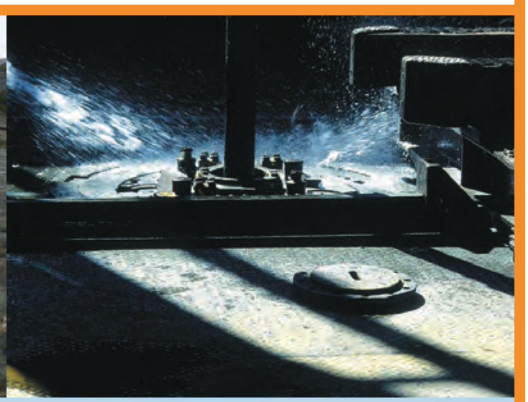
3rd Faroe Islands Exploration Conference

The Nordic House - Tórshavn - Faroe Islands
15th - 16th September 2009



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Jarðfeingi Session

Tuesday, 15th September 2009

8.45 – 12.25

The Norway Basin revisited: New aeromagnetic survey and implications for early spreading development in the Norwegian-Greenland Sea

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We reevaluate the structure and spreading evolution of the eastern Norway Basin based on a new high resolution aeromagnetic survey (NB07). The new dataset maps a flank of a complete oceanic spreading system from a continental oceanic transition region to an extinct ridge (e.g. Aegir Ridge). Our interpretation documents a volcanic continent-ocean transition along transform, rift and shear margin segments formed between the East Jan Mayen Fracture Zone and the Faroe Plateau. The detailed fabric of the Norway Basin documented by the new data indicates that two distinct tectonic phases have reshaped the basin before the cessation of seafloor spreading in the Oligocene time. Phase 1 (from 52 to 48 Ma) marks the earliest phase of spreading probably initiated in the central part of the Møre Marginal High. During this period, competing oceanic segments lead to the formation of overlapping systems and pseudo-fault development. We observe a significant change in the Norway Basin around 48 Ma (chron 21) and, based on observations from surrounding areas, we suggest that this marked a major tectonic event. During phase 2 (48-28 Ma), spreading rates decreased in the Norway Basin, spreading direction changed, and the number of rigid faulting with large displacement increased. The fan-shaped development of the spreading system initiated around C21 (~48-46 Ma) instead of C18-C17 (~40-38 Ma) or C24 (53.3-52.3 Ma) as previously proposed. This new observation also allows us to reevaluate the tectonic calendar of the Norwegian-Greenland Sea and discuss some implications on the syn- and post-breakup development of the surrounding continental margins.

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Transfer Structures and Segmentation of the Faroese Continental Margin

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The Greenland-Europe rift system is located on the Atlantic margin of NW Europe and extends from the Porcupine area offshore Ireland in the south to the Hammerfest and Nordkap basins in the Barents Sea in the north. This major rift system developed during the early phases of separation between Europe and Greenland in the Carboniferous and continued until the early Palaeogene, when rifting activity ceased during break-up of the NE Atlantic. Major faults in the rift system are generally oriented in either the Caledonian (NE-SW) or the Hercynian (NW-SE) direction. A third set of major N-S oriented faults were active mostly in the Jurassic and are related to the North Sea rift system.

Basin forming faults trending in the Caledonian direction accommodated NW-SE oriented lithospheric strain, while faults in the Hercynian direction primarily acted as transfer faults separating segments of different tectonic architecture. In general the transfer faults in the Greenland-Europe rift system are recognised as short fault segments (few kilometres to few tens of kilometres in length) with significant heave, which may be correlated. Frequently, significantly different or opposing dips are observed across the transfer faults. A few major NW-SE lineaments (100-400 km apart) are observed across the Greenland-Europe rift system and have been interpreted as regional transfer zones. Those in the northern part of the rift system appear to be approximate continuations of major lineaments separating regional Precambrian segments in the Fennoscandian Shield.

During the Carboniferous when post-Caledonian rifting was first initiated in NW Europe, the Faroe-Shetland and Hatton-Rockall Basins were aligned. Both basins appear to have been extended by a factor of two or more. During the Lower and Mid-Cretaceous, the Wyville-Thompson, Ness and Anton Dohrn transfer zones located to the SW of the Faroe Islands dextrally transferred continental extension. Thus the SW continuation of the Faroe-Shetland Basin is not located below the Hebrides and Irish continental shelf and slope, but instead within the Hatton-Rockall Basin.

The presence of deep rift basins, presumably Cretaceous or older, are imaged on multichannel seismic data within this area. Eroded remnants of rift basins with Cretaceous sediments have been reported from a shallow well on the Hatton Bank. Growth of the Rockall Trough, either as the result of a prolonged process, such as seafloor spreading, or during a short time span following rifting in the Faroe-Shetland and Hatton-Rockall basins, has resulted in the present offset of the two basins. We therefore view the Hatton-Rockall Basin as a potentially very interesting area of future exploration interest on the continental shelf to the southwest of the Faroe Islands.

A critical analysis of the structure and tectonic significance of rift-oblique lineaments ("transfer zones") in the Mesozoic-Cenozoic succession of the Faroe-Shetland Basin, NE Atlantic Margin

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NW-SE trending rift-oblique lineaments ("transfer zones") occur along the length of the NE Atlantic Margin. Previous authors have suggested these lineaments played an important role in providing conduits and/or barriers to sedimentation during the Cretaceous and Paleocene; it has also been suggested they were active as discrete, basin-wide strike-slip faults. This study uses a well-calibrated 3D seismic survey of regional extent to critically assess the structural and stratigraphic evidence for three rift-oblique lineaments in the UK sector of the Faroe-Shetland Basin (Victory, Clair and Judd Lineaments). Structures previously attributed to basin-wide strike-slip deformation can be more simply explained as igneous intrusions, hydrothermal vent complexes, gas chimneys and/or faults that transfer extensional strain between en-echelon rift segments. There is little evidence to suggest that activity along discrete, basin-wide lineaments controlled Paleocene sedimentation within the Faroe-Shetland Basin. Rather, sediment transport and deposition at this time are likely to have been controlled by along- and across-strike variations in the magnitude of thermal subsidence, which in turn reflect the three-dimensional nature of the underlying Mesozoic rift architecture.

Onshore evidence for progressive changes in rifting directions during continental break-up in the NE Atlantic and the role of NW-SE trending structures in the Faroe-Shetland basin

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Many existing models for the Palaeogene development of the NE Atlantic Ocean invoke NW-SE extension in basins along the margins, which are segmented by regional-scale NW-SE-trending strike-slip faults, termed 'transfer zones'.

Structures in the Faroe Islands provide evidence for a 3-phase tectonic evolution:

1) E-W to NE-SW extension, accommodated initially (1a) by dip-slip N-S and NW-SE trending faults, and continued (1b) by similarly-oriented dykes. Event 1 affects the majority of the FIBG stratigraphy, resulting in thickness variations, most notably across the Judd, Brynhild and Westray ('transfer') fault-zones.

2) Syn- to post-magmatic anticlockwise rotation of the extension vector led to (2a) N-S extension accommodated by ENE-WSW and ESE-WNW conjugate dykes, followed by (2b) crustal extrusion involving both E-W shortening and further N-S extension facilitated primarily by slip on ENE-WSW (dextral) and ESE-WNW (sinistral) conjugate strike-slip faults. During the final stages of this event (2c), the regional extension vector rotated into a NW-SE orientation, accommodated predominantly by NE-SW oriented dextral-oblique-slip faults.

3) Compression resulted in post-magmatic fault-reactivation characterised best by the entrainment of clastic materials into faults.

The progressive anticlockwise rotation of the extension vector identified here is broadly consistent with recently proposed NE Atlantic continental break-up reconstructions. Importantly, the evidence preserved onshore for the Palaeogene and onwards, suggests that the basin-scale NW-SE structures acted as normal faults during a pre-cursor margin-parallel extension event prior to oceanic opening in the Faroe-Iceland sector. This model does not preclude the possibility that the NW-SE structures reactivate pre-Cenozoic transfer faults in the underlying rifted margin.
Current models for the Palaeogene build up to formation of the NE Atlantic Ocean invoke NW-SE extension in basins along the margins, which are segmented by regional-scale NW-SE trending strike-slip faults, termed 'transfer zones'.

