Reservoir Quality and Rock Properties Modeling Results – Jurassic and Triassic Sandstones: Greater Shearwater (HPHT) Area, UK Central North Sea*

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Abstract

The complex burial and diagenetic histories of the Jurassic Fulmar and Triassic Skagerrak sandstones in the UK Central North Sea present significant challenges with regard to reservoir quality and rock property prediction. Commercial reservoir quality is retained despite deep burial and associated high temperatures and pressures. Shallow-marine Fulmar sands are normally compacted (mean IGV = 26±3%), yet have porosities of 21 – 33%. Porosity was preserved through inhibition of quartz cementation by clay and microquartz coatings and enhanced by dissolution of framework grains (~ 5%). Skagerrak fluvial sands are more compacted (mean IGV = 23±2%), exhibit minor feldspar dissolution (<1%), and have porosities of 16 – 27%. Quartz cement averages only 2±1.5% due to robust chlorite coats that cover 80% (±13%) of quartz surfaces. We modeled reservoir quality evolution using the forward diagenetic model Touchstone, which simulates porosity loss due to compaction and quartz cementation. Quantitative petrographic analyses and burial history data were used to calibrate Touchstone model parameters. The results were applied to deeper prospects for pre-drill prediction of porosity and permeability. In parallel, petrophysical data were used to characterize the elastic properties of the sandstones to provide a basis for quantitative seismic forward modeling. Experimental data and core-calibrated petrophysical results, reflecting variable in situ fluids and saturations, were used to build an elastic properties model. The model is robust and was used to generate fluid-filled sandstone properties, incorporating Touchstone results, for prospect-specific seismic attribute modeling. Well results from exploration wells are in good agreement with pre-drill Touchstone and elastic properties model predictions.

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AAPG Convention
Denver, Colorado
June 1, 2015

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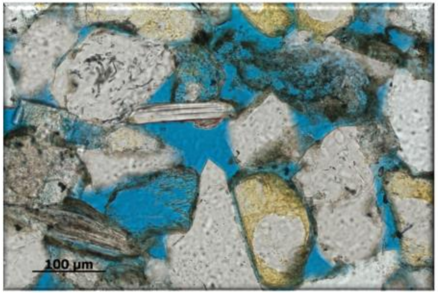
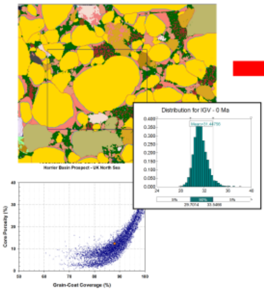


