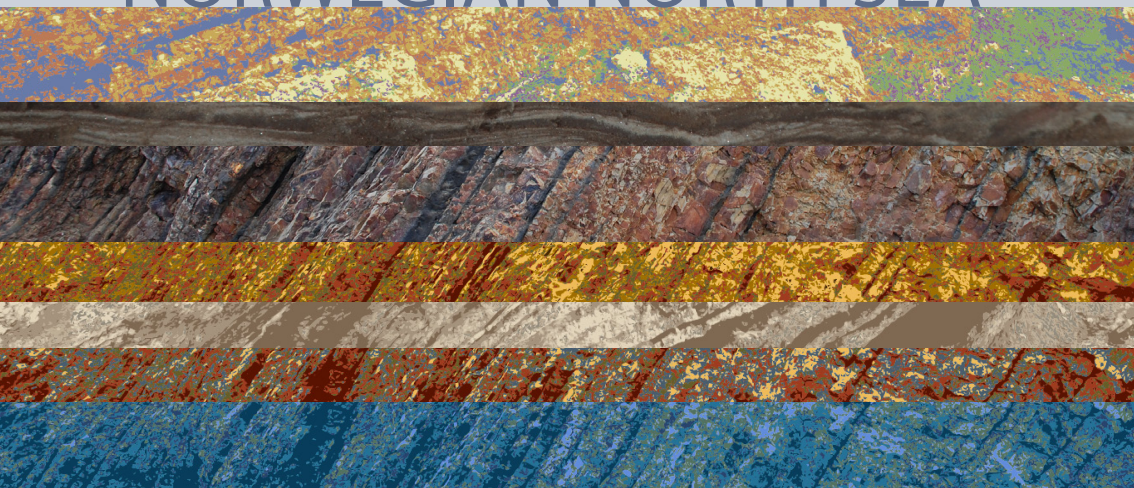
NORWEGIAN PETROLEUM DIRECTORATE

CO_2 STORAGE ATLAS

NORWEGIAN NORTH SEA



Introduction

The CO_2 Storage Atlas of the Norwegian part of the North Sea has been prepared by the Norwegian Petroleum Directorate, on request by the Ministry of Petroleum and Energy. One of the key objectives for this atlas is to provide input on where it is possible to implement safe long-term storage of CO_2, and how much capacity there is for geological storage of CO_2.

This study is based on detailed work on all relevant geological formations and hydrocarbon fields in the Norwegian part of the North Sea. The work is based on several studies as well as data from more than 40 years of petroleum activity in the North Sea basin.

21 geological formations have been individually assessed, and grouped into saline aquifers. The aquifers were evaluated with regard to reservoir quality and presence of relevant sealing formations. Those aquifers that may have a relevant storage potential in terms of depth, capacity and injectivity have been considered. Structural maps and thickness maps of the aquifers are presented in the atlas, and were used to calculate pore volumes. Several structural closures have been identified, some were further assessed.

A new geological study of the largest aquifer in the Norwegian sector of the North Sea, the Utsira-Skade aquifer, is included. A study of the CO_2 storage potential in the Frigg field is provided, together with a summary of the CO_2 storage potential in abandoned oil and gas fields. CO_2 storage in enhanced oil recovery projects is also discussed.

The methodology applied for estimating storage capacity is based on previous assessments, but the storage efficiency factor has been assessed individually for each aquifer based on simplified reservoir simulation cases. The assessed aquifers have been ranked according to guidelines which have been developed for this study.

