GEOLOGICAL AND ENVIRONMENTAL SUMMARY

Geophysical Data Availability

A considerable amount of data has been acquired through the years on the Jan Mayen Ridge, including the northern Dreki Area, by academic and government institutions, and the industry. A list of existing industry and government seismic datasets is given below. Further information on available seismic data can be found on the web-site of the NEA of Iceland (NEA) and in the Icelandic Continental Shelf Portal (ICSP; www.icsp.is).

1) Norwegian Petroleum Directorate, 1979: Jan Mayen Ridge within Jan Mayen agreement area, joint ownership, may be purchased through the Norwegian Petroleum Directorate, 600 km, shot and processed by GECO.
2) Norwegian Petroleum Directorate and NEA, 1985. Jan Mayen Ridge, mainly within Jan Mayen agreement area, joint ownership, 4000 km, shot and processed by GECO. Available as raw-stack and raw-mig at copy-cost upon request to the NEA. Reprocessed by Spectrum in 2009.
3) Norwegian Petroleum Directorate and NEA, 1988: Jan Mayen Ridge, Jan Mayen agreement area and southern Jan Mayen Ridge, joint ownership, 950 km, shot by the University of Bergen and processed by the NEA. Available as raw stack, raw mig, final stack and final mig upon request to the NEA. Reprocessed by Spectrum in 2009.
4) InSeis Terra, 2001: Southern Jan Mayen Ridge, non-exclusive speculative survey, 2800 km, owned and shot by InSeis Terra. Partly reprocessed in 2008, and bought by CGGVeritas in 2009, now owned by Spectrum.
5) TGS-NOPEC, 2002: Southern Jan Mayen Ridge and eastern Icelandic shelf, non-exclusive speculative survey, 800 km, owned, shot and processed by TGS-NOPEC.
6) Wavefield InSeis, 2008: Southern Jan Mayen Ridge, non-exclusive survey, 900 km, owned and shot by Wavefield InSeis, and bought by CGGVeritas in 2009, now owned by Spectrum.
7) Marine Research Institute, 2008. A multibeam bathymetric survey in June 2008 of 10,500 sq. km of the area. The data is available upon request to the NEA.
8) Fugro NPA, 2009: Satellite Synthetic Aperture Radar (SAR) seep study, with 186 slicks mapped and 8 higher confidence seepage slicks identified.
9) NEA of Iceland, 2010: Surface sediment sampling survey. Data available upon request to the NEA.
10) TGS-NOPEC, 2011: Sampling survey in autumn 2011.
11) Norwegian Geological Survey, 2011: JAS-11 aeromagnic survey in autumn 2011.

No deep wells have been drilled on the Icelandic continental shelf for the purpose of exploring for petroleum. Some shallow boreholes were drilled in the area during Leg 38 of the Deep Sea Drilling Program and the ODP Legs 151 and 162. The data is available at the web-site of the U.S. National Geophysical Data Centre (for further information see the IODP-USIO).

Geology and Hydrocarbon Potential

A joint Icelandic-Norwegian interpretation report on the geology of the Jan Mayen Ridge from 1989, based on the 1985 seismic survey, is available on the NEA web-site. Furthermore, a large number of geoscientific papers have been published about the area and a list of those can be found on the NEA website.

The Jan Mayen Ridge, also referred to as the Jan Mayen Micro-Continent (JMMC), including the part covered by the northern Dreki Area, is thought to have some potential for hydrocarbon accumulations because of its geological similarity to hydrocarbon basins, which were its next door neighbours prior to the opening of the northeast Atlantic Ocean. The basins in question are on- and offshore East Greenland and in particular North-East Greenland with a lot of interest in hydrocarbon exploration. The eastern analogues are basin areas located offshore western Norway, i.e. the Møre and Vøring basins, where oil and gas has been discovered in commercial quantities. The closest analogue is the Jameson Land Basin located onshore in central East Greenland, where oil and gas are known to have been generated and are potentially preserved in Mesozoic and even Palaeozoic sediments. This basin is of importance, as the JMMC was a part of that coast prior to the opening of the North Atlantic as we know it nowadays.

