Overpressure 2008 – Pressure prediction

HPHT Exploration Well Pore Pressure Prediction and Monitoring: Utilising VSP Look-Ahead, MWD Resistivity and MWD Sonic

A case study from the Central Graben of the North Sea

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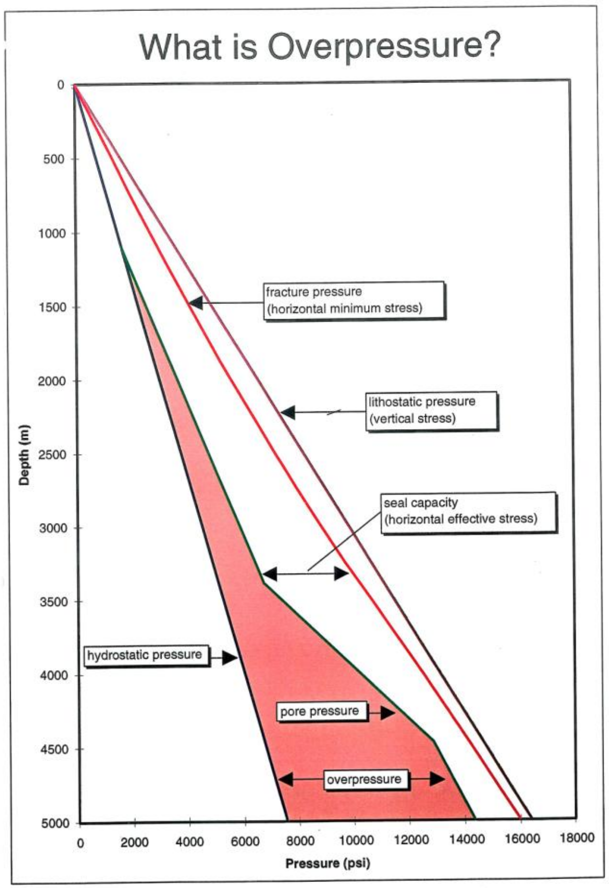
What Is Pore Pressure?

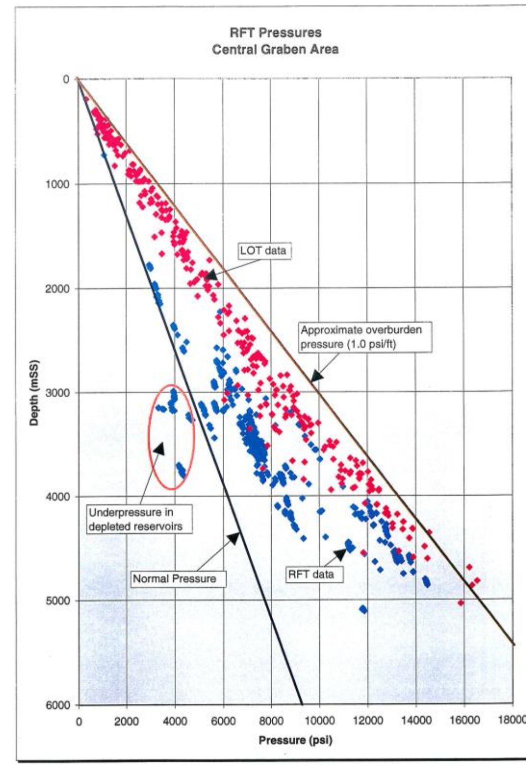


Hydrostatic pressure.

Weight of a column of water

Lithostatic Pressure.

Weight of Rock plus pore fluids



HTHP Well – NPD Definition

- Depth > 4000 , TVD
- Estimated SIWHP > 10,000 psi (689 bar)
- Estimated Temperature > 150 C

Key Equations

P=W*D*.0519

P = Pressure in PSI
W = Mud weight in PPG
D = Depth in feet

FG = (u/1-u)(OB-PP)+PP
(Eaton)

FG = Fracture Gradient (PSI/FT)
OB = Overburden in (PSI/FT)
PP = Pore Pressure (PSI/FT)
u = Poissons ratio (commonly .25)

Normal freshwater gradient 0.433 psi/ft, 8.34 ppg, 1.0 SG
Saltwater gradient 0.46 psi/ft, 8.6 ppg, 1.03 SG
To change PPG to psi/ft multiply by 0.0519
To change PPG to SG divide by 8.34
Overburden 1 psi/ft (approximation)
1bar = 14.506 psi
1 Atmosphere = 14.7 psi

Identifying Overpressure

- Seismic
- Electric Logs - Trends
- Drilling Parameters - Trends
- Mud density / Gas relationship
- Cutting Character
- Hole Behaviour
- Drilling exponents - Dxc, Nx, Nxb
- Shale Density
- Shale Factor
- Temperature
- Mud Resistivity / Conductivity

Causes of Overpressure

- **Stress**
  - Compaction Disequilibrium
  - Tectonic
- **Fluid Volume Increase**
  - Temperature (aquathermal)
  - Mineralogical Changes (Chemical)
    - Smectite to illite, gypsum to anhydrite, calcite re-crystallisation etc
  - Hydrocarbon generation and cracking
- **Fluid Movement and Buoyancy**
  - Osmosis
  - Hydraulic head
  - Fluid density

Good things about Overpressure

- **Higher deliverability (even from rocks of poor reservoir properties)**
- **Larger volumes of HC for a given trap volume**
- **Systematic impact on secondary and tertiary HC migration**
- **ES = OP – PP which meand in highly overpressured zones the effective stress is low which reduces the compaction effect of pressure solution at grain contacts – BUT by the time OP develops most mechanical compaction has already occurred.**
- **Issues:**
  - Shallow Gas
  - Deep wells expensive to drill. Require higher grade BOPs, more casing, slow drilling procedures
  - Higher Risk : Seal failure
  - Charged Fractures – Lateral Transfer, Centroid Effect. Crestal Drilling, Salt Domes

