D2.1: Full implementation of SWS pilot test site in a confined fractured chalk aquifer on the Island of Falster, Denmark
<table>
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<tr>
<td><strong>Grant agreement no:</strong></td>
<td>642228</td>
</tr>
<tr>
<td><strong>Work Package:</strong></td>
<td>WP2.1</td>
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<td><strong>Deliverable number:</strong></td>
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<td><strong>Partner responsible:</strong></td>
<td>GEUS</td>
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<td><strong>Deliverable author(s):</strong></td>
<td>Klaus Hinsby</td>
</tr>
<tr>
<td><strong>Quality assurance:</strong></td>
<td>Rasmus Jakobsen (GEUS), Klaasjan Raat (KWR)</td>
</tr>
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<td><strong>Planned delivery date:</strong></td>
<td>28 February 2017</td>
</tr>
<tr>
<td><strong>Actual delivery date:</strong></td>
<td>19 June 2017</td>
</tr>
<tr>
<td><strong>Revised version:</strong></td>
<td>30 October 2018</td>
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<td><strong>Dissemination level:</strong></td>
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**PU = Public**

**PP = Restricted to other programme participants (including the Commission Services)**

**RE = Restricted to a group specified by the consortium (including the Commission Services)**

**CO = Confidential, only for members of the consortium (including the Commission Services)**
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Executive Summary

The SubSol pilot test site has been fully implemented on the Island of Falster ahead of time. Two Geoprobe HPT (hydraulic profiling tool) soundings were made at two existing water supply wells, and based on these the final location and design of the test site were agreed upon between GEUS, KWR and GEO (the drilling company selected to drill the wells in the test site). After the completion of the test site geophysical borehole logging (including propeller flow logs) were performed in three of the new wells of the test site and three separate field campaigns with pumping and tracer test were conducted in order to describe the hydraulic characteristics of the site.

The description of the sediment samples collected during drilling shows that at least the upper 20-25 m of the Chalk was affected by glaciotectonics during the latest glaciation as Quaternary sediments were found inside the Chalk to depths of at least 22 meter below the Chalk surface. Observations during drilling and attempts of coring and comparison of the Geoprobe HPT soundings with flow logs from the wells show that the hydraulic characteristics are highly variable in the upper 10-25 m of the Chalk and that the upper approximately 10 meters from where the Water Works abstract water, apparently do not behave like a classical dual-porosity fractured Chalk with highly conductive fractures ($K \gg 10 \text{ m/day}$) and a matrix with a very small conductivity ($K \sim \text{mm/day}$). The Geoprobe and flow logs both indicate fracture flow in some parts of the upper 10 m, but surprisingly also that the “matrix” outside the fracture zones dominate in some parts, where it has a generally much higher hydraulic conductivity than the typical Chalk matrix with $K$-values similar to what is normally found in a medium-grained sand (20-30 m/day).

This has important implications for the assessment of different SubSol SWS techniques and the final design of SWS on Falster. Further investigations will analyse and explore how this may affect the SWS possibilities on Falster and how these findings will be applicable elsewhere. The Chalk on Falster situated at depths of more than 25 m below the Chalk surface (~ 35 m below surface) is currently believed to be similar to Chalk aquifers in the UK, France, Belgium and the Netherlands.
Introduction and previous studies in the Falster case study area

The Falster test site area was studied in two previous EU and National research projects “BaltCICA” (www.baltcica.org) part-funded by the BONUS programme on the Baltic Sea (www.bonusportal.org) and “Water4Coasts” part-funded by the Ecoinnovation program of the Danish Ministry of Environment and Food (http://eng.ecoinnovation.dk). Main results from the two projects can be found in Rasmussen et al. (2013) and Hinsby et al. (2016). The main objective of the studies conducted in BaltCICA was to assess climate change impacts on the fresh-saltwater boundary in the Chalk aquifer in the investigated area. Geophysical measurements (e.g. electromagnetic, both airborne and ground-based, as well as geophysical borehole logging) were conducted to find the existing fresh-saltwater boundary and support the development of a geological and an integrated groundwater-surface water model for climate change impact assessment and adaptation. The location of the test site is shown Figure 1.

