



# THE GREENLAND ANALOGUE PROJECT



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NUCLEAR WASTE  
MANAGEMENT  
ORGANIZATION

SOCIÉTÉ DE GESTION  
DES DÉCHETS  
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# THE GREENLAND ANALOGUE PROJECT GIVES INFORMATION ABOUT THE FUTURE GLACIATIONS IN SCANDINAVIA

Posiva Oy, SKB and NWMO have started a project on Greenland to increase knowledge about the conditions during an ice age. The main aim is to increase knowledge of the groundwater flow and the water chemistry adjacent to a continental ice sheet.

## MUST MEET THE REQUIREMENTS

As far as Posiva is concerned the basic question is how an ice age would affect a final repository for spent nuclear fuel. A final repository for spent nuclear fuel must meet the Finnish authorities' safety requirements during warm climates as well as during ice ages. Despite the inferred current global warming, we need to analyse cases of glaciation for the selected site, Olkiluoto, for a final spent fuel repository in Finland. We are in other words approaching a new ice age, regardless of whether this will be in 10,000 years, 50,000 years or even further in the future.

The main issue for Posiva, however, is not to investigate the most probable time for the start of the next ice age. In our safety analyses we must instead cover all the relevant possibilities, so as to ascertain the magnitude of the stresses for the final repository.

## WHICH CHANGES AFFECT THE BARRIERS?

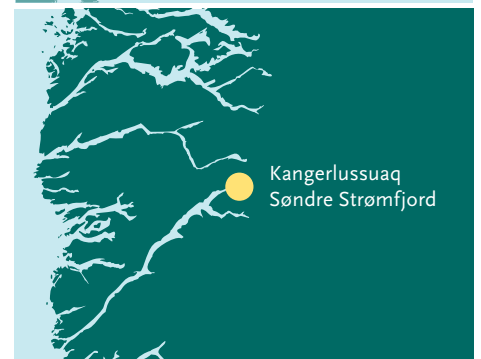
We are particularly keen to study the changes that affect the repository's protective barriers: the copper canister, the bentonite clay buffer

and the rock. We are also investigating changes in the surface and what happens if, in spite of everything, radioactive substances spread, e.g. in an environment near to an ice sheet where there is permafrost.

An important question in our analyses is how the groundwater flow and chemistry are affected during glaciations. For the final repository to be safe the ground water should not be too saline, have too low a salinity or contain dissolved oxygen.

## THE ICE SHEET GOVERNS WATER EXCHANGE

During warm (interglacial) periods groundwater exchange in the rock is regulated by precipitation and topography. During glaciations, however, the ice sheet governs this water exchange. The weight of the ice depresses the bedrock, and the stress load in the rock changes. The shape and hydraulic properties of the ice simultaneously govern where the groundwater forms and how it moves. This leads to the water in part being able to find new routes, and to changes in the water fluxes. The meltwater from the ice also has



## The Greenland Analogue Project (GAP)

**Participating organisations:** Posiva, SKB in Sweden, the Nuclear Waste Management Organization (NWMO) in Canada, and researchers from universities and geological surveys in the United States, Canada, United Kingdom, Denmark, Finland and Sweden.

**Location:** Kangerlussuaq, Greenland's west coast, east of Søndre Strømfjord.

**Shedule:** Preliminary activities in the field started in summer 2008. However, the project itself started in 2009 and will take approximately four years.

**Objective:** Reduce the uncertainties in future safety analyses for the final repository for spent nuclear fuel.



Over the coming years Posiva, SKB and NWMO will be investigating how the Greenland inland ice affects hydrology. PHOTO: Anne Lehtinen

a low salt content and contains dissolved oxygen, which could affect the functioning of the final repository in a negative way. When the climate is cold and permafrost spreads, e.g. before an ice sheet develops, this also affects the way the groundwater moves. Permafrost may also lead to more saline groundwater.

In order to study all these issues in more detail we have started analog studies in Greenland, where an ice sheet can be studied under the relevant conditions. The rock types in the selected area in western Greenland are highly reminiscent of those in the investigation sites in Finland, Sweden and Canada – a prerequisite for the study to be meaningful for Posiva, SKB and NWMO.