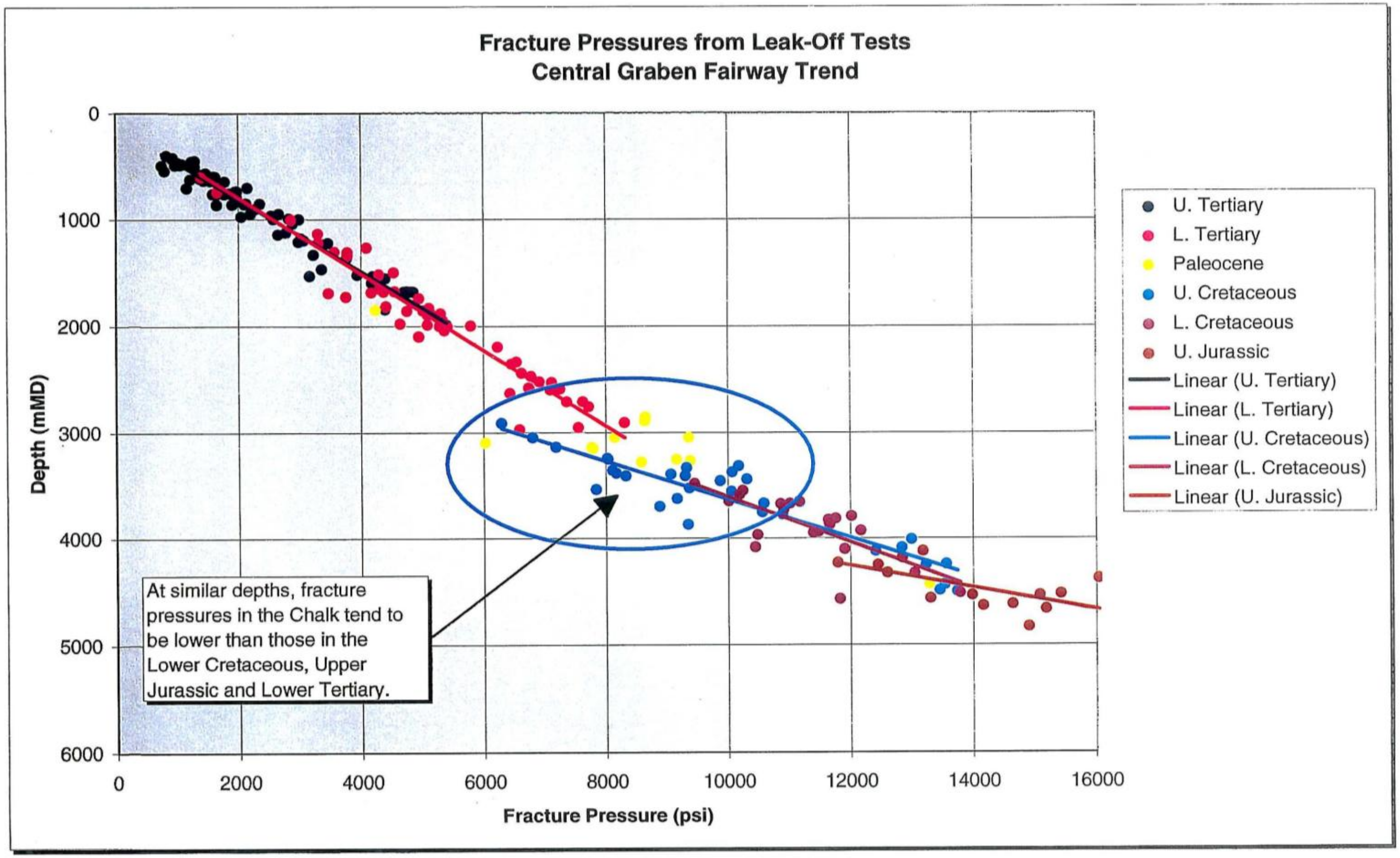
Causes of Seal Failure

- **Seals fail when total stress exceeds tensile strength of rock**
- **Total Stress**
  - = surface forces + body forces
  - = bending moment + pore pressure
- **Seal Capacity = Fracture pressure – pore pressure**
  - When seal capacity < 1000 psi (70 bar), seal failure is a very high risk

Propogation of Fractures

- Fractures provide effective conduits but offer little storage volume
- In a tight system, hydraulic fractures will propogate upwards until they encounter a system with enough storage volume to accommodate the excess fluids and adequately reduce the underlying pore pressure
- Upward propagation of fractures in the Central Graben is facilitated by an upward decrease in tensile strength from the Jurassic through the chalk.

