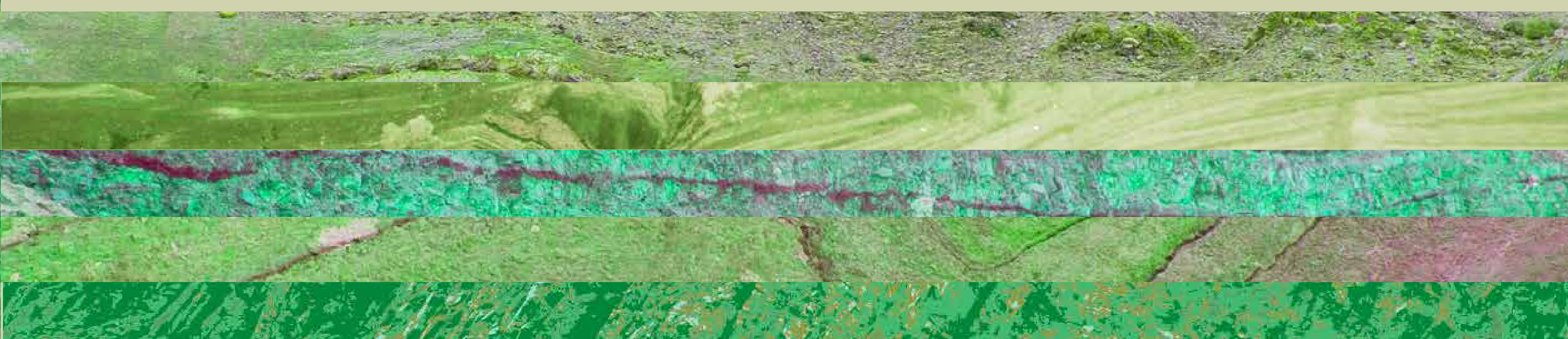
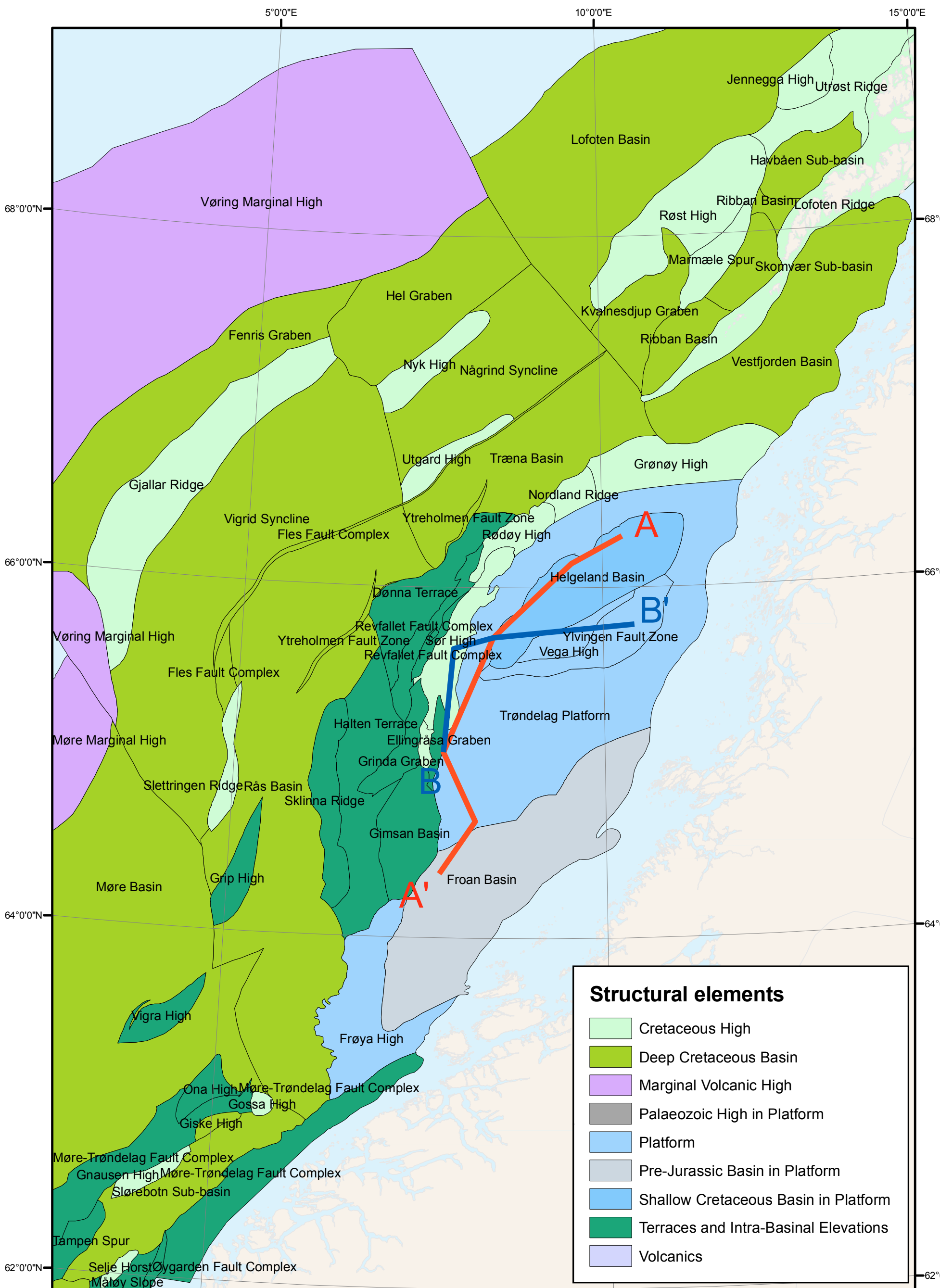
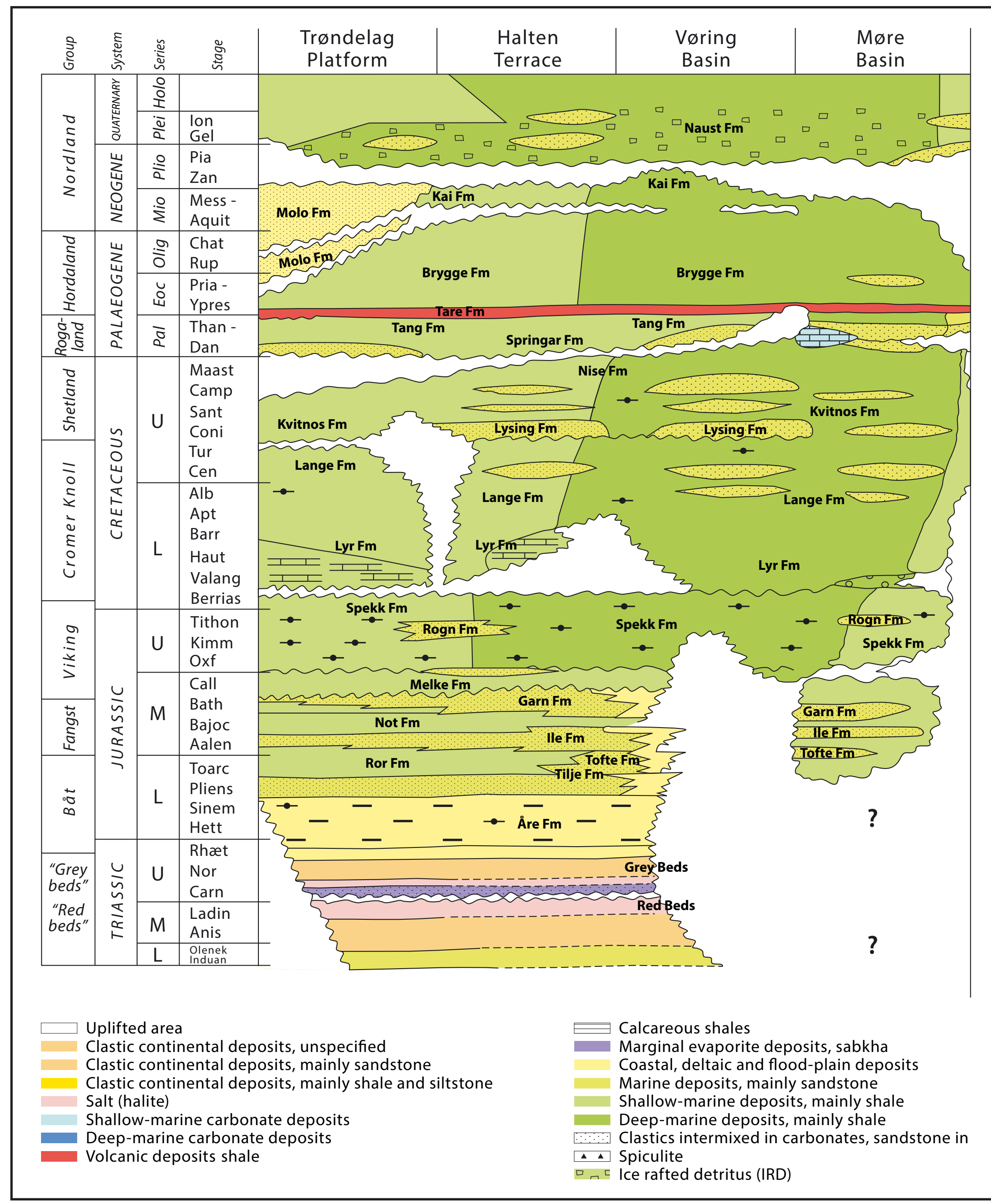
5. The Norwegian Sea



Eva K. Halland (Project Leader), Ine Tørneng Gjeldvik, Wenche Tjelta Johansen, Christian Magnus, Ida Margrete Meling, Jasminka Mujezinović, Fridtjof Riis, Rita Sande Rød, Van T. H. Pham, Inge Tappel

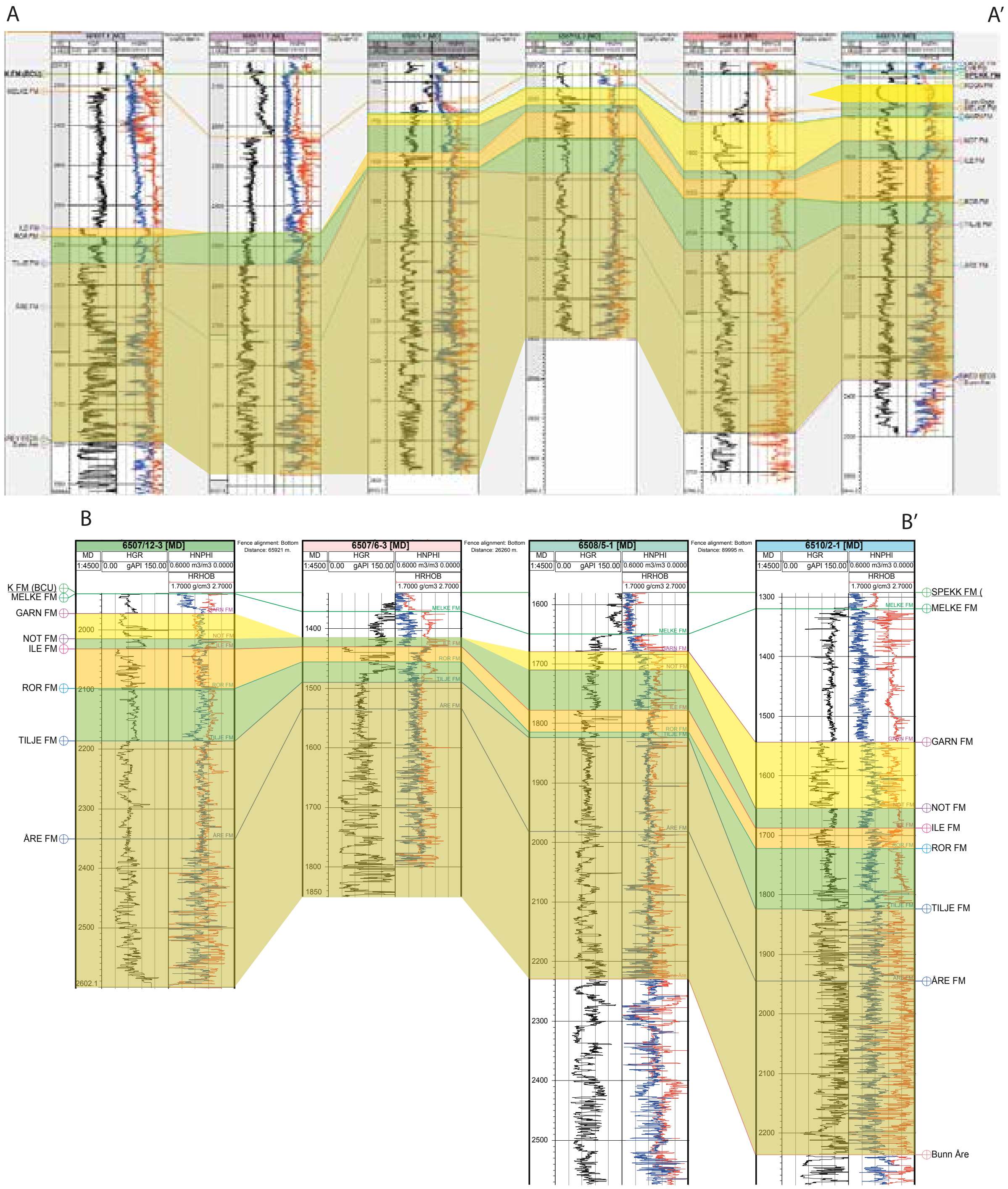


Structural elements in the Norwegian Sea.

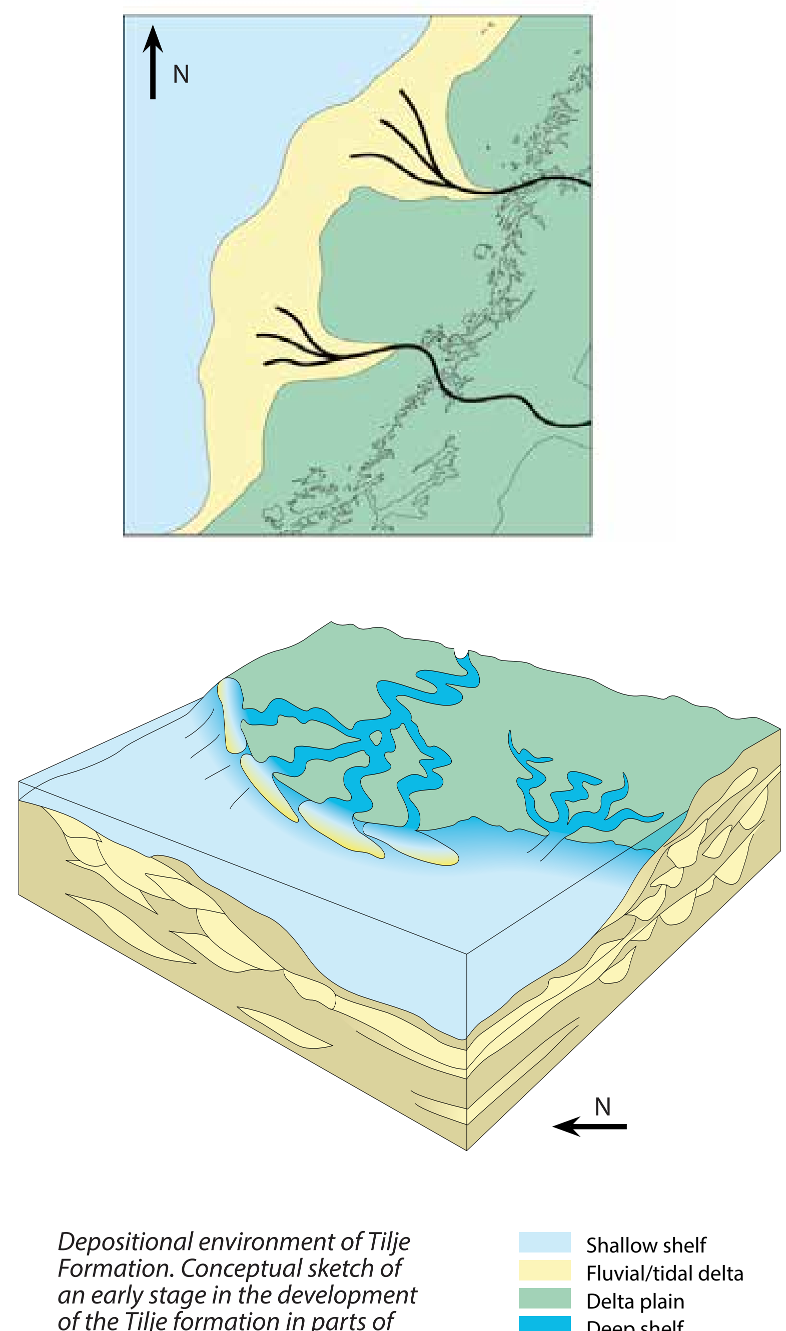


Lithostratigraphic chart of the Norwegian Sea (NPD).

5.1 Geology of the Norwegian Sea



Well section panels showing gamma and neutron/density logs reflecting thickness variations of the different formations. The Åre and Tilje Fms show more or less constant thickness throughout the area. The Ile and Garn Fms are thinning and shaling out towards the north. The Garn Fm is quite thick in well 6510/2-1, but less sandy, and is thinning towards the west.



Depositional environment of Tilje Formation. Conceptual sketch of an early stage in the development of the Tilje formation in parts of the Norwegian Sea.

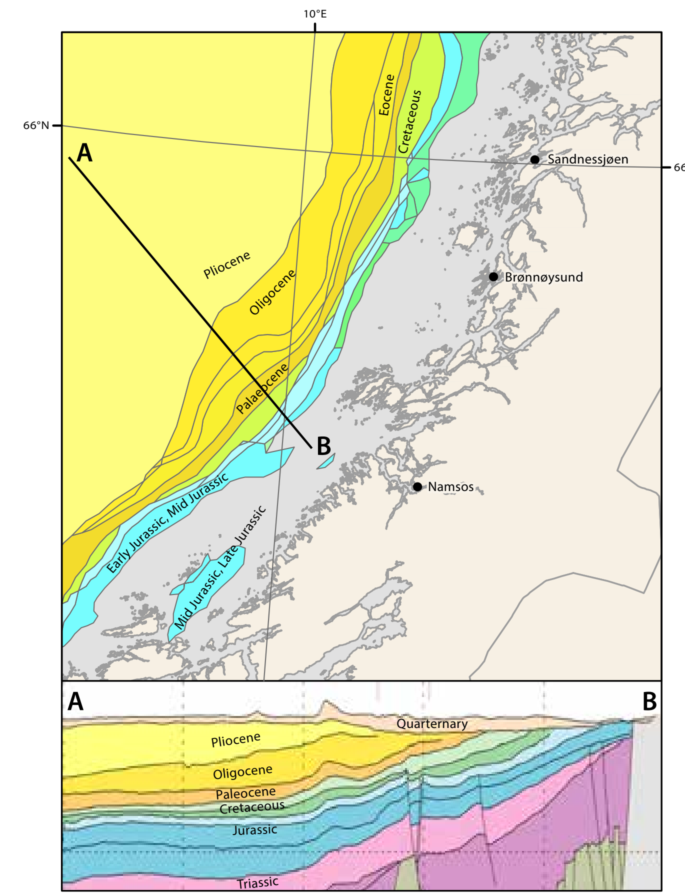
5.1 Geology of the Norwegian Sea

The Norwegian Sea covers most of the continental margin between approximately 62° and 69°3°′ N. The tectonic history of the Norwegian Sea can be divided into three major episodes: A) Final closure of the Iapetus Ocean during the Caledonian Orogeny (Late Silurian/ Early Devonian). B) A series of mainly extensional deformation episodes (Late Devonian to Paleocene), culminating with the continental separation between Greenland and Eurasia. C) Active seafloor spreading in the North Atlantic between Eurasia and Greenland (Earliest Eocene to present).

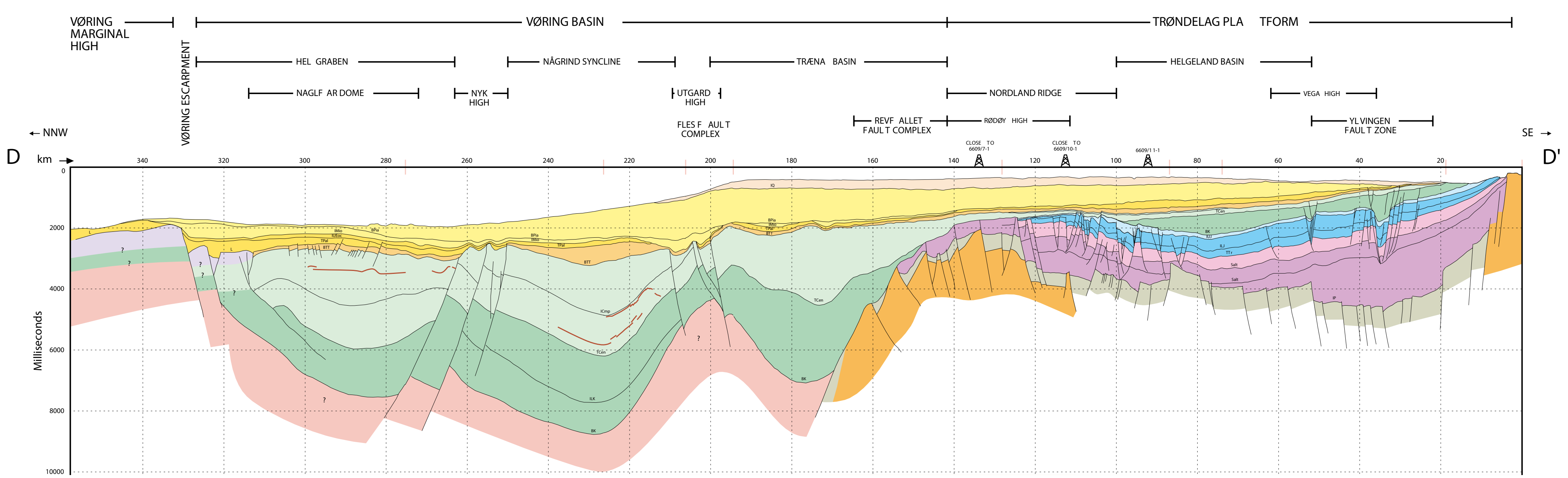
The area with the best potential for storage of CO_2 is the Trøndelag Platform (63° to 67° N), one of the main structural elements of the Norwegian Sea. The Trøndelag Platform contains the following structural elements: the Nordland Ridge, the Helgeland Basin, the Vega High, the Ylvingen Fault Zone, the Froan Basin and the Frøya High. The areas further west and south are considered less suitable for storage of CO_2 due to the active production of hydrocarbons, high temperature and high pressure and the depth of the relevant reservoirs.

