock property trends and uncertainties as facies-specific low frequency models for input into the inversion.



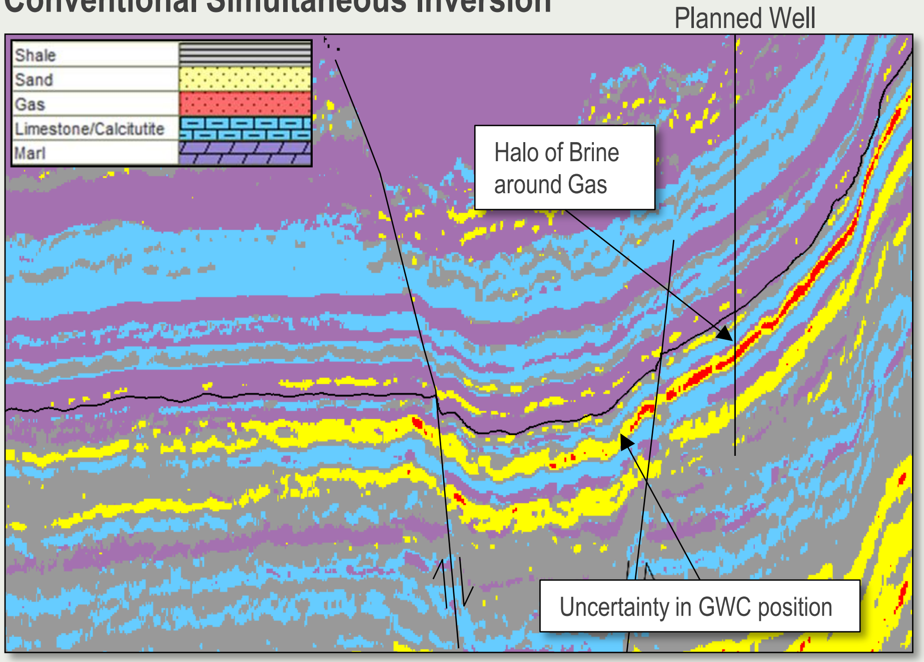
Ji-Fi: "Geological" Inversion



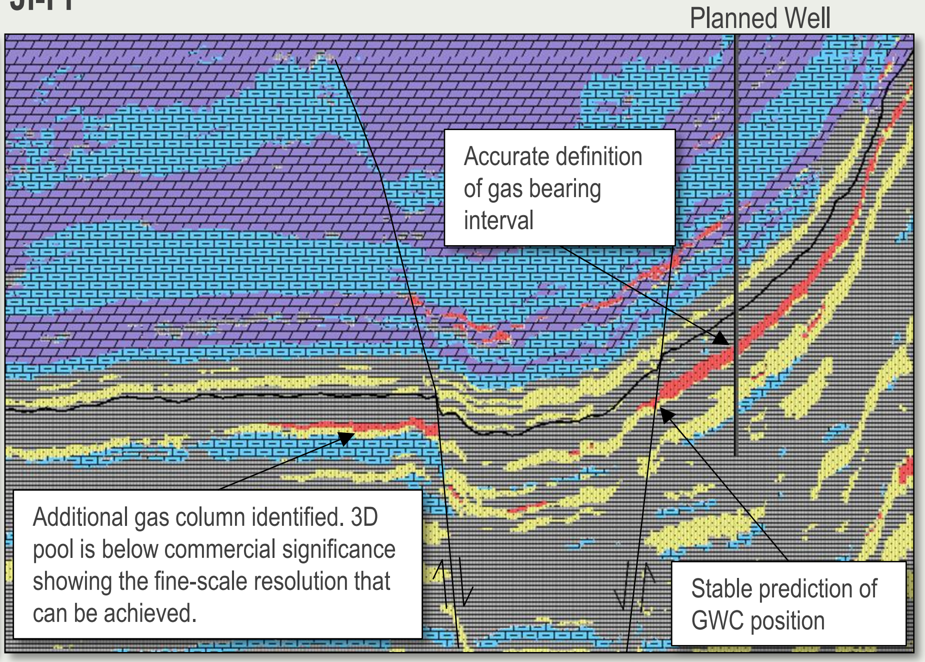
Sams et al., 2016

Solution: JiFi, Facies-based Inversion

Conventional Simultaneous Inversion



Ji-Fi



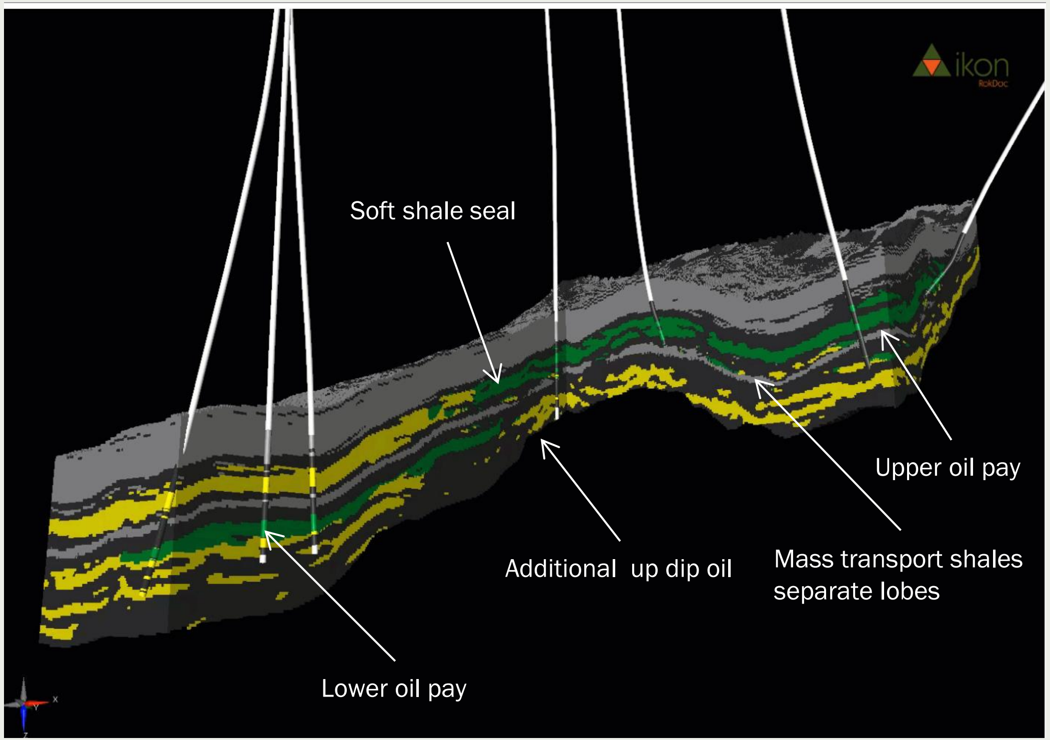
<u>Exploration in Triassic-Cretaceous reservoirs, NWS Australia</u>

Generate realistic geological models: conventional inversion suggests an implausible facies-fluid model and faulting

Clearly define trap: Ji-Fi offers greater resolution, defining the trap and identifying an additional gas column

Calculate reliable reserve estimates, improved hydrocarbon maturation: accurate predictions are achieved with limited well control

Ji-Fi Results: Jubilee Field, Ghana



3D JiFi inversion rendering of the prolific Cretaceous deep-water, intra slope, stacked lobe sequence at Jubilee