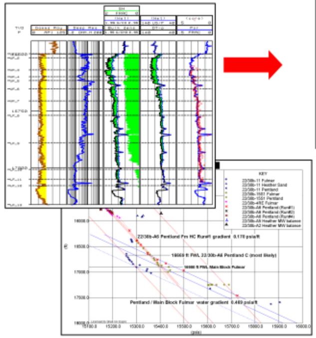
From Reservoir Quality to Rock Physics

Iterative, multi-disciplinary data interrogation & integration

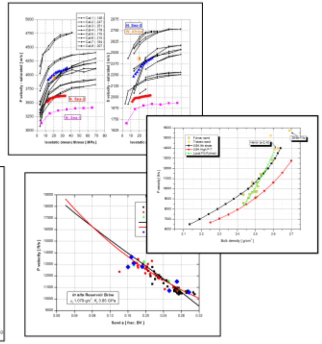
Sedimentary Petrology

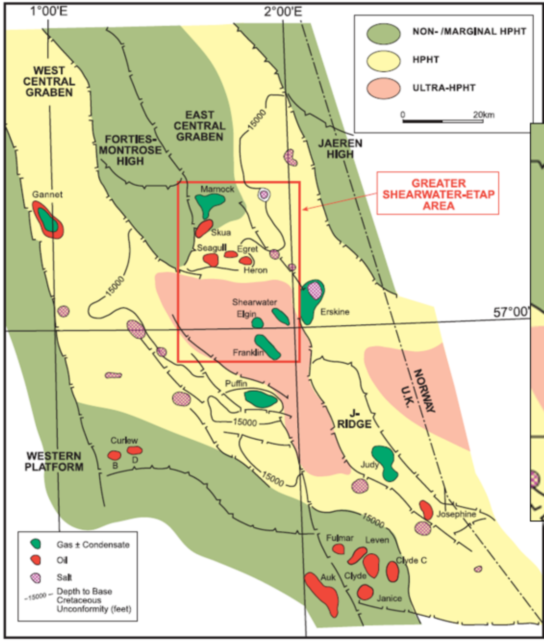


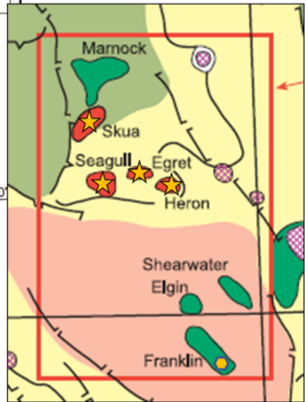
Seismic Petrophysics



Elastic Properties (Rock Physics)







<u>Skagerrak Reservoirs</u>

Depth – 3.4 – 4.8 km

T – 130 – 165 ^{0} C

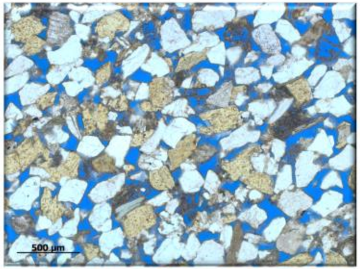
ETAP Area CNS Triassic - Skagerrak Sandstones

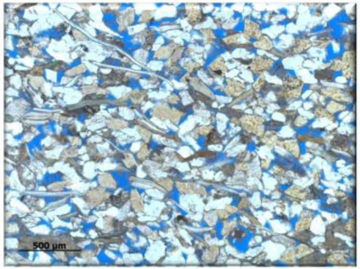
- Fluvial – lacustrine deposits, semi-arid environment

- RQ facies dependent

- Diagenesis
  - compaction
  - early carbonate cement
  - authigenic K-feldspar
  - chlorite grain coats
  - quartz cementation

- ϕ = 16 - 26%; Ka = 2 - 450 md
  Depth = 3.5 – 4.8 km
  T = 137 - 165°C
  VES = 34 - 48 MPa





Skagerrak Reservoir – J Block UK Quad 30

Sandstones with 30 – 35% Porosity

Range ~ 15 – 35%; P50 ~ 20%

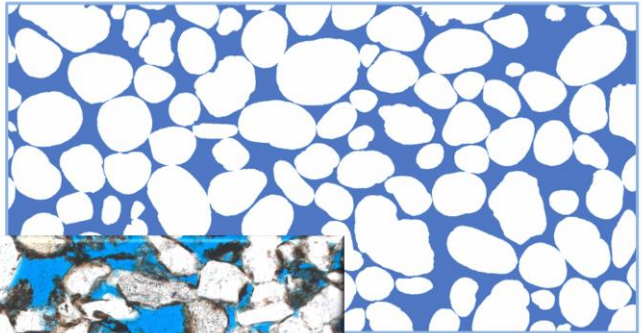
Nguyen et al., (2013) AAPG Bulletin
Grant et al., (2014) AAPG Bulletin

*Propose that extraordinary intergranular porosity held open by: **early overpressure** & **occult halite cement.***

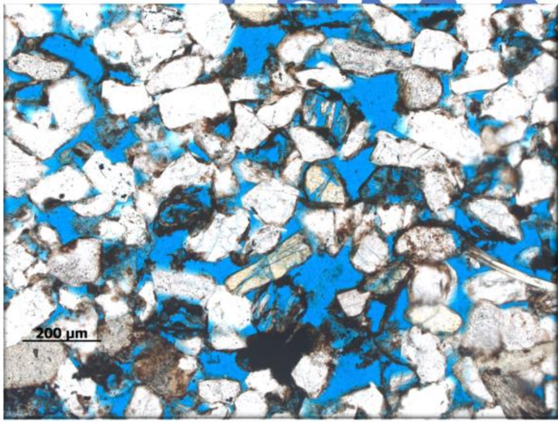
What do these sandstones look like in thin section as opposed to only a point on a graph?

