LOWER CRETACEOUS DEEP-WATER SAND PLAYS IN THE UK CENTRAL GRABEN

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Talk outline

• Setting the scene
  – Stratigraphy and proven sand fairways
• Moving forwards
  – Data used in study
  – Evidence for sand developments in the Central Graben
  – Leads
• Conclusions
The location of the study area is shown by the magenta coloured limit of 3D data. Structural framework at end Jurassic shows the E-W arm of the trilete rift system where the Lower Cretaceous plays are established, part of the northern arm (Viking Graben) which we won’t be considering here, and the UK part of the southern arm, the Central Graben – the focus of this talk.
1. Let’s introduce the Lower Cretaceous plays with this simplified stratigraphy chart. The Lower Cretaceous Cromer Knoll Group contains 2 sandstone formations, the Wick Formation in the Inner Moray Firth, and the Britannia Formation in the Outer Moray Firth, plus several sandstone members within the mudstone & carbonate Valhall Fm.

2. Lower Cretaceous plays have been divided into 2 play fairways, Late Ryazanian-Barremian and Aptian-Albian.

3. Potentially significant sandstone developments in the Central Graben indicated by pale yellow, and are based upon trace and minor sand occurrences. The Fischschiefer Bed is a regionally developed mudstone, generally characterised by a higher gamma & sonic response that represents a major flooding event during the early Aptian, and is the best approximation we have on seismic to regionally separating the 2 fairways.

4. Well symbols shows stratigraphic position of discoveries; well 21/15a-2 (drilled 1981) found gas shows in the Central Graben

Note – we don’t use the term Kopervik since this term was originally used for Lower Cretaceous shallow marine sands in the Norwegian sector
To summarise what has been published to date on the Lower Cretaceous fairways, we’ll look at summary palaeogeography maps for each, based largely on the work of Copestake et al (2003) in the Millennium Atlas.

Late Ryazanian-Barremian deep marine sands were deposited in the Inner Moray Firth, being shed off the Shetland Platform to the NW, the Scottish Highlands to the W, and locally off the Halibut Horst. Predominantly developed in hanging wall slope apron fans, but with development of narrow linear channels in the Inner Moray Firth (mapped by BGS regional mapping programme in 1980’s).

In the Central Graben area, Copestake et al (2003) recognised a significant development of deep marine sands in Quadrant 30, to the east of the shallow shelf sands (Devil’s Hole Sandstone Member) on the western side of the Auk Ridge in Quadrant 29. Interestingly, they also hinted at other possible sand bodies in the Central Graben (shown as ?), and indicated the potential for local derivation of sands from the Forties-Montrose High.

Note that throughout this Late Ryazanian-Barremian time period, the coastline was receding across the West Central Platform from the purple line (at end Jurassic) to an approximate position close to the present day coastline during the Barremian (continuing the Fulmar transgression).
The Aptian-Albian palaeogeography is broadly similar, with major sediment input from the Shetland Platform to the NW. But, long distance transport developed through a narrow channel belt from the Wick Sub-basin in the Inner Moray Firth, south of the Halibut Horst, across the Buchan Ridge to merge with the Britannia sands that were shed off the Fladen Ground Spur. Small occurrence of deep marine sands recognised in Central Graben by Copestake et al (2003) in block 29/5, potentially derived from an emergent part of the margin of the West Central Platform in Q28. Notably, in the Central Graben area, the Auk High and parts of the Forties-Montrose High and Jaeren High may also have been emergent and offer potential as sediment source areas.

In his most recent publication presented at the QE2 conference (6th Petroleum Geology of North-West Europe), Oakman (2004 [will now be published in 2005]) shows the Aptian-Albian sand fairway as more laterally extensive, and with linear, presumably channel belts, tracking SW-NE across the Ettrick Graben and South Buchan Graben, feeding into the northern parts of Quadrants 20 and 21, and merging with the sands derived from the NW.
Lower Cretaceous deep-water sands in the UK Central Graben

**Dataset**
- PGS MegaSurvey 3D
- Veritas Long Offset 3D, Q30 area
- 662 wells
  - 159 prove L Cret absent
  - 98 of 503 prove L Cret sand (71 outside known play fairway)

1. Two 3D seismic datasets were used covering Quadrants 21-23, & 29-30 – total area of 22,135 km²
2. Total of 662 released wells were assessed within or adjacent to the 3D coverage (there are few additional confidential wells)
   - 159 wells found the Lower Cretaceous to be absent (denoted by black cross); 503 wells found the Lower Cretaceous to be present (denoted by red or green spot; green = no sand found, red = sand present)
3. 98 wells found to contain sand within Lower Cretaceous (denoted by red spot), 71 of which are located outside the proven Aptian-Albian fairway (NB Late Ryazanian-Barremian fairway is entirely to the N and NW of this map)
Dataset

• Few wells in L Cret depocentres!