#### FOCUS ON ICE SHEET HYDROLOGY

The Greenland Analogue Project is largely about investigating the hydrology of the ice sheet and in the bedrock adjacent to the ice. The hydraulic conditions at the bed of the ice sheet, at the boundary with till and rock, are of great significance to where and how the groundwater forms under the inland ice.

Certain areas of the ice sheet are frozen to the bed. There is no free water here, and consequently there is no groundwater formation. Other areas of the ice sheet are basal melting, and in these parts the meltwater forms groundwater. The distribution of basal melting and basal frozen conditions is governed by many factors, including the climate on the ice surface, the ice's dynamics and movement and heat flow in the bedrock.

Water from the ice surface can also get down to the bottom through crevasses and moulins, and can form groundwater. This happens in areas close to the front of the inland ice, where melting is taking place on the surface. One uninvestigated issue is the size of the area over which this water can reach the base.

#### MELTwater PRODUCTION CALCULATED

A number of weather stations and GPS receivers were positioned on the ice in collaboration with Danish, Dutch and English researchers. Geological mapping of the bedrock in front of the inland ice

was also performed in preparation for the forthcoming drilling into the bedrock. Data from the weather stations are used to calculate how much meltwater is produced, and GPS receivers are measuring ice movement. There is a clear connection between these two parameters. How much the ice moves depends largely on how much meltwater is produced and the associated water pressure at the base of the ice. Through detailed study of how the ice's movements vary, we can thus draw indirect conclusions about the hydraulic conditions at the base of the ice.

#### RADAR MAPPING OF ICE THICKNESS

In summer 2009 the radar measurements continued. By surveying the ice and gathering data we can map the thickness of the ice, where it is basal frozen and where it is basal melting.

For Posiva, SKB and NWMO the hydraulic pressure at the base of the ice is a parameter of great interest, as it affects the groundwater flow. We are thus planning to drill through the ice at three to four



The meltwater from the inland ice forms tunnels in the ice. PHOTO: Victor Bense

locations along a profile from the ice edge and in over the ice sheet, up to 250 kilometres from the ice edge. Using the results from the radar studies we can select drilling sites where we know that the ice is melting at the base.

We will measure the subglacial water pressure in the ice boreholes to see how it varies locally, regionally and over time. Actual measurements of water pressure have never before been performed on this scale on an ice sheet. The results will be used to improve the assumptions in our reasoning and model simulations.

### **BEDROCK DRILLING IN FRONT OF THE ICE MARGIN**

In 2009, two pilot drillholes were drilled in to research area to define the depth of the permafrost and to get a first impression from the deep groundwater. We investigated, if the dissolved oxygen in the groundwater reacts with minerals in fissures and rocks, on its way down through the rock. However, the groundwater samples

from fieldwork season in autumn 2009 were still contaminated with drilling water. We will resample drillhole water in spring 2010 when the drilling water has hopefully flown out from the conductive fractures in the drillhole.

In summer 2011 we plan to investigate the depth to which the glacial meltwater has penetrated into the rock. We will drill a hole in the bedrock down to a depth of about 500 meters – roughly the same as the planned depth of the final repository in Finland and Sweden. The drillhole will start in the ice-free area near the ice margin and will go down obliquely under the ice sheet. The flow and chemical composition of the groundwater in the drillhole will be studied, in order to see how the inland ice has affected the groundwater and the conditions in the bedrock at 500 m depth.

In our work we are analysing a large number of cases, overestimating the consequences, in order to cover the prevailing uncertainties, e.g. for the hydraulic conditions in the event

of glaciation. It is noted that glacially formed groundwater could lead to erosion of the bentonite clay buffer under pessimistically selected conditions. This in turn means an increased risk of corrosive attack on the canisters.

### **OBSERVATIONS REDUCE UNCERTAINTIES**

To reduce the uncertainties in future safety analyses, for the final repository for spent nuclear fuel we need to know more about the processes at work during an ice age. The observations from the Greenland ice sheet constitute an important contribution towards improving the conceptual and mathematical models we are using. The results from some of our investigations will also be used, by other researchers within the field of geosciences, to estimate how sensitive the Greenland ice sheet is to global warming.



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