> "Critical porosity is the porosity above which the rock can exist only as a suspension. In sandstones the critical porosity is 36% - 40%, that is the porosity of a random close pack of well sorted rounded quartz grains."
>
> Dvorkin & Nur, 2001

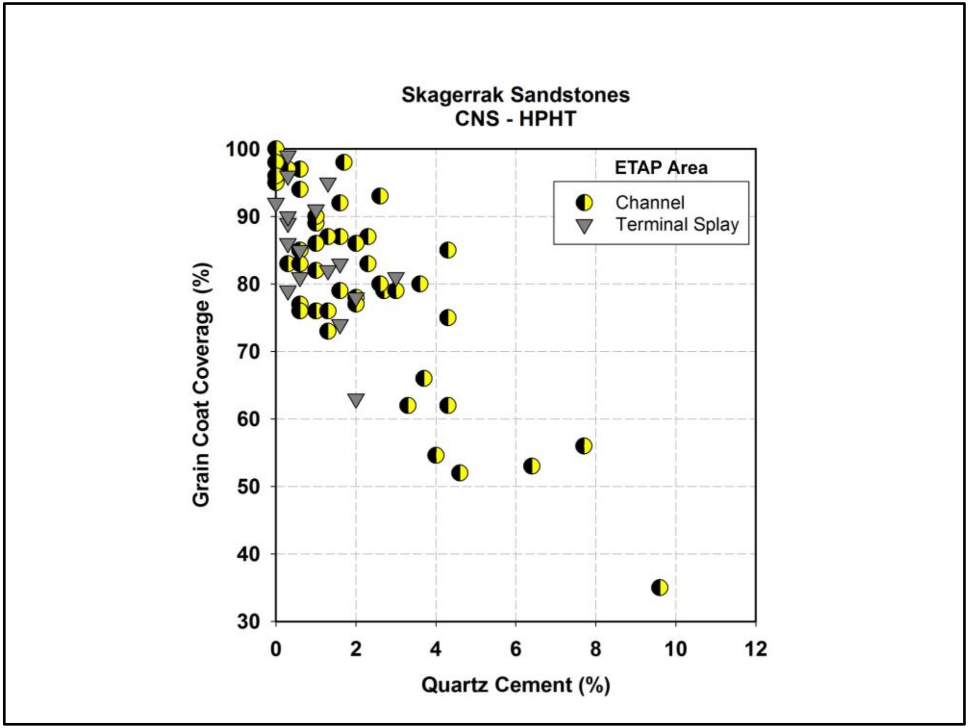
What does a sandstone with 30 – 35% porosity look like in thin section?



ϕ = IGV = 31%
Secondary ϕ = 0%
Micro ϕ = 0%

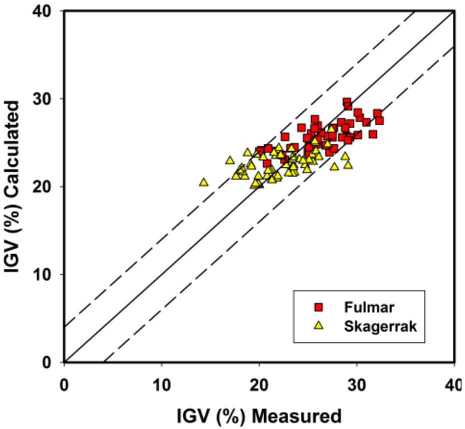


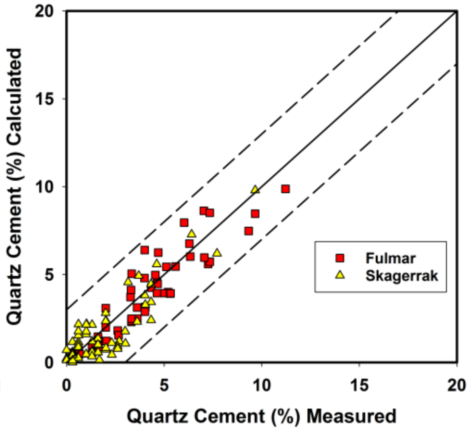
$\phi_{stressed\text{-}brine}$ = 31.4%
$K_{stressed\text{-}brine}$ = 39 mD
IGV = 26.8 %
Intergranular ϕ = 17%
Secondary ϕ = 8%
Micro ϕ = ~6.4%



