Department of Energy & Climate Change

Lower Cretaceous deep-water sand plays, UK Central Graben

Promote United Kingdom 2014

1. Abstract

Up to the present, exploration of the UK Lower Cretaceous deep-water sandstone play has been confined largely to the Moray Firth basins. The Lower Cretaceous of the Central Graben has been modelled as predominantly shale-prone, and hence unattractive to exploration. There is a growing realisation that this may not be the case.

Of the hundreds of wells drilled in the Central Graben area that targeted deeper Jurassic-Triassic reservoirs, virtually all have been located on the flanks of the graben, or on intra-graben highs. However, 131 of these wells have proved sandstones or traces of sandstones within the Lower Cretaceous outside the established fairways, giving grounds for optimism that more substantial deep-water sandstone developments may be present within the graben depocentres.

Interpretation of more than 31,000 km^2 of 3D seismic data, in combination with data from 1065 wells, forms the basis for revised palaeogeographic maps presented here.

Twenty-six leads have been identified within the Lower Cretaceous depocentres; most of these are located within stratigraphic traps in interpreted detached basin-floor fans.

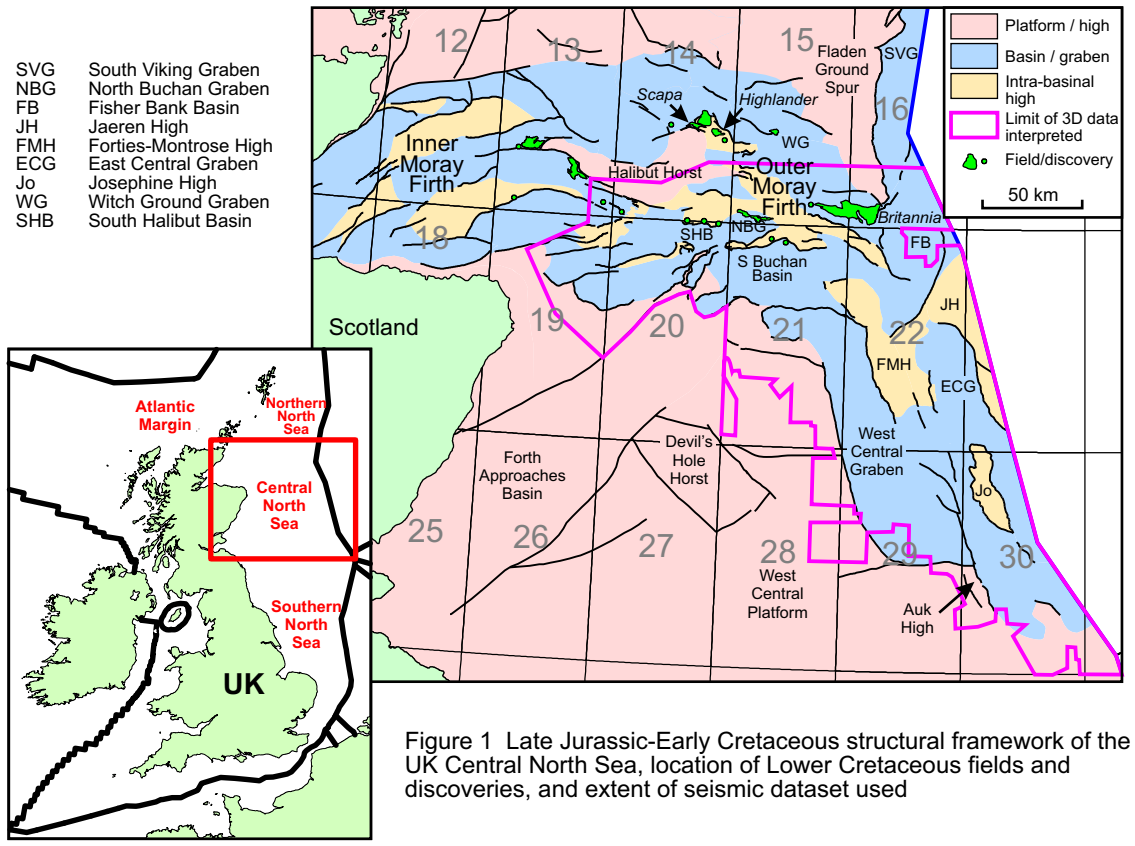

Figure 1 Late Jurassic-Early Cretaceous structural framework of the UK Central North Sea, location of Lower Cretaceous fields and discoveries, and extent of seismic dataset used

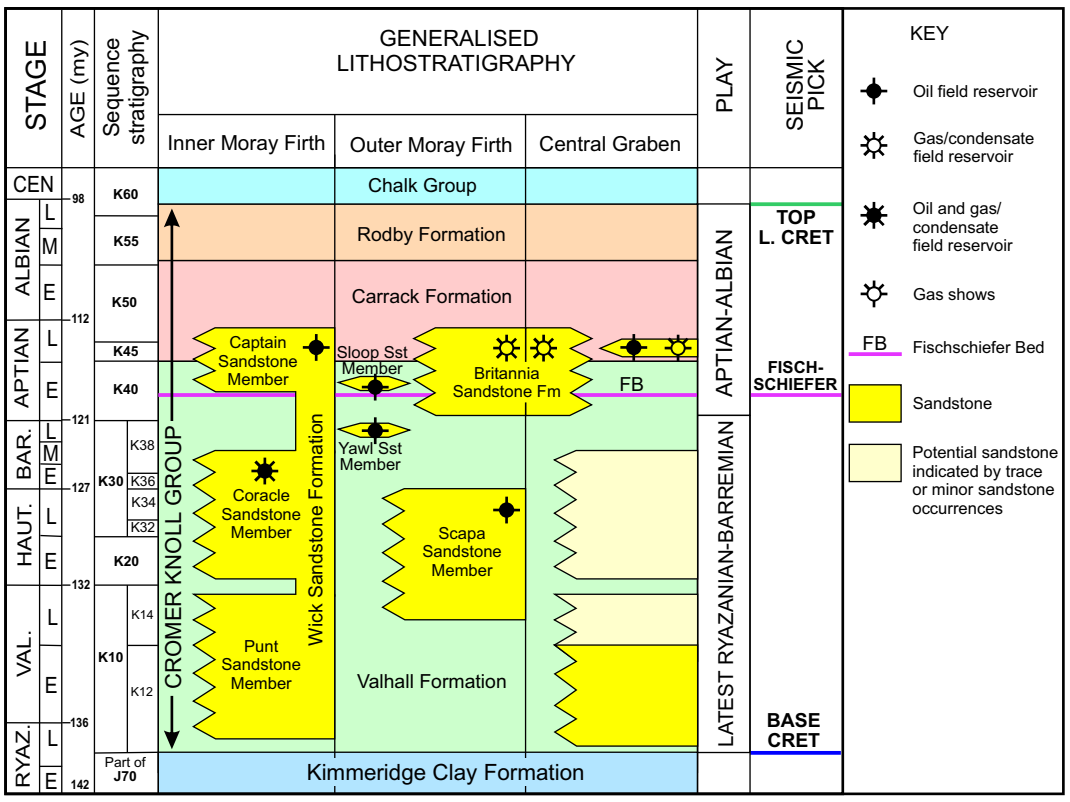

Figure 2 Stratigraphic summary chart of the UK Central North Sea Lower Cretaceous (chronostratigraphy and sequence stratigraphy after Copestake *et al*, 2003), also showing occurrence of hydrocarbons

2. Introduction

Lower Cretaceous fields and discoveries of the UK Continental Shelf (UKCS) are almost exclusively limited so far to deep-water sandstone reservoirs in the Moray Firth area of the UK Central North Sea (Figs. 1 & 2). As of end 2011, 29 fields and discoveries had been found in the Moray Firth area.

