NORWEGIAN JOURNAL OF GEOLOGY Vol 99 Nr. 2
https://dx.doi.org/10.17850/njg008

GEOLOGICAL SOCIETY OF NORWAY

You learn as long as you drill; research synthesis from the Longyearbyen CO_2 Laboratory, Svalbard, Norway

Snorre Olaussen[1], Kim Senger[1], Alvar Braathen[2,1], Sten-Andreas Grundvåg[3] & Atle Mørk[4]

[1]*Department of Arctic Geology, University Centre in Svalbard, P.O. Box 156, NO–9171 Longyearbyen, Norway.*
[2]*Department of Geosciences, University of Oslo, P.O Box 1047, Blindern, NO–0316 Oslo, Norway.*
[3]*Department of Geosciences, University of Tromsø—The Arctic University of Norway, P.O. Box 6050 Langnes, NO–9037 Tromsø, Norway.*
[4]*Department of Geoscience and Petroleum, Norwegian University of Science and Technology, NO–7491 Trondheim, Norway.*

E-mail corresponding author (Snorre Olaussen): snorre.olaussen@unis.no

From 2007 to 2015, eight wells were drilled and fully cored to test the feasibility of storing CO_2 emitted from the coal-fueled power plant in Longyearbyen, Svalbard. The drilling campaign identified three water-bearing sandstone aquifers; i) a lower aquifer in Upper Triassic strata; ii) a middle aquifer in Upper Triassic to Middle Jurassic; and iii) an upper aquifer in Lower Cretaceous strata. Only the two former are regarded as potential CO_2 storage units. Both units are unconventional reservoirs (storage units) consisting of fractured, low-porosity and low-permeability sandstones. The storage units are capped by a c. 400 m-thick Middle Jurassic to Lower Cretaceous mudstone-dominated succession, which acts as an efficient top seal. In addition, a c. 120 m-thick zone of permafrost provides an additional seal. Apart from characterising the CO_2 storage and cap-rock system, the drilling resulted in several unexpected results. These include: (a) the detection of severe underpressure of approximately 50 bar in the two storage units, (b) the discovery of gravity-flow deposits attributed to a hitherto unknown Hauterivian clastic wedge, and (c) the detection of producible thermogenic shale gas at a depth of 640 to 700 m. Moreover, core and wireline data from the wells combined with correlation to equivalent strata in nearby outcrops provide new insights into the age and depositional evolution of the succession. Thus, the data obtained from this project contributes to the regional stratigraphic understanding of the Mesozoic succession in Svalbard and the northern Barents Shelf. Until now, nearly 70 papers have been published in international peer-reviewed journals using data from or part of the Longyearbyen CO_2 Laboratory. In addition, 13 PhD candidates and 27 master students, linked to the project or using obtained data from the project, have graduated. The main achievement of our studies is that we have shown that unconventional fractured reservoirs are suitable for storing CO_2.

Keywords: Spitsbergen, CO_2 storage, fractured unconventional reservoir, shale gas, Mesozoic, underpressure, caprock, coring

Received 5. November 2019 / Accepted 22. November 2019 / Published online X

Introduction

Longyearbyen's coal-fueled power plant is a significant point-source CO_2 emitter in an environmentally sensitive Arctic terrain. To reduce the emissions from the power plant, and to characterise the CO_2 storage potential of the local subsurface, the Longyearbyen CO_2 lab project was established in 2007 (Braathen et al., 2012; Sand et al., 2014) based in an academic consortium backed by industry and the Research Council of Norway. With time, maintenance and ownership of significant infrastructure (e.g., well park with 8 drilled wells and nearly 4.5 km of drillcore) and datasets (seismic, water-injection tests, electric and lithological logs, etc.) were transferred to the UNIS CO_2 Lab, a company fully owned by the University Centre in Svalbard (UNIS).

Olaussen, S., Senger, K., Braathen, A., Grundvåg, S.A. & Mørk, A. 2019: You learn as long as you drill; research synthesis from the Longyearbyen CO_2 Laboratory, Svalbard, Norway. *Norwegian Journal of Geology 99*, 157-187. https://dx.doi.org/10.17850/njg008.

One of the great challenges in carbon capture and storage (CCS) is finding suitable reservoir units, i.e., storage units, with sufficient permeability and porosity for efficient injectivity of CO_2, combined with suitable pressure and temperature for CO_2 to be stored in a critical fluid phase. Another challenge is proving storability by identifying a cap rock with sufficient seal capacity to de-risk subsurface migration of a buoyant fluid. Finally, the actual storage units should be within a convenient distance to the CO_2 point source, i.e., the Longyearbyen power plant in this case. Fortunately, Adventdalen, a major valley close to Longyearbyen, offers Mesozoic strata where both storage formations and cap rocks are present, many being analogous to reservoir and seal units in the southwestern Barents Sea oil and gas province (Fig. 1) (Nøttvedt et al., 1993; Worsley, 2008).

In regard to the favourable geological setting, Svalbard should then be suitable for storage and sealing of buoyant fluids. Longyearbyen CO_2 Lab used pressurised water with tracers to test the injectivity in three out of the total eight wells drilled, while two other wells were used for short- and long-term pressure measurements. Besides step-rate and high-pressure water injection and leak-off tests (LOT), a unique dataset of fall-off pressure measurements covering several years after the injection tests was obtained to understand fluid flow behaviour. Fig. 2 shows the design of the deepest well drilled in the Longyearbyen CO_2 Lab.

Although being an onshore analogue, Svalbard shows some important geological differences to the oil and gas fields and discoveries of the southwestern Barents Sea. These include significant structural shortening (contraction in a fold and thrust belt) along western Spitsbergen during the Paleogene. Further, there are large magnitudes of Cenozoic subsidence and uplift, causing localised exhumation of deeply buried rocks. Accordingly, formerly deeply buried successions in western and central Spitsbergen (near the study site of Longyearbyen), now at a depth of a few hundred metres, rendered the Mesozoic sandstones tightly cemented, exhibiting low matrix permeability and porosity (Farokhpoor et al., 2010, 2013; Mørk, 2013; Magnabosco et al., 2014). Paleogene tectonics also resulted in extensive fracturing of the storage units and the cap rock (Ogata et al., 2014). Fluid-flow studies associated with the Longyearbyen CO_2 Lab particularly functioned as a case study of a potential storage unit qualifying as an unconventional (i.e., 'tight') fractured reservoir (Senger et al., 2015). This bridges across to global studies, as low-permeability and low-porosity rocks, are far more common in sedimentary basins worldwide. Although only tested by pressured water, we suggest that this pilot project provides a foundation for commercial ventures of CO_2 sequestration in unconventional storage units.

In addition to the open-access policy of a university-driven R&D project, the Longyearbyen CO_2 Lab has been rather unique in its strategy and workflow. New knowledge has generated new questions, guiding new academic and industrial innovative and focused research. The basic motivation; "you learn as long as you drill and test", has been realised in a vibrant knowledge pyramid following self-motivated risk management procedures.

Studies using material from the obtained data have thus far produced *c.* 70 peer-reviewed journal articles. Furthermore, the project facilitated the education of 13 PhD candidates and 27 masters, and established a graduate-level course in CO_2 sequestration. An overview of scientific articles and graduated students is given in Electronic Supplement 1 in this volume, and is also regularly updated on the project website at http://co2-ccs.unis.no/Publications.html.

The following summary is a continuation of the initial results presented by Braathen et al. (2012) who provided a brief review of the main tasks and results for the period between the project start in August 2007 and the end of Phase 1 in 2010. A summary volume in the Norwegian Journal of Geology (NJG), introduced by Sand et al. (2014), also summarises many of the key findings. The Phase II final report (freely available at http://co2-ccs.unis.no/Pdf/Longyearbyen%20CO2%20lab%20Phase%202%20Report_10_2015.pdf) provides important details following the active operational phase of the project. For details of all methods applied, see the Longyearbyen CO_2 Lab Phase II final report and former and enclosed publications (Electronic Supplement 1).

The aim of this paper is to present a summary of the more recent and partly surprising observations from the obtained subsurface data. This includes among others the discovery of unconventional gas and complex fluid-flow properties (PVT). Combinations of wireline logs (gamma-ray, P- and S-wave velocity and resistivity) and improved biostratigraphy and new data from chronostratigraphy, all based in fully cored sedimentary successions, have given new insights into the Mesozoic basin fill in Svalbard, and also to some extent, to nearby Arctic basins, including the northern Barents Shelf. Outcrops are commonly used to understand the subsurface geology in many buried sedimentary basins. However, the results reported in this volume also demonstrate the opposite; subsurface results have given us an improved understanding of the outcropping strata in Svalbard, which justifies the main title of this summary: "you learn as long as you drill".

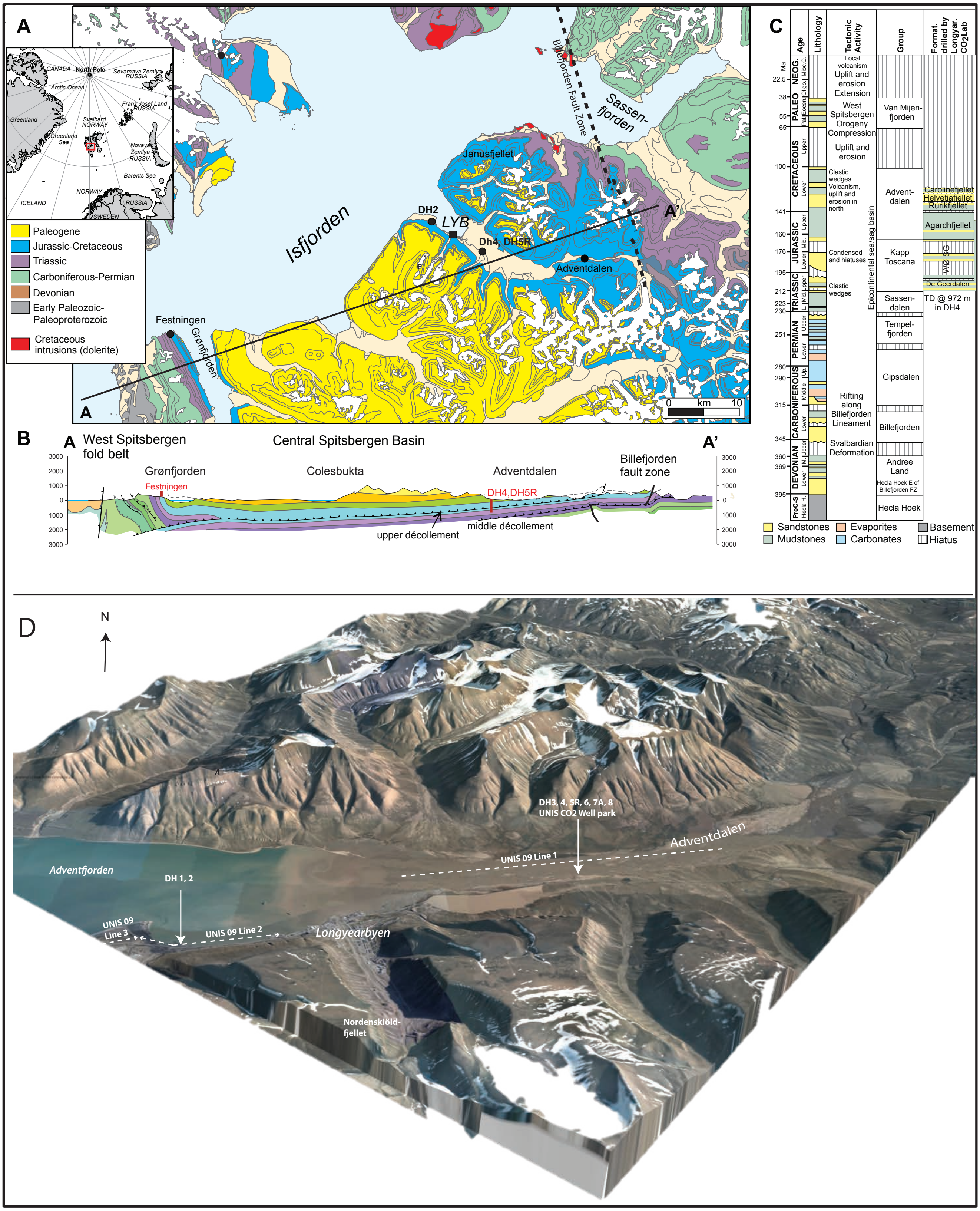


Figure 1. (A) Geological map showing the vicinity of Longyearbyen; (B) Geological cross-section and (C) Simplified stratigraphic column of Svalbard and the cored succession in the wells drilled near Longyearbyen. In the study area there are two thrust faults, seen as décollement zones that appear at two shale-dominated levels; in the Middle Triassic Botneheia Formation and the Middle Jurassic to Lower Cretaceous Agardhfjellet Formation (B). A lower regional décollement is located in evaporites of the Permian Gipshuken Formation (e.g., Bergh et al., 1997). (D). 3D view of the Adventfjorden and Adventdalen. Lines 1,2 and 3 are the acquired 2D regional seismic lines in Adventdalen and along the southern side of Adventfjorden. The seismic data are presented in Fig. 10.

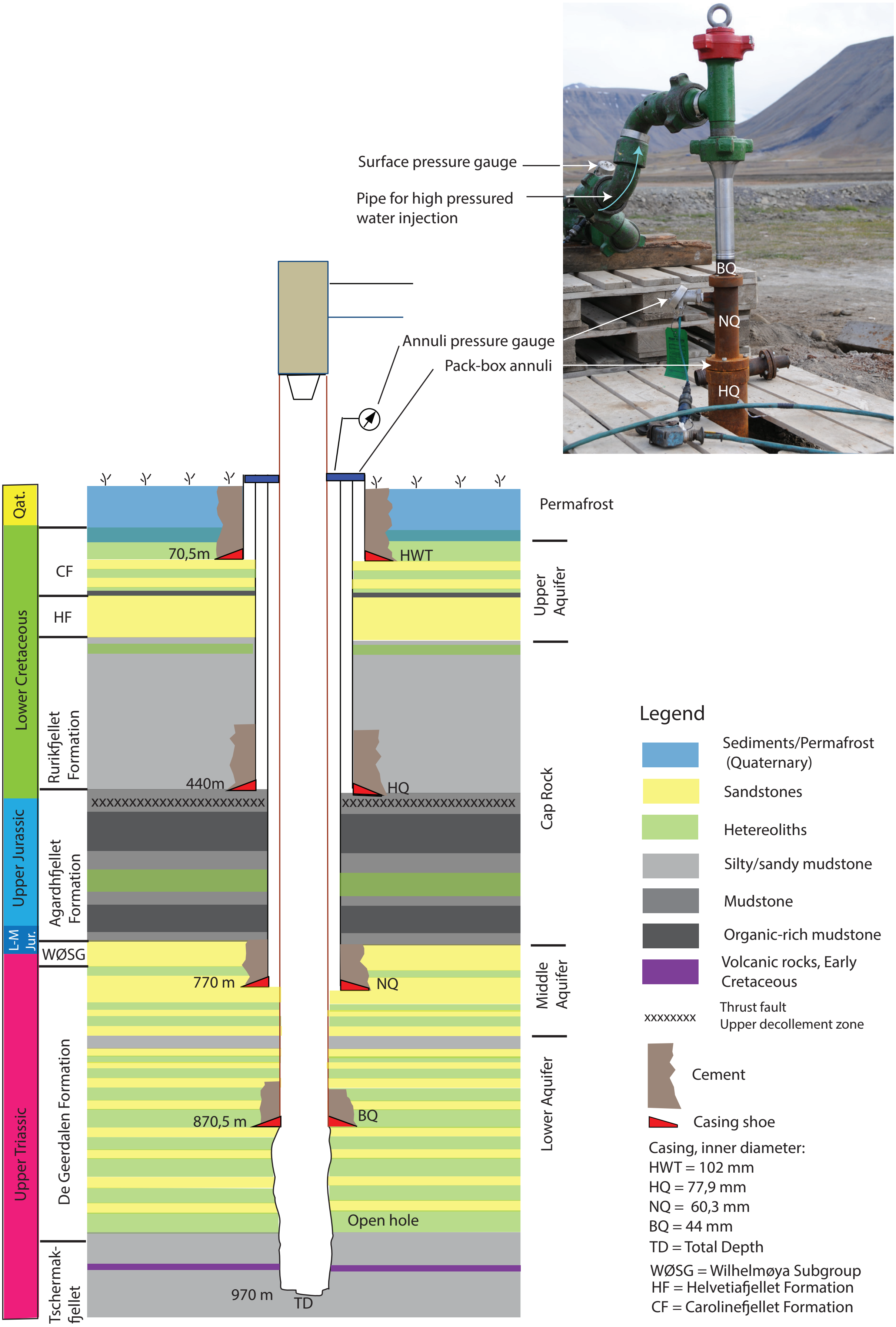


Figure 2. Well design of the borehole DH4; the deepest well drilled in UNIS CO$_2$ Lab, reaching 970 m. L–M. Jur. = Lower Middle Jurassic. The figure is not in vertical scale.

Highlights of the obtained subsurface results

Nearly all disciplines within geology and geophysics have benefited from the data obtained from the Longyearbyen CO_2 Lab. A wide range of spin-off research projects complement the main objective of characterising the reservoir-caprock system for CO_2 storage. Below follows a short summary of some of the most important results obtained from the subsurface investigations of the Mesozoic succession in Adventdalen.

Sedimentological facies analysis and sequence stratigraphy

Improved facies models. Core data and wireline logs combined with investigations of nearby outcrops have improved the general depositional models for all the drilled formations (Anell et al., 2014; Rød et al., 2014; Grundvåg et al., 2017, 2019; Olaussen et al., 2018; Jelby et al., in press; Koevoets et al., 2019a; Rismyhr et al., 2019). Representative sedimentary logs of all the cored units are shown in Figs. 3, 4 and 5.

*Hauterivian clastic wedge***.** The subsurface data have revealed the discovery of a previously unrecognised Hauterivian clastic wedge within the Rurikfjellet Formation in the two wells to the northwest of Longyearbyen (DH1 and DH2; Braathen et al., 2012; Grundvåg et al., 2017, 2019; Sliwinska et al., in press).

Late Quaternary glacial delta. One well, DH8, was specifically designed to drill and core near-surface sediments located in the permafrost zone. In this drillhole, a 60 m-deep frozen core consisting of post-glacial (i.e., early Holocene to present) sediments was successfully retrieved (Fig. 5). Detailed facies studies of the post-glacial succession in Adventdalen are given in Gilbert et al. (2018).