Central Graben Fracture Pressures

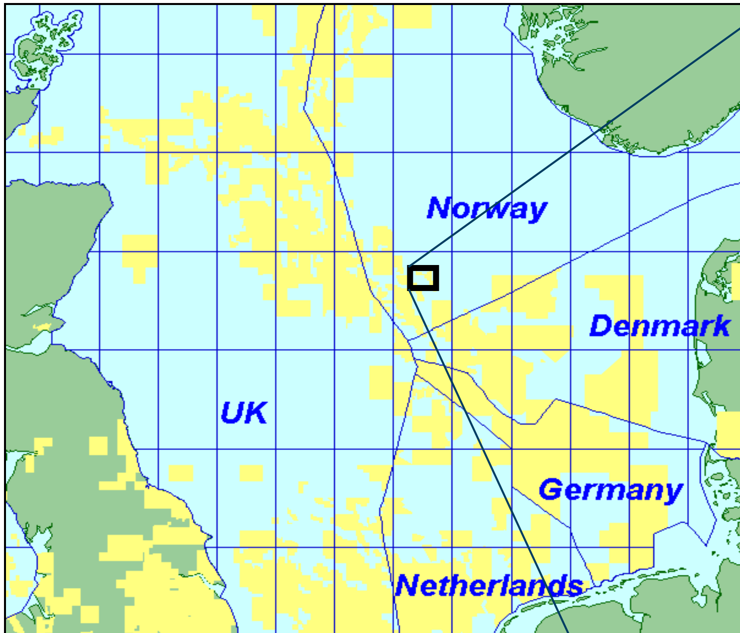


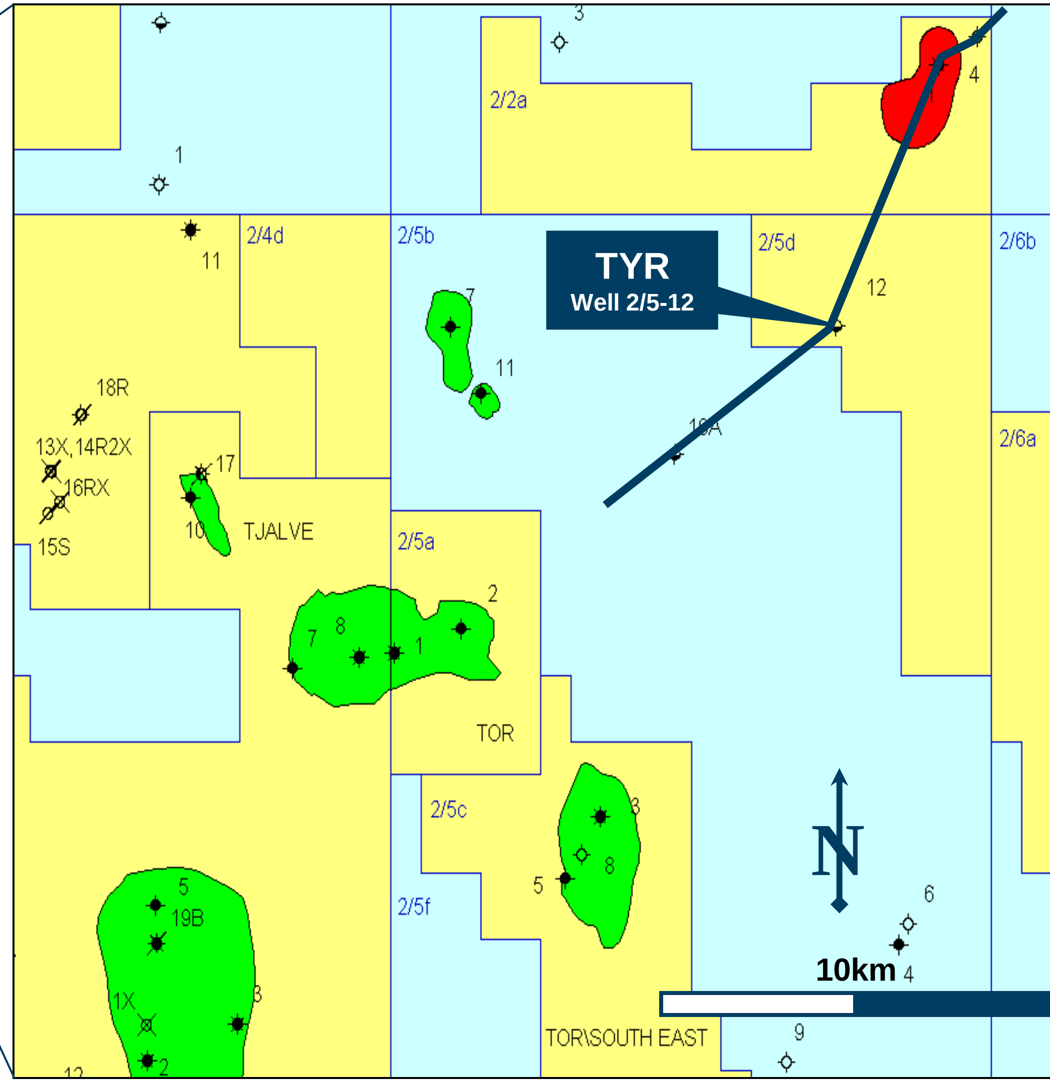
Understand Seal Failure and understand Migration

- The worse the seal the better the conduit
- By mapping seal capacity potential you are also mapping vertical migration potential
- Utilize appropriate pore pressure and bending moment criteria to identify vertical conduits

Location Map – Well 2/5-12

HESS DNO



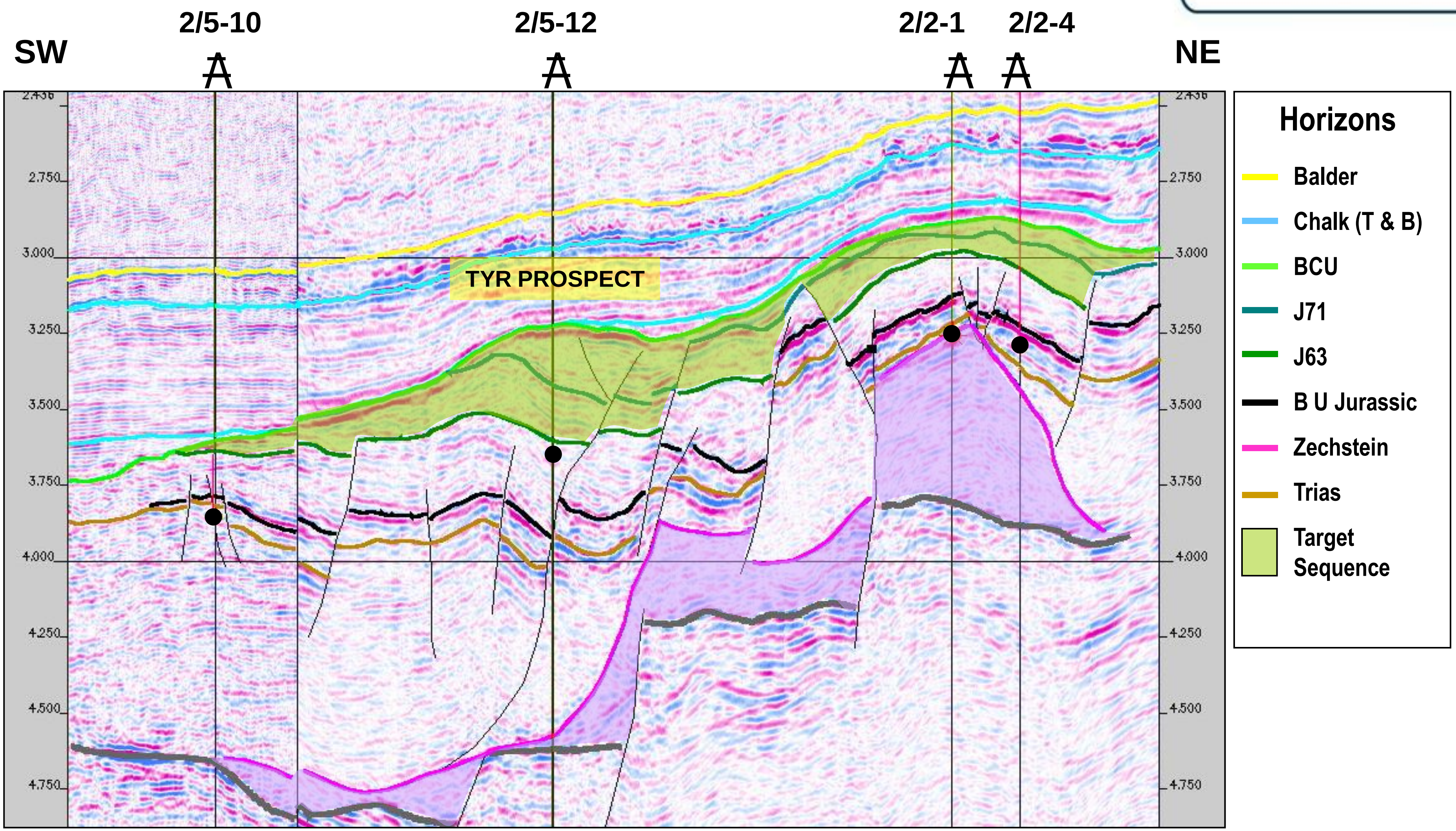


Exploration well 2/5-12 has been drilled in 2001/2002 by Amerada Hess (op.), DNO, BP, Enterprise, TFE & Gas de France.