Resolves high order lobe stratigraphic complexity

Identifies reservoir infill options

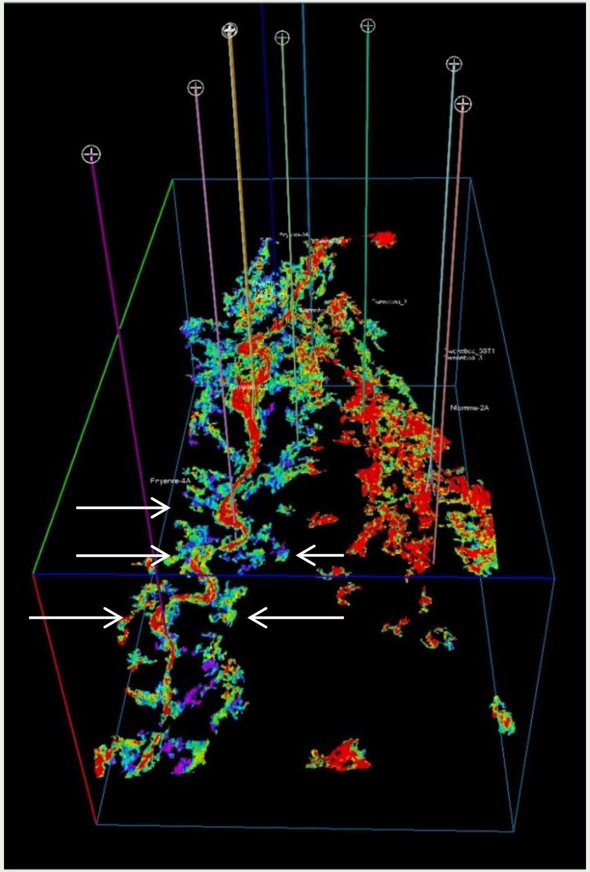
Potential to enhance optimised producer/injector trajectory as basis for dynamic sector models

Intra formation ‘soft shale’ seals (light grey) giving rise to stacked pay: multiple contacts and variable spill points

Shale drapes formed of mass transport complexes (dark grey), acting as flow baffles between lobes complexes, better defined in 3D to improve understanding of reservoir connectivity

Image courtesy of Tullow Oil Plc

JiFi Results: TEN Field, Ghana



Overbank deposits including crevasse splays and abandoned channel fills, outboard of main channel fairway, **which had not been previously drilled** therefore not picked up using conventional well-based inversion

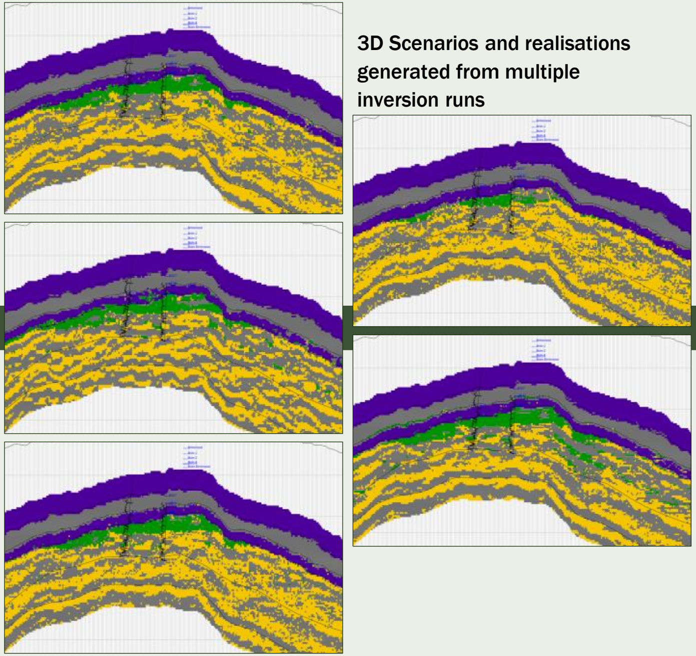
Reservoirs in the overbank deposits are likely to be oil-bearing, though thinner or poorer quality than in the main channel axis.

Ji-Fi highlights clearly the geometries of the untested potential away from main channel axis and offers targets for future appraisal.

Future appraisal plan will evaluate potential of additional reserves.