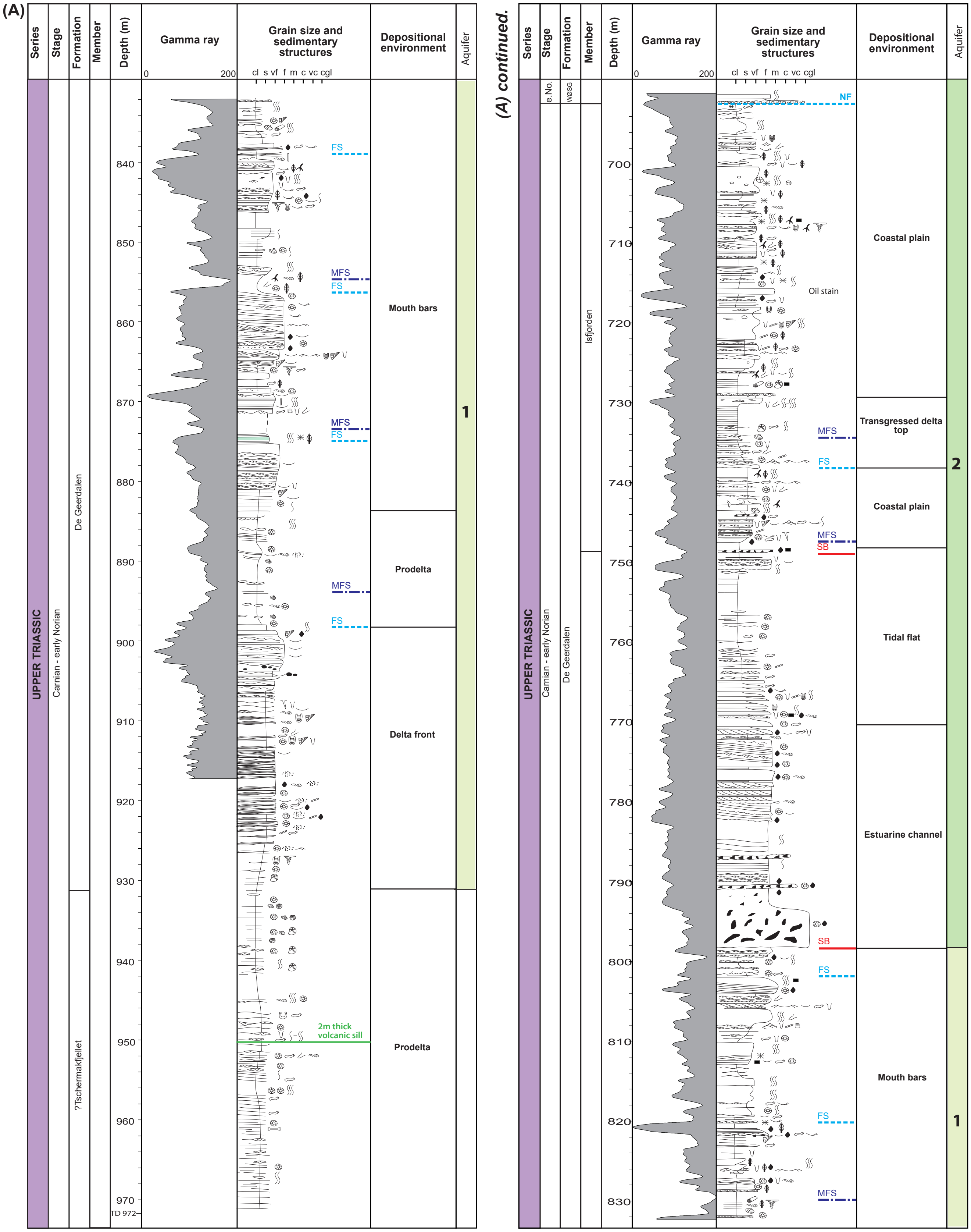
Key sequence-stratigraphic surfaces. Sedimentological core descriptions combined with wireline logs of the drilled succession enabled the recognition and definition of genetically linked stratigraphic units and their bounding surfaces (Fig. 6). Thus, we propose a subdivision of the various formations into non-hierarchical transgressive-regressive (TR) sequences that can be linked to the tectonic development of Svalbard and the northwestern Barents Shelf margin. Some of the bounding surfaces are key regional sequence-stratigraphic surfaces with a clear correlative link to nearby Arctic basins (Midtkandal et al., 2016; Grundvåg et al., 2017, 2019; Olaussen et al., 2018; Jelby et al., 2019; Koevoets et al., 2019a; Rismyhr et al., 2019). The following recognised surfaces are of regional importance and have been better age-constrained by our associated studies (Figs. 3, 4, 5, 6); i) the Norian flooding surface; ii) the lower Jurassic unconformity (down-cutting the Rhaetian unconformity on Spitsbergen); iii) the Bajocian unconformity; iv) the lower Bathonian flooding surface; v) the basal surface of the condensed Valanginian Myklegardfjellet Bed, which is closely associated with the Base Cretaceous Unconformity offshore; vi) the lower Barremian subaerial unconformity, and vii) the lower Aptian flooding surface associated with the early Aptian Oceanic Anoxic event; OAE1a (Midtkandal et al., 2016). OAE1, which also has a source-rock potential, has now been recognised in all the wells and in outcrops across the entire Lower Cretaceous outcrop belt on Spitsbergen (Grundvåg et al., 2019).

*Unconventional storage (reservoir) units***.** Petrographic and diagenetic studies have confirmed a prognosis of previous deeply buried sandstones with low matrix permeability and low to moderate porosity, in line with the maturation of the succession (Abay et al., 2017; Ohm et al., 2019). The low porosity of the sandstones is due to quartz and carbonate cementation. The higher porosity of 18 to 20% in sandstones of the Wilhelmøya Subgroup is a result of feldspar dissolution and offers non-effective porosity. i.e., dead-end pore space conforming to very low permeability in the range of 1–2 mD (Mørk, 2013). In contrast, the quartz-cemented quartz arenites of the Festningen Member of the Helvetiafjellet Formation have a porosity of 10% or less but record up to 100 mD in permeability.

Bio-, chrono-, chemo- and magnetostratigraphy

*New absolute age of the deltaic coastal plain segment of the Helvetiafjellet Formation***.** Absolute age dating of a 10 cm-thick bentonite in the middle part of the Helvetiafjellet Formation, i.e. the Glitrefjellet Member has yielded an age of 123.3 ± 0.2 Ma (Corfu et al., 2013). The indicated age better constrains the timing of volcanism related to the High Arctic Large Igneous Province (HALIP; Senger et al., 2014b; Polteau et al., 2016). In addition, a carbon-isotope signal attributed to the early OAE1a was identified in a lower Aptian mudstone at the base of the overlying Carolinefjellet Formation. Collectively, this suggests that the Barremian-Aptian boundary should be revised in the international geological time scale (Midtkandal et al., 2016). Recent magnetostratigraphic studies of Svalbard boreholes combined with the reported results given above, thus propose that the Barremian-Aptian boundary should be placed at 121.2 ± 0.4 Ma (Zang et al., 2018).

*High-resolution biostratigraphy***.** Biostratigraphic studies of the Upper Triassic to Lower Cretaceous succession have improved our tectonostratigraphic understanding of the Mesozoic succession in Svalbard and its link to the Barents Shelf and other adjacent Arctic basins (Smelror et al., 2018; Rismyhr et al., 2019). Detailed facies analysis


(A)
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
cl s vf f m c vc cgl
Depositional environment
Aquifer
UPPER TRIASSIC
Carnian - early Norian
De Geerdalen
?Tschermakfjellet
840
850
860
870
880
890
900
910
920
930
940
950
960
970
TD 972
FS
MFS
FS
MFS
FS
MFS
FS
2m thick volcanic sill
Mouth bars
Prodelta
Delta front
Prodelta
1
(A) continued.
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
cl s vf f m c vc cgl
Depositional environment
Aquifer
UPPER TRIASSIC
e.No.
Carnian - early Norian
WØSG
De Geerdalen
Isfjorden
700
710
720
730
740
750
760
770
780
790
800
810
820
830
NF
Oil stain
MFS
FS
MFS
SB
SB
FS
FS
MFS
Coastal plain
Transgressed delta top
Coastal plain
Tidal flat
Estuarine channel
Mouth bars
2
1

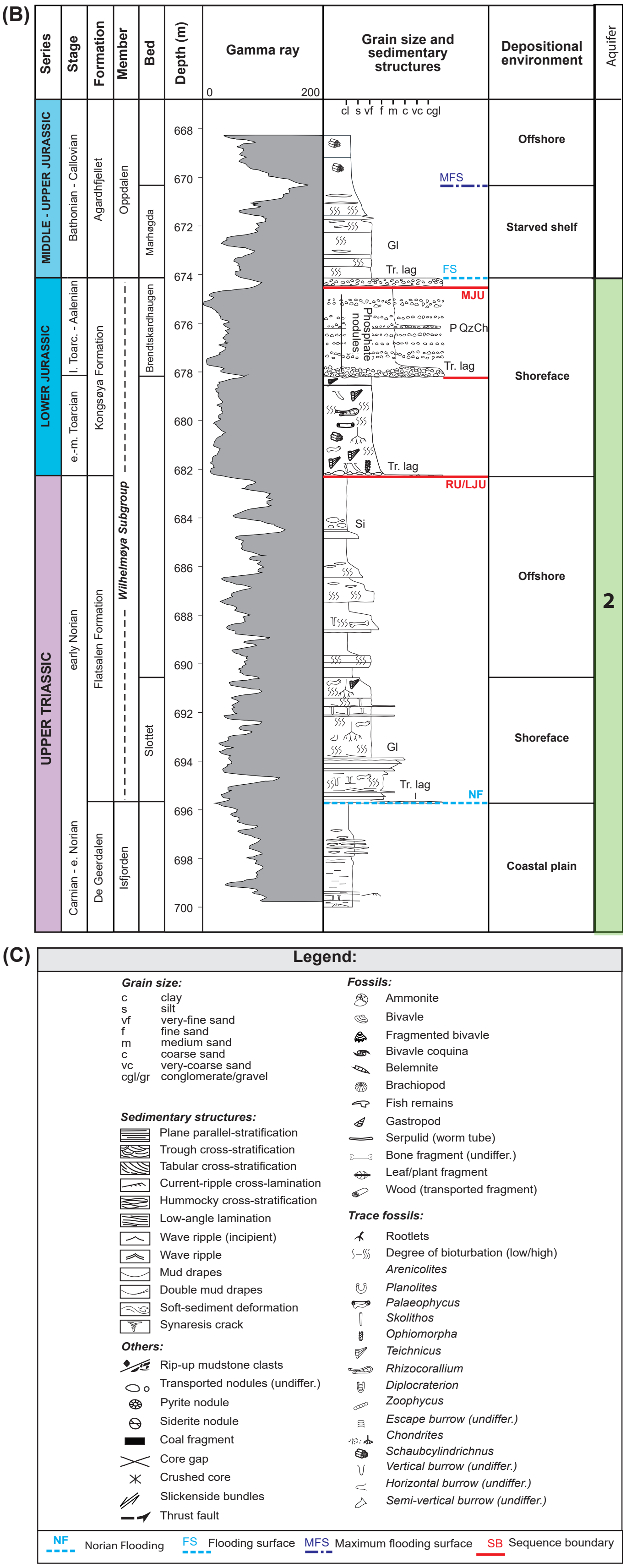
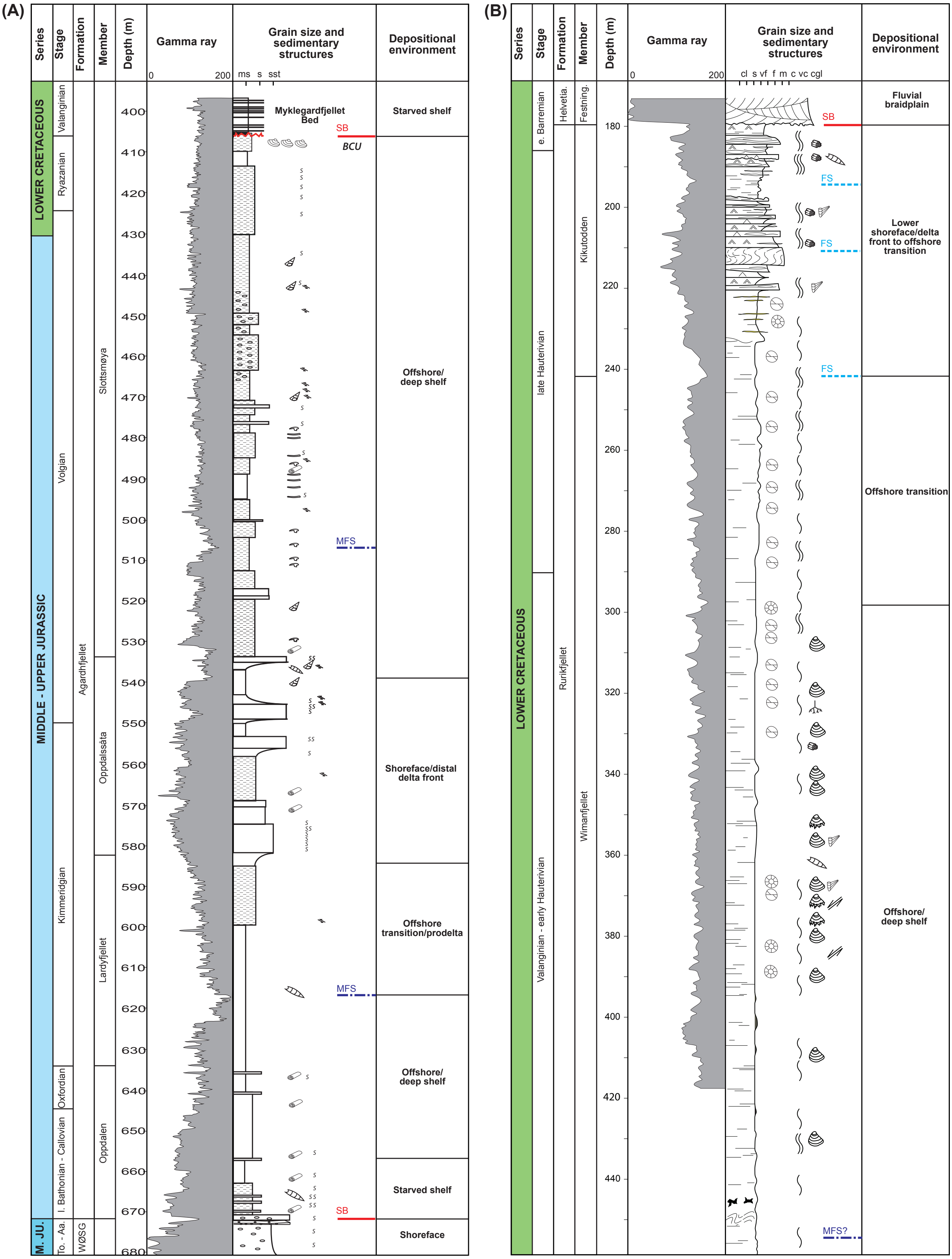


Figure 3. Logs of the Upper Triassic to Middle Jurassic succession, i.e., the main storage units, covering the Tschermakfjellet Formation, De Geerdalen Formation and Wilhelmøya Subgroup, modified from (A) Husteli (unpublished) and (B) Rismyhr et al. (2019), respectively.


(A)
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
ms s sst
Depositional environment
LOWER CRETACEOUS
MIDDLE - UPPER JURASSIC
M. JU.
Valanginian
Ryazanian
Volgian
Kimmeridgian
Oxfordian
l. Bathonian - Callovian
To. - Aa.
Agardhfjellet
WØSG
Slottsmøya
Oppdalssåta
Lardyfjellet
Oppdalen
400
410
420
430
440
450
460
470
480
490
500
510
520
530
540
550
560
570
580
590
600
610
620
630
640
650
660
670
680
Myklegardfjellet Bed
SB
BCU
MFS
MFS
SB
Starved shelf
Offshore/ deep shelf
Shoreface/distal delta front
Offshore transition/prodelta
Offshore/ deep shelf
Starved shelf
Shoreface
(B)
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
cl s vf f m c vc cgl
Depositional environment
LOWER CRETACEOUS
e. Barremian
late Hauterivian
Valanginian - early Hauterivian
Helvetia.
Rurikfjellet
Festning.
Kikutodden
Wimanfjellet
180
200
220
240
260
280
300
320
340
360
380
400
420
440
SB
FS
FS
FS
MFS?
Fluvial braidplain
Lower shoreface/delta front to offshore transition
Offshore transition
Offshore/ deep shelf

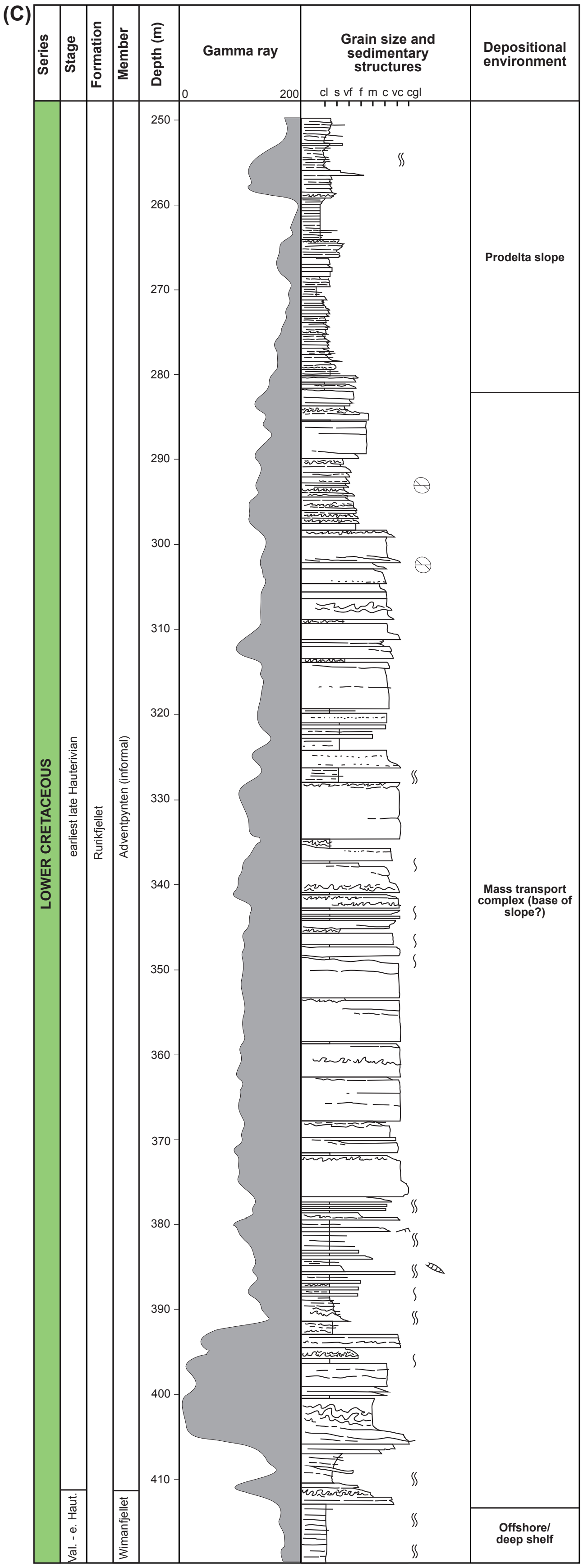
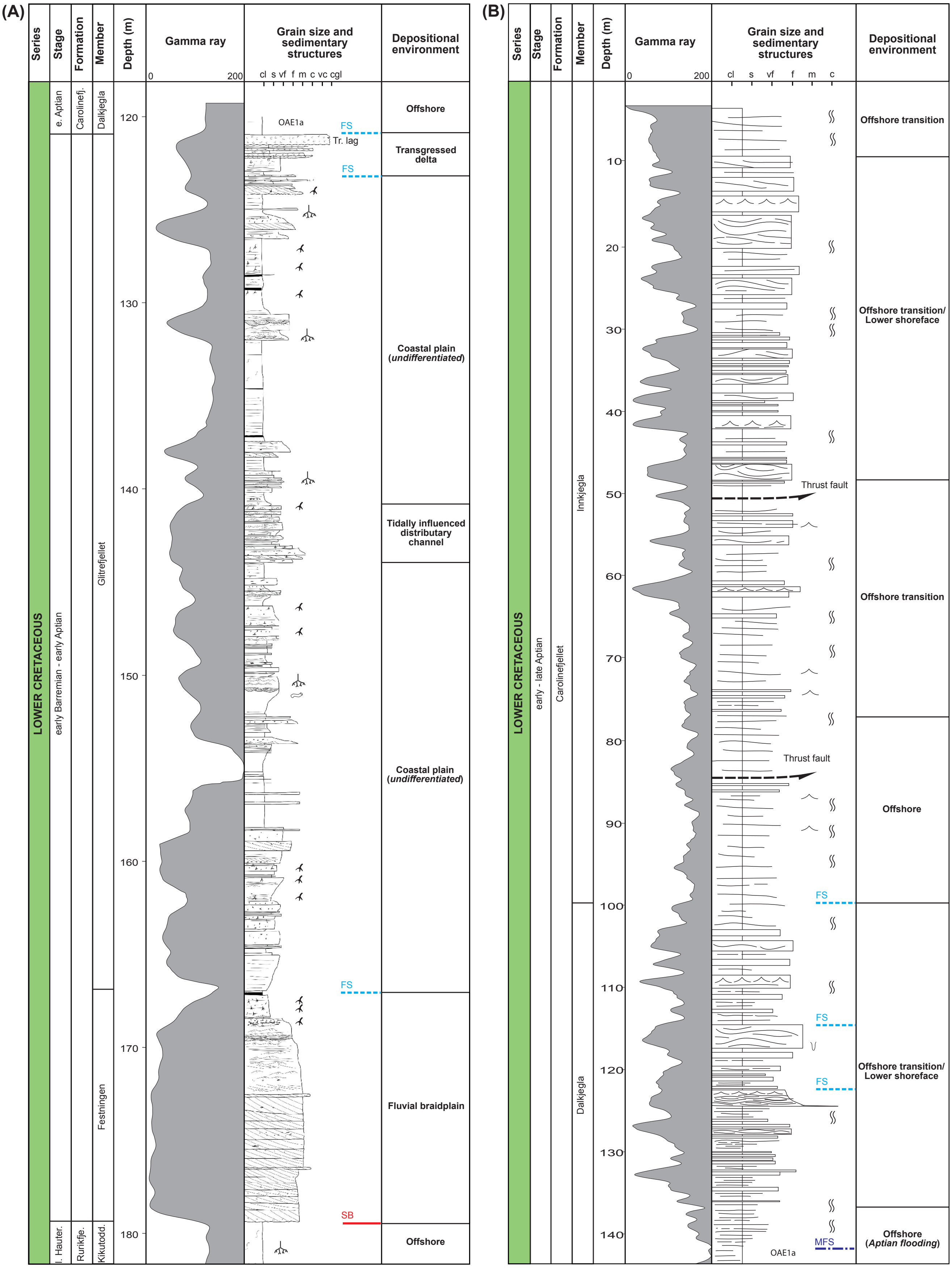