Carboniferous, Permian and Triassic: Rifting and formation of N-S to NE-SW trending rotated fault blocks occurred on the Halten Terrace and parts of the Trøndelag Platform in late Permian/early Triassic times. This was followed by deposition of a thick continental Triassic succession. Drilling in the Helgeland Basin has proven up to 2500m thickness of Triassic (Grey and Red beds) including two Middle Triassic evaporite intervals up to 400m thick. The evaporite intervals represent detachment levels for later extensional faults. These thick sequences are related to pronounced subsidence and deposition in a fluvial sabkha environment. This tectonic event was possibly preceded by Carboniferous and Permian rifting.

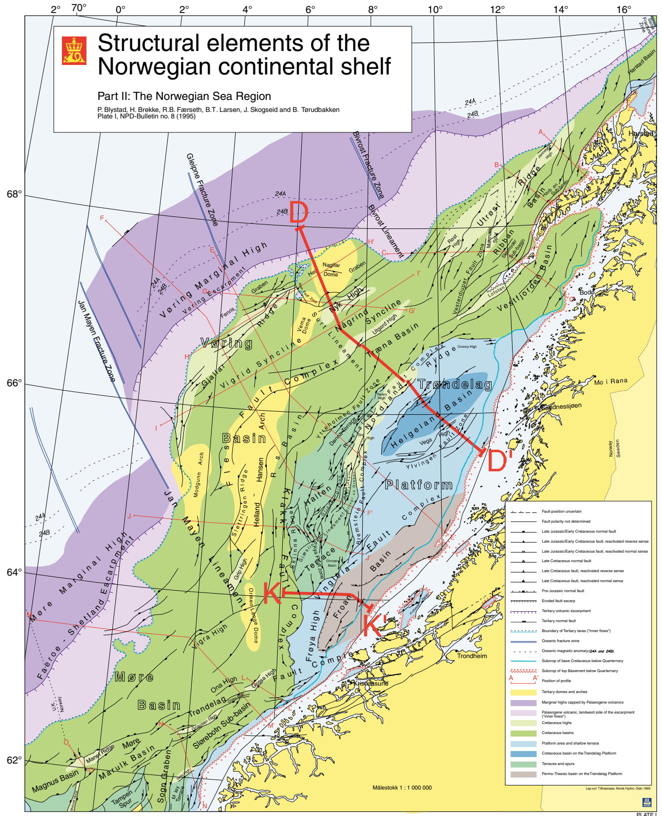
Jurassic and Cretaceous: During the Early and Middle Jurassic, the Trøndelag Platform and the Halten/ Dønna Terrace were parts of a large NS-trending subsiding basin which was infilled by a deltaic to fluvial depositional system. Sediment input from several directions through time has been interpreted. The Jurassic sediments become thinner towards the Nordland Ridge and the thickness increases over the Vega High and the Helgeland Basin. Starting in



Subcroping strata under the Quaternary offshore Mid Norway. Offshore map from NGU, Sigmond.



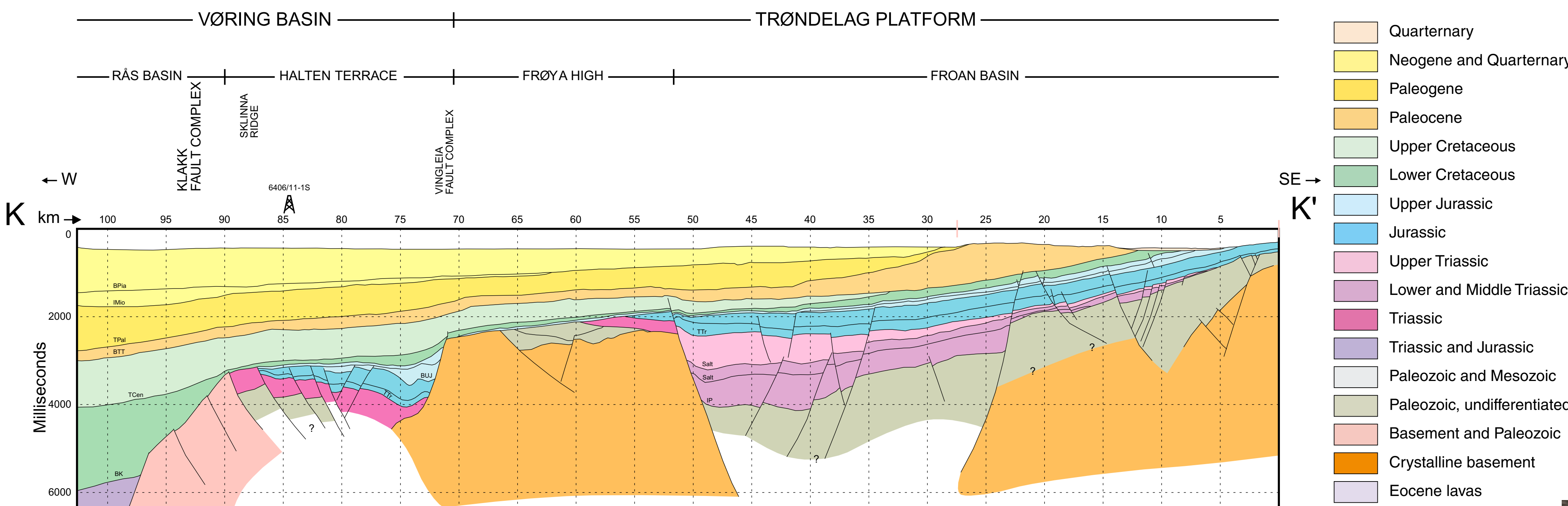
5.1 Geology of the Norwegian Sea



Structural element map of the Norwegian Sea. The Trøndelag Platform is shown by blue and gray colours. The depth and thickness maps in the following pages cover the Trøndelag Platform.

the middle Jurassic and culminating in the late Jurassic/early Cretaceous, the Norwegian Sea underwent a major tectonic phase with extension, faulting and thinning of the upper crust. The Halten and Dønna Terrace were downfaulted in relation to the Trøndelag Platform. Further to the west, the Vøring Basin subsided in relation to the terrace areas. During this extensional phase, both large-scale basement faults and listric faults were active, soling out into the Triassic salt. In the middle Jurassic, the Nordland Ridge and the Frøya High were uplifted, while the Helgeland Basin area subsided. Later, the Vega High was inverted, and faulting continued along the major faults well into the Cretaceous. The Froan Basin was a shallow sea during Late Jurassic, and it was later covered by thin, condensed Cretaceous sediments. In contrast, the Helgeland Basin area continued to subside. It has a thickness of up to 1500m of Cretaceous sediments. During the Late Cretaceous, there was a rapid subsidence west of the Nordland Ridge due to increased rifting in the west. At the same time, the structural highs and the Lofoten-Vesterålen area were uplifted.

Cenozoic: In the Paleocene, uplift of the Norwegian mainland resulted in progradation of clastic sediments from Scandinavia into the Norwegian Sea. Sandy deposits, sometimes with good reservoir properties, have been recorded north of the Nordland Ridge and in the Møre Basin (Egga sand). The progradation continued into the Eocene. The separation between Greenland and Eurasia and the onset of ocean floor spreading started in the Earliest Eocene. This is reflected in deposition of tuffs and tuffaceous sediments on a regional scale (the Tare Fm). On the Vøring and Møre Marginal Highs, lava flows and basaltic dike complexes were emplaced. The sediment input from Scandinavia was reduced in the Oligocene and Miocene. The deltaic Molo Formation has good reservoir sands, but is not sealed towards the sea floor. The Nordland Ridge was uplifted in the Late Cenozoic. In the Pliocene and Pleistocene, new uplift and glaciations caused erosion and deposition of thick sedimentary wedges onto the mid Norwegian shelf.



Upper Permian to Upper Triassic

On the Rødøy High, along the western margin of the Nordland Ridge, well 6609/7-1 drilled 34m of Upper Permian dolomitic limestone with thin sandstone layers overlying metamorphic quartzites.

The Permian rocks have not been given formal group or formation status, but are often correlated with the Permian in East Greenland.

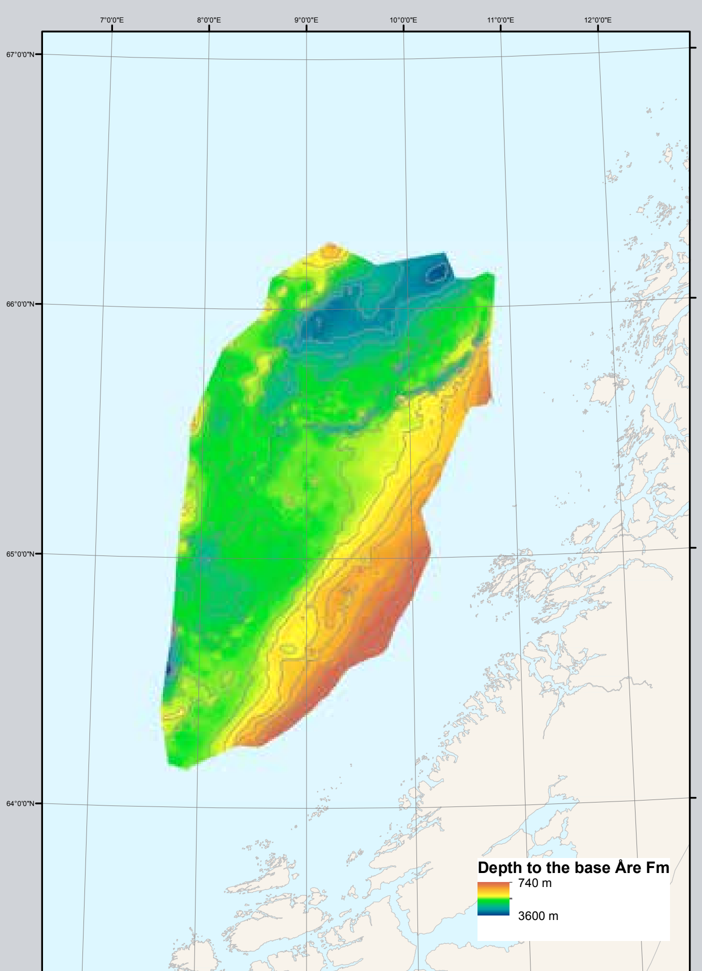
The Triassic rocks are given informal group names: Grey beds and Red beds. So far, no complete Triassic section has been drilled, but combined thicknesses of more than 2700m of both Grey beds and Red beds have been drilled (well 6507/6-1).

The Red beds form the lowest part of the drilled Triassic sequences and represent continental clastics deposited in an arid climate. The maximum thickness of Red beds is in the order of 2600m (well 6507/6-1, 2615m) and has been drilled on the southern extension of the Nordland Ridge.

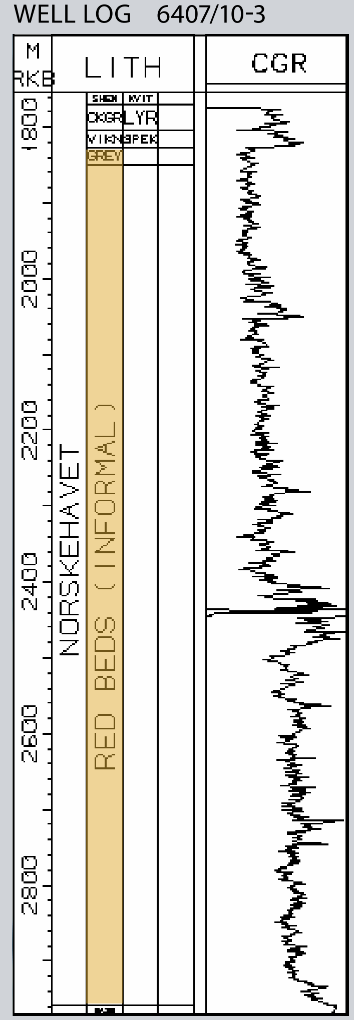
The Grey beds are interpreted to represent continental clastics deposited in a more humid climate than the Red beds. Maximum thickness of the Grey beds is in the order of 2500m (well 6610/7-2, 2489m).

The upper boundary of the Grey beds is towards the Upper Triassic and Lower Jurassic (Rhaetian to Toarcian) coal-bearing sediments of the Båt Gp (the Åre Fm).

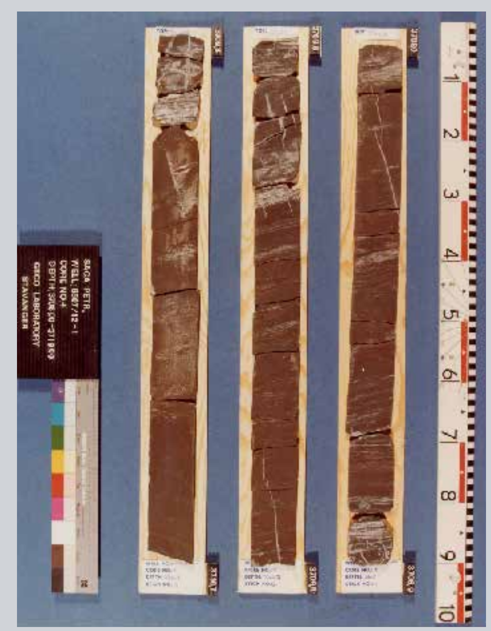
The Triassic also contains two evaporite sequences of Upper/Middle Triassic age (Ladinian–Carnian). Shallow boreholes (6611/09-U-1 & 2) along the Norwegian coast (66ºN) have drilled a combined thickness of 750m of Upper Permian and Lower Triassic sediments, including a possible source rock.



WELL LOG 6407/10-3



6507/12-1 RED BEDS, 3710.7 - 3708.9 m



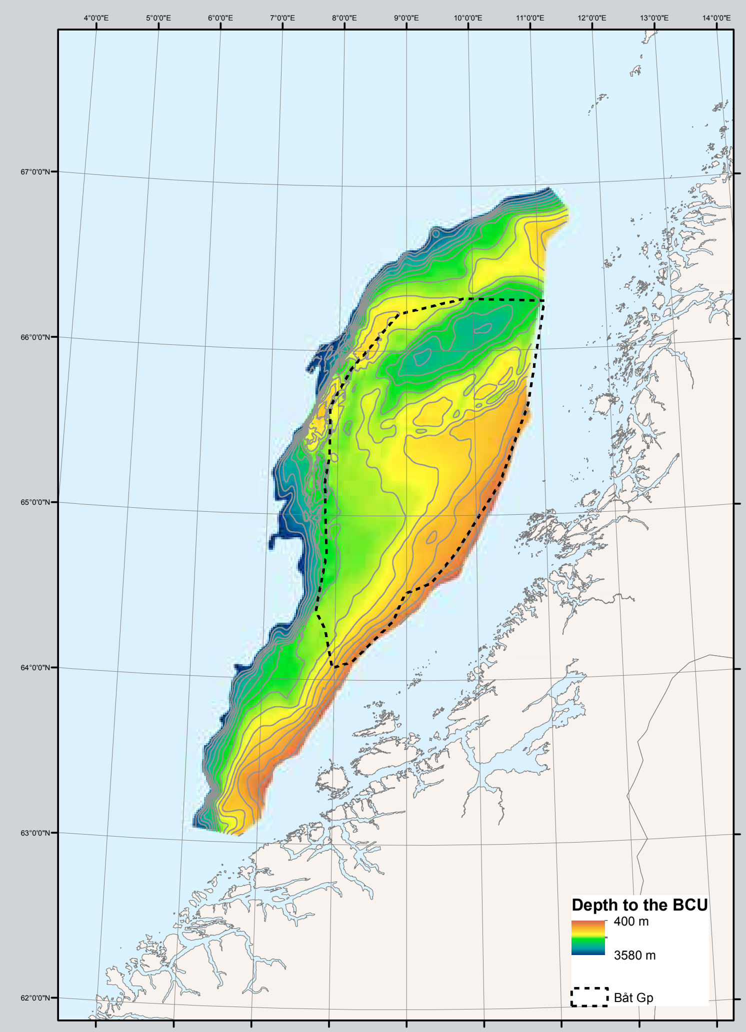
The Båt Group

Uppermost Triassic and Lower Jurassic
(Rhaetian to Toarcian)

The Båt Group is dominated by sediments deposited in deltaic to shallow marine environments overlying the Triassic Grey and Red beds (informal). This group is subdivided into four formations, the Åre, Tilje, Ror and Tofte Formations. The type well (6507/12-1) is located in the transition zone between the Halten Terrace and the Trøndelag Platform. The lower boundary of the group is defined below the first appearance of coal above the Triassic Grey beds. The upper boundary is defined at the base of a coarsening upwards sequence of the Ile Fm in the Fangst Gp. Marine influence increases towards the top of the succession and also to the north and west.

The Båt group is present in most of the wells drilled on Haltenbanken and Trænabanken with a maximum thickness up to 1000m (707m in the type well) in the eastern part of the Halten Terrace. Due to erosion, the upper part of the succession is progressively truncated towards the crestal parts of the Nordland Ridge. Shallow boreholes off the Trøndelag and Nordland coast indicate that mid Jurassic sediments onlap the metamorphic basement.

The burial depth of the Båt Gp. varies from 1000-2500m on the Trøndelag Platform and marginal areas of the Helgeland Basin. West of the Nordland Ridge the burial depth increases to more than 4000m. Porosities and permeabilities in the order of 25-35% and 100 mD to several darcys have been reported. However, rocks on the eastern part of the Trøndelag Platform have probably been buried deeper than the present depths indicate, due to Neogene erosion.



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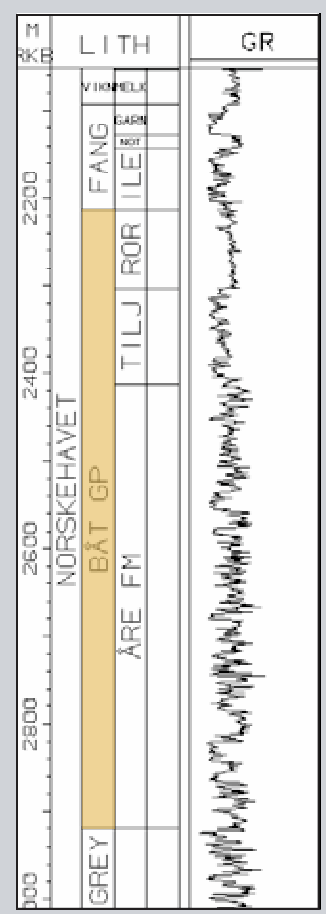
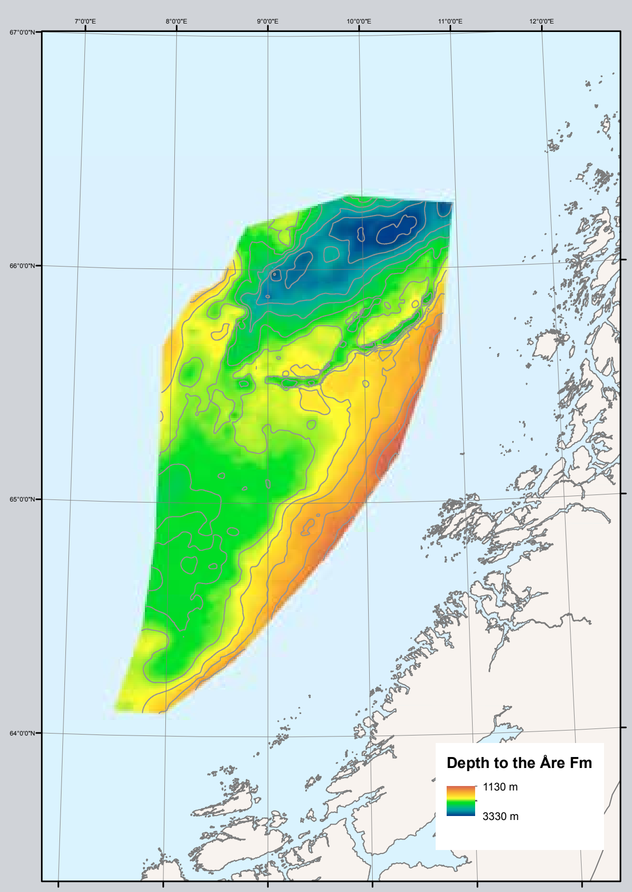


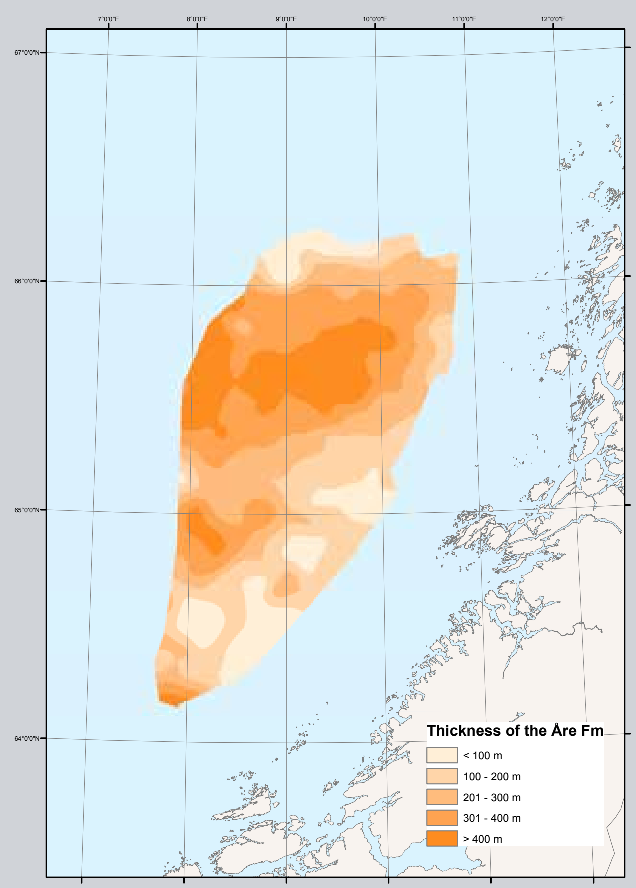
The Båt Group - Åre Formation

The Åre Formation (Rhaetian to Pliensbachian) represents delta plain deposits (swamps and channels) at the base with up to 8m thick individual coal seams. Where the coal bearing sequences are thinner, the sandstones are generally more coarse-grained. The Åre Fm is present in most wells drilled in the Haltenbanken and Trænabanken region, but is missing locally over the crest of the Nordland Ridge due to erosion.

