

A New Look at the Geology and Prospectivity of a North Sea Frontier Area with Modern Seismic - The East Shetland Platform

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Summary

The greater East Shetland Platform (ESP) area is characterized by numerous proven Devonian-Eocene fields, but is still one of the few remaining underexplored regions of the UK Continental Shelf.

In particular, Permo-Carboniferous carbonates and sandstones, Devonian sandstones and fractured basement in prominent structural traps have been successful, proving these units to be viable reservoirs. Some of these are large producing fields in nearby areas (e.g., Buchan, Clair, Auk, with >100 MMboe).

The improved imaging of the 3D broadband dual-sensor towed streamer data has allowed the interpretation of the Paleozoic horizons over the entire outer ESP region (17,500 km²), enabling interpreters to spread new light on its evolution.

Possible Paleozoic structural traps are often sealed by the overlying Cretaceous strata.

Source rocks could be provided by the 'classical' upper Jurassic Kimmeridge Clay (lateral migration from the basin depocentres lying further east). Potential additional oil-prone sources may be provided by middle Devonian shales (c.f., Beatrice Field).

Burial history modelling indicates that the best case scenario (late generation) did occur over parts of the study area. This supports previous geochemical analyses in analogue areas, which suggested a contribution from the Devonian source for the oils of large fields (e.g., Claymore and Clair fields).

Introduction and methodology

An area of about 17,500 km² at the edge of the underexplored (c. 10 wells/1000 km²) East Shetland Platform (ESP) has been covered by new 3D broadband dual-sensor towed streamer seismic (acquired in 2011-2015) (Fig. 1). Here, the interpretation of these surveys has been integrated with well data, backstripping and burial history modelling in order to unravel the structural and thermal history of the area and its hydrocarbon potential.