***Figure 4.** Logs of the Middle Jurassic to Lower Cretaceous succession and Rurikfjellet Formation. (A) The Agardhfjellet Formation is from DH2, modified from Koevoets et al. (2019a). (B) The Rurikfjellet Formation in well DH5R; modified from Jelby (2015). (C) The Adventpynten Member of the Rurikfjellet Formation in well DH1; modified from Grundvåg et al. (2017, 2019).*


(A)
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
cl s vf f m c vc cgl
Depositional environment
LOWER CRETACEOUS
e. Aptian
early Barremian - early Aptian
l. Hauter.
Carolinef.
Rurikfje.
Dalkjegla
Glitrefjellet
Festningen
Kikutodd.
120
130
140
150
160
170
180
OAE1a
FS
Tr. lag
FS
FS
SB
Offshore
Transgressed delta
Coastal plain (undifferentiated)
Tidally influenced distributary channel
Coastal plain (undifferentiated)
Fluvial braidplain
Offshore
(B)
Series
Stage
Formation
Member
Depth (m)
Gamma ray
0
200
Grain size and sedimentary structures
cl s vf f m c
Depositional environment
LOWER CRETACEOUS
early - late Aptian
Carolinefjellet
Innkjegla
Dalkjegla
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Thrust fault
Thrust fault
FS
FS
FS
MFS
OAE1a
Offshore transition
Offshore transition/ Lower shoreface
Offshore transition
Offshore
Offshore transition/ Lower shoreface
Offshore (Aptian flooding)

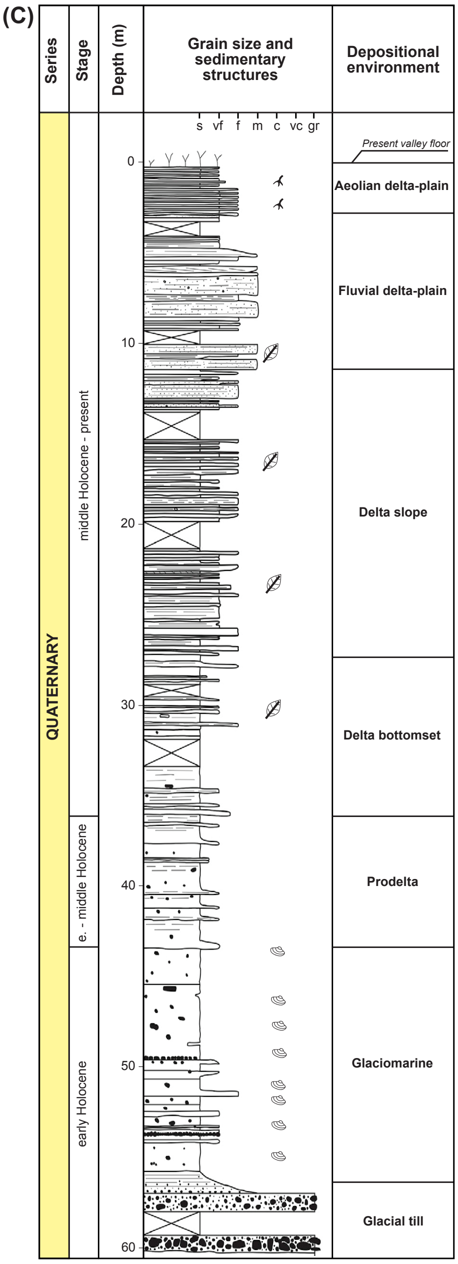


Figure 5. (A) Logs of the Lower Cretaceous Helvetiafjellet Formation; well DH5R, (B) Carolinefjellet Formation, well DH1, both modified from Grundvåg et al. (2017, 2019). (C) represents the Quaternary near-surface succession drilled in the permafrost zone (well DH8), modified from Gilbert et al. (2018).

combined with new palynology analysis of the thin (<20 m thick) and very condensed Norian to Bathonian succession, the Wilhelmøya Subgroup, have resulted in a revision of some of the key regional sequence-stratigraphic surfaces.

Revised biostratigraphy of Bathonian to Aptian. The biostratigraphy of the Adventdalen Group has been considerably improved thanks to high-quality material from the full coring and wireline logging (Fig. 7) (Grundvåg et al., 2017, 2019; Koevoets et al., 2018, 2019a, b; Hammer et al., 2019; Sliwinska et al., 2019). However, some challenges remain, especially around the Jurassic–Cretaceous boundary.

*$\delta^{13}C$ excursion for regional correlation***.** The updated biostratigraphic framework combined with the $\delta^{13}C$ excursion of the Bathonian to Volgian and Barremian to Aptian of the cored successions gives an additional tool for regional correlation (Koevoets et al., 2016; Midtkandal et al., 2016). Ongoing studies will include the Volgian to Hauterivian succession.

Organic geochemistry and hydrocarbons

*Originally oil-prone source rocks***.** Oil-prone source rocks are proven in the late Oxfordian to early Kimmeridgian succession and in the late Kimmeridgian Volgian/early Ryazanian successions in the CO$_2$ Lab wells. These will probably be in the gas window downdip of the well sites (Koevoets et al., 2016; Abay et al., 2017, 2018; Ohm et al., 2019).

Late-oil to gas window organic-rich shales. Based on vitrinite and T-max values (Fig. 8), the maturity of the Middle Jurassic to Lower Cretaceous, Agardhfjellet Formation, organic-rich mudstones has been better constrained. These mudstones are in the late-oil maturation to gas window. Furthermore, the oil and gas isotope composition of a Lower Cretaceous coal bed suggests that most of the succession is in the late-middle oil window generation, i.e., the formation has experienced maximum burial temperatures of 150–180°C (Koevoets et al., 2016; Abay et al., 2017, 2018; Grundvåg et al., 2019; Ohm et al., 2019).

High paleo-temperature gradient. The drill core data combined with published vitrinite reflectance and T-max data indicate that approximate 2,5km of overburden is missing above the valley bottom in Adventdalen (Fig. 8). A high paleo-temperature gradient of 50 to 54 °C/km for the Cenozoic (Eocene) is suggested in this area (Marshall et al., 2015; T. Throndsen, pers. comm. 2019).

*Lower Aptian potential gas condensate source rocks***.** At the base of the Carolinefjellet Formation, the lower Aptian mudstone unit which is associated with a regional flooding event i.e., the Aptian oceanic anoxic event; the

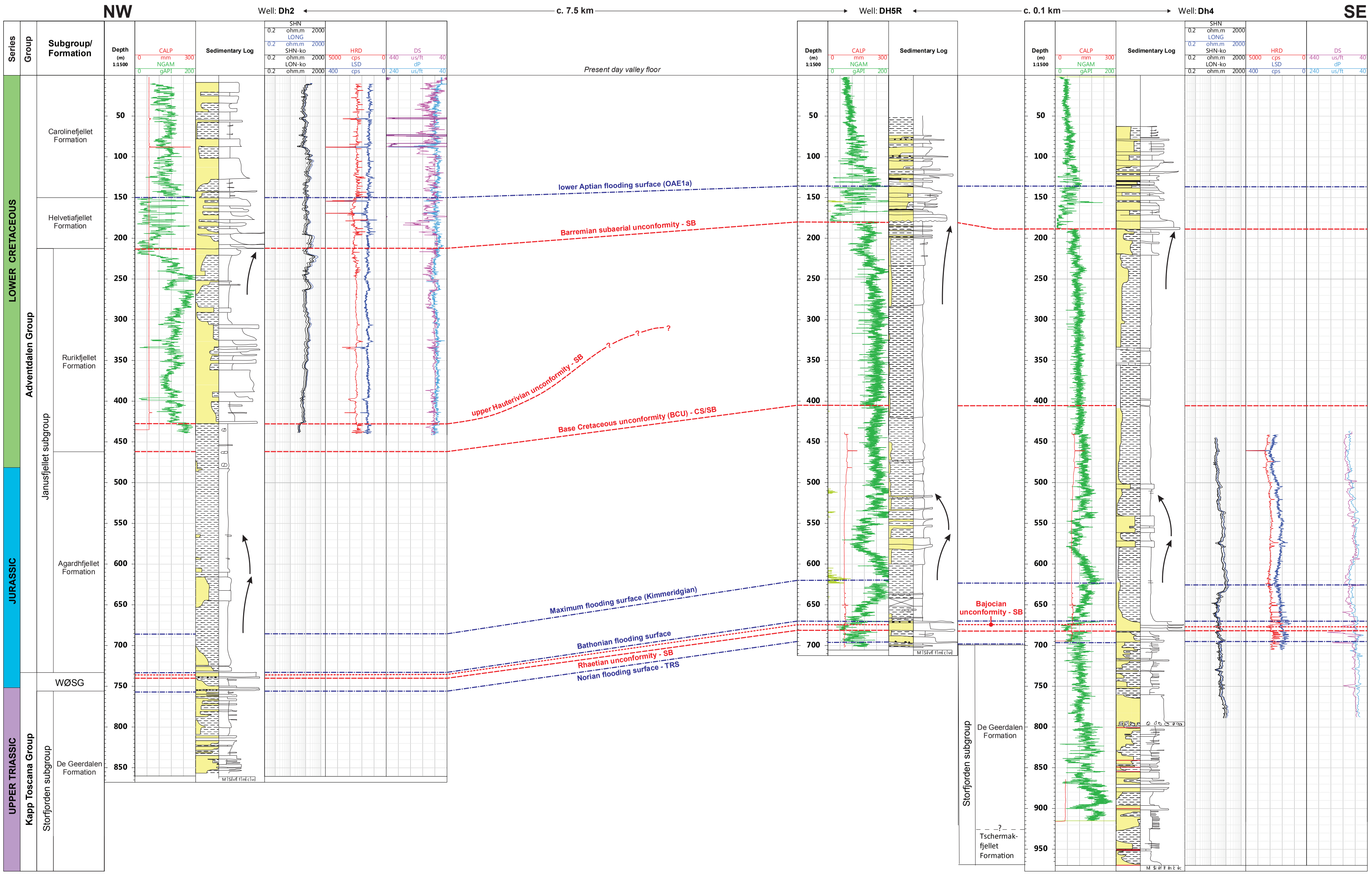


Figure 6. Proposed sequence stratigraphy for the drilled succession based on the wells drilled in the Longyearbyen CO_2 lab. Acronyms for wireline log tools: CALP – Caliper, NGAM – Gamma-ray, SHN/LONG – resistivity tools with different penetration depths, HRD/LSD – qualitative density, DS – travel time (S-wave), dP – travel time (P-wave). See Elvebakk (2008, 2010) for details.

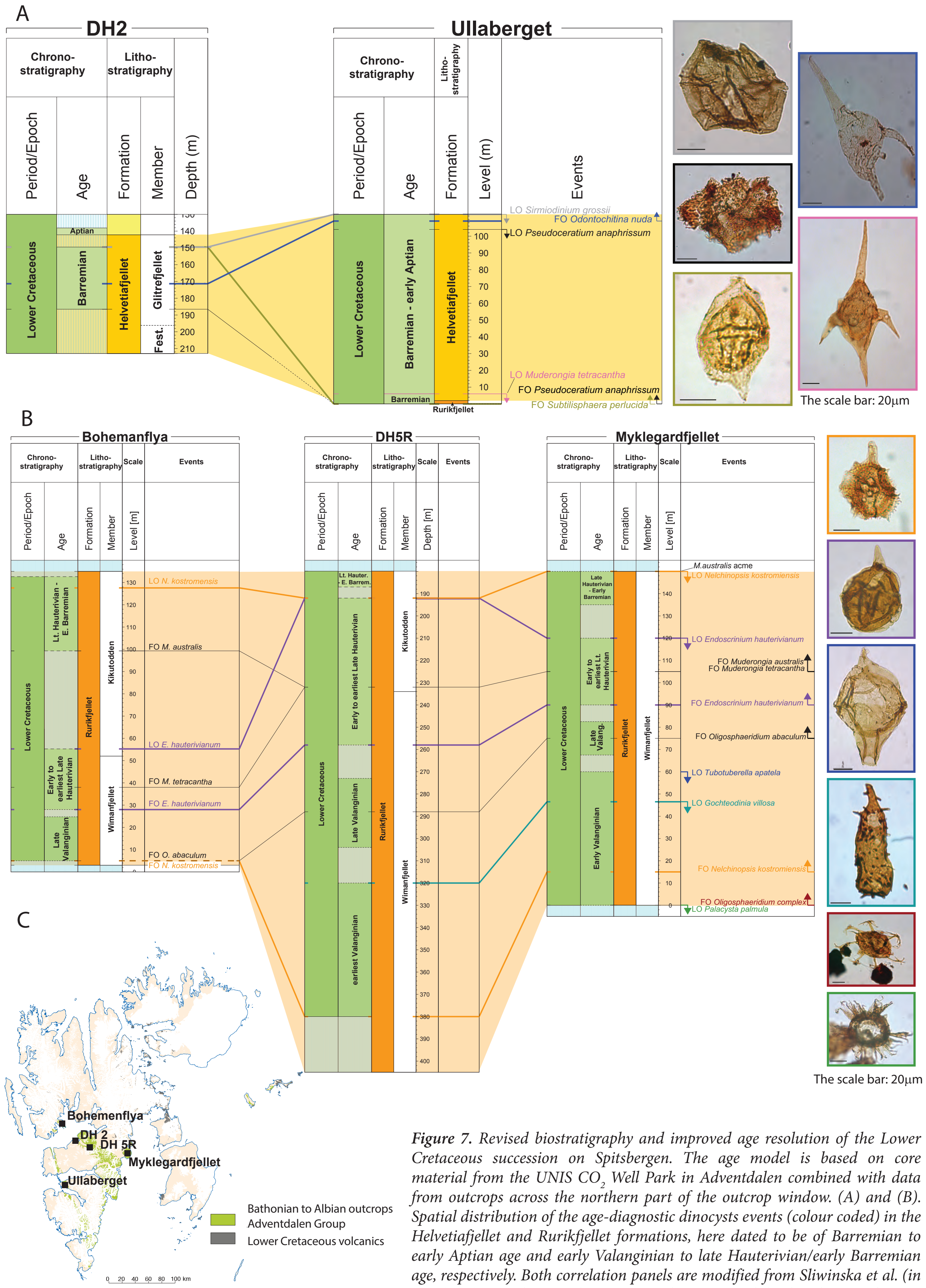


Figure 7. Revised biostratigraphy and improved age resolution of the Lower Cretaceous succession on Spitsbergen. The age model is based on core material from the UNIS CO_2 Well Park in Adventdalen combined with data from outcrops across the northern part of the outcrop window. (A) and (B). Spatial distribution of the age-diagnostic dinocysts events (colour coded) in the Helvetiafjellet and Rurikfjellet formations, here dated to be of Barremian to early Aptian age and early Valanginian to late Hauterivian/early Barremian age, respectively. Both correlation panels are modified from Sliwinska et al. (in press). (C) Map showing the investigated sections and the distribution of Lower Cretaceous strata in Svalbard. The map is compiled by Winfried Dallmann.

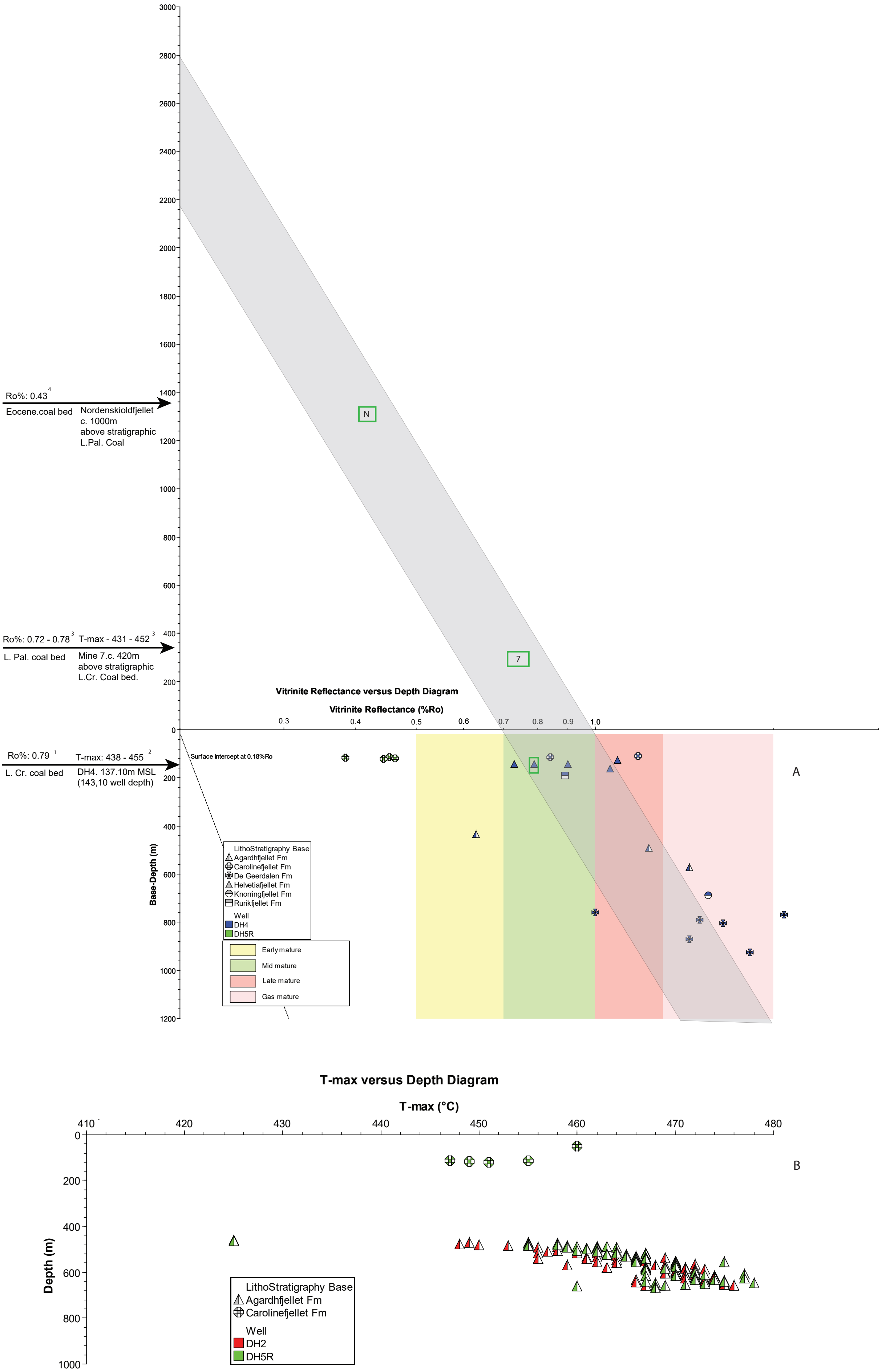

Ro%: 0.43 4
Eocene.coal bed
Nordenskioldfjellet c. 1000m above stratigraphic L.Pal. Coal
Ro%: 0.72 - 0.78 3
T-max - 431 - 452 3
L. Pal. coal bed
Mine 7.c. 420m above stratigraphic L.Cr. Coal bed.
Ro%: 0.79 1
T-max: 438 - 455 2
L. Cr. coal bed
DH4. 137.10m MSL (143,10 well depth)
N
7
Vitrinite Reflectance versus Depth Diagram
Vitrinite Reflectance (%Ro)
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
Base-Depth (m)
Surface intercept at 0.18%Ro
LithoStratigraphy Base
Agardhfjellet Fm
Carolinefjellet Fm
De Geerdalen Fm
Helvetiafjellet Fm
Knorringfjellet Fm
Rurikfjellet Fm
Well
DH4
DH5R
Early mature
Mid mature
Late mature
Gas mature
A
T-max versus Depth Diagram
T-max (°C)
410
420
430
440
450
460
470
480
0
200
400
600
800
1000
Depth (m)
LithoStratigraphy Base
Agardhfjellet Fm
Carolinefjellet Fm
Well
DH2
DH5R
B

Figure 8. *T-max values for vitrinite (A) and T-max (B) values from the cored succession. For details see Koevoets et al. (2016) and Ohm et al. (2019). Vitrinite and T-max are from a coal seam in the overlying coal in the Paleocene Firkanten Formation and the late Eocene Aspelintoppen Formation; see Marshall et al. (2015) for details. Although only a few points, a simplified trend can be established based on: i) a coal sample from the Lower Cretaceous Helvetiafjellet Formation (T. Throndsen, pers. comm. 2016) (green framed with a black pyramid in A); vitrinite value together with a coal sample from the Firkanten Formation in Mine 7 (Green framed 7 in A) (Marshall et al., 2015) and Aspelintoppen Formation on Nordenskjöldtoppen (Fig. 1) (Green framed N in A) (Throndsen, 1982). Using this vitrinite trend, more than 2 km of overburden is missing in the Adventdalen region. In a regional context this is consistent with a raised paleo-temperature gradient of 50 to 54 °C/km during the Cenozoic, cf. Marshall (2015) and T. Throndsen (pers. comm. 2019) respectively. The figure is modified from Ohm et al. (2019). 0 m in depth is 6 m above Mean Sea Level (MSL). L. Pal = Lower Paleogene; L. Cr. = Lower Cretaceous; (1)) T.Throndsen, pers. comm. 2015; (2)) Grundvåg et al. (2019); (3)) Marshall et al. (2015). (4)) Throndsen (1982).*

OAE1a is proven as a gas condensate-prone organic-rich mudstone. This mudstone unit is now recognised throughout Svalbard (Midtkandal et al., 2016; Grundvåg et al., 2017, 2019).