Reflection seismic data used for refraction analysis giving information of the small scale velocity distribution of near surface basalt flows

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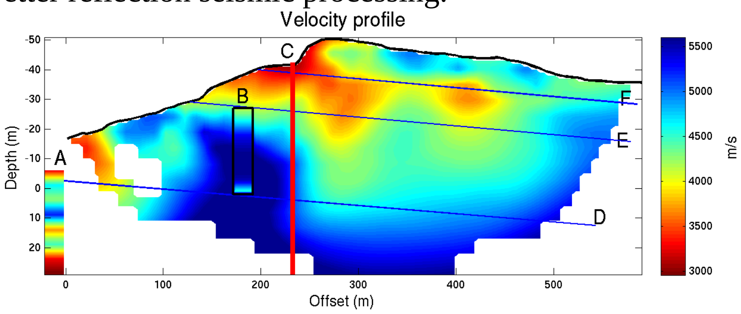
In 2003, surface seismic data were acquired in the Faroe Islands at Glyvursnes as part of the SeiFaBa project. The objective was to investigate seismic wave propagation in an area where the elastic properties of the basalt flows are relatively well known.

Here a refraction seismic analysis based on the two land seismic profiles is presented. The analysis aims to map the very shallow velocity distribution both vertically and horizontally. The analysis for each profile is based on a 600 m geophone layout with 120 channels. 250 g dynamite charges were used as sources at 10 m shot intervals, producing a 600 m long velocity profile giving velocity information down to 80 m depth. The velocity distribution of the profiles is consistent with, and can be related to, geologic features in the area, such as flow boundaries and a large-scale fracture. The gradients in the velocity profile compare quite well with the general dip of basalt flows in the area. The location of the large-scale fracture coincides with an area of large alteration of the horizontal velocity distribution. A 30 m thick flow unit that was identified by previous geological mapping shows relatively low velocities in the upper part with a positive downward gradient, related to the crust, and high velocities in the lower part, related to the core. This is consistent with the velocity distribution of another 28 m thick basalt flow unit contained in the Glyvursnes-1 well. The core-crust velocity characteristics are not resolved for the thinner flow units.

The velocity distribution has, as expected, large variations over short vertical distances. But the horizontal velocity variation is also significant. Over a horizontal distance of 50 m crossing the large-scale fracture, velocities vary from about 5500 m/s to 4000 m/s.

This analysis demonstrates that refraction modelling can be used to determine small-scale variation in the near-surface layers and to establish that the velocity distribution is indeed complex. In addition to revealing spatial properties of near-surface basalt flows, the refraction modelling can also form a basis for better reflection seismic processing.



The velocity profile obtained using a 60x16 grid with 10 m horizontal and 5 m vertical grid spacing. A) P-wave velocities from the Glyvursnes-1 well plotted with true location relative to the velocity profile. The log is resampled to 5 m for comparison with the 5 m vertical grid spacing of the model. B) The area marked with the black rectangle shows P-wave velocities from a flow-unit of about 30 m thickness obtained from the Glyvursnes-1 well log (depth location is 81-109 m) superimposed on the velocity profile. The log is resampled to 5 m. C) The location of a large-scale fracture. D, E and F are flow interfaces from previous geological mapping in the area, superimposed onto the velocity profile. D and E mark the base and top of a tabular flow unit of about 30 m thickness. Between E and F, two tabular flow units are contained. F marks the base of a compound flow unit followed by a tabular flow unit.

Constraining basalt thickness and sub-basalt velocities by combined analysis of ocean-bottom seismic and streamer data

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Combined analysis of ocean-bottom seismometer (OBS) and streamer data is critical in reducing uncertainty in sub-basalt exploration. A major concern is that errors in basalt thickness and sub-basalt velocities could result in a missed target in drilling; a mis-identification of base basalt can change the geological model. Standard streamer data analysis offers poor velocity estimation below top basalt while standard OBS data analysis gives weak depth control on base basalt. We provide extra constraint by interpreting the full offset extent of base basalt reflections and basalt diving waves. Our multi-step methods are: 1) identifying base basalt wide-angle reflections in OBS data and then their equivalent in the streamer data; 2) tracing the near-offset continuation of both wide-angle reflections into the respective water wave cones by means of multiple removal through predictive deconvolution, block shift and fk-filtering; 3) inverse ray modelling the basalt velocity using refracted basalt arrivals and base basalt depths from the full offset range of the base basalt reflection; 4) inputting model results to pre-stack depth migration velocity for modelling deeper layers. Here, we present results using data from the integrated Seismic Imaging and Modelling of Margins (iSIMM) Project, acquired across the Faroe-Shetland basin. Our results show well-constrained basalt velocities increasing from 4.5km/s at the top to 5.5km/s at the base, and thicknesses of up to 3km where basalts overlie a low velocity zone. A geologically-satisfying model of this low velocity zone is presented, with its base matching an observed basement reflection.

Imaging igneous intrusions in the lower crust on the Faroes and Hatton Bank margins using wide-angle Ocean Bottom Seismometer data.

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Stacked seismic sections produced from wide-angle ocean bottom seismometers (OBS) show clear, strong P-wave reflections interpreted as igneous intrusions arriving from lower crustal and upper mantle depths on the Faroes margin. The lower-crustal reflectors are also seen on a coincident long-offset multi-channel (MCS) profile, though the upper mantle reflections are a new observation. Strong wide-angle reflections are also seen in OBS data from Hatton Bank profiles where no corresponding MCS profiles were shot. Applying this technique to the Hatton Bank data will allow us to image this section of the margin and determine if the structure seen in the Faroes MCS survey is present at other locations along the margin. Producing such images with conventional MCS data has proved difficult due to their necessarily limited offsets, and the presence of refractions and multiples at offsets beyond the first break of the sea-bed reflection. Adapting this technique to the OBS shear wave data may allow us for the first time to image sub-basalt structure with converted shear waves. Our results demonstrate the benefit of imaging wide-angle OBS data, since many OBS surveys have been employed solely to perform travel-time inversions. The data come from the integrated Seismic Imaging and Modelling of Margins (iSIMM) project shot in 2002 with wide-angle OBS surveys northeast of the Faroe Islands and across Hatton Bank. These areas contain flood basalts of the North Atlantic Igneous Province, making conventional seismic imaging challenging.

Sub-Basalt Imaging of the Northeast Atlantic Margin Revealing New Frontier Plays

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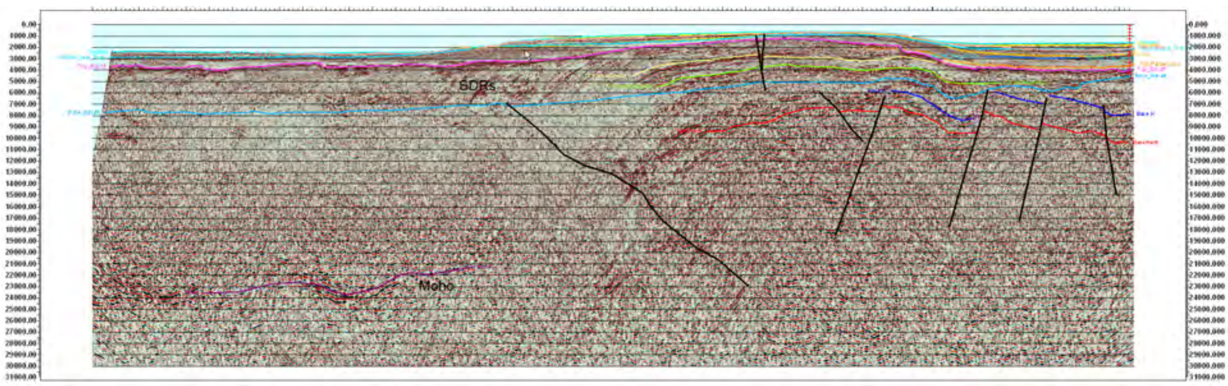
New seismic data is presented by ION/GXT as part of Ion's Global BasinSpans. Acquisition and PSDM are designed to provide optimum seismic imaging below Paleogene basalts which cover much of the NE Atlantic margin. Acquisition utilised a deep tow source and receiver configuration that maximized penetration through the basalts. Data was imaged to 30km in order to successfully reveal the basin architecture and crustal structure of the margin. All data has been PSDM using velocities derived from state of the art model building. The modelled depths are within 5% of the depths from calibration wells.