![Figure 1. Location of SubSol Study site on the Island of Falster, Denmark, western Baltic Sea.](image-url)
The main objective of the Water4Coasts study was to initiate the assessment of the potential application of new innovative techniques to control salt water intrusion and protect fresh water resources in the fractured Chalk aquifer of the Falster Island and similar settings, globally (Hinsby et al., 2016). The studies demonstrated that several issues needed to be investigated further before concrete solutions could be recommended including more detailed analyses of the hydraulic properties near the protected wells / well fields and the geochemistry and quality of the Chalk aquifer as well as groundwater and surface waters, which potentially could be used after treatment for injection and water banking e.g. between wet winter periods with low demands and abstraction and dry summer periods with high demands and abstraction.

Figure 2. a) The Falster case study area in the year 1780 with a natural lagoon between a Pleistocene push moraine and Holocene barrier islands and b) The same area in 2010 with indication of drainage canals, reclaimed land and a highly developed summer housing area, and the location of the geological cross sections shown in figure 3.
Locating and developing the SubSol Falster test site

Assessment of existing data
Data from the area from previous investigations and the Marielyst Water Works were included in the assessment of suitable test sites for detailed analyses of the hydraulic and chemical characteristics of the Chalk aquifer. The data from the detailed analyses are required in order to develop and assess different tailored site specific subsurface solutions to control salt water intrusion and protect the existing freshwater resource towards increasing chloride concentrations. GEUS identified three water supply wells together with the Water Works potentially suited for further investigations. The location of these are shown in Figure 4.
Figure 4. Location of potential water supply wells for detailed investigation of SubSol subsurface water solutions (SWS) indicated with yellow circles, and the investigation well shown in Figure 5 indicated with orange circle.

The two western most water supply wells were finally selected for further studies for practical reasons as the easternmost well is located on the Water Works itself and investigations here would disturb the daily work at the Water Works.
Figure 5. Geophysical borehole log in investigation well no. 242.344 about 1.2km southwest of the water supply wells 7 and 9 (Figure 4). The well clearly show the increasing salinity with depth and that only the upper 10-20 meters of the Chalk apparently contains freshwater suitable for drinking water supply.

Figure 6a and b show the evolution of the chloride concentration since 1990 in the two wells 242.212 and 242.231 or well 9 and 7, respectively of the Marielyst Water Works. Well 9 is rapidly approaching the drinking water standard of 250 mg/l, while the concentrations and increase is somewhat lower in well no. 7 (242.231).
Well no. 7 is screened in the upper 11 m of the Chalk with a 200 mm PVC screen, while well no. 9 has an unscreened open section in the Chalk. Geophysical borehole logging conducted by GEUS showed that well no. 9 had “collapsed” and could not be logged in the Chalk. The log of well no. 7 (Appendix 1) showed that the whole upper screened section of the Chalk contained freshwater with an electrical conductivity of around 500 µS/cm (well below the drinking water standard of 1000 µS/cm). Although well no. 9 had collapsed it still had a reasonable yield, and it was therefore decided to conduct further investigations close to the two wells in order to assess, which location would be best suited for the development of the final SubSol-SWS test site.

Conducted investigations for location of test site for detailed studies
It was decided to conduct Geoprobe HPT soundings as close to the two drinking water wells as possible to measure detailed high-resolution vertical variations of both the hydraulic and the electrical conductivity at the two wells. The results from the HPT soundings are shown in Figure 7a and b.
Figure 7. a) HPT log of well no. 7 (242.231) and b) HPT log of well 9 (242.212)
The HPT profiles from both wells indicates that fracture flow dominates in most of the Chalk section in both wells. However, in well 9 in the section 12-18 m below surface, the HPT log indicates a continuous, relatively high hydraulic conductivity. This only agrees partly with the flow log conducted in well T1 about 1 meter from HPT 9 where the flow log indicates relative high hydraulic conductivities from 16-20 m below surface especially at the bottom and top of this section. The flow log indicate small conductivities in the Chalk above 16 m below surface.

**Final selection of study site location**
Based on the conducted HPT soundings and the existing data for the investigated wells including the higher chloride concentrations in well no. 9 GEUS decided, in collaboration with the Water Works, to develop the test site for detailed SubSol / SWS studies at well no. 9.

**Development of study site for detailed evaluation of potential subsurface water solutions.**
After requesting offers from three different Danish drilling companies, GEUS decided to use the drilling section of the company GEO (http://www.en.geo.dk/front-page/) as a subcontractor for drilling and developing the wells of the test site. GEO is a highly respected geotechnical company in Denmark, and it has the largest experience in drilling and installation of monitoring wells in the investigated area.

It was decided to start by cleaning up well no. 9 and install a screen to prevent that the well collapsed again, and then conduct borehole logging in the “new” well. However, this work failed as the well kept collapsing, and it was not possible to install a screen without drilling a new well inside the old one.