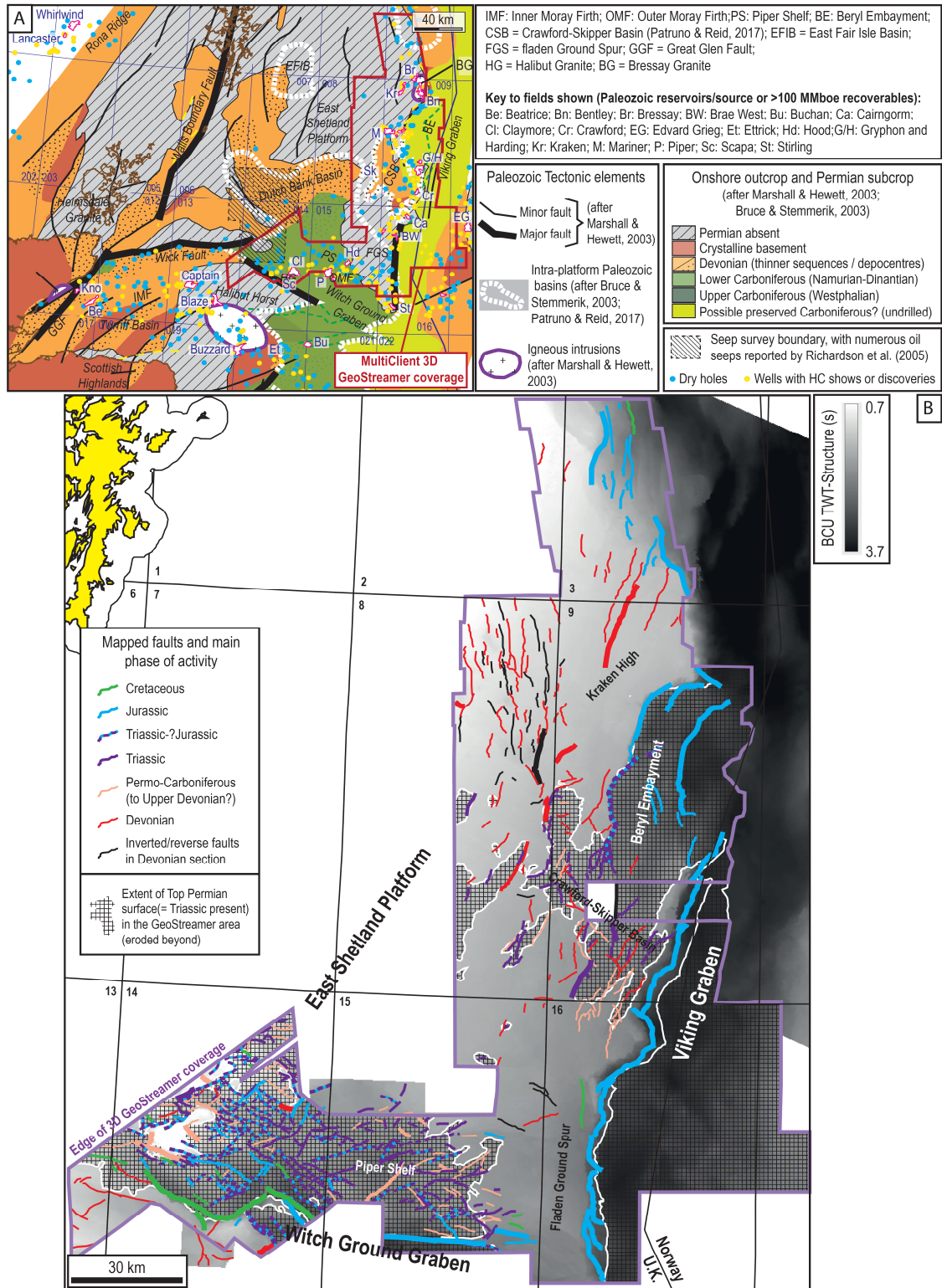


Figure 1 A) Paleozoic regional tectonic elements and location map of the studied 3D survey area. B) Fault interpretation on the 3D survey area, with the thicker lines representing basin bounding-faults.

Geological evolution and tectono-stratigraphy

The regional stratigraphy of the outer ESP is generally dominated by thick (≥ 1.5 km each) Tertiary and Devonian clastic units, occasionally separated by a thin Carboniferous to Mesozoic succession (Figs. 2 and 3). A history of repeated regional tectonic inversion has been identified. Three main phases of uplift and erosion occurred between the end of the Devonian and the end of the Cretaceous (Fig. 2): (1) during the Variscan orogeny; (2) in the Aalenian, due to the North Sea thermal doming; (3) in the Late Jurassic to Early Cretaceous due to the regional footwall uplift associated with the activity of the border faults; and (4) due to sporadic and localized Alpine-age compressions. Extensional tectonics was predominant during the Devonian (post-Caledonide extensional collapse), and during the Permo-Triassic and Jurassic rifting phases. Anomalously fast Palaeogene-age post-rift subsidence was driven by the thermal uplift of the Shetland-Orkney islands and led to the deposition of thick Paleocene-Eocene successions, with scattered important reservoir and seal intervals.

Both reverse faults and folds (of likely Variscan age) and several trends of extensional faulting have been mapped and classified, with a total of 633 faults (Fig. 1). Devonian is usually present with thicknesses >2 km and high tectonic subsidence (30-50 m/Myr, Figs. 2-3). The Fladen Ground Spur and Kraken High areas represent post-Devonian highs, with most of the upper Devonian-Jurassic missing (Fig. 1-3). The Piper Shelf and Crawford Spur areas, with well-preserved Permo-Carboniferous, are relative Variscan lows which evolved into Permo-Triassic rift basins (Figs. 1-2; Crawford-Skipper Basin, *sensu* Patruno & Reid, 2017). These are the only areas where units which are absent elsewhere due to Variscan/Aalenian erosion (e.g., lower-mid Jurassic and lower Permian-Carboniferous) are often preserved (Fig. 1) (Patruno & Reid, 2016, 2017).

Prospectivity, subsidence history and source rock maturation

A viable petroleum system is present on the ESP, including multiple Devonian-Palaeogene working reservoirs (Patruno & Reid, 2016). In particular, around the study area, Paleozoic-age fields include discoveries with >100 MMboe recoverable reserves (e.g., Clair, Buchan, Auk, Alma/Argyll). The Devonian-age Clair Field (Rona Ridge), above all, is the 6th largest oil field within the entire UKCS. The Palaeozoic-Triassic is however, the least explored interval on the ESP, mostly as a consequence of the limitations of the legacy conventional seismic, which struggled to reliably image beneath the Base Cretaceous Unconformity (BCU) (Fig. 3). When modern broadband seismic is utilized, significant sub-BCU structures are revealed, including large undrilled anticlines and fault-blocks mappable on Devonian reflectors.

The upper Jurassic Kimmeridge Clay Formation is the key source rock in the Viking Graben and Moray Firth and has a proven successful lateral migration route of up to 30 km from the master bounding faults (c.f., Mariner Field in the Quad 9). Additional charge may be provided by vertical or lateral migration from oil-prone Devonian source intervals (c.f., Beatrice and Clair fields). Here, 1D and semi-3D basin modelling has been carried out to de-risk the source rock maturation history.

Borehole temperature data from 19 wells over the study area have been utilized to reconstruct the present-day geothermal gradient distribution. The results mirror closely the outer ESP structural outline, with relatively depressed geothermal gradients (25-29°/km) over the main intra-platform basinal depocentres (Crawford-Skipper Basin and Piper Shelf to Witch Ground Graben areas) and heightened gradients (up to 32-38°/km) over the Halibut Horst and Kraken High areas, which host large granitic intrusions (Fig. 1A). Over the study area, the upper Jurassic source rock is therefore at best marginal mature, particularly over the Piper Shelf. In contrast, the Middle Devonian source rock is currently situated in the peak oil maturation window over much part of the platform, particularly when it is buried deeper due to a thickened post-Devonian fill in the intra-platform basin areas.