The thickness in the type well (6507/12-1) is 508m, and in the reference well (6047/1-2) the thickness is 328m. Generally, the thickness of the Åre Fm varies between 300 and 500m, with a maximum thickness of 780m in the eastern part of the Halten Terrace (Heidrun area).

The well coverage over the central and eastern Trøndelag Platform is limited. Well 6510/2-1R, located on the Vega High and Ylvingen Fault Zone, drilled 291m of Åre Fm. Wells along the western margin of the Trøndelag Platform down to the Draugen field show thicknesses of the Åre Fm between 250 and 300m. In the Froan and Helgeland Basins area, the Åre Fm varies in thickness between 300 and 500m from south to north.





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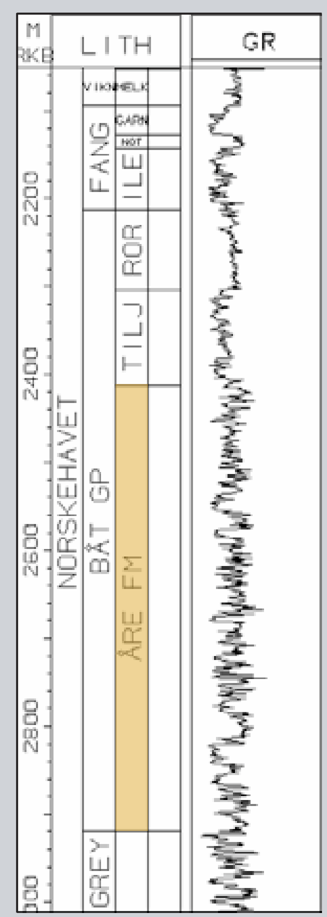
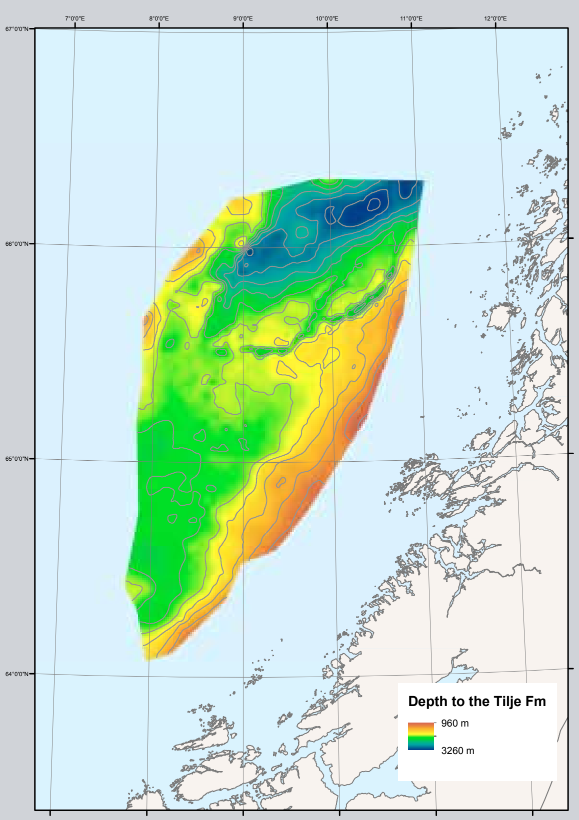


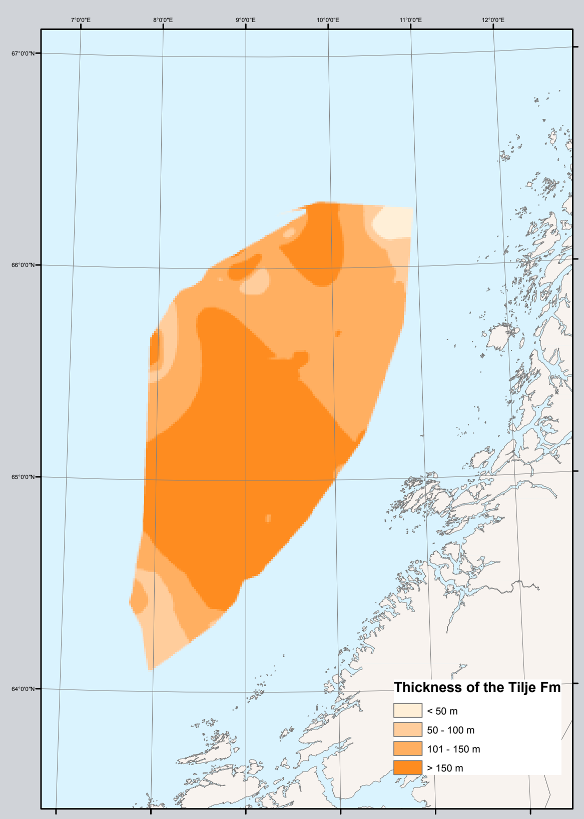
6507/12-1 ÅRE 2707.0 - 2709.7 m

The Båt Group - Tilje Formation

The Tilje Formation (Sinemurian to Pliensbachian) is defined at the top of a mudstone interval and consists of more sandy sediments deposited in near shore to intertidal environments with increased thickness of individual sandbodies. The mudstone interval is most pronounced on the Halten Terrace, but is difficult to pick further east on the Trøndelag Platform. Here coal beds are developed at a higher stratigraphic level than on the Halten Terrace. The formation is present in most wells in the Haltenbanken and Trænabanken region, but locally absent on the Nordland Ridge.

In the type well (6507/11-1), the thickness of the Tilje Fm is 98m, and on the Halten Terrace, thicknesses in the order of 100-150m are reported. Shallow boreholes close to the coast indicate time equivalent deposits dominated by coarser clastics. The same thicknesses are observed in the Trøndelag Platform area.





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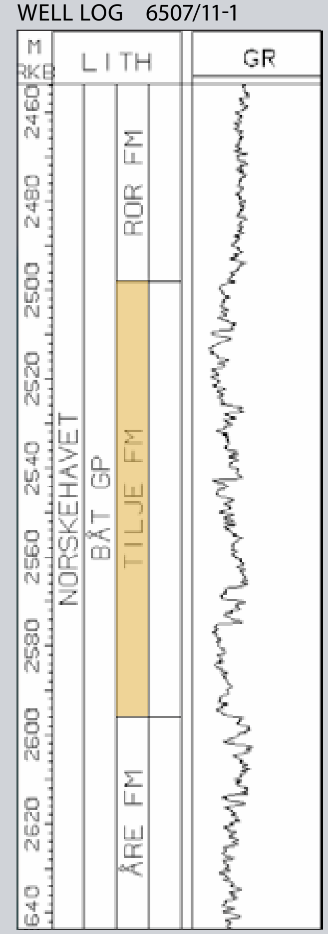
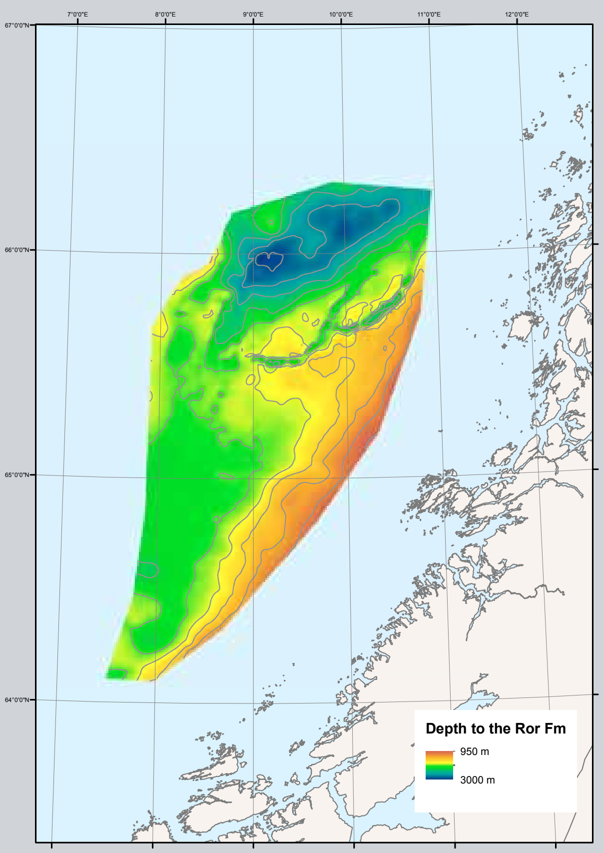


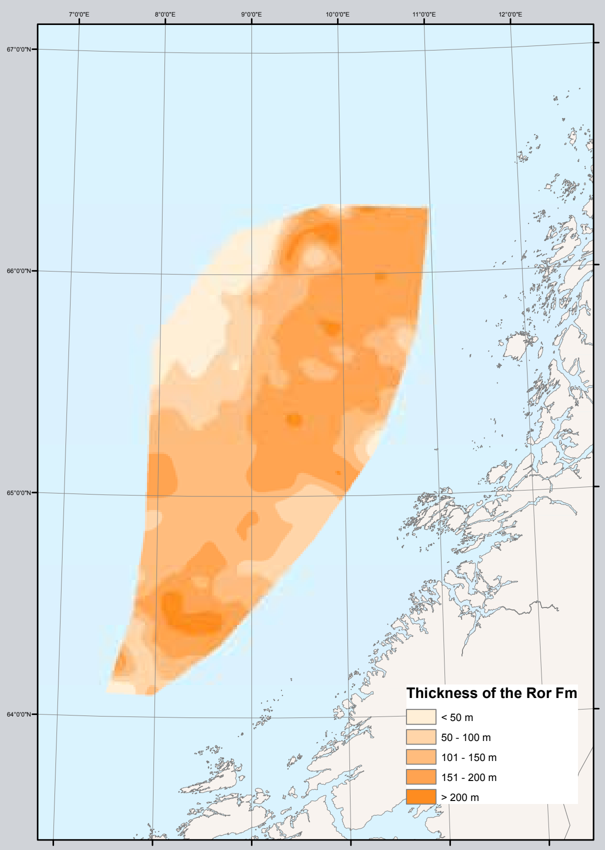
6507/11-1 TILJE 2527.7 - 2543.0 m

The Båt Group - Ror Formation

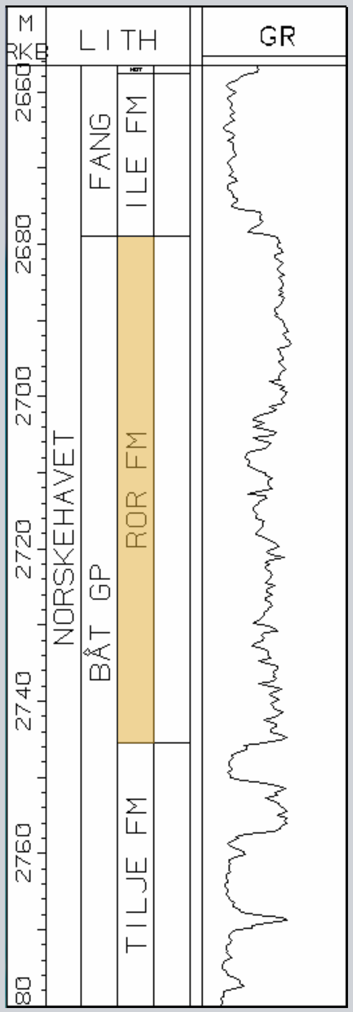
The Ror Formation (Pliensbachian to Toarcian) is defined by the abrupt transition from the sandstones in the Tilje Fm into mudstones, indicating an erosive base. The Ror Fm is present in all wells drilled on Haltenbanken, generally thinning towards the north-east. To the west, it interfingers with the sandstones of the Tofte Fm, and the oldest part of the Ror Fm is often absent. The Tofte Fm represents an eastward prograd-ing fan delta, reflecting a source area in the west. In the study area, the Tofte Formation does not occur, although local sandy beds have been encountered in the wells. The Ror Fm does not occur over large areas on the Nordland Ridge due to erosion/non-deposition. In the basinal areas, the mudstones of the Ror Fm might represent a seal, particularly towards the east.

In the type well (6407/2-1), the thickness of the Ror Fm is 104m, and thicknesses in the order of 70 to 170m have been recorded in wells on the Halten Terrace. On the Trøndelag Platform thicknesses between 100 and 200m are observed.





WELL LOG 6610/7-1



6610/7-1 ROR 2707.0 - 2713.0 m

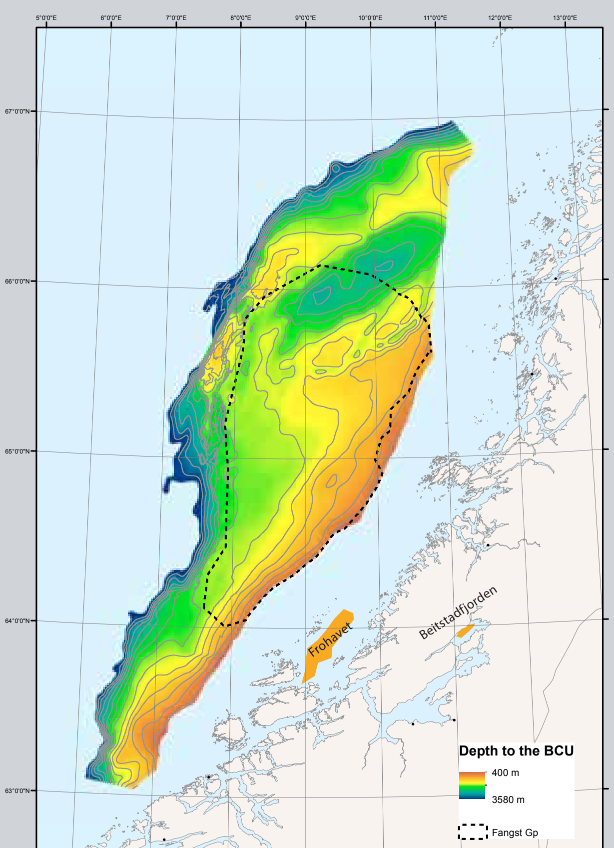
The Fangst Group

Lower to Middle Jurassic
(Upper Toarcian to Bathonian)

The Fangst Group is dominated by sediments deposited in shallow marine to coastal/deltaic environments overlying the Båt Group. It is divided into three formations, the Ile, Not and Garn Formations. The group is present over most of the Haltenbanken and Trænabanken area, except for the crestal parts of the Nordland Ridge, where it is eroded. The main development of the Fangst Gp is on the Halten Terrace. Along the southern margin of the Nordland Ridge, the succession is much thinner. On Trænabanken, there is a lateral facies change to marine mudstones of the Viking Gp, and only the lowest part of the Fangst Gp (the Ile Fm) is recognised.

Time equivalent sandstone dominated sequences subcrop on the seafloor along the eastern margin of the Trøndelag Platform. Outliers of Middle Jurassic sediments are present east of the Froan islands and in the Beitstadfjorden area in Trøndelag. Increased continental influence is inferred towards the Trøndelag Platform to the east, but well control is limited.

In the type well (6507/11-3), the thickness of the Fangst Gp is 124m and it typically varies between 100 and 250m.



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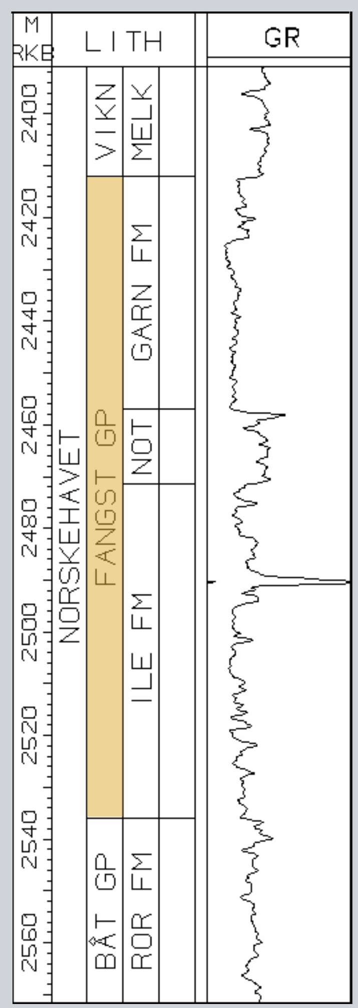
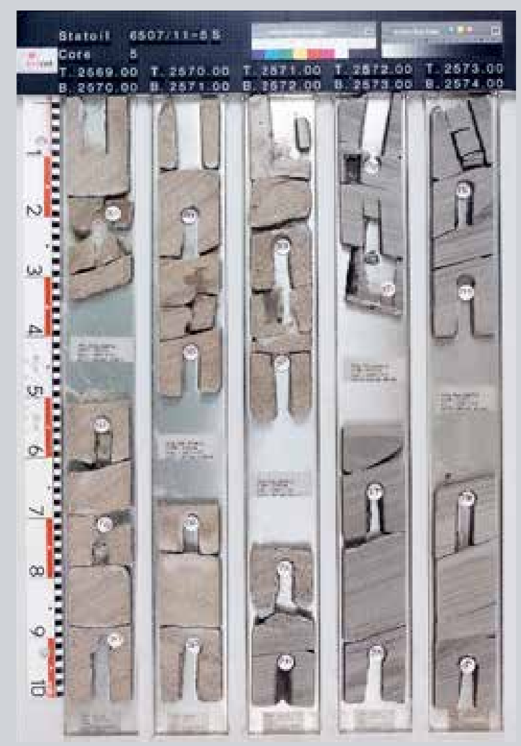


6507/11-5s ILE 2569-2574m

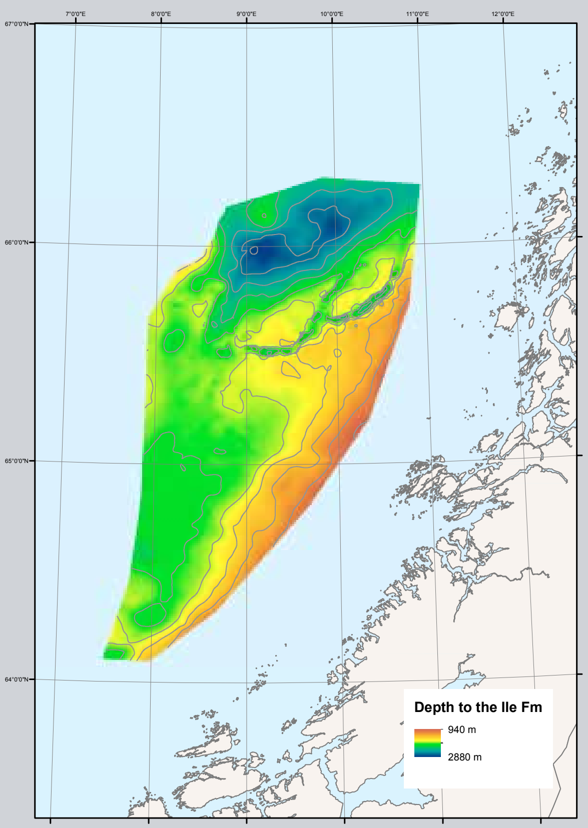


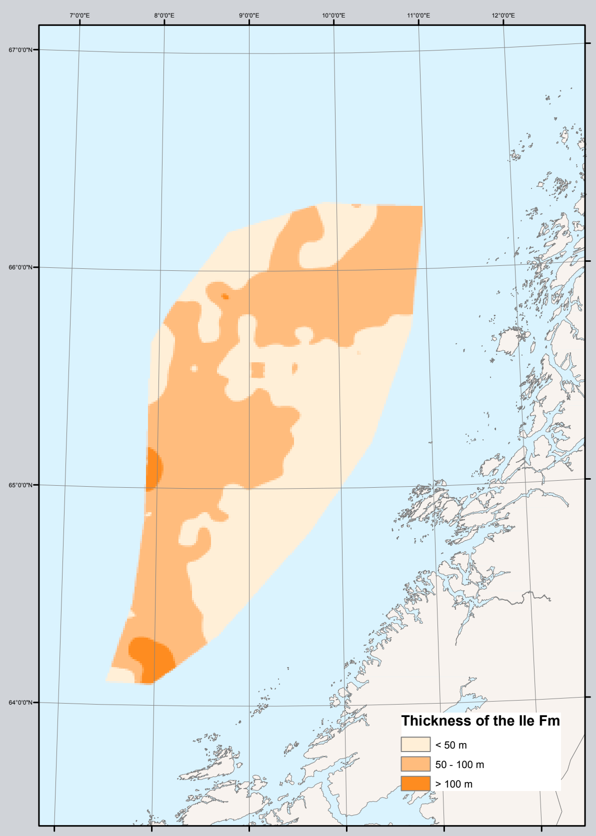
The Fangst Group - Ile Formation

The Ile Formation (Upper Toarcian to Aalenian) is defined at the base of a generally upwards coarsening sequence from siltstone to sandstone, often associated with more carbonate beds. The sediments of the Ile Fm are deposited in tidal or shoreline environments. The upper boundary is defined by the mudstones of the Not Fm. The Ile Fm is present over most of Haltenbanken, with a general thickening to the west and marked thinning to the northeast.

The thickness in the type well (6507/11-3) is 64.5m and 72m in the reference well (6407/1-3). The thickness of the Ile Fm varies between 50 and 100m over most of the Haltenbanken-Trænabanken area.

Sandstone dominated successions of similar age have been reported from shallow boreholes and sea bottom sampling in the eastern part of the Trøndelag Platform. The succession is thinner, however, ranging from 30 to 60m. The formation is shale dominated in the Vega High and Helgeland Basin.