*Middle Triassic migrated oil***.** Oil (bitumen)-stained sandstones in the De Geerdalen Formation are linked to migrated oil from the Middle Triassic Botneheia Formation. In addition, gas shows in this formation suggest migration from a deeper source (Abay et al., 2017; Ohm et al., 2019).

*Discovery of shale gas***.** Dry to semi-dry thermogenic gas was discovered during water injection testing of the Wilhelmøya Subgroup and the lowermost part of the Agardhfjellet Formation in wells DH7A and DH5R. A 59 m open-hole interval of the Wilhelmøya Subgroup and lowermost part of the Agardhfjellet Formation in DH5R was production tested (Fig. 9) and shows potential for unconventional production (Ohm et al., 2019).

Figure 9. *Flared thermogenic gas from open hole at 648–701 m depth, well DH5R. Stable semi-dry gas, i.e., 95% methane was produced at a stable rate of 1500 Sm^3/day, see Ohm et al. (2019) for details.*

Gas hydrates. Natural gas hydrates are likely to be present onshore Svalbard, as suggested by regional thermo-baric modelling (Betlem et al., 2019). In Adventdalen, the presence of higher-order hydrocarbons suggests that some of the gas trapped beneath the permafrost could well be in gas hydrate form. Experimental modelling of CO_2-hydrate formation in cores from the Helvetiafjellet Formation suggests that CO_2 hydrate may form an additional self-sealing unit at the pressure–temperature conditions in the upper aquifer (Almenningen et al., 2019).

Thermogenic gas leakage in nearby fjords. Past gas leakage indicated by pockmarks throughout Isfjorden has been relatively common (Roy et al., 2015) and a baseline study was conducted for Adventfjorden (Roy et al., 2014). Recently, thermogenic gas seepage was documented in Isfjorden and Storfjorden (Liira et al., 2019), and active gas seepage through the water column in Nordfjorden (Roy et al., 2019).

Geophysical studies

Poor geophysical images. Conventional 2D reflection seismic studies have suffered from weak imaging due to both high-velocity rocks and permafrost within the upper 120 m of heterolithic Holocene deposits. Accordingly, there is significant uncertainty on more detailed scales (Bælum et al., 2012). Strong reflectors below the deepest borehole are likely imaging Early Cretaceous igneous intrusions as also observed in nearby outcrops) and are penetrated in the DH4 borehole (Fig. 10) (Senger et al., 2013, 2014a,b). However, a well tie suggests good imaging of the base Helvetiafjellet Formation and near-top Kapp Toscana Formation reflectors, both known to represent key sequence-stratigraphic surfaces and regional reflectors. Further, the top of the Kapp Starostin Formation (Fig. 10) is identifiable, albeit at times distorted by possible intrusive sills. Overall, the mappable reflectors of the strata follow the general trend of the geological maps in the area (cf., Dallmann, 2015). Furthermore, the regional ties to commercial seismic profiles allow regional correlation of the drilled succession towards eastern Svalbard (Anell et al., 2014).

Microseimic water injection and flow detection. In addition to conventional seismic reflection data, a microseismic array was established using five, near-surface, 3C geophones (depth of 12 m) and two geophone strings. Strings were deployed in the DH3

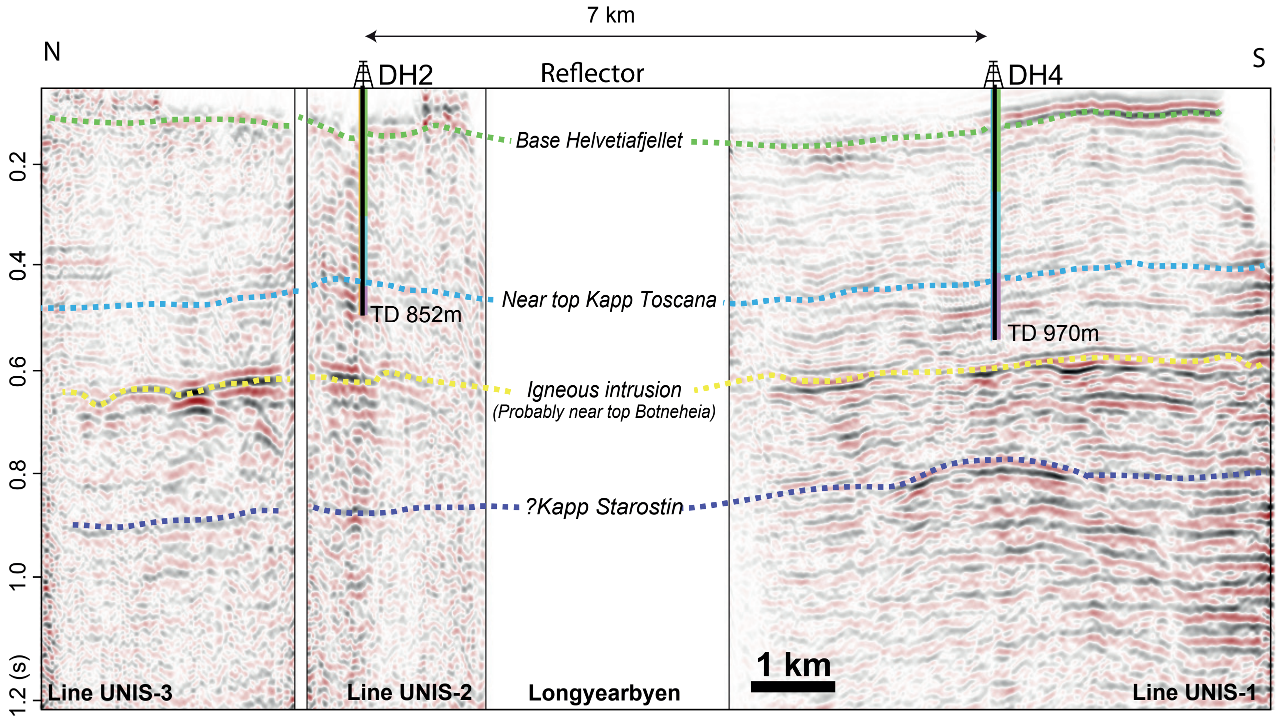


Figure 10. First-order seismic to well correlation, using project-acquired 2D seismic data linking the two drill sites near Longyearbyen. For details on the seismic acquisition, see Bælum et al. (2012).

(5-level 3C geophone string at 100–300 m depth) and DH4 (8-level 3C geophone string to 590 m depth, i.e., beneath the décollement zone) wells during the water-injection tests (Oye et al., 2013; Kühn et al., 2014). The most comprehensive water-injection test in 2010 resulted in a single ~M1 event, with seven aftershocks identified through normalised cross-correlation (Kühn et al., 2014). Subsequent water-injection tests did not result in detectable events. This result suggests that aseismic fracture propagation is necessary to obtain satisfactory history matching of water-injection tests.

Complex velocity structure. Part of the challenge with precisely locating micro-earthquakes relates to the complex velocity structure of the area, and especially the permafrost which is not characterised by the velocity logs at the UNIS CO_2 lab well park. Shear-wave seismic measurements were conducted to contribute to an improved velocity model (Lecomte et al., 2014).

Seismic interferometry. Seismic interferometry using seismic noise was also considered as a possible monitoring method, particularly attractive in the long-term (Tsuji et al., 2016).

*Passive seismic***.** The micro-seismic monitoring during the injection phase facilitated attempts to improve the signal-to-noise ratio in passive seismic data, for instance by adaptive cancellation (Harris et al., 2017)

*Magnetotelluric studies***.** The deep and well characterised boreholes in Adventdalen were also used to calibrate various non-seismic acquisition campaigns, including regional magnetotelluric studies targeting geothermal potential (Beka et al., 2016), joint MT–TEM profiling to characterise the resistivity structure of the uppermost 1 km (Beka et al., 2017) or combined nuclear magnetic resonance with audio-magnetotelluric data to characterise the water content in and around the permafrost in Adventdalen (Keating et al., 2018).

Wireline logging. Wireline logging (Fig. 11) including caliper, gamma-ray, resistivity, velocities (P and S waves) and acoustic televiewer have been important tools for improvement of facies associations, sequence studies and subdivision of reservoir (storage) units (Grundvåg et al., 2017, 2019; Koevoets et al., 2019a; Mulrooney et al., 2019; Rismyhr et al., 2019).

PVT, Fluid-flow studies

Storage capacity. First-order static storage capacity estimates suggest that adequate capacity is present for the modest volumes required by the local coal-fueled power plant (Senger et al., 2015). There is, however, uncertainty around the fluid injectivity of the different storage units and the dimensions of the pressure compartments in Adventdalen. While the two lower aquifers are underpressured, the upper aquifer has a slight overpressure (Fig. 12, 13).

*Natural fractures***.** The low to moderate matrix porosity is partly offset by an extensive network of natural fractures that contribute both to fluid injectivity and to storage capacity. Detailed field studies (Ogata et al., 2012, 2014) provide comprehensive input on fracture orientations within the main reservoir units. Conversely, metre-scale normal faults offsetting the Wilhelmøya Subgroup likely baffle fluid flow along the formation within the spatial extent of the CO_2 lab well park (Mulrooney et al., 2019).

Micro CT proves connectivity. Detailed characterisation of fractures using micro CT-scanning provides constraints on the fracture aperture (Van Stappen et al., 2014), including the effects of varying pressure on the aperture (Van Stappen et al., 2018). Flow properties from injection tests and advanced porosity and permeability studies using CT scanning have proven connectivity between fractures and matrix in the lower aquifers.

*Seismic velocity vs CO_2 saturation***.** Numerous laboratory experiments have been conducted on samples from the CO_2 lab boreholes. Moghadam et al. (2016a), for instance, investigated the seismic velocity of CO_2-saturated sandstones as a function of pressure and temperature. This is expanded by Moghadam et al. (2016b) who investigated how permeability changes as a function of confining stress and pore pressure. All these experiments are crucial to correctly predicting the relative permeability of CO_2 within the reservoir intervals, and particularly for constraining modelling parameters with site-specific data (Moghadam et al., 2019). Nooraiepour et al. (2018) utilise both electric and elastic parameters to characterise how CO_2 flow within a fracture will change the overall parameters, providing important constraints for designing multi-physical monitoring systems.

Fracture-dominated linear flow. Injection tests, some with a Strontium tracer, show that fractures were the main fluid-flow parameters in the identified aquifers. Step-wise increase in flow rates and thereafter shut in, followed by fall-off curves of reservoir pressure, record transitions from matrix (or radial) flow to fracture-dominated, more linear flow in rocks with some permeability such as reservoirs (Senger et al., 2015).

*Three aquifers***.** Based on gas composition and isotopes, $^{87}Sr/^{86}Sr$ data and pressure gradients, the succession can be subdivided into three aquifers, as outlined in Table 1. Only the lower and middle aquifers are planned as CO_2 storage units. In contrast to the two lower aquifers with underpressure, the upper aquifer is slightly overpressured (Braathen et al., 2012; Betlem et al., 2019). In the middle aquifer, i.e., the upper part of the De Geerdalen Formation and Wilhelmøya Subgroup, Sr data indicate good lateral connectivity between the UNIS CO_2 Lab Well Park and the well DH2 well, approximately 7 km to the west (Fig. 1, 12). In contrast, injection tests within the UNIS CO_2 Lab Well Park suggest baffling and barriers between adjacent wells within the hours-days time-frame of the injection tests (Mulrooney et al., 2019).

Compartmentalisation of the aquifers. Sr isotope data ($^{87}Sr/^{86}Sr$) from residual salts in wells DH2, DH4, DH6, DH7A combined with gas composition and isotopes for fluid communications define the vertical compartmentalisation of the three aquifers (Fig. 12) (Huq et al., 2017; Ohm et al., 2019) These data combined with measured reservoir pressure from the aquifers show the sealing capacity of a buoyant fluid within a threshold of pore pressure, albeit with a degree of flow from the underlying reservoir partially into the overlying shale (Birchall et al., in review).

Severe underpressure. Pressure conditions define the expected phase of CO_2 at reservoir conditions, with direct implications on storage capacity (Senger et al., 2015). The severe underpressure encountered in the lower and middle storage units (Braathen et al., 2012; Birchall et al., in review) would lead to gas-phase CO_2 in the initial phase, though this may change to a denser liquid phase as reservoir pressure increases during injection. Clearly, the shallow reservoir depth and the severe underpressure are potential operational challenges, with similarities to sequestering CO_2 in depleted (i.e., anthropogenic underpressure) hydrocarbon fields (Hoteit et al., 2019), and careful site-specific evaluation is required to maintain adequate injection rates. The water-injection tests, however, clearly confirm better than expected fluid injectivity, even given the low-moderate permeability.

Mixture of water-carbon dioxide-methane. Miri et al. (2014) used experimental data and statistical analyses to predict how CO_2 interacting with saline water and light hydrocarbons encountered in the boreholes will affect the fluid mobility in the subsurface. Hydrocarbon impurities are, for instance, shown to increase plume migration rates.

Underpressure due to decompaction, unloading and possible fracturing of shales. Birchall et al. (in review) characterise the underpressure in Svalbard and exploration boreholes in the northern Barents Sea, concluding that it is a recent phenomenon associated with the ongoing uplift. The main mechanism is due to decompaction, unloading and possible fracturing of shales. Underpressure is transferred to reservoir intervals through the migration of fluid into the decompacted caprock, in line with isotope data in Huq et al. (2017) and global analogues (Birchall et al., in review). Repeated glacial loading and unloading cycles as modelled by Wangen et al. (2016) are a likely candidate for its cause.

Strontium isotope studies show barriers. Strontium isotopes (Fig. 12) (Huq et al., 2017) suggest the presence of an effective barrier or seal between the lower and the middle aquifer at approximately 800 m (Fig. 12). Pressures also indicate a barrier here with

***Table 1**. Summary of the properties of the three aquifers studied in the Longyearbyen CO_2 Lab.*

Aquifer	*Boundary*	*Lithology*	*Thickness (m)*	*Facies*	*Net sandstone sandstone-shale ratio*	*Average matrix porosity permeability*	*Sandstone body architectures, fluid flow*
Lower Includes the lower part of the De Geerdalen Formation (DGF)	Gradual transition from the lower shale part of a coarsening-upward (CU) unit.	Immature sandstone and shale. Scattered thin coal beds.	175 m	Pro-delta to delta front in the lower part passing upwards into mouth-bar deposits.	O.4	12%–0.5 mD For details of DGF see Mørk (2013).	Tabular sandstone bodies. Distributary channels might intersect the delta front and delta plain giving additional shoe-string reservoir architectures. A potential good reservoir body for fluid flow. Deep burial has resulted in severe chemical compaction and formed a low porosity and permeability reservoir. Main fluid flow via fractures.
Middle Includes the upper part of the De Geerdalen Formation and the Wilhelmøya Subgroup (WØSG)	Sharp, erosive boundary. Probably local undulation due to incision.	Sandstone and shale. Heterolithic sandstone. Shale with scattered carbonates and thin coal beds in the middle part of the aquifer. Mature (quartz-rich), coarser grained sandstone in deposits of the WØSG	125 m	The lower 50 m represent estuarine deposits followed by tidal flat and coastal/delta plain deposits intersected by a thin marine incursion. The lowermost part possibly represents an incised valley fill. The WØSG consists of interbedded sandstones and mudstones of shallow-marine and offshore origin, respectively.	O.5	14% –1 mD For details of WØSG see Mulrooney et al. (2019).	The thick fining-upwards unit in the lower part has similarities to equivalent strata described from Hopen (Klausen & Mørk, 2014) and probably has more limited lateral continuity with a more shoe-string reservoir architecture. The heterolithic part has a more tabular architecture, but is characterised by more mud-rich sandstones. In addition, lateral continuation of paleosols with calcrete profiles will be efficient vertical barriers for fluid flow. Deep burial and chemical compaction have resulted in a low-porosity and permeability reservoir. The coarser grained sandstones in the WØSG have somewhat higher permeability and porosity up to 18%. However, the porosity is of a non-effective type (dead-end porosity). Main fluid flow via fractures, including micro fractures, which give additional flow from matrix in WØSG.
Upper Includes the Helvetiafjellet Formation (HF) and the Carolinefjellet Formation (CF)	Sharp erosive boundary, undulating at longer distances due to fluvial incision.	**HF:** Massive quartz sandstone, partly conglomeratic passing upward to interbedded sandstone and shale with some thin (cm- to dm-scale) coal beds. **CF:** Immature sandstone, commonly carbonate cemented (i.e. siderite), and interbedded shale.	70 to 200 m	Lower part (HF) represents fluvial braid plain deposits succeeded by coastal / delta plain with scattered distributary channels. Upper part (CF) consists of offshore mudstones and heterolithic sandstone units of offshore transition to lower shoreface origin.	O.6 (Only HF)		The lower part of the HF has a tabular architecture and occurs as lateral continuous bodies in the central and western parts of Spitsbergen. The coastal (or delta) plain deposits consist mostly of tabular beds, but lenticular-shaped distributary channels might give additional shoe-string architectures. In outcrops, CU units are seen connected with the channellised sandstone units. The upper part (CF) is characterised by lenticular sandstone bodies partly embedded in shale. Carbonate cementation has led to low porosities. The sandstone in HF is intensely quartz cemented. Chemical compaction has led to a low-porosity permeability reservoir. However, 10–20 cm-thick beds of loosely consolidated sandstones are commonly seen at the base of the HF at the boundary to the Rurikfjellet Formation. Preliminary analysis suggests that clay-coated grains have impeded quartz cementation. Good permeability measurements (c. 100 mD) and near-instantaneous pressure response following cross-well water-injection tests between DH5R and DH6 testify good injectivity, despite a low matrix porosity. We attribute this to a combination of clean and well-sorted sandstone beds and micro-fracturing.