GEUS discussed the possibilities and purpose of the test site, and the most suitable drilling procedures and well development etc. with GEO and decided to give up reestablishing well no. 9, and instead drill a total of 6 new wells at the test site around well no. 9 as indicated in Figure 7. The CMT wells are intended for sampling at specific depths.
Each well has 7 screens of 1 m, installed interleaved with the other CMT well and separated by bentonite seals.

Figure 7. The developed test site at water supply well no. 9. Well no. 9 is located between the new wells T1 (developed for tracer injection) and well UB1 potentially part of SubSol solutions for protection of the fresh water resource during the continued operation of well no. 9 (Kolind-Hansen, 2017).

Results of initial investigations in developed test site

Borehole geological and geophysical logs
After completion of the test site, sediment samples collected during drilling were described in the laboratory (Appendix 1) and geophysical borehole logging was conducted in wells UB1, UB2 and T1 (CMT 1 and 2 cannot be logged). The logging included propeller flow logging to evaluate the hydrodynamics of the boreholes. The geological logs are shown in Appendix 2. Generally 2-5 meters of Holocene mainly marine sands are found in the top of the profile followed by 4-8 meters of Quaternary clay (mainly tills) underlain by Cretaceous Chalk to the bottom of the borehole. In the investigated area the Chalk continues for several hundred meters below surface. In several of the boreholes the flow-log showed distinct inflow zones indicating the fractures in the chalk aquifer.
Figure 8. Selection of Chalk samples from depths between 15 and 23 meters collected during drilling of well no. CMT1. Kolind-Hansen, 2017.

Figure 9. Geological log of CMT 1 developed based on the collected samples from the well during drilling (figure 8), (Kolind-Hansen, 2017).
Geochemistry of the Chalk and potential geochemical reactions for nitrate reduction/risk of clogging

Chalk samples were also collected for analysis of the content of reducing minerals and harmful trace metals such as As and Ni.

Figure 10 show the results of geochemical analyses of the upper Chalk and the lower till mixed with chalk from the study site.

![Figure 10](image.png)

Figure 10. Percentage (weight) of pyrite in Chalk samples collected from a research well in the Falster study area. Red squares indicate results from core samples, blue diamonds are from bag samples. It was generally impossible to get core samples in the upper part of the Chalk where the water supply wells are located because it was very soft.

The results indicate a decreasing amount of pyrite with depth, with very low contents around 5 ppm below 40 m below surface. This indicates that the effects of injecting oxidized water should be small. The contents of some of the potentially problematic trace elements related to the pyrite content is shown in Figures 11 and 12. The amounts
correlate well with the measured pyrite content, indicating that most of the trace element content, except for copper, is derived from the pyrite during the extraction. The slightly higher trace element, except for copper, content in the clay could indicate a pool related to the silicate minerals that are only present in very minor amounts in the Chalk, which is highly dominated by calcite. The copper in the Chalk with very low pyrite contents must be present in other minerals. The content of trace elements in the pyrite in the Chalk is low, even for the highest As where the content in pyrite is only 0.5 ‰ by weight. In the Chalk as such, the maximum content of As is 1 ppm. These low contents indicate that the release of problematic trace elements due to injection of oxidized water will be small.

Figure 11. Concentration of As and Ni in clay till (green triangle) and Chalk (blue diamond) as a function of the FeS2 content

Figure 12. Concentration of Co and Cu in clay till (green triangle) and Chalk (blue diamond) as a function of the FeS2 content.
**Geochemical reactions and the potential for nitrate reduction**

The reduction capacity of the Chalk and the overlying clay till is currently estimated in batch experiments at GEUS – some preliminary results are shown in Figure 13.

Figure 13. Preliminary results from batch experiments estimating the reduction capacity of the Chalk and the overlying clay till.

The preliminary results from the batch experiments show very little reduction capacity of the Chalk itself, but that some capacity is available for oxygen reduction in the clay till above the Chalk and in the upper Chalk, where the last glacial advance in the area strongly affected the upper part of the Chalk. Hence, the preliminary conclusion is that there’s no significant capacity for nitrate reduction in the Chalk in the Marielyst area (Figure 13 and 14). Hence, the aquifer does not seem to constitute a potential mitigation measure for excess nitrate loadings from agriculture e.g. by injecting nitrate containing surface waters in the deeper brackish coastal part of the Chalk before discharge to the sea.
Figure 14. Preliminary results from batch experiments illustrating reduction of oxygen and production of sulphate by the following process: $\text{FeS}_2 + \frac{15}{4} \text{O}_2 + \frac{7}{2} \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 2\text{SO}_4^{2-} + 4\text{H}^+$

**Risk of clogging**

The geochemical analyses of the chalk and the batch experiments have identified pyrite as the reductant responsible for oxygen reduction in the Chalk by the process shown in the caption to figure 14. The pyrite does not seem to have a nitrate reduction potential (Figure 13 and 14), but reduction of pyrite produces iron hydroxides - Fe(OH)$_3$, which on the long term may cause clogging problems in the screen of the injection well. Further studies are however needed to estimate the time scale for this process.