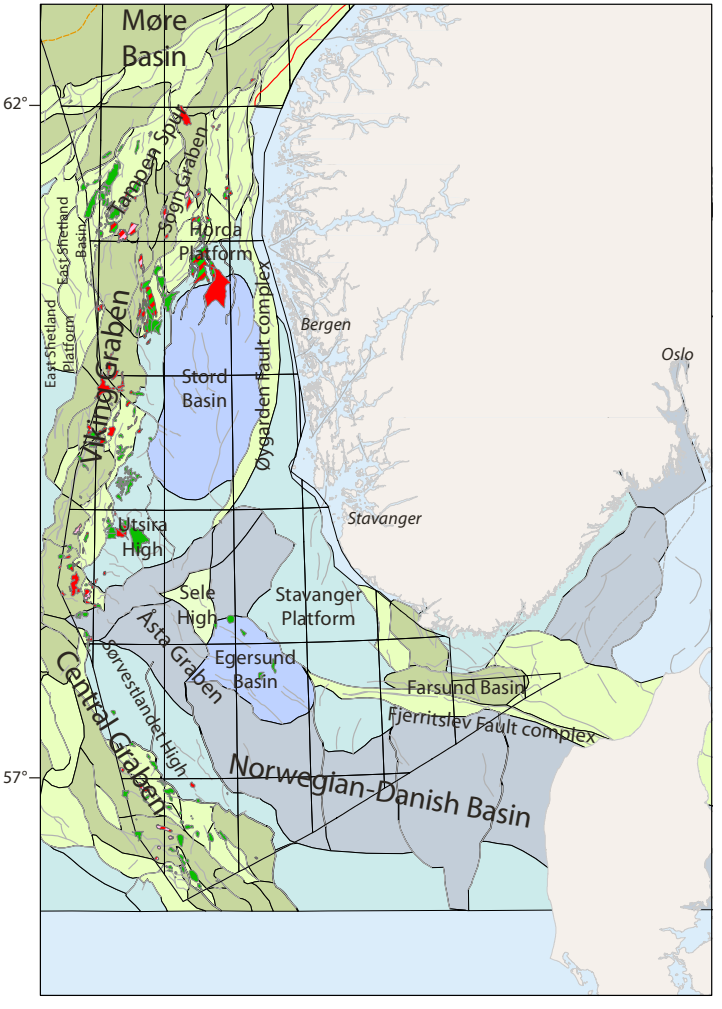
This atlas is based on large amount of data from seismic, exploration and production wells, together with production data. This data base is essential for the evaluation and documentation of geological storage prospectivity.

We hope that this study will fulfil the objective that the information can be useful for future exploration for CO_2 storage sites.

We have not attempted to assess the uncertainty range in the atlas, but we have made an effort to document the methods and main assumptions.

The assessments described in this atlas will be accompanied by a GIS data base (geographical information system). This will be published on the NPD web site spring 2012.

Geological provinces of the North Sea



Characterization of saline aquifers

Aquifers and structures have been evaluated in terms of capacity and safe storage of CO_2. Reservoir quality depends on the calculated volume and communicating volumes as well as the reservoir injectivity. Sealing quality is based on evaluation of the sealing layers (shales) and possible fracturing of the seal. Existing wells through the aquifers/structures and seals have also been evaluated.

Parameters used in the characterization process are based on data and experience from the petroleum activity on the NCS and the fact that CO_2 should be stored in the supercritical phase to have the most efficient and safest storage.

Each of the criteria in the table below is given a score together with a description of the data coverage (good, limited or poor). The score for each criteria is based on a detailed evaluation of each aquifer/structure. A checklist for reservoir properties has been developed. This list gives a detailed overview of the important parameters regarding the quality of the reservoir. Important elements when evaluating the reservoir properties are aquifer structuring, traps, the thickness and permeability of the reservoir. A corresponding checklist has been developed for the sealing properties. Evaluation of faults and fractures through the seal, in addition to old wells, are important for the sealing quality.

An extensive database has been available for this evaluation. Nevertheless some areas have limited seismic coverage and no well information. The data coverage is colour-coded to illustrate the data available for each aquifer/structure.

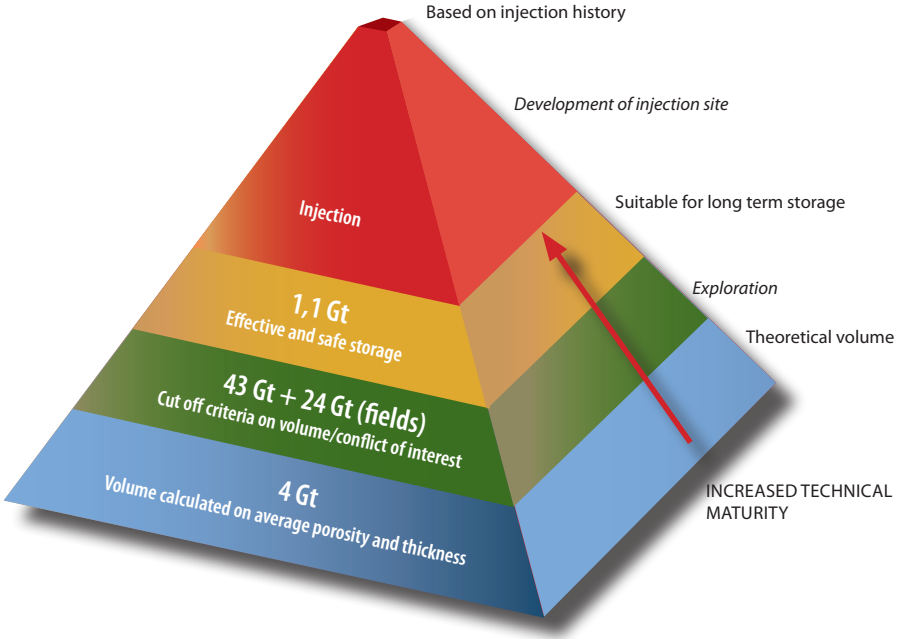
CHARACTERIZATION OF AQUIFERS AND STRUCTURES