Some of the most important Lower Cretaceous fields were discovered by chance during drilling to deeper Jurassic targets e.g Britannia, Scapa, Highlander. Each of these discoveries is located within a low or syncline, and has a strong stratigraphic trapping component. 78% of UKCS Lower Cretaceous fields and discoveries are located within stratigraphic or combination structural/stratigraphic traps. The limited lateral and vertical distribution of coarse clastics within the Lower Cretaceous section gives considerable opportunity for full or partial stratigraphic entrapment.

This poster aims to highlight the exploration potential of Lower Cretaceous deep-water sandstones within the UK Central Graben; it revises and updates Milton-Worssell *et al*. (2006). Our study comprised interpretation of 3D seismic data to provide a regional framework and review of all wells in the area. These data were then appraised in the context of the palaeogeographic development of the UK Central Graben and used as a basis for lead identification.

3. Established fairways

Two Lower Cretaceous plays are recognised: Latest Ryazanian-Barremian and Aptian-Albian (Fig. 2). The Fischschiefer Bed is one of the few regionally correlatable marker beds within the Lower Cretaceous. It represents a major flooding event during the early Aptian, and we have used this horizon as a proxy for the boundary between the two plays since it is stratigraphically very close to the Barremian-Aptian boundary (Fig. 3).

3.1 Latest Ryazanian-Barremian play

Deep-marine sandstones derived from the Scottish Highlands and Shetland Platform to the west and north-west were deposited in the Moray Firth basins, along with sandstones derived locally from intra-basinal highs such as the Halibut Horst. These sandstones were predominantly developed in hanging-wall slope-apron fans; however, incised narrow linear channel complexes have been identified in the Inner Moray Firth, extending from shoreface to basin, as an integral part of a mini-basin fill and spill process (Argent *et al*. 2000).

Lower Cretaceous shallow shelf sandstones occur locally on the West Central Shelf, and Copestake *et al*. (2003) recognised a significant development of latest Ryazanian to Early Valanginian deep-marine sandstones in the West Central Graben to the east of the Auk High.

3.1 Aptian-Albian play

The Aptian-Albian palaeogeography is broadly similar to the Latest Ryazanian-Barremian, with major sediment input from the Shetland Platform to the north-west. In addition to slope-apron type filling of the proximal Moray Firth depocentres, a long distance transport route developed through a narrow channel belt from the Captain Field area, extending south of the Halibut Horst, and into the South Buchan Basin. Overlapping slope-apron fans in the Britannia Field area were derived from clastics shed southward off the Fladen Ground Spur. Oakman (2005) suggested that the Aptian-Albian play is more areally extensive.

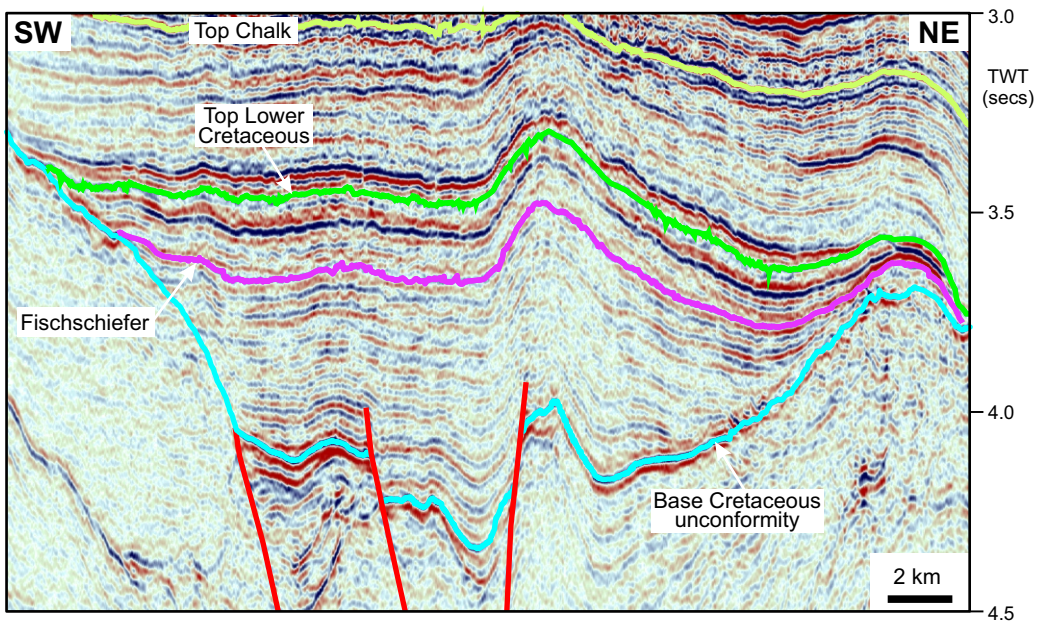

Figure 3 Seismic section across the West Central Graben showing the Fischschiefer horizon within the Lower Cretaceous. Seismic data courtesy of CGGVeritas.

4. Lower Cretaceous sandstones in the UK Central Graben

Since seismic imaging of Lower Cretaceous sandstones in the North Sea is commonly poor (Law *et al*. 2000), a robust depositional model must be developed from well and other data, or more sophisticated seismic techniques employed. In the UK Central Graben, Morgan *et al*. (2002) and Morgan and Went (2004) showed that anomalous AVO effects can be recognised from long-offset (6 km) 3D seismic data within channel-like features, and lobate, fan-like bodies in the Lower Cretaceous, which can be implied to represent the presence of sandstones.

Our study has utilised well data and conventional 3D seismic data to develop a model of possible sandstone distribution and geometry within the UK Central Graben.

Using more than 31,000 km^2 of 3D seismic data across the UK Central Graben and adjacent areas (Fig. 1), the top and base of the Lower Cretaceous have been interpreted along with the Fischschiefer horizon (Fig. 3). Isochron maps have been generated from these horizons for the entire Lower Cretaceous, and for the pre-and post-Fischschiefer components of the Lower Cretaceous.

Of the 1065 wells investigated within the study area, 769 proved the presence of Lower Cretaceous beds.

194 wells in our study area found traces or significant developments of sandstone within the Lower Cretaceous section (Figs. 4, 5 & 6). 131 of these wells are located outside the established fairways, that is, in an area previously deemed to be almost entirely mud-prone, and 6 of these record gas or oil shows.