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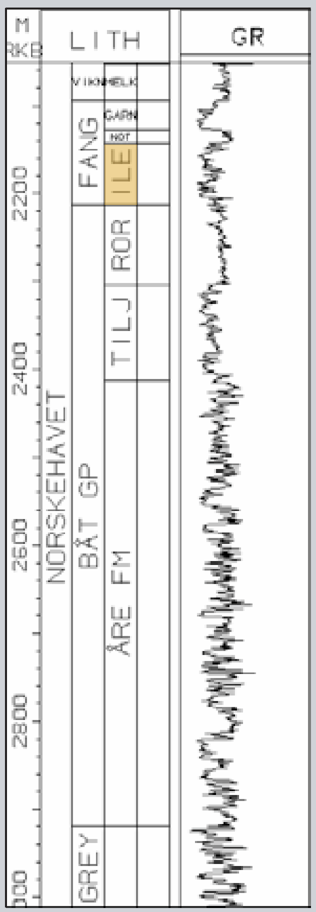
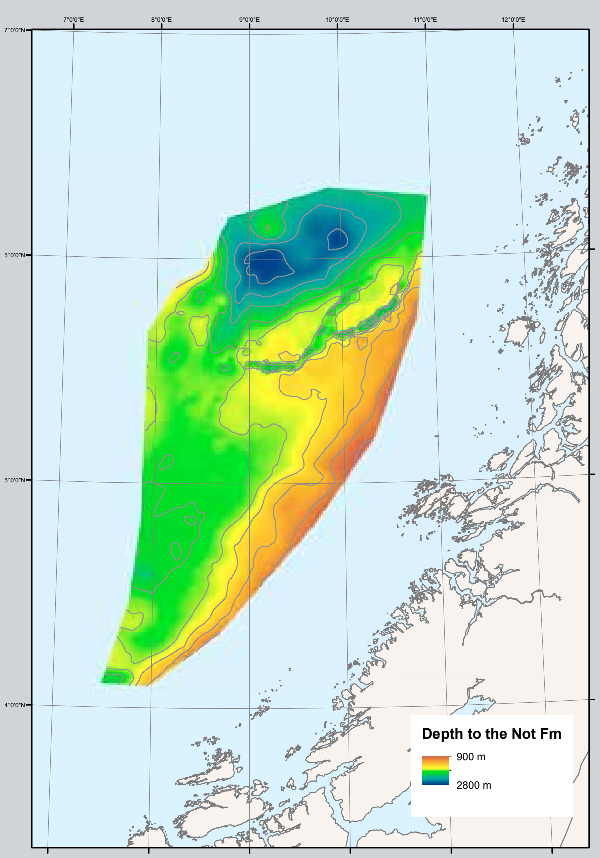


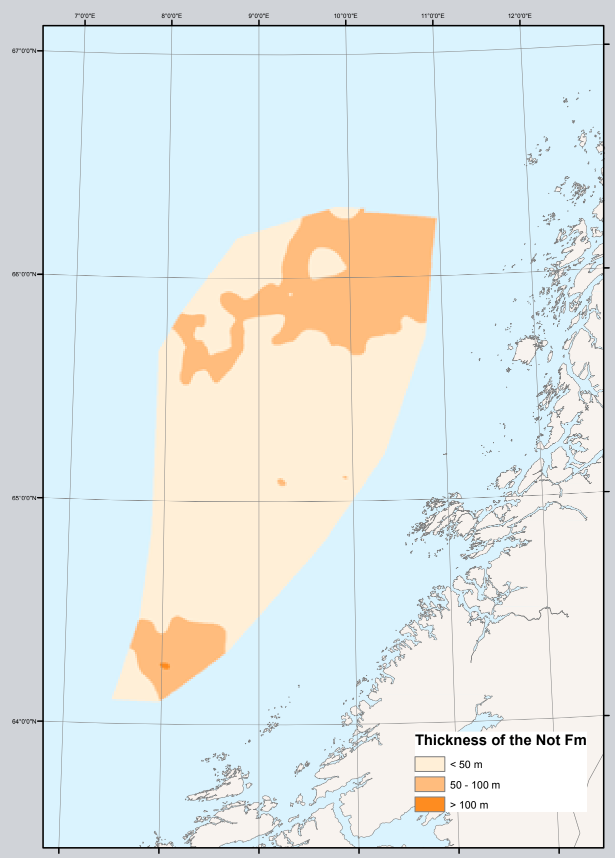
6508/5-1 ILE 1791 - 1795 m

The Fangst Group - Not Formation

The Not Formation (Aalenian to Bajocian) is developed as a mudstone dominated sequence coarsening upwards into bioturbated fine-grained sandstones deposited in lagoons or sheltered bays. The Not Fm is recognised over the entire Haltenbanken area, except on the eroded highs. The thickest development (<50m) of the Not Fm is on the southwestern part of the Halten Terrace, and the unit thins towards the east. On the Trøndelag Platform it has a consistent thickness of approximately 40m. The mudstones of the Not Fm could act as a seal.

In the type well (6507/1-3) the thickness is 14.5m and 37m in the reference well (6407/1-3).





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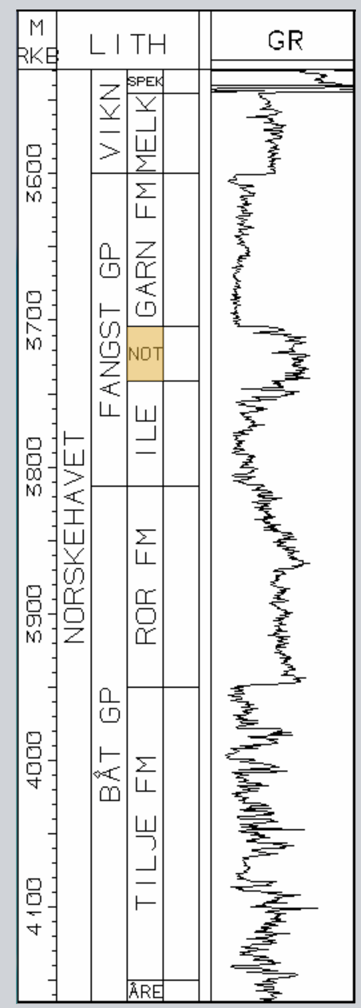


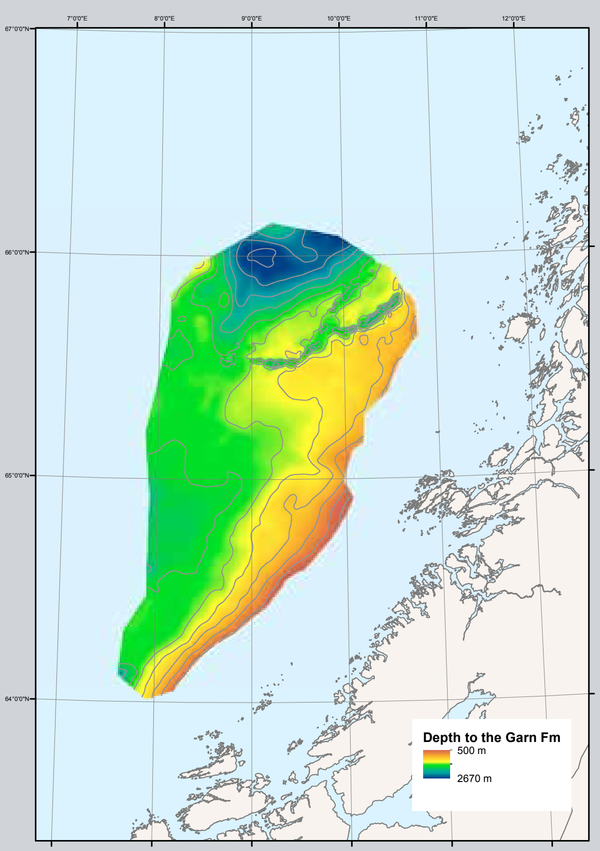
6507/11-3 NOT 2467 - 2472 m

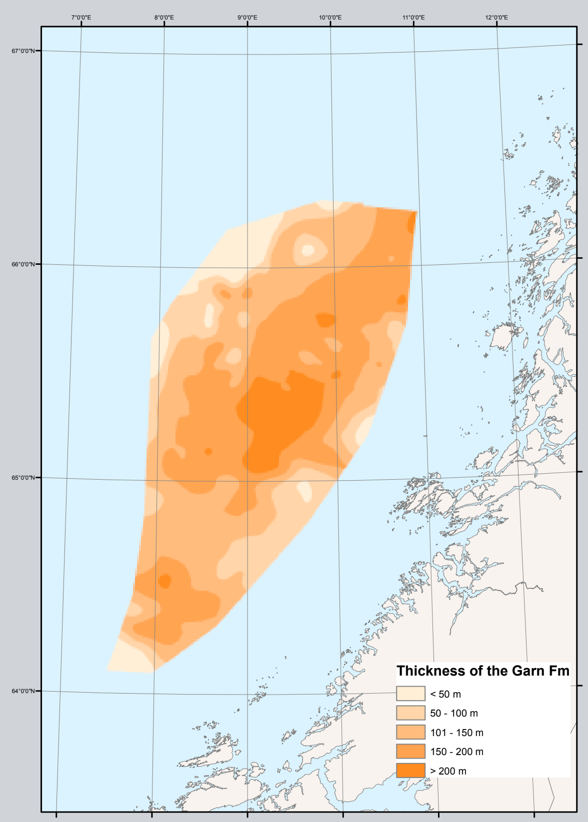
The Fangst Group - Garn Formation

The Garn Formation (Bajocian to Bathonian) is interpreted as progradation of braided delta lobes over the mud dominated Not Fm. The Garn Fm is present over the central part of the Halten and Dønna Terraces and the Trøndelag Platform, except over structural highs (Nordland Ridge) where the entire formation may be eroded. In the Ylvingen Fault Zone (well 6510/2-1R), the Garn Fm contains more silt, and further north, siltstones and mudstones are the lateral equivalents of the sandstones in the Garn Fm. It must be noted that well control on the eastern part of the Trøndelag Platform and in the deeper areas to the west is limited.

Depositionally, the sandstones of the Garn Fm are interpreted as a wave-dominated shoreface system with marine mud-dominated sediments deposited towards the north and south.

The thickness in the type well (6407/1-3) is 104m, and the formation may reach more than 100m on the Halten Terrace. The thickness of the Garn Fm is about 150m on the Trøndelag Platform. In the Froan Basin the formation is sand dominated compared to the northern part, where it becomes more shale dominated





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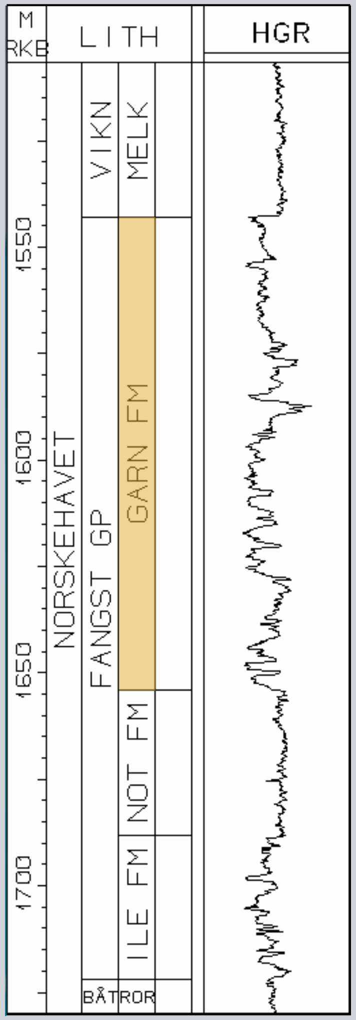


6407/1-3 GARN 3671.0 - 3675.0 m

The Viking Group

Middle Jurassic to Upper Jurassic/Lower Cretaceous
(Bajocian to Berriasian)

The Viking Group is defined in the northern North Sea and on Haltenbanken and Trænabanken. It is divided into three formations, the Melke, Rogn and Spekk Formations. The group is present over most of the Trøndelag Platform, but thins toward the Nordland Ridge where it is locally absent. The dominant lithology of the Viking Gp is mudstones and siltstones, with the exception of locally developed sands (Rogn Fm) in the Draugen field area and on the Frøya High. Sediments correlated with the Viking Gp have been found by shallow drilling and seafloor sampling in the eastern part of the Trøndelag Platform.

The thickness of the Viking Gp in the type well (6506/12-4) is 124.5m and 61m in the reference well (6407/9-1). Thicknesses up to 1000m are indicated on seismic data in down-faulted basins, and well 6507/7-1 on the Dønna Terrace drilled 658m sediments of the Viking Gp.

The Melke Formation (Bajocian to Oxfordian) is deposited in an open marine environment over most of Haltenbanken, but contains local sands in parts of the Dønna Terrace, the Revfallet Fault Complex and over the southern part of the Rødøy High. In the type well (6506/12-4), the thickness is 116.5m, but thicknesses in the order of 550m have been drilled in the area west of the Nordland Ridge.

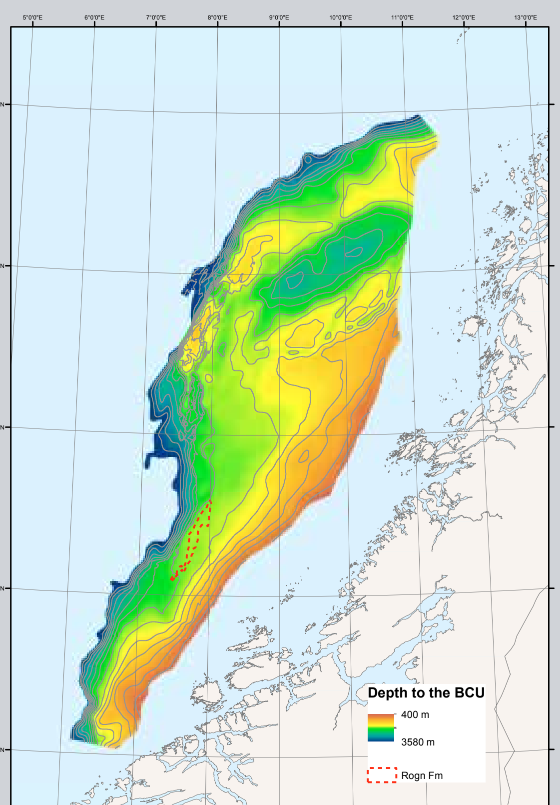
The Rogn Formation (Oxfordian to Kimmeridgian) sandstones occur within mudstones of the Spekk Fm in the Draugen field, the western part of the Froan Basin. A similar development is found on the Frøya High (well 6306/6-1). The sandstones of the Rogn Fm are interpreted as shallow marine bar deposits.

In the type well (6407/9-1), the thickness of the Rogn Fm is 49m and in the reference well (6306/6-1) the thickness is 93m.

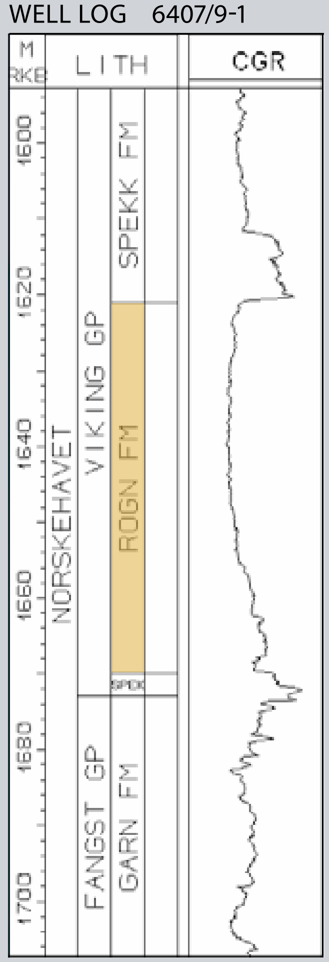
The burial depth of the sandstones of the Rogn Fm is around 1600-1700m in the Draugen field, and porosities in the order of 30% and permeabilities up to 6 darcy have been reported.

The Spekk Formation (Oxfordian-Berriasian) overlies the Melke Fm. The Spekk Fm was probably deposited over most of the Haltenbanken and Trænabanken area, but may be absent over structural highs such as the Nordland Ridge. The mudstones were deposited in marine anoxic water conditions, resulting in high organic content comparable with the time equivalent Draupne Fm in the northern North Sea, thus forming a major hydrocarbon source rock.

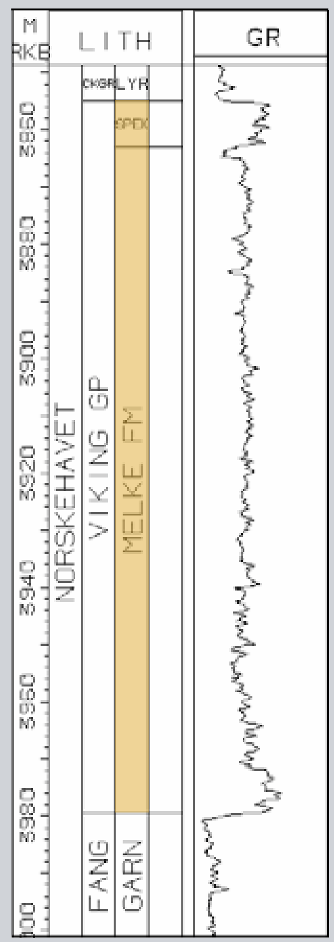
In the type well (6407/2-1), the thickness of the Spekk Fm is 65.5m, but thicker sections may be present in structural lows as on the Dønna Terrace. Black mudstones of similar age, also with high organic content, have been found in shallow boreholes off the coast of Trøndelag.



WELL LOG 6407/9-1



WELL LOG 6506/12-4



6407/9-1 ROGN 1651.0 - 1656.8 m

6306/10-1 MELKE 2747.0 - 2752.0 m

The Cromer Knoll and Shetland Groups

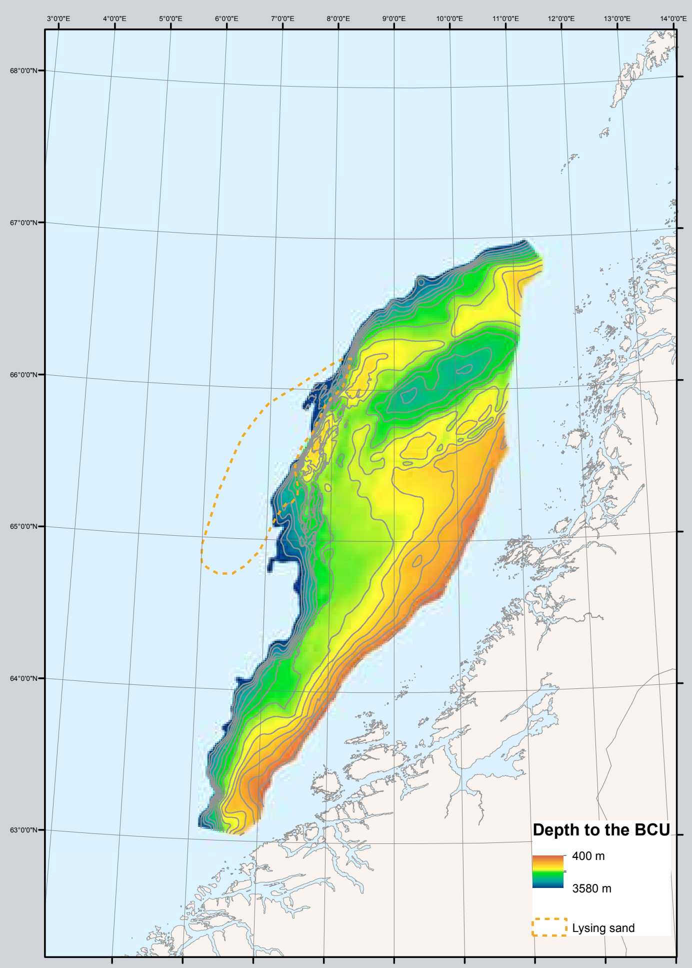
Upper Cretaceous
(Turonian to Maastrichtian)

The Cretaceous sediments in the Norwegian Sea are dominated by mudstones and siltstones, which form good seals. In the Halten and Dønna Terrace, certain intervals including the Lower Cretaceous Lange Formation and the Turonian-Coniacian Lysing Formation, contain locally developed sandstone units. In the northern part of the Vøring Basin, north of 67°N, the Nise Formation contains a thick succession of sandstones deposited as mass flows in a deep marine environment. The Santonian - Campanian sandstones of the Nise Formation were sourced from Greenland and shale out towards the south and east. Some methane gas discoveries have been made in the Nise Fm sandstones. Although these sandstones have quite good reservoir properties and a large volume, their CO2 storage potential was not evaluated, due to their remote location, and because they are located within a petroleum province. The Lange Fm, dominantly consisting of claystones, contains several local sandstone bodies which could act as thief sands. They are buried too deeply and have too small volumes to have any CO_2 storage potential.

Maastrichtian sandstones within the Springar Formation occur locally in the deep water areas. Their small volumes and poor reservoir properties make them unattractive for CO_2 storage.

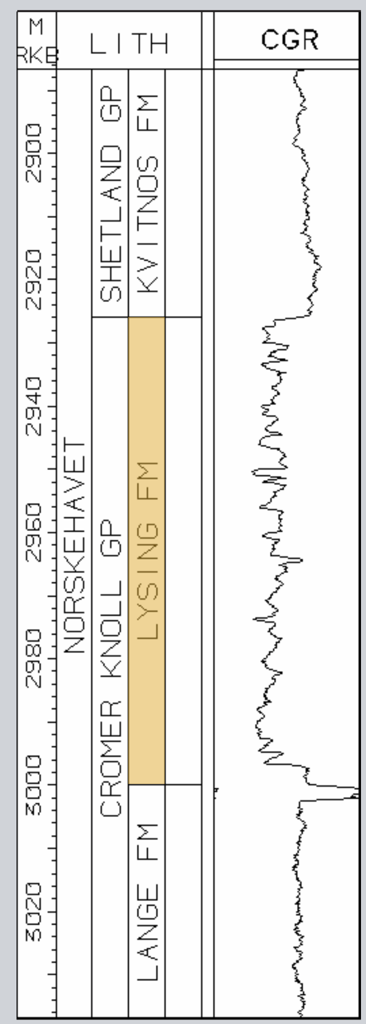
The Lysing Formation (Upper Cenomanian to Turonian/Coniacian)
The Lysing Fm forms the upper part of the Cromer Knoll Group, which consists of the Lyr, Lange and Lysing Formations. In the type well (6507/7-1), on the Halten Terrace west of the Nordland Ridge, the thickness of the Lysing Fm is 74m. In the Dønna Terrace area, sandstones within the Lysing Formation form a reservoir section with a thickness up to about 70 m. The Lysing Fm sandstones in the Dønna Terrace were probably deposited as submarine fans in a deep marine environment. Their source area is believed to be the Nordland Ridge and the highs further north. A few methane gas discoveries have been made in the Lysing Fm sands west of the Skarv Field.

Although the Lysing Fm sands have a significant aquifer volume, it was decided to exclude this formation from a further evaluation of its storage potential. The main reason is that the aquifer is overpressured in the main depositional area in the Dønna Terrace, leaving a small pressure window for CO_2 injection before the fracture gradient is reached. Also, it is located in a zone of petroleum exploration and future production, where conflicts of interest with CO_2 injection projects could occur.

