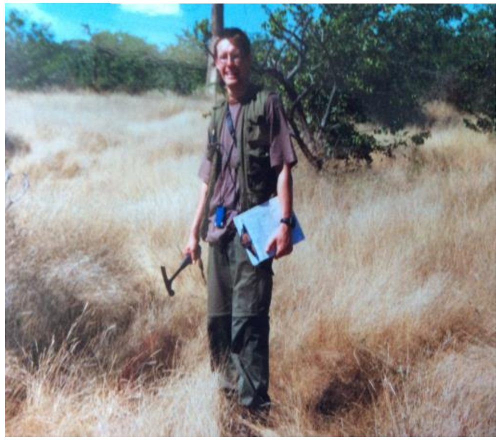
PPFG & WBS in Aker BP

Tron Golder Kristiansen, Chief Engineer D&W – Rock Mechanics

Content

- Organization
- Methodology
- How are we doing?
- Focus areas
  - Training
  - Seismic
  - Basin modeling
  - Measurement of shale pore pressure
  - Autonomous drilling
- Summary

Organization



- Operations geologist for well is responsible for having the work performed
  - Can do it himself/herself or have a colleague or a rock mechanics engineer do the analysis
  - "Best person for the job"
  - Inside reservoirs in production/injection operations the pore pressure prediction is made by the reservoir engineer
- Operations geologists and rock mechanics engineers are part of the D&W organization
- We have operations geologists and rock mechanics engineers as part of all our asset teams
- Internal peer review process for various types of wells in place
- Operations geologist also responsible for updating pore pressure during the operation in collaboration with the offshore wellsite geologist

Technical Requirements, Guidelines & Workflows

AkerBP

AkerBP

Technical Requirement

Technical Requirements for Pore, Fracture and Collapse Pressure Forecasting

Document no.:	51-000566
Rev. no.:	4.0
Date:	2022-06-10

AkerBP

Technical Requirement

Technical Requirements for Formation Integrity Pressure Testing

Document no.:	51-001529
Rev. no.:	3.0
Date:	2021-11-05

AkerBP

Guideline

Guideline for pore-pressure fracture gradient prediction (PPFG) and well stability (WBS)

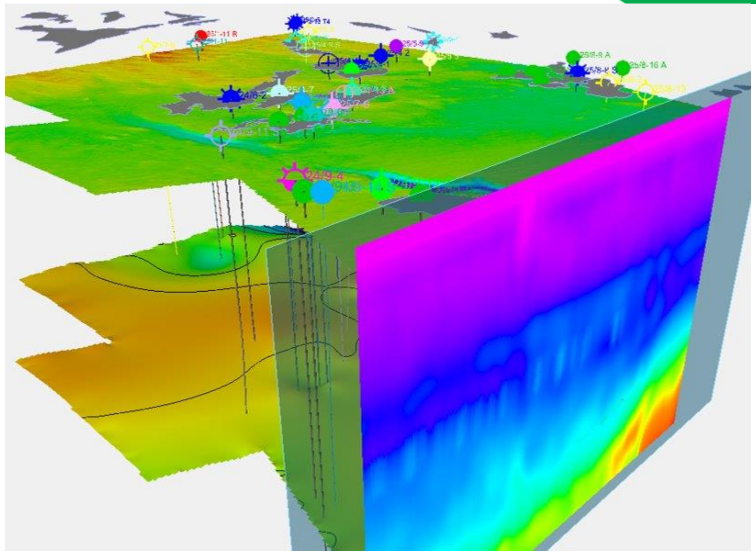
Document no.:	51-001183
Rev. no.:	1.0
Date:	2021-10-08

Remember to save document as a pdf

Pore Pressure, Fracture Gradient (PPFG) and Wellbore Stability (WBS) Review
Version 1.0

May 2021

Eng Geo Team



All assets have a 3D PPFG&WBS model in place

Petrel Shared earth—critical insight

Techlog Because every well counts

JewelSuite easy | fast | accurate

Rockfield

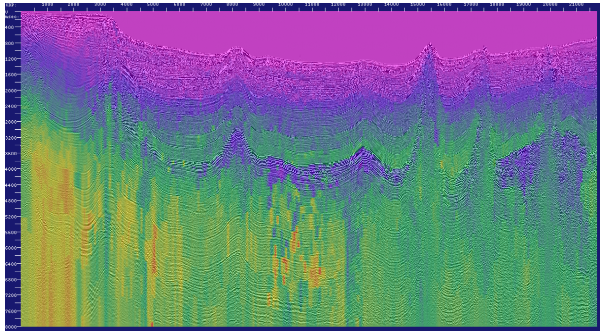
SINTEF

AkerBP

Pressure Prediction Methodology

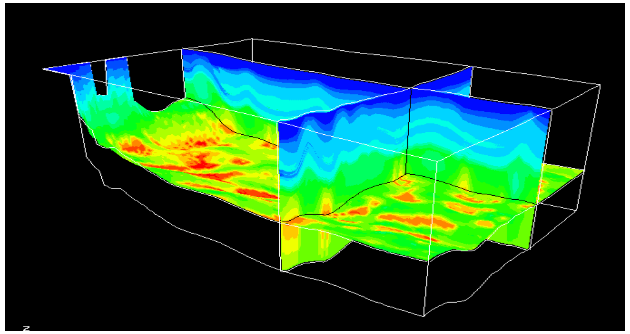
Integration

Seismic Velocities



- Geophysical technique
- Low resolution
- Mainly Shales, Sands can be inferred
- Data quality and resolution are the key issues

Basin Modeling



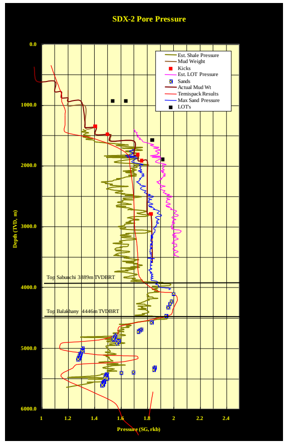
- Geological technique
- Moderate resolution
- Sands *and* shales
- Needs calibration data
- Capture geological uncertainty with multiple models

$$PP = OBG - (OBG - PP_n)\left(\frac{DT_n}{DT}\right)^m$$

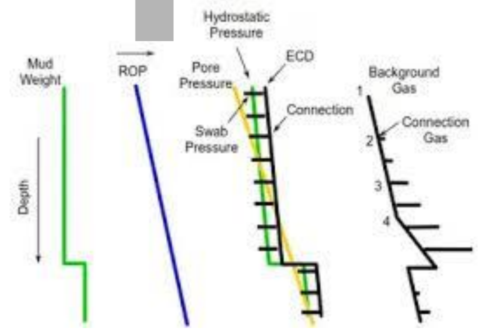
$$FG = f(OBG, PP, \nu, E, \alpha)$$

- Calibration, calibration, calibration !!!!!