**Pumping tests**

Several short and long term pumping tests have been conducted in at the test site in November/December 2016, January 2017 and April 2017. The data are still being analysed and no final conclusion has been made, but the conducted pumping tests indicate conductivities that vary significantly from a few meters /day and up to 172 meters/day most probably dependent on the amount of hydraulic active fractures affecting the water flow in the tested volume. Hence pumping tests indicate K-values both higher and lower than the results obtained from the Geoprobe test mentioned in section 2 (up 30 m/day).
Tracer tests
The Setup applied for the performed tracer tests are illustrated in Figure 13. The idea in the setup is to contain the injected tracer within a surrounding dipole flow field, enabling experiments with different flow velocities to assess the interaction between transport in fractures and diffusion into the surrounding matrix. The tracer tests were conducted with NaBr and NaCl in separate tests. NaBr and NaCl were added to an approximately 600 l container to obtain electrical conductivities of around 5000 and 7000 µS/cm, respectively. The temperature of the injected water was increased to 27/29°C in order to minimize the density effect of the increased salinity. The temperature needed to obtain the same density as the water in the aquifer was calculated using the geochemical program PHREEQC. The CMT 1 and CMT 2 wells (Figure 14) were pumped continuously at a low flow rate of 20-60 ml/min from all 14 screened intervals during the entire tracer test.

Figure 13. Injection of tracer into T1 just left of the green cover, through thin white hose – about 1 meter from the WSP no. 9 below the green cover. Blue hose injects water pumped from UB2 into UB1 to create the dipole flow field between UB1 and 2 illustrated in Figure 14. The manifold on top of the green cover is for removing air from the water prior to injecting it. The transparent plastic tube going into T1 was filled with water after the tracer injection to expel the volume of water in the well to avoid effects of the borehole during the tracer movement.
Figure 14. The developed test site indicating the setup for the conducted dipole tracer tests using NaBr, NaCl and temperature as tracers. Color markings on the wells in the cross-section to the left corresponds to the plan view of the intended flow field on the right. Blue arrows in the left diagram show the water movement. The water supply well of Marielyst Waterworks is situated between UB1 and T1 in the left side of the figure.

The results from the tracer tests indicate that most of the tracer diffuses into the matrix making it difficult to say whether we succeeded in actually seeing the tracer as it passed by wells CMT 1 and CMT 2.

**On-line monitoring of salt water intrusion (“salinity”) and SCADA/PLS**

The SubSol project is currently testing on-line monitoring systems delivered by two different environmental consulting companies COWI (www.cowi.com) and We-teco (www.we-teco.com). The two monitoring systems currently monitors salinity, temperature and water table variations in the tracer injection well (T1) at a depth of 17 m, and in the deepest monitoring well (UB1) at a depth of 35 m; 1 and 3 meter from the water supply well, respectively. The monitoring station for T1 was established by COWI in November 2016, while the We-teco station has been monitoring since April 2017.
Examples of screen dumps of results from the monitoring stations established by COWI and We-teco can be found in appendix 3.

Data similar to the data from the two stations are required for developing an automated control system (SCADA/PLS) for controlling the investigated SWS techniques, when such a system is in operation.

Chloride sensors have not been deployed in this study although it was anticipated in the original application as 1) previous test of these were not satisfying (Hinsby et al., 2016) and 2) electrical conductivity sensors are generally more stable and suffice for salt water intrusion monitoring.

Additional developments for SCADA/PLS systems by Subsol partners are described in deliverable D2.2 of the project.