Palaeo-burial trends and palaeo-geothermal histories have also been reconstructed, utilizing: (1) the heat flows of present-day geological analogues to the post-Caledonian Orcadian Basin (e.g., post-

orogenic extensional collapse in Central Italy) and; (2) decompaction and backstripping estimates to reconstruct the burial through time at different locations. Permian evaporites caused a geothermal decline; Jurassic rifting increased the gradient. The burial history modelling performed in this study suggests that a best-case late generation from the Devonian occurred over parts of the region and is supported by previous geochemical analyses, which postulated possible Devonian contributions for the oils of major fields near the ESP (e.g., Claymore, Piper, Clair fields) (see Patruno & Reid, 2016). Oil seep data in sectors of Quadrants 6, 7 and 14 suggest a working source at the very centre of the East Shetland Platform, at up to 80 km away from the closest Kimmeridge Clay source kitchen.

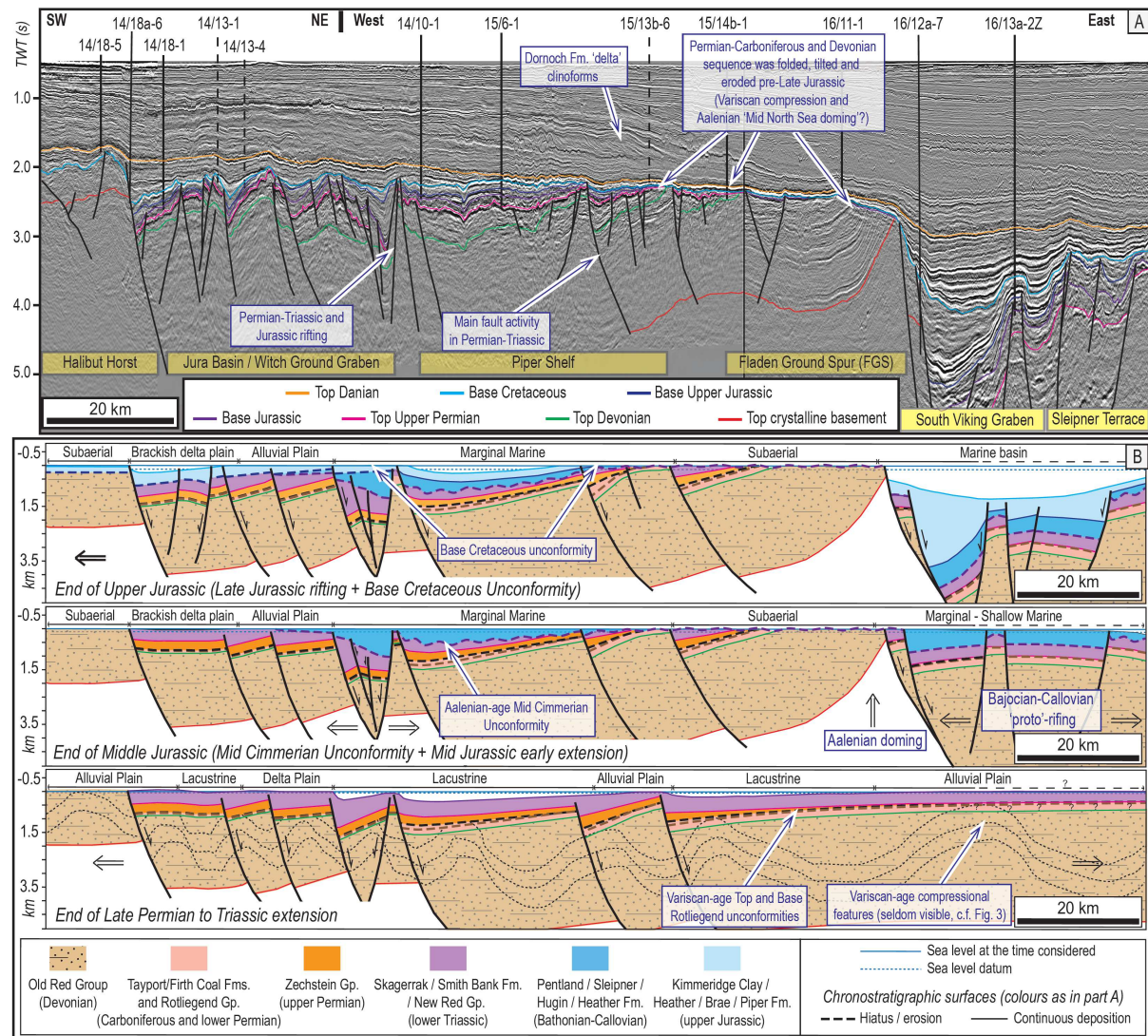


Figure 2 East-west oriented regional seismic cross-section (A) through UK Quadrants 14-15-16. (B) A series of decompacted cartoons highlighting the structural evolution along this transect. These were reconstructed based on: stratal geometries; inferred depositional thickness trends (seismic and wells); backstripping analyses; facies variations in the wells.