Offset Well Data



- Real pressure data
- Extrapolation to well location may not be valid



- Gas observations are important calibration points in deep wells

Communication of Results to Execution Teams

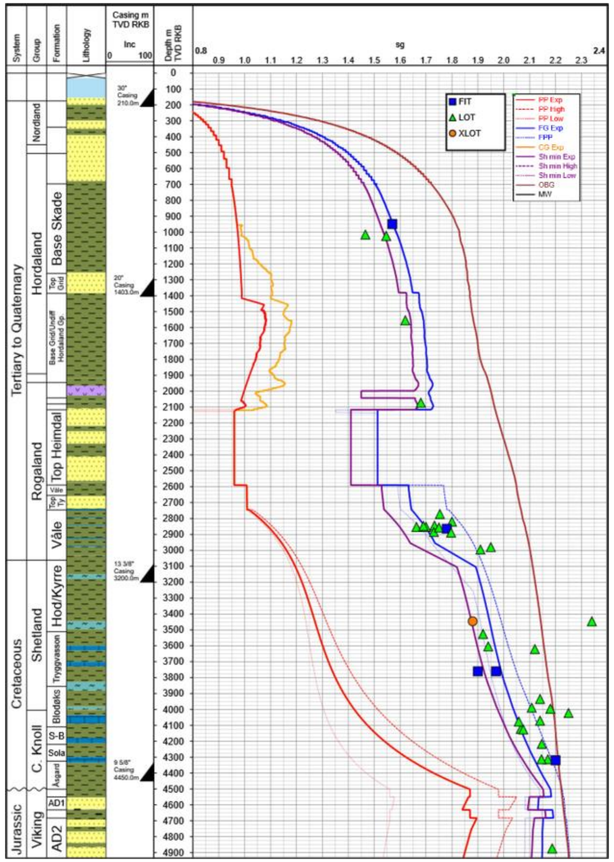
The PPFG forecast shall capture the expected pore and fracture gradient and its range of uncertainty as function of depth.

Unless otherwise agreed in a PPFG review, the PPFG forecast shall, as a minimum, contain the following curves for all wells:

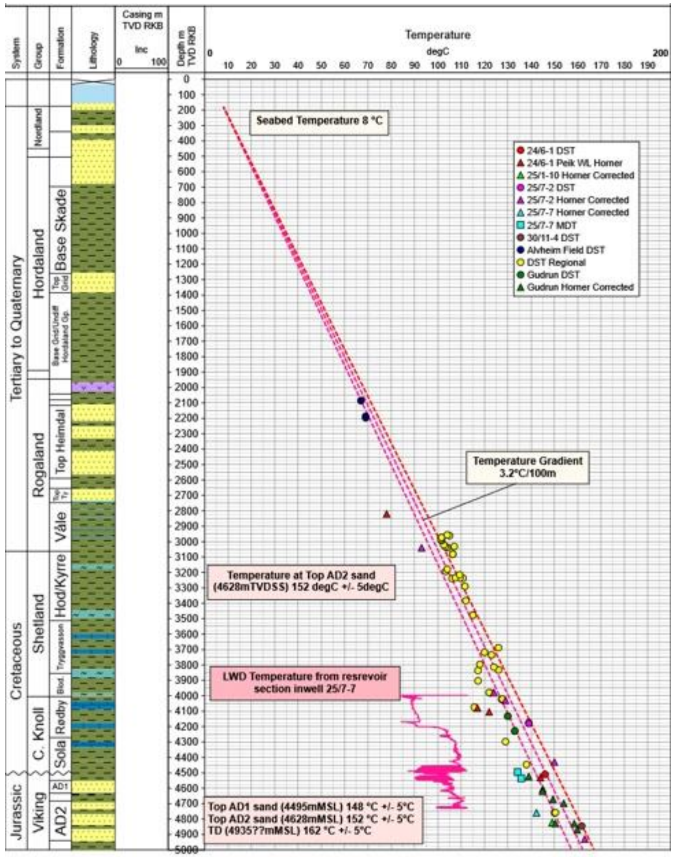
- Expected Overburden stress
- Expected Pore pressure
- Low Pore Pressure
- High Pore Pressure
- Expected Fracture pressure
- Low Fracture pressure
- High Fracture pressure
- Expected Minimum in-situ formation stress

- Low case pore pressure should be around P5 to P10
- The high case pore pressure should be in the P95-P99 area (not necessarily including highly unlikely, extreme pressure scenarios)
- The most likely pore pressure should be a P50 estimate
- The probabilistic values is assessed by analyst, not easy to calculate in a standardised way