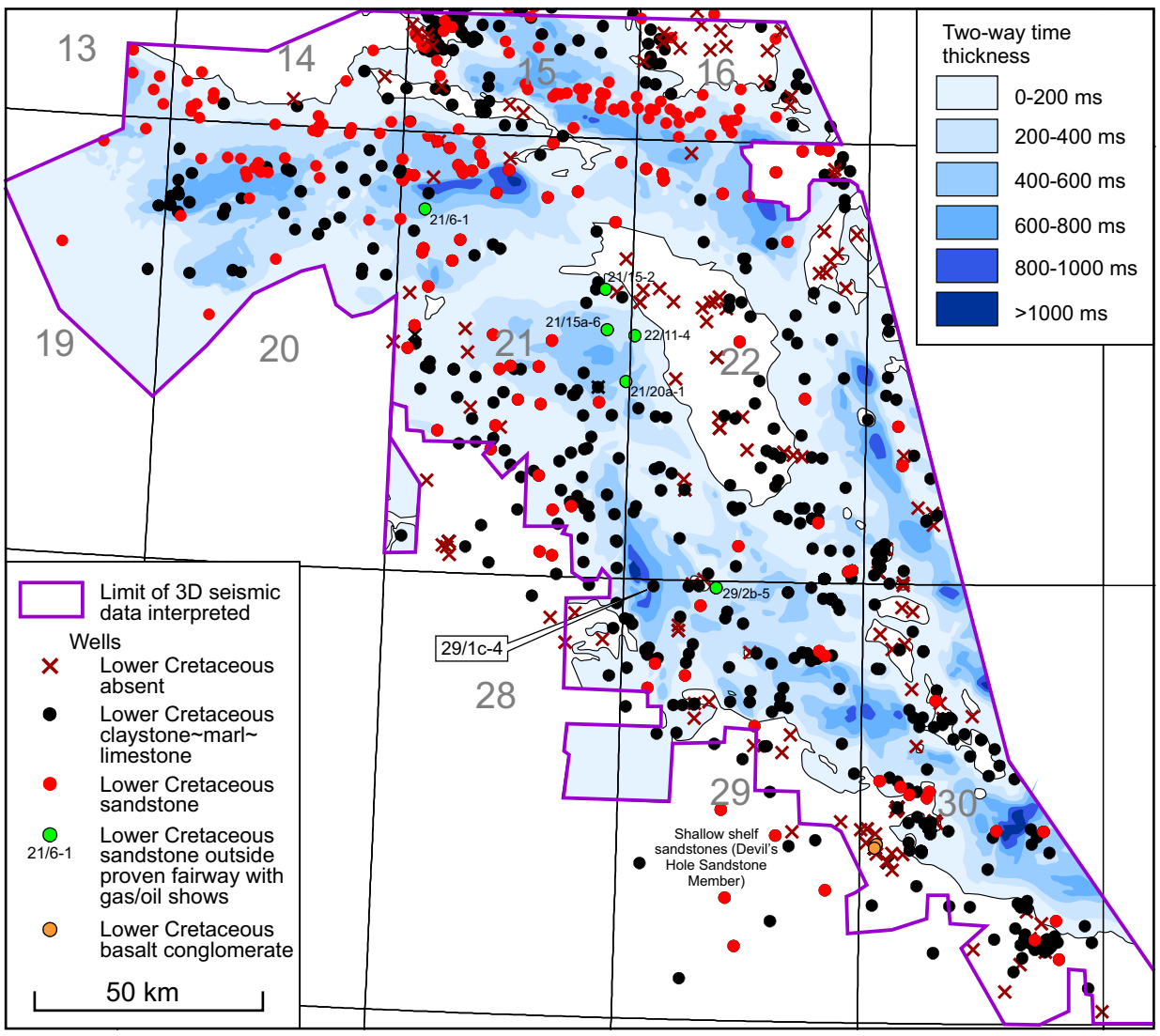

Figure 4 Lower Cretaceous well penetrations in the UK Central Graben area, also showing the isochron of the Lower Cretaceous interval. Note zero limit of isochron is limit of seismic resolution of Lower Cretaceous, not the absolute limit of the Lower Cretaceous.

Comparison of the total Lower Cretaceous isochron map, derived from seismic interpretation, with the distribution of Lower Cretaceous well penetrations shows almost all of the wells are located outside of the depocentres (Fig. 4). Well 29/1c-4 is the only well to have drilled a major depocentre, but it proved 1940 m (6366 ft) of Lower Cretaceous marine mudstones. All of the other UK Central Graben Lower Cretaceous depocentres remain untested by drilling, and may contain significant deep-water sandstone developments.

4.1 Latest Ryazanian-Barremian play

A total of 104 wells within the study area found sandstone in the latest Ryazanian-Barremian interval (outside the proven fairway) (Fig. 9), of which 34 wells contain sandstone beds in excess of 3m (10 ft) thick, and 70 wells have less significant sandstone developments.

Substantial thicknesses of latest Ryazanian-Barremian deep-marine sandstones have yet to be proved in the UK Central Graben. Most of the recorded minor sandstones occur predominantly within a basal unit of latest Ryazanian-Valanginian age, comprising beds up to 10 m (30 ft) thick e.g well 22/19a-3 (Fig. 5), but are commonly less than 3 m (10 ft) thick, e.g well 30/11b-1 (Fig. 5). Such minor sandstone occurrences are quite widely distributed across the Central Graben area.

Sandstones within the Lower Cretaceous cannot be imaged directly with conventional seismic data due to the low acoustic impedance contrast between the sandstones and overlying shales (Garrett *et al*. 2000, Law *et al*. 2000). However, possible sandstone bodies in the Latest Ryazanian-Barremian play may be postulated through geological modelling, utilising the isochron map for the base Cretaceous to Fischschiefer interval in combination with well data, and assessment of basin margin and intrabasinal sediment source areas.

The postulated areas of deep-water mass-flow sandstones within the UK Central Graben illustrated in Figures 7 and 10 are highly speculative, and require fuller investigation with more advanced seismic techniques.

Several areas are believed to have been emergent:

- The eastern margin of the West Central Shelf was emergent at the Auk High and probably also along strike along a 125 km strip (Fig. 7), and formed a potentially substantial sediment source area complicated by the eruption of basalts on the high during the Hauterivian (Trewin & Bramwell 1991, Trewin *et al*. 2003).
- The Forties-Montrose and Josephine highs were probably emergent also, along with parts of the Jaeren High (Fig. 7).
- A smaller intra-basin high located in the south-western part of Quadrant 22 is interpreted to have been emergent also, and to have been a potential clastic sediment source

4.2 Aptian-Albian play

A total of 161 wells in the study area found sandstones in the Aptian-Albian interval, 111 of which are located in the north within the established Aptian-Albian play. Of the remaining 50 wells outside the proven fairway, 13 contain sandstone beds in excess of 3 m thick, 34 contain less significant sandstone developments, and 3 found conglomerates with basalt clasts on the Auk High (Fig. 9) that Trewin & Bramwell (1991) and Trewin *et al*. (2003) have determined to be of Aptian-Albian age. These conglomerates are interpreted to have been derived from a Hauterivian basalt flow of localised extent on the Auk High (Trewin & Bramwell 1991, Trewin *et al*. 2003).