Generally it is important to emphasise that there is a progressive deepening of the Jan Mayen Ridge from the northern part to the south, with higher exposed ridges to the north and deeper Tertiary post Palaeocene basins to the south and along the flanks. Moreover, there is an increase in normal faulting and structural complexity towards the south, subdividing the ridge into the Main Jan Mayen Ridge and the Southern Ridge Complex. The eastern margin of the micro-continent developed as a volcanic passive margin with a series of seaward dipping reflectors (SDR). The western margin developed as a series of extensional and rotated fault blocks especially along the NW flank of the ridge, with listric faulting along the western to south-western flank of the ridge due to increased stretching of the Southern Ridge Complex.

The main geological development of the Jan Mayen Ridge

Prior to the onset of seafloor spreading in the northeast Atlantic 56 million years ago, the hydrocarbon basins mentioned above were located in close proximity to one another. Since that time they have gradually moved apart as a result of plate tectonic movements and the forming of the North Atlantic Ridge systems that created the surrounding oceanic basins and also Iceland.

The JMMC is a sliver of continental crust bounded by rifted continental margins on both sides. The eastern margin developed as the outermost part of the continental shelf of Greenland during the initial breakup of the continent and the opening of the Norway Basin, where the JMMC gradual separated from the continental shelf of Norway along its eastern edge during the opening of the Aegir Ridge between 56 Ma to approx. 21 Ma. The eastern margin is also characterized by an eastward thickening and dipping sections of basaltic lava flows that were erupted over the pre-existing continent, firstly during the pre-break up volcanic events (~57-56 Ma), where these lava flows can be connected between the Greenland coast and the western margins of the Norway Basin and the Faroe Islands, and a second event that caused the forming of basaltic lava flows due to the initial break up of the continents along the eastern margin of the JMMC, i.e. the SDR's. The eastern flank of the main Jan Mayen Ridge is not as heavily faulted as the Southern Ridge Complex which is heavily segmented and structurally complex due to extension and minor reverse faulting during a slight anti-clockwise rotation of the micro-continent and subsidence after the separation from Greenland.

Extensive volcanic activity occurred around the south easternmost flanks and southern edge of the JMMC that is visible on seismic data during a gradual re-adjustment of the mid-oceanic ridge system, which appeared to gradually "step over" from the Aegir Ridge to the Kolbeinsey Ridge between the end of the Middle Eocene, and especially between the Early Oligocene and the Early Miocene. During that time, fault and block separation increased in the southern parts of the ridge, forming the Southern Ridge Complex, possibly due to two attempted propagation of the mid-oceanic rift into the JMR; first during the Middle Eocene and again during the Early Oligocene, and finally breaking through at an old weakness zone along the far extended western flank of the JMR, forming the Kolbeinsey Ridge as it is known today. These processes introduced extensive stretching and structural complexity of the JMR

As mentioned above, the western margin developed as a result of rifting within the continental shelf of Greenland, forming small, more or less north-south striking rift basins (Jameson Land Basin and possibly Jan Mayen Basin) and highs (Liverpool Land Ridge and Main Jan Mayen Ridge). Later on, during the parallel onset of a gradually emerging Iceland Plateau and the re-adjustment of the Mid-Atlantic rifting structures from the eastern margin of the JMMC to the western margin of the JMMC, the micro-continent separated along the western edge of the JMMC from East Greenland during the opening of the Kolbeinsey Ridge from Early Miocene (21-20 Ma ago) to present, resulting in the isolated location of the JMMC far from shore and surrounded by oceanic crust formed during the rifting process. The western margin of the JMMC is characterized by tilted extensional fault blocks that are the result of a rifting phase prior the break up from the central East Greenland shelf, and an extensive complex of sills or lava flows which cover the deep basins west of the Jan Mayen Ridge. During the time that the southern tip of the JMMC moved over the main heat source that feeds into the active mid-oceanic ridge system, the crust heated up and caused not only stretching but also an uplift of the area, causing erosion of the high blocks within the ridge itself.