	Criteria		Definitions, comments
Reservoir quality	Capacity, communicating volumes	3	Large calculated volume, dominant high scores in checklist
		2	Medium - low estimated volume, or low score in some factors
		1	Dominant low values, or at least one score close to unacceptable
	Injectivity	3	High value for permeability * thickness (k*h)
		2	Medium k*h
		1	Low k*h
Sealing quality	Seal	3	Good sealing shale, dominant high scores in checklist
		2	At least one sealing layer with acceptable properties
		1	Sealing layer with uncertain properties, low scores in checklist
	Fracture of seal	3	Dominant high scores in checklist
		2	Insignificant fractures (natural / wells)
		1	Low scores in checklist
Other leak risk	Wells	3	No previous drilling in the reservoir / safe plugging of wells
		2	Wells penetrating seal, no leakage documented
		1	Possible leaking wells / needs evaluation
Data coverage	Good data coverage	Limited data coverage	Poor data coverage

Other factors:
How easy / difficult to prepare for monitoring and intervention. The need for pressure relief. Possible support for EOR projects. Potential for conflicts with future petroleum activity.

Data coverage
Good : 3D seismic, wells through the actual aquifer/structure
Limited : 2D seismic, 3D seismic in some areas, wells through equivalent geological formations
Poor : 2D seismic or sparse data

Storage maturation and capacities



The evaluation of geological volumes suitable for injecting and storing CO_2 can be viewed as a step-wise approximation, as shown in the maturation pyramid. Data and experience from over 40 years in the petroleum industry will contribute in the process of finding storage volumes as high up as possible in the pyramid.

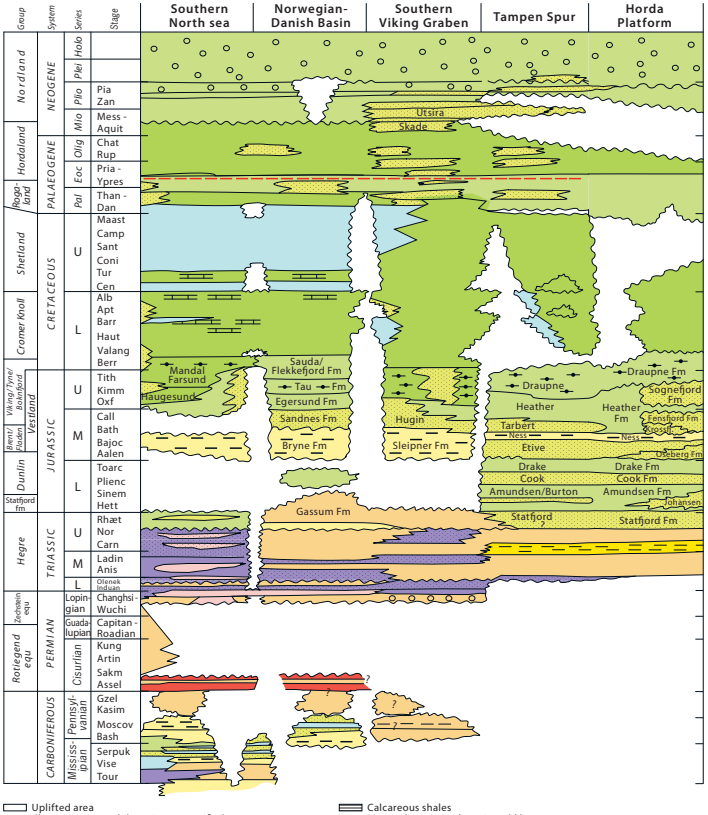
Step 4 is the phase when CO_2 is injected in the reservoir. Throughout the injection period, the injection history is closely evaluated and the experience gained provides further guidance on the reservoirs' ability and capacity to store CO_2.

Step 3 refers to storage volumes where trap, reservoir and seal have been mapped and evaluated in terms of regulatory and technical criteria to ensure safe and effective storage.

