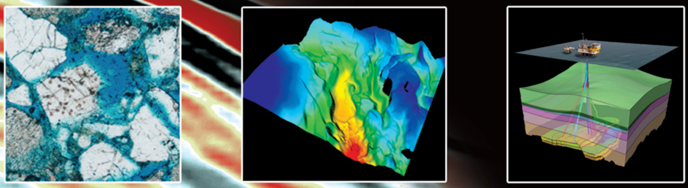

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New learning from exploration and development in the UKCS Atlantic Margin

19 - 21 May 2021

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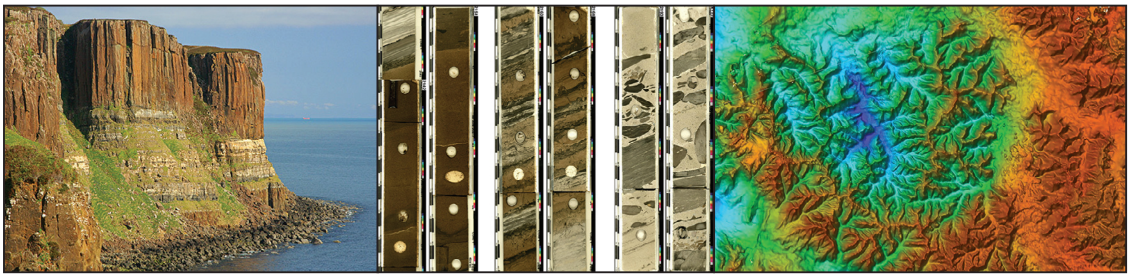

Abstract Book

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19th May 2021

Session one: Regional and Exploration Perspectives 1

Keynote: Wild west outpost to the final Frontier: The history of exploration activity along the NW European Atlantic Margin

John Underhill [1] Nick Schofield[2]
[1]*Heriot Watt University*
[2]*Aberdeen University*

The Atlantic Margin presents a number of different challenges to those facing the North Sea Rift System and other basins of the UK Continental Shelf. As well as the contrasting geology associated with being part of the North Atlantic passive continental (volcanic) margin, industry has had to develop the exploration technologies to cope with deep waters, hostile met-ocean conditions and its remote location.

Initially characterised by 14 dry holes (from 1972-1977), interest in the Faroe-Shetland basin was ignited by the discovery of the Clair Field, in addition to gas in the 206/11-1 and 207/1-3 wells. The Clair Field remained the largest undeveloped oil field in the UK offshore for 25 years until the combination of high-fidelity 3D seismic data acquisition, structural analysis and advent of horizontal drilling unlocked its full potential. Now on production, it is estimated to have a STOIIP of 8 Billion barrels and a production life that will extend for decades meaning it is likely to out-live that of the North Sea.

Five decades after the first exploration well was spudded, our understanding of the basin's history has matured and the tectonic consequences of Cretaceous rifting, Cenozoic transient uplift, igneous activity and basin inversion serve to contrast with more conventional Jurassic rifting and Cretaceous-Recent (post-rift) thermal subsidence seen in the North Sea. A wide variety of plays characterise the basin extending from the challenged basement fracture play, Upper Palaeozoic (Devono-Carboniferous, Clair Group) red beds, Mesozoic (Triassic, Jurassic and Cretaceous) clastics through to Cenozoic (Paleogene) sequences.

The aim of this presentation is to document the history of exploration, highlight the main tectono-stratigraphic events that have created the petroleum province, describe the controls on the main plays in the area and to evaluate the new exploration and low-carbon opportunities in the basin.

Keynote: WOS exploration portfolio maturation in the last 5 years

Anders Madsen
Total E&P UK

The start-up of gas production from the Laggan-Tormore fields in February 2016 followed by Glenlivet-Edradour in August 2017 marked a significant milestone for the West of Shetland and for Total. The development of the Greater Laggan Area (GLA) represents an extraordinary feat of engineering in a basin previously thought too technologically challenging to exploit. Since the first gas produced from GLA to the Shetland Gas Plant (SGP), Total' strategy, together with its partners, has been oriented towards providing additional gas to the infra-structure via exploration and 3rd party opportunities.

Total' strategic vision for WOS is to maximize value by successful and timely exploration. Total's exploration focus is centered around two independent gas plays: the Paleocene play and Lower Cretaceous play. The pre-BCU plays are considered too high risk with limited materiality. Over the last 5 years the strategy has therefore been to capture, mature and high-grade the Paleocene and Lower Cretaceous portfolio with a focus to drill prospects near the GLA infrastructure that provide short cycle development opportunities to fill ullage. An example was the Lower Cretaceous Glendronach discovery in 2018 that was drilled from the Edradour sub-sea template and appraised in 2019. The learnings from Glendronach have further de-risked the Lower Cretaceous play resulting in several high ranking prospects (e.g. Benriach). Several prospects have been matured using recently re-processed 3D seismic PSDM datasets that now provide short- and longer-term infrastructure led exploration opportunities. This includes the Paleocene Ballechin prospect in the same play as the Laggan-Tormore field and the 32nd Round award Cardhu prospect, a sister structure to the Glenlivet field.

On a longer term, Total still have the ambition to unlock the 'Northern Area Gas Hub' (NAGH) located in the Corona High area. While the Lyon well, drilled in 2019, was a disappointment to the industry Total still consider the area very prospective. A new play concept was captured in 32nd Round (License P2604) that contains one of the largest undrilled 4-way closure in WOS. Total will in the coming years, together with its partner Shell, mature the Lower Cretaceous Roseisle prospect to potentially unlock the NAGH.

The Role of Uplift on Petroleum Systems: Impact on Prospectivity in the SW Faroe-Shetland Basin

K.A. Wright[1], A. Bell [1,2], J.R. Underhill [1] and R.J. Jamieson [1]
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[2]Shell Global Solutions International B.V., Lange Kleiweg 40, 2288 GK, RIJSWIJK, Zuid Holland, Nederland

Periods of early Cenozoic uplift and erosion has been recognised across the UK Continental Shelf (UKCS) and are well documented in areas to the north and west, including the Faroe-Shetland Basin, the East Shetland Platform and Inner Moray Firth. These uplift events post-date Mesozoic rifting across the North Atlantic region and disrupt the basins' otherwise continuous record of post-rift subsidence. These areas are also prolific hydrocarbon provinces, with a long history of exploration and production. Given the rich database, it is surprising that there has been limited research into the impact of early Cenozoic uplift events on prospectivity, despite many studies in other basins around the world demonstrating that the effects of uplift can and often does, have significant impact on the petroleum system.
Our study focused on the Faroe-Shetland Basin, where two periods of Cenozoic uplift have been documented, 1) a regional unconformity during the lower Eocene, which records the temporary subaerial exposure and development of an extensive drainage system and 2) a regional unconformity during the mid-Eocene, which records compression and development of permeant localised uplift. Extensive seismic mapping and attribute analysis revealed key details of the regional depositional history during the early Cenozoic. These included the interplay between channels and underlying basement highs, and the development of a central incised valley fill system.
Minimum estimates of erosion for the two periods of uplift were calculated via a combination subsurface data, depth converted thickness maps and assessment of paleo-channel incision where channels existed. These estimates were used in a series of 1D basin models for well locations chosen across the study areas to represent the suite of stratigraphy and structural features. We present a full cycle study, from seismic interpretation to basin modelling, and the results of this data-driven approach on understanding the charge, migration and petroleum decompression story in the SW Faroe-Shetland Basin, with the most significant results being the effects of temporary and permeant uplift.

19th May 2021

Session two: Regional and Exploration Perspectives 2

Keynote: The challenges of exploring for and developing oil and gas fields in the Atlantic Margin: insights from an active operator

Iain Bartholomew
Siccar Point Energy

The UKCS Atlantic Margin has always been perceived as a challenging environment for oil and gas. Two main reasons: geological (igneous province) and operational (deep water hostile environment).

Since exploration started in the Atlantic Margin geoscientists have generated a vast number of play ideas and related leads and prospects. The first well was drilled in the Atlantic Margin area in 1972 and the first significant discovery made in 1977 (Clair). However, due to both geological and operational challenges, no field was brought on stream until 1997 (Foinaven) with Clair itself not coming on stream until 2005.

Less than 7% of all the UKCS offshore exploration wells have been drilled in the Atlantic Margin area (174 out of 2523). Compared to the North Sea, many opportunities remain undrilled. The OGA estimates that 6.3 billion barrels oil equivalent mean risked prospective resource is yet to be found in the West of Shetland area.

In the last 10 years there have been substantial technical advances in the basin that have enabled a much better understanding of the geology and has resulted in an increase in drilling activity.

Siccar Point have a substantial acreage position in the Corona High area. They acquired this area from the acquisition of OMV takeover and have continued to build on the technical work carried out by OMV.

The Corona High has two fully appraised but as yet undeveloped Paleocene/Eocene oil fields on it: Rosebank with intra-volcanic Colsay Mbr. non-marine reservoirs, and Cambo with post-volcanic Hildasay Mbr non-marine reservoirs. These two fields have over 2 billion barrels of oil in place in total. The Blackrock exploration well was drilled in 2019 which discovered thin oil-bearing Colsay non-marine reservoirs and requires further appraisal. There are many undrilled prospects and leads in the area with multiple target reservoirs including intra-volcanic sands, Mesozoic and Palaeozoic sands against and within structural highs, basin-floor sands, and fractured basement highs.

Key breakthroughs have been made by Siccar Point in the geological understanding of the area. These have been enabled by:

- New long-offset broadband and OBN seismic datasets which have allowed much higher fidelity interpretation both within and under extrusive and intrusive igneous sequences
- Keeping a strong focus on basic regional geological assessment
- Working with university research departments and licence partners to better understand the interaction between siliciclastic sediments and lava flows
- Working with university research departments and specialist consultancies to understand basin heat flow and hydrocarbon generation and migration

The breakthroughs that have been made in geological understanding are:

- The expected distribution of siliciclastic sedimentary sequences along the entire western edge of the Corona High restricted by lava flows creating topographic highs
- A realisation that local Kimmeridge source rocks are generating oil at the present day when taking new estimates of basement heat flow and the thicknesses of Paleocene intrusive sequences into account

On the operational challenges several step changes have happened which have unlocked the future development of the area:

- Enough experience has now been gained of drilling through volcanic sequences to give confidence in drilling these sorts of wells
- FPSO technology has progressed for deep water harsh environments: Siccar Point is developing the Cambo Field with a relatively low cost cylindrical vessel from Sevan
- Deep water sub-sea gas field developments have now been achieved with Laggan-Tormore coming on stream in 2016

Siccar Point Energy expects that the Corona High area, as well as many other areas in the Atlantic Margin will become the main oil and gas producing region for the UK.

Growth and maturation of an exploration portfolio through seismic acquisition and processing: a decade of seismic exploration in the West of Shetland

Conrado Climent, **Shiju Joseph**, Helen Cromie, Sam Cooper, and Jenny Morante-Gout
TOTAL UPSTREAM DANMARK A/S

Subsurface uncertainties in the West of Shetland (WoS) are often large due to complex geology, pervasiveness of volcanic material both extrusive and intrusive and, in the case of many plays, a lack of calibration wells.

With 160 exploration wells, primarily drilled based on suboptimal vintage 2D and 3D, often due to the challenging nature of seismic acquisition in the hostile environment, the underexplored WoS still holds significant high impact prospectivity. During the last decade, Total E&P U.K Ltd have, along with its partners and contractors, acquired, processed and reprocessed numerous 3D seismic surveys over large areas of the West of Shetland.

A combination of proactive planning, the integration of new seismic acquisition and processing technologies together with agile reactivity to new opportunities, allowed Total to obtain high-quality 3D seismic data over the entire held acreage. The extensive seismic database, fully integrated with all available data, equipped geoscientists to conceptualise novel plays, identify and mature new prospects including Glendronach, de-risk others and ultimately build a strong portfolio to fuel the exploration of the next decade.

This talk will summarise the last decade of Total's efforts in the integration of regional knowledge and exploration in the WoS from a seismic perspective: how long offset broadband 3D data, modern processing techniques and the seismic based studies has impacted the understanding of the basin and shaped decisions to acquire acreage and drill prospects, or relinquish acreage.

Exploration in the Northeast Rockall Basin 2013-2019

Clayton Grove[1] and Chris Forster[1]
[1]*Siccar Point Energy Ltd.*

The Northeast Rockall Basin (NERB) is located on the UK Atlantic Margin approximately 100 km NW of Stornoway (Isle of Lewis), with present day water depths between 100 m and 1100 m in the licensed acreage. The basin is closely analogous with the Faroe-Shetland Basin to the NE, which is separated by the Wyville Thomson Ridge bathymetric high.

The geology of the NERB is constrained by seven exploration wells locally, which provide useful stratigraphic information to the base of the Paleogene (TD in uppermost Cretaceous), although two wells TD in Precambrian basement rocks (164/25-2 and 153/03-1) and one well in Permo-Triassic red beds (164/25-1z). Petroleum has been encountered in three wells: a gas discovery was made in 154/01-1 (Benbecula), oil shows in side wall core samples were found in 164/28-1A and weak shows were observed in 164/25-1z. All evidence for petroleum has been found Paleogene sedimentary rocks. The petroleum has been typed to the Upper Jurassic source rocks (e.g. Kimmeridge Formation).

Seismic reflection data spans sparse 2D data shot in the 1970s, 1990s acquisition of denser 2D grids, late 90s acquisition of 3D centered on gaps in the igneous cover in basin-centre locations, and recently in the 2010s long offset 'broadband' 2D data. The seismic data quality is poor compared to what is available in the Faroe-Shetland Basin (FSB) in extent and quality, as the most up to date 3D acquisition and processing has not been utilised and the near-complete basin-wide legacy 3D datasets do not exist.

Despite the sparsity and quality of data, a working petroleum system has been proven and good quality reservoirs have been encountered. Sufficient information exists to show that the current basin configuration was probably due to rifting in the Lower Cretaceous, much like the Faroe-Shetland Basin, followed by post-rift sag until minor rifting in the Eocene affecting the basin margins. Periods of compression are evident from the Miocene to present, with significant basin inversion apparently localised to the Wyville Thomson Ridge and the West Lewis Basin. Reservoir quality sandstone intervals have been encountered in Permo-Triassic, Paleocene and Eocene strata, with the main potential seen in the Paleocene Vaila Formation (Fm.) and the Paleocene-Eocene Flett Fm. The Paleocene stratigraphy is related to the FSB but is notably different in that the reservoir-quality Vaila Fm. is part of sequence T22 and sequences T34 to T36 are formed of volcaniclastic material, suggesting widespread volcanism began earlier than in the FSB. The Flett Fm. is similar to the Corona Ridge in the FSB, comprising lava flows interbedded with excellent quality siliciclastic sandstone deposited in basins where competition for accommodation existed between the volcanic and siliciclastic components.

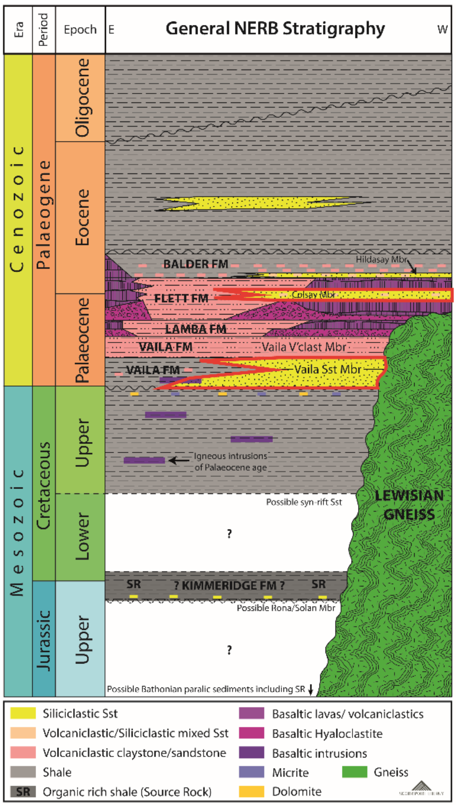
OMV UK began basin screening in 2013 under a bullish frontier exploration strategy during a high oil price environment. The screening included a review of the strategies and released databases from previous operators exploration of the basin. Significant quantities of 2D and 3D seismic data were licensed, well databases were brought up-to-date, biostratigraphic, gravity, magnetic and satellite seep data were purchased. Early on it was noted that the previous exploration campaigns focused on the basin-center, where the 3D surveys were shot through a 'hole in the lava' and that igneous intrusions were common. Crude basin models showed that the source rock (not drilled or directly mapped) could be in the oil window with conservative assumptions made. Mapping on legacy data against the comparatively underexplored basin margin showed that trapping potential existed up-dip of the wells with petroleum shows; although this meant exploring beneath lava flows. Before the licence application two main leads had been defined: the Flett Fm. 'Cumberland' lead and the Vaila Fm. 'Chorizo' lead, which were stacked and situated against the eastern basin-bounding high- the West Lewis Ridge (WLR).

