# Shallow and deep rocks as potential sources of geothermal energy in Denmark

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## ABSTRACT

In this paper, the suitability of shallow and deep reservoirs in Denmark are summarily reviewed from largely a sub-surface point of view. It is concluded that Denmark has a good to excellent geothermal resource potential in large parts of the country. An explanation is offered as to why there are only three operational geothermal projects in Denmark by comparing the development of geothermal resources in the Netherlands. The lack of attractive geothermal subsidies as well as a difficult geothermal licencing regime in Denmark are seen as hindrances to the development.

## 1. INTRODUCTION

Nail Resources Denmark BV obtained a geothermal licence on the islands of Lolland and Falster in Denmark in March 2018.

A Joint Venture with the Danish company BEET Energy ApS is being formed as plans for shallow geothermal projects are developed.

A subsequent application for a second licence targeting deep geothermal projects is shelved as developments surrounding the societal acceptance of such projects are awaited.

This paper provides a short overview of some elements of geothermal resources present in Denmark. In addition, it attempts to compare the geothermal landscape in Denmark with the Netherlands, countries the authors are most familiar with.

## 2. THE JOINT VENTURE

A geothermal licence for the entire area comprising the Lolland and Falster islands in southern Denmark was issued to Nail Resources Denmark BV. The licence was granted on 29 March 2018 and has a 6-year term. It is limited to District Heating.

Nail Resources Denmark BV was founded in 2016 by founding parties Nail Petroleum BV (50%) and Danica Resources ApS (50%).

In 2019, BEET Energy ApS farmed in for 40%. The significance is that, with a Joint Venture, the licence work programme will rest on sounder financial footing and benefits from an enlarged team of geothermal professionals from all joint venture partners.

## 3. DANISH GEOTHERMAL HISTORY

Figure 1 shows the geothermal history in Denmark has been dominated by DONG.

After DONG was given exclusive rights to explore for and extract geothermal energy in Denmark for 30 years, acreage holdings were relinquished throughout much of the period 1990-2010.

Geothermal exploration and exploitation resulted in a total of three operational geothermal projects, having operational geothermal plants. This is considered a minimal result in view of the resources spent in this period.

Characteristics of the three geothermal plants, now owned by various investors and shown on Figure 4, are summarised below:

1. Thisted (start 1984) comprises 1 producer and 2 injectors. Salt water is produced from the Gassum Formation (Upper Triassic) at a depth of around 1,250 m with water temperatures of 43°C
2. Margretheholm (start 2005) has 1 producer and 1 injector. It produces from the Bunter Formation (Lower Triassic) at a depth of some 2,600 m. Water temperature is 74°C
3. Sønderborg (start 2013) is the most recent project and also has 1 producer and 1 injector. Like Thisted, the Gassum Formation (Upper Triassic) yields water from around 1,200 m depth at temperatures of 48°C

## 4. SHALLOW RESERVOIRS

Shallow reservoirs in Danish geothermal exploration are here defined as reservoirs shallower than 1400 m below surface.

The Danish Geological Survey ("GEUS") has mapped Danish reservoirs that can be used for geothermal purposes at depths between 800 m and 3000 m below surface. Reservoirs located shallower than 800 m are deemed to have inadequate temperatures for geothermal exploitation and reservoirs deeper than 3000 m are believed to have limited reservoir potential due to diagenesis.

Potential reservoirs, see Figure 2, are exclusively seen in sandstone reservoirs and comprise the following formations:

1. Cretaceous: Frederikshavn Formation
2. Jurassic: Haldager Sand Formation
3. Triassic: Gassum Formation
4. Triassic: Skagerrak Formation
5. Triassic: Bunter Sandstone Formation

Geothermal potential reservoirs as mapped by GEUS are available online via GEUS's "Geotermi WebGIS-portalen" (ref. http://dybgeotermi.geus.dk/en/main/).

In shallow reservoirs, the Joint Venture is attempting to revolutionise the cost and applications for geothermal energy via various in-house projects. The projects focus on the currently untapped “near-shallow” geothermal resources (between 800 – 1400 m) by identifying near-shallow geothermal resources, simplifying drilling and completion techniques as well as developing fit-for-purpose, low cost surface equipment to exploit the low-grade heat. The projects not only attempt to develop methodologies to deliver low cost geothermal energy solutions, but it is also planned to demonstrate this with a proof-of-concept drilling and implementation project.