Conclusions

Interpretation of 3D broadband seismic data has allowed the regional mapping of Paleozoic-Jurassic reflectors over the entire outer East Shetland Platform, a key exploration frontier region of the UKCS. 3D seismic interpretation has been complemented with basin modelling and the analysis of reservoir and source rock analogues to demonstrate a feasible play system in the area. Due to improved 3D seismic imaging, deeper overlooked plays are now revealed and can be explored.

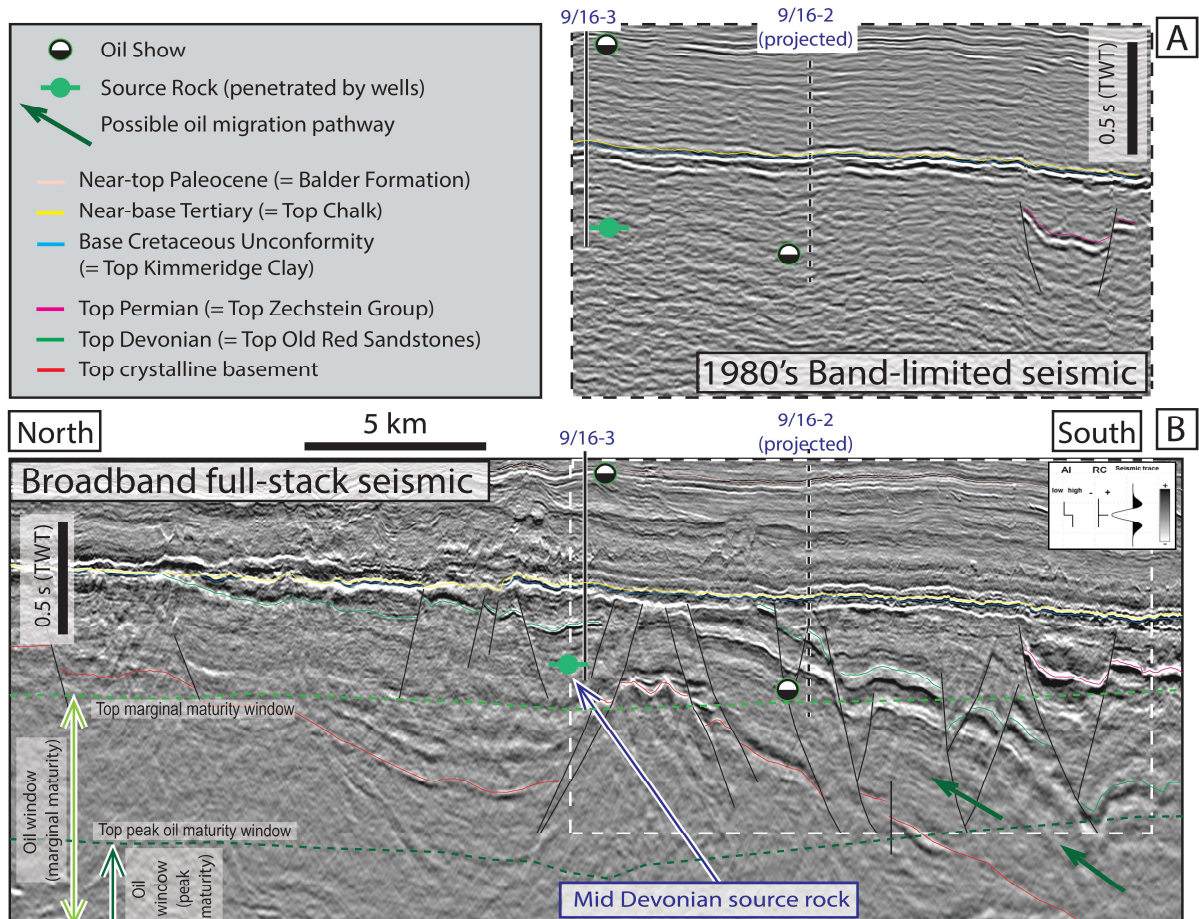


Figure 3 Comparison between legacy and dual-sensor broadband lines (B) (after Patruno & Reid, 2016, 2017). The depths of the present-day oil window are also shown (B). Old well results (Devonian oil shows and source penetration) are understood thanks to the new seismic (B). This clearly shows intra-Devonian reflectors, including an undrilled horst between the wells.

References

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