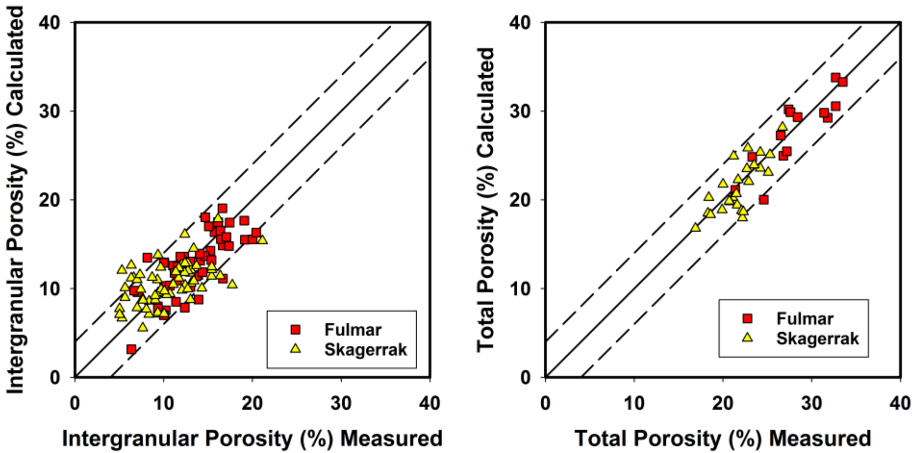
Presenter’s notes: Eastern Trough Area Project.