At last, a subsidence phase of the ridge followed the breakup from the continental shelf of Greenland shelf west of the JMMC caused by an overall cooling and thermal contraction of the area as the distance of the JMMC from the active ridge system increased during spreading. Deep sea deposits cover the entire ridge area and the surrounding oceanic crust with pelagic sediments, possibly contourite sedimentation between the steep sloped ridges and gravity flow deposits.

The main geological units for the Jan Mayen Ridge in order of decreasing age

1. Continental basement rocks of most probably similar consistency as the Pre-Cambrian Gneisses of the Liverpool Land Ridge and Jameson Land Basin areas.
2. If pre-basalt sedimentary rocks are present, they could pre-date the opening of the Greenland-Iceland-Norwegian Seas and could possibly be similar to the terrestrial to marine deposits of the Paleozoic (possibly Carboniferous or Permian), or the terrestrial to marine and deep marine deposits of the Mesozoic (possibly Triassic, Jurassic or Early Cretaceous) along the western margin of the Jan Mayen Ridge, e.g. possibly the Jan Mayen Basin. The main comparable onshore source rocks analogues would be the „Upper Permian Ravnefjell Formation“, the „Lower Jurassic Kap Stewart Formation“ or the „Upper Jurassic Hareelv Formation“.
3. Late Palaeocene pre-rift sediments are known in onshore analogues, showing fluvial channel deposits right below the main break-up unconformity containing eroded Cretaceous and older sediments. Such pre-rift sediments can possibly be imaged below the lava section across the Main Jan Mayen Ridge as well.
4. Basaltic lavas extruded during pre- and syn-break-up eruptions covering the area with thick basalt lava sequences. These are also referred to as „East Greenland Flood Basalt provinces“, especially during the forming of the „Plateau Basalts“ approximately between 56-54 Ma that covered the entire area across from the Scoresby Sund area, over the Blosseville Kyst and Kangerlussuaq area on the Greenland side, across to the Faroe Islands that also would affect the southern part of the Jan Mayen Ridge area and thinning toward the centre and northern part of the ridge.
5. Subaerial basaltic lavas extruded during initial breakup of the continent along the eastern margin of the ridge, also referred to as Seaward Dipping Reflectors (SDR’s).

6. Oceanic crust in the Norway Basin connected to the eastern margin of the JMMC as a result of the seafloor spreading processes along the Aegir Ridge.
7. Gradual cooling along the eastern margin of the JMMC caused subsidence and the creation of a shelf slope between inland Greenland and the active ridge system, creating space for shelf- and shelf slope deposits derived primarily from the Scoresby Sund area containing sediments from the erosion processes across the Jameson Land Basin and Liverpool Land Ridge areas, prior to the onset of rifting within the continental shelf of Greenland up to Mid-Eocene.
8. The rifting process along the western margin of the JMMC prior to the break up of the JMMC from Greenland caused a subsidence along the western margin of the Jan Mayen Ridge, also referred to as the Jan Mayen Basin. Thus the area was shut off from the sediment input from the Greenland margin over the Jan Mayen Ridge, but developed short-lived submarine fan systems that were locally sourced by steep, exposed highs within the Jan Main Ridge system. These erosional processes filled rapidly subsiding small graben structures with infill deposits during the rifting and extension processes within the continental shelf of Greenland, primarily infilling local sub-basin areas along the western flank of the Jan Mayen Ridge and small sub-basin structures across the Southern Ridge Complex between the Mid-Eocene and the Base Late Oligocene uplift and resulting unconformity.
9. Several sequences of aerially extensive, complex, flat-lying intrusives and lava flows emplaced during the rifting and uplift processes that led to the breakup of the JMMC from the central shelf of East Greenland from the Mid-Eocene, Late Eocene to Early Oligocene, and around the Late Oligocene to Early Miocene unconformity that marks the final break up time around anomaly 6.
10. Oceanic crust on the Iceland Plateau along the south western and western margin of the JMMC as a result of the seafloor spreading processes along the Kolbeinsey Ridge.
11. Deep sea deposits cover the entire ridge area and the oceanic crust formed during the spreading with pelagic sediments, possibly contourite sedimentation between the steep sloped ridges and gravity flow deposits. These Miocene to Pleistocene deposits are heavily interbedded or mixed with volcanic ash deposits that was produced during seafloor spreading on the Iceland Plateau and the Kolbeinsey Ridge.