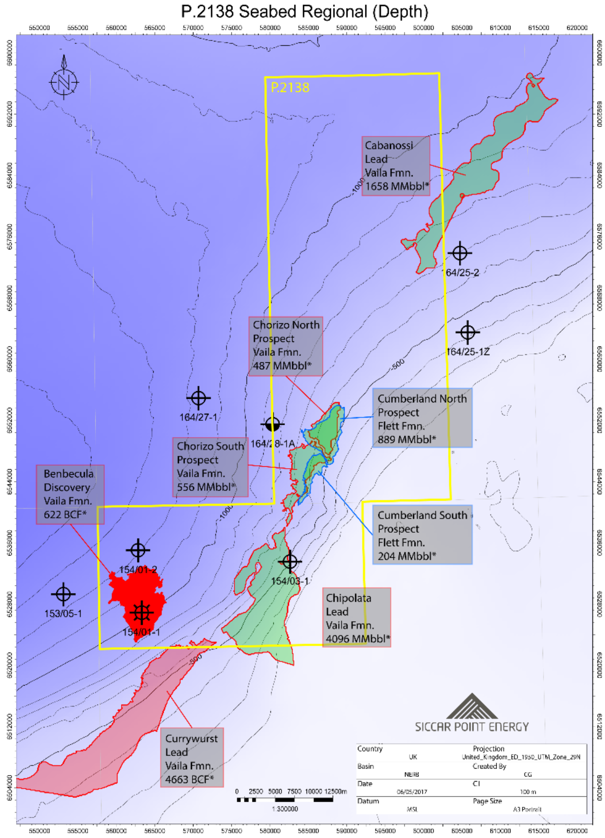
The bid was successful in the 28th Round and the P2138 joint venture (OMV UK, Statoil and DONG Energy) embarked on a 9-year Frontier Licence work programme which kicked off by shooting a grid of long offset 2D data (GeoPartners/Seabird RR14) designed to investigate the structural and stratigraphic configuration of the NERB & WLR, and cover the area to the east of the legacy 3D data to define Cumberland and Chorizo. The secondary objective was to aid deep imaging to map potential source rock horizons and screen for structural traps unimaged by legacy short streamer data. The RR14 was processed with 'DUG Broad' broadband processing techniques and provided imaging as good as legacy 3D data. The RR14 survey proved the existence of the WLR and that several horizons that could be tied to reservoir in wells pinched out against the high, up-dip of existing petroleum shows or accumulations. The extensional faulting in the Eocene was also confirmed. Once initial interpretations were made, gravity modelling was used to estimate depths to basement in the hypothesized source kitchen to provide a maximum depth to source and aid petroleum systems modelling.

Oil price crashed over the 2014 to 2015 winter, as the RR14 was being processed. As a result of the economic shock to the industry, £20 million was made available by the treasury to fund seismic surveying, of which c. £10 million was secured for the greater Rockall Basin area (WG15 survey). A number of the 2D lines were shot across the NERB. Despite the efforts of the government, frontier exploration became very unfashionable under the low-oil price environment and the NERB received no further licensing interest in subsequent licensing rounds.

Work continued prospecting in P2138 in earnest, during 2016 through to the sale of OMV UK to Siccar Point Energy in 2017, which involved seismic mapping on the newly received seismic datasets and additional data purchase. The mapping resulted in the definition of a number of new leads and progression of leads into prospects. In total, 7 new leads were defined in P2138. Leads in the Vaila Fm. are: Chorizo North, Chorizo South, Cabanossi, Chipolata and Currywurst. The leads in the Flett Fm. are: Cumberland North and Cumberland South. Water depths in the region of the leads range from 200 m to 1000 m. All leads are predicted to be oil, except Currywurst which is gas. The volumetric estimations are material, although the geological chance of success is low as a result of sparse data coverage (leads are not fully defined by 3D data).

The work program has shown that the elements of a working petroleum system exist in the NERB and material prospects are present. In order to progress the prospects to drilling, modern 3D seismic acquisition is required, which under the current economic conditions is not supported. Should modern 3D data be acquired, the NERB has the potential to become a successful petroleum basin.


Era
Period
Epoch
E
General NERB Stratigraphy
W
Cenozoic
Palaeogene
Oligocene
Eocene
Palaeocene
Mesozoic
Cretaceous
Upper
Lower
Jurassic
Upper
BALDER FM
Hildasay Mbr
FLETT FM
Colsay Mbr
LAMBA FM
VAILA FM
Vaila V'clast Mbr
VAILA FM
Vaila Sst Mbr
Igneous intrusions of Palaeocene age
Possible syn-rift Sst
LEWISIAN GNEISS
?
SR
? KIMMERIDGE FM ?
SR
Possible Rona/Solan Mbr
?
Possible Bathonian paralic sediments including SR
Siliciclastic Sst
Volcaniclastic/Siliciclastic mixed Sst
Volcaniclastic claystone/sandstone
Shale
SR Organic rich shale (Source Rock)
Basaltic lavas/ volcaniclastics
Basaltic Hyaloclastite
Basaltic intrusions
Micrite
Gneiss
Dolomite


P.2138 Seabed Regional (Depth)
P.2138
Cabanossi Lead Vaila Fmn. 1658 MMbbl*
Chorizo North Prospect Vaila Fmn. 487 MMbbl*
Cumberland North Prospect Flett Fmn. 889 MMbbl*
Chorizo South Prospect Vaila Fmn. 556 MMbbl*
Benbecula Discovery Vaila Fmn. 622 BCF*
Cumberland South Prospect Flett Fmn. 204 MMbbl*
Chipolata Lead Vaila Fmn. 4096 MMbbl*
Currywurst Lead Vaila Fmn. 4663 BCF*
64/25-2
164/25-1Z
164/27-1
164/28-1A
154/01-2
154/01-1
154/03-1
153/05-1
SICCAR POINT ENERGY

19th May 2021

Session three: Basement & Palaeozoic

Mapping the Faroe-Shetland Basin basement: key new data for Basin Modelling and exploration.

Alexander Finlay[1], Julian Moore[2] , Rob Strachan[3] & Brenton Fairy[1]
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Lithospheric crustal composition and structure acts as a primary control on the thermal regime in sedimentary basins, with up to 50% of surface heat flow originating from radiogenic heat production (RHP) from the upper crystalline crust and basin infill (Vilà et al., 2010). However, basin modelling is often performed with either little or no regard to the composition of the crust. We propose that the geochronological and mineralogical/petrological mapping of differing basement terranes is a critical tool that has to be undertaken in order to understand heat production. The motivation of this work is to provide an integrated database that allows the mapping of contrasting basement zones (some may be terranes) and for the heat flow(s) representative of each of zone to be parameterised and calibrated.

The Faeroes – Shetland Basin (FSB) continues to be a focus of active exploration. Away from the basin-bounding ridges, the FSB is dominated by Palaeogene reservoirs and petroleum sourced from the Upper Jurassic Kimmeridge Clay Formation, on the ridges themselves accumulations rely on Cretaceous seals that are unlikely to be competent prior to Tertiary burial. What is less certain is the age of generation, with most models predicting oil generation in the mid Cretaceous (e.g. Holmes et al., 1999) before Palaeocene reservoirs had been deposited. Various methods have been utilised to explain this (e.g. motels – Lamers and Carmichael, 1999 or overpressure delaying generation/expulsion Carr & Scotchman, 2003). One of the reasons for this is the data commonly being used in basin models and uncertainties in the complex geology of the basin. For example, Gardiner et al. (2019) modelled oil generation (utilising calculated values for basement Radioactive Heat as well as removing Palaeocene sill thicknesses) as occurring in the Palaeocene, in agreement with observed geology. Therefore, to be able to produce basin models accurately and precisely in the FSB model population and parameterisation should be driven by the geology and not the software defaults. Previous studies over emphasize the importance of 'critical' moment adding unnecessary complexity.

The metamorphic basement of the Faroe-Shetland Basin has commonly been assumed to be analogous to the Lewisian Gneiss Complex of the Hebrides and mainland N.W. Scotland. However, in 2014 Chemostrat produced a reconnaissance U-Pb zircon geochronology study that demonstrated that although the igneous protoliths are Neoarchean in age (c. 2.7-2.8 Ga), there is no evidence for the *high-temperature* Laxfordian (c. 1.7-1.8 Ga) reworking that is characteristic of the onshore Lewisian. This dataset was recently confirmed by a larger-scale study carried out by Holdsworth et al. (2019) who concluded that the FSB basement correlated with the Archaean Rae Craton of S.E. Greenland.

Therefore, to fully understand the variation in basement and quantify the data needed to produce accurate basin models across the FSB, Chemostrat Ltd and APT Ltd have collaborated to produce a new study that maps the composition, crystal size, fracture (thin section scale) age, deformation and RHP variations in basement as well as apatite thermochronology and maturity variation in sediments across the FSB.

This paper will present a summary of these findings and how they can be used to split the FSB into four distinct basement zones, each with different RHP properties (See Fig.1). Furthermore, we will show how this integrated dataset also provides key geological information outside of basin modelling such as how basement fractures vary across the FSB as well as surprising information on the provenance of sands in the basin. Finally we will look in detail on the boundary between two zones and propose a revised location of the Caledonian Front.

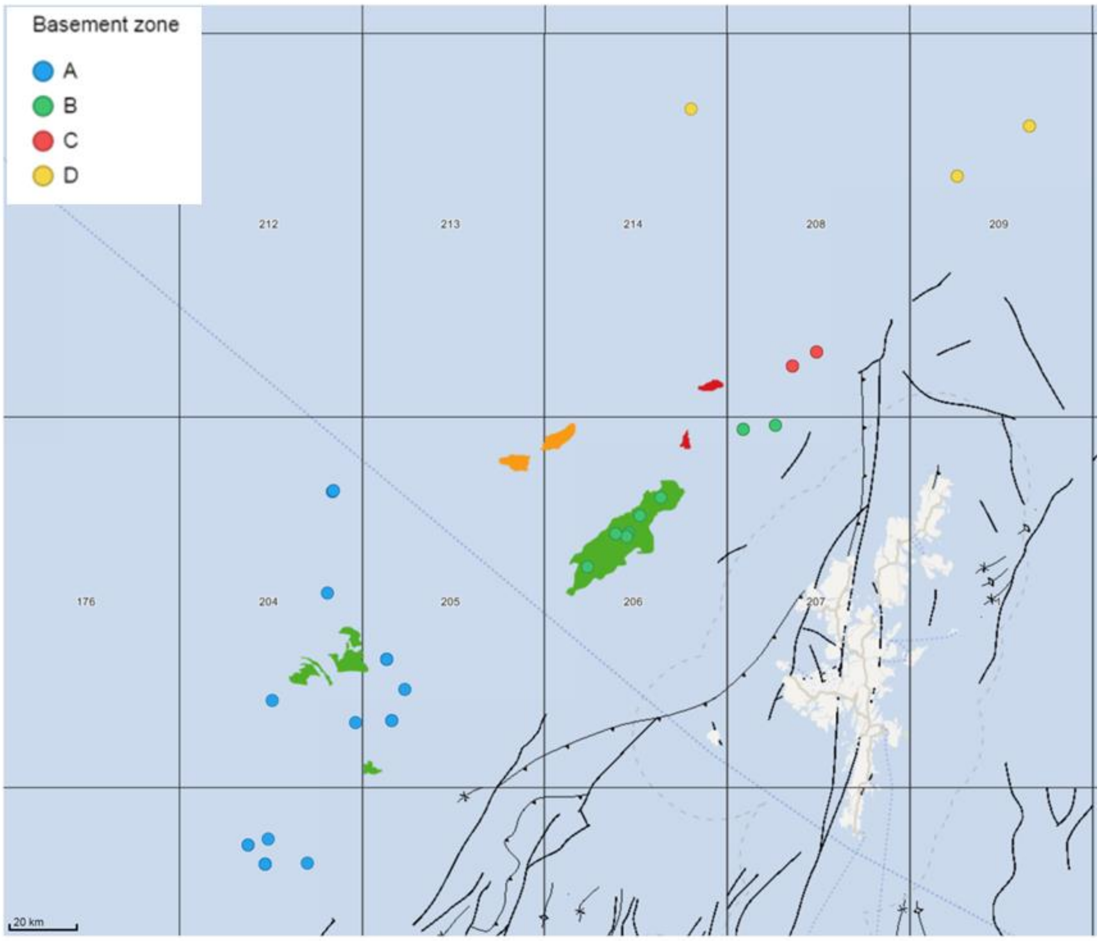

Figure 1 - Distribution of Basement wells sampled for this study, colour coded by interpreted basement zone.

Clair Ridge- Segment 2A: structural restoration and identification of multiple stratigraphic scenarios to reduce risk in well planning

Kamila Costaschuk
Shell International Ltd

The giant Clair field has recently entered its second phase of development, following first oil of the new Clair Ridge platform in Q4 2018. As part of the Clair Ridge development, a major back-to-back drilling campaign has commenced, targeting the five segments outlined in the FDP. Segment 2A which is the focus of this study was unpenetrated pre-development, however early drilling results have indicated unexpected stratigraphy and risk to reservoir presence. This study was therefore tasked to provide a range of new interpretations of structure and stratigraphy in order to estimate ranges of hydrocarbons in place, define likely interaction with neighbouring segments, and re-evaluate the targets within this segment in light of this new information.

Seismic interpretation was conducted to identify four alternate scenarios. Structural analysis was then used as a tool for validation of interpretations prior to building geocellular models in Petrel. CRS mapping for reservoir presence and distance to fault was then performed to identify lowest risk areas for potential targets. Dynamic data, correlation of well to seismic fracture data and reservoir juxtaposition across faults were used in assessing intra- and inter-segment flow potential.

Results of the study indicate there is a wide range of uncertainty related to the stratigraphic fill of Segment 2A. The main uncertainty driver controlling the volume of LCG preserved was identified as the extent of the intra-Clair unconformity. Secondary drivers were also identified such as fault spacing and position, basement pick, and Lower Clair group stratigraphy interpretation. Taking a range of interpretations allowed identification of areas that had reservoir presence across multiple scenarios. Structural restoration provided key insight into interpretation validity and paleo-topography prediction, and thus confidence in reservoir presence and unit stratigraphy. Juxtaposition of high net-to-gross units was found across the segment bounding faults and thus some form of pressure communication across the neighboring segments is expected. Fault related fracture patterns were observed over Clair Ridge with fracture density decreasing with distance from faults.

This study highlights the importance of taking a range of interpretations in areas where seismic data cannot be fully relied on to resolve reservoir presence and deliverability.

Understanding the provenance of the WoS Clair Region and how this has improved our understanding of Devono-Carboniferous reservoirs during exploration and field development.

Paula McGill[1,2] and Iain Greig[2]
[1] *HM Research Norway AS*
[2] *HM Research Consultants Ltd*

The clastic sediments of the palynologically barren Clair Group are widely distributed across the West of Shetland basins and represent sediments deposited during the Devonian and Carboniferous periods. They represent continental fluvio-lacustrine environments and reach over 1000 m thick in places. In addition to these great thicknesses of clastic sediments, they also host significant hydrocarbon reservoir volumes. The greatest challenge to understanding these sediments in greater detail lies in the absence of a biostratigraphic framework that would otherwise assist in basin-wide correlation. An alternative approach to better understand this sequence has been developed using evolving provenance signatures throughout the Clair Group, a change that can be detected by a number of heavy mineral analysis techniques.

Heavy mineral analysis on the Clair Group succession has provided a correlation framework using ten formations, some of which can be sub-categorised. This detailed stratigraphic framework lends to heavy mineral analysis being used as an aid to geosteering and the picking of casing shoe/coring points during drilling of production and exploration wells. Depending on rate of drilling, heavy mineral results have previously been acquired ahead of logging data, and in cases has allowed for the continuation of drilling where electronic logging tools have failed.

This presentation provides a case study overview from the Clair Region and how heavy mineral analysis has provided a better understanding of the area and how it assisted in continued development of the Field. The success of heavy mineral correlation in this region allows the speculation of its use in the surrounding basins.

19th May 2021

Session four: Mesozoic

The Lower Cretaceous Royal Sovereign: 40 years in the making

Hanna Albrechsten, Sam Cooper, Helen Cromie, Shiju Joseph, Conrado Climent, Jenny Morante-Gout
Total Upstream Danmark A/S

Exploration targeting the Lower Cretaceous deep-water rift stratigraphy along the western flank of the Rona Ridge, West of Shetland, has seen limited success. Coarse clastic turbidite systems shed off the West Shetland Platform during cyclic lowstands from the Aptian through to the early Turonian, and deposited reservoir quality sand as basinal equivalents of the shallow marine Victory Formation. Since the late 1970's these turbidite plays have been the target of several exploration wells in Quad 206, particularly chasing the Commodore Fm. (Cenomanian-Turonian) due to its attractive seismofacies and good reservoir quality. The older, Aptian-Albian Royal Sovereign Fm. has fewer penetrations and has previously been considered poorer quality.

The main prospectivity identified in these systems are large three way-dip structures that onlap against the Rona Ridge crystalline basement. The overpressure and presence of highly effective vertical pressure barriers are key to unlocking the prospectivity of these structures. The Commodore Fm. is generally observed to be near-hydrostatic with potentially severe implications on prospectivity due to the inability of the play to retain overpressure against the fractured basement. In contrast, the deeper Royal Sovereign Fm. is recognised to be regionally overpressured, supporting the presence of an effective lateral seal and improving the likelihood of discovering significant hydrocarbon accumulations.

The Glendronach gas discovery well 206/4a-4, drilled in 2018, was the first to penetrate a wedge of Royal Sovereign Fm. in a proximal position onlapping against a combined basement and Jurassic lateral seal, finally proving the hydrocarbon potential of the play after 40 years. The potential continues into the Benriach prospect, a sister structure to the north where seismic amplitude character implies continuation of the Royal Sovereign play.

Victory Field Update

Donal O'Driscoll, Rosie Jowitt, Dave Hanley

All Corallian Energy Ltd

The Victory Field is located 50km north-west of Shetland in UKCS Block 207/1a. The field comprises a rotated fault block structure with a Lower Cretaceous aged sandstone reservoir, charged with dry gas of thermogenic origin. The discovery well 207/01- 3 was drilled by Texaco in 1977, finding over 60 metres of net gas pay at 1,263 metres subsea. The reservoir was gas-bearing to base and tested gas at up to 9.2 million cubic feet per day before sanding up. The reservoir is a shallow marine sandstone characterised by high net-to-gross ratio and excellent porosity and permeability.

The discovery was described by Goodchild et al (1996), who estimated gas-in-place to be between 250 and 350 billion cubic feet. The Victory block was held by Texaco / Chevron with 100% equity from 1972 until 2018. Corallian Energy acquired 100% equity interest in December 2020 via the 32nd Round of Offshore Licensing, having applied for a Second Term Licence and committed to submitting a Field Development Plan with 18 months of award.

The Victory field is fully imaged by a 3d seismic survey that was acquired and processed by Shell in 1996. Interpretation of the 3d seismic data set, the discovery well 207/1-3 and the three offset wells 207/01- 1; 207/01- 2 and 207/01a- 5 help to bracket the extent of the discovery within the range of the resources estimated by Goodchild et al.