Touchstone Model Calibration





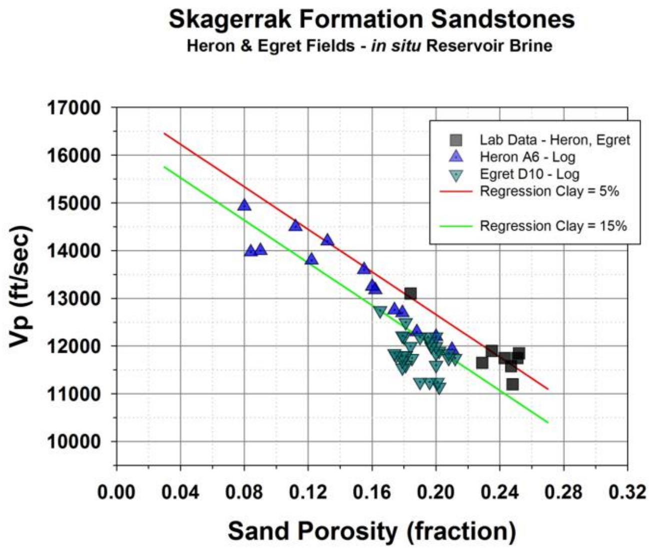
Touchstone Model Calibration

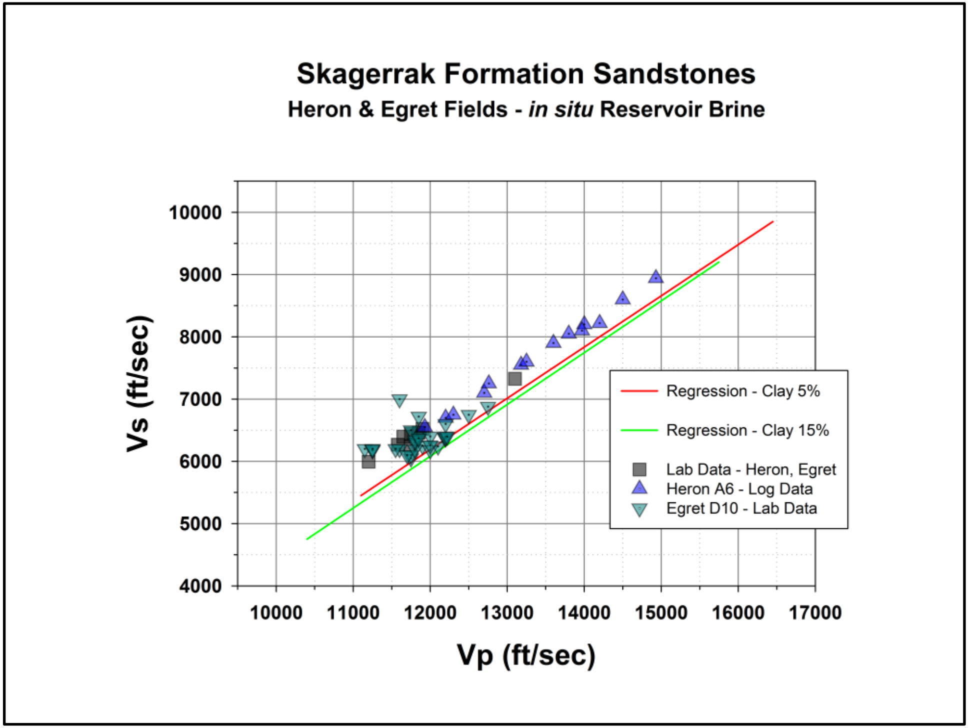


Acoustic Rock Properties Modeling

Data and Information Needed for Integration of Touchstone Models and Acoustic Rock Properties Models

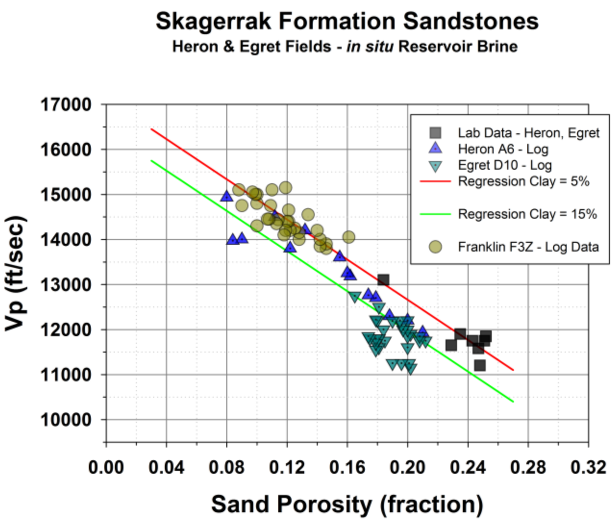
- *Detailed petrographic data and burial histories for calibration of Touchstone models.*
- *High quality stressed porosity and permeability measurements for calibration with thin-section data.*
- *Vp, Vs, stress measurements for representative samples*
- *Fluid acoustic properties*


Skagerrak Formation Sandstones
Heron & Egret Fields - *in situ* Reservoir Brine
Lab Data - Heron, Egret
Heron A6 - Log
Egret D10 - Log
Regression Clay = 5%
Regression Clay = 15%
Vp (ft/sec)
17000
16000
15000
14000
13000
12000
11000
10000
0.00
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
Sand Porosity (fraction)