4. Adding the isochron of entire Lower Cretaceous to the map shows that precious few wells were drilled within the depocentres.

   200ms = c.300m,
   1sec = c.2.1 km
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Dataset

- Two wells only within depocentres, both entirely mud-prone

5. Exceptions include 29/1c-4 (drilled in 1991; Lower Cretaceous = 6366 ft/1940m thick) in the West Central Graben, and 21/1b-17 (drilled in 1994; Lower Cretaceous = 3993ft/1217m thick) in the South Buchan Graben, both of which are unfortunately sand-free, marine mudstone dominated.
Core from the Britannia Field shows clean, high density turbidite facies with dewatering pipes and dish structures – typical of good quality reservoir in L Cret deep-water play. Core is from wells 16/26-B03 (on left – with dewatering pipes; drilled in 1995) and 16/26-24 (on right – with dish structures; drilled in 1993)

This seismic section illustrates the horizons that we have interpreted for this study, comprising the top and base Lower Cretaceous, and the Fischschiefer (which is the closest we could pick regionally on seismic to the Barremian/Aptian boundary i.e. the boundary between the Late Ryazanian-Barremian and Aptian-Albian plays.
Late Ryazanian-Barremian play

- 26 wells found sands including beds >3m (10 on West Central Platform)
- 34 wells found less significant sand developments (7 on West Central Platform)

A total of 60 wells in the study area of the Central North Sea found sand in the Late Ryazanian-Barremian interval – 26 wells with sand beds in excess of 3 m thick (denoted by yellow spot), and 34 wells with less significant sand developments (denoted by black cross).
Lower Cretaceous deep-water sands in the UK Central Graben

Late Ryazanian-Barremian play

- **Basalts** erupted on Auk High during Hauterivian
- **Tuffs** found in Lower Cret e.g. 21/10-7 & onshore UK (Speeton Clay & Fullers Earth)

A basalt flow found on the Auk High during appraisal drilling of the Auk Field has been dated as Hauterivian (Trewin et al 2003 & Trewin & Bramwell 1991). Tuffs occur within Lower Cretaceous mudstones in some wells in the Central North Sea e.g. 21/10-7 (age uncertain; drilled in 1985). Onshore UK, tuffs are found in the Speeton Clay (Barremian – thought to be derived from a buried source in the Southern North Sea; Knox & Fletcher 1978) and in the Fullers Earth of SE England (Aptian, possibly related to volcanic sources in Zuidwall, Holland, or the Fastnet Basin; Francis 1992)
Late Ryazanian-Barremian shallow shelf sands on the West Central Platform in Quad 29 have been known since 1967 when well 29/23-1 was drilled (other wells proving this sand were drilled between 1967-1976). Referred to the Devil’s Hole Formation, these shallow marine sands reach up to 141m (gross) at well 29/19-2 (drilled in 1976). In the example well (29/25-1, drilled in 1970), these sands are 43 m thick (gross), comprising two units within the Late Ryazanian-Early Valanginian interval.

All occurrences of Late Ryazanian-Barremian sandstones in the Central Graben area are water wet.
Late Ryazanian-Barremian deep-marine sands of substantial thickness have yet to be proved in the UK Central Graben area. The minor sand developments that we do see are in the Late Ryazanian-Valanginian within a basal unit, and may comprise beds up to 10m (e.g. 22/19a-3, drilled in 1992), but are commonly less than 3m thick (e.g. 30/11b-1, drilled in 1979). These minor sand occurrences are quite widely distributed across the Central Graben area.
Late Ryazanian-Barremian play

- Potential for numerous detached basin slope to basin floor sand bodies
- Sediment input from graben margins and intra-graben highs
- Potential for thin sand developments on flanks of graben beyond limit of seismic isochron

Potential sand bodies have been interpreted from isochron maps in combination with examination of seismic along the basin flanks for possible sediment entry points. Some are based on evidence of channel-like features seen on inversion data.
Late Ryazanian-Barremian play

- Location of regional sections 1 and 2 across the major barriers separating the Lower Cretaceous basins of the Central Graben from the South Buchan and Fisher Bank basins to the north.