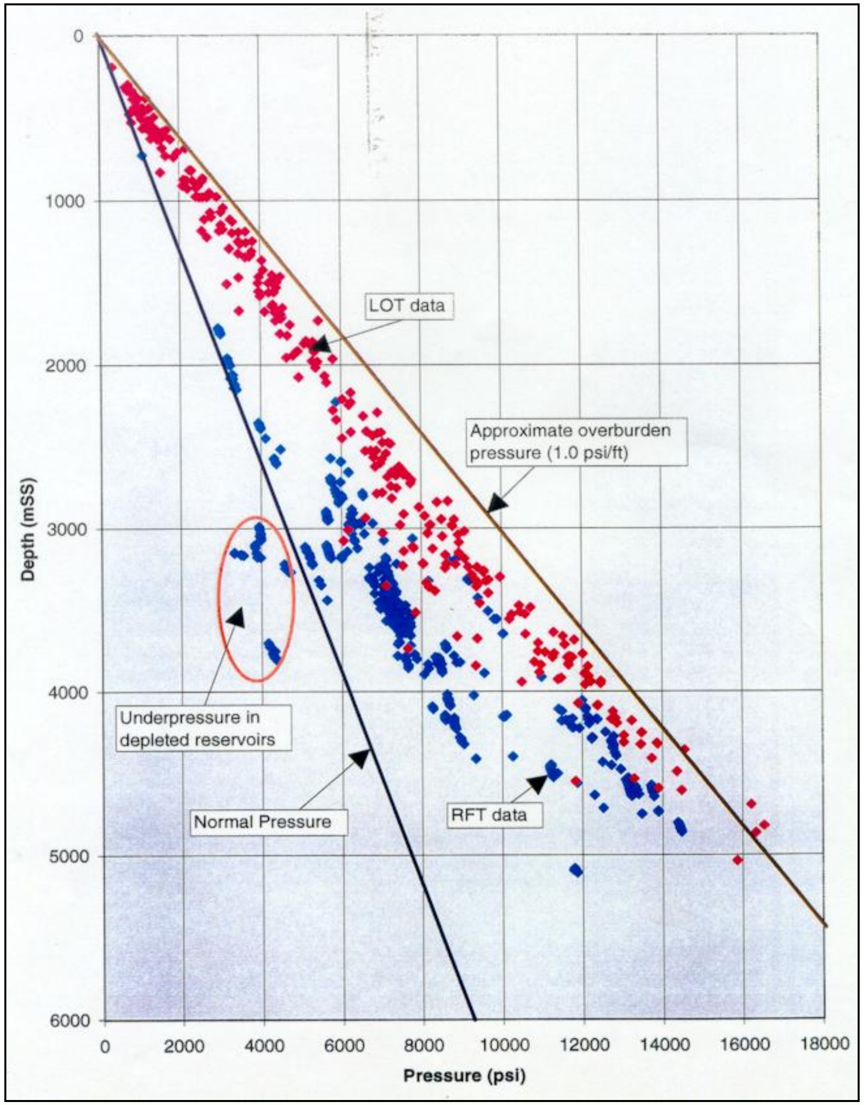
Purpose was to test the Late Jurassic Tyr Four-way dip closure.

The HPHT nature was technically challenging mainly with regard to high pore pressure and consequent risk of loosing the kick margin.

Composed Seismic Line Through Tyr Prospect and Adjacent Wells

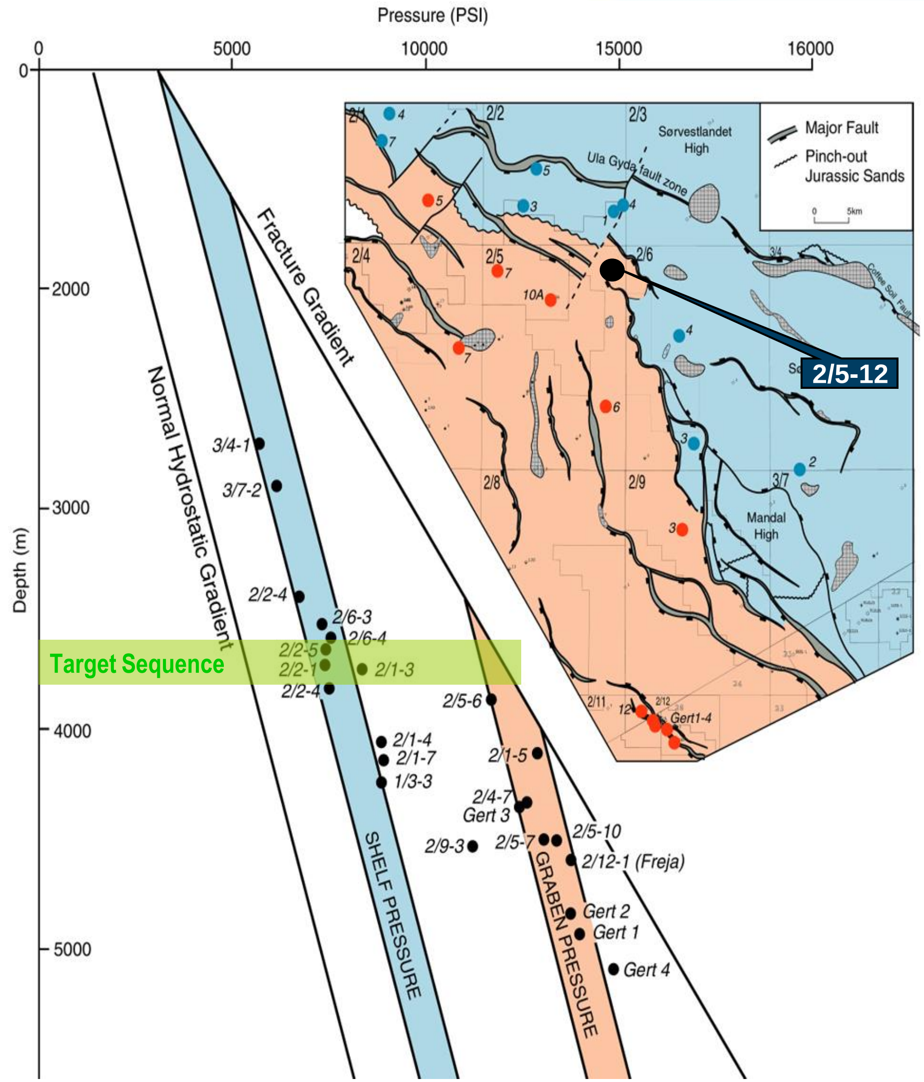


RFT Pressures – NSCG Area



Jurassic Pressure Regimes of the NSCG Area

- Location of the well 2/5-12 between shelf and basin opens the discussion on which pressure regime will be encountered.
- Basin pressures at reservoir depth predict pressures close to fracture gradient with low kick tolerance.
- Such a setting requires a careful well planning and experienced operation staff.
- Analogue wells from the Central Graben 2/5-6 and 2/4-14 demonstrated consequences of operational failure.



