[PS]East Shetland Platform Petroleum Geochemistry and Prospectivity*

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Abstract

An investigative study into the East Shetland Platform, part of the mature UK Continental Shelf petroleum province with a focus on geochemistry. The platform bounds the Viking Graben to the west. It was a high throughout most of the Mesozoic, having been affected by Variscan deformation. A thin veneer of recent Tertiary sediment cover is found. The platform is significant for clastic sediment routed through incised valleys and channels on it, into the adjoining basin. Unlike the basin, there remains considerable scope for further exploration on marginal areas such as the platform. The dataset consisted primarily of geochemical reports of highly biodegraded oils, dating back to 1977 of wells drilled in the area. The aim of the study was to determine a link between oils found on the platform and basin based Kimmeridge Clay Formation source rocks. This was done through evaluation of the biomarker data embedded in gas chromatogram and mass spectroscopy data where available in the dataset. Isoprenoids such as pristane and phytane, and terpanes such as gammacerane provided the best indicators of both source maturity and environment. Existing stratigraphic templates were adapted and applied to the raw data to further constrain outputs. The results confirmed the decrease in oil maturity further inbound of the platform, while demonstrating the ability of distal Kimmeridge shales to charge over long distances onto reservoir units on the platform. High well coverage in the area is conducive to 3D petroleum systems modelling in future investigations. Application of statistical tests on biomarker variability posited a possible link between contamination and the observed standard deviation in the measurements. This raises a possible avenue of further research into the effects of drilling on the natural biomarker signature in mature petroleum provinces.

EAST SHETLAND PLATFORM PETROLEUM GEOCHEMISTRY AND PROSPECTIVITY

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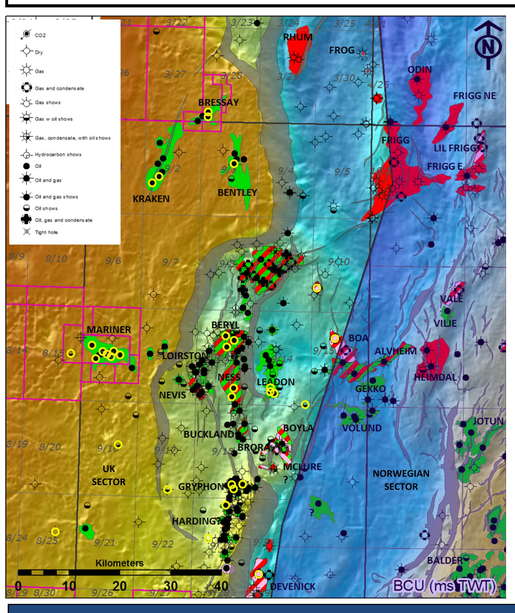
1.ABSTRACT

An investigative study into the East Shetland Platform, part of the mature UK Continental Shelf petroleum province with a focus on geochemistry. The platform bounds the Viking Graben to the west. It was a high throughout most of the Mesozoic, having been affected by Variscan deformation. A thin veneer of recent Tertiary sediment cover is found. The platform is significant for clastic sediment routed through incised valleys and channels on it, into the adjoining basin. Unlike the basin, there remains considerable scope for further exploration on marginal areas such as the platform. The dataset consisted primarily of geochemical reports of highly biodegraded oils, dating back to 1977 of wells drilled in the area. The aim of the study was to determine a link between oils found on the platform and basin based Kimmeridge Clay Formation source rocks. This was done through evaluation of the biomarker data embedded in gas chromatogram and mass spectroscopy data where available in the dataset. Isoprenoids such as pristane and phytane, and terpanes such as gammacerane provided the best indicators of both source maturity and environment. Existing stratigraphic templates were adapted and applied to the raw data to further constrain outputs. The results confirmed the decrease in oil maturity further inbound of the platform, while demonstrating the ability of distal Kimmeridge shales to charge over long distances onto reservoir units on the platform. High well coverage in the area is conducive to 3D petroleum systems modelling in future investigations. Application of statistical tests on biomarker variability posited a possible link between contamination and the observed standard deviation in the measurements. This raises a possible avenue of further research into the effects of drilling on the natural biomarker signature in mature petroleum provinces.