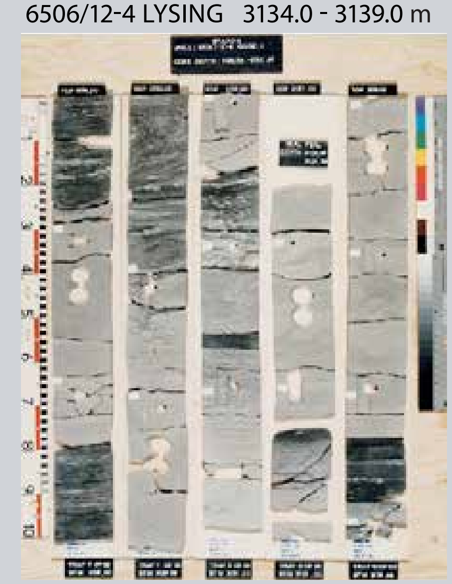


Outline of the Lysing Formation and Base Cretaceous depth map.

WELL LOG 6507/7-1



6506/12-4 LYSING 3134.0 - 3139.0 m



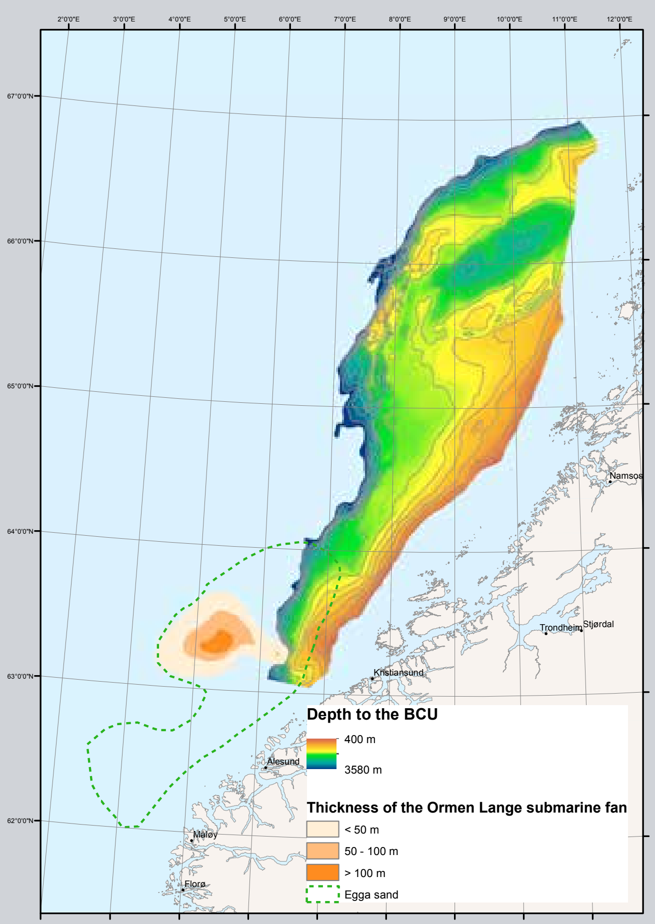
The Rogaland Group

Paleocene
(Danian)

The Late Cretaceous deposits in the Norwegian Sea were dominated by fine-grained sediments, and the source areas for sands were located to the north and west. In the Paleocene, the transport of sediments from Greenland to the Vøring Basin continued, but there was also significant sediment supply from Scandinavia to the Trøndelag Platform and Møre Basin. The main reservoir sand from the Paleocene-Eocene period is the Danian Egga sandstone.

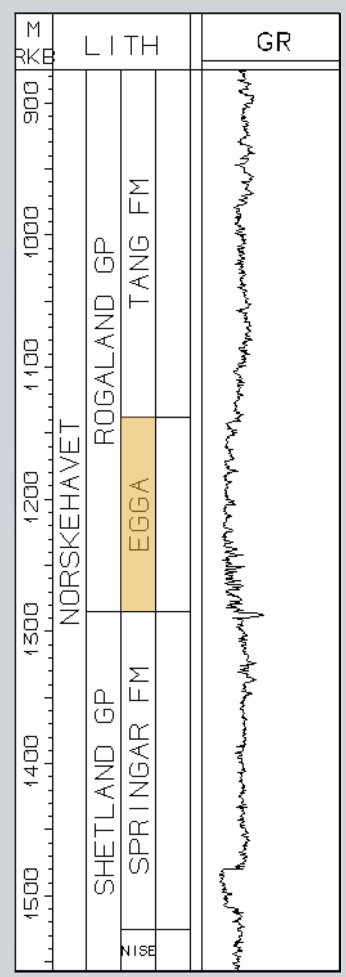
The Egga sandstone (Danian)
This Danian sandstone forms the main reservoir of the giant Ormen Lange gas field. At present, there is no type well or reference well defined. The sandstone has so far no formal stratigraphic formation name, but it has been referred to informally as the Egga formation on the NPD website. At the Ormen Lange field it is defined as a deep marine mass flow sandstone unit within the Rogaland Gp. In the field, a maximum thickness of 80m was found in well 6305/7-1. The Egga sandstones are found in several exploration wells in the Møre Basin and Slørebotn Sub-basin. The reservoir quality and thickness vary considerably depending on where the well is positioned in the different submarine fan systems. The Ormen Lange fan is possibly the largest submarine fan within the Egga sandstone, and the map below shows a thickness map of this fan along with the approximate outline of the sand system.

The shallow eastern part of the Møre Basin has a monoclinal structure where all sedimentary beds dip from the coast into the basin. Any structural closures are likely to be small. Consequently, an injection site for large volumes of CO_2 would probably need to have a stratigraphic component to the structure. Possibly the Egga sandstone aquifer could be used for injection of small volumes of CO_2, which could be residually trapped before they migrate to the sea floor. Such a case has been modelled for a Jurassic aquifer in the Froan Basin in section 5.2. This case has not been evaluated for the Møre Basin.

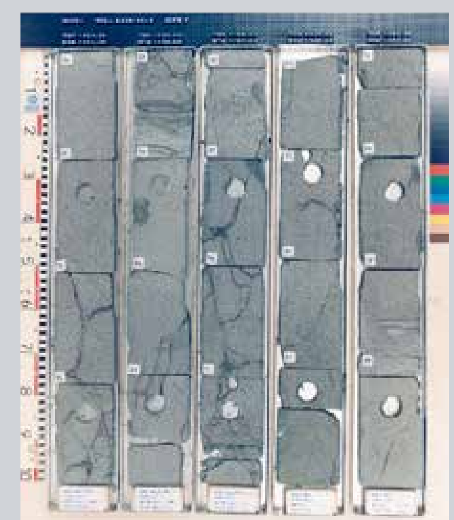


Base Cretaceous map and outline of the Egga formation. Distribution and thickness of the Ormen Lange submarine fan.

WELL LOG 6306/10-1



6306/10-1 EGGA 1164.0 - 1169.0 m



5. 2 Storage options in the Norwegian Sea

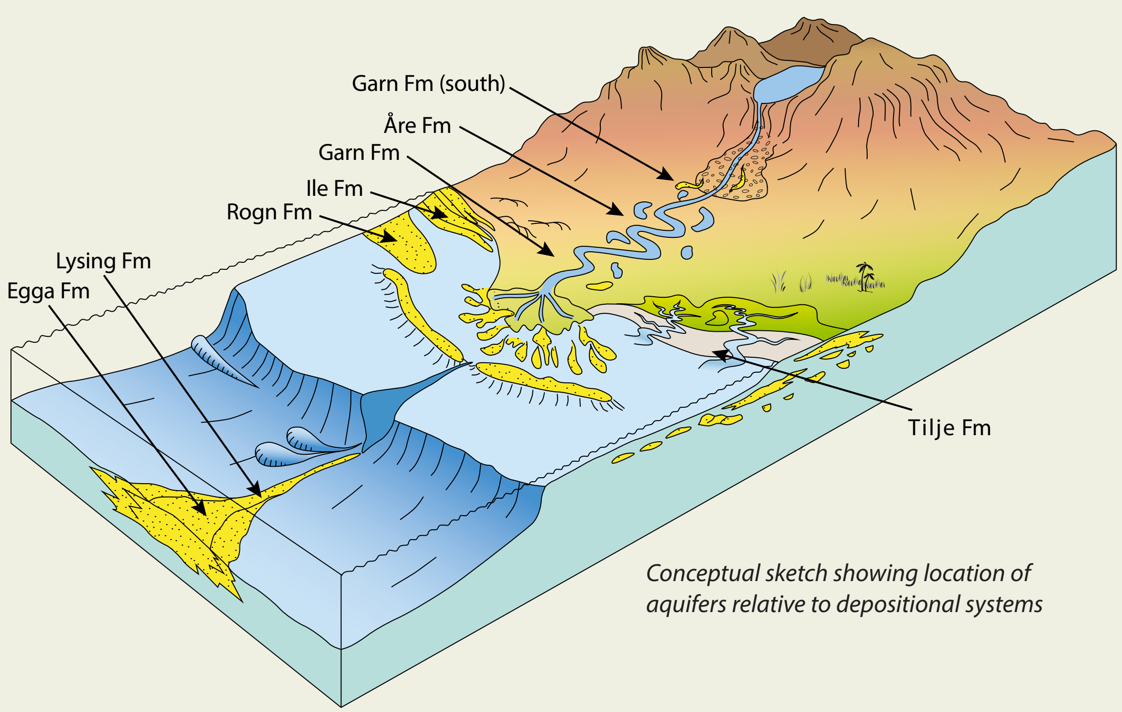
In the Norwegian Sea, the general conditions are met in the Trøndelag Platform including the Nordland Ridge and in the Møre Basin. Potential CO_2 storage in the shelf slope and deep sea provinces of the Norwegian Sea has not been evaluated (Cretaceous formations, section 4).

The aquifers in the Trøndelag Platform have been studied by compilation of published maps, new seismic mapping, well studies and well correlation. The Draugen area and the Nordland Ridge have good data coverage with 3D seismic and several wells, while the remaining area has 2D seismic data and a few exploration wells.

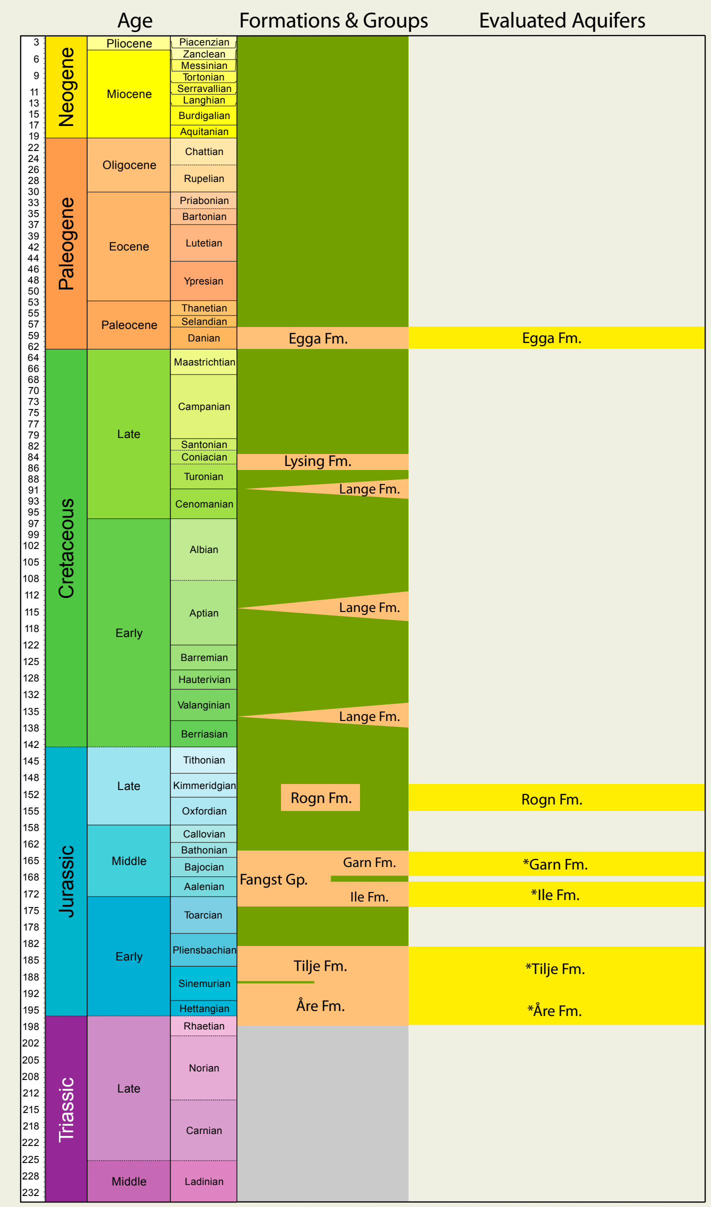
As described in section 4, the Jurassic succession in the Norwegian Sea Shelf is thick and contains several aquifers with storage potential for CO_2. The Halten and Dønna Terraces are important petroleum provinces. The hydrocarbons in these provinces are believed to be generated from Jurassic source rocks, mainly from the Spekk and Åre Formations. In the Trøndelag Platform, the Jurassic source rocks have not been buried deep enough to reach the oil and gas maturation window, and the hydrocarbons occurring here have migrated from the deeper basins and terraces. The approximate limit for hydrocarbon generation and migration is indicated by the red line (page 94). Some oil and gas may have been generated in the deepest part of the Helgeland Basin, although so far there has been no exploration success in this area.

In the petroleum provinces (west of the red line), exploration and production activities are expected to continue for many years to come. The most realistic sites for CO_2 storage in the petroleum provinces will be some of the abandoned fields. Consequently, an indication of the storage capacity of the fields has been given, but no aquifer volumes have been calculated for this area. Some of the oil fields are considered to have a potential for enhanced oil recovery (EOR) by use of CO_2 (section 8). A certain amount of the CO_2 used for EOR will remain trapped.

In the eastern area, all the large aquifers have been selected based on the established criteria (section 3.3), and storage capacity is estimated by the method described in section 3.4.



Conceptual sketch showing location of aquifers relative to depositional systems



* Evaluated prospects

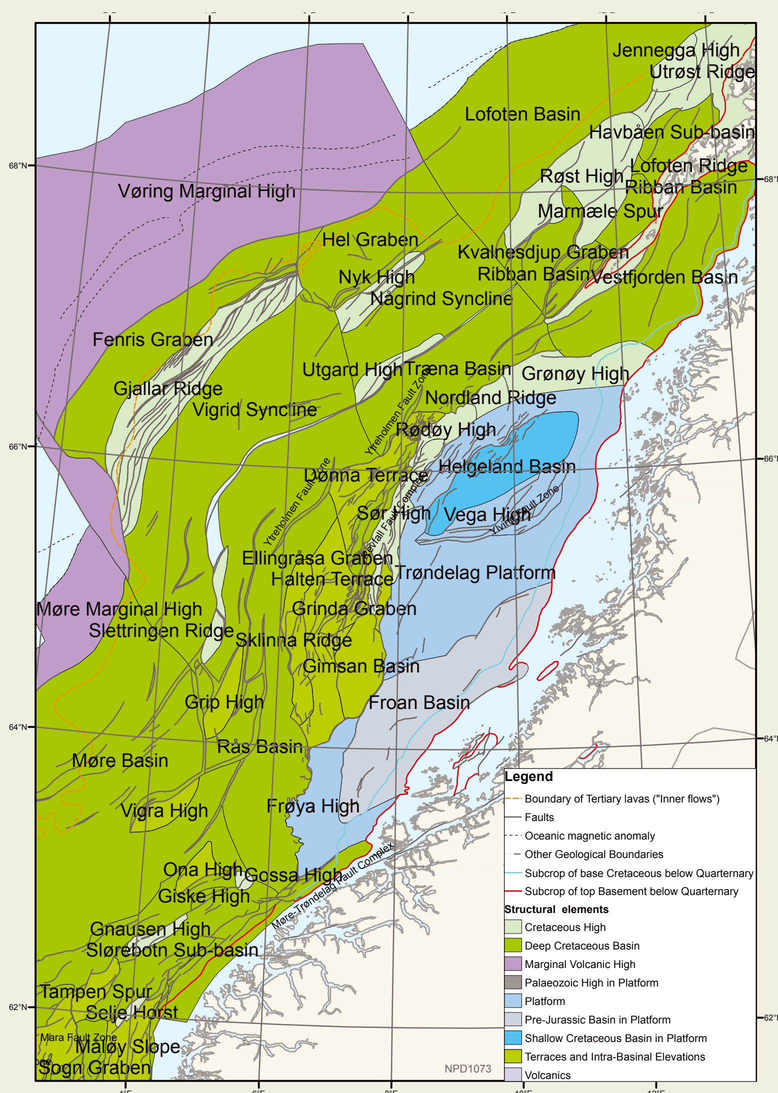
5.2.1 Saline aquifers

Froan and Helgeland Basins

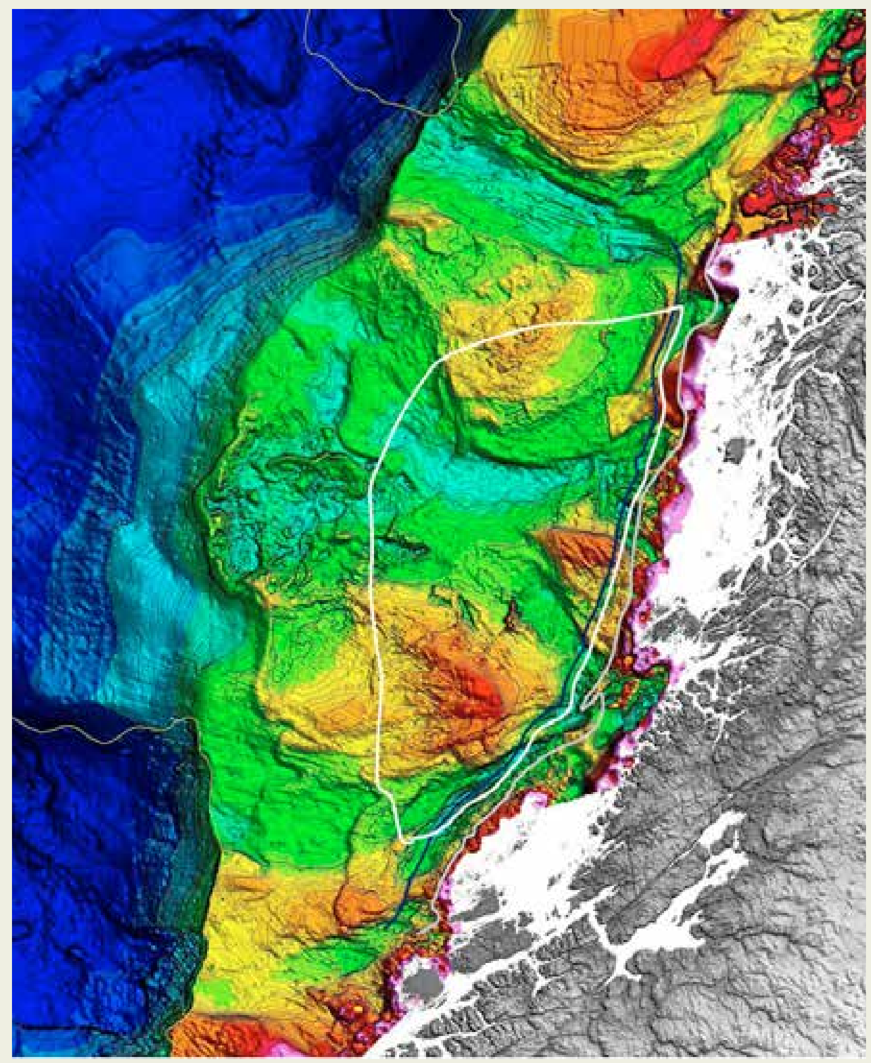
The evaluated Jurassic aquifers are located at the Trøndelag Platform, east of the Cretaceous basins which have a green colour in the structural element map. The aquifers are bounded by the subcrop to the Quaternary along the coast to the east, by the Nordland Ridge to the NW and north, and the Frøya High to the SW. The shallow Jurassic aquifers are separated from the Gimsan Basin by large faults and steep slopes. The pore pressure regimes show a general trend transition from high overpressure in the Halten Terrace in the west to hydrostatic pressure towards the Trøndelag Platform in the east. This indicates pressure equilibration across the faulted boundary in geological time. In the Helgeland and Froan Basins, all pore pressures are hydrostatic.

The Åre and Tilje Formations are treated as one aquifer at a regional scale due to the lack of regional sealing shales in the stratigraphy. Both these formations are heterogeneous, with coal beds and shale beds separating channelized sandstones. Internal baffles and barriers at a km scale should be expected, both within the Åre Formation and possibly between Åre and Tilje. Consequently, there is a risk of significant internal barriers within the aquifer and that the communicating volumes may be less than predicted. In the case of low connectivity, a higher number of injection wells than anticipated would be necessary to realize the desired injection volume of CO_2.

The Ror Formation is assumed to form a regional seal between the Tilje and Ile formations. The formation often forms a pressure barrier in the fields in the Halten Terrace, and tight shales have been proved in the Ror Fm in wells drilled in the Trøndelag Platform. Laterally, the seal might be broken by large faults.



Structural element map. The green area represents basins with thick Cretaceous infill, where Jurassic sediments are generally deeply buried.



Bathymetry map with outlines of the main study area and subcrop lines of Base Cretaceous and the basement. Bathymetry from the Geological Survey of Norway (NGU). Storegga slide to the SW.

