Pore Pressure and Fracture Pressure Prediction: Some Best Practices derived from Global Experience

Steve O’Connor, Alexander Edwards, Eamonn Doyle and Sam Green
Ikon GeoPressure, Durham, UK
Typical North Sea Profile

The vertical lithofacies variation within the Central North Sea can make well planning a challenging process.

Each new section may require a different compaction trend or a unique empirical or geological solution.

The final pore pressure model will be a combination of the different solutions.

Only then can fracture pressure and wellbore stability models be generated.
PPFG: Best Practices for Well Planning

Data
1. Access data/Public & proprietary
2. Data management
3. QC and condition data

Pre-Drill Models
4. Interpret off-set wells
5. Regional studies
6. 1D MEM’s
7. Seismic velocity analysis
8. Basin modeling
9. Pre-Drill Model

Drilling Support
10. Real-Time with Pre-drill and Basin Model support

Post Well Analysis
11. Post well analysis with QC’d final data set, knowledge transfer and reporting

Supported by software throughout

Feedback Loop
Set the Context: Learn from Others

Basic Geological History – websites, conference talks, papers, references stored in EndNote etc

- Pre-rift: Paleozoic of Parana Basin (onshore well: 2-TO-1-RS)
- Rift: -Neocomian basalts (Imbituba Fm).
- -Barremian Sequence (Cassino Fm). Continental seq in the well 1-RSS-3). Antithetic faults system.
- Post-rift: Starting in Aptian. Underdevelopment adiastrophic tectonic.
Make the Knowledge Available
Removing Poor Data

Examples of Data Quality Flags

- **HCAL** > ± 5% of the bit size
- **DRHO** > ± 0.1 g.cm⁻³
PPFG: Best Practices for Well Planning

Data
1. Access data/Public & proprietary
2. Data management
3. QC and condition data

Pre-Drill Models
4. Interpret off-set wells
5. Regional studies
6. 1D MEM’s
7. Seismic velocity analysis
8. Basin modeling
9. Pre-Drill Model

Supported by software throughout
Clay content in the Tertiary shale varies from 20-80%, greatly affecting the log response.

Compaction behaviour varies SIGNIFICANTLY from basin to basin around the world.

Porosity is the KEY input to a traditional pore pressure prediction technique, such as Eaton (1975) and Equivalent Depth Methods.

Therefore another “best-practice” approach is suggested based on void ratios, effective stress and clay content.

---

**Pre-Drill (Stages 4-9) - Tertiary Shales**

![Graph showing porosity vs. depth with various labels for different basins and locations.]

Clay content in the Tertiary shale varies from 20-80%, greatly affecting the log response.

Compaction behaviour varies SIGNIFICANTLY from basin to basin around the world.

Porosity is the KEY input to a traditional pore pressure prediction technique, such as Eaton (1975) and Equivalent Depth Methods.

Therefore another “best-practice” approach is suggested based on void ratios, effective stress and clay content.
Understanding Pp Mechanisms

Determining the active mechanism(s) within each shale package is critical to pore pressure prediction.

**Top Right**
- Rocks are low porosity
- Logs mimic low pressure
- Pore pressure could still be high
- Risk of underprediction
- Effects UNQUANTIFIABLE from logs

**Bottom Right**
- Rocks are high porosity
- Pore pressure is higher than porosity would indicate
- Risk of underprediction
- Effects can be QUANTIFIED from logs
Understanding the Shales

Cross-plot of CNL/Rho for all shales. Below 100°C the density remains constant (>2500 kg/cm³) with rapid change in porosity implying that the unloading is apparent and more likely associated with a lithology, facies change in these deeper, hot, Jurassic shales.

Vp and Rho cross-plot showing ‘evidence’ of unloading.
In order to use a log-based pore pressure prediction technique, such as Eaton or Equivalent Depth, a Normal Compaction Trend (NCT) must be derived.

The conventional approach is to use the normally pressured shale section to derive this NCT, then apply it to the overpressured shale section to determine the pore pressure.

However, a number of different compaction trends can be observed in the velocity and density data.

A multi-layer model, based on clay-type and lithofacies must be developed.
Geologically relevant values for the surface and matrix sonic values are inputted to constrain the normal compaction trend and produce a more meaningful output.

Vshale cut-off used to ignore sand-rich units
Definition of Compaction Curves

Mechanical Compaction

- Exponential relationship between effective stress and void ratio
- Void ratio is more sensitive at higher porosities but less at lower porosity
- Compaction rate dependent on clay content
- Clay content derived from core and calibrated to logs via a neural network

\[ e = \frac{\phi}{1 - \phi} \]

\[ e = e_{100} - \beta \ln\left(\frac{\sigma'_v}{100}\right) \]

\[ S'_v = P'_p + \sigma'_v \]

*After Yang & Aplin, 1998*

Bayesian Approach to Uncertainty

Objective:
To quantify the uncertainty in pore pressure predictions to the maximum possible precision allowed by the expert judgements, model and data.