**Discussion and conclusion on preliminary results**

The conducted investigations show that the upper 10-20 meters of the chalk where the water supply wells abstracts water for the water works are strongly affected (crushed and displaced) by glacioteclonics at the study site. The preliminary results indicate that these processes have a strong influence on the hydraulic characteristics of the Chalk in a way that makes the variation of the hydraulic conductivity highly unpredictable and also that the upper Chalk may be divided into two domains with different hydraulic characteristics. It seems that parts of the upper 10-20 meters behave like a single porosity medium and that other parts behave in the expected way as a dual-porosity fractured media as the Chalk generally does in North-Western Europe (Downing et al. 2005). From the assessments of the currently conducted investigations we believe that the location of these two domains are highly unpredictable and variable both horizontally and vertically due to the character of the glacial dislocations and erosion. Further studies in SubSol will evaluate the effects and significance of the glaciotreclontic impacts, and explore effective solutions to deal with this complicating factor.
**Remaining work**

Additional field work and assessment of pros and cons of potential SWS techniques.

**Tracer tests**

Due to the difficulties in getting clear data from the first tracer tests it will be necessary to install 1-2 new tracer injection/observation wells closer to the two CMT wells and carry out an additional tracer experiment. The best location of these wells are currently discussed and evaluated.

Injection or infiltration of different types of water into aquifers introduces a risk of affecting the groundwater quality around the injection wells in a negative way depending on the hydrochemistry of the injected waters and the geochemistry of the aquifer receiving the injected water.

**Water quality issues**

The risk of releasing trace elements by injecting oxidizing water in an ASR or ASTR (Aquifer Storage Transport and Recovery) water banking scheme appears to be small at the Falster site. Still there could be other risks, such as clogging, organic pollutants as well as microbial pathogens associated with this depending on the quality of the injected water. The most promising approach at the developed test site where the salt water intrusion appears to come from underlying fossil seawater rather than actual sea water intrusion appears to be avoiding the mixing in of the saltwater using a Freshkeeper scheme. However, injection of completely purified and possibly deoxygenated (e.g. by reverse osmosis etc.) rain-/drainwater harvested from a rainage canal approximately 150 m west of the water supply well is an alternative option, which also will be investigated further. Evaluation of geochemical processes which potentially may affect the groundwater quality negatively by injection of treated surface water or desalinized groundwater is still on-going.
Cost-benefit analyses of selected SWS-methods
Cost benefit analyses and technical pros and cons of the following potential subsurface water solutions for the Falster site will be conducted and evaluated during the rest of the project:

1: Freshkeeper/ASR : i.e. skimming brackish water from below the water supply well to avoid upconing of more saline water, desalination of the abstracted brackish water and reinjecting both the desalinized part and the produced brine at a) the level of abstraction of the water supply well (10-20 m below surface) and b) Depth > 35 m below surface, respectively close to the water supply well. The evaluation of this option will include assessment of the potential benefits of running the desalinization plant both winter and summer, and whether the desalinized water can be pumped directly to the water works to accommodate peak water demands in dry periods during summer time.

2: ASTR (Aquifer Storage Transport and Recovery) coastal. In this study we will assess the possibility of pumping water from the drainage canal located approximately150 m west of the water supply well, purifying (and deoxygenating) it and injecting it x meter upstream the water supply well. After injection the purified freshwater will flow slowly towards the abstraction well with a flow velocity that ensures that the centre of the injected freshwater plume will arrive at the abstraction well at the time of peak abstraction during the summer period.

3. Combinations of the two previous mentioned subsurface water solutions depending on results from the assessments conducted within option 1 and 2 described above (e.g. reinjection of desalinized brackish water upstream the water supply well).

New developments for SCADA/PLS systems.
The developments were delayed, but a datalogger/controller (BC1000), which can interface to an existing SCADA system and development schemes for algorithms controlling pumps in existing software working with SCADA systems were later developed by the Subsol partners Bluecontrol and Orbicon as described in D2.2 of the project.
References


Appendix 1. Geophysical borehole logs of selected wells

Note! Well no. CMT1 -2 and P100 have not sufficient diameter for borehole logging no logs therefore exists for these
The gammalog to the right of the lithology column (brown curve) indicate that the Till / Chalk boundary is located at a wrong depth. It should be at approximately 12 m depth according to the gammalog. This is supported by the borehole log from well T1 – about 1 m from WSP 9 (see next page). The well has collapsed in most of the open hole section leaving only 1-2 meters in the upper part open.
Borehole log of tracer injection well T1 (DGU no. 242,385)
Borehole log of tracer injection well UB1 (DGU no. 242.384)
Borehole log of tracer injection well UB1 (DGU no. 242.388)

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Well Name: UB1
Location: Manby, Malmo
Reference: Ground Surface, elev. +1m DVS90

Borehole logging by GEUS 25-29 October 2014. Pumping rate: 10 m³/h
Appendix 2: Geological Logs
Geological log of WSP 9 (DGU no. 242.212)