Analogue Well – 2/5-6

Well Histories

Lucky Case!

- 9 5/8" casing was set at 3539m near the base of the Chalk
- Top Jurassic was encountered at 3596m
- Drilling proceeded with a 15 PPG (1.8 SG) mud weight
- At 3915m a small influx from thin sand was taken and controlled
- Drilling proceeded to 3967m where another small sand body was encountered, and the well started to flow. The MW was steadily increased over a number of days in an attempt to kill the well. It was eventually brought under temporary control with a static MW of 17.1 PPG (2.05 SG). At 17.4 PPG (2.09 SG) the well started to flow again but took losses at 55 SPM. After numerous attempts over a period of 13 days the well was killed using a Temblok plug.
- A 7" liner was set and drilling proceeded
- On drilling out the liner shoe and a further 5m shale a large sand body of 17.6 PPG (2.11 SG) pore pressure was entered

Had the liner not been set the well could have been lost!

Analogue Well – 2/4-14

Well Histories

Unlucky Case!

- The 9 5/8" casing was set in the Hod Formation at 4437m. 8.5" hole was drilled with a MW of 17.34 PPG (2.08 SG). Top Jurassic was encountered at 4702m.
- Thin sandstone was drilled at 4707 and 4712m. The gas levels rose cutting the MW to 16.85 PPG (2.02 SG).
- The MW was raised to 17.51 PPG (2.10 SG) and at 4714m returns were lost. Lost circulation material, cured the loss and drilling continued with 17.43 PPG (2.09 SG) to 4734m where the well kicked.
- Several attempts to kill the well failed. The drill pipe became stuck so cement was pumped to kill the well. This was not successful and the pipe started to be forced out of the well. The shear rams were activated and the BOPs secured. The rig left the well after 30 days of problems.
- A re-entry was attempted and discovered that the high pressure had been transmitted up the annulus and as a consequence the casing had burst at 1370m.

1 year and 3 months after the kick well 2/4-15S killed well 2/4-14!

Key Processes for Pressure Prediction and Monitoring

HESS DNO

- **Pre-drilling:**
  - Pressure-Prediction by Seismic
  - Pressure-Prediction by offset data, logs, FWRs
  - Geologic modelling, faults, sand connectivity
  - Modelling of seal capacity in overburden (i.e. Chalk)

Do not address Transition Zone between overburden and HPHT Jurassic section

Modelling of the Transition Zone

- **While-drilling:**
  - Mudlogging techniques
  - Evaluation of log trends (PPFG & Eaton)
  - MWD Resitivity
  - VSP Look-Ahead
  - MWD Sonic

Traditional techniques: unreliable for the HPHT Jurassic

Complementary techniques chosen for well 2/5-12

Pre-Drilling: Pressure Prediction

- **Seismic**
  - CSD: Complex seismic Decomposition utilises seismic attenuation to derive pore pressure
  - PPRED: Pressures from Seismic Velocities. Generates a seismic line between wells. Calibrates end points with well data. Small changes in velocity between wells will have a major impact on PP forecast
  - High Res DIX and Predictive deapwater rock model
- **Geologic / Basin Modelling**
  - FobosPro
  - Basinmod
  - Temis
- **Well Log Data**
  - BP/KS multiwell study
  - Blaise
  - Sperry Sun PPFG

Limitations

- **Seismic**

Historically poor forecasting results.