## 5. DEEP RESERVOIRS

### 5.1 Potential Geothermal Reservoirs

We believe there are at least five geological intervals or sections that may offer the potential for development of deeper geothermal energy resources, concentrated in Jutland, Denmark. Our observation is based on seismic data and data from the Grindsted-1, Nøvling-1, Løve-1 and Jelling-1 wells. Temperature data are summarized in the following table.

Key wells are shown on Figure 4.

**Table 1 Potential Geothermal Reservoirs in Central Jutland Denmark**

| No. | Target | Temperatures recorded °C |
|---|---|---|
| 1 | Fault fractured zones in basement rocks of the RFH | 67 – 71 |
| 2 | Lower Triassic Bunter sandstones | 43 |
| 3 | Middle/Upper Triassic Tønder/Oddesund Formation sandstones | 41 |
| 4 | Upper Triassic Gassum Formation sandstones | N/A |
| 5 | Upper Jurassic - Lower Cretaceous Frederikshavn Formation/Rødby sandstones | 43 |

### 5.2 Basement fault fractured zones

Seismic data available to the Joint Venture shows that the basement rocks of the Ringkøbing-Fyn High (“RFH”) in central Jutland are cut by several deep going north and northwest trending faults and the Brande Graben.

Danish well Grindsted-1 (see Figure 4 for locations) was drilled just a few kilometres west of the Brande Graben to a total depth of 1647 m, bottoming in pre-Cambrian gneiss. It was drilled as an oil and gas exploration well. The bottom hole temperature was 67°C. This is a significant deviation from the average geothermal gradient of 25°C per km and may be related to the well’s location near the west bounding, deep going fault zone of the graben. Review of seismic data has shown that, apart from the deep going faults that bound the Brande Graben, there are other deep going faults and shallow basement horsts to the east and west of the Brande Graben in the RFH. Fractured fault zones, if found to be porous and permeable, would clearly constitute targets for geothermal exploitation.

Figure 3 shows an interpretation of a 2D seismic line which shows the potential for deep fracture zones which could serve as conduits for deeper sourced warmer water.

In Jelling-1, also an oil and gas exploration well, the 20 metres of basement drilled in the bottom of the well around 2000 m below surface, is described as granitic rock with a cover of weathered granite.

With respect to potential deep reservoirs, the Joint Venture is studying areas in Denmark where drilling records have shown shallow basement (1600 – 2000 m) to have anomalously high temperatures, ranging from 60°C to 70°C and possibly higher. There is evidence that faults penetrating deep into basement may also be conduits for water to rise quickly into a number of shallower Mesozoic sandstone sequences with good reservoir characteristics.

## 6. COMPARISON OF DANISH AND DUTCH GEOTHERMAL LANDSCAPE

A comparison of the geothermal landscape in the Netherlands and Denmark, the countries the authors are most familiar with, yields the following key characteristics:

- Operational Geothermal Plants
    - NL: 16-19 (with a total capacity of over 50 MWth)
    - DK: 3 (with a total capacity of some 30 MWth)
- Issued Licences
    - NL: 70-80
    - DK: 6
- No. of Commercial Players
    - NL: 20-40
    - DK: 5-10
- Subsidy regulation in place
    - NL: SDE+ (“Stimuleringsregeling Duurzame Energieproductie”), essentially a subsidy on revenues
    - DK: Capex Guarantee which is essentially a subsidy on capital overruns on any given geothermal project

Although there is a legal framework in place in Denmark and there is a willing government/regulator promoting geothermal projects as a renewable energy source, there are few operational projects in comparison with the Netherlands.

In the view of the authors, two main reasons are responsible for this:

1. Danish licensing procedures are complicated and should be simplified. Now licences are granted in a yearly application round for a specific purpose, e.g. a District Heating licence cannot serve Industrial Customers. This should be broadened and made attractive for investors.
2. An attractive subsidy is lacking. An increase of subsidy by introducing, next to the CAPEX-overrun guarantee scheme, a subsidy on revenues (like SDE+ in the Netherlands) would attract more investors.

## 7. CONCLUSIONS

1. Denmark has a good to excellent geothermal resource potential in large parts of the country
    a. From a sub-surface point of view, the geology is very suitable to exploit both shallow and deep reservoirs

2. To explain that there are only three operational geothermal plants in Denmark, it is indicated that there is a lack of attractive geothermal subsidies as well as a difficult geothermal licencing regime