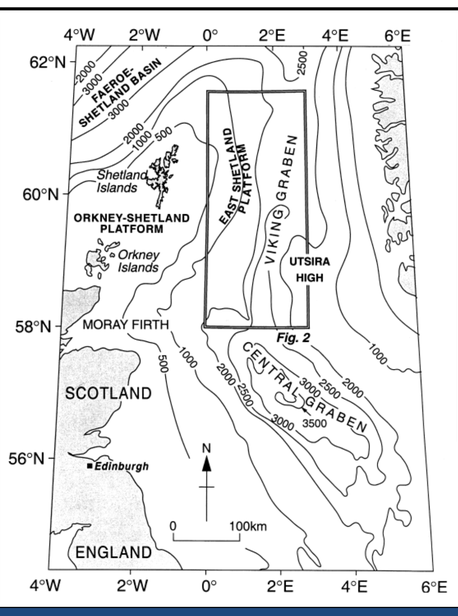


Fig 1 (far left): Depicts the existing fields of the East Shetland Platform in context of the UKCS licence blocks. Wells included in the dataset have been marked with yellow rings. (Adapted from personal communications J. Armstrong, 2015)

Fig 2 (left): A bathymetric profile of the Northern North Sea illustrating the main structural elements. (Adapted from Underhill, 2001).

2.GEOLOGICAL HISTORY & REGIONAL SETTING

The pre-Mesozoic is poorly understood in the North Sea as few wells have penetrated it offshore. Roberts et al, 1995 discussed the importance of pre-Mesozoic tectonic events as controls on rifting in the Northern North Sea. The NNE-SSW alignment of faults in the East Shetland Platform seems to suggest the influence of the Caledonian orogeny (Platt & Cartwright, 1998).

An important phase of Palaeozoic basin development and subsequent deformation is recognisable on the East Shetland Platform. The platform itself was a structural high since very thin Mesozoic-Cenozoic cover is found on it. Until recently the ability to image below the Mesozoic was very poor. Exploration wells on the eastern flank encountered an unconformable surface though this must not be confused with the key Mid-Cimmerian Unconformity throughout the North Sea.

The East Shetland Platform underwent limited subsidence during the Mesozoic. As a result Palaeozoic strata on the platform are less deeply buried than in the Viking Graben. The East Shetland Platform is overlain by 2 km of Tertiary. It forms a wedge that pinches out to the west of the platform.

The Bressay discovery is located on the East Shetland Platform above buried extensional faults related to Late Jurassic rifting. Gravity surveys suggest the East Shetland Platform promontory is cored by Late Caledonian Bressay Granite intrusion (Holloway et al, 1991).

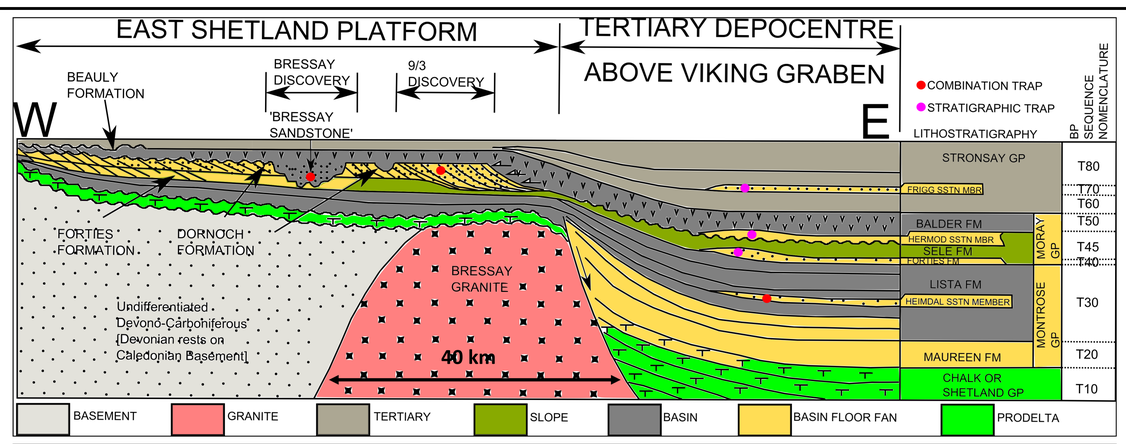


Fig 3: Schematic platform cartoon focused around Bressay discovery with major lithostratigraphic and sequence stratigraphic units shown. (Adapted from Underhill, 2001 & DECC, 2009)