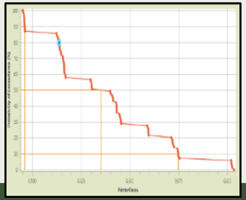
Image courtesy of Tullow Oil Plc

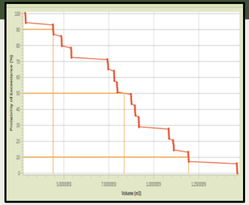
Uncertainty Analysis for Field Development



3D Scenarios and realisations generated from multiple inversion runs

Ranking on N:G

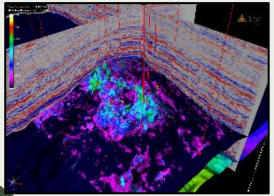


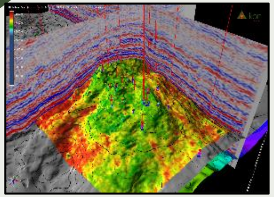


Ranking on gross rock volume

Probabilistic estimates of reservoir and hydrocarbon presence, volume, connectivity and elastic property uncertainty

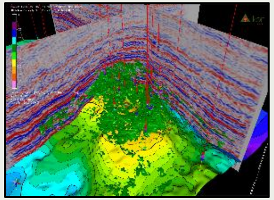
P50 Oil column thickness

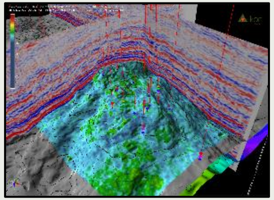


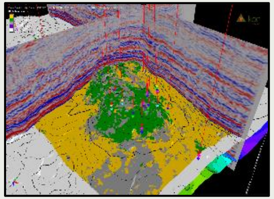


Elastic properties and uncertainties

P50 Oil geobody







3D facies distributions

Improve production forecasting: determine reservoir distribution and quality and incorporate into reservoir model

Optimise well locations: identify highly productive well locations using probabilistic estimates of in-place volumes and reservoir connectivity

Plan optimal drainage strategy and minimise development capex

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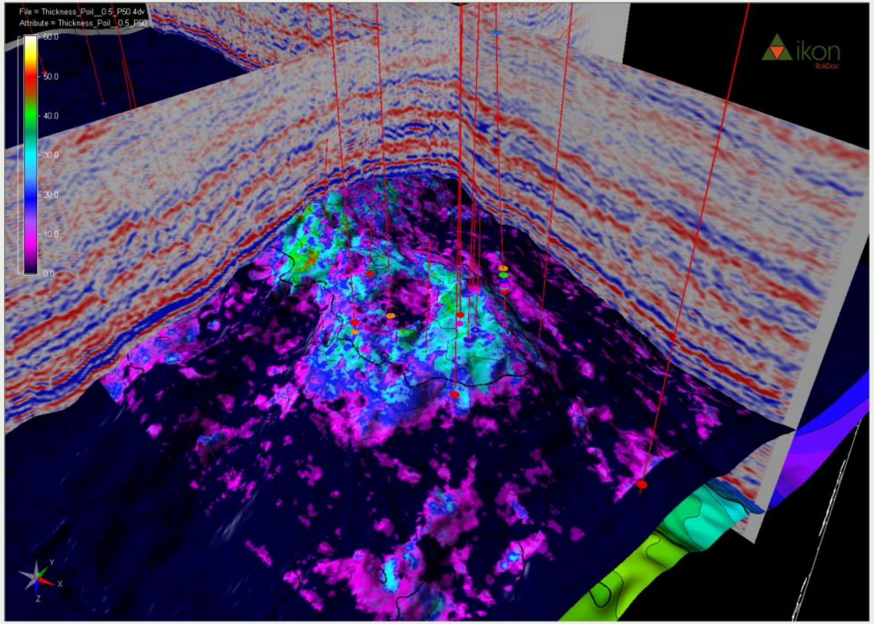
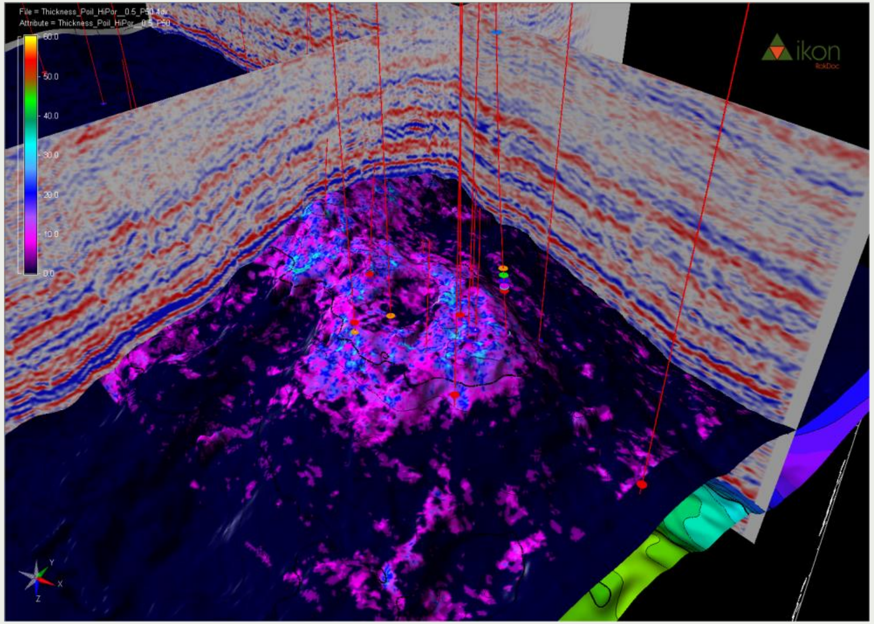
Multi-Realisation Analysis