The Faroes-Shetlands and Møre basins was covered by thick Paloegene basalts, which has hampered oil exploration. Few wells have been drilled in the Faroes sector, and not all successful at reaching base basalt, with the basalts being thicker than anticipated. The base basalt is a transitional zone and there is no clear seismic event at the base. However, deeper strata reflections are clearly imaged in many areas. Large-scale Cenozoic folds (Wyville-Thompson, Ymir, and Fugloy) and Mesozoic rotated fault blocks constitute major potential traps with Mesozoic reservoirs and Jurassic source rocks. To our knowledge many of these structures have never been recognised before and located in shallow waters at drillable depths, making this a viable but high risk play which has yet to be tested.

The new data has also helped to quantify the risk on the potential structures in these frontier provinces, which are some of the largest undrilled structures in NW Europe.



Section through Faroes–Shetland Basin showing coherent reflections of Mesozoic sediments in a large anticlinal structure below the Paleogene basalts.

ENI Session

Tuesday, 15th September 2009

13.25 – 17.05

Improvement of sub-basalt imaging by the Common Reflection Surface (CRS) method

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We present the results of the Common Reflection Surface (CRS) technology based approach aiming at an improved sub-basalt imaging. Basalt flows form the major problem in the Faroe-Shetland Basin due to their scattering effects and their generation of multiples masking sub-basalt reflections. For the case study 2D seismic profiles from three different surveys southeast of the Faroe Islands were used.

Unlike the horizontal-layering assumption of the NMO model, the CRS processing implies a subsurface with reflectors of arbitrary dip and curvature (common-reflection surfaces). In accordance with this complex model assumption, a reflection is not constrained to the seismic traces of a constant CMP position, but is distributed across several CMP locations. This leads to a high signal-to-noise ratio due to high CRS fold.

The method can also be used to improve prestack migration techniques by using CRS preprocessed input gathers. These can also enhance stacking velocity analysis to obtain a more reliable velocity field.

Another product of the workflow is CRS attributes defining the stacking operator. These are suitable for CRS tomography resulting in a reliable interval velocity field. For a subsequent PreSDM the number of velocity update iterations can be significantly reduced. Further improvements of the PreSDM workflow were obtained from noise suppression and regularisation of the input gather by the CRS technique.

Altogether a significant improvement of the imaging of sub-basalt structures is observed.

Why is dating basalt so difficult? A brief overview of $^{40}Ar/^{39}Ar$ dating system focussed on the North Atlantic Igneous Province

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The $^{40}Ar/^{39}Ar$ dating system applied to basalt can be highly successful and is frequently used to try to link eruptions with climatic events and mass extinctions. In the North Atlantic the technique is often used to aid correlation in fragmented lava fields on different islands and offshore. It is widely understood that basalt dating can be less than straightforward, and a proportion of data from any one study is likely to be contradictory and difficult to interpret. Alteration of the sample, the presence of excess argon, recoil of ^{39}Ar and possibly ^{37}Ar from matrix glass or alteration products are just three potential disturbances to the K-Ar system. There are other potential contributing factors to consider, however. Firstly, how does lava chemistry control the K-Ar system? Likewise how is the system influenced by the environment of lava emplacement? Whilst wet environments exert control on the physical volcanology, is it also a likely source and transport mechanism for excess argon uptake? There are also mass spectrometric considerations that could bring about improvements to basalt dating, relating to the accuracy and precision of the ^{36}Ar measurement, vital for correcting for the presence of atmospheric argon, and for testing for the presence of excess argon. To summarise, the $^{40}Ar/^{39}Ar$ dating in the FIBG is considered to be problematic because of the widespread zeolitisation, but it is likely that the picture is slightly more complicated, and that other parts of the North Atlantic Igneous Province experience a similar range of isotopic disturbances.

Timing, duration and tempo of eruption in the Faroe Islands Basalt Group through combined $^{40}Ar/^{39}Ar$ dating and interbed chemistry

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The timing of eruption of the Faroe Islands Basalt Group has been the subject of some controversy. New $^{40}Ar/^{39}Ar$ data for the Beinisvørð Fm suggest eruption in ~1 my c.56 Ma and published data suggest the Malinstindur and Enni formations also erupted in <1 my, at ca. 55 Ma, showing the rapid nature of the eruption of the Faroe Islands Basalt Group as a whole. The presence of numerous sedimentary horizons within, (and between) the basalt formations, provide evidence that eruption was not continuous. The chemistry of these sediments can provide information about the duration of the hiatuses between volcanic eruptions and in this lava field indicate that there are marked differences in eruption rate up the stratigraphy. The immature nature of many of the interbed sediments is shown by their chemistry, in particular the level of macronutrient elements, such as the MgO.

Study of the interbeds, combining the chemistry, sedimentology and palynology has shown the short duration of the hiatuses between eruptions within the Faroe Islands lava field, and has shown changes in the environments of sediment deposition, both stratigraphically and geographically, with some units becoming more mature to the south.

$^{40}Ar/^{39}Ar$ basalt data and chemistry of interlava sediments are used to demonstrate changes in the rates of eruption within the lava field of the Faroe Islands, providing a far more complete picture of changes in eruption rate and the environments on/around the lava field during eruption. To summarise, the data from the interbed sediments show an overall decease in the eruption tempo from the base of the Malinstindur to the upper parts of the Enni Fm, with short duration interbeds, colonised mainly by disturbance tolerant early successional communities.

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Subbasalt mapping of velocity and tectonic structure of the Wyville- Thomson and the Munkagrunnur Ridges- North Atlantic.

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Sub- basalt mapping of sedimentary basins in the North Atlantic has posed significant difficulties to the hydrocarbon exploration industry. The main problem is poor energy penetration or no penetration at all due to high reflectivity of the basaltic layers intercalated in the sedimentary sequence. The answer to this problem is twofold: deploy a low frequency tuned airgun signal and increase the length of the actively recording sensor- array in order to obtain wide azimuth penetration of the seismic energy.
We used a 60lt (~3600 cuin) sleeve gun to generate a seismic signal of 8 Hz dominant frequency. We deployed 57 Ocean Bottom Seismographs anchored at the seafloor that recorded 4 seismic channels (three geophones and one hydrophone). The stations were positioned at 3.5km spacing inline and shots were fired every 120m. They were recorded by the complete away that was continuously alert. The reason for this spacing and line length was that we indented to map the sedimentary and crustal structure in order to understand the geological significance of the Wyville-Thomson (WT) and Munkagrunnur Ridges and their connection to the deeper crust. We have also used refection migration technique that permits to depth migrate wide- angle reflections and refracted waves. We mapped first the velocity Vp of the structure and then used it to perform the migration of the Common Station (OBS) Gathers in order to delineate the tectonic significance of the geological units.
The result showed that the WT- and Munkagrunnur Ridges are compressional features generated after an extensional phase (rifting) at the early Palaeocene that produced the lava flows and sills. Inversion of the extensional tectonism produced the Ridges in the Eocene to Miocene Era.
The crust is stretched continental, ranging from 18km under the NE Rockall Through to 20km at the western end of the Shetland- Faroe Basin. In this part of the Rockall Through the sediments are nearly 6km thick and massive basalt flows encountered in 3km depth are 0.9 to 1km thick. They slightly thin on the WT- Ridge and thicken to nearly 1.5km in the Munkur Basin further east. Beyond the Munkagrunnur Ridge, which is also covered by more than 1.5km thick basalt, the Shetland Faroe Basin has more than 7km thick sediments, the basalt flows thinning significantly and are discontinuous towards east.

The Wyville-Thomson Ridge Complex – Aspects of the Tertiary Development

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Significant explorations have taken place around the Faroe Islands striving for the geological development in order to localize areas of potential hydrocarbon plays. In this study the Wyville-Thomson Ridge Complex (WTRC), a major anticline complex, southwest of the Faroe Islands is investigated by interpreting commercial 2D digital reflection seismic data. The objective is to present a structural model accounting for all the diverse motions affecting the WTRC and this was aided by interpreting the stratigraphic development of the neighbouring basins. It is found that the pointing direction of the apex alongside the Wyville-Thomson Ridge (WTR) and the Ymir Ridge (YR) changes; that the WTRC tilted towards the southeast due to thermal cooling; experienced a clockwise rotation in Late Paleocene – Middle Miocene; is segmented by two NE/SW trending fissures and adjacent faults bearing the Caledonian trend. A transcurrent fault, extending from the Ymir/Ness Lineament, is located underneath the south eastern part of the YR being active till late Early Eocene. In the Rockall Trough this transcurrent fault is located alongside the YR southern flank ending as a listric fault between the Darwin Seamount and the YR central part being active till Early Oligocene. Four compressional phases affected the area 1) Late Paleocene – Early Eocene 2) Top Eocene 3) Top Oligocene and 4) Middle Miocene. Besides the compressional phases the location of the Late Paleocene volcanic centres, the geometry of the ridges and the previously mentioned transcurrent fault controlled much of the compressional effect.

