THE CO_2 STORAGE ATLAS IN THE NORWEGIAN SEA WITH SIMULATION CASE STUDY NORDLAND RIDGE

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Evaluation of the Nordland Ridge (Norwegian Sea) for CO_2 storage

The Nordland Ridge has three large culminations, the Sør High, the Rødøy High and the Grønøy High. These highs are separated from the petroleum bearing terraces and basins to the west 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 there could be an option to inject excess CO_2 from future production.

The main reservoir zone evaluated for CO_2 storage is the Åre Formation. The main objective of the study is to estimate the amount of CO_2 that can be safely stored, mainly based on reservoir simulation. Of particular interest is storage of CO_2 volumes corresponding to possible CO_2 production from a nearby gas field (Victoria field).

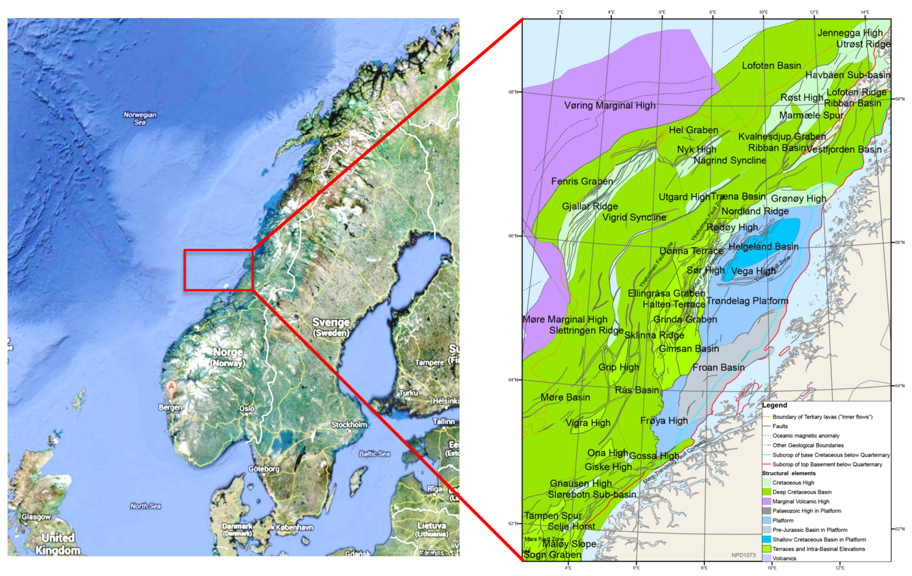
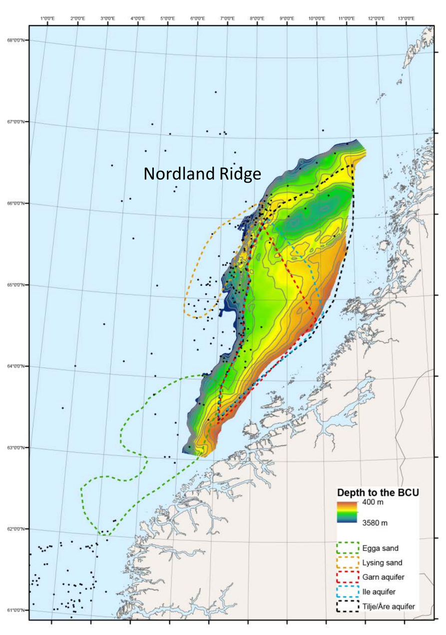


