Effect of groundwater flow on the subsurface temperature within crystalline rocks of southern Norway

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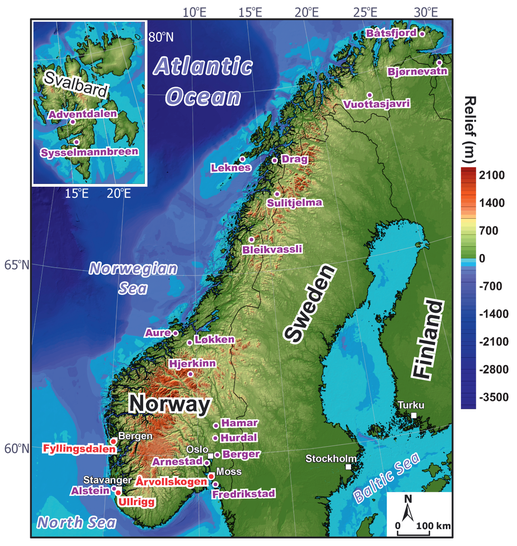
Overview

An attempt has been made to reveal the major features of the subsurface temperature distribution in the Fyllingsdalen, Ullrigg and Årvollskogen boreholes, which are located in southern Norway near Bergen, Stavanger and Moss, respectively. Thermal

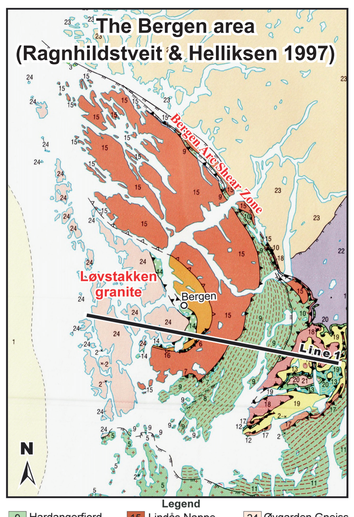


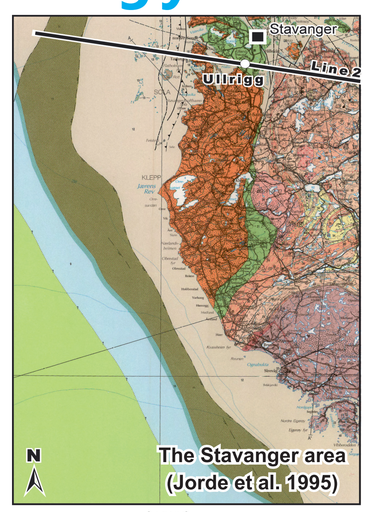
The geological feature of the Bergen area is the Bergen Arc System.

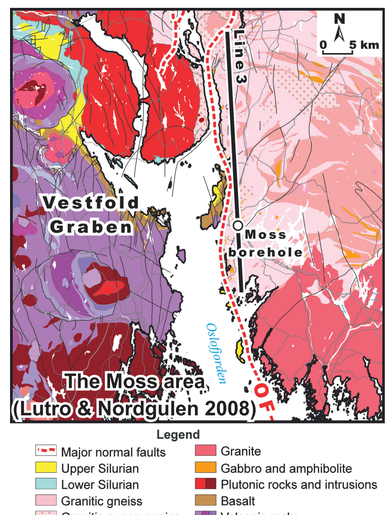
The Stavanger area covers the northwestern part of the Sveco-norwegian Rogaland Igneous Province.