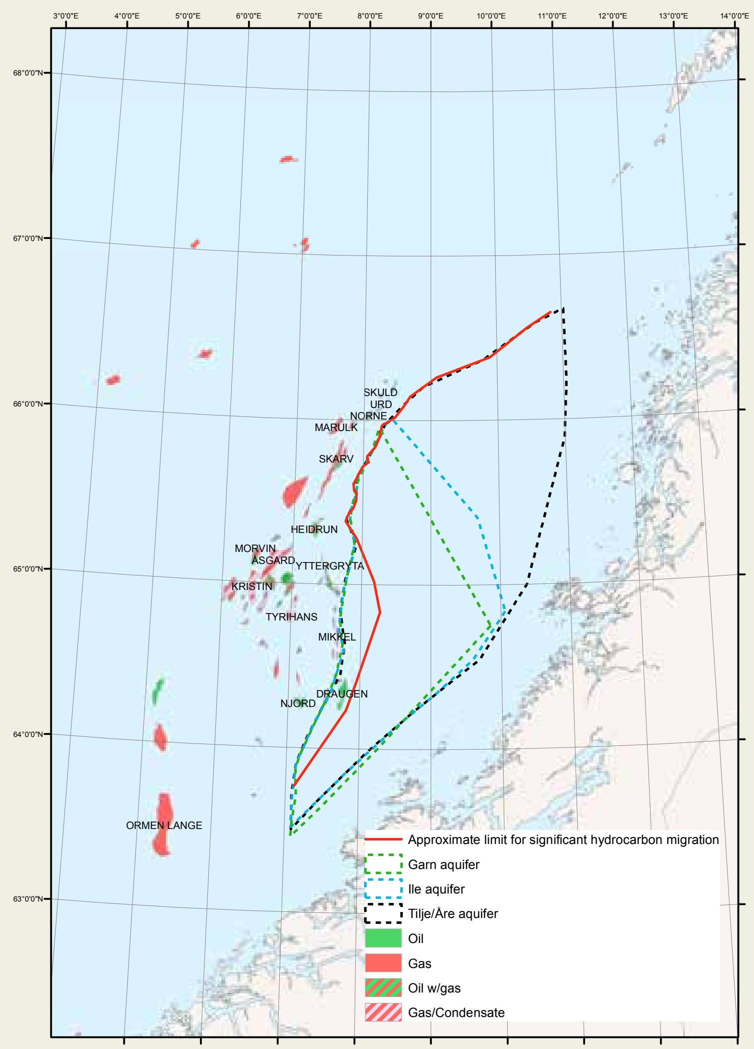
5. 2 Storage options in the Norwegian Sea

5.2.1 Saline aquifers

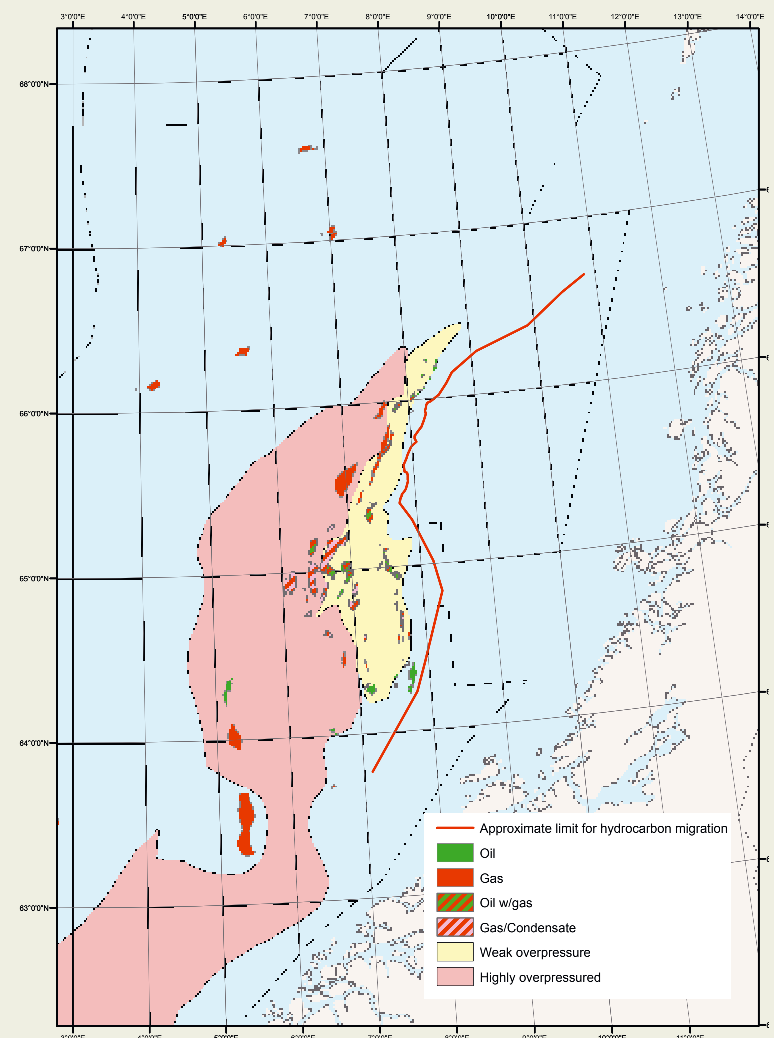
The Not Formation is developed as shale in the Trøndelag Platform, and the seismic data indicate a regional distribution. Consequently, it might be expected that the Not Formation will act as a barrier between the Ile and Garn Formations. In the modelling, however, Ile and Garn Formations have been grouped as one aquifer. This simplification was made because of the small volume of the Ile Fm and the existence of faults which could offset the Not Formation and juxtapose Ile with Garn.

The Ile and Garn Formations have very good reservoir properties at the shallow depths encountered in the Trøndelag Platform. The porosity and permeability used in the geomodel are based on the well log data and a few core measurements. The Garn Formation in the Froan Basin is dominated by shallow marine sediments where much better connectivity can be expected than in the tidal-dominated Ile and Tilje Formations. The Ile and Garn formations become more shale-rich towards the Helgeland Basin.

The Rogn Formation in the Draugen area has very good reservoir properties. It is separated from the Garn Formation by shales within the Spekk Formation with variable thickness. It is likely that there will be communication between the Rogn and Garn reservoirs. The Spekk, Melke and Cretaceous shales above the Garn Formation constitute an excellent top seal for the Jurassic aquifers.



Distribution of aquifers in the Trøndelag Platform. Red line shows the approximate limit for hydrocarbon migration



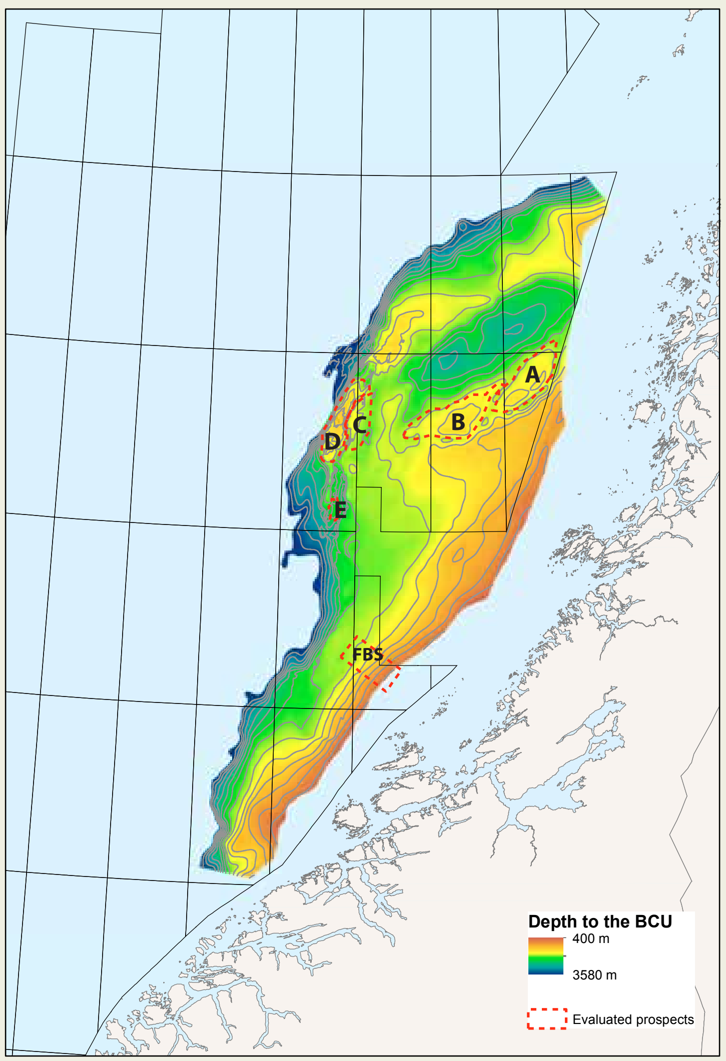
Hydrocarbon accumulations and pore pressure regimes in the Jurassic aquifers

5.2.1 Saline aquifers

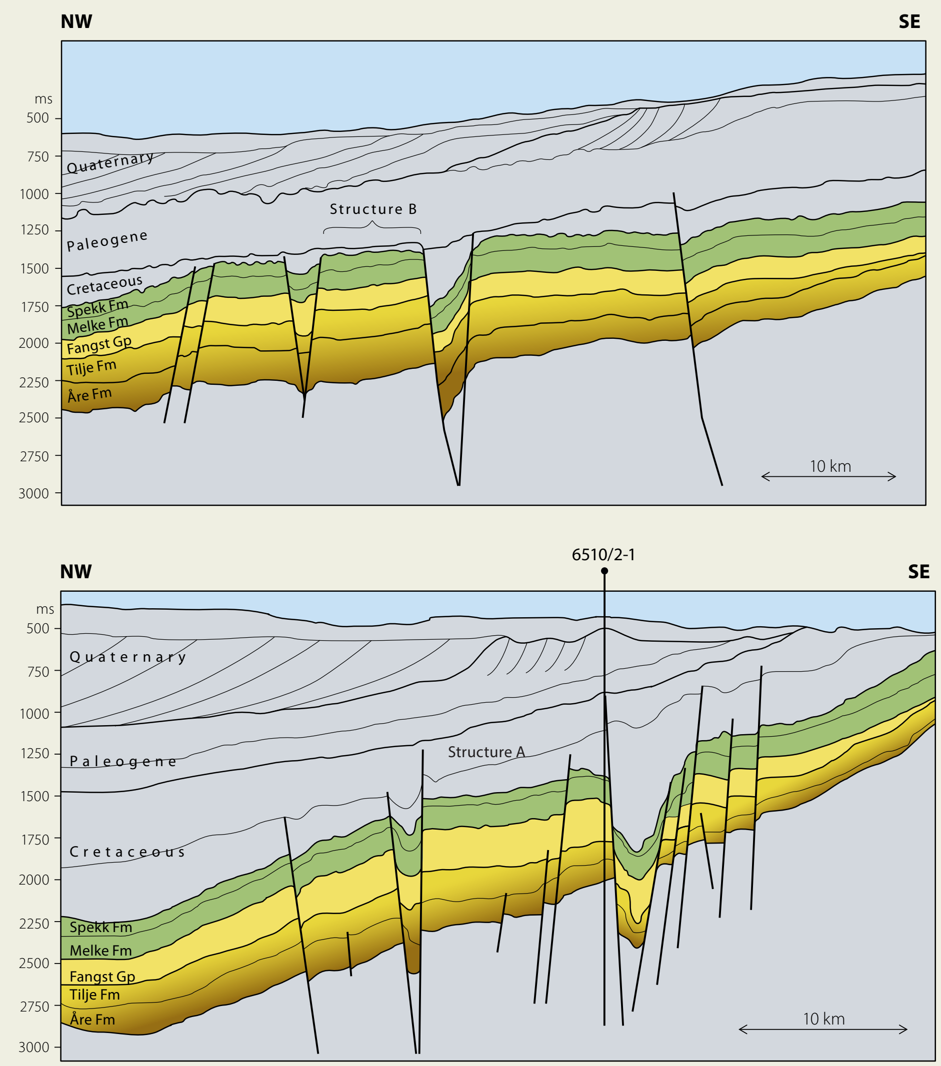
Compartmentalization

The northern part of the Trøndelag Platform and the Sør High of the Nordland Ridge are characterized by large graben features such as the Ylvingen Fault Zone and the Ellingråsa Graben. These grabens were probably formed by extension and collapse in the late Jurassic and early Cretaceous. Their size and depth suggest that they could be barriers to fluid flow in the Jurassic aquifers.

In the geomodel, the Ellingråsa Graben is treated as the western boundary of the Jurassic aquifers in the Trøndelag Platform. The Ylvingen Fault Zone could possibly seal off the northern from the southern part of the Åre-Tilje aquifer. Towards the north, in the Grønøy High, the aquifers are truncated by erosion. In the modelling of CO_2 injection, the lateral boundaries towards fault structures in the south, west and north are assumed to be closed. Towards the east, aquifers in the Froan Basin terminate at the base of Quaternary sediments below the sea floor. The sealing capacity of the Quaternary sediments along the eastern subcrop is probably low. As shown in the map, the topography of the sea floor is rugged, with basins and ridges carved out by glacial erosion. Comparison with seismic data indicates that the Quaternary cover can be several tens of metres thick in the basins, but much thinner in the slopes. The shallow well 6408/12-U-1 in the Froan Basin has only 6 m Quaternary cover. Most likely, there will be pressure communication between the Jurassic aquifers and the sea water along the subcrop line.



Regional BCU map showing the locations of prospects A to E and the location of the simulation grid in the Froan Basin (FBS). The map to the left is zoomed in on structures C, D and E.



NW – SE profiles across the SE flank of the Helgeland Basin. The closed structures A and B are indicated. The location is shown in p. 44.

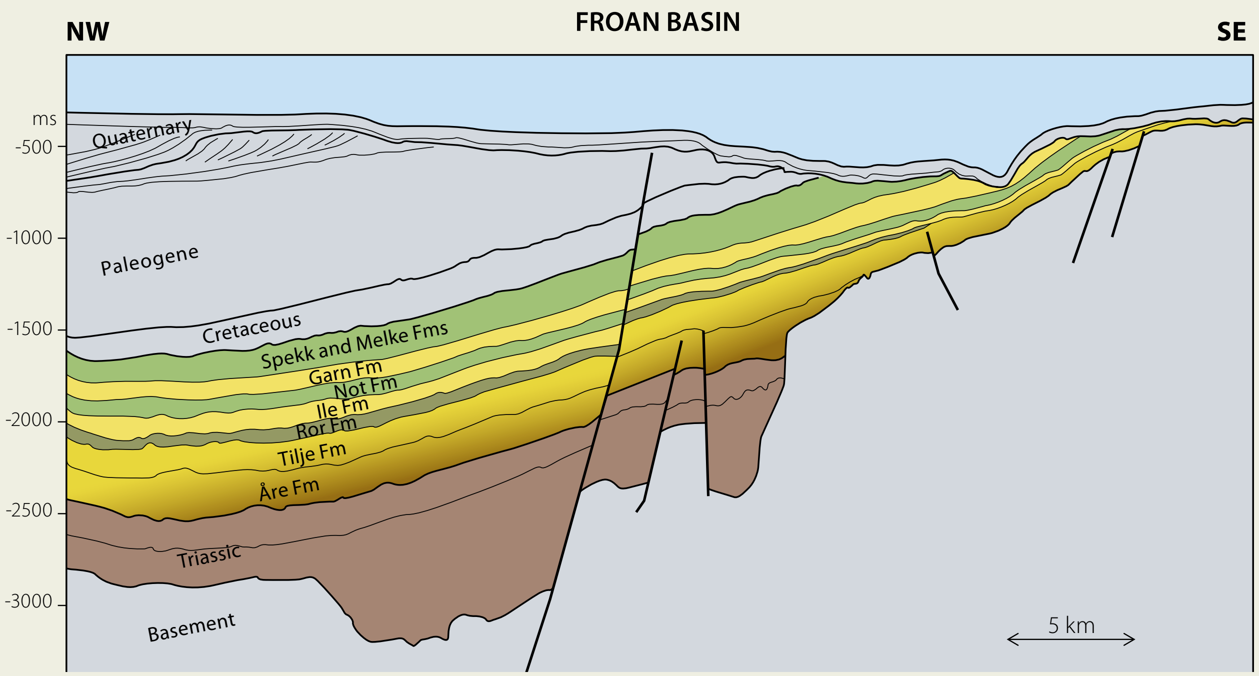
Froan Basin – long distance CO_2 migration

Modeling of CO_2 injection and migration in the Froan Basin

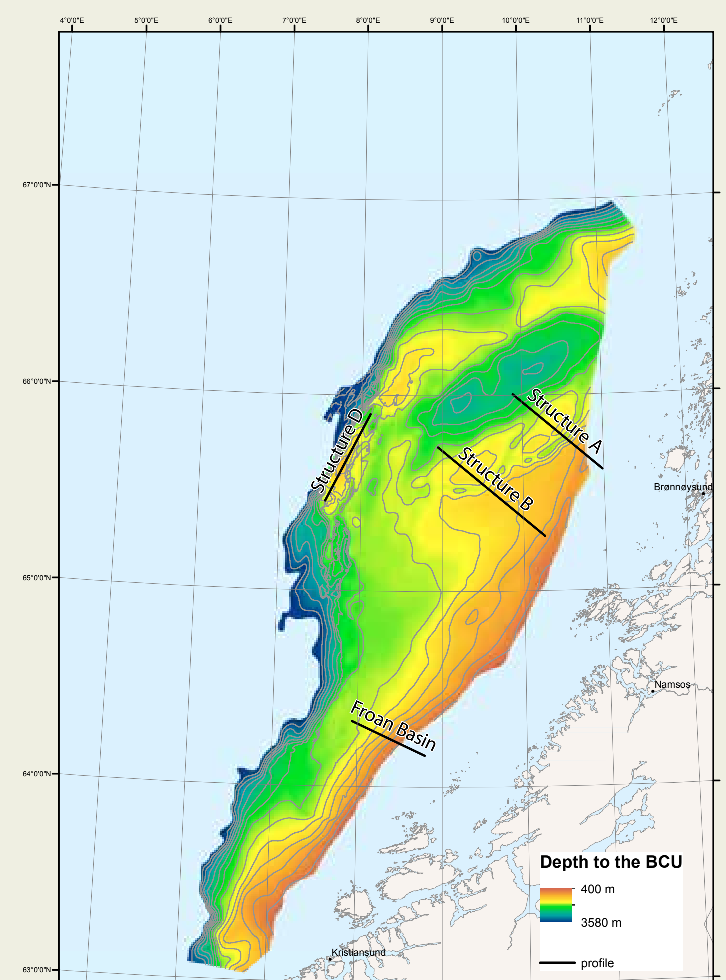
The aquifers in the southeastern part of the Norwegian Sea typically have a consistent dip of 1-2 degrees from the Norwegian coast to the basinal areas. In the case of permeable beds occurring along the dip slope, there is a risk that CO_2 injected down dip can migrate upwards where the aquifer is truncated by Quaternary glacial sediments. At that depth, CO_2 will be in gas phase. The glacial sediments mainly consist of clay and tills, and their thickness ranges from about 10 m to more than 200 m. Understanding the timing and extent of long distance CO_2 migration is of importance for evaluation of the storage capacity of outcropping aquifers. Consequently, a modelling study has been conducted on possible aquifers in the Froan Basin.

The Froan Basin is a sub-element of the Trøndelag Platform. It is bound by the Frøya High in the south, the Gimsan Basin and the Halten Terrace in the west, an outcropping basement in the east and the Trøndelag Platform in the north. The Froan Basin was formed by Permian-Early Triassic block faulting. The pre-Jurassic rocks of the Trøndelag Platform were deposited in the NE-SW trending echelon basins. In the early and middle Jurassic, the platform area subsided as one large basin, and the rate of sedimentation was in equilibrium with the rate of subsidence. Consequently, there is a relatively uniform thickness of Jurassic sediments overlying the Triassic and locally the Paleozoic graben infill. Reservoirs which could possibly be used for CO_2 injection are the Triassic and Jurassic sandstones. The main seal rocks are the middle to upper Jurassic Melke Fm and Spekk Fm shales as well as the overlying fine grained Cretaceous section. The main risk of leakage is the migration of CO_2 towards the Quaternary layer.

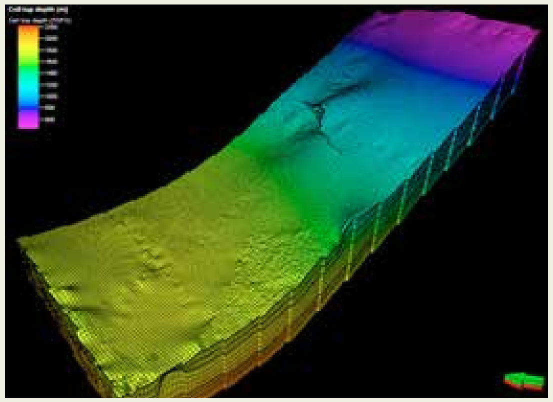
Based on simulation results (upscaling of sector model), about 400 mill tons CO_2 can be stored in the Garn and Ile aquifer (8 mill tons/year over 50 years). This will require 4 injection wells (2 mill tons/year per well) and yield an acceptable pressure increase (<20bar). After 10,000 years most of the gas will have gone into solution with the formation water or will be residually trapped.



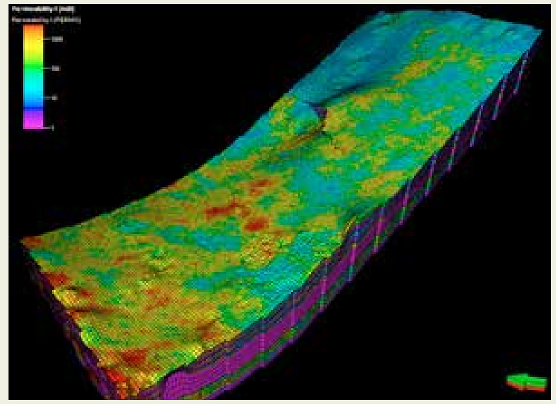
NW-SE profile showing the geometry of aquifers (yellow) and sealing formations (green) in the simulation model.



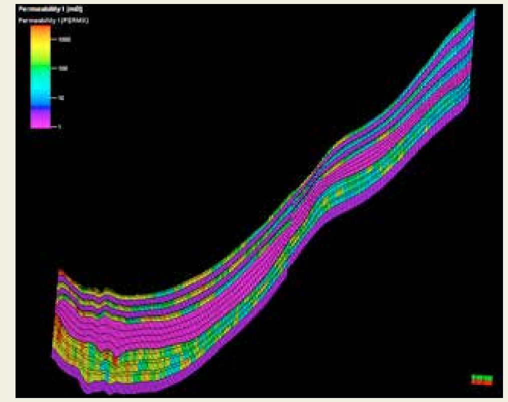
Froan Basin – long distance CO_2 migration



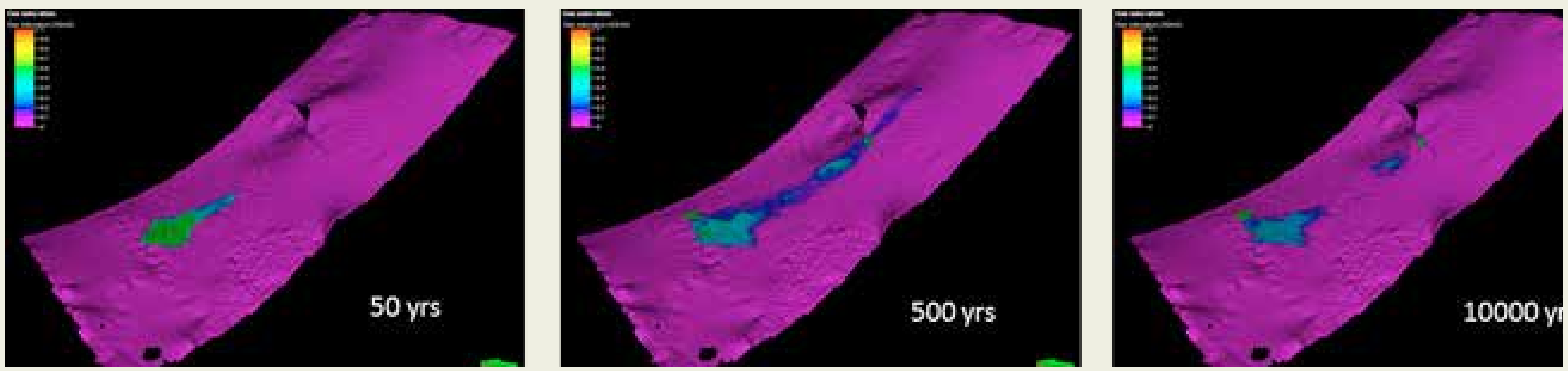
Simulation sector model, depths



Permeability distribution, top Garn



Permeability distribution, west-east cross section



CO_2 plume top Garn vs. time. The size of the model is 16 x 35 km.

