DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/59

Provenance of sediments in the Faroese-Shetland basin: Integration of wells in the Faroese sector

Progress report (Period 1st December 2006 – 31st of October 2007) prepared for SINDRI

Dirk Frei & Christian Knudsen

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF THE ENVIRONMENT

G E U S

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Summary

Project outline

The sedimentary successions from East Greenland and the UK margin, the two principal source areas for sediment input into the Faroese-Shetland basin, are characterised by distinctive, provenance specific signatures with respect to detrital zircon age distributions, detrital garnet compositions, and whole rock geochemistry (Morton et al. 2005a; Frei et al. 2005a & b; Knudsen 2005). This provides a robust framework for the identification of the source areas of sands in the deeper, central parts of the Faroe-Shetland Basin. Therefore, analysis of the zircon age distributions and whole rock geochemistry of representative samples from the new wells drilled in the Faroese sector of the basin will allow qualitative and quantitative modelling of the source areas of the sedimentary succesions in the deeper, central parts of the Faroese-Shetland Basin. In addition to the age signature, the trace element record of zircon reflects the geochemical nature of their source rocks and has the potential to be a very sensitive provenance indicator.

In this project, we are investigating (a) the major, minor and trace element composition of 200 whole rock samples and, (b) the U-Pb age signature of detrital zircons and their trace element geochemistry from 25 samples from the four wells so far drilled in the Faroese sector of the Faroe-Shetland basin. All material for this study has been sampled and are currently being prepared and analysed at GEUS. The results of these investigations will be used to identify provenance sensitive signatures and to use these provenance sensitive signatures in order to qualitatively and quantitatively constrain the source areas of the sediments drilled in the Faroese sector of the Faroe-Shetland basin.

Project status

The contract for the project was officially signed by ATLANTICON and GEUS in September 2007. Samples have been taken and are currently prepared and analysed at GEUS. We are aiming to issue a final project report to the SINDRI group at the end of March 2008, as originally anticipated.

Background and rationale of the project

A key issue for hydrocarbon exploration in the Faroer region is the understanding of sediment dispersal patterns and depositional systems in the Faroe-Shetland Basin prior to continental breakup in the Late Paleocene to Early Eocene. Identification of sediment provenance is crucial for this goal. Location of the source areas places important constraints on sediment transport pathways and intrabasinal sand body distribution. Furthermore, the nature of the sediment source has important implications for the porosity and permeability characteristics of the deposited sediments. Identified variations in source might also be used to establish correlation frameworks (at both local and regional scales) and can provide a basis for discrimination of individual sand bodies.

The focus of the first exploration round in the Faroes area was the Paleocene deep-water play. The Paleocene succession is characterised by a series of sandpulses related to uplift episodes of the eastern and western marginal areas, e.g UK mainland and East Greenland, respectively. The Paleocene play is the most recently described play in the area west of the Shetland Islands and Paleocene sandstones form the main reservoirs of the Foinaven and Schiehallion fields.

Plate reconstructions of the North Atlantic region indicate the former proximity of East Greenland to the Faroe Island region (Appendix A Fig. 1). Consequently, as hydrocarbon exploration pushes further westward in the Faroe-Shetland Basin, there are increasing questions as to the role that Greenland has played as a source of sediment to the basin. Field work by GEUS and CASP on the Cretaceous–Early Palaeogene sedimentary succession in Kangerlussuaq, East Greenland, has indicated the presence of sequence boundaries in the Upper Cretaceous succession and also between the Cretaceous and Palaeogene successions, promoting a long distance transport of sediment to the west. A study of tectonic lineaments that may have had fundamental control on sediment disperal patterns concluded that a major sediment input point may have existed in the Kangerlussuaq Basin in the earliest Paleocene. The cross rift supply of sands came to an end with the period of rifting, which preceded continental separation and flood basalt extrusion some time between the mid-Maastrichtian and earliest Eocene.

The SINDRI project ”Linking the Faroese area and Greenland: an innovative, integrated provenance study” conclusively demonstrated that the sedimentary sources from the eastern (i.e. UK margin) and western (i.e. Kangerlussuaq, East Greenland) marginal areas have distinctive provenance sensitive signatures with respect to detrital zircon age distributions and bulk rock geochemistry. Most strikingly, the western source (East Greenland) is generally characterised by the presence of a Middle Archean age component in detrital zircon age. In contrast, in the eastern source (UK margin) the Middle Archean age component in detrital zircon age distributions is almost completely absent (Appendix A Fig. 2).