The Moss borehole

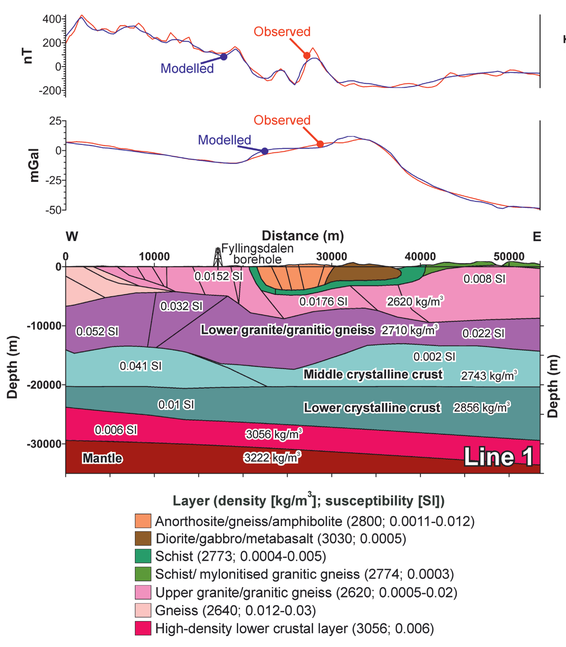
Geology





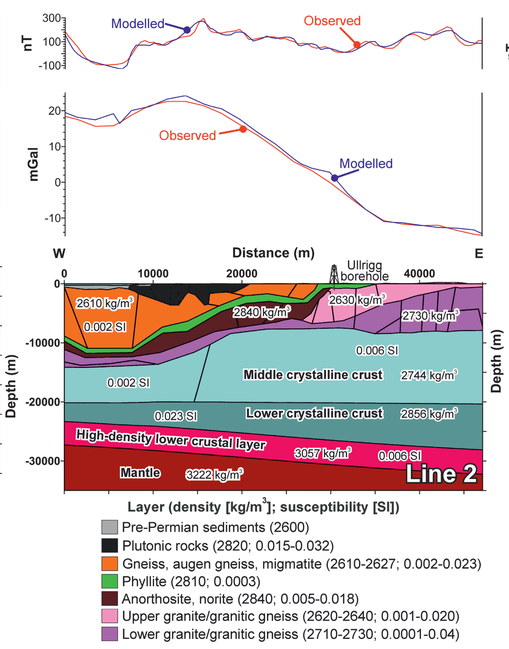


2D density and magnetic modelling



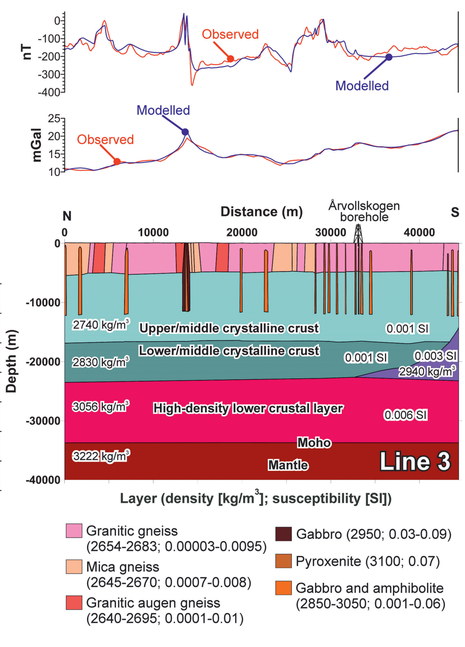
Layer (density [kg/m³]; susceptibility [SI])
- Anorthosite/gneiss/amphibolite (2800; 0.0011-0.012)
- Diorite/gabbro/metabasalt (3030; 0.0005)
- Schist (2773; 0.0004-0.005)
- Schist/ mylonitised granitic gneiss (2774; 0.0003)
- Upper granite/granitic gneiss (2620; 0.0005-0.02)
- Gneiss (2640; 0.012-0.03)
- High-density lower crustal layer (3056; 0.006)

Crustal-scale 2D structural model near the Fyllingsdalen borehole



Layer (density [kg/m³]; susceptibility [SI])
- Pre-Permian sediments (2600)
- Plutonic rocks (2820; 0.015-0.032)
- Gneiss, augen gneiss, migmatite (2610-2627; 0.002-0.023)
- Phyllite (2810; 0.0003)
- Anorthosite, norite (2840; 0.005-0.018)
- Upper granite/granitic gneiss (2620-2640; 0.001-0.020)
- Lower granite/granitic gneiss (2710-2730; 0.0001-0.04)

Crustal-scale 2D structural model near the Ullrigg borehole



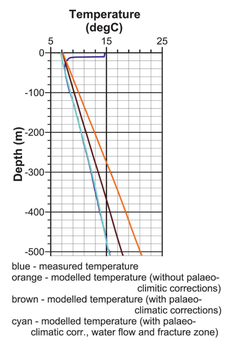
Layer (density [kg/m³]; susceptibility [SI])
- Granitic gneiss (2654-2683; 0.00003-0.0095)
- Mica gneiss (2645-2670; 0.0007-0.008)
- Granitic augen gneiss (2640-2695; 0.0001-0.01)
- Gabbro (2950; 0.03-0.09)
- Pyroxenite (3100; 0.07)
- Gabbro and amphibolite (2850-3050; 0.001-0.06)