A simulation sector model of the Garn, Not and Ile Formations was built covering about 10% of the total expected communicating aquifer volume. The top structure (Garn Fm) depth is about 1800 m in the western area and becomes shallower towards the east, with model cut-off at about 500 m depth. The main storage reservoirs are the Garn and Ile Formations with an average permeability of about 400 mD, separated by tight shales within the Not Formation. The Garn Formation consists of three reservoirs, separated by low permeable shale. The porosity and permeability have been stochastically modelled with both areal and vertical variation. The model layers are fine (<1m) at the top reservoir and underneath the shales to capture the vertical CO_2 saturation distribution.

The CO_2 injection well is located down dip, but alternative locations and injection zones have been simulated, with different injection rates. The injection period is 50 years, and the simulation continues for 10,000 years to verify the long term CO_2 migration effects.

The main criteria for evaluation of CO_2 storage volumes are the acceptable pressure increase and confinement of CO_2 migration (no migration to eastern model boundary within 10,000 years). CO_2 will continue to migrate upwards as long as it is in a free movable state. Migration stops when CO_2 is permanently bound or trapped, by going into solution with the formation water or by being residually or structurally trapped (mineralogical trapping has not been considered). The trapping achievement of sufficient volumes is depending on a good spreading of the injected CO_2. Vertical spreading can to some extent be controlled by injecting into lower reservoir zones, but it is sensitive to vertical permeability and also zonal permeability distribution in the area near the well. Areal spreading can mainly be achieved through use of several injectors.

The figures in the second row illustrate the free CO_2 saturation (green/blue) over 10,000 years.

Lower Jurassic interbedded sandstones, siltstones and shales belonging to the Neill Klinter Group at Constable Pynt, Jameson Land, East Greenland. The section is about 300 m high. These formations are time equivalent to parts of the Tilje, Tofte, Ror and Ile Formations in the Norwegian Sea, and the depositional environment is similar. Photo: NPD.

5.2.1 Saline aquifers

The Nordland Ridge aquifer

The Nordland Ridge has three large culminations, the Sør High, the Rødøy High and the Grønøy High. To the west these highs are separated from the petroleum-bearing terraces and basins by large faults. The Sør High is located close to many producing fields, discoveries and prospects. Because some of the gas discoveries, like 6506/6-1 Victoria, have a high CO_2 content, it is of interest to identify possible storage sites close to these discoveries where it might be possible to inject excess CO_2 from future production.

The Sør High is a structural closure with a culmination at 1000 m below sea level and an area exceeding 500 km^2. It is covered by 3D seismic data, and four wells have been drilled. The stratigraphy in the wells is interpreted in the NPD website as a few metres of Fangst Group overlying the Åre Formation. The seismic data show that there is an angular unconformity between the Åre Formation and the thinned Fangst Group. Small amounts of dry methane gas, possibly biogenic, have been encountered. There were no shows indicating heavier hydrocarbons. Due to tilting and block faulting below the unconformity, the Åre Formation has a variable thickness, commonly more than 200 m. The sandstones in the Åre Formation have similar properties as in the Froan Basin. Triassic Grey beds may contribute to the volume of the aquifer.

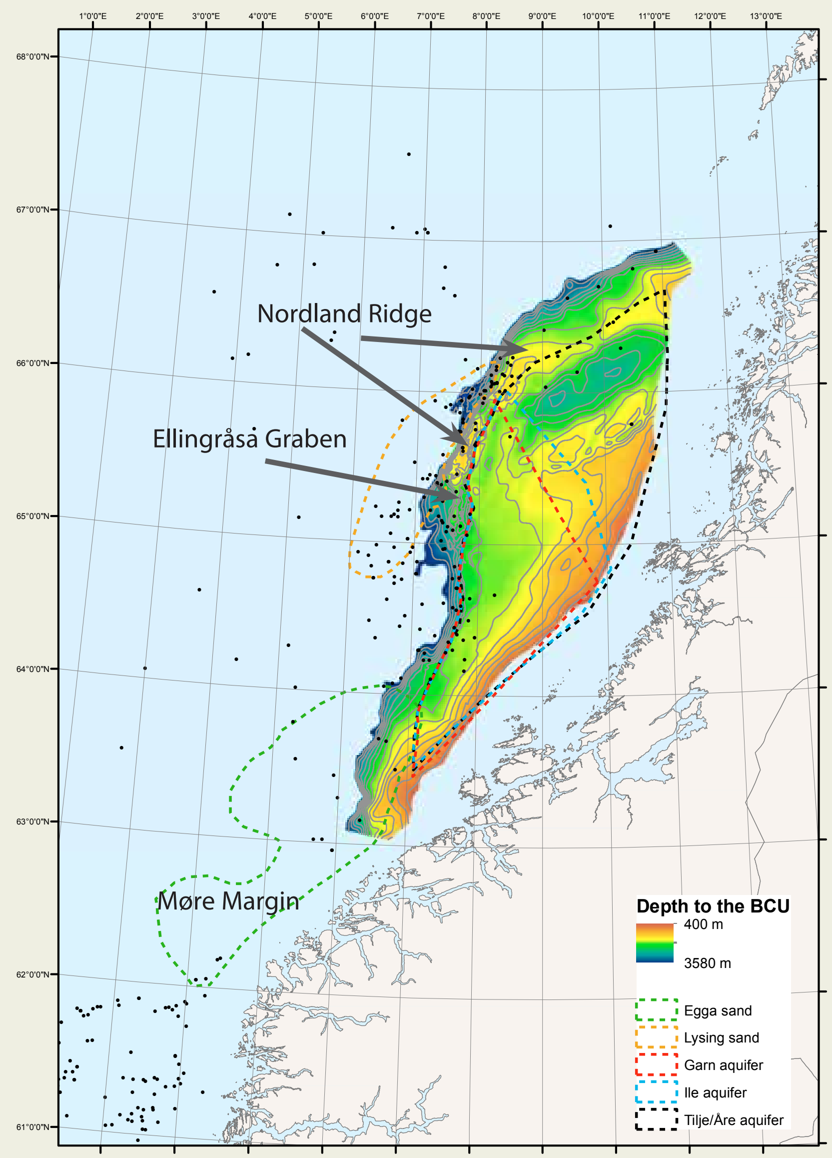
The Åre aquifer will probably have several local internal baffles and barriers. The top seal will be the overlying Quaternary sediments belonging to the Naust Formation, which has a minimum thickness of about 650 m. The sediments in the Naust Formation are unfaulted and consist of silt and clay. The geological setting of this top seal is analogous to the Utsira Formation in the Sleipner area. The small accumulations of methane gas in the Sør High show that the Naust Formation has a sealing capacity. Further maturation of the Sør High as an injection site for CO_2 would require a better quantification of the Naust sealing capacity.

Møre Margin

The Møre Margin south of the Frøya High is separated from the Froan Basin by the Jan Mayen Fracture Zone lineament. Its Mesozoic and Cenozoic geology is very different from the Trøndelag Platform. Along the Møre Margin, a thin Jurassic and thick Cretaceous section dip towards the deep Møre Basin. In this setting of regionally dipping strata, only a few closed structures of small sizes exist. The Jurassic reservoir sands tend to be thin, and no Cretaceous reservoir of interest has so far been proved by drilling. A few exploration wells drilled in the area have proved that gas has migrated into closed structures close to the coast. A possible storage option in the Møre Margin is thought to be the Paleocene submarine fans of the Egga sandstone, which constitute the reservoir of the Ormen Lange Field. This sand was derived from the Møre Paleogene highlands and has not been encountered in the Froan and Helgeland Basins. A limited Jurassic storage potential could exist in a narrow zone close to the coast. Both the Egga sandstone and the Jurassic aquifers subcrop towards a thin Quaternary section below the sea floor. CO_2 migration to the subcrop area and leakage to the sea is the most obvious risk for these aquifers. No closed structures suitable for CO_2 injection have been identified in the Møre Margin.

Ellingråsa Graben

The dry exploration well 6507/12-1 was drilled near the culmination of a large closed structure in the southern part of the Ellingråsa Graben. The well penetrated the Åre-Tilje, Ile and Garn aquifers between 2100 and 2900 m depths below sea level. The structure is within the area of possible hydrocarbon migration. Since this well was dry and no shows were reported, it is very unlikely that hydrocarbons can have migrated further into the Ellingråsa Graben. The 6507/12-1 structure has been assessed as a possible target for CO_2 injection. The storage efficiency depends on communication with the aquifers in the Halten Terrace and the producing Midgard gas field to the west. The calculation of the storage volume within the structure is based on a closure of 200 m and storage in all aquifers with a storage efficiency of 10%. Maturation of this prospect should include an evaluation of the communication with the Halten Terrace, Nordland Ridge and Trøndelag Platform. The 3D seismic data show that the Jurassic aquifers are strongly faulted, with the risk that the reservoir might be divided in many compartments. The faults do not appear to offset the Upper Jurassic and Lower Cretaceous sealing shales.



Simulation model of the The Nordland Ridge Structure D

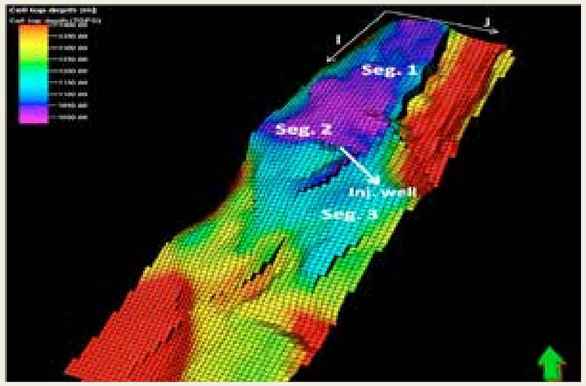
The simulation model of the Nordland Ridge Structure D was built for the purpose of assessing its CO_2 storage potential within the Åre Formation (Rhaetian-Pliensbachian, Lower Jurassic). The modelled Structure D is a closed structure with CO_2 storage potential in two structural domes.

Segment 3 is the deepest dome, and segments 1 and 2 combined represent the shallowest dome. There is a possibility for down flank aquifer communication to areas outside of the model.

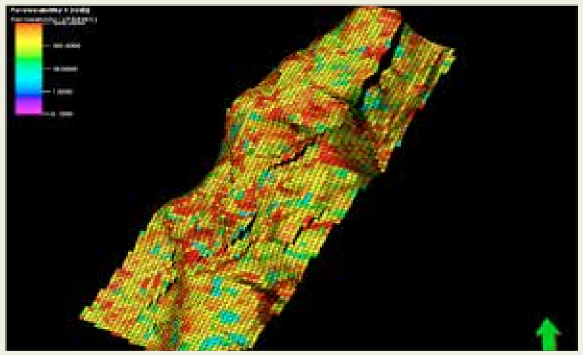
The depth of the top reservoir (Åre Formation) in two main storage domes is between 1000 m and 1150 m.

Generally the thickness of the Åre Fm varies between 300 and 500 m, with a maximum thickness of 780 m in the eastern part of the Halten Terrace (Heidrun area).

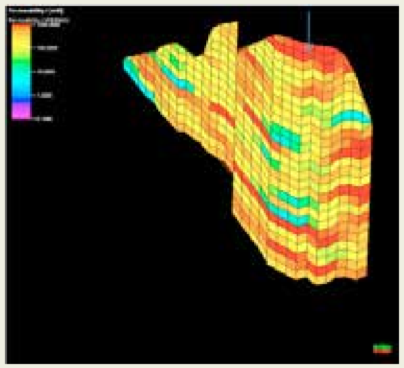
The Åre Formation consists of heterogeneous fluvial deposited sand channels with an uncertain communication. The average sand permeability is about 500 mD. The porosity and permeability have been stochastically modelled with both lateral and vertical variation. The CO_2 injection well is located down dip, at the apex of the two deepest main storage domes (segment 3).



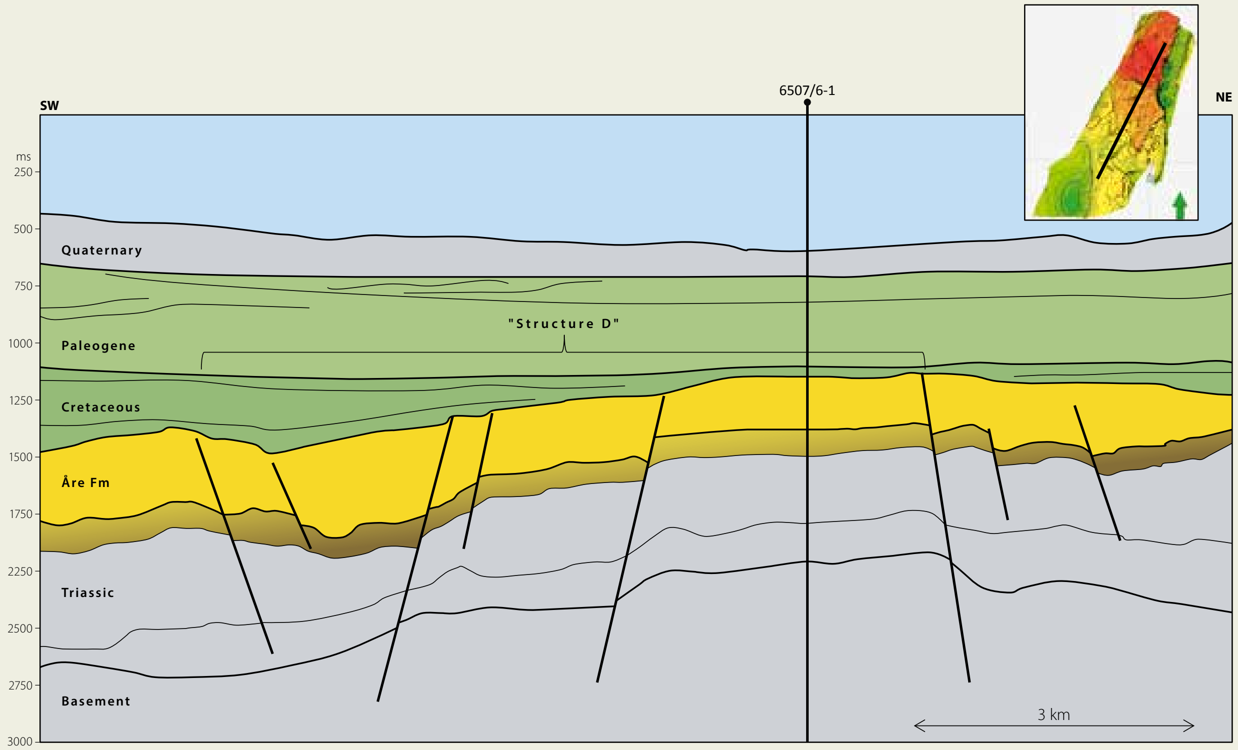
Simulation model depth, top Åre Fm.



Lateral permeability variations.



Vertical permeability variations (x-z, through well).



SW-NE profile showing the geomery of aquifer (yellow) and sealing formations (green) in the simulation model. The location is shown on p.44.

5. 2 Storage options in the Norwegian Sea

5.2.1 Saline aquifers

Different injection rates and volumes have been simulated. The figures above illustrate CO_2 saturation (green/blue) over 50 and 1000 years. The main simulation case injects 2 mill SM^3 CO_2/day (daily rate of 1/5000 of total volume) for 28 years with acceptable pressure increase and CO_2 plume spreading. CO_2 will continue to migrate upwards as long as it is in a free movable state.

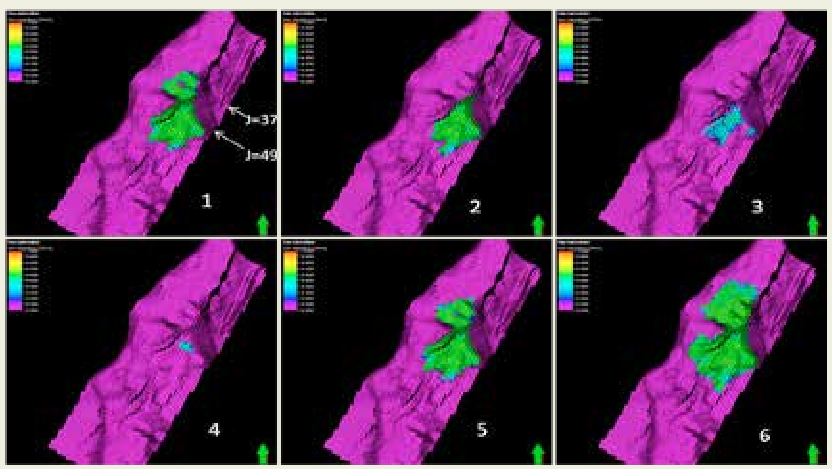
Migration ends when CO_2 is permanently bounded or trapped, by going into solution with the formation water or by being residually trapped (mineralogical trapping has not been considered).

Structural trapping is the main storage mechanism in the simulation model of the Nordland Ridge.

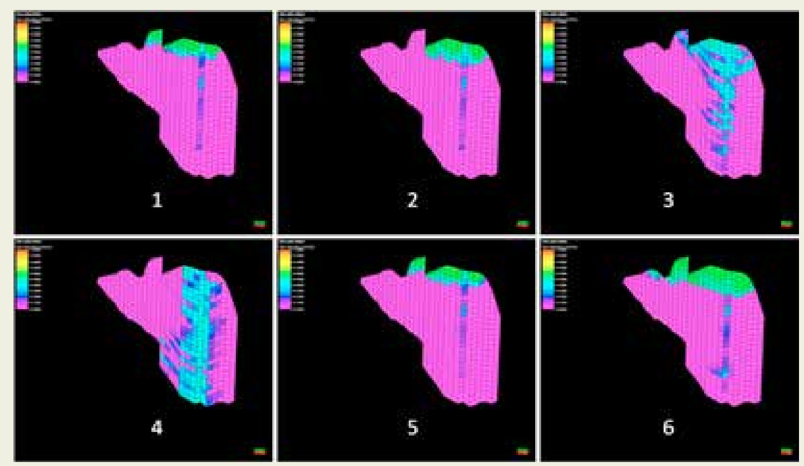
Applying a safety factor of 2 to the acceptable pressure increase, shows that 18.7 Mt of CO_2 can safely be stored in the Nordland Ridge within the Åre Formation.

Simulation Cases:

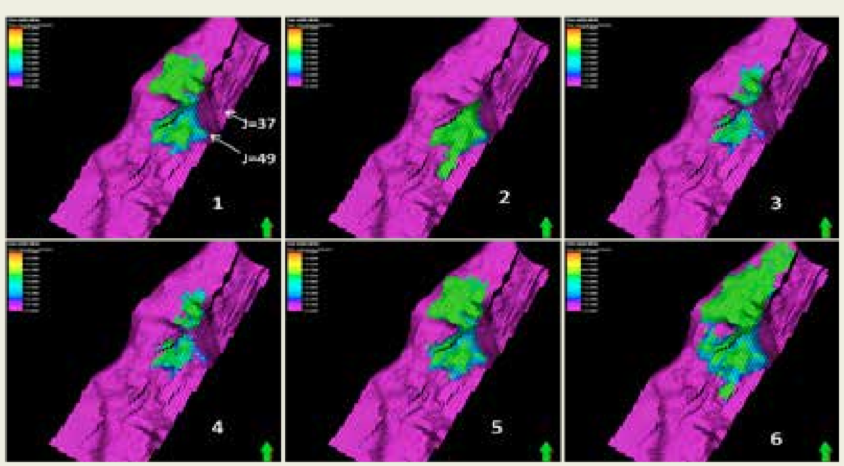
1. Geological model and properties.
2. Zero transmissibility (communication) across modelled faults. Most faults are not extensive and do not fully close off model communication. The degree of communication across faults is uncertain.
3. Zero transmissibility (communication) between model layers. Reflects that well logs show sand/shale sequence in individual model layers, but zero vertical communication is an extreme case, since the sand/shale sequences are not extensive. Vertical communication still goes on through "zig-zag" vertical communication via faults.
4. Combines Case 2 & 3 above.
5. Case with no CO_2 going into solution with water. Not expected to have significant effect when main storage mechanism is structural trapping.
6. Increased model pore volume by multiplying the pore volume of the boundary grid cells. Total model pore volume increases from 27 GSm^3 to 100 GSm^3, reflecting possible communicating pore volume. Injects 2.5 times the rates and volumes of the Case 1.



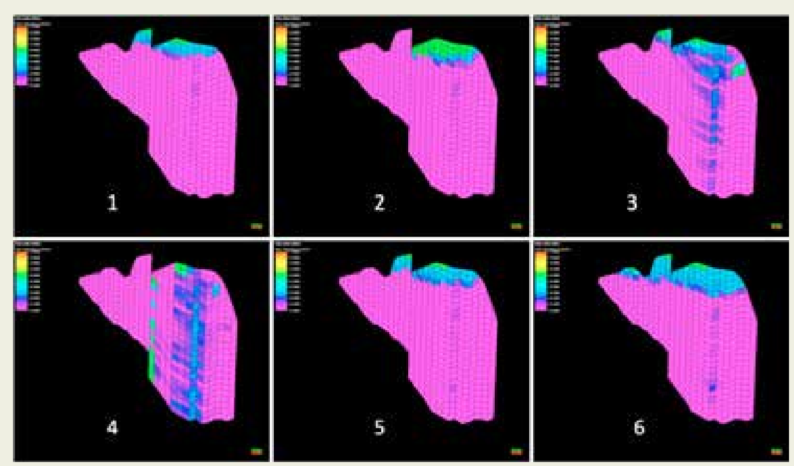
CO_2 plume top reservoir end of injection (50 yrs)



CO_2 plume x-z cross section (J=49) end of injection (50 yrs).