The influence from the western source (East Greenland) has not been proven in the stratigraphic intervals of the wells from the UK sector of the Faroe-Shetland Basin examined in the SINDRI project ”Linking the Faroese area and Greenland: an innovative, integrated provenance study". However, these wells are all located on the shallower, eastern margin of the basin and it can be expected that the western, greenlandic source has more importance for the deeper, central parts of the basin towards the Faroese area.

The results obtained during the SINDRI project "Linking the Faroese area and Greenland: an innovative, integrated provenance study" have established a robust framework for the identification of a western, greenlandic signature in the deeper parts of the Faroe-Shetland basin. The new techniques available for provenance studies and the distinctive signature of the greenlandic source provides a reliable way to distinguish the eastern and western provenance areas. In this project, we therefore apply these techniques to the new wells drilled in the deeper parts of the Faroe-Shetland basin in the Faroes sector, e.g. the wells 6004/16-1 Marjun (Amerada Hess), 6004/12-1 Svinoy (BP), 6004/17-1 Marimas (Eni), and 6005/15-1(Statoil). The position of the wells is indicated in Appendix A Fig. 3.

This study represents a logic continuation of the previous SINDRI project "Linking the Faroese area and Greenland: an innovative, integrated provenance study" and will establish a complete and coherent database for the interpretation of the provenance of sands in the Faroese-Shetland Basin. This database will subsequently be used to identify provenance sensitive signatures and to qualitatively as well as quantitatively describe the sources of the sedimentary successions in the deeper, central parts of the Faroese-Shetland Basin. Available data from other provenance studies of samples from the wells will be included in this on-going study.

Project aims

The overall aim of the proposed project is to qualitatively and quantitatively model the source areas of the sedimentary succesions in the deeper, central parts of the Faroese-Shetland Basin and to establish whether there is a link between the the Faroese-Shetland Basin and East Greenland or not. This question is highly relevant to Objective 2 of SINDRI, namely, regional geology and and evolution of the entire Faroese area.

The specific aims of the proposed project are:

- Identifying the provenance sensitive signatures (detrital zircon age distributions, zircon trace element signatures and detailed chemostratigraphy based on bulk rock geochemistry) in sands in the deeper, central parts of the Faroese-Shetland basin.
- Using the identified provenance sensitive signatures in order to qualitatively and quantitatively constrain the source areas (western, greenlandic versus eastern, UK margin signature) for sedimentary input into these parts of the Faroese-Shetland basin.
- Constraining possible changes in sediment supply during the evolution of the Faroese-Shetland basin.

Some of the most important questions relevant to hydrocarbon exploration in the Faroese area are:

- Is there a link between the sedimentary successions exposed in East Greenland and the Faroese-Shetland basin?
- If yes, what are the volumes of sedimentary material derived from this western, greenlandic source compared to the volumes derived from the eastern, UK margin source?
- What is the timing of the sedimentary input from these sources?

The proposed project will establish a coherent interpretative framework for the identification of the provenance of sands in the Faroese-Shetland Basin. This framework will allow to place tight constraints on these important questions.

Sampling and sample description

For this study we are using cutting samples from the wells 6004/16-1 Marjun (Amerada Hess), 6004/12-1 Svinoy (BP), 6004/17-1 Marimas (Eni), and 6005/15-1(Statoil). The cuttings from all 4 wells are stored at the JARDFEINGI, the Faroese Earth and Energy Directorate. Originally, it was anticipated to sample all four wells in a sampling campaign in January/Febrauary 2007. After access to well logs and well reports was granted by JARDFEINGI and the involved companies gave permission to sample the wells, a sample campaign was performed in May 2007. About 50 gr from 169 sandstone and tuff samples (see sample description in Appendix B) have been taken directly from the cutting boxes at stored at JARDFEINGI. These samples are currently processed at GEUS (see below for details on sample preparation and analytical techniques. An additional set of 50 mudstones will be sampled in a second sample campaign scheduled to take place in November 2007.