Several factors indicate that the northern Dreki Area may have significant hydrocarbon potential

- The Jan Mayen Ridge was once part of East Greenland.
- Best analogue comparison with East Greenland exploration examples are the Jameson Land Basin, or the Thetis and Danmarkshavn Basins, and Møre Basin on the Norwegian shelf.
- Post Palaeocene sedimentary rocks of sufficient thickness and age present in the ridge flank areas.
- Indications of pre-opening sedimentary strata of possibly Palaeozoic, Triassic-Jurassic and maybe Cretaceous age underneath the west flank areas of the ridge, i.e. Jan Mayen Basin.
- Potential reservoir rocks, e.g. local, shallow marine to generally marine deposits, especially submarine fans/turbidite deposits in the case of post Palaeocene deposits, and possibly limestone platform to continental deposits for the pre-opening formations if present.
- Potential traps present, both structural and stratigraphic.
- Hydrocarbon maturation is probably high; more gas prone if sufficient source rocks are present.

The area is, however, in the initial stage of exploration. Sufficient seismic reflection data is available to do in-depth studies, but no exploration or deep stratigraphic wells have been drilled in the area to confirm the existence of the suggested stratigraphy and their physical rock properties. Present interpretations can only be based on structural reconstructions from 2D seismic, magnetic, gravity or bathymetry data, regional comparison with closest analogue areas on-shore and offshore, and updated tectonic history reconstructions.

Environmental Conditions

Strategic Environmental Assessment

The Strategic Environmental Assessment (SEA) of the area was completed in 2009, and no major obstacles were identified. A report on the SEA, published in March 2007, is available on the website of the Licensing Round, as well as comments on the report and the responses to those. A research program was been implemented as a result of the SEA on natural conditions of the area. Most of this data is available upon request to the NEA. The research includes:

- A weather buoy recorded meterological, wave and surface current data 2007-2009.
- A mooring with ADCP current meters recorded data between November 2007 and December 2008.
- Shipboard ADCP current measurements on two transects in the area that were measured three times, in February, June and December of 2008.
- A multibeam bathymetric survey in June 2008 of 10,500 sq. km of the area. The data is available upon request to the NEA.
- A survey of benthic organisms was conducted in August 2008. Samples were collected and preserved and pictures were taken of the sea floor. A summary of the sampling as well as some further information on the survey are available upon request to the NEA.

Climate and condition of the sea

The average temperature in the northern part of the Dreki Area is below 10°C year-round, but the period January through March is usually coldest with average temperatures between 2°C to 0°C. The month of August is usually the warmest with average temperature of 7°C to 8°C. There is frequent precipitation, especially in the fall and winter. The average annual precipitation is near 700 mm, which is less than in Reykjavík. The distribution throughout the year is similar to the closest coastal areas of Jan Mayen and in the Eastern Fjords of Iceland. Precipitation, in the form of rain, sleet and snow, is quite heavy in the winter low pressure systems. If the temperature is close to freezing, the snow can form icing on the windward side of structures. Observations from weather stations in Iceland and Jan Mayen indicate that fog is the most common impairment to visibility in the northern part of the Dreki Area, and it is most frequent in the summer. Precipitation, especially snow, can cause poor visibility in the winter. From December to March the average wind speed is about 10 m/s and about 6 m/s in the summer.