Since award Corallian has progressed pre-FEED studies, including:

- Reprocessing of the 3D seismic from field tapes resulting in better imaging of the Lower Cretaceous section
- Synthetic seismic wedge modelling of the Lower Cretaceous reservoir interval
- Petrophysical re-evaluation of the discovery well and reservoir grain size analysis
- Reservoir depositional modelling
- Petroleum engineering evaluation of the original well test
- Preliminary well design including completion design for sand control
- Static and dynamic reservoir modelling
- Engagement with the nearby infrastructure owners.
- Planning for an Environmental Baseline Survey in the summer of 2021.

Results of these recent studies indicate that the field can be depleted using one production well. The authors will present an updated seismic interpretation and reservoir depositional model for Victory, along with a summary of subsurface modelling studies.

The Early Jurassic sedimentology, palaeobathymetry and palaeobiogeography of West of Shetland

T.J.H. Dodd[1], J.B.Riding[2], Kevin Page[3], J.E. Thomas[2], M.A. Stewart[1], *V. Starcher[1],* M.F. Quinn[1] and I.J. Andrews[1]

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The depositional environments in the Early Jurassic are relatively poorly understood West of Shetland. Key lithostratigraphical units in this area include the lowermost Stack Skerry and overlying Sule Skerry formations of the Skerry Group (Lower Jurassic). Previous work loosely defined a 'shallow marine, inner shelf setting' for the Stack Skerry Formation, and a 'shallow marine' environment during Sule Skerry Formation times. Furthermore, Early Jurassic ammonite zonations and associated palaeobiogeograhical distributions are reasonably well-constrained within the literature for the North Sea, and to some extent in the sedimentary basins West of Shetland. However, these models require constant updating in the event of new discoveries in parts of the world. This study forms part of a much larger consortium project completed between 2015 and 2018 that involved the British and Faroese geological surveys and industry partners (Faroe-Shetland Consortium Phase 3). One of the aims of this consortium project was to better assess the distribution and character of Jurassic strata in the Faroe-Shetland Basin, and the wider West of Shetland area in general.

This study analyses *c.* 50 m of conventional core data from the well 202/03a-3 in the West Solan Basin. Overall, the well contains 13 m of Stack Skerry Formation strata, overlain by 36 m of Sule Skerry Formation strata. Analyses included 1:10 cm scale sedimentological logging, capturing information on lithology, grain size and sedimentary structures, along with detailed palynological sampling of the succession. From this analysis, a re-evaluation of the sedimentary processes and palynological assemblages were completed in order to determine the overall environment of deposition and re-assess the age determinations made for those successions. During this analysis, well-preserved ammonite body fossils were obtained from parts of the core material that represent sediments of the Stack Skerry Formation, and were assessed as part of the study in order to support the sedimentological and palynological data.

The Stack Skerry Formation in well 202/03a-3 is comprises mudstones and siltstones, thinly interbedded with 'clean', ripple laminated, parallel-laminated, and well-sorted sandstones. The mudstones and siltstones commonly display moderate to intense bioturbation and range between 0.5–1 m in thickness. The thickly-bedded sandstones are clean, well-sorted, fine-grained and structureless, with some evidence for de-watering in the form of dish structures, particularly near bed bases. Individual sandstone beds range from 10–100 cm in thickness, and stack vertically forming up to 4 m thick, amalgamated packages. Occasionally, 2–3 cm-thick sandstones bed tops are composed of a carbonaceous-clast-rich, parallel-laminated, sometimes asymmetrically ripple laminated, argillaceous, normally-graded sandstone. Within these bed tops, clay and silt grade matrix concentrations increase upwards, along with the addition of mud-clasts and carbonaceous material. Well-preserved ammonite body fossils were encountered within 202/03a-3 within the Stack Skerry Formation, as well as feeding burrows representing the *Teichicnus* ichnogenera, of the *Cruziana* ichnofacies. The age of the Stack Skerry Formation is indicated by the presence of the dinoflagellate cyst *Liasidium variabile*, indicating a Late Sinemurian age, no younger than the Raricostatum ammonite zone.

The depositional environment of the Early Jurassic Stack Skerry Formation is interpreted as a shallow-marine, shelfal setting. The presence of ammonite body fossils proves an open marine setting was present during this time. The mudstones and siltstones represent background deposition on a marine shelf, with hemi-pelagic processes periodically interrupted by low-density (dilute) turbidity currents, potentially fed from fluvial systems, draining into a shelfal area and depositing thinly-bedded parallel and asymmetrical ripple laminated sandstones. The thickly-bedded structureless sandstones represent the deposits of high-density turbidity currents and/or hybrid event beds, which formed thick, sandstone-prone turbidite fans that occasionally disrupted the otherwise background sedimentation.

The overlying sediments of the Sule Skerry Formation comprise homogenous, dark grey to brown-coloured, parallel-laminated mudstones, with a complete lack of nodules, pyrite, shelly material, or bioturbation, and a general absense of coarse-grained material. The only visible heterogeneities are scattered patches of light grey-coloured laminae, composed of very fine-grained sand, which display an elevated micaceous component within the matrices. Palynological evidence from the Sule Skerry Formation in well 202/03a-3 includes the presence of acritarchs (*Micrhystridium* spp.), foram tests and rare dinocysts. Only negative evidence (absence of *Callialasporites* spp.) is found for these strata to be assigned to the Early Jurassic. The depositional environment of the sediments of the Sule Skerry Formation in 202/03a-3 is deep marine. The mudstones are considered to be deposited as hemi-pelagic fall-out within the water column, most likely within a deep-marine setting. The lack of bioturbation or shelly material within these sediments suggests an anoxic/dysaerobic bottom water. The marine interpretation for these sediments is supported by palynological evidence, with acritarchs, foram tests and dinocysts all suggestive of a relatively open marine setting during this time.

Macrofossil evidence in the form of 14 examples of well-preserved ammonite body fossils found within the Stack Skerry Formation in 202/03a-3, were identified as species *Echioceras* sp. and *Crucilobiceras* sp., assigned to the *Echioceras raricostratum* ammonite zone (latest Sinemurian). This zone can be subdivided into four subzones including the *Raricostatoides* Subzone to which all the specimens from 202/03a-3 are allocated. Not only do these ammonites provide a high-resolution biostratigraphical pick for the Stack Skerry Formation in well 202/03a-3, but this is by far the most northerly occurrence of this genus, indicating that there was a marine connection between Western Europe and the basins West of Shetland during this time.

In both formations, the sedimentary evidence, palynological determinations and ammonite body fossils suggest a model of geological evolution in which both shallow marine and deep marine conditions were present in the areas West of Shetland throughout the Early Jurassic. This supports regional models whereby marine conditions were well established by, and throughout, the Early Jurassic, with extensive connections through the Arctic and proto-Atlantic rift systems from the early Mesozoic onwards. In particular, this northerly occurrence of ammonites belonging to the *raricostatum* ammonite zone suggest a significant connection between the Arctic, proto-Atlantic and other Tethyan regimes. The findings of this study also speak to the model of active extension likely occurring in the areas West of Shetland during these times, forming the structural basin areas, along and through which the marine systems connected.

20th May 2021

Session five: Volcanic Associated Reservoirs 1

Keynote: The Role of Igneous Rocks within the Petroleum Systems along the Atlantic Margin - What have we learnt?

Nick Schofield[1], David Gardiner[2], Niall Mark[1], Simon Holford[3], Alex Edwards[4]
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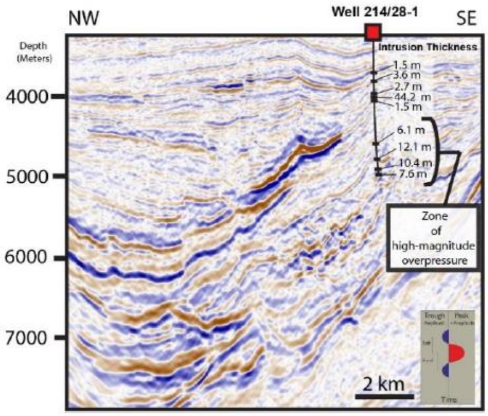
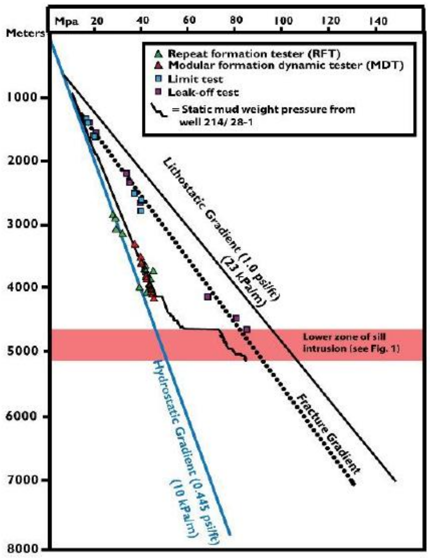
Introduction

In the last 10-15 years, an increased recognition of the potential role that subsurface igneous intrusive (and extrusive) systems have on prospective sedimentary basins of the Atlantic Margin has been established. Within this talk we will explore some of the current concepts that underlie our understanding of the interaction of igneous rocks with petroleum systems and investigate areas which our knowledge is still lacking.

Ability for Igneous Intrusions to act as Fracture Conduits to HC's and Overpressure



Along the entire Atlantic Margin an extensive suite of igneous intrusions exists, which forms a laterally and vertically extensive complex that transgresses basin stratigraphy. Recent work has suggested that intrusions may have played a key role in the migration of hydrocarbons through the sedimentary fill by acting as fractured migration conduits. In particular, the Laggan-Tormore fields have a close spatial relationship with the tips of intrusions. Fluid escape structures can be seen to have focussed from tips of intrusions which have cut up through the Clair Group reservoirs to the south of the Clair Field and within the UK Rockall, intrusions may have acted to baffle hydrocarbons away from obvious trapping structures.

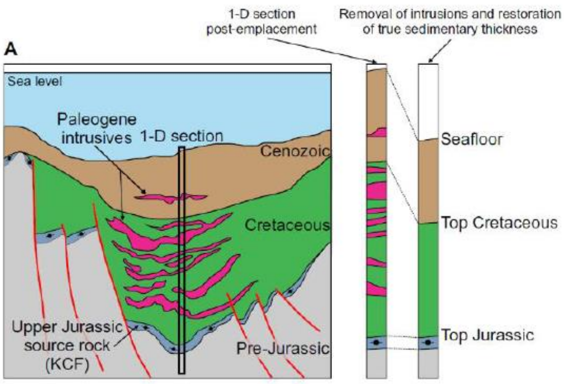


Additionally evidence from wells West of Shetland also points to the ability for intrusions to transmit large magnitude overpressure over large lateral and vertical distances from the area of generation, representing a potentially under-recognized hazard for drilling along the Atlantic Margin and in other basins.

Igneous Overthickening and Petroleum Systems along Atlantic Margin

The intrusion of magma into sedimentary sequences introduces a volume of material that must be accommodated in the subsurface rock mass. If magma intruding into a basin cannot be accommodated by localized deformation of the host rock, then this may create a geologically unique scenario in which a sedimentary unit or sequence can become artificially thickened (overthickened) postdeposition. This means that the present-day thickness of sedimentary sequences (e.g. the

Cretaceous within the FSB), as mapped and ascertained from seismic data across a heavily intruded sedimentary section, will appear to be thicker than when it was originally deposited. Under such circumstances, the thickness of the intrusions needs to be removed to determine the true thickness of the sedimentary unit prior to intrusion i.e. de-sill'd.



The intrusion of large amounts of igneous material into sedimentary sequences, when crystallized, fundamentally changes the thermal conductivity of that unit, as dolerite (which forms the vast majority of visible sills within the Atlantic Margin), possesses, as rock, a thermal conductivity in some cases twice that of the surrounding sediment. Therefore, post emplacement, the thermal conductivity of heavily intruded sections (e.g. the Cretaceous) is substantially increased.

When both the igneous overthickening, the change in thermal properties and correct basement heat flow are integrated within basin models, hydrocarbon generation along areas of the Atlantic Margin is substantially shifted towards younger generation.

Conclusions – The Tip of the Igneous Iceberg

Despite many advances in our understanding of the interaction of igneous rocks with the Petroleum Systems of the Atlantic Margin and specifically West of Shetland, it is clear that our understanding is still at a fledgling state. Our knowledge has progressed into a progressive realization of the integral, but sometimes surprising role that igneous intrusions may have on the petroleum system West of Shetland and beyond. However, much work is still required to allow us to fully unblock the complication in which igneous rocks bring to our petroleum systems along the Atlantic Margin.

Blackrock Operations Geology: delivering a successful well in complex lithologies

Richard Smout[1], Brian Bell[2,3], Colin Newton[4], Clayton Grove[1], Colin Higgins[1]
[1]Siccar Point Energy Ltd., [2]Brian Bell Geologist Ltd., [3]Glasgow University., [4]RPS Energy

The Blackrock well (204/05b-2) was spudded on 15 March 2019 and TD was reached on 29th April 2019. After wireline logging the well was abandoned as an oil & gas discovery. The well drilled the target objectives (Flett Formation) with a 12 ¼ inch bit, the siliciclastic sedimentary targets (sandstone) were interbedded with significant thicknesses of volcanic rocks (e.g. basaltic lava flows).

Offset wells that encountered Paleogene volcanic units and their overburden formations record a catalogue of lost time and technical issues which adversely affected data acquisition and budget. Well objectives were not met in more than one example. Blackrock was prognosed to contain similar lithologies to these problematic wells.

Offset wells recorded the following hazards that were thought to be relevant: tight hole in the Eocene claystone above the target horizon; mud losses in the Balder Formation (Fm.); mud losses in the Hildasay Member (Mbr.), mud losses in Flett Fm. lavas (both static and dynamic); directional drilling issues; magnetic basaltic lavas; mud gains in the volcanic stratigraphy related to prior losses; polygonal faulting in the Eocene; hard drilling through crystalline lava flows; ledges; swelling clays in the Balder and Flett Fms; coals interbedded with sedimentary and volcanic rocks.

In light of this, Siccar Point Energy (SPE) conducted mitigation measures prior to drilling. These included: a field trip to Isle of Mull to examine similar stratigraphy; thorough briefing and transfer of knowledge to all service company personnel (e.g. mud engineers and drill bit technologists); contracting a specialist hard rock geologist for training wellsite geologists; co-operation with adjacent licence operators; adopting a highly integrated geology and drilling team approach.

While drilling SPE deployed experienced West of Shetland wellsite geologists, SPE staff geologists, a specialist hard rock geologist and wellsite palynologists. Potential mud losses dictated that we did not exceed 10 ppg (pounds per gallon) equivalent circulating density (ECD) while drilling which required constant monitoring and included the use of an electro magnetic flow meter to detect very small losses and gains. A Kymera hybrid drill bit was chosen to drill both the extensive basalt lava flows and siliciclastic sediments. The mud was pre-dosed with lost circulation material (LCM). A research grade microscope was dedicated to wellsite geology enabling full depth of field imaging and detailed analysis.

No losses or gains were evident whilst drilling. Two Kymera bit runs were required to drill the Flett volcanics with the first bit achieving 533 meters, the longest run achieved in stratigraphy comprising >50% lava. Rate of penetration (ROP) was satisfactory and bit balling was not observed. ROP was also a good indicator of lithology. Directionally, the well was kept to near vertical. Logging while drilling (LWD) data gathering was of a high quality as was geological sample gathering. High resolution 3 m cuttings sample collection was achieved with extra sample catchers.

A success case wireline logging programme included a zero offset Vertical Seismic Profile, Reservoir Characterisation Explorer (RCX) for pressures, samples & down-hole fluid analysis, and a mechanical rotary sidewall coring tool. Good wellbore conditions enabled high quality data, rock and fluid samples to be obtained.

Post well interpretation involved numerous studies on the available material. Rotary Side wall cores were used for high resolution lithology identification and biostratigraphic resolution to enable a highly accurate composite log to be drawn.

In conclusion, we have shown that it is possible to drill through these problematic strata on budget and on time without compromising on data gathering and quality. Knowledge sharing with key contractors, a fully engaged drilling team, close attention to mud weight and drilling with a hybrid drill bit all significantly contributed to drilling success.

Photograph of Ocean GreatWhite DP Semisubmersible rig in Kishorn Harbour preparing for the 2019 drilling campaign. The rig had been towed from the far-east but mobilised to Blackrock under its own propulsion.

12 ¼ inch Kymera hybrid drill bits used in 204/05b-2. The combination of rollercone and PDC bit technology is highly effective in stratigraphy interbedded with lava.

Understanding sediment lava interlayers: key analogues from subaqueous to subaerial environments

Dougal A. Jerram [1,2], John M. Millett [3,4], Sverre Planke [4,1], Clayton Grove[5], Ian R. Sharp[6], Ragnar Poulsen[6], Tim Watton[6], Ulrike Freitag[6], Jessica Pugsley[4]

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Transitions between subaqueous to subaerial volcanic environments, and vice versa, are a common feature along volcanic margins, in emergent volcanic systems, and where continental volcanism encounters fluvio-lacustrine systems. In volcanic margins and at the basal sections of flood basalt sequences, these transitions can provide important information about the existing environment prior to volcanism, preserve key sedimentological data, and provide palaeo-sea level and shoreline indicators which can be used to map out this transition. The full spectrum of sedimentary systems may exist prior to the eruption of volcanic sequences ranging from sub-aerial arid to deep marine and everything in between with the availability and volume of water in the system having a primary influence on the resulting volcanic styles and deposits. In this contribution we look at a range of key field analogue examples from along the Atlantic conjugate rifted margins in order to highlight important variations in the nature and implications of the basalt-sediment transition.

Along the Angolan coast, Africa, remarkable outcrops which highlight continental to marine transitions are preserved in a number of locations. Here, five such examples are highlighted; shallow submarine pillow and hyaloclastites are interbedded with shelf sediments (Sumbe section), an emergent volcanic centre marks the transition from marine into subaerial eruptions (Ponta Negra section); lava flows enter a soft sediment shoreline to produce peperites (Uah section); lavas transition into a coastal area feeding invasive flows (Canico section); and an extensive section which displays many aspects of shallow intrusion and both submarine and subaerial eruption settings (Baia dos Elefantes section). Such extensive and well preserved examples can help us understand how to interpret similar geology in less well preserved areas and in subsurface data sets, where there is a need to better constrain the onset of volcanism and its manifestation within a changing palaeo-environment during its evolution.