Location of regional sections 1 & 2.
The Marnock Terrace which forms an ENE-WSW trending structural high connecting the Forties-Montrose High to the Jaeren High separates the East Central Graben to the south from the Fisher Bank Basin to the north. Very thin (sub-seismic) developments of poorly dated Lower Cretaceous beds are locally proved by wells on this barrier high.
The western arm of the Forties-Montrose High forms an E-W trending structural high that partially separates the West Central Graben to the south from the South Buchan Basin to the north. This barrier high formed an almost complete barrier during the late Ryazanian-Barremian, but was almost completely flooded during the Aptian-Albian. The Aptian-Albian section thins significantly across this structural feature.
Aptian-Albian play

- 8 wells found sands including beds >3m (3 wells found basalt conglomerate on Auk High)
- 14 wells found less significant sand developments

A total of 52 wells in the study area of the Central North Sea found sand in the Aptian-Albian interval, 27 of which are located within the established Aptian-Albian fairway. Of the remaining 25 wells outside the established play fairway, 8 wells contain sand beds in excess of 3 m thick (denoted by yellow spot), and 14 wells contain less significant sand developments (denoted by black cross). Three wells found conglomerates with basalt clasts on the Auk High (interpreted as Aptian-Albian in age by Trewin & Bramwell (1991) and Trewin et al (2003).
There fewer occurrences to date of Aptian-Albian deep marine sands than of the older Lower Cretaceous sands, but those found are geographically widely spread across the Central Graben area. The example wells show 10 m gross sand of probable Aptian age with gas shows in well 21/15a-2 (drilled in 1981), and 6m gross Aptian-Albian sand at well 29/5a-5 (drilled in 1985).
Core photo of Aptian-Albian basalt-clast conglomerate from well 30/16-3 on the Auk High.
**Aptian-Albian play**

- Potential for numerous detached basin slope to basin floor sand bodies
- Sediment input from graben margins and intra-graben highs
- Potential for thin sand developments on flanks of graben beyond limit of seismic isochron

Potential sand bodies have been interpreted from isochron maps in combination with examination of seismic along the basin flanks for possible sediment entry points. NOTE – Quadrant 21 west has not been fully evaluated (this will be more fully assessed when the project progresses with study of Quadrant 20)

There is no predicted sand in the deepest part of the West Central Graben (Q22SW/Q29NW) due to well control – 29/1c-4 is one of the two wells to prove a mud-prone Lower Cretaceous depocentre. There may be potential for Aptian-Albian sands in the northern part of this depocentre (i.e. in Quadrant 22SW).
Seismic imaging of Lower Cretaceous sands is known to be poor due to the low acoustic impedance contrast between the sands and overlying shales (e.g. Hannay, Goldeneye in South Halibut Basin e.g. Garret et al 2000, Law et al 2000). Multiples associated with intra-Upper Cretaceous intervals are also widely problematic.
Potential sands at several stratigraphic levels shed off Forties-Montrose High. Up-dip pinchout or local drape over underlying fault terraces provides trapping potential.
Potential Late Ryazanian-Barremian sands shed off an intra-graben high. Up-dip pinchout provides trapping potential in the western lead. The eastern lead involves stratigraphic pinchout and inversion folding.
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Late Ryazanian-Barremian lead 3

Potential Late Ryazanian-Barremian sands travelling down the flank of the basin may have been trapped within a mini-basin generated by salt/fault movements.
Potential sands at different stratigraphic levels shed eastwards off Forties-Montrose High. Possible mini-basin fill and spill. Up-dip pinchout provides trapping potential, but requires a detached basin floor sand body otherwise there will be high risk of bottom/lateral seal failure.
Interpreted detached basin floor sand lobe is intersected by Late Cretaceous inversion axis – therefore trapping potential. Basin floor fan is interpreted from seismic isochron map in combination with examination of seismic along the basin flanks for possible sediment entry points.
Conclusions

1. 71 wells in the Central Graben area outside the known fairways prove the presence of Lower Cretaceous sands.

2. Potential sand developments in both the Late Ryazanian-Barremian and Aptian-Albian plays are predominantly hanging wall slope apron fan bodies or detached basin floor fans, both derived from local sediment sources. The potential for development of narrow, linear channel belts such as those identified in the Inner Moray Firth and South Halibut Basin is believed to be low.

3. E-W and SW-NE trending palaeohighs largely separated the Central Graben basins from the South Buchan-Fisher Bank basins to the north.

4. A number of leads have been recognised; inversion data shows channel-like features.

5. Work is on-going; the area of study is to be extended.
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Thanks to PGS for permission to show examples from the Mega Survey 3D

Thanks to Veritas DGC for permission to show examples from the Quadrant 30 Long Offset 3D

References