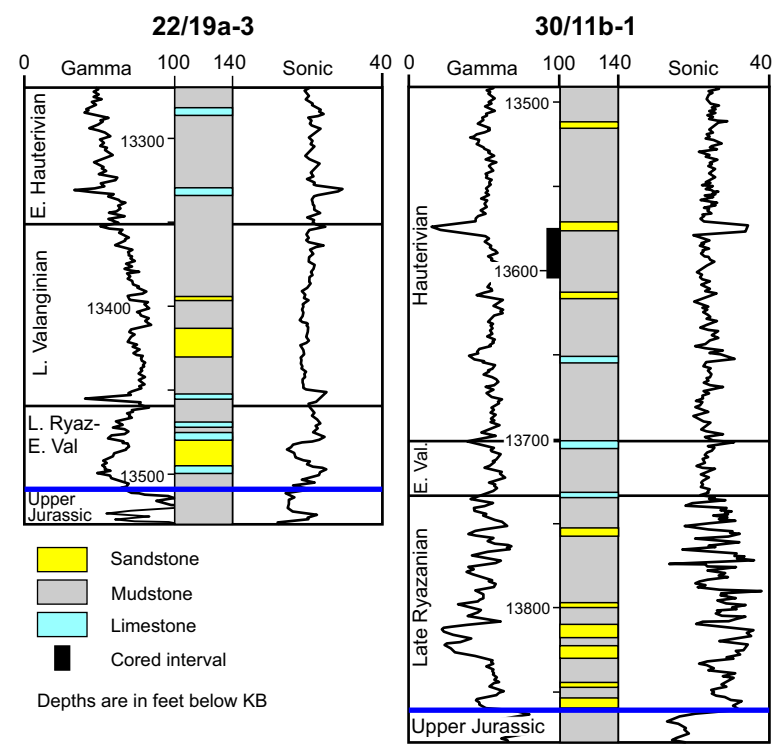

Figure 5 Selected well penetrations of Lower Cretaceous sandstones, Latest Ryazanian-Barremian play, UK Central Graben.

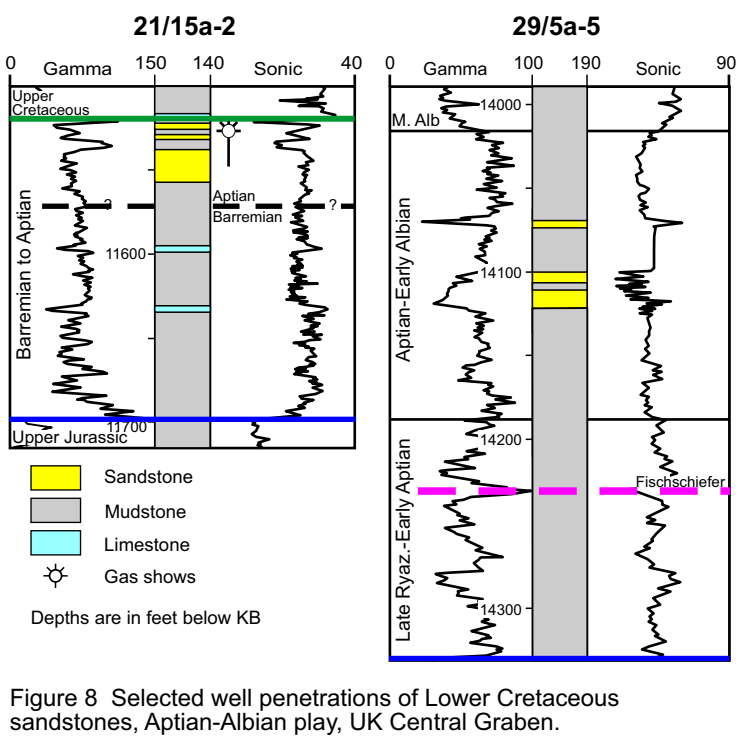

Figure 8 Selected well penetrations of Lower Cretaceous sandstones, Aptian-Albian play, UK Central Graben.

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There are fewer well penetrations to date of Aptian-Albian deep marine sandstones than of the older Lower Cretaceous sandstones in the Central Graben; however, those Aptian-Albian sandstones found are geographically widely spread across the Central Graben area (Fig. 11). Example sections from wells 21/15a-2 and 29/5a-5 are illustrated in Figure 8; well 21/15a-2 penetrated 10 m gross sandstone of probable Aptian age with gas shows, and well 29/5a-5 proved 6 m gross Aptian-Albian sandstone.

In common with the Latest Ryazanian-Barremian play, we have assessed the potential for unidentified Aptian-Albian sandstone bodies through basin analysis, utilising an isochron map for the Fischschiefer to top Lower Cretaceous interval in combination with well data, and evaluation of basin margin and intra-basinal sediment source areas (Fig. 11). The areas postulated for Aptian-Albian deep-water mass-flow sandstones within the UK Central Graben as illustrated in Figures 10 and 13 are highly speculative, and require comprehensive investigation with more advanced seismic techniques than were available to us.

Aptian-Albian sediments extend more continuously across the study area, indicating a degree of drowning of previously emergent highs (Fig. 11).

- Only two small areas on the eastern margin of the West Central Shelf are likely to have remained emergent (Fig. 11) and potentially supplying coarse clastics to the West Central Graben.
- The Forties-Montrose High and part of the Josephine High remained emergent, along with the north-western part of the Jaeren High (Fig. 11).

Coarse clastics derived from the UK landmass may have been deposited locally as shallow shelf sandstones on the West Central Platform. Very long transport routes would be required for any such sandstones to have fed across the platform into the West Central Graben.