Holocene marine sand

Quaternary glacial clay till

Cretaceous Chalk (very soft – affected by glaciotaltectonics)

Cretaceous Chalk (very soft – affected by glaciotaltectonics)

Open hole – now collapsed but well still producer. Water
Geological log of UB1 (DGU no. 242,384)

Borerapport

**Borored: Børge Ringøj**

**Kommune:** Guldborgsund

**Region:** Sjælland

**Boringsdato:** 1/9 2016

**Boringsdybde:** 38 meter

**Terrænkote:** 0,57 meter o. DNN

**Brandhvel:** GEO

**MON nr.:**

**Borhvel:** KUBI

**Præc.:**

- beskrevet: 29.11.2017

**Antal gæst:** 8

**Formål:**

**Forerensningsfjælle**

**Kortblad:** 15111180

**Datum:** EURERPA

**Anvendt**

**Forerensningsfjælle**

**UTM-zone:** 32

**Koordinatkø:** Landinspektor

**Koordinatmåder:** Landinspektor

**Notater:**

Gyldig 4.5. m.a. er analyseret af Ole Bonnke, DGUS. Sondag 31.5 meters dybe betegler, at den overliggende kalk antagelig er glacioblotseret.

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<td>Pige</td>
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<tr>
<td>GWK</td>
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Geological log of UB1 (DGU no. 242,384) – continued.

De Nationale Geologiske Undersøgelser for Danmark og Grønland

BORERAPPORT

DGU arkivnr: 242.384

Abbildung 3e - Bild 2 (klima-krono-til-iso-stratigraph)
**Geological log of UB2 (DGU no. 242,388)**

De Nationale Geologiske Undersøgelser for Danmark og Grønland

**BORERAPPORT**

**DGU arkivnr:** 242.388

**Boresøjle:** Bliste Ringøj

**Boresøjlenr.** 4073 Vindegårde

**Boringstid:** 8/9 2016

**Boringstiefe:** 26 meter

**Terrænskoordinater:** Ø 6 meter a. DNN

**Kommune:** Guldborgsund

**Region:** Sjælland

**Børnennr.:** DGU

**UBE nr.:** MB2

**Prøver:***

- **måned:** Maj 2016
- **antal:** 26
- **beskrevet:** 30/4 2017
- **antal genm.:** 0

**Formål:** Forskeringen/relasse

**Kortblad:** 1511HNB

**Datum:** EUR0290

**UAE:**

**UTM zone:** 32

**Koordinatblad:** Landinspektør

---

**Notater:**

Gryllikag 4 m ud af undersøgelse af Ole Berntsen, GEUS. Prøven indeholder mange eller af sandtoner som vekser på land side med betjening i stramdæmmer, rust og fjerde.

---

**Diagram:**

- **SARL:** Sandliest, grønbus, 5YR 5/4, svagt kaldhvid (postglacial sandtoner) i enden udgjort ved 1 m.

- **SARL:** Sandliest, svagt skiferet, svagt indtænkt sandtoner, mask. gul 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 2 m.

- **SARL:** Sandliest, svagt skiferet, grønbus, 5YR 5/4, svagt indtænkt sandtoner, mask. 5/10, 2 m. (prægl. svagt skiferet, svagt indtænkt sandtoner) i bunden udgjort ved 3 m.

- **LER:** Sandliest, svagt skiferet, grønbus, 2,5Y 4/7, svagt indtænkt sandtoner, mask. 5/10, 2 m. (prægl. sandliest, svagt skiferet, grønbus, 5YR 5/4, svagt indtænkt sandtoner, mask. 5/10, 2 m.) i enden udgjort ved 4 m.

- **SARL:** Sandliest, svagt skiferet, grønbus, 5YR 5/4, svagt indtænkt sandtoner, mask. 5/10, 2 m. (prægl. sandliest, svagt skiferet, grønbus, 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 5 m.

---

**Diagram:**

- **SARL:** Sandliest, svagt skiferet, grønbus, 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 6 m.

- **SARL:** Sandliest, svagt skiferet, grønbus, 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 7 m.

- **SARL:** Sandliest, svagt skiferet, grønbus, 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 8 m.