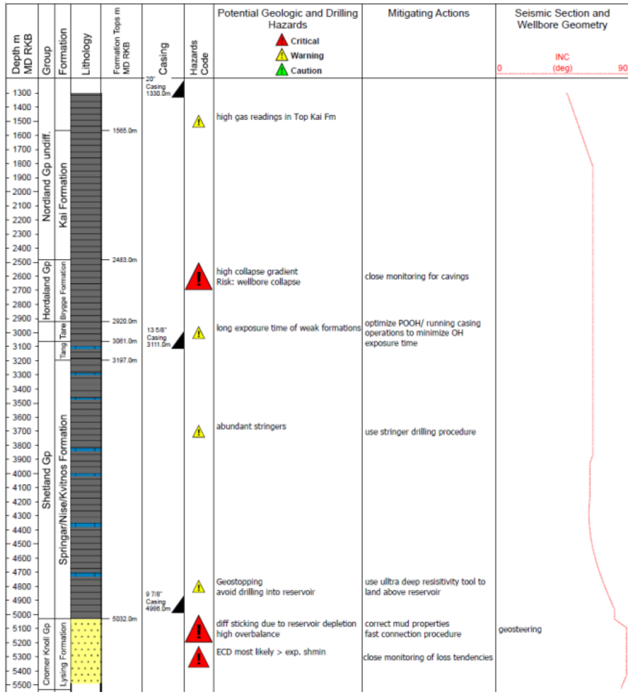
PPFG prognosis chart



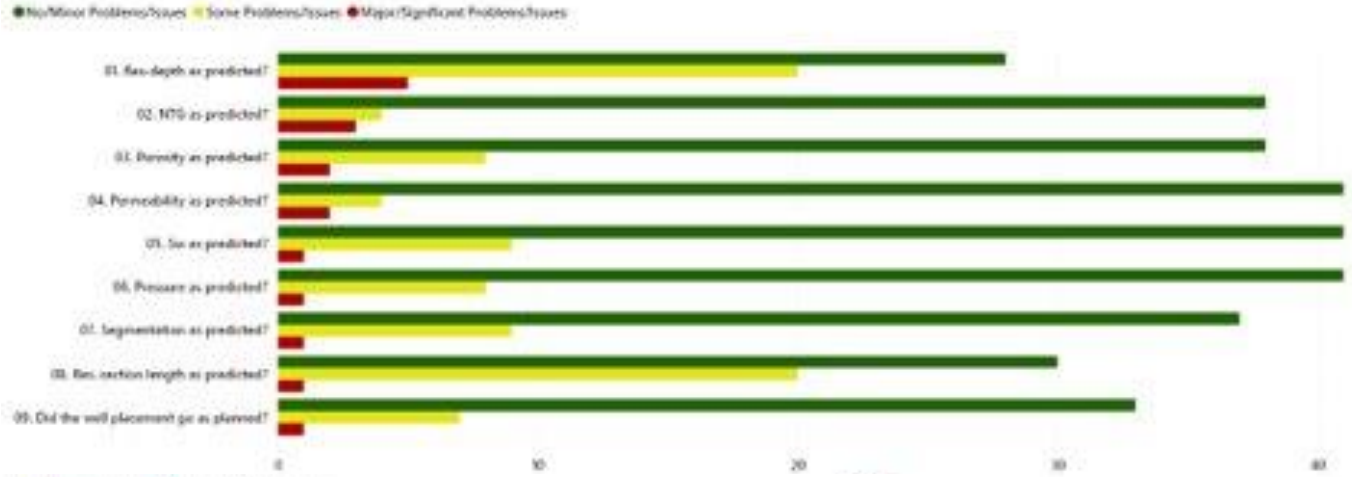
Temperature prognosis chart

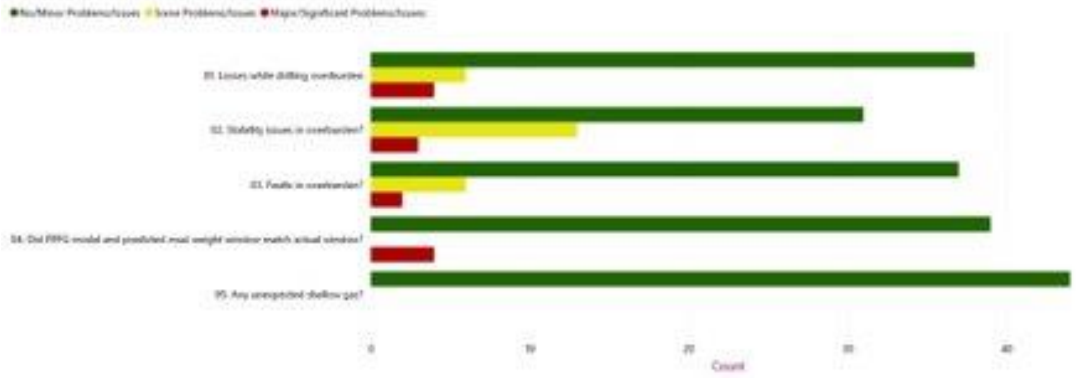


Pre risk chart



How are we doing?

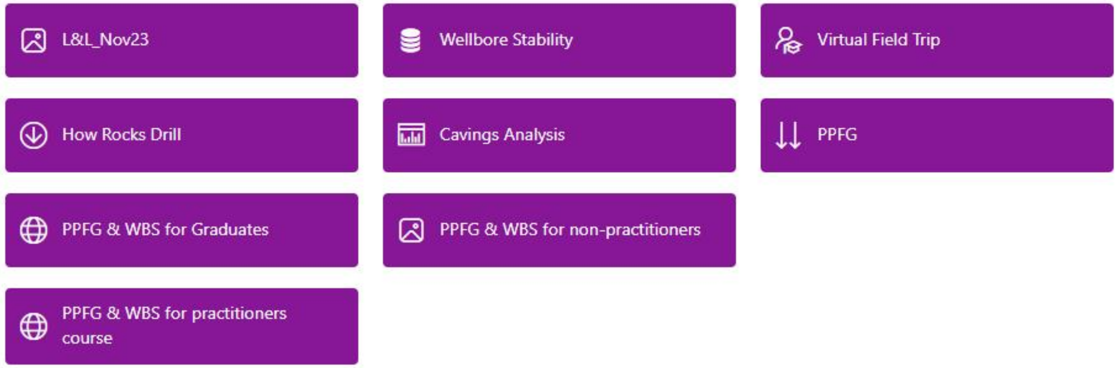




- Overall good performance, but not always spot on P50 estimates, but should be in the uncertainty range given
- We are tracking prediction versus actuals in a more qualitativly, but are working on an improved quantitative way

Training

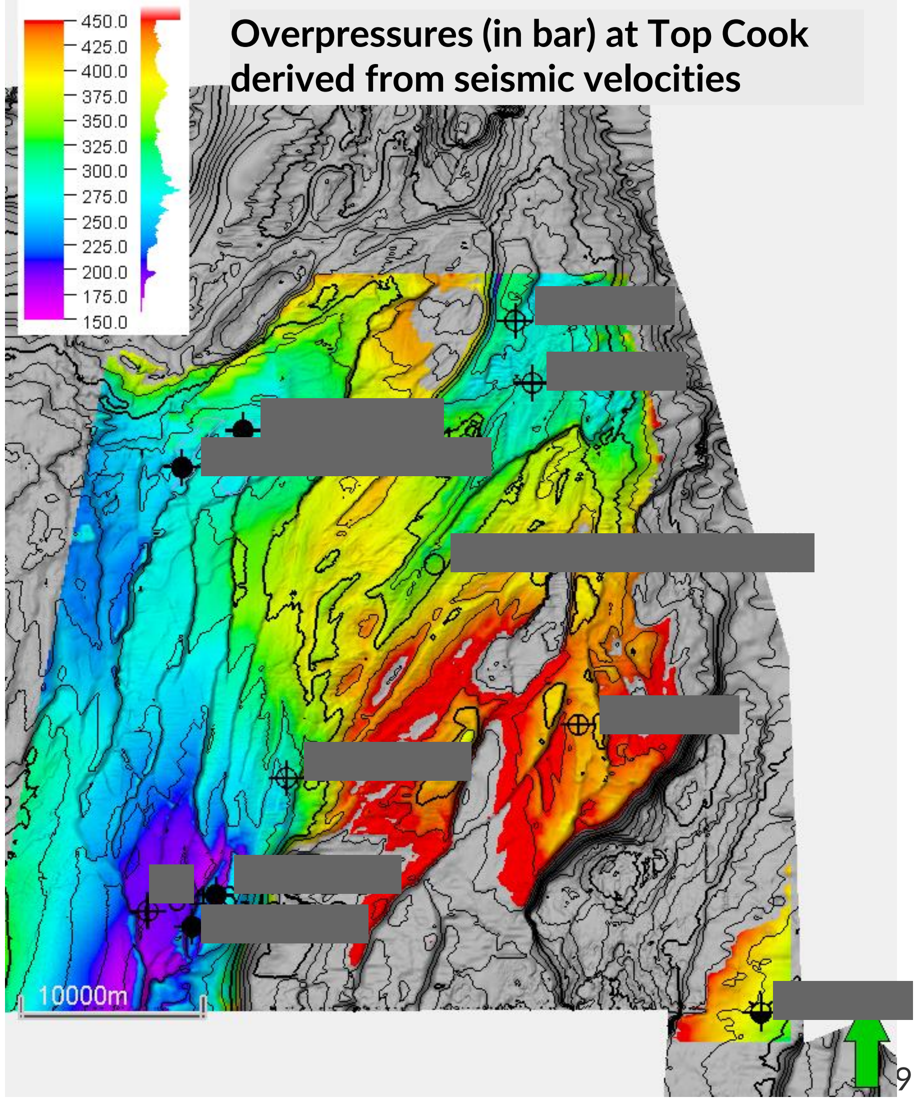
Understanding Drilling & Geoscience



- We are trying to calibrate the organization to the same understanding of the uncertainties around drilling and geology

Seismic

- Have had success with use of seismic when a high-quality seismic velocity cube is available
- As with offset sonic logs the seismic works best if overpressure generation is dominated by disequilibrium compaction
- Velocities depend only indirectly on pore pressure through a dependence of velocities on porosity (hence effective stress)
- For deep formations unloading (reduction of effective stress) by overpressures induced by, e.g., rock diagenesis or oil/gas generation, become more important and may become the main overpressure contribution
- This is important for HPHT fields (Jurassic or Triassic)
- Unloading results in smaller porosity changes than loading since rocks exhibit a more elastic response under unloading, while loading results in relatively large plastic, non-reversible rock compaction and pore-volume reduction
- However, for high unloading amplitudes (high overpressures), approaching zero effective stress, the pore-pressure sensitivity of velocities increases again (due to the formation of micro-fractures etc.).