Figure 1A



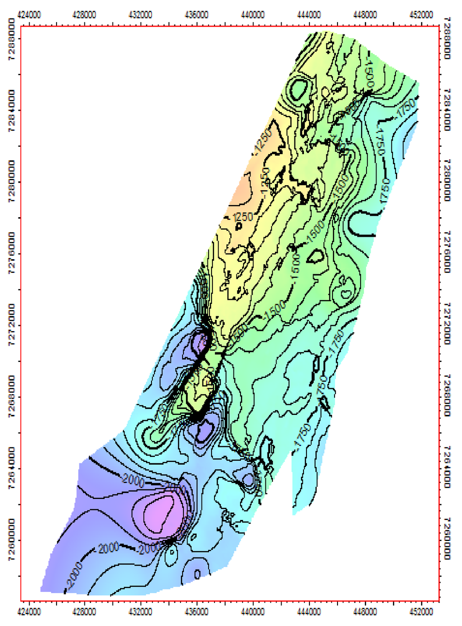


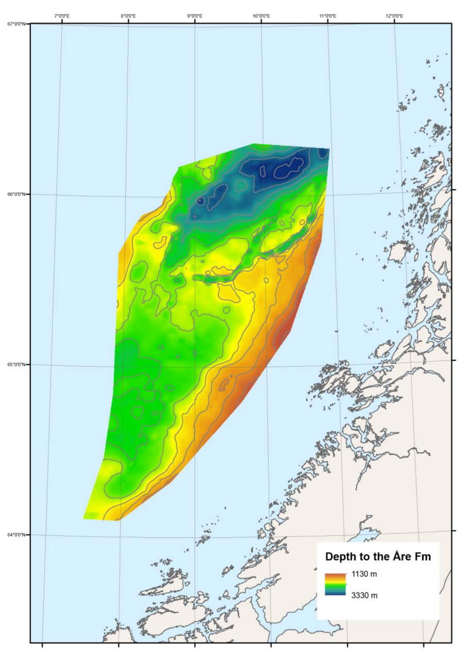
Figure 1B

Figure 1C

Figure 1A: Structural elements of the Norwegian Sea; **Figure 1B:** Depth to the BCU; **Figure 1C:** Base Åre Fm in the Nordland Ridge.

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

The upper part of the Åre Fm contains a laterally continuous mudstone interval with relatively uniform thickness, thinning slightly to the north. The thickness in the type well (6507/12-1) is 508m (Figure 3A & B) and in the reference well (6407/1-2), the thickness is 328m. Generally the thickness of the Åre Fm varies between 300 to 500m, with a maximum thickness of 780m in the eastern part of the Halten Terrace (Heidrun area). The depth and thickness maps of the Åre Fm are shown in figures 2A and 2B.



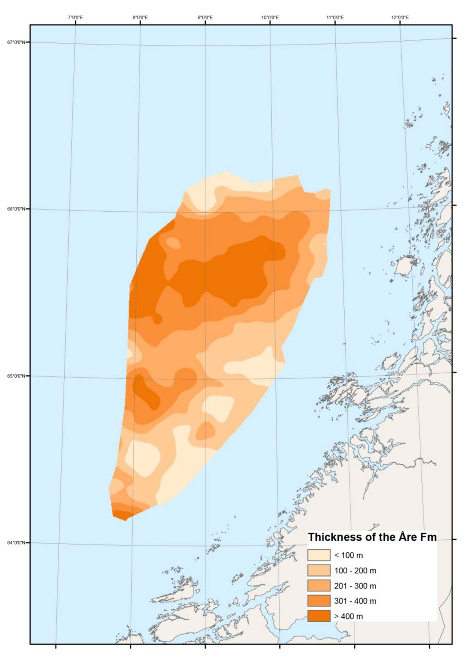


Figure 2A

Figure 2B

Figure 2A: Depth to the Åre Formation; **Figure 2B:** Thickness of the Åre Formation.