3.STRATIGRAPHY

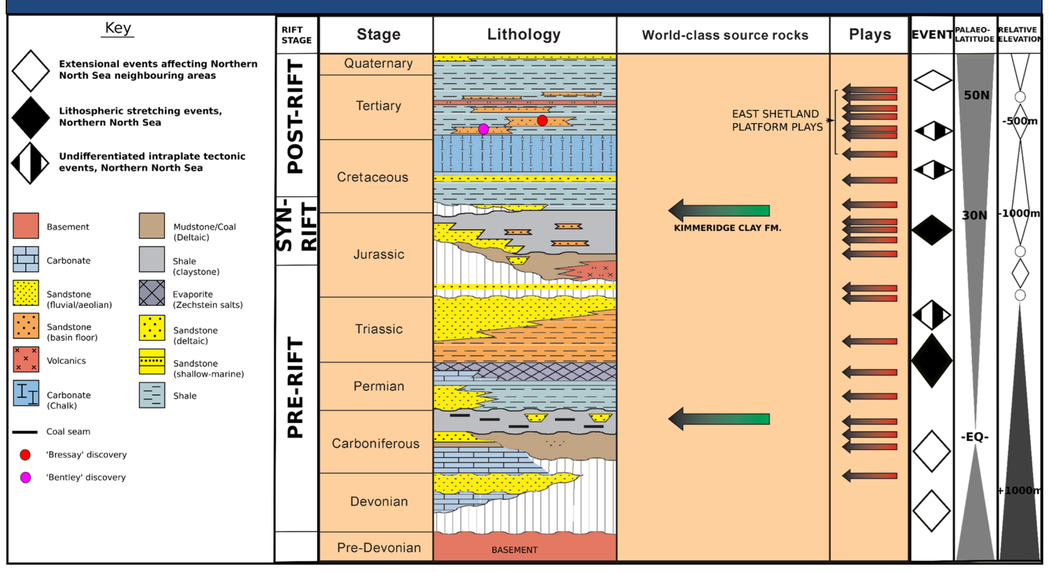


Fig 4: Known plays of the North Sea with corresponding lithostratigraphy, palaeolatitude, tectonostratigraphy, and bathymetry. (Adapted from Vining et al., 2005, Nottvedt et al., 1995 & Gray, 2010). For the purpose of the study the robust Deegan & Skull (1977) lithostratigraphic scheme is used. The BP T-series sequence stratigraphic scheme is useful for correlation.

4.INVESTIGATION WORKFLOW

- Conduct a literature review to gain an understanding of the regional context.
- Index the dataset for Gas Chromatogram (GC) and Gas Chromatogram –Mass Spectrometry (GC-MS) data.
- Reconstruct GC and generate biomarker plots using data.
- Analyse for environmental and maturity information pertaining to oils.

SUMMARY OF DATA	
Blocks	16 (example – 3/28-1, 9/14B-1, etc.)
Fields	9 (example – Bressay, Mariner, etc.)
Wells	39
Geochemistry reports	42 (compiled by Fugro, Robertsons, et al.)
Composite logs	39
Specialised reports	52 (includes brine analyses for example)
Oil analyses	17

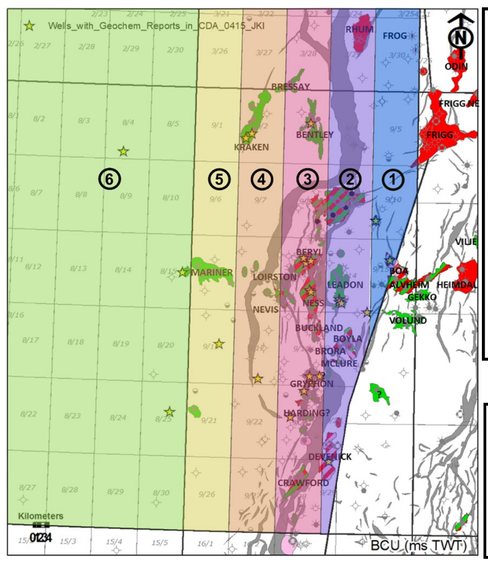


Fig 5: UK Continental Shelf (UKCS) licence block map with coloured overlay of study zones. These zones are of relative distance from the basin and are an attempt to help relate the results of geochemical analyses in an areal manner. These rough zones are used to understand the maturity trends of the oils on the platform.

5.EXPLORATION HISTORY

Over 4400 wells have been drilled in five decades of exploration activity in the area. This is reflected in the mature creaming curve shown for the Northern North Sea. There continues to be interest in exploration targeting areas marginal to the heavily explored basin centre. The existing presence of nearby infrastructure that could be used to exploit any such new finds makes this attractive for operators.