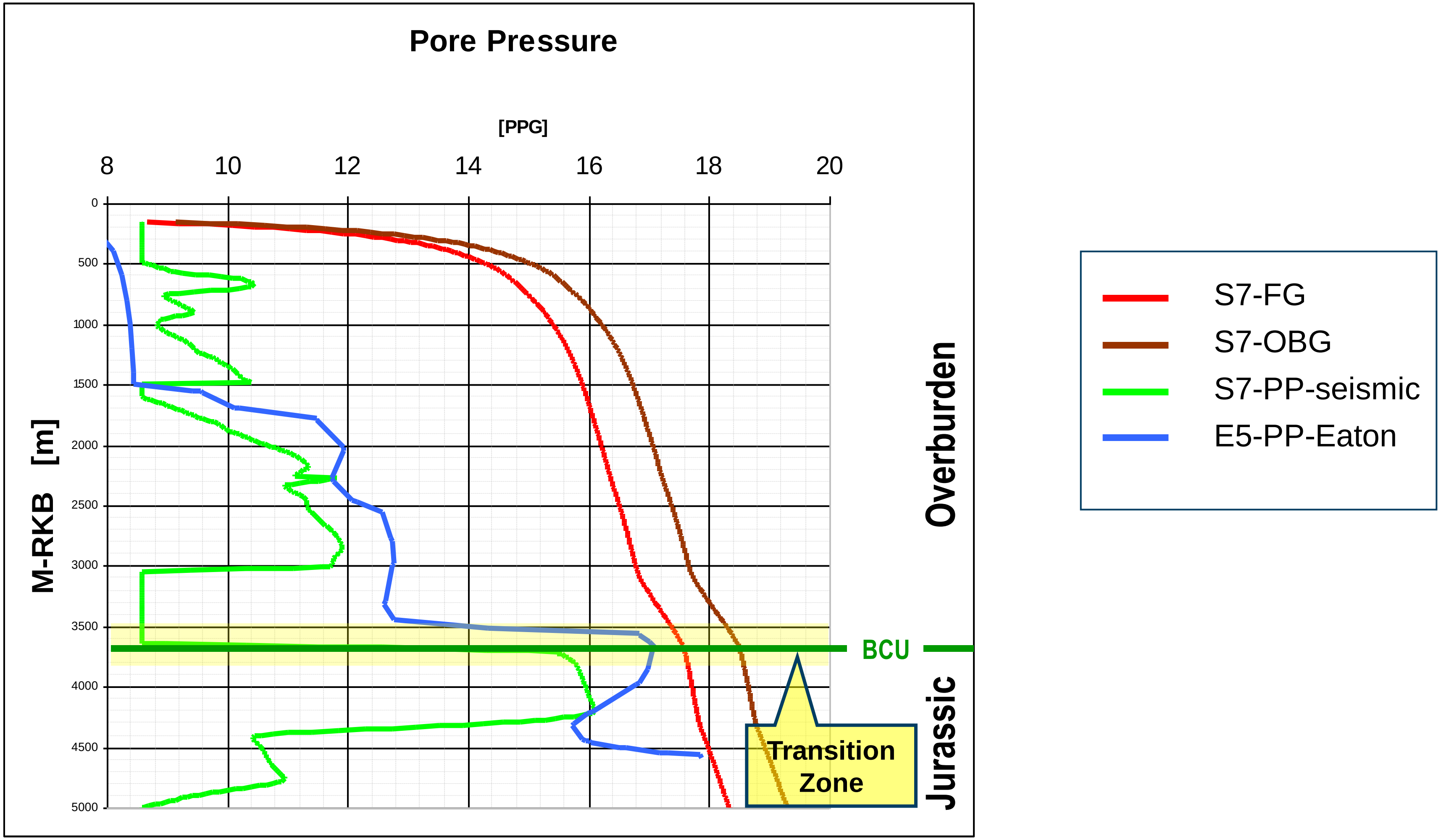
- **G / B M**

Complicated. Use in planning but not a real time tool

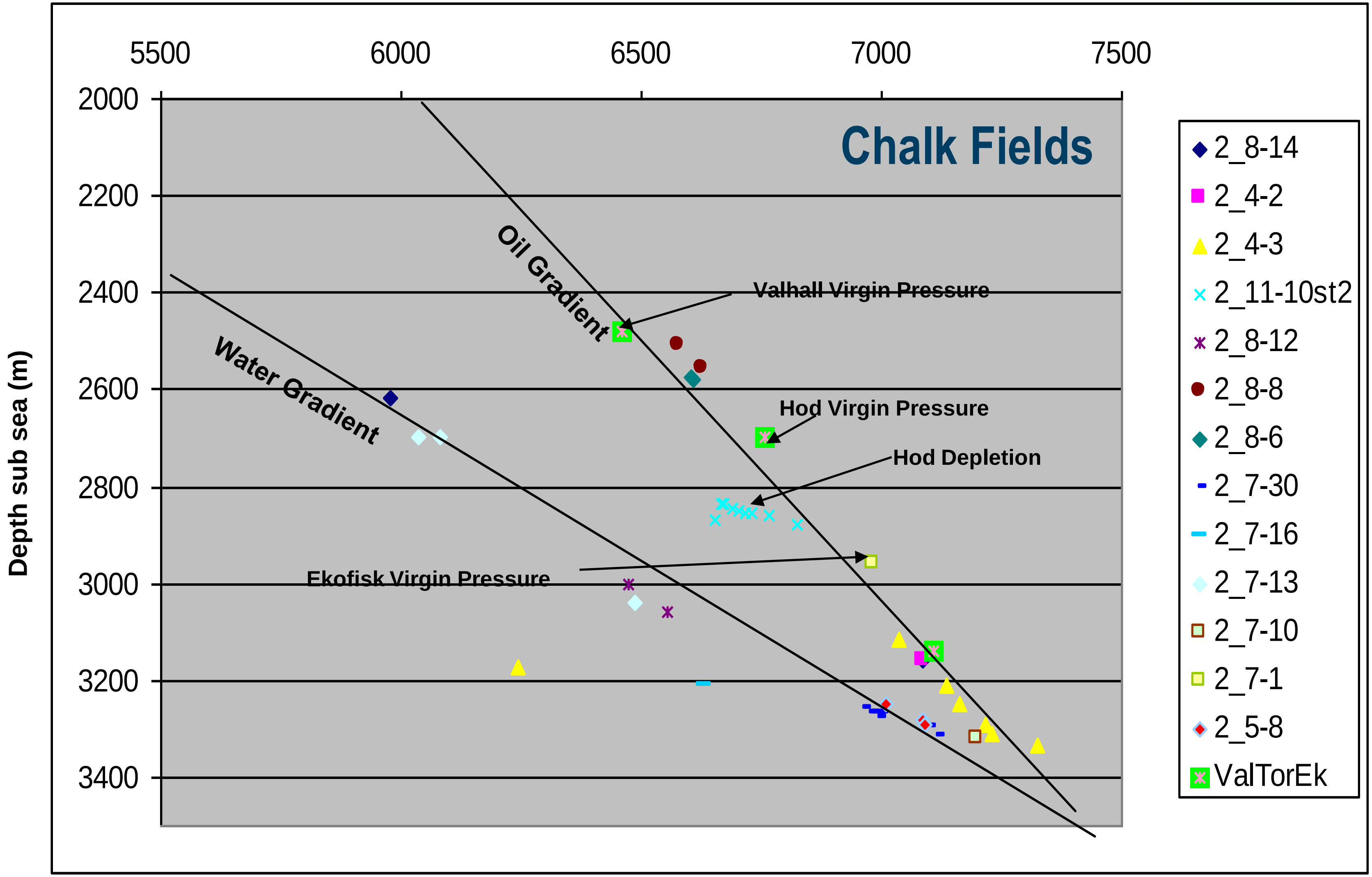
- **Log Data**

Often trend line dependent. Generally better after well drilled than during

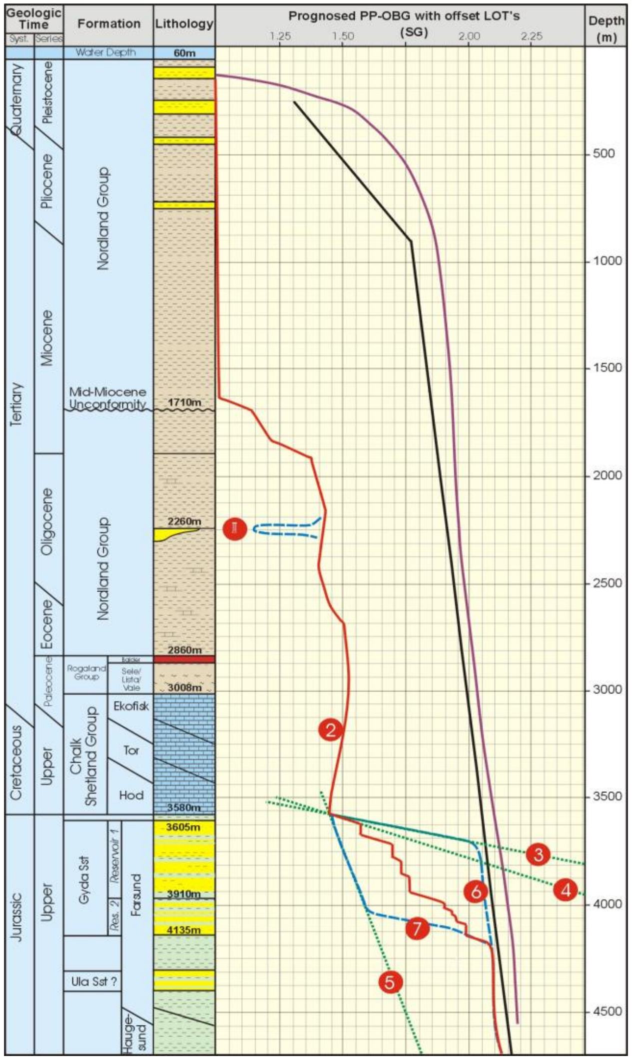
Pre-Drill Forecasts from Logs and Seismic