Basin Modeling

Building / Calibrating a 1D model

- 7 steps to calibrate the rock behaviour

1: Identify stratigraphic units to use.

- Number of units
- Current-day thickness
- Sedimentation rate (based on current thickness)
- Current day porosity

2: Identify compaction model for each lithology (i.e depositional porosity).

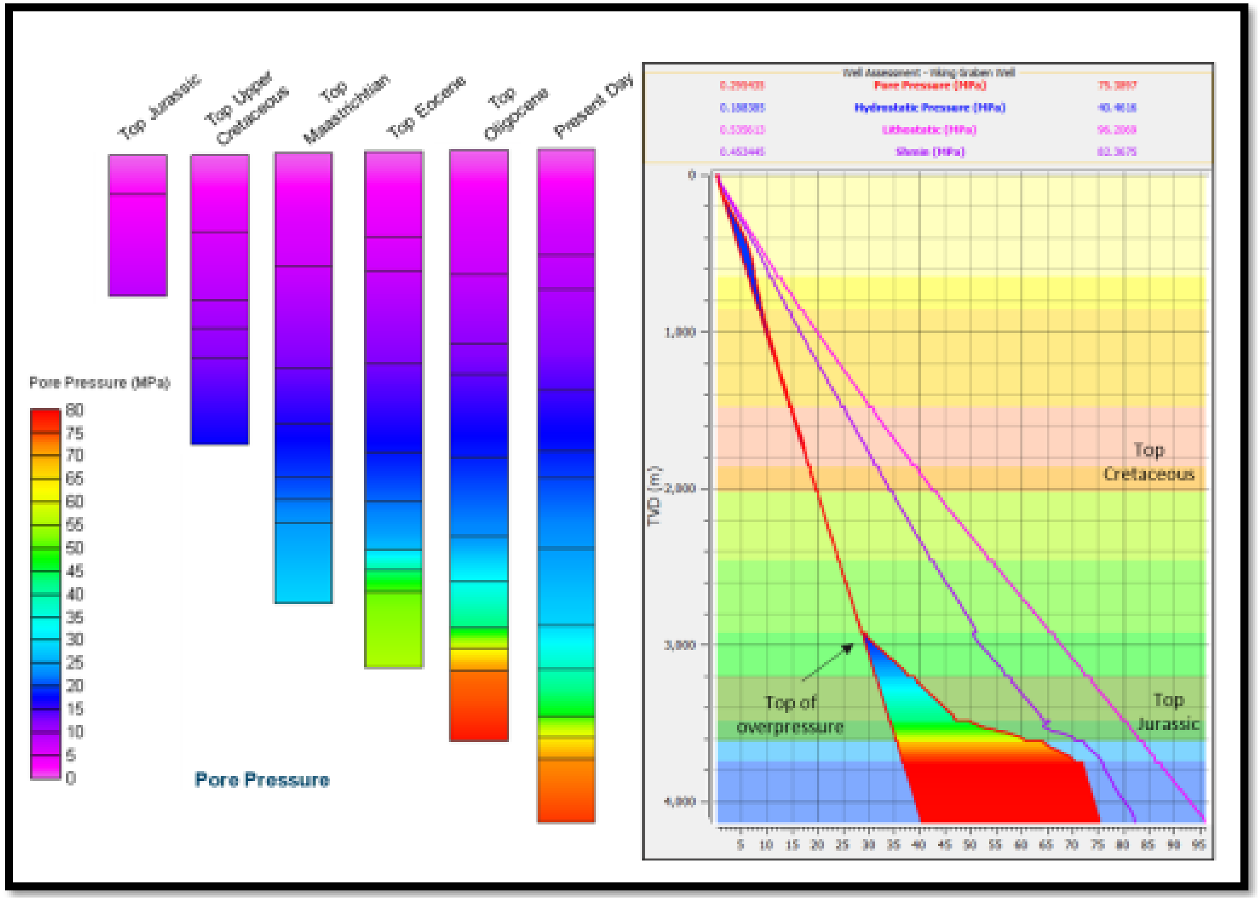
3: Estimate the depositional thickness of each layer.

4: Estimate chemical compaction upper and lower bound temperatures and compaction rate

5: Construct deposition model –base layer and depositional surface objects for each subsequent layer.

6: Perform initial simulation of deposition process

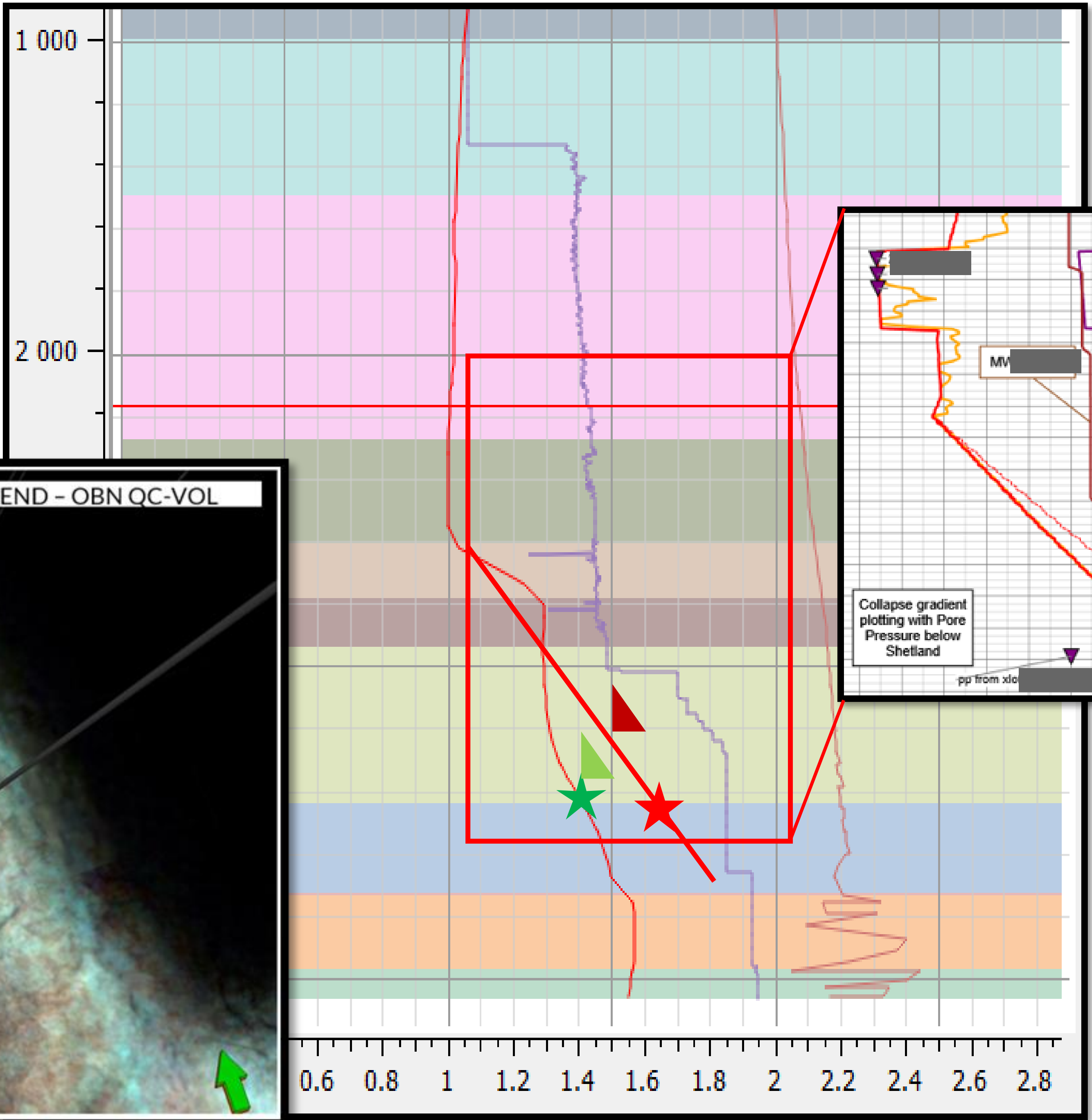
7: Compare predicted porosity and compacted thickness with current day- if needed return to step 5 to improve calibration