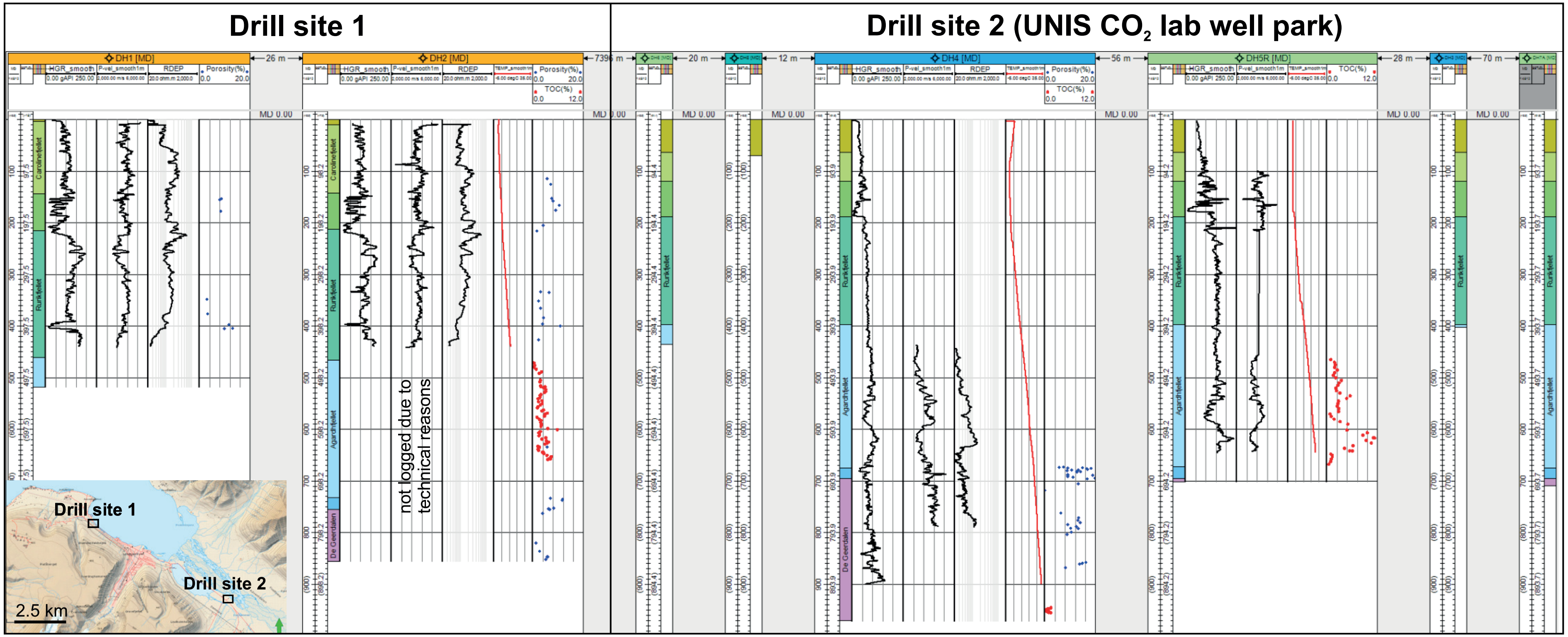


Figure 11. Summary of the wireline and core analysis data available in the wellbores drilled by the Longyearbyen CO_2 Lab. The inset map illustrates the location of the two main drill sites on opposite sides of Longyearbyen. Wireline logging was conducted by NGU (Elvebakk, 2008; Elvebakk, 2010; Braathen et al., 2012), TOC data (red) from Koevoets et al. (2016) and Senger et al. (2014) and porosity plug data (blue) from unpublished data and Mørk (2013).

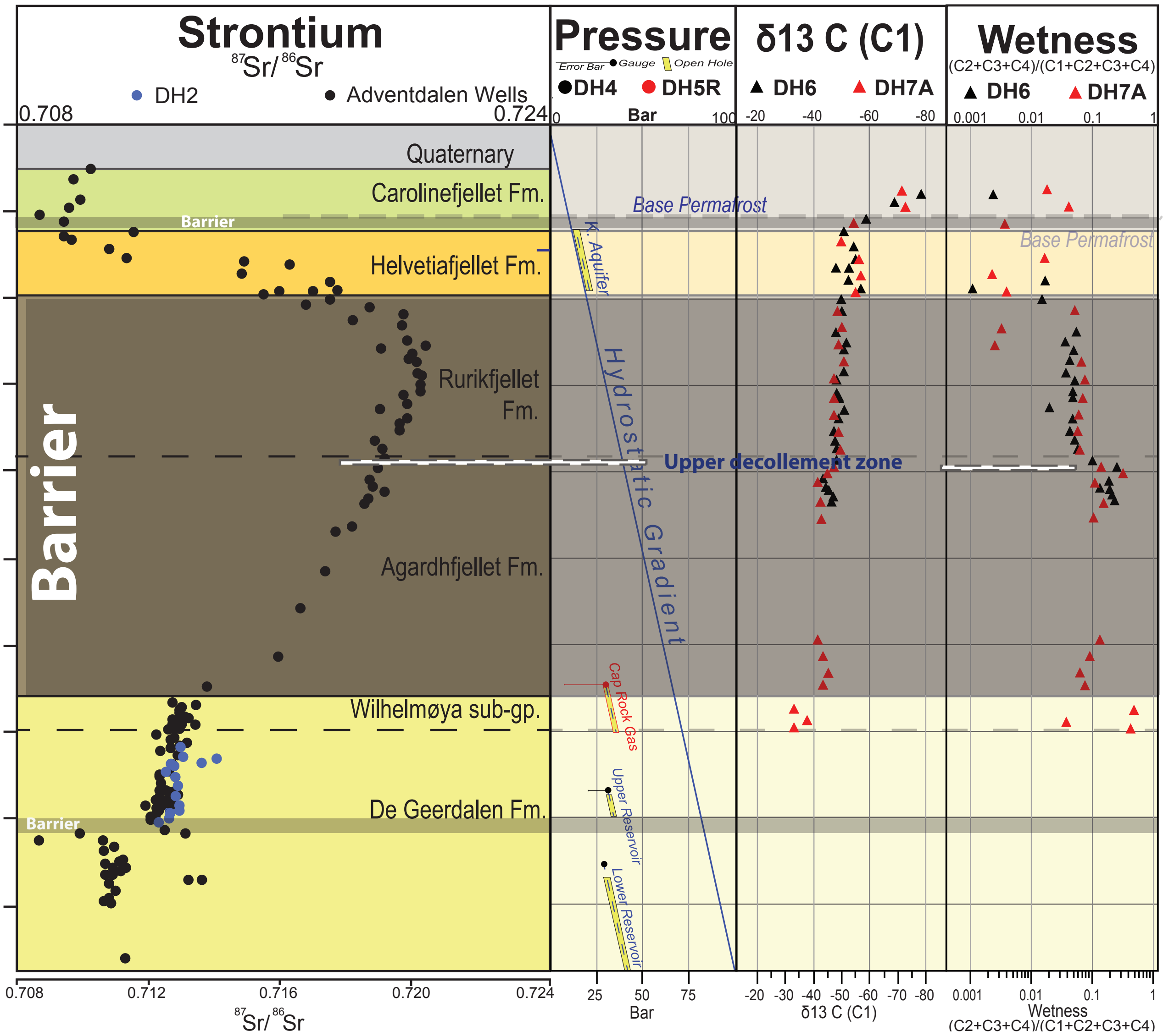


Figure 12. Strontium Isotopes, pressures and gas analyses from the Longyearbyen CO_2 Lab. See text for discussion.

the lower aquifer demonstrating greater magnitudes of underpressure than the middle aquifer. However, it should be noted that the pressures in the middle aquifer were slightly elevated due to drilling operations, giving rise to some uncertainty at the time of testing. The fact that the elevated pressure could be identified at all is testament to the long-term, high-quality testing carried out. The same subtle changes in pressure would not be identifiable in shorter-term pressure measurements in offshore tests (Birchall et al., in review).

Spitsbergen shows a variable geothermal gradient. The deep boreholes constrain the geothermal gradient in Longyearbyen, and are thus critical for considering the geothermal potential of Svalbard (Midttømme et al., 2015). By combining the CO_2 lab data with exploration boreholes onshore Svalbard (Senger et al., 2019), a high temperature anomaly is identified in eastern Spitsbergen. The Adventdalen wells record an average gradient of nearly 40 °C/km (Braathen et al., 2012; Betlem et al., 2018).

Caprock integrity

Pressure differences show efficient seal. The top seal of the two potential storage units is the Janusfjellet Subgroup. This is evidenced by the large pressure difference from the underlying under-pressured middle and lower aquifers, to the slightly overpressured upper aquifer. In addition, the same unit represents a major regional caprock across the Barents Shelf, sealing many of the hydrocarbon discoveries and producing fields.

Lower part of caprock in fluid communication with the middle aquifer. The caprock integrity is, amongst others, proven by gas analyses which show some step-change between the Wilhelmøya Subgroup and the overlying Agardhfjellet Formation that may reflect its barrier-like nature (Fig. 12). Pressure data in the lower parts of the caprock also show that severe underpressure is extending into the caprock itself. The isotope gradient through the shale-dominated Agardhfjellet and Rurikfjellet formations also suggests that fluid mixing has occurred from the reservoir into the caprock. Whilst fluid mixing has occurred in the caprock, its gradational nature through the caprock shows that the entire interval is still acting as a barrier. The upper part of the caprock shows a reversal of the gradient, again indicating some mixing from the above-lying upper aquifer, the Helvetiafjellet and Carolinefjellet formations. A décollement zone, a severely fractured damage zone with swelling clays, near the Agardhfjellet–Rurikfjellet formation boundary presented significant drilling problems at the DH1/DH2 drill site and gas analyses suggest that this interval may act as an even more effective seal within the caprock succession.

Permafrost as secondary seal. $\delta^{13}C$ isotope data are also consistent with the notion that the base of the permafrost acts as an effective barrier near the base of the Carolinefjellet Formation. We conclude that the 120 m-thick permafrost in Adventdalen, which includes bedrock and the unconsolidated Quaternary deposits in the upper 70 m towards the present-day valley floor (Gilbert et al., 2018) provides an additional seal. The sealing properties of the permafrost are manifested by the gas accumulation at its base (Betlem et al., 2019).

*Geomechanics of a fully cored caprock***.** The full coring of the shale-dominated caprock succession in four boreholes allows for detailed studies on geomechanics (Bohloli et al., 2014, 2015, 2016), analysis of permeability within subunits of the obtained cores (van Noort & Yarushina, 2016) and an integrated characterisation using wireline logs, drillcores and outcrop data (Senger et al., 2016).

Fault identification after CO_2 injection, Field and outcrop studies have documented extensive natural fracturing, as well as some faults. Lubrano-Lavadera et al. (2018, 2019) builds on these field observations and considers, through seismic modelling, whether the identified faults should be visible on seismic data under a variety of scenarios during and after CO_2 injection (e.g., brine-filled vs CO_2-filled, increasing complexity of background).

Figure 13. Artesian water from wellhead, producing 125 litres brackish water per minute from the Helvetiafjellet Formation, i.e., the upper aquifer.

Limited CO_2-brine-rock interaction. Alemu et al. (2011) conducted experiments to quantify the reaction rates of CO_2-rich brine on two samples of potential intra-formational barriers within the De Geerdalen Formation, and concluded that the low permeability allows only limited CO_2-brine-rock interaction.

Epilogue

Carbon capture and storage (CCS) is part of the solution required globally to reach the Paris agreement goals of keeping the global temperature increase well below 2°C above pre-industrial levels. Few studies on storage units have been carried out in Europe. Lack of test sites in suitable basins, and more so, the public oppositions to store CO_2 in the subsurface near communities have been major impediments to operations. The Longyearbyen CO_2 Lab offers a suitable locality for a test site that could explore challenges and outcomes of injection and storage of CO_2 in the subsurface. Furthermore, Longyearbyen offers a site with a supporting public opinion and limited political challenges, which typically relate to contamination of groundwater, anthropogenic earthquake activity (generated micro-earthquakes during water injection are well below the magnitude of natural earthquakes) or the not-in-my-backyard (NIMBY) syndrome. On the contrary, Longyearbyen's direct reliance on a coal-fueled power plant with the highest per capita CO_2 emissions in the world provides incentives to investigate the potential of CCS for reducing local emissions.

An important aspect of the Longyearbyen CO_2 Lab is the possibility to test and evaluate an unconventional reservoir (storage). The UNIS CO_2 Lab has operationally tested the subsurface by drilling, injection testing, geological reservoir studies and geophysical acquisition. This is a workflow common for exploration in the initial phase of a prospect discovery and evaluation in the gas and oil industry. The results are promising, suggesting that injection and storage of a small amount of CO_2 emitted from the coal power plant in Longyearbyen is feasible. Furthermore, it will be safe, as pressure differences prove that the main Upper Jurassic to Lower Cretaceous mudstone-dominated succession is an efficient seal (up to a pressure threshold for at least several tens of thousands of years). In addition, the approximate 120 m-thick permafrost will act as a secondary seal. Unfortunately, the project was not supported for injection testing with CO_2 that would have fully validated the storage formations and potentially contributed to significantly lowering Longyearbyen's CO_2 emissions.

On the other hand, if CCS does develop as a global climate mitigation method, numerous early career geologists and geophysicists have gained expertise in CCS technology in Longyearbyen by conducting their theses as part of the project, attending CO_2-related graduate courses at UNIS, or attending some of the international CCS summer schools or workshops held in Longyearbyen. Hence, our future CCS experts have greatly benefitted from the large-scale laboratory experiments conducted at the Longyearbyen CO_2 Lab. For the future, UNIS has placed itself on the map as a well-poised research institution that conducts innovative, need-driven research combining the best from industry and academia.

Acknowledgements. We acknowledge our sponsors for economic support; Baker Hughes, ConocoPhillips Norway; Equinor; Lundin Norway, Gassnova; Store Norske Spitsbergen Kulkompani; Leonhard Nilsen & Sønner; Statkraft; the Research Council of Norway (CLIMIT), Svalbard's Environmental Protection Fund, FME–SUCCESS, and FME–NCCS. Thanks to partners for excellent scientific cooperation; Institute for Energy Technology (IFE); Norsar; the universities in Oslo, Bergen, Stavanger and Trondheim; Sintef; UNI CIPR (now NORCE); Norwegian Geotechnical Institute (NGI), and the Geological Survey of Norway (NGU). In particular, we wish to emphasise our industrial sponsors; Baker Hughes, ConocoPhillips, Norway; Equinor;, Lundin Norway and Store Norske for their active involvement in the project including advisory support in operations in the project such as drilling, acquisition of data and logistics in a harsh Arctic environment. SAG also received funding from the ARCEx partners and the Research Council of Norway (grant number 228107). We are also acknowledging staff and students in UNIS during our operation and logistics. We also thank the UNIS directors for their support during the studies; Gunnar Sand, Ole Arve Misund and Harald Ellingsen, the support from the UNIS CO_2 Lab administration including Ragnhild Rønneberg (project management), Cathy Braathen (outreach), Sebastian Sikora (project management and logistics) and Fred Skancke Hansen (HSE leader), and the professional service from our drilling and test teams over the years; Trygve Dahl, Geir Ove Titlestad and Tor Jan Nilsen, and all the scientists and students involved with the Longyearbyen CO_2 lab project over the years. We thank Thomas Birchall, Malte Jochmann and Torbjørn Throndsen for discussion on the enigmatic pressure and maturation trends in the study area (and in Svalbard). Finally, we sincerely thank Morten Smelror for reviewing the paper.

References

Abay, T.B., Karlsen, D.A., Lerch, B., Olaussen, S., Pedersen, J.H. & Backer-Owe, K. 2017: Novel proof of Migrated Petroleum in the Mesozoic strata in Svalbard and detailed Organic Geochemical Characterization-Implications for Regional Exploration. *Journal of Petroleum Geology 40*, 5–36. https://doi.org/10.1111/jpg.12662.

Abay, T.B., Karlsen, D.A., Pedersen, J.H., Olaussen, S. & Backer-Owe, K. 2018: Thermal maturity, hydrocarbon potential and kerogen type of some Triassic to Lower Cretaceous sediments from the southwestern Barents Sea and Svalbard. *Journal of Petroleum Geoscience 24*, 349–373. https://doi.org/10.1144/petgeo2017-035.

Alemu, B.L., Aagaard, P., Munz, I.A. & Skurtveit, E. 2011: Caprock interaction with CO_2: A laboratory study of reactivity of shale with supercritical CO 2 and brine. *Applied Geochemistry 26*, 1975–1989. https://doi.org/10.1016/j.apgeochem.2011.06.028.

Almenningen, S., Betlem, P., Hussain, A., Roy, S., Senger, K. & Ersland, G. 2019: Demonstrating the potential of CO_2 hydrate self-sealing in Svalbard, Arctic Norway. *International Journal of Greenhouse Gas Control 89,* 1–8. https://doi.org/10.1016/j.ijggc.2019.06.010.

Anell, I., Braathen, A. & Olaussen, S. 2014: The Triassic–Early Jurassic of the northern Barents Shelf: a regional understanding of the Longyearbyen CO_2 reservoir. *Norwegian Journal of Geology 94*, 83–98.

Beka, T.I., Senger, K., Autio, U.A., Smirnov, M. & Birkelund, Y. 2017: Integrated electromagnetic data investigation of a Mesozoic CO_2 storage target reservoir-cap-rock succession, Svalbard. *Journal of Applied Geophysics 136*, 417–430, https://doi.org/10.1016/j.jappgeo.2016.11.021.

Beka, T.I., Smirnov, M., Birkelund, Y., Senger, K. & Bergh, S. 2016: Analysis and 3D inversion of magnetotelluric crooked profile data from central Svalbard for geothermal application. *Tectonophysics 686*, 98–115. https://doi.org/10.1016/j.tecto.2016.07.024.

Betlem, P., Midttømme, K., Jochmann, M., Senger, K. & Olaussen, S. 2018: Geothermal Gradients on Svalbard, Arctic Norway. *First EAGE/IGA/DGMK Joint Workshop on Deep Geothermal Energy*, 8.–9. Nov, Strasbourg, France. https://doi.org/10.3997/2214-4609.201802945.

Betlem, P., Senger, K. & Hodson, A. 2019: 3D thermobaric modelling of the gas hydrate stability zone onshore central Spitsbergen, Arctic Norway. *Marine and Petroleum Geology 100*, 246–262, https://doi.org/10.1016/j.marpetgeo.2018.10.050.

Birchall, T., Senger, K., Olaussen, S. & Braathen, A. in revision: Underpressure of the Northern Barents Shelf: distribution, causes and implications on the petroleum system *AAPG Bulletin*.

Bohloli, B., Choi, J., Skurtveit, E. & Pluymakers, A. 2016: Geomechanical interpretation for micro-seismic potential at CO_2 storage pilot on Svalbard, Norway. (Eds.): *Rock Mechanics and Rock Engineering: From the Past to the Future.* CRC Press, 1309–1313. https://www.onepetro.org/conference-paper/ISRM-EUROCK-2016-212.

Bohloli, B., Skurtveit, E., Grande, L., Titlestad, G.O., Børresen, M.H., Johnsen, Ø. & Braathen A. 2014: Evaluation of reservoir and caprock integrity for the Longyearbyen CO_2 storage pilot based on laboratory experiments and injection tests. *Norwegian Journal of Geology 94*, 171–187.

Bohloli, B., Skurtveit, E., Choi, J., Grande, L., Soldal, M. & Wilkinson, H. 2015: Shear Strength Parameters of Cretaceous Shales from the Cap-rock of the Longyearbyen CO_2 Storage Pilot, Svalbard. *Second EAGE Workshop on Geomechanics and Energy, 13–15 October 2015, Celle, Germany.* https://doi.org/10.3997/2214-4609.201414313.