Crustal-scale 2D structural model near the Årvollskogen borehole

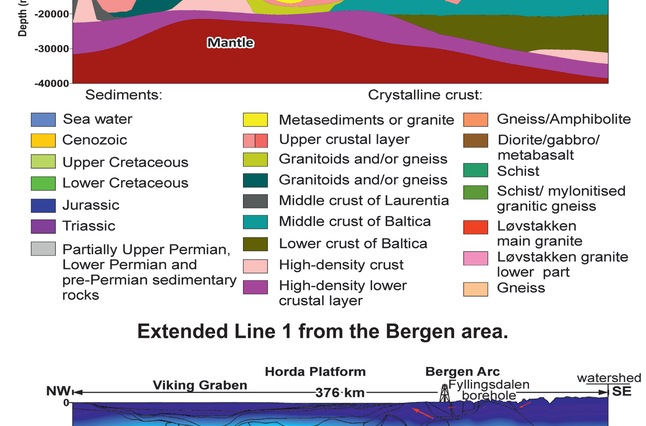
Based on 2D gravity and magnetic modelling, the 2D structural models have been constructed for the Bergen, Stavanger and Moss areas. These 2D models were used during

2D modelling of coupled groundwater flow and heat transfer

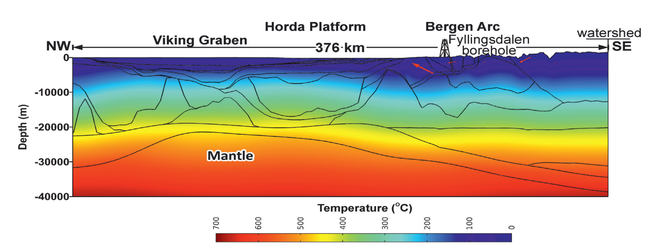
Two COMSOL modules of "Heat Transfer in Porous Media" and "Porous media and Subsurface Flow/Darcy's Low" have been used to carry out a fully coupled thermal modelling with taking into account the advection heat transfer due to groundwater flow.



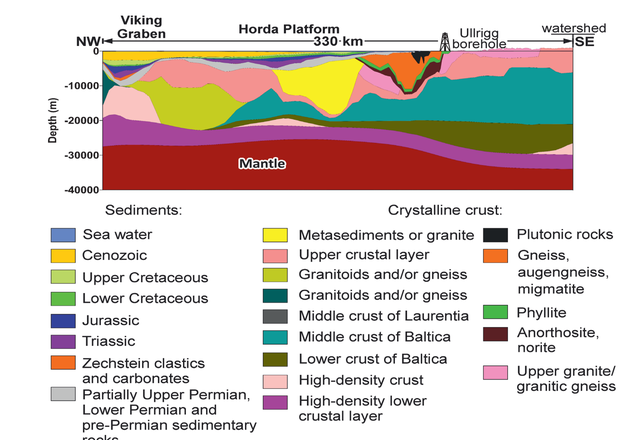
The Fyllingsdalen borehole.



Extended Line 1 from the Bergen area.



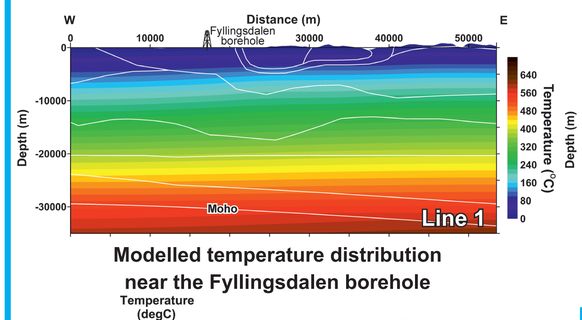
Modelled temperatures (extended Line 1).



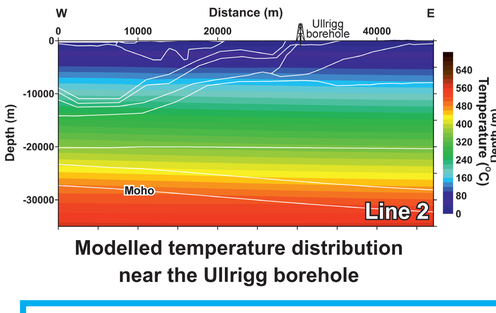
Extended Line 2 from the Stavanger area.