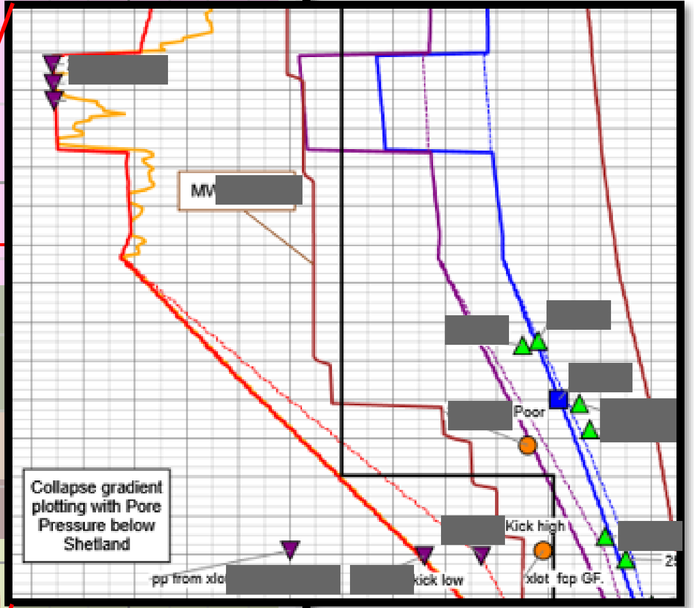


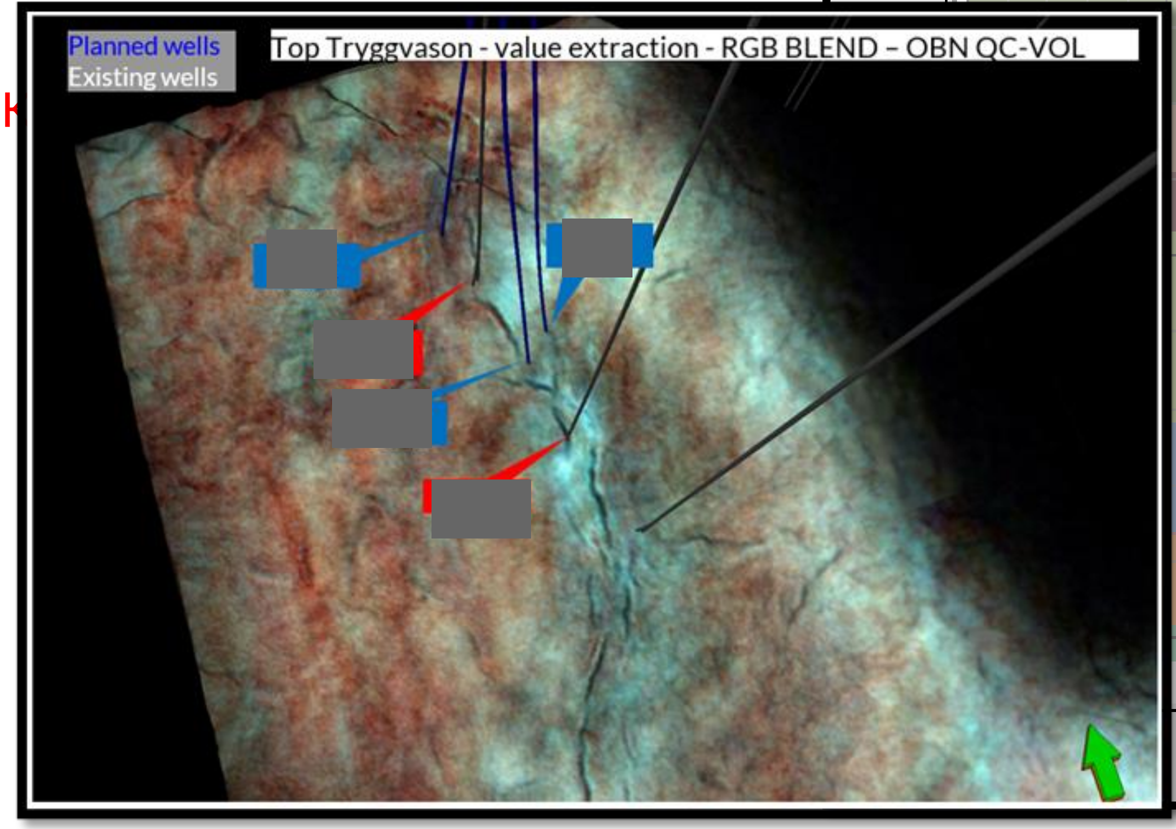
Case Example

NOTE : SG curve referenced TVDBML

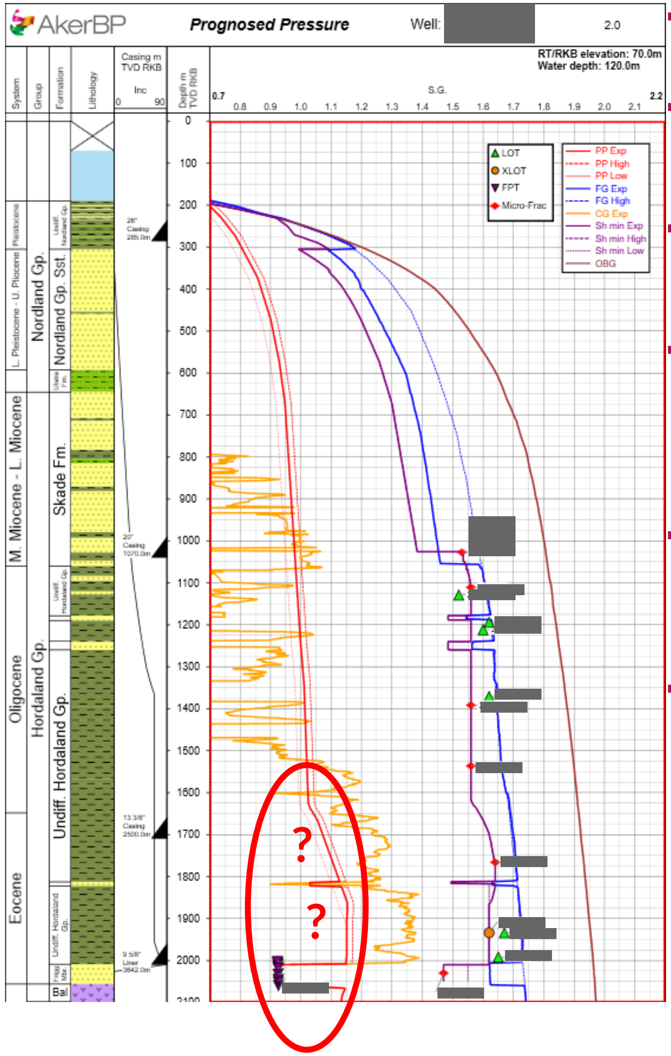
Back calculated PP from XLOT in offset well matches