WELL LOG 6507/12-1

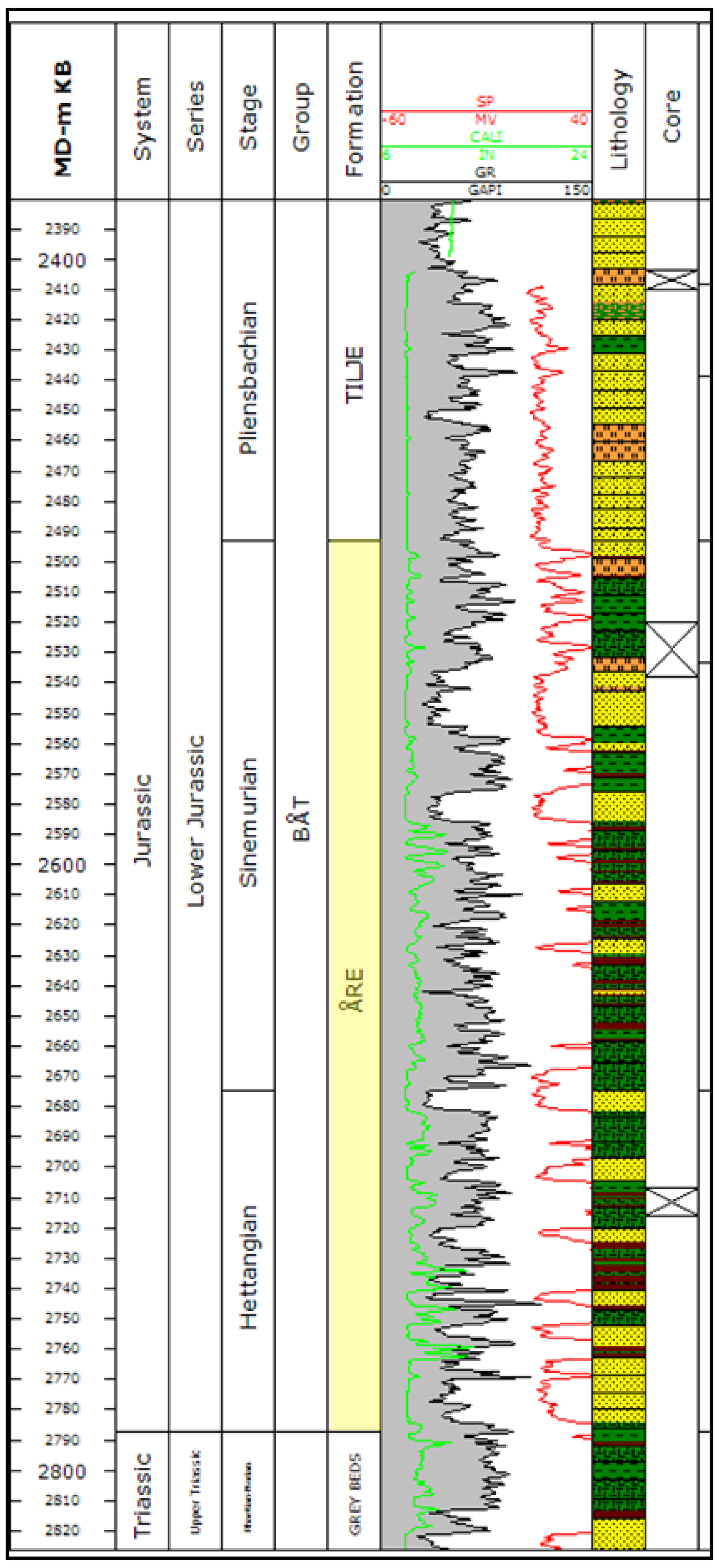


Figure 3A

6507/12-1 Åre Formation

2707,0-2709,7 m

2537-2538 m

Figure 3B

Figure 3A: Well summary including petrophisical logs (GR, Cali and SP), lithology, age, groups and formations; **Figure 3B:** Core photos of the Åre Formation.