Post-rift, mid-ocean ridge type flood basalts from the Wyville Thomson Ridge region southwest of the Faroe Islands

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The Wyville Thomson - Ymir Ridges form part of a complex basalt covered area of enigmatic origin separating the Faroe-Shetland Channel from the Rockall Trough. We report on samples of the volcanic basement dredged or drilled from the above ridges and the adjoining Faroe Bank. Most of the basalts are of mid-ocean ridge type depleted in incompatible trace elements. Five basalts give acceptable Ar-Ar ages ranging from about 56 to 50 Ma. The three youngest ages (50-51 Ma) are from the western and southern margin of Faroe Bank and the northern end of Ymir Ridge, respectively. It shows that widespread subaerial extrusion of flood basalts occurred within the area until about 4-5 Ma after the onset of seafloor spreading between the Faroes and Greenland. The new datings suggest that most or all of the basalts postdate the North Atlantic volcanic phase 1 (56-61 Ma). The implications for the interpretation of the geology of the area will be discussed.

Sindri – Research for the future

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The Faroese continental shelf is a focus area for international research into the geological evolution and exploration challenges posed by volcanically-affected basins. The SINDRI Group aim at stimulation focused research and economically supports innovative ideas that minimise these risks for hydrocarbon exploration.

Since 2001 the SINDRI Group have supported 33 research projects of which 10 are still ongoing. The research projects are carried out by independent research institutes and have significantly advanced our knowledge of seismic imaging and petrophysical properties of basalts, structural evolution of the Faroes, sediment dispersal systems and hydrocarbon systems in the Faroese Area.

Following the 3 rd Faroes Licensing Round a call for proposals has now been issued. Project proposals should be submitted under one or more of the following categories: 1) Relevant technologies for imaging within basalt-covered areas. 2) Regional geology and evolution of the entire Faroese area. 3) Definition of the hydrocarbon system of the entire Faroese area. The aim is to stipulate a research programme that may attract international knowledge to help unlock the basalt covered acreage to the future investigation of the Faroese Continental Shelf.

Hydrocarbon exploration on the Icelandic Continental Shelf – the first steps

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Iceland held its first licensing round for hydrocarbon exploration in the first half of 2009, offering the northern part of the Dreki Area that includes the southern part of the Jan Mayen Ridge (JMR). Two applications were received, whereas one was later withdrawn. An agreement with Norway on the northernmost part of the area stipulates that Norway may participate with 25% share in any exploration licenses within the treaty area. The licensing process is planned to be finalized by the end of October.

The JMR is a complex micro-continent located in the middle of the North Atlantic oceanic rift systems between the extinct Ægir Ridge in the Norway basin to the east, and the actively spreading Kolbeinsey Ridge to the west. In its pre-rift location the JMR micro-continent was sandwiched between the East Greenland margin and the Vøring- and Møre basin, but was isolated during the opening of the North-Atlantic Ocean. Its nature as a micro-continent has sparked a lot of academic interest and geological research. No deep borehole data exist for the area, and therefore prospectivity analysis efforts are focused primarily on seismic data and analogue comparisons. Naturally a considerable amount of 2D seismic data has been acquired for the area throughout the last 40 years, academic, governmental, as well as more recently acquired commercial surveys between 2001 and 2008, and with interest in the commercial sector to generate more denser 2D seismic grids in the future.

There are indications of Pre-Tertiary / pre-opening sedimentary strata below the lava flow sequences of the Paleocene. The presence of source rocks present the biggest uncertainty without actual proof of borehole data, but characteristic surface pockmarks and some seismic data anomalies, and the geological affinity of the nearby petroleum provinces of East Greenland and the North-West Europe, give indications that potentially source rocks, and therefore hydrocarbons can be expected in the JMR area. The seismic data indicate that potential hydrocarbon traps are present, such as structural traps, stratigraphic traps, and combination traps, e.g. rotated fault block structures, roll-over structures, sediment wedges of submarine fan deposits, or onlap stratigraphic traps. Prospective reservoirs could include basin fill and submarine fan deposits of the Tertiary, and the faulted and rotated reservoirs of Cretaceous or Jurassic age, most likely originated from East Greenland prior the separation of the JMR from East Greenland by the Kolbeinsey Ridge.

Atlantic Petroleum Session

Wednesday, 16th September 2009

09.00 – 12.15

ATLANTIC PETROLEUM

3D-modeling of intra-basaltic, shallow marine sandstones in East Greenland, analogue for the volcanic play of the Faroes and UK (Rosebank)

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The Kangerlussuaq area, SE Greenland is a well exposed succession of intra-basaltic siliciclastic sediments of Palaeocene age that provide analogy to the interbedded lava flows, volcaniclastic and siliciclastic sedimentary units of the volcanic play of the Faroes and UK area. The Sodalen Member choosen for study is an intra-basalt sandstone unit 4 to 10 m thick and contains a sequence grading from marine mudstones to deltaic sandstones deposited during a relative sea level fall.

Understanding the geometry of the interaction of sedimentary and volcanic processes is crucial for predicting the presence and lateral continuity of intra-basaltic reservoir units in offshore areas. This paper focuses on the 3D-mapping of this reservoir sand analogy.

The concept chosen combines fieldwork in Greenland, including sedimentological logging and sampling in addition to acquisition of digital, high resolution photos from a helicopter with the use of a photogrammetric procedure developed at GEUS. A 3D stereo plotter coupled with Stereo-Mirror technology is used and is based on high-oblique photogrammetry (close range, <800 m) triangulated with high resolution colour aerial photos, and constrained by detailed logs. Using this procedure it is possible to record the 3D position of the contacts of the sedimentary body, evaluate the stratigraphic relationships with volcanic units and offsets as well as cross-cutting relationships between faults and dikes with a resolution of 10 to 20cm. Further lateral extensions of sedimentary bodies, bedding planes and other internal structures such as foresets and on-lap geometries can also be recognised and recorded with precise 3D coordinates. All of these 3D features are stored in a database suitable for export to and subsequent modeling such as Petrel.

Sediment petrography of intra-basaltic, shallow marine sandstones in East Greenland, analogue for the volcanic play of the Faroes and UK (Rosebank)

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In the Kangerlussuaq area, southern East Greenland, the transition from sedimentation to flood volcanism is well exposed in outcrop. It is characterised by a basal fluvial unit followed by a succession of interbedded lava flows, volcaniclastic and siliciclastic sedimentary units. The present paper focus on sediment petrography of the lowest intra-basaltic sedimentary unit (informally the Sødalen member) which is considered as the most relevant analogue for the intra-basaltic reservoir sandstones in the Rosebank discovery. Traditional sediment petrography by transmitted light microscopy is coupled with new provenance methods as heavy mineral analyses by computer controlled scanning electron microscopy (CCSEM), zircon age determinations and bulk-rock geochemistry in order to evaluate the influence of volcanic detritus contra siliciclastic detritus on the reservoir properties.

The informal Sødalen member is a light yellowish sandstone and subordinate dark mudstone/siltstone, in places bioturbated, with large lateral facies variations. This 4 to 10 m-thick sedimentary body extends for more than 30 km in west-east direction. The texturally and mineralogically immature sands are of mixed siliciclastic and volcanic origin. The dominating volcanic rock fragments vary across the area, indicating a combined supply of local volcanic sources together with a more uniform siliciclastic source. The diagenetic formed cements are related to the detritus and especially the type and amount of volcanic fragments. Understanding the interaction of sedimentary and volcanic processes in the early volcanic phase is crucial for predicting lateral continuity and reservoir properties of intra-basaltic reservoir units in offshore areas.