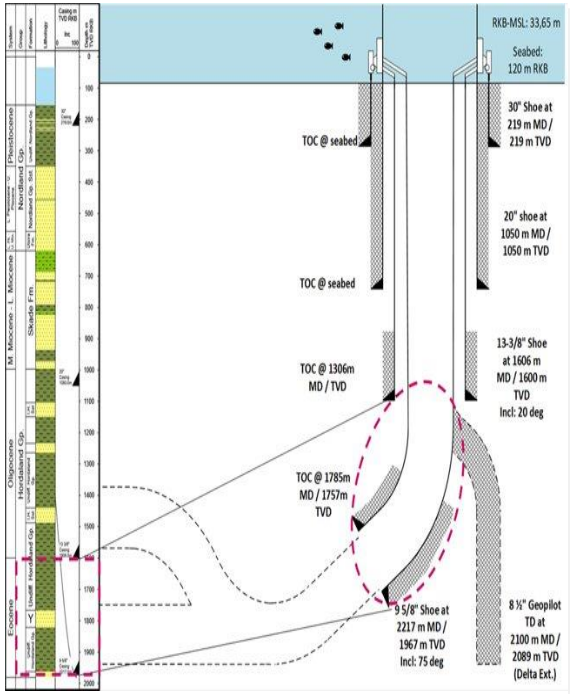


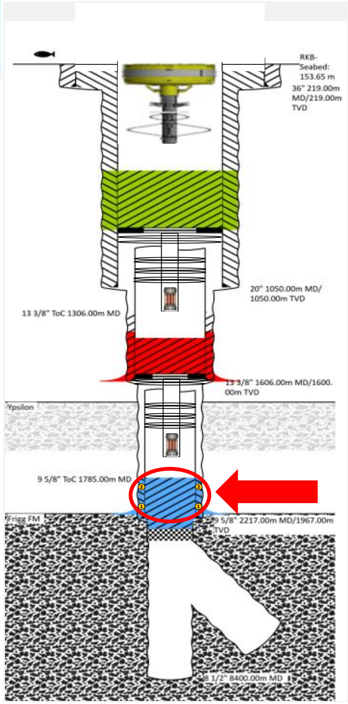


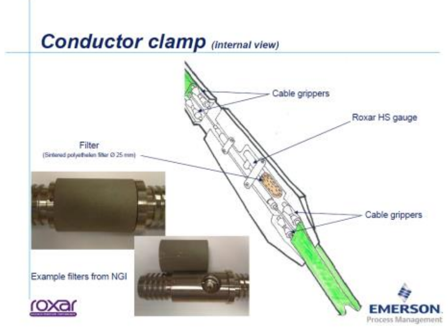
Measurement of Pore Pressure in Shales

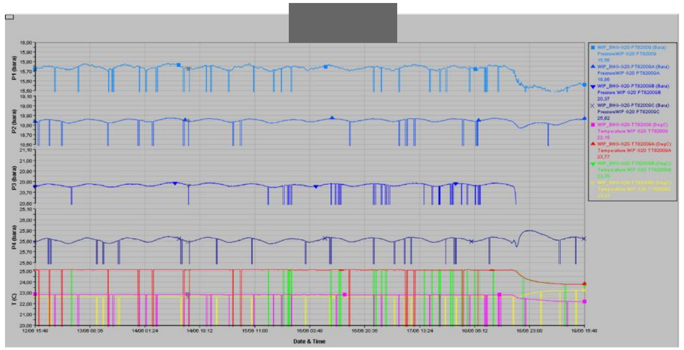


- The onset of pore pressure increase is uncertain and has been questioned in the past in the area
- We have indication that the log responses in this interval may be more driven by mineralogy or lithology changes than overpressure
- One key uncertainty is whether reported wellbore instability was pore pressure driven or drilling fluid/rock interaction driven
- In the appraisal well [redacted] Aker BP plan to install minimum 2, potentially 3, Metrol pressure gauges on the production casing inside the questioned Horda depth interval to enable acquiring pore pressure measurements in the low permeability claystone over a longer time period after P&A
- The business case: If the pore pressure is proven hydrostatic, this could mean savings for future [redacted] development wells by reduction in the number of casing strings in the well design
- Figure below show an installation at [redacted] where pore pressure has been measured in shallow shale and sands in the normal pressured sections since 2011 (not wireless)





