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.

References Cited


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

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From Reservoir Quality to Rock Physics

Iterative, multi-disciplinary data interrogation & integration

Sedimentary Petrology  Seismic Petrophysics  Elastic Properties (Rock Physics)
Skagerrak Reservoirs
Depth – 3.4 – 4.8 km
T – 130 – 165 °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
- $\phi = 16 - 26\%$; $K_a = 2 - 450$ md
  - Depth = 3.5 – 4.8 km
  - $T = 137 - 165^\circ C$
  - 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?

\( \phi = \text{IGV} = 31\% \)
Secondary \( \phi = 0\% \)
Micro \( \phi = 0\% \)

\[ \phi_{\text{stressed-brine}} = 31.4\% \]
\[ K_{\text{stressed-brine}} = 39 \text{ mD} \]
IGV = 26.8 \%
Intergranular \( \phi = 17\% \)
Secondary \( \phi = 8\% \)
Micro \( \phi \approx 6.4\% \)
Skagerrak Sandstones
CNS - HPHT

ETAP Area

Channel
Terminal Splay

Grain Coat Coverage (%)

Quartz Cement (%)
Touchstone Model Calibration

![Graph showing Touchstone Model Calibration with data points for Fulmar and Skagerrak. The graphs compare IGV (%) Measured vs IGV (%) Calculated and Quartz Cement (%) Measured vs Quartz Cement (%) Calculated. The data points are colored to differentiate between Fulmar and Skagerrak, with Fulmar represented in red and Skagerrak in yellow.]
Touchstone Model Calibration

![Graph showing intergranular porosity and total porosity compared to measured values. The graphs indicate good correlation between calculated and measured values.]
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
Prospect Janus –
- Triassic Skagerrak target
- Forecast $T = 164^\circ$C
- Forecast VES = 48 MPa
~ 12 MPa < hydrostatic
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 22/29-7

<table>
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<th>Depth (meters)</th>
<th>Sola Valhall</th>
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<th>Lower Skagerrak</th>
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P50 \( \phi \) = 20%
Janus - Well Results vs. Touchstone Prediction

- **Well Data - Log**
- **Terminal Spay - GC\textsubscript{40-100}**
- **Channel - GC\textsubscript{40-100}**

Frequency

Porosity (% bulk volume)

- P90
- P50
- P10
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.