- **SARL:** Sandliest, svagt skiferet, grønbus, 2,5Y 4/7, kalori (postglacial sandtoner) i midten udgjort ved 9 m.
Geological log of UB2 (DGU no. 242.388) - continued

BORERAPPORT

DGU arkivnr: 242.388

Allogensamle - Alder (mio., kvarr., mio., biotritiket)

<table>
<thead>
<tr>
<th>meter u.</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 4</td>
<td>mio., postglacial, holocen</td>
</tr>
<tr>
<td>4 - 11</td>
<td>glaciogen, glacial, kvarr.</td>
</tr>
<tr>
<td>11 - 26</td>
<td>mio., maastrichtien</td>
</tr>
</tbody>
</table>
## Geological Log of T1 (DGU no. 242.385)

### Borerapport

**De Danske Geologiske Undersøgelser for Danmark og Grønland**

**Identifikation:**
- **Borested:** Bille Ringej
- **Borestednavn:** 4973 Væggeløse

**Borerapport:**
- **Kommune:** Guldborgsund
- **Region:** Sjælland

**Boredata:**
- **Boredata:** 6/9 2016
- **Boredybde:** 21 meter
- **Terrasshøjde:** 0.64 meter o. M.

**Borareder:**
- **Brændværk:** GEO

**MO8 nr.:**
- **Brændværk:** GEO

**BJ-jar:**
- **Brændværk:** GEO

**B8-hvor:**
- **Brændværk:** GEO

**Format:**
- **Foruringsligning:** Kurthold
- **Form:** 2411 IN

**Anvisninger:**
- **UTM Zone:** 32
- **Koordinater:** Landinspektør

**Borereder:**
- **UTM E:\** 626006, 606400
- **Koordinater:** Landinspektør

**Notater:**
- Gyldig 4 m ud fra analysen af Ole Bentsen, GEUS. Prøvet indeholder mange rester af reptilplanter som vokser på land, samt mad brændelser i smeltedøj, ret og fisk b.

---

### Geologisk Log

<table>
<thead>
<tr>
<th>Indhold</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Sols</strong>, mest frit, inden for planter, mark med grænse 1.08 m, svagt kalkholdig (fdt). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>2</td>
<td><strong>Sols</strong>, mest meden, grænse 2.05 m, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>3</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>4</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>5</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>6</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>7</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
<tr>
<td>8</td>
<td><strong>Solskum</strong> (VND), stengs, svagt sand, inden for planter, svagt kalkholdig (pedagogisk salgsvæske). Prøve udtaget ved 1 m.</td>
</tr>
</tbody>
</table>

---

**Bemærkninger:**

- Henvisning af landet og smeltedøj.

---

**Kalkstein:**
- **Borested:** Bille Ringej
- **Borestednavn:** 4973 Væggeløse
- **Kommune:** Guldborgsund
- **Region:** Sjælland

**Boredata:**
- **Boredata:** 6/9 2016
- **Boredybde:** 21 meter
- **Terrasshøjde:** 0.64 meter o. M.

**Borareder:**
- **Brændværk:** GEO

**MO8 nr.:**
- **Brændværk:** GEO

**BJ-jar:**
- **Brændværk:** GEO

**B8-hvor:**
- **Brændværk:** GEO

---

**Format:**
- **Foruringsligning:** Kurthold
- **Form:** 2411 IN

**Anvisninger:**
- **UTM Zone:** 32
- **Koordinater:** Landinspektør

**Borereder:**
- **UTM E:\** 626006, 606400
- **Koordinater:** Landinspektør

**Notater:**
- Gyldig 4 m ud fra analysen af Ole Bentsen, GEUS. Prøvet indeholder mange rester af reptilplanter som vokser på land, samt mad brændelser i smeltedøj, ret og fisk b.
Geological log of T1 (DGU no. 242.385) – continued

De Nationale Geologiske Undersøgelser for Danmark og Grønland

BORERAPPORT

DGU arkivnr: 242. 385

Afgjøring af Altor (diluval, kvarter, glaciofluvial)

målt u.t.

0 - 2
2 - 4
4 - 4,5
4,5 - 10
10 - 12
12 - 13
13 - 21

fyld
melt - postglacial - flodcan
glacial - klufter - glacial - klufter
glacial - klufter - glacial - klufter

mål u.t.

20
40
60

KALKHAST, meget blødt, lige slaven, brudvæggh, hold hård, "Selvvedet". Førre udtoget ved 20 m. Højre Pibersten.