Modelling of Overburden Pressures - NSCG



Pre-Drill Forecast with Transition Zone Models



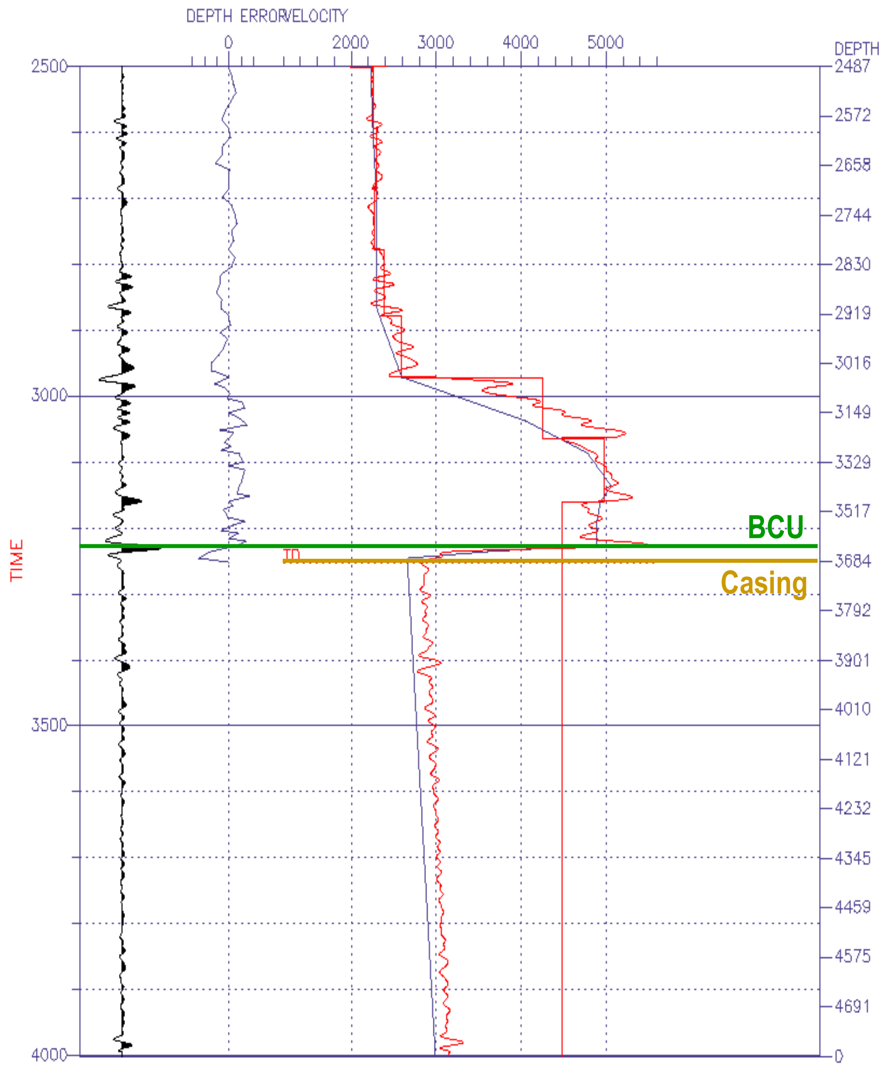
- **The transition to high-pressured Jurassic was studied from offset-wells, and the following rules of thumb could be derived:**

  1. **Pressure transitions in the pre Blodøks Formations of the Upper Cretaceous tend to be around 1.5 psi/ft**
  2. **Lower Cretaceous 3.5 psi/ft**
  3. **Upper Jurassic pressure gradient can reach up to 7.5 psi/ft**

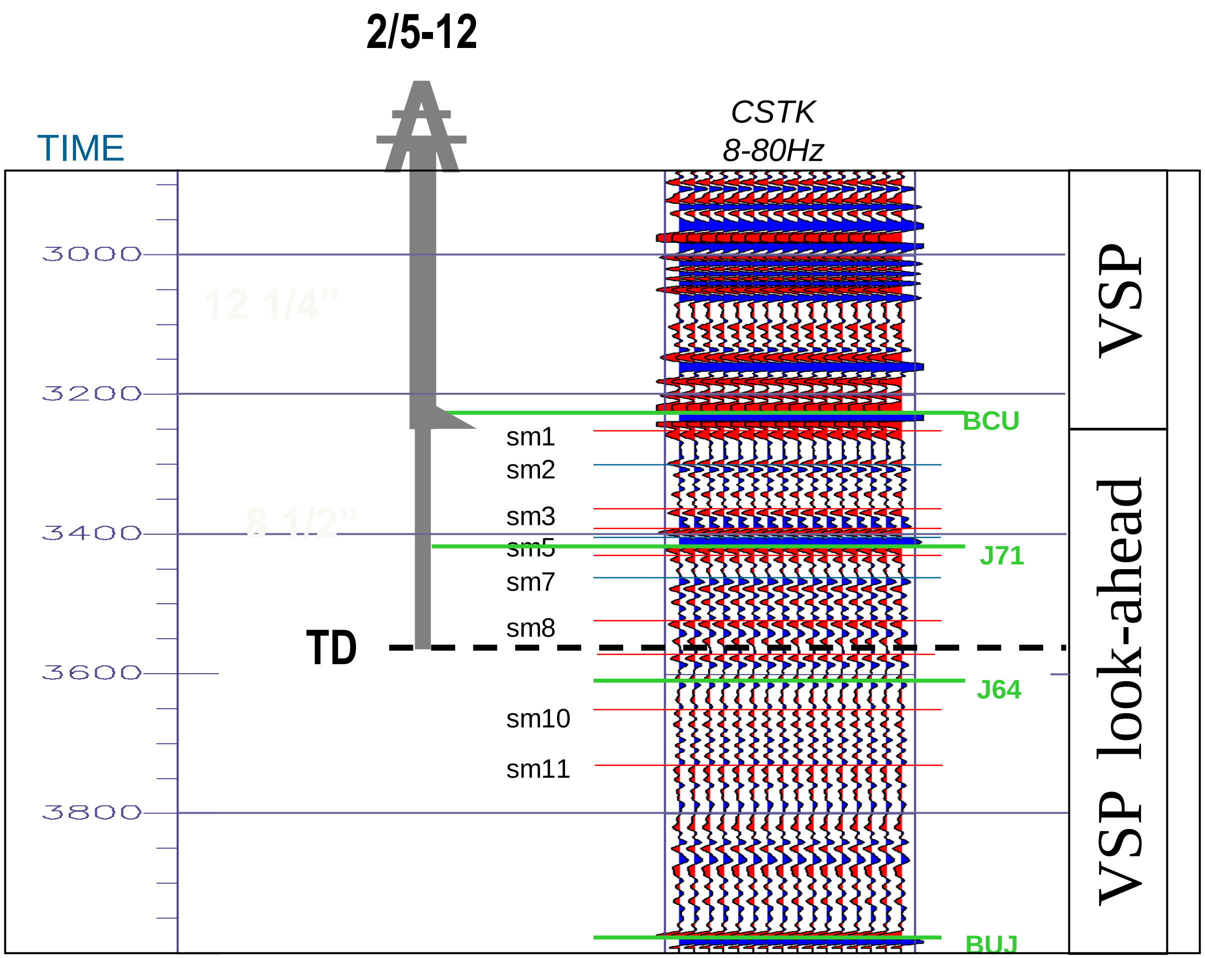
- **Whereas the final transition zone gradient is a function of the sealing capacity**