The arid to semi-arid system preserved in the pre-salt stratigraphy of the Parana-Etendeka province in the South Atlantic, provide an additional set of exceptional outcrops to study sediment lava transitions, as well as diagenetic influences of the volcanic system on the sediments preserved within and beneath them. To this extent the Huab Outlier of NW Namibia, is by far the best studied. The lava sequence can clearly be seen influencing accommodation space and preserving spectacular sedimentary features such as complete dune forms that would otherwise have been lost. Outcrop examples from seismic-scale down to detailed case studies enable unprecedented insights into the evolution of the lava sediment transition in arid settings.

Within the paleo-environments preserved in key outcrops within the North Atlantic Igneous Province, examples seen from the Isles of Skye and Mull include; wet transitional facies, exposed (low accommodation space) areas, and shallow marine hyaloclastite sequences. Summary sections will be shown for South Mull, and Skye, to show where work is ongoing within these areas. Finally, the modern volcanic systems on Iceland and Hawaii for example, can provide vital information about the formation and development of these palaeo-environments in real time and through early burial. Discussion will be focused as to where to identify where the best analogues studies exist or need to be prioritised to help inform exploration along the Atlantic Margin.

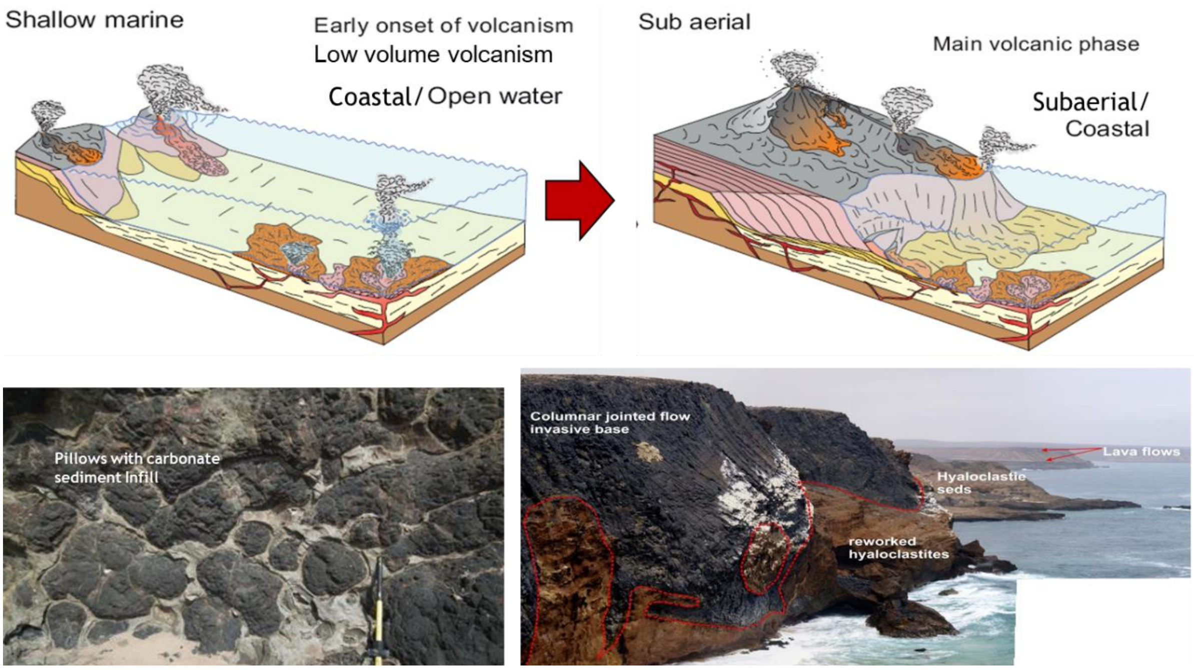

Figure 1. Changing palaeo-environments along volcanic margins during the onset and evolution of the volcanic sequence with examples highlighting submarine pillow/sediment sequences, hyaloclastites and coastal lava flows from Angola analogues presented in this contribution.

20th May 2021

Session six: Volcanic Associated Reservoirs 2

The influence of voluminous magmatism on Paleogene sedimentary systems in the West of Shetland and outer Møre and Vøring basins

Sverre Planke[1,2], Ben Manton[1], Dmitrii Zastrozhnov[1], John M. Millett[1,3], Dougal A. Jerram[2,4], Faye Walker[1,3], David W. Jolley[3], Nick Schofield[3], Ivar Midtkandal[2], Reidun Myklebust[6], Bent Kjølhamar[6]

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Massive breakup-related basaltic sequences and intrusions were emplaced along the UK and mid-Norway continental margins in the Paleogene. The magmatism was initiated at about 62 Ma, with a main peak around 56 Ma. This so-called North Atlantic Large Igneous Province (LIP) had a major impact on the Paleogene paleogeography and associated sediment provenance, transport, and depositional systems.

Extensive new 2D and 3D seismic data (Figure 1) have been interpreted in combination with borehole data and field analogues, to study the effect of the LIP magmatism on sedimentary systems along the West of Shetland and outer Møre and Vøring basins. Eleven horizons, including top and base basalt, were mapped in the West of Shetland area and correlated into the Norwegian Margin using conventional seismic horizon picking, combined with the interpretational concepts of seismic volcanostratigraphy and igneous seismic geomorphology. Particular focus has been given to 1) the nature of the base basalt transition and the nature of underlying or correlative sedimentary sequences, 2) the Inner Flows and Lava Delta seismic facies units, and 3) top basalt geomorphology.

The seismic mapping documents large lateral variations in the basalt thickness, from more than 2 km to a few hundred meters. Locally, the basalt is very thin or absent, e.g. on the Kolga, Mimir, Ygg, Skoll, and Grimm highs. Thin basalts are also mapped in the Erlend and Brendan's igneous complexes, where the basalt thickness is locally constrained by industry boreholes. Well-defined interfingering of basalt flows, and inter-lava sandstones are present in the Rosebank hydrocarbon discovery, documenting the complexity of the base basalt transition.

Igneous seismic geomorphological interpretation reveals extensive subaerial lava flow fields, shallow marine flows, and volcanogenic debris flows and lava deltas along the paleo-coastline along the entire margin. The 3D data also reveal spectacular Paleocene sedimentary channel systems, transporting sediments towards the west (Figure 2). A large (c.15x20 km) channel system is imaged within the Flett Formation comprising numerous dendritic amalgamating erosive channels. The channels are diachronous, with the oldest to the south and shallower channels occurring at Top Balder Formation level to the north. The Flett Formation channels in the West of Shetland area are potentially sand-rich because they are sourced from the Shetland Platform comprising e.g. Lewisian gneisses. The top basalt surface is also incised by fluvial channels with a west-to-east direction.

Our new interpretations form the basis of a recently submitted scientific IODP drilling proposal with objectives to constrain the magma production and emplacement processes, and the impact of the massive breakup magmatism on the Paleogene climate.

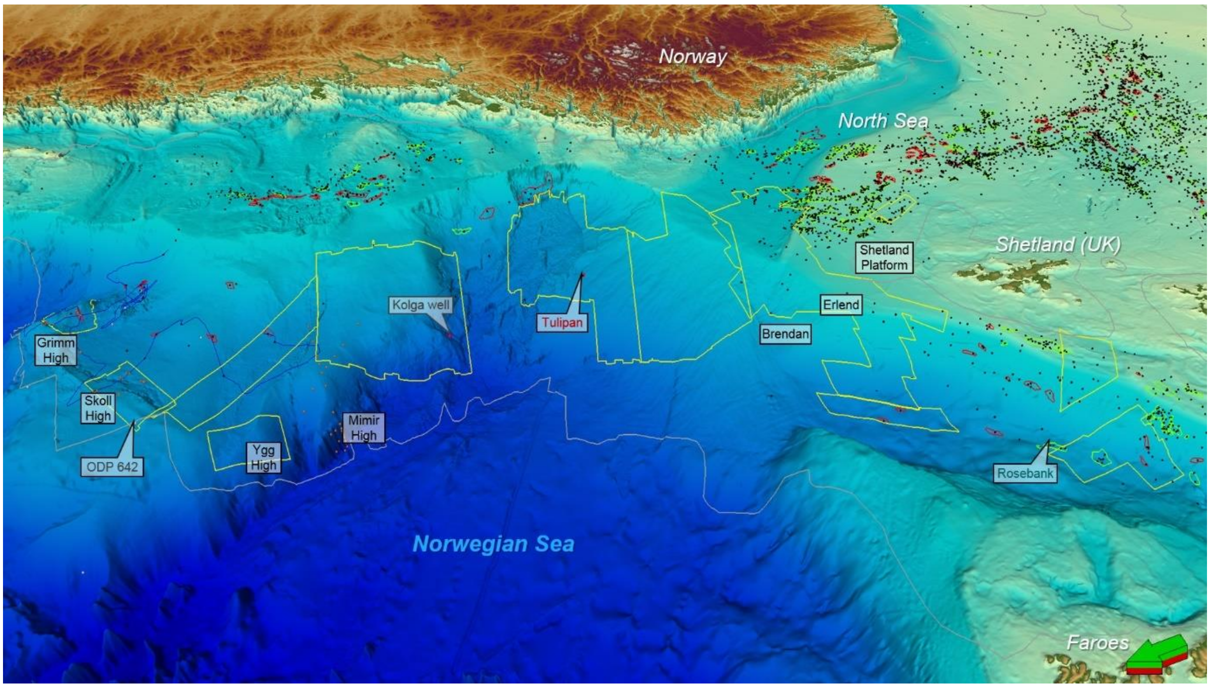

Figure 1. *Bathymetric map of the study region, including exploration and scientific wells (black and gray dots) and outline of hydrocarbon discoveries. Data coverage showing 2D^cubed^ region (gray outline), selected outer margin 3D seismic surveys (yellow outline), and seabed sampling locations (orange dots). Data courtesy of TGS.*

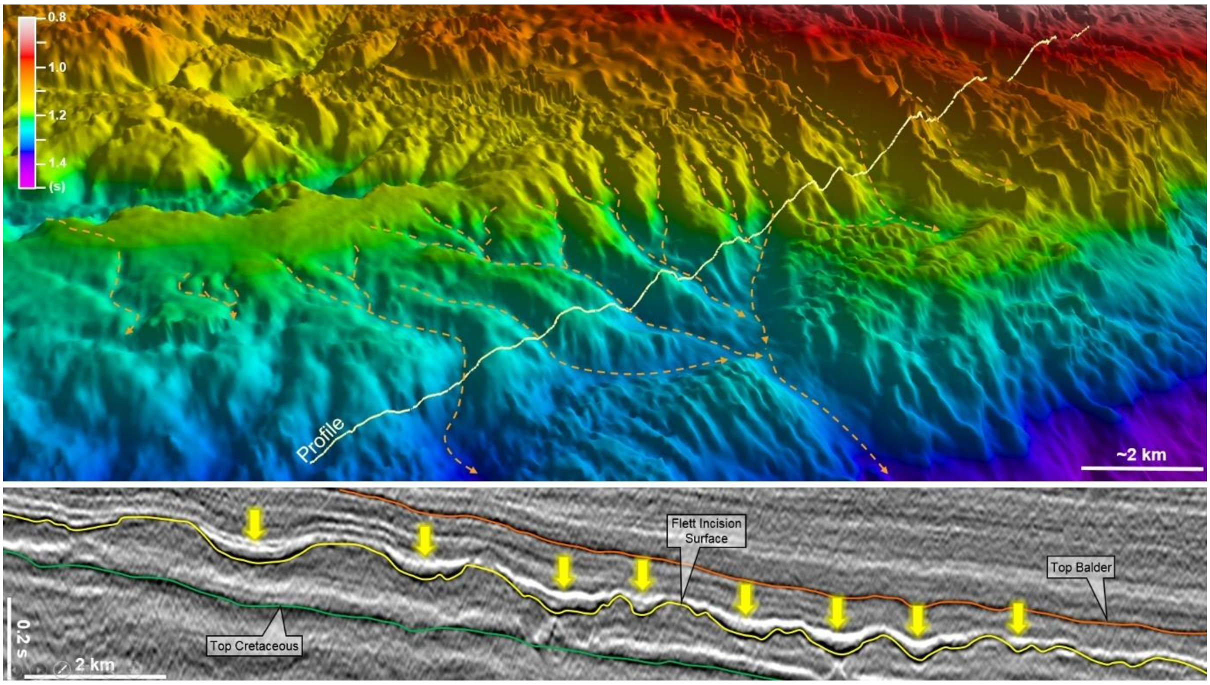

Figure 2. *Morphology of an intra-Flett incision surface showing a well-defined submarine channel system. Data courtesy of TGS.*

Rosebank – A World Class Intra-volcanic Reservoir

Peter Ablard, Cliona Dennehy, Dirk Wallis and Louise Duncan
Equinor UK Ltd

In January 2019 Equinor completed the acquisition of 40% operated interest in the Rosebank project, one of the largest undeveloped fields on the UK continental shelf, further strengthening its UK upstream portfolio.

The Rosebank Field is a significant hydrocarbon resource (C.300MMboe recoverable), located in the underexplored West of Shetland region, approximately 130 km West of the Shetland Islands in water depths of approximately 1100m. An exploration and appraisal campaign comprising six wells and five sidetracks along with an Ocean Bottom Node seismic survey characterize the elongate, SW-NE trending four-way anticlinal structure.

During Late Paleocene–Early Eocene times, Rosebank was located at the juxtaposition of an easterly advancing volcanic system and the northerly prograding Flett delta. As a result, the Rosebank reservoir sandstones are interstratified with volcanic rocks which results in challenges for drilling, imaging, depth prediction and reservoir characterization.

The volcanic rocks are predominately characterized by low viscosity extrusive basaltic lava flows and associated volcaniclastics. The principle Colsay Sandstone Member reservoir consists of several vertically stacked, high energy fluvial and deltaic reservoirs. Well log, drill stem test and core data indicate that reservoir quality is high, with porosities in the range of 19-23% and average permeability of approximately 3 Darcies. Oil quality is also high, with average oil gravity of 37º API and in situ viscosity of approximately 1cP at a mean reservoir temperature of 175º F.

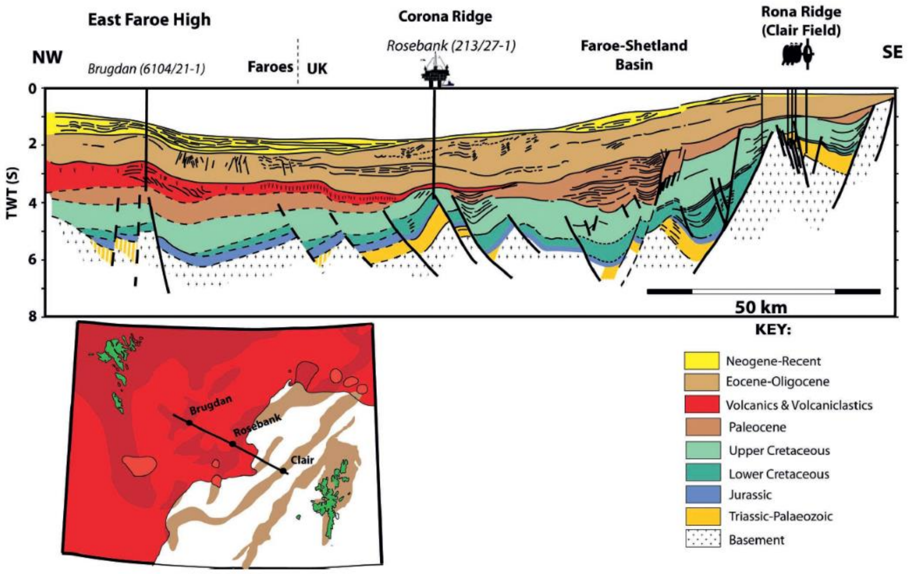

Figure 2: Schematic geological cross-section through the Faroe-Shetland Basin. The intra-volcanic Rosebank Field is located above the Corona Ridge (Schofield and Jolley 2013).

Using field-based analogues in de-risking hydrocarbon exploration in volcanically-affected basins

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Continental flood basalts that commonly blanket vast areas within prospective basins pose many challenges to hydrocarbon exploration, development, and ultimately production. Differences in drilling strategies (e.g. using fixed cutter, roller cone, or hybrid drill bits) through the buried volcanic sequences and the often widely spaced nature and paucity of well data means interpretations can be limited. This may also be compounded by the scale at which (e.g. decametre) seismic imaging can resolve volcanic facies. Intra-volcanic discoveries, most notably in the Faroe-Shetland Basin, has driven research to understand, for example, sedimentation and drainage pathways in flood basalt provinces, reservoir architectures, and the effects of volcanic debris on reservoir properties and/or sealing potential. Fieldwork undertaken in the Ethiopian Flood Basalt Province (EFBP), the Faroe Islands Basalt Group (FIBG) and the East Greenland Plateau Lavas (EGPL) has begun to address these questions and is bringing together observations from beneath, within, and above these provinces. Developing detailed volcanic stratigraphies in the FIBG and EFBP has shown they share many common features. It has enabled us to understand the spatial and temporal distributions of the volcanic and sedimentary lithofacies and the influence of pre-existing structure on these variations. This is helping, not only, to potentially predict the location of clean intra-volcanic, but also sub-volcanic reservoirs. Although the vast majority of interlava units are volcaniclastic in composition, detailed petrographic and heavy mineral studies are recording non-volcanic material preserved in these rocks in addition to clean interbedded sandstones. The provenance of this non-volcanic material is, for example, being deduced for the Faroese and Ethiopian samples and field/photogrammetric studies are highlighting the prevalence of channels and drainage pathways within the associated volcanic sequences. In East Greenland and Ethiopia, petrographic and geochemical analyses of crystalline volcanic clasts are also differentiating extraformational sources. In Ethiopia, for example, mafic, alkaline, and felsic debris, or mixtures thereof have been recorded within mass flow and fluvial deposits preserved in interlava sedimentary sequences that are locally >200 m thick. The variability in composition has implications for drainage development within lava fields as well as reservoir/sealing properties due to their differing susceptibilities to alteration. An extreme example is observed in East Greenland, where subarkoses with porosities of >20% are interbedded with cemented volcaniclastic sandstones suggesting they not only underwent different diagenetic histories, but very little mixing occurred between the two systems. These multi-disciplinary studies from a variety of analogous settings are beginning to elucidate the types, scale, and controls on sedimentation patterns in volcanic provinces and are providing parameters for de-risking exploration in these unconventional basins, including those of the UK continental shelf.

