Super Producers:
Revealing North Sea Injectites

Broadband data can reveal significant hydrocarbon potential in the Viking Graben area by providing superior images of complex structures like injectites.

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The North Sea Viking Graben has been a prolific hydrocarbon province, producing principally from Jurassic, Palaeocene and Eocene clastic reservoirs for more than 40 years. In this mature basin, many of these fields are in their later stages and experiencing declining production, so additional near-field step-out or extended-reach targets are in demand to augment production and prolong field life. The Tertiary injectites of the Viking Graben offer such an opportunity for relatively shallow incremental targets above producing reservoirs and adjacent to field infrastructure. Their complex, enigmatic geometries have made them a challenging play to understand and exploit in the past. However, the latest generation of broadband dual-sensor, towed streamer seismic data has enabled improved imaging and characterisation of these bodies, and the ability to de-risk lithology and hydrocarbon presence has enhanced the commercial relevance of even relatively modestly-sized features.

Super Producing Reservoirs

Injectites are created through post-depositional remobilisation of fluidised sands injected into the stratigraphy. Though often not large in area, these reservoirs are of particular interest due to their very high porosity and permeability and are often supported by a strong aquifer. For this reason, these features have been described as 'super producers'.

In the past, identification and characterisation of these Tertiary injected sands was challenging due to a lack of imaging resolution in legacy seismic data. This was exacerbated by the misleading interference of prominent side-lobe energy as the data was so limited in bandwidth. Recent broadband dual-sensor seismic data in the Viking Graben provides reliable, AVO-preserving pre-stack information and has significantly improved imaging and characterisation of these injectite targets, bringing clarity to known injectite fields such as Volund and Harding, as well as highlighting additional hydrocarbon potential for near-field exploration (Figure 1).

This improvement is the result of PGS having unified and processed its Viking Graben datasets using an advanced depth imaging workflow to create a GeoStreamer PURE pre-stack broadband depth dataset of around 18,000 km^2. The workflow consisted of anisotropic velocity model building and Kirchhoff depth migration including compensation for earth absorption, together with the implementation of the PGS complete wavefield imaging processing workflow, including FWI and separated wavefield imaging. This process offers a solution to many of the imaging challenges related to the varied geological setting, such as very shallow channels. The late Eocene injected sands were characterised and mechanically inserted as geobodies into the velocity model, which contributed to a final superior image of underlying features such as the targeted Palaeocene

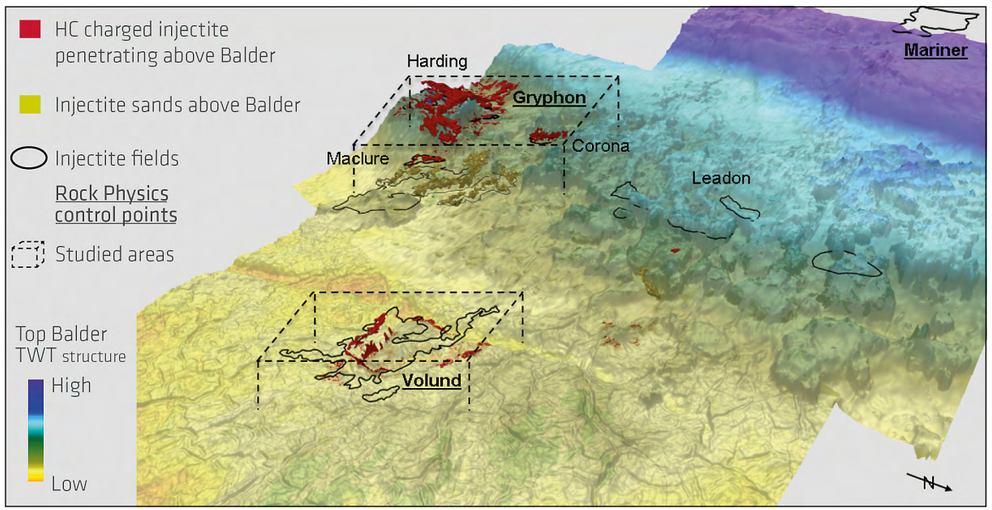


Figure 1: Key injectite features in the Viking Graben, North Sea.