Reservoir quality of the intra-basalt volcaniclastic units onshore Faroe Islands as an analogy to the offshore intra- and post-basalt epiclastic sedimentary rocks

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Mafic volcaniclastic sedimentary rocks are normally not expected to exhibit reservoir quality of sufficient quality to warrant it as a valid option regarding potential reservoir when exploring for hydrocarbons. I will try to show that this need not be the case, and suggest under which circumstances such units can constitute the reservoir in hydrocarbon exploration.

There are documentable examples of hydrocarbons being produced from volcaniclastic rocks. Why some work and others don't is only scarcely researched, which is why that I have sampled volcaniclastic interbeds from 65 geotechnical and scientific cores with a total length of 5 km, covering a large part of the onshore Faroese basalt group stratigraphy. Analysis of a total of 141 samples of volcaniclastic interbeds from the Beinisvørð, Malinstindur and Enni Formations showed the average porosity of the interbeds for these three formations are 16.2 %, 19.02 % and 22.97 %, respectively while the average permeability of the interbeds in the three formations are 0.3 mD, 2.22 mD and 4.88 mD. A closer look at individual volcaniclastic units e.g. the Argir Beds, shows an average porosity is 24.8 % and permeability is 13.3 mD.

The high variability in the reservoir qualities are a directly result of the complexity of what is normally uniformly referred to as "volcaniclastic units". These include sediments deposited in any number of ways and in different environments e.g. ashfall (tuffs), fluvial deposits, lacustrine and shallow to deep marine deposits. A closer look at the depositional setting, mineral content etc and correlating that with the measured reservoir quality measurements provides a way to predict in what kind of settings one can expect to find mafic volcaniclastic reservoirs that can be viewed as valid targets in petroleum exploration.

Porosity evaluation of volcaniclastic interbeds, Faroe Islands Basalt Group

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Traditionally, volcaniclastic interbeds have been considered to have poor reservoir potential due to their volcanic components readily altering to various clay minerals, but publicised discoveries within intra-lava successions in the Faroe-Shetland Basin may challenge this dogma. This study therefore, evaluates porosities and permeabilities for volcaniclastic interbeds from the Faroe Islands Basalt Group, Faroe Islands.

The Glyvursnes-1 borehole was drilled to a depth of ~700 m through the basalt dominated Malinstindur and Enni Formations and encountered 23 volcaniclastic intervals ranging in thickness from ~1 cm to >5 m (average: 60 cm). Porosity and permeability measurements were obtained from 22 samples collected from the thickest intervals (i.e. > 0.4 m). These samples gave an average porosity of 18.1% (range: 9.1-46.4%) and permeability of 1.13 mD (range: 0.12-6.04 mD).

Six volcaniclastic intervals, with measured porosity values, were selected from the borehole and compared to porosity values derived from the Neutron, Density and Sonic wire-line logs. The measured values for the three intervals from the Malinstindur Formation have a good correlation to the derived porosities (e.g. correlation coefficient (R^2) up to 0.85). Although the porosity values are different, the trend, or change in porosity across the interval, is replicated. The difference in R^2 for each interval is partly attributed to lithology, where the Malinstindur Formation interbeds are dominantly sandy whereas the thicker units, e.g. Argir Beds, show greater variability in grain size from clay-rich to granule-rich sections.

This study shows that although the volcaniclastic intervals may have low permeabilities their porosities have reservoir potential and that the values may actually increase distally towards the edge of the lava field where they may mix with siliciclastic components.

Seismic facies identification within basalts offshore East Faroes using 3D seismics

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Detailed interpretation of 3D reflection seismic data in the basalt sequences of the East Faroe High area has revealed a complex volcanic history. Using a combination of seismic sequence and facies analysis makes it possible to identify internal volcanic facies and their thickness variations, to estimate direction of lava supply and interpret palaeo-environments. The seismic volcano stratigraphy is crucial for understanding the volcanic history of the East Faroe High area and helps in estimating the position of the base basalt reflector.

From the analysis it can be seen that a complex interaction between submarine/subaerial lavas and sediments occur in combination with what appears to be intruded sills. The basalt succession comprises in ascending order; a shallow marine basin containing hyaloclastic lava from a possible shield-volcano in the NW and a prograding lavadelta from the SE. The lavas from the NW and SE prograded as hyaloclastic lava flows into the basin and interfingered. The lava supply from the NW ceased and the area was flooded from the SE by subaerial, parallel bedded lavas that filled minor basins and smoothed out the area. After the deposition the lower parts of the basalts were intruded by sills and in the Oligocene/Miocene the East Faroe High area became uplifted.

Analysing the seismic data in detail using seismic volcano stratigraphy and observing it in a 3D environment makes it possible to obtain a broader understanding of the geological development of the basalts in the area and thereby making it easier separating basalts from the non-basalt lithology and sills.

Understanding sedimentary provenance in the Faroe-Shetland basin: constraints from detrital zircon geochronology.

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We have investigated the U-Pb ages of detrital zircons in representative samples from wells in the Faroese sector of the Faroe-Shetland basin by LA-SF-ICP-MS. The resulting U-Pb age signatures in all samples investigated are remarkably similar and are almost identical to those patterns previously reported for wells in the UK sector of the Faroe-Shetland basin. The Archean age pattern in all samples so far investigated from the Faroe-Shetland basin are in excellent agreement with the Archean age pattern of the Hebridian Foreland. In contrast, the observed Archean age pattern are strikingly different from Archean age pattern observed in the sediments exposed in the Kangerlussuaq basin in southern East Greenland, the proposed Greenlandic source of sediment for the Faroe-Shetland basin. These findings suggest that the majority of the detritus drilled in the wells in the Faroe-Shetland basin is sourced from the UK margin and, excluding southern East Greenland as a prominent source of sediment. A general decrease in the modal abundance of Proterozoic/Paleozoic zircons relative to Archean zircons with increasing height in the stratigraphic column is observed in all wells in the Faroe-Shetland basin. This observation most likely reflects a change in sediment supply from a more distal source (i.e., the Scottish Mainland) to a more proximal source (i.e., the Hebridian Foreland) during the Paleocene. This would imply that either erosion of the Scottish Mainland ceased during the Paleocene or that the direction of sediment transport changed, possibly due to different uplift histories in the Hebridian Foreland and the Scottish Mainland.

Heavy mineral constraints on Paleocene sand transport routes in the Faroe-Shetland Basin

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An integrated sandstone provenance study involving heavy mineral analysis, major element geochemistry of garnet, trace element geochemistry of rutile, detrital zircon age dating and palynofloral analysis has been undertaken on Paleocene (T10-T38) sandstones in hydrocarbon exploration wells in the Faroe-Shetland Basin. This study has led to the identification of four siliciclastic sand types, each with a different provenance, together with volcaniclastic detritus. Sand type I was mainly derived from basement lithologies (Lewisian and/or Moine/Dalradian) on the Orkney-Shetland Platform, either directly or indirectly through recycling. Sand type II was derived principally through recycling of the Triassic on the Orkney-Shetland Platform. Sand type III, which is commonly found in association with volcaniclastic material, is interpreted as having an origin on the western margin of the basin. Sand type IV represents recycled Carboniferous (Namurian-Westphalian) sandstones on the Orkney-Shetland Platform. Although the westerly-derived sand type (III) has a zircon age spectrum dominated by the Archaean, the pattern contrasts with that found in Archaean-derived Paleocene sandstones from the Kangerlussuaq region of East Greenland. Derivation from more local Archaean basement is therefore inferred: possibilities include the crust below the Faroe Islands, the Blosseville Kyst of East Greenland and the Wyville-Thomson Ridge. Palynofloral analysis indicates that sand type III is invariably found in association with the 'Greenland flora', providing further support for input from the west. Most of the terrigenous sand was supplied from the Orkney-Shetland Platform, but western input is seen locally at T10, T35-T36 and T38 levels.

StatoilHydro Session

Wednesday, 16th September 2009

13.15 – 16.30

The 2006 Brugdan well (6104/21-1), some results and optimism for the future?

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In the summer of 2006 StatoilHydro and its partners drilled the 6104/21-1 (Brugdan) exploration well on Faroes offshore licence FL006. The well intended to test a 4-way dip closure over a deeper tilted (Mesozoic?) fault block. The predicted exploration targets were below the basalts in the Paleocene Flett and Vaila Formations. Secondary targets were prognosed within the basalt sequence itself.