## REFERENCES

GEUS and its supporting websites: http://dybgeotermi.geus.dk/en/main/

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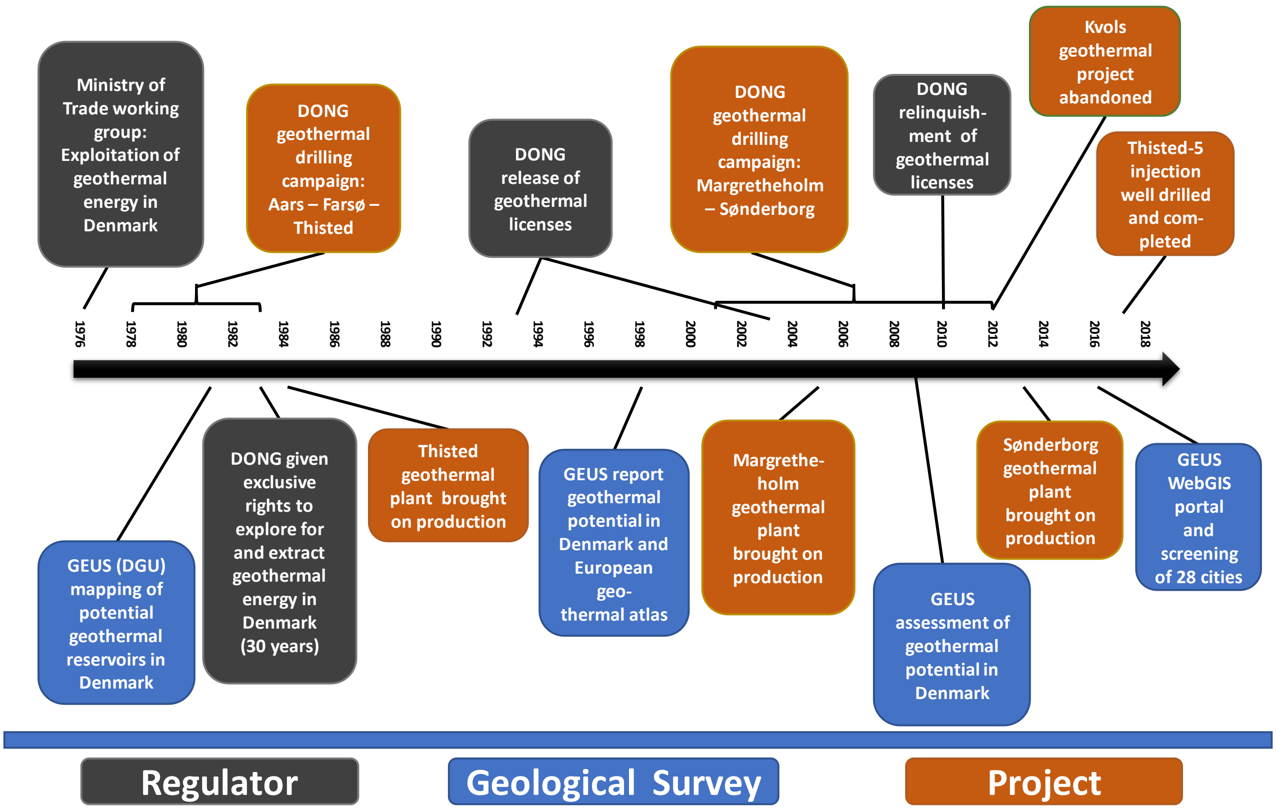