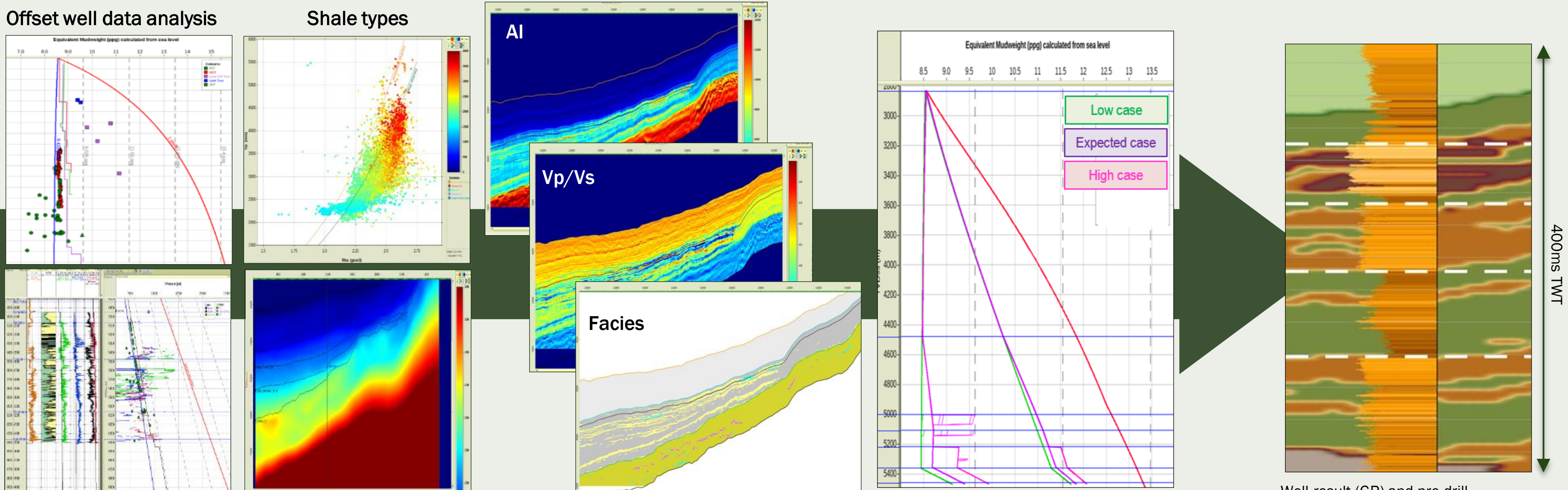
Multiple geologically plausible realisations





P50 Thickness for Oil (left) and high porosity Oil (right) bearing facies

Reduce Risk and Costs in Frontier Exploration



Integrated well plan

Well result (GR) and pre-drill facies prediction

Fast and efficient well planning: quickly extrapolate data to create realistic well plans

Consistent model building: capture all data type

Improve pre-drill models: better pore pressure and geomechanical models through data and software integration

Thank you

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