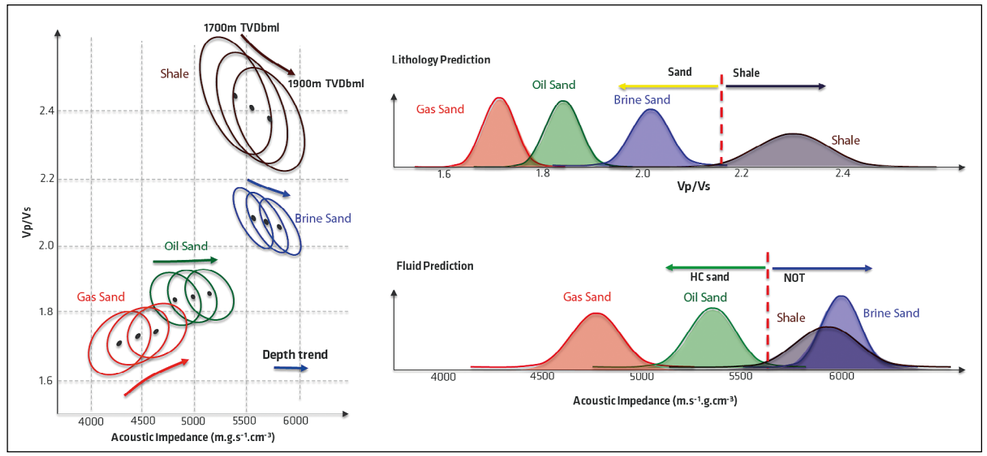


Figure 2: Rock physics analysis (depth trend analysis) and stochastic forward modelling of remobilised sandstones and shale lithologies performed on seven wells where Vp, Vs, density, and porosity logs were available.

injectites (Ciotoli et al., 2016).

In addition to this, detailed quality controlled AVO (amplitude versus offset) analysis was performed throughout the processing, along with reservoir-oriented processing, allowing a quantitative interpretation-ready pre-stack volume for the inversion.

Injectite Rock Physics to Assess Hydrocarbon Potential

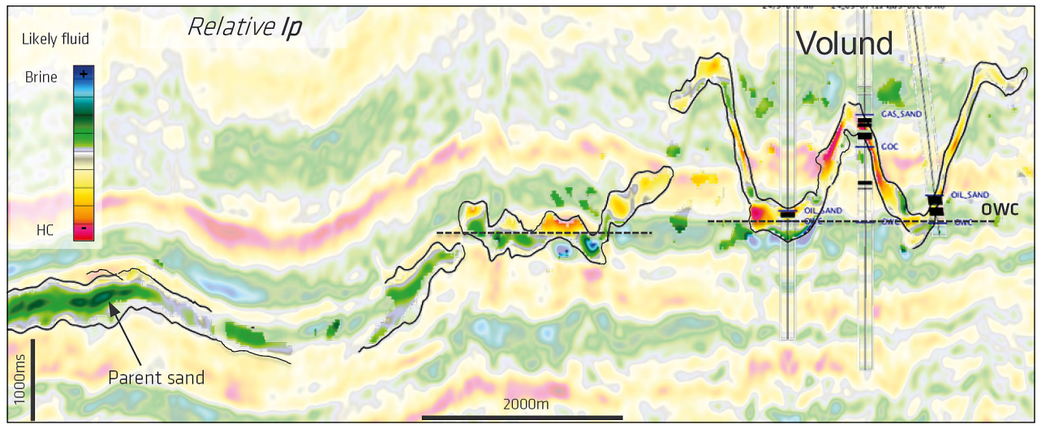
Tertiary injected sandstones from wells from both UK and Norwegian sectors in the North Sea were selected to perform a statistical depth-dependent rock physics analysis (Figure 2). Wells from the Mariner (Heimdal Formation Sandstone), Gryphon and Volund fields (Balder Formation Sandstone) were chosen. The fields are respectively located 1,100, 1,500 and 2,000m below the seabed. This allowed a good sampling of the sandstone characteristics with depth. Despite being buried at various depths, and being of different ages (Palaeocene-Lower Eocene sands), these reservoirs exhibit similar porosity values of around 34%.

Well results show that the GeoStreamer pre-stack AVO attributes can discriminate both lithology and fluids in many cases. In this context a lower Vp/Vs is expected for sand reservoirs compared to shale, while a low acoustic impedance within the sandy reservoir intervals indicates hydrocarbon charge and may be able to differentiate oil from gas. The combination of both Vp/Vs and acoustic impedance attributes is a requisite to accurately identify the hydrocarbon-charged injectites.

All Wells are Blind!

The availability of low frequency information delivered by broadband seismic data enables the derivation of seismic-driven pre-stack relative inversions without the use of any well input. Elastic properties can be estimated more reliably through a quantitative interpretation workflow (Ozdemir, H., 2009; Farouki et al., 2010; Reiser et al., 2012). The validity of the inversion results is confirmed with excellent well tie with the pre-stack GeoStreamer seismic elastic attributes (relative acoustic impedance and relative velocity ratio). Consistent fluid contacts were identified and mapped within the Volund complex (Figure 3). Figure 4 shows how these anomalies can be accurately mapped in 3D thanks to the reliable pre-stack elastic attributes

Figure 3: Relative acoustic impedance volume derived from pre-stack broadband dual-sensor streamer data showing parent sand and injected sands geometries of Volund field (Norway). Good well to seismic ties and oil-water contact observed matches with markers and rock physics analysis (low Ip (red) for hydrocarbon charged injectites, high Ip (blue) for brine saturated sands).