CO_2 plume top reservoir after 1000 yrs.



CO_2 plume x-z cross section (J=49) after 1000 yrs.

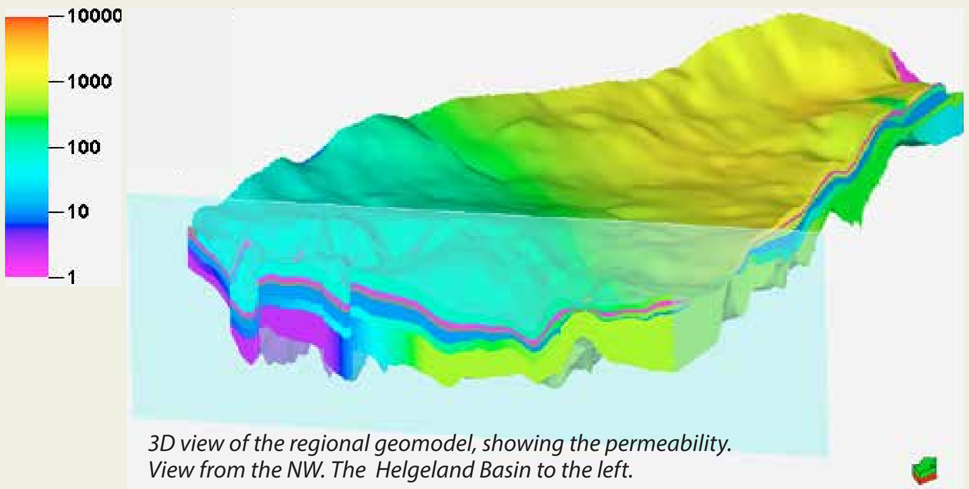
5.2.1 Saline aquifers

Storage capacity Tilje/Åre

In order to estimate the pore volumes and storage capacities of the aquifers, a regional geomodel was built with the Petrel software. The model was set up with a 500x500 m grid in the horizontal directions. In the vertical direction, each formation was represented by one layer. Average values for net/gross and porosity were estimated based on the logs and well reports from exploration wells in the area and manually contoured between the wells. The maps show that the Ile and Garn formations generally become more shale-rich to the NE. The major faults which have a potential to form barriers between different segments of the aquifers, were included in the model.

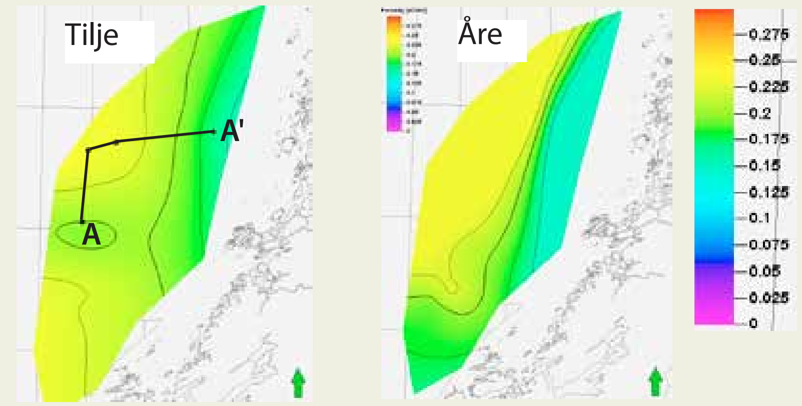
The purpose of this model was to calculate the total pore volumes of each aquifer and to assess how they are connected. Different approaches have been tested to estimate the storage capacity of the aquifers.

Permeability

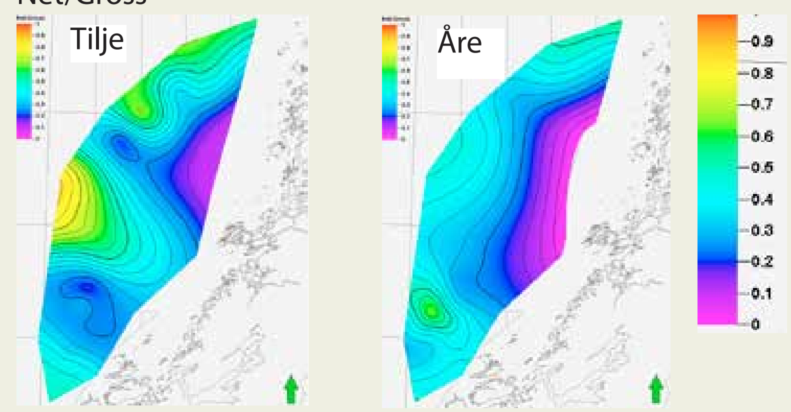


3D view of the regional geomodel, showing the permeability. View from the NW. The Helgeland Basin to the left.

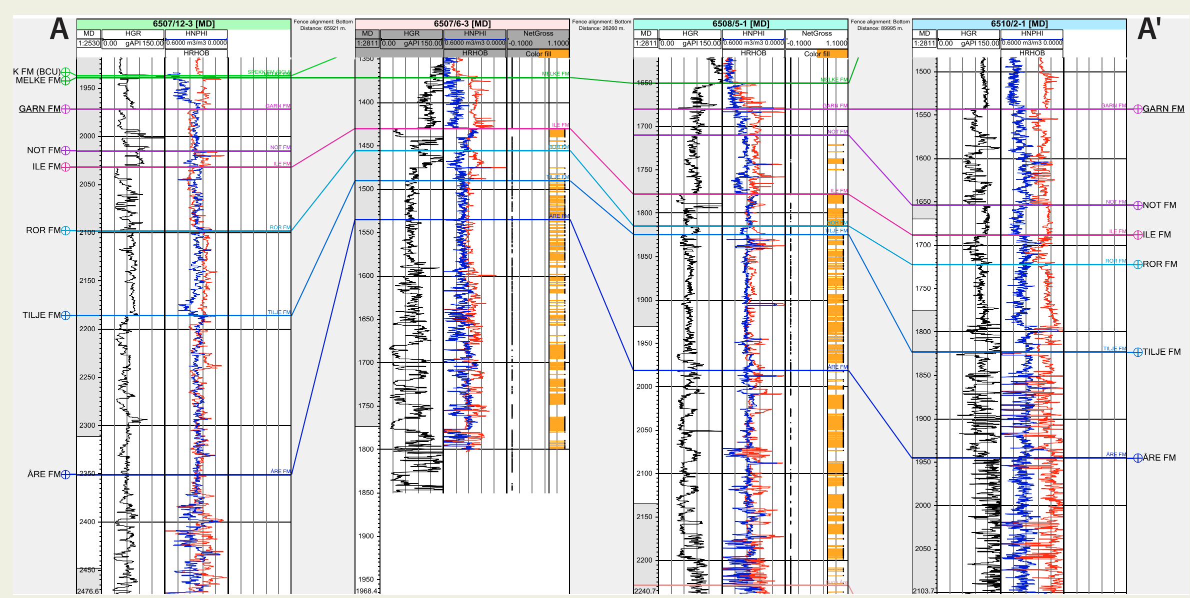
Porosity



Net/Gross



The Tilje/Åre aquifer		
Storage system		closed
Rock volume		9200 Gm^3
Net volume		2700 Gm^3
Pore volume		900 Gm^3
Average depth		1940 m
Average net/gross		0.30
Average porosity		0.21
Average permeability		140 mD
Storage effieciency		0.7 %
Storage capacity aquifer		4.0 Gt
Reservoir quality		
	capacity	2
	injectivity	2
Seal quality		
	seal	3
	fractured seal	2
	wells	3
Data quality		
Maturation		



Log correlation panel with gamma, porosity density and calculated net/gross. Layout showed in Tilje porosity map.

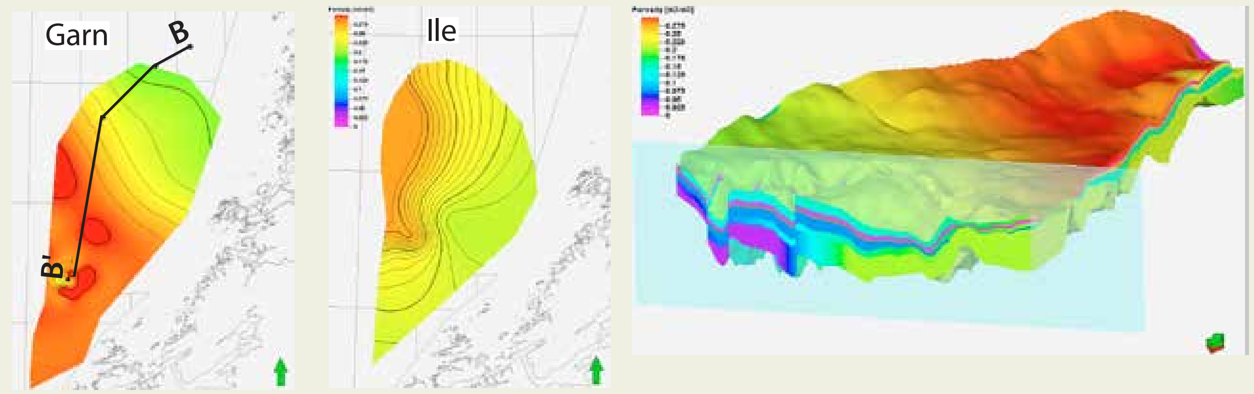
5.2.1 Saline aquifers

Storage capacity Garn/Ile

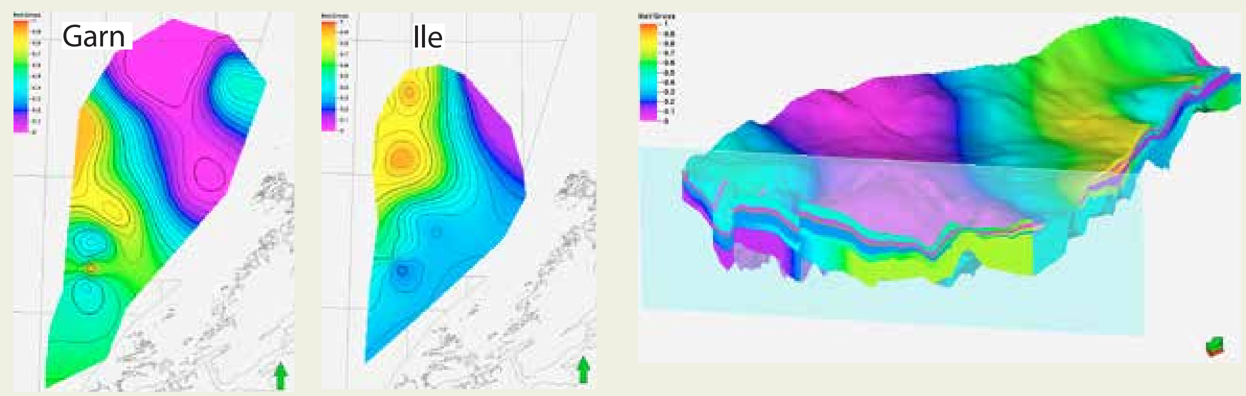
The first approach was to calculate the total pore volume and use a storage efficiency representing a closed system. The second approach was to calculate the pore volumes of the largest closed structures A, B and C presented below, and assume that they are in communication with the larger aquifer (half-open system). The third approach was to simulate injection in the Garn-Ile aquifer presented above, where the injected CO_2 volume is restricted because it is not allowed to reach the coastal subcrop.

In the table below, showing the results for the Garn – Ile aquifer, a half-open case and a closed case for the whole aquifer are presented to illustrate how important this is for the estimates of storage volumes. Large volumes can theoretically be stored if the aquifer is in pressure communication with additional large water volumes. In the Garn-Ile case, such pressure communication could take place with the sea along the subcrop line. Another alternative to creating a half-open system might be to inject CO_2 and produce water. The most optimistic case would be to assume that closed structures with a large storage capacity exist and could be filled with CO_2, without any migration to the half-open eastern boundary. Although interesting structures exist, we have not been able to identify such large storage volumes in closed structures in our mapping of the Garn-Ile aquifer. Based on the structures we can map and the simulations we have performed, we have chosen the lower estimate (closed aquifer) as the most likely scenario.

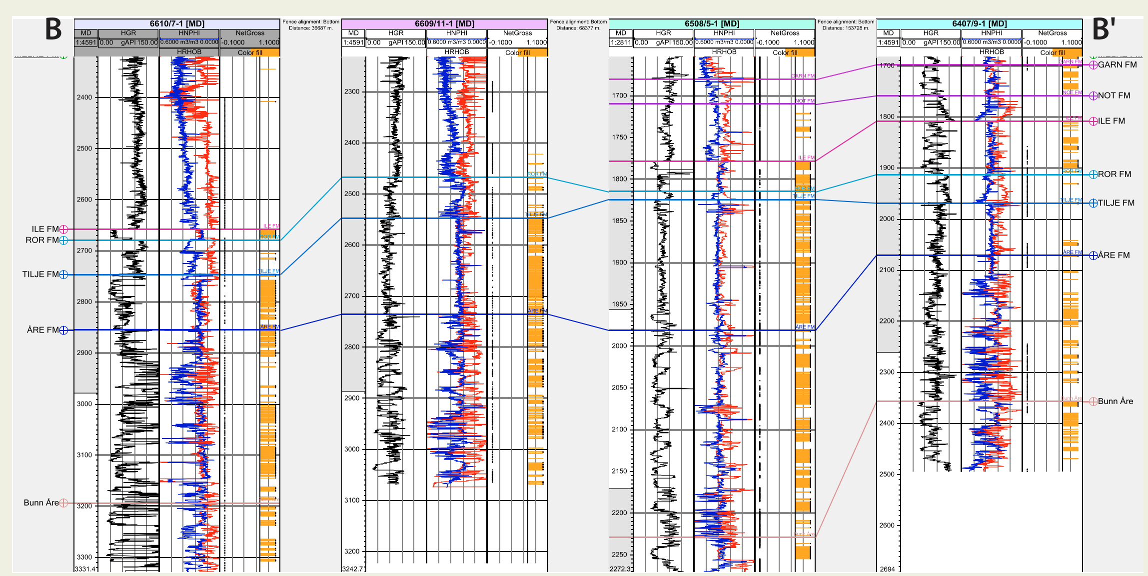
Porosity



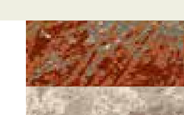
Net/Gross



The Garn/Ile aquifer		Summary	Summary
Storage system		half open	closed
Rock volume		4400 Gm^3	4400 Gm^3
Net volume		1100 Gm^3	1100 Gm^3
Pore volume		300 Gm^3	300 Gm^3
Average depth Garn Fm		1675 m	1675 m
Average depth Ile Fm		1825 m	1825 m
Average net/gross		0.25	0.25
Average porosity		0.27	0.27
Average permeability		580 mD	580 mD
Storage effieciency		4 %	0.2 %
Storage capacity aquifer		8 Gt	0.4 Gt
Reservoir quality			
	capacity	2	2
	injectivity	3	3
Seal quality			
	seal	3	3
	fractured seal	3	3
	wells	3	3
Data quality			
Maturation			



Log correlation panel with gamma, porosity density and calculated net/gross. Layout showed in Garn porosity map.



5. 2 Storage options in the Norwegian Sea

5.2.1 Saline aquifers

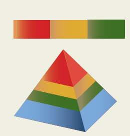
Possible injection prospects

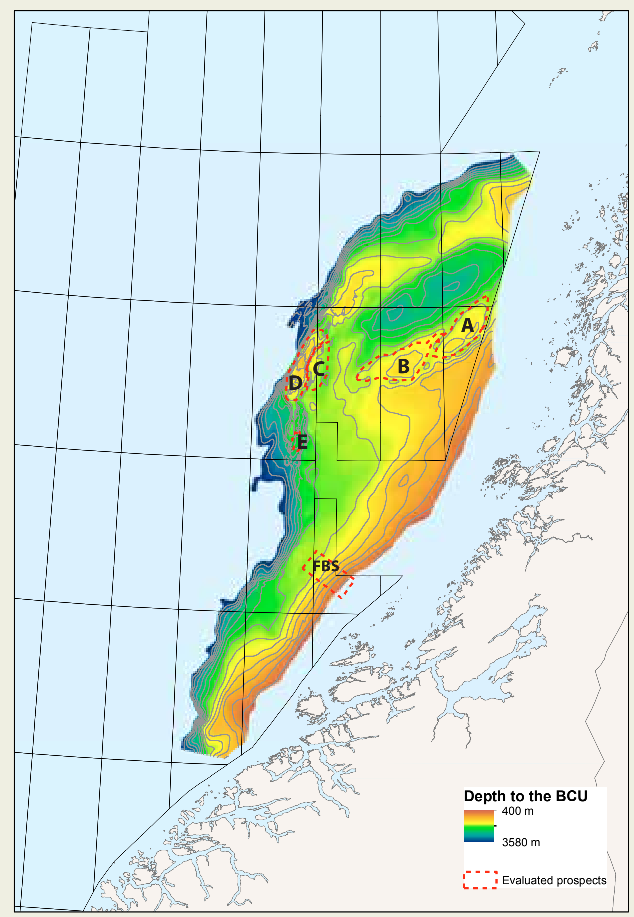
CO_2 can be injected in closed structures or in open aquifers. In a closed structure, the amount of CO_2 injected will be restricted by the maximum fracing pressure of the structure with a safety margin. Some of the CO_2 will be trapped as free CO_2 by the seal of the structure, and a certain amount will be dissolved in the water. In an open aquifer the amount of CO_2 will not be restricted by pressure, but it can gradually be trapped as residual and dissolved CO_2 in the water phase. In the Trøndelag Platform and Nordland Ridge, both alternatives have been studied. The map shows the outlines of five large closed structures which have been identified in the study. Structures A and B are located SE of the Helgeland Basin and comprise only the Åre-Tilje Trøndelag Platform aquifer. Structure C is bounded by the Ellingråsa Graben to the west, and it could trap CO_2 in all the aquifers of the Trøndelag Platform. Structure D belongs to the Nordland Ridge Åre Formation aquifer, while structure E is located in the Ellingråsa Graben, outside the Trøndelag Platform aquifer. The volumes of structures D and E are listed in the table. The volumes of prospects A, B and C are included in the calculation of the Trøndelag Platform aquifers. In a closed aquifer, the limiting factor for the volume which can be injected is the total pore volume of the aquifer, not the pore volume of the structure.

Seismic mapping was also carried out east of the Frøya High, south of the Draugen Field, to search for closed structures suitable for CO_2 trapping in that area. It was concluded that such structures may exist, but there is uncertainty related to their definition on 2D seismic data and to how far petroleum has migrated into the area east of the Frøya High.

The rectangle in the map shows the model area for the study of open aquifer injection into the Ile and Garn Formations.

Prospects			
Prospect name		D	E
Storage system		Half open	Open
Rock volume		270 Gm^3	10 Gm^3
Net volume		50 Gm^3	4 Gm^3
Pore volume		14 Gm^3	1 Gm^3
Average depth		1300 m	2200 m
Average net/gross		0.3	0.4
Average porosity		0.26	0.25
Average permeability		140 mD	300mD
Storage efficiency		1 %	10 %
Storage capacity prospect		100 Mt	70 Mt
Reservoir quality			
	capacity	3	2
	injectivity	2	2
Seal quality			
	seal	2	3
	fractured seal	3	3
	wells	3	3
Data quality			
Maturation			





Regional BCU map showing the locations of prospects A to E and the location of the simulation grid in the Froan Basin (FBS). The map to the left is zoomed in on structures C, D and E.

5. 2 Storage options in the Norwegian Sea

5.2.2 Summary

The results of the evaluation of aquifer storage capacity are summarized in the tables. The Trøndelag Platform including the Nordland Ridge is the area best suited for CO_2 storage. A thick Jurassic section is present and has been divided in two aquifers. The burial depth is approximately 1500-2000 m, and the reservoir quality of the clean sandstones is excellent.

The lower Åre-Tilje aquifer is distributed over the whole area and the potential injection volume is calculated to about 4Gt. The reservoir is heterogeneous, dominated by fluvio-deltaic to tidal deposits, and the connectivity both on a local and regional scale is uncertain. The upper Ile and Garn aquifers are developed as good reservoirs in the southern part (Froan Basin). The Garn reservoir has the best permeability and connectivity of the Jurassic sandstones. All the aquifers are subcropping towards the sea floor along the coast. The thickness of the Quaternary cover is variable. CO_2 injection projects should be planned to avoid long distance migration towards the subcrop and possible further seepage to the sea floor. Modelling of injection in the aquifer indicates that it is possible to inject at a rate and volume where the CO_2 is trapped and/or dissolved before it reaches the subcrop area. The conclusion is that the Garn and Ile storage capacity is relatively low, about 0.4 Gt.

Five large structural closures have been identified. Two of them (structures D and E) are located outside the Trøndelag Platform and add storage capacity to the area. Structures D and E are covered by 3D seismic data and wells and are regarded as more mature than the other structures and evaluated aquifers.

The Møre Margin is geologically different from the Trøndelag Platform and does not seem to hold a large storage potential due to its proximity to deep basins and subcropping aquifers.

In the petroleum provinces, the storage potential was calculated from the extracted volume of hydrocarbons in depleted fields. Such storage will usually require a study of the integrity of the wells which have been drilled into the field. If oil has been present, it is relevant to study the potential for increased recovery by CO_2 injection. Studies of EOR by CO_2 injection were performed some years ago for the Draugen and Heidrun fields.

Evaluated aquifers	Avg depth	Bulk volume	Pore volume	Avg K	Open/closed	Storage eff	Storage volume	Density in reservoir	Storage capacity
Unit	*m*	*Gm³*	*Gm³*	*mD*		*%*	*GRm³*	*kg/m³*	*Gt*
Garn/Ile	1675	4400	300	580	closed	0.2	0.6	700	0.4
Tilje/Åre	1940	9200	600	140	closed	1	6.0	700	4.0
Evaluated prospects									
Prospect D Åre	1300	270	14	140	half open	1	0.14	700	0.1
Prospect E Åre-Tilje, Ile-Garn	2200	10	1.0	300	open	10	0.1	700	0.07
Producing fields									1.1

For the Norwegian Sea, the total storage capacity in the green level of the pyramid is estimated to be 5.5 Gt. In the more mature areas (yellow level) the capacity is estimated to be 0.17 Gt.

Abandoned fields	Storage capacity, Gt
Producing fields	
Closure of production 2020 -2030	0.9
Closure of production 2030 -2050	0.2