The well was targeted, in its most likely case, to penetrate 1 km of basalt for which specialist drilling research had been carried out. In the end the well penetrated 2.5 km of sub aerial and hyaloclastite basaltic sequences before entering the Paleocene Lamba sequence. Basalt drilling was very efficient and much better than expected. It is known regionally the Lamba sequence, which is shale dominated, is a regional seal for the underlying Vaila sequence. Unfortunately before being able to test this deeper interval, the drilling string became stuck and the hole had to be abandoned. Hydrocarbon indications within the well demonstrated a working hydrocarbon system and the untested Vaila remains a still valid target for future exploration. It is hoped to test this interval in the Faroes offshore in the near future.

How Do You Solve a Problem Like Anne-Marie? Structural and Stratigraphic Considerations in Licence 005

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The Anne-Marie prospect in Licence 005 comprises a structural trap with four-way dip closure and the potential for multiple stacked Eocene and Paleocene reservoirs. Eni and partners plan to drill the prospect in spring 2010. Recent drilling activity in the Faroese offshore (6104/21-1 and 6005/13-1A wells) has yielded unexpected results, mainly with regard to a much thicker than predicted Paleocene Basalt Series. These results, coupled with the recent release of data for wells in the UK sector of the Faroe-Shetland Basin resulted in Eni re-examining the Basalt Series and deeper section in Licence 005.

Licence 005 is located over an east-west trending gravity modelled high which separates the Judd sub-basin to the south from the Corona sub-basin to the north. Interpretation of the deep structure that gives rise to the high is hampered by poor seismic imaging related to the late Paleocene Basalt Series and to the occurrence of sills and increased structural complexity below the basalt sheet. Well control and seismic data indicate that the Paleocene section below the Basalt Series is much thicker in the Judd sub-basin than in the Corona sub-basin. Three structural models have been considered to explain the deep structuration running through Licence 005: (1) a horst with predominantly north-south extension, (2) a transfer zone with predominantly east-west extension and (3) a wrench with predominantly east-west strike-slip movement. The favoured model is that which involves a transfer zone located south of the Anne-Marie prospect.

The Anne-Marie prospect lies near the edge of the Faroese basalt sheet, in a similar setting to the recent 213/27-1z Rosebank intra-basalt oil and gas discovery. A relatively good seismic character correlation between the Basalt Series in the two areas suggests the potential for an intra-basalt play at Anne-Marie.

New insight in basin development and sedimentation pattern in the outer part of the lava delta in Faroes Licences 013 and 014.

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The Faroes licences 013 and 014 were awarded to Geysir Petroleum and Atlantic Petroleum in the 2nd Faroese Licensing Round. The licences are located close to the UK/Faroese boundary, some 40 km from the Rosebank discovery. In Licence 013 the dominating structural element is the Faroe Escarpment running in a N-S direction through the licence area. It represents the edge of the lava delta. In Licence 014 the East Faroe High runs diagonally through the licence area in a NE-SW direction. Transfer zones intersecting the two licence areas have had an impact on the pattern of sedimentation.

Acquisition of new seismic data was part of the work commitment. A major effort in the processing of the data resulted in improved quality of the sub basalt section of the seismic data, thus allowing mapping of details in the sub basalt and intra basalt sections not possible on older data. The recent mapping has also focused on detailing the transfer zones in the Licence 13 & 14 areas. The inter relationship between the transfer zones and distribution of hyaloclastites into the area is clear. These long lived transfer faults have had a profound effect on the sedimentation pattern in the area throughout the Paleocene and possibly earlier.
Also intrabasaltic details have been mapped. In the nearby Rosebank well the intra basaltic sand is the main reservoir. Large channel systems from the Shetland Platform in the South running northwards have been mapped indicating possibility of sand in the licence 013 area.

The Wyville-Thomson Ridge – Exploring the largest undrilled anticline in North West Europe.

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The Wyville-Thomson Ridge (WTR) is a 25km wide and 200 km long, WNW-ESE aligned bathymetric ridge that sits in both Faroese and UK waters. Seismic data show the ridge to comprise a large anticlinal fold, with coaxial reverse faults along its flanks. Paleocene basalts are thought to sub crop the sea bed capping and potentially sealing the structure, whilst early Paleocene and pre-Tertiary clastic sediments are anticipated to form the main reservoir and source components.

Imaging of the base basalt reflector and with it the calculation of the overlaying basalt thickness is therefore of critical importance. Indicative ranges suggest a variable thickness for the basalt of between 500m to 2km which leads to an uncomfortably high uncertainty in exploration well cost (£14MM to £40+MM). Various techniques have been applied to quantify this thickness with limited success. These range from simple seismic velocity modelling to more advanced seismic processing techniques and also include the use of potential gravity field data.

A Marine Magneto-Telluric (MMT) survey has been proposed to directly detect the highly resistive basalt, and to provide an accurate estimate of its spatial thickness variation. Once concluded, an exploration well can then be efficiently targeted at an optimal location of minimum thickness, and the sub basalt structure can be successfully explored.

The large size of the WTR structure indicates that it is capable of holding many tens of billions of barrels of hydrocarbons, and for this reason it remains an exciting and potentially highly rewarding prospect.

Constraining risk in the Faroes - Shetland Basin

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Much of the remaining potential in the Faroes – Shetland Basin (FSB) lies in deep water, therefore, risking of exploration wells using geophysical data and geological modelling is critical. Understanding what geophysical methods are likely to help constrain the risk is a key part of this process. In the FSB this will be dependent both on the depth and the play type. Eocene potential, for example, is likely to be amenable to both seismic amplitude analysis and CSEM surveys. Prospects lying deeper within the Flett formation will be dependent on the reservoir type and the thickness and nature of any volcanic intervals. Deeper potential will always depend on the quality of the geophysical data available, which may limit the effectiveness of rock physics or CSEM, be it due to fidelity or resolution. The results of such studies must be integrated within a geological model, matching them against depositional scenarios and elements of the proposed petroleum system. This paper describes the work carried out on the Tornado prospect, lying close to the UK – Faroes median line in Quadrant 204. Tornado is defined by a seismic anomaly lying at the T38 (Lamba) level. The success of such prospects has a mixed history within the FSB, therefore an integrated geophysical and geological evaluation was carried out on this anomaly to address risk and uncertainty. This included a rock physics study, fault seal analysis and the acquisition of a CSEM survey. These results were then added to a more general geological understanding of the area to form a technical basis for drilling the prospect.

StatoilHydro in the Faroe Islands: Clever or Crazy?

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Hydrocarbon exploration commenced in the Faroe-Shetland Basin in the early 1970's. The first major oil discovery was in 1977 when BP found the Clair Field. Although the Clair reservoir is not high quality, the presence of around 5 billion barrels oil in place demonstrates the presence of a world class oil source rock in the basin, the late Jurassic Kimmeridge Clay Formation.

It was not until 1992 that the next major find was made when BP found the Foinaven Field, closely followed by the Schiehallion Field in 1993. Here the oil is trapped in high quality Paleocene Vaila Formation sandstones. This is the play StatoilHydro are chasing in The Faroe Islands, albeit Greenland sourced sandstones rather than Scotland sourced sandstones.

Because of the perceived "basalt problems", seismic imaging and potential hard rock drilling problems, exploration in the Faroes has lagged behind the UK drilling. Around 200 wells have been drilled on the UK side of the median line yet only six on the Faroes side. Meanwhile, seismic imaging through the basalts has improved dramatically and StatoilHydro's drilling of over 2.5km basalts in the Brugdan well has eradicated worries on slow drilling rates. One diamond impregnated bit drilled over 750m basalts at penetration rates around 10m/hr.

The early Faroes exploration chased the Foinaven-Schiehallion play in the Judd Basin, but proved disappointing as the seismic amplitude driven exploration demonstrated the features were lithologically created rather than being a seismic response due to hydrocarbons. Although Brugdan was dry, it was terminated stratigraphically early in Paleocene Lamba Formation shales which on the UK side are the regional seal to the Vaila Formation.

In summary, the play has yet to be successfully drilled on the Faroes side. StatoilHydro have picked up licences in all three Faroes Rounds in the belief that large hydrocarbon accumulations are still possible. We operate five licences with five or more large four-way dip-closed Vaila Formation prospects. We are in the process of choosing the best one to drill. We may have only one more chance. However, if that one well works we are sitting on excellent follow-up opportunities.