**Figure 1: Geothermal History in Denmark**

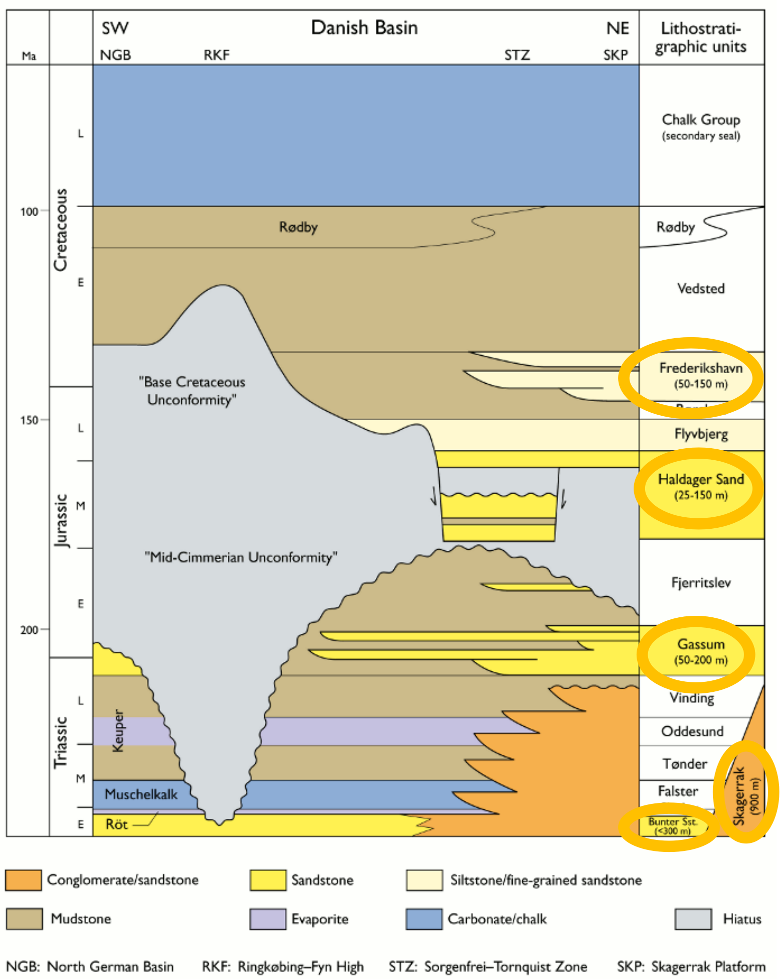


**Figure 2: Potential Geothermal Reservoirs in Denmark (Source: https://data.geus.dk/nordiccs/geology.xhtml)**

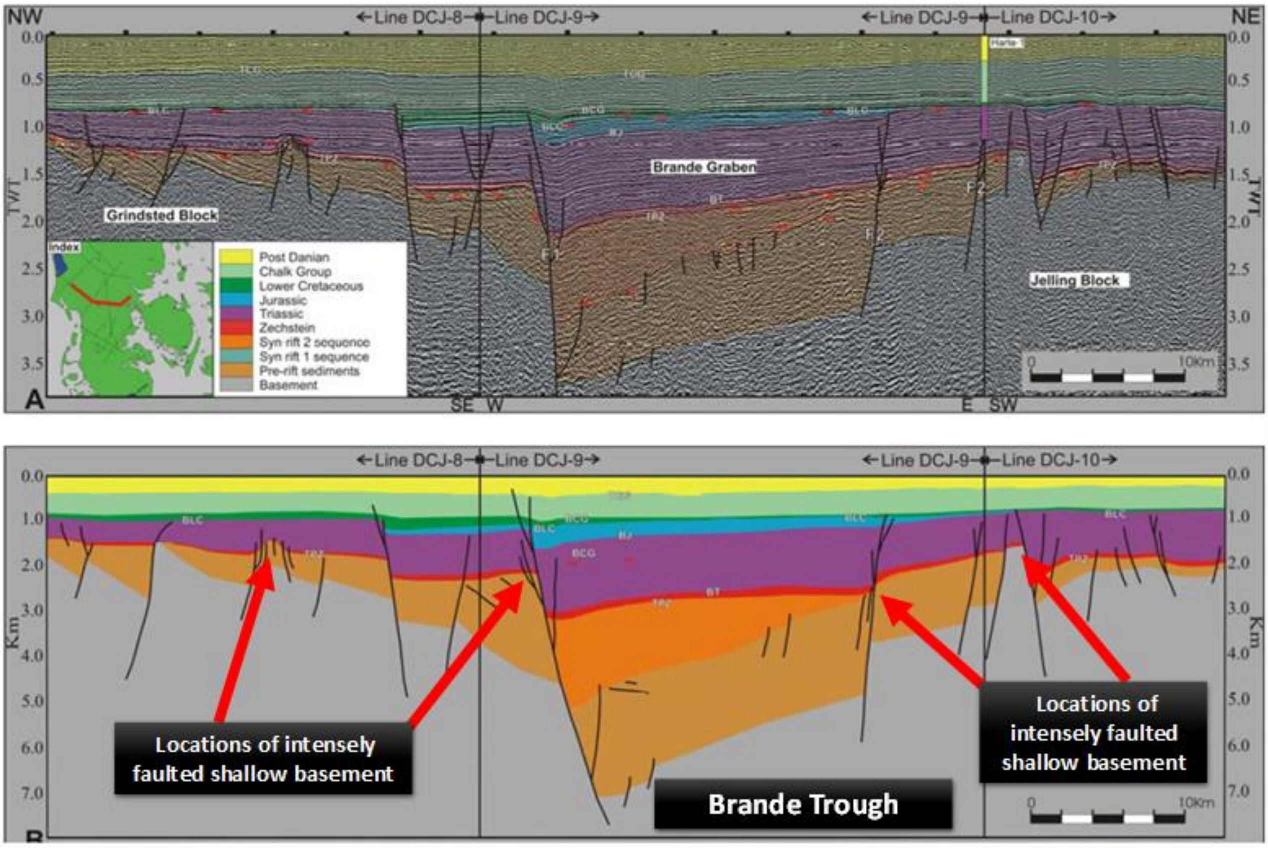


**Figure 3 modified from: S.B. Lyngsie, A.D. Andreasen, S. Hviid, H. Thybo. Rift dynamics in northern Europe: A case study of the Brande Graben, Denmark from integrated gravity, magnetic and seismic modelling, Tectonophysics.**