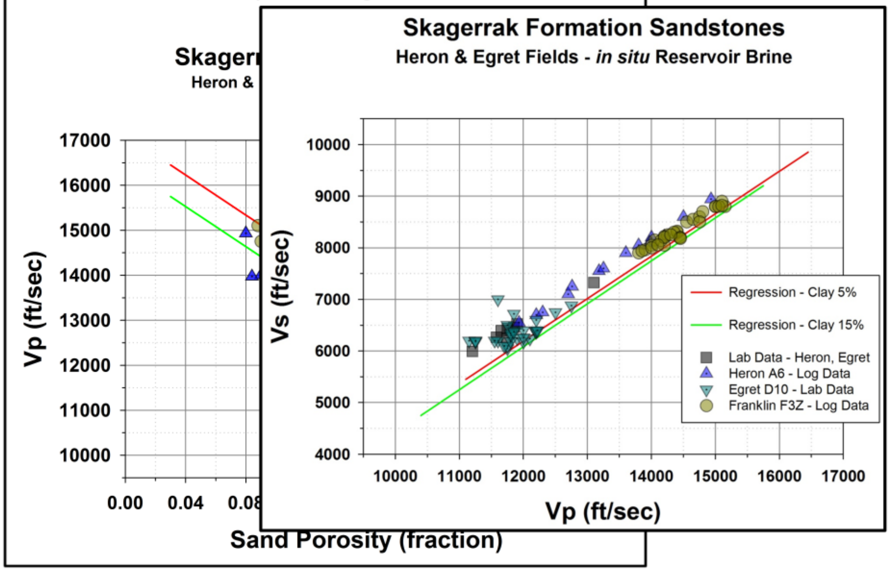


Skagerrak Formation Sandstones
Heron & Egret Fields - in situ Reservoir Brine
Vs (ft/sec)
10000
9000
8000
7000
6000
5000
4000
10000
11000
12000
13000
14000
15000
16000
17000
Vp (ft/sec)
Regression - Clay 5%
Regression - Clay 15%
Lab Data - Heron, Egret
Heron A6 - Log Data
Egret D10 - Lab Data

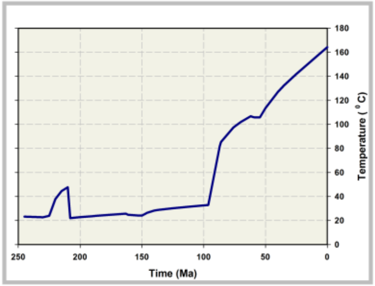
Blind Test – Franklin Deep Well – Skagerrak Penetration

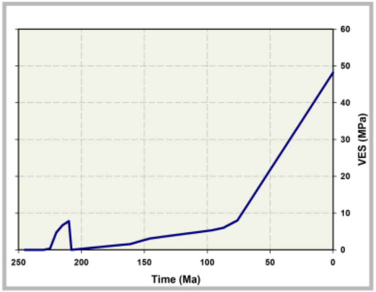


Blind Test – Franklin Deep Well – Skagerrak Penetration



Burial History – Thermal and VES Modeling





Prospect Janus –

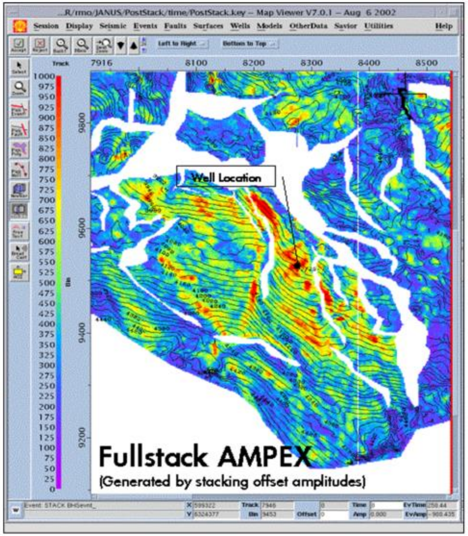
- **Triassic Skagerrak target**
- **Forecast T = 164°C**
- **Forecast VES = 48 MPa**
  ~ 12 MPa < hydrostatic

From Reservoir Quality to Rock Physics

- **Calibrated Touchstone Model**
  - porosity prediction
- **Acoustic Rock Properties Model**
  - Vp, Vs prediction
- **Fluid Rock Properties Model**
  - fluid effects on Vp,Vs

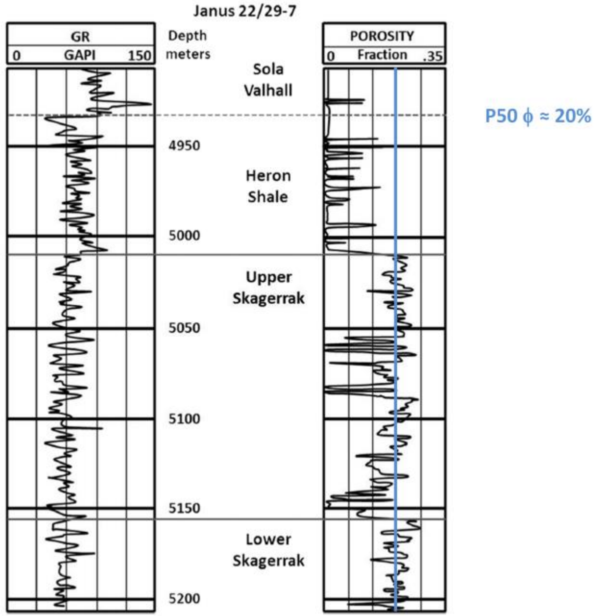
•Seismic Attribute Modeling
- rock & fluid scenarios compared with seismic data