20th May 2021

Session seven: Cenozoic Reservoirs 1

Quad 204: Maximising long-term recovery from brownfield assets using new wells and well work opportunities

Rob Wilcox
Deepwater, West of Shetland

The Schiehallion and Loyal fields are Tertiary stacked turbidite reservoirs in Quad 204. The fields have been re-developed since 2017 through the new Glen Lyon FPSO after an extended shut-in period. The redevelopment involved drilling of infill wells in existing reservoirs with identification of targets driven by 4D seismic interpretation and targeting new oil in deeper reservoir units.

Following start of drilling associated with the Quad 204 Project, in April 2015, more than 20 wells have been drilled. A 9th 4D seismic monitor survey was taken in 2018 providing further information on how the waterflood pattern has evolved since start-up. A well work and PLT campaign has been carried out to optimise production from existing wells and has provided insights into sub-seismic waterflood development.

This presentation will look at the integration of data to support description of new oil targets, infill targets and inform decisions on well work and the learnings associated with these.

The Lyon Prospect: Not another false AVO! A case example from the Faroe-Shetland Basin, UKCS Atlantic Margin.

Andy Alexander, Liam Holt*, Chris Forster, Richard Smout, Clayton Grove, Ben Hedley**
*Siccar Point Energy Limited, *now with Perenco, **now with Dana Petroleum*

In 2019, well 208/02-1 was drilled targeting the Lyon prospect using the Ocean Great White semi-submersible rig. Lyon was interpreted to be a combination structural and stratigraphic Balder Formation trap with a strong seismic amplitude anomaly extending over 70 km^2. Lyon represented a new play concept in the Faroe-Shetland Basin and had commercial potential to unlock smaller stranded gas discoveries such as Tobermory (214/04-1) and Bunnehaven (214/09-1). The Lyon reservoir was interpreted to include sandstone (siliciclastic or volcaniclastic) lithologies deposited in an inner to middle neritic marine paleo-environment sealed by transgressive Balder Formation claystone lithologies and charged with petroleum migrating from the underlying Upper Jurassic to Lower Cretaceous Kimmeridge Clay Formation source rock.

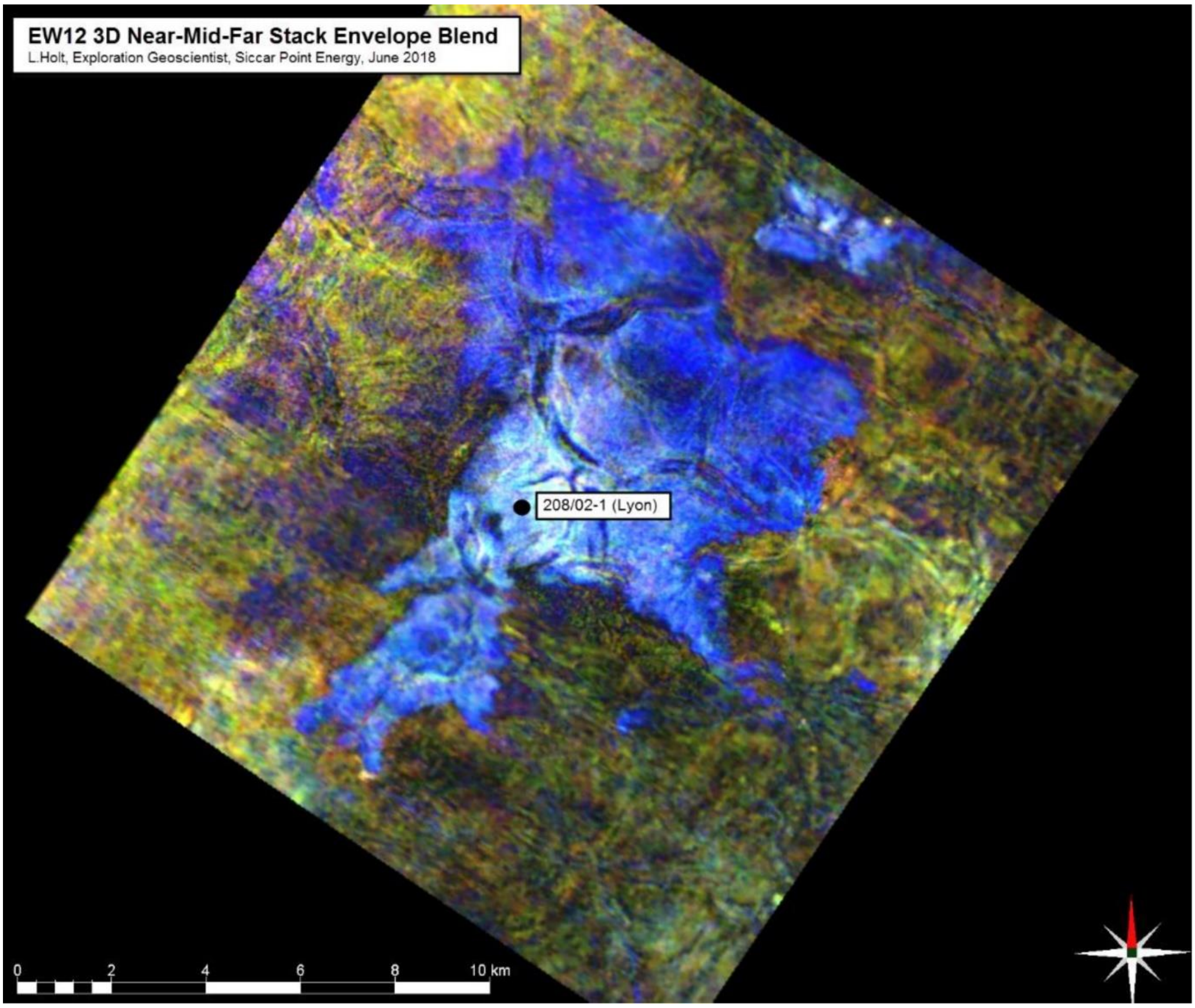

Figure 1. A Near-Mid-Far seismic stack envelope blend showing the Lyon prospect and the well location.

AVO classification is a much-used technique in the petroleum industry, as it provides a simple physical explanation of seismic amplitudes in terms of rock properties. The technique has proven successful in certain areas of the world, but in numerous other documented cases have been not successful. The technique suffers from ambiguities caused by lithology effects, tuning effects, overburden effects and processing and acquisition effects (e.g. Avseth, *et al.,* 2015) often resulting in a non-unique solution. In many failure cases, it is not the technique itself that failed but the interpretation of the technique and associated risk factors that were not fully understood.

The Lyon prospect pre-drill rock physics modelling and Direct Petroleum Indicator (DPI) analysis, including amplitude variation with offset (AVO) studies, concluded that the seismic anomaly could be explained by the presence of petroleum charge which was likely to be gas. The 208/02-1 well was drilled to test the commerciality of six hypothesised DPI's: 1) amplitude variation with offset effects; 2) amplitude shut-off at normal faults; 3) amplitude conformance to structural dip; 4) a postulated gas cloud above the target interval; 5) low frequency 'shadow' below the target and 6) a seismic 'flat-spot'. The key geophysical risk and perceived 'Achilles Heel' of rock physics modelling, low saturation gas (LSG), was also tested. Pre-drill geological risk for Lyon was 8% with a geophysical DPI index uplift of 22%. The key geological and geophysical risk factors were reservoir presence, reservoir quality and low saturation gas. The well found the key risk factors to be valid, drilling a sequence of thin-bedded siliciclastic siltstone, claystone and minor very fine siliciclastic sandstone with low saturation gas. Although a commercial petroleum volume was not proven, post well rock physics analysis and forward modelling shows the Lyon AVO to be true and *not* another 'false AVO'.

This presentation will address the interpretation of rock physics modelling in risking of amplitude prospects and the ambiguities often associated with the interpretation of DPI's, in particular 'false AVO' anomalies, by recognising the integration of geological and geophysical risk factors using the Lyon prospect as a case example.

T40-T45 paleogeography in the Flett Basin: Impact of volcanism on sedimentation

Remi Julien[1,], Henrik Olsen[1], Helen Cromie[1], Conrado Climent[1]
[1]*Total Upstream Danmark A/S,*

A new paleogeographic model for the Late Paleocene to Early Eocene T40-T45 sequence (Ebdon *et al.* (1995) chronostratigraphy nomenclature) for the Flett sub-basin has been constructed, integrating all available 2D & 3D seismic data and wells. During this time in the Faroe-Shetland basin, a significant and unique progradation/retrogradation cycle of the coastline took place. This short-lived cycle was likely caused by the existence of the proto Icelandic mantle plume. Its activity resulted in the broad uplift of the Flett sub-basin and in an intense basic sill intrusion into pre-existing Mesozoic and Paleocene sediments. At the same time, in the distal part of the margin, a regional-scale volcanic plateau was built in connection with the opening of the north east Atlantic.

During the early T40, the rapid uplift of the basin and its margins resulted in a drop of relative sea-level of approximately 500 meters. This uplift modified the pre-existing fluvial drainage system and enabled the development of a fluvial plain and its related paralic system immediately above the previous deep water sediments of the T38 sequence. The resulting sediment input was large enough to fill in part of the still available accommodation space and enabled approximately 80km progradation of the coast line.

Coeval to this progradation, distal parts of the basin remained in deep water conditions and were relatively starved of sediment input. Basic sill intrusions are likely to have caused semi-regional doming of the seafloor, impacting the potential deposition of any sands coming from the slope canyons. Submarine lava flows deposited in local depocentres along the Corona High may also have interacted with turbiditic sands.

To the west/north west, the massive development of a volcanic plateau confined the basin and likely influenced the nature of sediments deposited north west of the Corona High. The edge of this plateau provides a good control of the paleo-water depth. Subaerial conditions with a likely fluvial flood plain dominated by volcanic terranes may have prevailed over the plateau. East of the volcanic escarpment, sedimentation was dominated by lava flows and debris apron.

During early T45, a balance of sediment input versus available accommodation space was reached. It led to the aggradation of the continental flood plain / coastal system inherited from the T40 sequence. The upper part of the T45 sequence witnessed the acceleration of the subsidence due to the decrease of the Icelandic plume activity which ultimately caused a dramatic retreat of the shoreline towards the south west of the basin.

20th May 2021

Session eight: Cenozoic Reservoirs 2

The Paleocene Vaila Formation and its youngest Member, the Thanetian T35.4 Play, Flett Basin, West of Shetlands, UKCS Atlantic Margins Conference, INEOS Oil & Gas UK.

Peter Henry,
INEOS Oil & Gas UK.

Following the discovery of gas within post-rift Paleocene sandstones of the Vaila Formation at the Laggan Field in 1986, exploration has been fairly active within the Flett Basin, West of Shetland UK. Similar discoveries have been subsequently made at Tormore, Cragganmore and Glenlivet. Analysis of numerous wells drilled targeting amplitude anomalies, in conjunction with detailed 3D mapping, have allowed a robust stratigraphic framework to be constructed for the deep-water sands of the Vaila Formation. These major sand prone intervals, from oldest to youngest, include the T22 and T34 which are Selandian in age and the Thanetian T35.1-3. All of these intervals have reached the thicknesses required to provide commercial hydrocarbon volumes. The youngest play of the Thanetian in the Vaila Formation, the T35.4, had not been specifically targeted until JX Nippon drilled the Loanan well, 214/23-1, in 2016. This highly anticipated well targeted an amplitude anomaly within a structural closure, in the under explored northeast of the Flett sub basin. The well results disappointed; penetrating only 11m of fine grained sandstones with moderate porosity and low permeability. The Loanan outcome has subsequently increased the risk on reservoir for the remaining T35.4 prospectivity, and the question remains whether the thickness penetrated at Loanan is representative for the play. Work conducted on the T35.4 sand system indicates that they are deep-water high stand fans, almost identical in geometry to modern fans being deposited on the seabed of the Faroe Shetland Basin. Using scaling parameters derived from basin floor fan analogues, we demonstrate that the thickness at Loanan may not be representative and the T35.4 may still offer a commercially viable play.

Interconnected sand injectites in the Faroe-Shetland Basin and southern Møre Basin

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[4]*TGS, Asker, Norway*

Sand injectites are increasing viewed as potential exploration targets with high quality reservoirs formed by remobilization processes that separate sand from finer grained material. They often intrude mudstones which form high quality seals. How sand injectites connect to depositional sand units and how they interconnect to each other is significant in terms of reservoirs volumes and for potential fluid contacts.

In this study, two recently acquired 3D seismic datasets with sand injectites are compared: The northern Faroe-Shetland Basin (FSB), close to the Tobermory gas discovery and the southern Møre Basin. Sand injectites are interpreted based on their high amplitude (hard) reflections, caused by their high acoustic impedances. They have commonly 'v'-shaped geometries and more rarely 'saucer-shaped' geometries with flat bases and rising wings. They are somewhat similar to igneous sills but occur shallower in the geological succession and are about a tenth of their diameter (generally less than 5 km across).

The sand injectites in both study areas occur above the Balder Formation (Early Eocene) and below Base Pleistocene (Base Naust in the Norwegian sector). In both study areas there is a very hard reflection that crosscuts stratigraphy. It is interpreted as the Opal A/CT diagenetic boundary. In the FSB study area, where the sand injectites occur, there is a seismically distinct unit which occurs within lenticular bodies which consist of high amplitude, relatively coherent reflections (Fig. 1). It is interpreted to be the sand-rich mid-Eocene Strachan Fan. The Tobermory gas discovery (214/4-1) occurs within sandstone intervals within the fan.

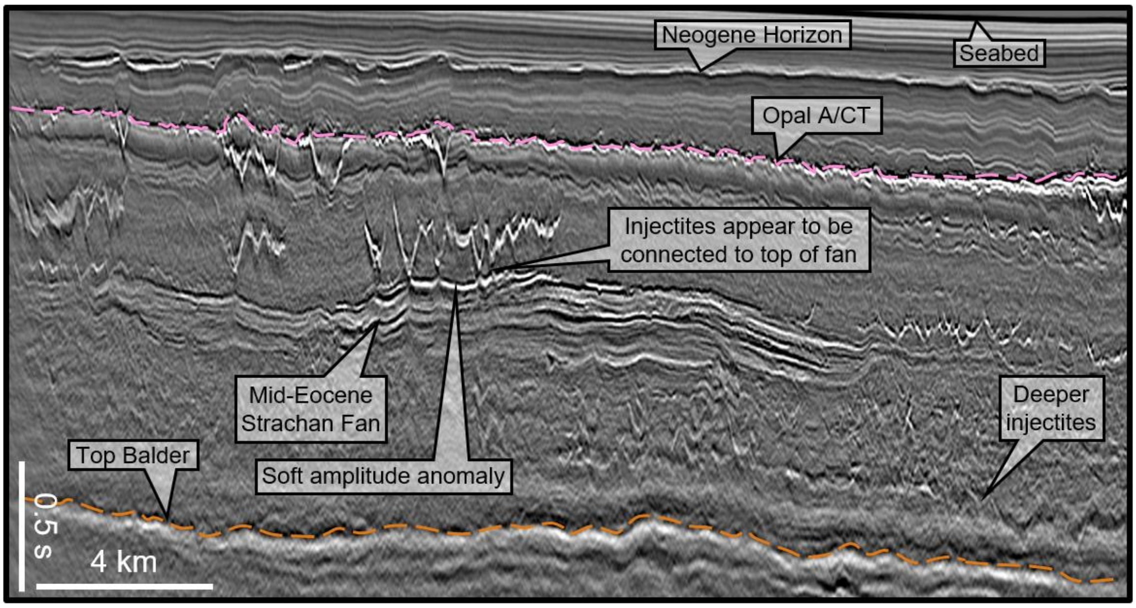

Fig. 1 *Sand injectites in the vicinity of the Strachan Fan, in the Faroe-Shetland Basin. Data courtesy of TGS.*

In the FSB study area, sand injectites are penetrated at the Tobermory (214/4-1) and Bunnehaven wells (214/9-1). Sand injectites above the Strachan Fan have stronger amplitude responses than the sand injectites below the fan and are generally distinct singular reflections (Fig. 1). Many of the sand injectites occur directly above the Strachan Fan suggesting the fan is the source of the sand (Fig. 1). The sand injectites nearly entirely occur below the Opal A/CT reflection.

In the southern Møre Basin study area hard reflections with 'v' and saucer-shaped geometries are interpreted as sand injectites (Fig. 2). However, geometrically these injectites are distinct from those observed in the FSB area, in that they occur in clusters. These clusters also contain incoherent high amplitude reflections (Fig. 2) which have similar amplitudes and a close association to the saucer-shaped reflections, which suggests they are also injectites but are not fully resolved in the seismic data. These clusters could represent interconnected injectite swarms such as those observed in the Panoche Hills, California. The injectites occur above the level of the Opal A/CT reflection, although where the injectites occur the reflection is often disrupted (Fig. 2).