Sample preparation and analytical techniques

The SINDRI project ”Linking the Faroese area and Greenland: an innovative, integrated provenance study” conclusively demonstrated that laser ablation – magnetic secorfield – inductively coupled plasma – mass spectrometry (LA-SF-ICP-MS) and bulk rock geochmistry are reliable, fast and inexpensive methods for advanced provenance studies (Frei et al. 2005c & d). Accordingly, the samples obtained from the new wells in the Faroese area (see Appendix A, Fig.3 and Appendix B) are analysed using these techniques. Samples from the wells have already been analysed using conventional techniques by Morton and co-workers. Accordingly, only the above highlighted techniques will be used, namely:

(1) $^{206}Pb/^{238}U$ - $^{207}Pb/^{235}U$ age dating of detrital zircons by LA-SF-ICP-MS in order to indentify the source components and quantify the relative importance of the respective source components. This will also yield $^{206}Pb/^{207}Pb$ model ages for all zircons and these ages can be compared to the $^{206}Pb/^{238}U$ - $^{207}Pb/^{235}U$ age data in order to evaluate to what extent the $^{206}Pb/^{207}Pb$ ages can be used without the information concerning effects of possible leadloss.

(2) Trace element concentrations in zircons determined by LA-SF-ICP-MS in order to indentify the source components and quantify the relative importance of the respective source components.

(3) Major- and trace element analysis of bulk rock samples by XRF and solution ICP-MS, respectively, for detailed chemostratigraphy.

Whole rock major and trace element analysis

The degree of sediment maturity is very variable in the sediments in the studied area. Apart from classical optical microscopy, major- and trace element analysis provides a rapid insight into the bulk rock composition and the changes it may have suffered during diagenesis and/or transport. Accordingly, a large number of whole rock samples will been analysed for their major and trace element compositions. This data will offer the possibility to delineate chemostratigraphical correlations within the basin.

All samples will be analysed for major-, minor-, and trace elements by XRF and solution ICP-MS. Two grams of each sample are ground to fineness (i.e. particle sizes of 63 µm and below) using a tungsten carbide ball mill and are subsequently dried at 110°C for 2 hours. Aliquots of about 1 to 1.5 grams of the resulting powder are subsequently used for bulk chemical analysis.

Fusion XRF

Dried sample powders are ignited in an electric furnace at 1000ºC for 1 hour. Homogeneous glass discs are produced by fusing 1 gram of ignited powder together with a borate flux in the proportion 1:7. The glass discs are analysed with a Phillips PW1606 multichannel X-ray fluorescence (XRF) spectrometer at GEUS for all major elements excluding Na, which is determined by atomic absorption spectrometry (AAS). Ba and Sr are determined by XRF because of the better precision compared with ICP-MS analyses due to the very high contents of these elements in most of the samples. The combined content of organic material and volatiles are obtained as the loss in ignition of the samples. Analytical details, including precision, accuracy, and detection limits are reported by Kystol and Larsen (1999).

AAS

For the determination of Na by AAS, about 0.25 to 0.5 g of the dried samples are treated with hydrofluoric acid in a PTFE beaker on a hot plate. After evaporation to dryness the residue is dissolved in a hydrochloric acid - potassium chloride solution and Na is determined using a Perkin Elmer PE2280 instrument at GEUS (Kystol and Larsen 1999).

ICP-MS

For solution ICP-MS a piece of the glass disc previously used for XRF (see above) is dissolved in a HF-HNO_3 mixture, evaporated to dryness and subsequently redissolved with HNO_3 and evaporated to dryness twice. The dry residue is then dissolved in HNO_3, and diluted; the resulting solution is analysed for trace elements using a Perkin Elmer 6100 DRC quadrupole ICP-MS at GEUS. This method is a modified version of the method described by Turner et al. (1999). The use of glass discs ensures that refractory minerals such as zircon and chromite are brought completely into solution. Routine analysis of international and in-house geo-standards demonstrated that the precision and accuracy are usually better than 5 % relative for the majority of the elements analysed.

U-Pb zircon geochronology using LA-SF-ICP-MS

In this study, high precision U-Pb ages will be determined for a total of 25 samples employing laser ablation – high resolution – magnetic sectorfield - inductively coupled plasma– mass spectrometry (LA-SF-ICP-MS) facility at GEUS.