Conclusions

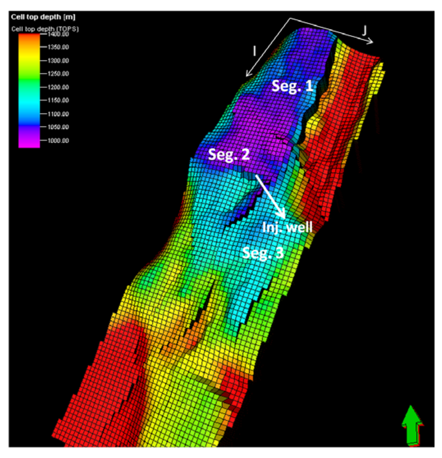
The simulation results show that all cases can inject for 2 mill Sm^3 CO_2/day for 28 years with respect to acceptable pressure increase and CO_2 plume spreading (Table 2).

Applying a safety factor of two to the acceptable pressure increase, it can be concluded that 10 GSm^3 (or 18.7 mill tons) CO_2can safely by stored in the Nordland Ridge within Åre Formation (Lower Jurassic) .

Simulation model of the The Nordland Ridge

A Simulation model of the The Nordland Ridge within Åre Formation (Lower Jurassic) was built for the purpose of assessing its CO_2 storage potential. The modeled Nordland Ridge is a closed structure with CO_2 storage potential in two structural dome highs (Figure 4). Segment 3 is the deepest dome, segment 1 and 2 combined is the shallowest dome, with possible down flank aquifer communication to areas outside the modeled region.

The top reservoir (Åre Formation) depth in the two main storage domes is about 1000 - 1150m. The Åre Formation consists of fluvial deposited sand channels and is heterogeneous with uncertain communication. The average sand permeability is about 500mD. The porosity and permeability have been stochastically modeled with both lateral and vertical variation. Reservoir, fluid and injection data are shown in Table 1.



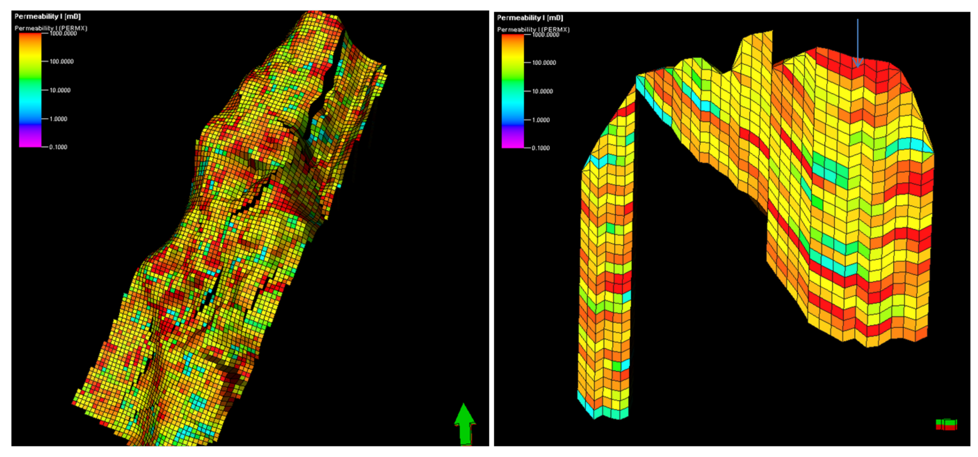
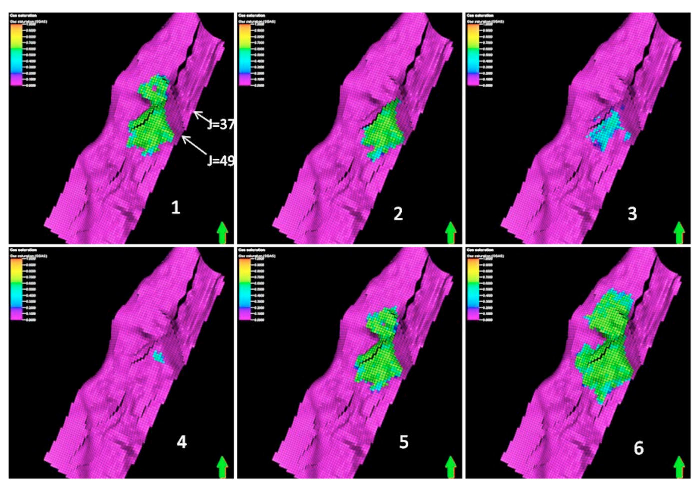


Figure 4A

Figure 4B

Figure 4A: The CO_2 injection well location. It is located slightly down dip apex of the deeper two main storage domes. Permeability variations (Figure 4B), lateral (left) and vertical (x-z, through well, right).