Methodology:
Bayesian analysis provides the only coherent framework for capturing all the uncertainties, including the misfit between the real system and the model.
Tertiary Sands

**Best Practice**
Changes in velocity/resistivity using Real Time data warn of approaching drainage

**Best Practice** = regional overpressure mapping allowing sand connectivity and isolation to be determined.

Sands can connect over areas much larger than acreage blocks so production effects etc can be not observed.
Carbonate Pressure Regimes

- Low Energy Depositional Setting
  - Low Porosity – Tight Rocks

- High Energy Depositional Setting
  - High Porosity – Reservoir Rocks

- Different Pressure Above & Below Pressure Transition Zone

Trend of shale pore pressure
(constant effective stress)
Jurassic/Triassic: North Sea

Integration of Multiple Technologies – seismic attributes, image logs etc. as part of pressure analysis

Inferred boundary before reviewing seismic

Approximate boundary after reviewing seismic
Final Pre-Drill Model: Uncertainty Factored In!
Fracture Pressure Algorithms

Several algorithms are available for calculating fracture pressure.

The most commonly applied are:

- Mathews & Kelly (1967)
  \[ P_{\text{fract}} = P_{\text{pore}} + K_i \text{VES} \]

- Eaton (1969)
  \[ P_{\text{fract}} = P_{\text{pore}} + \left( \frac{\mu}{1-\mu} \right) \text{VES} \]

- Breckels & Van Eekelen (1981)
  \[ P_{\text{fract}} = (0.053 \times Z^{1.145}) + (0.46 \times \text{OP}) \quad Z<3500 \text{ m} \]
  \[ P_{\text{fract}} = (0.264 \times Z) - 317 + (0.46 \times \text{OP}) \quad Z>3500 \text{ m} \]

- Daines (1982)
  \[ P_{\text{fract}} = \sigma_t + P_{\text{pore}} + (\text{VES} \times \left( \frac{\mu}{1-\mu} \right)) \]

\(\sigma_t\) is derived using \(P_{\text{fract}}\) equal to the shallowest LOP-LO and arranging the formula.
Empirically-Derived Fracture Gradients

The Gulf of Mexico

Based on Mouchet and Mitchel (1989)
Pore Pressure Stress Coupling

LOP data from 12 wells
Above 12,000 feet, same pore pressure
Below 12,000 feet shales and sands have very different pressures
Geomechanical 1D MEM’s: Borehole Stability

Rock Physics and Geopressure are key elements of the workflow

Feedback loops are built into the MEM calibration
Borehole breakout will occur in direction of $S_{hmin}$ in vertical wells
PPFG: Best Practices for Well Planning

Data
1. Access data/Public & proprietary
2. Data management
3. QC and condition data

Pre-Drill Models
4. Interpret off-set wells
5. Regional studies
6. 1D MEM’s
7. Seismic velocity analysis
8. Basin modeling
9. Pre-Drill Model

Drilling Support
10. Real-Time with Pre-drill and Basin Model support

Supported by software throughout
10. Real Time Analysis

Display and analyse ALL data in relation to each other
Start with the calibrated regional parameters as guides for monitoring while drilling

Need the right software for drilling data, e.g.
Depth-based data (also display in Time)
PPFG: Best Practices for Well Planning

Data
1. Access data/Public & proprietary
2. Data management
3. QC and condition data

Feedback Loop

Pre-Drill Models
4. Interpret off-set wells
5. Regional studies
6. 1D MEM’s
7. Seismic velocity analysis
8. Basin modeling
9. Pre-Drill Model

Drilling Support
10. Real-Time with Pre-drill and Basin Model support

Post Well Analysis
11. Post well analysis with QC’d final data set, knowledge transfer and reporting

Supported by software throughout
11. Post-Mortem Phase

<table>
<thead>
<tr>
<th>Review of drilling results</th>
<th>Integration of LWD/MWD to understand discrepancy pre-drill vs. reality</th>
</tr>
</thead>
</table>
| Knowledge Transfer Workshop and Future Well-Planning | “Could we have done anything better”?
Include key Ikon personnel and company’s G&G and drilling teams |
| | “From now on, we will adopt these practices based on what we now know”.|
| | Feedback Loop to update Expert System with new, hard data from well* |
| | *as Basin X becomes drilled (Wells 1, 2, 3 etc), we have hard data to refine the “TSM” thereby reducing the options but producing closer analogues |
| | 2 day workshop per new well |
| | Include 1 or 2 days extra for Assess Team training on RD software |
Conclusions

Data storage, retrieval and QC are a vital first step

Pre-drill work requires a “stratigraphic-based” understanding of rock properties
  - shales vary so use void ratio approaches
  - overpressure mapping – look outside of an acreage block!
  - for FP, correct linkage of Shmin to PP etc.

Integrate multiple technologies
  - Pore Pressure, Geomechanics and Rock Physics

Real Time data can reduce uncertainty only if the correct BHA is used AND the appropriate software (time, depth) is used

Many off-the-shelf models simply do not reflect what we see in basins such as the North Sea so use appropriate global analogues
Thank you – Any Questions?

Sam Green
sgreen@ikonscience.com
Tel: +1 403 681 9980
www.ikonscience.com