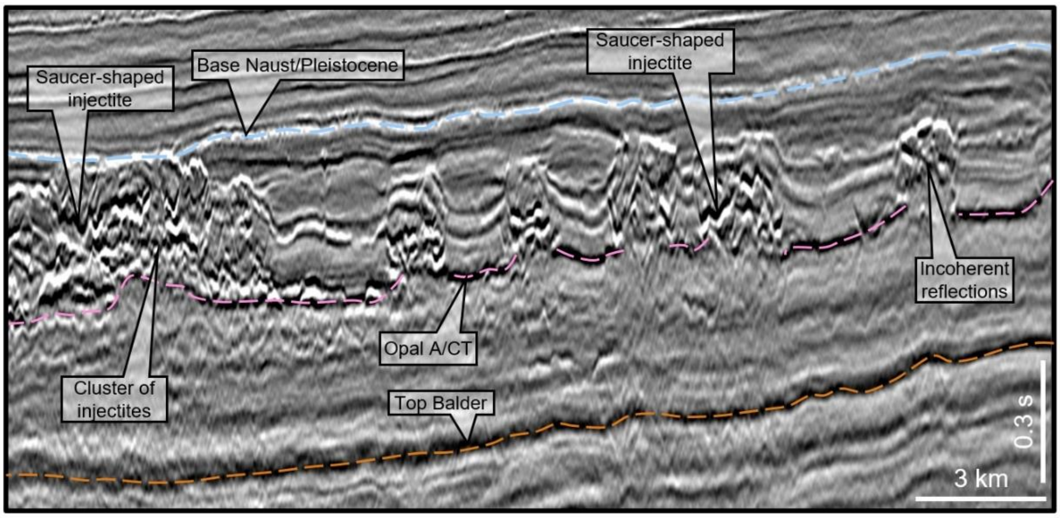

Fig. 2 *Interpreted sand injectite clusters in the southern Møre Basin. Data courtesy of TGS.*

The difference in geometry between the injectites in the two study areas may be related to their relationships to the Opal A/CT transition. The close relationship between the locations of the injectites and the Opal A/CT suggests the Opal A/CT was at its current location at the time of the shallowest sand injection. Along much of the Atlantic margin the Opal A/CT has been fossilized since the Neogene. The mineralization process at the Opal A/CT may lead to the rocks below the transition to be more brittle, leading to more distinct sheet-shaped intrusions, while the mudstones above the Opal A/CT may be less coherent, leading to complex intrusive geometries.

In both areas, the interconnectedness of the intrusions is significant from a reservoir evaluation perspective. In the FSB, the injectites connect to the top of the Strachan Fan increasing its reservoir volume and suggesting hydrocarbons may occur above the structural high of the fan. In the case of the injectites in the southern Møre Basin, they appear to be highly connected, suggesting hydrocarbons may be able to migrate significant distances through the injectite clusters.

Acknowledgements: *TGS are thanked for the provision of seismic data and the Facies Map Browser for well data.*

Unravelling the hydrocarbon charge history of the Tormore field using noble gas

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Resolving the charge history of a field is often undertaken using organic geochemistry tools, e.g. vitrinite reflectance equivalence, biomarkers and variations in isotopy of fluids. However, it is difficult to quantify the order and the volume of fluid interaction using such methods. We present a new approach for resolving the charge history and estimating the volumetric ratios of oil-water, gas-water and oil-gas using noble gases.

The noble gases (He, Ne, Ar, Kr and Xe) are present in trace quantities in all crustal fluids. They do not react with or degrade within hydrocarbon reservoirs in the same manner as organic tracers. Their distribution in crustal fluids is the result of physical interactions between different fluid sources and phases (Pinti & Marty, 1995; Kipfer *et al.,* 2002). Consequently, noble gases can be used to interpret the physical processes that are poorly constrained by reactive tracers.

In addition to their unreactive nature, noble gases can resolve the source of fluids by comparing the isotopic ratios of noble gases. Each isotope or isotopic ratio is indicative of a given “source”, in the subsurface there are three main sources:

- Mantle component (^{3}He and ^{129}Xe), sourced from the mantle entrained during the Earth’s accretion (Oxburg *et al*., 1986; O’Nions & Oxburg, 1988; Honda *et al*., 1991; Burnard *et al*., 1997; Graham, 2002).
- Crustal component (^{4}He, ^{21}Ne and ^{40}Ar), inherited from the hydrocarbon source rock and the in situ radiogenic and/or nucleogenic generation in the reservoir (Morrison & Pine, 1955; Sarda *et al*., 1988; Kennedy *et al*., 1990; Moreira & Allegre, 1988; Ballentine & Burnard 2002).
- Atmosphere-derived component (^{20}Ne, ^{36}Ar, ^{84}Kr and ^{132}Xe), which have entered the subsurface via aquifer recharge and/or entrained in the original formation water of the sediment (e.g. Kipfer *et al*., 2002).

The principle of using noble gases is relatively straightforward, when two fluids mix in the subsurface, the noble gases within the fluid will partition according to solubility. Combining this behaviour with their unique isotopic signatures, it possible to unravel the noble gas fingerprint of a given fluid and resolve its interaction with other fluids.

The noble gases (^{20}Ne, ^{36}Ar, ^{84}Kr and ^{132}Xe) are typically devoid in hydrocarbons, therefore any detection of these in hydrocarbon fluids, is indicative of interaction with water (Pujol et al., 2018). Noble gases have different solubilities in oil, water and gas, and therefore partition differently into each fluid type. Using the model outlined by Bosch & Mazor (1988) it is possible to predict the partitioning patterns of noble gas in water-oil and water-gas systems. Figure 1 shows the evolution of noble gas when an oil-like and a gas-like fluid interacts with an aquifer in a closed system (Bosch & Mazor, 1988). As more hydrocarbons pass through the aquifer, the hydrocarbons inherit a more aquifer-like signature. However, these models cannot be used to represent the charging history of a reservoir, as fluid charge history is more complex than the mixing of two fluids.

Using noble gas data collected from Tormore, we present a new application of the Bosch & Mazor method. By using these differences in partitioning behaviour to demonstrate multiple charges of different fluid and therefore deduce the order of the charge and the approximate volumetric ratios of the fluids.

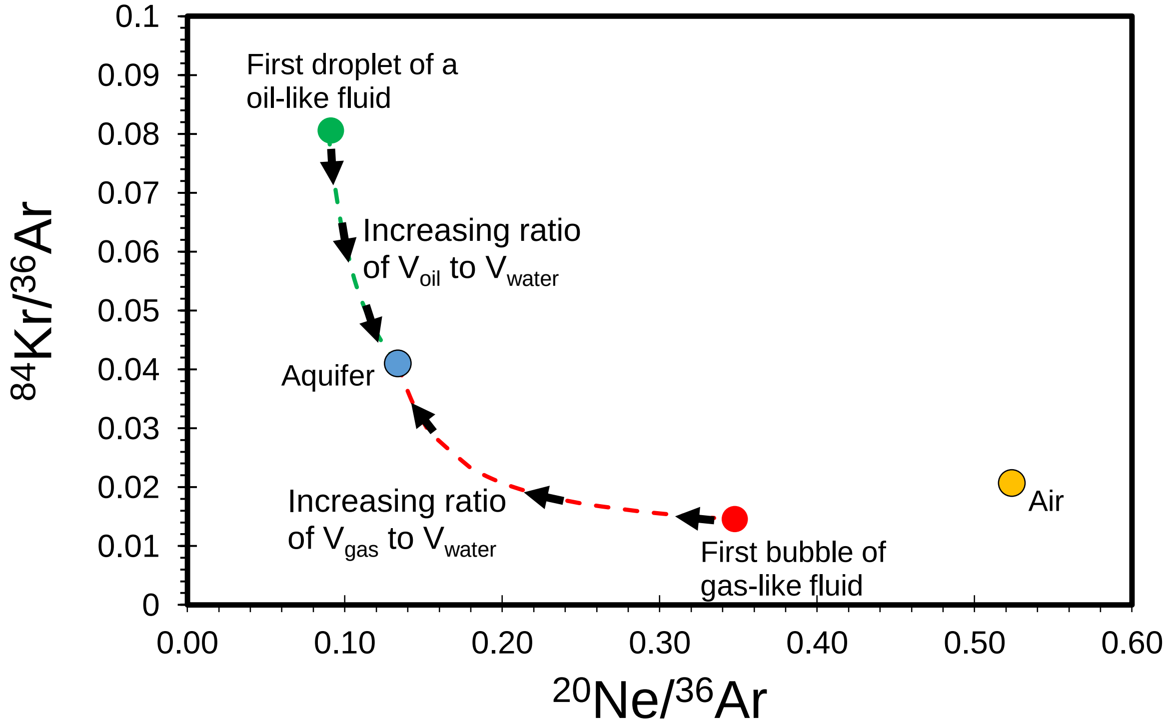

Figure 1. Closed-system batch fractionation under the reservoir conditions of Tormore. Noble gas fingerprints will evolve differently when they interact with an oil or a gas. The green line represents the partitioning pattern of an oil and the red line represents a gas. The first droplet/bubble represents an infinitesimally small volume of hydrocarbon fluid passing through an infinite aquifer. Given a large enough volume of hydrocarbons, the noble gases will fully partition in the hydrocarbons and inherit a noble gas fingerprint similar to the aquifer.

21st May 2021

Session Nine: Governance

West of Shetland exploration: a regulatory perspective

Alana Finlayson
Oil & Gas Authority

The Oil and Gas Authority's (OGA) role is to regulate and influence the UK oil and gas industry in order to maximise the economic recovery from the UK's hydrocarbon resources, helping to meet the UK's energy demands, whilst supporting the industry's energy transition and move to net zero carbon by 2050. Government forecasts show that oil and gas will remain an important part of our energy mix for the foreseeable future; and industry must, therefore, continue to find, develop and produce UK resources.

The UKCS holds substantial prospective resources. Mean prospective resources in mapped leads and prospects in the West of Shetland are estimated at 1.1. billion boe. This is supplemented by an additional mean prospective resource of 4.7 billion boe estimated to reside in plays outside of mapped leads and prospects, in areas where current data are sparse. It is encouraging that in recent years exploration has stepped out from the traditional Paleocene amplitude supported plays, to test less well understood plays such as the Lower Cretaceous, Jurassic and Basement; however, the potential of these plays is still not fully understood. The ultimate volume discovered will be determined by activity levels; how, coupled with the use of new or available data, industry generates new targets, and the efficiency of resource progression from plays through to drill- ready prospects.

The OGA, with Government funding, has supported industry exploration activities in recent years through the provision of £45 million for seismic data acquisition and subsurface studies. The OGA is also making unprecedented amounts of high quality seismic, well and production data, supplemented by geological mapping, openly available to all via the UK National Data Repository (NDR) and the OGA website. We have updated the reporting and publication of 'multiclient' geophysical data guidance aiming to make more data available for exploration purposes, and the OGA now routinely disclose results of Exploration and Appraisal wells soon after completion.

In collaboration with industry, the OGA established a new system of licensing rounds supported by the flexible Innovate licences, that can be designed by bidding groups to best meet the duration and technical requirements of their exploration work programme, based around studies, seismic and drilling phases. High bidding interest in the licence rounds run since these licences were introduced is clear evidence of the success of these measures. Following a review of the licensing regime, a new Climate Compatibility Checkpoint is to be introduced before each future licensing round to ensure any licences awarded are aligned with climate objectives, including net zero emissions by 2050. This dynamic checkpoint will enable the assessment of the ongoing domestic need for oil and gas while ensuring concrete action from the industry on decarbonisation.

The open availability of substantial volumes of data, and the significant remaining potential should ensure future activity in the West of Shetland and its continued contribution towards meeting the UK's future energy demands, while supporting the transition to net zero emissions.

Faroese perspective on the NW Atlantic Margin latest developments

Jana Ólavsdóttir[1], Óluva R. Eidesgaard[1] and **Barbara B. Hansen[1]**
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The Faroese area including the Faroese Continental Shelf (FCS) is a part of the Faroe-Shetland Basin located on the outer edge of the NW Atlantic Margin. A large part of the area is covered by Paleocene volcanic material with an age range of c. 62-54.5 Ma. The area outside the volcanic cover – the Judd Sub-basin - is affected by sills at deeper levels.

Exploration in the Faroese area initiated in year 2000 when the first licencing round was launched, and during these past twenty years nineteen licenses have been awarded to c. twenty companies. The focus on the exploration in the Faroese area was from the beginning the previously known Paleocene plays found on the other side of the border e.g. the Foinaven and Schiehallion plays and the first four wells were drilled adjacent to these discoveries in the Judd area. Three of the wells were drilled in 2001 and one in 2003. The results were that one well was a discovery, one well contained shows, one well contained traces while the fourth well was dry. The wells contained large amounts of good reservoir sands, but the problem was the lack of seal. Thereafter exploration moved into the volcanic covered area, but focus, in the majority of the wells, was still on the Paleocene sub-volcanic plays. Five wells were drilled although without the success of penetrating the volcanic succession. One likely exception is the Anne-Marie well which most likely drilled through thin intra-volcanic siliciclastic Vaila sands towards the total depth of the well. The results of these five wells was that two were dry, two contained traces while one contained three columns of gas with a thickness of 350 meters. Based on the well results an active hydrocarbon system was established in the area.

The reason why no well managed to drill through the volcanic sequence was mainly due to the complicated geology and the challenges that at that time were regarding seismic imaging. But the last twenty years of exploration and the immense work from both the oil companies operating in the area and the last years of re-evaluation work made at Jarðfeingi a better understanding of the volcanic thickness, placement and age of the volcanic sequence has been established, and this gives the possibilities for a better prognoses in future exploration in the pre-volcanic plays.

Additionally, the Rosebank and Cambo discoveries in the central part of the Faroe-Shetland Basin found early in this century, show possibilities within the intra- and post-volcanic sequences at the edge of the volcanics. Setting that are common in the Faroe area.

Interpretation of igneous rocks across the Rosebank Field, Corona Ridge, UKCS

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[6]Equinor, UK Ltd., Aberdeen, UK

The Rosebank Field is located in the Faroe-Shetland Basin and hosts hydrocarbons within fluvial to shallow marine siliciclastic sediments of the Late Paleocene to Early Eocene aged Flett Formation. The reservoir intervals are interlayered with volcanic packages making Rosebank an example if an inter-volcanic hydrocarbon discovery. The Rosebank volcanic sequence is split into a lower (RLV), middle (RMV_U and RMV_L) and upper (RUV) volcanic sequences inter-layered with Colsay Member (C1-C4) siliciclastic dominated intervals. This study outlines results from recent investigations focused on the Rosebank Field volcanic sequences and incorporates an appraisal of available drill cuttings, sidewall cores, core and wireline logs including selected image and geochemical log data from eight wells spanning the field.

A comprehensive cross-field borehole based lithofacies interpretation is presented characterizing simple, compound, and ponded effusive lava flow facies along with pillow lavas, invasive lava flows, volcaniclastic sediments along with evidence for various lava-sediment interaction processes. Geochemical analyses of core, sidewall core, and hand-picked cuttings spanning the field reveal separate high-titanium (RHT) and relatively lower-titanium (RLT) magma suites. These compositions overlap with Faroese lava compositions and can be identified and correlated across much of the field utilizing geochemical logging data which, in combination with the geochemical analyses, reveals a two-part stratigraphic sub-division of each of the RLV, RMV, and RUV. The identified chemical stratigraphy within the Rosebank Field offers important new correlation potential for future and potentially more regional boreholes.

Geochemical logging data is also used to define a simple volcanic proxy (Fe/10+Ti) which utilizes the elevated iron (Fe) and titanium (Ti) abundances within all effusive and volcaniclastic basaltic lithologies in the Rosebank Field to help differentiate siliciclastic from volcaniclastic sediments where other logging parameters often overlap. This approach improves confidence in assessing the presence of volcaniclastic sediments in uncored sections which can be important for assessing reservoir quality.

Finally, a scaled cross-field volcanic facies model is presented and compared to available seismic data. By comparing the borehole analyses with 3D seismic imaging, an eruption site is interpreted within the north of the field adding to documentation by previous studies for localized eruption sites within the area. The cross-field model provides a constrained spatial framework which can be used for synthetic seismic modelling and for testing different geological scenarios. This study presents new approaches for appraising inter-volcanic sub-surface sequences which should have applicability in other subs-surface volcanic appraisal settings along the Atlantic margins.

21st May 2021

Session Ten: Technology 1

Chemostratigraphic framework for the Faroe-Shetland Basin

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The Faroe-Shetland Basin (FSB) comprises a series of complex and variable play types; the volcanic nature of which, can increase uncertainties during exploration due to variable biostratigraphic recovery and uncertainties mapping seismic. Chemostratigraphy is based on the ability to characterise mineralogical heterogeneities within a rock succession using inorganic geochemical data, with chemostratigraphic correlations resulting when similar geochemical trends can be identified between rock successions. The forensic nature of the technique makes it an invaluable tool within the FSB, where the volcanogenic origin of the sediments proves to be advantageous.

Intrusive igneous rocks and volcanic rocks are widespread within the FSB and include widespread lavas, volcaniclastic deposits, intrusive complexes and volcanic centres. Moreover, the volcanic material is known to make an important contribution to the overall nature of the Cenozoic sedimentary rocks. The chemically distinct volcanogenic horizons of the Kettla Member and Balder Formation form readily identifiable chemostratigraphic and chronostratigraphic markers, which can be used to constrain key sedimentary reservoirs. Between these two major events, smaller scale cyclicity within key elemental ratios can be linked with volcanic activity, although these in turn are further attributed to magmatic uplift, basin inversion and/or sea level changes.

To date, >75 wells from across the margin have had chemostratigraphy applied to them, with the resultant geochemical data, combined with mineralogical (XRD, heavy minerals analyses, petrography) and geochronological (U-Pb detrital zircon) data being utilised to constrain and correlate the Palaeocene and Eocene strata encountered. The Cenozoic successions can be divided into distinct chemostratigraphic sequences, which broadly correspond to the Lamba, Vaila, Flett and Balder formations. These sequences in turn, can be sub-divided into a series of chemostratigraphic packages which provide a higher-resolution stratigraphic tie across the margin.

This paper presents a summary of the resultant chemostratigraphic correlations ranging across the UK sector, from the Rockall Basin in Quad 154 to the north-eastern extent in Quad 219. Furthermore, it will highlight the practical use of this data when constraining key sandstone bodies for further reservoir and provenance-based investigations.

Assessment of the complex hydrocarbon charge history based on 3D broadband seismic data recently acquired and processed in the Westray area, West of Shetlands

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[2] *WesternGeco, Aachen, Germany*

The West of Shetlands represents an underexplored area and remains at the frontier of exploration, principally due to uncertainties in the hydrocarbon charge and seismic imaging. Several well-established producing fields exist, but, despite the number of additional leads, many potential prospects remain undrilled with repeated license relinquishments. Discoveries have been predominately found in the Paleogene, some in the Mesozoic reservoirs and, recently, even in the Lewisian basement, but charge, in many cases, is still a key risk, ultimately due to the uncertainty when using inadequate seismic data.