The LA-SF-ICP-MS facility for U-Pb zircon age determinations at GEUS consists of a NewWave Research/Merchantek UP213 laser ablation system equipped with a frequency quintupled Nd-YAG laser emitting at a wavelength of 213 nm coupled to an Element2 (ThermoFinnigan, Bremen) single-collector double focusing magnetic sectorfield ICP-MS equipped with a fast fieldregulator for increased scanning speed. Analytical details are reported by Frei et al. (2006).

LA-SF-ICP-MS trace element analytical techniques

All zircons that will be analysed for U-Pb ages will subsequently be analysed for a range of geochemically important trace elements (Li, Sc, Ti, Cr, Co, Ni, Cu, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, and U) at GEUS using the same LA-SF-ICP-MS instrumentation also employed for U-Pb age dating (see above).

Sample preparation for zircon geochronology and trace element analysis

For all age determinations and trace element analysis, zircons are separated from the bulk samples using conventional heavy liquid and magnetic separation methods. The final separation step is made by hand-picking individual zircon grains from the heavy and non-magnetic fraction using an binocular microscope. The individual zircon grains are mounted on double-sided, transparent adhesive tape and subsequently embedded in 1-inch diameter circular epoxy mounts for polishing.

Time schedule

The suggested project duration was from the 12/2006 until the 03/2008. Although the final signature of the contract by ATLANTICON did not take place until September 2007, oral permission for the start of the project was granted in February 2007. Permission to sample all four wells was granted by JARDFEINGI and the respective operators of the wells at the end of April 2007. The majority of the samples (and most significantly all samples needed for zircon U-Pb age dating and trace element analyses) are now at GEUS and are currently prepared and analysed. A limited amount of mudstone samples for chemostratigraphy will be sampled during a second sample campaign in November and subsequently analysed for major, minor and trace elements at GEUS in December. We estimate that all data for the final report will be available at the end of January 2008. Therefore, we expect that the project will be finished within the anticipated timeframe and that a final report will be issued at the end of March 2008 as originally suggested (an updated time schedule for the project is given below).

Time schedule:	2006	2007				2008
	3Q	1Q	2Q	3Q	4Q	1Q
Compilation of existing data from well reports	X	X				
Sampling and mobilisation of samples		X	X		X	
Sample preparation				X	X	
Progress report				X		
Whole-rock geochemical analysis				X	X	
LA-SF-ICP-MS of Zircons					X	
Compilation of new data						X
Comparison with previous data						X
Summary and large scale correlation						X
Final report						X

Publications

Results originating directly from this SINDRI project will be made available to the SINDRI Group in the final project report that we anticipate do deliver by the end of the third quarter of 2008. However, it is the intention that the results should be made available to the public by publications after the project has been finalised and permission has been granted by the SINDRI group.