Sea temperature in the Dreki Area is about 0°C to 1°C during the winter, but up to 7°C in late summer. Most of the time the sea surface temperature is higher than air temperature, because of the advection of cool air from the north. This difference in temperature between the air and the sea is, however, negligible during the summer.

It seems that the wave height in the Dreki Area is generally significantly lower than in the area south and west of Iceland or at the west coast of Norway. In the Dreki Area the wave height reached once in 100 years is about 12 m, while the corresponding wave height off the west coast of Norway is 14-16 m. The mean of the highest wave height reached in the Dreki Area once a year, as well as the wave height reached in 98% of cases, is around 5-6 m.

Little pack ice has drifted into the area in recent decades although the pack-ice period 1965 to 1971 is an exception. The southwest corner of the area has nevertheless been free of ice during this time. Icing creates temporary problems during the winter, but its frequency varies greatly from year to year, and increased frequency is related to the periods characterised as pack-ice years. Increased probability of heavy icing is associated with spindrift in sharp northerly winds. The main weather related difficulties for oil production in the northern part of the Dreki Area are considered to be the risk of icing in the winter and lack of good visibility (more likely in the summer). A buoy has collected meterological and wave data in the Dreki Area since November 2007.

Biota

No islands or skerries rise out of the sea in the Dreki Area, and the biota in the northern part of the area is therefore primarily in the ocean, but birds also go through looking for food or passing over on their way to other areas. Commercial fisheries are related solely to fish stocks, especially pelagic species.

Large changes have occurred in the biota of the ocean area between Iceland and Jan Mayen in recent decades. The changes are associated with the shifting equilibrium between cold currents to the north and the flow of the Atlantic sea north of Iceland around the West Fjords. These changes have then been reflected in changes occurring, for example, in the distribution and migration pattern of herring in the 1960s and changes in the migration pattern of capelin in recent years. Further information on the hydrography and currents in the Dreki Area have been acquired, with current measurements collected on a mooring for one year and shipboard measurements of currents collected along transects that were measured at three different times during that period.

The biomass of zooplankton is greater near the Dreki Area than in most places around Iceland. The area is an important feeding ground for organisms nourished by zooplankton, like pelagic fish, especially herring and probably capelin, but it is also important for whales. There are several samples of benthic species in the Dreki Area that show great variability in the type of bottom and benthic communities. There are many sensitive benthic species in the north seas that are confined to specific features on the sea bottom. Any disturbance of the bottom can have a serious effect on the species' communities. Various different types of benthic habitats in the Dreki Area have been mapped, with special attention given to the potential presence of sensitive or rare habitats and species.

There is no information available about the demersal fish in the area. Part of the explanation can be that the area is not near any known fishing area and is rather deep. On the other hand, there is a possibility that delimited stocks of deep-sea fish are present. Such stocks have been found under similar conditions off the continental shelf south and west of Iceland.

The whale counts that have been made do not detect possible changes in the distribution of whales caused by activities in so small an area as that of the oil exploration area. For this purpose much tighter search lines and more frequent counts would be required. It is most efficient to make such counts from an airplane, but ships and other surveillance trips in the area could also be utilised. During such trips, skin samples could also be collected for genetic analysis to cast light on the whale stocks' types, which is important in evaluating the potential impact on stocks.

The number and distribution of seals in the Dreki Area depends primarily on the presence of pack ice there, but the edge of the pack ice in recent decades has been at a considerable distance to the west of the Dreki Area.

The Dreki Area is probably traversed by dozens of species of sea birds over the entire year. It can also be assumed that each species shows great variability in distribution and number depending on the season, how long they remain in the area, the feeding conditions, and where suitable food is available each time, depending on the ice conditions, etc. Based on the available knowledge, it can be assumed that the most common species in the contemplated oil area are fulmar, black-legged kittiwake, Brünnich's guillemot, common guillemot, puffin, razorbill and little auk. These species are among the most common ones in the North Atlantic.