In recent years, efforts were made to address the seismic data quality in the area as well as increasing offset and record length to take into account renewed interest in the former acoustic basement. Identification of faulting, lithology, and source rock location are now additional key objectives for these acquisition campaigns with a focus on broadband data with finer spatial sampling. The multiclient 3D broadband Westray prestack depth migration (PSDM) data set released in 2018 (Figure 1) addressed some of the geophysical seismic imaging challenges and, as a result, the data have provided a greater understanding of both the proven and unproven plays.

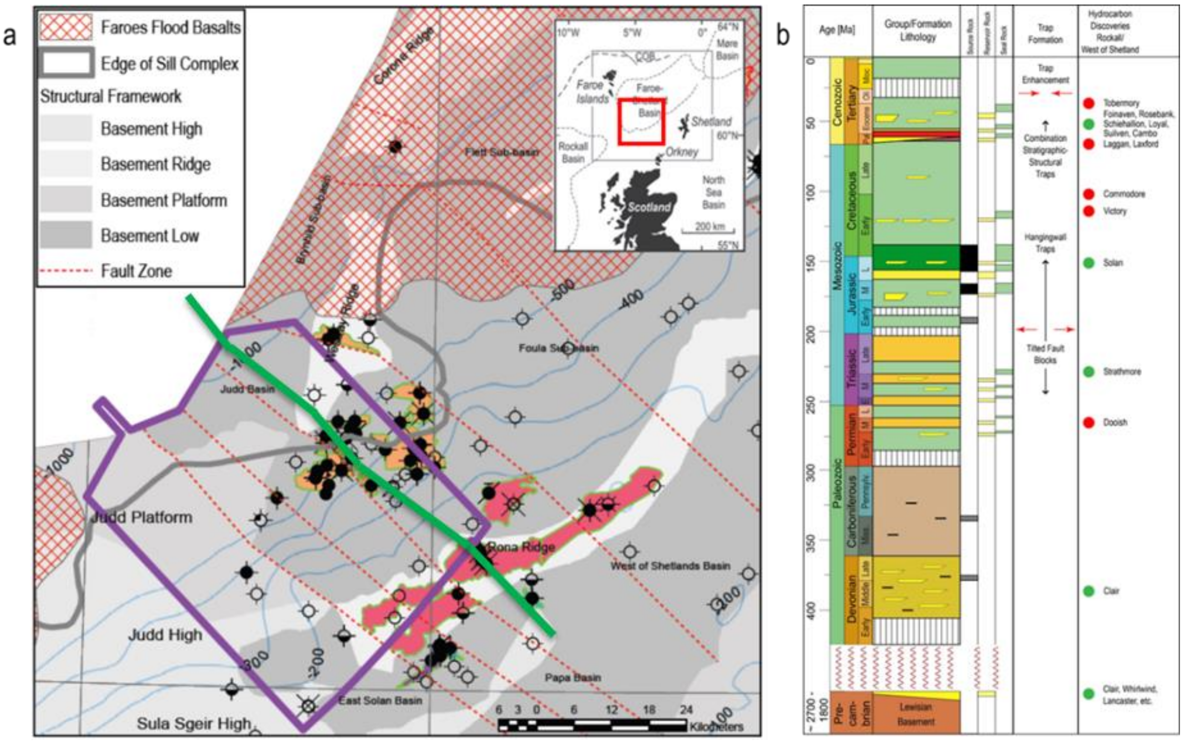

Figure 1: a) Structural map of the southwestern part of the West of Shetland Basin highlighting the area of the Westray 3D multiclient PSDM data set in purple. b) Generalized stratigraphic column of the UK Atlantic Margin basins.

Several geological challenges in the area are addressed: i) delineating the complexity of the Jurassic-Paleocene petroleum system; ii) a better understanding of Mesozoic prospectivity with potential analogues to Solan and Strathmore; and iii) improved basement fault network imaging being crucial to the understanding of discoveries such as Lancaster.

Seismic interpretation of the Westray 3D data set, integrated with additional interpretation such as basin fill, stratigraphy, or structural evolution, forms the basis for the petroleum system modeling (Figure 2).

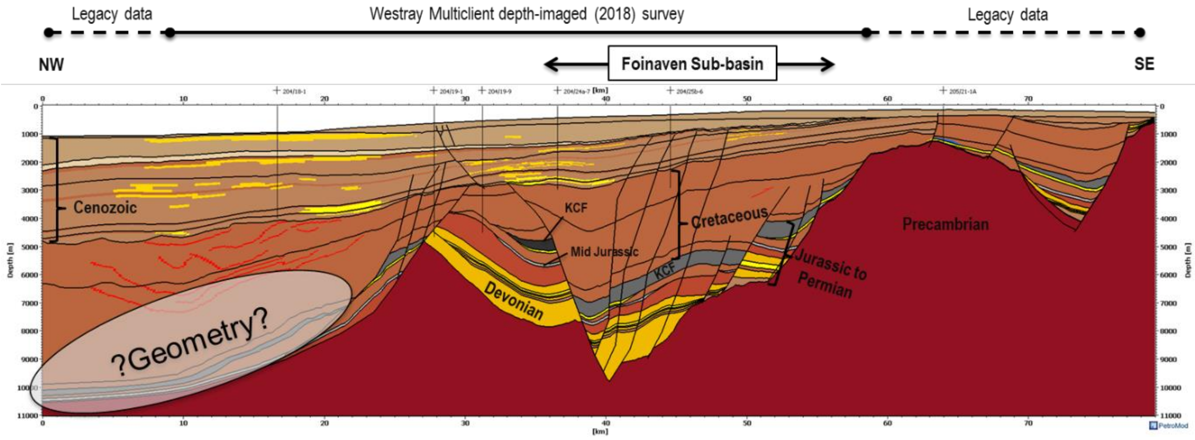

Figure 2: 2D petroleum system model crossing the Foinaven Sub-basin and the Rona Ridge highlighting litho-facies distribution (see green line in Figure 1 for location).

Interpreting legacy seismic data extending towards the south and southeast was integrated to compare Triassic and Jurassic discoveries in the East Solan Basin with potential analogues in the Westray area. We evaluated uncertainties such as i) thermal history including the impact of magmatism and amount and timing of erosion on source rock maturation, ii) presence, depth, and properties of source rocks in the deeper undrilled parts of the basins, iii) sealing capacity, especially of Paleogene strata, and iv) effect of timing and properties of faults on hydrocarbon charge.

Our analysis indicates that critical parameters for successful exploration are the assessment of i) Cretaceous and Paleogene burial, ii) timing and amount of erosion to evaluate timing of both source rock maturity and sealing efficiency, iii) faults, their properties and timing, and iv) where present, the thermal impact of igneous intrusions.

The new imaging of this area of the West of Shetland and analysis of the seismic itself have been used to identity and de-risk prospects as well as aid reservoir characterization. The interpretation of this new seismic dataset has provided answers to enigmatic discoveries by following the migration of hydrocarbons from source to trap. This survey has taken a step towards completing our understanding of the petroleum systems in the various tectonics settings of the Westray area and provide confidence in making future drilling decisions.

We will present the exploration potential of the Westray area drawing on our experience along the UK Atlantic Margin gained through continued study over during the last years.

Protagonist or Antagonist: Secondary Mineralisation in Volcaniclastic Rocks and its Implications for Hydrocarbon Exploration

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The impact of volcanism on hydrocarbon systems in prospective basins has come to the fore with the recognition of viable commercial volcaniclastic reservoirs, most prominently, the 2004 Rosebank discovery in the Faroe-Shetland Basin. In addition, the discovery of volcaniclastic seals in working hydrocarbon systems, e.g. the Turkana Basin, North Kenya, has given rise to new hydrocarbon play concepts involving volcaniclastic sequences. Despite this, there is still a distinct lack of quantitative studies assessing the character of volcaniclastic rocks, particularly the complex secondary mineralisation which can occur during burial and diagenesis. As a result, volcaniclastic rocks are often considered problematic and are overlooked or avoided during the development of exploration plays. It is, therefore, imperative to quantify the nature, thickness, and architecture of volcaniclastic rocks to better understand their role in hydrocarbon prospectivity in volcanic-bearing basins, like those along the NE Atlantic Margin.

This ongoing project uses well-exposed onshore analogues of flood basalt provinces from the NE Atlantic Margin (East Greenland, the Faroe Islands), as well as from Ethiopia, to quantify the thickness and architecture of intralava sedimentary sequences. More than 280 intervolcanic samples (volcaniclastic and siliciclastic) have been collected from these analogues at varying depths of burial (0-5 km) to analyse (Figure 1). Thirty-three selected samples have undergone Quantitative X-Ray Diffraction (QXRD) analysis to quantify their mineral assemblages, and to assess how primary composition and burial temperature control the presence and abundance of certain secondary minerals, including various zeolite and clay mineral species. The samples also have Mercury Injection Capillary Pressure (MICP) and conventional Poro-Perm data to quantify their petrophysical attributes, including air permeability, microporosity, pore throat distribution, and entry capillary pressures. This has enabled an assessment of their reservoir potential, as well as an assessment of their sealing capacity using the Sneider classification scheme.

Principal component analysis of the QXRD and MICP data enables a comprehensive examination of how secondary minerals (clays and zeolites) can extensively impact the petrophysical characteristics of volcaniclastic rocks. This has (for the first time publically) led to the relationship between secondary mineralisation and sealing potential to be established and quantified in volcaniclastic rocks. The results of this study show, that as well as providing potential reservoirs with good effective porosity, volcaniclastic rocks can also form effective top and side seals at shallow depths (<2 km), which can form relatively early in play development. The combination of QXRD and MICP data also allows for an assessment of the factors which control mineralisation, and as a consequence, the sealing or reservoir potential e.g. primary composition (mafic versus felsic), burial depth, geothermal gradients and environmental conditions.

This study has major implications for the NE Atlantic Margin, as well as other volcanic-bearing basins, where sub- and intra-lava volcaniclastic sequences are prolific and laterally extensive. It provides a comprehensive assessment of the role volcaniclastic rocks play in hydrocarbon exploration, and reconsiders the antagonistic perception of volcaniclastic sequences in hydrocarbon-bearing basins.

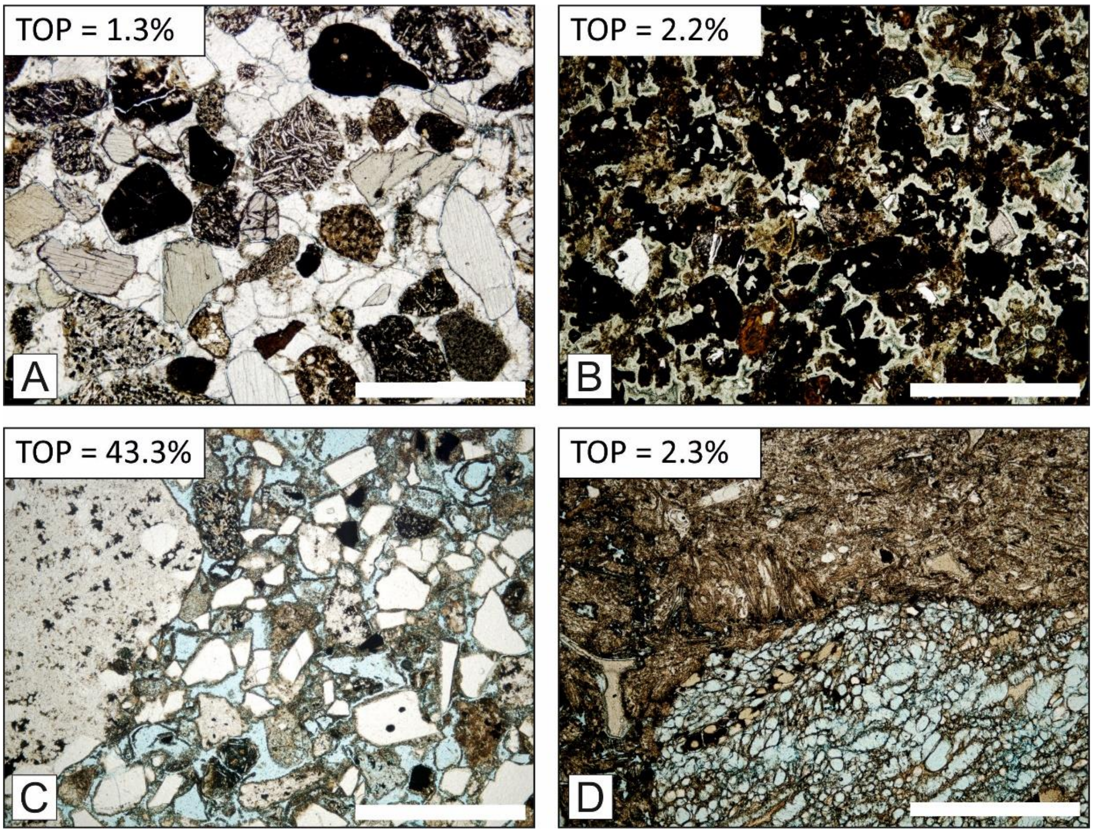

Figure 3: A selection of petrographical images of volcaniclastic sandstones collected from three onshore analogues (East Greenland, the Faroe Islands and Ethiopia). Volcaniclastic sandstones can show a variety of different compositions, which can lead to a range of optical porosities (TOP – total optical porosity). Pore space is stained blue. (A) and (B) Mafic-derived sandstones, (C) Felsic-derived sandstone, (D) Felsic tuff with pumice clast. Scale bars are 1 mm.

21st May 2021

Session Eleven: Technology 2

New insights to controls on the hydrocarbon habitat of the South-West British Isles

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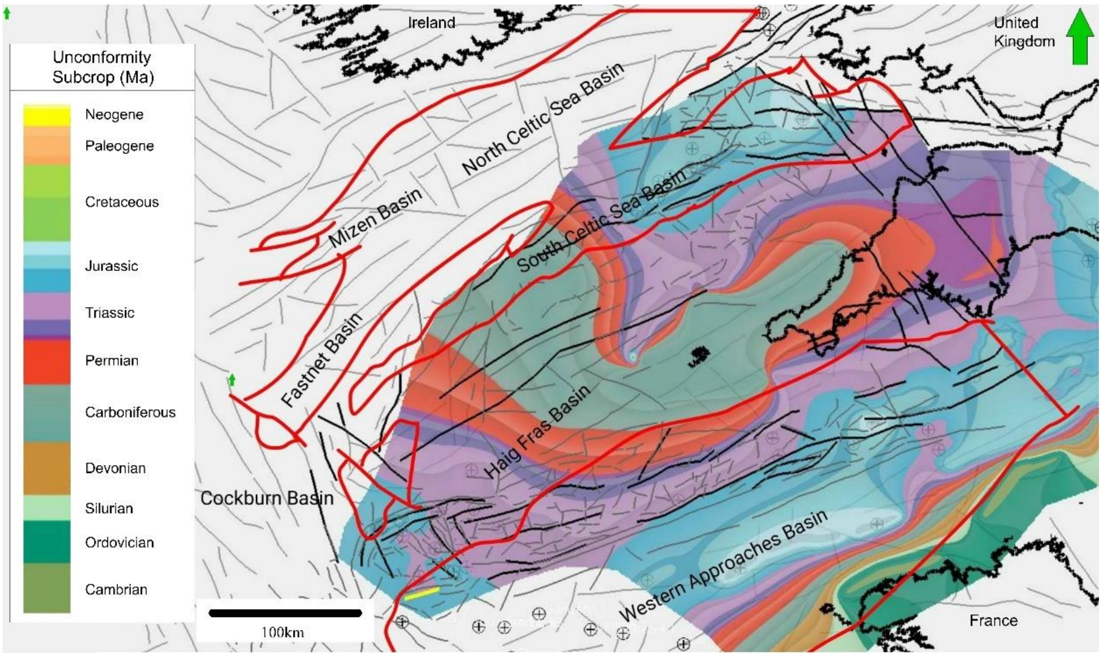
[1] Imperial College London, Earth Science and Engineering

In the Western Approaches Basin, the main Jurassic hydrocarbon system of the Lower Lias has been seriously impacted by an intra-Cretaceous uplift event. The event is seen on seismic as a series of unconformities, with suggested eroded strata of up to 2.8 km. The unconformity is also evident in the neighboring South Celtic Sea, Fastnet, Mizen, Cockburn, and Southwest Channel Basins, all characterized by poorly developed petroleum systems. The intra-Cretaceous event is significantly weaker in the North Celtic sea, where the Jurassic petroleum system is active, resulting in numerous discoveries such as Dragon Kinsale, Ballycotton and Seven Heads, and Barryroe. The varying success of petroleum exploration across these basins requires an understanding of the potential cause[s] of this intra-Cretaceous event.

Regional evidence of the intra-Cretaceous event from the North Atlantic basins has been examined, by interpreting unconformity subcrop patterns from seismic, well data and surface geology. Regional mapping of the unconformity initiation age across the basins, together with the subcrop patterns analysis, allows the evaluation of potential controls on the event such as mantle plume/uplift, continental margin rifting, or volcanic activity. This will be supported by detailed mapping of the Biscay and North Atlantic depositional sequences to identify structural and depositional anomalies that cannot solely be explained by the opening of the Bay of Biscay. The results are used to suggest areas with remaining hydrocarbon prospectivity.



QEMSCAN cuttings digitisation of offshore Faroe Islands wells

Omma, J.[1], Eidesgaard, Ó R.[2], Benedictus, A.[1], Szewczyk, A.[1]
[1] *Rocktype Ltd.*
[2] *Jarðfeingi (Faroese Geological Survey), Tórshavn, Faroe Islands*

As the oil & gas industry becomes more digital and data-centric there is an increased call to create Big Data digital datasets to analyse in algorithmic, next generation subsurface workflows. We have QEMSCAN analysed nearly 5000 cuttings samples from first returns to TD for the Faroe Islands offshore wells (8 of 9 wells currently analysed, Fig. 1).