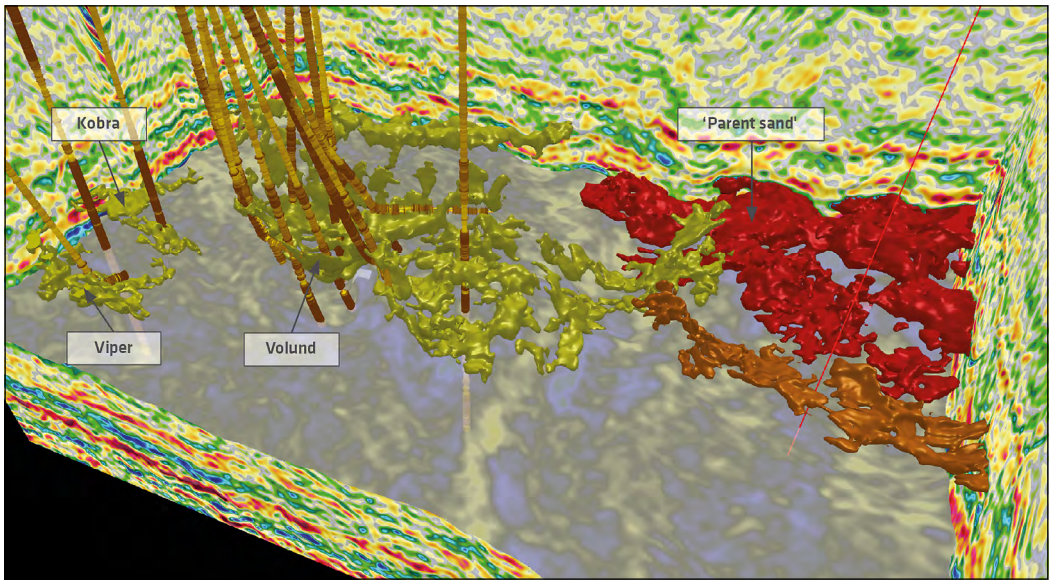


Figure 4: 3D geobodies volume extraction based on elastic attributes illustrating the Volund field and its satellites (Kobra and Viper) as well as the parent sand of the injectite features.

and highlights the Volund field and two of its satellites, Kobra and Viper.

A similar workflow was performed in the UK-Q9 sector on PGS MC3D Beryl GeoStreamer high-density (50m streamer separation) seismic dataset. In this area, the injectites are of Early Eocene age and located within extended reach of infrastructure associated with mature producing fields. These shallow injectites had been missed by earlier drilling campaigns that targeted deeper reservoirs and relied on vintage seismic data with more limited bandwidth and resolution. The improved imaging and the robustness of the pre-stack elastic attributes from the dual-sensor towed streamer broadband data proved to be essential to confidently identify, characterise and de-risk the injectite geometries (Figure 5). As a result, a number of prospects have been identified and assessed using lithology-fluid prediction to high-grade the most attractive anomalies where an oil-filled reservoir is predicted from the combined use of elastic attributes.

Improved Imaging and Characterisation

GeoStreamer seismic pre-stack depth migrated data significantly improves the imaging of the Tertiary injectite reservoirs of the North Sea. Our geological understanding of injectites has improved alongside awareness of their commercial potential, especially as shallow, near-field, step-out targets have been revealed. The robust pre-stack elastic attributes derivation for the Tertiary injectites studied in the UK/Norway Viking Graben also enables reliable characterisation of reservoir lithologies and the de-risking of fluid type. These attributes show very good correlation with well data.

Rock physics analysis using appropriate key wells from the UK and Norwegian Viking Graben indicates that good lithology and fluid discriminations can be expected using elastic attributes, supporting the conclusions of the seismic inversion analysis.

The re-mobilised injected sandstones in the Tertiary of the Viking Graben exhibit extremely high porosity and permeability. Even modest-sized injectite features can represent attractive, relatively shallow, near-field objectives due to their known high producing rates and proximity to existing infrastructure. The new broadband data highlights many remaining untested injectite features that can be confidently characterised and de-risked using relative pre-stack attributes.

Acknowledgements: *The authors would like to thank PGS for permission to publish this work and colleagues for their support and fruitful discussions on this subject.*

References available online. ■

Figure 5: Minimum amplitude of relative Vp/Vs displayed on a regional Top Balder Horizon (100 ms extraction window above the horizon). (a) conventional frequency bandwidth: identification, characterisation and de-risking are significantly challenging, as band-limited elastic attributes are inadequate to confidently predict reservoir lithology or fluid; (b) shows equivalent case using broadband pre-stack attributes: low Vp/Vs values correlate with proven Tertiary re-mobilised sand discoveries and fields and show additional promising injectite features.