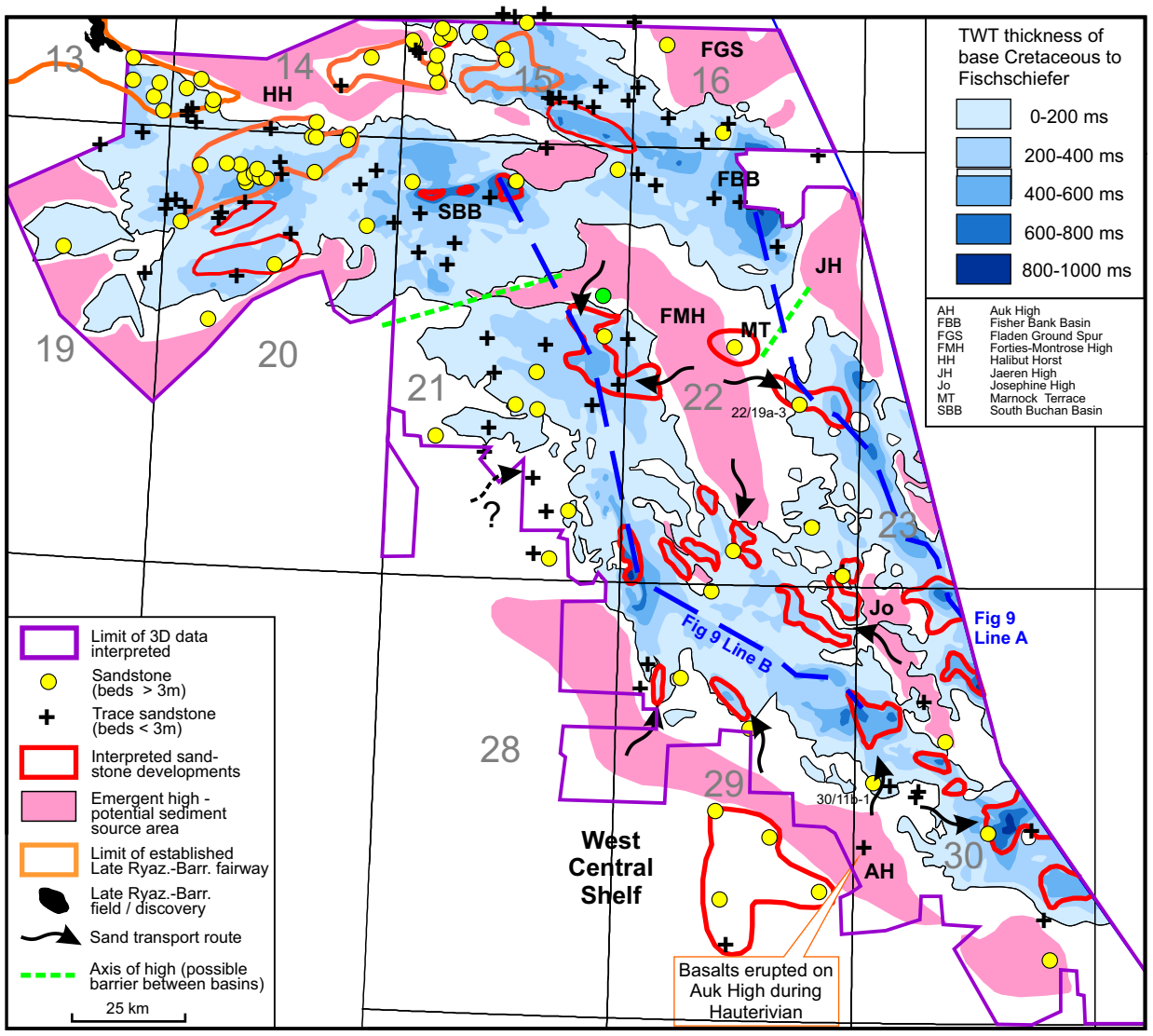

Figure 7 Well penetrations of sandstone, and interpreted possible sandstone developments within the latest Ryazanian-Barremian, also showing isochron map of the near equivalent seismic interval, base Cretaceous to Fischschiefer. Note zero limit of isochron is limit of seismic resolution, not absolute limit of unit.

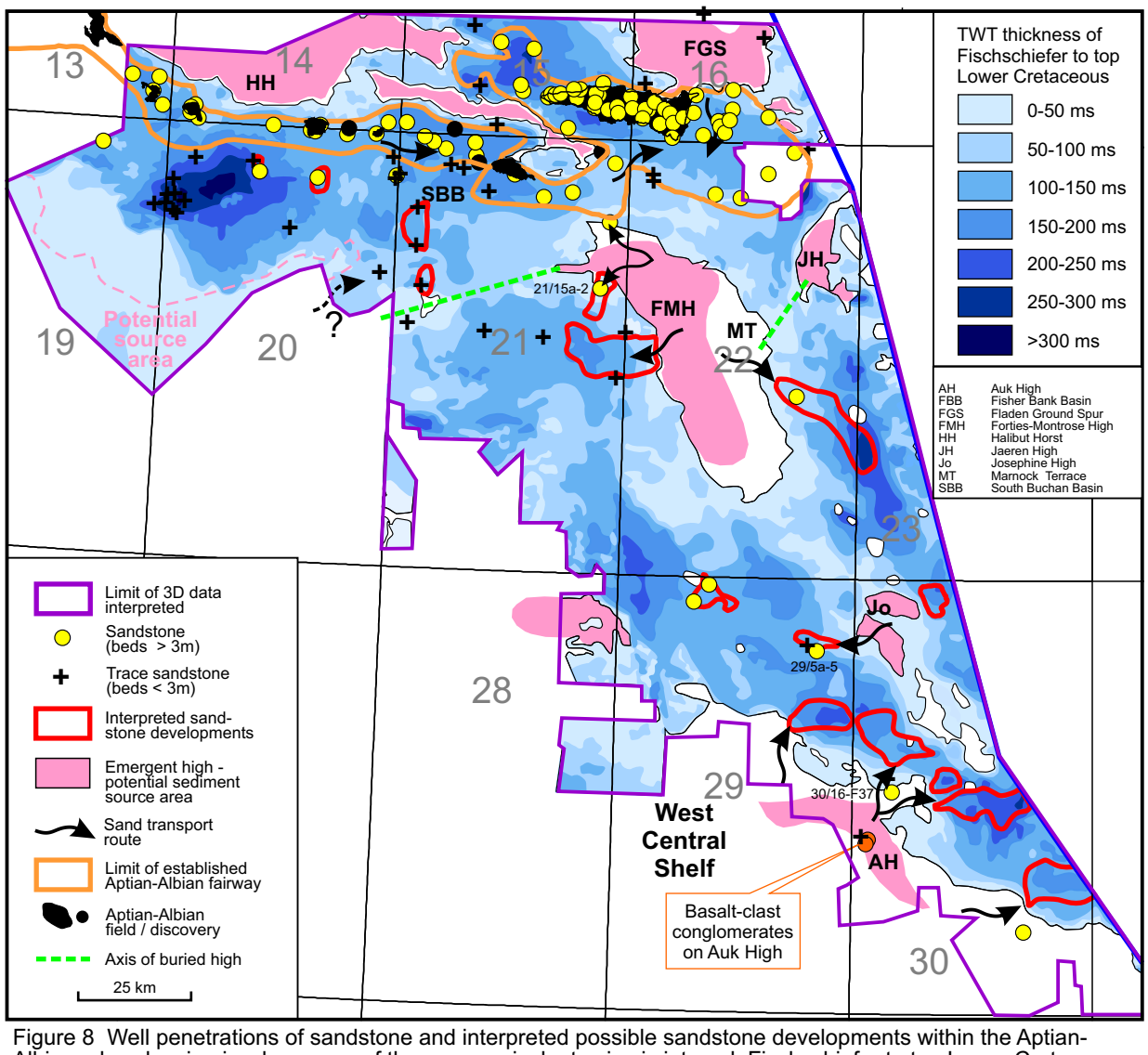

Figure 8 Well penetrations of sandstone and interpreted possible sandstone developments within the Aptian-Albian, also showing isochron map of the near equivalent seismic interval, Fischschiefer to top Lower Cretaceous. Note zero limit of isochron is limit of seismic resolution, not absolute limit of unit.