This talk will present results from the analyses, including cuttings photographs, modal mineralogy, per lithotype mineralogy (separating results from sandstones, siltstones, shales, limestones per sample), cuttings size, grain size, calculated log properties and digital images (Fig. 1). Stratigraphic, sediment provenance and reservoir quality interpretations derived from the analysis of the data will also be presented.

These digital petrographic data, available for all cuttings samples in a well, are currently being tested as training data for generative machine learning models, focussed on determining rock & sediment facies from the seismic data, populating seismic cubes with high resolution rock and fluid characteristics, away from wellbore control.

We intend to extend the QEMSCAN dataset across the border to the UKCS and are currently digitising 75 wells on the Norwegian continental shelf, to be completed in 2020.

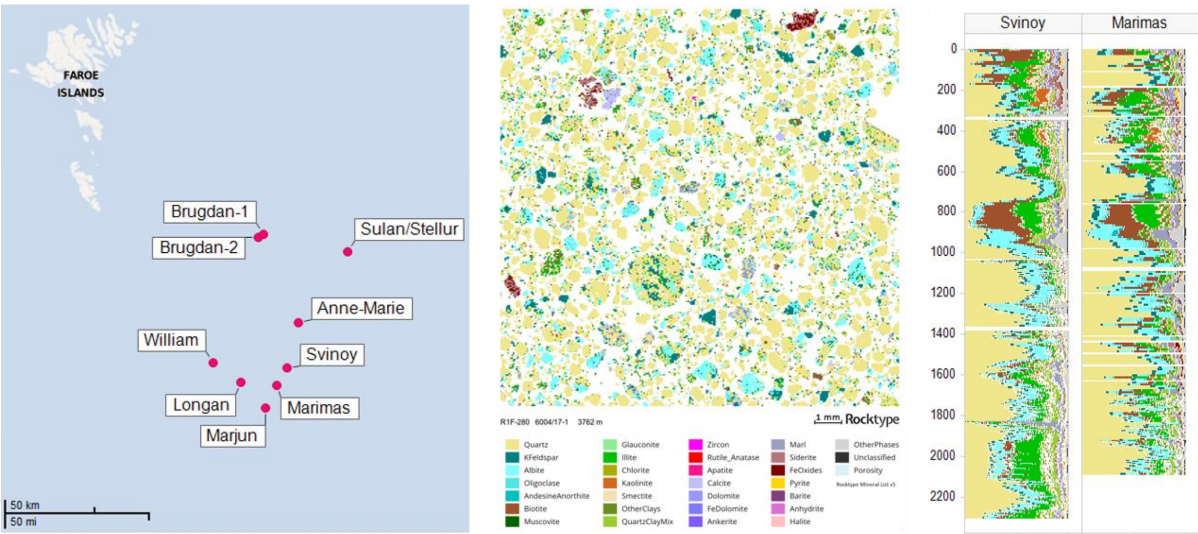


Figure 1. Left: wells included in this study. All samples except for the Brugdan-2 well have been analysed to date. Middle: QEMSCAN image from one of ~5000 samples available in this dataset. Right: Full well modal mineralogy plots for two of the study wells.

De-risk West of Shetland (WoS) Area Exploration using Generalized Radon Transform (GRT) Depth Imaging and Unsupervised Machine Learning methods

Can Yang[1], Elia Gubbala[1] and Jagat Deo[1] Andrew McKenzie[2], Tim Thompson[2]
[1]*Seismic Image Processing Ltd.*
[2]*Suncor Energy*

West of Shetland (WoS) area is located offshore NW Scotland on the SE margin of the Atlantic Ocean and comprises numerous sub-basins and intra-basin highs that are host to several significant hydrocarbon discoveries. But less than 200 exploration wells have been drilled WoS in the last 40 years, this area is a frontier area. After analysis of exploration technical challenge in this area, it was highlighted that most failed wells were drilled on poorly defined or invalid traps and on prospects that lacked reservoir or poor top seal (Loizou, 2008). Mis- interpretation of high-amplitude features has contributed to the failure of several wells. These exploration technical issues can be related to seismic processing and imaging problems from the past exploration activities.
In last 30 years Kirchhoff migration has been dominated for seismic imaging, but it has some limitations like multi-ray path calculation and complex structure area imaging (Etgen et al., 2009). For de-risking the WoS exploration new Angle domain pre-stack depth migration algorithm Generalized Radon Transform (GRT) has been applied to preserve true amplitude and output exact angle gathers which are two important factors for Reservoir Characterization. GRT is ray-based migration scheme but it carried out in angle domain. One gather comparison is displayed in Figure1.

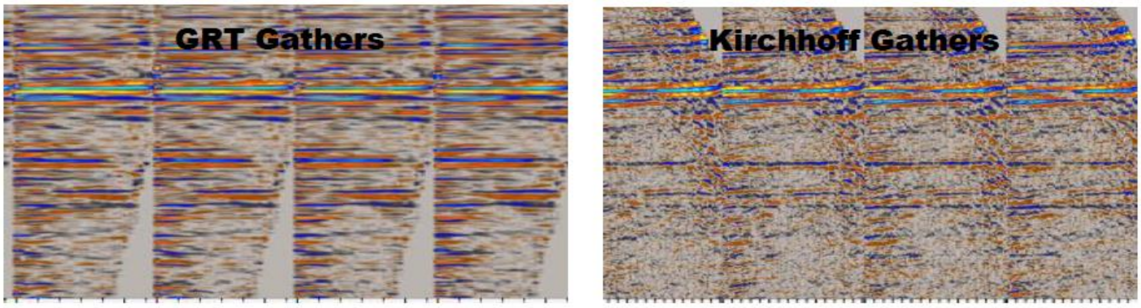


Figure 1. Pre-Stack Imaged Gather examples (left is GRT gathers and right is Kirchhoff gathers).

Machine Learning methods have been applied into different industries in recent years. For oil and gas exploration machine learning methods can be integrated to improve efficiency, decrease uncertainty and de-risk exploration. Different authors have integrated machine learning into Seismic Interpretation workflow, like salt body boundary detection, horizon and fault interpretation. General QI workflow integrated with machine learning methods is displayed in the below Figure 2.

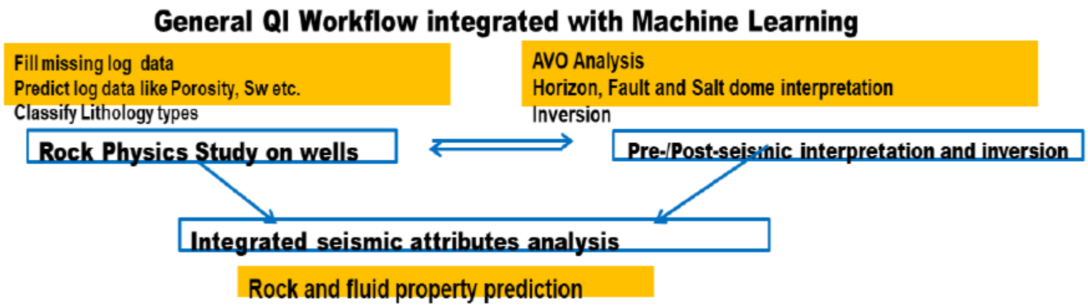


Figure 2. General QI workflow integrated with machine learning methods.

Laura et al. (2018) provided using machine learning clustering algorithm to pick AVO anomaly area. After the target area has been chosen the detailed seismic attributes analysis is needed for reservoir study. Principal component analysis (PCA) and Self-organizing map (SOM) unsupervised machine learning methods applied by Roden et al. (2015) in seismic attributes analysis can quickly pick the details of the reservoir. In the QI workflow, first the Fuzzy C-means clustering algorithm is used to quickly scan for AVO anomalies. From Fluid replacement modelling and synthetics analysis on one of the dry wells in the area, for brine case amplitude of top reservoir increases a bit at far offset. For oil/gas cases, AVO anomaly at top reservoir can be considered as class II/III. One cluster which matches with AVO class II/III has been plotted in Figure 3, one real angle gather has been chosen on the cluster map for gradient analysis. The AVO anomaly at target horizon on the gather shows class II/III. The overlay slice map shows AVO cluster map from machine learning match with EEI fluid slice very well that increase our confidence on fluid distribution area for further reservoir study. Unsupervised machine learning algorithms like Self-organizing Map (SOM) can be applied on seismic attribute volumes to pick geo-bodies/sweet spots.

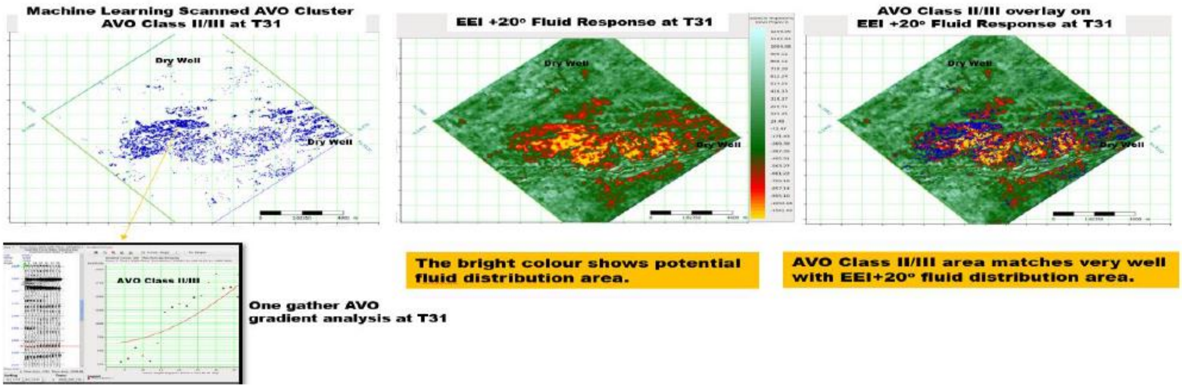


Figure 3 The Left image shows machine learning scanned AVO class II/III cluster at target horizon and one real angle gather gradient analysis. In the middle is EEI fluid slice at target horizon and on the right shows overlay the cluster map (blue points) and EEI fluid slice.

For de-risking WoS area exploration GRT angle migration has been applied to preserve true amplitudes and provide high-quality angle gathers directly through migration process. Machine learning methods like Fuzzy c-means clustering enables to quickly scan seismic angle gathers from large area and find AVO anomaly area for further study. PCA and SOM unsupervised machine learning methods provide more accurately exploration targets after choosing and combining different seismic attributes through the algorithms. The integrated depth imaging and QI machine learning workflow is proven to identify and de-risk exploration targets in the West of Shetlands in a time- and cost-efficient manner, whilst generating a high-quality seismic image and associated fluid attributes.

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The Geological Society of London is a professional and learned society, which, through its members, has a duty in the public interest to provide a safe, productive and welcoming environment for all participants and attendees of our meetings, workshops, and events regardless of age, gender, sexual orientation, gender identity, race, ethnicity, religion, disability, physical appearance, or career level.

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It also applies to members of the Society attending externally organised events, wherever the venue.

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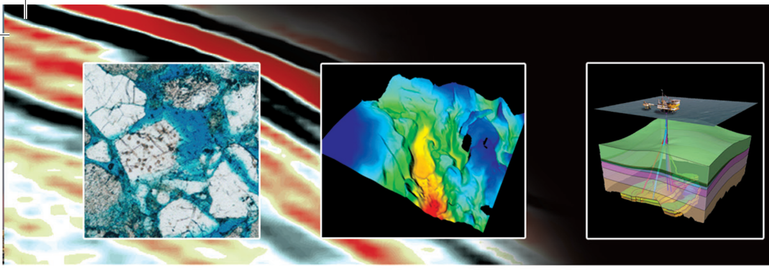

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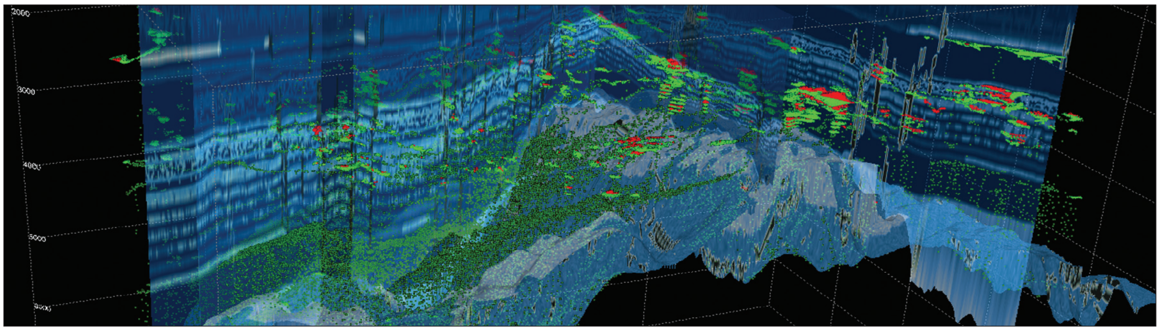
Call for Abstracts - Extended Deadline 31 May 2021

Basin and Petroleum Systems Modelling

Best Practices, Challenges and New Techniques

28 - 30 September 2021

The Geological Society, London and Virtually



The prediction of viable petroleum systems is critical to meet the growing energy demand. At the same time, the energy sector is shifting from traditional hydrocarbon to alternatives, and new disciplines such as carbon capture and storage are emerging. This meeting will discuss the importance of Basin and Petroleum System Modelling (BPSM) in exploration and evaluation of resources, focussing on best practices, recent developments, novel applications, and opportunities for the future. New and improved digital capabilities have enabled a more integrated approach to analysis; therefore, the impact of newly available data and technologies in BPSM will be reviewed.

BPSM key topics

- Best practices in different exploration scenarios: mature, frontier, and unconventional areas
- Effectiveness of modelling geological processes: heat flow; erosion; kinetics; thermal conductivity
- New techniques in BSPM
- Linking to new disciplines: carbon capture and storage; reservoir engineering; geothermal; and more
- Dealing with predicted risk and uncertainty
- Charge and migration modelling
- Case studies

The conference will bring together professionals from academia, government agencies, and industry to discuss BPSM through a series of presentations and panel discussions, suitable for both a specialist basin modeller and for a general exploration geologist. A dedicated student short talk will encourage participation from a new generation.

Convenors:

Christine Yallup
Halliburton

Rachel Round
Halliburton

Michael Abrams
Imperial College London

Friedemann Baur
Chevron

David Gardiner
IGI

Rachel Gavey
APT (UK)

Daniel Palmowski
Schlumberger

Will Prendergast
Independent Consultant

Dani Schmid
Geomodelling Solutions

Robert Newbould
Premier Oil

Keynote talks:

Zhiyong He
Zetaware

Neil Frewin
Shell

For further information please contact:

For more information please contact Sarah Woodcock, sarah.woodcock@geolsoc.org.uk, or visit the conference website: https://www.geolsoc.org.uk/09-rescheduled-pg-petroleum-systems-modelling-2021

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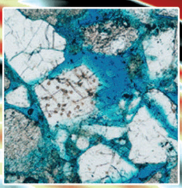

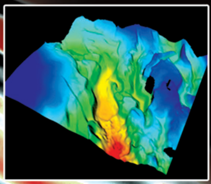

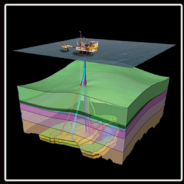

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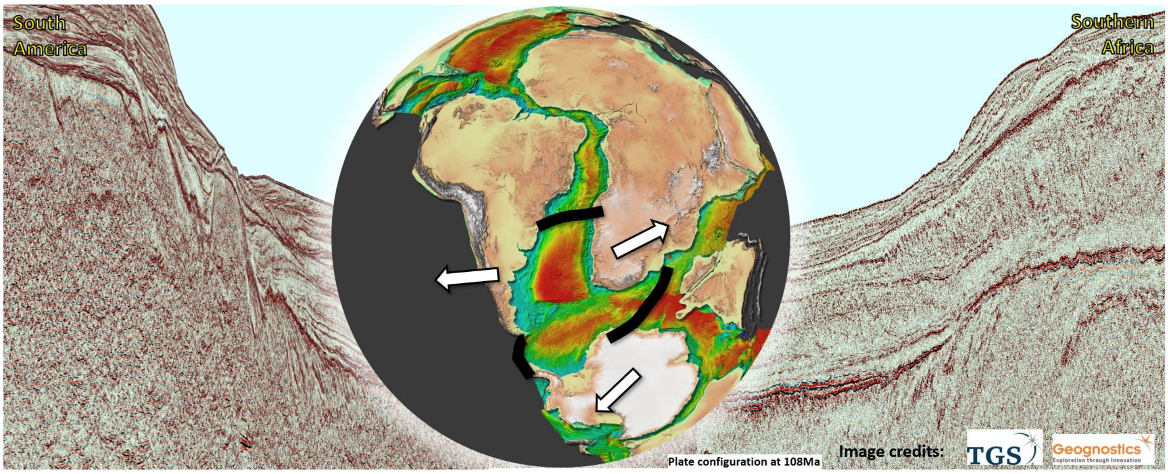
Call for Abstracts

Petroleum Geology of the Southern South Atlantic

6-8 October 2021

The Geological Society London



There has been a significant increase in interest towards the Southern South Atlantic by the exploration community in the past few years. Significant resources have been discovered in Falklands/Malvinas (Sea Lion, 2010) and South Africa (Brulpadda & Luiperd, 2019 & 2020) as well as commercial success in the 1st Argentina offshore licensing round (2018).

This three-day conference aims to bring together both academic and industry geoscientists to discuss the current state of understanding of the geology and petroleum systems in this emerging petroleum province. Topics ranging from plate- to prospect-scale will be covered.

The committee welcomes the submission of abstracts on the following themes:

Day 1 - Tectonics & Regional Processes
Plate modelling, dynamics of mantle & topography, inherited structures & controls on source rocks, rifting, volcanism & SDR development

Day 2 - Play Elements
Source to sink, source rocks, thermal & basin modelling, deep water clastic reservoir rocks, carbonates, contourites, oceanography and ocean gateways

Day 3 - From Prospect to Discovery
New play types & models, thermal controls on reservoir systems & exotic fluids, uncertainty modelling in frontiers, operational challenges, new data techniques & technologies, technical advances in source rock prediction & thermal modelling

Convenors:

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Impact Oil & Gas - *Chair*

Josh Springett
ExxonMobil

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