Different injection rates and volumes have been simulated, and the main scenario injects 2 mill SM^3 CO_2/day. The main criteria for evaluation of CO_2 storage volumes are acceptable pressure increase and confinement of CO_2 migration. CO_2 will continue to migrate upwards as long as it is in free and movable condition. Migration stops when CO_2 is permanently bounded or trapped, by going into solution with the formation water or by being residually trapped, or becoming structurally trapped (mineralogical trapping not considered). The main storage mechanism in the Nordland Ridge is structural trapping in the two main domes.



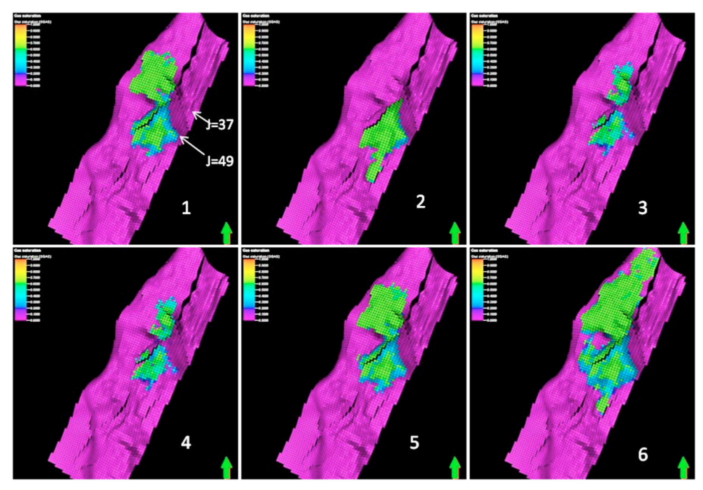
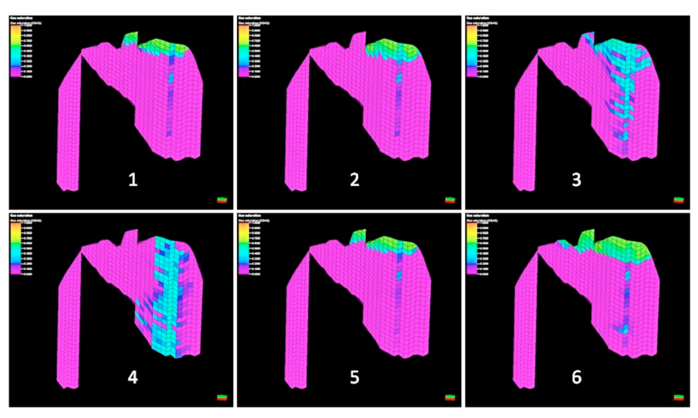


Figure 5A

Figure 5B

Figure 5A: CO_2 plume top reservoir end of injection (50 yrs). Cases: 1)Ref Case 2) No fault comm. 3) No layer comm. 4) No fault and layer comm. 5) No CO_2 in solution 6) High Case **Figure 5B:** CO_2 plume top reservoir after 1000yrs. Cases: 1) Ref Case, 2) No fault comm. 3) No layer comm. 4) No fault and layer comm. 5) No CO_2 in solution 6) High Case.