The Latest Ryazanian to Barremian basins of the Central Graben are largely separated from those of the Outer Moray Firth to the north by E-W to SW-NE trending palaeohighs (Figs. 7 & 9):

- The Marnock Terrace forms a SW-NE trending structural high connecting the Forties-Montrose High to the Jaeren High (Fig. 9, Line A). Very thin (sub-seismic resolution) developments of poorly dated Lower Cretaceous beds have been proved locally by wells on this high.
- The western arm of the Forties-Montrose High forms an E-W trending structural high (Fig. 9, Line B). This high appears to have formed an almost complete barrier during the Latest Ryazanian-Barremian. Thus, Latest Ryazanian-Barremian mass-flow sediments within the Central Graben are likely to be entirely separate from those proven within the Outer Moray Firth area.

These highs appear to have remained significant during Aptian-Albian times (Figs. 8 & 9), and the possibility of contiguous Aptian-Albian mass-flow sandstones extending southward into the Central Graben depocentres is considered to be remote.

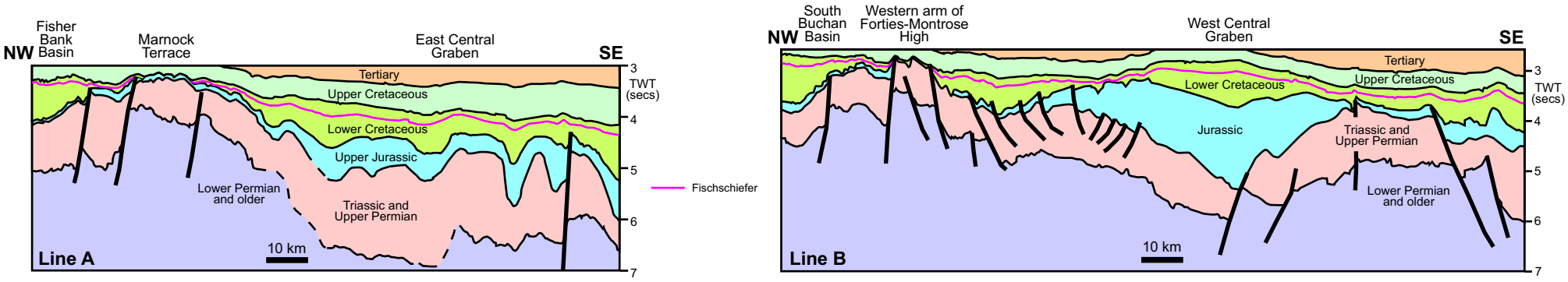

Figure 9 Regional geoseismic lines showing structural highs dividing the Lower Cretaceous basins of the East Central Graben and West Central Graben from the Fisher Bank and South Buchan basins respectively. Location of lines shown on Fig. 7.

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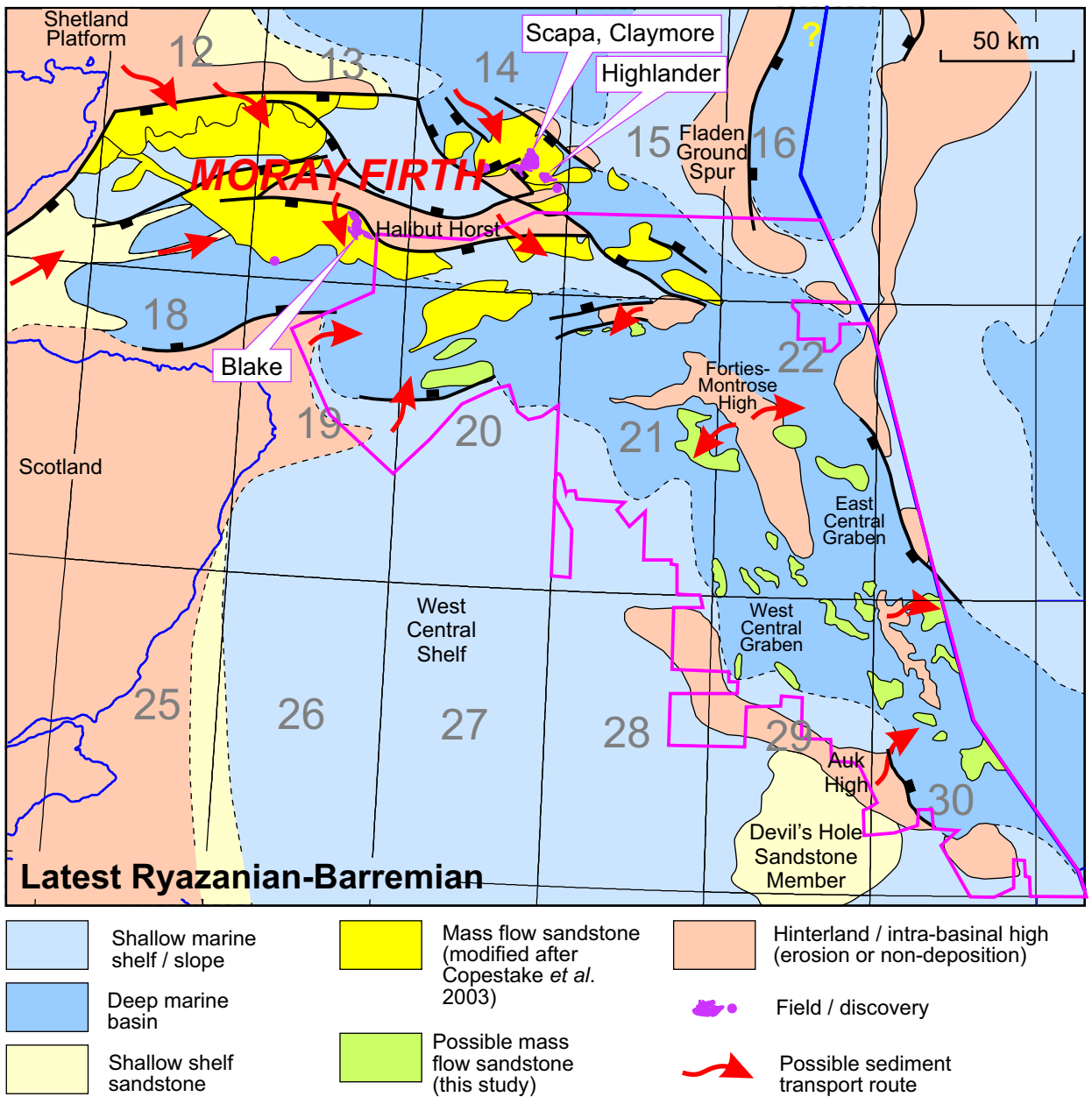


Figure 10 Post-analysis: possible distribution of sandstones within the Latest Ryazanian-Barremian play of the UK Central North Sea (modified after Copestake *et al*. 2003)