Step 2 is the storage volume calculated when areas with possible conflicts of interest with the petroleum industry have been removed. Only aquifers and prospects of reasonable size and quality are evaluated. Evaluation is based on relevant available data.

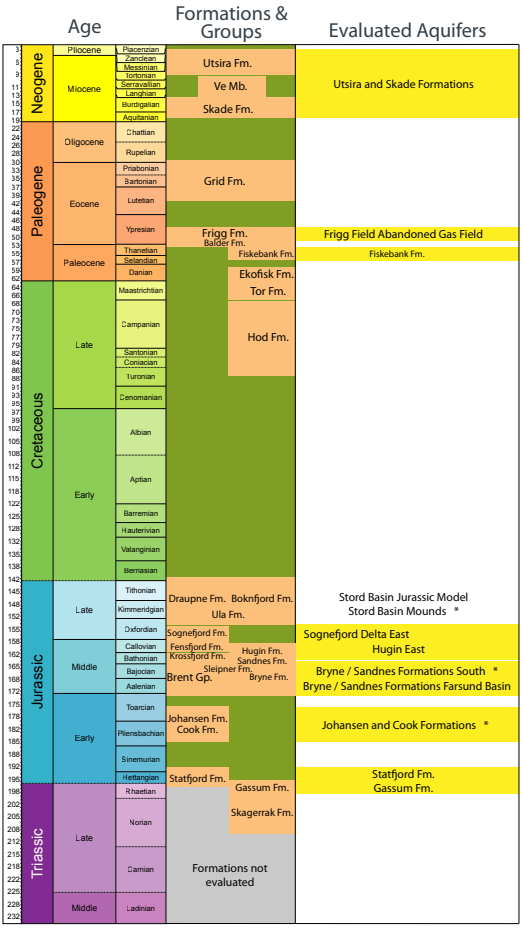
Step 1 is the volume calculated on average porosity and thickness. This is done in a screening phase that identifies possible aquifers suitable for storage of CO_2. The theoretical volume is based on depositional environment, diagenesis, bulk volume from area and thickness, average porosity, permeability and net/gross values.

Lithostratigraphic chart of the North Sea



- Uplifted area
- Clastic continental deposits, unspecified
- Clastic continental deposits, mainly sandstone
- Clastic continental deposits, mainly shale and siltstone
- Salt (halite)
- Shallow-marine carbonate deposits
- Deep-marine carbonate deposits
- Volcanic deposits
- Calcareous shales
- Marginal evaporite deposits, sabkha
- Coastal, deltaic and flood-plain deposits
- Marine deposits, mainly sandstone
- Shallow-marine deposits, mainly shale
- Deep-marine deposits, mainly shale
- Clastics intermixed in carbonates, sandstone in shale
- Spiculite