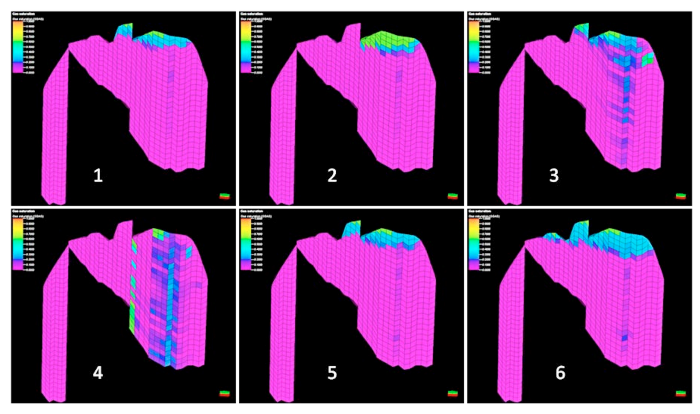


Figure 6A

Figure 6B

Figure 6A: CO_2 plume x-z cross-section (J=49) end of injection (50 years). Cases: 1) Ref. case, 2) No fault comm., 3) No layer comm., 4) No fault & layer comm., 5) No CO_2 in solution, 6) High Case (PV= 3,7 x Ref. case, Inj.rate= 2,5 x Ref. case).

Figure 6B: CO_2 plume x-z cross-section (J=49) after 1000 years. Cases: 1) Ref. Case, 2) No fault comm. 3) No layer comm. 4) No layer and fault comm. 5) No CO_2 in solution 6) High Case (PV= 3,7 x Ref. case, Inj.rate= 2,5 x Ref. case).

Reservoir, fluid and injection data	
Reservoir depth	1000-1300 m
Av. porosity:	24,4%
Av. N/G	0,55 (fraction)
Av. permeability, horizontal	537 mD
Av. permeability, vertical	145 mD
Pressure	110 - 150 bar
CO_2 density	670 -750 kg/m^3
CO_2 viscosity	0,05 – 0,07 cP
Injection rate	2 mill Sm^3 CO_2/d
Total CO_2 injection (50 years)	68 mill tons
Victoria produced CO_2	19 mill tons

Table 1

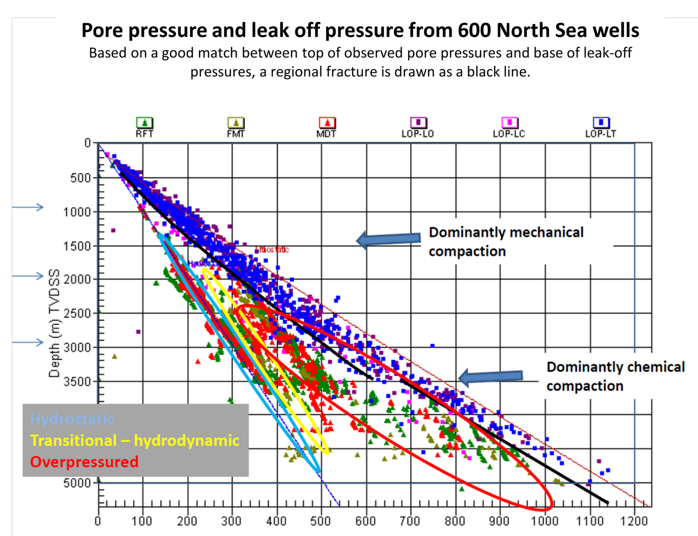


Figure 7

A maximum pressure build-up of about 35 bar is considered acceptable at depths of about 1000. The injection well is located at about 1150 m depth, adding another 7 bar to the fracturing pressure (Figure7).

Press.	Ref. case		Tight faults		Tight layers		Tight fault &layers		High case	
Incr. (bar)	Avg.	Near well	Avg.	Near well	Avg.	Avg.	Avg.	Near well	Avg.	Near well
14 yrs	16	19	15	23	12	20	10	41	10	22
28 yrs	29	30	28	34	24	33	20	55	20	29
50 yrs	47	47	46	50	41	48	35	76	34	41

Table 2

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