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APPENDIX A: Figures

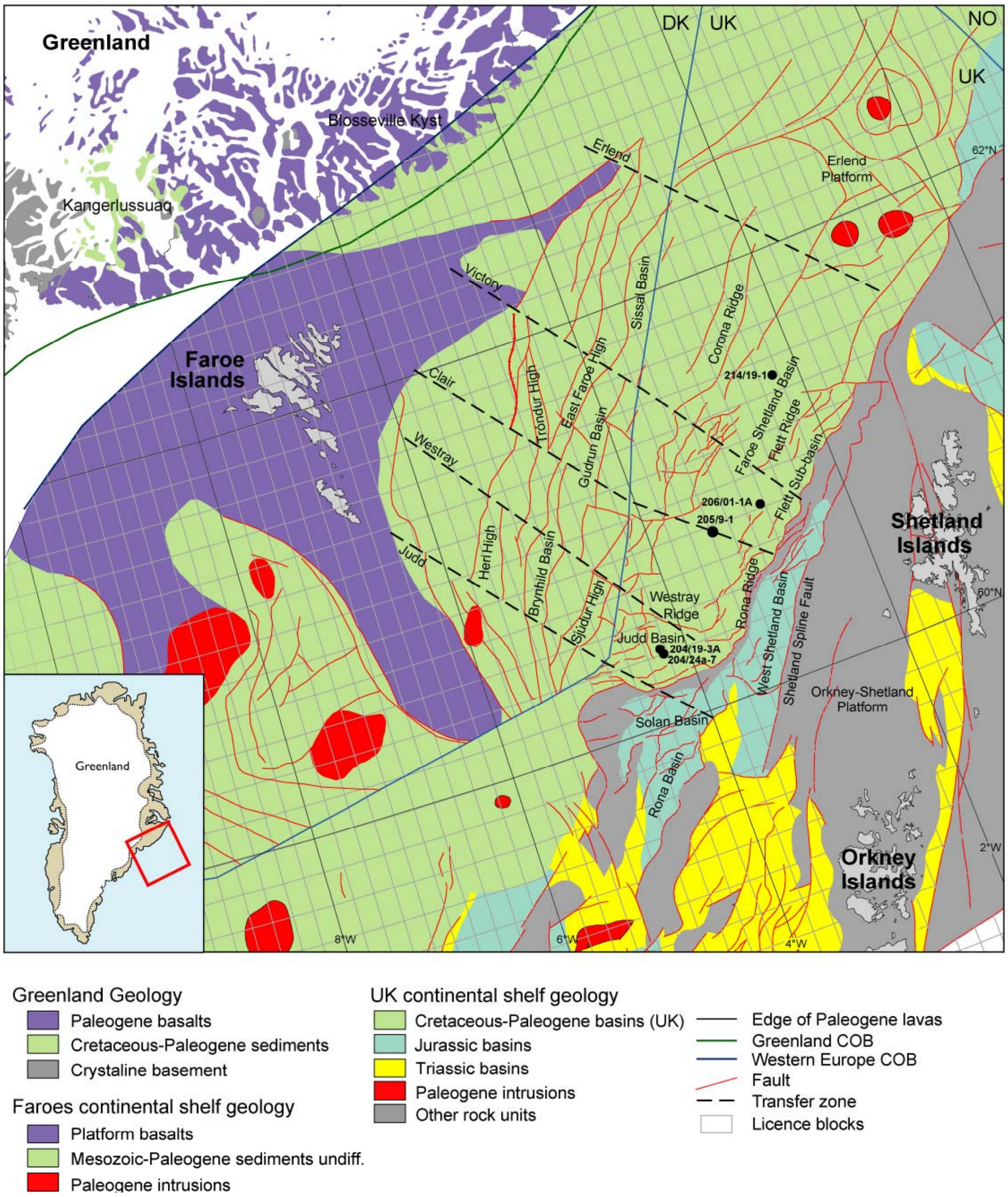

Figure 1. Location map of East Greenland and the Faroe-Shetland region depicting the geographical position of the areas investigated in this study. Also shown are on- and offshore geology, main structural elements, transfer zones and position of the wells investigated in this study. Note that the position of Greenland is shown prior to Paleogene sea-floor spreading (modified from Larsen et al. 2005).