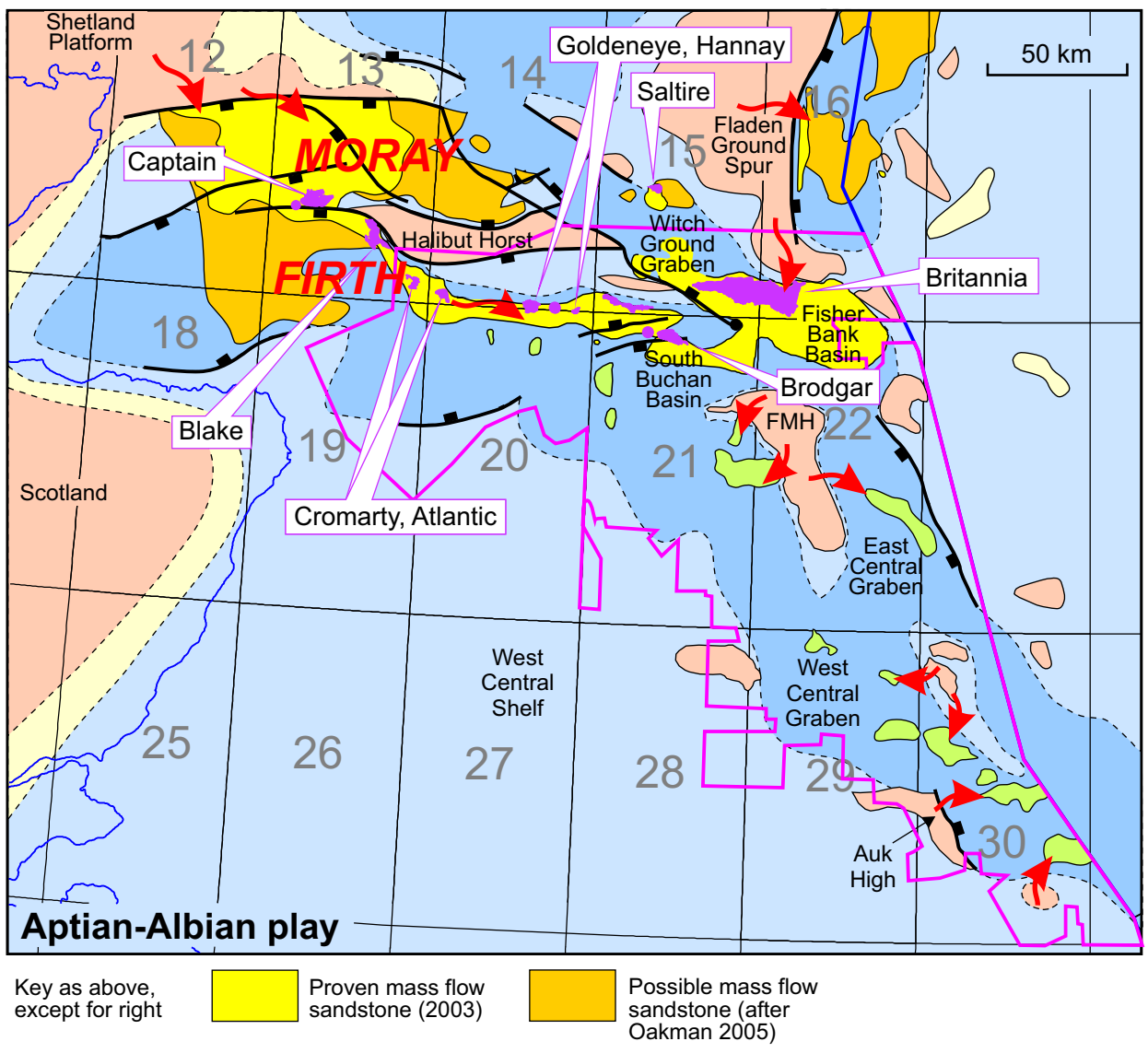


Figure 11 Post-analysis: possible distribution of sandstones within the Aptian-Albian play of the UK Central North Sea as identified in 2003 (after Copestake *et al*. 2003), by Oakman (2005), and by this study

Lower Cretaceous deep-water sand plays, UK Central Graben

5. Leads

Twenty-six leads have been identified from our analysis of Lower Cretaceous deep-water sandstone distribution in the UK Central Graben, all of which have a strong stratigraphic component. Trapping styles are as follows:

- Hanging-wall fans located adjacent to active or residual fault scarps (Latest Ryazanian-Barremian leads only)
- On-slope, ponded mini-basin fill (Latest Ryazanian-Barremian leads only)
- Detached basin-floor fans (Latest Ryazanian-Barremian and Aptian-Albian leads)

Two Latest Ryazanian-Barremian leads have been mapped on either side of an intra-basinal high within relatively minor hanging-wall basins in the West Central Graben (Fig. 12). Regional tilting up to the west provides the optimum trap configuration of up-dip stratigraphic pinch-out, and avoids the potentially problematic issue of lateral seal risk where these postulated Lower Cretaceous sandstones may be in cross-fault contact eastwards with Jurassic to Triassic sandstones of the footwall.

Basin fill and spill processes were recognised by Argent *et al*. (2000) within the Late Ryazanian-Valanginian Punt Sandstone Member of the Inner Moray Firth, whereby sand-rich sediments accumulated within the first basin encountered, and only spread to neighbouring basins once the first basin was filled to spill point, from when the feeder channel was able to incise and cross inter-basinal highs. Several mini-basins have been identified on the margins of the UK Central Graben, within which the Latest Ryazanian-Barremian sequence is isolated from the main basin in the graben, but the Aptian-Albian sequence continues across the intervening high. The smaller lead on the western side of Figure 13 comprises the ponded fill of a basin-margin mini-basin, and may have bottom seal risk if the pre-Cretaceous section comprises Jurassic or Triassic sandstones.

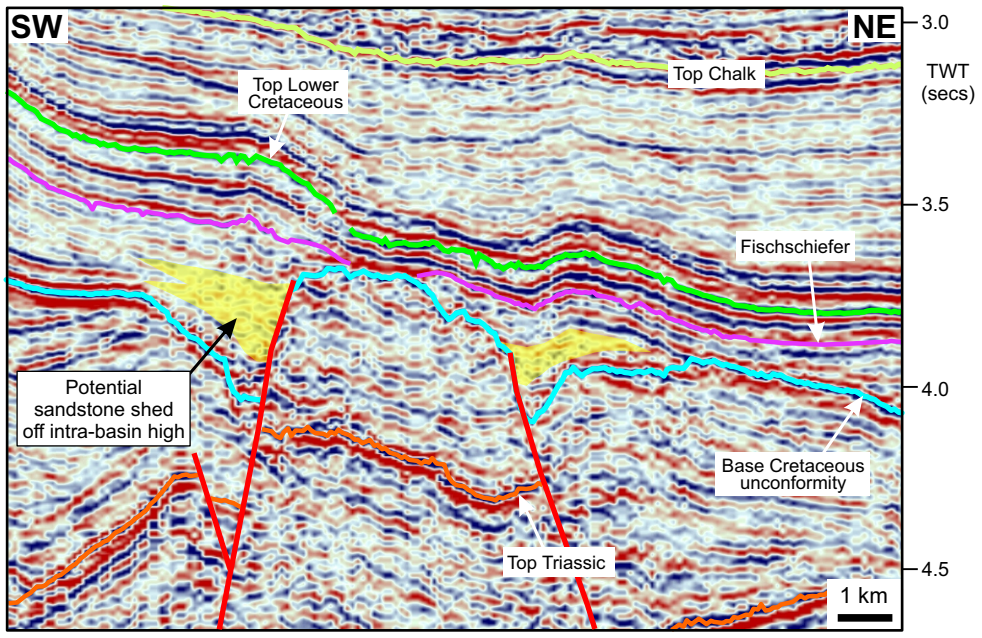


Figure 12 Seismic section across the West Central Graben showing leads within the Latest Ryazanian-Barremian play. MC3D MegaSurvey seismic data courtesy of PGS.