Braathen, A., Bælum, K., Christiansen, H.H., Dahl, T., Eiken, O., Elvebakk, H., Hansen, F., Hanssen, T.H., Jochmann, M., Johansen, T.A., Johnsen, H., Larsen, L., Lie, T., Mertes, J., Mørk, A., Mørk, M.B., Nemec, W., Olaussen, S., Oye, V., Rod, K., Titlestad, G.O., Tveranger, J. & Vagle, K. 2012: The Longyearbyen CO_2 Lab of Svalbard, Norway—initial assessment of the geological conditions for CO_2 sequestration. *Norwegian Journal of Geology 92*, 353–376.

Bælum, K., Johansen, T.A., Johnsen, H., Rød, K., Ruud, B.O. & Braathen, A. 2012: Subsurface structures of the Longyearbyen CO_2 Lab study area in Central Spitsbergen (Arctic Norway), as mapped by reflection seismic data. *Norwegian Journal of Geology 92*, 377–389.

Corfu, F., Polteau, S., Planke, S., Faleide, J.I., Svensen, H., Zayoncheck, A. & Stolbov, N. 2013: U–Pb geochronology of Cretaceous magmatism on Svalbard and Franz Josef Land, Barents Sea Large Igneous Province. *Geological Magazine 150*, 1127–1135. https://doi.org/10.1017/S0016756813000162.

Dallmann, W.K. 2015 (ed): Geoscience Atlas of Svalbard. *Norsk Polarinstitutt Report Series 148*, 292 pp.

Elvebakk, H. 2008: Results of borehole logging in CO_2 wells, Dh1–CO_2–07 and Dh2–CO_2–07, Longyearbyen, Svalbard. *NGU Report 2008.054*, 25 pp.

Elvebakk, H. 2010: Results of borehole logging in well LYB CO_2, Dh4 of 2009, Longyearbyen, Svalbard. NGU, Trondheim, Norway, 35 pp.

Farokhpoor, R., Lindeberg, E., Torsæter, O., Mørk, M.B. & Mørk, A. 2013: Permeability and relative permeability measurements for CO_2- brine system at reservoir conditions in low permeable sandstones in Svalbard. *Greenhouse Gases Science and Technology 4*, 36–52. https://doi.org/10.1002/ghg.1375.

Farokhpoor, R., Torsæter, O., Baghbanbashi, T., Mørk, A. & Lindeberg, E. 2010: Experimental and Numerical Simulation of CO_2 Injection Into Upper–Triassic Sandstones in Svalbard, Norway. *Society of Petroleum Engineers*, *SPE-139524-MS,* 11 pp. https://doi.org/10.2118/139524-MS.

Gilbert, G.L., O'Neill, H.B., Nemec, W., Thiel, C., Christiansen, H.H. and Buylaert, J. 2018: Late Quaternary sedimentation and permafrost development in a Svalbard fjord-valley, Norwegian high Arctic. *Sedimentology 65*, 2531–2558. https://doi.org/10.1111/sed.12476.

Grundvåg, S.-A., Marin, D., Kairanov, B., Śliwińska, K.K., Nøhr-Hansen, H., Jelby, M.J., Escalona, A. & Olaussen S. 2017: The Lower Cretaceous succession of the northwestern Barents Shelf: Onshore and offshore correlation. *Marine and Petroleum Geology 86*, 834–857. http://dx.doi.org/10.1016/j.marpetgeo.2017.06.036.

Grundvåg, S.-A., Engholm Jelby, M., Śliwińska, K.K., Nøhr-Hansen, H., Aadland, T., Elvelund Sandvik, S.E., Tennvassås, I., Engen, T. & Olaussen, S. 2019: Sedimentology and palynology of the Lower Cretaceous succession of central Spitsbergen: integration of subsurface and outcrop data. *Norwegian Journal of Geology 99,* 1–32. https://doi.org/10.17850/njg006.

Hammer, Ø., Alsen, P., Grundvåg, S.-A., Jelby, M.E., Nøhr-Hansen, H., Olaussen, S., Senger, K., Śliwińska, K.K & Smelror, M. 2019: Comment on 'Redox conditions, productivity, and volcanic input during deposition of uppermost Jurassic and Lower Cretaceous organic-rich siltstones in Spitsbergen, Norway' by Rakociński et al. (2018). *Cretaceous* Research 96, 241–243. https://doi.org/10.1016/j.cretres.2018.09.017.

Harris, D., Albaric, J., Goertz-Allmann, B., Kuehn, D., Sikora, S. and Oye, V. 2017: Interference Suppression by Adaptive Cancellation in a High Arctic Seismic Experiment. *Geophysics 82*, 1–41. https://doi.org/10.1190/geo2016-0452.1.

Hoteit, H., Fahs, M. & Soltanian, M.R. 2019: Assessment of CO_2 Injectivity During Sequestration in Depleted Gas Reservoirs. *Geosciences 9*, 19 pp. https://doi.org/10.3390/geosciences9050199.

Huq, F., Smalley, P.C., Mørkved, P.T., Johansen, I., Yarushina, V., Johansen, H. 2017: The Longyearbyen CO_2 Lab: Fluid communication in reservoir and caprock,. *International Journal of Greenhouse Gas Control 63*, 59–76, https://doi.org/10.1016/j.ijggc.2017.05.005.

Jelby, M.E. 2015. *Sedimentology and sequence stratigraphy of the Lower Cretaceous Rurikfjellet Formation, central Spitsbergen*. Unpublished MSc thesis, University of Copenhagen, Denmark, 87 pp. https://doi.org/10.1190/geo2016-0452.1.

Jelby, M.E., Grundvåg, S.-A., Helland-Hansen, W., Olaussen, S. & Stemmerik L. 2020: Wave-modified hyperpycnites and unsteadily generated tempestites across a wide ramp: Towards a polygenetic model for hummocky cross-stratification. *Sedimentology* https://doi.org/10.1111/sed.12671.

Keating, K., Binley, A., Bense, V., Van Dam R.L. & Christiansen, H.H. 2018: Combined geophysical measurements provide evidence for unfrozen water in permafrost in the Adventdalen valley in Svalbard: *Geophysical Research Letters 45*, 7606–7614. https://doi.org/10.1029/2017GL076508.

Koevoets M.J., Abay T.B., Hammer Ø. & Olaussen S. 2016: High resolution organic carbon-isotope stratigraphy of the Middle Jurassic – Lower Cretaceous Agardhfjellet Formation of Central Spitsbergen, Svalbard. *Palaeogeography, Palaeoclimatology, Palaeoecology 449*, 266–274. http://dx.doi.org/10.1016/j.palaeo.2016.02.029.

Koevoets, M.J., Hammer, Ø., Olaussen, S., Senger, K. & Smelror, M. 2019a: Integrating subsurface and outcrop data of the Middle Jurassic to Lower Cretaceous Agardhfjellet Formation in central Spitsbergen. *Norwegian Journal of Geology 98*. https://dx.doi.org/10.17850/njg98-4-01.

Koevoets, M.J., Hammer, Ø. & Little, C.T.S. 2019b: Palaeoecology and palaeoenvironments of the Middle Jurassic to lowermost Cretaceous Agardhfjellet Formation (Bathonian–Ryazanian), Spitsbergen, Svalbard. *Norwegian Journal of* Geology 99, 1–24. https://dx.doi.org/10.17850/njg99-1-02.

Koevoets, M.J., Hurum, H.H. & Hammer, Ø. 2018: New Late Jurassic teleost remains from the Agardhfjellet Formation, Spitsbergen, Svalbard. *Norwegian Journal of Geology 98*, 289–299. https://dx.doi.org/10.17850/njg98-2-01.

Kühn, D., Oye, V., Albarica, J., Harris, D., Hillersc, G., Braathen, A. & Olaussen, S. 2014: Preparing for CO_2 storage in the Arctic – Assessing background seismic activity and noise characteristics at the CO_2 Lab site, Svalbard. *Energy Procedia* 63, 4313–4322. https://doi.org/10.1016/j.egypro.2014.11.467.

Lecomte, I., Polom, U., Sauvin, G., Ruud, B.O., Christiansen, H. & Gilbert, G. 2014, Shear-wave Reflection-seismic Pilot Study at the UNIS CO_2 Lab site, Longyearbyen, Svalbard. *Abstract 76th EAGE Conference and Exhibition 2014, 16–19 June 2014, Amsterdam, Netherlands.* https://doi.org/10.3997/2214-4609.20141243.

Liira, M., Noormets, R., Sepp, H., Kekišev, O., Maddison, M. & Olaussen, S. 2019: Sediment geochemical study of hydrocarbon seeps in Isfjorden and Mohnbukta: a comparison between western and eastern Spitsbergen, Svalbard. *Arktos 1,* 49–62. https://doi.org/10.1007/s41063-019-00067-7.

Lubrano-Lavadera, P., Kühn, D., Dando, B., Lecomte, I., Senger, K. & Drottning, Å. 2018: CO_2 storage in the high Arctic: efficient modelling of pre-stack depth-migrated seismic sections for survey planning. *Geophysical Prospecting 66*, 1180–1200. https://doi.org/10.1111/1365-2478.12637.

Lubrano-Lavadera, P., Senger, K., Lecomte, I., Mulrooney, M.J. & Kühn, D. 2019: Seismic modelling of metre-scale normal faults at a reservoir-cap rock interface in Central Spitsbergen, Svalbard: implications for CO_2 storage. *Norwegian Journal of Geology*. https://dx.doi.org/10.17850/njg003.

Magnabosco, C., Braathen, A. & Ogata, K. 2014: Permeability model of tight reservoir sandstones combining core-plug and Miniperm analysis of drill core; Longyearbyen CO_2 Lab, Svalbard. *Norwegian Journal of Geology 94*, 189–200.

Marshall, C., Uguna, J., Large, D.J., Meredith, W., Jochmann, M., Friis, B., Vane, C., Spiro, B.F., Snape, C.E. & Orheim, A. 2015: Geochemistry and petrology of palaeocene coals from Spitzbergen — Part 2: Maturity variations and implications for local and regional burial models. *International Journal of Coal Geology 143*, 1–10. https://doi.org/10.1016/j.coal.2015.03.013.

Midtkandal, I. Svensen, H., Planke, S., Corfu, F., Polteau, S., Torsvik, T.H., Faleide, J.I., Grundvåg, S.-A, Selnes, H. & Olaussen, S. 2016: The Aptian oceanic anoxic event (OAE1a) in Svalbard and the age of the Barremian-Aptian boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology 463*, 126–135. http://dx.doi.org/10.1016/j.palaeo.2016.09.023.

Midttømme, K., Jochmann, M., Henne, I., Wangen, M. & Thomas, P. 2015: Is Geothermal Energy an Alternative for Svalbard? *The Third Sustainable Earth Sciences Conference and Exhibition, 13–15 Oct, Celle, Germany*, p. 1–5. https://doi.org/10.3997/2214-4609.201414251.

Miri, R., Hellevang, H., Braathen, A. & Aagaard, P. 2014: Phase relations in the Longyearbyen CO_2 Lab reservoir-forecasts for CO_2 injection and migration: *Norwegian Journal of Geology 94*, 217–232.

Moghadam, J.N., Mondol N.H., Aagaard P. & Hellevang, H. 2016a: Experimental investigation of seismic velocity behavior of CO_2 saturated sandstones under varying temperature and pressure conditions. *Journal of Greenhouse Gases Science and Technology* 6, 734–751. https://doi.org/10.1002/ghg.1603.

Moghadam, J.N., Mondol, N.H., Aagaard, P. & Hellevang, H. 2016b: Effective stress law for the permeability of clay bearing sandstones by the Modified Clay Shell Model, *Journal of Greenhouse Gases Science and Technology* 6, 752–774. https://doi.org/10.1002/ghg.1612.

Moghadam, J.N., Nooraiepour, M., Hellevang, H., Mondol, N.H. & Aagaard, P. 2019: Relative permeability and residual gaseous CO_2 saturation in the Jurassic Brentskardhaugen Bed sandstones, Wilhelmøya Subgroup, western central Spitsbergen, Svalbard. *Norwegian Journal of Geology 98*, xx. https://dx.doi.org/10.17850/njg005.

Mulrooney, M.J., Larsen, L., Rismyhr, B., Van Stappen, J., Senger, K., Braathen, A., Mørk, M.B., Olaussen, S., Cnudde, V. & Ogata K. 2019: Fluid flow properties of a potential unconventional CO_2 storage unit in central Spitsbergen: the Upper Triassic to Middle Jurassic Wilhelmøya Subgroup. *Norwegian Journal of Geology*. https://doi.org/10.17850/njg002.

Mørk, M.B.E. 2013: Diagenesis and quartz cement distribution of low permeability Upper Triassic–Middle Jurassic reservoir sandstones, Longyearbyen CO_2 lab well site in Svalbard, Norway. *American Association of Petroleum Geologists Bulletin 97*, 577–596. https://doi.org/10.1306/10031211193.

Nooraiepour, M., Bohloli, B., Joonsang, P. Sauvin, G., Skurtveit, E. & Mondol, N.H. 2018: Effect of brine-CO_2 fracture flow on velocity and electrical resistivity of naturally fractured tight sandstones. *Geophysics 83*, WA37–WA48. https://doi.org/10.1190/geo2017-0077.1.

Nøttvedt, A., Cecchi, M., Gjelberg, J.G., Kristensen, S.E., Lønoy, A., Rasmussen, A., Rasmussen, E., Skott, P.H. & Van Veen, P.M. 1993: Svalbard-Barents Sea correlation: a short review. *In* Vorren, T.O., Bergsager, E., Lie, E. & Lund, T.B. (eds.): *Arctic Geology and Petroleum Potential*, Norwegian Petroleum Society Special Publication 2, pp. 363–375. https://doi.org/10.1016/B978-0-444-88943-0.50027-7.

Ogata, K., Senger, K., Braathen, A., Tveranger, J. & Olaussen, S. 2012: The importance of natural fractures in a tight reservoir for potential CO_2 storage: the case study of the upper Triassic to middle Jurassic Kapp Toscana Group (Spitsbergen, Svalbard). *In* Spence, G.H., Redfern, J., Aguilera, R., Bevan, T.G., Cosgrove, J.W., Couples, G.D. & Daniel, J.-M. (eds.): *Advances in the Study of Fractured Reservoirs*. Geological Society, London, Special Publications 374, pp. 21. https://doi.org/10.1144/SP374.9.

Ogata, K., Senger, K., Braathen, A., Tveranger, J. & Olaussen, S. 2014. Fracture systems and mesoscale structural patterns in the siliciclastic Mesozoic reservoir-caprock succession of the Longyearbyen CO_2 Lab project: implications for geological CO_2 sequestration in Central Spitsbergen, Svalbard. *Norwegian Journal of Geology 94*, 121–154.

Ohm, S.E., Larsen., Olaussen, S., Senger, K., Birchall, T., Demchuk, T, Hodson, A. Johansen, I., Titlestad, G.O. & Braathen, A. 2019. Discovery of shale gas in organic rich Jurassic successions, Adventdalen, central Spitsbergen; Norway. *Norwegian Journal of Geology.*

Olaussen, S., Larssen, G.B, Helland-Hansen, W., Johannessen, E.P., Nøttvedt A., Riis, F., Rismyhr, B., Smelror, M. & Worsley, D. 2018: Mesozoic strata of the Kong Karls Land, Svalbard, Norway; a link to the northern Barents Sea basins and platforms, *Norwegian Journal of Geology 98*, 1–69. https://doi.org/10.17850/njg98-4-06.

Oye, V., Braathen, A. & Pollom, U. 2013: Preparing for CO_2 storage at the Longyearbyen CO_2 Lab: microseismic monitoring of injection tests. *First Break 31*, 95–101.

Polteau, S., Hendriks, B.W., Planke, S., Ganerød, M., Corfu, F., Faleide, J.I., Midtkandal, I., Svensen, H.S. & Myklebust, R. 2016: The Early Cretaceous Barents Sea Sill Complex: Distribution, 40 Ar/39 Ar geochronology, and implications for carbon gas formation. *Palaeogeography, Palaeoclimatology, Palaeoecology 441*, 83–95. https://doi.org/10.1016/j.palaeo.2015.07.007.

Rismyhr, B. 2012. *Sedimentological facies models of the lower part of the Realgrunnen Subgroup in the Goliat Field compared with outcrops.* Unpublished Master Thesis, University in Bergen, 134 pp.

Rismyhr, B., Bjærke, T., Olaussen, S., Mulrooney, M.J. & Senger K. 2019: Facies, palynostratigraphy and sequence stratigraphy of the Wilhelmøya Subgroup (Upper Triassic–Middle Jurassic) in western central Spitsbergen, Svalbard. *Norwegian Journal of Geology.* https://doi.org/10.17850/njg001.

Roy, S., Senger, K., Braathen, A., Noormets, R., Hovland, M. & Olaussen, S. 2014: Fluid migration pathways to seafloor seepage in inner Isfjorden and Adventfjorden, Svalbard. *Norwegian Journal of Geology 94*, 99–119.

Roy, S., Hovland, M., Noormets, R. & Olaussen, S. 2015: Seepage in Isfjorden and its tributary fjords, West Spitsbergen. *Marine Geology 363*, 146–159. https://doi.org/10.1016/j.margeo.2015.02.003.

Roy S., Senger, K., Hovland, M., Römer, M. & Braathen A. 2019: Geological controls on shallow gas distribution and seafloor seepage in an Arctic fjord of Spitsbergen, Norway, *Marine and Petroleum Geology 107*, 237–254. https://doi.org/10.1016/j.marpetgeo.2019.05.021.

Rød, R., Hynne, I.B. & Mørk, A. 2014: Depositional environment of the Upper Triassic De Geerdalen Formation - An E–W transect from Edgeøya to central Spitsbergen, Svalbard. *Norwegian Petroleum Directorate Bulletin 11*, 21–40

Sand, G., Braathen, A. & Olaussen, S. 2014: Longyearbyen CO_2 Lab – tales of research and education. *Norwegian Journal of Geology 94*, 77–82.

Senger, K., Roy, S., Braathen, A., Buckley, S., Bælum, K., Gernigon, L., Mjelde, R., Noormets, R., Ogata, K., Olaussen, S., Planke, S., Ruud, B. & Tveranger, J. 2013: Geometries of doleritic intrusions in central Spitsbergen, Svalbard: an integrated study of an onshore-offshore magmatic province with implications for CO_2 sequestration. *Norwegian Journal of Geology 93*, 143–166.

Senger, K., Planke, S., Polteau, S., Ogata, K. & Svensen, H. 2014a: Sill emplacement and contact metamorphism in a siliciclastic reservoir on Svalbard, Arctic Norway. *Norwegian Journal of Geology 94*, 155–169.

Senger, K., Tveranger, J., Ogata, K., Braathen, A. & Planke, S. 2014b: Late Mesozoic magmatism in Svalbard: a review. *Earth Science Reviews 139*, 123–144. https://doi.org/10.1016/j.earscirev.2014.09.002.

Senger, K. Tveranger J., Braathen, A., Olaussen S., Ogata K. & Larsen L. 2015: CO_2 storage resource estimates in unconventional reservoirs: insights from a pilot-sized storage site in Svalbard, Arctic Norway. *Environmental Earth Sciences 73*, 3987–4009. https://doi.org/10.1007/s12665-014-3684-9.

Senger, K., Mulrooney, M., Braathen, A., Ogata, K. & Olaussen, S. 2016: Integrated Characterization of an Organic-rich Caprock Shale, Svalbard, Arctic Norway. *Fifth EAGE Shale Workshop, 2.–4. May, Catania, Italy*, 5 pp. https://doi.org/10.3997/2214-4609.201600430.

Senger, K., Brugmans, P., Grundvåg, S.A., Jochmann, M., Nøttvedt, A., Olaussen, S., Skotte, A., & Smyrak-Sikora, A. 2019: Petroleum, coal and research drilling onshore Svalbard: a historical perspective. *Norwegian Journal of Geology 99.* https://doi.org/10.17850/njg99-3-1.