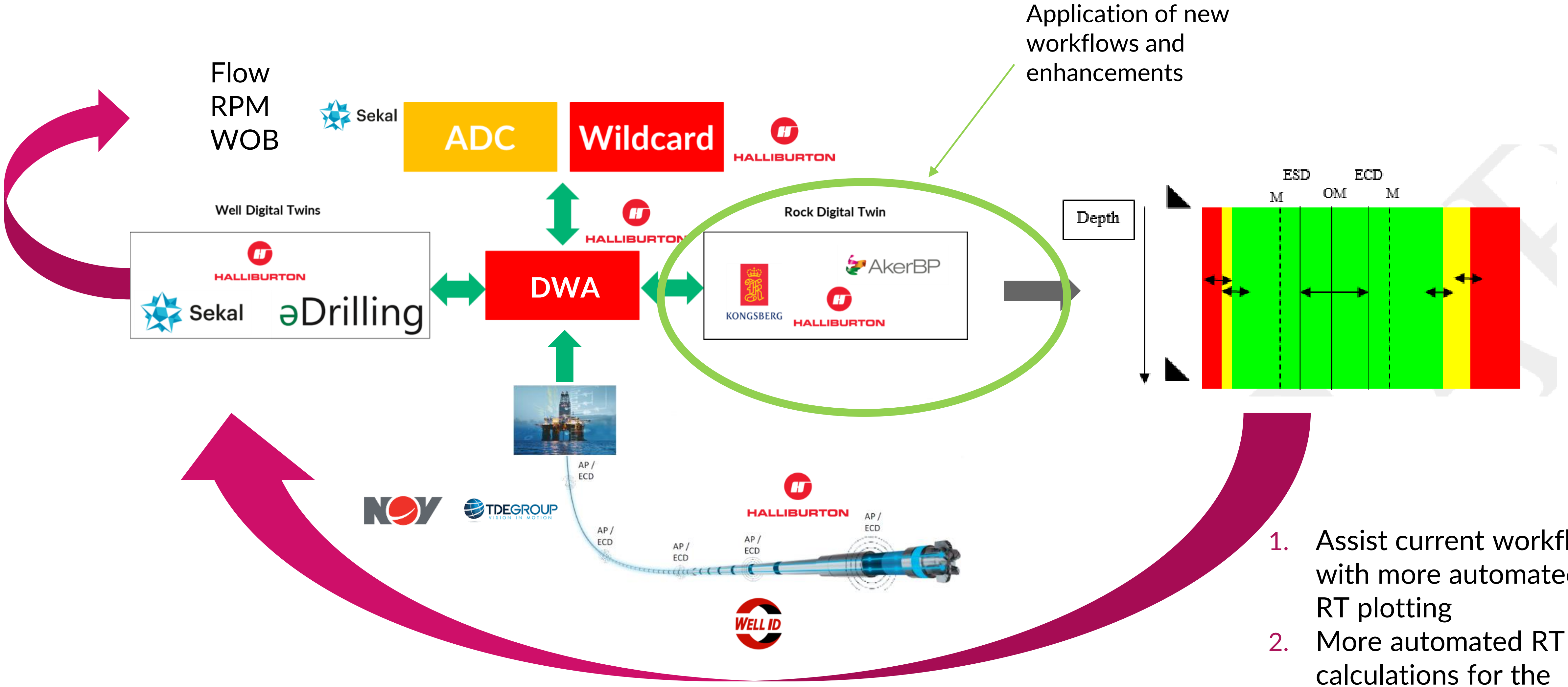




- «Home-made» [redacted] installation for [redacted] and [redacted] shallow section installed in 2011