Mapped geological formations and corresponding saline aquiferes

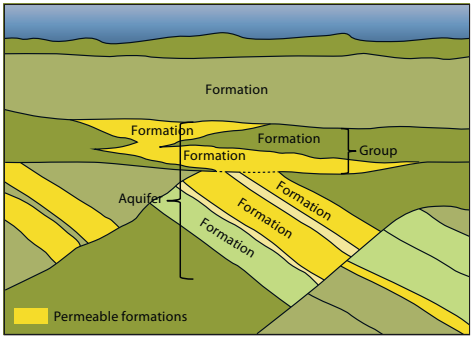


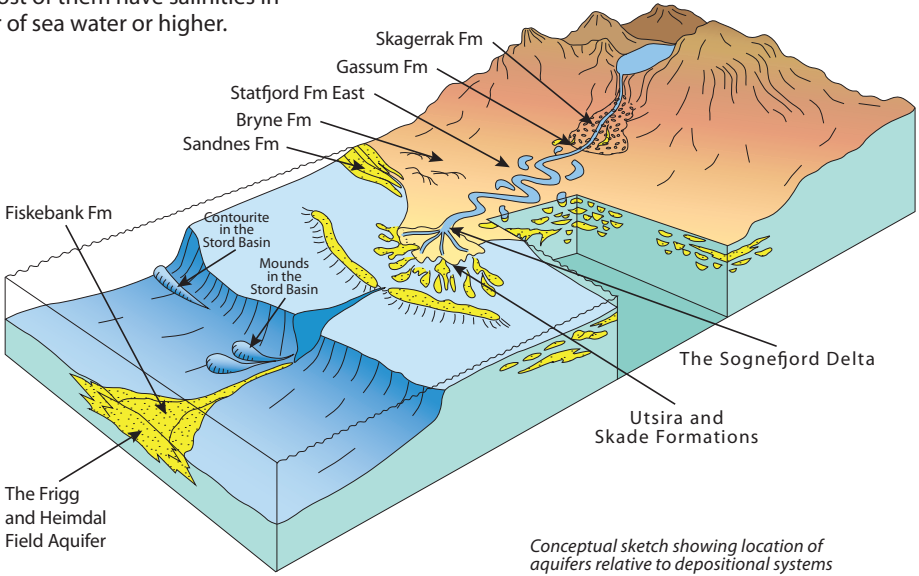
* Evaluated prospects

Saline aquifers

Definition and principles for selection of storage sites

An aquifer is a body of porous and permeable sedimentary rocks where the water in the pore space is in communication throughout. Aquifers may consist of several sedimentary formations and cover large areas. They may be somewhat segmented by faults and by low permeable layers acting as baffles to fluid flow. Maps, profiles and pore pressure data have been utilized in order to define the main aquifers. All the identified aquifers in the area of this atlas are saline, most of them have salinities in the order of sea water or higher.





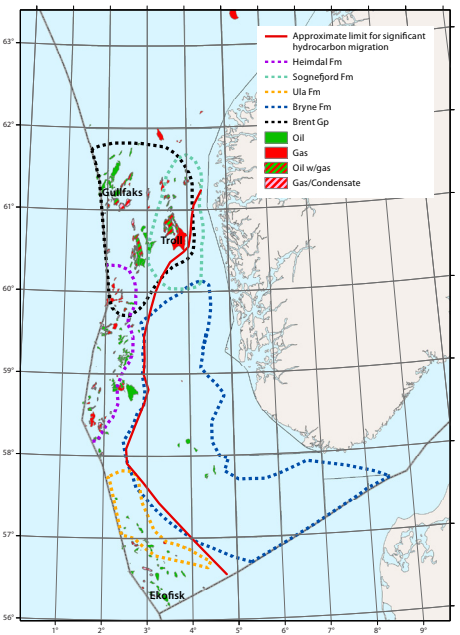
Conceptual sketch showing location of aquifers relative to depositional systems

Aquifers in the hydrocarbon provinces are treated separately

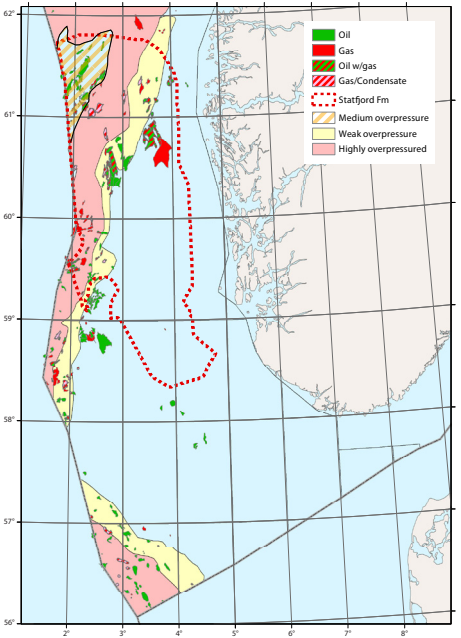
In the western provinces, west of the red line in the lower middle figure, Paleogene and older aquifers contain hydrocarbons. East of the line, discoveries have only been made in local basins where the Jurassic source rock has been buried to a sufficiently high temperature to generate hydrocarbons.

In the eastern area, all the large aquifers have been selected based on the established criteria and storage capacity is estimated by the method described in the atlas. In the petroleum provinces, it is considered that exploration and production activities will continue for many years to come. The most realistic sites of CO_2 storage will be some of the abandoned fields, in particular the gas fields. Consequently, an indication of the storage capacity of the fields has been given, but no aquifer volumes have been calculated.

Some of the oil fields are considered to have a potential for use of CO_2 to enhanced oil recovery. Some of the CO_2 used for EOR will remain trapped. The capacity for this type of CO_2 trapping has not been calculated.