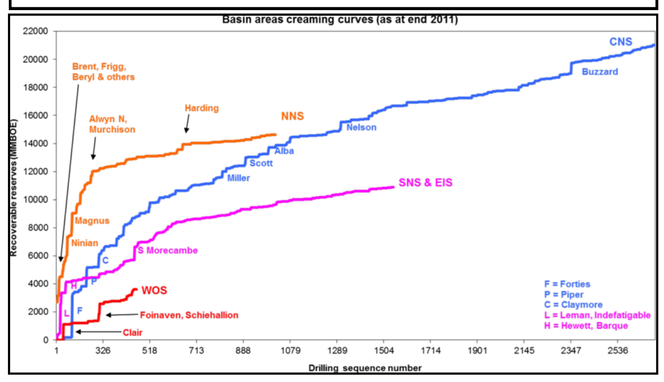


Fig 6 (right): UKCS production history creaming curves against number of wells drilled. NNS in orange. (From Austin et al., 2014)

6.GEOCHEMICAL ANALYSES

Significant evidence of biodegradation, mainly due to bacterial action, is observed in the oils as demonstrated from the GC data. Signs include the presence of Unresolved Complex Matter (UCM) humps of resins, asphaltenes & NSO compounds; lack of key biomarkers (or presence of denatured ones such as demethylated hopane from GC-MS peaks at m/z 191) and very few alkane peaks.

When peaks are present they are in the C12-C16 range associated with diesels and lignosulphates. This is due to the use of a synthetic paraffin based drilling mud called XP-07 (in early flow tests due to failure the recommendations made for improvement were to heat the oil; use a more permissive liner and an oil based mud during drilling). XP-07 is known to be highly prone to bacterial breakdown.

In this part of the North Sea producing reservoirs are mostly shallow. Microbial attack is temperature limited to a max range of 150-180°F. Thus it is reasonable to presume that deeper targets will be safer from the effects of biodegradation. Oils present are low gravity (10-15°API), viscous, highly acidic with aromatics and cycloparaffins constituting 40% and 30% respectively. Triterpane distribution details the effects of biodegradation and indicates oils to be genetically similar across multiple fields in the study area.

Gaps in the data were extrapolated thus introducing uncertainty to be noted. Additionally some techniques such as GC-MS were not fully developed at the time of well spudding.

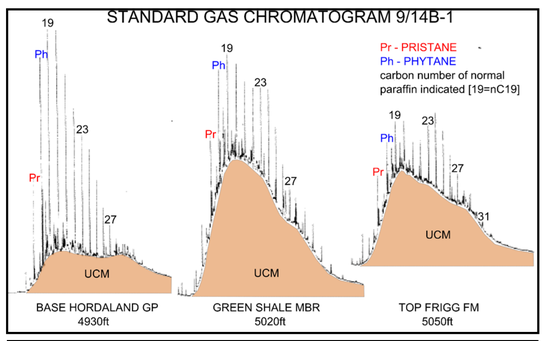


Fig 7: Sample GC from dataset well report demonstrating large baseline drift prevalent in the oils of the study area.

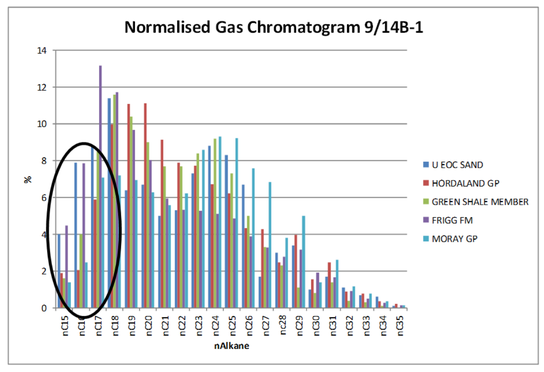


Fig 8: Normalised chromatogram allows noteworthy features of alkane envelope to be distinguished. Circled area indicates water washing and devolatisation due to exhumation and sub-aerial exposure of the platform margin in the Mesozoic.

7.SOURCE—A DEVONIAN QUESTION

An isolated pocket of unaltered 30°API oil is found (~3730') in the Bressay oil column (3530—3765') that is at odds with the much heavier highly biodegraded 11-15°API crudes typical in this area. It could likely be a result of poor reservoir connectivity but equally possible is a secondary migration phase. This secondary migration is likely to be from a source much deeper than 5000' & hence older (kerogen analysis corroborates this). When the Devonian is thermally mature for oil based on geochemical parameters, a caveat remained in that vitrinite exhibits extremely low TOC, thus poor source potential.

Fingerprint analyses and biomarkers from GC & GC-MS detail source provenance, the result of which in most instances is that an anoxic marine setting is implied based on alkane envelope and corresponding biomarkers. This is in agreement with observed mature Kimmeridge Clay in the Viking Graben. This unit is too thin and immature on the platform to locally generate. Thus platform margin oils laterally sourced from graben.