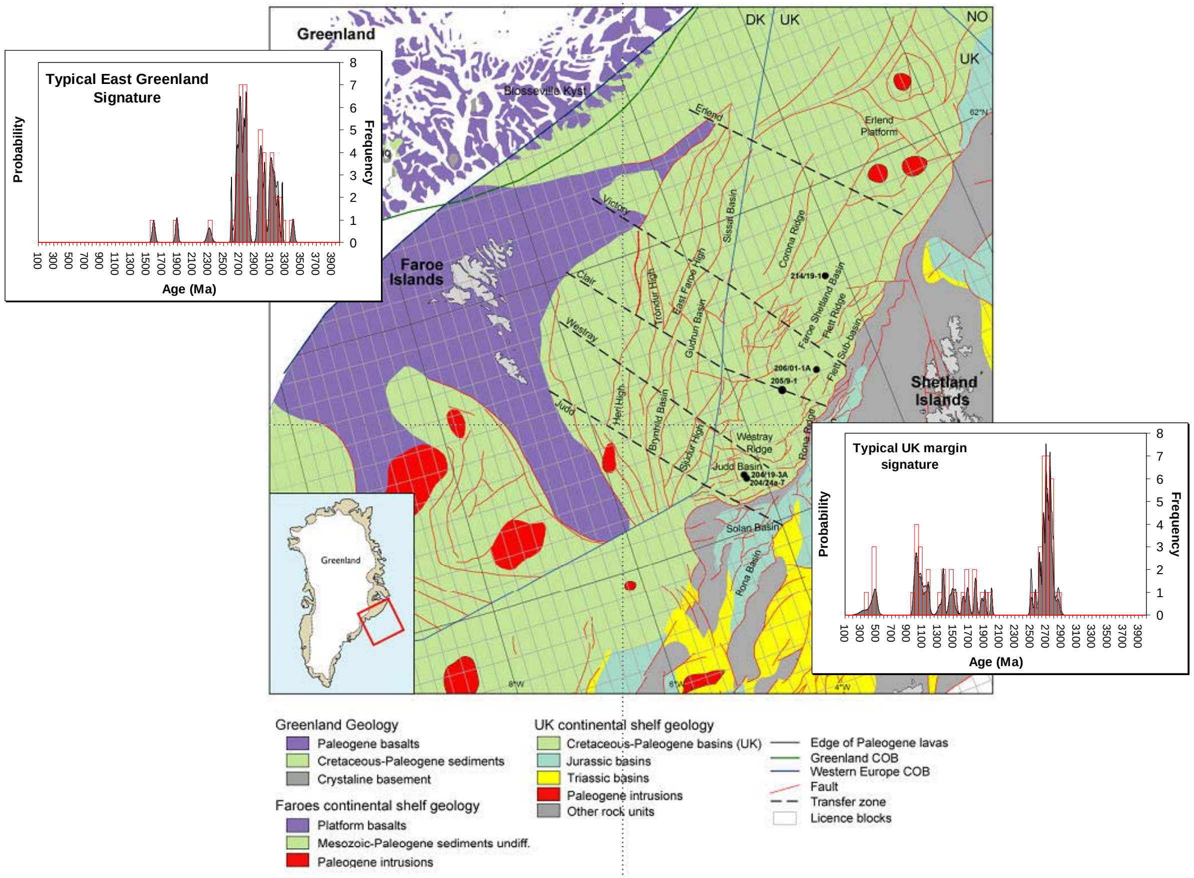

Figure 2: Map of East Greenland and the Faroe-Shetland region depicting the geographical position of the areas investigated by Frei et al. (2005b) and their characteristic zircon age spectra. Also shown are on- and offshore geology, main structural elements, transfer zones and position of the wells investigated by Frei et al. (2005b). Note that the position of Greenland is shown prior to Paleogene sea-floor spreading (modified from Larsen et al. 2005).

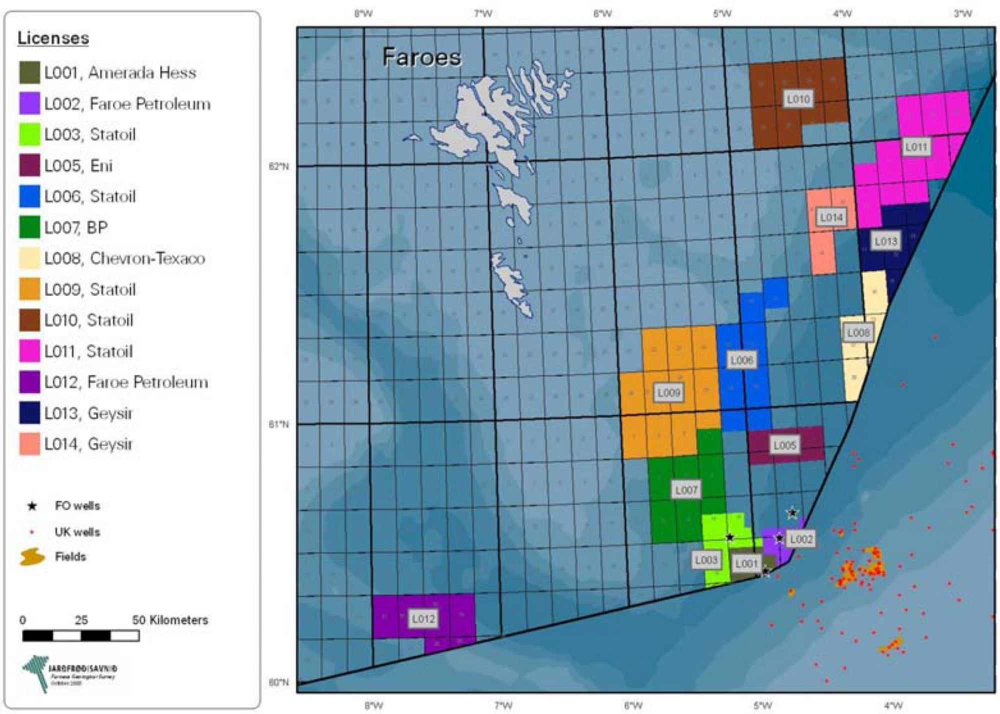

Figure 3: Map depicting the geographical position of the wells investigated in this study (modified from JARDFEINGI).