Śliwińska, K.K., Jelby, M.E., Grundvåg S.-A., Nøhr-Hansen, H., Alsen, P. & Olaussen, S. In press. Dinocyst stratigraphy of the Valanginian to Aptian succession (the Rurikfjellet and Helvetiafjellet formations) from Spitsbergen, Norway. *Geological Magazine.*

Smelror, M., Larssen, G.B., Olaussen, S., Rømuld, A. & Williams, R. 2018: Late Triassic to Early Cretaceous palynostratigraphy of Kong Karls Land,Svalbard, Arctic Norway, with correlations to Franz Josef Land, Arctic Russia. *Norwegian Journal of Geology 98*, 1–31. https://dx.doi.org/10.17850/njg004.

Throndsen, T. 1982. Vitrinite reflectance studies of coals and dispersed organic matter in Tertiary deposits in the Adventdalen area, Svalbard. *Polar Research 2*, 77–91. https://doi.org/10.3402/polar.v1982i2.7005.

Tsuji, T., Ikeda, T., Johansen, T.A. & Ruud, B.O. 2016: Using seismic noise derived from fluid injection well for continuous reservoir monitoring. *Interpretation 4*, SQ1–SQ11. https://doi.org/10.1190/INT-2016-0019.1.

van Noort, R. & Yarushina, V. 2016: Water and CO_2 Permeability of a Shale Sample Core from Svalbard. *Energy Procedia, 97*, 67–74. https://doi.org/10.1016/j.egypro.2016.10.021.

van Stappen, J., De Kock, T., Boone, M.A., Olaussen, S. & Cnudde, V. 2014: Pore-scale characterisation and modelling of CO_2 flow in tight sandstones using X-ray micro-CT; Knorringfjellet Formation of the Longyearbyen CO_2 Lab, Svalbard. *Norwegian Journal of Geology 94*, 201–215.

van Stappen, J., Meftah, R., Boone, M., Bultreys, T., De Kock, T., Blykers, B., Senger, K., Olaussen, S. & Cnudde, V. 2018: In Situ Triaxial Testing To Determine Fracture Permeability and Aperture Distribution for CO_2 Sequestration in Svalbard, Norway. *Environmental Science Technology 52*, 4546–4554. https://doi.org/10.1021/acs.est.8b00861.

Wangen, M., Souche, A., & Johansen, H. 2016: A model for underpressure development in a glacial valley, an example from Adventdalen, Svalbard. *Basin Research 28*, 752–769. https://doi.org/10.1111/bre.12130.

Worsley, D. 2008: The post-Caledonian development of Svalbard and the western Barents Sea. *Polar Research 27*, 298–317. https://doi.org/10.1111/j.1751-8369.2008.00085.x.

Zang, Y.W., Minguez, D., Ogg, J.G., Olaussen, S. 2018: Magnetostratigraphy across U–PB–Dated horizons in Svalbard boreholes to partly resolve the debated age of the Barremian Aptian boundary. *Abstract GSA Annual meeting Indianapolis, 4–7 November, Indiana, USA*. https://doi.org/10.1130/abs/2018AM-323068.

Electronic and Printed Supplement 1.

Peer-reviewed publications, graduated PhD and MSc theses that include data or material from UNIS CO_2 LAB from 2008 to 2020

Compiled by Cathrine Braathen[1], Alvar Braathen [1,2], Snorre Olaussen [2] & Kim Senger[2].

[1]*Department of Geosciences, University of Oslo, P.O Box 1047, Blindern, NO–0316 Oslo, Norway.*
[2]*Department of Arctic Geology, University Centre in Svalbard, P.O. Box 156, NO–9171 Longyearbyen, Norway*

Near all disciplines within geology and geophysics have benefited from the obtained data from Longyearbyen CO_2 Lab. The list below represents, so far, c. 70 peer reviewed papers published in international peer-reviewed journals obtained from data made available by the Longyearbyen CO_2 Lab. In addition, 13 PhD candidates and 26 master students graduated as part of the project or using data from the operation. This list will be updated annually on the home page: http://co2-ccs.unis.no/Publications.html, and followed up by Cathrine Braathen (e-mail; catherine.braathen@geo.uio.no) and Kim Senger (Kim.Senger@UNIS.no).

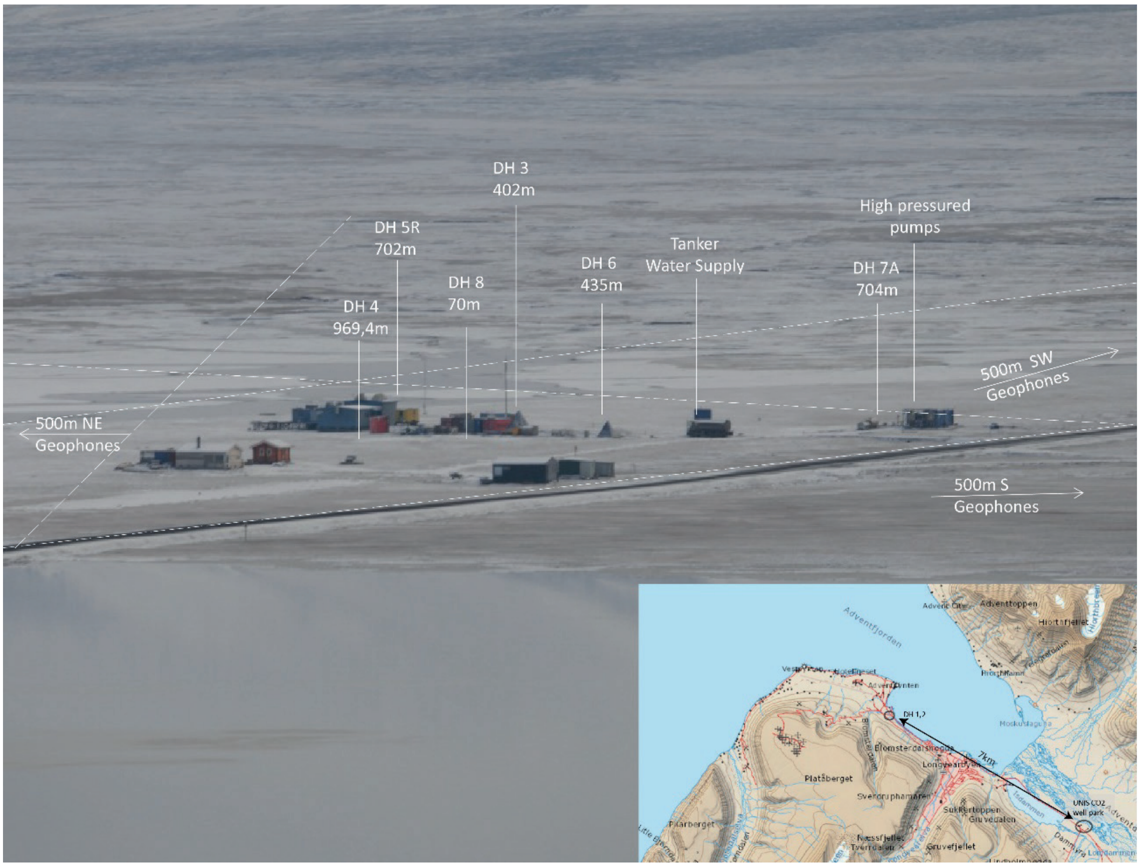


Figure 1. Overview of the UNIS CO_2 Lab well park in Adventdalen, south-east of Longyearbyen. The inset map shows the UNIS CO_2 Lab well park location, as well as the location of the DH1 and DH2 boreholes near Longyearbyen airport. All publications in this appendix are partly based on data from these boreholes. The numbers beneath the well numbers indicate s total drilled depth (TD) of each borehole. All wells apart from DH3 are now plugged and abandoned (P&A). In addition, temporary shallow geophones were installed within a 1 km radius of the UNIS CO_2 Lab well park during the operational phase. Stippled lines shows position for some of the conventional 2D seismic lines acquired in this area.

Figure 2. Word cloud illustrating the multi-discplinarity of the topics addressed by the Longyearbyen CO$_2$ Lab project. The word cloud is generated from titles of all associated publications, conference presentations and media coverage.

Peer-reviewed international publications 2011–2020 and in press.

Abay, T.B., Karlsen, D.A., Lerch, B., Olaussen, S., Pedersen, J.H. & Backer-Owe, K. 2017: Novel proof of Migrated Petroleum in the Mesozoic strata in Svalbard and detailed Organic Geochemical Characterization-Implications for Regional Exploration. *Journal of Petroleum Geology 40, 5–36.* https://doi.org/10.1111/jpg.12662.

Abay, T.B., Karlsen, D.A., Pedersen; J.H., Olaussen, S. & Backer-Owe, K. 2018: Thermal maturity, hydrocarbon potential and kerogen type of some Triassic to Lower Cretaceous sediments from the southwestern Barents Sea and Svalbard. *Journal of Petroleum Geoscience 24, 349–373.* https://doi.org/10.1144/petgeo2017-035.

Aker, E., Bjørnarå, T., Braathen, A., Brandvoll, Ø., Dahle, H., Nordbotten, J.M., Aagaard, P., Hellevang, H., Alemu, B.L., Pham, V.T.H., Johansen, H., Wangen, M., Nøttvedt, N., Aavatsmark, I., Johannessen, T. & Durand, D. 2011: SUCCESS: Subsurface CO$_2$ storage – Critical Elements and Superior Strategy. *Energy Procedia 4*, 6117–6124. https://doi.org/10.1016/j.egypro.2011.02.619.

Anell, I., Braathen, A., Olaussen, S. & Osmundsen, P.T. 2013: Evidence of faulting contradicts a quiescent northern Barents Shelf during the Triassic. *First Break 31*, 31–40. https://doi.org/10.3997/1365-2397.2013017.

Anell, I., Braathen, A. & Olaussen, S. 2014: The Triassic–Early Jurassic of the northern Barents Shelf: a regional understanding of the Longyearbyen CO$_2$ reservoir. *Norwegian Journal of Geology 94*, 83–98.

Alemu, B.L., Aagaard, P., Munz, I.A. & Skurtveit, E. 2011: Caprock interaction with CO$_2$: A laboratory study of reactivity of shale with supercritical CO$_2$ and brine. *Applied Geochemistry 26*, 1975–1989. https://doi.org/10.1016/j.apgeochem.2011.06.028.

Beka, T.I., Smirnov, M., Birkelund, Y., Senger, K. & Bergh, S. 2016: Analysis and 3D inversion of magnetotelluric crooked profile data from central Svalbard for geothermal application. *Tectonophysics 686*, 98–115. https://doi.org/10.1016/j.tecto.2016.07.024.

Beka, T.I., Senger, K., Autio, U.A., Smirnov, M. & Birkelund, Y. 2017: Integrated electromagnetic data investigation of a Mesozoic CO$_2$ storage target reservoir-cap-rock succession, Svalbard. *Journal of Applied Geophysics 136*, 417–430. https://doi.org/10.1016/j.jappgeo.2016.11.021.

Betlem, P., Senger, K. & Hodson, A. 2019: 3D thermobaric modelling of the gas hydrate stability zone onshore central Spitsbergen, Arctic Norway. *Marine and Petroleum Geology 100*, 246–262. https://doi.org/10.1016/j.marpetgeo.2018.10.050.

Betlem, P., Birchall, T., Ogata, K., Skurtveit, E., Park, J. & Senger, K. in press: Digital drill core models: using structure-from-motion as a tool for the characterisation, orientation, and digital archiving of drill core samples. *Remote Sensing*.

Bohloli, B., Skurtveit, E., Grande, L., Titlestad, G.O., Børresen, M.H., Johnsen, Ø. & Braathen, A. 2014: Evaluation of reservoir and caprock integrity for the Longyearbyen CO$_2$ storage pilot based on laboratory experiments and injection tests. *Norwegian Journal of Geology 94*, 171–187.

Bohloli, B., Choi, J., Skurtveit, E. & Pluymakers, A. 2016: Geomechanical interpretation for micro-seismic potential at CO$_2$ storage pilot on Svalbard, Norway. *Rock Mechanics and Rock Engineering: From the Past to the Future, CRC Press*, 1309–1313. https://doi.org/10.1201/9781315388502-230.

Braathen, A., Bælum, K., Christiansen, H.H., Dahl, T., Eiken, O., Elvebakk, H., Hansen, F., Hanssen, T.H., Jochmann, M., Johansen, T.A., Johnsen, H., Larsen, L., Lie, T., Mertes, J., Mørk, A., Mørk, M.B., Nemec, W., Olaussen, S., Oye, V., Rod, K., Titlestad, G.O., Tveranger,J. & Vagle, K. 2012: The Longyearbyen CO$_2$ Lab of Svalbard, Norway—initial assessment of the geological conditions for CO$_2$ sequestration. *Norwegian Journal of Geology 92*, 353–376.

Braathen, A., Anell, I., Osmundsen, P.T. & Olaussen, S. 2013: Evidence of faulting contradicts a quiescent northern Barents Shelf during the Triassic. Comment and Replay. *First Break 31*, 69–72. https://doi.org/10.3997/1365-2397.2013017.

Bælum, K. & Braathen, A. 2012: Along-strike changes in fault array and rift basin geometry of the Carboniferous Billefjorden Trough, Svalbard, Norway. *Tectonophysics 546–547*, 38–55. https://doi.org/10.1016/j.tecto.2012.04.009.

Bælum, K., Johansen, T.A., Johnsen, H., Rød, K., Ruud, B.O. & Braathen, A. 2012: Subsurface structures of the Longyearbyen CO$_2$ Lab study area in Central Spitsbergen (Arctic Norway), as mapped by reflection seismic data. *Norwegian Journal of Geology 92*, 377–389.

Corfu, F., Polteau, S., Planke, S., Faleide, J.I., Svensen, H., Zayoncheck, A. & Stolbov, N. 2013: U–Pb geochronology of Cretaceous magmatism on Svalbard and Franz Josef Land, Barents Sea Large Igneous Province. *Geological Magazine 150*, 1127–1135. https://doi.org/10.1017/S0016756813000162.

Farokhpoor, R., Torsæter, O., Baghbanbashi, T., Mørk, A. & Lindeberg, E. 2010: Experimental and Numerical Simulation of CO_2 Injection Into Upper-Triassic Sandstones in Svalbard, Norway. *Society of Petroleum Engineers 139524.* https://doi.org/10.2118/139524-MS.

Farokhpoor, R., Lindeberg, E., Torsæter, O., Mørk, M.B. & Mørk, A. 2013: Permeability and relative permeability measurements for CO_2- brine system at reservoir conditions in low permeable sandstones in Svalbard. *Greenhouse Gases Science and Technology 4, 36–52.* https://doi.org/10.1002/ghg.1375.

Gilbert, G.L., O'Neill, H.B., Nemec, W., Thiel, C., Christiansen, H.H. & Buylaert, J. 2018: Late Quaternary sedimentation and permafrost development in a Svalbard fjord-valley, Norwegian high Arctic. *Sedimentology 65*, 2351–2558. https://doi.org/10.1111/sed.12476.

Grundvåg, S.-A., Marin, D., Kairanov, B., Śliwińska, K.K., Nøhr-Hansen, H., Jelby, M.J., Escalona, A. & Olaussen, S. 2017: The Lower Cretaceous succession of the northwestern Barents Shelf: Onshore and offshore correlation. *Marine and Petroleum Geology 86, 834–857.* https://doi.org/10.1016/j.marpetgeo.2017.06.036

Grundvåg, S.-A., Engholm-Jelby, M., Śliwińska, K.K., Nøhr-Hansen, H., Aadland, T., Elvelund-Sandvik, S.E., Tennvassås, I., Engen, T. & Olaussen, S. 2019: Sedimentology and palynology of the Lower Cretaceous succession of central Spitsbergen: integration of subsurface and outcrop data. *Norwegian Journal of Geology 99*, 1–32. https://doi.org/10.17850/njg006.

Hammer, Ø., Alsen, P., Grundvåg, S.-A., Jelby, M.E., Nøhr-Hansen, H., Olaussen, S., Senger, K., Śliwińska, K.K. & Smelror, M. 2019: Comment on 'Redox conditions, productivity, and volcanic input during deposition of uppermost Jurassic and Lower Cretaceous organic-rich siltstones in Spitsbergen, Norway' by Rakociński et al. (2018). *Cretaceous Research 96, 241–243.* https://doi.org/10.1016/j.cretres.2018.09.017.

Harris, D., Albaric, J., Goertz-Allmann, B., Kuehn, D., Sikora, S. & Oye, V. 2017: Interference Suppression by Adaptive Cancellation in a High Arctic Seismic Experiment. *Geophysics 82, 1–41.* https://doi.org/10.1190/geo2016-0452.1.

Huq, F., Smalley, P.C., Mørkved, P.T., Johansen, I., Yarushina, V. & Johansen, H. 2017: The Longyearbyen CO_2 Lab: Fluid communication in reservoir and caprock. *International Journal of Greenhouse Gas Control 63*, 59–76. https://doi.org/10.1016/j.ijggc.2017.05.005.

Jelby, M.E., Grundvåg, S.-A., Helland-Hansen, W., Olaussen, S. & Stemmerik L. 2019: Wave-modified hyperpycnites and unsteadily generated tempestites across a wide ramp: Towards a polygenetic model for hummocky cross-stratification. *Sedimentology (in press).* https://doi.org/10.1111/sed.12671.

Koevoets M.J., Abay T.B., Hammer, Ø. & Olaussen, S. 2016: High resolution organic carbon-isotope stratigraphy of the Middle Jurassic–Lower Cretaceous Agardhfjellet Formation of Central Spitsbergen, Svalbard. *Palaeogeography, Palaeoclimatology, Palaeoecology 449, 266–274.* http://dx.doi.org/10.1016/j.palaeo.2016.02.029.

Koevoets, M.J., Hammer, O., Olaussen, S., Senger, K. & Smelror, M. 2018: Integrating subsurface and outcrop data of the Middle Jurassic to Lower Cretaceous Agardhfjellet Formation in central Spitsbergen. *Norwegian Journal of Geology 98, 1–34.* https://dx.doi.org/10.17850/njg98-4-01.

Koevoets, M.J., Hurum, H.H. & Hammer, Ø. 2018: New Late Jurassic teleost remains from the Agardhfjellet Formation, Spitsbergen, Svalbard. *Norwegian Journal of Geology 98, 289–299.* https://dx.doi.org/10.17850/njg98-2-01.

Koevoets, M.J., Hammer, Ø. & Little, C.T.S. 2019: Palaeoecology and palaeoenvironments of the Middle Jurassic to lowermost Cretaceous Agardhfjellet Formation (Bathonian–Ryazanian), Spitsbergen, Svalbard. *Norwegian Journal of Geology 99, 1–24.* https://dx.doi.org/10.17850/njg99-1-02.

Kühn, D., Oye, V., Albarica, J., Harris, D., Hillers, G., Braathen, A. & Olaussen, S. 2014: Preparing for CO_2 storage in the Arctic – Assessing background seismic activity and noise characteristics at the CO_2 Lab site, Svalbard. *Energy Procedia 63, 4313–4322.* https://doi.org/10.1016/j.egypro.2014.11.467.

Liira, M., Noormets, R., Sepp, H., Kekišev, O., Maddison, M. & Olaussen, S. 2019: Sediment geochemical study of hydrocarbon seeps in Isfjorden and Mohnbukta: a comparison between western and eastern Spitsbergen, Svalbard. *Arktos 5, 49–62.* https://doi.org/10.1007/s41063-019-00067-7.

Lubrano-Lavadera, P., Drottning, Å., Lecomte, I., Dando, B.D.E., Kühn, D. & Oye, V. 2017: Seismic Modelling: 4D Capabilities for CO_2 Injection. *Energy Procedia 14, 3432–3444.* https://doi.org/10.1016/j.egypro.2017.03.1474.

Lubrano-Lavadera, P., Kühn, D., Dando, B., Lecomte, I., Senger, K. & Drottning, Å. 2018: CO_2 storage in the high Arctic: efficient modelling of pre-stack depth-migrated seismic sections for survey planning. *Geophysical Prospecting 66, 1180–1200.* https://doi.org/10.1111/1365-2478.12637.

Lubrano-Lavadera, P., Senger, K., Lecomte, I., Mulrooney, M.J. & Kühn, D. 2019: Seismic modelling of metre-scale normal faults at a reservoir-cap rock interface in Central Spitsbergen, Svalbard: implications for CO_2 storage. *Norwegian Journal of Geology 99, 65–83.* https://dx.doi.org/10.17850/njg003.