On an X-axis maturity is generally observed as decreasing in maturity moving westward from the platform margin. In some cases like the Kraken field a maturity trend in the Y-axis is seen where maturity decreases going southwards, ie away from the basin (the Heimdall sandstone reservoirs here are charged from the North Viking Graben).

Main issue faced with geochemical characterization of the Devonian using dataset was that in instances where well TD at Devonian, biodegradation resulted in there being few to no reliable biomarkers as stated earlier. But this is largely due to wells only penetrated top Devonian consisting of low TOC sands sub-aerially exposed post Variscan. Mid Devonian lacustrine shales are in fact a good source shown to work in the Orcadian basin.

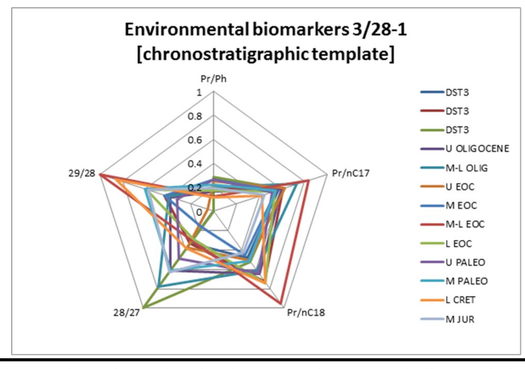


Fig 9 (above): Biomarker radar plot demonstrating range of oils sampled.

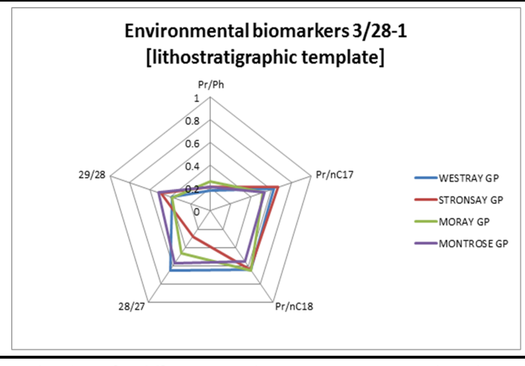


Fig 10: Application of a different template causes some trends to become more apparent, though outliers are lost. Important to keep in mind as this introduces uncertainty to inferences.

8.A STATISTICAL EXAMINATION

Given the highly statistical nature of the raw data an attempt was made at hypothesis testing using standard deviation of biomarker readings. However there was insufficient standard deviation data to do so. Those wells that did possess reliable standard deviation data are shown in Fig 11. these results raise some interesting questions with respect to variability seen between wells and in individual wells themselves. It is posited that the difference in variability of biomarkers could be a function of the length of time after drilling OR the introduction of contaminants. The combination of these two is also a possibility. For a conclusive inference it is suggested that a similar statistical approach be taken to data from wells over a larger areal extent of the North Sea. This could potentially reveal interesting trends in biomarker readings.

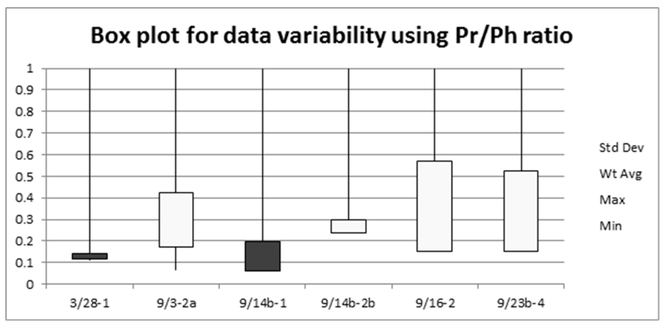


Fig 11: Standard deviation of biomarker readings for wells in project dataset having most reliable data. Note the distinct variability difference for wells 9/14b-1 and 9/14b-2b, both from the Leadon field. It is posited that this could be due to the 5 year gap between the drilling of the two wells. Equally it is possible that drilling contaminants (eg XP-07) are the cause for this.

9.CONCLUSION

- Biodegradation observed in majority of dataset wells.
- Alkane evidence for bacterial influence as well as synthetic contaminants such as oil based muds (XP-07).
- Matching biomarker fingerprints indicates platform reservoirs able to be charged from basinward mature Kimmeridge Clay Fm.
- Maturity trend seen to decrease away from graben source, however sporadic evidence of localised source inconclusive for Devonian play.
- Potential for future studies of transport pathways into platform and further statistical examination to ascertain what effect drilling has on natural geochemical signatures.

10.RERERENCES & ACKOWLEDGEMENT

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