APPENDIX B: Samples

Table 1: Samples employed in this study from well 6004/16 Marjun (Amerada Hess)

Sample Nr.	Depth [m]	Rock type	Geology
230507-1	1483	Sandstone	Stronsay Group
230507-2	1480	Sandstone	Stronsay Group
230507-3	1477	Sandstone	Stronsay Group
230507-4	1474	Sandstone	Stronsay Group
230507-5	1516	Sandstone	Balder Fm.
230507-6	1528	Sandstone	Balder Fm.
230507-7	1534	Sandstone	Balder Fm.
230507-8	1543	Sandstone	Balder Fm.
230507-9	1810	Sandstone	Balder Fm.
230507-10	1816	Sandstone	Balder Fm.
230507-11	1822	Sandstone	Balder Fm.
230507-12	1828	Sandstone	Balder Fm.
230507-13	1885	Sandstone	Balder Fm.
230507-14	1900	Sandstone	Balder Fm.
230507-15	1906	Sandstone	Balder Fm.
230507-16	1912	Sandstone	Balder Fm.
230507-17	1993	Sandstone	Lambda Fm.
230507-18	2002	Sandstone	Lambda Fm.
230507-19	2011	Sandstone	Lambda Fm.
230507-20	2038	Sandstone	Lambda Fm.
230507-21	2134	Sandstone	Lambda Fm.
230507-22	2140	Sandstone	Lambda Fm.
230507-23	2155	Sandstone	Lambda Fm.
230507-24	2161	Sandstone	Lambda Fm.
230507-25	2224	Kettla Tuff Mbr.	Lambda Fm.
230507-26	2221	Kettla Tuff Mbr.	Lambda Fm.
230507-27	2251	Sandstone	Lambda Fm.
230507-28	2259	Sandstone	Lambda Fm.
230507-29	2246	Sandstone	Lambda Fm.
230507-30	2288	Sandstone	Lambda Fm.
230507-31	2453	Sandstone	Lambda Fm.
230507-32	2459	Sandstone	Lambda Fm.
230507-33	2471	Sandstone	Lambda Fm.
230507-34	2540	Sandstone	Vaila Fm.
230507-35	2552	Sandstone	Vaila Fm.
230507-36	2567	Sandstone	Vaila Fm.
230507-37	2807	Sandstone	Vaila Fm.
230507-38	2822	Sandstone	Vaila Fm.
230507-39	3152	Sandstone	Vaila Fm.
230507-40	3167	Sandstone	Vaila Fm.
230507-41	3176	Sandstone	Vaila Fm.
230507-42	3498	Sandstone	Vaila Fm.
230507-43	3508	Sandstone	Vaila Fm.
230507-44	4157	Sandstone	Vaila Fm.
230507-45	4163	Sandstone	Vaila Fm.
230507-46	4172	Sandstone	Vaila Fm.

Table 2: Samples employed in this study from well 6005/15-1 (Statoil)