Magnabosco, C., Braathen, A. & Ogata, K. 2014: Permeability model of tight reservoir sandstones combining core-plug and Miniperm analysis of drillcore; Longyearbyen CO_2 Lab, Svalbard. *Norwegian Journal of Geology 94*, 189–200.

Mørk, M.B.E. 2013: Diagenesis and quartz cement distribution of low permeability Upper Triassic–Middle Jurassic reservoir sandstones, Longyearbyen CO_2 lab well site in Svalbard, Norway. *American Association of Petroleum Geologists Bulletin 97,* 577–596. https://doi.org/10.1306/10031211193.

Midtkandal, I. Svensen, H., Planke, S., Corfu, F., Polteau, S., Torsvik, T.H., Faleide, J.I., Grundvåg, S.-A., Selnes, H. & Olaussen, S. 2016: The Aptian oceanic anoxic event (OAE1a) in Svalbard and the age of the Barremian–Aptian boundary. *Palaeogeography, Palaeoclimatology, Palaeoecology 463,126–135.* http://dx.doi.org/10.1016/j.palaeo.2016.09.023.

Miri, R., Hellevang, H., Braathen, A. & Aagaard, P. 2014: Phase relations in the Longyearbyen CO_2 Lab reservoir – forecasts for CO_2 injection and migration. *Norwegian Journal of Geology 94*, 217–232.

Moghadam, J.N., Mondol N.H., Aagaard P. & Hellevang, H. 2016a: Experimental investigation of seismic velocity behavior of CO_2 saturated sandstones under varying temperature and pressure conditions. *Journal of Greenhouse Gases: Science and Technology 6, 734–751.* https://doi.org/10.1002/ghg.1603.

Moghadam, J.N., Mondol, N.H., Aagaard, P. & Hellevang, H. 2016b: Effective stress law for the permeability of clay bearing sandstones by the Modified Clay Shell Model. *Journal of Greenhouse Gases: Science and Technology 6, 752-774.* https://doi.org/10.1002/ghg.1612.

Moghadam, J.N., Nooraiepour, M., Hellevang, H., Mondol, N.H. & Aagaard, P. 2019: Relative permeability and residual gaseous CO_2 saturation in the Jurassic Brentskardhaugen Bed sandstones, Wilhelmøya Subgroup, western central Spitsbergen, Svalbard. *Norwegian Journal of Geology 99, 1–12.* https://doi.org/10.17850/njg005.

Muller, A. & Knies, J. 2013: Trace elements and cathodoluminescence of detrital quartz in Arctic marine sediments-a new ice-rafted debris provenance proxy. *Climate of the Past 9, 2615–2630.* https://doi.org/10.5194/cp-9-2615-2013.

Nooraiepour, M., Bohloli, B., Joonsang, P., Sauvin, G., Skurtveit, E. & Mondol, N.H. 2018: Effect of brine-CO_2 fracture flow on velocity and electrical resistivity of naturally fractured tight sandstones. *Geophysics 83, WA37-WA48.* https://doi.org/10.1190/geo2017-0077.1.

Mulrooney, M.J., Larsen, L., Rismyhr, B., Van Stappen, J., Senger, K., Braathen, A., Mørk, M.B., Olaussen, S., Cnudde, V. & Ogata, K. 2019: Fluid flow properties of a potential unconventional CO_2 storage unit in central Spitsbergen: the Upper Triassic to Middle Jurassic Wilhelmøya Subgroup. *Norwegian Journal of Geology 99*, 85–116. https://doi.org/10.17850/njg002.

Ogata, K., Senger, K., Braathen, A., Tveranger, J. & Olaussen, S. 2012: The importance of natural fractures in a tight reservoir for potential CO_2 storage: the case study of the upper Triassic to middle Jurassic Kapp Toscana Group (Spitsbergen, Svalbard). *In* Spence, G.H., Redfern, J., Aguilera, R., Bevan, T.G., Cosgrove, J.W., Couples, G.D. & Daniel, J.M. (eds.): *Advances in the Study of Fractured Reservoirs,* Geological Society of London, Special Publications 374, pp. 395–415. https://doi.org/10.1144/SP374.9.

Ogata, K., Senger, K., Braathen, A., Tveranger, J. & Olaussen, S. 2014a: Fracture systems and mesoscale structural patterns in the siliciclastic Mesozoic reservoir-caprock succession of the Longyearbyen CO_2 Lab project: implications for geological CO_2 sequestration in Central Spitsbergen, Svalbard. *Norwegian Journal of Geology 94*, 121–154.

Ogata, K., Senger, K., Braathen, A. & Tveranger, J. 2014b: Fracture corridors as seal-bypass systems in siliciclastic reservoir-cap rock successions: Field-based insights from the Jurassic Entrada Formation (SE Utah, USA). *Journal of Structural Geology 66, 162–187.* https://doi.org/10.1016/j.jsg.2014.05.005.

Ohm, S.E., Larsen, L., Olaussen, S., Senger, K., Birchall, T., Demchuk, T., Hodson, A. , Johansen, I., Titlestad, G.O. & Braathen, A. 2019: Discovery of shale gas in organic rich Jurassic successions, Adventdalen, central Spitsbergen, Norway. *Norwegian Journal of Geology 99, in press.*

Olaussen, S., Larssen, G.B., Helland-Hansen, W., Johannessen, E.P., Nøttvedt A., Riis, F., Rismyhr, B., Smelror, M. & Worsley, D. 2018: Mesozoic strata of the Kong Karls Land, Svalbard, Norway; a link to the northern Barents Sea basins and platforms. *Norwegian Journal of Geology 98, 1–70.* https://doi.org/10.17850/njg98-4-06.

Olaussen, S., Senger, K., Braathen, A., Grundvag, S.A. & Mork, A. 2019: You learn as long as you drill; research synthesis from the Longyearbyen CO_2 Laboratory, Svalbard, Norway. *Norwegian Journal of Geology 99*, 157–187. https://dx.doi.org/10.17850/njg008.

Oye, V., Braathen, A. & Pollom, U. 2013: Preparing for CO_2 storage at the Longyearbyen CO_2 Lab: microseismic monitoring of injection tests. *First Break* 31, 95–101.

Polteau, S., Hendriks, B.W., Planke, S., Ganerød, M., Corfu, F., Faleide, J.I., Midtkandal, I., Svensen, H. S. & Myklebust, R. 2016: The Early Cretaceous Barents Sea Sill Complex: Distribution, $^{40}Ar/^{39}Ar$ geochronology, and implications for carbon gas formation. *Palaeogeography, Palaeoclimatology, Palaeoecology 441, 83–95.* https://doi.org/10.1016/j.palaeo.2015.07.007.

Rismyhr, B., Bjærke, T., Olaussen, S., Mulrooney, M.J. & Senger K. 2019: Facies, palynostratigraphy and sequence stratigraphy of the Wilhelmøya Subgroup (Upper Triassic–Middle Jurassic) in western central Spitsbergen, Svalbard. *Norwegian Journal of Geology 99, 35–64.* https://doi.org/10.17850/njg001.

Roy, S., Senger, K., Braathen, A., Noormets, R., Hovland, M. & Olaussen, S. 2014: Fluid migration pathways to seafloor seepage in inner Isfjorden and Adventfjorden, Svalbard. *Norwegian Journal of Geology 94, 99–119.*

Roy, S., Hovland, M., Noormets, R. & Olaussen, S. 2015: Seepage in Isfjorden and its tributary fjords, West Spitsbergen. *Marine Geology 363*, 146–159. https://doi.org/10.1016/j.margeo.2015.02.003.

Sand, G., Braathen, A. & Olaussen, S. 2014: Longyearbyen CO_2 Lab – tales of research and education. *Norwegian Journal of Geology 94*, 77–82.

Senger, K., Planke, S., Polteau, S., Ogata, K. & Svensen, H. 2014a: Sill emplacement and contact metamorphism in a siliciclastic reservoir on Svalbard, Arctic Norway. *Norwegian Journal of Geology 94*, 155–169.

Senger, K., Roy, S., Braathen, A., Buckley, S., Bælum, K., Gernigon, L., Mjelde, R., Noormets, R., Ogata, K., Olaussen, S., Planke, S., Ruud, B. & Tveranger, J. 2014b: Geometries of doleritic intrusions in central Spitsbergen, Svalbard: an integrated study of an onshore-offshore magmatic province with implications for CO_2 sequestration. *Norwegian Journal of Geology 93*, 143–166.

Senger, K., Tveranger, J., Ogata, K., Braathen, A. & Planke, S. 2014c: Late Mesozoic magmatism in Svalbard: a review. *Earth Science Reviews 139, 123–144.* https://doi.org/10.1016/j.earscirev.2014.09.002.

Senger, K., Tveranger, J., Braathen, A., Ogata, K., Olausen, S. & Larsen, L., 2014d: First-order CO_2 storage capacity assessment in unconventional reservoir: insights from a pilot-sized sequestration site in Svalbard, Arctic Norway. E*nvironmental Earth Sciences 23, 1–23.* https://doi.org/10.1007/s12665-014-3684-9.

Senger, K., Tveranger, J., Braathen, A., Olaussen S., Ogata, K. & Larsen, L. 2015: CO_2 storage resource estimates in unconventional reservoirs: insights from a pilot-sized storage site in Svalbard, Arctic Norway. *Environmental Earth Sciences 73, 3987–4009.* https://doi.org/10.1007/s12665-014-3684-9.

Senger, K., Brugmans, P., Grundvåg, S.A., Jochmann, M., Nøttvedt, A., Olaussen, S., Skotte, A. & Smyrak-Sikora, A. 2019: Petroleum, coal and research drilling onshore Svalbard: a historical perspective *Norwegian Journal of Geology 99, 1–30.* https://doi.org/10.17850/njg99-3-1.

Tsuji, T., Ikeda, T., Johansen, T.A. & Ruud, B.O. 2016: Using seismic noise derived from fluid injection well for continuous reservoir monitoring. I*nterpretation 4, SQ1–SQ11.* https://doi.org/10.1190/INT-2016-0019.1.

van Noort, R. & Yarushina, V. 2016: Water and CO_2 Permeability of a Shale Sample Core from Svalbard. *Energy Procedia 97, 67–74.* https://doi.org/10.1016/j.egypro.2016.10.021.

Van Stappen, J., De Kock, T., Boone, M.A., Olaussen, S. & Cnudde, V. 2014: Pore-scale characterisation and modelling of CO_2 flow in tight sandstones using X-ray micro-CT; Knorringfjellet Formation of the Longyearbyen CO_2 Lab, Svalbard. *Norwegian Journal of Geology 94*, 201–215.

Van Stappen, J., Meftah, R., Boone, M., Bultreys, T., De Kock, T., Blykers, B., Senger, K., Olaussen, S. & Cnudde, V. 2018: In Situ Triaxial Testing To Determine Fracture Permeability and Aperture Distribution for CO_2 Sequestration in Svalbard, Norway. *Environmental Science Technology 52, 4546–4554.* https://doi.org/10.1021/acs.est.8b00861.

Wangen, M., Souche, A., & Johansen, H. 2016: A model for underpressure development in a glacial valley, an example from Adventdalen, Svalbard. *Basin Research 28, 1–18.* https://doi.org/10.1111/bre.12130.

PhD theses 2011–2019

Abay, T.B. 2017: *Mesozoic source rocks and petroleum extracts in Svalbard.* PhD thesis, University of Oslo, 85 pp.

Beka, T. 2016: *Geoelectrical structures beneath Spitsbergen-Svalbard derived from magnetotelluric imaging.* PhD thesis, University of Tromsø, 137 pp.

Bælum, K. 2011: *Geophysical and geological investigations of subsurface reservoirs – case studies of Spitsbergen, Norway.* PhD thesis, Arctic Geology Department, UNIS and University of Bergen.

Farokhpoor, R. 2012: *Experimental Investigation of the Role of Relative Permeability and Wettability in Geological CO_2 Storage in Saline Aquifer.* PhD thesis, NTNU, Trondheim, 148 pp.

Gilbert, G.L. 2018: *Cryostratigraphy and sedimentology of high-Arctic fjord-valleys.* PhD thesis, Arctic Geology Department, UNIS and University of Bergen, 76 pp.

Koevoets, M.J. 2017: *Paleoenvironments and invertebrate paleontology of the Upper Jurassic, Svalbard.* PhD thesis, Museum of Natural History, University of Oslo and the Arctic Geology Department, University Centre in Svalbard, 250 pp.

Lord, G.S. 2017: *Sequence stratigraphy and facies development of the Triassic succession of Svalbard and the northern Barents Sea.* PhD thesis, NTNU and Arctic Geology Department, University Centre in Svalbard, UNIS, 250 pp.

Moghadam, J.N. 2016: *Investigation of petrophysical and rock physical aspects of CO_2 storage in sandstone reservoirs - An experimental study.* PhD thesis, Faculty of Mathematics and Natural Sciences, Department of Geoscience University of Oslo, 79 pp.

Mulrooney, M.J. 2017: *Faults affecting the Triassic Barents Shelf: Syn-kinematic deposition, deformation mechanisms and driving forces.* PhD thesis, Faculty of Mathematics and Natural Sciences Department of Geosciences, University of Oslo and Arctic Geology Department, University Centre in Svalbard, 102 pp.

Senger, K. 2013: *Impact of geological heterogeneity on CO_2 sequestration: from outcrop to geomodel.* PhD thesis, Uni CIPR, University of Bergen and Arctic Geology Department UNIS, 66 pp.

Skurtveit, E. 2014: *Deformation of sandstone reservoirs. Insight from experiments and field studies.* PhD thesis, University of Oslo, 46 pp.

Srikumar R. 2015: *Offshore gas/fluid seeps in Svalbard*. PhD thesis, Department of Arctic Geology, the University Centre in Svalbard and Department of Earth Science, University of Bergen, 62 pp.

Van Stappen, J. 2017: *A micro-CT Investigation into Pore-scale CO_2 Sequestration Processes in Fractured Reservoir Rocks.* PhD thesis, Faculty of Sciences, Ghent University, Belgium, 257 pp.

MSc theses 2008–2019

Aadland, T. 2014: *Sedimentological, stratigraphical and petrographical analysis of the Dalkjegla Member, Carolinefjellet Formation, Spitsbergen, Svalbard.* MSc thesis, Arctic Geology Department, University Centre in Svalbard, UNIS and University of Bergen, 147 pp

Abbas, M. 2015: *Geomechanical characterization of shale caprock of the Longyearbyen CO_2 storage pilot*. MSc thesis, University of Oslo, 100 pp.

Ask, M. 2013: *Palynological dating of the upper part of the De Geerdalen Formation on central parts of Spitsbergen and Hopen.* MSc thesis, University of Bergen.

Boxaspen, M.A. 2014: *Sedimentologi av den alluvialt dominerte øvre trias De Geerdalenfomasjonen på den sentrale delen av Spitsbergen og eksempler på sammenlignbare facies i den ekvivalente Snadd-formasjonen i Barentshavet*. MSc thesis, Arctic Geology Department UNIS and University of Bergen, 104 pp.

Christiansen, A.T. 2014: *Spatial, seasonal and temporal variations in carbon lability in permafrost soils within Adventdalen Svalbard.* MSc thesis, University of Copenhagen.

Farrell, L.R. 2011: *Appraisal of the Longyearbyen CO_2 Project, a Fractured Reservoir.* MSc thesis, University of Edinburgh, 108 pp.

Fromreiden, S. 2014: *Geomicrobial characterisation of a 60 m long permafrost core, taken over a future CO_2 storage site at Svalbard.* MSc thesis, University of Bergen.

Gilbert, G.L. 2014: *Sedimentology and geocryology of an Arctic fjord head delta (Adventdalen, Svalbard).* MSc thesis, Arctic Geology Department, University Centre in Svalbard, UNIS and University of Oslo, 133 pp.

Engen, T.M. 2018: *A sedimentological study of the Lower Cretaceous Glitrefjellet Member, Svalbard.* MSc thesis, University of Tromsø and The Arctic University of Norway, UNIS, 139 pp.

Harstad, T.S. 2016: *Sandstone Provenance of the De Geerdalen Formation, Svalbard.* MSc thesis, Department of Geology and Mineral Resources Engineering, NTNU, 98 pp.

Haugen, T. 2016: *A Sedimentological Study of the De Geerdalen Formation with Focus on the Isfjorden Member and Palaeosols*. MSc thesis, NTNU and Arctic Geology Department, University Centre in Svalbard, UNIS, 155 pp.

de Hilke, T. 2016: *Fluid flow in the dual porosity system of the Longyearbyen CO_2 Lab.* MSc thesis, Faculty of Science, Ghent University, Belgium, 66 pp.

Hovgaard, J. 2014: *Organic-Geochemical studies of microbial activity in Permafrost.* MSc thesis, Aarhus University, Denmark.

Hynne, I.B. 2010: *Depositional environment on eastern Svalbard and central Spitsbergen during Carnian time (Late Triassic): A sedimentological investigation of the De Geerdalen Formation*. MSc thesis, Arctic Geology Department, University Centre in Svalbard, UNIS and NTNU, 144 pp.

Jelby, M.E. 2015: *Sedimentology and sequence stratigraphy of the Lower Cretaceous Rurikfjellet Formation, central Spitsbergen*. MSc thesis, University of Copenhagen and Arctic Geology Department, University Centre in Svalbard, UNIS, 87 pp.

Lord, G.S. 2013: *Steep Fracture Patterns And Their Characteristics Within The Triassic De Geerdalen Formation On Svalbard: An emphasis on regional trends, local variations and lithological controls.* MSc thesis, NTNU and Arctic Geology Department, University Centre in Svalbard, UNIS, 206 pp.

Mikkelsen, E. 2009: *Monitoring of CO_2 Sequestration at the Longyearbyen CO_2 Lab by Time-lapse Seismic. An Interdisciplinary Rock Physics Study*. MSc thesis, NTNU, 86 pp.

Mork-Jansson, W.A. 2011: *Avsetningsmiljø og sekvensstratigrafi av Rurikfjelletformasjonen, Svalbard.* MSc thesis, University of Bergen and Arctic Geology Department University Centre in Svalbard, UNIS, 93 pp.

Rismyhr, B. 2012: *Sedimentological facies models of the lower part of the Realgrunnen Subgroup in the Goliat Field compared with outcrops.* MSc thesis, University of Bergen and Arctic Geology Department, University Centre in Svalbard, UNIS, 134 pp.

Rosseland-Knutsen, E. 2013: *Sedimentology of the Offshore-to Tide-Dominated Upper Triassic De Geerdalen Formation on Central Spitsbergen and Examples of Comparable Facies in the Equivalent Snadd Formation.* MSc thesis, Arctic Geology Department, University Centre in Svalbard, UNIS and University of Bergen, 126 pp.

Rød, R.S. 2011: *Spatial occurrences of selected sandstone bodies in the De Geerdalen Formation, Svalbard, and their relation to depositional facies.* MSc thesis, NTNU and University Centre in Svalbard, UNIS, 123 pp.

Sandvik, S.E. 2014: *Description and comparison of Lower Cretaceous deposits from Svalbard and the southern Loppa High.* MSc thesis, Arctic Geology Department, University Centre in Svalbard, UNIS and University of Bergen, 126 pp.

Storaker, A. 2008: *CO_2-rensing av eksosgass fra kullkraftverket i Longyearbyen*. MSc thesis, NTNU.

Tennvassås, I. 2018: *Characterisation of palaeosols in the Lower Cretaceous Helvetiafjellet Formation, Svalbard*. MSc thesis, Faculty of Science and Technology, Department of Geosciences, University in Tromsø, The Arctic University of Norway and Arctic Geology Department, University Centre in Svalbard, UNIS, 139 pp.

Van Stappen, J. 2013: *Pore-scale Characterization and Modelling of Kapp Toscana Group reservoir sections using X-ray micro-CT.* MSc thesis, University of Ghent, Belgium, 97 pp.

Wærum, G.O. 2011: *Bruddmønstre i øvre triaslagrekken ved Vindodden på Svalbard: opptreden, geometri og dannelsesmekanismer samt betydning for CO_2 lagring*. MSc thesis, University of Tromsø.