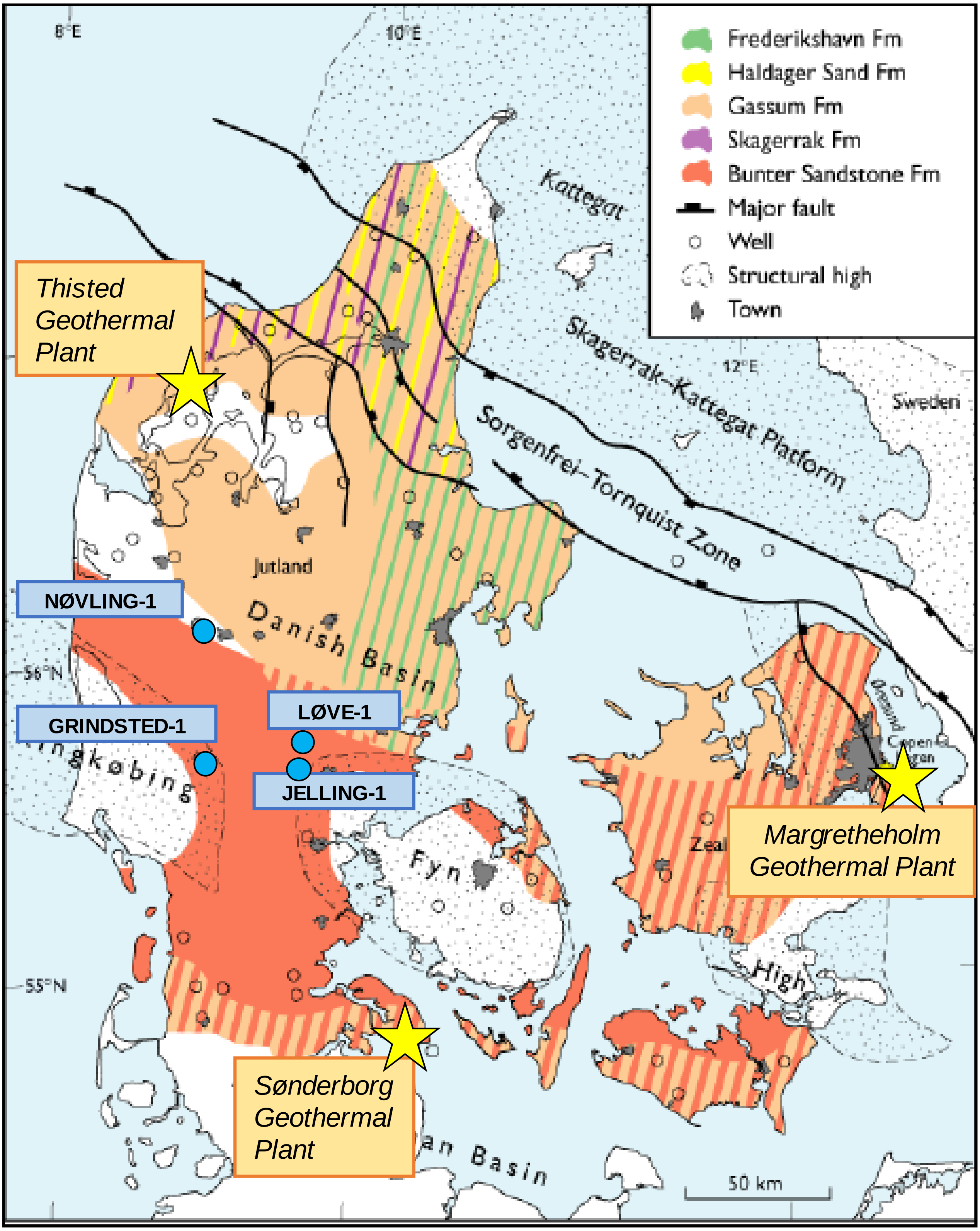


**Figure 4 Location Map of key wells and geothermal plants. Base map from GEUS showing reservoirs suitable for Geothermal exploitation in Denmark.**