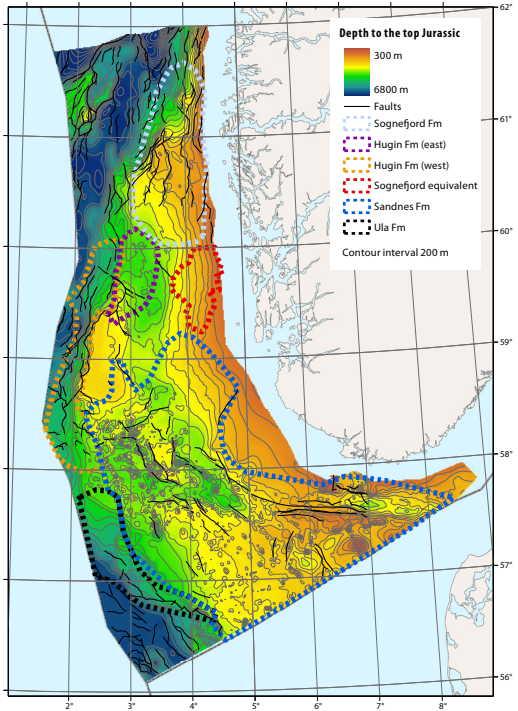


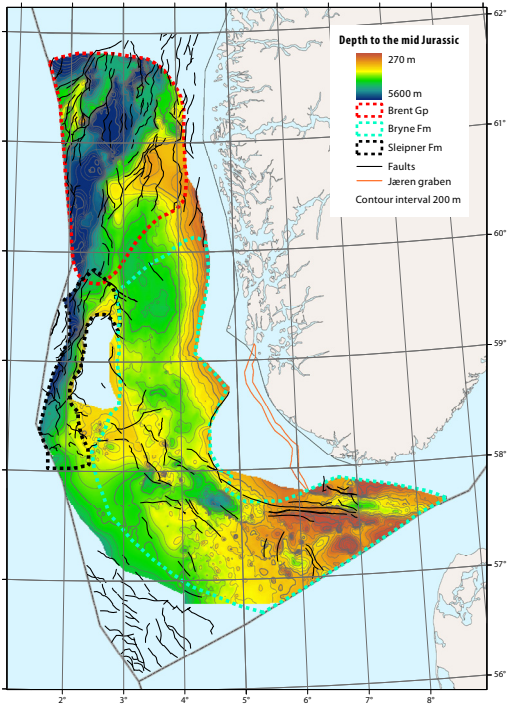
Distribution of major aquifers at the Jurassic levels relative to the petroleum provinces



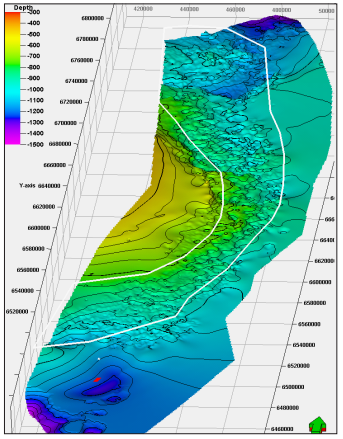
Some aquifers occur in both provinces

Distribution of evaluated aquifers

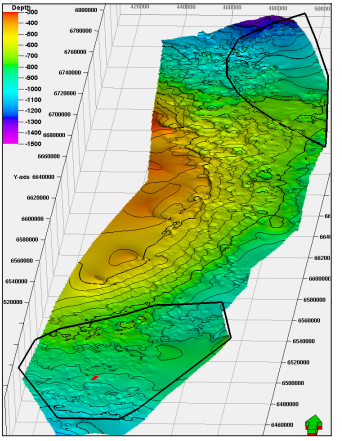




The Utsira and Skade aquifer

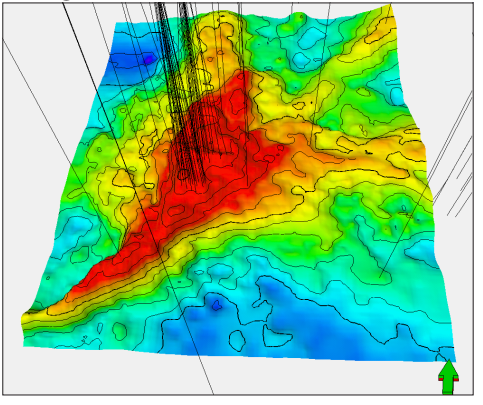


Top of Skade Formation. The white polygon indicates area which may be favorable for CO_2 storage. Red dot shows Sleipner injection area. The grid squares are 20 km x 20 km.



Top of Utsira Formation. The black polygons indicate areas which may be favorable for CO_2 storage.

Storage of CO_2 in abandoned fields



Structural map of the Frigg field with all wells

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For more information and purchase of the CO_2 storage atlas:
www.npd.no

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