2D conductive thermal modelling

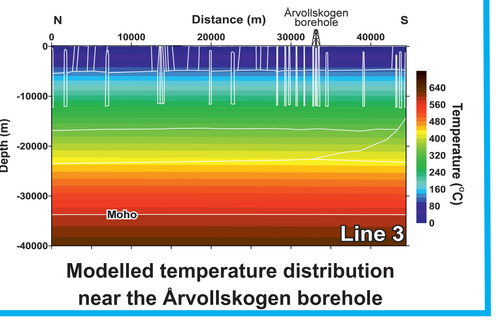
A 2D thermal modelling has been done with the help of COMSOL Multiphysics. During the purely conductive 2D thermal modelling, the COMSOL module of "Heat Transfer in Solids"



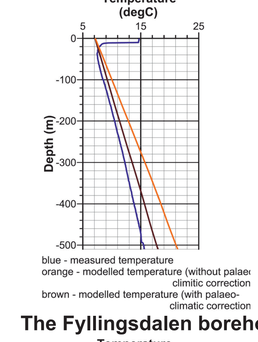
Modelled temperature distribution near the Fyllingsdalen borehole



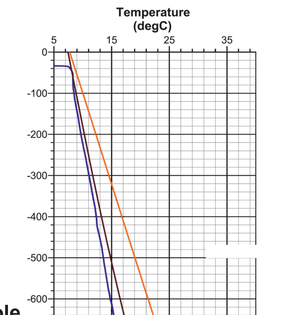
Modelled temperature distribution near the Ullrigg borehole



Modelled temperature distribution near the Årvollskogen borehole

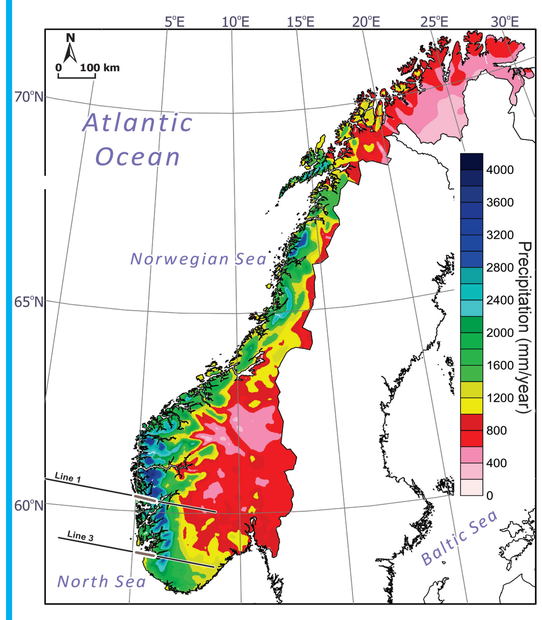


The Fyllingsdalen borehole

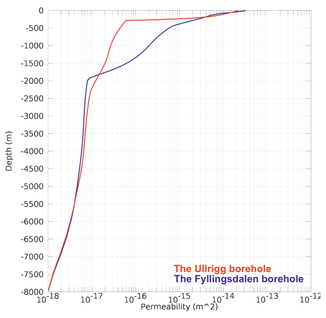


The Ullrigg borehole

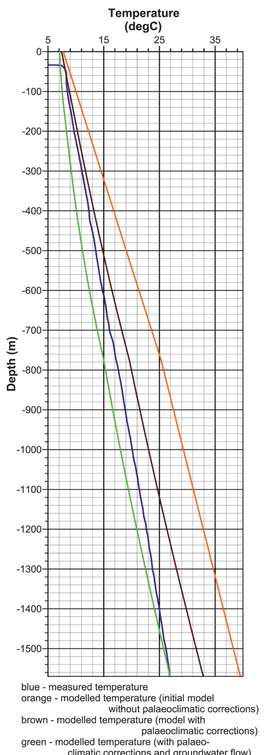
The Årvollskogen borehole



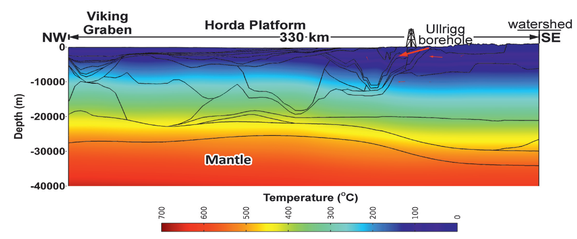
Normal annual precipitation (NMI, 2013)



Permeabilities of crystalline rocks.



The Ullrigg borehole.



Modelled temperature (extended Line 2).

Summary

Results of the modelling of coupled groundwater flow and heat transfer indicate that the advective cooling due to groundwater flow is one of the important factors for the reduction of temperatures in two boreholes within southwestern Norway where the normal annual precipitation is one of the highest in Europe. On the other hand, the influence of the groundwater flow on subsurface temperatures is most likely relatively low within southeastern Norway which is the rain-shadow area. Thus, the atmospheric precipitation-related groundwater flow through the crystalline rocks of southwestern Norway can affect the regional-scale conductive thermal field in terms

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