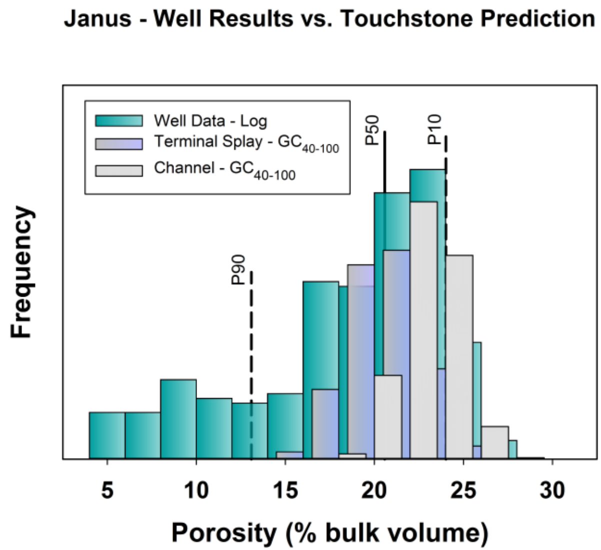
Modeling results indicate that seismic amplitudes would not yield unambiguous indications of brine vs. hydrocarbon fluids



Presenter's notes: In geophysics and reflection seismology, **amplitude versus offset** (AVO) or **amplitude variation with offset** is the general term for referring to the dependency of seismic attribute, amplitude, with the distance between the source and receiver (the offset). AVO analysis is a technique that geophysicists can execute on seismic data to determine a rock's fluid content, porosity, density or seismic velocity, shear wave information, fluid indicators (hydrocarbon indications).
The phenomenon is based on the relationship between the reflection coefficient and the angle of incidence and has been understood since the early 20th century when Karl Zoeppritz wrote the Zoeppritz equations. Due to its physical origin, AVO can also be known as **amplitude versus angle** (AVA), but AVO is the more commonly used term because the offset is what a geophysicist can vary in order to change the angle of incidence.
Interpretation: An AVO anomaly is most commonly expressed as increasing (rising) AVO in a sedimentary section, often where the hydrocarbon reservoir is "softer" (lower acoustic impedance) than the surrounding shales. Typically amplitude decreases (falls) with offset due to geometrical spreading, attenuation and other factors. An AVO anomaly can also include examples where amplitude with offset falls at a lower rate than the surrounding reflective events.
AVO is not fail-safe: An important caveat is that the existence of abnormally rising or falling amplitudes can sometimes be caused by other factors, such as alternative lithologies and residual hydrocarbons in a breached gas column. Not all oil and gas fields are associated with an obvious AVO anomaly (e.g., most of the oil found in the Gulf of Mexico in the last decade), and AVO analysis is by no means a panacea for gas and oil exploration.

Prospect Janus
Drilled - 2002
Well Results





Janus - Well Results vs. Touchstone Prediction
Well Data - Log
Terminal Splay - GC40-100
Channel - GC40-100
P90
P50
P10
Frequency
5
10
15
20
25
30
Porosity (% bulk volume)

Summary & Conclusions

- Rigorous, quantitative petrographic analyses & forward modeling, seismic petrophysics and rock physics models provide a foundation for quantitative seismic forward modeling for Triassic Skagerrak reservoirs in HPHT settings of the Central North Sea.
- The multi-disciplinary approach applied in this study was successfully used to forecast reservoir quality for a deep, high-risk prospect.
- When properly applied, the approach has potential for broad application in exploration targeting sandstone reservoirs.