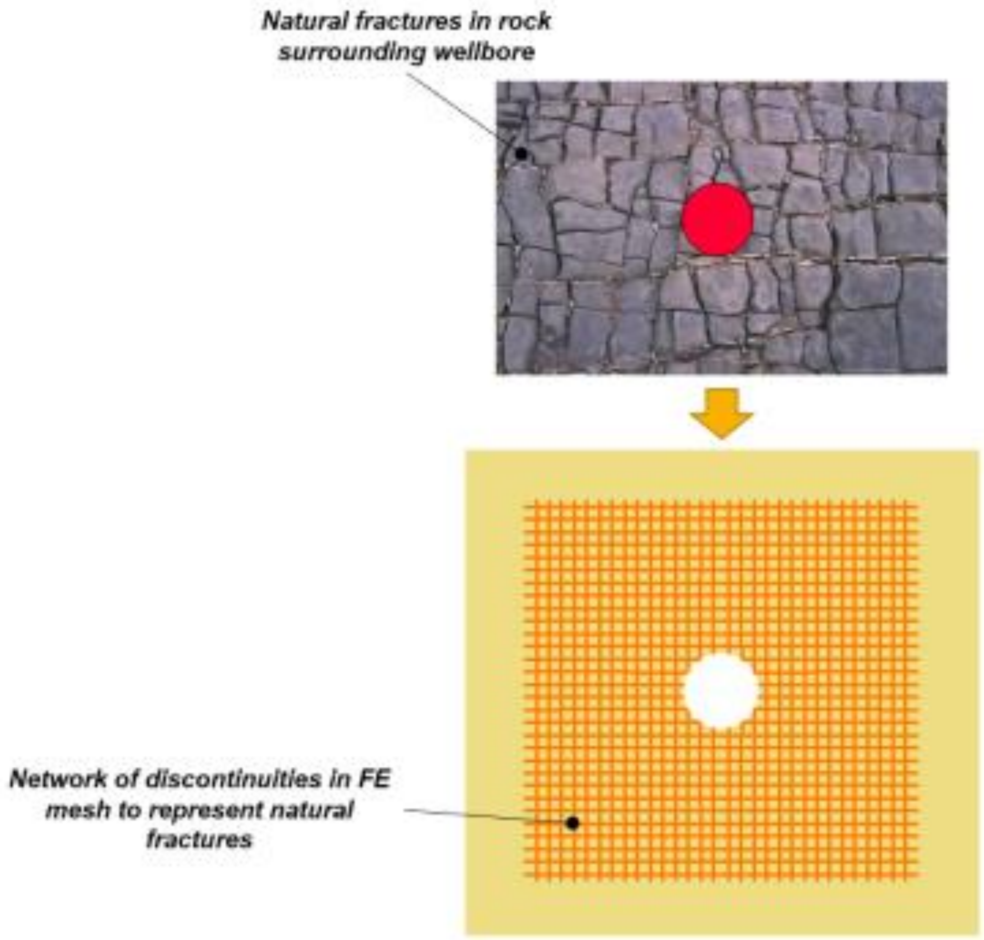
Autonomous Drilling in the Future

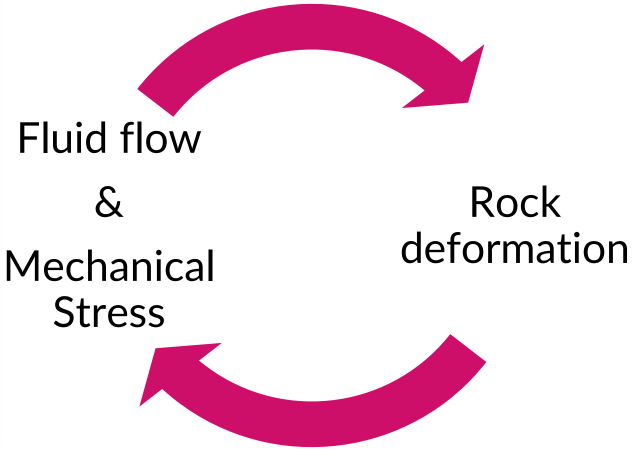
«Data flow» for Simulator & Rig

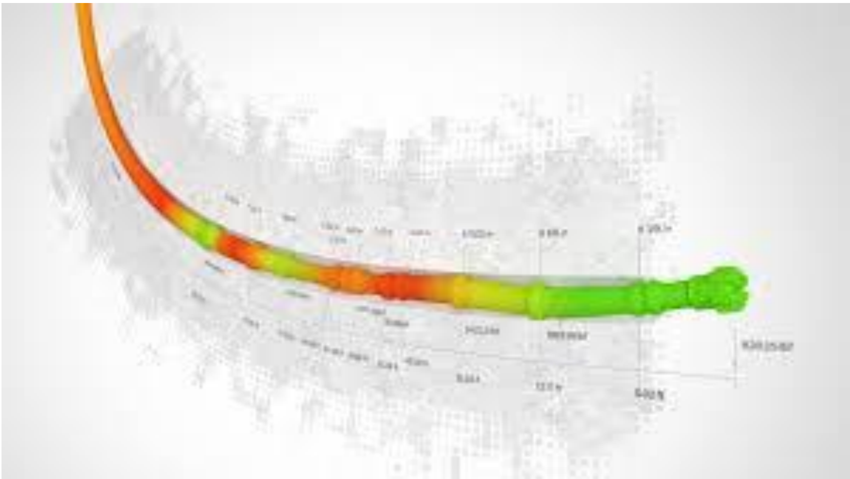


1. Assist current workflow with more automated RT plotting
2. More automated RT calculations for the future

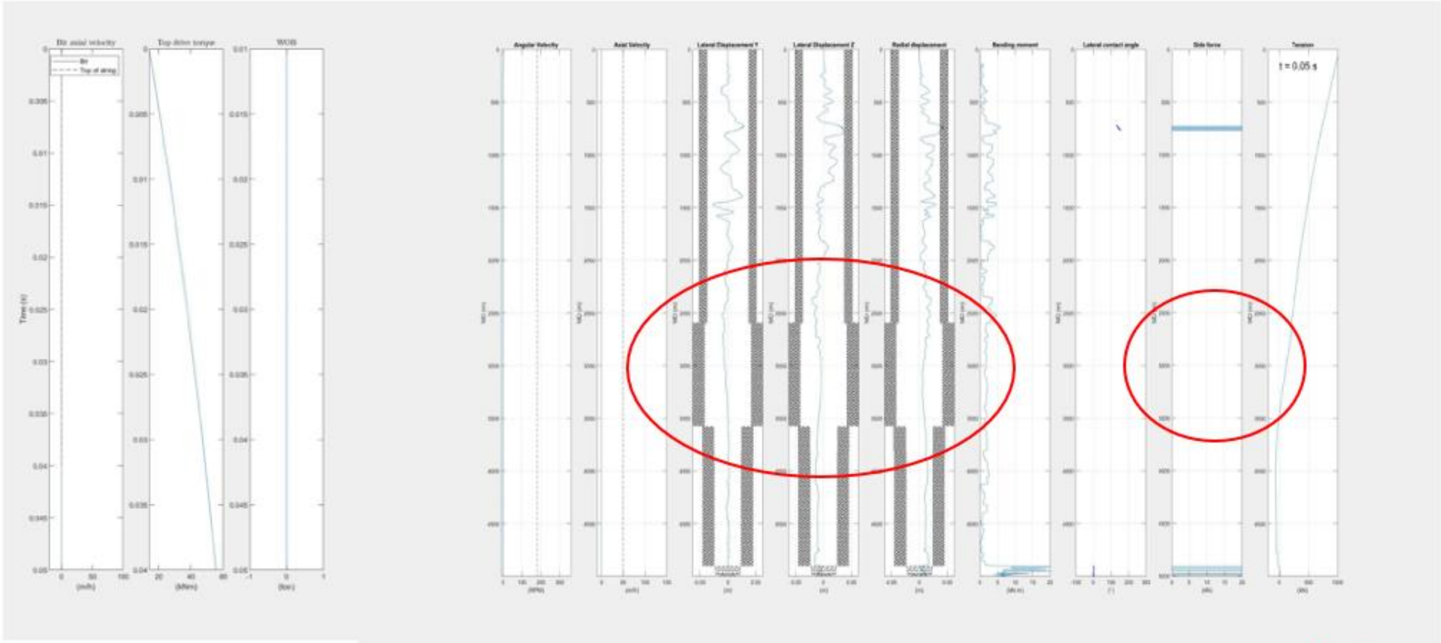
Fractured Shale Stability (Lower Hordaland/Faults)



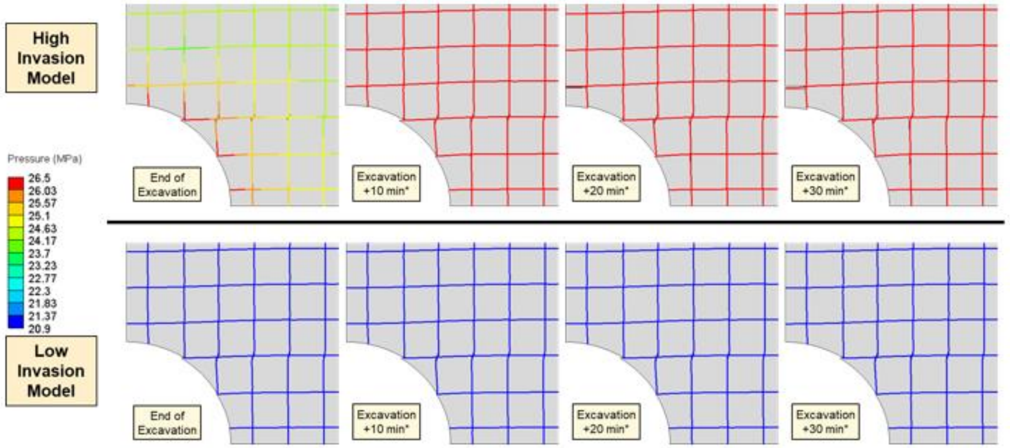




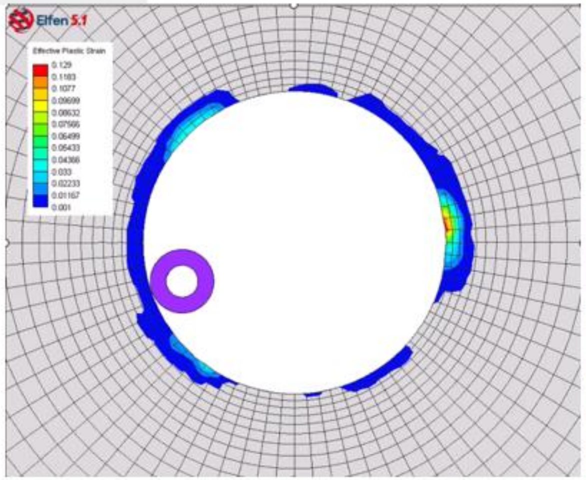
Fractured Rocks and Drillpipe Impact

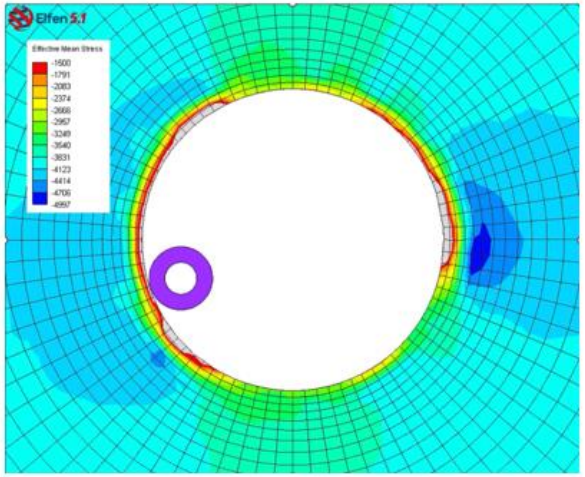


Drillstring Dynamics Simulations by Norce



Rock Mechanics Simulations by Rockfield





Summary

- Operations geologist is the responsible person for pore pressure prediction and wellbore stability for his well, but with support from wellsite geologists, rock mechanics engineers and reservoir engineers
- Using an Eaton type of model with calibration of exponent (m) and normal compaction line based on local conditions and offset well data (calibration, calibration, calibration !!!!), gas observations important in deep wells
- Communication of results to drilling engineer is important – standardization helps – also quantifying high, most likely and low as P95-P99, P50 and P5-P10 (exact probabilistic quantification is difficult, but intention is useful)
- We are tracking our predictions over time against observations, but were working on an improved method compared to what is in place today
- Current focus areas
  - Training – need to make sure we are talking about the same thing and uncertainty - standardization
  - Seismic – good success recently and will work on integrating the use into standard workflows
  - Basin modeling – useful for deep exploration wells so will work on integrating the use into standard workflows
  - Measurement of shale pore pressure – available technology that can help us optimize casing design
  - Rock physics and petrophysical evaluation as part of pore pressure prediction – since we see potential impact of mineralogy on standard pore pressure prediction methods, we will investigate integrating these methods into our standard workflows
  - Autonomous drilling – will require RT update of pore pressure and wellbore stability and potentially also use of more advanced rock mechanics models than are typically used in industry today

www.akerbp.com