KALKHAST, meget blødt, lige slaven, brudvæggh, brudvæggh, "Selvvedet". Førre udtogt ved 20 m. Højre Kystsandstone Pibersten.
**Geological log of CMT1 (DGU no. 242.386)**

<table>
<thead>
<tr>
<th>Datum</th>
<th>12/06/2016</th>
<th>Tykkelse</th>
<th>25 meter</th>
<th>Tørrvæske</th>
<th>0,53 meter a. DN</th>
</tr>
</thead>
</table>

**Formålsøjle: Forureningen/forurening**
- **Kortlængde:** 15/111/W11
- **Datum:** EUFEBR
- **UTM zone:** 32
- **Koordinater:** Landindepark
- **UTM koordinater:** 89/200, 20/040

**Notater:**
- Gytteleg 4 m ud. er analyseret af Ole Brenderup, GEUS. Preve i indhold mange arter af undersøgelse som vekser på levnsom med brækkede i stranden, mor og forde.

---

**Diagram:**
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 4
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 5
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 6
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 7
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 8
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 9
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 10
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 11
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 12
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 13
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 14
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 15
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 16
- **SAND, vest fra, kalkstein 10/4/4, kalkstein (postglacial siltstone).** Prøvet udført ved 17
Geological log of CMT1 (DGU no. 242.386) – continued

BORERAPPORT
DGU arkivnr: 242.386

Højden m.o.l.: 25.00

1. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "frilayet". Prøve udtaget ved 20 m.
2. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 15 m.
3. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 21 m.
4. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 22 m.
5. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 23 m.
6. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 24 m.
7. KALKMÆRKE, meget blok, destr. som knotet, hvid/lav, "skifteflint". Prøve udtaget ved 25 m.

Afgjørelsesmiljø - Alder (G. mæ., h. mæ., l. h. mæ., biostratigrafi)

meter m.o.l.
0 - 4 mænr. - postglacial - højtocen
5 - 11 glaciaklaster - glacial - kvartär
11 - 25 mænr. - maastrichtien
Geological log of CMT2 (DGU no. 242.387)

De Nationale Geologiske Undersøgelser for Danmark og Grenland

Borerapport

DGU arkivnr: 242. 387

Borested: Bøle Ringeq
4873 Vágsvæk

Kommune: Guldborgsund
Region: Sjælland

Boredata

Boredata: 14/0 2015
Boinglesdybde: 26 meter
Terrænskote: 0 meter a. DNN

Boregrader: GEO
BIL: CMT2

Formål
Forrening/mellemlag

Kontaktdnr.: 18111NNH
Datum: BEURFRB

Arenemodeller

UTM-coord.: 322
Koordinatsystem: 60040

Formål
Forrening/mellemlag

Kontaktdnr.: 18111NNH
Datum: BEURFRB

Arenemodeller

UTM-coord.: 322
Koordinatsystem: 60040

Koordinatsystem: Landmesterschaft

Noter

Gyldig 6 m ut er analyseret af Ole Børresen, GeoU. Prøven indeholder mange steder af sagnetplanten som vekker på last vest med braksted i staaender, nør og fajde

Diagram:

- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
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- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
- SUB: sed. litl. galleren Tørv f. m, uvag klakhvæl, (postglacial olihvedeundens). Prøve udtaget ved 1 m.
Geological log of CMT2 (DGU no. 242.387) – continued

De Nationale Geologiske Undersøgelser for Danmark og Grønland

BORERAPPORT

DGU arkivnr: 242.387

---

### Geological Log

<table>
<thead>
<tr>
<th>Meter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4</td>
<td>Marine - postglacial - Holocene</td>
</tr>
<tr>
<td>4-12</td>
<td>Glacial - Quaternary - Ice Age</td>
</tr>
<tr>
<td>12-26</td>
<td>Marine - Tertiary/Quaternary</td>
</tr>
</tbody>
</table>

---

**Legend:**
- Green: Marine sediments
- Grey: Glacial sediments
- Red: Ice Age sediments

---

**Notes:**
- Green: Marine sediments
- Grey: Glacial sediments
- Red: Ice Age sediments

---

**Key:**
- F: Ice Age sediments
- G: Glacial sediments
- M: Marine sediments

---

**Scale:**
- 1 cm = 1 m

---

**Varnished:**
- 1 cm = 1 m

---

**Layer:**
- 1 cm = 1 m

---

**Subsurface:**
- 1 cm = 1 m

---

**Subsoil:**
- 1 cm = 1 m

---

**Soil:**
- 1 cm = 1 m

---

**Rock:**
- 1 cm = 1 m
Appendix 3: Screen dumps of near real-time measurements

Screeendump from COWI monitoring station:

Screeendump from We-teco monitoring station visualized at Thingspeak:
https://thingspeak.com/channels/250041/private_show