1 Oligocene Sst	**5** PP Transition of 1.6 psi/ft
2 Reg Chalk Water Grad	**6** Scenario without shelf communication
3 PP Transition 7 psi/ft	**7** with shelf communication
4 PP Transition 4.5 psi/ft	

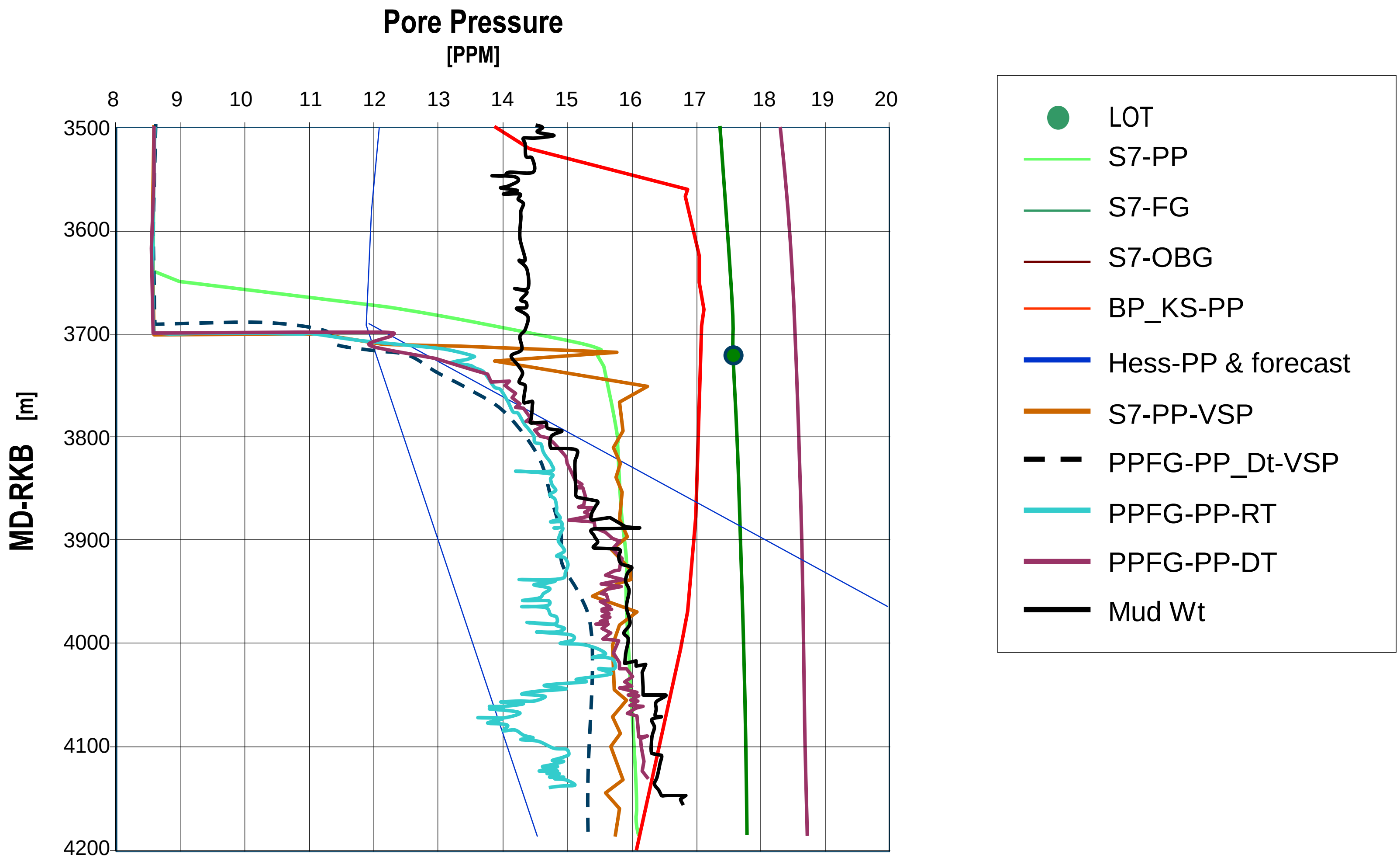
Inversion Analysis of Seismic Velocities Based on VSP Data



Corridor Stack of the VSP Look-Ahead



Actual Versus Forecasted PP for Transition Zone and Jurassic



Conclusions

- **2/5-12 was a good example of how to drill a HTHP exploration well**. The primary targets were explored and a decision to TD was made in a timely and safe manner, within AFE. Location of the 9 5/8 casing was crucial
- **Detailed planning of the well design** is essential to ensure good picks for casing shoes and operational limits for drilling
- **Benefits of look-ahead VSP**
  - Highlights potential lithological changes ahead of the bit.
  - Look-ahead VSP data can be analysed for pressure to update pore pressure forecasts
- **Sonic and VSP look-ahead** allows update of depth model and very accurate depth prognosis before reaching bed boundaries or potential pressure changes
- **MWD Sonic and resistivity** are very useful for pressure analysis whilst drilling. Having two data sets using different measurements for analysis improves the confidence of the analysis
- **MWD sonic is more reliable than resistivity** for pressure prediction, as the sonic velocity is far less susceptible to changes in fluid and rock properties than the resistivity measurement
- **All of the pressure analysis tools have limitations,** therefore reliance on one method is not advisable. Utilising several techniques gives a lot more confidence in the analysed results when they are in close agreement. Increasing background drill gas can be indicative of increasing pore pressure in the lowermost chalk and Lower Cretaceous.
- **Modelling the pressures** utilising offset data is important where the analysis is thought to be weak or problematic. Detailed offset studies are essential to capture this information. Capillary pressure measurements can help determine the sealing capacity of differing lithologies
- **OBG and FG from Seismic** were excellent. The PP was very poor in the Tertiary and Cretaceous, but good in the Jurassic. It gives averaged values for large intervals and is not responsive to transition zones.