Exploration potential on the Faroese Continental Shelf; an update

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The exploration effort on the Faroese Continental Shelf has progressed considerably during the 15 years that have elapsed since the first commercial seismic survey was acquired in 1994. These 15 years have seen some questions answered, but also gave rise to new questions.

The primary issue has been the Palaeogene volcanics that cover almost the entire Faroese Continental Shelf. The results from the first seismic surveys showed reflections below the top basalt reflector. The problem was that reflections on different surveys did not correlate, casting doubt on the value of the maps generated from these data. Using other data types did, due to lack of constraints on the initial model, result in ambiguous results. Recent advances in seismic acquisition and processing have however, shown that it is now possible to image far beneath the top of the volcanics.

What has emerged as the primary issue is, despite the lack of wells, to understand the geology to such a degree that it is possible to predict what the now mappable reflectors represent, and how the volcanics have affected the parameters relevant for hydrocarbon exploration.

The Faroe Shetland Basin is assumed to have been more or less symmetric prior to the emplacement of the volcanics, where potential reservoir units on the southeastern side are sourced from Shetland platform, while similar age units on the Faroese side are likely sourced either locally or from Greenland. This had to change when volcanism started, and disagreements regarding timing of volcanism had an impact on exploration, both regarding deposition of reservoir units, and also impact on source rock maturity considering that up to several kilometres of lava were emplaced in a relatively short time span.

We will discuss the exploration potential in the light of the current understanding of the geology and how the volcanism is likely to have affected different plays in different areas.

Poster Presentations

Abstracts

The posters will be on display throughout the whole of the conference.

The application of tectono-stratigraphic models to the sub-basalt region of the Faroe-Shetland Basin, NE Atlantic Margin.

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Seismic imaging of rift-oblique lineaments ("transfer zones") within the Faroe-Shetland Basin is problematic due to a thick (up to 7km) Cenozoic lava and hyaloclastite succession deposited at the time of continental separation. Nevertheless, ongoing sub-basalt seismic mapping, onshore field mapping and regional potential field interpretations point to the existence of clear NW-SE trends, primarily within the northwestern (Cretaceous - Early Cenozoic) part of the basin. Detailed tectono-stratigraphic analysis of these sub-basalt structures is not possible with current datasets. The second part of this presentation therefore synthesizes and applies results obtained from a study of analogous structures within the better-imaged NW Vøring Basin, offshore Norway.

The NW Vøring Basin is characterised by two NE-SW trending structural highs - the Gjallar Ridge and Nyk High – that formed during Late Cretaceous-Palaeocene rifting. The Gjallar Ridge and Nyk High are offset in an apparent dextral sense across the northern end of the NW-SE trending Surt Lineament, where the Rym Accommodation Zone has formed. A second NW-SE trending feature – here termed the Gleipne Accommodation Zone – intersects the Gjallar Ridge but has a much less distinct structural expression than the Rym Accommodation Zone. Each of these sets of structures appear to have had an important impact on syn-rift sedimentation within the NW Vøring Basin. Application of these findings to the Faroe-Shetland basin suggests that structures analogous to the Surt Lineament may have an expression in the potential field data, but structures analogous to the Gleipne Accommodation Zone are much more difficult to identify using current datasets.

Lava field variations as an analogue for sedimentary dispersal patterns in the Faroe-Shetland Basin

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The Palaeogene Faroe Islands Basalt Group (FIBG) of the NE Atlantic has an areal extent of at least 120000 km^2, which includes the western side of the Faroe-Shetland Basin, where the constituent lava flows of the FIBG hampers hydrocarbon exploration. This includes understanding sedimentary dispersal patterns beneath and within the FIBG. The FIBG is, however, exposed on the Faroe Islands and in an attempt to understand thickness variations and dispersal patterns within the volcanic pile a number of lithohorizons were modelled using the spline interpolation tool, part of the spatial analyst extension in ArcGIS 9.2. These lithohorizons are, from oldest to youngest, the Beinisvørð-Prestfjall Unconformity (BPU), the base of the Kvívík Beds, the Malinstindur-Sneis Unconformity (MSU) and the base of the Argir Beds. Interpolation of these surfaces across the northern Faroe Islands have a mean dip of a few degrees in an essentially ESE direction, whereas the BPU on Suðuroy generally dips towards the NE. The four surfaces across the northern Faroe Islands cover a stratigraphic thickness of *ca.* 1.6 km and the three youngest surfaces are generally conformable. The exception is the BPU which diverges away from the other surfaces suggesting a possible angular unconformity at this level. Indeed the construction of thickness maps suggests that the strata above the BPU thicken to the SE. The thickness map constructed from the subtraction of the MSU from the base of the Argir Beds suggests that the northern Faroe Islands is dissected by NW-SE trending highs and lows, with the highs located along western Streymoy and along the fjord to the SE of Kalsoy. A similar pattern may be tentatively inferred for the thickness map produced between the base of the Kvívík Beds and the MSU on Streymoy and northern Eysturoy. These thickness variation patterns for intervals from above the BPU is in general accordance with the suggestion that the Faroe Islands are transacted by NW-SE trending transfer zones that are inferred from potential field data in the Faroe-Shetland Basin. Mapping onshore the Faroe Islands supports the premise that the thickest accumulations of lava flows and sedimentary units are likely to be found offshore on the NE sides of the inferred transfer zones and consequently, the onshore mapping may help to constrain the relative sizes of these depressions.

Reflection seismic data used for refraction analysis giving information of the small scale velocity distribution of near surface basalt flows

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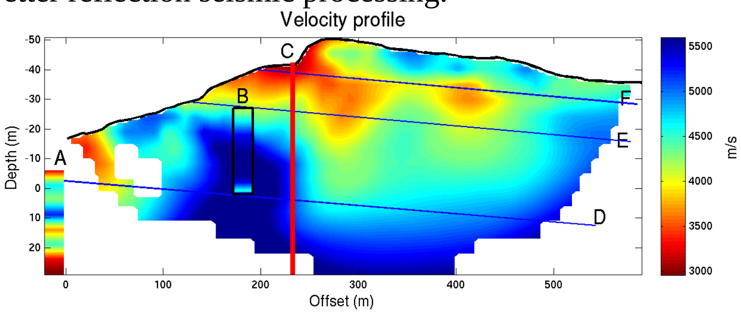
In 2003, surface seismic data were acquired in the Faroe Islands at Glyvursnes as part of the SeiFaBa project. The objective was to investigate seismic wave propagation in an area where the elastic properties of the basalt flows are relatively well known.
Here a refraction seismic analysis based on the two land seismic profiles is presented. The analysis aims to map the very shallow velocity distribution both vertically and horizontally. The analysis for each profile is based on a 600 m geophone layout with 120 channels. 250 g dynamite charges were used as sources at 10 m shot intervals, producing a 600 m long velocity profile giving velocity information down to 80 m depth. The velocity distribution of the profiles is consistent with, and can be related to, geologic features in the area, such as flow boundaries and a large-scale fracture. The gradients in the velocity profile compare quite well with the general dip of basalt flows in the area. The location of the large-scale fracture coincides with an area of large alteration of the horizontal velocity distribution. A 30 m thick flow unit that was identified by previous geological mapping shows relatively low velocities in the upper part with a positive downward gradient, related to the crust, and high velocities in the lower part, related to the core. This is consistent with the velocity distribution of another 28 m thick basalt flow unit contained in the Glyvursnes-1 well. The core-crust velocity characteristics are not resolved for the thinner flow units.
The velocity distribution has, as expected, large variations over short vertical distances. But the horizontal velocity variation is also significant. Over a horizontal distance of 50 m crossing the large-scale fracture, velocities vary from about 5500 m/s to 4000 m/s.
This analysis demonstrates that refraction modelling can be used to determine small-scale variation in the near-surface layers and to establish that the velocity distribution is indeed complex. In addition to revealing spatial properties of near-surface basalt flows, the refraction modelling can also form a basis for better reflection seismic processing.



The velocity profile obtained using a 60x16 grid with 10 m horizontal and 5 m vertical grid spacing. A) P-wave velocities from the Glyvursnes-1 well plotted with true location relative to the velocity profile. The log is resampled to 5 m for comparison with the 5 m vertical grid spacing of the model. B) The area marked with the black rectangle shows P-wave velocities from a flow-unit of about 30 m thickness obtained from the Glyvursnes-1 well log (depth location is 81-109 m) superimposed on the velocity profile. The log is resampled to 5 m. C) The location of a large-scale fracture. D, E and F are flow interfaces from previous geological mapping in the area, superimposed onto the velocity profile. D and E mark the base and top of a tabular flow unit of about 30 m thickness. Between E and F, two tabular flow units are contained. F marks the base of a compound flow unit followed by a tabular flow unit.