Sample Nr	Depth [m]	Rock type	Geology
230507-47	1880	Sandstone	Balder Fm.
230507-48	1890	Sandstone	Balder Fm.
230507-49	1900	Sandstone	Balder Fm.
230507-50	1990	Sandstone	Balder Fm.
230507-51	2000	Sandstone	Balder Fm.
230507-52	2060	Sandstone	Flett Fm.
230507-53	2070	Sandstone	Flett Fm.
230507-54	2080	Sandstone	Flett Fm.
230507-55	2350	Sandstone	Flett Fm.
230507-56	2370	Sandstone	Flett Fm.
230507-57	2427	Sandstone	Flett Fm.
230507-58	2436	Sandstone	Flett Fm.
230507-59	2476	Sandstone	Lambda Fm.
230507-60	2485	Sandstone	Lambda Fm.
230507-61	2760	Kettla Tuff Mbr.	Lambda Fm.
230507-62	2831	Sandstone	Vaila Fm.
230507-63	2841	Sandstone	Vaila Fm.
230507-64	3005	Sandstone	Vaila Fm.
230507-65	3016	Sandstone	Vaila Fm.
230507-66	3209	Sandstone	Vaila Fm.
230507-67	3219	Sandstone	Vaila Fm.
230507-68	3918	Sandstone	Vaila Fm.
230507-69	3930	Sandstone	Vaila Fm.
230507-70	3945	Sandstone	Vaila Fm.

Table 3: Samples employed in this study from well 6004/12-1 Svinoy (BP)

Sample Nr	Depth [m]	Rock type	Geology
230507-71	2265	Sandstone	Balder Fm.
230507-72	2274	Sandstone	Balder Fm.
230507-73	2472	Sandstone	Balder Fm.
230507-73	2481	Sandstone	Balder Fm.
230507-73	2517	Sandstone	Balder Fm.
230507-74	2526	Sandstone	Balder Fm.
230507-75	2643	Sandstone	Balder Fm.
230507-76	2673	Sandstone	Lambda Fm.
230507-77	2694	Sandstone	Lambda Fm.
230507-78	2793	Sandstone	Lambda Fm.
230507-79	2814	Sandstone	Lambda Fm.
230507-80	2871	Sandstone	Lambda Fm.
230507-81	2886	Sandstone	Lambda Fm.
230507-82	3117	Sandstone	Lambda Fm.
230507-83	3192	Sandstone	Lambda Fm.
230507-84	3212	Sandstone	Lambda Fm.
230507-85	3485	Sandstone	Lambda Fm.
230507-86	3503	Sandstone	Lambda Fm.
230507-87	3536	Sandstone	Vaila Fm.
230507-88	3554	Sandstone	Vaila Fm.
230507-89	3656	Sandstone	Vaila Fm.
230507-90	3665	Sandstone	Vaila Fm.
230507-91	3737	Sandstone	Vaila Fm.
230507-92	3755	Sandstone	Vaila Fm.
230507-93	3833	Sandstone	Vaila Fm.
230507-94	3851	Sandstone	Vaila Fm.
230507-95	3997	Sandstone	Vaila Fm.
230507-96	3926	Sandstone	Vaila Fm.
230507-97	3965	Sandstone	Vaila Fm.
230507-98	3992	Sandstone	Vaila Fm.
230507-99	4172	Sandstone	Vaila Fm.
230507-01	4181	Sandstone	Vaila Fm.
230507-02	4232	Sandstone	Fugloy Sand
230507-03	4235	Sandstone	Fugloy Sand

Table 4: Samples employed in this study from well 6004/17-1 Marimas (Eni)

Sample Nr	Depth [m]	Rock type	Geology
240507-04	1870	Sandstone	Balder Fm.
240507-05	1930	Sandstone	Balder Fm.
240507-06	2070	Sandstone	Balder Fm.
240507-07	2100	Sandstone	Balder Fm.
240507-08	2223	Sandstone	Balder Fm.
240507-09	2280	Sandstone	Balder Fm./Pippin
240507-10	2380	Sandstone	Lambda Fm.
240507-11	2410	Sandstone	Lambda Fm.
240507-12	2650	Kettla Tuff Mbr.	Lambda Fm.
240507-13	2720	Sandstone	Lambda Fm.
240507-14	2800	Sandstone	Lambda Fm.
240507-15	2970	Sandstone	Lambda Fm.
240507-16	2990	Sandstone	Vaila Fm.
240507-17	3050	Sandstone	Vaila Fm.
240507-18	3110	Sandstone	Vaila Fm.
240507-19	3130	Sandstone	Vaila Fm.
240507-20	3300	Sandstone	Vaila Fm.
240507-21	3340	Sandstone	Vaila Fm.
240507-22	3501	Sandstone	Vaila Fm.
240507-23	3516	Sandstone	Vaila Fm.
240507-24	3813	Sandstone	Vaila Fm.
240507-25	3819	Sandstone	Vaila Fm.