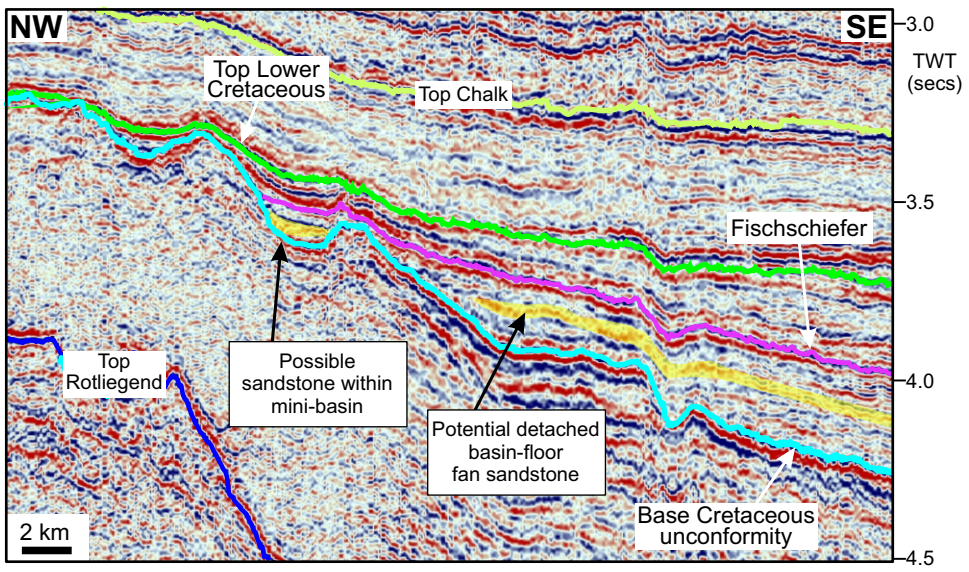
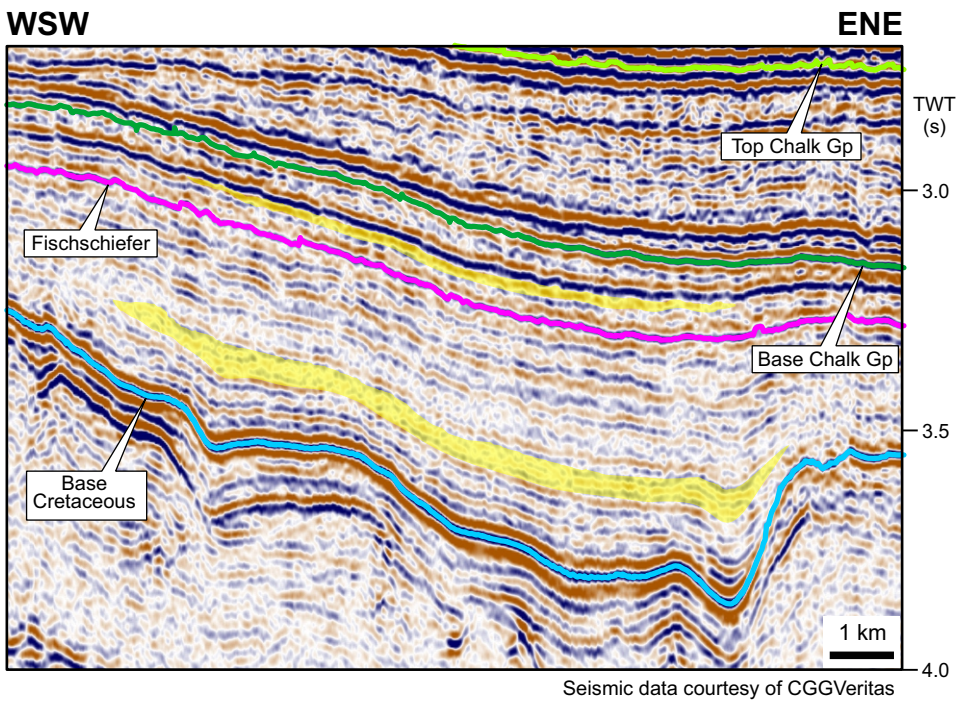


Figure 13 Seismic section across the East Central Graben showing leads within the Latest Ryazanian-Barremian play fairway. MC3D MegaSurvey seismic data courtesy of PGS.



Seismic data courtesy of CGGVeritas

Figure 14 Seismic section from the West Central Graben. The target reservoirs are conjectural basin-floor sandstones within the Latest Ryazanian-Barremian play and the Aptian-Albian play.

In the established Lower Cretaceous fairway of the Moray Firth basins, detached basin slope to basin floor channel and fan-lobe sands are recognised as the most important play type, especially within the Aptian-Albian play (Oakman 2005). In the UK Central Graben, the majority of the mapped leads are located within detached basin floor fans, with either full stratigraphic pinch-out trapping, or combination stratigraphic pinch-out and down-dip closure trapping. Detached basin floor fan traps characterise all of the Aptian-Albian leads recognised in this study.

Figure 13 illustrates an example of a potential detached basin-floor fan within the Latest Ryazanian-Barremian play; this lead requires up-dip stratigraphic pinch-out at the proximal end of the fan.

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6. Summary

A regional appraisal of the Lower Cretaceous strata in the UK Central Graben gives grounds to support the possibility that deep-water sandstones could be important future exploration targets.

- The Lower Cretaceous depocentres of the UK Central Graben are largely untested; however, 131 wells found traces or significant developments of Lower Cretaceous sandstone within the study area *outside* the established fairways.
- The Lower Cretaceous sandstone plays within the Central Graben are likely to be entirely separate from the established fairways to the north. E-W to SW-NE trending palaeohighs may have acted as barriers to southward sediment transport.
- Predicted sandstone developments in both the Latest Ryazanian-Barremian and Aptian-Albian plays are predominantly detached slope-apron and basin-floor fans. they are most likely to have been derived from local sediment sources around the margins of the Central Graben.
- The potential for stratigraphic entrapment of hydrocarbons within postulated detached deep-water sandstones in the Lower Cretaceous depocentres of the East Central Graben and West Central Graben is high. Example leads are relatively high risk, primarily in terms of reservoir presence, but also in terms of trap definition since the predicted sand bodies and their lateral distribution cannot be discerned directly on seismic data.
- This preliminary study has identified 26 leads in total; they are quite deeply buried (3350-5850 m / 11000-19000 ft), and are located within, or on the flanks of deep graben where the effects of overpressure are likely to be seen.