The nature and significance of post-magmatic faults on the NE Atlantic margin: evidence from the Faroe Islands

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Detailed geological observations have revealed the development of regionally-late, fault-related deformation structures on the Faroe Islands that are typically associated with different styles of clastic-sedimentary infilling. These include: 1) Thin (0.1-0.3m wide) clay smears associated with pre-existing faults that have been reactivated, cross-cutting early fault rocks and mineralisation features. 2) Wider (0.3-1m wide) clastic infills developed along pre-existing mineralised faults, that display internal faults and/or asymmetric drag-fabrics defined by clast alignments, often suggesting the opposite sense of movement to the original host fault. 3) Saucer-shaped, 0.1-0.6m thick, clastic horizons that display fluvial to debris-flow lithofacies, preserving sedimentary structures, such as cross-bedding, channel bar and scour-structures. 4) Anastomosing mm-scale and planar dm-scale injection features that exploit pre-existing fractures within the surrounding basaltic units. These structures post-date all other episodes of faulting recognised in the Faroe Islands and, unlike earlier episodes, lack significant amounts of associated mineralisation. It is proposed that this reflects their development at shallow depths, near to the surface and very late in the geological history, possibly during regional uplift.

Structures equivalent to the late, clastic-filled faults of the Faroes may occur in other parts of the NE Atlantic margin, particularly along the axes of large gentle folds that are widely developed in the region. Displacements observed are all well below seismic resolution, and such structures may be more widespread across the region than previously anticipated. Importantly, the probable unsealed nature of these structures makes them potential fluid-migration pathways within the Cenozoic volcanic sequences of the NE Atlantic region.

Comparison of Clastic and Hyaloclastic Deltas and Implications for the Application of the Sequence Stratigraphic Method

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Hyaloclastites deltas represent an important component of sedimentary basin fill proximal to volcanic centres. Hyaloclastic material shares many characteristics with clastic sediment, with similar depositional processes and controls on stratigraphic architecture such as eustasy, subsidence and sediment supply. It can therefore be assumed a hyaloclastic delta system will have features comparable to those used within siliciclastic sequence stratigraphic analysis.

The application of sequence stratigraphic principles to hyaloclastite deltas was considered using 2D seismic reflection data from the Faroe-Shetland basin, North Atlantic margin. This study focuses on a late Palaeocene hyaloclastic delta, located at the present day Faroe-Shetland escarpment. The central and northern portion of the delta has previously been identified as an area where reflections within the volcanic pile prograde and then back step.

The seismic imagery shows a series of repeated seismic packages, defined using seismic reflection geometries. The prograding succession is ~2.7 km thick and deposited over 5 Myrs, causing the hyaloclastic shoreline to shift ~ 8 km to the south. This rapid rate of progradation is due to the voluminous pulses of flood basalt volcanism and is higher than progradation seen in clastic systems.

Many of the basic key sequence stratigraphic principles such as the use of seismic reflection onlap, downlap and truncation should be applicable as a criteria for reconstructing relative sea level and basin fill history. It is expected that as the system is distinct from that of a clastic system, it may justify some modification of the classic sequence stratigraphic concepts.

Keywords: 2D seismic data, Faroe-Shetland basin, Palaeocene, sequence stratigraphy, volcaniclastic delta

Fracture Trends onshore Faroe Islands; indications of the tectonic evolution during Palaeogene volcanism

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The current debate regarding the tectonic evolution of the North Atlantic in the Palaeogene has resulted in the introduction of the theory that some of the large scale NW/SE to NNW/SSE oriented structures (i.e. Munkagrunnur Ridge, Faroe Bank Channel Basin, Wyville Thomson Ridge) were initially generated by a transient rift event in the Early Palaeocene.

The primary evidence presented so far in the literature is based on areal and temporal distribution of the volcanic rocks associated with the North Atlantic Igneous Province, and on geophysical interpretation and analyses of the large scale structural NW/SE to NNW/SSE oriented structures mentioned above.

No work is yet to be found in the literature regarding evidence either for or against the theory of the transient volcanic rift in the early Palaeogene.
One way is to look at fractures onshore Faroe Islands. Such fractures can relatively easily be mapped on areal photographs as lineaments, which again can be verified through fieldwork.

I will here look at the fracture orientations onshore Faroe Islands, and try to tie them to tectonic events and thus show that analyses of these does provide support for the theory of two discrete rifts that are separated in time, but contemporaneous with the two major volcanic episodes found onshore Faroe Islands.

I will then outline how this work suggests that the area evolved during the volcanic period.

The implications of this theory for hydrocarbon exploration and for the understanding of the deeper onshore geology will then be suggested.

Magnetic data in a basaltic environment: challenging but usefull

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Potential field data is one of the key data types to be acquired early in the exploration effort in new provinces. This was also the case on the Faroese Continental Shelf. It was, however soon evident that it was not straightforward to interpret magnetic anomalies seen on the acquired data.

The data which have been acquired includes both marine and airborne data, the latter as closely spaced high resolution data. The primary data set in used here are the regional highresolution aeromagnetic data acquired by World Geoscience (now Fugro Airborne Services) in 1995. Data coverage is 4500/1500 west of 6 degrees West and 9000/3000 m east of 6 degrees west.

The work presented here includes a review of the magnetic properties of the faroese basalt and how especially the remanent magnetisation has a very strong influcence on the measured magnetic response, and in many cases up towards an order of magnitude stronger then the induced magnetism.

The strong remanent magnetism, which has different polarities through the stratigraphic column, results in some distinct magnetic anomalies that can be traced offshore. Mapping these anomalies reveals how the Faroese Platform has evolved since the emplacement of the flood basalts.

Extending the interpretation away from the Faroese Platform providence evidence for the timing of the Heri High, East Faroe High and Ólavur High complex. The latter is usefull information for exploration companies when assessing the chance of success of prospec

Exploring for hydrocarbons in a volcanic province; Case Faroese Continental Shelf

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Hydrocarbon exploration has, in recent years, experienced a change in focus, with new areas being actively explored, and this includes areas with challenges which previously had been considered near insurmountable. One of these challenges is to explore for hydrocarbons in flood basalt provinces.

The challenges flood basalts pose in relation to hydrocarbon exploration can be subdivided relative to the used methodology (i.e. geophysics) or geology. The geological issues can further be subdivided into play issues relating to their relative age to volcanism or relative to the type of effect. i.e. timing, thermal effects, effects on burial history or reservoir.

The primary methods used in the exploration for hydrocarbons are geophysical in nature; seismic acquisition being the most commonly used method. Others include gravity, magnetics and more recently different forms of electromagnetic methods have been tested. Basalt does, however, prove to have adverse effect on most geophysical methods applied.

Recent advances in seismic acquisition and processing have enabled imaging of units below the top of the volcanic section, which earlier was referred to as “acoustic basement”. The challenge to acquire better images still persist and it will likely be a few years before we will see seismic imaging within basalt provinces comparable to what can be obtained in sedimentary basins.
Seismic imaging is only one of the issues when exploring in a basalt province, flood basalt volcanism can also have a pronounced effect on several different geological factors relevant to hydrocarbon exploration.

Any pre-volcanic sediments are subjected to increased pressure due to the loading of the basalt, and to an increased heat flow, the magnitude of which is dependent on distance from the heat source.

Flood basalt volcanism is rapid in geological terms, but there is still ample time for sedimentary units to form during the volcanic period. These can thus form potential reservoir, who's mineralogical nature is dependent on the location relative to provenance areas.

The flood basalts continue to have an effect on post-volcanic units. Mainly through sedimentary processes, where sediments derived from exposed basaltic areas can constitute potential reservoirs or be mixed with siliciclastic sediments from non-volcanic areas, and thus make up a mixed reservoir.

We will on this poster try to discuss some of the issues mentioned above in an attempt to highlight some of the challenges one needs to be aware of when exploring for hydrocarbons in flood basalt provinces. All examples are taken from the Faroese Continental Shelf.

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